Bulletin 10

The Possibilities of

OIL IN SOUTH DAKOTA

A Preliminary Discussion

By

Roy A. Wilson

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LETTER OF TRANSMITTAL

Vermillion, S. D., February 11, 1922.

Hon. T. W. Dwight, President,
State Board of Regents.

Dear Sir:

The natural resource about which there is the greatest interest at present is undoubtedly petroleum. And South Dakota as a potential new oil field is a problem demanding immediate attention if illegitimate promotion is to be prevented and reputable development encouraged. Mr. Wilson's reconnaissance survey of the oil possibilities of this state is a very important part of the thorough investigation being undertaken by the Survey. The results of his field work and study are herewith incorporated under the title "The Possibilities of Oil in South Dakota, a Preliminary Discussion," which I recommend being published as Bulletin No. 10 of our Survey.

Respectfully,

Freeman Ward,
State Geologist.

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INTRODUCTION

Up to the present time South Dakota has produced no oil. A similar statement holds true for natural gas, with the exception of some production in the central part of the State. In this region gas, associated with artesian water, occurs in a few localities in quantities sufficient for local use.

It is only in recent years that attention has been directed to the State as a possible source of oil and gas in commercial quantities. Previous lack of exploration has been largely due to the supposedly unfavorable geologic features. Over a large part of the State the rock strata lie nearly horizontal, no well-marked structures showing outside the Black Hills uplift. This general absence of distinct folding has caused those interested in oil field development to direct their attention to the adjacent states where structures are more evident.

The declining production in some of the great oil fields of the nation and the increasing importance of petroleum products in our industrial and everyday life are causing areas hitherto considered unfavorable or of minor significance to receive active consideration as possible oil and gas regions. The State of South Dakota, especially that part west of the Missouri River, is one of the localities in which explorations for petroleum have been recently started. For some years haphazard prospecting has been carried on but in many instances the drilling has been shallow and frequently without sufficient geologic evidence to warrant the tests made.

With the above facts in mind and in response to numerous inquiries regarding oil possibilities in various parts of the State, the State Geological Survey has for some time planned a study of South Dakota for petroleum possibilities, but lack of sufficient funds has delayed the beginning of the work. At the last legislative session a sum was appropriated sufficient to start the investigations.

The purpose of the State Geological Survey is not only to furnish the people in the State with information relating to its mineral deposits and other natural resources, but also to give the public the services of competent geologists without the usual monetary considerations. Geologic work carried on by official surveys has great value aside from its scientific features. Responsible organizations and conservative capital generally tend to place much reliance on the work of official surveys, inasmuch as the investigations are carried on in an impartial way, and, unlike work done by private organizations, the resulting information is available to all who may be interested.

The geology of a considerable part of South Dakota has been worked over in some detail by the State and United States geological surveys but there are extensive areas which have been scarcely touched, except in an exploratory manner—this being true of much of the region considered in the following bulletin. Furthermore, very little attention has been given to geologic features bearing upon possible oil and gas deposits. The oil and gas investigations by the State up to the present time consist of reconnaissance studies in a number of localities by the State Geologist and detailed work in the White River Badlands near Interior. The United States Geological Survey has published a preliminary statement dealing with oil and gas possi-

Ward, Freeman, Bibliography of South Dakota Geology; South Dakota Geological and Natural History Survey, Circular 5, 1915.
Ward, Freeman, Oil in South Dakota; South Dakota Geological and Natural History Survey, Circular 1, December, 1917. Ward, Freeman, The Possibilities of Oil and Gas in Harding County; South Dakota Geological and Natural History Survey, Circular 4, October, 1918.
Ward, Freeman, The Possibilities of Oil in Eastern Pennington County; South Dakota Geological and Natural History Survey, Circular 8, October, 1921.
OIL IN SOUTH DAKOTA

The field work for this report was begun the first of July, 1931, and continued into the early part of November. During most of the season the writer was aided by an assistant. The Brunton pocket transit, aneroid barometer, and hand level were used in the mapping and determination of structural features. Travel over the region was largely by automobile. The numerous roads and the fact that much of the country is gently rolling prairie, over which a car can pass, even where roads are absent, made it possible to cover an extensive amount of territory. Generally, the party was guided by a resident thoroughly familiar with the region under consideration, a fact which greatly facilitated the work. In a number of localities, people interested in the investigations cooperated by taking care of the living expenses and furnishing automobiles and fuel at their own expense. This assistance has been of very material aid in forwarding the field studies and in extending the utility of the funds designated for the work.

The area studied this season includes much of that part of the State lying with the Cheyenne and west of the Missouri rivers. Short trips were made into adjoining parts of North Dakota, Montana, and Wyoming. South of the Cheyenne River reconnaissance studies were made in portions of Haakon, Stanley, Jackson, and Pennington counties. A number of points bordering the Black Hills from Belle Fourche to Edgemont were visited, but inclement weather, due to the lateness of the season, did not permit any thorough investigations in this region.

The next year the writer's thanks are rendered for efficient assistance in the field work. The courteous cooperation of those individuals and organizations furnishing well logs and other data is gratefully acknowledged. Such material has been of considerable value in compiling this bulletin. Space does not permit individual acknowledgment of the hearty cooperation and many interesting observations recorded during the season. The general desire to aid the State Survey in its work was found to be true of practically all communities visited. Without this active cooperation much that has been accomplished this season would have been impossible.

PART I

THE APPLICATION OF GEOLOGY TO OIL FIELD DEVELOPMENT

1. INTRODUCTORY STATEMENT.

The material incorporated in this section of the bulletin constitutes common knowledge to those familiar with the various phases of oil field development. However, since this publication is primarily intended for the general information of the people of the State and those interested in its resources, it is assumed that many of the readers may be more or less unfamiliar with the basic principles of oil geology and the application of this science to the petroleum industry. Therefore it has been considered advisable to include the following discussion of the more important fundamentals relating to oil geology and oil land development. An understanding of these fundamentals on the part of the public is highly essential as an aid to proper exploration and development of the resources considered. The information in this part of the bulletin should also be of service in gaining a clearer conception of the parts that follow. The reader who desires to go into the following topics more thoroughly will find references to standard textbooks on the subject of oil geology at the end of the bulletin.

2. THE ORIGIN AND ACCUMULATION OF PETROLEUM

The various hydrocarbons which make up natural gas, petroleum, and its residual solids are now generally thought to have originated from the distillation of organic matter. This organic matter was broken down in sediments which form the strata of rocks. It is possible for hydrocarbons to form through inorganic agencies, but such occurrences in nature are rare. It is probable that no commercial accumulations have formed in this manner.

Plants and animals have contributed to the formation of petroleum and its related products, although there is considerable difference of opinion as to the relative importance of each in this process. The weight of accumulated evidence indicates that the plant and animal matter forming oil and gas were entrapped in the mud deposited in marine waters that have covered portions of our continent at various times in geologic history. After the burial of this organic material in the marine mud, a process of decomposition has followed, resulting in a residue of fatty and waxy substances.

Since all oil and gas deposits of commercial importance have formed in marine sediments, it is assumed that the salt in the water has acted as a preservative or in some other special manner to pre-

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*The natural hydrocarbons constitute a complex chemical series in which carbon and hydrogen have united in various ratios to form a great number of compounds. In addition to the elements carbon and hydrogen, occur impurities, such as nitrogenous products, sulfur, and oxidized substances. The various series, of which the paraffin and naphthenic series are the most important, range from gaseous compounds, through the liquids (oils), to the solids (asphalt, etc.).*
vent normal decay. The part that salt plays in the process, however, is not well understood. Organic matter buried in fresh water sediments does not tend to form petroleum, because its more readily accessibility to oxidation causes a mode of decay unfavorable for this process.2 The same is probably more or less true of organisms buried in sandstones or other coarse sediments. Sandstones are generally less fossiliferous than shales or limestones, owing to the fact that organic matter buried in coarse sediments is frequently destroyed by secondary processes before sufficient time has elapsed for fossilization to occur.

As the marine muds containing the fatty and waxy residue become deeply buried under overlying sediments, the muds compact to form rock (shale). The pressure and heat produced by the weight of overlying sediments and deformation or folding of the rocks cause a natural distillation of the organic residue, and a product composed of a mechanical mixture of oil, gas, and water is formed.

MIGRATION OF PETROLEUM INTO RESERVOIR ROCKS

The causes of migration and accumulation of the originally disseminated petroleum and gas are varied, and involve complexities which cannot be considered in this discussion. It is probable, however, that the movement of the petrolierous products out of the shales, where they largely originated, and into more porous reservoir rocks has been primarily influenced by pressure and capillary attraction.3 The compacting of the shales due to pressure causes a partial expulsion of the oil, gas, and water. Associated with this process is the selective segregation of the oil, gas, and water due to differences in capillarity of the substances. The water, owing to its greater capillarity, tends to remain in or work into the smaller pore spaces. Thus the oil and gas are forced into the larger pore spaces of the adjoining reservoir rock.

STRUCTURE OF RESERVOIRS AND RELATION TO ACCUMULATION OF PETROLEUM

The essential features of a reservoir for oil and gas are a pervious bed or stratum, capped and preferably underlain by an impervious bed. The pervious bed is generally a sandstone, but may be limestone, conglomerate or other rock type. Fractures in rocks also serve, but to a much less extent, as gathering places for petroleum. The impervious cap rock of the reservoir is generally water.

Fig. 1. Accumulation of Oil and Gas in an Anticline

3The great oil shale deposits of the Green River basin and adjacent areas in Wyoming, Colorado, and Utah illustrate a case where petrolierous substances have formed in inland lakes or non-marine bodies of water. It is quite possible, however, that these lakes were somewhat saline.

3Capillary attraction is due to the adhesion of liquids to the walls of their containers, and is typical of liquids enclosed in minute spaces. The degree of attraction is determined by the surface tension of the liquid. The movement of moisture through soil or of ink through a blotter illustrates this phenomenon.

saturated shale, clay, or marl, but may be a dense limestone or a tightly cemented sandstone.

The accumulation of petroleum in a reservoir in commercial quantities requires the presence of various types of structures to form traps. The separation of the oil, gas, and water in these structural traps is due largely to gravity, the lightest substance or gas moving to the top, the heavier oil lying below this, and the heaviest substance or water lying under the oil. If the reservoir rocks were not folded but lay horizontal this separation would occur but the oil and gas would be distributed over so wide an area in the sand that they would not be commercially recoverable. The value of folds lies in their serving to concentrate the petroleum to very restricted areas. The value of folds is much greater if they are closed, that is, if the strata dip away on all sides from the highest point of the fold.

Fig. 2. Accumulation of Oil and Gas in a Terrace Structure

The structural traps in which oil and gas accumulate are of various types. The common types are illustrated in figures 1 to 5. Domes and anticlines constitute the most favorable structures. They are typical of the Rocky Mountain fields. The dome is a special type of anticline in which the width of the fold is nearly equal to the length. Other types of structures in which oil and gas occur are synclines, monoclines, and terraces. Igneous intrusions, seated faults, unconformities, joint cracks, sealing of sand by asphallic deposits, and contact of sedimentaries with crystalline rocks, may also serve as traps for oil and gas. These last named types are less common.

Fig. 3. Accumulation of Oil and Gas, Due to Decreasing Porosity of Sand

WATER IN THE RESERVOIR ROCK

If the sand is saturated with water, the oil and gas will lie at or near the top of the structure. If the sand is partially saturated, the oil will lie part way down the structure. In rare cases the sands are nearly free of water and the oil lies in the lowest part of the structure. These relationships are illustrated in figures 1, 7 and 8.

The water in the sands may have two sources. The salt water is generally what was incorporated in the marine sediments at the time they were deposited. Ground water, which may enter into the sand from the surface, has its origin in the moisture that falls upon the
ground and works its way through the soil into the cracks and fissures of the bed rock. The movement of this water through the sand may aid in concentrating the oil and gas by pushing those substances before it to the highest part of the structure, where they arrange themselves in the manner already described. The character and movement of the water in sands constitute an important problem in every oil field, and especially in those fields where numerous wells are drilled close together. The wells which penetrate the sands set up varied currents, which may cause the flooding of some oil wells by water and an increased flow of oil in others.

**Fig. 4. Accumulation of Oil and Gas, Due to Irregularities of the Upper Surface of Sandstone Stratum**


**ESCAPE AND DISSEMINATION OF OIL AND GAS**

The oil and gas which enter a porous rock from surrounding shales may escape or be disseminated. If the reservoir rock is horizontal, or nearly so, and has a fairly uniform porosity, the petroleum would be too widely disseminated through the rocks to give commercial yields. In such a sand, however, a pool might be formed by a barrier due to local cementation, tight packing of the sand grains, or pinching out of the sand. The finding of accumulations formed in this manner is largely a matter of accident as they give little, if any, surface indication of their presence.

**Fig. 5. Accumulation of Oil and Gas, Due to Faulting**


If the reservoir rock is exposed by erosion, faulting, or porous overlying beds, the oil and gas may gradually seep out until the reservoir is largely drained. Evidence of the escaping petroleum is indicated by oil or gas seeps, the asphaltic character of the outcropping rocks, or solid hydrocarbons filling fissures near the surface. As the oil reaches the surface, the more volatile parts evaporate, leaving behind, in the case of heavier oils, a solid or semi-solid residue generally known as asphalt. This asphaltic material may sometimes seal up the sandstone bed, where it is exposed, and serve as a trap for commercial quantities of oil or gas lying below. The presence of asphaltic material in outcropping sands may not always be a favorable indication, as this evidence may indicate that most of the oil has escaped. This may be probable if no folds occur down from the outcrop to form traps.

**PRINCIPLES OF PETROLEUM GEOLOGY**

**MEANING OF THE TERM "OIL POOL"**

Although the term "oil pool" is commonly used this usage does not mean that oil actually occurs in pools or lakes as is true of water over the earth's surface. The oil and gas fill the minute pore spaces in the sand or reservoir rock. Sandstone, shale, and other rocks appear solid and dense to the eye, but examination under the microscope shows that they are filled with very minute cavities or pore spaces. Some sandstones have a porosity running as high as 30 per cent, and yet such sandstone would appear as a solid rock to the eye. The average porosity of sandstones is about 10 per cent. Shales, owing to the looseness of the materials of which they are composed, have a much smaller porosity, and are very impervious to the passage of oil and gas, especially if saturated with water. The amount of oil commercially recoverable from oil-bearing rocks is not equal to the pore space but is generally only a part of the total reservoir content.

**3. ORIGIN OF THE ROCKS ASSOCIATED WITH OIL AND GAS DEPOSITS**

The rocks generally associated with oil and gas deposits belong to a group known as the sedimentary rocks. These have been formed from sediments which accumulated under various conditions over the continent during geologic time. Some of the sedimentary rocks represent river and lake deposits; others, colluvial and wind deposits; others, which dominate by far over the continent as a whole, represent deposits laid down in great shallow seas that have since been parts of North America from time to time in geologic history. It is with this last type of sediments that the oil geologist is especially interested, since they form by far the most important source of oil and gas.

**Fig. 6. Accumulation of Oil and Gas in Lenticular Sands**


The marine sediments in which petroleum deposits have been formed are mainly shales, sandstones, and limestones. The shale has been formed from mud; the sandstone from sand; and the limestone from lime shells of marine animals and from lime precipitated out of solution in the water. The gravels and pebbles of the old sea beaches form conglomerates. The above rocks, with the general exception of limestone, are also formed in lakes, rivers, and oceans, and are, therefore, not limited to the land. The coarse sediments tend to be deposited near shore and the finer sediments away from the shore. Hence the conglomerates and sandstones are more typical of near-shore areas, where the shallowness of the water permitted a continual agitation and current action, allowing only the coarsest material to settle. In the more quiet offshore waters the finer sediments settle to the bottom. The limestones have formed where the waters are most clear. Such areas tend to be in the quiet or offshore waters, although clear waters near shore would permit the formation of limestone. The factors deter-
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Figure 7. Anticline Concealed by an Unconformity


mining the formation of sandstone and shale are varied. Under certain conditions sandstones have formed at great distances from shore and shales very near shore. In general, however, the sediments increase in coarseness towards the land, the shales grading shoreward into sandstones.

The chief source of these sediments is the material carried into the seas from the eroding land areas by rivers and other transporting agencies. The erosive action of the waves on the shore line has also contributed to the formation of sedimentary rocks. The lime which has formed the limestone has been carried into the seas in solution and then used by marine animals to build their shells, or else precipitated out by chemical reactions. The sand, mud, and silt have been carried in suspension into the areas of deposition.

The grains of sand and particles of mud and silt have been compacted together by pressure due to weight of overlying sediments and by the deposition between the grains of cementing materials carried in solution by circulating waters. The common cementing materials in sedimentary rocks are iron oxide, silica, and lime. When the cementing material is some form of iron oxide, the colors are various shades of brown, yellow, green, purple, or red. When rocks contain lime and silica as cement, they tend to be light colored.

Figure 8. Accumulation of Oil in Synclines When Sand Is Water-Free


Where the conditions of sedimentation were frequently changing, the resulting rocks show a rapid variation in character, both laterally and vertically. Such conditions are especially characteristic of fresh water deposits and near shore deposits of some of the former great inland seas. Uniform conditions of sedimentation over long periods of time have resulted in rocks of uniform composition and character through great vertical and lateral extent. This is well illustrated by the Pierre shale, which has very similar features through thicknesses of a thousand feet or more and over an area of several thousand square miles. Uniform conditions of sedimentation were more typical in the off-shore areas of the former inland seas.

PRINCIPLES OF PETROLEUM GEOLOGY

4. ORIGIN OF STRUCTURAL GEOLOGY

The term structure is very loosely used in oil geology, but in its general sense it relates to the folding or tilting of the sedimentary rocks from the nearly horizontal position in which they were laid down. Since the rocks in which oil and gas deposits are found are formed from sediments deposited in the shallow seas that have covered parts of the continent in former geologic time, it is evident that these bedded rocks were at first nearly horizontal, any slight initial dip they had being due to the slopes of the sea bottom over which the sediments accumulated.

The fact that sedimentary rocks containing marine fossils now cap the highest mountains indicates that they have been pushed up to this great height by tremendous wrinkleings of the so-called earth’s crust (mountain building movements).

The distance to which the bedded rocks have been disturbed away from the mountains depends upon the character of the formations and the magnitude of the mountain building movements. The pronounced folds in the strata of Wyoming and Montanas are due to the nearness of these areas to the Rocky Mountain uplift. Eastward from the Rocky Mountains the bedded rocks show less and less folding until they lie nearly horizontal in the plains region of the Dakotas. The Black Hills uplift has greatly folded the rocks in the immediate area of the uplift, but on the east side the sedimentary rocks quickly change to a nearly horizontal attitude, as the uplift was not great enough to disturb the strata for any appreciable distance. Pronounced folding is widespread on the western side of the Black Hills, owing to the proximity of the Rocky Mountain uplift. Over the Great Plains region away from the Rocky Mountains and the Black Hills the bedded rocks are warped into broad and gentle folds, but as far as known, no pronounced folds occur, as the region is too far removed from the areas of mountain building.

Often associated with the wrinkling of the earth’s crust in producing mountains are the intrusions of igneous (volcanic) rock. These intrusions when occurring on a grand scale, as is the case in some of the great mountain ranges, play a very important part in the folding of rocks. Generally, the smaller intrusions have had little effect upon the surrounding strata. Bear Butte, near the Black Hills illustrates an igneous intrusion (laccolith) which has locally bowed up the sedimentary rocks.

The relation of a region to centers of mountain building is an important matter in oil geology. It must always be considered when determining the presence or absence of folding and the character of folding in any region. Often structures are produced by local causes that may have no relation to regional deformation. Such structures will not persist to any depth and hence have no value as possible traps for oil or gas.

5. WHAT THE OIL GEOLOGIST LOOKS FOR AND WHY

The features of most vital interest in prospecting for oil may be listed as follows:

1. Evidence of folds or structures
2. Surface indications of oil and gas
3. Formations that might be possible sources of petroleum
4. Possible reservoir rocks
5. Features indicating that oil and gas may have escaped
6. Depth of drilling
7. Relation of area to transportation, fuel, and water problems
STRUCTURES

Since commercial pools of petroleum are generally found in traps formed in folded or tilted rocks, it is evident that the structural conditions in any region are of great importance. Oil and gas may accumulate in anticlinal beds, domes, and monoclines, which are the types of producing structures in the Montana and Wyoming fields. The surface evidence of structures is roughly proportional to the degree of folding. Where the folds are pronounced, as in Wyoming and Montana, the structures are generally well defined, as graphically; where the folds are slight, as is true over much of South Dakota, careful detailed work is required to determine their presence. An unconformity (figure 7) illustrates a case where a fold does not show at the surface. Accumulations of oil or gas in such concealed folds are generally only discovered by penetration of the drill.

Bedrock Evidence.—In working out the structural features of a prospective area the geologist is chiefly interested in bedrock exposures. These are all carefully studied and the dip and strike readings of each outcrop recorded. Extreme care must be used at all times to determine whether the beds are in place or whether they have slumped or sagged, due to erosional activity. The non-parallel dip and fold in a domical bed, cross-bedding and inclination of beds due to deposition, must be distinguished from true deformation. All these features produce dipping beds and yet have no relation to regional folding. They are especially apt to be misjudged in areas where the beds lie nearly horizontal, as they do over much of South Dakota. For illustrations of these structures see plates I and II. After a study has been made of the dip and strike of numerous outcrops, the geologist can then determine the nature and magnitude of the folding.

