69TH CONGRESS 1st Session | HOUSE OF REPRESENTATIVES | DOCUMENT No. 91

DEPARTMENT OF THE INTERIOR
Hubert Work, Secretary

U. S. GEOLOGICAL SURVEY
George Otis Smith, Director

Bulletin 786

# CONTRIBUTIONS TO ECONOMIC GEOLOGY

(SHORT PAPERS AND PRELIMINARY REPORTS)

1926

## PART II.—MINERAL FUELS

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1927

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[The letters in parentheses preceding the titles are those used to designate the papers for advance publication]



# ILLUSTRATIONS

# CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1926

## PART II. MINERAL FUELS

# THE GEOLOGY OF THE INGOMAR ANTICLINE, TREASURE AND ROSEBUD COUNTIES, MONTANA

By K. C. HEALD

## INTRODUCTION

*Field work.*—The data presented in this report are based on field work by K. C. Heald and W. W. Rubey in October, 1922. Division of mapping by the two observers is indicated on the small diagram on Plate 1. The observers worked singly, determining locations and altitudes by triangulation. Outcrops of certain beds were traced continuously, so far as this was possible.[1] Geologic structure was determined by means of numerous observations of altitude on beds of known stratigraphic position, supplemented by dip and strike observations, which, wherever the method seemed justified, were made by determining relative position and altitude of three points on single beds with outcrops 10 feet or more in extent. Where maximum dips could not be certainly observed components of the dips were recorded and used in determining the structure.

*Acknowledgments.*—The writer takes pleasure in acknowledging his indebtedness to the Absaroka Oil & Development Co. for information furnished through the company's chief geologist, Mr. A. A. Hammer, and to Mr. Darwin Harbicht, of Ingomar, whose knowledge regarding conditions in the Ingomar region greatly facilitated and expedited the geologic work.

*Publications with a bearing on the Ingomar area.*—The only publications dealing specifically with the Ingomar area are a short notice issued to the press August 1, 1921, by the United States Geological Survey giving the results obtained in a brief examination of the Ingomar anticline made in June, 1921, by W. T. Thom, jr., and C. E. Dobbin, of the Geological Survey; and University of Montana Bulletin 4, by C. H. Clapp, Arthur Bevan, and G. S. Lambert, dealing with the geology and oil and gas prospects of cen-

[1] The relative stratigraphic position of these beds is indicated on Plate 1 by arbitrarily chosen numbers, No. 1 indicating the lowest bed, and so on.

tral and eastern Montana, published in June, 1921. The press notice was accompanied by the only map showing the geologic structure of the anticline which has, to the writer's knowledge, been published. Neither of the papers mentioned describes in detail the stratigraphy of the area.

C. F. Bowen, in Bulletin 621 of the United States Geological Survey, published in 1916, and also in Professional Paper 125, gave details of stratigraphy observed in the Porcupine dome, a few miles to the east. Certain stratigraphic details mentioned in Geological Survey Bulletin 611, "Guidebook of the western United States, Part A," published in 1915, also relate to this region. The descriptions of the Judith River formation and discussions dealing with its character and correlation may with advantage be read by any geologist who contemplates work in this area, both because the observed details may be of help to him and because he is more likely in turn to observe something that will be a contribution to knowledge regarding the Judith River formation if he is thoroughly acquainted with previous ideas regarding its character, correlation, source, and conditions of deposition. Among works of this nature are those cited below:

Hatcher, J. B., Relative age of the Lance Creek beds of Converse County, Wyo., the Judith River beds of Montana, and the Belly River beds of Canada: Am. Geologist, vol. 31, p. 369, 1903.

Stanton, T. W., and Hatcher, J. B., The stratigraphic position of the Judith River beds and their correlation with the Belly River beds: Science, new ser., vol. 18, p. 212, 1903.

Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River Beds: U. S. Geol. Survey Bull. 257, 1905.

Peale, A. C., On the stratigraphic position and age of the Judith River formation: Jour. Geology, vol. 20, pp. 350–549, 640–652, 738–757, 551–557, 652–669, 741–761, 1912.

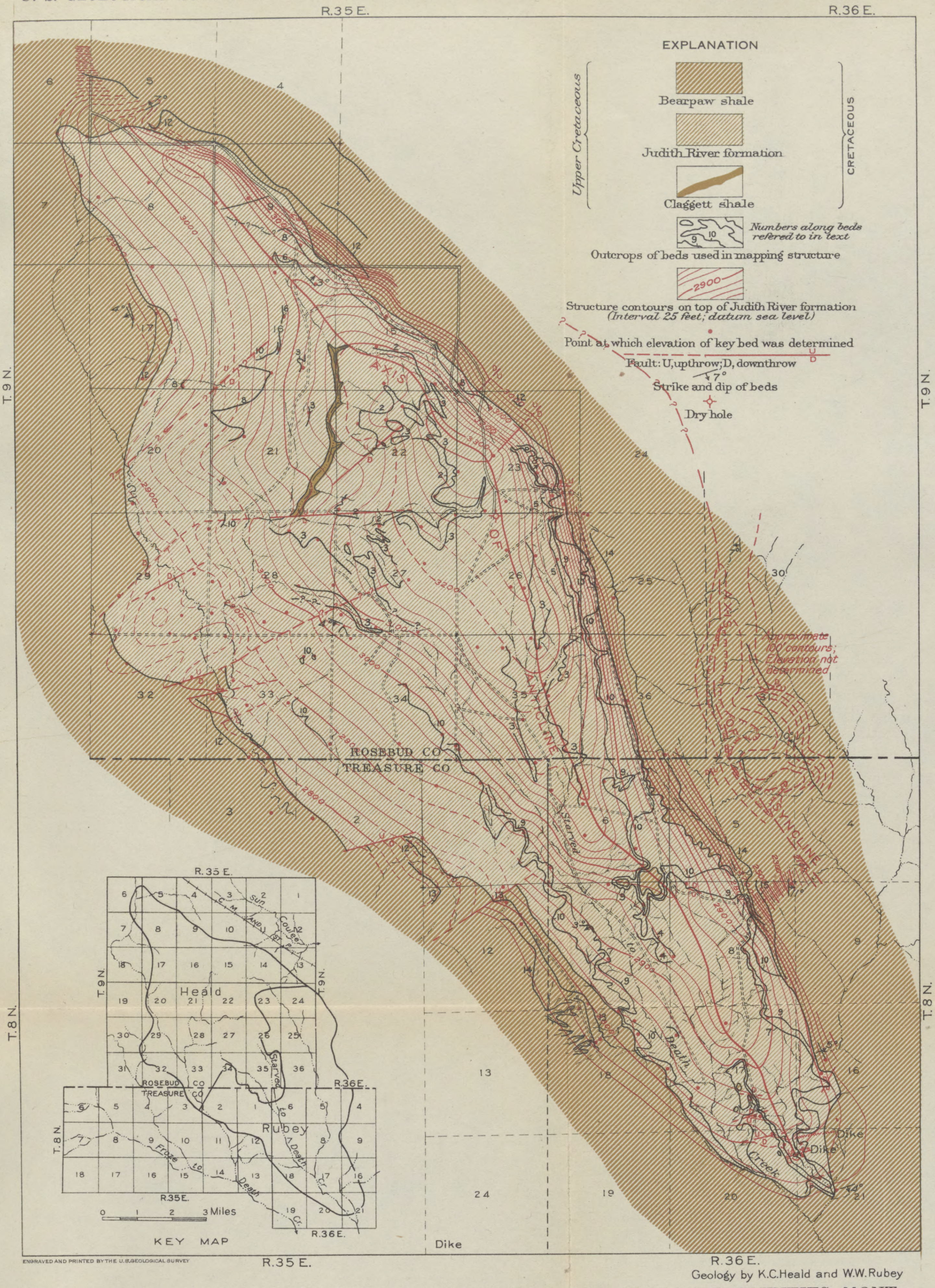
Bowen, C. F., Possibilities of oil in the Porcupine dome, Mont.: U. S. Geol. Survey Bull. 621, pp. 61–70, 1916.

Bowen, C. F., Gradation from continental to marine conditions of deposition in central Montana during the Eagle and Judith River epochs: U. S. Geol. Survey Prof. Paper 125, pp. 11–21, 1919.

Hancock, E. T., Geology and oil and gas prospects of the Huntley field, Mont.: U. S. Geol. Survey Bull. 711, pp. 105–148, 1920.

## GEOGRAPHY

*Location.*—The Ingomar anticline lies in T. 9 N., R. 35 E., and T. 8 N., Rs. 35 and 36 E. Montana principal meridian, Rosebud and Treasure Counties, Mont. (See fig. 1.) The anticlinal fold passes beyond the boundaries of the townships named, but that part which is of interest in connection with the possible occurrence of oil or gas falls within their limits. The nearest town is Ingomar, on the Chicago, Milwaukee & St. Paul Railway, about 1¼ miles northwest




GEOLOGIC MAP OF THE INGOMAR DOME, ROSEBUD AND TREASURE COUNTIES, MONT.

Scale $\frac{1}{63,360}$

1 0 1 2 MILES

of the northwesternmost outcrop of Judith River sandstone brought up by the anticline, and only a little more than half a mile north of the axis of the anticline, which there trends northwestward across an area of Bearpaw shale.

*Roads.*—Supply points for drilling activities on the anticline are the town of Ingomar and the flag station of Thebes, about 6 miles east of Ingomar. The Electric Highway, which passes through Ingomar and skirts the northwest flank of the anticline for about 3 miles, is an excellent automobile road for dry-weather hauling. During wet weather the Bearpaw shale, over which this highway is in part constructed, forms a very sticky mud on which heavy hauling is almost impossible. Therefore if it becomes desirable to do

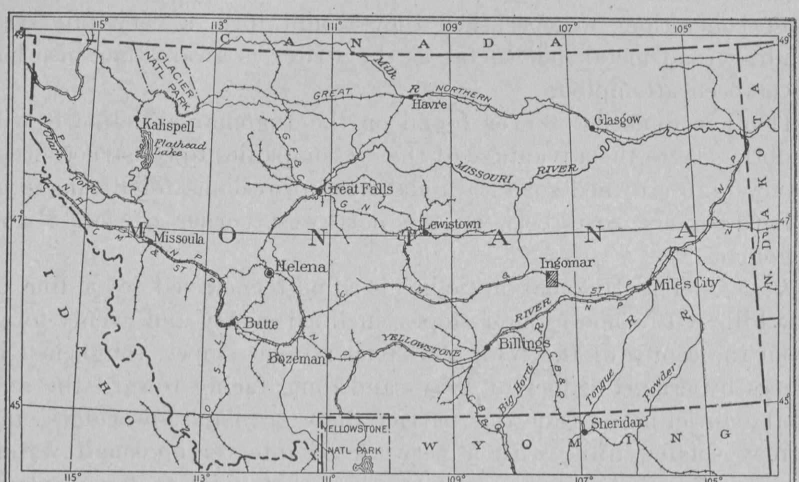



FIGURE 1.—Index map showing location of Ingomar anticline, Treasure and Rosebud Counties, Mont.

much hauling when such weather conditions prevail it will probably be desirable to construct a road diagonally from the northwest to the southeast corner of sec. 8, T. 9 N., R. 35 E., thence follow the highway east along the south line of sec. 9, leave the highway at the southeast corner of sec. 9, and follow the crest of the hogback made by the upper sandstone beds of the Judith River formation. Such a road would be upon sand or sandstone all the way from the northwest corner of sec. 8 and should be passable in almost any weather. In the area where the Judith River is the surface formation it should be possible to lay out roads to reach almost any point at any time of the year. Such roads should detour to avoid outcrops of the bentonitic shales that form a part of the middle member of the Judith River. These bentonitic shales cover small areas in secs. 15, 16, 21, 22, and 27, T. 9 N., R. 35 E., and in the bottoms of some of the deeper valleys, as in sec. 8, T. 8 N., R. 36 E.

The road between the northwest corner of sec. 8, T. 9 N., R. 35 E., and Ingomar runs over Bearpaw shale and must be surfaced if it is to be made passable during wet weather. No alternate route that may be selected will obviate this difficulty, nor is there an easily accessible source of surfacing material. The sandstone beds of the Judith River and Lance formations crumble into incoherent sand under traffic, and there are no limestones or siliceous shales in either the Bearpaw shale or the Judith River formation. Experiments with the heavy limestone concretions of the Bearpaw shale to test their suitability for road surfacing are desirable. There are zones in the Bearpaw shale where these concretions lie almost in contact with one another over wide areas. It has been suggested that if these concretions were crushed they would form a very fair self-binding road metal, but so far as the writer is aware their use has never been attempted.

If oil in quantity is ever found on the Ingomar anticline it will doubtless be to the advantage of the oil companies to construct either a very high crowned road with elaborate provisions for drainage or a hard-surface road between the northwest corner of sec. 8 and Ingomar.

*Relief*.—The Ingomar anticline is almost encircled by a line of low hills with smooth outer slopes, inclined gently and evenly away from the center of the fold, and steeper inner slopes, roughened in places by craggy ledges of gray sandstone, facing toward the axis of the anticline. Inside this barrier there are flats, low ridges, and a few isolated hills, with a network of intervening small water-courses, dry except during wet weather, that unite to form valleys that break through the encircling wall of hills and connect with the main drainage channels of the region.

Differences in altitude between hill crest and valley bottom in the vicinity of the anticline are probably everywhere less than 200 feet and throughout most of the region are less than 100 feet. In fact, were it not for the gullies with their steep walls, it would be possible to drive a car almost anywhere in the region except up the steep face of the hills that encircle the anticline and over some hills inside this rim where heavy ledges of sandstone have induced the development of steep slopes and low cliffs.

Almost everywhere throughout the Ingomar region the character of the surface indicates accurately the character of the rocks that underlie it. Ridges are without exception due to the presence of the more resistant rocks. Thus the line of hills that encircle the anticline is due to thick beds of sandstone in the upper part of the Judith River formation. Ridges farther from the axis of the fold are due to zones in the Bearpaw shale that contain many concretions of limestone and of siderite. The low conical hills apparently occur only where concretions in the Bearpaw shale are particularly numerous. Broad, smooth slopes are developed on the tops of inclined beds of sandstone or of zones of concretions in the shale. Most of the flats that are not in valley bottoms signify that the underlying rocks are flat-lying or nearly so, although a few miles from the anticline there are remnants of a smooth upland surface that probably extended over the Ingomar region before the vigorous cutting that produced the present topography began.

Figure 3, a sketch profile across the anticline, gives an idea of the way the geologic structure is indicated by the topography.

*Drainage.*—The Ingomar region is drained by the Yellowstone River system, to the south, through Froze to Death and Starved to Death Creeks and their tributaries. Small valleys and draws that feed the major streams have been formed so extensively both over and around the anticline that, except for a few very small wind-scooped hollows, there are no undrained areas.

*Water supply.*—There are no permanent streams in or near the Ingomar anticline, although pools of water stand in the beds of Froze to Death Creek and its large tributaries except in very dry years. Water for human consumption and for stock is obtained from a number of never-failing springs supplemented by wells within the rim of hills that encircles the anticline. There are a few springs in the Bearpaw shale outside this line of hills, and a few wells that have yielded water have been dug or bored in this shale, but such springs and wells almost invariably yield water unfit for human consumption, and some of the spring water is also unfit for stock because of its mineral content. The high mineral content renders the Bearpaw water unsuitable for use in boilers.

Springs and wells inside the rim of hills that inclose the anticline obtain their supply from the Judith River and Claggett formations. The best water seems to come from thick sandstones in the upper part of the Judith River formation, but water from silty sandstones near the middle of the formation is also potable, although, to judge from the deposits near springs, it has a greater mineral content than the water higher in the formation. The water in the uppermost sandstone bed of the Claggett formation appears to be both less in amount and poorer in quality than waters from the Judith River beds.

Supplies ample for use in oil-well drilling can be developed at any one of a number of springs or wells. The water for the Absaroka Oil & Development Co.'s test well in sec. 26, T. 9 N., R. 35 E., was pumped from a spring in sec. 23, T. 9 N., R. 36 E.

It seems probable that water suitable for both domestic and industrial purposes could be obtained in the area where the Bearpaw shale crops out by drilling to the Judith River formation, which should lie less than 1,500 feet below the surface anywhere between the Ingomar anticline and the Porcupine dome.

*Culture.*—The only settlement with more than one of two families near the Ingomar anticline is the town of Ingomar, which has a population of about 200. Although small, it is a shipping center of importance to the sheep industry, which is highly developed in the surrounding region, and of less importance as a shipping point for cattle. Dry-land farming has been attempted with discouraging results wherever the Judith River formation is at the surface. Elsewhere the clays of the Bearpaw formation yield a lean soil that is apparently not suitable for raising crops. Most of the area has been homesteaded and either is or was at one time privately owned, but crop failures, low prices for the produce that was raised, and high costs of machinery and living necessities have combined to drive the owners from the land, so that now abandoned houses are characteristic features of the landscape.

*Fuel.*—The Ingomar anticline and the region immediately surrounding it are practically bare of trees. Even the sagebrush is stunted on much of the upland area, although in some of the valleys it grows luxuriantly. Wood for fuel must be hauled many miles from the pine-bearing outcrops of the Lance and Fort Union formations. Coal would naturally be used for fuel in any extensive drilling operations. Coal is mined near Roundup, only about 70 miles from the town of Ingomar, so there should be little difficulty in obtaining an adequate and fairly cheap supply. A showing of gas encountered at about 520 feet in the well drilled by the Absaroka Oil & Development Co. encourages a hope that gas enough for drilling may be found somewhere on the anticline.

## STRATIGRAPHY

### ROCKS EXPOSED

The rocks exposed on and adjacent to the Ingomar anticline are sedimentary shales and sandstones of Cretaceous age and a few dikes of igneous rock. Most of the sediments are of marine origin, but a few were formed where the water was brackish, and others were probably deposited by streams. Three formations are exposed in whole or in part on the anticline—the lower part of the Bearpaw shale, which consists of clay shale with thin streaks of bentonite, limy concretions, and very thin, discontinuous layers of sandstone; the Judith River formation, which comprises sandstone and shale with a little bentonite; and the uppermost part of the Claggett shale, which appears to be represented on the Ingomar anticline by a soft, massive sandstone. The igneous rock in the dikes is a porphyritic lamprophyre. To the southwest of the Ingomar anticline the Bearpaw shale is overlain by the Lance formation, of Tertiary (?) age.

Over most of the area the outcrops of the Judith River and Claggett formations can be easily distinguished from those of the Bearpaw, for the Judith River and Claggett tend to produce hilly surfaces with sandy soil, in contrast to the smooth flats, ridges, and conical hills covered with clay soil that are characteristic of the Bearpaw exposures, but in a few places, notably on the west flank of the Ingomar anticline, where the rocks lie almost flat, the surfaces underlain by the Judith River and Bearpaw formations are so similar that it is difficult to say where one formation stops and the other begins.

### BEARPAW SHALE

The Bearpaw shale surrounds the Ingomar anticline and crosses its axis in sec. 21, T. 8 N., R. 36 E., and sec. 6, T. 9 N., R. 35 E. Near the south end of the anticline there are a few small outliers that cap low hills. Elsewhere it has been stripped from the anticline. There is no sharp line of division between the Bearpaw and the underlying Judith River formation—in fact, a collection of brackish-water fossils obtained from a sandstone near the top of the beds mapped as Judith River was considered by Reeside[1] a Bearpaw rather than a Judith River fauna. The boundary mapped between the Bearpaw and Judith River formations is a convenient lithologic dividing line, but it is probably not the precise boundary for the highest mappable sandstone bed (the one containing the Bearpaw fossils) was considered the uppermost bed of the Judith River formation. The contact between the Bearpaw shale and the overlying Lance formation was neither mapped nor studied.

The thickness of the Bearpaw shale was not measured in this field work, although it was determined at more than 600 feet. Bowen[2] states that on the Porcupine dome, to the east, it is 900 to 1,100 feet, while Woolsey, Richards, and Lupton[3] believed it to be more than 1,000 feet in the Bull Mountain coal field to the west. It therefore seems reasonable to ascribe a thickness of about 1,000 feet to the formation in the vicinity of the Ingomar dome.

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[1] Personal communication.

[2] Bowen, C. F., Gradations from continental to marine conditions of deposition in central Montana during the Eagle and Judith River epochs: U. S. Geol. Survey Prof. Paper 125, p. 12, 1920.

[3] Woolsey, L. H., Richards, R. W., and Lupton, C. T., The Bull Mountain coal field, Musselshell and Yellowstone Counties, Mont.: U. S. Geol. Survey Bull. 647, p. 18, 1917.

Probably 95 per cent or more of the entire thickness of the formation is shale, deposited under marine conditions. The remaining 5 per cent consists of limestone and siderite in the form of concretions and bentonite in layers 2 feet or less thick. The concretions occur in bands or zones, some of which may be traced for miles, although most of them are probably much less persistent. Some of these concretions are distinctive in color, size, or shape. For instance, one band of closely spaced reddish-brown concretions, none of which appeared more than 2 feet in diameter, was noted. Another band of concretions near the Judith River-Bearpaw contact contained fragments of fossil plants. Others were notable for the abundance and perfect preservation of the fossils that occurred in them. No characteristics were noted that could be relied upon for positive identification, but there were several that aided continuous tracing of concretion-bearing layers in the shale.

Although generally similar throughout, in detail the shale that makes up the Bearpaw is uniform in neither appearance nor composition. Much of it is massive, without easily detected bedding planes, but there are also layers of brown to dark-gray fissile shale that, at least in places, is carbonaceous. These layers of fissile shale are particularly important in geologic work, because they can be traced without great difficulty, and they exhibit definite bedding planes on which determinations of dip and strike can be made. In spite of the great thickness of the Bearpaw shale in this district there is little doubt that by careful work thin members of it can be traced with sufficient precision to determine the structure of the area in which it forms the surface rock.

The stratigraphic section given below is a composite of several partial sections and probably contains minor inaccuracies, although it is believed that the measurements are fairly accurate.

*Section of Bearpaw shale on the flanks of the Ingomar anticline*

| | Feet |
|---|---|
| Top, somewhere in Bearpaw shale. | |
| Shale, light brownish gray, massive, littered with chips of light-gray calcareous concretions that carry many fossils including *Inoceramus* and *Baculites* | 12 |
| Brownish-gray massive shale without concretions | 34 |
| Dark-gray fissile shale; breaks into thin plates | 19 |
| Shale, medium brownish gray, massive. At the top occurs an irregular line of small concretions, about 1½ inches in diameter and three-fourths inch thick, brownish gray on weathered surface, light gray on fresh surface. A fragment of a large cephalopod was found at this horizon. At the base of this shale band is a bed of bentonitic material about 2 feet thick that may be either ocherous or greenish, and contains needles of selenite | 18 |

| | Feet |
|---|---|
| Two lines of concretions with interbedded shale. The concretions are dove-gray on weathered surface, dark gray on fresh surface. They contain fragments of large *Baculites*. The interbedded shale is gray and fissile | 6 |
| Shale, massive, light brownish gray on weathered surface | 13 |
| Shale, massive, medium brown to dark brown on weathered surface. At the top of this layer is a line of calcareous concretions, dark gray to brownish on weathered surface, about 2 feet in greatest dimension and an inch or less thick | 14 |
| Poorly exposed. Contains some fissile dark-gray shale, but most of the interval is occupied by massive brownish-gray shale with a few inconspicuous layers of concretions and some thin bands of bentonite | 190 |
| Shale, light to medium brownish gray, massive. At the top is a zone of concretions, light to medium gray on fresh surface, dove gray to grayish brown on weathered surface. Individual concretions average about 2½ feet in diameter and 1 foot thick. No fossils were found | 38 |
| Shale, most of thickness massive, but some fissile shale near top. Massive shale is brownish gray; fissile shale light gray. At the top of the shale are concretions, dove-gray on fresh surface, with thin bands of dark aragonite and honey-yellow calcite, from 1 to 2 feet in diameter and about 1 foot thick. Contains a few pelecypods | 38 |
| Shale, poorly exposed. Most of it is massive and light brownish gray. Discontinuous line of concretions at top, grayish brown on weathered surface, dark gray on fresh surface; average about 1 foot in diameter | 68 |
| Shale, fissile, light gray to purplish brown, with one or more thin beds of bentonite associated. At the top is a zone of concretions that weather grayish brown but are dove gray on fresh surface. Concretions contain veins of honey-colored calcite and also some pelecypods | 20 |
| Shale, massive and brownish gray near top, more fissile near bottom. At the top of this shale is a layer of very ferruginous concretions, 1 to 3 feet in diameter and perhaps as much as 1 foot thick. The concretions are cut by veins of yellow calcite and contain a very few small pelecypods | 50 |
| Judith River formation. In some places soft gray sandstone, in others brown carbonaceous shale is in contact with the Bearpaw. | |

The oil geologist may be interested in the detail of the Bearpaw shale in this region, as there are large areas where it is the only surface formation, and he must have a knowledge of these details to be able to interpret the structural conditions correctly. He may also be interested in the fact that the basal part of the Bearpaw shale was evidently laid down in shallow water near shore, and that this basal part contains some beds of shale that appear rich in organic matter, suggesting that they may be a source of oil or of gas where conditions of cover, water circulation, and structure are favorable.

### JUDITH RIVER FORMATION

The Judith River formation in the Ingomar area is exposed only over the crest of the anticline where it occupies an oval area about 10 miles long and 3½ miles wide in T. 9 N., R. 35 E., and T. 8 N., Rs. 35 and 36 E. It is overlain on the flanks of the anticline by the Bearpaw shale. The contact between the two formations is not sharp, and the boundary adopted for mapping is paleontologically doubtful.

The age of the Judith River formation in this region is revealed by its relation to the Bearpaw shale, which immediately overlies it and which can be traced continuously to areas where its age has been established by previous work. Fossil collections gathered from both the Bearpaw and the Judith River formations on and near the Ingomar anticline leave no doubt as to the correctness of the general formation identifications, even if the relations of the Bearpaw and Judith River and the similarity of the Judith River formation in the Ingomar region to the same formation in near-by areas were not in themselves conclusive.

The thickness of the formation on the Ingomar anticline is about 245 feet. The figure was obtained by combining many measurements, each covering a part of the formation. There are undoubtedly local variations in thickness, but the figure given is an average that is believed to be within 20 feet of the thickness on any part of the anticline. It shows that the formation is more than twice as thick as it is on the Porcupine dome, where Bowen[4] measured a section about 20 miles north and a little east of the Ingomar anticline, for he records thicknesses of 115 feet in sec. 8, T. 12 N., R. 38 E., and 125 feet "near head of Big Porcupine Creek," and in both measurements he includes a basal sandstone that probably corresponds to a sandstone that on fossil evidence has been mapped as Claggett in the Ingomar area.

