South Dakota
Geological and Natural History Survey
Freeman Ward, State Geologist

## Bulletin 10

The Possibilities of

# OIL IN SOUTH DAKOTA

A Preliminary Discussion

*By*
Roy A. Wilson

Series XXII March, 1922 No. 3

Bulletin
University of South Dakota

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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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**PART IV**



# 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 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 consideration. 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[1] but there are extensive areas which have been scarcely touched, except in an explanatory 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[2] and detailed work in the White River Badlands near Interior.[3] The United States Geological Survey has published a preliminary statement dealing with oil and gas possi-

[1]Ward, Freeman, Bibliography of South Dakota Geology; South Dakota Geological and Natural History Survey, Circular 5, 1919.

[2]Ward, Freeman, Oil in South Dakota: South Dakota Geological and Natural History Survey, Circular 1, December, 1917. Ward, Freeman, The Possibilties of Oil and Gas in Harding County: South Dakota Geological and Natural History Survey, Circular 4, October, 1918.

[3]Ward, Freeman, The Possibilities of Oil in Eastern Pennington County: South Dakota Geological and Natural History Survey, Circular 8, October, 1921.

bilities over parts of the Great Plains region, including South Dakota,[1] Some work of a non-technical character has also been done in a number of localities by private interests.

Known geologic features indicate that the more promising areas for oil and gas in South Dakota lie in the plains country west of the Missouri River. The reason for this statement will be set forth in a later part of the bulletin. In view of this fact, the investigations have been started in the above described region. The lack of detailed knowledge of the geology and especially of the structural characteristics of extensive areas in the west half of the State made it necessary to spend the present field season in a preliminary reconnaisance of as much of this territory as the time and methods of work would permit. The purpose of this preliminary examination was to determine what areas merited further studies.

The field work for this report was begun the first of July, 1921, 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 of the party and furnishing automobiles for field use. 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 north of 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 reconnaisance 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.

It will be evident from a comparison of the area surveyed with the time employed that the observations were necessarily generalized and in many cases incomplete. However, sufficient time was spent in each region to determine whether further investigations were advisable. With the progress of the work a large number of facts have been gathered relative to those geologic features of the region as a whole that bear upon the oil and gas possibilities. These have been assembled and coordinated in the following bulletin, and it is hoped that they will give at least a generalized idea of the petroleum outlook and serve as a guide for further studies on this problem.

To Mr. Edward S. Goff 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 friendly services rendered the field party during the season. A 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.

[1]Darton, N. H. Structure of Part of the Central Great Plains, U. S. G. S. Bulletin 691, pp. 12-18, or Bulletin 691-A. Also: U. S. G. S. Press Bulletin on Cedar Creek Anticline, January 11, 1922.

# 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

#### ORIGIN OF PETROLEUM

The various hydrocarbons[1] 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 buried in the sediments which form the stratified rocks. It is possible for hydrocarbons to form through inorganic agencies, but such occurences 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 time in geologic history. After the burial of this organic material in the marine muds, 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-

[1]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, sulphur, and oxidized substances. The various series, of which the paraffin and naphthene 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 ready accessibility to oxidation causes a mode of decay unfavorable for this process.[1] 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 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 petroliferous products out of the shales, where they largely originated, and into more porous reservoir rocks has been primarily influenced by pressure and capillary attraction.[2] 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 these 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

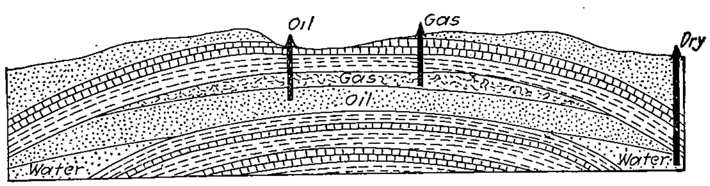



**Fig. 1. Accumulation of Oil and Gas in an Anticline**
From Cox-Dake-Muilenburg: Field Methods in Petroleum Geology. Copyright, McGraw-Hill, New York.

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

[2]Capillary 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.

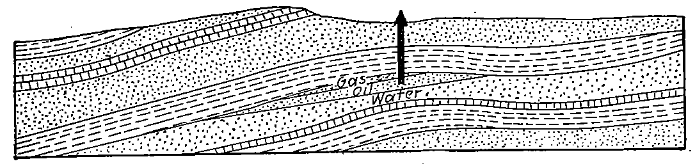



**Fig. 2. Accumulation of Oil and Gas in a Terrace Structure**
From Cox-Dake-Muilenburg: Field Methods in Petroleum Geology. Copyright, McGraw-Hill, New York.

The structural traps in which oil and gas accumulate are of various types. The common types are illustrated in figures 1 to 8. 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, sealed faults, unconformities, joint cracks, sealing of sand by asphaltic deposits, and contact of sedimentaries with crystalline rocks, may also serve as traps for oil and gas. These last named types are less common.

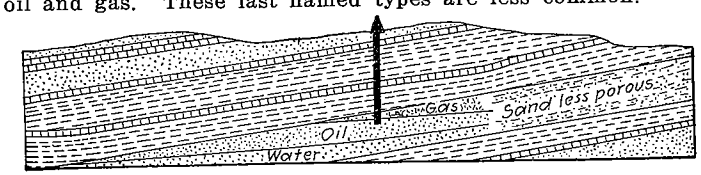



**Fig. 3. Accumulation of Oil and Gas, Due to Decreasing Porosity of Sand**
From Cox-Dake-Muilenburg: Field Methods in Petroleum Geology. Copyright, McGraw-Hill, New York.

### 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 and gas 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 these 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.

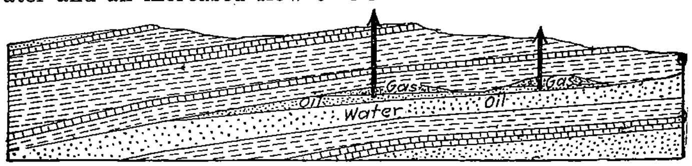



**Fig. 4. Accumulation of Oil and Gas, Due to Irregularities of the Upper Surface of Sandstone Stratum**

From Cox-Dake-Muilenburg: Field Methods in Petroleum Geology. Copyright, McGraw-Hill, New York.

ESCAPE AND DISSEMINATION OF OIL AND GAS

The oil and gas which enter a porous rock from surrrounding 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.

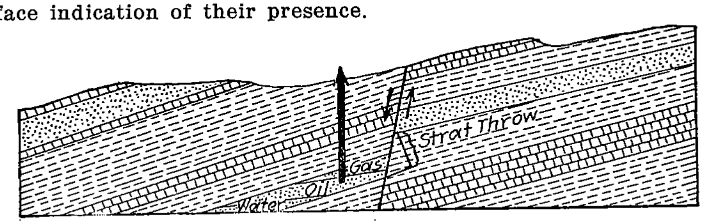



**Fig. 5. Accumulation of Oil and Gas, Due to Faulting**

From Cox-Dake-Muilenburg: Field Methods in Petroleum Geology. Copyright, McGraw-Hill, New York.

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.



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 micropscope 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 fineness 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, eolian (wind blown) deposits; others, which dominate by far over the continent as a whole, represent deposits laid down in great shallow seas that have invaded 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.

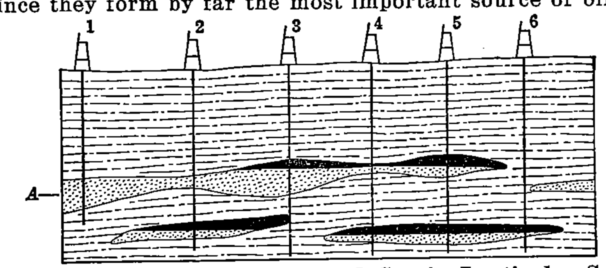



**Fig. 6. Accumulation of Oil and Gas in Lenticular Sands**

From Hager: Practical Oil Geology. Copyright, McGraw-Hill, New York.

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 limy 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 over 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 coarser material to settle. In the more quiet off-shore 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 off-shore waters, although clear waters near shore would permit the formation of limestone. The factors deter-

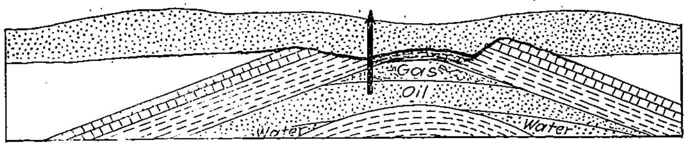



**Fig. 7. Anticline Concealed by an Unconformity**

From Cox-Dake-Muilenburg: Field Methods in Petroleum Geology. Copyright, McGraw-Hill, New York.

mining the formation of sandstone and shale are varied. Under certain conditons 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.

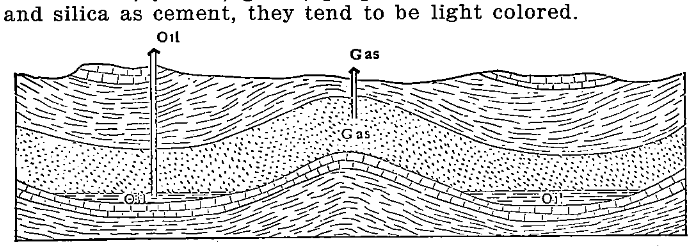



**Fig. 8. Accumulation of Oil in Synclines When Sand Is Water-Free**

From Cox-Dake-Muilenburg: Field Methods in Petroleum Geology. Copyright, McGraw-Hill, New York.

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.



## 4. ORIGIN OF STRUCTURAL FEATURES

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 were 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 wrinklings 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 Montana 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 beds that are slightly inclined but not folded, but such accumulations are generally discovered by drilling and give little or no surface indications of their presence. Hence they have slight significance in undeveloped or undrilled territory, where the geologist can be guided only by surface evidence.

The various types of folds will usually be disclosed at the surface, where the bed rock is exposed or, if the bed rock is concealed, topographic evidence may indicate their presence. This is especially true of anticlines, 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 topographically; 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.[1] 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 top and bottom contacts of lenticular beds, 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 prove misleading in areas where the rocks 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 of slightly folded 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 point 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 trend and shape of a structure very clearly.