Topographic Evidence.—In a region where exposures are scarce or poor the geologist can do little in the determination of accurate structure. Such conditions especially prevail in areas where bedded strata. Topographic evidence may be a great aid in indicating structural features in such areas but must be used with a great deal of caution.

Among the topographic features that relate to structure may be listed escarpments, systematic arrangement of hills and valleys, trend of streams, profiles of slopes, and erosional features peculiar to different formations.

The term "escarpment" is applied to a more or less continuous line of steep slopes or cliffs produced by erosion or faulting. Escarpments occur in regions of slightly dipping beds where the more resistant layers form projecting ledges that may trend over a considerable distance. Ridges produced by steeply dipping beds are called "hogbacks" in geologic nomenclature. Where the strata lie nearly horizontal, hogbacks will not develop, as the exposure of any given hard stratum is broad and forms a flat-topped hill (mesa), or a butte if the elevated part is an isolated erosion remnant of limited summit area. As the dip of a formation increases, the outcrop becomes progressively narrower and the hill formed by it becomes sharper, until the hogback feature becomes pronounced. Hogbacks are common in the steep folds of Wyoming and Montana, where they often mark the tips and trend of a structure very clearly.

Where the strata lie nearly horizontal, the exposure of any given formation may be widespread, producing uniform erosional features over a considerable area. An irregular network of valleys and hills with little system to their arrangement develops on such a surface. In areas where the formations dip, however, the outcrops are narrower and more linear, and the alternating hard and soft layers produce a striking array of hills and valleys related to the dip, and strata cropping strata—in other words, a series of ridges separated by valleys. Such systematic arrangement of ridges and valleys in a region where the bed rock is concealed is indicative of dipping beds and suggests a possible structure.

Streams tend to follow along softer rocks or those which are more readily eroded. They also tend to follow along the crests of folds which are generally zones of weakness in the rocks. The distribution of streams in a region where bedrock evidence is lacking, should be carefully studied, as it may show the relation to underlying rock materials, which are in turn governed by the structure of the region.

The profiles of hills and elevations in general may show a relation to the attitude of the strata. If the strata are nearly horizontal, the region is generally due to strata which are more resistant to erosion. For this reason the attitude of the resistant formation may be reflected in some part or much of the outline of the hill it has developed. This is illustrated by the buttes of northwestern South Dakota, formed by the hard layers in the nearly horizontal beds. If the strata composing the buttes are inclined, the tops of the buttes may show the same degree and direction of inclination as the strata.

Generally each formation of a given region will have erosional features peculiar to itself and a recognition of these distinctive types of erosion will aid in determining the distribution of each formation, even though the bedrock is not exposed. By this means the variations in the width and trend of the surface portion of each formation may be determined and partial conclusions drawn from this as to the attitude of the formations.

SURFACE INDICATIONS OF OIL AND GAS

Frequently the presence of oil and gas in the underlying rocks is indicated by surface evidence in the form of oil seeps, gas seeps, or outcrops of bituminous rocks. Such evidence does not necessarily signify commercial supplies but is valuable when considered in connection with other features.

Oil Seeps.—Petroleum may escape to the surface through erosional exposure of the reservoir rock, through fault or joint planes, or through porous beds overlying the reservoir. As a rule, the character of the seeping oil left in the reservoir is not indicated by the character of the seep, since the oil escaping through fractures and holes may have lost its more volatile products and hence be heavy and more viscous. If the original oil in the rocks is a light, high grade type this would not hold so true.
OIL IN SOUTH DAKOTA

Oil seeps generally disclose themselves by coating the surface of streams, wells, or springs. The oil occurs as an iridescent scum on the water and may be thick and viscid. Such seepage should not be confused with iron or manganese oxide films which are very common in wells and springs and also have an iridescent and oily appearance. The film can be readily tested. If it breaks into irregular fragments when disturbed, the film is not due to oil. A film of oil will stretch out in stringy lines when disturbed with a stick and pull together again when the stick is withdrawn. Furthermore the oil film will be inflammable and may have a characteristic odor.

If such tests prove the presence of oil, the next procedure is to determine whether the oil has seeped from a well or spring, or has been "salted." If the seep has a natural source it will be persistent over an indefinite period of time. If "salted" the oil will be temporary, and collection of the oil will soon exhaust the supply. In any case the oil should be skimmed off the surface for analysis. Analysis will disclose whether the oil is a refined or crude product. Drilled wells may be "salted" through the penetration into the hole of oil used in drilling. Streams and springs may be "salted" by the dripings of oil from passing automobiles or other vehicles. Occasionally, organic matter in the vicinity of a spring or well may contribute material which might temporarily coat the surface of the water with an iridescent film. Water issuing from coal beds may sometimes have a black, greasy appearance. In any case, careful investigation will disclose the true source of the seep. Samples collected for analyses should be carefully skimmed into a thoroughly clean bottle.

If the seep is found to be authentic, this fact alone does not warrant testing the region for petroleum. The other factors mentioned in the above bulletin, such as favorable structures, etc., must also be present. It must be kept in mind that an oil seep may come from a source too slight to be of commercial value, or may represent the final remnants of a once larger underground oil body. Furthermore, the source of the oil does not necessarily underlie the seep. The oil may have migrated a considerable distance laterally before emerging from the ground. In any event an oil seep is nothing to get excited over, and has little significance unless favorable structures exist in the region.

Gas Seeps.—Seepages of gas from the earth may or may not be from petroleum strata. Gas seeps generally consist of methane (marsh gas), carbon dioxide, nitrogen, hydrogen sulfide, and other gases. Marsh gas forms the bubbles that are seen rising in the water in marshy or boggy areas and is due to the decay of organic material in the water. Marsh gas may also issue from the earth in regions containing coal beds, the gas being produced by chemical changes in the coal. Methane is also the principal constituent of natural gas and hence may indicate the presence of petroleum material in the underlying rocks. Methane is inflammable and if escaping in sufficient quantities may be ignited. The other gases enumerated above are not always inflammable and have little value as indicators of oil deposits. Non-combustible gas seeps occur in a number of places in South Dakota.

If there is any question about the origin of the gas, samples should be collected for analysis. The following method of collecting

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1A term used, especially in mining, to indicate the placing of some mineral or other commodity, as coal, in the walls of the mine workings by human agencies with the intent of making it appear that the mineral naturally occurred there. In the same manner water wells and springs may be "salted" with petroleum.

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PRINCIPLES OF PETROLEUM GEOLOGY

the sample is suggested by K. C. Heald of the United States Geological Survey Bulletin.

"The only sure way to learn the true nature of the gas is to have it analyzed. A two-quart sample is enough for analysis. The sample may be taken in a two-quart bottle or in two one-quart bottles, through a large funnel. The bottle should be filled with clean hot water without soap. If the gas is bubbling up through water the bottle should first be filled with clean water and it should then be held below the surface, neck down, with the funnel inserted in its neck and held or guided by the ground over the bubbling gas. The mouth of the bottle should then enter the bottle through the funnel and displace the water, which will be forced out of the bottle. When no more gas can get into the bottle and while the bottle is still inverted under water the funnel should be a large funnel and a new, tight-fitting cork should be jammed firmly into the bottle without topping or tilting it.

"If the seepage is not under water, a sample of the gas can be taken by building clay around and over the escape so that a part of the gas shall come out of an opening that can be covered with the large end of a big funnel. Clay should be packed tightly around the edge of the funnel so that the gas will enter the funnel and pass out of its tip. A bottle should be inverted over the tip of the funnel for about twenty minutes and then gently lifted off, without tilting, and tightly corked.

Bituminous Rocks.—The escape of petroleum to the surface of the earth often leaves a solid or semi-solid residue which impregnates more or less of the rock from which the oil has seeped. This residue represents the least volatile parts of the oil and may be the fossil equivalent of some other bituminous substance. Generally bituminous substances are present in the outcrops of sandstones or limestones which are more or less petroliferous. Such deposits do not prove the presence of oil in commercial quantities in the buried portion of the bituminous rock. The finding of bituminous material in rocks indicates in any case that petroleum has escaped or is escaping from the rocks. Whether it exists in commercial quantities in the buried portion of the rock is entirely another matter. Due may indicate either the final portion of a former commercial supply or that the rocks are petroliferous but only slightly so. If no favorable structures exist down dip in which the oil could be trapped, the bituminous material is of minor importance. In such cases the structures might exist a considerable distance from the exposed area. The depth to the bituminous horizon at any point would be an important factor. If a favorable structure were found, the reservoir rock under it might be at too great a depth for feasible testing.

Generally, bituminous rocks are characterized by brownish, dark gray or black colors, although the weathered surface may be the normal color of the rock. Often where the surface of the rock is weathered the breaking of the specimen will disclose fresh bituminous material. Where these rocks are of a light, highly volatile type, the rock may show no evidence of its petroliferous character. Testing of the specimens, however, will disclose the presence of bitumens. The following test is outlined by Woodruff:

1. Select a representative specimen of rock to be tested. It is generally advisable to obtain several samples as large as one to five pounds each.

2. Break them up, and thoroughly mix the pieces. If the samples consist of sand, mix the sand.
OIL IN SOUTH DAKOTA

"3. Dry the sample on a plate in the sun or over a radiator. Do not dry it over a fire; to do so may drive the oil from the rock or sand.

"4. Crush the sample to a powder. Mix the powder. Loose sand does not need to be crushed.

"5. Place about a tablespoonful of the sample in a bottle. Pour chloroform or carbon tetrachloride over the sample until it is thoroughly saturated and there is about half a tablespoonful of the liquid above the crushed rock or sand. Cork the bottle, but not too tightly. Shake occasionally for fifteen or twenty minutes.

"6. Place a white filter paper in a glass funnel over a white dish.

"7. Pour the contents of the bottle into the funnel. After the liquid has passed through, place the white dish in a window where the liquid can evaporate.

"8. Examine the filter paper. If the rock contains more than a trace of oil, there will be a brown or black ring on the filter paper.

"9. After the liquid in the dish has evaporated, examine the remaining substance. It is the petroleum which was in the rock.

Apparatus for Testing.

"One dinner plate on which to dry specimens.

"Some means for crushing rock.

"One or more bottles, 4 to 6 ounce size, with corks, in which to treat the rock.

"Chloroform or carbon tetrachloride.

"One glass funnel, 3 or 4 inches in diameter.

"Two dozen round filter papers, 6 inches in diameter.

"Two or more white dishes."

FORMATIONS THAT MAY BE SOURCES OF OIL

A favorable structure has slight value unless the region contains, either exposed or within reasonable depth, formations that might be a source of oil. The possibility of oil having migrated considerable distances vertically and laterally must be considered in this connection, but in untested territory this factor is of secondary importance. The problem relating to distance of migration of petroleum is a disputed point among oil geologists, but the statement often heard that oil has commonly migrated scores of miles is not supported by the evidence in hand.

Since marine shales have probably formed the chief source for petroleum, the geologist investigating prospective areas is on the lookout for such rock. In most of the great oil fields of the world, marine shales are common. This is especially true of the Rocky Mountain fields, where the producing sands lie between great thicknesses of shale.

Generally, petroliferous shales are dark colored. Light colored shales are unfavorable, as they may indicate oxidation and a paucity of organic matter. Oil shales are very suggestive. Their presence indicates that the associated strata are more or less petroliferous. Oil shales do not prove the presence of commercial accumulations but they must be given consideration in prospecting.

Limestones and fossiliferous sandstones also suggest a possible source of petroleum-forming matter, but as a rule, these rocks are more important as reservoirs than as sources of oil and gas.

POSSIBLE RESERVOIR ROCKS

A region which does not contain reservoir rocks within feasible drilling depth has no value, even though the features already discussed are all present and favorable. The various reservoirs in the order of their importance are sandstones, porous limestones, fissures and cavities in various sedimentary rocks, and vesicles and fissures in igneous rock. The last named group is of slight importance.

Sandstones constitute far the most common reservoirs of oil and gas pools, when the oil fields of the United States as a whole are considered. They are typical of the Montana and Wyoming fields. Limestones are of slight importance in the proved fields of the northwest but are very important in other parts of the United States. Fissures in sedimentary rocks are in rare cases of importance as reservoirs for petroleum. The Florence field of Colorado belongs to this class.

The presence of reservoir rocks in a region is indicated either by exposures or evidence that such rocks underlie the region, though not exposed. It is this latter case that is of especial interest to the geologist in untested areas. There is a common belief among laymen that because a given oil sand occurs in one region it will be found elsewhere, even in a district far removed from its place of known occurrence. There is no geologic basis for this assumption of widespread distribution of sands. Sandstones, owing to their mode of origin, tend to be restricted and lenticular in occurrence. Such a sand as the Dakota, which covers many hundreds of square miles, is exceptional and has resulted from conditions of deposition that have held true only at rare intervals in geologic time.

In the discussion relating to the origin of sedimentary rocks it was indicated that since sandstones are derived from coarser sediments, they tend to form near shore, being replaced often by shales or limestones in the offshore areas. Hence the sandstones will be largely restricted to the near shore areas of the growing petroleum bearing sediments were laid down. This is well illustrated by the oil sands of Wyoming and Montana. These sands when traced eastward tend to thin out and disappear. Some of them are quite extensive, however, indicating that conditions existed over a broad area away from the shore line. Over South Dakota with the exception of the westernmost part, sandstones are absent above the Dakota formation and below the Fox Hills formation, according to the evidence now in hand. This is explained by the fact that during the Upper Cretaceous times the sea covering South Dakota was too far removed from the shore line to receive sediments coarse enough to form sandstone. The possibility of land masses, now buried, which might have contributed materials must, of course, be considered. A thorough knowledge of known paleogeographic conditions during and preceding the period when the possible petroleum bearing horizons were deposited is absolutely essential before prospecting for oil in an unproved territory can be properly carried on. The finding and working out of structures is only a phase of oil geology and of little value when considered alone.

The following quoted paragraph is pertinent on this point:

"Structural conditions favorable for the storage of profitable amounts of bitumen are fairly well understood. But the most favorable structure conceivable will not yield oil unless oil is already there. Whenever the question arises of the advisability of prospecting untested regions, many miles from the outcrop of strata suspected of being bituminous and far from any known production, it becomes necessary to attempt to forecast, with as much of precision as may be possible, the conditions under which the suspected strata were deposited. In order to do this it is necessary to possess knowledge of the

1Paleogeography is the study of the geographic conditions over the earth during the various periods of geologic history.
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stratigraphy over extensive areas and to know much of sedimentary processes both favorable and unfavorable for the accumulation of bituminous substances. This branch of the science of petroleum geology is still in its infancy and its future progress depends upon extensive knowledge of many different things. Petroleum geology is an applied science and as such can only progress in proportion to the amount of science there is to apply. The time is now come when we are called upon to advise concerning the undertaking of expensive explorations in places where there is little direct, visible evidence of oil and gas and none of which are yet as fully prepared as we should be to undertake this service. Hence we must all be research men whether we will it or not. There is a vast difference between the broad minded and widely experienced geologist and the mere structure hunter. The man who emerges in the competitive struggle will prove to be the one who suffers no detail to escape him and who in his final conclusions has taken full cognizance of every line of evidence possibly available. All this necessitates much time and labor. Snap judgments and the taking of unjustifiable chances may be tolerated for the brief time while the present mania for petroleum is in full swing and while fortunate financiers seek to dispose of large excess profits but in the long run the successful economic geologist must be a scientist and as nearly as possible everything which that word means. Intimately it may be remarked as a matter of personal opinion, that mere structure-hunting is about as interesting as the keeping of books in a village grocery store. In a region where all possible oil horizons are deeply buried the probabilities of finding such horizons are uncertain unless their presence has been proved on both sides of the area in question, by sound geologic evidence. The presence of "stray sands" that always be considered "stray sands" are sandstones occurring in areas where neither surface evidence nor known paleogeographic conditions have indicated their presence. Such sands are found only where conditions are favorable for the escape of oil and gas. This factor must always be considered in prospective territory. The finding of oil seeps should bring up the question of possible exhaustion of the oil that once may have been present in that area. There is no positive way of determining this matter except by testing with the drill. The structural features of the region will have some bearing on this question. If the region is much folded and faulted, the chances for escape of the petroleum are greater than in areas where the rocks have not been greatly disturbed. The age of the petroleum horizons would also be of importance. The possibilities of exhaustion in formations showing seepage would be relatively greater with increasing geologic age of the horizon concerned. The quality of the petroleum would also be a factor. Light, volatile oils will escape more readily than the heavy, viscous oils. The latter may even seal up the exposed reservoir, through evaporation of the lighter constituents and deposition of the heavy residue, thus forming a trap for a pool at some point back of the outcrop.

DEPTH OF DRILLING

In determining the value of a new territory for oil and gas prospecting, the geologist must make estimates of the probable depth it will be necessary to drill in order to reach the oil sands. The drilling of an oil well always involves great expense and the cost of drilling rapidly increases with increasing depth of the well. Therefore, even though other geologic features may be very favorable, the depth to the oil sands may be too great to merit testing. The feasible depth of drilling in any "wildcat" area is determined by balancing the expense of drilling and the chances of suc-

6. METHODS OF GEOLOGIC WORK IN OIL FIELD DEVELOPMENT

In the exploration for petroleum deposits the geologic work is divided into the following steps:

1. Reconnaissance or preliminary examination
2. Detailed mapping and geologic study of favorable areas
3. Drilling, with geologic supervision

If a commercial deposit of oil is found, then the geologist is of service in locating new wells and in solving the numerous and sometimes complex problems of recovery that are typical of every oil field. Since South Dakota is still in the ranks of the non-producing states, the phases of geology applying to producing fields are not of immediate importance. The following discussion is confined to the phases of field work leading up to and including the drilling of the test well.

RECONNAISSANCE WORK

The first step in the study of a region for oil and gas possibilities is a preliminary or reconnaissance examination. The purpose of reconnaissance work is to determine what parts, if any, of the area are of most merit. Detailed geologic study and mapping. Although reconnaissance work does not involve much detailed investigation, yet the skilled field geologist by this method can acquire a fairly thorough grasp of the geologic features of a region and their bearing upon possible oil and gas deposits.

Reconnaissance work deals with the following:

1. The search for evidence of folds in the bed rock.
2. If folds are found, whether they are of a character to form possible traps for petroleum or gas.
3. Formations present that might be a source of petroleum.
4. Possible reservoir rocks present.
5. Depth of drilling necessary to reach possible oil horizons.
7. Evidence that oil has escaped.
8. Accessibility of the region to transportation facilities.

All of the features enumerated above have been discussed in sufficient detail to give the reader a generalized idea as to why they are of interest to the geologist. Points 1, 2, 3, 4, and 5 are of great importance in any area. Points 6 and 7 are of local importance: many oil fields contain no surface evidence of the pools that underlie them. Points 8 and 9 are of importance in developing the field, but must be given attention by the geologist. A possible area might have very favorable geologic features and yet be so inaccessible that it would not merit development under existing conditions. The fuel and water problem is of significance in the semi-arid regions of western South Dakota.

Since the purpose of reconnaissance work is to determine whether a region merits further detailed study, it is evident that such preliminary work must save much time and money by eliminating areas that are unpromising. For a geologist to start detailed work without first making a preliminary examination of the region as a whole is bad.
practice. This generalized preliminary knowledge gives a much clearer idea of the detailed features when they are studied.

When large areas must be examined rapidly the reconnaissance method is used. In such cases the geologist may desire only to find evidence of structure or map out proof of the presence of structure, or at times to determine their approximate extant. In any case reconnaissance work will show whether structural conditions are present and whether the geologic features of the region can be studied in detail. In a region where exposures are few in number, detailed work might disclose nothing which could not be determined by reconnaissance studies. In a region where the structures are pronounced and well exposed, the readiness with which geologic investigations can be carried on might give a sufficiently detailed insight into the structural features of the region during the preliminary studies.

In any case before a region is drilled it should be mapped in detail and the geologic features carefully examined. There is some tendency on the part of those who are unfamiliar with geologic methods to feel that reconnaissance studies are too hasty to give the geologist a fair insight into the possibilities of a region. If the geologist is properly trained, however, he can very quickly determine the broader structural and stratigraphic features of an area. This knowledge will be sufficient in indicating whether the region merits detailed study. Furthermore, the geologist who is working in a new territory where the structural and stratigraphic features are similar to a well known area can do detailed work in one part of the region and get thoroughly familiar with the representative formations and structural features, and then quickly determine the possibilities of adjacent areas by noting the relations they show to the region in which more thorough investigations were made. Where similar geologic features hold true over a broad area, a knowledge of one locality is a great aid in interpreting the conditions in an adjoining locality.

The ultimate purpose of reconnaissance work is the study of the regional geology. If the regional geology indicates conditions unfavorable for oil and gas deposits then the region is not worth further examination.

**DETAILED WORK**

If reconnaissance studies show that a region merits further examination, then the next procedure is the making of a structure map of the area in question and a detailed investigation of the geologic features. All this must be done before the drilling is commenced. To drill a structure without first determining its exact shape and magnitude greatly adds to the chances of failure. The proper location of the test well can be determined only after a careful structure contour map has been made which will show the approximate form of the fold. Without this map the locating of a test well is largely a matter of guess work, unless the structure is unusually well marked and defined at the surface. While the topography of a region gives some indications of the structure of the underlying bedrock, it is only of minor importance, except in certain localities. The location of a test well on the basis of topographic evidence alone is a dangerous procedure in any case and almost certain to result in failure.