The formation falls naturally into two divisions—an upper sandy member about 85 feet thick, and a lower member that is also sandy but that contains thick beds of shale, in all about 160 feet thick. The underlying Claggett has at its top a sandstone that might be included in the Judith River because of similarity in lithology and absence of any detectable erosional break at its upper surface, but the fossil evidence shows it to be Claggett. Seemingly it corresponds to a sandstone that was included in the Judith River formation in the Lake Basin and Huntley area by Hancock,[5] who says,

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[4] Bowen, C. F., Gradations from continental to marine conditions of deposition in central Montana during the Eagle and Judith River epochs: U. S. Geol. Survey Prof. Paper 125, p. 15, 1920.

[5] Hancock, E. T., Geology and oil and gas prospects of the Huntley field, Mont.: U. S. Geol. Survey Bull. 711, p. 121, 1920.

"The most resistant sandstone * * * is the one that seems to be the approximate equivalent of the upper part of the Claggett formation in its type area, but for convenience of mapping it is here treated as the base of the Judith River formation," and to a similar sandstone included in the Judith River in the Tullock Creek coal field by Rogers and Lee.[6]

*Upper member.*—The upper member is for the most part sandstone, but there are also some beds of shale, and in some places the upper sandstone beds seem to pinch out and give way to carbonaceous shale with one or more streaks of coal 2 inches or less thick. In other places massive sandstones grade laterally into thin sandstones with interbedded gypseous shales. The conditions are interpreted diagrammatically in Figure 2, and the appearance of

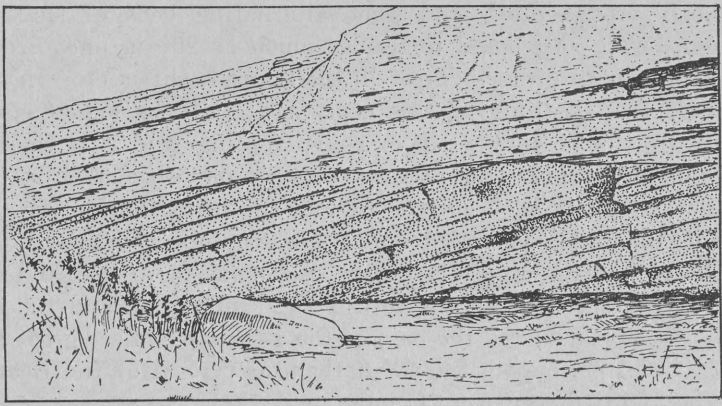


FIGURE 2.—Detail of cross-bedding in the upper part of the Judith River formation

different phases of the upper beds of the Judith River is illustrated in Plate 2.

These upper beds of the Judith River formation in this region appear to be delta deposits that were laid down along the margin of a shallow sea. Presumably the material was transported by sluggishly moving streams or by coastal currents, and part of it was dropped in brackish water, where the salinity of the sea was lessened by the rivers, while elsewhere fresh-water conditions prevailed. In such an environment there would be some swamps bordering lagoons and sounds where flourishing vegetation would result in the accumulation of carbonaceous shale and thin coal beds, but apparently conditions in the shallow sea did not favor the existence, or at least the preservation, of much carbonaceous or bituminous matter in the marine beds. Undoubtedly such accumulations gath-

[6] Rogers, G. S., and Lee, Wallace, Geology of the Tullock Creek coal field, Rosebud and Big Horn Counties, Mont.: U. S. Geol. Survey Bull. 749, pp. 13–16, 1923.

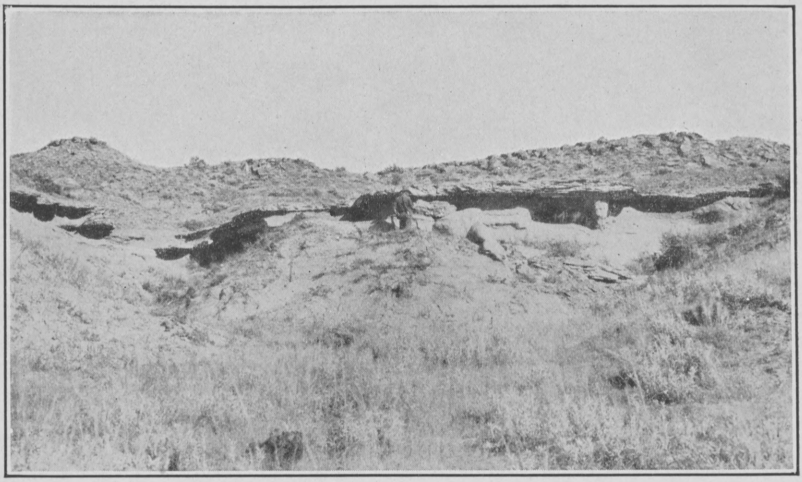
ered in local areas, and there black shales rich in bituminous matter will be now found in the basal part of the Bearpaw shale or in the Judith River formation, but such areas will probably be small.

The sandstones in the upper part of the Judith River formation are brownish gray or white on exposed surfaces and almost everywhere brownish gray on fresh surfaces. They are composed of quartz, feldspar, black chert, mica, and a very few other constituents. In places the feldspar content is so high that the rock might appropriately be classified as an arkose or graywacke. The chert may make up from 2 to 20 per cent of the rock. The micas, muscovite and biotite, although apparently present in every bed, are rarely conspicuous. The grains are small, and, as is common in fine-grained rocks, many of them are angular.

In places certain beds in the upper sandstone member are conspicuously cross-bedded, and some alternating beds of shale and sandstone were also noted to dip as much as 20° in one direction where the true dip was about 3° in the opposite direction. In small exposures cross-bedding of this type may easily be misinterpreted as true dip due to fault drag or sharp folding, and it is therefore important to recognize the presence of steep depositional dips. Casts of *Halymenites major* occur throughout the formation on the Ingomar anticline, and some beds contain great numbers of these nubbly, branching fossils. Other fossils are scarce except in the sandstones near the contact between the top of the sandy zone and the shale that has been considered the base of the Bearpaw, where great numbers of fossil pelecypods, many of them as typical of the Bearpaw as of the Judith River, were found.

The shales in the upper part of the Judith River formation range in color from brown to light gray. In places the gray shales are very sandy; the brown shales owe their color to limonite and to carbonaceous matter. Gypsum, in white powdery crystals, large colorless translucent crystals, and joint and fissure fillings, is common in all the shale beds. Bands of limonitic clay 2 inches or less in thickness are common and in places grade into material so limy that it may be classified as limestone. Near the top of the formation the carbonaceous shales contain a few very thin lenses of coal, which is of interest only in relation to the origin of the beds.

The upper member of the Judith River formation is well exposed in the SE. ¼ sec. 6 and at the southeast corner of sec. 15, T. 9 N., R. 35 E., and from the latter point southeastward along the ridge that marks the east flank of the anticline. The shale phase of the upper part of the Judith River is well exposed along the east section line in the NE. ¼ sec. 32, T. 9 N., R. 35 E. Other exposures of the brown carbonaceous shale near the top of the formation may



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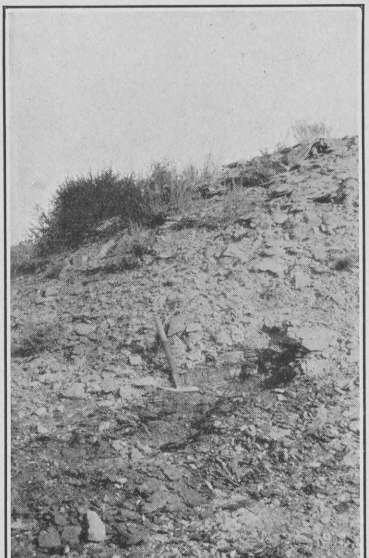

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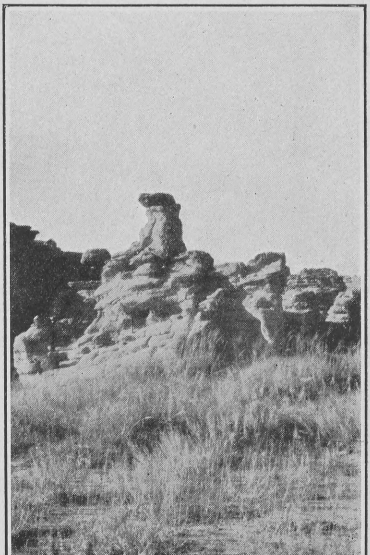

*C*

UPPER BEDS OF THE JUDITH RIVER FORMATION

be seen along the west flank of the anticline and at its north end in sec. 5, T. 9 N., R. 35 E.

*Lower member.*—The lower member of the Judith River formation on the Ingomar anticline comprises beds of limonitic concretionary sandstone, uncemented sand, shale, and bentonite. The most conspicuous beds are the hard brown limonitic sandstones, which yield much more slowly to erosion than the overlying and underlying sands and shales, so that they now cap low steep buttes and ridges. The composition of these hard sandstones seems to be the same as that of the higher sandstones except for a dark-green mineral that was not identified and for the iron content, which is irregularly distributed, so that in places the rock is very hard and dark colored. In other places it is soft and light yellowish gray. Some of the concretionary zones can be traced for more than a mile, but for the most part the concretions are not confined to any definite bedding plane, and what looks like a continuous zone of concretions may transgress across the bedding planes.

The sands are like the concretionary sandstones except that they lack the limonite. The shales range in color from light gray to dark brown, and near the base of the formation there is a highly bentonitic shale about 6 feet thick that weathers light blue. Other shales in the member contain some bentonite, but only the bed mentioned has a percentage large enough to make it conspicuous. The beds of brown shale owe their color to plant débris. All the shales contain much gypsum.

Fossil wood has been found in many parts of the formation, but on the Ingomar anticline it is particularly characteristic of the zone that contains the limonitic concretionary sandstones. One silicified log 40 feet or more in length and with a butt over 2 feet in diameter was seen, but most of the fossil wood is in small fragments. The concretionary sandstones also carry bone fragments. Most of those found were too small to give a clue to the identity of the animal from which they came, but C. W. Gilmore, of the United States National Museum, recognized fragments of the shell of a turtle of the genus *Aspideretes*, and also fragments from the centrum and the tibia of a dinosaur. In these same sandstones there were a few casts of smooth-shelled pelecypods and multitudes of casts of *Halymenites major*.

Particularly good exposures of the lower part of the Judith River formation occur in secs. 21, 22, 27, and 28, T. 9 N., R. 35 E. This part of the formation may be recognized by the driller because of the succession of thin hard sandstones with intervening soft material, the greenish cast of some of the sandstones, and the tendency of the bentonite to swell and cave when it is wet.

*Possibilities of oil in the formation.*—The Judith River sediments on the Ingomar anticline do not seem promising as possible source beds of oil. However, the formation contains from 20 to 40 feet of shale that is carbonaceous and a little that seems bituminous. Gas has almost certainly been evolved from the organic matter in this shale, and its relations to possible reservoir beds and to thick shales that would hinder extensive migration across the bedding justify the hope that at least small gas pools will be trapped in the Judith River sandstones where these sandstones are under a few hundred feet of shale cover and where the carbonaceous beds are well developed. In the areas of carbonaceous shales water wells in the Judith River formation should also yield small volumes of gas—perhaps enough to be separated for lighting and heating a single house.

It appears that the conditions in central Montana during Judith River time did not favor the formation of black shale, bituminous limestone, or other sediments similar in type to those thought to be the source of oil in the oil fields of the United States. Apparently there was a broad plain bordered by a shallow sea without " deeps " or areas where large bodies of stagnant or " dead " water favored the accumulation and preservation of organisms that under other conditions would be quickly decomposed. This is also indicated by the nature of the shales in the basal part of the Bearpaw. If regional conditions were thus unfavorable it is to be expected that any areas where oil originated in the Judith River formation must be very small. The formation of gas, however, apparently does not require such highly specialized conditions as that of oil, and it is not surprising that volumes of gas have been found in beds that occupy the general position of the Judith River formation in the Glendive-Baker region.

## ROCKS NOT EXPOSED

### WELL LOG

Below the rocks that crop out on and around the Ingomar anticline lie some 3,000 feet of Cretaceous strata that have been penetrated by the drill, and the presence below them of about 2,500 feet more of sedimentary rocks can be forecast with a fair degree of certainty.

The driller's log of a well drilled in 1920 and 1921 by the Absaroka Oil & Development Co. is given below, with the writer's interpretation as to the formations penetrated:

*Log of well of Absaroka Oil & Development Co. on the James Savage lease, in the NW. 1/4 sec. 26, T. 9 N., R. 35 E.*

| | Feet |
|---|---|
| Judith River formation: | |
| Cellar | 0–20 |
| Sandrock | 20–65 |
| Shale | 65–85 |

| | Feet |
|---|---|
| Claggett shale: | |
| Sand | 85-94 |
| Gray shale | 94-520 |
| Eagle (?) sandstone: | |
| Sandy shale with little gas | 520-525 |
| Gray shale | 525-560 |
| Sand | 560-570 |
| Colorado shale: | |
| Shale | 570-830 |
| Hard shell | 830-832 |
| Gray shale, practically no change | 832-1, 806 |
| Hard sand | 1, 806-1, 810 |
| Dark shale | 1, 810-2, 040 |
| Shale, more brown, and thin hard streaks of sandy rock a few inches to a foot and a half thick | 2, 040-2, 285 |
| Gray shale, soft and very cavey with pieces of green shale and chunks of soapstone | 2, 285-2, 350 |
| Black shale | 2, 350-2, 485 |
| Shale | 2, 485-2, 675 |
| Lime shell | 2, 675-2, 685 |
| Shale | 2, 685-2, 690 |
| Shale, some sand | 2, 690-2, 745 |
| Limy gray sand | 2, 745-2, 800 |
| Dark-gray shale | 2, 800-2, 835 |
| Dakota (?) sandstone: | |
| Fine gray sand, limy | 2, 835-2, 843 |
| Black shale | 2, 843-2, 850 |
| Dark sandy shale | 2, 850-2, 858 |
| Gray sand, lime | 2, 858-2, 865 |
| Fine-grained sandy lime | 2, 865-2, 873 |
| Fine white sand | 2, 873-2, 879 |
| Dark sandy shale; no lime | 2, 879-2, 886 |
| Gray sand with dark-red grains | 2, 886-2, 894 |
| Fine gray sand; some red particles | 2, 894-2, 900 |
| Kootenai formation: | |
| Red shale | 2, 900-2, 907 |
| Soft dark shale | 2, 907-2, 925 |
| Red shale | 2, 925-2, 932 |
| Soft red and gray shale | 2, 932-2, 938 |
| Soft dark-gray shale | 2, 938-2, 944 |
| Chiefly gray shale | 2, 944-2, 950 |
| Soft red shale | 2, 950-2, 957 |
| Mostly red lime; some shale | 2, 957-2, 962 |
| Red limy shale | 2, 962-2, 976 |
| Red shale | 2, 976-2, 992 |
| Gray shale | 2, 992-3, 000 |
| Gray and red shale | 3, 000-3, 008 |
| Maroon shale | 3, 008-3, 016 |
| Gray sandy shale | 3, 016-3, 024 |
| Soft sandy maroon and gray shale | 3, 024-3, 027 |
| Sand, limy, gray | 3, 027-3, 034 |
| Gray sand; some lime | 3, 034-3, 038 |
| Fine-grained angular white to gray sand; some iron pyrite | 3, 038-3, 040 |

## CLAGGETT SHALE

*Area covered in Ingomar anticline.*—The top bed of the Claggett shale (a soft massive sandstone about 40 feet thick) is exposed in a small area where streams have cut deeply into the sediments over the axis of the Ingomar anticline. The narrow strip where Claggett rocks are exposed covers less than half a square mile, in secs. 15, 16, 21, and 22, T. 9 N., R. 35 E. So little has been removed by erosion that practically the entire thickness of the Claggett everywhere underlies the Ingomar anticline.

*Correlation.*—The Claggett shale on the Ingomar anticline was identified by the fossils it contains. The exposed part of the formation consists of sandstone and interbedded shale so similar to the overlying Judith River rocks that until the fossils were identified it was thought that the sandstone represented the basal part of the Judith River and that no Claggett was exposed. However, a good collection of invertebrate fossils was obtained from the sandstone, and J. B. Reeside said of it that "so far as there is a distinctive Claggett fauna this assemblage, with the addition of *Tancredia americana*, would represent it very well." Mr. Reeside's determinations are given below.

Pteria nebrascana (Evans and Shumard).
Pteria linguaeformis (Evans and Shumard).
Ostrea sp. undet.
Pecten (Syncyclonema) rigida Hall and Meek.
Modiola attenuata (Meek and Hayden).
Anatina lineata Stanton.
Liopistha undata Meek and Hayden.
Lucina subundata Hall and Meek?
Sphaeriola? endotrachys Meek and Hayden.
Cardium speciosum Meek and Hayden.
Legumen planulatum Conrad?
Mactra gracilis Meek and Hayden.
Lunatia subcrassa Meek and Hayden.
Cinulia concinna Hall and Meek.

There is no indication of an unconformity between the Claggett and Judith River formations on the Ingomar anticline, and it seems certain that here, as elsewhere in Montana, there is a perfect gradation between them. In western Montana, where the two formations are differentiated on the basis of their respective marine and continental origin, there is much more justification for distinguishing between them than here, where at least a part of the Judith River formation is marine. To the east it becomes practically impossible to draw a line that will mark a definite change in conditions of deposition, and it is quite impossible to pick out the horizon that served as the line of demarcation between the two formations near their type localities in north-central Montana.

*Character.*—The Claggett shale on the Ingomar anticline is thought to be about 435 feet thick. A positive statement as to its thickness is not justified, for although it seems very probable that sandy shale recorded as occurring at a depth of 520 feet in the Absaroka Oil & Development Co.'s well on the anticline represents the Eagle, there is no proof to establish this beyond question. Figures of thickness must perforce depend on well records, as there are no exposures near by where the entire thickness can be measured. On the McGinnis Creek (Alice) dome, about 24 miles north of Ingomar, the thickness is apparently about 500 feet. Still farther north, in the Cat Creek area, Reeves[7] found an average thickness of about 430 feet. In the Huntley area, east of Billings and about 60 miles southwest of the Ingomar anticline, Hancock[8] found an average thickness of about 550 feet and in the Crow Indian Reservation, still farther south and west, Thom[9] determined the average thickness to be 400 to 500 feet.

The records of wells show the Claggett to consist almost entirely of shale throughout the eastern part of Montana. This is to be expected, as the massive sandstones that are so prominent southwest and west of Billings thin and disappear eastward. The exact nature of the shale penetrated by the wells can not be determined, for practically without exception the drillers have recorded it simply as "shale," with no comment on its variations in color, hardness. or mineral composition.

The sandstone at the top of the Claggett formation on the Ingomar anticline is about 40 feet thick. Like the sandstones of the Judith River formation it is composed chiefly of quartz and colorless feldspar, with very minor amounts of black chert, mica, and a few dark minerals, though it may contain distinctive mineral constitutents.

The upper sandstone bed in the Claggett shale is in places strongly cross bedded. Here and there indurated masses make prominent knobs, towers, or more irregular figures. Lentils of dark-gray shale a few inches to several feet long and a fraction of an inch to 3 inches thick are common. In places there are many casts of the probable seaweed *Halymenites major*, although no place was seen where these are as abundant as they are in some of the Judith River sandstones. The top of the sandstone is limonitic and grades through a series of thin sandstones and interbedded shales into a thick bed of sandy shale with some layers of clean gray shale that are free from sand.

*Origin.*—The shales and sandstones of Claggett age were probably deposited in a wide-spreading flat-bottomed sea that en-

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7 Reeves, Frank, Oil fields of central Montana: U. S. Geol. Survey Press Bull., 1920.

8 Hancock, E. T., Geology and oil and gas prospects of the Huntley field, Mont.: U. S. Geol. Survey Bull. 711, p. 110, 1919.

9 Thom, W. T., jr., Oil and gas prospects in and near the Crow Indian Reservation, Mont.: U. S. Geol. Survey Bull. 736, p. 38, 1922.

croached westward upon the land when the eastern two-thirds of Montana subsided uniformly and with relative rapidity. The change from the conditions under which the Eagle sandstone accumulated to those that gave rise to the Claggett beds shows that the shore line of this sea moved westward more than 100 miles in a very short time. The subsidence was probably a uniform sinking rather than a tilting that would permit the sea to creep gradually over the old land surface. This sea was gradually filled with the muds that formed the Claggett shales by rivers that brought their load from a land mass that was probably located in western Montana, Idaho, Washington, and Oregon.

*Possible value as a source of oil.*—Apparently the Claggett strata are not to be looked upon as a source of oil. The shales are somber in color and in places black, and this color must be due to a content of organic matter, but apparently this organic matter occurs in amounts so small as to have given rise to few if any accumulations of oil and gas that will prove commercially important. It is, of course, possible that the gas and oil that have been reported from the underlying Eagle sandstone and from the overlying Judith River sandstones have come in part or entirely from the Claggett.

It is not safe to disregard entirely the chance that any marine formation composed dominantly of shales that plainly show an appreciable content of organic matter may give rise to some important accumulations of oil or of gas, and reservoir beds associated with such a formation or fractured and fissured rocks in it should be studied carefully for traces of these substances, but the evidence now available would not justify prospecting in an area where the chances of finding oil appear to depend on its having originated in this formation.

## EAGLE SANDSTONE

The Eagle sandstone, named by Weed [10] from exposures on Eagle Creek, in Chouteau County, Mont., is one of the most conspicuous formations of central Montana. In the type section on Missouri River it is considered to be the basal formation of the Montana group, but recent work [11] has shown that in some areas there are underlying shales which are also of Montana age and grade without perceptible break into shales of Colorado age. Bowen,[12] who made a careful study of its easternmost exposures, came to the con-

[10] Weed, W. H., U. S. Geol. Survey Geol. Atlas, Fort Benton folio (No. 55), 1899.

[11] Thom, W. T., jr., Oil and gas prospects in and near the Crow Indian Reservation, Mont.: U. S. Geol. Survey Bull. 736, p. 38, 1922.

[12] Bowen, C. F., Gradations from continental to marine conditions of deposition in central Montana during the Eagle and Judith River epochs: U. S. Geol. Survey Prof. Paper 125, pp 11–21, 1920.

clusion that it thins eastward and disappears west of the latitude of the Ingomar anticline, but the records of wells on this anticline and on the Maginnis Creek (Alice) dome, to the north, show about 40 feet of sandy shale and sandstone that very probably represent this formation. There are neither fossils nor lithologic evidence to check this correlation, but the position of the Eagle between two formations that consist predominantly of shale makes this assignment seem logical. It is believed by the writer that farther east the Eagle sandstone is represented by a sandy shale and that careful work may reveal characteristics other than its sandiness that will serve to identify it.

Showings of gas were yielded by the Eagle sandstone on the Ingomar and Maginnis Creek anticlines. This was to be expected, for the Eagle carries either gas or oil, particularly gas, in many places. In the Lake Basin district, west of Billings, both gas and oil are found in it. To the north, near Havre, wells have been yielding gas from it for many years. Many wells drilled where the Eagle is 300 feet or more beneath the surface have reported gas in this formation, but have made no attempt to exploit the gas, because there is little or no market for it near most of the localities where it has been found. In Wyoming the Shannon sandstone member of the Steele shale, which is probably, in part at least, equivalent to the Eagle sandstone, has yielded considerable volumes of oil in the Shannon, Pilot Butte, and Big Muddy fields. Clearly there is a source of gas and oil associated with this sandstone, either in the basal part of the overlying Claggett shale, in the topmost beds of the underlying Colorado shale, or perhaps in carbonaceous beds in the Eagle itself.

On the Ingomar anticline or east of it the chance of commercially important gas production from the Eagle sandstone seems negligible, but it is quite possible that this sandstone will yield enough gas for lighting and heating single houses or even small groups of houses.

### COLORADO SHALE AND DAKOTA (?) SANDSTONE

The deposits of Colorado age, which underlie the Eagle standstone and overlie the Dakota sandstone where that formation is present, are divisible into several formations in most places where they appear at the surface but are rarely differentiated by well drillers and where undifferentiated are usually called Colorado shale, as they consist chiefly of shale. If the Colorado deposits of the Ingomar anticline are lithologically the same as those that occupy the same stratigraphic position in northeastern Wyoming they contain representatives from top to bottom of the Niobrara, Carlile, Greenhorn, and Graneros formations In south-central Montana, however, the Colorado group is divided lithologically into the Niobrara, Carlile, Frontier, Mowry, and Thermopolis formations. It appears that the deposits in the Ingomar region are more like those in northeastern Wyoming than those in south-central Montana, for there is nothing to suggest the sandstones of the Frontier formation in the log of the Ingomar well. They are, however, here treated as a unit and designated Colorado shale.

The Colorado deposits have a sandy base, and below them, in the Black Hills region and to the east, lies the Dakota sandstone. There is no sharp break between the Colorado and Dakota in eastern Wyoming, and it is the writer's belief that the Dakota can logically be considered a basal phase of the Colorado shale and that the overlying sandstones with intervening shales mark recessions and advances of the Colorado sea as it advanced from the south and east.

The well on the Ingomar anticline indicates that the combined thickness of the Colorado shale and the Dakota (?) sandstone is about 2,330 feet.

*Thickness and character of Colorado shale.*—The record of the well drilled on the Ingomar anticline by the Absaroka Oil & Development Co. shows the Colorado to be about 2,265 feet thick. The record is lamentably lacking in details, and little can be learned about the composition of the Colorado deposits beyond the facts that they are made up of shale, that is gray in the upper half, brown and bluish gray over an interval near the center, and black and gray near the base, with a very few thin beds of sandstone and limestone. One of these thin sandstone beds that is about 1,000 feet above the base of the Colorado may be the equivalent of the Mosby sandstone of the Cat Creek field.[13] Either a sandstone, a lime "shell," or a sandy shale is recorded at this horizon in the logs of most of the wells in this part of Montana that are deep enough to reach it.

The Colorado shale on the Ingomar anticline seems thick when compared to measurements of 1,985 feet or less on the Maginnis Creek (Alice) dome, 1,924 feet in the Cat Creek field,[14] 2,150 feet in the Huntley field,[15] about 2,050 feet in the Crow Indian Reservation,[16] and about 1,975 feet on the Porcupine dome.