[1]The dip of bedded rocks is the angular departure of the bedding planes from the horizontal. Dip readings are given in degrees and not per cent. The direction of dip is always given, as well as the amount of dip. The direction of dip is down slope, not up slope. The strike of beds is the direction of trend of outcrop across country. The maximum dip is always at right angles to the direction of the strike. The terms "local dip and strike" and "regional dip and strike" are used to differentiate between local irregularities of an outcrop and the more regular regional attitude and trend.



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 system of hills and valleys related to the strike of the outcropping 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 the streams may show a 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 underlying strata. Elevated points in a region are 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 surface oil may have lost its more volatile products, and hence tend to 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 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 scums should not be confused with iron and 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 into 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 the ground or whether the well or spring has been "salted".[1] If the seep has a natural source it will be persistent over an indefinite period of time. If "salted" the film will be temporary, and collection of the oil will soon exhaust the supply. In any case the oil should be skimmed until a sufficient quantity is obtained for analysis. Analysis will disclose whether the oil is a refined or crude product. Drilled wells may be accidentally "salted" through the penetration into the hole of oil used in drilling. Streams and springs may be "salted" by the drippings 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 iridescent films. 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 this part of the 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 formerly larger underground pool. 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 come from petroliferous strata. Gas seeps generally consist of methane (marsh gas), carbon dioxide, nitrogen, hydrogen sulphide, etc. Marsh gas forms the bubbles that are seen rising to the surface of 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 petroliferous material in the underlying rocks. Methane is inflammable and if escaping in sufficient quantities may be ignited. The other gases enumerated above are not inflammable and have little or no 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

[1]A term used, especially in mining, to indicate the placing of some mineral such as gold, etc., 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.



the sample is suggested by K. C. Heald of the United States Geological Survey.[1]

"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 must be thoroughly cleaned with 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 over the bubbling gas. The gas will 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 withdrawn and a new, tightly fitting cork should be jammed firmly into the bottle without tipping 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 occurs in the form of asphalt or 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. The residue 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 might be trapped, the bituminous material is of minor importance. In some 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 the escaping oil has been 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.

[1]Heald, K. C., Hints on Oil Prospecting, U. S. Geological Survey Press Bulletin, No. 449, June, 1920.

"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 possiblity 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 this type of 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 by far the most common retainers 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 off-shore areas. Hence the sandstones will be largely restricted to the near-shore areas of the seas in which the 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 favorable for their formation 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 absence 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 sediments must, of course, be considered. A thorough knowledge of known paleogeographic[1] 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:[2]

"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 foretell, 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

[1]Paleogeography is the study of the geographic conditions over the earth during the various periods of geologic history.

[2]Baker, C. L., Bulletin American Association of Petroleum Geologists, Vol. 5, No. 1, pp. 10-11.

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 us 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 ahead 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. Incidentally 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" must 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 by the drill.

### POSSIBILITY OF OIL AND GAS HAVING ESCAPED

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 petroliferous horizon 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 success (based upon geologic evidence) against the depth to which the hole can go and still produce oil at a profit. At the present time it is not considered advisable in the Montana and Wyoming fields to drill test wells deeper than 3,500 feet. With an increase in the price and demand for petroleum, however, this limiting depth will naturally be increased. In areas where geologic conditions are not all favorable this limiting depth might be decreased.



## 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. Reconnaisance 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 reconnaisance examination. The purpose of reconnaisance work is to determine what parts, if any, of the area under consideration 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
6. Surface evidence of oil and gas
7. Evidence that oil and gas may have escaped
8. Accessibility of the region to transportation facilities
9. Fuel and water problems.

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 reconnaisance work is to determine whether a region merits further detailed study, it is evident that such preliminary studies 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, but not definite proof of the presence of structures, or may locate structures and determine their approximate extent. In any case reconnoissance 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 reconnaisance 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 over a broad area can do detailed work in one part of the region to 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 reconnaisance 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 reconnaisance 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



horizontal to the eye. The location of a test well in such an area without careful and thorough mapping and geologic examination by a well trained geologist is the height of folly. Such a region offers the most difficult sort of geologic work, as so much is left to speculation and so little to actual observation. If a region does not offer enough in the way of exposures so that a plane table map can be made of its structural features, it is hardly worth testing; the chances of failure are much too great.

In a region where exposures are sufficient to construct a plane table map of the structure, the procedure of mapping is somewhat as follows:

A key bed is first selected, which is to be used as a basis for de-

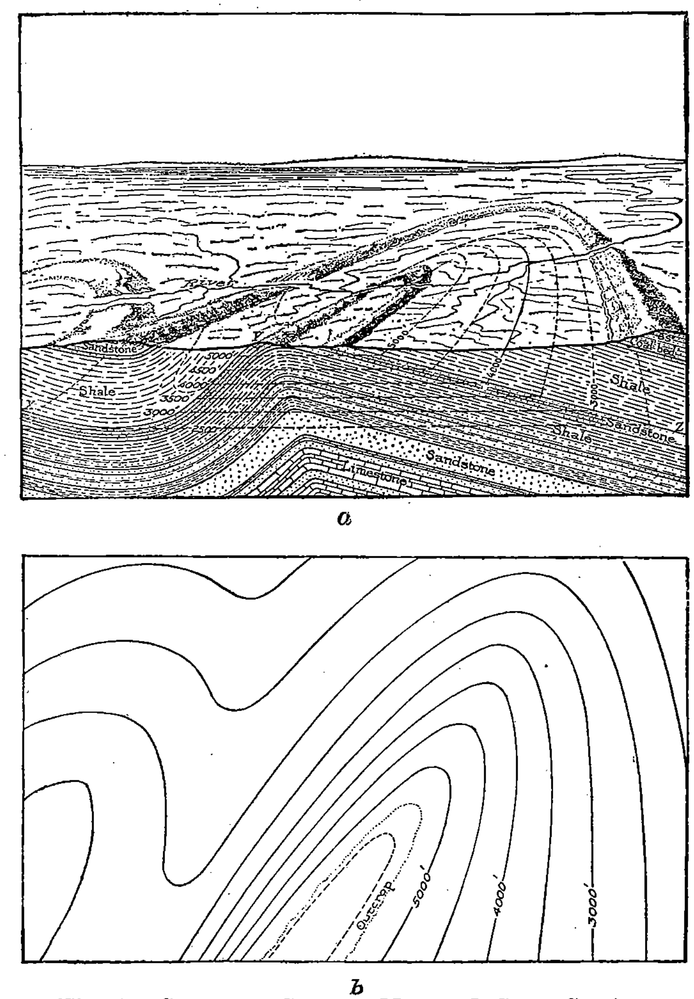



**Fig. 9. Structure Contour Map and Cross Section**
From Hager: Practical Oil Geology. Copyright, McGraw-Hill, New York.

termining the shape and outline of the structure to be mapped. A key bed is generally some stratum in the exposed formation which is well marked, widespread, and can be readily followed. Careful elevation readings are taken on the top or bottom contact of this bed at all exposures and these are accurately located on the map. Numerous sections of the formation are measured from place to place, so that where the key bed is concealed or has been eroded, its elevation at that point can be determined from its known elevation above or below the strata exposed. If, for instance, a certain layer of shale occurs 100 feet below the key bed and a ledge of sandstone occurs 200 feet above the key bed, an exposure of the shale will indicate that the key bed is about 100 feet above, and an exposure of the sandstone that the key bed would lie 200 feet lower, if present.

After all the elevations it is possible to obtain on the key bed have been plotted on the map, the next procedure is to draw in the structure contour lines. Contour lines connect points of equal elevation. These contours give a very close idea of the structure. A map showing a structure marked by contour lines and a cross section of the structure are shown in figure 9.

The reader must not confuse a structure contour map with an ordinary topographic map. The former shows elevations on a stratum in the bed rock. The latter shows the elevation of the land surface above sea level. The writer was shown a supposed structure map this season which was simply a crude topographic map showing hills and valleys, and had absolutely no relation to the attitude of the underlying bedrock.

### LOCATING THE DRILLING SITE

If detailed mapping shows a favorable structure and other geologic features are favorable, the next step is the location of the drilling site.

The general practice is to locate the test well on or near the high point of the structure. By the high point in the structure is not meant a high point in the topography. A structural high is often a topographic low. The tendency of stream to follow the crest of folds has already been mentioned. The reader must keep clearly in mind the fact that the surface relief may bear absolutely no relation to the underlying rock folds.

The reason for locating a test well on the high point of a structure is evident from the fact that oil and gas tend to accumulate at or near the crest of folds. It is also generally true that the greatest distribution of oil occurs on the side of the fold having the more gentle dip. Practically all folds are unsymmetrical, that is, one side dips more steeply than the other. Hence if the test well is located off the top of the structure it should be on the side of less dip, since the chances of missing the oil pool are less on this side. Generally, after a careful structure contour map has been made of the fold, the position of the drilling site is determined by the geologist from a graphic computation. Incidentally it may be mentioned that to locate a drilling site by the use of a divining rod or so-called "doodlebug"[1] is as practical as throwing a daub of mud haphazardly on the map.

## 7. CHANCES OF FINDING OIL OR GAS

After proper and careful geologic work has been done and the drilling site carefully located, the next step is the drilling of the well.

The chances of finding oil or gas with all this careful preliminary work are greatly increased over what they would be were development undertaken in a haphazard manner.

[1]Instruments of various forms supposed to have the power of locating oil and gas deposits.



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 though 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 rock 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 careful and skilled geologic work cannot eliminate chances of failure in an untested region.

At best, investing money in a "wildcat"[1] well is a gamble, and it is only the person who can afford to lose his money and not feel 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 colored 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, submits a written or verbal report to the organization or person 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 uninformed 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 features 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, etc., should always be 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 fiuding 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.

[1]A term used in the petroleum industry for unproved territory.

