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Geological and Natural History Survey
Freeman Ward, State Geologist

CIRCULAR 20

The Possibilities of Oil in Western Ziebach County

By

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EXPLANATION

The Survey issues two series of publications as follows:

BULLETINS.—Some subjects have been investigated a longer time, full data have been gathered, such preparatory or experimental work as was necessary has been entirely or nearly finished. In other words, the study of the subject is actually completed or so nearly so that the results can be relied on and published with a degree of confidence as to their value; and the treatment is full and thorough. In such a case the matter is published as a bulletin.

CIRCULARS.—But often during the progress of the work enough information is at hand to be of value to those interested, yet not enough for a complete treatise. A part of a county or a part of a certain subject may be finished, perhaps, and publication waiting for the complete investigation of the whole county or the whole subject. There may be a demand for statistical matter, or lists of references, or current information, etc., which would hardly do for a formal bulletin. Such partial reports, summary reports, reports of progress, lists, or unit fragments of larger subjects, etc., are handled in circulars.

It is planned to publish the circulars frequently and the bulletins at longer intervals. With this arrangement much information will reach the public with a minimum of delay.

Inquiries may be addressed to the State Geologist, Vermillion, S. D.

FIGURE 3 CIRCULAR 20

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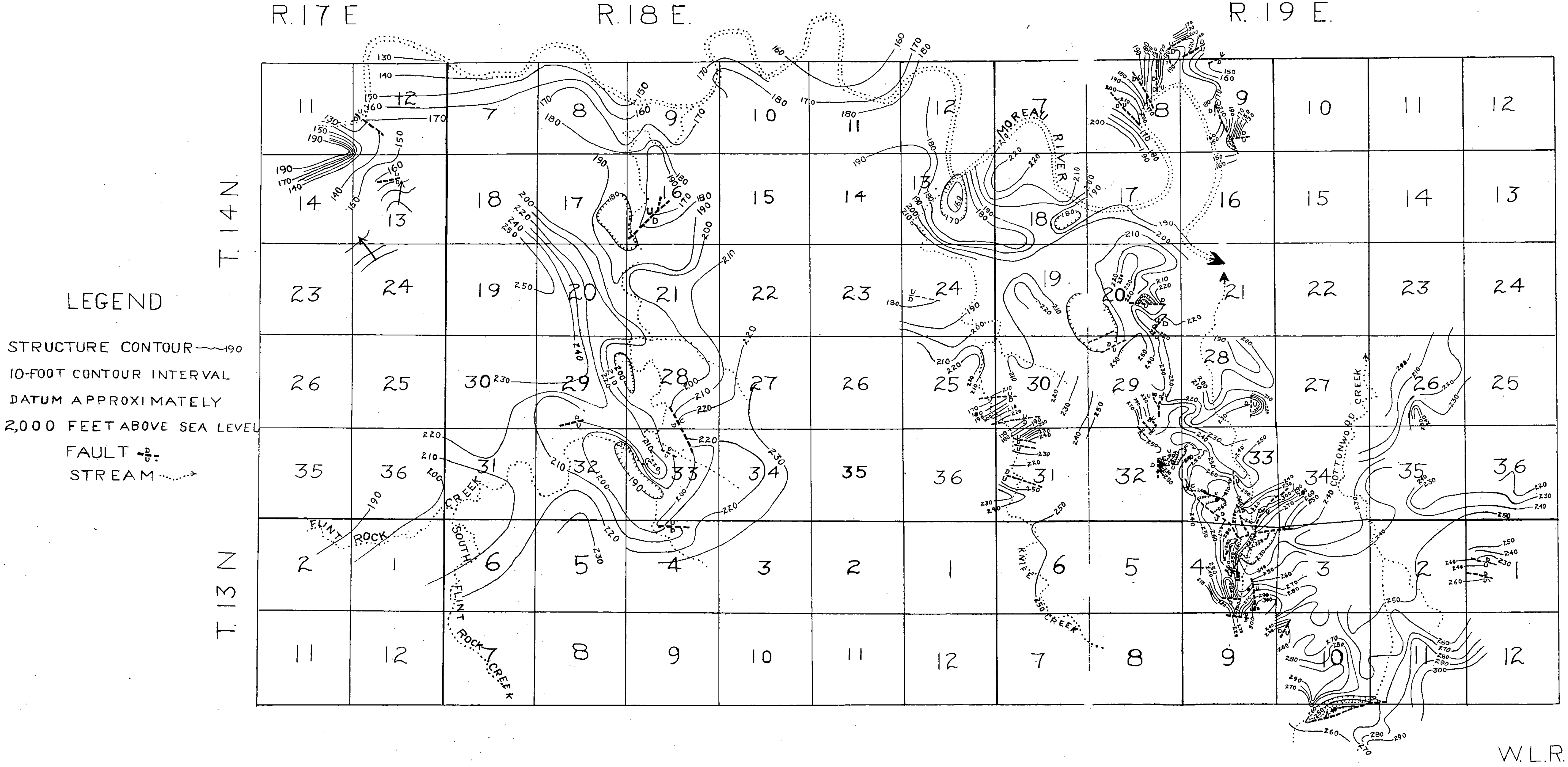

I. GENERAL CONDITIONS

1. Location.—The area discussed in this circular is located in the northwestern quarter of South Dakota in western Ziebach County and a small portion of the extreme southeastern part of Perkins County. It includes all or parts of Townships 13 and 14 N., Ranges 17, 18 and 19 E. The location of this area, together with the other areas mapped by the South Dakota Geological Survey, is shown in Fig. 1. The line of the Chicago, Milwaukee and St. Paul Railway passes through Red Elm, about four miles south of the southern boundary of the area, to Faith, about eight miles south of the southwestern portion.

2. Field Work.—About seven weeks were devoted to field work in the area. Food and transportation for the party were provided by Mr. B. V. Tidball, of Faith. A telescopic alidade, plane table and stadia rod were used in the field work, and stadia shots were taken on all the important outcrops of the key beds. The party consisted of Sydney Halvorson, instrument man, and the writer, geologist.

3. Topography and Field Conditions.—The region discussed in this report comprises several different types of topography. A considerable area consists of flat or gently rolling prairie, practically devoid of all exposures of the bed rocks. A small area at the north-

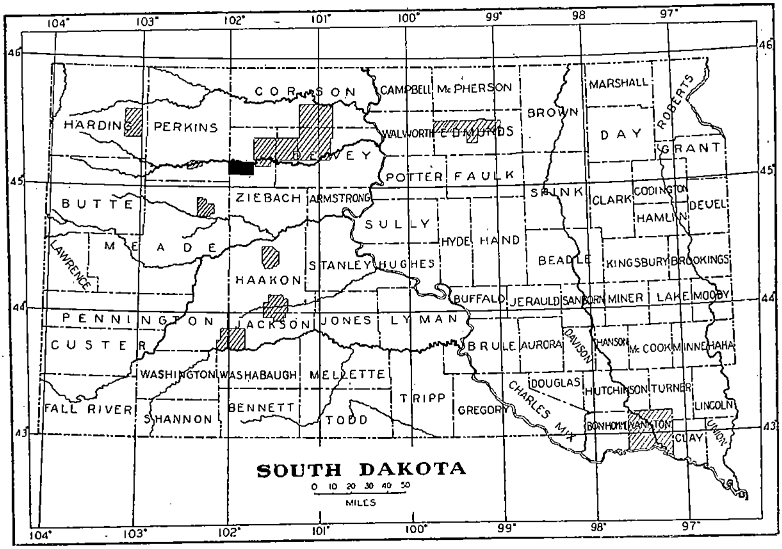

Fig. 1. Index Map

Black portion shows area covered by this report.
Shaded portions give locations of other reports already published.

ern boundary is occupied by the Moreau River flood plain. This portion is nearly flat and composed of nearly unconsolidated gravels and alluvium. A third portion, chiefly in the valley of the small creek between Cottonwood Creek and Knife Creek, consists of badlands. It is cut up into a network of small, steep-sided valleys, with bare slopes of bed rock. Along the Moreau River and its larger tributaries there are also high cliffs or cut banks, which sometimes rise precipitously for about 100 feet. The total relief of the region is nearly 300 feet.