The thickness at Vananda, about 20 miles southeast of the Ingomar anticline, is believed by the writer to be about 2,435 feet, or

[13] Lupton, C. T., and Lee, Wallace, Geology of the Cat Creek oil field, Garfield and Fergus Counties, Mont.: Am. Assoc. Petroleum Geologists Bull., vol. 5, No. 2, p. 253, 1921.

[14] Idem, p. 263.

[15] Hancock, E. T., Geology and oil and gas prospects of the Huntley field, Mont. U. S. Geol. Survey Bull. 711, pl. 15, 1920.

[16] Thom, W. T., jr., Oil and gas prospects in and near the Crow Indian Reservation, Mont.: U. S. Geol. Survey Bull. 736, pp. 38–40, 1923.

about 175 feet more than it is at Ingomar, although the well record on which the opinion is based is admittedly an imperfect one. The differences in thickness between the Colorado deposits at the Ingomar and Vananda wells and in the Cat Creek district are more apparent than real, for a part of the shale in the upper part of the Colorado on the Ingomar anticline and at Vananda is probably the homotaxic equivalent of the lower part of the Eagle sandstone farther north and west.[17]

*Origin of Colorado shale.*—The Colorado shale presumably originated from flocculent mud settling in a comparatively shallow sea. There is no conclusive evidence that the sea was shallow enough to permit occasional emergence of the muddy bottom, but the forms now fossil that lived in that sea are not deep-water types. The sea must have swarmed with life, as many of the beds of shale are black with bituminous or carbonaceous matter, and this makes it one of the most promising of the possible source beds of oil in the stratigraphic section of this region. There is no doubt that most of the light oil that has been produced in Wyoming originated is some member of the Colorado shale, and there is nothing to indicate that it is not quite as well adapted to yield oil in Montana. Unfortunately, however, in the Ingomar region there are no beds of porous sandstone interbedded with the fat black shale like the oil-yielding sandstones of the Frontier, Mowry, and Thermopolis formations of Wyoming, and consequently even if oil has originated in the Colorado shale it has not accumulated under conditions that will permit it to be recovered by wells.

*Dakota (?) sandstone and overlying sandy beds.*—In the lower 100 or 200 feet of the Colorado shale are widespread sandy beds that for convenience may be discussed with the underlying Dakota (?) sandstone, which in this general region is commonly about 50 feet thick. These basal sandstones in many places yield evidences indicating that they were laid down by fresh-water streams, either on deltas or in river beds, but the shales that alternate with them locally carry marine fossils.

The well on the Ingomar anticline found 210 feet of silty sandstone, sandy shale, and fine-grained sandstone at this horizon. The well at Vananda found a little less than 200 feet, and other wells in this general region have found about 300 feet of these beds.

The main producing sand of the Cat Creek field of Montana is equivalent to the sandstone here called Dakota (?). Sandstone in this general position also carries either gas or oil in a number of

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[17] This exceptional thickness of the Colorado shale in the Ingomar region has been pointed out by A. A. Hammer in "A study of some Upper Cretaceous sedimentation and diastrophism in the State of Montana," presented before the American Association of Petroleum Geologists at its meeting at Wichita, Kans., in March, 1925.

fields in Wyoming. It was therefore reasonable that the earlier prospectors should hope to find it productive in the Ingomar-Porcupine region. However, it has not only proved barren of either oil or gas, but in the well drilled on the Ingomar anticline it did not even yield water. This means either that the sand is so fine grained that the intergranular pores are too small to permit water to move out of them unless propelled by great gas pressure, or else that the original pores of the rock have been filled by some cementing material such as calcium carbonate.

Wells have been drilled through this succession of sandstones and shales on the Ingomar anticline, McGinnis Creek (Alice) dome, Porcupine dome, and Vananda anticline. None of these wells have found more than a trace of oil or gas, in spite of their location on the most pronounced anticlinal features of the region. It can not be said that these tests definitely prove that the zone of sandstones and shales is barren in this region, or even on the anticlines tested, for it is a demonstrated fact that one test does not condemn an anticline. Furthermore, there is no proof that the wells mentioned were drilled at the points on the anticlines most likely to prove oil-bearing, although those on the Ingomar anticline and McGinnis Creek dome seem well located. However, the lack of even a pronounced trace of oil or gas is very discouraging, and further drilling to test this zone can not be recommended unless localities that present structural conditions very different from those tested and that seem decidedly promising can be selected for the test.

It may be pointed out that on the Cat Creek anticline, the Elk Basin anticline, the Greybull anticline, and elsewhere within a radius of 200 miles where sandstone in the general position of the Dakota (?) of the Ingomar anticline is productive of oil or gas there are faults of such magnitude that the sand is brought into juxtaposition with the dark shales of the overlying Colorado, so that it might receive oil from those shales without the necessity of downward migration; also that these same faults might well serve as avenues of migration up which oil from a deep source—such as the Phosphoria or the Madison—might move. If similar profound faulting can be found in the Ingomar-McGinnis-Porcupine region the prospect for production adjacent to the faults would, in the opinion of the writer, be much greater than on the unfaulted or slightly faulted folds.

The Dakota (?) sandstone of the Ingomar anticline is apparently present throughout central Montana and is a good key bed or horizon marker to help the driller recognize the exact position of the bottom of his well in the stratigraphic section. Furthermore, it commonly carries water, which, at least in some places, is potable and suitable for boiler use.

### KOOTENAI AND MORRISON (?) FORMATIONS

The Kootenai formation, of Lower Cretaceous age, and the Morrison formation, of Lower Cretaceous or Upper Jurassic age, probably underlie the Ingomar anticline and other parts of this general region. The well on the Ingomar anticline penetrated 140 feet of beds believed to belong to these formations. These beds do not reach the surface near the Ingomar anticline, but they or their equivalents crop out in the nearest uplifts that expose this part of the column. Variegated shales of maroon, gray, green, and pink colors, in places sandy; sandstones, locally conglomeratic; and thin lentils of limestone are characteristic of the Kootenai and Morrison (?) formations at the nearest points where they are accessible for examination. These beds may have a thickness of about 300 feet in the Ingomar region, but there is nothing in the character of the sediments, which are of fresh-water origin, nor in the history of oil development in the Rocky Mountain region that offers much basis for hope that oil in important quantity will be found in them.

### SUNDANCE OR ELLIS FORMATION

Rocks of Upper Jurassic age, consisting of strata that accumulated in a shallow sea, are very probably present under the Ingomar anticline. Shale predominates, but there are thick beds of sandstone, particularly near the base and near the top, and a few thin limestones that are commonly very fossiliferous. Around the Black Hills and Big Horn uplifts and throughout the larger part of Wyoming these marine Jurassic rocks constitute the Sundance formation. Somewhat similar rocks of the same general age to the west and northwest are called the Ellis formation.

Erosion preceded and at least locally followed the deposition of the Jurassic beds, which consequently exhibit somewhat abrupt changes in thickness. These changes, however, are not believed to be great enough to introduce gross inaccuracy in an estimate of the thickness of the formation under the Ingomar anticline. The Ellis formation of the Little Rocky Mountains is about 250 feet thick.[18] In the Snowy Mountains it is about 150 feet thick.[18] In the Pryor Mountains the Sundance shows a maximum thickness of 625 feet, and on the Soap Creek dome it may be as thick as 680 feet. A thickness of 425 feet measured just north of the mouth of Big Horn Canyon,[19] on the east side of the mountains, is a reliable

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[18] Bauer, C. M., and Robinson, E. G., Comparative stratigraphy in Montana: Am. Assoc. Petroleum Geologists Bull., vol. 7, No. 2, pp. 174–175, 1923.

[19] Thom, W. T., jr., Oil and gas prospects in and near the Crow Indian Reservation, Mont.: U. S. Geol. Survey Bull. 736, p. 40, 1922.

measurement. On the northwest slope of the Black Hills[20] the Sundance formation is about 325 feet thick. The position of the Ingomar anticline is probably much closer to the center of the Logan Sea, in which the marine Jurassic accumulated, than the Little Rocky Mountains or the northwest slope of the Black Hills. It is therefore reasonable to think that the formation will be considerably thicker under the Ingomar anticline than it is in those places. Perhaps 350 to 400 feet is a reasonable figure to assign to the Ingomar area.

These rocks are a possible source of oil and gas. The Sundance has yielded small amounts of heavy black oil in fields in central Wyoming, and the principal production of the Kevin-Sunburst field of Montana is derived from the Ellis. It must be conceded that there is no absolute proof in any of the fields that the oil originated in the Jurassic, and in the Kevin-Sunburst field a more probable source is the underlying Madison limestone. It is not justifiable to prospect in southern Montana solely in hope of finding oil at the Jurassic horizon, and the presence of these beds adds comparatively little to the possibilities of a region.

### TRIASSIC (?) ROCKS

Triassic rocks are probably absent under the Ingomar anticline and to the north. If present they probably consist of not more than 50 or 100 feet of red shale that possibly may be interbedded with layers of white gypsum, and they would be of little importance either as reservoir beds or as a source of oil. The possibility that oil may have originated in these rocks can not be entirely disregarded, however, for occurrences of oil in the basal part of the Chugwater formation (which the writer thinks accumulated in shallow salt water) have been noted in the Casper-Alcova region of central Wyoming, and it is thought that the oil there originated in the "Red Beds" (Chugwater) rather than in overlying or underlying strata.

### PERMIAN (?) STRATA

Permian strata are probably absent in the Ingomar region. This means that the Phosphoria formation (lower part of the Embar) of the Big Horn Basin, which serves both as a source and as a reservoir for heavy asphaltic oil in the vicinity of Thermopolis and Grass Creek, can not be expected to contribute to the oil-yielding possibilities of the Ingomar region.

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[20] Darton, N. H., U. S. Geol. Survey Geol. Atlas, Devils Tower folio (No. 150), p. 2, 1907.

### PENNSYLVANIAN STRATA

Beds of Pennsylvanian age are almost certainly present in the Ingomar region. To the south, in the Pryor Mountains and in the Crow Indian Reservation, there is the Tensleep sandstone, of Pennsylvanian age, with a maximum thickness of about 75 feet, and below it strata that have been referred to the Amsden formation [21] of Pennsylvanian and Mississippian age, which may include as much as 365 feet of red shale, thin beds of red and white limestone, and quartzitic sandstone. Most of the oil in the Soap Creek pool was found in these strata. To the southeast, in the Black Hills, the Minnelusa sandstone, with a maximum thickness of about 1,000 feet, consists of massive to thin-bedded gray to buff sandstone, sandy shale, lentils of red shale, and thin dolomitic limestone.[22] Locally it contains thick lenses of gypsum.

In view of these observations it seems probable that from 600 to 1,200 feet of Pennsylvanian strata are present in the Ingomar region, comprising sandstone, limestone, and shale of marine origin. The Pennsylvanian beds contain some oil in the Black Hills region, in the Soap Creek pool, in the Big Horn Basin, and in the Devils Basin. In all these regions the oil is black, heavy, and asphaltic. In none of them have large pools been developed.

The chances for oil in the Ingomar region are critically though not exclusively dependent upon the presence of an oil-yielding phase of these Pennsylvanian strata. The writer believes that the lower beds in the Pennsylvanian—the local coarse materials immediately overlying the unconformity at the top of the Madison limestone—are more likely to contain oil than the higher beds.

### MADISON LIMESTONE

The Madison limestone, of Mississippian age, apparently underlies all of eastern Montana and most of Wyoming. Where not exposed its character is of course largely unknown, but presumably it closely resembles the Madison limestone exposed in the Big Horn Basin, which in places comprises more than 1,000 feet of limestone or dolomite, without any appreciable amount of interbedded shale. Parts of this limestone are decidedly bituminous, and it is probably the source of oil that has been found in the overlying Amsden formation in the Big Horn Basin and in the Casper region of Wyoming.

A well 4,800 feet deep on the crest of the Ingomar anticline would probably test the upper 100 feet of the Madison limestone. The pres-

[21] Thom, W. T., jr., Oil and gas prospects in and near the Crow Indian Reservation, Mont.: U. S. Geol. Survey Bull. 736, p. 41, 1922.

[22] Rubey, W. W., The Rocky Point plunging anticline: U. S. Geol. Survey press notice, Nov. 14, 1924.

ent cost of drilling to such a depth, the practical certainty that oil, if found, would be heavy and asphaltic, and the low present value of such oil would all discourage such prospecting, even were the chances of finding oil much brighter than they appear to be. When to these factors is added the failure to find any appreciable quantity of oil in the Madison in a number of wells that have been drilled into that formation, it is apparent that an attempt to test the Madison limestone in the Ingomar region is unjustified until wells drilled elsewhere have demonstrated the worth of the formation as a source of oil.

## IGNEOUS ROCKS

On the south end of the anticline, in the NW. 1/4 sec. 21 and adjoining parts of sec. 20, T. 8 N., R. 36 E., Treasure County there are several small dikes of igneous rock intruded into the Judith River and Bearpaw formations. These dikes are from a few inches to a few feet in width and are composed of extremely weathered light to dark greenish-brown material. According to E. S. Larsen, formerly of the Geological Survey, the rock is a porphyritic lamprophyre, too much altered for accurate study but containing recognizable biotite, calcite, serpentine, and apatite. In the dikes are numerous inclusions, commonly several inches in diameter, of massive, finely crystalline light brownish-gray limestone and some small fragments of reddish quartzite, light-gray shale, and weathered igneous rocks.

The dikes are notably discontinuous—for example, one that has a maximum width of 5 feet is traceable only 35 feet horizontally. The strike of the dikes is generally east, ranging between N. 83° W. and N. 68° E.; the longest one, which is from 1½ to 3 feet wide and extends continuously for nearly half a mile, strikes N. 70°–80° E. and is slightly curved.

The fissures in which the dikes occur are small normal faults, which show displacements of less than 5 feet and which dip steeply both to the north and to the south. Two of the shorter dikes are nearly vertical, but the longest one dips about 65° N. The shale and sandstone of the Judith River and Bearpaw formations are practically unaffected by the intrusions, and along only one of the dikes are the adjacent sedimentary beds even noticeably hardened, and this effect is not recognizable more than a few inches from the dike walls.

Near the southwest corner of sec. 24, T. 8 N., R. 35 E., 3 miles west of these dikes and approximately in the line of their strike, stands a rather low but conspicuous knoll known locally as Froze-to-Death Butte, which is formed by an eastward-trending dike in the

Bearpaw shale. In this dike, as in the others, the igneous rock is badly weathered and contains many inclusions. In some small limestone inclusions from this locality were found fossils that, according to G. H. Girty, of the Geological Survey, are of Carboniferous age. If, as seems likely, these small rock fragments came from the Madison limestone, they have been carried up a vertical distance of probably more than 5,000 feet by the intrusion. It is of considerable interest that the magma that formed these dikes was both sufficiently liquid to travel a mile or more and so cool that it did not appreciably alter the small limestone fragments that it carried.

## STRUCTURE

The Ingomar anticline, in outline, is shaped somewhat like an inverted canoe with sharp ends and a bulge in the middle, although it is not symmetrical enough to more than suggest the resemblance. (See structure map, pl. 1.) A longitudinal cross section would show

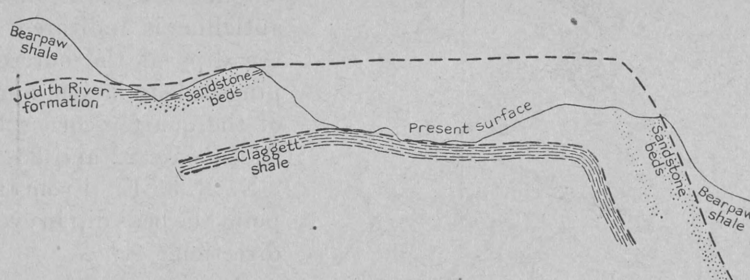


FIGURE 3.—Idealized cross section across the Ingomar anticline, Mont.

a smoothly curved line, concave downward, with a pronounced steepening of the rate of curvature at the northwest end of the fold. A transverse cross section would show great unevenness in rate of curvature, for the dips on the east side of the arch are in places as steep as 20°, whereas on the west side they are everywhere 4° or less.

The presence of the anticline is clearly revealed by the hills that form a rim roughly outlining it. These hills are due to the greater resistance to the weathering and erosive action of rain and possibly of wind that is offered by the sandstone ledges in the Judith River formation than by the weaker beds above and below. Figure 3 shows the general conditions on a line crossing the highest part of the anticline in a northeasterly direction.

The axis of the anticline trends northwest. It is clearly defined as far south as the center of sec. 21, T. 8 N., R. 36 E., and probably extends several miles farther southeast. At the northwest extremity of the fold as mapped there appears to be a sharp swing to the east in the SW¼ sec. 5, T. 9 N., R. 35 E. However, it is entirely possible that this apparent change in the trend of the axis is due to a fault, and that the axis of the main fold continues to the northwest, although if so it apparently plunges steeply. The length of the part of the anticline that was mapped is about 11 miles, and its greatest width is probably 5 to 6 miles.

The closure of the anticline is known to be at least 600 feet, and it is believed to be about 1,000 feet, although proof of the extra 400 feet of closure was not obtained. The highest point on the anticline is indicated by the dips of the outcropping beds to be just north of the quarter corner between secs. 22 and 23, T. 9 N., R. 35 E. From this point the beds dip in every direction.

*Position of the crest with depth.*—The east flank of the anticline is so much steeper than the west flank that the fold is decidedly asymmetrical, and this suggests the possibility that the crest of any fold in rocks several thousand feet beneath the surface may not lie vertically below the crest of the fold that was mapped by determining the dips of the surface rocks. Three possibilities must be considered. The crest of the deep-lying fold may be west of that of the surface fold, as is indicated in Figure 4, A. This is the relation that would exist if the anticline were due to pressure applied from the side with equal intensity on

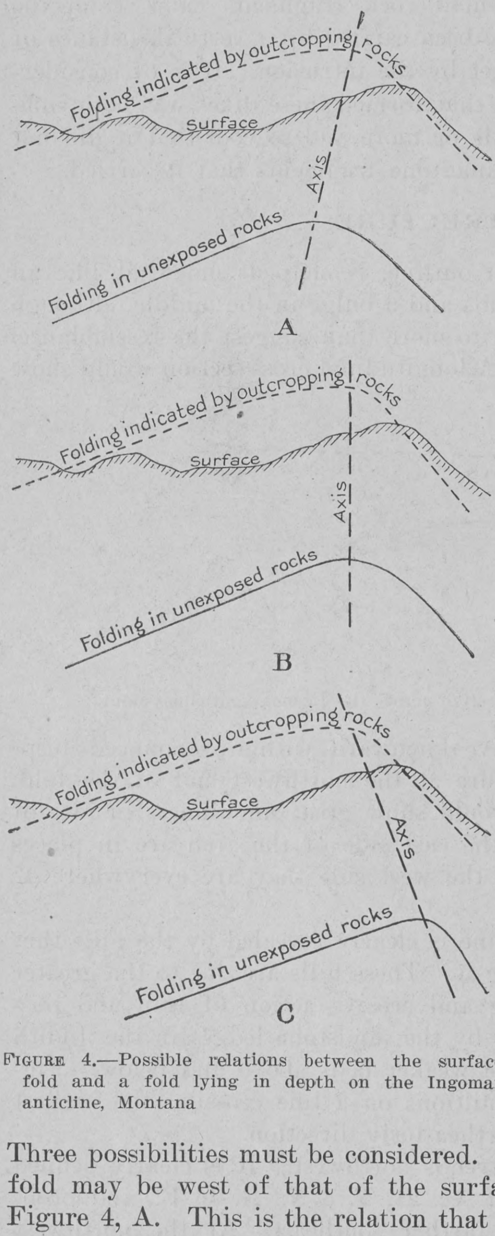


FIGURE 4.—Possible relations between the surface fold and a fold lying in depth on the Ingomar anticline, Montana

every bed of rock, and if all the beds were equally strong. Again, the axial plane of the fold may be vertical, and the anticline in depth may be vertically below the anticline on the surface, as shown in Figure 4, B. It is the writer's opinion that folds of this type occur where the arching of the beds is due to subsidence or compacting of soft beds over a buried core of hard, rigid rock. Finally, the axis may incline toward the steep side of the fold, as shown in Figure 4, C. An anticline of this type may be due to a fault that breaks the deep rocks, but merely stretches the surface strata if they are comparatively plastic.[23]

The writer believes that the Ingomar anticline does not conform exactly to any one of these three types, but that in the relations of the beds in depth to those at the surface it agrees more nearly with the second than with the first and third. It must of course be recognized that the deductions here presented regarding the relations between surface and deep-lying structure are based solely on theoretical grounds and are therefore speculative. They are advanced because it is believed that future prospecting, if attempted, should be guided by a definite theory concerning such relations rather than by the structure indicated by outcropping rocks.

*Faults.*—The gently dipping west flank of the Ingomar anticline is broken by at least eight and probably many more small faults that trend almost at right angles to the axis of folding of the anticline. The direction of trend ranges from N. 45° E. to N. 80° E., showing a progressive change from northwest to southeast along the fold. The greatest displacements on these faults occur very low on the flanks of the anticline, and the faults appear to die out as they near the axis. There are a number of faults with throws less than 10 feet that cut the east flank of the anticline and that have the same general trend as those on the west flank, but it was impossible to find evidence indicating that any fault crosses the axis, and it is certain that no fault with a throw of more than 20 feet cuts the east flank of the anticline between sec. 5, T. 9 N., R. 35 E., and sec. 16, T. 8 N., R. 36 E.

The faults are all of the normal type, but on some of them the strata south of the fault have dropped, while on others the beds north of the fault have dropped. This is shown diagrammatically in Figure 5. The greatest throw noted was on a fault in the south-central part of sec. 2, T. 8 N., R. 35 E., where the south side has dropped about 80 feet with respect to the north side.

It is believed that the greatest northeastward-trending fault that cuts the anticline is probably in sec. 6, T. 9 N., R. 35 E., but its presence was neither proved nor disproved, because the exposed strata there belong to the Bearpaw shale, and except where they

[23] Lee, Wallace, personal communication, 1921.

are cut by gullies it is difficult to determine the precise structural conditions. The probable presence there of a fault with large throw is suggested by an abrupt change in the strike of the beds in sec. 5, T. 9 N., R. 35 E., and by an apparently abrupt increase in the north dip along the line between secs. 5 and 6. If no fault is present, then the anticline is terminated on the northwest by a sharp synclinal flexure, trending almost due northeast.

A fault with a throw of about 110 feet was noted on the east flank of the syncline that borders the Ingomar anticline on the east. The axis of this syncline passes a little east of the west line of sec. 31, T. 9 N., R. 36 E., and the fault was noted in the central part of the same section. The trend of this fault agrees with that of the faults on the flanks of the anticline. Its downthrown side is on the north. It is important, as it indicates that the faults are not restricted to the anticline.

It is believed that the faults all originated at approximately the same time, regardless of whether the strata are dropped to the north

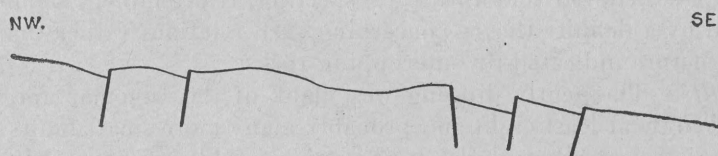


FIGURE 5.—Sketch showing the general relations along a line drawn northwest through secs. 33 and 29, T. 9 N., R. 35 E., Mont., on the surface of the Judith River formation. Not drawn to scale

or to the south. This is suggested by the apparent continuity of a fault in secs. 28 and 29, T. 9 N., R. 35 E., which has a downthrow to the north at the west end of the fault and to the south at the east end. Presumably there must be some place on this fault where the fault plane is vertical and there is no throw at all. Such faults are commonly called "scissors faults" and are not rare. As a rule such faults are almost vertical.

*Origin of anticline.*—The writer believes that the Ingomar anticline originated by underthrust from the northeast during the period of folding that affected northern Wyoming and south-central Montana early in Eocene time and that it has been altered little if at all by any subsequent deformation. The ultimate cause of this thrust to the southwest is at present a matter of opinion rather than of demonstrated fact, though what seems by far the most plausible explanation would connect it with the regional uplift that produced the Porcupine dome, a broad uplift more than 40 miles long and 25 miles broad, with consequent readjustment of the surrounding strata.

If the anticline originated as has been suggested here, and the thrust was transmitted through the competent deeper Pennsylvanian and older beds, the upper 3,000 feet of strata presumably were merely lifted more or less passively on the back of the stronger underlying beds, and the fold shown by the surface rocks will agree very closely with and almost overlie the anticline in the Pennsylvanian rocks, though there will probably be a slight eastward inclination of the axis in depth.

*Summary statement.*—The Ingomar anticline is a northwestward-trending fold, more than 11 miles long and 5 or 6 miles wide at its widest point, with a steep northeast flank dipping about 20° and a gentle southwest flank dipping about 4°. The highest point on the anticline is just north of the quarter corner between secs. 22 and 23, T. 9 N., R. 35 E., and from this point the beds descend more than 600 feet in every direction, although the descent along the crest of the anticline is very gradual. On the gently dipping southwest flank there are eight or more small faults that trend about at right angles to the axis of the anticline. The presence of these faults, together with the asymmetrical shape of the anticline and the known softness of the upper 3,000 feet of strata that underlie the surface over its crest, leads to the conclusion that it was formed by underthrust from the northeast, and also that the folding in the Pennsylvanian beds will probably conform closely to that manifested by the surface strata.

## REVIEW OF OIL POSSIBILITIES

The failure of a single-test well does not condemn an anticline that is as large as the Ingomar anticline, although it may well retard further drilling until the price of oil promises a reward that will justify exploration in areas where the probability of failure is higher than it is in wholly undrilled territory. The Ingomar anticline was tested by an excellently located well that penetrated a sandstone (Dakota?) at the base of the Colorado shale and went a short distance into the Kootenai. The strata that lie below the bottom of this well must be given almost the same rank as possible containers of oil as they had before the well was drilled. Those that were penetrated by the well may carry oil elsewhere on the anticline. The lack of oil in the well discourages this belief but does not preclude it. The lack of gas in the well is more condemnatory than the lack of oil, for gas will escape from a sand that is too tight to release any oil it may contain.