It is far too common a practice to leave out the unfavorable part of a geologic report when such a report is inserted into the prospectus or other literature used for the sale of shares or leases in a wildcat proposition. Such a practice constitutes a deliberate attempt to mislead the person who may invest funds in the proposition. If it does not constitute a legal fraud it at least constitutes a moral fraud. It is frequently true that the unfavorable features of a region far outweigh the favorable features, and in such case it is apparent that the deleting of references to unfavorable conditions gives a totally erroneous impression of the area in question. The geologist who takes pride in the accuracy and reliability of his work should see to it that his reports are properly and fairly presented to the public. The people who invest their money in wildcat development should first make sure that they have been informed of both the unfavorable as well as favorable features and that the geologic work has been competent and reliable.

## 9. LEASING[1]

If geologic examination indicates that a region has possibilities for oil and gas a number of methods may be followed in testing out the area. The first procedure in any case is to obtain the right from the land owners in the district to prospect for oil and gas. This may be done in three ways: by purchasing the land, by purchasing the oil and gas rights, by leasing. In wildcat territory the latter method is almost always followed, since the risks are too great to warrant the tying up of capital by purchase.

The leasing may be done by local or outside interests. The lease forms vary in different regions as to details, but in general include an agreement to drill for oil and gas within a specified time, after which time, if drilling has not commenced, a specified rental is paid or the lease surrendered. Generally a one-eighth royalty is to be paid to the land owner if oil is found. If gas is found a rental is generally paid, although the royalty basis may be used in this case also. The lease contains provisions for the payment of royalty and rentals, damages resulting to property, use of oil and gas by lessor, disposal of pipe lines, etc., on the lessor's land, and other features that may be peculiar to a given locality. Care should be taken to make certain that the land descriptions in leases are properly entered. The wife should sign the lease as well as the husband. If the lessor is single, a widow, or a widower this should be specified. All leases should be properly recorded. As a rule the lessee pays the lessor one dollar to make the lease legally binding. It is advisable to have a lease put in escrow until oil or gas is discovered. This saves trouble and expense in having the lease canceled in case of failure to develop the property on the part of the lessee.

In obtaining the leases it is wise to have the acreage in the favorable area blocked as well as possible, rather than widely scattered. The leasing of land is often a matter requiring great diplomacy and skill and in many oil territories men who make this work their business ("lease hounds") are to be found. The matter of obtaining leases from non-resident land owners is always a problem, and may involve considerable expense. Great care should be taken to see that the lessor has proper title to the land in question. At times a land owner on a strategic part of the prospective area may refuse to lease 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:

[1]For laws relating to leasing, etc., see Thornton, "Laws Relating to Oil and Gas." See also the following bulletins of the U. S. Bureau of Mines entitled "Abstracts of Current Decisions on Mines and Mining": Bulletins 61, 79, 90, 101, 113, 118, 126, 143, 147, 152, 159, 164, 172, 174, 179, 183. For the recent leasing law relating to Government lands see U. S. Bureau of Mines Bulletin, 206; "Petroleum Laws of All America," J. W. Thompson.



LEASE No.................................

## OIL AND GAS LEASE[1]

From

..............................................................................

..............................................................................

To

The .............................................................. Co.

Date .................................................... 19.......
Term .................................................... Years
No. Acres ..............................................................
Township ..............................................................
County ..............................................................
Received ..............................................................
at ............................ o'clock ............................ M.
Recorded ................................................ 19.......
in ............................ County, ..................................
Record of Leases, Vol. .............................. Page ......................
..............................................................................
Recorder
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 ................................}
COUNTY OF ................................} ss.

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.......

..............................................
..............................................

[1]L. S. Pangity, Prospecting for Oil and Gas, pp. 197-201.

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........

....................................

....................................

THIS AGREEMENT, made and entered into this .................... day of ...................................., A. D. 19........, by and between .................................... .................................... hereinafter called the Lessor, and ...................................., a .................................... corporation, called the Lessee

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 their constituents 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 ....................................
containing ....................................
(....................................) 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 to pay for the product 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 said 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 by 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 proportional 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 .................................... credit in The .................................... Bank of ....................................; or by check made payable to .................................... order and mailed to .................................... at ....................................

Lessor agrees that Lesese 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 hereinbefore 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 have the right 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 default of payment by Lessor and be subrogated in full 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.

Signed and Acknowledged in the Presence of:

| | |
|---|---|
| ................................................ | ................................................(Seal) |
| ................................................ | ................................................(Seal) |
| ................................................ | ................................................(Seal) |
| ................................................ | ................................................(Seal) |
| ................................................ | |

THE ................................................ COMPANY,
By ................................................

## 10. DRILLING COMPANIES

The drilling of a test well for oil and gas is generally carried on by drilling companies which make a specialty of this work. In wildcat territory the people in a community in which favorable structures are thought to exist may organize a company for the purpose of blocking acreage to be drilled. In such cases the actual drilling may be carried out by two methods. The company may either buy or rent a drilling outfit, employ drillers and drill the well themselves, or else turn over a certain amount of leases to an outside drilling company in return for which the drilling company agrees to drill one or more wells to a certain depth. In other instances an oil company may lease and drill of their own accord.

Finances for development purposes may be raised either by the sale of leases (whose value is enhanced by the prospects of drilling) or by the sale of stock. In any case where stock or leases are sold to the public the selling company should not only have the usual permit from the State Securities Commission but should also have authoritative evidence that the geologic report forming the basis for their operations is backed by sound scientific investigations. A geologic report is not enough, however. Conclusive evidence should be presented showing that the geologist or geologists concerned are competent and of good standing in the profession. Since the standing or ability of a geologist can only be determined by a recognized member of the profession, it is to be recommended that all geologic reports and statements presented to the State Securities Commission in connection with applications for permits, be approved by the State Geologist before such a permit is issued. This will serve to eliminate the fakes who reap a rich harvest in wildcat territory.

It is also to be recommended that all geologic reports used to advertise a prospective area in connection with the sale of stock or leases be backed by a signed statement from the geologist stating the following:

1. His references
2. His technical training
3. His experience
4. His permanent address

This statement should be submitted upon request to any purchaser of stock or leases who desires to see it.

## 11. DRILLING FOR OIL AND GAS

There are two methods in general use for the drilling of wells, the standard or churn-drill system, and the rotary system. Various modifications of these systems are practiced in different fields and they are also combined in drilling the same well. Space will not permit a detailed consideration of all the features relating to operations and apparatus under each system. It is important that the reader should have a general idea as to the relative merits of each system of drilling and the conditions to which each is best adapted.

**Standard System.**—This is the system commonly used in most fields. The drilling outfit consists of the rig, engine, boiler, casing, and the various appliances for handling the tools and cable.



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 depth the height of the derrick is 90 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 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 rigs may be 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 6¼ or 8¼ 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 cased off and hence the number of different sized casings 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 pumped 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 features 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 a rotary rig can be used with any satisfactory results, hence this system of drilling is valueless 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 casing and up the outside. This aids in preventing caving and shuts off gas sands by exerting pressure on the sides of the hole.

**Cost of Drilling.**—The cost of drilling is governed by the following 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 shipped in from a distant source and often must be hauled some distance from the railroad to the point of drilling. As a rule, one well must bear all this expense in addition to the drilling costs. Another thing that may raise the cost of a test well 50 to 100 per cent or more 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 or less known and unfavorable conditions can be planned for in advance. Furthermore, in producing fields the rigs and other drilling materials may be used more than once, and thus the cost of the drilling materials is distributed over more than one well. If the wildcat well is located in an especially inaccessible place, the cost of drilling may rise to high or even prohibitive figures.

The method of drilling will be an important factor in estimating drilling costs. Where shallow drilling is planned, the portable rig will as a rule give satisfactory results at a less cost than the so-called standard. For deep drilling in wildcat areas the standard system is the best, as the rotary system is not fitted for prospecting purposes. The dangers of passing through oil sands without recognizing them and the poor log make the rotary system of little value in prospecting, even though it may be better adapted to the rocks of the region. In areas adapted to the rotary system and where knowledge of underground conditions permits its use, the rotary system is cheaper than the standard. 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 drilling cost. The transportation problem would naturally be governed by the accessibility of the proposed well to transportation facilities. Even though geologic conditions were favorable, the heavy transportation costs might make the cost of the well prohibitive 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 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 certain strata, the cost of the well may be raised as much as 100 per cent. Another factor governing the cost of test wells when equipment and rigs must be bought is the market 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 is reached the cost increases very rapidly. At least $100,000 should be figured on as the probable total cost of a well drilled with a standard rig to a depth of 3,000 feet.



**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[1]

..............................................................................................................

THIS AGREEMENT made and entered into this .............................. day of .................................................. 19........, by and 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 ..............................................................................................................
a corporation, company or individual, organized and existing under the laws of the State of ....................................................................., and having its principal place of business at ..............................................................
hereinafter called the CONTRACTOR:

WITNESSETH

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

The CONTRACTOR agrees to drill a well for the .......................... in accordance with the specifications hereinafter contained.
Well to be known as ....................................................................................
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 ................................, County ..........................................................,
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 said well from the surface to a depth to be indicated by the ...................................................... Company from ..........................................

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 sufficiently to ascertain if the water has been shut off, and the well shall then be allowed to stand for ........................................ hours to test the same. If the

[1]Pangity, 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 .............................. 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 land.

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 supply stores 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 accept the same as safe and satisfactory for such drilling purposes and agrees to assume all risks of accidents to themselves and employees from breakage or any and all other causes.



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.

Any breach of this 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 controversy 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 hereinabove written.

The .................................................. Company
By ..........................................................

Witness ......................................................
Witness ......................................................
Witness ......................................................

The .................................................. Contractor
By ..........................................................

Witness ......................................................
Witness ......................................................
Witness ......................................................

**The Well Log.**—The importance of 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 large companies. Where a competent geologist does not oversee the keeping of the log, it is recommended that samples be carefully collected every ten feet, and properly dried, bottled, and labeled as to depth encountered. These samples should then be available for geologic study. Various forms for keeping logs are in use. The form illustrated in figure 10 is to be recommended.

