POSSIBILITIES OF OIL IN THE PORCUPINE DOME, ROSEBUD COUNTY, MONTANA.

By C. F. Bowen.

INTRODUCTION.

Requests for information concerning possible occurrences of oil and gas in Montana are frequently received by the Geological Survey. Partly to meet this demand for information, partly because the area described has attracted more or less local attention as a possible oil field, and finally, to place before the public information concerning

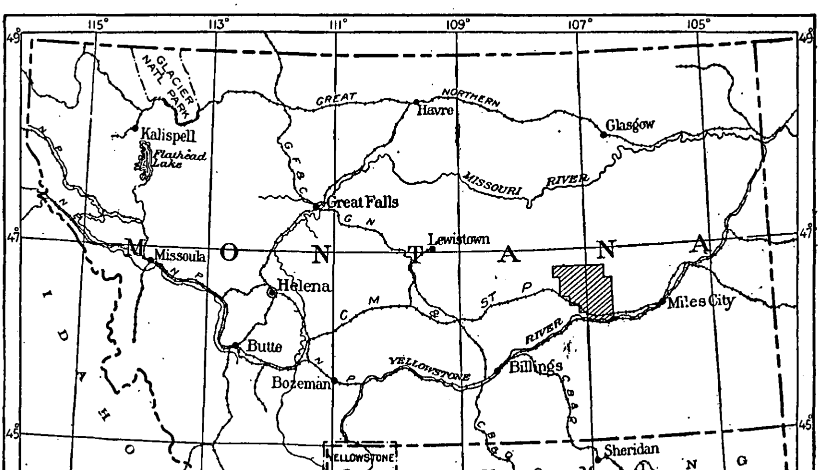


Figure 6.—Index map of Montana showing location of the Porcupine dome.

the log of the deep well drilled for water at Vananda, on the Chicago, Milwaukee & St. Paul Railway, this paper has been prepared.

The examination has demonstrated the existence of structural and stratigraphic conditions suitable for the accumulation of oil and gas if these substances were originally contained in the strata, but it has not proved their existence in the area examined. In fact, there are no known surface indications of oil or gas in this area, and no well other than the water well mentioned above has been drilled to determine whether or not they occur below the surface.

In the following pages it is proposed to describe the stratigraphy and structure of the area, to point out some of the more commonly recognized principles controlling accumulations of oil and gas, and to apply these principles so far as practicable to the area under consideration.

The Porcupine dome lies north of Forsyth, east of the Chicago, Milwaukee & St. Paul Railway, and is included in the drainage basin of Porcupine and Little Porcupine creeks. It includes Tps. 7 to 12 N., Rs. 36 to 40 E. of the principal meridian, Montana. (See fig. 6.)

BASIS OF REPORT AND MAP.

The information here presented regarding this field was obtained by C. A. Bonine and the writer in the summer of 1914 while making a reconnaissance survey of an area lying principally to the north and northwest of the Porcupine dome. In the prosecution of that work the eastern and northern margins of the dome were examined and mapped in more or less detail. Information concerning the remainder of the area is based on two hasty reconnaissance trips across it during the progress of the work.

The accompanying map (Pl. X) has been compiled from township plats of the General Land Office, from the writer's field sheets, and from such information as was obtained in the reconnaissance trips referred to above. Because of the lack of detailed knowledge of the southern and western parts of the area the geologic boundaries and structure of these parts can not be accurately depicted and no attempt has been made to do more than outline roughly the area of the dome and show its general structure. These representations are merely approximations and will be modified as to details by future careful work, but it is believed that the general features are in the main correct. In the eastern and northern parts of the field, where more detailed work was done, the formations, except the Colorado and Claggett, are differentiated and their boundaries accurately located.

GEOLOGY.

SEDIMENTARY ROCKS.

GENERAL SECTION.

The formations exposed at the surface in this area extend from the Lance formation down to the upper part of the Colorado shale, inclusive. A deep well put down at Vananda by the Chicago, Milwaukee & St. Paul Railway Co., in an attempt to obtain an adequate supply of water for railway and domestic use, is believed to have penetrated the underlying rocks down to the Kootenai or some related formation. Through the courtesy of the railway company the writer is permitted to publish the record of this well, and it is therefore possible to present a section of the formations represented in this part of Montana extending from the Lance down to the upper part of the Kootenai (?). These formations include in ascending order the Kootenai (?), Colorado, Claggett, Judith River, Bearpaw, and Lance. The sequence, character, and thickness of these formations are shown in the geologic table and well record given below.