### POSSIBLE OIL-YIELDING BEDS

The shallowest of the strata that may carry oil or gas on the Ingomar anticline is the Eagle sandstone. This sandstone, according to the log of the Absaroka well in sec. 26, is present on the anticline as a sandy shale with about 10 feet of sand at the base. Apparently a layer about 30 feet above this sandstone is particularly porous, for it was recorded as showing a little gas. Gas occurs at this general horizon in many parts of Montana, and it would be surprising indeed if none should be found there in the Ingomar region. Possible sources of gas both overlie and underlie the sandstone, and as it grades into shale toward the east the artesian water from the west is prevented from washing it clean of any gas or oil it may contain. Small amounts of gas are to be expected at this horizon in wells drilled on the crest or west flank of the domed part of the Ingomar anticline. It lies about 450 feet below the base of the Judith River formation. The gas-bearing stratum is probably less than 15 feet thick everywhere on the anticline.

The beds at the horizon of the Frontier formation, which is the premier oil-yielding zone of Wyoming, can not be expected to bear oil on the Ingomar anticline. In fact, there is no certainty that the Colorado shale is any more sandy or otherwise more favorable for yielding oil at the Frontier horizon than it is elsewhere. A sand 4 feet thick was struck at a depth of 1,806 feet in the Absaroka well, and this may indicate that the adjacent shale is sandy, but there is no certainty of this, and the sandstone mentioned may not even be one of the Frontier sandstones.

In the Big Horn Basin and in the Lost Soldier field of Wyoming the Mowry shale has yielded high-grade oil. No oil has been produced from this shale either in Montana or in Wyoming as far east as the Ingomar anticline. It may carry some oil here, but even if it does, appreciable accumulations are not to be hoped for unless fissuring has made conditions favorable for oil to gather in the gashes or cracks, or unless there is some local condition that resulted in the formation of sandstone beds in the Mowry.

A lower portion of the Colorado shale that has yielded some oil is a sand or sandy zone in its lower part. This is known as the Muddy sand throughout most of the Wyoming oil fields, and in the Black Hills region a sand at a similar horizon is called the Newcastle sandstone. It is not believed that one continuous sandstone at this horizon underlies much of Wyoming and Montana, but there is a zone of shale in which one and locally more beds of sandstone are present. Apparently this sandstone is entirely absent or represented by sandy shale in the Ingomar region.

The sandstone at the base of the Colorado group (the Dakota? sandstone) yields oil in the Cat Creek field, where it is known as the First Cat Creek sand. A sand at a similar horizon yields gas in the Elk Basin field and either oil or gas in many fields in the Big Horn Basin, as well as in more southerly fields, and it was the primary objective of wells drilled on the Ingomar anticline and on the McGinnis Creek and Porcupine domes, but it failed to yield oil on any of these anticlines and also on many others more remote from the Ingomar anticline. Even in Wyoming it is apparently barren except on anticlines that are severely shattered by faulting. This may mean that the main source of oil is above the sandstone and that the oil percolates into it only when faulting brings a raw edge of the sandstone in contact with an oil-saturated shale. Again it may mean that the source of the oil is some distance below the sandstone and that the oil will not reach it unless fracturing of the underlying beds provides openings up which the oil and gas can rise. This hypothesis seems the more likely one, particularly as a number of the fields that yield oil from this Dakota (?) sandstone also yield it from deeper beds.

This faulted condition, which apparently is favorable for the occurrence of oil in this Dakota (?) sandstone in Wyoming and in the Cat Creek field, is not present on the Ingomar anticline. The nearest approach to it is in secs. 20, 21, 22, 27, 28, 29, and 33, T. 9 N., R. 35 E., where a number of small faults were noted. However, these faults are not comparable in magnitude to those on the productive anticlines, nor is their location with respect to the highest part of the anticline such as to make them effective in localizing a pool of oil. There is no certainty that they persist in depth and cut the oil sand. If they do they might permit upward migration of oil from deeper beds, and that oil, if prevented by tight sand from reaching the top of the dome might accumulate near the faults or east of them, in secs. 22 and 27. This is a possibility that should be considered in any future prospecting of the anticline, and a well to test the Dakota (?) sandstone in this respect should be located about in the center of the SW. 1/4 sec. 22, T. 9 N., R. 35 E.

The Kootenai, below the Dakota (?), has yielded oil in the Cat Creek field of Montana. The oil is very similar to that in the Dakota (?) sandstone and apparently is derived from the same source. That source, in the opinion of the writer, may possibly be in the Kootenai or in the Morrison (?) but is more probably in the deeper-lying Jurassic or the still deeper Pennsylvanian. The statements about the absence of oil in the Dakota (?) where the field is not strongly faulted also apply to the sandstones in the Kootenai.

The well on the Ingomar anticline did not reach the heavy basal sandstone of the Kootenai, nor did any other well in the region except the one drilled on the McGinnis Creek dome. That well went much deeper than the basal Kootenai but did not encounter any oil. A well on the crest of the Ingomar anticline would have to drill to a depth of about 3,250 or 3,300 feet to go through this basal sandstone.

The Morrison is productive of some oil and a great deal of gas in fields of the Big Horn Basin in Wyoming, but nothing has been noted to encourage a hope that the beds in Montana that are tentatively correlated with the Morrison will carry oil except the productivity of sands in the Kootenai in the Cat Creek oil field. If the oil in these sands rose along faults from a deep source, it must have passed by the Morrison (?) sandstones, and under such conditions it would presumably impregnate these sandstones to some extent. The Morrison (?) beds can not be entirely disregarded, for they contain sandstones suitable to serve as reservoirs, but they hold little promise.

The Jurassic should be looked on as the next logical objective of prospecting below the Dakota (?). It is true that beds at this horizon have yielded comparatively little oil in either Montana or Wyoming, but both the origin of the beds and their position immediately above Carboniferous strata demand that some consideration be given to them. They should be ranked as a possible rather than a probable container of oil, particularly in view of the probable absence of thick sands and of their location with respect to the shores of the sea in which the strata were deposited.

Probably next below the Jurassic will be found the Pennsylvanian strata, and these carry greater promise of oil than any others except perhaps the Dakota (?) sandstone. A well drilled on the crest of the anticline in the NW. 1/4 sec. 23, T. 9 N., R. 35 E., should reach these strata at about 4,000 feet or possibly a little less.

A good site for a deep test on the anticline is near the center of the N. 1/2 sec. 22, T. 9 N., R. 35 E. This location is a short distance down the west flank of the fold, but the highest point on the fold in the deep strata may not exactly underlie that on the surface as discussed under the heading "Structure." If the axial plane inclines to the west to bisect the angle made by the flanks of the anticline, the crest of the anticline at a depth of 4,000 feet will be more than 400 feet west of the crest at the surface.

The several zones mentioned do not include all the possible oil-carrying beds. If the faulting on the west flank of the anticline acted on parts of the Colorado shale in such a way as to increase its porosity—perhaps by developing a great many joints or shear planes, or perhaps by shattering and jumbling the strata—it is entirely possible that "shale oil" is present. This is oil that accumulated in fissures, joints, or other openings in shale. Notable quantities of oil have been obtained from the Colorado shale in the Salt Creek, Teapot, and Lost Soldier fields, in Wyoming. The

Moffat and Iles domes, in Rio Blanco County, Colo., and the Osage field, in Wyoming, also contain shale oil. Large amounts of gas and oil have come from the Florence field, Colorado, and from several pools in the Mid-Continent and Appalachian fields. As a rule this "shale oil" is not considered worth prospecting for, as the total yield of the wells in the Wyoming fields is not commonly great, and the occurence of the oil is so erratic that there is great uncertainty about striking it even when it is known to be present on an anticline. It may therefore be regarded simply as one possibility that will decrease somewhat the hazard of loss that will attend drilling on the faulted west flank of the Ingomar anticline. Shale oil is most likely to be found on the west flank in secs. 16, 17, 20, 21, 22, 27, 28, 29, 32, 33, and 34, T. 9 N., R. 35 E. If found at all it will almost certainly be in the Colorado shale and probably in the upper 1,600 feet of the shale.

## TYPES OF OIL

Any oil found above the base of the Colorado shale will very probably be comparable to that found in other fields that yield oil from this formation. It may be expected to be light green in color, have a specific gravity between 30° and 45° Baumé, be of mixed paraffin and asphalt base, and be a fair oil for the production of gasoline.

Oil from the Dakota (?), Kootenai, Morrison, and Jurassic beds, if present, may be either a green light oil of mixed base or a heavy dark oil of asphalt base. To judge from the results in fields that have yielded oil from these strata the probability is that any oil occurring in these beds in the Ingomar region will be dark and heavy.

Oil from the Pennsylvanian will almost unquestionably be heavy, dark, and asphaltic, with a rather high sulphur content. Its value for the production of gasoline will probably be low. Whether or not it will be comparable to the Gulf coast oils as a source of lubricants can not be said. At the present time the heavy black oils of the Rocky Mountain fields are a drug on the market, but there is no doubt that they will be eagerly sought during the next 10 years.

## DRILLING THAT HAS BEEN DONE ON THE INGOMAR ANTICLINE AND OTHER FOLDS IN THIS REGION

The well on the Ingomar anticline, which reached a depth of 3,040 feet, found no oil and only a slight showing of gas, which came from a thin bed of sandy shale at 520 feet, probably in the Eagle sandstone. The well was located on the axis though not on the highest structural point of the anticline. This point is about half a mile north-northwest of the well and is probably about 35 feet higher structurally, although it may be as much as 50 feet.

The well passed completely through the Dakota (?) sandstone, which, according to the log, was dry, not only of gas and oil but also of water. As this sandstone commonly carries water where oil is absent, this record shows an unusual condition, which is probably to be interpreted as meaning that pores between the sand grains have been filled by fine sediments or by some cementing material, such as calcite, silica, or iron oxide. The fact that the driller records beds at this horizon as "lime" and "sandy lime" lends strength to the view that the pores are filled by a calcareous cement.

It can not be said, however, that the Dakota (?) sandstone horizon on the Ingomar anticline has been thoroughly tested, for "tight" patches of small extent in sandstone are not unusual and do not necessarily represent conditions that persist throughout the area.

At least three other wells in this general region have been drilled through the Dakota (?) sandstone. One of these, at Vananda, about 7 miles south and 8 miles east from the Ingomar well, encountered water in the Dakota (?) which rose within 50 feet of the surface. A well drilled on the Porcupine dome unquestionably passed through the Dakota (?) and according to newspaper statements found a small quantity of black oil some distance below this horizon. It is believed that this well went through the Kootenai. In spite of reports that oil was encountered at a number of horizons, none has been produced either from this well or from other wells on the Porcupine dome. The third well is on the McGinnis Creek dome, 30 miles north of the Ingomar well. This well was reported to have reached a depth of 3,810 feet. No oil was obtained, but it is reported that water was found in the Dakota (?) and in lower sands as well.

## POSSIBILITIES OF THE REGION AS A WHOLE

The fact that out of four wells drilled on pronounced anticlinal folds in the Porcupine-Ingomar region three found water in the Dakota (?) and the fourth failed to find either water or oil is ample justification for refusing to drill further in this region with the Dakota (?) as an objective, unless conditions are found that are decidedly different from those that proved unfavorable. The most desirable condition would be pronounced faults. If such faults, trending approximately north, and consequently at right angles to the supposed direction of artesian flow in the sandstones, are found it will be justifiable to test the Dakota (?) sandstone on the east side of the faults, provided the sandstone does not lie at prohibitive depth, and the prospects of success would be enhanced if shale oil is found in the Colorado and gas in the Eagle.

So far as the writer can learn, the Jurassic has been tested by only a single well in this region, and the deep-lying Pennsylvanian has been touched by only one well and has not been deeply penetrated by any well. The Pennsylvanian strata in Wyoming are more generally oil bearing than the Cretaceous strata, although the yields both of fields and of individual wells that draw from the Pennsylvanian are much lower than those of fields where the oil is found in Cretaceous beds, and the black, heavy Pennsylvanian oil has sold for so little during the last few years that prospecting for such oil has had little encouragement. Deep drilling in areas of good anticlinal structure in the Ingomar region may possibly discover oil in the Pennsylvanian rocks and in the Jurassic or the basal part of the Morrison (?) beds, but the Pennsylvanian is much more promising than the higher beds.

In many respects the Porcupine dome is the most attractive field for prospecting in this part of Montana. It must be recognized, however, that all parts of this great uplift are not equally favorable, and that prospecting should be confined to areas where not only the regional but also the local structure is attractive. The writer believes that attention should first be given to the north and northeast flank of the dome, which should be carefully examined for anticlinal wrinkling and for faulting. If this dome is due to vertical uplift, as appears most likely, there should be sharper local folding and more profound faulting on the flanks than over the summit.

To the west of the Ingomar anticline the Eagle may yield considerable volumes of gas on anticlines where this sandstone lies under several hundred feet of strata. It has proved to be gas bearing in the Lake Basin field, in the territory just south of the Bearpaw Mountains, in the Havre district, and elsewhere in Montana. It has never yielded any great amount of oil, although small amounts have been found in it in a number of localities and although the Shannon sandstone of Wyoming, which occupies the same general position in the stratigraphic column as the Eagle, has yielded oil in the Salt Creek, Big Muddy, and Pilot Butte fields.

# GEOLOGY OF THE CAT CREEK AND DEVILS BASIN OIL FIELDS AND ADJACENT AREAS IN MONTANA

By Frank Reeves

## INTRODUCTION

*Scope of report.*—The area herein considered consists of about 75 townships lying in Petroleum County and adjacent portions of Fergus, Garfield, and Musselshell Counties in central Montana.

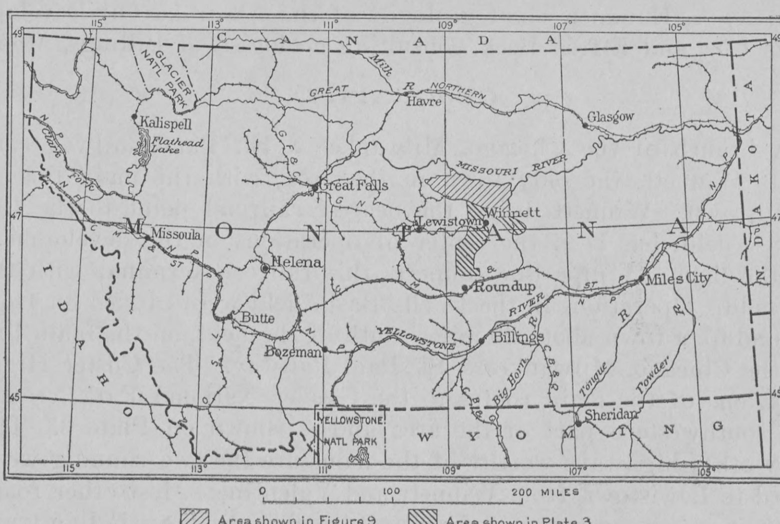


Figure 6.—Index map of Montana, showing location of area including Cat Creek and Devils Basin oil fields

(See fig. 6.) The Cat Creek and Devils Basin oil fields are, respectively, in the eastern and southern parts of the area. For the preparation of this report about four months was spent in the field in the summers of 1920 and 1921, the chief purpose of the investigation being the collection of information for use in the administration of the Federal oil leasing law.

In order that the results of this field work could be used in the development of the recently discovered Cat Creek and Devils Basin oil fields and the search for new fields, four press notices were issued early in 1921 and 1922 describing the essential features of the geology of the area and giving the writer's opinion as to the probable extent of the known fields and the possibility of obtaining oil in other parts of the area. The purpose of the present report is to assemble all the geologic data obtained in the field work and brought to light in the development of the two oil fields and to discuss some of the oil-field problems and the future oil possibilities of the area.

*Acknowledgments.*—Efficient assistance was given to the writer in 1920 by J. M. Vetter and Bruce White and in 1921 by M. N. Bramlette, James Gilluly, and Lloyd Fenstermacher. The writer received well logs and much information regarding oil-field development from geologists, officials of oil companies operating in the region, and ranchers, to whom he desires here to express his thanks. He especially desires to acknowledge the aid given by C. E. Beecher, F. X. Schwarzenbek, R. B. Kelly, and J. R. Reeve, of the Bureau of Mines; C. Max Bauer, chief geologist of the Mid Northern Oil Co.; A. A. Hammer, chief geologist of the Absaroka Oil Development Co.; and Elfred Beck, consulting geologist, of Billings, Mont.

## GEOGRAPHY

A branch of the Chicago, Milwaukee & St. Paul Railway connects Winnett, the only town in the area, with the main line at Lewistown. Winnett, being the nearest railroad point to the Cat Creek field, has been the center of operations in the development of the field. A pipe line connects this railroad terminal with the oil field. Operations in the Devils Basin field were carried on from Roundup, a town about 20 miles south of the field, on the main line of the Chicago, Milwaukee & St. Paul Railway. The Custer Highway, one of the main routes to the Glacier National Park, crosses the southwestern part of the area and is shown on Plate 3. The only other highways worthy of the name are the two running westward to Lewistown from Winnett and Valentine. Most other roads in the area, except those on the gravel benches, are but winding trails across the prairie.

There are a few isolated sheep and cattle ranches in the area, and near the two railroads dry-land farming is practiced with varying degrees of success. Where there is water for irrigation, however, large crops of alfalfa, grain, vegetables, berries, and even fruit, such as apples, cherries, and plums, may be raised. Under natural conditions the plains, where they are underlain by shale, support a sparse growth of buffalo grass, black sage, and greasewood. In areas underlain by sandstone, mountain sage, bluejoint grass, and on northern bluffs, bull pine grow. Bull pine, Douglas fir, and scrub cedar also flourish in the " breaks " along the larger streams in both shale and sandstone soil. Cottonwood and willow grow on the bottom land along the rivers and larger creeks.

The climate of the area shows a wide range of temperature, from very hot in summer to very cold in winter, the extreme range during some years being as much as 160°. The annual rainfall is small, averaging about 12 inches, and most of it occurs in the winter and spring.

## TOPOGRAPHY

The area, although entirely within the Great Plains province, has a diversified topography. In areas adjoining Musselshell and Missouri Rivers the surface is rough. This is especially true of the area along the Musselshell and its tributaries between Missouri River and the Cat Creek oil field. In this area the outcropping rocks are mainly the sandstones of the Lance formation, and their erosion has produced a badland type of topography. Although along Missouri River and Armells Creek in the northern part of the area the relief attains the maximum for the area—600 to 800 feet—the topography is not so rugged there as along the Musselshell and its tributaries, because the valleys are cut in soft shales. Outside of these rougher areas the surface forms range from the smooth, level, grass-covered gravel benches to the rough, uneven, sagebrush-covered plains, which are broken by numerous gullies and valleys of meandering streams. The topography of the plains is further varied by hogbacks of sandstone produced in the weathering of steeply dipping strata and by the escarpments marking the outcrop of these same beds where they are less steeply inclined. Where the strata are folded into domes these escarpments may inclose basins where the strata that crop out in the crest of the dome are soft, or they may form domelike ridges where these strata are hard. In the area west of Winnett a number of small buttes of igneous rocks rise a hundred feet or so above the surrounding plains. In the western part of the area there are shallow lakes and ponds, some of which are dry during most of the summer and fall.

Musselshell and Missouri Rivers are the major streams of the region and drain the entire area here described. Most of the secondary streams flow eastward into the Musselshell. Only those that rise in the Big Snowy Mountains—McDonald, Elk, Flat Willow, and South Willow Creeks—contain running water throughout most of the year.

The altitude of the area ranges from 4,100 feet at the top of gravel benches in the southwestern part of the area to 2,200 feet at the mouth of Musselshell River.

## STRATIGRAPHY

*General section.*—The sedimentary rocks exposed in this general region consist of about 11,000 feet of strata ranging in age from pre-

Cambrian to Recent. Of these strata about 5,400 feet crop out in the area mapped, the oldest exposed being the upper part of the Kootenai formation, of Lower Cretaceous age. Knowledge of the older rocks has been obtained from their outcrops in the Big Snowy Mountains, 20 miles west of the area. The Madison limestone, of lower Mississippian age, is the oldest formation that has been penetrated by wells drilled in the area. The sequence and character of the formations present in the region are given in the subjoined table. The formations penetrated in wells are shown graphically in Plate 3. In the following pages the Colorado shale, Kootenai, Ellis, and Quadrant formations are described in greatest detail, because they include the strata that are of most importance in a study of the oil resources of the area.

*Alluvium.*—The alluvium deposits occur on the bottom lands of flood-plain origin along the major streams of the area and on the smooth-surfaced slopes of alluvial-fan origin which extend outward into valleys that are bordered by prominent ridges or bluffs.

*Glacial drift.*—In the northern part of the area there are numerous scattered boulders and pebbles composed mainly of red granite, together with some basic igneous rocks and limestone erratics which were deposited by the continental glacier that covered northern Montana during parts of Pleistocene time. The line shown in Figure 9 marks the southern limit of these materials. As no glacial till is associated with them, it is possible that the ice sheet did not extend as far south as this boundary and that these boulders may have been carried by ice floating out from the glacier on bodies of water formed by the damming of streams by the glacier.

*Bench gravels.*—In the extreme southern and northwestern parts of the area there are high benches whose flat, even surfaces form prominent features of the landscape. Each of these benches consists of a deposit of gravel and sand that has a thickness of 10 to 50 feet. These materials are derived from strata that crop out in adjacent mountains and are presumably remnants of coalescent alluvial fans formed by streams rising in those mountains and depositing their load of detrital material where they debouched upon the surrounding plains. As a result of periodic elevations of the region or change in climate the streams have partly eroded the older benches and built successively younger ones. Thus the benches remaining are but remnants of benches formed at different levels and in different periods. Those occurring in this area are probably of early Pleistocene and later age. Only the highest benches in the southern part of the area were mapped. They have an altitude of 3,800 to 4,100 feet above sea level and slope from the mountain at about 20 feet to the mile. The presence of these benches on the

*Sedimentary formations in central Montana*

| Era | Geologic age | Group and formation | Thickness (feet) | Character |
|---|---|---|---|---|
| Cenozoic. | Recent. | Alluvium. | 0-50± | Flood-plain and alluvial-fan deposits of clay, sand, and gravel. |
| Cenozoic. | Pleistocene. | Glacial drift. | 1-10 | Boulders and gravel of granite, other igneous rocks, and limestone. |
| Cenozoic. | Pleistocene. | Bench gravel. | 10-50 | Deposits of gravel and sand forming flat-topped benches. |
| Cenozoic. | Eocene. | Fort Union formation. | 1,850-1,950 | A nonmarine sandy formation containing massive sandstone, buff and gray shale, and coal beds. |
| Cenozoic. | Eocene (?). | Lance formation. | 820 | A brackish to fresh water sandy formation containing brown and gray sandstone, shale, clay, and earthy lignite. |
| Mesozoic. | Upper Cretaceous. | Montana group: Bearpaw shale. | 1,000-1,200 | Steel-gray to black and greenish-black marine shale containing beds of bentonite and lumpy concretions. |
| Mesozoic. | Upper Cretaceous. | Montana group: Judith River formation. | 200-500 | Beds of fresh and brackish water origin containing sandstone, sandy shale, and gypsiferous and lignitic clay. |
| Mesozoic. | Upper Cretaceous. | Montana group: Claggett shale. | 430-650 | Dark-gray to brownish-black marine shale containing beds of bentonite and yellow calcareous concretions. |
| Mesozoic. | Upper Cretaceous. | Montana group: Eagle sandstone. | 120-220 | Massive beds of white to buff sandstone and sandy shale; Virgelle sandstone member at base. |
| Mesozoic. | Upper Cretaceous. | Colorado shale. | 1,740-2,080 | Dark-blue to black marine shale containing beds of bentonite, calcareous concretions, sandy shale, and sandstone. |
| Mesozoic. | Lower Cretaceous. | Kootenai formation. | 450-500 | Nonmarine red and green shale, sandstone, and nodular limestone. |
| Mesozoic. | Lower Cretaceous(?). | Morrison (?) formation. | 200-300 | Variegated shales, lenses of sandstone, and thin limestone beds. |
| Mesozoic. | Upper Jurassic. | Ellis formation. | 150-1,300 | Marine sandy limestone, calcareous sandy shale, and sandstone. |
| Paleozoic. | Pennsylvanian. | Quadrant formation. | 1,288-1,670 | Beds of marine and nonmarine red and black shale, limestone, and sandstone. |
| Paleozoic. | Mississippian. | Madison limestone. | 1,950 | Massive and thin-bedded marine limestone. |
| Paleozoic. | Cambrian. | | 300 | Conglomeratic limestone with flat pebbles. |
| Paleozoic. | Cambrian. | | 750 | Mainly greenish micaceous shale. |
| Paleozoic. | Cambrian. | | 75 | Coarse sandstone with layers of quartz conglomerate. |
| Proterozoic. | Algonkian (Belt series). | | [a] 300 | Dark limy shale. |

[a] Thickness exposed.

flanks of the Devils Basin and other anticlines in the region to the west and their absence on the crests of the folds across which they apparently once extended are believed by the writer to indicate that there has been a slight movement along the axes of the anticlines since the deposition of the gravel, with consequent removal of it from the elevated areas.

*Fort Union formation.*—Beginning with the Fort Union formation, which is considered of early Tertiary (Eocene) age, there appears to be a conformable sequence of strata down to at least the base of the Kootenai formation, and no marked evidence of angular unconformity until the pre-Cambrian beds are reached. In the Bull Mountain syncline, just south of the area mapped, the Fort Union formation is represented by 1,850 to 1,950 feet of massive sandstone and interbedded shale containing valuable beds of coal. In the area mapped only the lower part of the Fort Union is present, and this is found only in the synclinal trough south of the Devils Basin anticline. At the base is the Lebo shale member, which consists of about 250 feet of tan shale, including near its base the Big Dirty coal, a 6 to 10 foot bed of earthy coal that weathers into conspicuous outcrops. Above the Lebo shale the Fort Union contains sandy shale and thick beds of grayish-white sandstone. These rocks form the sandstone bluffs in T. 10 N., R. 25 E., on the southern edge of the topographic basin from which the Devils Basin anticline received its name.

*Lance formation.*—The Lance formation, like the Fort Union, is mainly of fresh-water origin and consists of gray to buff irregularly bedded clayey sandstone, gray to black gumbo clay, sandy shale, brownish ferruginous concretionary layers, and lenticular earthy lignite that has been mined on a small scale at one or two localities near Valentine post office, in the northern part of the area. At the base of the Lance there is a series of black shales and thin beds of yellow sandstone transitional to the underlying Bearpaw shale, indicating the absence of any marked hiatus between the two formations. These transitional beds, tentatively assigned to the Lance formation, may possibly represent the Fox Hills sandstone. The entire Lance formation is present on the south flank of the Devils Basin anticline, where it has a thickness of approximately 800 feet. Its basal part only is present in the Blood Creek syncline, in the northeastern part of the area.