DAILY TOUR REPORT

| Company | Lease | Well No | Day | Date | Tour |
|---|---|---|---|---|---|
| | | | | | Morning |
| | | | | | Afternoon |

Formations

| Depth | | Formation | Color | Texture | | | Hardness | | | Contents | | | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Water | | | | Gas | | Oil | | | | |
| From | To | | | Coarse | Medium | Fine | Hard | Medium | Soft | Dry | Sweet | Salty | Sulfur | Barren | Gas | Barren | Poor | Medium | Rich | |
| | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |

| Casing | | | | | | Time | | | |
|---|---|---|---|---|---|---|---|---|---|
| Last Casing Put in Hole | | | Casing now used | | Remarks | Driller | Hours | Tool Dressers | Hours |
| Size | Depth From | Depth To | Size | Depth | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

**Fig. 10. Well-log Form**

From Hager: Practical Oil Geology. Copyright, McGraw-Hill, New York.

## 12. 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,[1] 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

[1]Ellis, A. J., The Divining Rod, A History of Water Witching; U. S. Geological Survey, Water Supply Paper, No. 416, pp. 5-6.



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 misuse 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' or for the sale of their 'instruments' are deliberately defrauding the people, and that the total amount of money they obtain is large.

"To 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 hunts 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 guess 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 from which the oil and gas have 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:[1] "The only class of lines which are 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 posibilities.

PROXIMITY OF A DISTRICT TO OTHER OIL FIELDS

It is commonly stated in wildcat territory that the location of the region relative to adjacent producing territory is a very favorable feature. The matter of geographic location itself has nothing at all to do with the chances for or against oil being found. As the reader who 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, structures, etc., exist in a locality, then 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 previous statement relative to proximity of fields also applies here. The value of a region for oil and gas is determined by geologic conditions and not by surface features. Oil may occur under any kind of surface. Surface features, while often of aid in interpreting underground structural 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

[1]Clapp, F. G., Special chapter in Bacon and Hamor's "American Petroleum Industry," p. 40.



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 salty hardpans, and in some places distinctly saline pools. The salts forming these deposits 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 owe their origin to the sincere desire of a community to determine if their region has any possibilities for oil and to the equally unscrupulous or misguided desire of some "so-called" geologist or promoter to work on the credulity and purse strings of the people. In other instances persons with a supposed practical knowledge of geologic conditions in oil fields have located, leased, and even drilled in a region where there was absolutely no geologic basis for the test. Thousands of dollars have been wasted in this manner in all wildcat territory, and South Dakota is no exception to the rule. The remedy to this situation lies in enlightening the public, as far as it is possible, to the absolute necessity of careful and detailed investigation by competent, well trained geologists before a region can be conscientiously recommended for testing. The work of those individuals who practice the profession of geology and pose as geologists before the public, without the proper technical and practical training, not only places discredit upon recognized members of the profession but also causes much harm to legitimate and honest exploration and development.

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 in its complexities and value to man. As the various theories, based on careful analyses 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 for these substances 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 simply reduces chance to 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 of post graduate work. To this technical training, and of equal importance, should be added several years' field experience, part of which has been spent under the guidance of competent members of the profession.

It is highly essential, therefore, that the various communities of the State that have occasion to employ or deal with petroleum geologists first 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 imposters 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 but much practical training have attained success, yet these cases are very rare. The practical geologist is not equipped to do sound work. 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:

1. Reference[1]
2. Technical training
3. Field experience
4. Standing in the profession

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



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 good standing in the profession and a thorough training, since the qualifications for membership are high. Information as to 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 geologic 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 petroliferous. 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 and to thin out when traced laterally. A knowledge of the shore lines of the sea in which the oil bearing sediments were deposited is very 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 will be found if the 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 outweight 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 to 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-catting, 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 attended to 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 eruption 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.

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.

Badlands are typical of semi-arid regions, where 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 washed 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. Badlands showing all stages of development from incipient 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, makes evident 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 structure. 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 surface agencies.

### 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—grass 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 of 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 slopes of buttes and other elevated points, the bedrock over much of the plains region of South Dakota is generally concealed by alluvium, grassy sod, or other vegetation. In the areas east of the Missouri River the heavy covering of glacial drift has also concealed the bedrock 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 structural conditions. In such areas the wells which have been drilled or dug for water are of great importance in giving the geologist clews 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 local structures, 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 area are of relatively late geologic age, the older sediments lying 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 development. The hundreds of wells that have been drilled for artesian water 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 to as yet and nothing definite is known of their distribution or character. 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 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 detrimental factor which holds true to a greater or less extent for all areas. The difficulty of determining structure is further aggravated by the fact that where bedrock exposures occur they belong to formations which have a widespread tendency to slump, warp, and form landslips during the process of erosion, or which possess structures, due to the mode of deposition of the sediments, that tend to complicate dips formed by deformation of the beds. Therefore, the geologist who is working in the areas where these formations outcrop must be extremely cautious in his deductions and ever on the alert to distinguish the true from the false.

The following outline of the broader structural features of the State will serve as a background upon which to build the later discussion (Part III) of the detailed features.

The two geologic provinces previously described, the Black Hills uplift and the Plains region, are characterized by distinct structural differences. In the Black Hills province the sedimentary rocks are folded into a steep dome encircling the central pre-Cambrian mass and upon which are superimposed local folds of various types and magnitude. In the Plains region the stratified rocks lie nearly horizontal, the regional dip generally averaging less than one degree. The rocks are warped, however, into broad, shallow basins and ridges upon which are superimposed smaller folds. It is these secondary folds that are of chief interest to the petroleum geologist, since some of them may serve as traps for oil and gas. It is evident, however, from what has been stated, that to decipher these minor structures will prove an extremely difficult problem, since the general lack of bedrock exposures, the slumps, and false structures make the determination of folding from surface studies practically impossible in some areas.

The present information relative to the broader structural features of the formations underlying the Great Plains region in South Dakota is based largely upon well logs. The Dakota sandstone, due to its widespread distribution over the State and its general ease of recognition, forms an excellent key bed. The hundreds of wells which have been drilled into this formation for artesian water have afforded data for the determination of the attitude of this sand. Unfortunately, the artesian wells penetrating the Dakota are largely confined to the eastern and southern parts of the State and to the area bordering the Black Hills. Thus there is a broad stretch of country west of the Missouri River and especially north of the Cheyenne River over which no wells have been drilled into this sandstone. The information relative to structural conditions in this area must be based on a study of the attitude of surface formations, a matter fraught with considerable uncertainty, since the exposed formations consist mainly of the badly slumped Pierre shale or the erratic, lenticular and cross-bedded strata of the Tertiary.

The studies up to the present time, however, by Darton and others have given a very generalized idea, at least, of the regional structure of the State based upon the attitude of the Dakota sandstone. The structure contour lines on the appended geologic map show the elevation of the top of the Dakota sandstone above sea level. Well log data mainly, and the study of the attitude of surface formations in those areas where wells have not been drilled, form the sources from which the elevation readings for these contours were deduced. The broken lines indicate approximate contours.

A study of the attitude of the Dakota sandstone as indicated by these contours shows that the dominant structural feature of the Plains region is a northwesterly plunging basin lying between the Black Hills uplift on the west and the pre-Cambrian quartzite and granite masses on the east. This great structural basin is modified by broad folds, generally of slight magnitude.

## CORRELATION TABLE FORMATIONS IN EASTERN WYOMING AND SOUTH DAKOTA

| Era | Period, etc. | Eastern Wyoming | Black Hills | West and Northwest S. Dak. | Eastern S. Dak. |
|---|---|---|---|---|---|
| CENOZOIC | Tertiary | White River | White River | White River | Absent |
| | | Fort Union | Absent | Fort Union 425 | |
| | Tertiary? or Cretaceous? | Lance | | Lance: Ludlow lignitic member 0-350; Cannonball marine member 0-225; Somber beds 425 | |
| MESOZOIC | Upper Cretaceous, Montana Group | Fox Hills ss; Parkman sand; Teapot sand | | Fox Hills Sandstone 25-400 | |
| | | Shannon sand; Pierre shale | 1200-1400+ | Pierre Shales | 1000+ |
| | Upper Cretaceous, Colorado Group, Benton | Niobrara | 175-225 | Niobrara Chalk and Shale | 200+− |
| | | Carlile shale; Wallcreek sand | 500-600 | Carlile Shale | 200 |
| | | Greenhorn limestone | 65 | Greenhorn Limestone | 25-50 |
| | | Graneros shale; (Mowry); Muddy sand | Mowry Shale member; 900-1150; Newcastle ss. member | Graneros Shale | 65-105 |
| | Upper Cretaceous, Dakota | Cloverly | Dakota ss 20-200 | Dakota (undifferentiated) | 150-400 |
| | Comanchean (Lower Cretac.) | | Fuson sh 30-150; Minnewaste ls 0-30; Lakota ss 100-300 | | |
| | Cretaceous? Jurassic? | Morrison | Morrison sh 0-150 | Distribution and character of the formations under the Dakota are unknown | Pre-Cambrian Granite and Quartzite |
| | Jurassic | Sundance | Unkpapa ss 0-225; Sundance sh ss 100-300 | | |
| | Triassic | Chugwater, sh, ss. | Spearfish, sh ss 550-695 | | |
| PALEOZOIC | Carbonif., Permian | Embar ls | Minnekahta ls 30-50; Opeche sh 75-130 | | |
| | Carbonif., Penn. | Ten sleep ss; Amsden formation | Minnelusa ss 400-500 | | |
| | Carbonif., Miss. | Madison ls | Pahasapa ls 300-600; Englewood ls 30-50 | | |
| | Ordovician | Bighorn ls | Whitewood ls 0-80 | | |
| | Cambrian | Deadwood ss | Deadwood ss 50-450 | | |
| | | 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 petroliferous 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 petroliferous 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.[1] As far as the writer is aware, no bituminous material has been found in the Pahasapa 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 mainly 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 Opeche 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 distribution of the formation is apparently restricted to the western part of the State.

The remaining formations of the Lower Mesozoic, including the Morrison, Lakota, and Fuson 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 consists of shales which are of 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 grouping 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 very widespread, 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.