Generally, the exposures in a region are not very numerous and often they are few and far between. This is especially true of those areas that are removed from regions of mountain uplift, such as South Dakota and the plains region in general. The determination of structure in such regions is a difficult matter even when precise and careful methods are used in mapping. Exposures are infrequent and the rocks are so slightly folded that they appear essentially

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**Fig. 9. Structure Contour Map and Cross Section**

PRINCIPLES OF PETROLEUM GEOLOGY

The reasons for some wells being dry, others finding gas only, and others water only, are illustrated in figures 1 to 8. It must be also remembered that even if an ideal structure is present, and the proper reservoir and source rocks are present, the well may be dry. This often happens. Again the reservoir sand may have variations in porosity or composition which have caused abnormal or unsuspected distribution of the oil and gas. The reservoir may contain gas only, or all the oil and gas may have escaped and only a trace be left. All of these possibilities hold for any field, no matter how favorable surface indications may be. They cannot be ignored or predicted. The most skilled geologic work cannot eliminate chances of failure in an untested region.

At best, investing money in a “wildcat” well is a gamble, and it is only the person who can afford to lose a hundred dollars for the loss that should indulge in this form of speculation. It is not the purpose of the writer to disparage this phase of the petroleum industry, but it is only fair and just that the reader who is uninformed on such matters should know the true situation. The highly skilled statements far too common in the literature advertising an unproved oil field are generally uncalled for and misleading. If oil geologists were able to predict matters as positively as some of these statements indicate, the profession would have worked itself out of a job long ago.

8. THE GEOLOGIC REPORT

The geologist, after having completed the examination of an area, has written a report on the material for which he was paid. The area is then divided into sections and mapped for the purpose of finding oil and gas, and these reports are submitted to the oil companies for whom the examination was made. In the case of geologic work by official surveys, the report on a region is published and distributed to the public.

The form of geologic report is determined by the purpose for which it is intended. The statements in any report should be concise and clear, free of all embellishments, and so arranged that there will be no danger of giving the unqualified reader a false conception of the value of the area under consideration. Generally a geologic report is based upon reconnaissance studies, and hence should consider all the factors which were discussed under that topic. There is frequently a tendency for geologic reports to give too little attention to those factors other than structural which are so important in passing on the merits of a given territory. To state that the structural features are favorable is not enough. Such matters as the relative possibility of reservoir rocks, formations which may constitute a source of petroleum, sand, and shale are considered.

It is especially desirable that all geologic reports specify, in as explicit detail as the geologist’s knowledge of the region will permit, the chances for and against the finding of oil or gas. To find all the conditions in a region favorable is very exceptional indeed. Unfavorable features of some character are practically always present and these must be given equal consideration with the more promising indications. There is at times a tendency even on the part of competent geologists in the effort to please clients, to sustain the client’s naturally favorable opinion of an area by not giving enough emphasis to unfavorable indications. Among the untrained and so-called practical geologists this practice is common, and the presence of some sort of structure is generally considered sufficient basis to warrant a test well.

The value of a geologic report is of course commensurate with the degree of thoroughness with which the field work was done and the ability of the geologist concerned.

*4A term used in the petroleum industry for unproved territory.
and cause considerable difficulty in the efforts to block the acreage properly. Such a practice in areas where the development is legitimate and based on sound geologic evidence is unfortunate. A lease form follows:

LEASE No. .................................................................
OIL AND GAS LEASE
From ........................................................................
..............................................................................
The ......................................................... Co. ........................
..............................................................................
Date ......................................................... 19    ........
Term ........................................................................
No. Acres ......................................................................
Township ........................................................................
County ........................................................................
Received ........................................................................
at .............................................................................
M. Recorded ........................................................................
..............................................................................
in ........................................ County, ...................................
Record of Leases, Vol. ........................................ Page ........
..............................................................................
Recorder's Fee $ ......................................................

RELEASE

THE ......................................................... CO., Lessee, having paid the Lessor one dollar and all amounts due hereunder, and having elected to surrender the within lease and all its rights thereunder, does hereby surrender and cancel the same and hereby endorse its surrender hereon.
In witness whereof, it has hereunto set its hand, this .............................................................. day of .............................................................. A. D. 19   ................
Witness: THE ......................................................... CO., .............................................................. Per ..............................................................
THE STATE OF .............................................................. ss.
COUNTY OF ..............................................................
Personally appeared before me, a ..............................................................
in and for said County ..............................................................
.............................................................. who acknowledged the signing of the foregoing instrument to be .............................................................. voluntary act and deed for the uses and purposes therein mentioned.
In testimony whereof, I have hereunto set my hand and affixed my notarial seal this .............................................................. day of .............................................................. A. D. 19   ................


†L. S. Pangity, Prospecting for Oil and Gas, pp. 197-201.
THE STATE OF S.S.
COUNTY OF ____________________________

Personally appeared before me, a ________________ who acknowledged the signing of the foregoing instrument to be his voluntary act and deed for the uses and purposes therein mentioned.

In testimony whereof, I have hereunto set my hand and affixed my notarial seal this day of A.D. 19__

A. H. ________________

THIS AGREEMENT, made and entered into this day of A.D. 19__ by and between ________________, a corporation, called the Lessee, and ________________, a corporation, called the Lessor, WITNESSETH: That the said Lessor, in consideration of the sum of one dollar, the receipt of which is hereby acknowledged and of the covenants and agreements hereinafter contained, does hereby grant unto the Lessee all of the oil and gas and all of the constituents of either, in and under the lands hereinafter described, together with the exclusive right to drill for, produce and market oil and gas and the constituent and also the right to enter thereon at all times for the purpose of drilling and operating for oil, gas and water and to possess, use and occupy so much of said premises as is necessary and convenient in removing the above named products therefrom, by pipe lines or otherwise, for a term of twenty (20) years and so much longer thereafter as oil, gas, or their constituents are produced in paying quantities thereon, all of that certain tract of land situated in Section No. ________________, Township of ________________, County of ________________, and State of ________________, bounded substantially as follows: On the North by lands of ________________; On the East by lands of ________________; On the South by lands of ________________; On the West by lands of ________________. (______________) acres, more or less, being all the land owned by Lessor in said Township. It being understood, however, that no well shall be drilled within (______________) feet of the barn or dwelling on said premises without the consent of Lessor.

In consideration of the premises the said parties covenant and agree as follows: Lessee to deliver to the Lessor in tanks or pipe lines one eighth (1/8) of the oil produced and saved from the premises and pay to the produce of each gas well from the time and while gas is marketed, an annual rental of (______________) Dollars ($__________) payable annually.

Lessee to drill a well on said premises within ________________ from this date or pay to Lessor ________________ Dollars ($__________) each thereafter until such well is drilled or this lease surrendered. If a gas well be completed before the end of the term for which rental has been paid for delay, the unearned portion of said rental shall be a credit on the gas well rental.

Lessee to bury, when so requested by Lessor, all pipe lines used to conduct gas or oil off the premises and to pay all damage to growing crops caused by operations under this lease.

Lessor may lay a line to any gas well on the lands and take gas produced from said well for use for light and heat in one dwelling house on said land, at Lessor's own risk, subject to the use and the right of abandonment of the well by Lessee. The first two hundred thousand cubic feet of gas taken in each year shall be free of cost, but all gas in excess of two hundred thousand cubic feet taken in each year shall be paid for at the current published rates of the Lessee in the town nearest the premises above described and the measurement and regulation shall be by meter and regulators set at the tap on the line. This privilege is upon condition that Lessor shall subscribe to and be bound by the reasonable rules and regulations of the Lessee to the use of free gas.

It is agreed that said Lessee may drill or not drill on said land, as Lessee may elect, and that the consideration and rentals paid and to be paid constitute adequate compensation for such privilege. Should it be determined that Lessor is not the owner of the entire tract above described, then and thereupon Lessor shall receive a proportionate amount in accordance with the rentals and royalties for any fraction of the above premises so owned.

Payment of all moneys due on this lease may be made, by cash or check, to ________________, by deposit to ________________, or check made payable to ________________ order and mailed to ________________ at ________________ Bank of ________________, Chicago, Ill., or by check made payable to ________________ or ________________, at ________________ order and mailed to ________________ at ________________.

Lessor agrees that Lessee is to have the privilege of using sufficient oil, gas, or water, for fuel, in operating premises and the right at any time to remove any machinery or fixtures placed on said premises and further, upon the payment to the Lessor of one dollar and all amounts due hereunder, said Lessee shall have the right to surrender this lease or any portion thereof by written notice to Lessor describing the portion of the above tract that it elects to surrender or by returning to Lessor the lease with the endorsement of surrender thereon or recording the surrender of this lease on the margin of the record hereof, either of which shall be a full and legal surrender of this lease to all of said tract or such portion thereof as said surrender shall indicate and a cancellation of all liabilities under same of each and all parties hereto, to the extent indicated on said surrender, and the acreage rental hereinafore set forth shall be reduced in proportion to the acreage surrendered.

All covenants and conditions between the parties hereto shall extend to their heirs, executors, successors and assigns and the Lessor hereby warrants and agrees to defend the title to the lands herein described: Lessor further agrees that the Lessee shall be at any time to redeem for Lessor, or otherwise acquire by payment, any mortgages or any other liens upon the above described lands which in any manner affect the Lessee's interest therein in the event of failure of payment by Lessor and be subrogated to all the rights of the holder thereof the same as if Lessee were the original owner of said mortgage or lien.

IN WITNESS WHEREOF, the parties hereto have hereunto set their hands and seals.
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The height of the derrick, which is the most conspicuous part of the rig, varies with the depth of drilling. For wells of 3,000 feet or greater the height of the derrick is 80 feet or more. The larger and heavier the string of tools used the greater must be the strength and height of the derrick.

Steam power is almost always used to run the engines. The problem of water and fuel for drilling purposes constitutes an important feature, especially in the semi-arid regions of South Dakota. Natural gas is used as fuel where it can be obtained cheaply. Fuel oil and coal are also in common use. Wood is not only used in out-of-the-way places where the other types of fuel cannot be easily obtained. Gasoline engines have been used for power but are unsatisfactory.

For drilling shallow wells not exceeding 2,000 feet in depth portable rig are used. Their chief advantage is the ease of moving the rig from place to place. In moving the regular standard rig it must be torn down and re-erected.

The size of the hole to be drilled is governed by the depth and the number of strings of casing to be used. Where several water sands or caving sands must be cased off, the hole becomes much reduced in size. Generally in wildcat wells holes of 2,500 to 4,500 feet in depth start with 16 inch or 18 inch casing and may be reduced to as much as a 3 inch casing. Holes are generally finished with 6 1/4 or 8 1/4 inch casing. In wildcat wells the amount of casing and the number of strings necessary cannot be accurately predetermined, but in drilled areas, the logs of other wells indicate the depth and number of water or caving sands which must be capped off and hence the number of strings of casing that must be used.

The Rotary System.—This system which has come into use more recently is of especial value in drilling through soft and unconsolidated strata such as occur in the Gulf Coast fields and in parts of California.

The equipment includes a derrick, revolving table or whirler, two hydraulic pumps, boiler, engine, and line shaft to furnish power. The casing is fastened to the revolving table, which acts on tool-steel rollers.

Drilling is accomplished by rotating the string of casing, on whose lower end is a toothed cutting shoe. The rock material broken by the rotating shoe is carried to the surface by water driven down the casing under pressure and which rises outside the casing. Only the revolving casing is used, the escaping muddy water puddling the sides of the well below this point so that the material stands alone.

The bad feature of the rotary drill, and one which makes it practically valueless for test wells, is the fact that the mud stream used in drilling is very apt to obscure even strong showings of oil, and hence an oil bearing formation may be passed through unnoticed. The weight of the water column suppresses all minor evidences of oil and gas. Another bad feature of the rotary system, especially for testing out undrilled areas, is the fact that a very obscure log is furnished. A good log is one of the most vital evidences of a wildcat test, as it aids immensely in guiding further development. It is absolutely necessary to have a definite knowledge of underground conditions as shown by correct logs of other drilled wells before any drilling rig can be used with any satisfactory results, hence this system of drilling is little used in wildcat territory.

Some of the good features of the rotary system have been applied to the cable tool system by introducing the circulation of a thin mud slip through a special circulating head down through the
OIL IN SOUTH DAKOTA

casing and up the outside. This aids in preventing caving and shuts
gas sands by exerting pressure on the sides of the hole.

Cost of Drilling.—The cost of drilling is governed by the follow-
ing factors:
1. Location of the well
2. Method of drilling
3. Fuel, water, and transportation facilities
4. Depth of drilling

5. Various factors peculiar to a given region.

Wells drilled in wildcat territory tend to cost more than those
drilled in producing fields. This is due to the fact that the rig, engine,
boiler, and other accessories generally must be hauled in from a
remote source and often must be transported some distance from the
well to the point of drilling. As a rule, one well must bear all this
expense in addition to the drilling costs. Another thing which may
increase the cost of a test well is the unforeseen drilling difficulties which
may be experienced in putting down the well, due to the character of the
strata. These matters are not so important in productive fields, as the underground conditions are
more favorable. Furthermore, in producing wells the rig and other drilling
materials may be used more than once, and thus the cost of the
materials may be distributed over more than one well. If the
drilling materials are distributed over more than one well, if the
drilling may rise to high or even prohibitive figures.

The method of drilling will be an important factor in estimating
the cost of drilling. Where shallow drilling is planned, the portable rig will
be used as a rule. Where deep drilling is planned, the standard system of
drilling is used. For deep drilling in wildcat areas the standard system is
the best, as the rotary system is better adapted to these conditions.
The dangers of drilling through oil sands without recognizing them
and the poor logs make the rotary system of little value in prospecting.
and the poor logs make the rotary system of little value in prospecting.
In areas adapted to the rotary system and where knowledge of under-
ground conditions permits its use, the rotary system is cheaper than other
methods.

Conversely, in regions adapted to the standard rig,
rotary drilling would be much more expensive.

Fuel, water, and transportation problems are important factors in
computing the drilling cost. The transportation problem would naturally
be governed by the accessibility of the proposed well to trans-
portation facilities. Even though geologic conditions might make the cost of the well
probable under existing conditions. In semi-arid regions the water
problem might prove a serious factor. The fuel problem would be
governed by the relation of the region to coal, gas, or oil supplies and
the cost of drilling a well would generally bear a close relation to the
transportation problem.

The cost of drilling test wells in the Rocky Mountain fields varies
greatly. Where considerable difficulty is met with in drilling through
considerable strata, the cost of the well may be raised as much as 100
percent. Another factor governing the cost of drilling is the time when
the equipment is placed on the job. The price of these materials,
per cent. Another factor governing the cost of drilling is the time when
the equipment is placed on the job. The price of these materials,

Wells drilled in South Dakota will generally go to depths of 3,000
feet and many of them to considerably greater depths. The cost of
such wells will probably vary from $50,000 to $150,000. After a
depth of 3,000 feet, the cost increases very rapidly. At
depth of 3,000 feet, the cost should be figured on as the probable total cost of a
well drilled to a depth of 3,000 feet.

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Drilling Contract.—In every case a drilling contract should be
entered into. The form of the contract is governed by the system of
drilling used and by local factors. A drilling contract follows:

DRILLING CONTRACT

THIS AGREEMENT made and entered into this ___________ day of __________________, 19 ____________ between the following named parties:

a corporation organized and existing under the laws of the State of __________________, and having its principal place of business at __________________. and

having its principal place of business at __________________. and

hereinafter called the CONTRACTOR:

WITNESSETH

That the parties hereto, for and in consideration of their mutual
agreements hereby agree as follows:

The CONTRACTOR agrees to drill a well for the ____________________________________________________________ and
in accordance with the specifications hereinafter contained.

Well to be known as ___________________ and
Lease number ___________________ Well number ___________________________
Serial number ___________________ on that certain piece of land known and
described as follows:
Land Owner, Lot or Farm name ____________________________ Situated in ___________________ Township ___________________, Section ___________ Township ___________________.

State of ___________________ and the Company agrees to pay the CONTRACTOR
for said work, the amount, in accordance with the terms, hereinafter
prescribed.

DRILLING CONDITIONS

The CONTRACTOR shall commence the drilling of said well
within ___________________ days after the execution of this agreement and
shall prosecute the work of drilling said well continuously thereafter
until said well is fully completed to the entire satisfaction of the
Company.

The CONTRACTOR shall set a string of ___________________ inch casing
in said well from the surface to a depth of ___________________ to be indicated by the
Company from ____________ Company from ___________________ Company.

The CONTRACTOR shall also set a string of ____________ inch casing
in said well from the surface to a depth to be indicated by the
Company.

The CONTRACTOR shall also set a string of ____________ inch casing
in said well from the surface to a depth to be indicated by the
Company.

The CONTRACTOR shall set all the above named casings and
any other casing, in accordance with and under instructions of the
Company and after the setting of each string of casing the well shall be bailed and the
well shall then be allowed to stand for ___________________ hours to test the same. If the

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*Pangley, L. S., Prospecting for Oil and Gas, pp. 149-152.
water has not been shut off after the setting of any string of casing, the CONTRACTOR will then furnish .......... days' free labor, under the instructions of the .......... Company, in a further endeavor to shut off the water.

GUARANTEES
The CONTRACTOR agrees that all work shall be done in a good and workmanlike manner; that the casing when set shall be open to its full diameter and to its full length so as to permit the passage throughout its entire length, of the next smaller size casing, free and unobstructed.

In event of the inability of the CONTRACTOR to complete said well in accordance with the terms and conditions hereof, for any cause, the CONTRACTOR shall immediately commence the drilling of a new well at a point to be indicated by the parties, on the above described property, which new well shall be completed in accordance with all the terms and conditions hereof, provided however, that the CONTRACTOR shall carry such new well to the depth at which the first well is lost, free of any additional cost to the .......... tools, materials and supplies
The .......... Co. shall furnish a Standard derrick complete and the same shall be erected at a certain point on the above described property.

The .......... Co. shall also furnish all pipe, casing and tubing necessary to drill said well.

The CONTRACTOR shall furnish all labor, all machinery and drilling tools, all drilling lines, all casing lines, and blocks, all working and fishing tools and any and all other materials, supplies and tools not specifically provided to be furnished by the .......... Co.

All material and apparatus which it is specifically provided to be furnished by the .......... Co., shall be in good condition and shall be maintained in good condition by and at the expense of the CONTRACTOR and shall be returned to the .......... Co., at the expiration of this contract in good condition and repair, subject to the ordinary wear and tear.

measurements and records
The CONTRACTOR shall keep a complete and accurate log of the well, which shall at all times be open to the inspection of the .......... Co., and its duly authorized representatives. The .......... Co., and its duly authorized representatives may at any and all times inspect the work and conditions and take such measurements as they shall desire.

liens
The CONTRACTOR agrees to save and hold harmless the .......... Co., and the land hereinabove described from any and all claims or liens of labor or supplymen or suppliers arising out of the drilling of said well and against the claims of CONTRACTOR'S employees for injuries received in the course of said work upon said land from any and all causes whatsoever.

The CONTRACTOR agrees to examine the drilling derrick as built and any and all other apparatus which may be furnished by the .......... Co., and agrees to assume all risks of accidents to themselves and employees from breakage or any and all other causes.

principles of petrology
payments
The .......... Co., agrees to pay to the CONTRACTOR the sum of $ .......... per linear foot for each foot of hole drilled and cased to the entire satisfaction of the .......... Co.

breach
Upon the failure of either party to fully keep and perform each and all of the terms of this agreement, then the agreement may at once be terminated at the option of the party not in default.

If the defaulting party be the .......... Co., then all work completed shall be forthwith paid for to the CONTRACTOR at the full contract price per linear foot.

If the defaulting party be the CONTRACTOR, then all right to moneys due under this contract shall be forfeited.

The contract by the .......... Co., requiring the CONTRACTOR to shut down for more than .......... consecutive hours shall entitle the CONTRACTOR to $ .......... per day during the time actually shut down in excess of .......... consecutive hours.

Delays occasioned by strikes or the elements or any and all other causes beyond the control of either party shall not be deemed a breach of this contract.

arbitration
Any and all disputes or controversies arising out of this agreement shall be referred to three arbitrators, one to be selected by each of the parties hereto and the two so selected to appoint a third. A decision by the majority of such arbitrators shall be binding upon both parties.

Time is the essence of this agreement and this agreement runs in favor of and is binding upon the successors and assigns of each of the parties hereto.

In witness whereof, the parties hereto have caused their respective names and seals to be hereunto affixed by their officers first thereunto duly authorized by resolution of their respective Companies or Boards of Directors, the day and year first hereinafore written.

The .......... Co.,
By
Witness
Witness
Witness

The .......... Co.,
By
Witness
Witness
Witness

The well log—The well log cannot be overstated. The chief value of the well log lies in its indication of underground conditions and the important aid given to further prospecting from the proper interpretation of the log. The log is of especial importance in wildcat areas where information may be extremely scant with regard to subsurface features.

Generally the log is kept by the driller, who may use terms in describing the formations passed through that are clear enough to him but have little meaning to the geologist. For this reason geologic supervision of the log is essential and is now practiced by all the
11. POPULAR FALLACIES

In every region where interest in oil possibilities is rife, there exist a number of popular fallacies which have absolutely no basis either in experience or in scientific fact. The various current fallacies are discussed briefly here.