One noteworthy fact brought out by the well record and by the areal mapping of the surface formations is the absence of the Eagle sandstone, which forms so conspicuous a unit at the base of the Montana group farther west. The writer was able to determine within very narrow limits the easternmost point at which the Eagle can be recognized, and can positively assert that it is not present as a mappable unit east of Musselshell River.

Geologic formations exposed in the Porcupine dome, Montana.

System.	Group.	Formation.	Thickness.	Character.
			Feet.	
Quaternary.				Alluvial gravel, sand, and silt along Yellowstone and Musselshell rivers and some of the smaller streams.
Tertiary (?).		Lance formation.		Brown, irregularly bedded sandstone, alternating with "somber" gray shale.
Cretaceous.	Montana.	Bearpaw shale.	900-1,100±	Dark-gray shale in which occur calcareous concretions containing marine invertebrate fossils.
		Judith River formation.	100-200±	Upper sandstone member, light-brown to light-gray massive sandstone. Middle member, light-gray to dark-gray shale. Lower member, sandstone, which weathers brown and gives rise to large bowlder-like masses. The formation is of fresh-water origin in the western part of the field and of marine origin in the eastern part.
		Claggett and Colorado shales.	3,000	Dark-gray to black shale; upper part highly plastic when wet and contains fossils characteristic of the Claggett formation; lower part slightly darker in color, more fissile and less plastic when wet, and contains fossils of Colorado age.

Log of well drilled by the Chicago, Milwaukee & St. Paul Railway Co. at Vananda, in sec. 5, T. 7 N., R. 38 E., Montana, between October 23, 1913, and October 17, 1914.

[Elevation of mouth of well, 2,704 feet above sea level.]

Formation.[a]	Driller's description.	Thickness.	Depth.
		Feet.	*Feet.*
Judith River formation.[b]	Shale, sandy	23	23
	Sand; 30 gallons of water an hour	7	30
	Shale, yellow	16	46
	Sand	11	57
	Shale and sand	24	81
	Sand	8	89
	Shale, yellow	16	105
	Sand	14	119
	Sand and shale	24	143
	Shale, blue	46	189
	Sand; flow of alkaline water, 2,400 gallons an hour	26	215
Claggett shale.[c]	Shale; disintegrates when exposed to air	685	900
(d)			
Colorado shale.	Shale,[e] black surface; whitens on exposure to air	140	1,040
	Shale	907	1,947
	Oyster-shell rim, fossil determined by former State geologist of South Dakota as *Inoceramus labiatus*.	5	1,952
	Shale, dark brown	107	2,059
	Hard rock	29	2,088
	Shale, soft; color changes on exposure from dark to light brown.	32	2,120
	Shale, light brown	40	2,160
	Slate	40	2,200
	Soapstone	13	2,213
	Shale, white	23	2,236
	Shale, dark	45	2,281
	Shale, black	19	2,300
	Shale, brown	100	2,400
	Shale, dark, caving	31	2,431
	Slate, caving	19	2,450
	Limestone	41	2,491
	Shale	239	2,730
	Shale and lime shells	15	2,745
	Shale, soft, caving	35	2,780
	Shale and lime shells	20	2,800
	Shale, soft, caving	105	2,905
	Shale, dark	35	2,940
	Shale and lime shells	103	3,043
	Sandstone, hard } May represent the Mowry shale member.	32	3,075
	Limestone, black, sandy }	18	3,093
	Limestone }	42	3,135
	Slate }	55	3,190
Kootenai (?).	Sand, water bearing; water rose within 50 feet of surface.	10	3,200
	Sandstone, compact	30	3,230
	Limestone	19	3,249
	Shale, white	23	3,272
	Shale, red	7	3,279
	Shale, white	8	3,287
	Shale, red	27	3,314
	Shale, white	8	3,322
	Shale, red	35	3,357

a Correlation revised by author.
b Called Lance in log furnished by railway company.
c Called Pierre in log furnished by railway company.
d In view of the lithologic similarity between the Claggett and Colorado the position of this boundary must be regarded as uncertain.
e Called Niobrara in log furnished by railway company.

KOOTENAI (?) FORMATION.

The Kootenai (?) formation, according to the writer's interpretation of the Vananda well record, was encountered at a depth of 3,200 feet and was penetrated by the drill to a depth of 157 feet.