In spite of the fact that part of the area consists of badlands, it appears that materials for oil well drilling could be moved quite cheaply. During most of the year the surface of the prairie is hard and smooth enough for hauling. The top of the Flint Rock anticline is about ten miles from the Chicago, Milwaukee and St. Paul Railway station at Faith, while the top of the Red Elm anticline is only about four miles from the Red Elm station.

Water for drilling, on the other hand, would be rather difficult to obtain. Water for drilling on the top of the Flint Rock structure would have to be obtained from the Moreau River, a little over two miles away, or from Flint Rock Creek, about a mile away. In order to obtain water for testing the Red Elm anticline it would be necessary to lay a line to the Moreau River, about three and three-fourths miles north, or to Cottonwood Creek, about a mile and a quarter to the east. In dry weather the supply from Cottonwood Creek might not be sufficient.

Some of the mineral rights on the lands in the area are owned by homesteaders, some by the government; some also belong to the Sioux Indians, but this is chiefly off the structures.

II. STRATIGRAPHY

1. EXPOSED ROCKS

A. Fox Hills.—Only two bed rock formations are exposed in the area, the Fox Hills and the Lance. The Fox Hills marks the transition between the uniform marine shales of the Pierre, and the rapidly alternating shales, sandstones, and coal beds of the continental Lance formation At the base of the Fox Hills is a thick series of banded shales and sandstones. The bands are generally an inch or two in thickness in the lower part of the formation, but in the upper part the percentage of sandstone increases, and some of the sandstone bands are several feet thick. The base of these banded beds is generally not exposed in the area, but they appear to be generally 80 feet or more in thickness. Near the base of this formation or possibly in the top of the Pierre, there is in places a layer of concretions containing innumerable ammonites of all sizes, and other fossils. This layer may be seen to the south and east, but does not outcrop in the area mapped, except possibly along the Moreau River in the northeastern part of the area. In the upper part of the banded series there are several soft, white sandstone layers, generally 1 to 3 feet in thickness, and containing soft, oblong or flattened brown or white sandstone concretions, and often lenses or concretions of hard gray limestone. These sandstone layers were used locally as key beds, but it is extremely difficult to correlate them across concealed areas.

The most important key beds are in the uppermost part of the Fox Hills formation. Immediately above the banded formation, there is a stratum of fine grained, light colored sandstone which is generally from 10 to 40 feet thick, and which often contains roundish, knobby sandstone concretions, weathering brown. These concretions are in general larger, harder and browner than the concretions of sandstone in the thin sandstones below. The character of the rocks immediately above this stratum varies greatly within short distances. In many places it is overlain by lignitic shales, in some places by banded shale and sandstone, like the formation below the sandstone. In certain areas it is overlain by 20 to 40 feet of shale, and then by another sandstone, which frequently has a marked resemblance to the lower sandstone. In one or two exposures, there are two additional sandstones above the lower sandstone, both of which contain rounded concretions like the lower sandstone, and are otherwise similar to it. In general the sandstones grow yellower, coarser, more lenticular and more cross-bedded upwards, but in many cases the concretions in the upper sandstones cannot be distinguished from those of the lower sandstone by their physical characteristics.

A bed of shells is frequently developed just above the lower sandstone. In the western part of the area this consists chiefly of oyster shells, while in the eastern part, in the vicinity of the Red Elm anticline, it is composed almost entirely of clam shells. A few snail shells were also noticed in this stratum. The bed of oyster and clam shells is not everywhere developed at its horizon. It consists rather of patches or lenses, sometimes nearly 30 feet thick, and composed largely of shells, and it is absent over considerable areas. A stratum of sandstone and shale is here and there developed between the top and bottom of the oyster bed. On the north side of the Moreau River to the northwest of the area the bed between the oyster shell beds consists of brown, lignitic shales, soft sandstones and banded shales and sandstones. This layer is 38 feet thick in one place. North of the Red Elm anticline a bed of clam shells occurs both above and below a massive sandstone which marks the top of the banded beds. Oyster and clam shells also occur scattered through the top of this sandstone, in the eastern part of the area, and a few small shells are found very sparsely scattered through the banded beds for about 50 feet below it. To the northeast of the Arrowhead Hills, to the west of the area mapped, there is an exposure on the south bank of the Moreau River in which the lower sandstone and the sandstones above it have run together, forming a thick stratum of white or yellowish sandstone at least 92 feet thick, with the round knobby concretions, like that in the sandstone below the oyster shell bed, scattered through it from top to bottom. As neither the top nor the base of the sandstone is exposed, it may be much thicker than 92 feet. About 45 feet above its base is a layer of brownish, shaly, lignitic sandstone, which a few hundred yards further west thickens up greatly, becoming a layer of lignitic shale 15 or 20 feet thick, and containing the oyster shells.

B. Lance.—The boundary between the Fox Hills and Lance was drawn at the horizon where the banded, dark, bluish gray shales, light, yellowish gray sandstones and thicker, yellowish gray sandstones containing the rounded concretions gave place to the yellowish or brownish lignitic shales and coarser yellowish sandstones. This change does not take place at the same horizon everywhere, and in fact the base of the brown lignitic shale beds varies over a stratigraphical interval of over 50 feet, and typical Fox Hills strata sometimes overlie brown lignitic shales. It is evident, therefore, that the change from the brackish water conditions of the Fox Mills to the fresh water conditions of the Lance took place at different times in different places, and that, after the waters had receded, they sometimes returned.

In general, the base of the Lance beds lies about 30 feet above the top of the sandstone which was used as a key bed, though in other places it is immediately above the sandstone, and in section 9, T. 14 N., 19 E., the banding of the Fox Hills is apparently continued up into the lower part of the Lance, the bands consisting of an alternation of brown, lignitic shale, one inch thick, and yellowish sandstone several inches thick.

The most striking characteristic of the Lance formation is the irregularity and lenticularity of its beds. Sections measured through this formation a thousand feet apart may differ greatly, and, in fact, the beds may actually be observed to lens out even in a single exposure. The formation consists chiefly of brownish or yellowish sandstone interbedded with shale of various colors, which frequently are lignitic. No bed was observed which could be recognized over wide areas without having been traced continuously. Near the basal portion there are several hard ledges of white sandstone, weathering brown, and also beds of rather hard sandstone, containing numerous scattered particles of lignite, iron ore, and petrified wood, giving them a peculiar, twisted appearance. However, these beds occur at several horizons, and it is very difficult to correlate them in different exposures, except by actually walking out the key strata. About 150 feet of Lance is exposed in this region. The areal distribution of Fox Hills and Lance is shown in Figure 2.

