THE LANCE CREEK OIL AND GAS FIELD, NIOBRARA COUNTY, WYOMING.

By E. T. Hancock.

INTRODUCTION.

The Lance Creek oil and gas field is situated in Niobrara County, east-central Wyoming, about 25 miles from the east line of the State. The center of greatest activity is about 45 miles southwest of Edgemont, 80 miles northeast of the Big Muddy field, and 85 miles east and a little south of the Salt Creek field. The Lance Creek field can be reached either from Edgemont, on the Chicago, Burlington & Quincy Railroad, or from Lusk or Manville, on the Chicago & Northwestern Railway. The east end of the field, as shown on the geologic map (Pl. X), is about 22 miles due north of Lusk, and the west end is about the same distance north of Manville.

HISTORY OF DEVELOPMENT.

According to notes submitted to the writer by Dr. J. E. Hawthorne, of Lusk, the early history of development in the Lance Creek field is briefly as follows:

As early as 1912 Dr. Hawthorne made an effort, by advertising, to obtain the necessary funds to drill a hole on Buck Creek. He failed to interest anyone at that time, but on April 29, 1913, what is known as the Lusk, Wyoming, Oil Co. was incorporated. After consulting L. W. Trumbull, State geologist, the company decided to drill a hole in the extreme northeast corner of sec. 15, T. 35 N., R. 64 W. Drilling was begun in August, and by June, 1914, when the funds were exhausted, a depth of 2,250 feet had been reached. A California company, represented by H. A. Rispin, then attempted to finish the hole but did not drill deeper than 2,600 feet.

In April, 1913, Mr. McWhinnie, of Douglas, shipped a portable rig to Lusk. The rig was taken out to the SE. ¼ sec. 31, T. 36 N., R. 64 W., early in June, and on July 12 the drill had reached a depth of 268 feet. Later drilling was continued to 1,200 feet, and the hole was then abandoned.

In the summer of 1914 Edwin Hall organized the Pine Dome Oil Co., composed of Salt Lake mining men. A standard rig was procured, and drilling was begun in the N. ½ sec. 33, T. 36 N., R. 65 W.

Owing to the development of a crooked hole at a depth of 1,700 feet, this company also abandoned the field.

The Montana-Wyoming Oil Co. of California, represented by H. A. Rispin, started a well in the SW. ¼ SE. ¼ sec. 3, T. 35 N., R. 65 W., about the 1st of November, 1916. This company drilled about 200 feet and then abandoned the work until the following year. The well was finally finished in 1919 by the Western States Oil Co., which brought in a water well.

In 1916 Dr. Hawthorne procured from the State a lease on sec. 36, T. 36 N., R. 65 W., and subleased it for a period of seven months to the California company represented by Mr. Rispin. The lease was subsequently extended for five months. Later Dr. Hawthorne obtained another lease from the State and subleased the tract to the Ohio Oil Co. This company erected a standard rig and commenced drilling on September 27, 1917. The drill penetrated the first oil sand at a depth of 2,689 feet on March 13, 1918. This sand yielded 80 barrels of oil during the first 24 hours. The company resumed drilling April 29, 1918, and reached the principal oil sand October 6, 1918. When the drill had penetrated the sand to a depth of 2 feet 6 inches the well flowed at the rate of about 1,500 barrels during the first 24 hours. Since that date a number of other wells have been drilled in the principal oil sand, with results set forth on pages 117–120.

ACKNOWLEDGMENTS.

In presenting this report the writer desires to express his thanks to David White for valuable suggestions and criticisms and to Robert M. Campbell for assistance in the field. He feels particularly indebted to Mr. R. F. Gray, county surveyor of Niobrara County, for information relative to section and quarter corners. He also wishes to thank the oil and gas operators for their willing cooperation in furnishing the records of deep borings. Finally, he wishes to express his appreciation for the many acts of courtesy by the citizens of Lusk and vicinity.

PURPOSE OF THE PRESENT INVESTIGATION.

The principal object of the investigation was to procure all the information obtainable relating to the composition and structure of the sedimentary beds and the conditions controlling the accumulation of oil and gas, and to arrange that information in such form as to promote the economic development of the field. To attain that object it was necessary to trace out and locate the beds on the surface and to determine their dip or degree of inclination at close intervals.

FIELD WORK.

The field investigation that furnished the basis for the present report was carried on between September 11 and November 5, 1918. The field observations were made and the maps prepared under the supervision of the writer. In the process of mapping nearly all the locations were made by triangulation, and the elevations were determined by means of vertical angles. The instrument used was the ordinary 15-inch plane table and telescopic alidade. Two base lines were carefully measured by means of a steel tape, one in the valley of Lance Creek and the other near the east end of the field. After the plane table had been carefully oriented at the extremities of the base lines, the derricks and a number of previously constructed monuments were located by intersection. A certain elevation was assumed for the instrument at the south end of the base line on Lance Creek, and the elevation of each subsequently located point was determined from this assumed elevation. Later these elevations were adjusted to conform to the correct elevation of the top of the casing of the Ohio No. 1 or discovery well, as determined by the Illinois Pipe Line Co. In the process of mapping many of the land corners were located either by intersection or through the use of the stadia, after the instrument had been carefully located by triangulation. The section lines were then drawn to conform as nearly as possible to the located corners and to the data shown on the official township plats.

SURFACE FEATURES.

CHARACTER OF SURFACE AS RELATED TO FUTURE DEVELOPMENT.

Most of the development work that is being carried on in the Lance Creek field is confined to the relatively low-lying tract between the more or less continuous ridge of the Fox Hills sandstone on the north and the escarpment formed by the White River beds on the south. The two principal points of supply are Lusk and Manville, on the Chicago & Northwestern Railway. The oil companies and Niobrara County have, at considerable expense, laid out and constructed an excellent graded road the entire distance from Lusk to the productive portion of the field, where the main camps of the Ohio, Buck Creek, and Midwest oil companies are located. A short distance south of the field is a secondary road that extends from the principal highway in a northwesterly direction over the ridge underlain by the White River beds and down to the valley of Lance Creek.

An excellent road has also been laid out from Manville to the oil field, and construction work is well underway. This road, which is to take the place of the one previously used, will furnish a direct

route from the Chicago & Northwestern Railway to the west end of the field.

Trails lead from the principal highways to the different parts of the field. These have received very little attention, but in general the streams have not cut their channels very deeply, and therefore it is not a difficult matter to reach most any part of the field even with heavily loaded trucks.

DRAINAGE.

There are no perennial streams in the Lance Creek field. Even Lance Creek, which has a well-defined channel, is dry the greater part of the year. The long gullies in the western part of the field either lead down to the valley of Lance Creek or to Little Lightning Creek, its tributary from the west. The gullies that open into Lance Creek from the east all head near the top of a divide which separates the drainage system of the western part of the field from that of the eastern part. The run-off from the east slope of the divide either empties into Young Woman Creek or finds its way into Buck Creek. Whichever course it takes, it finally reaches Lance Creek, for Buck Creek joins Lance Creek about 7 miles north of the field, and the drainage into Young Woman Creek reaches Lance Creek about 6 miles farther down its course. Although the principal streams in the Lance Creek field are without running water most of the year, there is sufficient seepage so that the deeper portions of their beds generally contain standing water, and even where the bed is entirely dry water can be obtained by drilling to a very slight depth.

STRATIGRAPHY.

GENERAL FEATURES.

The oldest beds exposed in the Lance Creek field lie about 1,650 feet below the top of the Pierre shale of the Montana group and are exhibited at the crest of the anticline in the western part of the field. In the Powder River dome,[1] which lies about 15 miles west of Salt Creek, oil seeps are found in the Sundance, Morrison, and Dakota (?) (Cloverly) formations and in the Mowry shale member of the Benton shale, as shown in the columnar section of the Powder River field on Plate XI. In a discussion of the strata of the Lance Creek field in relation to oil accumulation it is therefore necessary to consider the formations at least as low as the Jurassic. The nature of the beds between those that crop out and the oil and gas bearing sand is well shown in the log of the discovery well on page 113. The composition of the underlying formations can only be inferred through comparison with other localities.

[1] Wegemann, C. H., The Powder River oil field, Wyo.: U. S. Geol. Survey Bull. 471, pp. 56–75, 1912.

The following section, which is believed to represent the stratigraphy in the Lance Creek field as low as the base of the Sundance formation, was made up from data collected in the Upton-Thornton field, 80 miles to the north, and from the records of borings at Cambria.[2] The section from the top of the Dakota to the bottom of the second fire clay in the Morrison is taken from the log of the bore hole of the Antelope mine. The part of the section comprising the lower portion of the Morrison formation and the Sundance formation is taken from the log of the deep well at Cambria.

Rock formations in the Lance Creek field, Wyo.