[1]Washburne, Chester W., Gas Fields of the Big Horn Basin: U. S. Geological Survey, Bulletin 340, p. 361, 1908.



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 on the Little Missouri River south of Camp Crook and 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 Niobrara and Greenhorn limestones are both fossiliferous 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 fossiliferous in places, merits little consideration as a possible source of oil and gas. The formation has been eroded from broad areas. It is also much cut up and channeled by active current action of the near shore waters in which it was deposited. Furthermore the formation lies under 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 northwestern South Dakota contain slight local accumulations of gas formed by chemical changes in the coal beds, 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 is 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 in which the sediments 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 characteristics and distribution are considered in ascending geologic age.

### DEADWOOD FORMATION

The Deadwood sandstone, although having the features requisite for a reservoir rock, is probably 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

Wyoming, the Deadwood formation is locally saturated with oil[1] but it is probable that the oil has seeped into the sandstone from overlying younger formations against which the Deadwood sandstone has been up-folded.

### 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 and other Paleozoic formations in the plains region would be unfeasible, 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 Mitchell and the granite outcrops of Bigstone Lake, in which areas these strata were probably never deposited.

In the earlier literature, the Lakota, Fuson, and Dakota formations were collectively know as the Dakota sandstone, but studies in the Black Hills area resulted in the tri-partite 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 Fuson formations have been definitely recognized as distinct stratigraphic units. In eastern South Dakota the Lakota and Fuson formations have not been recognized as yet in the mass of sandstones lying below the Benton shales,

[1]Heald, K. C., The Oil-bearing Horizons of Wyoming: Bulletin American Association of Petroleum Geologists, vol. V, no. 2, pp. 187-88.



and the term Dakota is applied to all these basal Upper Cretaceous beds. Darton[1] 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 Fuson 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 Fuson formation consists of shales with local beds 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 Fuson 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 this formation constitutes 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 considerable areas at least. A freshwater origin is further emphasized by the local occurrence of lignite beds. The character and distribution of the Dakota sandstone indicate 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 circulation of artesian water in this formation. 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 pro-

[1]Darton, N. H., Geology and Underground Waters of South Dakota; U. S. Geological Survey, Water Supply Paper, no. 227, p. 41.

ducing. 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 Black Hills.[1]

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 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 sands 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 petroliferous 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 Munn[2] 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 this connection. According to known evidence the folds in the Dakota of the plains region are broad and gentle. This is suggested both by the artesian well logs and surface evidence. It is possible, however, that folding in the Dakota may be more pronounced than is indicated at the surface, the overlying soft shales having absorbed the stresses. If the folds are slight it is probable that the artesian water has sufficient head to circulate actively through them, thus preventing any separation of the oil. The greater capillarity 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 capillarity 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 more probable that gas may be found in the tops of 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.

[1]A slight quantity of high grade oil is reported from the Dakota sands near Minot, North Dakota. The Dakota sandstone is highly asphaltic in parts of Canada.

[2]Munn, M. J., The Anticlinal and Hydraulic Theories of Oil Accumulation: Economic Geology, vol. IV, pp. 509-529, 1909.



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 of 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 made higher by folding. The latter case is one explanation offered for the oil in the Kootenai sands of Montana. Pronounced folds, however, are necessary for this migration across formations into lower sands. In South Dakota the folds in the prairie regions are probably all slight and hence oil would not be likely to get into the Dakota-Lakota sands from the Upper Cretaceous shales, as it would necessitate downward movement. Circulating waters might possibly carry oil downward. If circulating waters do not act in this capacity the Dakota-Lakota sands must get their oil from underlying strata. The bearing of this possibility upon oil in the Dakota-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 PIERRE SHALES

Lying above the Dakota-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 Carlile shales and the interstratified Greenhorn limestones. Above the overlying Niobrara limestones lie the thick Pierre shales, the most extensive formation of the State. It is in these horizons in Wyoming that most of the important oil sands occur and hence it is important to determine to what extent these sands persist eastward into South Dakota.

A study of the paleogeographic map (figure 12)[1] 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 times. The Benton 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 western part of Montana. The eastern shore line lay 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 shore in the vicinity 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 this 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 sandstones as far east as the western border of the State. The waters of the Pierre sea over central and eastern Montana and Wyoming fluctuated in depth; brackish[2] 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-

[1]Stanton, T. W., and Vaughn, T. W., The Fauna of the Cannonball Marine Member of the Lance Formation: U. S. G. S. Prof. Paper, 128-A, fig. 2, p. 16. See also: Schuchert, Charles, Paleogeography of North America: Bulletin Geol. Soc. of America, vol. XX, 1908.

[2]Brackish waters are those which represent a transition from marine to fresh water conditions.

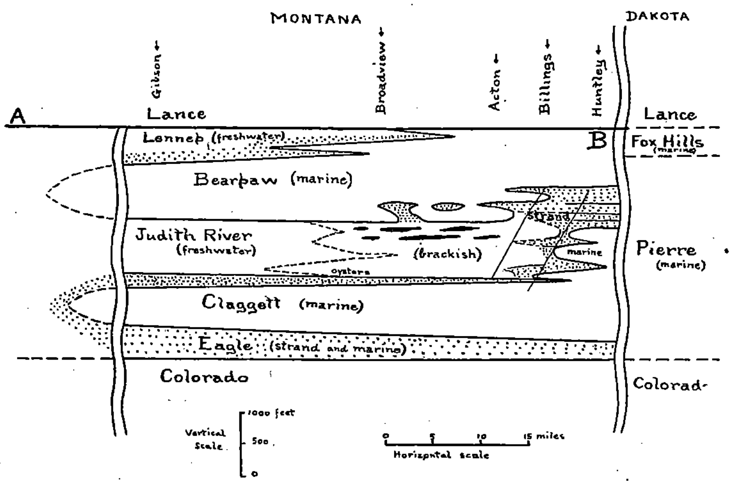



**Fig. 11. Lensing Out of Sands in the Upper Cretaceous of Eastern Montana**

From W. T. Thom, Jr.: Johns Hopkins University Circular, New Ser. No. 3, 1917, 68-73.

wards the western border of South Dakota the sands pinch out and are largely absent over much of the State. A few thin and lenticular beds are present in the westernmost areas and slight local seams 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 immediately underlies the Niobrara chalk; in others it is separated from that formation by black shale which locally attains a thickness of 100 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. * * * The lower sandstones in the Benton group are much less definite in position and occurrence * * *."

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

[1]Darton, N. H., Geology and Underground Waters of South Dakota: U. S. Geological Survey Water Supply Paper, no. 227, p. 62.



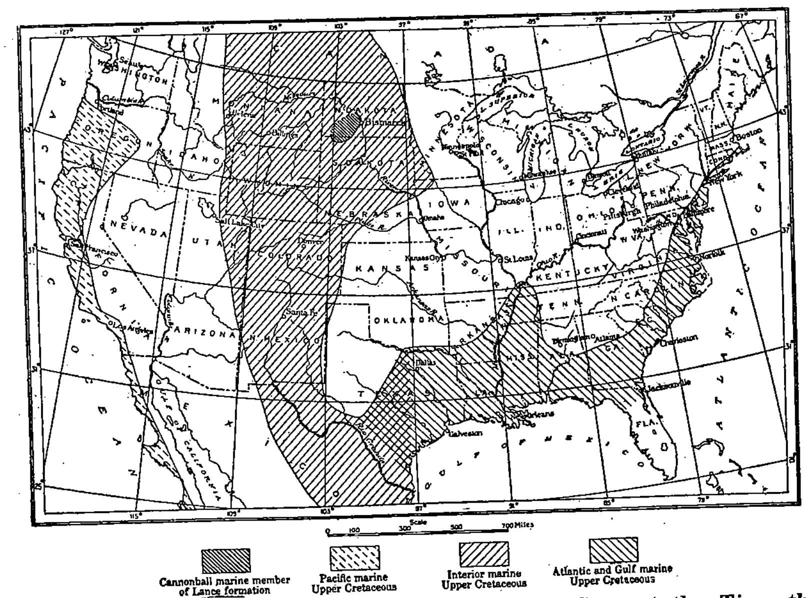



**Fig. 12. Probable Extent of Upper Cretaceous Seas at the Time the Pierre Shale Was Deposited**

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 Carlile 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.[1]

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.[2]

[1]The log of the Standing Butte well shows a thin sand in the upper part of the Benton shales. See page 81.
[2]Clapp, C. H. and others, Geology and Oil and Gas Prospects of Eastern Montana: Bulletin Montana State Bureau of Mines, no. 4, pp. 84-88.

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 Cedar Creek anticline of eastern Montana. 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 SANDSTONES

The rocks of the Fox Hills and overlying Tertiary fresh-water beds while offering ideal reservoir conditions are too near the surface and hence too greatly 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 fields occur in areas adjacent to mountain uplifts where deformation has 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 faulting 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 folds. 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 POSSIBILIIES

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 synclinorium 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.)

In the westernmost part of the State the Black Hills uplift has developed folds in the adjacent plains region which are moderately prominent. The zone of folding produced by this uplift roughly



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 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 rapid vertical and horizontal gradation of bedding. This lenticularity, 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 monotonously 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 place and that the dip represents true deformation and is not due to 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 and is much less in many areas. Hence, localities showing pronounced dips should be studied carefully for possible local causes of deformation. The writer does not mean to imply that conspicuous folding cannot occur in those areas removed from the Black Hills uplift, but the general character of 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 plains region of South Dakota have thus far been too generalized to afford any accurate information on the detailed structural features. The reconnaissance 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 steep dips 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 shale beds may 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 anticlines and synclines with dips on the limbs of the folds up to eight degrees or more. The fact that the more resistant beds of lime concretions interstratified in the 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 strikes of the exposures 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 detailed studies are necessary to determine this point. It may be mentioned that the general small 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 would admit of 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 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 uplift. The generally slight deformation at this time of the rocks 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 rocks that in themselves are incapable of any ready stress transmission, suggest the possibility of surface expression of deformation in deeply buried competent rocks.[1] It is possible that the

[1]See especially a paper by A. E. Fath, The Origin of the Faults, Anticlines, and Buried Granite Ridge of the Northern Part of the Mid-Continent Oil and Gas Field. U. S. Geological Survey, Professional Paper, 128-c, 1920.



underlying pre-Cambrian crystallines, Paleozoic rocks (if present), and the Dakota sandstone 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, however, 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.[1]

Further investigations should disclose important evidence bearing upon the above mentioned possibilities as to the origin of the local folds in the Pierre 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 Moreau 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 originated 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 remnants on the Pierre shale suggest that these 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 nearby areas the Fox Hills lies 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 the overlying Lance formation, may have transmitted 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 over- and underlying 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

[1]Gardescu, I. I., and Johnson, R. H., The Effect of Stratigraphic Variation on Folding: Bull. Am. Assoc. of Petroleum Geologists, vol. 5, no. 4, pp. 481-3.