C. Key Beds.—The best key beds in the area are the sandstone immediately below the oyster shell bed, and the oyster shell bed itself. The main oyster shell bed is at the same horizon, but the fact that it varies in thickness from 30 feet to one inch, and the fact that it is often split by a thick shale parting, impairs its usefulness. The sandstone just below is much more regular in thickness. It is

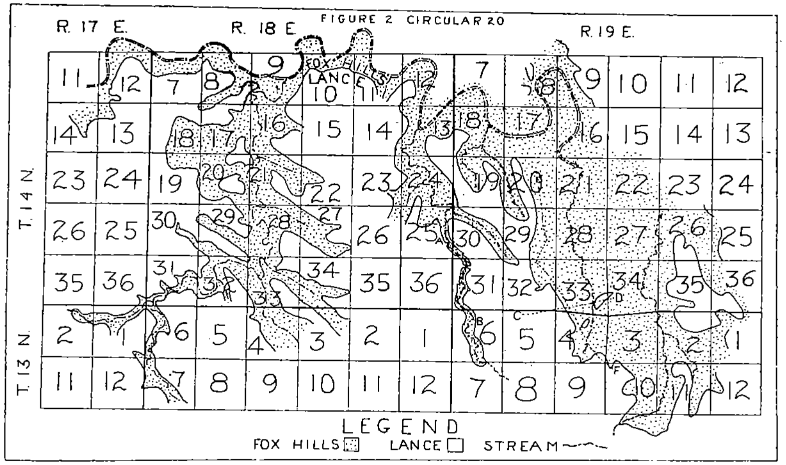

Fig. 2

true that its characteristics sometimes do not serve to distinguish it from the overlying sandstone, but it may often be identified by finding the oyster shells over it, or by its general position in the section.

The thin sandstones associated with limestone concretions, which occur in the Fox Hills below the main key bed, and the hard sandstones already mentioned in the lower part of the Lance were used locally as key beds.

D. Residual Boulders of Tertiary Rocks.—While no actual exposures of the White River or other early Tertiary rocks may be found in the area mapped, their occurrence on the tops of the neighboring buttes indicates that they once covered the territory. Residual boulders, believed to have been derived from the White River formation, occur scattered in great numbers over the whole area. These consist in a large part of blocks of a very hard, flinty looking sandstone which the microscope shows to be a very fine sandstone cemented by amorphous or microcrystalline silica. The boulders contain casts or traces of reedlike plants. Boulders of this remarkable rock are said to lie scattered over the northern part of South Dakota from the Missoui River to the western boundary of the State. According to Todd, it is found in place in the White River formation of the Cave Hills. Other boulders probably derived from the White River formation are chert or cherty limestone, and, in the southern boundary of section 33, T. 14 N., R. 19 E., large blocks of coarse, quartzitic sandstone and conglomerate.

E. Gravels and Alluvium.—Beds of alluvium and gravel of more recent date than the formations already discussed are found in the valleys and lower hills of the area. The gravel consists largely of boulders of chert, flint, bluish-gray limestone, and the flinty sandstone containing plant remains. This gravel is found as high as 150 or 200 feet above the Moreau River.

Finer materials exist at lower levels, in the flood plains of the rivers and along their borders. This material is composed largely of clay and sand, sometimes in well stratified beds, which from a distance may resemble the underlying Cretaceous rocks, as in section 21, T. 14 N., R. 19 E. The alluvium differs from underlying rocks in being wholly unconsolidated, in the absence of concretions, and in the occasional beds of gravel which are interbedded with the sand and clay of the alluvium.

2. THE UNEXPOSED ROCKS

A. General Character and Thickness.—The rocks below the Fox Hills formation are not exposed in the area, but the upper part of the Pierre shale outcrops a few miles to the south and east of it, where it consists of soft, dark bluish gray clay shale weathering light brown. There are no exposures of the strata below this formation nearer than the Black Hills, about 100 miles west-southwest. A well is now being drilled on Irish Creek, 21 miles northeast of the Flint Rock Creek structure, and 15 miles northeast of the Red Elm structure, and as this has been drilled with a diamond drill, it gives an excellent idea of the formations down to the base of the Niobrara. Another well has been drilled at Standing Butte, about 85 miles east-southeast, and the best idea of the section below the base of the Niobrara is obtained from the Black Hills section and the log of this well; but owing to the great distance of these from the area, the exact thickness and characters of the formations below the Niobrara are quite uncertain.

The following table is a tentative estimate of the formations which would be encountered in drilling a well on the top of the Flint Rock or Red Elm anticline:

Name	Thickness	Character
Fox Hills	200	Soft, grayish yellow sandstones and banded dark gray clay shales and thin sandstones.
Pierre Shale	1,500	Soft, dark bluish gray clay shale, with considerable grayish harder dolomitic shale, and at base about 150 feet of grayish black shale, with about 75 feet of bluish gray soft clay shale below it.
Niobrara Formation	275	Soft, grayish calcareous shales, containing white specks, and chalky, shaly, gray limestone, also containing numerous white specks.
Carlile Shale	200-400	Bluish gray or black shales, with dolomitic shale at top, and possibly a sandstone 100-150 feet below top.
Greenhorn Limestone	0-50	Harder gray limestone.
Upper part of Graneros Shale	200-400	Soft, bluish gray to black shale.
Lower part of Graneros and Dakota Sandstone	300-700	Bluish gray or black shale, with one to four sandstones.
Fuson, Lakota, Morrison, Unkpapa, Sundance and Spearfish Red Beds	Unknown	Shales and sandstones. May be absent.

B. Possible Oil Sands.—The log of the Irish Creek well seems to indicate that there are no good sandstones suitable for producing oil in the Pierre shale of this region. The Niobrara formation also does not seem to be suitable for producing oil in this area. Though chalky formations have been known to produce oil the Niobrara is too shaly and impure to serve as an oil "sand."

The first formation in which there is any good reason to expect a sandstone is the Carlile shale. The well at Pierre reported an artesian water sand 10 feet in thickness 55 feet below the base of what was regarded as the Niobrara. The Hunter well in the southwestern corner of Montana reported a sandy shale with a showing of gas, which may be in the top of the Carlile shale. In eastern South Dakota there is a widespread sandstone yielding water which lies either at the top of the Carlile or a short distance below it. In the northern part of the Black Hills, north of Belle Fourche, there are no sandstones in the upper portion of the Carlile, according to Folio No. 164, and only a very thin sandstone in the base of the Carlile. The Irish Creek oil well has passed through 84 feet of shales below what is supposed to be the base of the Niobrara without finding a sandstone. If this sand is present in the area under consideration it is probably from 80 to 150 feet below the base of the Niobrara, and is likely to be thin.

Thin sandstones are reported in the base of the Carlile in the Black Hills, but there is no way of telling whether they are present in this area or not. However, as they are only about 5 feet thick in the Black Hills, and are not reported at all from the Hunter well and probably not from the Standing Butte well, it does not seem very likely that they are suitable for producing oil in this area. A sand was reported in the Standing Butte well 395 feet below the assumed base of the Niobrara, but this is supposed to be in the Graneros.