System.	Series.	Group.	Formation and member.	Character.	Thickness (feet).
Quaternary.	Recent.		Alluvium.	Sands and loams with some admixture of coarse material.	Variable.
Tertiary.	Oligocene.		White River formation.	Very soft unconsolidated greenish-gray to white sand, interbedded with reddish to grayish clay shale. Commonly overlain by greenish-gray, very coarse grained sandstone, in places coarsely conglomeratic.	Variable.
Tertiary (?).	Eocene (?).		Lance formation.	Sandstone and sandy shale, with thin beds of coal.	Only the lower beds were examined.
Cretaceous.	Upper Cretaceous.	Montana.	Fox Hills sandstone.	Sandstones with some sandy shales. Some of the sandstones, especially those near the top, include numerous large reddish-brown concretions, many of which are very fossiliferous.	500
			Pierre shale.	Dark-gray shales interbedded with thin beds of hard sandstone and thicker beds of soft sandy shale.	700
				Dark-gray shale, including thin beds of sandy shale and beds of fossiliferous calcareous concretions.	600
				Shannon(?) sandstone member, coarse-grained greenish-gray sandstone with many yellowish-brown iron-stained concretions.	16–50
				Predominantly dark-gray shale, but including lenticular masses and some very thin beds of fossiliferous calcareous concretions.	1,950
		Colorado.	Niobrara formation.	Soft shaly limestone or impure chalk, including some clay and sand.	200

[2] Darton, N. H., U. S. Geol. Survey Geol. Atlas, Newcastle folio (No. 107), p. 4, fig. 5, 1994.

Rock formations in the Lance Creek field, Wyo.—Continued.

System.	Series.	Group.	Formation and member.		Character.	Thickness (feet).
Cretaceous.	Upper Cretaceous.	Colorado.	Carlile shale.		Dark shale with thin beds of soft sandstones (Wall Creek sandstone member) near the base.	700
			Greenhorn limestone.		Impure limestone.	50
			Graneros shale.		Dark-gray to black shale including many large calcareous concretions, especially in the upper part.	575
				Mowry shale member.	Hard light-gray sandy shales containing numerous fish scales. Bentonite beds near the top and to some extent near the base.	100
					Dark sandy shale grading upward into typical Mowry shale.	25
				Newcastle sandstone member.	Reddish to light-yellow sandstone associated with black carbonaceous shale.	3–50
					Dark-gray to black shale.	175
			Dakota sandstone.		Thin-bedded to massive hard buff sandstone.	60?
	Lower Cretaceous.		Fuson formation.		Shale and thin-bedded sandstone.	20
			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

UNEXPOSED ROCKS.

JURASSIC SYSTEM.

SUNDANCE FORMATION.

The Sundance formation is exposed at many places in the Black Hills and at certain other localities in eastern Wyoming—for example, in the Powder River field, west of the Lance Creek field, and in the vicinity of Hartville, on the south. By comparing the formation in these different localities it is possible to form a reasonably accurate notion of its composition in the Lance Creek field. As an aid in

making such a comparison the reader is referred to the columnar sections on Plate XI.

At Cambria the Sundance formation is composed essentially of light-gray and pinkish shale, with one 25-foot buff sandstone near the base. Farther southeast, in the Edgemont quadrangle,[3] the formation contains a much larger proportion of sandstone and is overlain by a fine-grained massive cliff-forming sandstone, known as the Unkpapa sandstone, whose maximum thickness is 225 feet. The greatest development of this sandstone in the Black Hills region is in the hogback east of Hot Springs and Cascade Springs, and it gradually decreases in thickness toward the west.

The Sundance formation as exposed near North Platte River, about 13 miles northwest of Hartville, Wyo., is reported[4] to be about 200 feet thick. The lower part consists of about 140 feet of buff to nearly white sandstone, and the upper 60 feet includes a variable amount of more or less slabby sandstone with interbedded clays. The formation is exposed in the Powder River field,[5] in sec. 33, T. 41 N., R. 81 W., along the bed of a canyon that enters Salt Canyon from the north. Here about 10 or 15 feet of the formation is brought to the surface by a sharp minor fold. The exposure consists of argillaceous limestone beds a foot or two in thickness which yield abundant fossils and, interbedded with the limestone layers, numerous beds of dark-gray shale.

CRETACEOUS (?) SYSTEM.

MORRISON FORMATION.

The Morrison formation, which is doubtfully referred to the Cretaceous system, overlies the Sundance conformably. It represents fresh-water conditions of sedimentation, whereas the Sundance represents marine conditions.

The section of a drill hole at the Antelope mine at Cambria[6] (see columnar section for Upton-Thornton field, Pl. XI) shows two beds of fire clay, one 3 feet and the other 7 feet thick, separated by sandstone. The deep well at Cambria[7] was begun just below the 7-foot bed of fire clay and penetrated 130 feet of light-gray to pinkish shale, also included in the Morrison formation.

According to the description of the formation given by Darton and Smith,[8] it is 100 feet thick west of Minnekahta, S. Dak., but farther east it thins out and disappears. For the Edgemont quad-

[3] Darton, N. H., and Smith, W. S. T., U. S. Geol. Survey Geol. Atlas, Edgemont folio (No. 108), p. 4, 1904.

[4] Smith, W. S. T., U. S. Geol. Survey Geol. Atlas, Hartville folio (No. 91), p. 3, 1903.

[5] Wegemann, C. H., The Powder River oil field, Wyo.: U. S. Geol. Survey Bull. 471, p. 61, 1912.

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

[7] Idem, p. 8.

[8] Darton, N. H., and Smith, W. S. T., U. S. Geol. Survey Geol. Atlas, Edgemont folio (No. 108), p. 4, 1904.

rangle as a whole it may be said that the formation ranges in thickness from practically nothing to 125 feet and consists of grayish, greenish, and maroon massive shale, including thin beds of fine-grained white sandstone. Like the underlying Sundance formation, the Morrison is exposed along North Platte River about 13 miles northwest of Hartville,[9] and in that locality it contains about 100 feet of massive shales or hardened clays of various colors—green, purplish, reddish, light and dark gray to nearly black—with one or more thin beds of moderately hard, compact light-grayish limestone.

In the Powder River field, according to Wegemann,[10] the formation is about 250 feet thick and consists of shale with a few hard sandstone beds from 3 to 8 feet thick. The shale in the lower part of the formation has a greenish tinge, but that in the upper part is maroon.

CRETACEOUS SYSTEM.

LOWER CRETACEOUS SERIES.

The Morrison formation of northeastern Wyoming is commonly overlain by a rather massive sandstone. In the Powder River field, according to Wegemann,[11] it is overlain by a course conglomeratic sandstone 56 feet in thickness with a thin bed of coal at its base. In that field the sandstone is a lithologic unit, but 25 miles to the north, where it crops out along the Big Horn uplift, it consists of numerous thin layers of sandstone with interbedded shale. In the report on the Powder River oil field this sandstone was doubtfully referred by Wegemann to the Dakota sandstone. In his second report on the Salt Creek oil field,[12] however, the same beds are included in the Lower Cretaceous series under the name Cloverly formation, mainly on the evidence of fossil plants which were collected from layers of shale that lay between beds of conglomerate near the base. These fossils were identified by F. H. Knowlton as undoubtedly Kootenai species, and hence there is little doubt that the conglomerate is equivalent in age to at least part of the Kootenai[13] of Montana. Overlying the conglomerate is 80 feet of dark, unfossiliferous shale, above which is a 14-foot bed of shaly sandstone whose top layers are strongly ripple marked. According to Wegemann, this bed, though comparatively thin, is found at many places throughout this region and appears to be of wide extent, and accordingly he suggests that if the formations of the Black Hills are all present in the Salt Creek field, the 14-foot sandstone may represent

[9] Smith, W. S. T., U. S. Geol. Survey Geol. Atlas, Hartville folio (No. 91), p. 3, 1903.
[10] Wegemann, C. H., The Powder River oil field, Wyo.: U. S. Geol. Survey Bull. 471, p. 61, 1912.
[11] Idem, p. 62.
[12] Wegemann, C. H., The Salt Creek oil field, Wyo.: U. S. Geol. Survey Bull. 670, p. 15, 1917.
[13] Fisher, C. A., Southern extension of the Kootenai and Montana coal-bearing formations of northern Montana: Econ. Geology, vol. 3, pp. 77-99, 1908.

the true Dakota and the shale overlying the conglomerate may be the equivalent of the Fuson shale, of Lower Cretaceous age; he also suggests that the Dakota may be absent and that the shale and sandstone referred to may belong to the Benton.

Above the Morrison beds in the locality about 13 miles northwest of Hartville are from 250 to 300 feet of sandstones with several beds of shale and clay, which have been grouped together by Smith [14] under the name Dakota sandstone. Smith says, however, regarding this method of grouping:

> While it is possible and even probable that the lower part of this series of rocks corresponds to the Lakota (Lower Cretaceous) of the Black Hills, no formation corresponding definitely to the Fuson or Minnewaste was observed, so that the line of division between the Upper and Lower Cretaceous rocks (if the latter are represented) can not be drawn except arbitrarily. For this reason the rocks have been mapped without subdivision.

Many of the sandstones show distinct bedding, a few of them exhibit cross-bedding, and several present ripple-marked surfaces. The beds of clay or shale occurring with the sandstones are from 2 to 8 or 10 feet in thickness and of reddish, yellowish, or grayish color. In the Black Hills, on the opposite side of the Lance Creek field from the Hartville region, 150 to 350 feet of beds generally intervene between the Morrison beds and the Dakota sandstone. These beds seem to be the equivalent of the Lower Cretaceous rocks in other localities.

In the Newcastle quadrangle, for example, the Morrison is overlain by 150 to 200 feet of massive, cross-bedded, coarse gray to buff sandstone with local coal beds and conglomerate, known as the Lakota sandstone. This is overlain by 15 to 30 feet of gray to red shales with thin sandstones, known as the Fuson formation. Farther southeast, in the Edgemont quadrangle, the Lakota formation is from 200 to 350 feet thick, and between the Lakota and the Fuson formation is a limestone 25 feet in maximum thickness, which has been named in the Edgemont folio the Minnewaste limestone. This limestone is, however, not of widespread occurrence in the Black Hills. Its principal outcrops extend from the vicinity of Cascade Springs to Buffalo Gap, S. Dak., and it thins rapidly toward the south and west.