WITCHING FOR OIL AND WATER

This is without question the most popular of all the fallacies and has ardent supporters in every region. The following quotation by O. E. Meinzer,3 of the U. S. Geological Survey, summarizes the situation relative to this superstition:

"The use of a forked twig, or so-called divining rod, in locating minerals, finding hidden treasure, or detecting criminals is a curious superstition that has been a subject of discussion since the middle of the sixteenth century and still has a strong hold on the popular mind, even in this country, as is shown by the large number of inquiries received each year by the United States Geological Survey as to its efficacy, especially for locating underground water, and the persistent demands that it be made a subject of investigation by the Survey. . . . A truly astonishing number of books and pamphlets have been written on the subject.

"It is doubtful whether so much investigation and discussion have been bestowed on any other subject with such absolute lack of positive results. It is difficult to see how, for practical purposes, the

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entire matter could be more thoroughly discredited, and it should be obvious to everyone that further tests by the United States Geological Survey of this so-called 'witching' for water, oil, or other minerals would be a waste of public funds.

"A large number of more complicated devices for locating water or other minerals are closely related to the forked twig.

A favorite trick for appealing to uneducated persons and yet making specific disproof impossible is to give as the working principle of such a device some newly discovered and vaguely understood phenomenon as, for example, radioactivity. Many such devices have been in existence since the seventeenth century, and almost without exception the claims that are made for them are very great. If any genuine instrument were invented, its merits would no doubt in time become well recognized, as have those of other real inventions. The magnetic needle used in detecting iron ore is, of course, not included in this category of spurious instruments.

"It is by no means true that all persons using a forked twig or some other device for locating water or other mineral are intentional deceivers. Some of them are doubtless men of good character and benevolent intentions. However, as anything that can be deeply veiled in mystery affords a good opportunity for swindlers, there can be no reasonable doubt that many of the large group of professional finders of water, oil, or other minerals who take pay for their 'services' as if the sale of their 'instruments' are deliberately defrauding the people, and that the total amount of money they obtain is large.

"Of all inquirers the United States Geological Survey therefore gives the advice not to expend any money for the services of any 'water witch' or for the use or purchase of any machine or instrument devised for locating underground water or other minerals."

With regard to the numerous cases cited where actual deposits of water or other minerals have been discovered by this method, it is sufficient to say that these deposits were discovered in spite of the instruments used. As one writer has well put it, "Even a blind pig rooting for nuts is bound to find some if there are plenty and he hunt long enough.

Where individuals use various sorts of instruments or contrivances to find oil the person with common sense simply need observe that these men 'are ready to prove the correctness of their guesses with somebody else's money, but there is hardly a record of an oil witch sinking his own money on his certain knowledge, and of the thousands of devices tested not one has proved to be of the slightest value as a means of finding oil.' Furthermore, it is quite evident that if there was value of any sort to such contrivances the large oil companies would have utilized them long ago instead of spending time and money on careful geologic investigations.

FALSE IDEA OF MOTHER POOLS

The statement that a certain region is underlain by a great mother pool of oil and gas has moved to distant commercially productive fields has been circulated at one time or another in every region prospected for oil. Marvelous indeed is the individual who can see into the ground and detect the presence of such a pool. In the first place, as previously stated, oil and gas do not occur in actual pools or lakes but fill the minute intergranular spaces in the solid rocks. In the second place, while under exceptional conditions oil and gas may migrate considerable distances laterally, the source of the oil in practically all oil fields is found to be close to the area where it is discovered. The idea of a mother pool is without foundation of any sort.
IDEA OF OIL FIELDS EXTENDING IN LINES THROUGH THE COUNTRY

The belief that oil fields extend in definite lines through the country has given fond hopes to many a district which was supposed to lie on or near such a line. With regard to the probability of such an arrangement of oil fields the writer can do no better than to quote Dr. F. G. Clapp: "The only class of lines are those of real value in prolonging oil pools are 'structure contour lines,' drawn by the geologist on his maps, and which when followed outward from an initial well will furnish some clue to the probable direction of the pool."

Underlying this fallacy is the fact that the location of oil fields is in part determined by the location of folds, which are in turn determined largely by the location of centers of deformation. Since lines of folding tend to parallel associated mountain ranges, the oil fields of these folds also show a crude linear arrangement. This is only true, however, in the broadest sense and individual pools may be developed in any direction. A little study of the factors governing the accumulation of oil and gas will make this evident. Although a certain district may lie in a line between two producing fields this fact has absolutely no significance in determining its oil and gas possibilities.

PROXIMITY OF A DISTRICT TO OTHER OIL FIELDS

It is commonly stated in wildcat territory that the location of the minimum relative to adjacent producing territory is a very favorable feature. The character of geographic location itself has nothing at all to do with the chances for or against oil being found. What is under consideration here is the previous history of the area. If it has studied the previous parts of this bulletin is well aware it is geologic conditions and not the geographic location of a region that determine its oil and gas possibilities. If favorable geologic features such as proper types of rock, structural conditions, etc., exist in a locality, and if there are possibilities of oil being found. If the region has unfavorable geologic features, even though it may lie next to a producing field, the chances for oil and gas are slight.

PREDICTING OIL POSSIBILITIES BY THE CHARACTER OF THE TOPOGRAPHY

Frequently the statement is heard that a certain country looks like an oil region, or resembles some oil field, and hence is favorable. The above statements may be true but they have absolutely no bearing on the chances for oil in the region in question. The statement that a region is favorable because of its geologic conditions and not by surface features. Oil may occur under any kind of surface. Surface features, while often of aid in interpreting upbuilding conditions and the character of the formations present, in themselves have no significance as indicators of oil.

ASSOCIATION OF COAL AND OIL

The presence of coal deposits does not indicate the presence of oil deposits. The two are in no way related. In fact these two types of mineral fuels are formed under entirely different conditions. Coal deposits are formed in fresh water areas such as swamps, marshes, borders of lakes, flood plains of rivers, etc. Petroleum has developed in sediments laid down in marine waters. It happens that in a number of oil fields coal bearing formations occur, but they were laid down at a different geologic time and are not genetically related to the oil. It is true that some gas may be developed by the chemical changes in coal beds, but this gas is not related to petroleum deposits. Oil has been found in regions where coal formations do not occur. The occurrence of coal beds and oil pools in the same region is a matter of accidental association.

ASSOCIATION OF SALT DEPOSITS AND OIL

What has been said of the association of coal and oil also applies to the association of salt deposits and oil. In the Gulf coast fields of North America, salt domes have played an important part in forming traps for oil and gas, but the two types of deposits are not genetically related.

In parts of western South Dakota the evaporation of waters which contain considerable amounts of various salts in solution has formed salt lakes, and in some places distinctly saline pools. These salt lakes have been derived from certain mineral constituents of the underlying formations which have been taken into solution by the ground waters. These occurrences of salt have absolutely no bearing on the possibilities for oil and gas.

13. THE "PETROLEUM GEOLOGIST," HIS VALUE, TRAINING, AND LIMITATIONS

Since South Dakota is still entirely "wildcat" territory with no positive evidence within any part of its boundaries of commercial supplies of petroleum, the State is subject to all the false reports and unwarranted development schemes that are common to unproved districts in which there is active interest. Some of the reports relating to the unusually promising possibilities of a given district or district of origin. As the great salt domes have been derived from certain mineral constituents of the underlying formations which have been taken into solution by the ground waters. These occurrences of salt have absolutely no bearing on the possibilities for oil and gas.

Years of careful and detailed study of conditions in oil fields and the many factors which have been found to govern the origin and accumulation of petroleum, have developed the science of petroleum geology, which now ranks with the other sciences of our civilization. As the various theories, based on careful analysis of conditions in oil fields, have been evolved and tested in practice, more and more accurate information has been gained relative to the conditions which determine and govern deposits of oil and gas. The results have brought about a tremendous reduction in the proportion of unproductive wells.

The bearing of these facts upon the value of geology to the petroleum industry is self evident. Today every successful oil company has its corps of well-trained geologists, who play a vital part not only in the exploratory work but also in the development of proved oil fields. The work of the petroleum expert does not end with the discovery of a commercial deposit of oil. His services in working out
improved methods for recovering the oil and retarding the decline of producing wells are of the highest importance. Although geology has been of inestimable value in the petroleum industry, the science also has its limitations. There is a tendency on the part of some people to attribute to the oil expert who has been successful in locating an important deposit of petroleum some mysterious power or faculty which the ordinary individual does not possess. The geologist can see into the ground no more clearly than any other individual. Any person who claims that he can positively determine the presence of oil or gas before testing with the drill is an absolute imposter and deserves no consideration on the part of the public.

The element of chance always enters into the location of oil wells and is especially high in wildcat or unproved territory. The application of geology to oil field development thus is at the smallest possible factor. Although geologic conditions may in every way be favorable in an unproved area, drilling often results in complete failure. This has happened any number of times in the industry. Conversely, producing fields have been developed in areas where the evidence seemed largely against the possibilities for finding oil or gas. These cases, however, are the exception and not the rule. They do not discredit the value of the science as an aid in locating petroleum deposits.

It is generally recognized in the profession that the proper technical equipment for the petroleum geologist includes the usual four years' work in a standard university, in which geology has been pursued as the major subject, followed by one to three years technical graduate work in fields of special interest. In addition, several years' field experience of professional type is necessary before one can be considered a professional geologist who can make sound judgments. It is highly essential, therefore, that the various communities of the State that have occasion to employ or deal with petroleum geologists make certain that the individual in question has the proper technical and practical training and is in good standing in the recognized profession. Careful attention to this precaution may not only effect a saving of hundreds of dollars but will also quickly eliminate impractical and those so-called geologists who do not come up to the standards discussed above. While it is true that some geologists with slight technical and personal training may have attained success, yet these cases are very rare. The practical geologist is not equipped to do sound work. One must have a proper knowledge of the many principles involved in geology and its various branches can be acquired only by a thorough technical education. As a matter of business and pride the geologist should be willing to produce authoritative evidence of his training and experience. In fact it is the right of those who ask for his services to demand this.

It is urged that persons desiring information as to the ability and integrity of any oil expert they contemplate employing write to the State Geologist, who can readily determine the status of individuals with any standing in the profession. Such service to the people of the State constitutes a function of this department, but this service can be of value only in so far as the public sees fit to avail itself of it.

In any event, before a geologist is employed the following facts should be obtained regarding him:

A reference from a bank or business house is of value in indicating business integrity, but has no value in indicating scientific ability.

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Practically every oil geologist of any standing in the profession is a member of the American Association of Petroleum Geologists. While membership in this organization does not guarantee his ability, yet it indicates a good understanding in the profession and a thorough training, since the qualifications for membership in this organization can be obtained by writing to the Secretary, at Norman, Oklahoma.

14. SUMMARY

In concluding this general discussion on the application of geology to oil field development, the following summary has been added to emphasize those features thought to be of most vital interest to the public in general.

1. Do not invest money in oil stock of any kind in unproved regions unless you can afford to lose it. No matter how favorable the geology and other features may be the chances of failure to find commercial deposits are always great.

2. There is no way of foretelling positively whether oil or gas in commercial quantities exists under the ground in a region. The drill only can disclose this. Oil and gas seeps, if authentic, are only suggestive and simply indicate that certain underlying rocks are petroleumiferous. Such seeps do not prove commercial quantities.

3. Any person who claims the power to locate oil and gas deposits with instruments, or the divining rod is either ignorant of the simple fundamentals of petroleum geology or a fraud. The fact that such methods receive no consideration from responsible oil companies indicates their worthlessness.

4. The presence of a favorable structure is not the only factor necessary before drilling. Other geologic features such as possible reservoir rocks, presence of rocks which might be a source of petroleum, etc., must be considered. Many a good structure has been drilled without success.

5. Oil sands are not continuous everywhere. Sandstones because of their mode of deposition tend to be more or less restricted area to thin out when traced laterally. A knowledge of the oil bearing sediments were deposited is essential. The sandstones will be confined largely to the near-shore areas.

6. The structure may be favorable, reservoir conditions may be favorable, and yet no oil or gas may be found if the proper organic matter necessary to form these substances was never present.

7. In drilling for oil and gas, see that a method is used which will give a good accurate log and disclose the presence of any oil in the sands. Remember that the rotary system is not satisfactory in drilling test wells.

8. Drill to the proper depth. After competent geologic advice has indicated the depth necessary to reach probable oil horizons, see that the drilling contract allows for the necessary depth. Many a well has been a failure because of too shallow drilling.

9. Keep a careful and accurate log. Such a log may result in the saving of thousands of dollars later on.

10. Where the structure is favorable and geologic conditions in general are favorable, the failure of one properly drilled well does not condemn the area. In many an oil field a dry well has been drilled near a great producer. After two or three properly drilled wells on the structure have failed to disclose pay sands then it is time to become pessimistic.

11. Read all literature advertising a prospective area with due caution. Remember that it is natural to be optimistic in such literature and to omit unfavorable features. Nearly every possible oil and
gas territory has unfavorable as well as favorable features, and sometimes the former far outweigh the latter. "Extracts from geologist's report" are often only the favorable extracts.

12. Employ nothing but reliable geologists. The skilled technical expert will be more expensive but may save you thousands of dollars in the long run.

13. Do not employ a geologist unless he can give satisfactory and authoritative evidence as to proper technical training, proper field experience, and proper standing in the profession. Satisfactory ranking in all three of these requirements is absolutely essential as a guarantee to proper and accurate geologic work.

14. In all cases before employing a geologist you are urged to write the State Geologist, who will furnish you with a list of recognized men in the profession that are available for consulting work.

15. Remember that in wildcat prospects the rewards are big if oil is found but do not let this fact cloud your common sense and good judgment. There is no "sure thing" in wild-cattting, no matter how favorable the indications may be. Any person who guarantees that oil will be found in an untested region is either an imposter or an ignoramus.

16. Finally, before investing in oil stock be sure of the following facts: that you can afford to lose your money; that the geologic work leading up to the drilling has been done by competent, certified experts; that you are aware of all the unfavorable as well as favorable geologic features of the area; that the well is to be drilled properly and to a sufficient depth for a fair test; that all contracts and agreements relating to the development of the prospective area are legal and properly arranged and entered into. With these precautions properly observed you have on the average about one chance in thirty-five of realizing a return on your investment. The return, however, may be large. It is this occasionally spectacular profit on such investments that makes them so attractive to some people.

PART II

GENERAL GEOLOGIC FEATURES OF SOUTH DAKOTA

1. TOPOGRAPHY

GENERAL FEATURES

With the exception of the Black Hills uplift, the major part of South Dakota consists of rolling prairie with buttes, mesas, badlands, and more or less hilly areas developed in scattered localities.

The Missouri River and its larger tributaries describe meandering courses in broad, shallow valleys, bordered by steep bluffs or grassy slopes. The many smaller tributaries consist of grassy swales and ravines or steep-sided gullies, nearly all of which are free of running water during a great part of the year.

The Black Hills constitute a distinct province but will not be considered in this bulletin since the possibilities for oil and gas in the immediate area of the Hills are too remote to merit attention here.

The generally uniform topography of the prairie regions of South Dakota is due to the extensive exposures of nearly flat-lying and hence uniformly eroding formations. The slight gradients of the streams and the general lack of water to feed them has greatly retarded their erosive power so that the valleys are shallow and more or less filled with alluvium deposited by overloaded streams in periods of flood. As a result the relief differences in any locality are slight except where accentuated by buttes or other elevated points.

While the regional topography is characterized by this general uniformity, the local topography may show considerable diversity of relief and form, especially in those areas where Tertiary formations are developed. The local topographic features that are of special importance are buttes, escarpments and badlands.

The significance of buttes in their relation to oil and gas possibilities is that they form topographic features reflecting regional attitudes of the bedrock. They indicate that the bedrock lies nearly horizontal and hence that folding in the region is very slight. The conception held by some people that buttes are due to "gas blowouts" or some sort of volcanic or igneous activity is without foundation. The fact that they are composed of bedded rocks, sandstones, shales, or limestones, directly related to the surrounding formations, indicates the impossibility of the origin postulated above. Bear Butte near the Black Hills is due to volcanic or igneous activity, but Bear Butte is composed of igneous and not sedimentary rock. Often loose ledges of rock have broken off from the main mass of the butte and lie tilted at a greater or less angle into the surrounding grassy slopes, thus giving the appearance of a disturbance of some kind, but a short examination will show their true origin. Scattered masses and ledges of resistant rock, generally sandstone, may dot the prairie or lie imbedded in the soil in the vicinity of buttes and elsewhere, but they all represent erosional remnants and are not due to disturbance of any sort.
OIL IN SOUTH DAKOTA

As previously stated, the term "escarpment" is applied by the geologist to any steep slope or cliff which has a linear trend. Escarpments are developed in flat-lying as well as dipping rocks; hence they do not necessarily indicate the presence of structures favorable for oil. Vegetation tends to be sparse and the strata are in general unconsolidated and readily susceptible to wearing away by running water and other agencies of erosion. Their immediate origin lies in the fact that the soil and plants have been worn away, exposing the underlying soft rocks to direct attack by erosion. The resulting development of steep slopes and intricate gullies and hollows makes it difficult for the soil to regain foothold. The badlands may gradually spread until they cover a large area, thus showing all stages of destruction. Insufficient beginnings to extensive tracts occur at the heads of ravines and along the stream courses in those parts of the State covered by the White River and Lance formations. These formations, owing to the character of their rocks, are especially favorable to badland development.

There is a tendency on the part of some people to believe that badlands have been formed by disturbances of the bed rocks and hence indicate areas that may be favorable for oil. The fact that they are due to a special mode of erosion, however, evidences the lack of any such relation. The only interest badlands have for the oil geologist is the fact that they offer excellent exposures for the study of structures. Great caution must be used in working out structures over badland areas, as the beds tend to slump and sag due to differential erosion. Beds tilted in this manner may be very deceptive to one not trained to distinguish true deformation from folding produced by some agency.

RELATION OF TOPOGRAPHY TO UNDERLYING ROCK FORMATION

Each formation is distinctive in the character of its materials and hence in its method of erosion. For example, the Pierre Shale tends to form rolling, gumbo country, the basal Lance formation erodes into badlands areas, and the Fox Hills, Fort Union, and Upper Lance formations produce rolling grass covered areas with scattered buttes. This relationship between the character of the topography and that of the underlying rocks is of great value to the geologist in those areas where the bedrock is largely concealed. A knowledge of the type of topography produced by a certain formation is of great value in tracing out or mapping it where the bedrock is concealed.

Another matter which may be considered in this connection is the relation of the vegetation to the underlying rocks. The vegetation varies according to the composition of the soil. The common types of prairie vegetation—grasses and sagebrush—will generally show a distribution in which the former favors the more sandy areas and the latter the more shaly areas. Often soils are formed from materials transported by water, wind, and other agencies. In such cases the character of the soil and vegetation may bear little relation to the underlying rocks. This is especially true of the stream courses and depressions where water or wind-borne materials tend to collect.

RELATION OF TOPOGRAPHY TO EASE OF GEOLOGIC WORK

With the exception of the badland areas, stream courses, and the slope of the plains area south of the Platte River the bedrock is largely covered by alluvium, gravel and sand, or other vegetation. In the areas east of the Missouri River the heavy covering of glacial drift has also concealed the underlying rocks except in a few localities. In view of this widespread concealment of the strata, geologic work in the plains region of South Dakota is very difficult. In some areas the geologist must rely entirely on surface features such as erosional forms, vegetation, etc., for his interpretation of the underlying structural and stratigraphic conditions. For work of any reasonable accuracy, however, it is essential that bedrock exposures be present. The lack of such exposures is a serious handicap in the deciphering of structures. Wells which have been drilled or dug for water are of great importance in giving the geologist clues as to character of the underlying formations.

2. STRATIGRAPHY

GENERAL RELATIONS

South Dakota has within its boundaries two distinct geologic provinces, one formed by the Black Hills uplift, the other constituting the Great Plains. The Black Hills uplift consists of a central core of pre-Cambrian crystalline rocks, around which the Paleozoic and Mesozoic sedimentary rocks have been tilted at steep angles. Eastward from the Black Hills the steep-dipping strata quickly change to the nearly horizontal attitude that is characteristic of the Great Plains province. The sedimentary rocks bordering the Black Hills have been secondarily folded into prominent structural features, but over the Great Plains region pronounced local folds are largely absent and the nearly horizontal attitude of the sedimentary rocks is broken only by gentle undulations of the strata.

In the Great Plains province the exposed formations, owing to their nearly horizontal attitude, cover broad areas. With the exception of projecting ridges of pre-Cambrian quartzite and granite in the southeastern and northeastern parts of the State, the rocks of the Great Plains are of relatively late geologic age, the older sedimentary rocks being deeply buried in nearly all areas. Around the Black Hills uplift, however, the older rocks are brought to the surface.

The formations of greatest interest in the consideration of petroleum possibilities are those exposed over the Great Plains. Over this region, from all evidence now in hand, the formations exposed around the Black Hills lie at too great a depth for feasible drilling under existing conditions of oil field developments. The huge number of abandoned wells that have been drilled in eastern part of the State east of the Missouri River indicate that the Paleozoic and early Mesozoic rocks are absent over a large part of the eastern half of the State. West of the river, outside of the Black Hills region, these older rocks have not been drilled and, therefore, the distribution of their surface or character is unknown. This applies to all formations lying below the Dakota-Lakota sandstones, or those whose outcrops are limited to the Black Hills uplift.

For the reader who is unfamiliar with the classification of the formations of South Dakota, the appended correlation table has been added, showing the relation, thickness, and characteristics of each formation. In the geologic map at the back of the bulletin the distribution of the exposed formations of the Great Plains region is shown. The older formations exposed around the Black Hills and in the eastern part of the State are separated on the map into two groups, the pre-Cambrian crystalline rocks and pre-Lakota sedimentary rocks. The generalized structural features of the State are shown on the cross sections.