This part of the formation consists mainly of alternate layers of red and white shale, overlain by a thin bed of limestone, and this in turn by a bed of sandstone 40 feet thick. In the upper part of this sandstone water was encountered, which rose within 50 feet of the mouth of the well. As this is the only sandstone below the 215-foot level which contained water, it suggests that the sandstone bed near the base of the Colorado is too fine grained to permit the ready circulation of liquids.

COLORADO AND CLAGGETT SHALES.

That part of the undifferentiated Colorado and Claggett formations which represents the Colorado consists chiefly of dark-gray to black, somewhat fissile shale, containing some intercalated thin layers of sandy shale and sandstone in its upper part and, according to the interpretation of the driller of the Vananda well, thin beds of limestone and sandstone near the base. The sandy phases observed in the field in the upper part of the formation are not recorded in the log of the well, an omission which indicates that they are either lenticular in character or were overlooked by the driller. In some places the shale contains numerous large limestone concretions, but whether or not these are characteristic of any definite horizon was not ascertained.

That part of the undifferentiated beds corresponding to the Claggett consists of 600 or 700 feet of dark-gray shale that becomes exceedingly plastic when wet. Calcareous concretions occur throughout this part of the formation but are exceptionally prevalent near the top, where many of them show a well-developed cone-in-cone structure. The Colorado and Claggett are so similar in lithologic character that they were not differentiated in this area, the chief distinction between them being the absence of sandy phases in the Claggett and its greater plasticity when wet, less fissile character, and slightly lighter color. The two formations can, perhaps, be accurately differentiated in this area only by a careful study of their contained fossils.

JUDITH RIVER FORMATION.

The Claggett is overlain by sandstone and shale of marine origin, which correspond stratigraphically to the fresh-water Judith River formation farther west. This formation consists of two massive sandstones, separated by an intervening shale, having a total thickness at the head of Porcupine Creek of about 125 feet. Below this there is a sandy transition zone to the typical dark shale of the underlying Claggett. The upper 200 feet of the Vananda well log represents this formation; whether it represents all of the formation or only a part of it is not positively known, but the writer is of the opinion that only a part of the Judith River formation is represented in the well record. If this opinion is correct the formation is either considerably thicker at Vananda than in the area in which it was mapped, or the transition zone to the Claggett has been interpreted by the driller as consisting largely of sandstone.

BEARPAW AND LANCE FORMATIONS.

The Judith River is overlain by the Bearpaw shale, which has the same physical and lithologic characters as the Claggett. The Bearpaw is succeeded by sandstone and shale of the Lance formation, which are of fresh-water origin.

IGNEOUS ROCKS.