UPPER CRETACEOUS SERIES.

DAKOTA SANDSTONE.

The Dakota sandstone, as it has been definitely recognized in the Black Hills, ranges in thickness from 50 to 150 feet. In some places it is thin bedded in the upper part and massive in the lower part; in others it is entirely massive. It is ordinarily gray to buff and generally weathers brown.

[14] Smith, W. S. T., U. S. Geol. Survey Geol. Atlas, Hartville folio (No. 91), p. 3, 1903.

COLORADO GROUP.

The Colorado group in northeastern Wyoming includes the Niobrara formation, Carlile shale, Greenhorn limestone, and Graneros shale. The last three formations are equivalent to the Benton shale elsewhere. None of these formations are exposed at the surface in the Lance Creek field proper. They are well exposed in the Old Woman anticline, about 15 miles east of this field, and also in the Mule Creek oil field, about 30 miles northeast of the producing area in the Lance Creek field. The thickness and character of each of these formations are shown in the table on pages 95–96.

FORMATIONS EXPOSED IN THE LANCE CREEK FIELD.

The lowermost beds exposed in the Lance Creek field are those at the highest point on the anticline, in the western part of the field. They occur about 360 feet below the top of a sandstone which is probably the equivalent of the Shannon sandstone in the Powder River and Salt Creek fields. The formations that have been exposed by erosion in the Lance Creek field are described below.

CRETACEOUS SYSTEM.

PIERRE SHALE.

The Pierre shale occurs at the surface throughout the comparatively low area between the more or less continuous ridge formed by the Fox Hills sandstone on the north and the escarpment caused by the White River formation on the south. Being composed essentially of shale, it weathers down to a comparatively even surface. The bulk of the formation is composed of dark shale containing lenticular masses and more or less continuous beds of calcareous rock. The comparative hardness of the calcareous beds causes many of them to stand out above the general surface, and in places the succession of more or less independent jagged masses furnishes the only available key to the structure. These limy beds and lenticular masses, weathering, break up into a vast number of angular fragments and exhibit various kinds of fossil shells. Among the fossils collected from the upper portion of the Pierre shale during the process of the field work the following species were identified by T. W. Stanton:

Actaeon attenuatus Meek and Hayden.
Anchura sp.
Baculites ovatus Say.
Cucullaea shumardi Meek and Hayden.
Fish scale.
Inoceramus barabini Morton.
Lingula nitida Hall and Meek.
Mactra gracilis Meek and Hayden.
Modiola meekii (Evans and Shumard).

Mytilus? sp.
Ostrea sp.
Protocardia subquadrata (Evans and Shumard).
Scaphites nodosus Owen.
Syncyclonema rigida (Hall and Meek).
Yoldia evansi Meek and Hayden.

In many places where the shale is exposed a careful observer is able to detect thin layers of sandstone or thin seams of gypsum. One conspicuous layer of sandstone is exposed in the bottom of the gully between Rabbit Mountain and the main escarpmment in the western part of sec. 4, T. 35 N., R. 64 W. A sandstone resembling it is well exposed at the north edge of the outlier of the White River formation near the north line of sec. 6 of the same township. Layers of sandstone show how the beds are inclined at numerous places in the east end of the field and furnish some clue as to structure in the western part, where most of the shale is concealed by the overlapping beds of the White River formation. In certain localities beds of the yellow clay known as bentonite occur in the shale and assist very materially in deciphering the structure. One of these beds forms the dip slope in the W. ½ sec. 2, T. 35 N., R. 65 W., and appears to dip south at an angle of 3° 6′. A similar bed of bentonite, in all probability the same bed, is exposed on the north side of the anticlinal axis in the SE. ¼ sec. 26, T. 36 N., R. 65 W. There the bed of yellow clay dips north at an angle of 16°. The structure and also the total amount of the Pierre shale exposed in this field are indicated by thicker sands which occur in the upper portion of the Pierre and which are traceable for some distance on the surface.

The Shannon (?) sandstone crops out along the small gully immediately west of the No. 1 or discovery well, near the northwest corner of sec. 36, T. 36 N., R. 65 W. It rises gently toward the south, forming the dip slope, and arches over at the top of the anticline about 1,500 feet southwest of the discovery well. Scattered exposures of this sandstone were observed as far west as the center line of sec. 27. From dip determinations it is believed to lie about 1,300 feet below the base of the group of sandstones mapped as the Fox Hills sandstone. The gas well in the SW. ¼ NW. ¼ sec. 34 is reported to have reached the first producing sand at a depth of 3,303 feet, whereas in the discovery well that sand was encountered at a depth of 3,663 feet. It is evident, therefore, that the beds which reach the surface at the gas well are about 360 feet below the top of the Shannon (?) sandstone, and accordingly about 1,660 feet of the Pierre shale is exposed in this field. Immediately overlying the Shannon (?) sandstone is a zone about 600 feet thick, including some soft sandy shale but composed mainly of dark shale with numerous fossiliferous calcareous concretions. Nearly all the beds from the top of this

zone up into the Fox Hills sandstone are exposed along the east bank of Lance Creek in the NE. ¼ sec. 28, T. 36 N., R. 65 W., as shown in the following section:

Section showing the uppermost part of the Pierre shale and the lowermost beds of the Fox Hills sandstone along the east bank of Lance Creek in the NE. ¼ sec. 28, T. 36 N., R. 65 W.

	Ft.	in.
Fox Hills sandstone:		
Sandstone, very light colored and very soft, not well exposed	25	
Sandstone, light yellow, soft and massive; contains a few concretions and rather uniformly distributed beds of hard reddish-brown sandstone from 6 to 18 inches thick	96	
Soft sandstone and sandy shale in thin beds; contains three thin beds of hard brown shelving sandstone showing numerous ripple marks	30	
Sandstone, light yellow, fine grained	1	
Sandstone and sandy shale in alternating layers of light yellow and dark color	3	6
Sandstone, massive, yellowish	3	
Sandstone, reddish brown, slabby; dip 24°		7
Sandstone, containing thin seams of sandy shale	4	
Sandstone, very massive, light yellow	7	
Sandstone, soft, containing thin beds of dark sandy shale and a few thin beds of hard sandstone, especially in the upper portion; strike east, dip 27° N	162	
Pierre shale:		
Shale, very dark, containing thin layers of reddish-brown sandstone; becomes much lighter colored near the top, as it merges into the Fox Hills formation; strike east, dip 27° N	72	
Sandstone; weathers to rounded surfaces; cut off abruptly by a shear zone	36	
Shale, dark; contains ten separate layers of reddish-brown concretions. *Baculites* fairly abundant. Strike east, dip at top 27½°	67	
Shale, dark, slightly sandy; contains very few concretions and is not very fossiliferous	120	
Interval, not well exposed but in all probability composed of very soft beds	100	
Belt composed essentially of soft sand but includes many thin seams of hard yellowish-brown sandstone	84	
Shale, very sandy	85	
Shale, grayish brown, sandy; weathers yellowish gray. Has many calcareous concretions which contain *Inoceramus barabini* Morton and *Anchura* sp. Dip 23° N. 40° W	34	

A 30-foot bed of soft light-gray sandstone included in the Lance Creek section is exposed in the NE. ¼ sec. 27, T. 36 N., R. 65 W. The bed was traced and mapped eastward to a point a few hundred feet east of the prominent butte composed of White River beds in sec. 25, T. 36 N., R. 65 W. Where the bed was last recognized it dips 20° N.

FOX HILLS SANDSTONE.

The great mass of Pierre shale is overlain with apparent conformity by many hundred feet of sandstones and sandy and carbonaceous shales, including some coal beds. A long period of time elapsed after the beginning of the influx of coarse sediments before there was a complete change from marine to brackish and fresh waters, and during that period the beds of the Fox Hills formation were laid down. After the formations were uplifted to their present position they were attacked by the agencies of erosion, but the overlying sandy beds, being harder and more resistant, were not removed as rapidly as the soft shales. As a result the area underlain by the Pierre shale is bordered on the north and west by a more or less continuous ridge underlain by the Fox Hills sandstone and the lowermost fresh and brackish water beds of the Lance formation. Most of the beds constituting the Fox Hills sandstone are exposed along the east bank of Lance Creek in the NE. ¼ sec. 28, T. 36 N., R. 65 W., and are shown in the stratigraphic section on page 102. There is a gradual transition from the Pierre shale to the Fox Hills sandstone, owing to the gradual influx of sandy material, but for the purpose of mapping the base of the Fox Hills was drawn at the base of the 162-foot zone as shown in the section, there being thus approximately 330 feet of the formation exposed at that locality. Throughout most of the Lance Creek field the formation is not well exposed, but farther north the Fox Hills and overlying "*Ceratops* beds" (Lance formation) and also some of the Pierre shale are much better exposed and are well described by Hatcher [15] as follows:

> Along the southeastern border, especially between Lance and Buck creeks, are many fine exposures of the *Ceratops* beds and the underlying Fox Hills. Perhaps the best exposure is that made by a small tributary emptying into Buck Creek, about 4 miles east of Lance Creek and one-half mile northwest of the Buck Creek pens used by the cattlemen for round-up purposes. This watercourse has here cut its way in a southerly direction at right angles to the strike down through the lower half of the *Ceratops* beds, through the underlying Fox Hills sandstones, and into the Fort Pierre shales. At this place the bed of Buck Creek and the rounded hills of that region at the head of this stream, embraced between the border of the *Ceratops* beds and Fox Hills sandstones on the north and the bluffs of Miocene clays and conglomerates on the south, are composed of Fort Pierre shales. All the strata of this entire section dip to the northwest at an angle of 16 degrees. The exposure is a continuous one, and, commencing from below, the section is as follows:
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> At the base are the Fort Pierre shales, of unknown thickness, several hundred feet of which are exposed. They consist of argillaceous, finely laminated dark shales, quite soft and easily eroded. They contain many limestone concretions and numerous invertebrates. Among others are *Baculites ovatus*, *B. compressus*, *Scaphites nodosus*, *Placenticeras placenta*, *Nautilus dekayi*, etc.
>
> Overlying the Fort Pierre deposits is an alternating series of sandstones and shales with an estimated thickness of 500 feet. In the lower portion of this series the shales

[15] Hatcher, J. B., The *Ceratops* beds of Converse County, Wyo.: Am. Jour. Sci., 3d ser., vol. 45, p. 138, 1893.

predominate, but toward the middle the sandstones are in excess, and in the upper 50 feet they entirely replace the shales. The sandstones are of a yellowish-brown color, very fine grained, firm, and well stratified below, but softer and quite massive at the top, where they contain numerous large concretions and a rich marine invertebrate fauna. * * *

Next come the *Ceratops* beds, with an estimated thickness of 3,000 feet, resting directly upon the Fox Hills series. Immediately above the Fox Hills is a very thin but persistent layer of hard sandstone, well stratified, and easily cleavable along the lines of stratification. This stratum of sandstone is about 6 inches thick and is regarded as the dividing line between the marine and fresh-water beds.

In the geologic mapping the top of the Fox Hills sandstone is drawn at the 6-inch bed of sandstone, which Hatcher regards as the dividing line between marine and fresh-water beds. The sandstones which he mentions as containing numerous large concretions and a rich marine invertebrate fauna are exposed almost continuously along the west side of Buck Creek, and from the Buck Creek narrows as far east as the formation was mapped. They were also recognized in isolated exposures from the vicinity of Buck Creek as far west as Lance Creek. The appearance of these sandstones as they are exposed along the east side of Buck Creek valley is shown in Plate XII. The following fossils were collected from the Fox Hills beds at different localities in the Lance Creek field and identified by T. W. Stanton:

SE. ¼ sec. 33, T. 37 N., R. 63 W., from concretions in the sandstones near the top of the formation:

Anchura sp.
Callista sp.
Crenella elegantula Meek and Hayden.
Cylichna scitula Meek and Hayden.
Dentalium gracile Hall and Meek.
Fish scale.
Protocardia subquadrata (Evans and Shumard).
Scaphites conradi (Morton)?
Veniella humilis Meek and Hayden.

NW. ¼ NW. ¼ sec. 22, T. 36 N., R. 64 W., from concretions in the sandstones near the top of the formation:

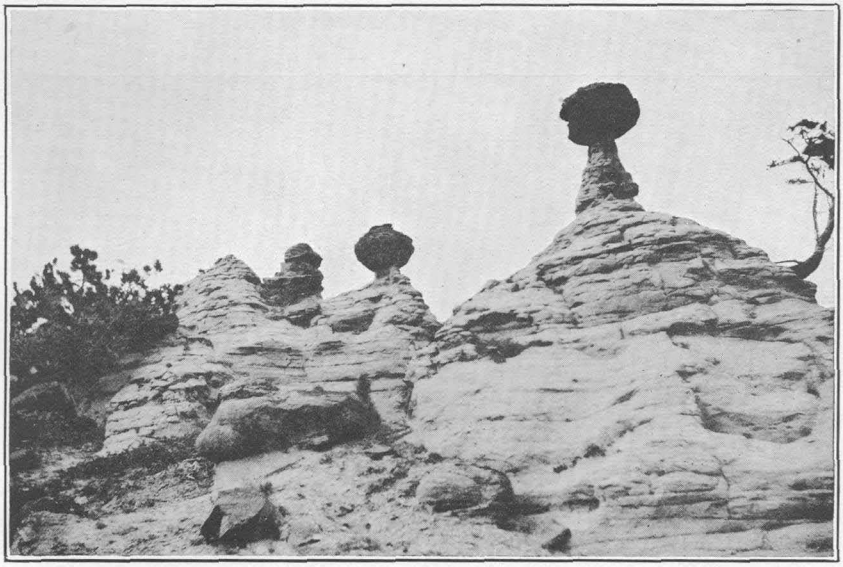
Burrows of a boring mollusk.
Veniella humilis Meek and Hayden.

NE. ¼ SE. ¼ sec. 20, T. 36 N., R. 64 W., from a sandstone about 100 feet above the base of the formation:

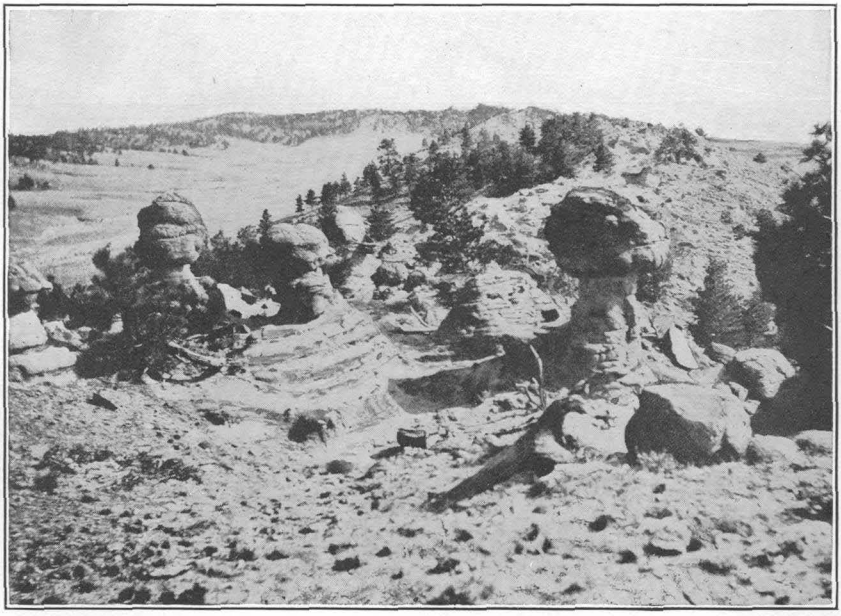
Inoceramus sp.
Nucula sp.
Protocardia subquadrata (Evans and Shumard).
Scaphites conradi var. intermedius Meek?
Tellina scitula Meek and Hayden.
Veniella humilis Meek and Hayden.

SE. ¼ SE. ¼ sec. 12, T. 35 N., R. 66 W., from thin beds of sandstone exposed in the east bank of Little Lightning Creek:

Avicula fibrosa Meek and Hayden.
Baculites ovatus Say.



A.



B.

SANDSTONE INCLUDING LARGE REDDISH-BROWN CONCRETIONS NEAR THE TOP OF THE FOX HILLS SANDSTONE, EAST SIDE OF BUCK CREEK VALLEY, SEC. 33, T. 37 N., R. 63 W., WYO.

A, Showing results of weathering; *B*, View looking northwest. The tree-covered ridge at the top is developed, in part, on the same sandstone dipping westward on the opposite side of the valley.

Lucina subundata Hall and Meek.
Lunatia concinna (Hall and Meek)?
Nucula cancellata Meek and Hayden?
Scaphites conradi (Morton).
Veniella humilis Meek and Hayden?
Yoldia evansi Meek and Hayden.

TERTIARY (?) SYSTEM.

LANCE FORMATION.

The light-colored massive sandstones at the base of the Lance formation form Pine Ridge, in the SE. ¼ sec. 23, T. 36 N., R. 65 W. They crop out almost continuously as far east as sec. 12, T. 36 N., R. 64 W., but farther north and east they are not so conspicuous. West of Lance Creek these beds are well exhibited along the gulch extending southeastward through sec. 29, T. 36 N., R. 65 W., where the beds of the White River formation have been eroded and the uppermost Fox Hills and lowermost Lance beds appear, dipping 30° northwest. Toward the southwest they soon pass beneath the White River beds and are next seen in the SW. ¼ sec. 31 of the same township. Thence the beds can be traced continuously as far as the NE. ¼ sec. 12, T. 35 N., R. 66 W., but farther southwest they are entirely concealed. Where they were last recognized a brackish-water bed composed mainly of the shells and casts of *Ostrea subtrigonalis* dips 24° W. A similar brackish-water bed was seen near the east side of sec. 29, T. 36 N., R. 65 W., and shells of *Corbicula planumbona* Meek were collected near the control point at the top of the high ridge in the NW. ¼ sec. 22, T. 36 N., R. 64 W., from a layer of sandstone near the top of the conspicuous white sandstones that form Pine Ridge, about 4 miles farther west.