*Montana group.*—Four formations, the Bearpaw shale, Judith River formation, Claggett shale, and Eagle sandstone, make up the Montana group in this region. In the area mapped these formations consist of marine shale and sandstone that is largely of nonmarine origin. As Stebinger[1] and Bowen[2] have shown, the Judith River and Eagle formations merge eastward into the Pierre shale.

[1] Stebinger, Eugene, The Montana group of northwestern Montana: U. S. Geol. Survey Prof. Paper 90, pp. 61–68, 1914.

[2] Bowen, C. F., Gradations from continental to marine conditions of depositions in central Montana during the Eagle and Judith River epochs: U. S. Geol. Survey Prof. Paper 125, pp. 11–21, 1919.

Consequently across the area mapped there are changes in thickness and character of the formation, but as these have been described by Bowen, they will not be considered in detail here. On the flanks of the anticlinal folds in the area the Bearpaw and Claggett shales form belts of low relief, and the Judith River formation and Eagle sandstone form hogbacks and ridges.

The Bearpaw shale, which is of marine origin, in the western part of the area consists of about 1,100 feet of steel-gray shale and in the eastern part of the area is slightly thicker and contains near its top layers of greenish-black shale. In the southern part, south of Devils Basin, the shale is dark gray to black and has a thickness of approximately 1,200 feet. In all localities where the formation was examined it contains thin beds of bentonite and irregular concretionary lumps, some of which have a flattened spherical form and are 2 to 3 feet in diameter. Most of these concretions are fossiliferous. On exposure to the weather they crumble into reddish or grayish-white lumps. In the northern part of the area there is a thick bed of grayish-white bentonitic clay at the base of the formation.

The Judith River formation in the extreme northwestern part of the area consists of about 500 feet of irregularly bedded lenticular gray to tan sandstone, sandy shale, and gypsiferous and lignitic clays. In the eastern and southern part of the area the beds are more clayey and are only about 200 feet thick.

The Claggett shale consists of dark marine shale which to the northwest takes on a brownish tinge. Toward the east the shale becomes more clayey. In the northern part of the area the formation contains a triple bed of bentonite at its base and thin beds of the same material in other parts. In most areas the Claggett shale is distinguishable from the Bearpaw and Colorado shales by the presence in its upper portion of calcareous yellow concretionary beds which weather out in large yellow slabs that are unlike the concretions in the other shale formations. The measured thickness of the Claggett shale in the area ranges from 430 to 650 feet, but the variation is probably due to the thickening and thinning of this formation during the folding of the strata, for in some localities the beds have been thinned to one-third of their probable normal thickness.

The Eagle sandstone varies in character in the area mapped, but in most localities a threefold division in it can be recognized—an upper bed of soft grayish-white nonmarine sandstone, a middle bed of gray to dark sandy shale, and a lower bed of buff massive to thin-bedded marine sandstone known as the Virgelle sandstone member. To the east the middle shale member thickens and the sandstone members become thinner. East of Musselshell River the formation, though still represented by sandy shale, has lost its identity as a sandstone formation and has little topographic expression. From the Musselshell westward the sandstone members become thicker and more massive, and in the western part of the area the middle shale member entirely disappears. In these localities the Eagle sandstone forms prominent escarpments and hogbacks at its outcrop. The rim rock inclosing the west end of the Cat Creek oil field and the east end of Devils Basin is produced by the Eagle sandstone.

*Colorado shale.*—The Colorado shale, though composed almost entirely of marine shale, contains many beds of bentonite, calcareous concretions, sandy shale, and one or two thin layers of sandstone. Many of these beds have a widespread development and possess characteristics that make them easily recognizable and therefore valuable as horizon markers. These members are described in the section given below.

*Section of the Colorado shale measured in Brush Creek and Kootenai domes*

| | Feet |
|---|---|
| 1. Blue and gray shale containing sandy shale at top and many beds of bentonite, 5 to 10 feet thick | 520 |
| 2. Calcareous gray sandstone (Sage Hen limestone of Lupton and Lee [3]) | 5 |
| 3. Dark-blue shale containing gray calcareous concretionary beds 1 to 2 feet thick | 40 |
| 4. Dark-blue shale containing two or three yellow calcareous concretionary beds, 2 to 5 feet thick | 50 |
| 5. Dark clay shale containing two bands of red ferruginous concretions that weather into small chips | 10 |
| 6. Dark-blue shale containing a bed of bentonite 10 feet thick | 110 |
| 7. Calcareous fine-grained sandstone containing numerous fossils of *Exogyra columbella*, *Callista orbiculata*, and *Pseudomelania*; forms prominent escarpments and is a valuable horizon marker (Mosby sandstone member) | 5 |
| 8. Black shale containing a number of gray calcareous concretionary zones | 55 |
| 9. Black shale containing two yellow calcareous concretionary beds | 50 |
| 10. Dark shale | 200 |
| 11. Grayish-white fissile sandy shale and fine-grained clayey sandstone with thin lamination of dark shale bearing fish scales (Mowry shale member) | 100 |
| 12. Black shale | 390 |

[3] Lupton, C. T., and Lee, Wallace, Geology of the Cat Creek oil field, Fergus and Garfield Counties, Mont.: Am. Assoc. Petroleum Geologists Bull., vol. 5, No. 2, pp. 252–275, 1921.

| | |
|---|---|
| 13. Sandy shale; not recorded in many wells in Cat Creek field but is represented in the western and southern part of the area by a flaggy sandstone containing scattered black pebbles; probably close equivalent to the Muddy sand of Wyoming | 20 |
| 14. Black shale, basal part sandy | 250 |
| 15. Flaggy, ripple-marked fine-grained yellowish-gray sandstone containing fresh-water unios and markings resembling worm tracks (First Cat Creek sand) | 40 |
| 16. Gray to white shale | 5 |

In this section Nos. 2, 5, 7, 11, 13, and 15 are the most important horizon markers. These beds have a widespread development throughout central and northern Montana and after they have once been seen can usually be recognized wherever they are exposed. Because of its hardness the Mosby sandstone (No. 7) is usually recorded in the logs of wells drilled through it and for the same reason forms at its outcrop prominent escarpments and ridges. For these reasons it is probably the best of all the horizon markers and is often used as a datum plane on which structure contours are drawn. In the Cat Creek oil field and in most of the domes in the northern part of the area the Mosby sandstone occurs about 1,065 feet above the First Cat Creek sand. In the Devils Basin field, in the southern part of the area, it is about 1,125 feet above the same sand. The thickness of the Colorado shale in the northern part of the area and in most of northern Montana is about 1,800 feet. It thickens toward the south, being about 2,100 feet thick in Devils Basin and 2,500 feet in the Soap Creek field. The variation in the thickness and lithologic character of the Colorado shale in Montana is adequately summed up by Bauer and Robinson.[4]

The writer has followed the practice of the earlier workers in the region and included everything in the Colorado shale occurring between the Eagle sandstone and the red shale of the Kootenai formation. He is of the opinion, however, that the sandstone at the base of the Colorado shale, the First Cat Creek sand, is equivalent in part to the Dakota sandstone, for the reason given in a report on an adjacent area.[5] A tentative correlation of the Colorado shale with the Cretaceous formations of Wyoming is given in Plate XI of the same report.

*Kootenai and Morrison (?) formations.*—Between the Colorado shale and the marine calcareous sandstone of the Ellis formation of Upper Jurassic age occur in this region from 600 to 700 feet of beds of nonmarine origin which belong, largely at least, to the Kootenai

[4] Bauer, C. M., and Robinson, E. G., Comparative stratigraphy in Montana: Am. Assoc. Petroleum Geologists Bull., vol. 7, No. 2, pp. 165–171, 1923.

[5] Reeves, Frank, Geology and possible oil and gas resources of the faulted area south of the Bearpaw Mountains, Mont.: U. S. Geol. Survey Bull. 751, p. 92, 1924.

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formation, though the basal part has been assigned to the Morrison by earlier workers in the field. Owing to the general similarity of these beds and the absence of any discernible boundary between them, they will here be described together. They consist of variegated clayey shale, lenticular cross-bedded, coarse-grained to conglomeratic sandstone, and thin beds of nodular fresh-water limestone and lenses of coal. There is a great lateral variation in the beds and especially in the sandstones, most of which occur only as lenses. As a whole, however, the beds may be divided into three parts, consisting of an upper red shale series, a middle sandstone series, and a lower varigated shale series. The upper series is about 150 feet thick and is composed mainly of red clayey shale which at its outcrop forms areas of low relief with a red soil. These beds crop out in the crest of the Kootenai and Devils Basin domes. The middle sandstone series is about 200 feet thick and contains sandstone with some interbedded red and gray shale and thin nodular limestone. In the Cat Creek field most well logs show two sandstones in this part of the Kootenai. The upper one has a variable thickness but averages about 40 feet; the lower one, which is separated from the upper by about 60 feet of red shale, is in places multiple-bedded and is 60 to 100 feet thick. These are the Second and Third sands of the Cat Creek field. Oil is obtained from the upper sand and the lower usually yields large volumes of fresh water under artesian head. At the outcrop of this part of the Kootenai in the region to the west of the area here considered, sandstones at about the same horizons appear. Apparently the lower sandstone is to be correlated with the massive ridge-forming sandstone that overlies the coal bed of the Lewistown and Great Falls coal fields. The lower variegated shale series lies between this sandstone and the underlying Ellis formation. Its thickness ranges from 200 to 300 feet. The beds consist mainly of red, green, and gray clayey shale in which are lenses of sandstone and one or two beds of sandy gray to yellowish limestone. The coal bed occurring near the top of the series farther west is not reported in the logs of the wells drilled in the Cat Creek and Devils Basin fields, and may not be present in these areas.

The upper part of these strata of fresh-water origin lying without visible unconformity between the overlying marine Colorado shale and the underlying marine Jurassic was first correlated with the Kootenai formation of Canada on the basis of fossil-plant determinations made by Newberry.[6] As a result of further studies of plant collections by a number of geologists Fisher[7] assigned all these fresh-

[6] Newberry, J. S., Geological notes—The Great Falls coal field, Mont.: School of Mines Quart., vol. 8, p. 329, 1887.

[7] Fisher, C. A., Geology of the Great Falls coal field, Mont.: U. S. Geol. Survey Bull. 356, pp. 28–36, 1909.

water beds occurring in the Great Falls coal field to the Kootenai formation, with the exception of the lower 60 to 120 feet of strata, which he tentatively referred to the Morrison formation because of the discovery in them of dinosaur bones provisionally regarded by C. W. Gilmore as of Jurassic age. Calvert,[8] without finding positive evidence as to the presence of the Morrison in the Lewistown coal field, included the basal 125 feet of the beds with that formation, selecting as a boundary between it and the Kootenai the top of a persistent sandstone member 10 to 15 feet thick lying from 60 to 90 feet beneath the coal bed. Thus it is apparent that there is no clear evidence that the Morrison formation is present in the region, but inasmuch as the beds referred to it have the same stratigraphic position and lithology as the Morrison in southern Montana, it seems quite possible that they may be of Morrison age. This conclusion is supported by the fact that in the Little Rocky and Bearpaw Mountains, in northern Montana, these beds are absent, the Ellis being immediately overlain by the beds which in central Montana have been generally referred to the Kootenai formation.

*Ellis formation.*—At its outcrop in the east end of the Big Snowy Mountains, immediately west of the area mapped, the Ellis consists of 150 feet of grayish-white fossiliferous and glauconitic sandstone and calcareous shale. Farther west, in the Lewistown coal field, according to Calvert,[9] the Ellis consists of 65 to 440 feet of sandstone and thin limestone in which there are red and gray shales and in some localities gypsum beds. The writer doubts whether there are beds of red shale and gypsum in the Ellis, for the formation where he has studied it in detail on the east and south flanks of the Big Snowy Mountains and on the north slope of the South Moccasin Mountains, as well as in the Bearpaw and Little Rocky Mountains, consists of marine beds in which there are no red shale or gypsum. On the other hand, such beds commonly occur in the upper part of the underlying Quadrant formation. In the sections given by Calvert,[10] the gypsum beds and red shale are in the lower part of the section, and therefore may belong to the Quadrant. At most outcrops of the Ellis the presence of the formation, if not its limits, can be definitely recognized by the occurrence of fossil shells, among which *Ostrea strigilecula*, *Gryphaea calceola*, and *Belemnites densus* are fairly common. Glauconite in the form of small greenish rounded particles is also characteristic of most beds of the Ellis where the writer has studied them, and is not present in appreciable amount

[8] Calvert, W. R., Geology of the Lewistown coal field, Mont.: U. S. Geol. Survey Bull. 390, p. 22, 1909.

[9] Idem, pp. 19–21.

[10] Idem, p. 20.

in beds of adjacent formations. Where such conditions exist they furnish a guide for the recognition of the formation in wells from which drill samples are collected. As the writer had no drill samples from the deep wells in the area mapped, he was unable to determine with much certainty the upper and lower limits of the Ellis. Carefully kept logs of wells that have been drilled deep enough, however, show a series of 250 to 300 feet of sandstone and limy shale at depths of 600 to 700 feet below the First Cat Creek sand, which probably are closely equivalent to the Ellis formation. At the top of the series there is usually a sandstone and beneath it a limestone or red shale marking the top of the Quadrant formation.

*Quadrant formation.*—The Quadrant formation at its outcrop in the Big Snowy Mountains consists of beds varying widely in lithologic character and color. There is probably no other formation in the region which shows so great a variety of sedimentary rocks. The predominating beds consist of variegated sandy and limy shales. In these occur many thin beds of fossiliferous gray and pinkish limestone and some of sandstone. The limestone beds are marine and are usually interbedded with red shale. A series 100 to 200 feet thick of such beds in which the limestone predominates occurs in the top of the formation. The few sandstone members in the formation are coarse grained and lenticular and weather reddish brown to yellow. Black petroliferous shale, plant-bearing beds, and gypsiferous shale are also included in the formation.

The Quadrant formation is separated from the overlying Ellis by a marked unconformity, which is described in detail in the section given on page 52. No evidence of an unconformity was noted at the base of the formation at its outcrop in the Big Snowy uplift. In the area mapped a number of wells have been drilled into the Quadrant formation. The strata penetrated by the drill in general resemble those at the outcrop of the formation in the Big Snowy Mountains. In a few wells in Devils Basin oil has been obtained in a thin calcareous sandstone occurring 500 to 600 feet below the top of the formation. The thickness of the Quadrant varies at its outcrop in the region. In the Big Snowy Mountains it is 1,200 to 1,300 feet thick. In the Judith Mountains, according to Weed and Pirsson,[11] its thickness is only 40 feet. Palmer [12] reports it to have a maximum thickness of 70 feet in the South Moccasin Mountains. In the Bearpaw and Little Rocky Mountains the Quadrant is entirely absent, the Ellis there resting on the Madison limestone. In

[11] Weed, W. H., and Pirsson, L. V., Geology and mineral resources of the Judith Mountains of Montana: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 471–473, 1898.

[12] Palmer, H. C., The South Moccasin Mountains, Mont. (unpublished manuscript).

the Devils Basin oil field the logs of the two wells (Nos. 19 and 24, pl. 3) that have been drilled through the formation show that it has, as defined by the writer, a thickness of 1,320 feet and 1,288 feet, respectively. The only other well in the area that has been drilled through the formation (No. 3, pl. 3), located on the Kootenai dome, shows, according to the writer's interpretation a thickness of 1,670 feet.

Stratigraphically, the deepest well drilled in the Cat Creek field, the Frantz Oil Corporation's well in sec. 27, T. 15 N., R. 26 E., penetrated 1,350 feet of the Quadrant without reaching the base of the formation.

The exact age of the beds assigned to the Quadrant formation in central Montana is in doubt. As pointed out by Bauer and Robinson,[13] their stratigraphic position and lithology suggest that they are equivalent, in part at least, to the Tensleep sandstone and Amsden formation of southern Montana and Wyoming, which are mainly of Pennsylvanian age. Yet, according to G. H. Girty, the fossils collected by M. I. Goldman and the writer near the top of the Quadrant formation in the Big Snowy Mountains have a definite Mississippian facies. Below is a list of the fossils as determined by Mr. Girty from this collection, which was made from a bed occurring about 200 feet below the top of the section on page 53 showing the character of the Quadrant on the north flank of the Big Snowy Mountains:

Enchostoma sp.
Lingula sp.
Lingulidiscina n. sp.
Schizophoria n. sp.
Chonetes aff. C. sericeus.
Productus ovatus var. latior.
Productus ovatus var. minor?
Avonia arkansana.
Martinia aff. M. contracta.
Composita aff. C. subquadrata.
Sphenotus aff. S. octocostatus.
Aviculipecten sp.
Modiola fontainensis?
Leptodesma? sp.
Trepospira? sp.
Naticopsis n. sp.
Meekospira? sp.
Cytherella? sp.

The following sections, measured in 1922 by M. I. Goldman and the writer, show the character of the Ellis formation and the upper

[13] Op. cit., pp. 177–178.

part of the Quadrant formation in the Big Snowy Mountain uplift:

*Section of the Ellis formation and the upper part of the Quadrant formation near Button Butte, sec. 18, T. 14 N., R. 24 E.*

| | Feet |
|---|---|
| Ellis formation: | |
| Grayish-white flaggy sandstone, weathering brownish yellow, rippled-marked in top part; some glauconite in partings | 40 |
| Dark sandy shale only partly exposed, glauconitic at base | 13 |
| Sandy series; basal part consists of flaggy greenish-gray sandstone members 1 to 4 feet thick, weathering dirty yellow, separated by glauconitic sands with thin clay partings which divide the sand into lentils from one-eighth to 1 inch thick and a few inches long. Top of series is limy and less glauconitic | 50 |
| Dirty greenish-yellow glauconitic sandy limy shale | 25 |
| Fossil marl containing *Gryphaea calceola* var. *nebrascensis* Meek and Hayden, *Camptonectes* sp., *Cyprena?* *cinnabarensis* Stanton, *Pleuromya subcompressa* (Meek), *Natica* sp., *Kepplerites?* sp., *Sphaeroceras?* sp.[14] | 1 |
| Sandy limy shale with boulders described below | 1 |
| | 130 |
| Quadrant formation: | |
| Pinkish to brownish-gray limestone, top surface glazed and partly silicified and marked by borings one-eighth to 1 inch in diameter and one-half to 1 inch deep. Surface also marked by peculiar radial markings that look like cracks filled with clay and by potholes containing angular to well-rounded boulders of quartzite, 6 inches to 2 feet thick, veined and shattered with borings on top and bottom sides similar to those in the underlying limestone | 10 |
| Pink limy shale | 13 |
| Grayish-white limestone interbedded with pink limy shale | 20 |
| Hard, massive grayish-white fossiliferous crystalline limestone | 5 |
| Pink limy shale | 13 |
| Grayish-white crystalline limestone separated by thin beds of shale | 15 |
| Pink limy shale and thin limestone | 15 |
| Hard, bluish-gray limestone | 19 |
| Hard, fossiliferous well-bedded limestone and limy shale forming a resistant series that weathers in vertical cliffs. The upper part consists largely of limy shale containing persistent chert bands, 6 inches to 2 feet thick. Total exposed | 150 |

[14] Determination by T. W. Stanton.

*Section of upper part of Quadrant formation on north flank of Big Snowy Mountains, sec. 12, T. 12 N., R. 19 E.*

[Section begins with the highest rocks exposed and probably starts near the top of the formation]

| | Feet |
|---|---|
| Hard light-gray well-bedded limestone | 15 |
| Pink limy shale | 8 |
| Hard well-bedded light-gray fossiliferous limestone with beds of pink shale 1 to 2 feet thick occurring every 10 feet. *Composita subquadrata*[15] collected near top of series | 60 |
| Gray fossiliferous limestone | 5 |
| Pink limy shale | 3 |
| Massive to well-bedded gray limestone, weathering pink | 30 |
| Hard irregularly bedded light-gray limestone with elongated chert nodules | 2 |
| Thinly laminated or banded gray and pink limestone | 1 |
| Hard light-pink fossiliferous limestone | ½ |
| Red and green shale | ½ |
| Hard light-gray irregularly bedded limestone | 3 |
| Maroon and gray shale | 3 |
| Hard finely laminated bluish-gray limestone stained reddish brown | 3 |
| Maroon and green shale | 8 |
| Massive argillaceous and calcareous mottled sandstone | 10 |
| Mottled limy shale and thin-bedded limestones | 10 |
| Maroon and green shale with thin beds 6 inches thick of yellowish-green argillaceous limestone containing *Productus ovatus*[15] | 8 |
| Maroon and green shale | 15 |
| Hard yellowish-gray fossiliferous limestone | 2 |
| Maroon and green shale | 3 |
| Black shale | ⅕ |
| Grayish-yellow limestone containing ostracodes | 4 |
| Black petroliferous and fossiliferous shale | 4 |
| Hard greenish-gray calcareous clay containing fossils (listed on page 51) | 2 |
| Light-brown limy shale | 4 |
| Brittle brown petroliferous paper shale | 2 |
| Dark-brown shale with thin bands of red shale | 25 |
| Sandy shale | 5 |
| Thin-bedded coarse-grained sugary brownish-yellow sandstone grading upward into a sandy shale | 10 |
| Dark-brown shale, carbonaceous near base | 30 |
| Irregularly bedded to cross-bedded coarse-grained sandstone containing stems and fragments of plants and ferruginous concretions, weathering brownish yellow | 15 |
| Dark-blue shale changing to light gray toward top, with thin ferruginous and calcareous bands 1 to 2 inches thick near top | 100 |
| Massive to cross-bedded medium to coarse-grained sugary sandstone, weathering brownish gray to reddish brown, lower part contains chert and ferruginous masses | 70 |

[15] Determinations by G. H. Girty.

| | Feet |
|---|---|
| Concealed | 19 |
| Dark shale with yellow nodular limestone at top | 10 |
| Grayish-green limy shale with thin flaggy beds of oolitic and petroliferous limestone and chert pebbles | |
| Gray limy shale | 35 |
| White sandstone | 1 |
| Light-gray sandy and limy shale | 50 |
| Grayish-white coarse-grained sandstone | 6 |
| Variegated sandy and calcareous shale | 20 |
| Sandy argillaceous limestone with fragments of red shale | 2 |
| Pink limy and sandy shales, basal part concealed | 70 |

*Madison limestone.*—The Madison limestone at its outcrop in the Big Snowy Mountains, according to Calvert,[16] is 1,950 feet thick and consists of massive gray limestone interbedded with shaly limestone and at the base 200 feet of chocolate-brown limestone, which, when struck with a hammer, gives off a fetid odor.

*Pre-Carboniferous formations.*—As the pre-Carboniferous formations lie too deep to be reached by the drill in this area, they will not be discussed here. Descriptions of them at their outcrops in adjacent regions have been given by Weed and Pirsson [17] and by Calvert.[18]

## IGNEOUS ROCKS

In the area west of Winnett, mainly in Tps. 13, 14, 15, and 16 N., R. 25 E., igneous rocks in the form of volcanic necks, dikes, and sills are exposed at a number of places. The volcanic necks are elongated masses of irregular shape, having a maximum length of 1,000 feet and a maximum width of 300 feet. The igneous rocks in these necks are gray to yellowish brown and range from a fine-grained tuff to a coarse volcanic breccia containing fragments of sedimentary rocks and tuffaceous material. The inclusions of sedimentary rocks consist largely of shale ranging from small angular fragments to large blocks several feet in diameter. Thin sections of some of these rocks were examined in the Geological Survey's petrographic laboratory by Clarence S. Ross, who reports that most of them appear to be rhyolites in which many of the phenocrysts and a large part of the groundmass are altered to calcite. These igneous masses with the associated narrow zones of hardened shale, form high buttes that are prominent features of the landscape. Some of them occur in pairs or in groups of three, with their longer axes in alinement and par-

[16] Calvert, W. R., unpublished report on Paleozoic formations in the Big Snowy Mountains, cited by Walcott, C. D., Relations between the Cambrian and pre-Cambrian formations in the vicinity of Helena, Mont.: Smithsonian Misc. Coll., vol. 64, No. 4, pp. 275–276, 1914–1916.

[17] Op. cit., pp. 464–470.

[18] Op. cit., pp. 273–276.

allel to the dikes occurring in the region, a position suggesting that they may have been fed by such dikes. How deep these igneous masses have been eroded and how much material, if any, was intruded on the surface of the region through these channels can not be determined. It may be stated, however, that these rocks, as well as the associated dikes and sills, do not cut strata younger than the Colorado shale. The dikes are 2 to 4 feet wide and reach a probable maximum length of 2 miles. They trend N. 50°–60° E., which is the direction of most of the faults in the area. The dike rock is commonly a fine-grained dense rock of a brick-red to reddish-yellow color. Mr. Ross states that in the thin sections studied he could detect some small angular fragments of quartz and feldspar, but that most of the original minerals had been so altered to iron oxide and calcite that they could not be identified.

Two sills were noted in the area. One of them, in sec. 6. T. 14 N., R. 25 E., 11 miles west of Winnett, follows a bedding plane in the Colorado shale a few feet above the Mowry shale member and ranges in thickness from 2 to 4 feet. Only a few hundred feet of the outcrop was traced, and it probably has no great extent. This rock represents an unusual type, resembling closely in mineral composition the peridotites in Arkansas and at Kimberly, South Africa, but, unlike them, occurring as a thin, hard, dense sheet. Ross,[19] who made a petrographic study of the rock, describes it as a nephelite-haüynite-alnoite.

As there had been newspaper reports that some of the igneous rocks occurring in the area contain gold and silver, the writer collected a number of samples of them, but after assaying these samples Ledoux & Co., of New York, reported that only the merest traces of gold and silver were present.