The question of the possibility of sandstones in the Graneros in this area is tied up with the problem of the origin of these sandstones. If the sands which formed them were derived from the western shore of the sea in which the Graneros formation was laid down, then they might be expected to thin out and disappear to the east. If, on the other hand they were derived from the eastern shore of the sea, which is supposed to have been in western Iowa, then they might thicken up and become more numerous towards the east. Certain facts suggest that the lower part of what is known as the Granerous in the Black Hills area may in reality be the equivalent of the top of the Dakota sandstone of eastern South Dakota, and that towards the east this lower part of the Graneros becomes more sandy, until in the eastern part of the State it is a sandstone with subordinate shale several hundred feet thick, which is logged as the Dakota sand. This is merely put forth as a suggestion; it will be investigated further and reported on in later publications.

Four sandstones are reported in the Standing Butte well below what is supposed to be the top of the Graneros. At present there is not sufficient evidence to identify these sandstones and correlate them with the formations of the Black Hills. About all that is known about these is that they lie between the top of the Graneros and the top of the Spearfish Red Beds, which are said to have been encountered below them. In the Black Hills Sundance generally contains some reddish beds, and the Unkpapa is often pink, but the available reports on the well do not indicate any reddish or pink strata above the Spearfish beds. Hence there is nothing to show whether these sandstones all belong to the Dakota series of the eastern part of the State, whether they consist of the Dakota sandstone and the Lakota, or whether they consist of the Dakota, Lakota and older sandstones. If they are all equivalent to the Dakota sandstone further east, or even if only two of them may be correlated with it, the above theory of an easterly source would look much more probable.

If it could be established that the upper part of the Dakota sandstones interfinger with shales and finally die out towards the west, the prospects for oil in western South Dakota would look much brighter, for these sandstones would mean possible reservoir rocks, and their termination towards the west would prevent the unfavorable artesian circulation.

Some of the sandstones encountered in the Standing Butte well are probably present under the area described in the present report, at depths of from 2,400 to 3,400 feet. In the Standing Butte well the interval between their top and bottom was about 600 to 700 feet. Drilling should not be discontinued when the first water-bearing sandstone is encountered, for another may lie a short distance below. No test should be considered complete unless it penetrates to the red beds.

III. COST OF DRILLING

The cost of drilling oil wells varies not only with the depth, but with the location, distance from railroads, and drilling water, presence of water sands which must be cased off, hardness of formations and amount of caving. The Red Elm and Flint Rock anticlines are closer to drilling water and railroads than most of the country in western South Dakota, and there are probably no important water sands between the top of the Pierre and the top of the Carlile. Below the top of the Graneros a number of sands yielding large flows of water may be encountered, and preparations should be made to case them off. The formations are nearly all very soft, and the actual drilling would not be an expensive proposition. As, however, most of the Pierre, part of the Carlile and probably part of the Graneros consist of very soft, caving shale, which becomes a plastic mud when in contact with water, it would be necessary to follow the drill closely by casing, and consequently a considerable amount of casing would be needed. This would presumably be the chief item in the cost of the well.

Three methods of drilling might be used—the cable tool, rotary, and diamond drill. It appears to the writer that the best one for wildcatting in the area under consideration is the diamond drill. The diamond drill is much cheaper than the other two, and gives a much better idea of the formations, which is highly valuable whether oil is encountered or not. If necessary the diamond drill hole may be bailed down and the flow of oil tested. The cost of drilling a 3,300 feet diamond drill hole would probably be in the neighborhood of $30,000, possibly only $25,000. If rotaries were used, the cost would probably be considerably more, while cable tool should be the most expensive, owing to the cavy formations.

The writer is indebted to Mr. J. S. Mitchell, of the Sullivan Machinery Company, for information on the diamond drill.

IV. STRUCTURE

1. Regional Structure.—The area under discussion is on the southeastern edge of the Lemmon Basin, and consequently the regional dip is to the northwest. The amount varies from about 15 feet a mile in the area mapped to two or three feet a mile in the ten miles south of the Red Elm anticline. According to elevations obtained in an aneroid traverse, about 10 miles south of the top of the Red Elm anticline the key bed is at an elevation only a few feet higher than it is on the top of the anticline, and dipping steeply north. These facts indicate that the Red Elm anticline is on a regional arch or terrace. The Flint Rock anticline is on the north flank of this regional terrace or arch.

2. Detailed Description.—In the region covered by the structure map, there are two main anticlines, the Flint Rock anticline, which is in the southwestern part of T. 14 N., R. 18 E., and the Red Elm anticline, which is in sections 3, 4, 9, and 10, T. 13 N., R. 19 E. There is also an anticlinal structure on Knife Creek, in section 31, T. 14 N., R. 19 E., and along the southern border of the area mapped in section 4, T. 13 N., R. 18 E., and sections 11 and 12, T. 13 N., R. 19 E., there is a rapid rise in the beds toward the southeast, indicating other anticlines southeast of these areas. In addition to these major folds, there is a complicated development of small folds and faults, as is indicated by the structure map. There are, however, a great number of small folds and faults which are not indicated on the structure map. The region along the Moreau River east and west of the mouth of Knife Creek was not studied in detail and there are doubtless many more faults in that area than are shown on the map (see Figure 3).

The Flint Rock anticline is a rather broad, gentle anticline, especially at its northern end. Several faults are associated with this anticline, the largest of which, in section 12, T. 14 N., R. 17 E., has a throw of 40 to 50 feet. The downthrow side of the faults is generally on the side toward the axis of the anticline, as is the case throughout the area. As most of the region covered by this anticline is grass covered prairie with very few exposures, it is likely that there are more faults than are indicated on the map. At its southeast end the anticline becomes narrow and steep, some local dips to the southwest running as high as thirty degrees.

The closure of the Flint Rock anticline appears to be in the neighborhood of 40 to 50 feet, but it cannot be determined with accuracy, and may be more than 50 feet. There are no exposures to the west of the top of the structure, on the divide between Flint Rock Creek and the Moreau River. However, it is closed on all sides except the west, and as the key beds are dipping to the west where they pass under the valley of the Moreau River to the southwest of the structure, it is likely that the structure is closed to the west also.

In the west-central portion of section 20, T. 14 N., R. 18 E., and in the southeastern corner of section 18, T. 14 N., R. 18 E., there are outcrops of the oyster shell bed which represent the highest known part of the anticline. These oyster shell beds rise about 60 feet above the sandstone key bed at the point of closure, on Flint Rock Creek two miles south. As, however, the thickness of the oyster shell beds varies as much as 30 feet, these outcrops do not indicate the exact closure. To the west and south of the outcrops there is a wide area in which there are no exposures, and the key beds might be found by core drilling to be still higher in this territory. The closed area in the Flint Rock anticline appears to be in the neighborhood of three square miles. To the south of the structure the reversal of the regional dip is at an angle of about 15 feet to the mile.

To the east of Flint Rock Creek, between it and Knife Creek, there are several scattered areas which were not visited, owing to lack of time.