The writer was unable, for lack of time, to study the details of even the lower portion of the Lance formation in this field. He did, however, measure a section at Pine Ridge, in the SE. ¼ sec. 23, T. 36 N., R. 65 W., which shows fairly well the composition of the lower part of the formation. The base of the Lance formation is not well defined here, owing to the lack of good exposures, but the bottom of the following section is probably not far from that horizon.

Section of the lower beds of the Lance formation in the SE. ¼ sec. 23, T. 36 N., R. 65 W.

	Feet.
Soft sand and sandy shale containing thin beds of rusty-colored sandstone. The entire mass presents a pinkish color	9
Sandstone, light yellow, soft; weathers into cavern-like forms	3
Shale, sandy; weathers pinkish	2
Sandstone, light colored	3
Sandstone, rusty colored; weathers into rounded forms	4
Sandstone, light brown, hard; forms conspicuous bed; weathers out into loglike forms	3

	Feet.
Shale and sand containing thin layers of sandstone; in weathering forms a pronounced pinkish to light-gray belt	35
Sandstone, lighter colored and softer than that below	18
Sandstone, yellowish brown, massive, very much in contrast with the white sandstone below; exhibits considerable cross-bedding	60
Sandstone, very soft, containing a large amount of carbonaceous material	25
Sandstone, soft, thin bedded	6
Shale, dark gray; contains some carbonaceous material, very sandy at top	8
Shale, carbonaceous	2
Shale, dark gray	4
Sandstone, light yellow, soft and massive	6½
Coal (sandstones above and below show many fragments of fossil plants)	5
Sandstone, soft; contains considerable carbonaceous shale	5
Sandstone, white, very massive; crops out at top of Pine Ridge	15
Interval not well exposed but seems to consist mainly of sandy and carbonaceous shale, including thin beds of sandstone	25
Shale, black, carbonaceous; contains thin seams of coal and many thin streaks of sulphur	10
Sandstone, very white and massive; erodes into rounded surfaces	63
Sandstone, soft; contains several thin layers of hard reddish-brown sandstone which project above the surface	80
Shale, very sandy	40
Sandstone, rusty colored and hard	5

TERTIARY SYSTEM.

WHITE RIVER FORMATION.

After the Upper Cretaceous beds and those of the Lance formation, of doubtful Tertiary age, were uplifted to their present attitude they were deeply eroded, and finally, as a result of the oscillatory movements of the land, the waters again encroached upon the land area, and a considerable thickness of light-colored beds, now known as the White River formation, was laid down. That formation, in all probability, covered all of the Lance Creek field and lay as a horizontal sheet over the great arch of Cretaceous beds, but the agencies of erosion, such as wind, rain, and running water, have swept the beds from the crest of the arch and revealed that fold as a possible trap for the accumulation of oil and gas. If erosion had progressed still further the westward extension of the great anticline would be better known, for at present its west end is completely obscured by these horizontal beds. The northward limit of these beds is indicated by a rather well-defined escarpment and by outliers which form isolated buttes still farther north within the broad area occupied mainly by the Pierre shale. The formation is composed essentially of very soft, unconsolidated greenish-gray to white sand,

interbedded with reddish to greenish-gray shales. These beds are commonly overlain by greenish-gray, very coarse grained sandstone, in places coarsely conglomeratic. The reddish sandy shale near the base of the formation is sometimes mistaken for the "Red Beds" by those who are unfamiliar with the stratigraphy of the region.

QUATERNARY SYSTEM.

ALLUVIUM.

The only notable deposits of alluvium in this field are those which produce the rich, level land along Lance Creek. There the admixture of silts, sand, and gravel has been spread out from time to time as the stream has shifted its course.

STRUCTURE.

SALIENT 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 exhibited 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 Lance Creek field occupies a great arch or anticline of sedimentary beds west of the Old Woman anticline, from which it is separated by a shallow syncline. The crest of this arch can be traced with considerable accuracy for about 18 miles. It forms a reversed or sigmoid curve and extends from sec. 5, T. 35 N., R. 65 W., northeastward to the Ohio No. 1 or discovery well, near the northwest corner of sec. 36, T. 36 N., R. 65 W.; thence almost due east to a point one-eighth of a mile south of the center of sec. 25, T. 36 N., R. 64 W.; and thence a little east of north to the point where Buck Creek cuts across the Fox Hills escarpment, in sec. 29, T. 37 N., R. 63 W. The southwestward extension of the crest of the arch is obscured by the overlapping White River beds. The dip of the beds on the northwest flank of this great arch gradually steepens from 3° near its north end to 27° on Lance Creek, and from Lance Creek southwestward the dip is fairly uniform. The beds on the opposite flank of the arch dip southeastward for an indefinite distance at angles of $2\frac{1}{2}°$ to 5°.

The Fox Hills sandstones, which at one time arched over the Lance Creek anticline, have been eroded away, leaving at the surface along the crown of the arch beds that lie several hundred feet below the top of the Pierre shale. The relatively low and even surface eroded on the shale is limited on the north by the conspicuous ridge formed by the Upper Cretaceous Fox Hills sandstone and on the

south by younger Tertiary beds, which conceal the older formations in that direction for many miles. The great arch of sedimentary beds is doubtless separated from the Hartville uplift by a broad syncline, but the western part of the syncline is obscured by the overlapping White River beds. The position of the east end of the synclinal axis can be recognized by opposite dips in sec. 36, T. 36 N., R. 64 W., and the SE. ¼ sec. 3, T. 36 N., R. 63 W.

METHOD 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 structure, 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 measurements of the degree of inclination of the beds at the surface and of stratigraphic thicknesses and upon data from deep borings. It shows how a portion of the earth's crust would appear if it were cut along a vertical plane and the portion on one side of the plane were removed. The section is an excellent aid in understanding the 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 of the section, which is undesirable. In oil and gas investigations, where the interpretation and representation of structure are extremely important, the method of showing 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 position of some particular stratum above or below a certain datum plane—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. X) it was decided to show throughout the field, as accurately as the data available would allow, the elevation of the top of the sand that yields most of the oil and gas. Any particular contour is the line of intersection between the top of the 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 difference of 100 feet in position above or below 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 sand approaches much nearer to horizontality.

Structure contours furnish a convenient method for presenting a comprehensive idea regarding the structure of an entire field. Their practical value depends, of course, upon their accuracy, and the degree of accuracy depends upon the number of data available. In certain developed oil fields it is possible to obtain numerous well logs and to recognize in them, either directly or through the relation to other beds, the position of the particular bed which it is desired to contour. In such a field the depth at any point to the contoured bed can be ascertained very accurately by subtracting from the surface elevation the elevation of the bed as shown by the structure contour. In other fields, where little drilling has been done and especially where few of the records have been preserved, it is necessary to depend almost entirely upon surface data, such as dips, measured intervals between beds, and elevations on traceable beds. 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. In the Lance Creek field the structure contours shown by broken lines are drawn on the basis of dips, measured intervals, and elevations on traceable beds. Those which are represented by unbroken lines are based entirely upon well records.

Throughout the field the contours near the base of the Fox Hills sandstone are reasonably accurate, because the Shannon (?) sandstone crops out near the discovery well, and, as explained on page 101, the dip determinations indicate a thickness of about 1,300 feet between that sandstone and the base of the Fox Hills formation. Southeast of the outcrop of the Fox Hills formation, in the eastern part of the field, the dips can be easily recognized, but there are very few beds in the Pierre shale that can be traced more than a few hundred feet. The writer obtained no well data from that portion of the field, and consequently the structure contours for it are less accurate. Practically all of the southwestern part of the field is overlain unconformably by the White River formation, of Oligocene age, and it seemed inadvisable to the writer to continue the structure contours any farther in that direction for fear of misleading those who studied the map without reading the text. The writer's views concerning the structure in the southwestern part of the field are stated briefly, however, under the heading "Suggestions for development" (p. 120).

OIL AND GAS.

GENERAL PRINCIPLES CONCERNING THE ORIGIN, MIGRATION, AND CONCENTRATION OF OIL AND GAS.

The primary source of petroleum is not definitely known, but most oil geologists believe that it is mainly of organic origin. It seems probable that most of the petroleum in the earth's crust has

originated from plants rather than animals, for two reasons—first, that the carbonaceous remains of plants are far more abundant than those of animals in the rocks; second, that the hydrocarbon-bearing parts of animals decompose more readily than the corresponding parts of plants. It has been estimated that more than 99 per cent of the carbonaceous material in the earth's crust is of plant origin. Aside from the water which they contain, plants consist mainly of elements that enter into the composition of petroleum and natural gas, namely, oxygen, hydrogen, and nitrogen. Although it is true that the soft parts of animals are composed mainly of the same elements, yet they decompose much more readily and therefore are more likely to be dissipated into the atmosphere or picked up by running water before being buried so deeply that oxidation and decomposition cease. In certain localities petroleum and natural gas have been found intimately associated with plant remains; in others these substances are more directly associated with the hard parts of animals, such as the shells of mollusks; but the great accumulations of petroleum and natural gas show conclusively that they migrate extensively. Hence it is generally very difficult to say whether these substances originated where they now occur, or whether they originated elsewhere and gradually migrated to their present situation as a result of the chemical and physical processes that are continuously at work within the earth's crust. The oil-bearing "sands" in the Lance Creek field are overlain and underlain by shales containing calcareous concretions, many of which are very fossiliferous. It seems possible that the oil now contained in the sands originated to some extent from the soft parts of the sea animals represented by the fossils, but probably it was derived mainly from carbonaceous material included in the dark shales themselves.