## STRUCTURE

### METHODS OF MAPPING THE STRUCTURE

The contours in Plate 3 show the altitude of the First Cat Creek sand above sea level. Within the area mapped this sand crops out only in the crests of the Devils Basin and Kootenai domes and is penetrated by the drill only in a few wells outside of the small area of the Cat Creek field. Its altitude elsewhere was determined by subtracting from the altitude of outcropping beds the stratigraphic interval between those beds and the First Cat Creek sand. The fol-

[19] Ross, C. S., Nephelite-haüynite-alnoite from Winnett, Mont.; Am. Jour. Sci., 5th ser., vol. 11, No. 63, pp. 218–221, November, 1924.

lowing table gives the intervals that were used in contouring different parts of the area:

*Intervals between the First Cat Creek sand and top of overlying key beds*

| Bed or formation | Devils Basin and adjacent localities | Cat Creek and adjacent localities | Bed or formation | Devils Basin and adjacent localities | Cat Creek and adjacent localities |
|---|---|---|---|---|---|
| Big dirty coal | 5,150 | ---------- | Colorado shale: | | |
| Lance formation | 5,070 | ---------- | Top | 2,030 | 1,740 |
| Bearpaw shale | 4,250 | 3,670 | "Red chip" zone | 1,250 | 1,190 |
| Judith River formation | 3,050 | 2,570 | Mosby sandstone member | 1,125 | 1,070 |
| Claggett shale | 2,850 | 2,370 | Mowry shale member | 815 | 800 |
| Eagle sandstone | 2,200 | 1,940 | Muddy(?) sand | 220 | ---------- |

In localities where the beds dip more than 10° these intervals are appreciably less than the vertical distance between the beds and should be multiplied by the cosine of the angle of the dip of the surface beds. However, where the strata dip 30° or more, as along the margin of the Cat Creek-Devils Basin uplift, this procedure can not be followed, for

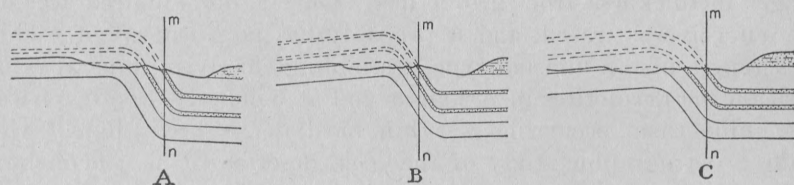


FIGURE 7.—Three possible interpretations of the structure along the margin of the Cat Creek-Devils Basin uplift, Mont.: A, Concentric type; B, similar type; C, combination of concentric and similar types

it is based on the assumptions that beds lying vertically beneath an outcropping bed have the same dip as the surface bed and that there is no thickening or thinning of the intervening formations. Such a condition can not exist in beds as sharply folded as those under consideration. One of the three types of folding shown in Figure 7 must represent the character of the folding along the steeply dipping margins of the uplift. In section A, which shows folding without change of thickness, the dips of the several beds where they are intersected by the vertical line m–n are markedly different. In section B all beds intersected by the line m–n have the same dip, but this is made possible only by pronounced thinning of the formations. In section C there are both thinning of the formations and change in the dip along the line m–n. Hence in none of these possible types of structure could the altitude of an unexposed bed be obtained by subtracting from the altitude of an exposed overlying bed the stratigraphic interval between the beds multiplied by the cosine of the angle of dip of the exposed bed.

If such a procedure were followed in contouring the structure on the flanks of the uplift shown in Plate 3, the contours would show a lower altitude for the First Cat Creek sand halfway down the flank than it attains at the foot of the uplift, where the beds are nearly flat-lying and stratigraphic intervals can be used in determining the altitude of this sand. The procedure actually used in contouring the First Cat Creek sand in these belts was to make a structural cross section of the sand from the crest of each dome to the flat-lying beds beyond the belt of steeply dipping strata. An illustration showing how this was done is given in Figure 8. The solid lines show the known or definitely inferable attitude and position of the beds. The dashed lines are drawn to conform as closely as possible to these data. The cross sections thus obtained are then used in determining the position of the contour lines on the steeply dipping flank of each dome. These positions or points of equal altitude are connected by contour lines which are made to parallel as closely as possible the sinuosities of the outcrops of the highly

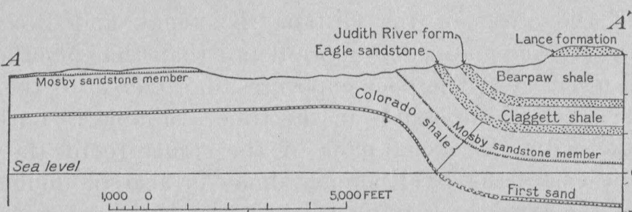


FIGURE 8.—Restoration of structure across Mosby dome, Mont., along line *A–A'*, Plate 3

inclined beds along the margin of the uplift. The result is, as shown on Plate 3, that the contours along the margins of the uplift are not the most closely spaced where the dips of the surface beds are the greatest.

## ACCURACY ATTAINED IN MAPPING THE STRUCTURE

Owing to the rapid reconnaissance character of the field work the structural map presented in Plate 3 can not be regarded as possessing the accuracy that a detailed survey of the area would furnish; but the structure of some portions of the area is more accurately mapped than that of others, in part because of the greater relative detail of the field work, the simpler character of the structure, and supplementary aid furnished to the writer in those portions. In the parts surveyed in the greatest detail one township a week was mapped by the writer and two assistants. The Devils Basin field was surveyed in this manner and is therefore the most accurately mapped portion of the area. The writer's work in this field is also supplemented by the detailed mapping of the crest of the dome within the 4,000-foot contour line by C. L. Arnett and A. M. Lloyd for the Absaroka Oil Development Co., under the supervision of A. A. Hammer. In the Cat Creek field the mapping was done at the rate of about two townships a week. This field work was supplemented later in the office by the contouring of producing areas by the use of well logs and altitudes furnished by the producing companies. The faults shown on the map in these areas are based on the subsurface structure in the First Cat Creek sand, and consequently they show the traces of the fault plane where they intersect this bed and not the traces of the faults at the surface. The writer's work in this field was also supplemented by data obtained from Lupton and Lee's map of the Cat Creek field.[20] The structure of the crest of the dome lying east of Musselshell River, is taken from this source. The territory outside of the Cat Creek and Devils Basin fields was surveyed by the writer and assistants at the rate of about four townships a week, and consequently the mapping of this territory has only the degree of accuracy that could be attained in rapid reconnaissance work. The structure of the crests of the Oiltana, Kootenai, and Box Elder domes, however, was mapped in more detail than that of other portions of the territory. The poor exposures on the crest of the Brush Creek dome made it impossible in the time available to outline its crest satisfactorily. The character of the structure of the minor dome on the east flank of Kootenai dome is also in doubt. The structure of the large area lying between the Kootenai and Devils Basin domes is largely generalized on Plate 3. To map this area in detail would require the detailed methods of mapping used in the Mid-Continent fields. The contours in Figure 9, showing the structure of the territory north of the Devils Basin-Cat Creek uplift, are based chiefly on dip and altitude determinations of a sandstone occurring near the base of the Lance formation where that formation crops out in the southeastern part of the territory and on the altitude of the Judith River formation where it is exposed along Armells Creek and Missouri River in the northwestern part of the territory. There is a broad intervening area of about 20 townships across which the structure is projected. The Bearpaw shale, which is the surface formation in this area, furnishes no recognizable key beds or bedding planes that can be used in determining the structure. No faulting or local flexures were noted during the rapid reconnaissance of the territory shown in Figure 9, and it is doubtful whether a more detailed examination would reveal such structural features.

[20] Op. cit., p. 256.

## STRUCTURAL PROVINCES REPRESENTED IN THE AREA

The larger structural features of central Montana are shown in the contour map compiled by Thom and Dobbin and published in 1923.[21] This map, modified by the writer in several details, is reproduced in Plate 4. It will be noted that the area considered in this report occupies parts of two structural provinces—a broad, shallow syncline, known as the Blood Creek syncline, and a rectangular structural feature, here called the Big Snowy-Judith Mountain anticlinorium.

### BLOOD CREEK SYNCLINE

The Blood Creek syncline is a broad, shallow eastward-pitching syncline which, according to Thom and Dobbin,[22] extends eastward across Garfield and McCone Counties. The northern part of the area mapped lies in this syncline. As indicated in Figure 9, the syncline here has no well-defined axis and takes on more the character of eastward-inclined strata that have been tilted toward the northeast for a distance of 10 to 12 miles in the formation of the Big Snowy-Judith Mountain uplift. These northeasterly dips beyond the highly tilted strata associated with the uplifted block range from 3° to that of the nearly flat-lying strata into which they merge. The strata outside of this belt of northeasterly dips are inclined southeastward at the rate of about 25 feet to the mile.

### BIG SNOWY-JUDITH MOUNTAIN ANTICLINORIUM

One of the most prominent structural features of central Montana is the rectangular area that includes the Big Snowy and Judith Mountains at its west end and the broad belt of uplifted strata which extends eastward from these mountains to and a short distance beyond Musselshell River. This is the area called by Bowen [23] the Big Snowy anticline and a part of the area called by Lupton and Lee [24] the Big Snowy anticlinorium. Inasmuch as the structural feature is not a simple anticline, it will be here referred to as the Big Snowy-Judith Mountain anticlinorium. In the writer's opinion the Porcupine dome, which was included in the anticlinorium by Lupton and Lee, is sufficiently differentiated in character and position to warrant its separation. Thus limited, this anticlinorium is about 80 miles long and 40 miles wide, and consists in reality of three distinct structural features whose association in one uplifted block

[21] Thom, W. T., jr., The relations of deep-seated faults to the surface structural features of central Montana: Am. Assoc. Petroleum Geologists Bull., vol. 7, p. 11, 1923.

[22] Oral communication.

[23] Bowen, C. F., Coal discovered in a reconnaissance survey between Musselshell and Judith, Mont.: U. S. Geol. Survey Bull. 541, pp. 329–337, 1914.

[24] Lupton, C. T., and Lee, Wallace, Geology of the Cat Creek oil field, Fergus and Garfield Counties, Mont.: Am. Assoc. Petroleum Geologists Bull., vol. 5, p. 269, 1921.

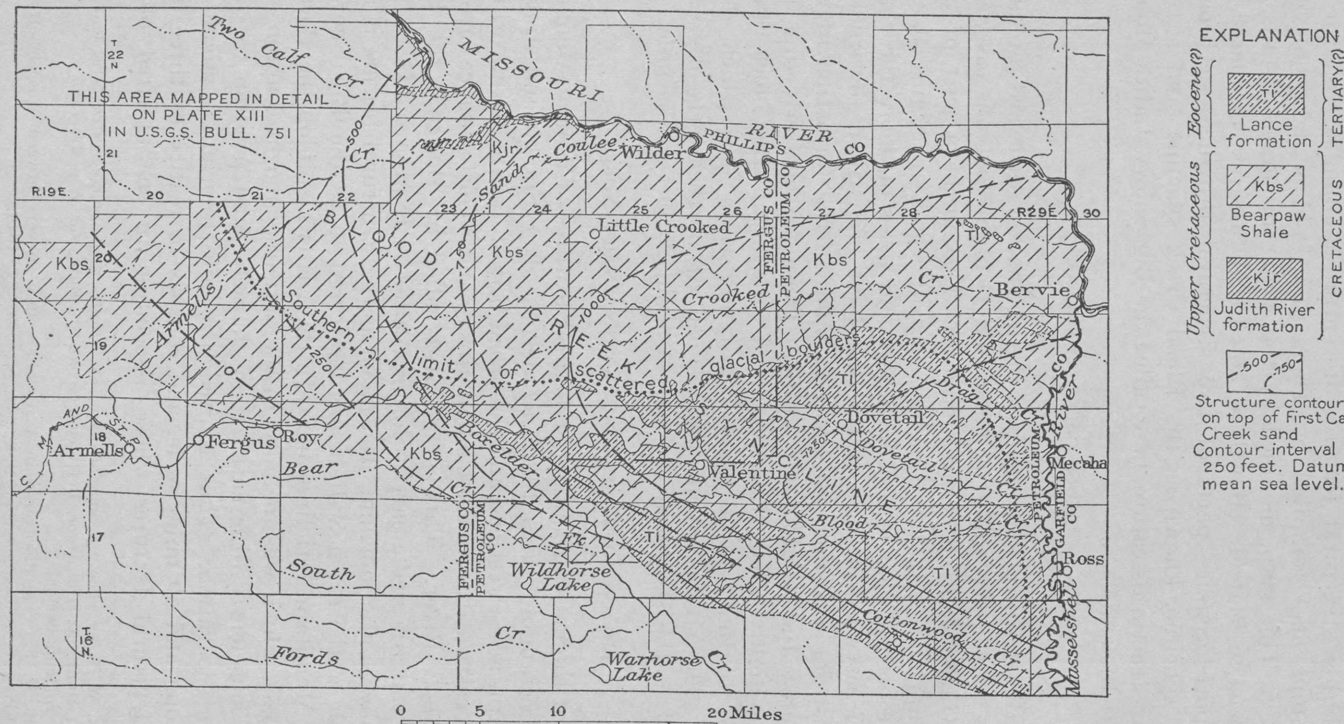


FIGURE 9.—Areal and structural geology of the Blood Creek syncline, north of the Cat Creek field, Montana


STRUCTURE CONTOUR MAP OF CENTRAL MONTANA

Compiled by W. T. Thom, jr., and C. E. Dobbin in 1923; northern part revised by Frank Reeves in 1926 may be due more to their close grouping than to a common origin. These features, as previously stated, are the Big Snowy and Judith Mountains and the uplifted block lying east of them, which will be referred to as the Cat Creek-Devils Basin uplift. Although it is the consideration of the last-named feature which is of the most importance in connection with the present study, the structure of the two mountain groups will be briefly described.

### BIG SNOWY MOUNTAINS

The structure of the Big Snowy Mountains, according to Calvert,[25] is that of an asymmetric elliptical anticline about 40 miles long and 20 miles wide, with dips of 40° to 60° on the south limb and a maximum of 20° on the north limb. Their structural height, or the amount of upward flexure of the beds, is about 9,000 feet, and their topographic height above the surrounding plains is about 5,000 feet. Paleozoic formations and about 300 feet of the pre-Cambrian are exposed in the center of the uplift. As the lowest rocks exposed are not metamorphosed beyond the stage usually attained in the consolidation of deeply buried sedimentary rocks, and as there are no dikes or other igneous rocks in the center of the uplift, it can not be inferred that the mountains are underlain at a shallow depth by a large intrusive body.

### JUDITH MOUNTAINS

Lying immediately north of the Big Snowy Mountains and separated from them by a topographic and structural saddle are the Judith Mountains. These mountains, as described by Weed and Pirsson [26] consist of an eroded cluster of laccolithic domes in which are exposed strata ranging in age from Middle Cambrian to Cretaceous, together with the underlying laccolithic masses and associated dikes and sills. The most prominent of these domes have a structural height of 5,000 feet and a topographic height above the surrounding plains of about 2,000 feet. The structure of these mountains is clearly that produced by laccolithic intrusions. The few faults present are of the normal type and have a radial trend in relation to the domes. Closely associated with the laccoliths of the Judith Mountains are those of the Moccasin Mountains, lying about 10 miles to the west. Several low circular domes occurring between the Judith and Big Snowy Mountains are probably of laccolithic origin.

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[25] Calvert, W. R., Big Snowy Mountains and vicinity (unpublished report in files of U. S. Geol. Survey).

[26] Weed, W. H., and Pirsson, L. V., Geology and mineral resources of the Judith Mountains of Montana: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 437-616, 1897.

### CAT CREEK-DEVILS BASIN UPLIFT

*Extent and relations to surrounding structural features.*—The uplifts of the Big Snowy and Judith Mountains merge eastward into a single structural feature known as the Cat Creek-Devils Basin uplift. The larger feature of this uplift is a rectangular area about 50 miles long and 40 miles wide in which the strata attain a structural height of 2,000 to 4,000 feet above the nearly flat-lying strata surrounding the area. Erosion has, however, so planed off the uplift that it has practically no topographic expression. To the north of the northern margin of the uplift the strata continue to dip northeastward at low angles for a distance of 12 to 15 miles, beyond which they lie practically flat. To the south the uplift is bordered in its western part by a deep synclinal basin known as the Bull Mountain syncline. Farther south, at a distance of 50 miles from the southern margin of the uplift, is the Lake Basin zone of en échelon faults, which trends N. 70° W., or practically parallel to the margins of the uplift. To the west the uplift, as has been indicated, merges into the structure of the Big Snowy and Judith Mountains. To the east it merges into the flat-lying strata of the plains. Farther east is the Porcupine dome, which may be of laccolithic origin.

*Structure of the uplift.*—The main feature of the structure of the Cat Creek-Devils Basin uplift is that of an eastward-tilted block which is marked along its northern and southern margins by belts of highly inclined strata that trend N. 70° W. Between these marginal belts, which are each about a mile wide, the strata lie fairly flat except for their slight eastward inclination and the presence of elliptical domes and plunging anticlines. The most pronounced and numerous of the domes occur along the margins of the uplift. In the central part of the uplift in the area mapped by the writer the structure is characterized by plunging anticlines similar in type to those found in some of the Mid-Continent fields. Three such plunging anticlines are shown on the map. The area mapped by the writer represents only a narrow belt across the uplift and is practically the only part of it in which the contours shown in Plate 4 are based on field surveys. The mapped structure of the rest of the uplift represents merely the compiler's interpretations and inferences based on scanty information, and consequently it may be at variance with the real structure in parts of the uplift.

*Domes along the margins of the uplift.*—As indicated in Plates 3 and 4, there are along the margins of the uplifts a series of elliptical domes in which the strata attain a higher structural position than they do in the intervening parts of the uplift. These domes do not lie along a continuous axis of folding but form an en échelon series, their axes trending N. 35°–55° W. and therefore not parallel to the trend of the series as a whole, which is the same as that of the margins of the uplift, or N. 70° W. The data furnished by the logs of the many wells drilled in the Cat Creek oil field furnish clear evidence of the en échelon character of the folding there, and detailed work in other areas would undoubtedly show that the en échelon structure is more pronounced than is indicated in Plate 3. This feature of the structure of the domes has also an expression in the sinuous trend of the outcrops of the highly inclined Eagle sandstone and Judith River formation along the margins of the uplift. The crests of these domes are fairly flat. From their axes to the bordering synclines, 6 to 10 miles distant toward the central part of the uplift, the strata are inclined at angles of 2° to 6°. On the opposite flank the dips are only 2° to 6° for the first half mile, beyond which they attain the high inclinations characteristic of the strata along the margins of the uplift; but at a distance of a mile from the axes of the domes the beds again attain a nearly horizontal attitude. (See cross section in pl. 3.)

As indicated on Plate 3, these domes vary greatly in size and amount of closure. All the domes in the uplift, so far as the writer is aware, except the Button Butte dome, which lies slightly west of the area mapped, are elliptical domes of an asymmetric character. All except those along the southern margin of the uplift show the steeper dips on their northeast flanks. Plate 4 shows that the two folds southwest of the Devils Basin dome are also asymmetric and that the steeper dips are on their southwest flanks, as they are in the Devils Basin dome. The structure of the individual domes will not be described, as there is no feature of it which is not presented more clearly and accurately by the contour map on Plate 3 than would be possible by a description.

*Faults.*—Another feature of the structure of the uplifted block is the belt of en échelon faults associated with the folding along the Cat Creek marginal fold. A few faults of like trend occur in the central part of the uplift, and two were observed in the crest of the Gage dome, in the southwest corner of the area mapped. None, however, were noted along the southern margin of the uplift. These faults have a northeasterly trend, usually N. 50° to 60° E. As the marginal belts have a general trend of N. 70° W. and the domes of N. 35° to 55° W., the average trend of the faults intersects the general trend of the series of domes at 55° and the axes of the individual domes at 80°.

The presence of these faults is quite obvious where they cut the sandstone formations on the flanks of the domes, because of the manner in which the outcrops of these highly tilted beds are offset, but across the crests of the domes, where the Colorado shale crops out, the faults in many places are obscure, and trenching is required to locate them. Some of the larger companies operating in the field have had this work done, and their geologic staffs undoubtedly have a great amount of information regarding faults which it is hoped they will publish in the near future. Some of the faults shown in Plate 3 were observed by the writer in the field or suggested by the structure of the First Cat Creek sand as determined from the study of well logs. Others mapped by Lupton and Lee [27] east of Musselshell River are also shown. The data at hand indicate that most of the faults range in length from 1 to 2 miles and that many of them extend across the crests of the domes. The displacement ranges from a few feet to a maximum of possibly 200 feet. On the crests of the domes it rarely exceeds 50 feet. The fault planes in the Cat Creek field, according to Lupton and Lee,[28] are practically vertical. Observations by the writer of faults in the Judith River formation on the outer portions of the field, however, show dips of 60° to 70°. Another observation of a fault plane cutting the crest of the Gage dome showed an inclination of 59°. All the faults observed were of the normal type. In forty-five of the forty-nine faults along the Cat Creek anticline shown on the map the downthrow is on the southeast. Four out of the five faults involving the Judith River formation on the south flank of the Mosby dome are downthrown on their northwest side. Small-scale thrust faults showing displacements of a few feet and inclinations of the fault planes of 10° to 20° were also observed in an outcrop of the Colorado shale in sec. 23, T. 13 N., R. 25 E., in the central part of the uplifted block. Many of the faults that cut shale formations are marked by the presence of plates of calcite one-eighth to one-fourth of an inch thick, which are in places slickensided and striated.

The offsetting of the axes of domes along the faults in the Cat Creek oil field, according to Lupton and Lee,[28] is due to lateral movement along the faults. It is evident, however, that in that case the lateral movement is the predominating one in some of the faults, because the axes of folds are offset in places as much as 2,000 feet, whereas the vertical displacement is rarely more than 100 feet. Faults along which so pronounced a lateral movement took place must have been produced by different forces from those that produced most of the faults in this area, which show only vertical displacement. In view, however, of the similarity of the faults in trend, length, and amount of vertical displacement, it is probable that all of them had the same origin and that there was no appreci-

[27] Op. cit., p. 256.
[28] Idem, p. 271.

able amount of lateral movement along any of them. The offsetting of the axes of the domes through lateral movement is also improbable in view of the short length of the faults and the similar degree to which the strata are folded on their opposite sides. Such an explanation of the apparent offsetting of the axes assumes that the faulting is later than the folding. In the writer's opinion the faulting and folding were contemporaneous. The fractures along which the faulting occurred apparently originated in the early stages of the deformation, the folding of the strata taking place along different axes on opposite sides of the faults. The dissimilar folding on opposite sides of the faults would result in a slight lateral displacement of the strata, but it can be demonstrated that this would amount to only a small percentage of the vertical movement and would therefore be practically negligible.

*Thinning of shale formations on the margins of the uplift.*—On the margins of the uplift the shale formations are markedly thinned. This thinning is most readily determined in the Claggett shale, because of its position between the highly inclined beds of the Eagle sandstone and Judith River formation. On the flanks of most of the marginal domes the thinning amounts to 20 or 30 per cent of the normal thickness of the formation. The thinning of the Bearpaw shale is also readily apparent on the south flank of the Devils Basin dome, where the entire formation is exposed in a narrow outcrop between the highly inclined beds of the Judith River and Lance formations. The thinning here is at least 30 per cent. Thinning of the Colorado shale is not so readily determined because erosion has not exposed the formation far enough down on the flanks of the domes to reveal the maximum thinning. The entire formation is exposed, however, on the south slope of the Devils Basin dome, where it is thinned about 500 feet, or 25 per cent. Farther down the flanks of the folds the formation is probably thinned to a greater extent. The logs of wells drilled in the Cat Creek oil field show a perceptible thinning of the Colorado shale slightly north of the axis of the fold in the surface shale, where the dips are only 3° to 5°. The interval between an orange-colored calcareous bed that crops out in the crest of the West dome in secs. 13 and 14, T. 15 N., R. 29 E., and the First Cat Creek sand is about 1,240 feet just south of the axis of the fold in the surface rocks, whereas a few hundred feet to the northeast, slightly north of the axis of the fold in the surface rocks, the interval is about 1,100 feet. The wells drilled along the West dome show that the axis of the fold in the First Cat Creek sand is not offset to the south of the axis of the fold in the surface rocks but lies vertically beneath that axis. Thom[29] believes that this failure of the axial plane of

[29] Op. cit., p. 10.

such an asymmetric fold to be inclined toward the limb of lesser dip can only mean that the fold in the surface rocks passes into a fault in depth. The writer believes, however, that this feature is explained by the thinning of the strata on the steeper flanks of the domes and that it has no significance beyond showing that the uplift was accompanied by lateral pressure.

*Relation of structure to igneous intrusions.*—There is, so far as the writer knows, only one dome which is probably of laccolithic origin in the Cat Creek-Devils Basin uplift. The Button Butte dome, about 20 miles southwest of Winnett, just west of the area mapped, shows a greater structural height than any of the other domes east of the Big Snowy or Judith Mountains, the top of the Quadrant being exposed in its crest. The circular shape of this dome, as shown by a contour map prepared under the supervision of C. Max Bauer, of the Midwest Refining Co., and the occurrence of dikes and other igneous bodies in the area indicate that it is probably of laccolithic origin. The fact that similar intrusives are not definitely associated with any of the elliptical domes in the localities in which they are found and that they are absent also in the more pronounced domes along the margin of the uplift suggests that those domes may not be due to igneous intrusions. It is probable that igneous activity played only a small part in the formation of the major uplift. The northeast trend of most of the dikes, paralleling that of the faults, suggests that the dikes have followed joint planes produced by the forces that caused the faulting.

*Period of uplift.*—The evidence furnished by the record of the sedimentary rocks of the region indicates, in the writer's opinion, that the major uplift of the Big Snowy and Judith Mountains anticlinorium took place in Tertiary time, some time after the deposition of the Fort Union formation, which is involved in the folding, and before the accumulation of the highest gravel benches, of Pleistocene age, which lie nearly horizontal on the highly inclined Fort Union and older formations. That the movement which produced the uplift began in the early part of Upper Cretaceous time appears improbable to the writer, because of the general uniformity in lithology and thickness of the Upper Cretaceous and early Tertiary formations above or adjacent to the Cat Creek-Devils Basin uplift. The fact that the Colorado shale, which is the surface formation over most of the uplift, shows a close correspondence in character here and in all other parts of central Montana seems to indicate similar conditions of deposition for it over the entire region. Practically each individual bed shown in the section on pages 46–47 is duplicated at all the outcrops of this formation in central Montana, whether they occupy areas of uplift or undisturbed areas. The character of some of these beds indicates very special conditions of deposition, which surely would have been interrupted by any marked local movements in the sea floor.

There is a definitely recognizable change in character and increase in thickness of all the Cretaceous formations toward the southwest, due to the fact that in those directions lay the land areas from which the detrital material making up these formations was derived. Some changes are noticeable across the area of uplift, but they are not of such a character as to indicate to the writer that any of the material was derived from the Big Snowy Mountains. The most marked change in the Cretaceous formations of the region is the increase in sandiness of the Colorado, Claggett, and Bearpaw shales. This change takes place in a southwesterly direction from the Cat Creek oil field around the south flank of the Big Snowy Mountains and farther to the southwest and apparently has no relation to the Big Snowy uplift.