The strata are highly disturbed in an area extending in a north-northwesterly direction for about six miles from the northeast corner of section 9, T. 13 N., R. 19 E. This whole strip is marked by numerous faults, steep dips, steep folds only 40 or 50 feet across and small areas in which the strata are crumpled or tilted on edge. In sections 8 and 9, T. 14 N., R. 19 E., there is a series of fault blocks tilted to the east at angles of 2 to 10 degrees. Further south the belt of folding and faulting becomes roughly anticlinal, the strata in the central portion lying about 50 feet higher than on both sides. This is especially true of the southern part of section 33, T. 14 N., R. 19 E., where the beds dip away from the central part of the belt at angles of several degrees. The central portion of this anticline has been dropped down by faulting, forming a graben. In this case also the effect of the faulting is to counteract the rise due to the dip of the beds. The strata rise towards the anticline, but are faulted down so that they are no higher at its axis than they are at some distance from it. In the southern part of section 33, T. 14 N., R. 19 E., the strata are lower in the graben in the central part of the anticlinal area than they are for several miles on both sides of it. The relations are shown by Figure 4, Section No. 2, which is a section across the anticlinal area in an east-west direction passing close to the south boundary of section 33. The locations of the sections given in Figure 3 are indicated in Figure 2. Section No. 3, Figure 4, is taken along the anticlinal area in a north-northwesterly direction. It shows the complexity of the structure, the tendency for the strata in the vicinity of the faults to be turned up in a direction opposite to the drag and the numerous small grabens. In the central portion of section 4, T. 13 N., R. 19 E., the graben in the center of the anticlinal area becomes a syncline and, in the southeastern corner of that section, the depressed central portion seems to disappear. This is the highest known part of the anticline, and the point of greatest closure.

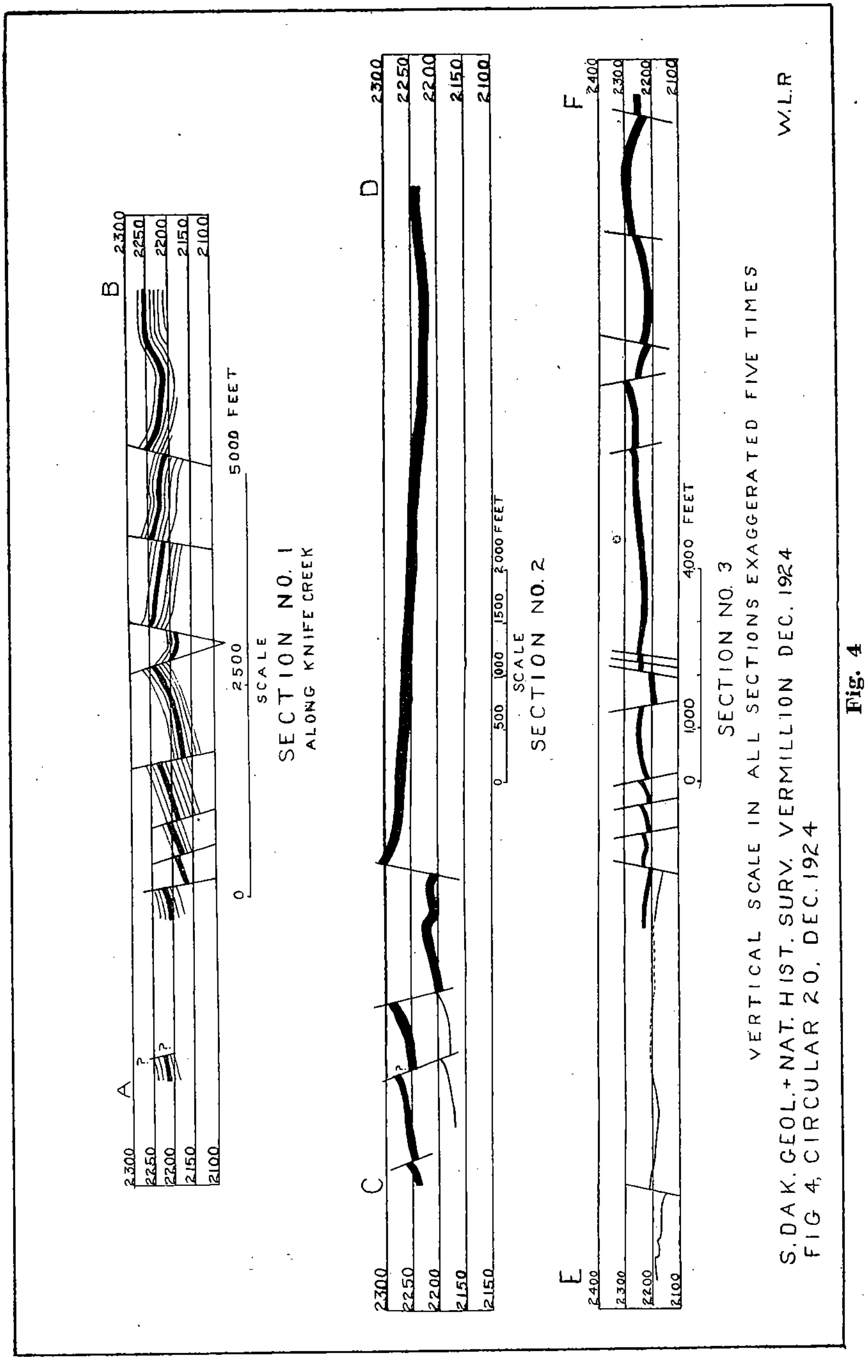

Fig. 4

The actual closure of the Red Elm anticline is also difficult to determine, owing to the absence of exposures on the southwest side. The closure in all other directions is 40 to 50 feet. The beds to the west of this highest point on the structure are dipping steeply to the westward. Nearly a mile south the beds are about 40 feet lower in elevation and also dipping south. This suggests that the anticline is closed to the southwest, but the only way to tell for sure would be to put down a shallow hole and obtain a core. Owing to the lack of exposures to the southwest, it is not possible to determine the acreage in the closed area either, but if the structure is closed to the extent of 40 to 50 feet towards the southwest, the closed area is about a square mile. It lies in sections 3, 4, 9 and 10, T. 13 N., R. 19 E. The dips on the west and northwest flanks of this anticline run as high as 6 degrees, on the north and on the northeast the dip is 2 to 3 degrees, but to the east the dip is relatively gradual. There are dips to the south and southeast running as high as 8 to 10 degrees, but they are close to faults. The manner in which the faults southeast of the top are arranged with their downthrow sides towards the top of the anticline should also be noted.

Another anticlinal area lies along Knife Creek, chiefly in sections 30 and 31, T. 14 N., R. 19 E. A section across this anticlinal area is shown in Figure 4, section 1. The area is anticlinal only in respect to the dips, for, owing to the fact that the strata are dropped down by the normal faults about as much as the dip causes them to rise, the portion near the axis of the anticlinal area is no higher than the region at a distance, in the synclinal area which bounds it. In fact, the axis of the anticline is occupied by a small graben only 700 or 800 feet across. As this anticlinal area is exposed only along the channel of Knife Creek, it is not possible to map the structure to the east and west of the exposed area bordering Knife Creek.