A careful examination of the structure of the rocks and its relation to concentration 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:

1. A reservoir rock. This is commonly known as an oil sand, and as a rule it is porous, although it may be a very sandy shale, a fractured rock of any kind, a loose conglomerate sufficiently porous to allow the accumulation of oil or gas, or a limestone composed largely of interlocking crystals of calcite.

2. An impervious cap rock to seal over the reservoir rock and prevent the upward escape of the oil and gas.

3. Folds in the rock favoring the accumulation of oil and gas in certain places, these substances migrating from more extensive areas of adjoining beds that are less favorably situated for their retention.

4. 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 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 that are nonporous these substances, under the influence of gravity, separate and arrange themselves according to density. The gas, being the lightest, rises to the crest of an anticline; the oil separates out below; and the water seeks the deepest portions of the beds. In accordance with the theory of organic origin it is believed that these substances were originally disseminated in the carbonaceous shales and limestones adjacent to the oil sands. Experience has shown, however, that the principal concentrations of oil and gas occur in the sands near the upper part of a fold. It is evident, therefore, that the fine particles of oil and gas have been forced out of the denser beds into the more porous sands and that this movement was followed by a slow migration up through the sands into the upper part of the fold.

Capillary attraction is in all probability an effective agent in the concentration of oil and gas. The size of the opening in rocks varies approximately with that of the constituent grains, being greatest in conglomerate and coarse sands and least in the clay shales. Inasmuch as water has about three times the surface tension of crude oil, capillary attraction must exert about three times as much force upon it. As the amount of the capillary pull varies inversely as the diameter of the pore, the tendency is for capillarity to draw water rather than oil into the smaller openings and to crowd the oil and gas into the more porous sands. It is believed that when, as a result of surface tension, the oil and gas have become segregated into bodies of considerable size, they arrange themselves under the influence of gravity and move upward through the pores of the sand under hydrostatic pressure. It has been shown by experiment that if a bubble of gas, in rising through water, comes into contact with a globule of oil the two unite and the oil forms a thin continuous film around the gas bubble. It seems probable, therefore, that the upward migration of oil is influenced considerably by the upward movement of bubbles of gas.

Detailed field observations have shown not only that many of the accumulations of oil and gas are intimately related to anticlines and domes, but also that gas, oil, and water are arranged in the manner indicated above. Although the recognition of these facts has caused most geologists to accept the anticlinal theory in its broader aspects, many of them are willing to accept it only in a modified sense, as recent study has shown that the accumulations of oil and gas occur not only in the crowns of arches but also in many places on the flanks where the dips are interrupted for some distance, the local flattening of the beds 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 is near the bottoms of synclines, or at any point where the forces obstructing the movement of the particles of oil are equal to or in excess of those which promote such movement. In saturated rocks the ideal structural form is a dome that includes a thick bed of porous sand effectively sealed above and dipping gently for a considerable distance, but such a form is not common in nature. In many domes the dips are interrupted by other structural features, and in consequence the collecting area is small. The oil sands may be lenticular, or, on the other hand, continuous sands may be offset along fault planes. If the fault remains partly open, fluids migrating through the porous sands rise to the surface and escape. It has been found that many oil seeps are accompanied by deposits of asphalt. If the fault is sealed by clay, asphalt, or some other impervious substance, the oil and gas may be concentrated in the sand near the fault plane and the result is practically the same as where 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 sand.

From the facts above outlined it is not surprising that some accumulations of oil and gas occur in areas where from all surface indications the conditions are unfavorable, and that some areas which appear to have the most favorable structure are barren. These conditions are mentioned briefly, not with a view of questioning 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 that may in any way retard the movement of fluids and the result in concentration.

RECENT DEVELOPMENT IN THE LANCE CREEK FIELD.

A few of the principal facts regarding early development in the Lance Creek field are given on pages 91–92, under the heading "History of development." Since the completion of the field work in June, 1919, several new wells have been completed, and before this report is available others will doubtless be drilled to the principal oil sand, so that, with respect to development, the facts shown on the accompanying geologic map (Pl. X) are incomplete. Wells at which,

according to recent reports in the oil journals, drilling has been discontinued are represented on the map as inadequately drilled. At certain wells the discontinuance was probably due to unfavorable results in neighboring wells; other wells may be only temporarily shut down. It will be some time before the limits of the pool are definitely determined, although the surface geology, together with the records of some of the wells that have already been drilled, strongly suggests the location of the most promising territory.

CHARACTER AND RELATION OF THE SANDS AS EXHIBITED IN WELL RECORDS.

Most of the wells that have been completed in the Lance Creek field range in depth between 3,300 and 4,000 feet, and the formation penetrated is almost entirely shale. There are, however, certain sands which were recognized in some of the wells and which doubtless could have been recognized in others if the drill cuttings had been more carefully preserved. The log of the discovery well is complete, and as it is probably typical of the field, it is given below.

Log of well No. 1,[a] Ohio Oil Co., in the NW. ¼ sec. 36, T. 36 N., R. 65 W.

Driller's interpretation.		Thickness.	Depth.
		Feet.	*Feet.*
Muddy shale		6	6
Hard sandrock	[Shannon (?) sandstone]	19	25
Sandrock	[Shannon (?) sandstone]	55	80
Shale and soft sand	[Shannon (?) sandstone]	25	105
Hard rock	[Shannon (?) sandstone]	25	130
Hard shale and sandrock	[Shannon (?) sandstone]	15	145
Shale and mud		20	165
Muddy shale		20	185
Gummy shale		40	225
Gray shale		30	255
Shale		75	330
Tough gray shale		20	350
Shale; showing of gas at 2,070 feet		1,720	2,070
Gray shale with shells		35	2,105
Hard shell		10	2,115
Shale		175	2,290
Gray shale		40	2,330
White slate		20	2,350
Shale		75	2,425
Shale with shells; gas at 2,425 feet		15	2,440
Sandy shale		65	2,505
Hard shell		2	2,507
Sandy shale		58	2,565
Gray sandy shale		15	2,580
Broken sand; trace of oil at 2,615 feet		50	2,630
Sandy shale		30	2,660
Shale		29	2,689
Oil sand [Wall Creek sandstone]		12	2,701
Shale		19	2,720
Sandy shale		10	2,730
Shale		78	2,808
Soft shale		178	2,986
Shale, color changeable		90	3,076
Soft black shale		130	3,206
Shale		27	3,233
Hard shell		17	3,250
Shale		83	3,333
Dark lime		127	3,460
Shale		197	3,657
Hard shell		6	3,663
Sand (oil sand)		2½+	3,665½+

[a] The Ohio Oil Co. has several wells designated No. 1, and to identify the well the number should be read in connection with the location.

It is possible to recognize in the above and other logs the several sands in the Lance Creek field, and for convenience they are discussed below in the same order as they are encountered in drilling.

SHANNON (?) SANDSTONE.

The sandstone that is regarded as probably the same as the Shannon sandstone of the Salt Creek field crops out along the gully immediately west of the discovery well, near the northwest corner of sec. 36, T. 36 N., R. 65 W. It rises gently toward the south, forming a dip slope, and arches over the top of the anticline about 1,500 feet southwest of the discovery well. Exposures of this sandstone were observed here and there as far west as the center line of sec. 27. In some places along the outcrop the sandstone is only about 16 feet thick, but in others it is much thicker. It is coarse grained, has a greenish-gray color, and contains many yellowish-brown iron-stained concretions. At the top there are many small dark-colored concretions which, upon weathering, become light gray. The log of the discovery well as given above shows sandy beds extending from 6 to 145 feet beneath the surface, but the exposures along the outcrop did not indicate so great a thickness.

In the Ohio Oil Co.'s well No. 1 near the northwest corner of sec. 31, T. 36 N., R. 64 W., the Shannon (?) sandstone is probably represented by a 38-foot sand whose top lies at a depth of 195 feet, and in the Midwest Refining Co.'s well No. 3, in the SW. ¼ sec. 25, T. 36 N., R. 65 W., it is represented by 40 feet of gray sandrock beginning at a depth of 40 feet. It is also exhibited in the log of the Ohio Oil Co.'s well No. 1 in the SW. ¼ NW. ¼ sec. 32, T. 36 N., R 64 W., as a hard sand containing a little water and extending from 300 to 330 feet beneath the surface. The sandstone lies near the surface at the Ohio No. 1 and Buck Creek No. 7 wells, near the center of sec. 35, T. 36 N., R. 65 W., and is eroded from the higher portion of the anticline farther west, where the gas wells are situated. If, as explained on page 101, the two bentonite beds on opposite sides of the anticline are the same, the Shannon (?) sandstone should dip beneath the surface on the southeast side of the anticline, near the Midwest well No. 1, in the NE. ¼ sec. 3, T. 35 N., R. 65 W., but it was not recognized there.

WALL CREEK SANDSTONE.

It is possible to recognize in many of the well logs in this field a sandy zone approximately 1,050 feet above the principal oil sand. In the discovery well this zone extends from 2,580 to 2,701 feet beneath the surface, and its top is 1,083 feet above the top of the principal oil sand. In some of the well logs this material is recorded as sand, in others as sandy shale, and in a few as alternating beds of

shale and sand containing some oil and gas. The stratigraphic position of these sandy beds is similar to that of the Wall Creek sandstone in the Powder River and Salt Creek fields, the sandstone at the top of the eastern anticline in the Mule Creek field, and the sands that yield oil in the Upton-Thornton field. Although none of the wells in the Lance Creek field are producing oil from this sandstone, it has given promise of yielding a fair output in some of the wells and should be watched carefully and recorded in the logs as accurately as possible.