## OIL AND GAS

There are two producing fields in the area mapped—the Devils Basin and Cat Creek fields, the location of which is shown on Plate 3. So far only the Cat Creek field has proved of commercial importance, the Devils Basin field having yielded oil to date from but four wells, only three of which can be called commercial.

### DEVILS BASIN FIELD

#### HISTORY OF DEVELOPMENT AND PRODUCTION

The Devils Basin field was opened in December, 1919, when the Van Dusen Oil Co. struck a heavy oil in a well drilled in the east end of the Devils Basin dome, in sec. 24, T. 11 N., R. 24 E. (No. 28, pl. 3). Though the capacity of the well was at first reported to be 100 barrels a day, it later proved to be only a 10-barrel well; but as it was the first real oil strike in Montana outside of the Elk Basin field, on the Wyoming-Montana line, its success started active drilling in central Montana, which continued rather briskly for the next two years and resulted in the discovery in 1920 of the Cat Creek field. During this period 17 more wells were drilled in the Devils Basin field, but inasmuch as only one other commercially productive well was obtained only four more wells have been drilled in the locality during the last four years. The results of operations at present (July, 1926) are a total of 23 wells drilled, only three of which are commercially productive. These producing wells, which have a potential capacity of approximately 100 barrels of oil daily, are at the east end of the dome. Offsets to two of them drilled 400 and 600 feet distant obtained but minor shows of oil, although they were drilled below the sand from which oil was obtained in the producing wells. In the six wells drilled 1 to 4 miles farther west along the crest of the dome showings were obtained at depths between 1,000 and 1,100 feet. Wells 22, 23, and 26 are reported to have produced a little oil. Some of the wells, owing to their shallow depth or unfavorable location, can not be considered adequate tests. The only wells drilled deep enough to reach the Van Dusen sand were Nos. 19, 21, 22, 23, 24, 25, 26, 28, 29, 31, 32, 32A, 33, 33A, and 35. The unsatisfactory results obtained from the wells drilled in this field have discouraged further drilling. Inasmuch as the daily potential production of the field has not materially exceeded 100 barrels, and as the nearest railroad town, Roundup, is 20 miles distant, no pipe line has been laid to the field; consequently no disposition is made of the oil except as fuel in the drilling of wells near by. During 1921, when drilling was most active, a total of about 6,000 barrels of oil was produced from the field. Since that time the annual production has been approximately one-fifth of this amount.

### VAN DUSEN SAND

The oil obtained in the Devils Basin field is encountered in the different wells at depths ranging from 1,120 to 1,175 feet, in what is called the Van Dusen sand. This sand is variously described in the well logs as sandy shale, limestone, or sand 5 to 10 feet thick. It is apparently lenticular, as some of the offset wells encountered no sand at or near the depth from which oil was obtained in the adjacent producing well. The slight dip of the rocks in the crest of the dome, where most of the wells were drilled, and the absence of any known faults indicate that the failure to encounter the oil sand in some of the offset wells at the depth at which it was expected was probably not due to the greater depth of the sand in these wells. The unusual variation in the character of the sediments encountered and the absence of any one persistent and easily recognizable bed in the formations pentrated, together with the obvious incompleteness of the logs, make it impossible to correlate with any degree of certainty the formations and beds in the different wells. As a result, however, of the study of the formations at their outcrops, about 10 miles to the west, in the Big Snowy Mountain uplift, it is possible to recognize the formations penetrated, even though their exact limits can not be determined. Most of the wells drilled on the dome begin in the Kootenai formation and end in the Quadrant formation. These wells pentrate about 400 feet of Kootenai and possibly some Morrison beds, which consist largely of red shale interbedded with lenses of sandstone. Beneath this series there are 100 to 200 feet of limy and sandy shales which belong to the Ellis formation. Beneath the Ellis and beginning with a series of red shale and thin limestones that are reached at a depth of about 600 feet is the Quadrant formation, which consists of a varying series of variegated shale, limestone, and thin sandstones, the character of which is described on pages 50–54. The deepest wells drilled in the area (Nos. 19 and 24, pl. 3) penetrated a few hundred feet of the Madison limestone. The Van Dusen sand, according to the above interpretations, occurs in the Quadrant formation 500 to 600 feet below its top. The formations penetrated by wells drilled in the Devils Basin field are shown graphically in Plate 5.

### GRADE OF OIL

The oil encountered in the Van Dusen sand in the Devils Basin field is a dark heavy viscous oil which has a gravity of 24.7° Baumé. The following analysis of a sample collected from the Alberta Black Coal Co.'s well in sec. 25, T. 11 N., R. 24 E. was made by N. A. C. Smith, of the Bureau of Mines:

*Analyses of oil sample from Devils Basin field, Mont.*

[Air distillation with fractionating column; barometer 767]

| Temperature (°C.) | Fractions (percentage by volume) | Specific gravity | Temperature (°C.) | Fractions (percentage by volume) | Specific gravity |
|---|---|---|---|---|---|
| 125–150 | 4.6 | 0.760 | 200–225 | 2.8 | 0.827 |
| 150–175 | 2.6 | .790 | 225–250 | 3.8 | .840 |
| 175–200 | 2.8 | .810 | 250–275 | 6.4 | .850 |

Approximate summary:

| | |
|---|---|
| Gasoline | 10 |
| Gas oil | 17.5 |
| Burning oil | 13.0 |
| Medium lubricating distillate | 6.6 |
| Viscous lubricating distillate | 10.5 |
| Residues and loss (sulphur 1.6) | 42.4 |

Specific gravity of oil 0.905 (24.7° B.)

### SOURCE OF THE OIL

At its outcrop in the Big Snowy Mountains the Quadrant formation contains beds of petroliferous limestone and black shale; consequently, the oil in the Van Dusen sand is probably derived from the formation in which it is found. The oil closely resembles the heavy oils found elsewhere in the Rocky Mountains in the Embar and Tensleep formations, which are believed to belong in approximately the same part of the geologic column.

The origin of these heavy Carboniferous oils of the Rocky Mountain fields is a problem of considerable geologic interest. The Cretaceous oils in the region are practically all light-gravity oils. The fact that these Cretaceous oils are closely associated with black shale and the Carboniferous oils with limestone has led some students of the problem to attribute the difference in character to differences in the original organic material from which the oils were derived. Mabery[31] suggested this as an explanation of the difference between the Appalachian oils and the limestone oils of Ohio and Indiana, and this hypothesis still has its supporters. It appears doubtful, however, whether this hypothesis explains the heavy oils of the Wyoming and Montana Carboniferous for the source material of these oils is probably not appreciably different from that of the Appalachian and Mid-Continent Carboniferous oils, and those oils are all of high grade. In the further consideration of this obscure problem the writer would like to suggest that the low grade of the oils from the Quadrant and Embar may be due to a deterioration of the oil as a result of contact with sulphate-bearing waters. It is generally recognized that in most fields the oil that is in contact with water is the heavier oil. Rogers[32] attributes this difference to reactions between the hydrocarbons and the sulphates in the water, the final result of which is the production of a carbonate-bearing water and a heavier and lower grade of oil. The Embar and Quadrant formations either contain or are closely overlain by gypsum beds, which constitute an obvious source for the sulphates, and there is an active circulation of ground water in the Rocky Mountain region generally. Thus fresh supplies of sulphate water are constantly being brought into contact with the oil in these formations, making possible its deterioration. The reason that most of the Cretaceous oils in the Rocky Mountain region have not deteriorated like the Carboniferous oils of the same region lies possibly in some degree in the lesser amount of gypsum and slower circulation of ground water in the Cretaceous beds, but the greater age of the Carboniferous oils, which have been subjected to the effects of sulphate water for a much longer time than the Cretaceous oils, is probably the most important factor. If the Cretaceous oils were allowed to remain underground until they were as old as the Carboniferous oils now are, and were subjected to continuous active artesian circulation, they would probably deteriorate and be reduced in volume. This conclusion leads to the inference that the Carboniferous oils of the region may be remnants of former larger bodies of oil.

### FUTURE POSSIBLE PRODUCTION

In view of the facts that only 3 commercial wells have been obtained out of the 23 drilled in the Devils Basin field and that the oil is of low grade, there is little inducement for further drilling in the field, at least until the price of oil reaches a much higher figure than

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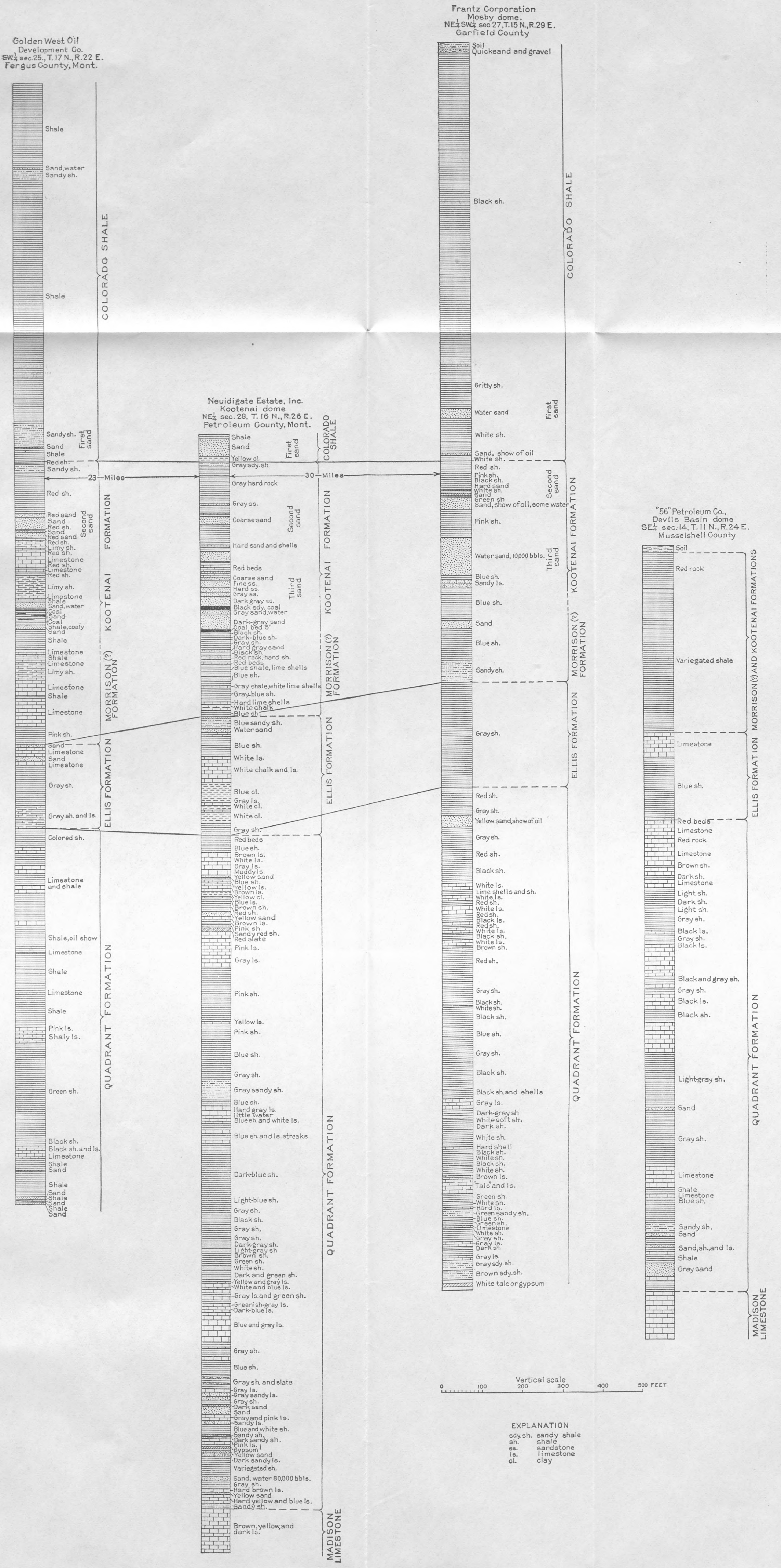
[31] Mabery, C. F., A résumé of the composition and occurrence of petroleum: Am. Philos. Soc. Proc., vol. 42, No. 172, p. 51, 1903.

[32] Rogers, G. S., The Sunset-Midway oil field, Calif., Part II, Geochemical relations of the oil, gas, and water: U. S. Geol. Survey Prof. Paper 117, pp. 26–32, 1919.




COLUMNAR SECTIONS OF FORMATIONS PENETRATED IN WELLS IN AND NEAR THE CAT CREEK AND DEVILS BASIN FIELDS, MONTANA at present (July, 1926). It would appear that no large volume of production may be expected from the Van Dusen sand. The structural positions of wells Nos. 19, 21, 22, 23, 24, 26, 29, 30, 31 and 31A (see pl. 3) appear to make them adequate tests of the possibilities of this sand in the crest of the dome, and the unsuccessful results obtained in wells Nos. 25 and 35 also indicate that oil may not be expected in the sand on the flanks of the dome. Whether or not oil may be obtained in the Quadrant formation below the Van Dusen sand or in the underlying Madison limestone is doubtful. Wells Nos. 19 and 24, which occupy a structural position presumably as favorable as could be selected penetrated the entire Quadrant formation and the upper part of the Madison limestone, and although they obtained traces of oil at two or three horizons, they did not find oil in commercial quantities. The Quadrant formation and the underlying Madison limestone undoubtedly contain porous beds in the proper relation to impervious beds to act as oil reservoirs and an abundance of organic material of a kind that might be expected to yield oil. Such conditions, however, are present in the Colorado shale and Kootenai formation in scores of domes in central Montana and elsewhere in the Rocky Mountain region that have been tested and proved barren of oil, yet experience has shown that these formations are more likely to yield oil in commercial volumes than the Quadrant formation or Madison limestone. Consequently there appears to be but little reason for continuing to assume that there are any large volumes of oil in the untested portions of the dome, although it is quite possible that small volumes of heavy oil may yet be obtained in this locality. Further tests if made should be confined to the crest of the dome within the area marked by the 4,000-foot structural contour line shown in Plate 3. Such tests should continue to and a few hundred feet into the Madison limestone if oil is not obtained at shallower depths.

## CAT CREEK FIELD

### HISTORY OF DEVELOPMENT AND PRODUCTION

In February, 1920, the Frantz Oil Corporation drilled a well near the center of the Mosby dome, in the southwest corner of the SE. 1/4 NW. 1/4 sec. 21, T. 15 N., R. 30 E. At a depth of 800 feet a sandstone, now generally known as the First Cat Creek sand, was encountered which yielded a strong flow of fresh water. A second sandstone, now commonly spoken of as the Second Cat Creek sand,[33]

[33] In an article entitled "Oil fields in central Montana," published in the Engineering and Mining Journal for Apr. 17, 1920, p. 936, O. B. Freeman suggested that this sand be called the Lupton sand, after the geologist who located the discovery well, but the common practice has been to speak of it as the Second sand, and the writer has here adopted that name.

was penetrated at a depth of 998 feet and yielded oil to the amount of about 10 barrels daily. Three more wells were drilled in the same dome during the spring of 1920, but these encountered only strong flows of water in both sands. Four other wells drilled about the same time, 1 to 2 miles south of the axis of the dome, were carried to the First sand without finding oil and were shut down. The results obtained from these wells made the prospect for the discovery of a commercial pool look doubtful, but in May the Frantz Corporation struck oil in the First sand in their test of the West dome, in the northeast corner of the SE. 1/4 NE. 1/4 sec. 14, T. 15 N., R. 29 E. This well was at first reported as a 200-barrel producer, but in August its output increased to 2,500 barrels a day. The success of this well stimulated development, and during the fall of 1920 a number of other wells producing from the First sand were brought in along the crest of the West dome with initial daily production ranging from 50 to 2,500 barrels. A pipe line was laid to Winnett, a railroad town 20 miles southwest of the field, and development progressed at a rapid rate, with the result that during 1921, the extent of the major portion of the field was determined. Most of the oil produced during this time was obtained from the First sand along the crest of the West dome in a narrow belt 3 miles long and 1,000 to 2,500 feet wide. A few Second sand wells were also obtained in the crest of the Mosby dome. In the second half of 1921 and the first half of 1922 the daily production averaged about 4,500 barrels. In June, 1922, the Frantz Harlan No. 3, in the southwest corner of the NW. 1/4 sec. 10, T. 15 N., R. 29 E., in the west end of the field, was drilled to the Second sand and produced about 1,000 barrels the first 24 hours. The discovery of oil in the Second sand in the West dome resulted in the deepening to the Second sand of a number of wells that had been producing from the First sand in this portion of the field. Good production was obtained in the Second sand in the wells drilled in the highest part of the dome, but water was encountered at slightly lower structural levels, indicating that the edge-water line was higher in the Second sand than in the First sand. The daily production of the field increased rapidly and reached its maximum of about 8,500 barrels daily in August, 1922, since which the decline has been gradual, as indicated by the graph in Figure 10. At present (July, 1926), the daily production is about 2,800 barrels. The total production of the field to date is slightly over 9,000,000 barrels. Of about 285 wells drilled in and immediately adjacent to the producing field, 190 have been producing oil wells. Of these 131 obtained oil in the First sand and 59 in the Second sand. As shown in Plate 3, most of the producing wells are on the West dome. On the Mosby dome, 22 commercially pro-

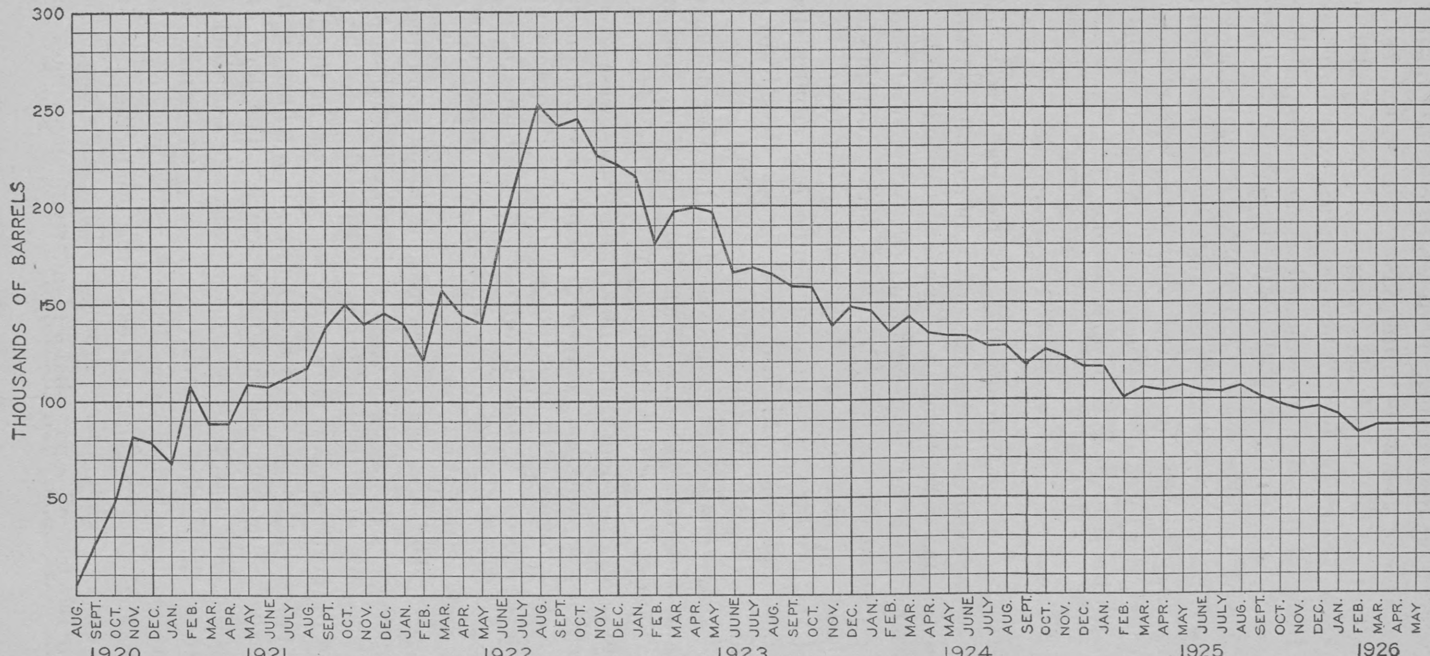



FIGURE 10.—Oil produced in the Cat Creek field, Mont., by months, 1920–1926

ductive wells have been drilled, 19 of which obtained oil in the Second sand. One or two wells in the NE. 1/4 SE. 1/4 sec. 21, T. 15 N., R. 30 E., on this dome, have also obtained shows of oil from shale at a depth of about 250 feet. Outside of the two main producing areas a little oil has been encountered along faults in the NE. 1/4 NW. 1/4 sec. 12, T. 15 N., R. 28 E; NW. 1/4 SE. 1/4 sec. 8, T. 15 N., R. 28 E.; SW. 1/4 NE. 1/4 sec. 17, T. 15 N., R. 30 E.; and NW. 1/4 NW. 1/4 sec. 26, T. 15 N., R. 30 E. In each of these localities the production is confined to one or two small wells, offsets encountering water in both the First and Second sands. Nineteen of the original producers in the field have been abandoned.

## OIL SANDS

The drillers recognize four sands in the Cat Creek field—the Mosby, First, Second, and Third sands. Practically all the oil obtained so far has come from the First and Second sands. In one or two wells a little oil has been found in a stray sand 7 to 45 feet below the Second sand. The First sand is the chief producer, the area yielding oil from it being larger than that from the Second sand and the production from it declining less rapidly than that from the Second sand. All the sands except the Mosby contain water under artesian head where they do not yield oil.

*Mosby sand.*—The logs of wells drilled in the West dome record a 5 to 10 foot sand at 1,000 to 1,075 feet above the First sand and at a depth of 100 to 300 feet beneath the surface. This bed crops out in the Mosby and East domes and in all the domes west of the Cat Creek field. The fact that it forms conspicuous escarpments and may be easily recognized by its lithology and fossil content makes it a valuable key bed. A description of this sandstone is given on pages 46, 47. Small amounts of gas and water have been encountered in a few wells in the Mosby sand.

*First sand.*—The sand from which most of the oil is obtained in the Cat Creek field occurs at the base of the Colorado shale. As stated on page 47, this sandstone is probably equivalent to the Dakota sandstone of northern Wyoming. At its outcrop in the Kootenai dome, 20 miles west of the Cat Creek field, it is a yellow argillaceous ripple-marked sandstone 40 to 60 feet thick. The logs of wells drilled in the Cat Creek field record it as 25 to 60 feet thick, and in some parts of the field it apparently consists of two sandstone members separated by a bed of shale. The large volumes of water that flow from the wells on the margins of the producing area indicate that the sand is fairly coarse grained. This sandstone is overlain by 100 to 150 feet of sandy shale. Underlying it in most parts of the field and areas of its outcrop there is usually 5 to 10 feet of white clay shale, beneath which is red shale. In the locality of the Deveraux well, in the west end of the Cat Creek field, the white clay shale is reported in some logs to be 50 feet thick. In the wells drilled on the Mosby dome along Musselshell River the First sand is encountered at a depth of approximately 800 feet. Along the crest of the West dome it is encountered at a depth of 1,100 to 1,400 feet.

*Second sand.*—At 160 to 235 feet below the top of the First sand oil is obtained in both the Mosby and West domes in a sandstone which is commonly spoken of as the Second Cat Creek sand. This sandstone is of Kootenai age and lies 100 to 150 feet below the top of the formation. Its thickness ranges from 10 to 60 feet, but in most areas it is about 40 feet thick. In most of the well logs it is recorded as consisting of two sandstone members separated by a shale break 5 to 10 feet thick. In the red shales overlying the sand thin lenses of sandstone are reported in some of the well logs, but no great amounts of oil have been obtained in them. The Second sand at its outcrop farther west contains less clay matter than the First sand and is grayer and coarser grained.

*Third sand.*—At 100 to 150 feet below the top of the Second sand, a third sand is encountered in the deeper wells drilled in the Cat Creek field. This sand, called the Third sand by the drillers, ranges in thickness from 60 to 100 feet. It is multiple-bedded and apparently corresponds to the thick coarse-grained ridge-forming sandstone overlying the coal bed mined in the Lewistown and Great Falls fields. Large volumes of water are encountered in the Third sand in the wells drilled to it on the edge of the Cat Creek field. So far no oil has been obtained in this sand, in the main producing areas, although shows and slight production have been reported from it in the drilling centering about the Deveraux well, in sec. 12, T. 15 N., R. 28 E. Two wells, the Franz Wildschutz No. 12, in the center of the NE. ¼ NE. ¼ sec. 14, T. 15 N., R. 29 E., and the Thermopolis Cat Creek well No. 2, on the east line of the SW. ¼ SW. ¼ sec. 11, T. 15 N., R. 29 E., were deepened to this sand, but only large flows of water were encountered. The location of these wells in the center of the producing area and on the highest portion of the dome make it appear very doubtful whether much oil will be obtained in this sand in any part of the field.

## WATER CONDITIONS IN THE SANDS

The oil sands where they do not contain oil yield large volumes of fresh water under artesian head. In the early drilling in the area around the edge of Cat Creek and in the Oiltana and Brush Creek domes, 5 to 12 miles west of the field, water to the amount of thousands of barrels a day flowed from wells penetrating the First, Second, and Third sands. The largest volumes were encountered in the Third sand, some of the wells yielding as much as 100,000 barrels of fresh water daily. Such water is undoubtedly taken into the sands at their outcrops around the Big Snowy and Judith Mountains, 35 to 40 miles west of the field. As these outcrops are 3,500 to 4,000 feet above sea level, or 1,800 to 2,300 feet above their highest level in the Cat Creek field, there is opportunity for the development of a pronounced hydrostatic pressure. However, owing to the low level of the ground-water table in the region, the leakage of water from the sands through fissures, wells, and other openings, and the resistance encountered to flow through the fine-grained sand, this hydrostatic head is not equal to the difference between the altitude of the sand at its outcrop and that at the point at which it is penetrated by the drill. In the first wells drilled the pressure was sufficient to cause the water to spout a few feet above a 10-inch casing. The escape of such great quantities of water from these sands in and near the Cat Creek field has resulted in a marked reduction of the hydrostatic pressure and yield of water. According to Schwarzenbek,[34] who has made an extensive study of the water conditions in the Cat Creek field, the hydrostatic pressure in June, 1924, was much less in the Second sand than in the First. In edge wells at that time the water from the First sand rose high enough to flow out of the well, but that from the Second sand stood a few hundred feet below the top of the well. The yield of water in the wells pumping both oil and water decreased rapidly during 1923 and 1924. A similar decrease in the production of oil occurred and is attributable, at least in part, to the decline in the hydrostatic pressure. This decrease is most noticeable in the wells drawing from the Second sand. Many of the wells that were producing from this sand in the crest of the West dome are being plugged back and are being pumped from the First sand. This greater decline in the hydrostatic pressure of the Second sand is perhaps due in part to the fact that in most edge wells that encountered water in the First sand this water was cased off, whereas that encountered in the Second sand was allowed to flow freely from the well. Inasmuch as the pressure of the water surrounding the oil pool tends to force the oil from the sand into the oil wells, it is obviously important not to lower this hydrostatic pressure by allowing needless discharge of water from wells in or near the productive oil field. It is probable that, if com-

[34] Schwarzenbek, F. X., General information on the Cat Creek oil field, Mont., June, 1924 (unpublished report in the files of the Bureau of Mines, Washington, D. C.).

petitive drilling did not make it impossible, in Cat Creek and other fields where water conditions are similar the flooding of the sands now so successfully used in some of the old fields of Pennsylvania could be accomplished naturally, thereby making it possible to recover larger percentages of the oil from the sands.