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.

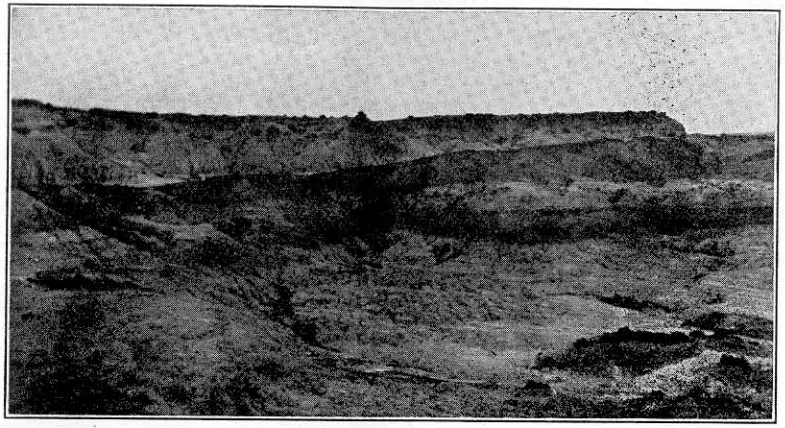
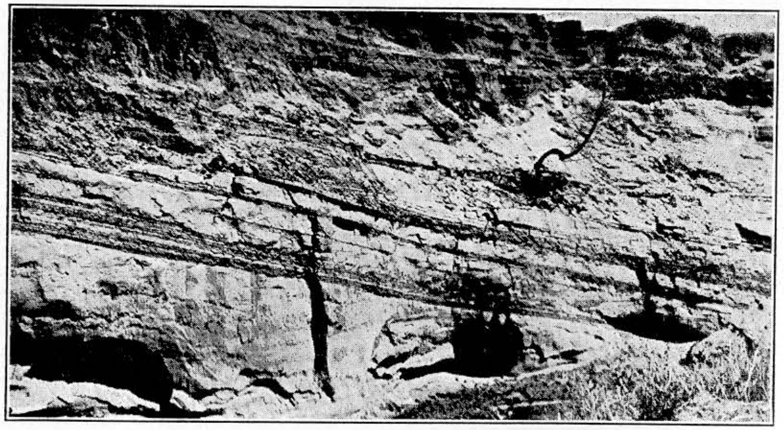


**Plate I, A. Lenticular and Irregular Bedding in the Lance Formation**



**B. Cross Bedding in the Fox Hills Formation**
Photo by Josef, Faith, S. D.

Cross-bedding is especially typical of sandstones and the coarser sediments. It is due to the active and changing current action of streams and the near-shore areas of lakes and seas. Wind currents also develop this structure in dune sands. Cross-bedding is generally recognized by the fact that the individual beds are very localized and the dips vary in direction, both laterally and vertically, over a few feet. The individual beds may be fairly extensive, in which case the attitude of the beds may be mistaken for structure. This is well



illustrated by the White River formation in the Slim Buttes area at Reva Gap.[1] 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-bedded 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-bedded in many areas. The White River formation frequently shows this structural feature. The Lakota sandstone of the Black Hills region is frequently cross-bedded.

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 I).

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.

[1]Winchester, D. E., Cross-Bedding in the White River Formation of Northwestern South Dakota: Journal of Geology, vol. 21, no. 6, pp. 550-556, 1913.

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 mainly 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 petroliferous shales."[1] 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.

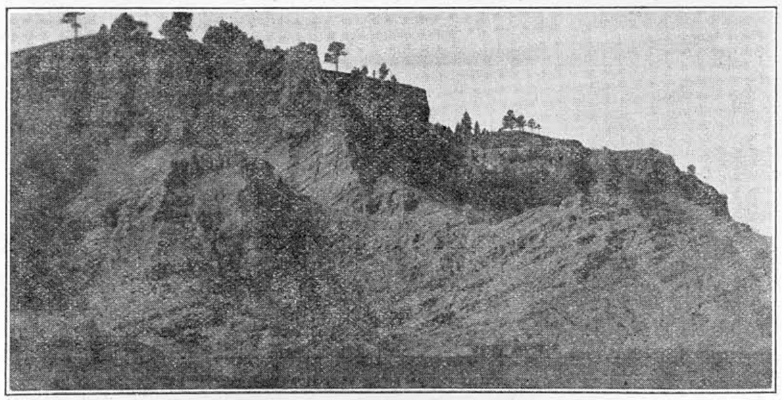
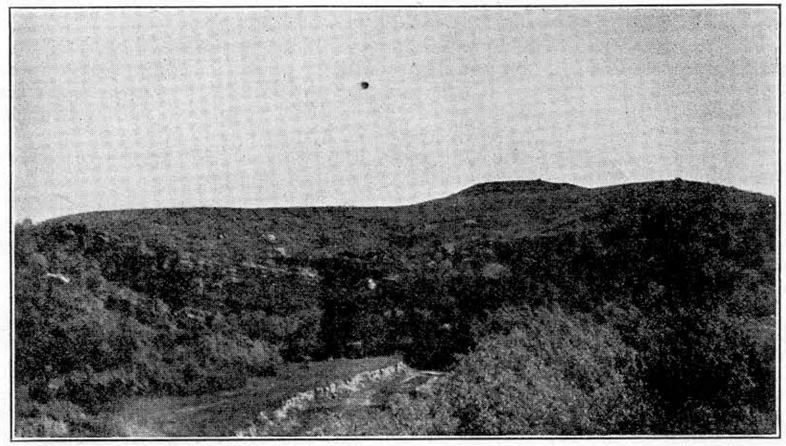


**Plate II, A. Large Scale Cross-Bedding in the White River Formation, Reva Gap, Slim Buttes**

[1]Clapp, C. H. and others, Geology and Oil and Gas Prospects of Central and Eastern Montana: University of Montana Bulletin, Bureau of Mines and Metallurgy, Series No. 4, 1921, p. 87.





**B. Folding in Lance Formation, Slim Buttes, Due to Slumping and Landslips**

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 deformational 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.

## 6.—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 49). 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 its recognition. These features will be briefly considered.

**The Pierre Shale.**—The Pierre shale consists of dark blue or dark 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 erodes 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 tables, varies in thickness from 300 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 Moreau 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 tables, the basal or somber beds having the greatest development in this region. The basal beds of the Lance consist of dark or gray shales, clays, and sandstones with associated beds of iron concretions. The beds are very lenticular 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 somber beds of the Lance commonly erode into rough topography or badlands. Such badlands are well developed in areas along the Moreau, 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 consist of gray sandstones with shale and clay. The sandstones tend to form hard, log-like masses. Ball-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 member 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 West 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 underlying 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 3,700 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 upwarpings 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 upwarpings are indicated on the map by continuous lines where the location is fairly accurate and by broken lines where the location is roughly approximated.

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 they trend northeast-southwest. 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 described 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 strata. Coal seams are the only possibility, but even these are generally restricted in their distribution. Even where a fairly 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 form 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 may 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 its 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 near-shore areas, the active currents channeled out portions of the deposits 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.)



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[1] 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 warpings 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 illustrations occur 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.

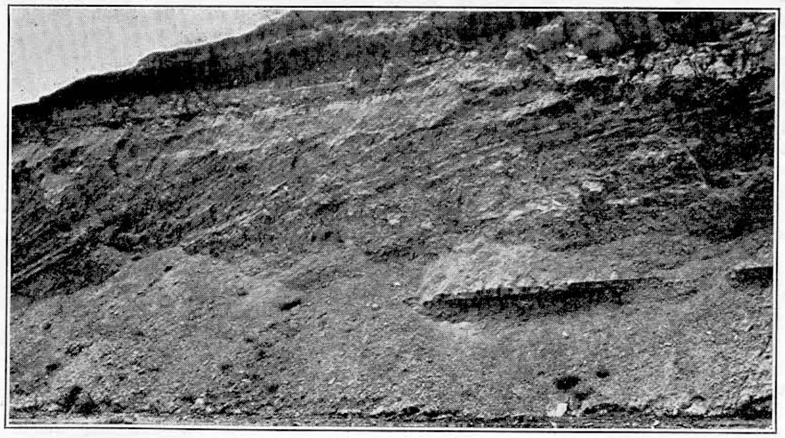
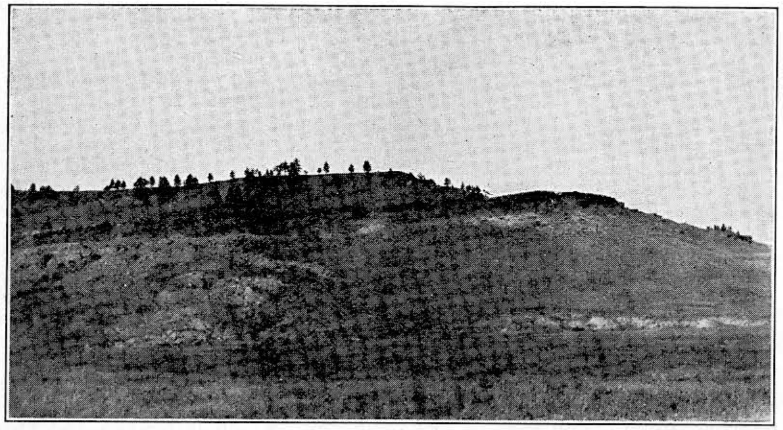


**Plate III, A. Folding in Fox Hills Formation on Moreau River, Northwest to Faith, S. D.**

Photo by Josef, Faith, S. D.