PRINCIPAL OIL AND GAS SANDS.

The formations included between the base of the Sundance and the top of the Dakota are discussed in considerable detail on pages 96–99, and the subdivisions of the Colorado group are mentioned on page 100, but inasmuch as the sands near the base of the Colorado do not crop out in the Lance Creek field but are exposed not far distant, it seems appropriate to study some of the lower beds first as they are exposed elsewhere and later as they are exhibited in some of the well logs of this field. Northeast of this field, in the vicinity of Newcastle, the Dakota sandstone is immediately overlain by about 225 feet of dark shale that erodes very readily, producing a relatively low area between the long dip slope formed by the Dakota sandstone and the more or less jagged ridge formed by a sandstone that overlies this shale. The extent of this sandstone along the flanks of the Black Hills uplift and outward from that uplift 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 field it occurs as a reddish-brown, moderately soft sandstone encircling the central portion of the Thornton dome and occurring as isolated patches near the top of the dome. It is apparently only 2 or 3 feet thick at the northwest end of the dome, but at 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 the 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 locality 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, a few miles east of the Lance Creek field. The conditions there are set forth below.

About three-fourths 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, and the shale is in turn overlain by a succession of sandstone and carbonaceous shale beds almost 38 feet thick, which give rise to a very conspicuous ridge. This group of beds, the details of which are shown in the following section, is in all probability equivalent to the oil-bearing sand at Newcastle.

Section near north end of Old Woman anticline.

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

The group of sandy beds described above is doubtless widely distributed throughout Wyoming. The beds were recognized by the writer on the south slope of Como Ridge, about 6 miles east of Medicine Bow, and are in all probability equivalent to the sand that occurs near the middle of the Thermopolis shale at different localities in Big Horn Basin, commonly known by drillers as the Muddy sand. In the writer's recent report on the Mule Creek oil field [16] this sand was named the Newcastle sandstone member of the Graneros shale, because at Newcastle it is of unusual thickness and contains oil. It is the writer's opinion that the principal oil and gas sands in the Lance Creek field are the stratigraphic equivalent of the Newcastle sandstone and should be called by that name.

In the Lance Creek field the Newcastle sandstone is usually composed of two distinct beds of sand separated by a layer of hard sandy shale, and in that respect it resembles a portion of the section near Wright's camp, at the north end of the Old Woman anticline. (See above.) The upper sand varies considerably in thickness and averages about 20 feet. The shale interval between the upper and lower sands also varies considerably, but the average thickness is about 15 feet. Evidence concerning the thickness of the lower sand is lacking, for in most borings the drill has penetrated only a portion of the sand, but the total thickness of the two sands and the intervening shale is probably not greater than 50 feet. As a result of lenticularity, variable porosity, or some other property of these sands, the results of drilling have in certain places been somewhat disappointing. The behavior of gas, oil, and water in the wells is a subject that requires special study, and after more data are available such a study should be made for the purpose of determining how the physical and chem-

[16] Hancock, E. T., The Mule Creek oil field, Wyo.: U. S. Geol. Survey Bull. 716, p. 42, 1920 (Bull. 716-C).

ical properties of the sands influence the migration and accumulation of these substances.

RESULTS OF DRILLING.

At present it is impossible, with the meager data at hand, to tabulate more than a few of the results of the drill. The facts set forth in the following table have been obtained from various sources, mainly since the field work was completed, and although some of the depths shown may be slightly in error they are believed to be essentially correct. The information relating to well logs obtained by the writer in the course of the field work was supplemented by additional data obtained through F. B. Tough and B. H. Scott, of the United States Bureau of Mines, relating to the composition of the principal oil sand in some of the wells recently completed.

Results of drilling in most of the wells completed in the Lance Creek field.

Company.	No. of of well.	Location.				Depth to top of upper sand (feet).	Elevation of top of upper old sand about sea level (feet).	Contents of sand.	Reported production, with authority.
		Quarter.	Section.	Township N.	Range W.				
Midwest Refining Co	1	NE	28	36	64	3,965	500	Oil in upper sand	1,200 barrels a day, initial production: Wyoming Oil News, Sept. 6, 1919.
Ohio Oil Co	1	NE	33	36	64	4,138	362	Water in upper sand	
Do	1	NW	31	36	64	3,850	572	Water in upper and lower sands.	
Do	2	NW	36	36	65	3,702	700	Oil in lower sand	250 barrels a day: Wyoming Oil News, Sept. 6, 1919.
Do	1	NW	36	36	65	3,663	748	Oil in upper sand	1,200 barrels a day initial production: Oil and Gas Jour., Oct. 18, 1918. Settled production 400 barrels: Wyoming Oil News, Sept. 6, 1919.
Do	5	NW	36	36	65	3,744	725	Oil in lower sand	Flush production, 2,000 barrels Wyoming Oil News, Oct. 18, 1919. Later production 1,100 barrels: Wyoming Oil News, Sept. 6, 1919.
Midwest Oil Co	33	NE	3	35	65	3,665	743	Water in upper sand	
Buck Creek Oil Co	28	NE	35	36	65	3,668	779	Oil in upper and lower sands	800 barrels a day: Wyoming Oil News, Sept. 6, 1919.
Do	14	NE	35	36	65	3,632	789	do	
Do	4	SE	26	36	65	3,650	740	Oil in upper sand	1,300 to 1,500 barrels: Oil Trade Jour., December, 1919.
Do	7	NW	35	36	65	3,668	816	Oil in third sand	
Do	1	SW	34	36	65	3,400	985	Gas in upper sand	Estimated initial production, 50,000,000 cubic feet: Oil and Gas Jour., Oct. 25, 1918.
Do	27	NW	34	36	65	3,303	1,052	do	
Midwest Refining Co	1	SW	27	36	65				30,000,000 cubic feet: Oil and Gas Jour., Oct. 2, 1919.
Buck Creek Oil Co	30	SE	34	36	65	3,585	880	Water in upper sand	
Ohio Oil Co	1	NE	4	35	65	3,405	1,006	Gas in upper sand	Estimated initial production, 8,000,000 cubic feet.
Western States Oil Co	1	SE	3	35	65	3,840	555	Water in upper and lower sands.	
Ohio Oil Co	1	NW	3	35	65	3,427	955	Oil in lower sand	600 barrels a day: Wyoming Oil News, Sept. 6, 1919.
Do	3	NW	36	36	65				
Do	1	SW	4	35	65	3,556	921		Flush production, 2,500 barrels: Wyoming Oil News, Dec. 27, 1919. Production Jan. 10, 1920, 1,800 barrels a day: Ohio Oil Co.
Do	2	NE	4	35	65	3,479	950	Water in upper sand (?)	

Most of the figures of production in the above table indicate the supposed production September 6, 1919. Some of the estimates of flush production, as given in the oil journals, are probably too high. The Wyoming Oil News summarizes the situation in the Lance Creek field by saying: "The present production of oil is around 4,650 barrels per day, with some of the wells pinched down. The capacity of the gas wells is around 150,000,000 cubic feet per day."

Most of the oil from the Lance Creek field is conducted through a pipe line to the Chicago & Northwestern Railway at Lusk, Wyo., and there emptied into tank cars ready for shipment to the refineries. According to the Oil Trade Journal of November, 1919, the Ohio Oil Co. then expected to have in operation in about three months the first unit of what will eventually become a large absorption plant for the manufacture of casing-head naphtha. The original plan was to install a high-pressure plant that would treat 10,000,000 cubic feet of gas a day, but later it was decided to install a low-pressure plant that will handle the gas at a pressure of 30 pounds instead of 80 to 100 pounds.

On the higher portion of the anticline the upper sand generally shows high gas pressure. In wells Nos. 1 and 27 of the Buck Creek Oil Co., in sec. 34, T. 36 N., R. 65 W., and in well No. 1 of the Ohio Oil Co., in sec. 4, T. 35 N., R. 65 W., the gas seems to occur in large volumes and the rock pressure is reported to be nearly 1,000 pounds to the square inch. This is probably also true of the two gas wells of the Midwest Refining Co., one near the south quarter corner of sec. 27 and the other in the NE. ¼ sec. 33, T. 36 N., R. 65 W., but the writer is unable to verify this statement. It is probable that the lower limit of gas in the upper sand on the axis of the anticline is not far west of the group of wells in the NE. ¼ sec. 35, T. 36 N., R. 65 W., as well No. 28 of the Buck Creek Oil Co. is reported to have given a strong showing of gas when the drill entered the first sand, but as the well was drilled deeper the proportion of oil greatly increased. Farther west the body of gas lies structurally as low or even lower along the northwest flank of the anticline but apparently not as low along the southeast flank.