3. STRUCTURE

Aside from the region of the Black Hills uplift, where the rock exposures have clearly defined the related structural features, the determination of structure over South Dakota is a difficult problem. The general lack of bedrock exposures over the prairie regions, due to the heavy covering of soil, alluvium, and glacial drift, is a
CORRELATION TABLE FORMATIONS IN EASTERN WYOMING AND SOUTH DAKOTA

<table>
<thead>
<tr>
<th>Era</th>
<th>Period, etc.</th>
<th>Eastern Wyoming</th>
<th>Black Hills</th>
<th>West and Northwest S. Dak.</th>
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<td>CENOZOIC</td>
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<td>Fort Union 425</td>
<td>Absent</td>
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<tr>
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<td>Fort Union</td>
<td></td>
<td>Ludlow lignitic</td>
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<tr>
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<td>Lance</td>
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<tr>
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<td>Montana Group</td>
<td>Fox Hills Sand</td>
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<td>Cannonball marine</td>
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<tr>
<td></td>
<td></td>
<td>Parkman sand</td>
<td></td>
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<td></td>
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<td>Teapot sand</td>
<td></td>
<td>Somber beds 425</td>
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<td></td>
<td></td>
<td>Pierre shale</td>
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<td>Shannon sand</td>
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<td></td>
<td>Niobrara</td>
<td>1990+</td>
<td>Pierre Shales</td>
<td>1990+</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Carville shale</td>
<td>175-225</td>
<td>Niobrara Chalk and Shale</td>
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<td>569-600</td>
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<td>Graneros Shale</td>
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<td>Cloverly</td>
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<td>Newcastle ss. member</td>
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<td>(Lower Cretac.)</td>
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<td></td>
<td>Unkapa ls</td>
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<td>Sundance</td>
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<td>Minnewaska ls</td>
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<td>Bighorn ls</td>
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<td>Deadwood ss</td>
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<td>Carboniferous</td>
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<td></td>
<td>Penn.</td>
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<td></td>
<td>Miss.</td>
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<tr>
<td></td>
<td>Ordovician</td>
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<td></td>
<td>Cambrian</td>
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Pre-Cambrian Crystalline Rocks
PART III

PETROLEUM POSSIBILITIES IN SOUTH DAKOTA

The geologic features of South Dakota which bear upon the possibilities for oil and gas may be divided into two classes: those which apply to much of the State, and those which apply to specific areas. Those features characteristic of much of the State will be considered first.

1. FORMATIONS IN WHICH OIL AND GAS MAY HAVE ORIGINATED

It has been indicated in Part I of this bulletin that a great portion of the organic matter which has formed petrolierous products has been preserved in shales, marls, and limestones. From these rocks the oil and gas have migrated into associated sandstones or more porous zones, the later concentration or dissemination of these products being determined by structural conditions.

In the consideration of oil possibilities in an unproved region it is thus very important to determine, as far as possible, whether strata favorable for the formation of hydrocarbons are present, and if so, to consider their horizontal and vertical distribution. If a study of the stratigraphic column shows the presence of no formations in which conditions were favorable for the formation of hydrocarbons, there is no need of going further into the problem of oil and gas possibilities for that district. The presence of favorable structures and reservoir rocks would have no significance if the presence of the hydrocarbons was never proved to begin with.

A study of the columnar section for South Dakota indicates that a number of horizons are present which might be sources of petrolierous matter. These will be considered in ascending order of their geologic age.

PALEOZOIC ROCKS

The Paleozoic rocks are exposed only around the Black Hills, but according to present evidence the Upper Paleozoic formations, at least, probably underlie much of the State west of the Missouri River.

The Paleozoic strata consist mainly of limestones and sandstones. Shales are of much less importance. The chief development of limestones occurs in the Upper Paleozoic. Of the Upper Paleozoic limestones, the Pahasapa formation, which is so well developed in the Black Hills, is probably extensively developed over other areas in the State, and it is probably this formation or closely related strata which occur in the southeastern part.

The Pahasapa is sparingly fossiliferous in the Black Hills region, but this fact merits its being considered as a possible source of petroleum. It is possible that in areas where the formation is concealed, fossils may be abundant and hence form a source for commercial quantities of oil and gas. The Madison limestone of Wyoming and Montana, which is provisionally correlated with the Pahasapa
formation, is bituminous in the Big Horn basin area. As far as the writer is aware, no bituminous material has been found in the Pahaska limestone.

The Minnekahta formation is the other Paleozoic horizon that merits consideration as a possible source of oil. This formation is also well developed in the Black Hills uplift and doubtless extends over a considerable area to the east. The formation consists of limestone and is locally bituminous. It is probable that the Minnekahta limestone is much less extensive under the prairie regions of the State than the underlying Pahasapa limestone. The formation in the Black Hills region is thin, averaging less than fifty feet in thickness.

The other formations of the Paleozoic System are either too restricted in their distribution or too barren of fossils to merit consideration as possible source-rocks for oil.

LOWER MESOZOIC FORMATIONS

A considerable part of the Lower Mesozoic, as well as the Upper Paleozoic beds consist of red shales and sandstones probably deposited under semi-arid conditions and in part representing deposits in fresh waters. They are barren of fossils or poorly fossiliferous and hence have slight value as possible sources of petroleum. The formations especially characterized by these features are the Opeechee shales of the Upper Paleozoic, and the Spearfish sandy shales, provisionally classed as Triassic.

Above the red beds of the Spearfish lie a series of shales and sandstones of marine origin, the Sundance formation. The formation is abundantly fossiliferous and contains sandstone and limestone lenses which might form reservoir rocks. This formation deserves consideration as a possible source of hydrocarbons. It is reported that the Sundance formation in the vicinity of Bear Butte is slightly bituminous, but this has not been verified. The formation is apparently restricted to the western part of the State.

The remaining formations of the Lower Mesozoic, including the Morrison, Lakota, and Fusan beds, offer slight possibilities as source rocks for petroliferous materials, since they are largely of fresh water origin.

UPPER CRETACEOUS FORMATIONS

It is in this general horizon that the important deposits of petroliferous source-rocks occur. The greater part of the Upper Cretaceous rocks in South Dakota consist of sandstones with marine origin. That the muds from which these shales were formed were full of organic matter is suggested by the general dark color of the rocks and the prolific fossil content of the numerous interstratified lime concretions. The formations included under this group are the Graneros, Carlile, and Pierre shales. It is from sandstones interstratified in these shales or equivalent beds that much of the oil and gas of the Rocky Mountains fields is derived. The original source of the oil now found in the intercalated sandstones was doubtless from the shales. The petroliferous character of the Upper Cretaceous shales is a characteristic feature of their exposures in Wyoming and Montana. In South Dakota, the outcrops of the Graneros and Carlile formations are confined to the Black Hills region and the southeast part of the State. The Pierre shale, however, is widely spread, covering approximately two-thirds of the State. The petroliferous character of the Pierre shale is indicated not only by its general somber color, but also by the presence of thin beds of interstratified oil shales.

OIL FORMATIONS AND DISTRICTS

A bed of oil shale averaging six or eight inches in thickness is exposed along the bluffs of the Cheyenne River valley between Ash Creek and Cherry Creek. Oil shale has been reported from the Pierre formation in northeastern Little Missouri River south of Campbell coal bed from Charles Mix County. It is probable that detailed investigations will disclose a number of localities in which such shales occur. The beds are too thin, however, to be of commercial value.

The Greenhorn and Washburne shales are both petroliferous and so may form possible source rocks. The Greenhorn limestone is of less importance in this connection owing to its general thinness. The Fox Hills formation, which constitutes the Upper horizon of the Cretaceous strata, although abundantly petroliferous, has not been prospected. Furthermore the formation is a light cover of pervious Tertiary beds over much of its area of distribution, and thus any petroliferous matter that may have developed in the rocks could have readily escaped.

TERTIARY FORMATIONS

The Tertiary formations consist of fresh water deposits and hence have no value as source rocks for oil and gas. As stated in Part I of this bulletin, practically all known commercial supplies of petroleum have been found in marine strata. Any oil found in the Tertiary beds probably has migrated upward into them from underlying marine Cretaceous strata.

The lignite bearing Tertiary beds of northeastern South Dakota contain slight (local accumulations) of oil and gas in the lignites, but these deposits are too insignificant to be of commercial value.

2. POSSIBLE RESERVOIR ROCKS

If the region is found to have favorable source-rocks, the next procedure in the determination of the depth, thickness, distribution, and other features of possible reservoir rocks in which any oil or gas formed may have accumulated.

The assumption often made, that certain sands occur in a given region because they are present in some other district ignores a fundamental geologic principle which was brought out in Part I, but is repeated here for the purpose of emphasis. As previously indicated, the deposition of marine sediments is governed by the relation of the area of deposition to the shores lines of the sea at the time the sediments were formed. It was also indicated that the sandstones are largely confined to the near shore areas, these sediments grading off-shore into finer muds or shales. Thus it is very important that in those areas where the reservoir rocks are not exposed the probability of their presence should be verified by a careful study of paleogeographic conditions which prevailed during the period of deposition. Such studies may show that the sandstones or other reservoir rocks present in another region have thinned out in the area under consideration.

The stratigraphic column for South Dakota indicates the presence over parts of the State of several formations which have the features essential for the retention of accumulations of oil and gas. Their thicknesses and distribution are considered in ascending geologic age.

DEADWOOD FORMATION

The Deadwood sandstone, although having the features requisite for a reservoir of too great a geologic age to offer any possibilities for oil. Any commercial deposits which once may have existed in this formation have doubtless long since been lost. In
OIL IN SOUTH DAKOTA

Wyoming, the Deadwood formation is locally saturated with oil; but it is probable that the oil has seeped into the sandstone from underlying formations against which the Deadwood sandstone has been upfolded.

PAHASAPA LIMESTONE

The porous character forms feasible reservoir conditions. It is probable that this formation or equivalent rocks are fairly extensive over the western half of the State at least, and hence are apt to be present in all regions favorable for testing.

MINNELUSA FORMATION

This formation consists dominantly of sandstone with local layers of limestone and shale. The sandstone is generally more or less calcareous. The Minnelusa sandstone is a source of artesian water in the Black Hills area and hence indicates a condition favorable for the migration of oil and gas. The formation has been found to be slightly petroliferous on the western side of the Black Hills. Its outcrops are reported to be locally bituminous on the eastern side of the Black Hills, but this has not been verified. The oil obtained from the Minnelusa formation on the western side of the Black Hills is of a heavy, black type, and suggests a residue from former more extensive pools.

The Minnelusa formation thins eastward in the Black Hills area, and may not extend any great distance under the plains region of South Dakota. In view of its petroliferous character and its favorable reservoir features, this formation should be tested out in areas removed from the Black Hills uplift where structural conditions are favorable. Under present economic conditions the testing of this sand and other Permian formations in the plains region would be feasible, owing to the great depth of drilling necessary to reach them.

SUNDANCE FORMATION

This formation contains a water-bearing sandstone in its lower part in the exposures around the Black Hills uplift. Although the Sundance formation is probably restricted to the western part of the State, it must be considered as a possible oil horizon because of its fossiliferous character and the presence of a sandstone member which forms a favorable reservoir rock. The lithologic character of the rocks, however, may be found to vary greatly in areas away from the Black Hills. The Sundance formation is oil-producing in Wyoming.

The overlying Unkpapa sandstone, which is probably largely restricted to the region of the Black Hills also merits consideration in its areas of occurrence.

THE DAKOTA-LAKOTA SANDSTONES

The series of sandstones, shales, and clays included in the Dakota-Lakota formations doubtless underlie the entire prairie region of South Dakota, aside from a part of the pre-Cambrian quartzite ridge near Belle Fourche and the granite outcrops of Bigstone Lake, in which these strata were probably never deposited.

In the earlier literature, the Lakota, Fusion, and Dakota formations were collectively known as the Dakota sandstone; but studies in the Black Hills resulted in the tripartite division indicated above. Over the Great Plains region as a whole, these basal Upper Cretaceous sandstones are still referred to as the Dakota formation, as it is only in the Black Hills uplift that the Lakota and Fusion formations have been universally recognized as distinct stratigraphic units. In eastern South Dakota, the Dakota and Fusion formations have not been recognized as yet in the mass of sandstones lying below the Benton shales.

and the term Dakota is applied to all these basal Upper Cretaceous beds. Darton1 states that it is possible that in eastern South Dakota "the formation there termed Dakota may include, locally, at the base the Morrison, Lakota and Fusion formations of the Black Hills and of the Rocky Mountain regions.

Over South Dakota the Dakota-Lakota beds show considerable variations in thickness and lithology. In the Black Hills uplift the Lakota varies from about 100 to 300 feet in thickness and consists largely of coarse-grained, cross-bedded sandstone with thin local shale partings. The Fusion formation was local in extent and is composed of sandstone and has an average thickness of about 65 feet. The Dakota formation is composed of sandstone of moderately coarse texture, averaging 100 feet or less in thickness.

In the eastern half of the State the Dakota sandstone, which may include, as stated above, the Fusion and Lakota formations, varies from 150 to about 400 feet in thickness. The Dakota is not exposed, but the many artesian wells which have penetrated it give a fairly accurate knowledge of its characteristics. The formation consists primarily of moderately fine-grained sandstone with interstratified beds of shale, the arrangement of these strata varying from place to place. Over much of eastern South Dakota the Dakota sandstone lies directly on the pre-Cambrian crystalline rocks, indicating that the Paleozoic and Lower Mesozoic rocks are generally absent from this region.

Unlike most sandstone formations which, as previously indicated, tend to be lenticular and restricted in their distribution, the Dakota sandstone covers many thousands of square miles over the Great Plains region. The widespread distribution of the formation is still a problem not yet satisfactorily explained. Such widely spread sandstones are called "sheet sands." They have been formed only at rare intervals in geologic history.

The generally uniform character of the Dakota formation suggests uniform conditions of sedimentation over extensive areas during its deposition. These facts are in accord with a marine origin, but on the other hand the presence of fresh water fossils in many areas of exposure and the frequent occurrence of cross-bedding in the sands suggest a fresh water or brackish water origin for the sandstone over areas at least. A freshwater origin is further emphasized by the local occurrence of lignite beds. The character and distribution of the Dakota sandstone indicates widespread shoaling waters, a condition which preceded the extensive submergence of these areas by the Upper Cretaceous seas in which the great thicknesses of Benton and Pierre shales were formed.

The above detailed description of this formation has been considered advisable in view of the great interest the Lakota-Dakota sandstone has to those interested in the possibilities of the State. It is in this general horizon that those who are testing or planning on testing the prairie regions of the State hope to find commercial accumulations of oil or gas.

That the Dakota and related sandstones have the porosity requisite for the ready passage of oil and gas through the beds is indicated by the active production in the tripartite division indicated above. On the west side of the Black Hills oil is found in this general horizon, and commercial production is obtained in the Mule Creek and Lance Creek fields. The Greybull sand of the Big Horn Basin and the Cloverly formation of the Powder River field of Wyoming, both of which are probably equivalent to the Dakota-Lakota, are oil-producers.

OIL IN SOUTH DAKOTA

Producing. In the Black Hills region of South Dakota the Lakota sand, especially, has been found to be at least locally saturated with oil, but as yet no production has been obtained. The Lakota sandstone is bituminous in a number of localities of exposure around the eastern side of the region. The artesian water content of the Dakota-Lakota sands is a factor which has an important bearing on the possibilities of these rocks as reservoirs for oil and gas. The great number of artesian wells which have been drilled into the Dakota sand in the eastern half of the State and in the Black Hills region indicate that the rocks are quite thoroughly saturated with surface waters which have entered the sands in the areas of exposure around the Black Hills and the Rocky Mountain foothills. The question as to whether this saturation of the artesian water by actively circulating fresh water would wash out or disseminate any oil that may have entered the sands is open to some debate. The hundreds of wells which have been drilled into the Dakota formation in the eastern half of the State and around the Black Hills have thus far shown slight traces of oil only in the latter area. This fact is significant, since it seems that if the Dakota was saturated with oil to any appreciable degree evidence of this would have been indicated at some time or another in one or more of the many wells which have penetrated this horizon. On the other hand, the locally bituminous character of the Dakota-Lakota formations in the Black Hills region and the presence of natural gas in the artesian water suggest that petrolierous materials are present in these sands to some extent, although not necessarily in commercial quantities.

It is possible that oil may have been carried by the water to points favorable for its accumulation, such points being formed by folds or irregularities in the upper surface of the sand (figure 4). The hydromotive theory of Munn2 postulates that water in motion carries the oil with it, the oil tending to float into any structural features encountered.

The structural features of the Dakota sandstone must be considered in connection with its oil content. According to known evidence the folds in the Dakota of the plains region are broad and gentle, and it is suggested both by the artesian water and by the bituminous character of the sandstone in the Black Hills that this horizon was not affected by any folding that might have prevented oil from entering these formations. The artesian water has sufficient head to circulate active through them, thus preventing any separation of the oil. The greater capacity of the water would also aid this upward movement if the pores are sufficiently small. On the other hand, the presence of large pore spaces in the higher parts of even a slight fold might permit the oil to separate and accumulate in these larger pore spaces. The immiscibility of the oil and water and the greater capacity of the water, as previously described, would tend to prevent the water from circulating through this area of accumulation. The fact that the Dakota sandstone is frequently very porous somewhat favors this postulation.

On the whole, present evidence is not especially favorable for the Dakota sandstone as a reservoir rock for oil. It is probable that gas may be found in some of the domes or folds that may exist in this sand. The presence of gas in the artesian waters indicates that the shales adjacent to the Dakota sand are supplying this product in quantities which may locally be of some importance.

1A slight quantity of high grade oil is reported from the Dakota sands near Minot, North Dakota. The Dakota sandstone there is about 200 feet thick, with an interbedded shale 8 feet thick. The oil is of high gravity and is bituminous. The field is not large and is worked at a loss; the oil is not of any commercial value.


OIL FORMATIONS AND DISTRICTS

When oil and gas move out of the rocks in which they originate into the reservoir rocks they generally move upward. Since nearly all the oil in the Rocky Mountain fields now being extracted has originated in the Upper Cretaceous shales, it is evident that this oil has moved upward into stratigraphically higher sands or lower sands higher by folding. The latter case is the one most commonly offered as an explanation. If the Kootenai sands of Montana. Pronounced folds, however, are necessary for this migration across formations into lower sands. In South Dakota the oil in the prairie regions are probably all slight and hence would not be a source of the Dakotas-Lakota sands from the Upper Cretaceous shales, as it would not necessitate downward movement. Circulating waters might possibly carry oil downward. If circulating waters do not act in this capacity the Dakota-Lakota sands may get their oil from any underlying strata. The possibility of oil upon the Dakotas-Lakota, especially with reference to the distribution of pre-Lakota strata and the character and quantity of any pre-Lakota oil, merits serious consideration.

THE BENTON AND PIERRRE SHALES

Lying above the Dakotas-Lakota sandstone and below the Fox Hills sandstone is a great series of dark marine shales containing two persistent limestone horizons, the Greenhorn and Niobrara formations. As indicated in the geologic sections, the Benton group includes the Graneros and Carlille shales and the interstratified Greenhorn limestones. Above the overlying Niobrara shales lies the thick Pierre shale, the most extensive formation of the State. It is in these formations in Wyoming that most of the important oil sands occur and hence it is important to determine to what extent these sands persist in South Dakota. Figure 12 shows the stratigraphic map (figure 12) shows the approximate extent of the sea in which the Pierre shale was deposited and gives a generalized idea of the extent of the sea and position of the shore lines during Upper Cretaceous time. The Pierre and Niobrara seas were more widespread than the Pierre waters. As indicated in the figure, the western shore line of the sea extended in a general north-south direction through the eastern part of Idaho and the western part of Montana. The sea was only a short distance beyond the eastern boundary line of South Dakota, forming a large bay.

According to present evidence, the land areas bordering the eastern part of South Dakota were low and featureless, and hence erosion was slight: only a small amount of coarse sediment was carried into the sea. Conditions were thus unfavorable for the accumulation of much sandstone in eastern South Dakota, even though the area was relatively near shore.

The western shore line was far removed from the western boundary of South Dakota, but two features favored the extensive deposition of sandstone as far east as the western border of the State. The waters of the Pierre sea were central and eastern Montana and Wyoming fluctuated in depth; brackish and fresh water conditions alternating with marine conditions over extensive areas. This fact and the bordering high land areas, due to the gradual uplift of the Rocky Mountains, favored the deposition of sandy sediments over extensive areas at frequent intervals and for great distances east of the shore. As a result sandstone strata are fairly numerous and extensive in the Upper Cretaceous of Wyoming and Montana. To...
wards the western border of South Dakota the sands pinch out and are largely absent over much of the State. A thin and lenticular bed is present in the westernmost areas and slight local lenses may occur in the eastern portion of the State. The gradation of the sands of the Pierre Sea eastward into the shales is shown in figure 11, which illustrates conditions in east-central Montana.