[1]Winchester, D. E., and others, The Lignite Field of Northwestern South Dakota: U. S. G. S. Bull. 627, pp. 36-38.



**B. West Limb of Camp Crook Anticline, near Camp Crook**

For the possible modes of origin of these local folds the reader is referred to the discussion on pages 60-66. 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. Those 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 probably at too great a depth for feasible testing under existing conditions, at least over much of the region. The approximate depth to 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 con 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 Darton's estimates, the top of the Dakota is nearly 4,000 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 geologic features by no means warranted such a procedure.

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 indicate a structure. 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 of the prairie region eroded ledges of sandstone or other hard rocks lie imbedded in the sod 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 such dips have defined what appear to be closed domes 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, money, 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

Lemmon. 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 Moreau 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 reliance 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 Moreau River northwest of Faith, on Freesteel Creek northeast of Isabel, and on Cherry Creek in the vicinity of Opal. The value of these folds and the more uncertain folding observed 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 Black Hills proper but the folds of the adjacent prairie 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 49).

**Structural Features.**—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 Crook, Cedar Creek, and related structures indicate the northwest continuation of the uplift.



**Structures North of the Black Hills.**—Relative to the structural features in the northwest corner of South Dakota and adjacent parts of Montana, North Dakota, and Wyoming, the following quotation is taken from a press notice of the U. S. Geological Survey:[1] "The Cedar Creek fold may be looked upon as an offset continuation of the northern end of the Black Hills uplift, whose direct extension fades out into a series of low flexures that parallel the Cedar Creek anticline in the area south and west of Baker. These flexures are commonly marked by steep, short westward slopes and by much longer and more gradual northeastward slopes. * * Domes that are probably due to minor cross folds have been imposed upon the axes of the large anticline and to a less degree upon the smaller anticlines."

Over much of western Harding[2] and Butte counties the strata show more or less warping but only a few folds are sufficiently conspicuous to be noticeable to the eye. The regional dip is usually less than one hundred feet to the mile in an easterly direction, although much steeper dips occur on the limbs of the most prominent folds. The general trend of the folding is northwest-southeast. Minor folds, whose axes vary in trend, are not uncommon. The deformational features show a gradual increase in magnitude westward.

Over a great part of Butte County, in the areas removed from the immediate vicinity of the Black Hills, the rocks appear essentially horizontal. This apparent absence of folding is possibly due to the fact that the Pierre shale, because of its massive soft character and lack of differentiated bedding, does not show structure as well as the harder and more variegated Fox Hills and Tertiary formations.

The structures in the northwest part of the State which deserve consideration are, in the order of their importance, the Fox Hills dome[3] (marking the south end of the Cedar Creek anticline); the Camp Crook anticline; a dome in the central part of Tp. 22 N., R. 1 E.; the Gallup Creek dome;[4] an anticline south of the west Short Pine Hills; and anticlines crossing the south and north ends of the North Cave Hills. Detailed work will doubtless disclose other structures, probably of lesser magnitude.

The anticlines in the Cave Hills area are very shallow and appear to lack closure. The details of these folds, the Gallup Creek structure, and the anticline south of the West Short Pine Hills were not studied. The general extent of these and other structures is shown on the map.

The Fox Hills dome, a secondary fold in the south end of the Cedar Creek anticline, is well marked by the exposure of the soft, white sandstone of the Fox Hills formation surrounded by basal beds of the Lance. It is possible that several local exposures of dark blue shale which appear in the stream banks in the southeast corner of Tp. 23 N., R. 2 E., may be Pierre shale, as they lie below the exposed Fox Hills. The dips on this structure average one to five degrees, the southwest limb showing the steeper slopes.

The small dome in Tp. 21 N., R. 1 E., is developed in the basal Lance. This structure shows dips up to three degrees.[5]

The Camp Crook anticline is the most conspicuous fold in this general area. Although the main part of this structure lies north of

[1]Press Notice, U. S. Geological Survey, January 11, 1922: Oil and Gas Prospects in the Cedar Creek Anticline and Vicinity, in Montana, North Dakota and South Dakota.
[2]Ward, Freeman, The Possibilities of Oil and Gas in Harding County: South Dakota State Geological and Natural History Survey, Circular No. 4.
[3]Name applied by U. S. Geological Survey.
[4]Name applied by the U. S. Geological Survey.
[5]Ward, Freeman, op. cit.

Camp Crook; evidence of the fold extends south to the west Short Pine Hills. The west limb of the structure about six miles north of Camp Crook 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 number of reports.[1]

The major structural feature constitutes the monoclinal dipping beds which surround the uplift, forming a great eroded dome. Upon these monoclinal dips are superimposed anticlinal noses which plunge away from the uplift, terraces, and closed folds of varying magnitude. 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 anticline constitutes the southeast prolongation of the Black Hills uplift, the other described structure forming a cross-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 three large anticlinal noses which plunge southward 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 away from 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 horizons.

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 have been drilled in the immediate vicinity of the Black Hills. A general summary of the results of these tests follows. Since much of the information was derived by interviewing local people, some of whom were not familiar with the details of development, the writer cannot vouch for the accuracy of some of the following statements.

**Belle Fourche Area:** A well drilled about six miles northwest of Belle Fourche on an anticline trending in a northwest 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 1,530 feet. A thin sand said to be 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 was also slightly petroliferous. 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 Mowry shale. It is reported that the depth attained was 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

[1]See Bibliography.



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 sulphide.

Several other tests have been made in this general area with negative results. The sand towards the base of the Graneros (Newcastle sand), the Lakota sand, and the Minnelusa sand appear to be slightly petroliferous. The Lakota is locally bituminous in its outcrops south of Belle Fourche. The Minnelusa sand in the Rockyford region west of Spearfish is petroliferous.

**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 defined by the Mowry and Graneros shales. 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 sites and the possibility of this large flow for irrigation purposes 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 are said to be locally petroliferous, but this was not verified.

**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 northeasterly direction west of Edgemont. This zone of folding is marked by a large anticline on Old Women Creek on the Wyoming side and by folding 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 petroliferous in the Old Women Creek anticline. The Dakota-Lakota sands 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 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 main Black Hills uplift to have largely escaped the danger of the loss of any contained petroleum through too great an amount of deformation.

The 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 Midwest Oil Company. The well, which is located near Slim Butte, apparently passed through the Benton shales and Lower Mesozoic red beds to the base of the Mesozoic or top of the Paleozoic. The depth of the well is 2,445 feet. A slight showing of gas was found at 875 feet.

The other well was drilled near the Pine Ridge Agency in the central part of Tp. 35 N., R. 45 W. No log has been obtained but the reports indicate that the test showed no promising indications of oil.

The log of a well drilled by the Midwest Oil Company on the Nebraska side of the structure shows that the Dakota sand was penetrated at a depth of 1,490 feet. The hole was stopped after penetrating this sand for 150 feet. 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 areas 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.[1] This sand varies greatly in thickness but has its best development in the Newcastle field. It is the chief oil horizon in the Newcastle, Moorcroft, Lance Creek, and Osage fields. This sandstone, according to Darton[2] is the same sand that occurs on the east side of the Hills near the base of the Graneros shale in various localities. It is very probably the petroliferous sand encountered in the well near Belle Fourche and the wells on the St. Onge structure. It is possibly correlative with the Muddy sand of Wyoming.[3]

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 Carlile 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 Fuson and Dakota are at least locally petroliferous. The Lakota 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 westerly 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.[4] According to this bulletin the abundant supply of gas found in the vicinity of Glendive and on the

[1]Hancock, E. T., The Mule Creek Oil Field, Wyoming: U. S. Geological Survey Bulletin 716, pp. 40, 51.
[2]Darton, N. H., Geology and Underground Waters of South Dakota: U. S. Geol. Survey Water Supply Paper 227, p. 20.
[3]Heald, K. C., Oil-bearing Horizons of Wyoming: Bull. Am. Assoc. Petroleum Geologists, vol. 5, no. 2, p. 198.
[4]Op. cit.



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 * * * 30 feet of sand, thought to be the Fox Hills, between 560 and 590 feet, and other sands at 725 to 735, 800 to 816, and 845 to 920 feet. A five foot bed of limestone was penetrated at 2,400 to 2,405 feet, and thinner lime 'shells' between 1,490 and 2,400 feet. * * * The lime shell at 2,400 feet is thought to mark the top of the Colorado shale, and when the hole was abandoned the bottom was probably slightly less than 1,000 feet above the Dakota sandstone.

"As this well did not penetrate the Dakota, Lakota, or Sundance sands it shed no light on the presence or absence of oil in its vicinity; and as it was fairly well down on the northwest flank of the Coal Creek dome its position was not particularly favorable for a test well."

The log of the above well is of interest because of its nearness to South Dakota.

A well drilled on what is known as the Seven Mile structure east of Alzada, Montana, gives the following log:[1] Colorado shale, 0-1,573 feet; Dakota-Lakota sand and shale, 1,573-1,786. The well stopped at this depth. A showing of oil was found at a depth of 1,654 to 1,670 feet in the Dakota. A 7-foot sand layer was found at 253 feet, an 8-foot sand bed at 592 feet, and a 5-foot sand bed at 860 feet. The Dakota-Lakota horizon contained several water sands.

## POSSIBLE OIL HORIZONS IN WESTERN SOUTH DAKOTA

The greatest possibility for oil sands is in the Upper Cretaceous in this part of the State. The reason for this statement has been made evident in previous pages. The evidence, however, of the wells drilled in adjacent areas of Montana and Wyoming indicates that the sands of the Upper Cretaceous are thin or have disappeared in this general region.