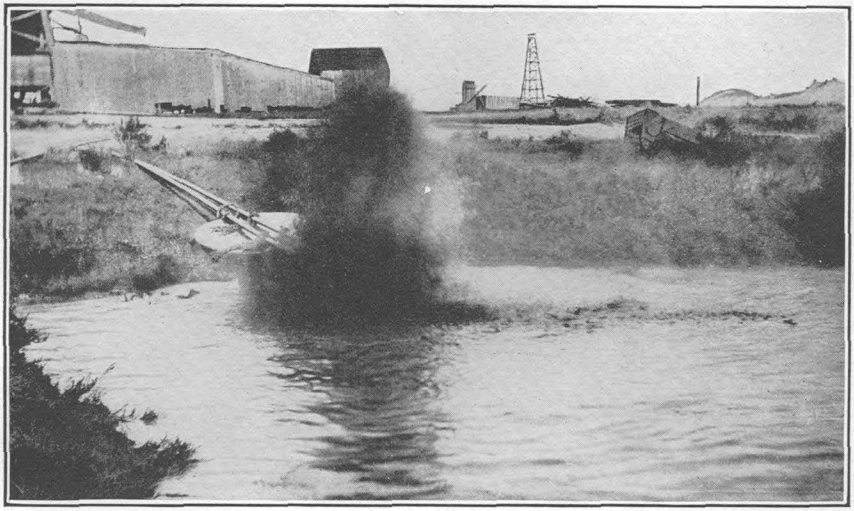
After the discovery well was drilled in, the oil rose to the surface and discharged into the earthen storage reservoir with great force, as shown in Plate XIII. This flow took place at intervals of approximately one hour and lasted for about 30 minutes each time. Tanks to hold the oil were constructed as rapidly as possible, and finally the oil was turned into the pipe line. There is in all probability a body of oil below the gas which is trapped in the upper part of the fold, but neither the upper nor the lower limit of the oil can be determined until further drilling is done. The few wells that have been drilled

indicate that the main body of oil occurs at a lower level along the northwest flank of the anticline than it does along the southeast flank.

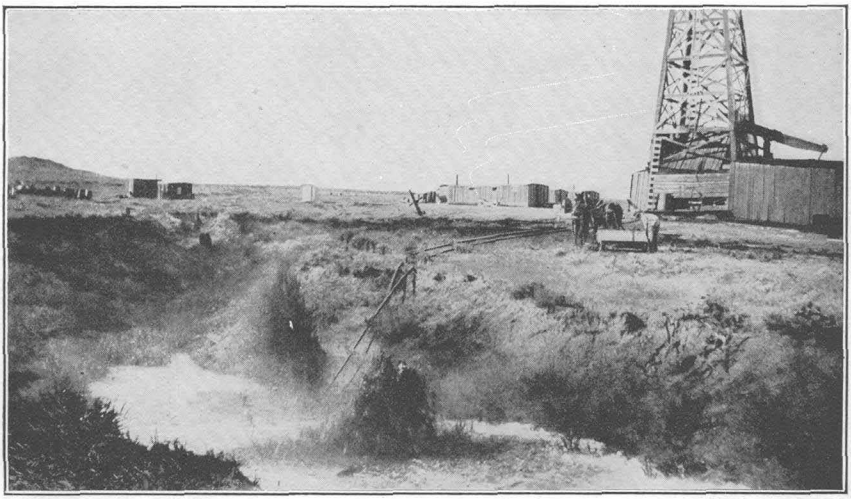
The two wells (Nos. 30 and 33) near the southeast corner of sec. 34, T. 36 N., R. 65 W., are shown as water wells, as it is reported that water was encountered in each well in the upper sand. Deeper drilling may prove that the lower sand contains oil, and if through skillful manipulation the upper sand is properly cased off, these wells may still become producers. It was reported that early in January the Ohio Oil Co. was at work cementing off the water in the upper sand in its No. 2 well in the NE. ¼ sec. 4, T. 35 N., R. 65 W. The peculiar occurrence of oil and water in the upper and lower sands, as shown in the above table, indicates that the upper sand should invariably be carefully tested. If the supply of oil is not satisfactory this sand should be mudded and a string of pipe put through it and cemented before drilling into the lower sand. If the upper sand is nonproductive and yet does not contain water, this practice will prevent the oil and gas under high pressure from the lower sand from escaping into the upper sand. If the upper sand is water bearing and the lower sand is productive it will prevent the productive sand from being flooded as soon as the rock pressure in this sand becomes lower than the water pressure exerted from the upper sand.

SUGGESTIONS FOR DEVELOPMENT.

According to the writer's interpretation of the structure there is little probability of finding in the area east of T. 36 N., R. 65 W., pools of oil comparable to that which lies in that township and the one immediately south, and yet it seems reasonable to expect that some oil may have accumulated near the axis of the anticline, at least as far east as the east line of sec. 26, T. 36 N., R. 64 W. Northeast of that line the anticlinal axis is more steeply inclined and the conditions are not quite as favorable. The two water wells in sec. 31, T. 36 N., R. 64 W., one near the northwest corner and the other near the north quarter corner, suggest a slight lowering of the anticlinal axis at that locality. If such is the case there is probably a corresponding rise in the axis immediately east of that place and a slight closure a short distance west of well No. 1 of the Midwest Refining Co. in sec. 28. The field evidence seems to indicate that the anticlinal axis pitches eastward rather rapidly from that point. If the structure is as shown, the gas, oil, and water would naturally migrate up the steeply dipping sands, mainly from the northwest, and finally tend to accumulate where the axis becomes more nearly horizontal or where it is gently arched. If the Newcastle sand is reasonably thick and porous and continues northwestward from the anticlinal axis for a considerable distance, it is reasonable to expect a certain amount of



A.



B.

DISCHARGE OF OIL INTO A DAMMED-UP GULCH AT THE OHIO OIL CO.'S DISCOVERY WELL IN THE NW. ¼ SEC. 36, T. 36 N., R. 65 W., LANCE CREEK FIELD, WYO.

concentration in the sand near the anticlinal axis and for some distance down the dip, especially north of the axis. The most promising territory lies west of the east line of sec. 26, T. 36 N., R. 64 W., because there the anticlinal axis is more nearly horizontal and also because farther east the depth of the sand increases very rapidly. The best part of this promising territory appears to lie southwest of the developed portion of the field, more or less in line with the hypothetical anticlinal axis, as indicated on Plate X by the broken line extending across secs. 5 and 8. The abrupt rise in the anticlinal axis from the vicinity of the discovery well westward is the natural result of the abrupt change in the strike of the beds. If the strike continues in a southwesterly direction for a considerable distance beyond this abrupt change, then the anticlinal axis in all probability also pitches toward the southwest. The trend of the structure contours southeast of the anticlinal axis seems to indicate that the higher contours close around the fold rather quickly and that the axis pitches in a southwesterly direction, very much as it does from the highest portion of the anticline eastward toward the discovery well.

Other sands lower than those which have been tested in the Lance Creek field should ultimately be tested near the highest portion of the Lance Creek anticline. It is the writer's belief that in the Mule Creek field the oil comes from a portion of the Lakota sandstone. In the Greybull field the Greybull sandstone member of the Cloverly formation produces most of the oil and gas. In the Powder River field the approximate stratigraphic equivalent of the Cloverly, 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 also in the Sundance formation. In the Lander field the Carboniferous portion of the Embar group bears some oil, and a 1,730-foot boring on the Old Woman anticline, a short distance east of the Lance Creek field, is reported to have found considerable oil, doubtless in the Minnelusa sandstone, also of Carboniferous age.

In an area structurally so promising as the producing portion of the Lance Creek field, it seems advisable for the different operating companies to combine, if possible, and drill at least one well near the top of the fold in order to test all the sands, or at least all including those in the Sundance formation. According to the table of formations on pages 95–96 all these sands could be tested by drilling to a depth of approximately 4,200 feet.

QUALITY OF THE OIL AND GAS.

The following analysis of a sample of oil from the Ohio Oil Co.'s discovery well is fairly typical of most of the oil in the Lance Creek field. A much heavier black oil is reported, however, from the Buck Creek Oil Co.'s No. 7 well in the NW. ¼ sec. 35, T. 36 N., R. 65 W.

Analysis of oil from discovery well of Ohio Oil Co. in the NW. ¼ sec. 36, T. 36 N., R. 65 W.

[Made in the laboratory of the Bureau of Mines. Distillation in Bureau of Mines Hempel flask. Amount distilled, 200 cubic centimeters. Depth of well, 3,665½ feet; depth to principal oil sand, 3,663 feet.]

Gravity at 15° C.:		
Specific		0.807
Baumé	degrees	43.5
Air distillation, with fractionating column:		
Barometer reading	millimeters	740
Distillation begins	degrees C.	25
To 150° C.:		
Total distilled by volume	per cent	29.8
Specific gravity (125°–150°)		0.760
150° to 300° C.:		
Total distilled by volume	per cent	32.9
Specific gravity (275°–300°)		0.825
Vacuum distillation, without fractionating column (175°–300°):		
Pressure	millimeters	39
Total distilled by volume	per cent	21
Residuum	do	16.3
Sulphur	do	0.043

The gasoline content of the gas from three of the wells of the Ohio Oil Co. in the Lance Creek field, as shown by an absorption test made by J. K. Gibson, of the Hope Natural Gas Co., is shown by the following data, which were furnished by the Ohio Oil Co.:

Data on gas wells of Ohio Oil Co.

Well No.	Location.				Volume of gas (cubic feet per day).	Pressure at which test was made (pounds to the square inch).	Specific gravity of gasoline recovered.	Gasoline content (gallons per 1,000 cubic feet of gas).
	Quarter.	Section.	Township N.	Range W.				
1.....	NW.....	36	36	65	800,000	42	0.712	1.184
1.....	NW.....	3	35	65	4,500,000	75	.778	1.277
1.....	NE.....	4	35	65	8,000,000	100	.769	1.153