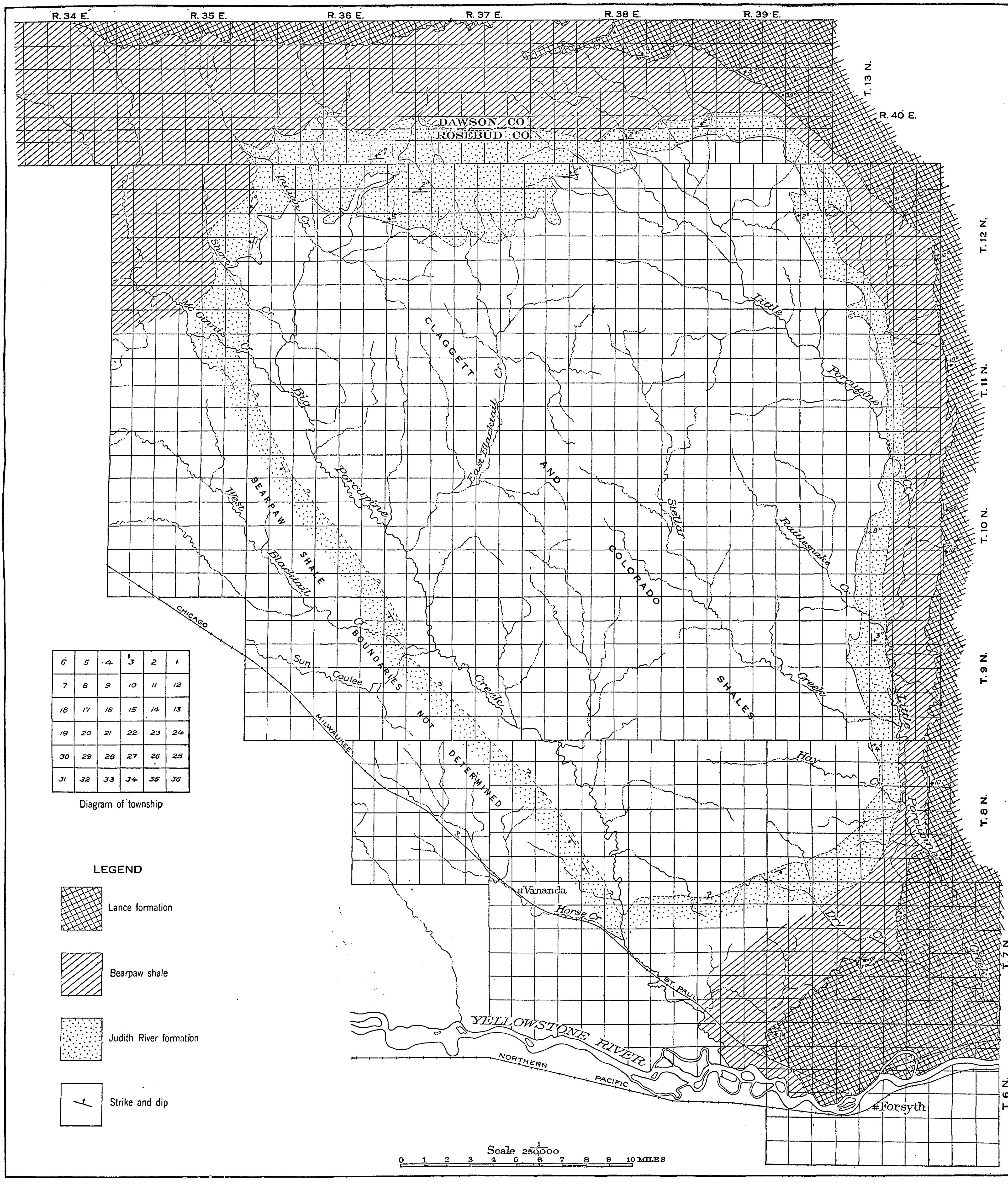
A vertical dike about 9 feet thick and half to three-quarters of a mile long occurs on the top of the divide west of Stellar Creek, probably near the north boundary of T. 10 N. The dike is a reddish-brown vesicular rock containing small flakes of biotite, a considerable proportion of calcite, and numerous inclusions of black shale, the largest of which is more than 2 inches in longest diameter. In the thin section this rock is seen to be so thoroughly altered that its original character can not be determined. The matrix consists almost wholly of calcite and ferritic material in which occur blades and flakes of biotite and an occasional small cryptocrystalline phenocryst having about the index of refraction of quartz or feldspar. This is the only occurrence of igneous rock noted.

STRUCTURE.

The dominant structure of this area is that of an elongate, roughly triangular dome whose outline is indicated by the inner margin of the Judith River formation. Within that margin the dome has a maximum north-south diameter of about 33 miles and a maximum east-west diameter of 27 miles. Along the east and north sides of the dome the Judith River formation dips away from the axis of uplift at angles ranging from 1° to 8°, the steeper dips being on the east side. The dips on the west side of the dome have not been accurately determined, but are thought to range from 1° to 4°, except perhaps locally. Minor folds, such as are known to occur farther out in the surrounding plains, may also exist within the domed area, but details of this character have not been worked out.

FACTORS CONTROLLING THE ACCUMULATION OF OIL AND GAS.

For the accumulation of oil and gas there must be (1) a competent source of supply; (2) a proper receptacle for their accumulation and retention; and (3) structural conditions permitting their concentration into a small area (a so-called "pool") from their originally disseminated condition in the rocks in which they originated.



MAP OF THE PORCUPINE DOME, ROSEBUD COUNTY, MONT.

With regard to the source of supply it may be stated, without entering into a discussion of the origin of oil or gas, that they are found in commercial quantities only in sedimentary rocks and probably originated from organic matter entombed within the strata at the time of their deposition. There is also a vague but general impression among geologists that much of the oil and gas now found in pools has been derived from shale, though it is also recognized that fossiliferous limestone and possibly sandstone are also adequate sources of supply.