The following resume of the sandstones present in the Benton shales of eastern South Dakota is given by Darton.1 "Although the Benton group consists mostly of shale, it includes beds of sandstone containing more or less water, which is a source of supply for some artesian wells in the eastern portion of the State. The principal water-bearing sandstone is a bed which occurs at, or near the top of the formation. In some places it underlies the Niobrara chalk; in others it is separated from that formation by black shales which locally attain a thickness of 190 feet. The upper sandstone of the Benton is usually less than 25 feet thick, but ordinarily it is coarse and contains water in moderate amount and under considerable pressure. In the Black Hills exposures a sandy bed at about the same horizon as the above mentioned lower sandstone, is a persistent feature of the Graneros shales, except in the Belle Fourche region, where it is very thin and locally absent. It occurs "locally, but apparently in the same horizon, from 150 to 300 feet above the Dakota sandstone. Its maximum thickness is about 30 feet." This sand is probably the same as the Newcastle sand on the western side of the Black Hills, where it is slightly productive of oil. The sand is quite shaly and hence too impervious to form a good reservoir rock. As a result the production is slight. This objectionable feature is probably true of all the sands which occur in the Benton-Pierre

Fig. 11. Lensing Out of Sands in the Upper Cretaceous of Eastern Montana


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Fig. 12. Probable Extent of Upper Cretaceous Seas at the Time the Pierre Sand Was Deposited

From U. S. Geol. Surv.: Prof. Paper 128-A, Fig. 2, 1920.

groups of South Dakota, owing to the thinness of the beds and the mixture of fine mud and silt due to off-shore deposition.

The upper sandstone described by Darton for eastern South Dakota lies at about the same horizon as a sand developed in the Carlii shale of the Black Hills area. The general positions of these sands are indicated in the correlation table. Other thin, local sandy strata occur in the Benton-Pierre shales, but are of no value as reservoir rocks for the reason previously given. Development will probably show an almost complete absence of these sandy lenses in the Upper Cretaceous beds of central South Dakota.

The Niobrara limestone must be considered as a possible oil horizon, although the relative chances for oil in this formation are remote. The Niobrara limestone or chalk maintains a constant thickness, averaging 200 feet, over much of South Dakota. It is locally porous. In the Salt Creek field of Wyoming this formation has yielded considerable amounts of oil.

In eastern Wyoming and adjacent parts of South Dakota the Mowry shale is thin but it is generally somewhat petroliferous. Wherever sandy layers are present in this formation there is a chance for at least slight accumulations of oil. In the Newcastle district the Mowry affords a slight production. This formation is probably confined to the western part of the State. It has been suggested that much of the oil of Montana and Wyoming has originally come from this formation or equivalent horizons.

1The log of the Standing Butte well shows a thin sand in the upper part of the Benton shales. See page 81.

In northwestern South Dakota it is possible that a thin sand, representing the eastward extension of the Judith River beds, may be found in the Pierre shale. (See figure 11.) This sand is gas producing on the Cheyenne River anticline of eastern South Dakota. It is possible that this formation may have thinned out before reaching the State. Upper Cretaceous shales of adjacent parts of Montana and Wyoming may extend into this area but they probably will be thin.

FOX HILLS AND TERTIARY SANDBTONES

The rocks of the Fox Hills and overlying Tertiary fresh-water beds while offering ideal reservoir conditions are too near the surface and too recently deposited by sediments incised by erosion to have any possibilities for oil or gas in South Dakota. Unimportant pockets of gas occur in the Tertiary formations, probably of local origin.

3.—POSSIBILITIES OF OIL IN FRACTURES OF THE CRETACEOUS SHALE

In the Florence field of Colorado, according to present evidence, the important reservoirs occur in fissures in the Pierre shale. In Wyoming, the Salt Creek field contains considerable oil in shale fissures. In these areas the oil has worked into the fissures from underlying or adjacent sandy beds, deformation of the strata aiding the migration by faulting and fracturing the shale beds. The possibility of oil being found in fissures of the Pierre or underlying shales of South Dakota must be given consideration, but there is one factor which is against this possibility, if the present conception of the structural features of the State is correct. The above described fissures are at present at the mountain uplifts, where the beds have been more or less intense, and hence faulting and fissuring have been pronounced features. In South Dakota, aside from the Black Hills region, the shales are probably but slightly deformed. It is probable that they are therefore dense and compact throughout and that slight fissuring and fracturing have largely been confined to the surface portions where erosion and weathering are active. The possible presence of fissures in the deeper parts of the shale bodies must not be ignored, as such structures may have been formed by differential compacting of the beds or deformational features which are not evident at the surface. The finding of oil deposits in such areas of accumulation will be largely a matter of chance, as it will be difficult to predict their presence from surface features. Fissuring would be especially expected under the higher parts of the oils. It is probable that some of the natural gas found in the central portions of the State is derived from fissures in the Pierre and underlying shales.

4.—THE RELATION OF THE STRUCTURAL FEATURES OF THE STATE TO PETROLEUM POSSIBILITIES

The previous discussion of the broader structural features of South Dakota indicated that away from the Black Hills uplift the strata are nearly horizontal and that the slight folding to which they have been subjected has formed broad, gentle undulations with some local flexures of a more pronounced character. The dominant structural feature of the State is a wide and shallow synclinal which plunges northwest. The major structural features are shown by the structure contours of the upper surface of the Dakota sandstone. (Geologic map and the cross-sections.)

Trends in a general northwest-southeast direction from the northwest corner of the State, the area of the Cedar Creek anticline, to the Pine Ridge Indian Agency, the area of the Chadron anticline. The detailed features of these and related folds will be considered in the discussion of oil and gas prospects in the various areas.

OIL FORMATIONS AND DISTRICTS

Over the remainder of the State the nearly horizontal attitude of the strata is only locally interrupted by noticeable folds and flexures and it is probable that most of these are due to local agencies and do not represent true deformation.

The formations exposed in this general region are of such a character as to complicate greatly the proper interpretation of the structural features. The outcrops consist almost entirely of Tertiary strata and Pierre shale. The former rocks, owing to their dominantly fresh-water origin, are characterized by a gradation of both vertical and horizontal gradation of bedding. This peculiarity, together with frequent cross-bedding, has produced a discordance of bedding-planes which makes it difficult to determine the true attitude of the strata. Lack of satisfactory exposures over broad areas complicates this difficulty. The Pierre shale, although deposited under much more uniform conditions of sedimentation, has generally slumped or crumpled along the stream banks where good vertical sections are exposed, and hence it is difficult to determine true dips in this formation. Furthermore, the monotonous homogeneous character of the shales affords little in the way of satisfactory key beds from which the true attitude of the strata can be determined.

In view of the above facts and the generally slight regional dip of the strata, it is unsafe to place much reliance upon local dip readings. Before such readings can be recorded safely it must first be determined that the beds are in plane and that the dip represents true local causes and not some local cause which has only affected the surface portions of the formation.

The regional dip over most of the plains area of the State generally averages less than 75 feet to the mile. In many areas too, the general dip is not adequately shown by the surface features. The writer does not mean to imply that conspicuous folding cannot occur in those areas removed from the Black Hills. The regional character formed by the exposed formations makes them so susceptible to deformation from local causes that this factor must always be given serious consideration where the beds show any marked dips.

The geologic studies of the past season sustained the previous interpretations of the regional structure in the areas examined, but the strata in certain districts were found to be considerably more disturbed than the regional structure would lead one to suspect. The limited time spent in each district did not permit any thorough studies of the structural features. The investigations, however, indicate that most of the dips and folds are not due to regional deformation but are of local origin.

STRUCTURES IN THE PIERRE SHALES

The soft shales of the Pierre formation show an almost universal tendency to slump and crumple where exposed along the banks of streams. The resulting steep attitudes of the shales resemble very closely rock folds which are in place, but in every area where this feature was studied in detail the dips and strikes showed great variations in direction, with no definite system of arrangement. Generally, positive evidence of slumping is present in the form of masses of shale which have slid down the slopes. The tops of the
bank are cut by crevices in some cases for considerable distances back from the valley walls. The dipping shale beds often occur in irregularly arranged block-like masses of varying size which are at times slightly faulted against each other.

In some localities, especially on Cherry Creek south of Faith, the shales have been folded into small antitlins and synclines with dips on the limbs of the folds up to eight degrees or more. The fact that these beds of lime concretions in the Jurassic shale are involved in this folding suggests that stresses of considerable magnitude have been active and that these structures may represent true deformation. On the other hand a plotting of the dips and strike of these deposits in this area showed no definite system of folding. Furthermore, elevations taken on local key beds disclosed a slight region dip broken only by minor undulations. In this and other areas examined the steep dips seem to extend below the stream bottom, a fact which suggests that the deformation persists in depth. However, it is probable that many of the streams, in certain localities at least, are filling in, rather than cutting their channels, and hence have built up their deposits above the old valley bottom. It is also conceivable that surface deformation would extend a short distance below the stream channels.

The folding described above indicates a considerable amount of lateral compression and the question of the adequacy of stresses of local origin to cause this folding merits careful consideration. Further observation is necessary to determine the size of the individual folds (the largest observed were about 50 feet wide) and the fact that they show little systematic relation to each other are factors which favor local stresses. The general weakness of the shales, the local crumpling on a considerable scale. The settling and differential tilting of the shale blocks due to erosion and drying out may have been a source of lateral stress. Hydration of the shale and resulting expansion is also a possible source of lateral compression, although this factor would certainly not be very active in this semi-arid region. Expansion due to volume changes in certain enclosed minerals has doubtless been too slight to be of any importance.

It is also possible that stresses from more distant or deeper sources may have caused folding in the Pierre shale and related formations of the plains region of the State. The major structural features of the State were produced by the Rocky Mountains and Black Hills uplifts and the resulting differential deformation at this time in the plains region may be explained by the fact that the soft Upper Cretaceous shales were too incompetent to transmit the resulting stresses for any distance away from the centers of uplift, the stresses being relieved by adjustment within the mass. Some unusual local weakness of the rocks, however, may have transformed even any weak, transmitted stresses into local folds of considerable magnitude.

A number of striking Illustrations occur over our continent of areas in which pronounced deformation has occurred distant from areas of mountain uplift, such areas being separated from the mountain uplifts by strata that are only slightly folded. Such disturbed areas in the midst of otherwise nearly flat lying strata and which involve themselves are incapable of any ready structural transmission, suggest the possibility of surface expression of deformation in deeply buried competent rocks. It is possible that the underlying pre-Cambrian crystallines, Paleozoic rocks (if present), and the Jurassic sandstones may be involved in folding which does not show at the surface except in certain areas where the soft overlying Cretaceous shales have for some reason more readily transmitted these deformational movements upward. In general, the softer the soft shales would absorb this folding and give little, if any, indication of it at the surface.

Differential settling of the soft and unconsolidated sediments due to irregularities in the underlying pre-Cretaceous rock surface and irregularities in hardness of the strata in general, may have also set up lateral compression which has caused local folding. Further investigations should disclose important evidence bearing upon the above mentioned possibilities and to local features and related formations. The evidence now in hand, however, points strongly to erosional processes as the paramount cause of these structural features. If this is true, they have no value as possible oil bearing structures, since they are restricted to the surface parts of the formations.

FOLDS IN THE FOX HILLS FORMATION

Sharp folding occurs in the Fox Hills sandstone at the head of Ash Creek northwest of Philip and in certain localities along the Mobero River. Steep dips occur in other areas in this formation, but in the observed cases they represent cross-bedding or other forms of primary dip.

The folding in the Fox Hills sandstone in the two regions mentioned above may have been produced in a manner similar to that described for the underlying Pierre shale. In the Ash Creek region the formation occurs in steeply tilted blocks more or less erratically arranged. This feature and the fact that the Fox Hills of this area constitutes erosional surfaces. The soft and steeply tilted masses have settled into the softer underlying shales from a former nearly horizontal position to their present attitude, due to the irregularity of erosional processes in the soft shales. In many areas the Fox Hills lie essentially horizontal, a fact which sustains this conclusion.

Relative to folding in the Fox Hills formation, it is also suggested that this formation, owing to its greater competency as compared with the soft Pierre shales and less ability to completely transmit stresses more readily. In former geologic times the Fox Hills sandstones were continuous over much of the western part of South Dakota and extended up to the Black Hills. It is possible that the mountain building movements at the close of the Cretaceous may have transmitted stresses more readily through these harder sandstones over greater distances. Thus folds might be developed in the Fox Hills formation in areas considerably removed from the centers of disturbance but would be much less marked in the overlying softer sediments.

FOLDING IN THE TERTIARY ROCKS

Local folds, usually of unimportant dimensions, are fairly frequent in the soft shales and clays of the Lance formation. Some of these structures are due to differential settling of the beds during erosion and others doubtless have resulted from causes previously mentioned.

PRIMARY STRUCTURES

Primary structures are those developed in the rocks at the time they were formed and include such features as cross-bedding and

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dips due to various modes of deposition. Such structures are, as a rule, readily apparent to the geologist, but since they have been interpreted as representing true deformation by those not familiar with the fundamentals of geology, it has been considered advisable to devote a short space to their discussion.

Illustrated by the White River formation in the Slim Buttes area at Reva Gap. Here the grits, conglomerates, clays, and marls of this formation show a steep uniform dip over a considerable area and on first examination this dip might easily be mistaken for true structure, but other features present indicate the cross-beded character. Furthermore, the underlying Lance formation is essentially horizontal. If these steep dips represent deformation, the Lance certainly would have been incorporated in the folding.

Cross-bedding is typical of deposits formed on land by streams and the wind and those formed in the near-shore areas of seas and lakes. This feature is especially typical of the Lance formation, which represents deposits formed in streams, lakes, marshes, and by the wind. The Fox Hills sandstone which was deposited by the retreating Pierre Sea, and hence formed in shoaling waters where current action was common, is also cross-beded in many areas. The White River formation frequently shows this structural feature. The Lakota sandstone of the Black Hills region is frequently cross-beded.

While in the broadest sense all strata tend to be lenticular, since they do not persist indefinitely over lateral extent, yet the term lenticular bedding is especially applied to strata which show rapid variations over vertical and lateral extent. This feature, like cross-bedding, is typical of areas where conditions of deposition were frequently changing and is common in fresh water deposits and near-shore marine deposits. The Tertiary formations, especially the Lance, and the Fox Hills sandstones, commonly show this feature. Where lenticular bedding is pronounced, the contacts of bedding planes may be considerably inclined, a feature which may lead one who is not familiar with this phenomenon to suspect the presence of a structure (see plate 1).

In general the deposition of sediments upon an inclined floor will produce initial dips, which may be preserved in the resulting rocks, especially if they are not subsequently subjected to any marked folding. These initial or primary dips are apt to prove confusing and lead to the erroneous interpretation of structure, especially in such areas as the plains region of South Dakota, where the strata lie in a nearly horizontal position. Where the rocks are well folded primary dips can be distinguished readily from dips due to folding.

5.—RELATION OF STRUCTURES TO OIL POSSIBILITIES

As stated in the introduction to this bulletin, perhaps the outstanding reason for the delayed interest in South Dakota as a possible area of oil and gas production has been the general conception that the strata of the State were too slightly folded to offer any great possibilities as traps for the accumulation of commercial quantities of oil. The various geologic studies of the State up to the present time have in general sustained this opinion but, on the other hand, a great part of the geologic work in those areas thought to offer the greatest possibilities for oil has been two generalized to give accurate information as to detailed structural features.

The reconnaissance studies of the past season disclosed local folding of considerable magnitude in certain areas, the possible origin of which has already been considered. If these folds are surface features and have no extension in depth, they are of no significance as oil structures. This view is now held by the writer for most of these folds.

It was found to be generally true in those areas where key beds were extensive enough to permit the recording of a sufficient number of elevation readings, that the low regional dips are interrupted by gentle undulations of that strata. It is probable that detailed work will show some of these undulations to be closed and hence forming domes or closed anticlines. No attempt was made to work out the details of the folding during the past field season, since the purpose of the investigations was merely to determine whether structures existed and, if so, their general size, distribution and relationships.

The dips on these secondary folds are low, generally under two degrees. The question arises as to whether structures with such low dips, even if closed and associated with the proper source rocks and reservoir rocks, would be productive of oil. In the Montana and Wyoming fields the productive structures, with few exceptions, have dips averaging ten degrees or more. Whether these steep dips are essential to production from the Cretaceous rocks is a disputed matter, but the developed areas seem to bear out this belief. The necessity of steep dips in Montana is explained by the fact that the oil is found in sands below the source rocks and hence the folds must be sufficiently steep to permit the oil "to migrate upward through cross fractures toward the crest of the fold where the sands have been uplifted above the petrolierous shales." Some geologists hold the belief that this oil has come from sources below the sands.

In the Mid-Continent field the producing structures frequently possess dips as low as those which apparently characterize the secondary folds in the plains areas of South Dakota. The fact that the Mid-Continent production is from Upper Paleozoic sands, which are more consolidated and of greater age than the Cretaceous sands of Montana and Wyoming, may explain this difference in the dips necessary for productive structures in the two regions. Space will not permit a further discussion of this problem, but the writer believes that even though the producing folds of the Rocky Mountain fields seem to require relatively high dips, the evidence is not sufficiently conclusive to rule out the slight folds of South Dakota as possible oil structures.

It is possible that a detailed study of the structural features of South Dakota will show that many of the folds, owing to their slight dips, lack closure and form broad open folds, terraces or noses. While such structures should not be entirely ruled out as possible oil producers, their value, in the light of tested areas, is materially below those structures which are closed. In the Wyoming and Montana fields the producing folds, with very few exceptions, are well closed domes or anticlines.

Another factor in determining the value of structures in the State is the matter of drainage area for the oil. Many of the folds observed during the field studies are very localized, covering only a portion of a section. Such structures (unless superimposed upon larger favorable folds), even though possessing the other requisite features, would have too restricted a drainage area to afford commercial quantities of oil.

The possibility of buried structures must be considered. It has been indicated that folding which does not show at the surface may occur in the Dakota sandstone or underlying rocks. This is especially probable in those areas underlain by Paleozoic strata which were doubtless more or less folded during the deformatinal movements that closed the Paleozoic Era. If such folding occurs, the fact that it antedates the deposition of the Cretaceous sediments indicates why it would not show at the surface. If the Dakota sandstone is secondarily folded, however, the folding was doubtless developed at the close of the Cretaceous period after the overlying shales were deposited. These soft shales absorbed the deformation and thus failed to transmit it to the surface. It will not be any easy matter to work out such buried folds, although detailed studies may disclose much more evidence on this problem than is now at hand.
68.—OIL AND GAS POSSIBILITIES IN VARIOUS PARTS OF THE STATE

The investigations have disclosed a considerable amount of information relating to the detailed features of various districts of the State which bear upon oil and gas possibilities. In presenting this information the State has been divided for convenience of description as follows:
1. Area north of the Cheyenne and west of the Missouri Rivers (not including the westernmost part of the State).
2. Area of the Black Hills uplift (including the plains region north and south of the uplift).
3. Area south of the Cheyenne and west of the Missouri River (not including the westernmost part of the State).
4. Area east of the Missouri River.

AREA NORTH OF THE CHEYENNE AND WEST OF THE MISSOURI RIVERS

Geologic Formations.—The general thickness, characteristics and stratigraphical relations of the geologic formations developed in this region are shown in the adjoining correlation table (page 9). The distribution of the formations in this and the other regions considered is shown on the geologic map.

The formations represented are, in ascending geologic age, the Pierre, Fox Hills, Lance, Fort Union, and White River. Of these the Pierre, Fox Hills, and Lance formations are of importance in considering the oil possibilities, the Fort Union and White River rocks covering too small an area to merit much attention.

Each of these formations has certain lithologic characteristics and erosional features which aid in their recognition. These features will be briefly considered.

The Pierre Shale.—The Pierre shale consists of dark blue or brown shales of monotonously uniform character which weather into “gumbo” soil. Lenses of calcareous concretions occur at various horizons in the shale, and these generally contain fossil sea shells of various types.

The formation generally enters into rounded hills of uniform slope. The valleys tend to have steep banks, along which the shale has commonly slumped. The formation is named from its development near Pierre.

The Fox Hills Sandstone.—The Fox Hills formation, as indicated in the legend, ranges in thickness from 500 feet in the eastern part of the region to 75 feet or less in the western areas. In the former localities the strata consist of sandstones and variegated shales, all light colored. The sandstones consist of hard brown layers which tend to form buttes upon erosion. Such buttes are well developed south and east of Isabel. Thick beds of soft, light colored sandstone, generally cross-bedded, are common. In the eastern areas where the formation is most shaly it tends to erode into badlands. This erosional feature is well developed north of Dupree near the Missouri River. These badlands can be distinguished from those of the overlying Lance formation by the general light color of the rocks and the absence of lignite seams. In the western areas the formation consists mainly of light colored sandstone. In general, the formation erodes into rolling grass-covered prairie with no great amount of surface relief. The type locality of the Fox Hills strata is on Fox Ridge.

The Lance Formation.—This formation is divided into three members as indicated in the table, the basal or sembeds having the greatest development in this region. The basal beds of the Lance consists of dark or gray shales, clays, and sandstones with associated beds of iron concretions. The beds are very irregular and cross-bedded. Impure to fair lignite seams and carbonaceous shales are common. In many areas this member contains fragmentary fossil bones of Dinosaurs. The basal sembeds of the Lance commonly erode into rough topography of badlands. Such badlands are well developed in areas along the Missouri, Grand, and Little Missouri rivers. Sagebrush is common in areas where this member occurs.

The Cannonball member of the Lance is best developed in the vicinity of Lemmon and westward. It consists of gray sandstones with shale and clay. The sandstones tend to form hard, argillaceous masses. Bull-like sandy concretions are common in this member, from which phenomena it gets its name. The cannonball member grades westward into the Ludlow lignitic member, which contains the important lignite beds of northwestern South Dakota. The Ludlow consists of gray or yellow sandstones and gray shales. Locally the rocks have been fused into red, slag-like masses due to burning coal beds. The Ludlow and Cannonball members of the Lance formation erode into rolling, grass-covered prairie containing scattered buttes.