3. The Relation Between Structure and Topography.—The investigation of the area revealed a number of features which are not only of scientific interest, but which are of practical importance in the determination of the structure of the region. One of these is the marked relation existing between the structure and the topography. There is in this area a striking tendency for valleys to occupy synclines and for the ridges and divides to occupy the anticlines. In the western part of the area, for example, Flint Rock Creek flows in a syncline until it crosses the Flint Rock Anticline. As soon as it has crossed the anticline, which is here narrow and steep, the creek turns sharply and flows northward in another syncline, which lies east of the Flint Rock Creek anticline. In order to show this relation between structure and drainage, the streams have been indicated by dotted lines on Figure 3. Cottonwood Creek runs in the syncline south of the Red Elm anticline, and then turns north and runs in the syncline east of that anticline. In the faulted section south of the anticline, as is indicated by the map, Cottonwood Creek runs along the fault in the portion which is lowest structurally. The stream which flows in the first valley west of Cottonwood Creek also flows in the pronounced syncline or graben that lies in the central part of the anticlinal area running north-northwest from the Red Elm anticline. The area about the top of the Flint Rock anticline forms a hill on the divide between Flint Rock Creek and the Moreau River. The anticlinal area about the top of the Red Elm anticline and running north-northwest from it also corresponds roughly with the conspicuous ridge which bounds the local area of badlands on the southwest. The crest of the ridge is, however, a little southwest of the highest part of the structure, but as the slope to the northeast is much steeper, it may be that the divide has been shifted from an original position over the axis of the anticline.

It is apparent that the topography is affected by the actual differences in altitude of the beds, and not by their dips. In the areas in the graben in the south part of section 33, T. 14 N., R. 19 E., both the strata and the surface are at a low level, though the beds dip away from it on both sides at angles of several degrees. Similarly a downthrown block, in the southwestern portion of section 9, T. 14 N., R. 19 E., is occupied by lowlands, although the strata dip away from it to the northeast at an angle of 6 to 10 degrees. Furthermore, the anticlinal area on Knife Creek, in which the beds lie at about the same general elevation, but are tilted so that they dip away from a central point, has no appreciable effect on the topography.

It should be clearly understood that, while there is a marked relation between structure and topography, this relation does not form a reliable guide to the structure, for there are a great many places which are on ridges and hills but which are not in the closed anticlines.

4. **Slumping.**—In soft, semi-consolidated deposits like those of the area under consideration, slumping is of such frequent occurrence that it is of fundamental importance to be able to distiguish its effects from the results of folding and faulting. It appears that slumping is very prominent in certain regions, while in others it is practically absent. The chief factors favoring slumping appear to be the plasticity of rocks, the presence of ground water, strong relief, and a long period of time. In this area the slumping appears to be confined almost entirely to the banks of the Moreau River and its larger tributaries. Where ground water is scanty and the topography of extremely recent origin there is practically no slumping. The amount of deformation of the rocks does not seem to be of great importance, for in the badland areas north of the top of the Red Elm anticline there is very little slumping, though the rocks have been subjected to the greatest amount of folding and faulting. In one case, however, a slump along the Moreau River has apparently moved along a fault plane. The length of the slumped masses varies from a few feet to over 500 feet. There is no indication of any rapid or sudden sliding on a large scale. Most of the huge blocks have probably crept down very slowly, and they generally dip towards the direction from which they came, though most of the large blocks in this area dip at quite a low angle.

The possibility of slumping is not confined to recent geologic time, for slumps may have taken place along unconformities buried in the bed rocks. No unconformities marking buried hills and valleys are known in the top of the Pierre or the lower part of the Fox Hills formation, and therefore Cretaceous slumps large enough to affect the interpretation of the structure are not to be expected in these strata. The upper part of the Fox Hills formation and the whole of the Lance formation in the area are, however, much affected by shallow channels and local unconformities. In spite of the fact that a large area of badland topography was examined in which slumping during Fox Hills and Lance time could have been readily detected, no signs of any such slumping were observed, either in the area mapped or adjacent territory examined. It should, however, be recognized that slumping which occurred when the topography was essentially the same as it is now may become obscured by wash or alluvium.

As many of the structural features of the area have a certain resemblance to the effects of slumping, and as their interpretation is of fundamental importance in understanding the structure and oil possibilities, the criteria used to distinguish between the features due to slumping and those due to faulting and folding will be set forth at some length. The criteria indicating slumping are as follows:

1. Between the slumped blocks and the ground which did not move there is frequently a trench or depression containing undrained hollows.

2. If the slumping is related to the present topography the slumped mass will of course have moved towards the valleys and lowlands, and if there is any marked dip it is likely to be towards the highland from which it came.

3. Between the slumped block and the bed rock there is apt to be a zone filled with soil and loose fragments, and this zone differs from a true fault breccia in the fact that some of the material is derived from the surface, and that the spaces between the fragments are often unfilled.

4. The fractures induced by slumping are much less likely to be mineralized than those produced by faulting. In this area none of the fractures produced by slumping were observed to be mineralized.

5. The gliding planes of the slump are pronounced curves, steep near the upper part of the block, flatter on the lower part. Where the horizontal motion of the slump is large compared with the vertical, as is generally the case in this area, the low angle portion of the gliding plane is dominant. The dips of the fault planes are rarely low.

6. The folding and crumpling produced by slumping is generally on a small scale.

The existence of true faults and folds may be determined by the following criteria:

1. These structural features have no relation to the existing hills and valleys. The dips on the limbs of anticlines and synclines, and on the monoclines produced by faulting, may be continuous across several ridges and valleys.

2. In this area the faults are generally marked in part of their course by a gouge, which sometimes forms a ridge extending several feet above the general ground surface.

3. The fault planes generally dip at an angle of 45 to 70 degrees, which is steeper than the gliding planes of the larger slumps.

4. Some of the faults are hinge faults, that is, the same side is in some places thrown up, relative to the opposite side, in other places down, an occurrence which would scarcely be expected along a fracture produced by slumping.

5. There are numerous grabens bounded by normal faults dipping towards each other, and this relationship would be extremely difficult to account for by slumping.

6. If dips or fractures in the Lance or Fox Hills formations were due to slumping in Lance or Fox Hills time, the overlying beds would have a different dip, as in an angular unconformity, or the fractures would end abruptly at the unconformity. No such relations were observed in the area.

7. Where the same bed may be traced continuously across areas of faulting and folding, with no gaps large enough for valleys, there is no possibility for slumping of any age.

8. The crumpling and small faulting extend to considerable depths, as is indicated by the core of the diamond drill hole at Irish Creek, in which they extend down to 1,200 feet.

5. **The Reversed Drag of the Faults.**—One remarkable feature of the numerous faults of the area is the manner in which the strata near the faults are bent in the opposite direction to the drag. Sometimes this reversed drag turns them up, sometimes down, and it occurs in some places on only one side of the fault, in others on both sides. This reversed drag occasionally bends the strata as much as ten degrees. It is found in dozens of places, and appears to be a fundamental attribute of the structure of the area. This same feature has been observed by the writer in several widely scattered areas in the United States, and it appears that it is much more common than has been generally supposed. The reversed drag in some of the smaller faults affects the beds for a distance of only 50 feet or less from the fault plane, while in some of the largest faults the beds are bent for a distance of about 500 feet from the faults. In many cases there is a true drag close to the fault, in the normal direction, but this usually extends for only a few feet from the fault plane.