The presence of oil or gas in the rocks may be indicated at the surface by the occurrence of oil seeps or springs, gas emanations, asphaltic deposits, or rocks impregnated with bituminous matter or emitting a petroliferous odor. The existence of any or all of these surface indications does not demonstrate that oil and gas occur in commercial quantities, as such indications are known in regions which on development have proved to be unproductive. On the other hand, lack of surface indications is by no means conclusive proof that oil and gas do not occur; many of the most productive pools furnish no surface evidence of the existence of oil or gas. It may be laid down as a fundamental principle, therefore, that the existence of oil or gas in commercial quantities can be demonstrated only by the drill.

As originally formed in the parent rock, whatever its character, oil and gas exist in a widely diffused state, and in order to be available for commercial use they must be collected into local areas called pools. That this condition may be realized, a proper receptacle must be available for their accumulation and retention. Such a receptacle consists of a porous medium (sandstone, porous limestone, or fractured shale), hermetically sealed above by some relatively impervious body, such as a bed of shale or clay or a water-saturated stratum.

The existence of a proper receptacle may be ascertained by a surface study of the formations, if these are exposed within or adjacent to the area under investigation, provided the formations or their individual members are continuous in extent. On the other hand, if the beds are lenticular, a surface study of the formations may be of little value in determining the existence of porous members or the depth at which they may be encountered in any particular locality. In such areas the required information, like that regarding the occurrence of the oil, can be obtained only by drilling.

The structural conditions under which gas and oil accumulate are manifold, but in this discussion the simplest conditions are assumed, namely, that the structure is regular and that the oil rock is homogeneous, of continuous extent, and overlain by an impervious cover. Perhaps the only definite statement possible is that oil or gas do not generally accumulate in commercial quantities in strata which are perfectly flat. In order for concentration in commercial quantities to be accomplished, it seems necessary that the strata shall have been flexed, tilted, or folded in some manner. The structural forms which experience has shown to be most favorable are domes, anticlines, terraces, monoclines, synclines, and fissures, named perhaps in the order of their value.

The structural position of gas and oil pools seems to depend largely on the character of the strata, the presence or absence of water, and the character of the oil. Of these factors the degree to which the receptacle is saturated with water seems to be of first importance. Experience has demonstrated that the following statements generally hold good: (*a*) If the strata are saturated with water, the gas and oil, being the lighter, will be forced to the highest available point, and will therefore occupy the crests of domes or anticlines. (*b*) These conditions, however, will be modified if the strata, instead of having a regular dip from the apex to the margins of the dome or anticline, descend irregularly, producing a steplike or "terraced" structure. In this event the oil and gas will be likely to accumulate on the flats or terraces. (*c*) If the receptacle is only partly saturated with water, the oil and gas will occur on the limbs of folds at the upper level of saturation. (*d*) If the strata are dry, the oil and gas will migrate to the lowest available point of the receptacle—that is, to the axis of the syncline, the terraces of a monocline, or the limb of a fold, or to a point where further downward migration is prevented by some other cause. (*e*) If both oil and gas are present in the same stratum, the gas, being the lighter, will usually though not invariably be found above the oil.

Factors tending to modify the above statements are lenticularity of the receptacle, its varying degrees of porosity, variations in the viscosity and specific gravity of the oil, the readjustment of the water level since the accumulation of the oil and gas into pools, subsequent tapping of the pools either by fracturing or erosion, which may allow the accumulated material to dissipate slowly into the air or surrounding strata, and possibly variations in the direction and degree of movement of water in the rocks.

Stated in another way, under the influence of gravity alone oil would migrate to the lowest point of the porous stratum, but as the effect of gravity is modified by the above-named factors the oil collects at the lowest available point, whether this be the axis of an anticline or syncline or some intermediate position.

In applying the foregoing principles to the area under discussion the following facts may be stated: (*a*) There are no known surface indications (oil seeps, gas emanations, asphalt deposits, or strata impregnated with bitumen or emitting bituminous odor) of oil or gas in the area. (*b*) The structure consists of an elongate dome having a north-south extent of about 35 miles and a maximum east-west extent of 25 miles. Around the periphery of the dome the strata, so far as examined, have regular and rather uniform dips of 1° to 8°; at the crest of the dome they are probably almost flat. (*c*) Sandstones which might have been utilized for the accumulation of oil and gas, if such substances were present in the surrounding rocks, occur in the Judith River formation (now eroded from the center of the dome), near the base of the Colorado shale, and in the underlying Kootenai (?). (*d*) Save for the Vananda well this field is entirely undeveloped.