The Fort Union Formation.—The Fort Union formation generally consists of hard yellow sandstone and gray shale, it is especially well developed west of Lemmon where these strata form many of the higher points.

The White River Formation.—The White River formation is restricted to a few buttes in Perkins County, the Slim Buttes, and Section and East Short Pine Hills. The formation is easily recognized by its white color, which makes the strata stand out in marked contrast to the surrounding darker beds of the Lance.

Structural Features.—The major structural feature of this region is a broad, shallow structural basin. The general form of this basin is indicated by the structure contours of the upper surface of the Dakota sandstone, shown on the areal geology map. As indicated by these contours the deepest part of this basin in South Dakota is in the vicinity of Lemmon, where the top of the Dakota sandstone is probably from 5,000 to 4,000 feet below the surface. From this area the strata rise to the west, south, and east.

Over much of this area, aside from the western part of Harding County, the dips are slight, generally averaging one degree or less. In view of this fact it is probable, as previously indicated, that much of the folding which occurs superimposed upon this major syncline will lack closure and be more in the form of slight, broad terraces and noses.

The studies in this general region indicate that secondary upwarps of the strata are not uncommon, a few of which have been sufficiently pronounced to produce dips as high as four or five degrees. Dips of this magnitude, however, are exceptional. The general location of the axes of the more important upwarps are indicated on the map by continuous lines where the location is fairly accurate and by broken lines where the location is roughly approximate. These secondary folds appear to be arranged around the basin with their axes trending at right angles to the regional dip of the area in which they occur. On the west side of the major syncline or basin the secondary folds trend northwest-southeast, and on the east side southeast-northwest. East-west folds probably may be found in the southern areas. In view of the fact that the compressive force which developed these structures was exerted from a generally westerly direction, due to the Rocky Mountains and Black
Hills uplift, it is probable that most of the minor folds will be found to have general north-south rather than east-west trends. Therefore, it is to be suggested that on the south rim of this basin where the above dip and minor folds tend to cross each other, folds of larger magnitude will be found. The appearance of greater disturbances of the strata of the Pierre shale and Fox Hills formations in the Cherry Creek-Cheyenne River area may be thus explained. This suggestion, however, is purely conjectural.

In searching for folds in the area underlain by the structural basin, dips opposed to the regional slope of the strata are of significance, since they indicate reversals. Thus on the east limb of the basin easterly dips would be significant and on the west limb westerly dips. Dips in the same general direction as the regional slope of the strata have little significance unless they are unusually pronounced.

Great caution must be used in recording dip readings, since many of them do not represent true deformation. This factor has already been considered at some length but certain local aspects of the problem merit consideration at this point.

In the Lance formation and especially the basal somber beds, cross-bedding, lenticular bedding, and sloping beds due to other causes of deposition are common. In fact uniform bedding does not occur. Hence the inclined bedding planes are of little if any value in recording structure, since they are not due to deformation.

If structural mapping is done in the Lance at all, key beds must be used and they are difficult to find owing to the great lenticularity of the seams. The seams are the oar of possibility, but even these are generally restricted in their distribution. The key beds or satisfactory key bed is used the possibility of lack of parallelism of the beds below, due to the lenticular character of the strata, must be considered. While the coal seams from the best key beds the writer observed a number of areas in which the coal beds were locally folded, this folding not being reflected in the adjacent strata. Since coal beds, due to their mode of origin, tend to be originally horizontal, any folding which they show indicates deformation, but in the cases described above, the fact that the adjacent strata do not reflect this folding suggests another origin for it. It is well known that in the swampy and boggy areas where peat is forming the peat beds tend to get higher in the central part of the bogs, due to the expansion of the mass from absorbed water. Thus an initial dip may even be produced and preserved in coal beds. It is possible that some of the flexures observed in the above described areas have originated in this manner. The danger of mapping such folds is evident.

In view of the above features of the Lance formation it is the writer's belief that little reliance can be placed upon a study of key beds for the working out of more local structures. For a study of the regional structure the Lance strata will give more satisfaction.

The strata of the Fox Hills formation, although much more uniformly deposited, are locally characterized by dipping bedding planes which do not represent deformation. Most of the observed cases of such local dips were found to be due to contemporaneous erosion and deposition. As the sands were deposited in the nearshore areas, the active currents channeled out pools. These sands and new sediments were laid down on the steep sides of such channels. Thus steep local dips were produced which in some areas suggest folding. Associated with such sand deposits are lenticular and irregular masses of clay, indicating rapid changes in the conditions of deposition. (Plate I, B.)

Plate III. A. Folding in Fox Hills Formation on Moreau River, Northwest to Faith, S. D.

Photo by Josef, Faith, S. D.

Dips due to erosional processes, such as slumping and sagging of the beds are common in the Lance and Pierre and to a less extent in the Fox Hills. The area of Fox Hills' badlands north and south of Dupree shows such slumping. This feature is also well illustrated in the small tract of badlands just west of Ladner. In the vicinity of the Slim Buttes, landslides down the slopes of the Buttes have produced slumping and crumpling on a grand scale in the White River and Lance beds. The lateral pressure exerted by the weight of the great blocks of strata in their downward movement has also caused considerable folding, which upon first examination might be mistaken for structure. (Plate II, B.) The following quotation from Bulletin 627 of the U. S. Geological Survey well describes this feature: "There are numerous places where slumping of beds produces effects similar to faulting as well as folding. This slumping is not confined to any particular formation, as rocks of the Lance and the younger formations are much distorted and broken by landslides. The largest landslide in the field is in Section 20, T. 19 N., R. 8 E., where a block of the White River formation about 125 feet thick, 500 feet wide, and half a mile long is exposed in the bottom of a narrow valley. The base of the formation, which is broken and tilted in this slide, is nearly 200 feet lower in altitude than the corresponding horizon in the Slim Buttes, three-fourths of a mile away, and much lower than rocks of the Lance formation which crop out along the sides of the valley."

In addition to the broad warping already described and the more pronounced local structures due to depositional and erosional features, local folding apparently due to deformation was observed in a number of areas. The most marked example of this is found in the Fox Hills sandstones northwest of Faith, south of Faith in the Fox Hills and Pierre strata of the Cherry Creek and the Cheyenne River areas, in the Fox Hills formation northeast of Isabel, and in the Lance formation on Thunder Butte and Worthless (Irish) creeks.

OIL IN SOUTH DAKOTA

B. West Limb of Camp Crook Antiline, near Camp Crook

For the possible modes of origin of these local folds the reader is referred to the discussion on pages 69-66. Most of these folds are too restricted to offer any possibilities as oil structures, but a few of them, while apparently of no great promise, merit careful study. This is especially true of the folding in the Cherry Creek area, the Isabel region, and northwest of Faith.

The question of the persistence of this folding with depth naturally involves their origin. These folds due to surface agencies do not continue to any appreciable depth. Those folds due to regional deformation may undergo changes with depth depending upon the manner in which they have developed. If the reader will recall the previous discussion of the possible ways in which the folds of this region may have been produced and the peculiarities of folding in each formation, it will become evident that the more local folds in the Lance strata, even though due to true deformation, are of little value owing to the lack of parallelism between the beds. The possibility of an unconformity between the Lance and Fox Hills must also be considered. This matter is in dispute among geologists. The study of the Fox Hills-Lance contact in South Dakota by the writer has not indicated any widespread presence of an unconformity. If it does exist, this fact decreases still more the value of the Lance as a formation from which to interpret underlying structure.

Depth of Drilling.—The depth of drilling will be determined by two factors: the stratigraphic position of the sands in which it is hoped to find oil, and the relative thicknesses of the formations to be drilled through.

In the discussion of possible reservoir rocks in the State it was pointed out that aside from the westernmost parts of the State there are probably no sands of any importance above the Dakota-Lakota formations. It is in this general horizon that the first chances for oil occur. Any reservoir sands which may exist under the Dakota are at least 200 feet below the surface and are rather scarce. The Dakota formation is underlain by a depth of table rocks, and the top of the Dakota in any district can be determined by noting the elevation of the top of the formation with reference to sea level, as indicated by the nearest structure contour, and then subtracting this reading from that of the surface elevation in that area if the contour is above sea level, and adding the two elevation readings if the contour line is below sea level.

The fact that no deep wells have been drilled in this general region makes it impossible to determine with any accuracy the thickness of the concealed formations. A relative idea can be obtained from a comparison with known thicknesses in adjacent regions. The structure contours for the Dakota sandstone in this part of the State, while only approximately correct, are probably not greatly in error. A study of the regional structure as indicated by the surface formations has formed the basis for the drawing of the contours.

The outstanding feature for this region is the general deep drilling, the Dakota sandstone lying 3,000 feet or more below the surface over much of the area. The deepest drilling will be in the vicinity of Lemmon where, according to Taber’s estimates, the top of the Dakota is nearly 5,000 feet below the surface. Naturally, drilling will be shallowest in those areas where the oldest formation, the Pierre shale, is exposed and the most deeply eroded. The shallowest drilling is probably in the general region of the Cheyenne River. (See cross section.) From this area northward into the basin, the Dakota-Lakota sandstones become progressively more deeply buried.

Present Development.—More or less interest has existed for several years in various parts of this general region regarding the possibilities for oil, but it has been mainly in the past two or three years that this interest has reached the pitch where active leasing and plans for the development of supposedly favorable areas have been initiated. Thousands of acres have been leased, mainly by local people, and much of the leasing has been in areas in which the geology, features by no means warranted such an expenditure of effort.

Unfortunately, practically all of the individuals who have made the pioneer studies of this region for oil have been either promoters or men with little or no training in geology, aside from some practical knowledge. As a result, even though their intentions may have been sincere, they have created false hopes in districts where no apparent basis exists for testing for oil. While it is easy enough to recognize dip in beds or to work out a visible fold, yet, as previously indicated, many such features in this area are not related to regional deformation. Because so-called escarpments in the Montana and Wyoming fields often clearly define a fold, due to the steeper dip of the strata, escarpments in the nearly horizontal beds of this and other parts of South Dakota have been thought to have the same nature. The only area observed by the writer where structures are defined by escarpments is in the area of folding in the westernmost part of the State, where the structures are more pronounced, due to the Black Hills uplift. In many localities the preglacial eroded ledges of sandstone or other hard rocks lie imbedded in the soil at steep angles and have been interpreted as marking dipping beds. Hard layers of cross-bedded sandstone exposed as in the above case have also been interpreted as representing true deformation. Cross-bedding in general, the sloping top and bottom contacts of lenticular beds, dips due to deposition, slumped beds, and other similar structures have been given great value. In a few rare cases through coincidence some of these features have appeared with what are considered as oil or anticlines, this fact seeming to prove to those unfamiliar with geologic processes the absolute presence of a structure. Lack of competent knowledge in properly interpreting these structural features has caused a great waste of time and effort.

Although a number of districts have proceeded so far as to arrange for the testing of supposed structures, actual drilling has been started only in one locality—about six miles southwest of
In this area a rotary rig under the direction of the Lemmon Oil Basin Company is said to have drilled a considerable distance into the Tertiary and underlying Pierre shale. The operations have been conducted under secrecy, however, and no reliable information is available relative to this test. Aside from an apparently local fold in the NE ¼ 4, Tp. 21 N., R. 17 E., and a warping of the Fort Union beds in the vicinity of White Butte, no folds were observed in this region. The rocks show a regional northwest dip averaging one degree or less. The absolute unreliability of the Lance formation in interpreting the underlying structure has already been considered. In this area, the Dakota sandstone, the first possible oil horizon, lies at a depth of nearly 4,000 feet, according to Darton's estimates.

Although leased areas are promiscuously scattered over this entire territory, leasing has been especially active in the Lemmon district, along the Missouri River Valley, in the general vicinity of Isabel, southwest and south of Faith on Cherry Creek, and along the Cheyenne River.

Reconnaissance observation indicated more or less regional warping of the strata in all of these areas where key beds were sufficiently well developed to run elevations. The least reliability is placed upon folding observed in the Pierre and Lance formations. It is probable that detailed mapping of the structure over this general territory will disclose many minor folds of varying extent and magnitude with dips generally under two degrees and rarely exceeding four or five degrees. The pronounced folds in which dips tend to exceed five degrees are probably largely of local origin and of no value as oil structures.

Undoubted folding was observed in the Fox Hills exposed on the banks of the Missouri River north and south of the Black Hills, on Freestone Creek east of Isabel, and on Cherry Creek in the vicinity of Opal. The more pronounced and the more uncertain folding in the Pierre shale and Lance formations can be determined only by careful studies. Doubtless, detailed work will disclose folds similar to those mentioned above in other areas.

REGION OF THE BLACK HILLS UPLIFT

The region of the Black Hills uplift constitutes a geologic province distinct from the other parts of the State, owing to the marked contrast of the highly to moderately folded strata of this region with the nearly horizontal bedding elsewhere. This region includes not only the property proper but the folds of adjacent country which clearly mark the extensions of the main uplift. In addition to the areas bordering the Black Hills the western half of Harding County and a considerable area southeast of the Hills as far east as the western half of Shannon County are included in this districts, all of this area showing related structural features.

Geologic Formations.—The general characteristics of the Pierre, Fox Hills, and Tertiary formations are similar to those of the areas farther east. The Fox Hills in this region is much thinner and the Lance formation lacks the Cannonball marine member. The generalized features of the older formations exposed around the pre-Cambrian crystalline core of the Black Hills are indicated in the correlation table (page 72). Geologic Formations.—The major structural feature is the large eroded dome forming the Black Hills. The general trend of this uplift is in a northwest-southeast direction. The Chadron anticline and associated folds mark the southeast extension, and the Camp Creek, Cedar Creek, and related structures indicate the northwest continuation of the uplift.

OIL FORMATIONS AND DISTRICTS

Structures North of the Black Hills.—Relative to the structural features in the southern part of the State, with the exceptions of the northern end of the Black Hills, the Camp Creek anticline, and the Coal Creek formation of the Lance formation, these features are evidently of minor importance. The Coal Creek formation of the Lance formation is generally marked by a steep, short westward slope. The occurrence of the Coal Creek formation in the southern part of the State is fairly well known but there is little or no evidence of its occurrence in the northern part of the State.

The Camp Creek anticline is the most conspicuous fold in this general area. Although the main part of this structure lies north of...
Camp Creek; evidence of the fold extends south to the west Short Pine Hills. The west limb of the structure about six miles north of Camp Creek is marked by dips as high as ten degrees and forms a conspicuous escarpment in this locality. (Plate III, B.)

The Black Hills Area.—Space will not permit a detailed description of the numerous structures developed around the Black Hills. The geology of this area has been worked out in considerable detail and the results of these studies are available in a wealth of reports. The major structural feature constituting the monoclinic dipping beds which surround the uplift, forming a great eroded dome. Upon these monoclinic dips are superimposed anticlinal noses which plunge away from the uplift, terraces, and closed folds of medium curvature. Many of the structures lack closure. The axes of the principal folds are shown on the map.

Structures South of the Black Hills.—Southeast of the Black Hills a large and well closed anticline is developed in the southwestern part of Shannon County and extends southeastward into Nebraska. This structure is known as the Chadron anticline. Northwest of this a smaller but fairly conspicuous anticline occurs. The Chadron anticlinal constitutes the southeast prolongation of the Black Hills uplift, the other described structure forming a cros-fold. These two structures are sufficiently removed from the Black Hills proper to constitute distinct folds in a region where the strata in general are not greatly deformed.

West of this region toward Edgemont the dominant structures consist of large anticlinal noses which plunge southwest from the main uplift.

Present Development.—A considerable number of artesian wells have been drilled around the borders of the Black Hills and at various places in the inner parts of the uplift. While some of these wells, especially those nearest the uplift, have penetrated even to the Deadwood sandstone, they have given no indications of commercial amounts of oil. Small amounts of gas and traces of oil (apparently local pockets), have been found at several locations.

The test wells for oil in South Dakota have been largely confined to this general portion of the State owing to the more pronounced character of the structures. Most of the wells drilled by the writer are listed in the following summary.

Belle Fourche Area: A well drilled about six miles southwest of Belle Fourche on an anticline trending in a northwesterly direction through Tp. 10 N., R. 1 E., started in the Graneros shale and is said to have penetrated to the Lakota sand at a depth of 4,359 feet. A well three or four feet thick and lying about 250 feet above the Dakota was found to contain traces of oil. This is probably the sand that is petroleum-bearing at Newcastle (Newcastle Sand). The Lakota sand is also slightly petrolierous. Water was encountered in the Dakota, and the other sands.

About twelve miles northwest of Belle Fourche and across the line into Wyoming a well was drilled on a structure which is clearly marked out by the outcrops of Gravelly shale. It is reported that the well has penetrated 2,380 feet. The drill stopped in Paleozoic rocks (Pahasapa?). The hole starts at the top of the Graneros. A sand containing traces of oil was passed through, the position of which is not known. It is probably a part of the Minnelusa. The well when visited was furnishing a heavy flow of warm artesian water, possibly from the Minnelusa sands. The water was charged with hydrogen sulfide.

Several other tests have been made in this general area with negative results. The sand towards the base of the Graneros (Newcastle Sand) under the Lakota sand, and the Minnelusa sand, and apparently slightly petrolierous. The Lakota is locally bituminous in its outcrops south of Belle Fourche. The Minnelusa sand in the Rocky Ford region west of Spearfish is petrolierous.

St. Onge: A general north-south trending fold east and north of St. Onge, and which from surface evidence does not appear to be closed, has been tested by twelve shallow wells. This structure is superimposed upon the large anticline marked on the map. The structure is developed by the Mowry and Graneros shales and appears to be slightly petroleumiferous. The detailed logs of these wells have not been obtained. Gas was encountered in a thin, lenticular sand, apparently the Newcastle. The gas in one well is reported to have had considerable pressure. Analysis showed an important nitrogen content and a trace of helium.

Bear Butte: The conspicuous laccolith forming Bear Butte has arched up the strata into a pronounced local dome. A well drilled into this dome on the west side of the butte started in the red beds of the Mesozoic and penetrated the Minnelusa at a depth of about 800 feet. A very large flow of artesian water was obtained. It is reported that the initial flow was 50,000 barrels or four million gallons a day. The immediate region contains excellent reservoir conditions and the possibility of this large flow of water merits careful consideration. It is understood that such a project is contemplated. As far as could be ascertained no traces of oil were found. Exposures of sand in the Sundance formation in this uplift, evident from the outcrops, from which this well was not drilled.

East and Southeast Side of the Black Hills: Several test wells have been drilled in the vicinity of Rapid City, Hermosa, and Fairburn with negative results. Sands down to the Minnelusa were tested.

Edgemont: A pronounced fold which marks the connection of the uplift of the Laramie Mountains with the Black Hills trends in a northeast direction west of Edgemont. This zone of folding is marked by a large anticline on the Old Women Creek on the Wyoming side and by another on Cottonwood Creek north of Edgemont. A well drilled in the Cottonwood Creek area is reported to have found oil showings in the Newcastle(? ) sand. The Minnelusa sand was found to be petrolierous in the Old Women Creek anticline. The Dakotas were also reported to show traces of oil. The logs of these various wells were not obtained. The Deadwood sandstone is penetrated by two artesian wells in the vicinity of Edgemont and affords a good flow of artesian water. Slight showings of oil were reported from these two wells.

Chadron Anticline: This fold, although apparently having its main development south of the State line in Nebraska, from the structural standpoint at least is one of the most promising in South Dakota. The dips are sufficiently steep to make it compare favorably with the producing structures of Wyoming and Montana. It is far enough removed from the Black Hills uplift to have largely escaped the danger of the loss of any contained petroleum through too great an amount of deflection. On several tests, however, on the Chadron anticline have given negative results. Two wells have been drilled in South Dakota on this fold. The log of one of these wells has been kindly furnished by the Mid-
Cedar Creek Anticline comes from the Judith River formation (figure 11).

A test well drilled north of Ekalaka on what is known as the Medicine Rocks structure was abandoned at a depth of 3,475 feet. The results of this well are summarized by the above bulletin as follows: "The hole penetrated..." (additional details cut off). No traces of oil were found.

**West Side of the Black Hills.**—Although not in South Dakota, this region merits brief consideration because of its close relation to the area on the South Dakota side of the Black Hills. Areas on the Wyoming side have been quite thoroughly prospected and some production of oil has been obtained. A brief resume of the development follows:

The fields of this general region are the Rockyford, Moorcroft, Upton-Thornton, Newcastle, Mule Creek, Lance Creek, and New Osage. Of these the last three are giving commercial amounts of oil. In general the oil is heavy, but of fair quality. The chief producing sand is the Newcastle member of the Graneros shale. This name has been applied to a sand lying about 225 to 300 feet above the Dakota sand in the Graneros shale. This sand varies greatly in thickness but has its best development in the Newcastle field. It is the Oil horizon in the Newcastle, Moorcroft, Lance Creek, and Osage fields. This sandstone, according to Darton, is the same sand that occurs on the east side of the Hills near the base of the Graneros sand in various localities. It is very probably the petroliferous sand indicated in the well near Belle Fourche and the wells on the St. Onge structure. It is possibly correlative with the Muddy sand of Wyoming.