Two theories may be adduced to explain this phenomenon. The motion along the fault plane may have been reversed, or the reversed drag may be due to the adjustment of forces at the time of the faulting. It does not appear to the writer that the first theory will explain the features found in the area under consideration. As the faults are generally normal, the reversal of motion would mean reversed faulting, yet no reverse faults were observed. Hence if the motion was reversed it must have stopped before it had gone far enough to make the fault reverse, and it would be a rare coincidence if this happened in so many cases. As some of the faults dip at an angle of nearly 70 degrees, it would require a force equal to two or three times the weight of the uplifted block to cause a reversal of motion, even neglecting the friction along the fault plane. It seems probable that the soft strata of the area would buckle up into folds before sufficient pressure could accumulate to cause reverse faulting. Moreover, many of the faults are sealed by a hard gauge, which is more resistant than the surrounding unfractured strata. The reversed drag in some places extends several hundred feet from the fault plane, and it does not seem possible that this state of affairs could have been brought about without a great deal of reversed motion. Yet the reversed motion was never observed to be sufficient to produce a reversed fault. Moreover, many of the cases of reversed drag occur along the faults bounding a graben. As the graben is often narrow, and the faults dip towards each other, it does not seem reasonable to suppose that a great deal of motion has taken place in either direction. The strata within two or three feet of the fault plane are often dragged in the normal direction, and this indicates definitely that the last motion was not in reverse direction.

According to the elastic rebound theory of earthquakes, the fault is caused by the tendency of a rock which has been bent to assume is original shape. This causes the rocks to snap along the fault plane, and then the beds on each side of the fault plane tend to assume their original configurations. Suppose, for example, that over a certain area the rocks began to settle, forming a structural basin bounded by monoclinal flexures. When the bending at the flexures reaches the breaking point of the rock a fault would occur and a graben would be formed. Owing to the elasticity of the formations, the rocks close to the fault, on the upthrow side, would tend to rise at the time of faulting till they were parallel with the rest of the strata which had not been bent. If the force caused by the elasticity were not sufficient to raise the strata near the fault till they were parallel to the remainder of the strata on that side of the fault, then there would be a normal drag along the fault. If the force were just sufficient to bring the beds up till they were parallel with the rest of the beds, then there would be no drag along the fault. If, on the other hand, the force produced by the elasticity were so strong that it continued to drive the beds upward after they had been made parallel with the beds away from the fault, then there would be a reversed drag along the fault. It appears from a study of the region that the reversed drag is more likely to be caused by some adjustment of the forces during faulting, of which the foregoing is a possible example, than by the reversal of motion along the fault plane.

6. **Nature of the Faults.**—With the exception of a few insignificant faults having throws of two or three feet, all of the faults were found to be normal faults, whenever it was possible to determine their nature. The few minute reverse faults might well be produced in normal faulting, by minor adjustments in the fault blocks. The dip of the fault planes is generally from 45 to 70 degrees, with an average of about 60 degrees. Several hinge faults were observed, one of which, in section 33, T. 13 N., R. 19 E., is large enough to show on the structure map, Figure 3. Most of the faults are short, the greatest length being not much over half a mile, and there are innumerable small faults, not shown on the map, which extend for only a few hundred feet. The amount of throw of the faults changes very rapidly from place to place. As already remarked, many of the faults are marked by a hard gouge, which usually consists of sand cemented into a hard rock by gypsum of calcareous material. This frequently occurs in patches along the fault plane. In some places a ridge of gouge ten feet high marks a fault with a throw of only a few feet. In this case it is possible that the motion was at right angles to the fault plane, pulling the two walls apart.

7. **Nature of Folding.**—Since the faults are all normal, one would be tempted to believe that the region had never been subjected to lateral pressures, but the presence of folds and crumpled strata shows that this is not the case. The folds range in breadth from several miles to a few inches. Some of them are broad and gentle, like the north end of the Flint Rock anticline, with dips of only about 15 feet a mile, while others are only 20 or 30 feet across and dip as much as 30 degrees, and between these groups there are all gradations. The crumpling and small, sharp folding occur chiefly in the lower part of the Fox Hills formation, owing to its plastic nature, while the overlying sandstones are more likely to be faulted. This small, steep folding and crumpling also occur in the grabens, especially close to where the two faults bounding the graben meet. In the area where the faults bounding the graben in section 4, T. 13 N., R. 19 E. meet, the beds are twisted into small folds, broken into fault blocks, and even turned up on edge for a few feet. As already stated, this crumpled and fractured condition of the rocks continues to a considerable depth, but the crumpling at least is probably largely confined to the plastic formations like the Pierre and the lower part of the Fox Hills.

8. **The Collapse of Anticlines Due to Tension.**—It is well known that the outer portions of arches and anticlines are subjected to a certain amount of tension. Where the lateral pressure is great, however, as when hard rocks deep beneath the surface are thrown into folds, the tensional force due to the bending may be small compared to this lateral pressure, with the result that the rocks remain highly compressed and no tension faults or cracks are formed. In such cases the adjustments are made by one bed slipping over the other, the upper beds moving towards the axis of the anticline. If, however, a series consisting of strong beds below and weak, plastic beds above was folded, the lateral pressure causing the folding would be transmitted through the lower resistant beds, overcoming the tensional forces. In them the adjustments might take place by the slipping of one bed over the other. As, however, the lateral pressure could not be transmitted any great distance through the weak beds nearer the surface, the tension would not be counterbalanced by lateral pressure, and consequently tension cracks and normal faults might appear over the anticlines.

This condition is found in the area, which is underlain at great depths by resistant Paleozoic or Pre-Cambrian rocks, while the majority of the Cretaceous beds, especially the Pierre shale, are weak and plastic. Most of the Pierre shale will soften up and become a mud when soaked in water, even when it is obtained from far below the surface. Hence one would expect to find that in the folds the resistant rocks would be subjected to compression and that the adjustments in them would take place by the slipping of one bed over another, while the strata in the Pierre shale and above would be subjected to tension cracks and faults. The soft, uniform, clayey nature of the Pierre shale prevents the slipping along bedding planes; the beds overlying it are composed chiefly of sandstones, which are less plastic and more subject to fracturing; and the strata now exposed were probably close to the surface when the folding took place. These facts may have helped to accentuate the tensional faulting over the anticlines.

It is obvious that the normal faults produced in this manner would tend to offset the dips of the anticlines. That is, the downthrown sides of the faults would lie towards the axis of the anticline, and there would be a tendency for grabens with a triangular cross section to be dropped down over the axis. If this is the case, it is a matter of great importance, for it may mean that the amplitude and closure of the structures are much greater at depths than they are at the surface.

Anyone observing only the dips of the strata would be led to believe that the folds were much larger than is actually the case, for the total dip sometimes amounts to several hundred feet. If the faults which bring the strata down die out in depth, while the beds still keep their same dip, the rise of the strata might be several hundred feet, and the closure of the anticlines might be several times as much as it is at the surface. As has been already stated, there is frequently a graben in the center of the anticline, surrounded by normal faults dipping towards the anticlinal axis. It might be supposed that the depths at which the faulting ceased could be determined by calculating the depth at which they would meet if they continued at the same dip, but if this is the case the depths would vary from a few hundred feet to several miles. It may be that the faults die out in the shales before reaching the depths at which they would meet. On the other hand, other faults may be present at depths, arranged in echelon with the surface faults, so that the faulting may continue below where the surface faults would meet. According to the theory stated below, the tensional faults should disappear at the depth where the strata became rigid enough to transmit the great lateral pressure which caused the folding. The upper portion of the Pierre shale is all extremely plastic, as already stated, but near the base there is a stratum of hard, fissile, bituminous shale which is much more rigid. The Niobrara limestone, the Benton shales and the Dakota sandstone are probably as a whole slightly more rigid than the Pierre shale; the Paleozoic limestones, if present, are still more rigid, while the Pre-Cambrian crystallines are the most rigid of all.