From these facts the following inferences may be drawn: (*a*) The lack of surface indications of oil and gas suggests strongly that these substances do not occur in the Judith River formation, which is exposed at the surface, but is no proof of their presence or absence at the base of the Colorado or in the underlying Kootenai (?), as these formations lie at depths of 2,100 to 2,300 feet below the top of the Colorado shale and probably about 1,500 or more feet below the crest of the dome. (*b*) In so far as the structure alone is concerned, it is favorable for the accumulation of oil and gas into pools. (*c*) The sandstones of the Judith River formation are not probable receptacles of oil or gas, as these sandstones are well exposed in the field and show no indications of the presence of any bituminous substance. (*d*) Oil or gas may or may not occur in the sandstones at the base of the Colorado and in the underlying Kootenai (?). Sandstones at similar stratigraphic positions are oil bearing in Wyoming. The Colorado shale is the chief source of oil in the Salt Creek, Bighorn Basin, and southwestern Uinta County fields and contains small quantities in the Douglas, Moorcroft, and Lander fields. Sandstones underlying the Colorado, ranging in age from Morrison to Dakota and therefore in the approximate position of the Kootenai (?), contain small quantities of oil in the Bighorn Basin, Powder River, Douglas, and Moorcroft fields. But these formations are not known to be oil bearing in Montana, although gas has been found in the Pierre shale near Glendive. (*e*) The failure of the Vananda well to encounter oil or gas (so far as the record available to the writer indicates) does not conclusively demonstrate the absence of these substances, because the Vananda well is on the southwest flank of the dome and so far as known is not on a structural terrace or other irregularity. In dry rocks, therefore, such as the sandstone at the 3,050-foot level, the oil if present would be likely to accumulate farther down the slope; whereas in saturated rocks, such as the sand at the 3,200-foot level, oil if present would be more likely to accumulate farther up the slope, at the top of the water level.

Opposed to the favorable structural and stratigraphic conditions and the presence of formations known to be oil bearing in other regions is the fact that not a single promising occurrence of oil is known in the State. In fact, with a few exceptions, not even traces of oil have thus far been discovered. This is largely true also regarding gas, though indications of gas are more numerous than those of oil, and it is reported that gas was encountered in considerable quantity in the well put down by the Northern Pacific Railway Co. near Glendive.

The apparent scarcity of oil and gas in Montana may be due in part to lack of proper and adequate exploration, but it may also be due to the absence of these substances in the strata.[1]

CONCLUSIONS.

The presence or absence of oil or gas in the Porcupine dome field can be demonstrated only by thorough and systematic exploration with the drill. The only positive statement that can now be made regarding their possible occurrence is that the structural and stratigraphic conditions are favorable for their accumulation. The most promising place, in the opinion of the writer, for testing the field is near the crest of the uplift; that is, on the divide between Porcupine and Little Porcupine creeks, probably in Tps. 10 and 11 N., R. 38 E., because the underlying sandstones come nearest to the surface there and because the water encountered in the sandstone 3,200 feet below the mouth of the Vananda well is believed to saturate that stratum, and would therefore force the oil and gas, if present, to the crest of the anticline. The mouth of the Vananda well has an altitude of 2,704 feet above sea level. As the water encountered in the sandstone at the 3,200-foot level rose within 50 feet of the surface, the water level in this sandstone is about 2,650 feet above the sea, and hence if oil occurs in the sandstone it would be expected to occur at or below that level. Nothing is known of the attitude of the rocks so far below the surface, but if they are approximately parallel to those at the surface, it is probable that the water-bearing sandstone does not reach an altitude of much more than 2,650 feet in any part of the dome; therefore it is a fair inference that the water-bearing sandstone is completely saturated with water, and if it contains oil or gas they will be found at the crest of the sandstone and near its upper surface. For this reason it is advisable to drill near the axis of the dome, which, as suggested above, is probably in Tps. 10 and 11 N., R. 38 E. It can not be emphasized too strongly that the existence of oil or gas in this field is at present merely conjectured from the favorable structure and the fact that formations of the same age and character as those represented here are known to contain oil in other places. Under these circumstances nothing but systematic and intelligent exploration should be undertaken and all haphazard ventures should be discouraged, at least until some conclusive results have been obtained.

[1] About the time this report went to the printer gas was obtained in a well at Havre. This development has been examined by a geologist of the Survey, and a report on it is in preparation.