In the Black Hills area and the southwest corner of the State the following changes have probably occurred in the sands of adjacent areas in Wyoming. The Newcastle sand is thin or absent in the western part of South Dakota. It is probably too thin to be of any value as an oil horizon. The other producing sands of the Upper Cretaceous, according to the evidence of drilled wells and exposures around the Black Hills, have thinned out. The Wall Creek (Frontier) sand has probably graded into the Greenhorn limestone or the shales immediately above, as no sand is present at this horizon on the east side of the Black Hills. This sand begins to first appear in the Osage field according to present correlations. The Shannon sand, which is thin in the Lance Creek field, has disappeared in South Dakota. The Parkman and Teapot sands, the highest productive sands of east central Wyoming, have possibly graded into the Fox Hills formation.[2] The Dakota-Lakota and underlying horizons previously discussed (pages 51-60) are probably present over all this area.

In the northwestern part of the State it is possible that the Judith River sands may extend as far as South Dakota. There is much less possibility of the Eagle sandstone extending this far. An artesian well at Camp Crook which penetrated the Pierre shale for about 1,000 feet is reported to have encountered no sands. The first

[1]Furnished by W. C. Vanderwoort of Marmath, South Dakota.
[2]Heald, K. C., op. cit., pp. 204-5.

probable sands of this area are those of the Dakota-Lakota horizon. The reservoir horizons below the Dakota-Lakota discussed on pages 53-54 are probably present over much of this region.

AREA WEST OF THE MISSOURI AND SOUTH OF THE CHEYENNE RIVER[1]

**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 and 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.[2] Fossils collected from calcareous concretions in this zone were identified by Dr. Stanton of the U. S. Geological Survey as types occurring about 200 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 Interior and on Standing Butte, northwest of Fort 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 synclinorium which has its steeper dips in the southwest corner of the district, where it grades into the Chadron anticline. In general, the regional dip flattens out northward and a broad terrace, possibly a very slight geanticlinal uplift, is 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,[3] 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).

[1]Ward, Freeman, The Possibilities of Oil in Eastern Pennington County: South Dakota Geological and Natural History Survey Circular 8.

[2]Darton, N. H., Personal communication. See also Prof. Paper 32, U. S. G. S., p. 148.

[3]Ward, Freeman, The Possibilities of Oil in Eastern Pennington County: S. D. State Geol. Survey, Circular No. 8.



**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 thus far active drilling has been confined to three localities, the Standing Butte district, Plum Creek, and Scenic.

**Standing Butte District:** A standard rig has been set up a 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 2,050 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:

| | | Thickness in Feet. |
|---|---|---|
| | Pierre shale | 1,100 |
| | Niobrara | 200 |
| Benton 385 ft. | Shale, dark (Carlile) | 105 |
| | Sand (water bearing) | 10 |
| | Limestone (Greenhorn) | 10 |
| | Shale, dark (Graneros) | 310 |
| Dakota-Lakota 315 ft. | Sand (water, traces of oil and gas) | 50 |
| | Shale | 155 |
| | Sand (water) | 36 |
| | Shale | 24 |
| | Coarse Gravel | 5 |
| | Bentonite (?) | 10 |
| | Shale | 35 |
| | Total, feet | 2,050 |

If the formations, as above indicated, are properly identified, this log shows that the thin water-bearing sand in the upper part of the Benton its still 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 horizons 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 1,300 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. Pronounced slumping 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.

**Scenic:** A test is being made near the town of Scenic 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 Scenic, 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:**[1] 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 structural features by the State Geological Survey, show 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 structure by the structure contour method over any 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 out 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 consist of pre-Cambrian crystallines. 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

[1]Ward, Freeman, The Possibilities of Oil in Eastern Pennington County: South Dakota State Geological and Natural History Survey, Circular No. 8.



eastward. 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, Carlile shale, Niobrara limestone, and Pierre shale constitute the exposed bed rocks. The Fox Hills and White River may be locally present.

The general structural features of the region are summarized by Darton[1] 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 anticlne 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 artesian wells to disclose showings of petroleum has fairly conclusively proved the improbabilities of finding oil in this region. Wells drilled in the vicinty 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 slumped 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."[2]

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

[1]Darton, N. H., Geology and Underground Waters of South Dakota: U. S. G. S., Water Supply Paper No. 227, p. 33.
[2]Visher, S. S., The Geography of South Dakota: South Dakota State Geological and Natural History Survey, Bulletin 8.

It is reported[1] that in 1917 the gas in Pierre and Fort Pierre was obtained from five artesian wells and was "distributed to 365 domestic and four industrial consumers including the water works and the Electric Light Plant."

At this time the State Capitol well was flowing 16,000 cubic feet of gas per twenty-four hours, or about 11.1 cubic feet per minute. In 1910 the flow was 59 cubic feet per minute. The ratio of water to gas in this well was about six to one. This gas is obtained from a water sand at 1,175 to 1,185 feet. Other flows of gas were found at 533 to 650 feet, and 1,130 to 1,140 feet.

The following summary of the natural gas situation in South Dakota,[2] although much out of date, outlines the situation about as well as any later publication could: "There are several minor areas scattered through 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 McCook 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 upward from below, and also from the same horizons as the principal flows of water. That the upper flows may not be from below, but are derived from the level where they appear seems strongly suggested, at least, by the occurrence at Blunt of a water stratum between showing no gas. Besides, the upper strata about Pierre seem to 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 Lakota, 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 plant remains with some coal around 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 Lakota. Moreover, this may be assisted by the flow of water eastward along the same channels.

"Further north, particularly around Selby and Ipswich, gas may be derived from beds in the Montana, which in its upper part especially 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 anticlinal folds in the strata to concentrate 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 over much of the region north of White River and west of the Missouri, besides that already mentioned east of that stream."

[1]Report of State Engineer.
[2]Todd, J. E., Mineral Resources of South Dakota. South Dakota Geological Survey, Bulletin No. 3, 1902, pp. 114-118.



No analyses of natural gas from South Dakota are available at the time of writing this bulletion. It is known that the gas from the St. Onge structure was characterized by a high nitrogen content, an absence of oxygen, carbon dioxide, and carbon monoxide, and a trace of helium. Gas from the Pierre region was also found to contain a trace of helium. The natural gas of South Dakota is a dry gas.[1] A dry gas is more typical of sands containing little or no oil. Hence the gas in South Dakota does not necessarily indicate the presence of oil. In many regions commercial amounts of gas occur without the associated presence of oil.

The unusually high nitrogen content of the gas from the St. Onge structure is not typical of the gas occurring in the central part of the State, although it is probable that analyses will show an average nitrogen content of ten to twelve per cent. Natural gas in North Dakota coming from similar horizons as that of South Dakota shows twelve to sixteen per cent of nitrogen and seventy-one to eighty-two per cent methane. The South Dakota gas probably contains somewhat similar percentages. The chemical composition of the gas is important since it throws some light on the possible association of oil. A gas containing a nitrogen content as high as that indicated above is often not associated with oil. The theory has been advanced that such gases have been "obtained from the atmosphere, the oxygen having been removed by its combination with reducible substances such as sulphides, leaving a residue of nitrogen * *. Associated with the nitrogen there occasionally is found a small amount of helium, which is also an ordinary constituent of air in small quantities."[2] This description fits the South Dakota gases, which show traces of helium and may average a high content of nitrogen. The sparse, yet widespread occurrence of iron sulphides in the Upper Cretaceous shales and Dakota sandstones might possibly form the reducible substances indicated above. Some grave difficulties face this postulation but it is offered for consideration.

The possibility that a part of the gas at least is given off from the shales into crevices and fissures from which it escapes to the surface when penetrated by wells through mixture with the artesian water under pressure, also merits consideration. Such gas is known as "shale gas." The following quotation from Emmons[3] illustrates some of the characteristics of shale gas. The similarity of this description to that of the gas occurring in South Dakota is to be noted:

"Shales that yield oil also yield gas. In some regions gas only is obtained from the shale reservoirs. In Cleveland, Ohio, and in the surrounding country wells have been sunk in the shale for domestic supply. As a rule the pressure is low and the yield small but the wells have long life, so that farmers find the fuel suitable for domestic use. Some wells supply one or two farm houses."

Orton, describing the differences between shale gas and reservoir gas notes that: "Shale-gas wells are generally of small volume, compared to wells deriving their gas from sand reservoirs. Moreover they lack uniformity of rock pressure. Wells drilled in close proximity, and to the same depth may have very different pressures. In sand reservoirs, pressures are generally greater and more nearly uniform. In the wells yielding shale gas there is no definite horizon from which their gas supply is derived. The stratum that yields it

[1]Gas associated with oil generally contains some of the lighter portions (most volatile) of the oil and is called a wet gas. Gas occurring in reservoirs where there is little or no associated oil is a dry gas. A dry gas is mainly composed of methane, if inflammable.
[2]Petroleum, Asphalt, and Natural Gas: Bull. 14, Kansas City Testing Laboratory, p. 120.
[3]Emmons, W. H., Geology of Petroleum, pp. 158-9.

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 altogther 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 will also 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 that 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 thinness 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:[1] "In preparing for new tests, plans should also be made to drill to a depth of at least 4,300 feet along the crest of the Cedar Creek Anticline, or to somewhat greater depths if the Plevna, 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 Glendive, 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 near-by town * * may afford a market for the gas."

In the areas east of the Black Hills uplift, if localities worthy of drilling are found, those which lie in districts where artesian water might be obtained should be given preference in testing. A good flow of artesian water would be an excellent repayment for a deep test, even if no commercial quantities of oil were encountered. Such areas

[1]U. S. Geological Survey Press Bulletin on Cedar Creek Anticline and Adjacent Areas, Jan. 11, 1922.



according to Darton[1] 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 up 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.

# 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.

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## GEOLOGY OF SOUTH DAKOTA

Various references on the geology of South Dakota are contained in the footnotes to this bulletin. For a more complete list of references see:


1. Ward, Freeman—Bibliography of South Dakota Geology: State Geological and Natural History Survey, Circular 5, 1919.
2. O'Harra, C. C.—Bibliography of the Black Hills Region, State School of Mines, Bulletin No. 11, 1917.


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