It should be understood that this theory has not been definitely proved in this area and, furthermore, even if it is true that the closure becomes much greater at depths, the change may take place only at depths which could not be reached by the drill. Hence an anticline having a large closure at the surface is much better than one having the possibility of a large closure below the surface, though at the same time the relation of the faults to the anticlines is a distinctly favorable feature.

9. The Reliability of Local Dips.—For a number of reasons, the structures in this neighborhood cannot be mapped with any degree of accuracy by simply plotting the dips of the strata measured with a clinometer. It is well known that slumps are apt to cause apparent local dips which have no relation to the structure, though in this region dips caused by slumping are comparatively rare. In most of the area the dips are too low to be measured in local exposures. It would have been impossible to map the Flint Rock anticline by this method, owing to the low dips. In the Lance formation deposition on uneven surfaces and other stratigraphic irregularities cause may local dips, though these dips were never observed to be more than a few degrees. When the dips are steep they are apt to be very unreliable, owing to their rapid variation. As already mentioned, there are many small, steep folds only a few feet across, local dips along fault planes, and small fault blocks tilted in various directions. Hence, where there are isolated exposures, it is impossible to tell whether the dips are continuous between them. Moreover, even when the exposures are practically continuous and the dips steep, it is impossible to form any correct idea of the structure upon the basis of the dips alone, for the faults may continually bring the strata down as much as the dips cause them to rise. Anyone attempting to map the structure by means of the dips alone would be apt to form a greatly exaggerated idea of the size and closure of the anticlines.

On the other hand, a complete idea of the structure cannot be obtained simply by taking widely scattered elevations on the key beds, without considering the dips and faults. The careful observation of the local dips may reveal the existence of faults and fault blocks which could not be determined by such scattered elevations, and the question of whether the structural features are due to faulting or folding obviously has an important bearing on the oil possibilities.

V. OIL POSSIBILITIES

1. Fundamental Conditions.—Before an area should be considered encouraging for the occurrence of oil, four conditions must be present:

1. Porous reservoirs must be present to contain the oil.
2. Impervious rocks must lie above the reservoirs to prevent the oil from escaping.
3. Strata containing organic material from which oil may be formed should be associated with the reservoir rocks.
4. Some sort of trap, such as a closed anticline, should be present to concentrate the oil and prevent it from escaping to the surface.

At least two porous sandstones are believed to lie below the Red Elm and Flint Rock anticlines, and these would be of sufficient thickness and porosity to produce oil. The thick series of shales overlying the sands, especially the Graneros, Carlile and Pierre shales, would make very good impervious seals to prevent the oil from reaching the surface. It is possible that oil would occur in fractures in the limestones, provided that the deformation is intense enough to fracture them. The black shales in the bottom of the Pierre are rather hard in places, and they might be fractured enough to be porous in the areas of most intense deformation.

Bituminous shales which might serve as source rocks for the oil probably also occur at about the horizons of the oil sands, for such shales are generally dark colored, usually brown or black, and black shales are reported from close to the horizon of the Dakota sandstone in southeastern Montana, and in the outcrops in the Black Hills. Dark colored shales are reported from the same horizon in the Standing Butte well. As at least one closed structure is present, there is some reason for thinking that all these four requirements have been fulfilled; though at the same time it should be recognized that very little is known about the deeper strata of this area.

2. Effect of Faulting.—In many areas, as in eastern Texas, faulting is known to be favorable to the accumulation of oil, because the fault forms a trap which causes an accumulation of oil on the down-dip side. It is doubtful, however, if any of the faults in the area under discussion are likely to cause an accumulation of oil in this fashion. The faults may die out with depth, or other faults in different positions may take their places. Furthermore, there are so many faults that even if they continue down to the oil sands a great many insignificant accumulations might be produced instead of a few important ones.

Some have claimed that faults are unfavorable for the occurrence of oil, because they would allow the oil to escape to the surface; while others have thought that the faults might have a favorable effect by furnishing a passage for the migration of the oil. The danger that the faults would allow the oil to escape is much lessened by the character of the Pierre and Benton shales, especially the former. The Pierre shale is so soft and plastic that it would be likely to close the openings along the fault planes. On the other hand, in soft shales, such as those of the area, there are no joints, and it is possible that the oil might be prevented from migrating from the source rock to the oil sands until an opening was formed by the faulting. Although, as already mentioned, it may be that the great number of faults may obstruct the migration of the oil to the top of the anticline, nevertheless it should be remembered that several oil pools in the Rocky Mountain region are located in anticlines cut by a considerable number of faults.

3. **Effect of Intensity of Folding.**—In the northwestern part of South Dakota there are two different types of folds—large, gentle undulations practically without faults, and steep, faulted structures. As neither has been tested, it is not known which is the most favorable for oil. However, many of the oil pools in Cretaceous rocks occur in steep anticlines, though by no means all of them, and two of the gentle anticlines south of the Black Hills have been tested with negative results. It appears, therefore, that some of the steep, faulted structures should be tested.

At first sight it would appear that the Flint Rock anticline is better than the Red Elm anticline, for the closed area is much larger. However, the fact that the Red Elm anticline is on a regional arch or terrace, is in an area of more intense deformation and is steeper, and the more pronounced arrangement of the faults about the Red Elm anticline, might be considered favorable indications.

4. **Effect of Artesian Circulation.**—The fact that sandstones containing fresh water are generally barren of oil, and that sandstones in which oil occurs usually contain salt water, has been interpreted to indicate that pronounced artesian circulation, intense enough to flush out the original salt water of the oil sands, is unfavorable to the accumulation of oil. The oil pools might be washed out by the artesian currents, or the oxygen, sulphates or other substances dissolved in the fresh water may combine with the oil and destroy it. In the west-central portion of South Dakota there are a number of artesian wells which produce hot water along with some gas. It is possible that this heat is caused by the combination of chemicals dissolved in the artesian water with oil, gas or carbonaceous matter in the associated shale. In general, waters become more salty towards the Lemmon Basin in the northwestern part of the State, though none of the available analyses indicate salinity at all approaching that of sea water. In the southwestern part of Montana, however, the Hunter well of the Absoraka Development Company encountered in what was supposed to be the Dakota and Lakota sandstones water which was nearly as salty as some sea water. Hence, although no wells have penetrated to these sandstones in the region under consideration, there is some reason to believe that the artesian circulation is very much reduced there, and that some of the sandstones might contain brackish or salty water. This is of course a very favorable feature.

5. **Chances for Finding Oil.**—It should be clearly understood that, in areas removed from production, it is impossible to determine the presence of oil in advance of the drill. Even where all the conditions are favorable, as far as can be ascertained from the surface, many of the closed anticlines are dry. Possibly some idea of the chances for striking oil in the structures under consideration may be obtained from the statement that of the large, closed structures of the Rocky Mountain region, recommended for testing by several geologists, only about one out of three is productive in commercial quantities; and the structures in the area mapped do not appear to be as favorable.

VI. CONCLUSIONS

1. Two faulted anticlines, at least one of which has a fair amount of closure, have been located in the area covered by this report.

2. Other conditions for the accumulation of oil are believed to be present.

3. The structures are quite close to a railroad, and fairly close to drilling water.

4. The anticlines present structural problems of considerable interest, which may have an important bearing on their oil possibilities.