The Minnelusa sand is oil bearing in the Rockyford field and in the Old Women anticline. In the Upton-Thornton field, the oil sands occur near the base of the Carville shale. In the Osage field the Wall Creek sand, which lies slightly above the horizon of the Greenhorn limestone, is oil bearing. The Wall Creek sand is a phase of the Frontier sand, an important oil horizon of Wyoming. The Minnelusa and Dakota are at least locally petroliferous. The Dakota is the chief oil horizon in the Mule Creek field.

Of the above oil fields, those which occur on the flanks of the Black Hills are characterized by terraces or slight anticlinal warpings on a westly dipping monocline. The Mule Creek, Lance Creek, and Osage fields are further removed from the uplift and have better closure.

**DEVELOPMENT IN ADJACENT PARTS OF MONTANA**

The development in this general area has been well summarized in a recent press bulletin of the U. S. Geological Survey on the Cedar Creek Anticline and related features. According to this bulletin the abundant supply of gas found in the vicinity of Glendive and on the

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probable sands of this area are those of the Dakota-Lakota horizon. The reservoir horizons below the Dakota-Lakota discussed on pages 55-56 are probably present over much of this region.

AREA WEST OF THE MISSOURI AND SOUTH OF THE CHEYENNE RIVER:

Geologic Formations.—As indicated on the geologic map, the exposed geologic formations of this area are the Pierre shale, Fox Hills, and White River beds.

The Pierre shale, which mainly covers the northern and eastern parts of the territory, is similar in character to that of other areas already described. It contains, however, one stratigraphic feature not observed elsewhere by the writer. On Plum Creek, near its junction with the Cheyenne River, a series of yellowish to gray strata consisting mainly of calcareous sandy clay, sandstones, and limestones, all thin-bedded, are indefinitely exposed. The thickness of this member appears to range up to 75 feet or more. The tendency of these rocks to weather into buff or reddish colors gives them a close resemblance to the Niobrara, with which they have been confused. Similar horizons have been observed in the Pierre elsewhere. Fossils collected from calcareous concretions in this zone were identified by Dr. Stanton of the U. S. Geological Survey as types occurring about 300 feet below the Fox Hills sandstone.

The Fox Hills sandstone covers a considerable area in the vicinity of Cottonwood and northwest of Philip. That this formation was once widespread over the region is indicated by erosion remnants near Standing Butte, northwest of Port Pierre. In the Cottonwood region the exposed strata are composed of light colored, friable sandstones with intercalated hard, brown, platy sand layers. The massive friable beds are generally cross-bedded. The general color of the formation is light yellow. The thickness of the formation will probably not exceed 100 feet.

The White River formation covers much of the southern part of the region. The detailed features of this formation have been described in a number of reports and need not be considered here. The formation is easily recognized.

Structural Features.—The major structural feature of this area is a northwesterly plunging synclinal which has its steeper dips in the southwest corner of the district, where it grades into the Chadron anticline. In general, the regional dip to the northeast is a gentle antiformal uplift, developed in the vicinity of the Cheyenne River. (See cross sections and structure contours on geologic map.) But little of the detailed structural features have been worked out, but it is probable that such work will show local undulations of the strata similar to those developed north of the Cheyenne River. A reconnaissance study of the Fox Hills formation northwest of Philip indicated slight folding. The general discussion of the possible origin and character of the structural features north of the Cheyenne River and of the special structures in the Pierre and Fox Hills of that area applies also to this region. (See pages 60-65, 69-72.) At the head of Ash Creek the Fox Hills sandstones show pronounced local dips. The possible origin of this feature has been discussed (page 63).

Development.—The history of oil exploration in this region is similar to that of the country north of the Cheyenne River. Much promiscuous leasing has been carried on, but this has been confined to three localities, the Standing Butte district, Plum Creek, and Scenic.

Standing Butte District: A standard rig has been set up short distance west of Standing Butte (Sec. 9, Tp. 7 N., R. 27 E., B. H. M.) and a test well completed to a depth of 2,650 feet. The log of this well is of great importance since it is the first deep test in this general district and is giving valuable information as to the character of the concealed formations. The log of the well is provisionally interpreted as follows:

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,100</td>
<td>Pierre shale</td>
<td>200</td>
</tr>
<tr>
<td>105</td>
<td>Shale, dark (Carlisle)</td>
<td>30</td>
</tr>
<tr>
<td>385 ft.</td>
<td>Limestone (Greenhorn)</td>
<td>10</td>
</tr>
<tr>
<td>50</td>
<td>Shale, dark (Graneros)</td>
<td>310</td>
</tr>
<tr>
<td></td>
<td>Sand (water, traces of oil and gas)</td>
<td>30</td>
</tr>
<tr>
<td>155</td>
<td>Shale</td>
<td>24</td>
</tr>
<tr>
<td>36</td>
<td>Sand (water)</td>
<td>35</td>
</tr>
<tr>
<td>24</td>
<td>Shale</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>Bentonite</td>
<td>35</td>
</tr>
<tr>
<td>35</td>
<td>Shale</td>
<td>30</td>
</tr>
<tr>
<td>Total feet</td>
<td></td>
<td>2,650</td>
</tr>
</tbody>
</table>

If the formations, as above indicated, are properly identified, this log shows that the Pierre shale was not present but tending to thin out, and that the upper part of the Dakota sandstone contains traces of oil. This last fact is significant as it suggests the possible presence of oil in the Dakota horizon to the west. At the time of writing, details regarding the character of this oil were not in hand. The log also shows that the Pierre shale in this area is at least 1,360 feet thick, since 200 or more feet of this shale has been eroded in the vicinity of the well. The continuation of this well should furnish some interesting information relative to the pre-Dakota stratigraphy.

The brief visit made to the Standing Butte well did not permit any detailed studies of the structure of the area. Prominent slump of the Pierre shale was noted and no evidence of regional folding was observed. In considering the structural features of this and the other areas in which tests are being made, the features mentioned in the preceding discussions of the structures of the State and of the Pierre shale should be kept in mind.

Plum Creek District: No detailed information is as yet in hand regarding drilling operations in this area. Several shallow tests have been made on a supposed structure near the mouth of Plum Creek. Further testing is planned for this district.

The reconnaissance studies in this general region disclosed an unusual amount of slumping, local faulting, and crumpling of the Pierre shales. The fact that this area appears to lie in a general east-west zone of marked surface deformation of the Pierre shale suggests the possibility that this may reflect some special underlying deformation. The contours on the Dakota sandstone, as indicated in the cross section along the 102° meridian, show a flattening of the
northwest plunging synclinorium into a great terrace. It is possible that this terrace may even be upwarped into a slight, broad anticline. The general east-west course of the Cheyenne River may be partially determined by such a structure. These suggestions, however, are purely matters of speculation in the light of present evidence. In connection with the above suggestions the reader is referred back to the discussion on pages 62-63.

As indicated in the north-south cross section, this region and the general area of the Cheyenne River for some distance westward, due to deeper erosion, mark the shallowest drilling in the prairie regions of western South Dakota for testing out the Dakota-Lakota sands.

For this reason, the presence of proved structures in this belt of territory should merit testing in advance of favorable areas to the north and south.

Sceneic: A test is being made near the town of Sceneic for oil but no information is at hand regarding the details. A short visit to the area by the State Geologist showed no evident deformation and the strata appear to be essentially horizontal. Detailed studies may disclose local warping of the strata. The White River beds are exposed in the vicinity of Sceneic, the Pierre and Fox Hills showing to the north. The arrangement of the exposures of these formations is readily explained by erosional processes alone.

Interior: The presence of basal Fox Hills (?) beds and Pierre shale in a restricted area west of Interior surrounded by White River beds, suggests the possibility of a domatic uplift. Detailed mapping of the structure, as shown by the State Geologic Survey, shows local undulations in the Fox Hills. The Pierre outcrops are too restricted for study. Lack of sufficiently extensive key beds in the White River formation prohibits this formation being used for the satisfactory mapping of the structure by the structure contour method over the appreciable extent of territory. The studies in this area suggest regional warping, but sufficient evidence is not at hand to indicate whether the Pierre exposures represent part of a closed structure.

AREA EAST OF THE MISSOURI RIVER

The great number of artesian wells drilled in this general territory have tested the upper Cretaceous horizons in a fairly thorough manner and the results have in every case been negative. All of the Upper Cretaceous strata, including the Dakota-Lakota sands, are removed from considerable areas. Present evidence indicates that over much of this part of the State the rocks below the Dakota-Lakota are part of the Cambrian crystalline. It is possible that strata are present below the Dakota-Lakota in the westernmost part of the region. What has been said of adjacent areas west of the Missouri River will also apply to the region bordering this river on the east.

Over much of the eastern part of the State the rock formations are covered with glacial drift, making surface studies of the geology difficult. The great number of artesian wells, partly compensate for this by giving a large amount of evidence on underground conditions. On the whole, the stratigraphic conditions in this general region are very unfavorable for oil possibilities.

The geologic formations and their character and thickness are indicated in the columnar section. The thinning out of the Upper Cretaceous rocks is the outstanding change in going from the Black Hills westward. The possible reservoir rocks of this region were considered on page 58.

As indicated on the areal map, the pre-Cambrian crystalline rocks, the Graneros shale, Greenhorn limestone, Carville shale, Niobrara lime-
stone, and Pierre shale constitute exposed bed rocks. The Fox Hills and White River may be locally present.

The general structural features of the region are summarized by Darton as follows: "In the outcrops the rocks appear to lie horizontal, but there are low dips in various directions. The principal feature is a general rise to the southeast, which, together with the diminishing height of the land, brings to view in that direction the lower formations in succession. There is also a low anticline with its axis trending westward through Mitchell toward Chamberlain, which brings the Niobrara and Benton formation and Sioux quartzite to the surface over an area of considerable extent in the James River valley. This uplift is coincident with an old ridge of Sioux quartzite which was a shore during the deposition of the Dakota sandstone and, to a less extent, during BENTON time, but apparently was almost if not entirely covered by the Niobrara waters."

"The pre-Cambrian crystalline rocks which underlie the central Plains rise rapidly in the eastern part of South Dakota and finally reach the surface."

The regional structural features of this part of the State are shown by the contours on the geologic map and by the east-west cross section.

Development.—But little has been done in the way of prospecting this territory for oil. The failure of the great number of widely distributed exploratory wells to disclose showing, and the many conclusively proved the improbabilities of finding oil in this region. Wells drilled in the vicinity of Gettysburg and Watertown, apparently gave negative results. A test well is being drilled near Blunt, but thus far has apparently disclosed nothing of importance. Tests are contemplated in a number of other areas in the vicinity of the Missouri River. Studies of the structure in this general region show no folding of worth-while importance. The Pierre shale is badly slumpd or poorly exposed and hence does not offer itself to the successful determination of structural features. In fact the satisfactory determination of structure in this region is nearly impossible because of the heavy covering of drift and alluvium.

NATURAL GAS

Natural gas associated with artesian water occurs at a number of localities in the central and eastern part of the State, but the chief areas of production are in the Missouri River region adjacent to Pierre and northeast. But little detailed information is at hand relative to this product. Areas in which gas has been found are indicated on the geologic map.

The output has been small and unimportant, with the possible exception of the Pierre area, where for nearly twenty years a large portion of the lighting and cooking in Pierre and Fort Pierre was done by natural gas. It comes to the surface dissolved in the water of several artesian wells and is collected in tanks built over them."

Much of the gas is used on farms which contain gaseous artesian wells.


It is reported that in 1917 the gas in Pierre and Fort Pierre was obtained from five artesian wells and was "distributed to 355 domestic and four industrial consumers including the water works and the Electric Light Plant."

At this time the State Capitol well was flowing 18,000 cubic feet of gas per hour, or about 11.1 cubic feet per minute. In 1916 the flow was 59 cubic feet per minute. The ratio of water to gas in this well was about six to one. This is gas obtained from a water sand at 1,175 to 1,185 feet. Other flows of gas were found at 530 to 650 feet, and 1,130 to 1,140 feet.

The following summary of the natural gas situation in South Dakota, although much out of date, outlines the situation about as well as any later publication could: "There are several minor areas scattered throughout the James River valley, besides the main area, which, so far as has been determined lies along the Missouri River."

"In nearly all of the cases reported, the gas has been found in Cretaceous formations varying from the Dakota to the Montana. The possible exceptions are the minor areas in Turner and McCooy counties, where the source may be from peaty accumulations preceding, or contemporaneous with, the Glacial period, though these have not been distinctly discovered."

"Moreover, the gas seems clearly to come from different levels, some above the water, which may possibly be accounted for by leakage of water from below, and also from the same horizon as the principal flows of water. That the upper flows may not be from below, but are derived from the level where they appear to be strongly suggested, at least, by the occurrence at Blount of a water stratum between the shale and the sand. Besides, the upper strata correspond to the exposures of sandstone about Sioux City, which are known to contain thin beds of lignite in patches. These correspond to the Dakota in the later and narrower sense. The upper deep source at Ashton would correspond to the same."

"The stronger supply, which comes with the lower flows at Pierre and north, probably come from the Dakota, as the lower part of the original Dakota is now called. Although traces of coal are not reported from that level at this end of the State, it is known to abound in peat beds as far west as the Black Hills."

"Another and perhaps more probable source may be pointed out for the lowest supplies, viz: the probable beds of coal in the eastern edge of the Carboniferous. * * * Gas from that source may be conceived to escape from the eroded eastern edge of that formation into the lower portion of the overlapping Dakota. Moreover, this may be assisted by the flow of water eastward along the same channels."

"Further north, particularly around Solby and Ipswich, gas may be derived from beds in the Montana, which in its upper part is known to have accumulated carbonaceous matter in some regions, foreshadowing the conditions toward the north which formed the numerous beds of lignite in the succeeding epoch of the Laramie."

"No clear trace has yet been found of low artesian folds in the strata to the north of the gas, though such may appear as more borings are made. If so, they may assist in foretelling where gas may be found in abundance and where not. As it is, it seems likely that gas may be counted on as appearing with the artesian water or much of the region north of White River and west of the Missouri, besides that already mentioned east of that stream."

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may be several hundred feet thick, and gas is likely to be found at any point in the descent. Shale-gas wells, though in the same field, may be expected to show a considerable range in depth. Some shale-gas wells occur independently of oil production. Gas may be abundant, while petroleum is altogether wanting. Shale-gas wells are long lived. Weak flows are maintained for long periods. Shale gas is not dependent on the structural arrangement of the rocks which contain it. It is not associated with oil or water, it can not be displaced nor crowded out by them."

QUANTITY AND QUALITY OF OIL

There remains for final consideration a brief statement as to the possible quantity and quality of any oil which may be discovered in South Dakota.

The quantity of oil which may have accumulated in any region is governed by so many indeterminate factors that is is a matter of rank speculation to make any estimates for an unproved region such as South Dakota. The almost complete absence of traces of petroleum in the many deep wells drilled over various parts of the State for artesian water and the fact that the natural gas does not suggest associated oil are features which point to only slight amounts of oil in the upper Cretaceous horizons. This statement applies the least, of course, to those areas not yet tested by deep wells. The seeps in the Black Hills region indicate heavy oils which may either mark residues of former more extensive pools or an original heavy oil which has never existed in large quantities. The testing of the sands in this region has shown only small amounts of oil present in the buried strata. Any statements relative to the possibilities in the deeper untested strata of the State are unwarranted at this time.

If the structures of the plains region are found to be oil bearing the extensive areas covered by some of the broad, low upwarps would allow for a large gathering ground, a feature which might favor large production.

The quality of oil is determined by the amount of natural refining it has been subjected to up to the time of recovery or emergence from the earth. The refining appears to be governed by age and amount of deformation of the oil-bearing rocks. Other things being equal, the greater the age of the strata the higher the quality of oil; the greater the deformation of the region the higher the quality of the oil. In the light of these statements any oil in the Upper Cretaceous rocks of South Dakota would be of relatively low grade because of the comparatively young geologic age of the strata and the slight amount of deformation over most of the State. This is borne out by the seeps in the Black Hills region. Oil occurring in the deeply buried rocks, however, might be of a higher grade not only because of its greater age but due to the greater pressure of the overlying strata.

PART IV

SUMMARY AND CONCLUSIONS

FAVORABLE FEATURES

1. Presence of formations (Pierre shales and Benton shales) within feasible drilling depth over much of the State in which oil and gas could originate.
2. Presence of several fairly pronounced folds in the westernmost part of the State under which certain sands from Montana and Wyoming may extend.
3. Oil shale in the Pierre formation and oil seeps in the Black Hills region indicate at least traces of petroleum in some of the strata.

UNFAVORABLE FEATURES

1. Unfavorable geologic conditions and the fact that hundreds of artesian wells have quite thoroughly tested the Dakota, with negative results, indicate but little possibility for oil in commercial quantities east of the Missouri River.
2. Aside from the westernmost part of the State the Plains region west of the Missouri River offers no great chances for oil because of the following features:
   a. Probable absence of reservoir sands above the Dakota-Lakota formations.
   b. Dakota-Lakota formations may lack commercial deposits of oil because of their artesian water content.
   c. The above facts mean deep drilling.
   d. Folds are generally slight and in many cases probably not closed.
   e. Difficult to work out structure because of the great irregularity of the Tertiary strata, extensive slumping and crumpling of the Pierre shale, and general absence of satisfactory key beds. The Fox Hills formation is probably the best from which to work structure, but its distribution is restricted.
3. The folds in the immediate vicinity of the Black Hills are probably too greatly faulted and fissured to hold oil, aside from local small deposits. The folds also generally lack closure. Some of the domes in this area may be due to laccolithic intrusions and would thus be of no value.
4. Points a, b and c in 2 also will probably apply to the favorable structures in the westernmost part of the State.
5. The natural gas in the State is not the type that is commonly associated with oil.
6. If more pronounced folds do occur in the harder buried strata of the plains region, such folds are probably largely concealed by adjustment of the stress in the overlying soft Upper Cretaceous shales or by unconformities. Hence it will be difficult to determine their location from the surface.
CONCLUSIONS

A compilation and study of all the known geologic facts which bear upon oil possibilities in South Dakota and the results of the reconnaissance studies of the past season indicate that on the whole the possibilities for oil in the State are not very promising. Much further detailed work, however, is necessary in the western half of the State before any final statement can be made on this problem.

The evidence in hand is fairly conclusive as to the slight possibilities for oil in any part of South Dakota east of the Missouri River. Furthermore, the satisfactory determination of local structures in this area, if other favorable features did exist, is practically impossible because of the widespread concealment of the bedrock by glacial drift and alluvium.

With regard to the vast prairie region west of the Missouri River and east of the Black Hills uplift, the knowledge now in hand is all of a generalized nature, but in the light of this knowledge the writer does not hold out great hopes for any future commercial production of oil. The most unfavorable features for this general territory are: the apparent absence of reservoir rocks above the Dakota sand; the artesian water content of the Dakota-Lakota formations, which might otherwise be a very promising horizon; and the general lack of folds sufficiently pronounced to form suitable structure, if the producing structures of oil fields to the west are to be used as a comparison. Deep drilling makes some areas prohibitive for testing at the present time.

The areas adjoining the Black Hills offer but slight hope for reasons already given. The folds in the northwest and southeast corners of the State are more favorable but the probable thickness or absence of reservoir sands within feasible drilling depths is an unfavorable feature. Furthermore, the Chadron anticline has been tested by several fairly deep wells with negative results. However, the writer believes that this structure has not been sufficiently tested to be finally condemned.

The Fox Hills dome, Camp Crook anticline, and the other more pronounced structures in the western part of Harding county should be tested in the order named. In this area the chances are much greater for gas than for oil. The following statement is pertinent for this area: "In preparing for new tests, plans should also be made to drill to a depth of at least 4,000 feet along the crest of the Cedar Creek Anticline, or to somewhat greater depths if the Pierre, Camp Crook, or other folds are to be tested. The combined thickness of the Pierre and Colorado shales amounts to about 4,000 feet near Glen-dive, and this thickness perhaps decreases slightly toward the south, because of a slight thinning of the shales above the Black Hills uplift. Drilling to depths so great involves very heavy costs, and it is by no means certain that commercial oil pools are present in any of the uplifts here considered, but the higher domes at least of the Cedar Creek fold merit a test for oil when higher prices again stimulate prospecting. Small volumes of natural gas may probably be obtained from the sands that represent the Judith River formation in all the pronounced structural domes, but they will be of little value except where a nearby town or factory may afford a market for the gas."

BIBLIOGRAPHY

The following bibliography is not an attempt to list the numerous references consulted in preparing this bulletin but contains a list of the more recent references other than those mentioned in the footnotes which bear upon oil possibilities in South Dakota. A list of standard textbooks on oil geology is given for those who wish to delve further into this subject.

POPULAR TEXTBOOKS ON OIL GEOLOGY

5. Thompson, A. Beeby—Oil Field Development.

For a brief popular discussion of oil geology, oil fields of the United States, drilling methods, refining, etc., see Pahaska Quarterly, February 1918, South Dakota State School of Mines, Rapid City, S. D.

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According to Darton1 would be along the Grand and Moreau river valleys west to about the 102°30' meridian; along the entire Cheyenne valley and for some distance beyond its chief tributaries; along the Bad River valley to nearly the 102° meridian; along the White River valley to and considerably beyond the 102° meridian; and along the entire valley of the Missouri River.

For a complete list of these references see:

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OIL POSSIBILITIES IN ADJACENT AREAS

EASTERN WYOMING

See the following U. S. Geological Survey bulletins:
Hancock, E. T.—Mule Creek Field: Bulletin 716-c.
Hancock, E. T.—Lance Creek Field: Bulletin 716-e.

Reports are being prepared on the Rockyford and New Osage fields.

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