Undoubtedly such a process has gone on to some extent in the Cat Creek field, because Schwarzenbek shows that the edge-water line moved up the dip fairly rapidly during the early days of development. Owing to the swabbing of some of the wells, however, and the rapid withdrawal of the oil, the water coned toward these wells. Under such conditions the edge-water line became irregular, and the water in some portions of the sand ceased to drive the oil before it, and in the other portions its driving force was diminished through the lowering of its hydrostatic head by the escape of the water.

The edge-water line was originally nearer the crests of the domes in the Second sand than in the First, there being practically no water encountered in the First sand in the early drilling in the West dome. As many of the First sand wells have gone entirely to water and approximately half of the remainder are producing small volumes of water with the oil, only the wells near the crests of the domes and the higher portions of the fault blocks are free of water in both sands.

## CHEMICAL CHARACTER OF THE WATER

The analyses of 11 samples of water collected from the First, Second, and Third Cat Creek sands in and immediately adjacent to the Cat Creek oil field show that the salinity of the water ranges from 351 to 2,524 parts of total solids in a million parts of water. The relative freshness of these waters is apparent when they are compared with the waters of the Mid-Continent and Appalachian oil fields, which have a salinity of more than 100,000 parts per million. The mineral content of most of these waters is made up principally of the salts of sodium, in marked contrast to the mineral content of the shallow well and spring waters of the region, which are composed largely of the salts of calcium and magnesium. These differences, however, are more or less regional, have no relation to the occurrence and distribution of oil, and will not be discussed here.[35]

A difference in the character of the waters which is related to the occurrence of oil is to be found in the acid exchange of the waters. The waters coming from the oil sands outside of the oil-producing areas contain about equal amounts of the sulphate and carbon-

[35] For a discussion of this difference between the surface and deep well waters in Montana, see Renick, B. C., Base exchange in ground water by silicates as illustrated in Montana: U. S. Geol. Survey Water-Supply Paper 520, pp. 53–72, 1924.

ate (or bicarbonate) radicles but almost none of the chloride radicle, whereas the waters that are in contact with the oil contain large percentages of the carbonate (or bicarbonate) and chloride radicles and only a very small amount of the sulphate radicle. This difference is shown graphically in Figure 11, which shows the proportions of the principal acid radicles, as expressed in terms of their reacting values, for a number of samples of water collected in northern Fergus County. In such a diagram [36] a water consisting of equal amounts

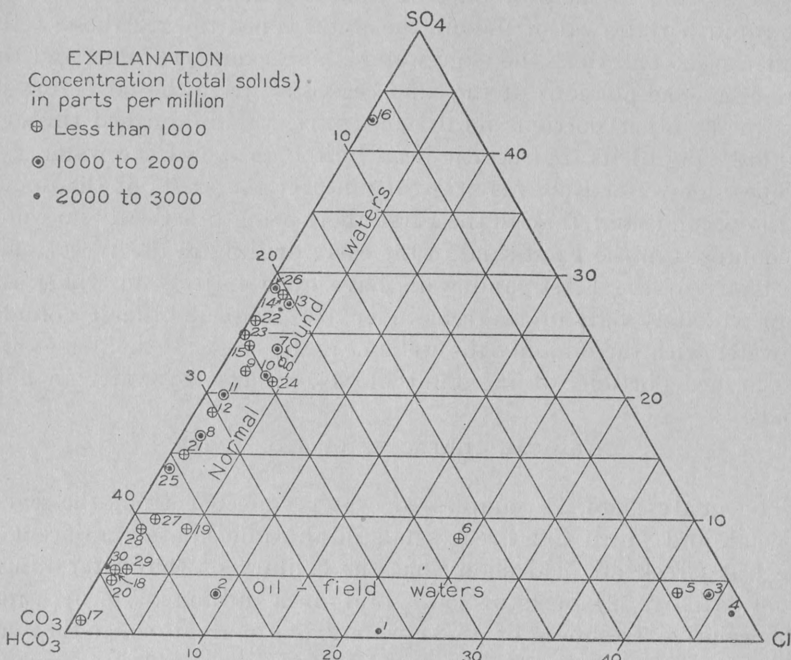



FIGURE 11.—Proportions of sulphate ($SO_4$), carbonate and bicarbonate ($CO_3$ and $HCO_3$), and chloride (Cl) in ground waters of Fergus County, Mont., plotted in terms of percentage reacting values. Numbers refer to table on p. 80.

of these radicles would fall in the center of the diagram, whereas one containing all sulphates would fall at the upper apex, one containing all carbonates or bicarbonates would fall at the lower left-hand apex, and one containing all chlorides would fall at the right-hand apex. It will be noted that the waters coming from producing oil wells (samples 1–5) fall near the base of the diagram, indicating the almost total absence of sulphates, and that the waters obtained from these same sands outside of the oil-producing areas (samples

[36] Diagrams of this type have been used by W. H. Emmons in discussing mine water (The enrichment of ore deposits: U. S. Geol. Survey Bull. 625, p. 85, 1917), and by G. S. Rogers in discussing oil-field waters (op. cit., p. 60).

7–15) fall into the group in which are included the waters derived from the water wells and springs of the regions (samples 16–30). This group is characterized by the presence of carbonates and sulphates, and by the almost total absence of chlorides. This absence of sulphates in oil-field water is fairly common and is attributed by Rogers[37] to the reducing action of hydrocarbons, the sulphate being reduced to sulphide, which passes off as hydrogen sulphide, and an equivalent portion of the oil being oxidized to carbon dioxide or carbonate. The action of the oil upon the waters, then, is to substitute carbonate for sulphate. The chlorides present in large percentages in the waters in contact with the oil may owe their origin to the presence of fossil sea water still remaining in the sands, as such water is usually high in chlorides. This evidence that the portions of the sands producing oil have been protected from the active circulation of the ground water present in other areas of the sands is also corroborated by the larger saline content of the water that is found with the oil (see table on p. 80), which tends to corroborate the conclusion reached on page 81 that the oil owes its presence in the sand to the barriers offered by the faults to the active circulation of water.

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[37] Op. cit., p. 27.

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*Location and source of water samples shown in Figure 11*

| Sample No. | Name of well | Location | | | | Total solids (parts per million) | Depth of water (feet) | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Quarter | Sec. | T. N. | R. E. | | | |
| 1 | Frantz Clayton No. 5 | NE | 14 | 15 | 29 | 2, 524 | 1, 277 | Oil and water from First Cat Creek sand. |
| 2 | Frantz No. 5 | NE | 14 | 15 | 29 | 2, 154 | 1, 105± | Do. |
| 3 | Mid-Northern No. 3 | NW | 13 | 15 | 29 | 1, 383 | 1, 170 | Do. |
| 4 | Mid-Northern Green Nos. 14A, 16A | NW | 14 | 15 | 29 | 1, 478 | 1, 460± | Oil and water from Second Cat Creek sand. |
| 5 | Montacal No. 1 | NE | 20 | 15 | 30 | 686 | 1, 000± | Do. |
| 6 | Pyramid No. 1 | NE | 9 | 15 | 29 | 351 | 1, 568? | Edge water well from Second Cat Creek sand. |
| 7 | Lavadeur No. 1 | SE | 1 | 15 | 28 | 1, 175 | 1, 890? | Water well in Third Cat Creek sand. |
| 8 | Lavadeur No. 3 | SE | 1 | 15 | 28 | 1, 071 | 1, 520 | Water in First Cat Creek sand. |
| 9 | do | SE | 1 | 15 | 28 | 993 | 1, 785 | Water in Third Cat Creek sand. |
| 10 | Frantz No. 1 | SW | 27 | 15 | 30 | 1, 118 | 1, 235 | Water well in Third Cat Creek sand. |
| 11 | Absaroka No. 1 | NE | 1 | 14 | 30 | 1, 003 | 1, 400±? | Do. |
| 12 | Alexander Syndicate No. 1 | NW | 25 | 16 | 27 | 850 | 1, 015 | Do. |
| 13 | Ohio No. 1 | NW | 26 | 16 | 27 | 1, 301 | 955 | Do. |
| 14 | West Dome No. 1 | NE | 18 | 16 | 26 | 972 | 200 | Do. |
| 15 | Golden West No. 1 | SE | 25 | 17 | 22 | 600 | 1, 296? | Do. |
| 16 | | NE | 28 | 11 | 15 | 1, 830 | 1, 116 | Deep water well. |
| 17 | | NE | 5 | 15 | 18 | 505 | 417 | Do. |
| 18 | | | 23 | 15 | 17 | 372 | 198 | Do. |
| 19 | | SW | 33 | 12 | 25 | 410 | 213 | Shallow water well. |
| 20 | | NW | 6 | 12 | 23 | 514 | 12 | Do. |
| 21 | | SW | 33 | 15 | 27 | 414 | 8 | Do. |
| 22 | | NE | 6 | 12 | 27 | 733 | 20 | Do. |
| 23 | | NE | 34 | 12 | 28 | 990 | 22 | Do. |
| 24 | | NW | 7 | 13 | 24 | 174 | 5 | Do. |
| 25 | | SW | 27 | 15 | 23 | 1, 248 | ? | Do. |
| 26 | | SW | 17 | 15 | 21 | 1, 965 | 30 | Do. |
| 27 | | NE | 28 | 15 | 18 | 254 | 74 | Do. |
| 28 | | SE | 1 | 12 | 26 | 281 | 0 | Spring. |
| 29 | | SE | 28 | 13 | 22 | 378 | 0 | Do. |
| 30 | | NW | 19 | 12 | 23 | 2, 852 | 0 | Do. |

Samples 1–7 collected by F. X. Schwarzenbek, U. S. Bureau of Mines; analyses by R. L. Hamilton for Mid-West Refining Co. Remaining samples collected by J. M. Hall, U. S. Geological Survey; analyses by H. B. Riffenburg, U. S. Geological Survey.

## ACCUMULATION OF THE OIL

The part played by the faults in the accumulation, migration, and yield of oil in the Cat Creek field is a subject of considerable interest but one which the writer, because of his lack of intimate knowledge of the development of the field, can not adequately discuss. He believes, however, that the major factor in the accumulation of the oil has been the doming of the strata, for the oil-producing areas are confined to the crests of the domes. Apparently the accumulation of the oil was contemporaneous with or immediately subsequent to the doming and faulting of the strata, which are believed to have been contemporaneous, as pointed out on page 65. In the writer's opinion the oil was derived from the overlying Colorado shale and passed into the First sand during the period of compacting of the sediments, when the waters buried with the shales were being squeezed out and forced into the sandstones that afforded channels of escape. It probably was later collected in the crest of the domes by the movements set up in the oil and water during the formation of the domes, before the initiation of the active regional artesian circulation of the water now present in the sands. Where the vertical displacement along the fault planes amounted to 150 feet or more, as it does in some of the larger faults, the Second sand was brought into contact with the First sand, and under these conditions oil migrated into the Second sand. Probably the major control that the faults exerted on the accumulation of the oil was in determining the direction of its movement. The offsetting of the sands with shales along most of the faults sealed them; the tendency, therefore, was for the oil that reached the sand in a fault block to move to the higher portion of that block. As a result oil has accumulated much lower structurally on the noses of these faulted folds than on their flanks. Although the faults may have played only a small part in the accumulation of the oil they undoubtedly were an important factor in preventing the oil from being flushed out of the sands by the artesian water circulation, which probably was not set up until after most of the oil had accumulated. In this and practically all the other oil fields of the Rocky Mountain region there is evidence of an active circulation of ground water, due in part to the high altitude of the outcrops of the strata around the major uplifts and their exposure at much lower levels in the surrounding plains. Such circulation tends to remove, as Rich [38] has pointed out, the connate water buried with the sediments and any oil that accumulates in them. The result is that a very large percentage of the domes in which the geologic

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[38] Rich, J. L., Moving underground water as a primary cause of the migration and accumulation of oil and gas: Econ. Geology, vol. 6, pp. 347–371, 1921.

conditions are otherwise favorable for the accumulation of oil contain only water. The domes that yield oil are those fairly remote from the major uplifts and protected in some way from flushing. The faults, under proper conditions, may afford this protection. Most of the unproductive domes are also faulted, but apparently these faults have not been of such a character or so situated as to offer the necessary protective barriers. Perhaps in the course of geologic time the oil in the remaining pools would also be dissipated in the same manner if it were not removed by man. The observed fact that faulted domes more commonly yield oil than unfaulted domes is, the writer believes, explained better by this hypothesis than by that put forth by Mills,[39] which attributes the segregation of oil in the vicinity of faults to the flow of water and gas toward these vents.

### GRADE OF OIL

The oil produced in the Cat Creek field has a mixed base and contains but little sulphur. It has a gravity of 47° to 50° Baumé and is therefore about 6° lighter than the average Appalachian oil and 10° lighter than the average Mid-Continent oil. Its gasoline content is 1½ times that of the average Appalachian oil and twice that of average Mid-Continent oil. The oil from the First sand, the chief producing sand, is 2° Baumé lighter than the oil from the Second sand and 25° lighter than the oil from the Van Dusen sand in the Devils Basin field.

The following analyses of the oil from the First and Second Cat Creek sands were made by N. A. C. Smith, of the Bureau of Mines:

*Analyses of oil samples from the Cat Creek field*

[Air distillation with fractionating column; barometer 760]

| Temperature (° C.) | Sample 1, First sand | | Sample 2, Second sand | |
|---|---|---|---|---|
| | Fractions (percentage by volume) | Specific gravity | Fractions (percentage by volume) | Specific gravity |
| 50-75 | 3. 1 | 0. 678 | | |
| 75-100 | 7. 4 | . 696 | 0. 3 | 0. 688 |
| 100-125 | 13. 4 | . 723 | 8. 9 | . 719 |
| 125-150 | 15. 1 | . 746 | 15. 7 | . 743 |
| 150-175 | 12. 4 | . 766 | 14. 3 | . 763 |
| 175-200 | 11. 5 | . 785 | 12. 3 | . 782 |
| 200-225 | 10. 7 | . 802 | 12. 5 | . 798 |
| 225-250 | 8. 4 | . 814 | 10. 4 | . 812 |
| 250-275 | 7. 5 | . 824 | 7. 5 | . 823 |

Approximate summary:

| | Sample 1 | Sample 2 |
|---|---|---|
| Gasoline and naphtha | 62. 9 | 54. 2 |
| Kerosene | 26. 6 | 30. 4 |
| Gas, oils and residues | 10. 2 | 15. 13 |
| Sulphur | . 3 | . 27 |

Sample 1. Frantz Wildschutz No. 1, sec. 14, T. 15 N., R. 29 E., specific gravity at 15° C. 0.799 (=49.7 B.).
Sample 2. Frantz Charles No. 1, sec. 21, T. 15 N., R. 39 E., specific gravity at 15° C. 0.788 (=47.7° B.).

[39] Mills, R. V. A., Natural gas a factor in oil migration and accumulation in the vicinity of faults: Am. Assoc. Petroleum Geologists Bull., vol. 7, No. 1, pp. 14–24, 1924.

SOURCE OF THE OIL

It seems most probable to the writer that the oil in the Cat Creek field is derived from the Colorado shale. The black color of this shale indicates that it contains an abundance of organic matter. That this organic matter is of the proper kind to yield oil is indicated by chemical tests, which show the presence of both free oil and pyrobitumens. The fact that most of the oil produced in the Rocky Mountain region is obtained from sands in the Colorado shale or in its stratigraphic equivalents is also persuasive evidence that this formation is petroliferous. The manner in which the oil may have reached the First and Second sands is discussed on page 81. The smaller amount of oil in the Second sand and its absence in the Third and probable absence in the lower sands has much weight as indicating that it was derived from the overlying Colorado shale rather than from the underlying Ellis and Quadrant formations, as was suggested by Lupton and Lee.[40] According to these geologists the faults offered a ready means for the upward migration of the oil.

The reason, apparently, for suggesting that the oil is derived from the lower formations is the belief that such a migration would produce an oil of light gravity out of the heavy oils commonly found in those formations. Ever since Day[41] discovered that oil is fractionated when it is passed through dry fuller's earth and suggested that the light oils such as the Carboniferous and Devonian oils of the Appalachian field might be the result of upward migration of heavy oils similar to those found in the Trenton or older limestone in Ohio and Indiana, there has been a natural tendency to attribute variations in the grade of oil in any field or region to such migration. Yet, according to Kalickij's analysis,[42] this hypothesis is based on two misconceptions—first, that sedimentary rocks have the same fractionating property as fuller's earth, whereas, according to Day's own experiment, they either lack it altogether or possess it to only the faintest degree; second, that oil-bearing formations which contain interstitial water have properties that fuller's earth possesses only when it is finely sieved and powder-dry. Another strong argument against migrations is brought forward by Höfer,[43] who points out that if such a migration took place all the strata through which the

[40] Lupton, C. T., and Lee, Wallace, Geology of the Cat Creek oil field, Fergus and Garfield Counties, Mont.: Am. Assoc. Petroleum Geologists Bull., vol. 5, No. 2, pp. 257–258, 1921.

[41] Day, D. T., A suggestion as to the origin of Pennsylvania petroleum: Am. Philos. Soc. Proc., vol. 36, No. 154, pp. 112–115, 1897.

[42] Kalickij, Von K., Ueber die Migration des Erdols: Russ. Com. géol. Bull., vol. 30, pp. 585–643, 1911.

[43] Cited by Kalickij, Von K., idem, p. 600.

oil migrated should be saturated with oil. All the evidence at hand indicates that the shales lying between oil sands and the suggested source of the oil are saturated with water and not oil. The fact also that they have undoubtedly always contained water in itself would make it impossible for oil to migrate through them, for Gilpin and Cram[44] have shown that water will displace oil in fine-grained material. Some of the supporters of the migration hypothesis in the Day sense, however, suggest that the movement took place along fault planes and joints. But the possibility that such movement could produce a fractionation of the oil appears to be scant, because the movement is not interstitial. That migration produces a low-grade oil rather than a high-grade oil, at least under the special conditions where the oil is affected by contact with sulphate waters, is the conclusion reached by Rogers[45] as a result of his studies of the relations between oil and water in the Sunset-Midway oil field of California.

In view of the objections to fractionation by migration above set forth the writer believes that it is unlikely that the high quality of the Cat Creek oil is attributable to migration. A relatively slight modification of the normal Cretaceous oils would produce oils of this quality. But whatever difficulties the quality of this oil may appear to raise against the Cretaceous shales as a source, the difficulties would be greater in assuming deeper seated sources, because the oils differ less from the normal Cretaceous oils than from the heavy oils of the older rocks. Furthermore, no difficult and obscure hypotheses are required by this concept to account for the presence of the oils in the reservoirs in which they are found. The First Cat Creek sand is in depositional contact with the dark shales, and the Second sand has been brought into contact with this sand by existing faults, so that the problem of accumulation under this concept involves no difficulties.

The suggestion that has been offered by some geologists that the high quality of the oil is due to the pronounced folding in the area does not appear to the writer to be well substantiated. Little relation can be found between the degree of folding in oil fields and the grade of the oil. In many of the Tertiary fields, such as those of California, Rumania, Galicia, and Russia, where the formations are highly folded and faulted, the oils are of low grade, whereas in other fields where the folding is very slight, such as those of the Mid-Continent and Appalachian regions, the oils are of high grade. The most obvious relation, in the opinion of the writer, is that the

[44] Gilpin, J. E., and Cram, M. P., The fractionation of crude petroleum by capillary diffusion: U. S. Geol. Survey Bull. 365, 1908.

[45] Op. cit., pp. 26–32.

older oils, when they are not too far deteriorated, are of the higher grade.

### FUTURE POSSIBILITIES OF THE FIELD

The curve showing the amount of oil per month shipped from the Cat Creek field (fig. 10) indicates a decline in the production of the field since August, 1922, when the peak was reached as a result of the deepening of the wells to the Second sand. This decline, except for minor fluctuations, has been gradual. Although during this period the price of oil has offered no great incentive for operators to increase their production, yet there has been sufficient competition in the field to lead to the drilling of a number of new wells during the last two years. The 64 wells producing at the peak in August, 1922, were increased to 100 wells in June, 1924. Inasmuch as there are only a few inside locations yet to be drilled, it is likely that the future decline in the production of the field will not be less than it has been during the last two years, unless there should be an extension of the field or the discovery of new producing sands, but the possibilities of such an extension or of important additional discoveries are not promising. The limits of the producing areas appear to be fairly well defined, and although it is possible that new strikes will be made on some of the fault blocks similar to those made in the Jack Rabbit well, in the southwest corner of the NE. ¼ sec. 17, T. 15 N., R. 30 E., and the Deveraux well, in the northeast corner of sec. 12, T. 15 N., R. 28 E., the fact that these discoveries did not add extensive producing areas to the field make it improbable that any considerable amount of additional production will be obtained outside of the present known areas. The possibility of obtaining oil in sands below the First and Second sands is not great. As stated on page 75 the Third sand has been fairly adequately tested. Two wells, the Thermopolis Cat Creek well No. 2, on the east line of the SW. ¼ SW. ¼ sec. 11, T. 15 N., R. 29 E., and the Frantz Corporation well, in the northeast corner of the SW. ¼ sec. 27, T. 15 N., R. 30 E., have been drilled through the Ellis formation and for 257 and 1,350 feet, respectively, into the Quadrant formation without encountering oil. Inasmuch as these wells were not drilled through the Quadrant formation and were not located on the highest parts of the domes, they are not adequate tests of the oil possibilities of the formations beneath the Cat Creek sands. Further tests made near the crests of the domes may encounter oil in the Quadrant or the upper part of the Madison limestone, which should be reached at a depth of 2,500 to 2,700 feet below the top of the First Cat Creek sand. Any oil that may be found in these formations, however, is likely to be of low grade and scarcely likely to be present in great quantity.

## POSSIBILITY OF THE DISCOVERY OF OTHER OIL FIELDS IN THE AREA

Inasmuch as most of the oil in the Rocky Mountain region is found in the crests of pronounced domes protected from water flushing and as the oil in the only commercial field of central Montana is obtained from the First and Second Cat Creek sands, it would appear that the best chances for the discovery of new fields in the area mapped lie in testing the domes shown on Plate 3, from the crests of which the Cat Creek sands are not eroded and in which they are not too deep to be reached by the drill. These conditions are fullfilled in the Box Elder, Brush Creek, and Oiltana domes. Two wells have been drilled, however, in the Brush Creek and Oiltana domes through the Cat Creek producing sands, and although these wells were located on or near the crests of the domes, oil in commercial quantities was not encountered, the sands instead yielding large flows of water, the freshness of which is an indication that the water circulation has been so active in the sands as to remove any oil that may have previously accumulated. The Box Elder dome yet remains to be tested, but inasmuch as it is not faulted, or at least not so extensively as the Oiltana dome, there is less reason to expect that oil may be encountered in it than in the Oiltana dome. Tests of the Bear Creek dome, lying 6 miles west of the Box Elder dome, have been unsuccessful, and the chances for obtaining oil there were probably better than in the Brush Creek dome, because the Bear Creek dome is affected by pronounced faulting. Tests also have been made of some of the plunging anticlines in the central part of the uplift without success. In practically all the test wells large volumes of fresh water were encountered in the Cat Creek sands. Therefore, in view of the fact that the more favorable areas for the accumulation of oil in the Cat Creek sands have been largely tested, without success, it seems doubtful whether any commercial fields will be found in these sands in the area mapped outside of the present known producing areas. The possibility of encountering oil in deeper sands can not be overlooked, but the results obtained in the deep test made in the Devils Basin and Kootenai domes do not justify great optimism.

## WELL DATA

*Summary of wells drilled in the area outside of the Cat Creek field*

| No. on map | Company | Location | | | | Altitude of well (feet) | Total depth (feet) | Date of completion | Results | Depth of sand (feet) | Lowest formation penetrated | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sec. | T. N. | R. E. | Dome or locality | | | | | | | |
| 1 | West Dome | 18 | 16 | 26 | Kootenai dome | 3,095 | 1,605 | 1920 | Dry | | Quadrant | Fresh water in all formations. |
| 1-A | California | 25 | 17 | 24 | Box Elder dome | | 950 | 1926 | do | | Kootenai | Water in all sands. |
| 2 | Hogan O'Neil | 20 | 16 | 26 | Kootenai dome | 3,160 | 635 | 1920 | do | | do | |
| 3 | Neudigate | 28 | 16 | 26 | do | (?) | 2,410 | 1923 | 80,000 cubic feet of gas. | 730–740. Ellis. | Madison | Gas drowned out by water. |
| 4 | Cat Creek Consolidated. | 26 | 16 | 26 | do | 2,937 | 570 | 1920 | Dry | | Colorado? | |
| 5 | Ohio Oil | 26 | 16 | 27 | Brush Creek dome | 2,941 | 1,779 | 1920 | do | | Quadrant | Large flows of fresh water from Kootenai sands. |
| 5-A | Gier Bros. No. 1 | 28 | 16 | 27 | do | | 2,350 | 1924 | do | | do | Do. |
| 6 | Alexander Syndicate | 25 | 16 | 27 | do | (?) | 1,015 | 1921 | do | | Kootenai | Large flows of water in Kootenai sands. |
| 6-A | Wilson-Fisher | 9 | 15 | 27 | McDonald Creek dome. | | 970 | 1926 | do | | Colorado shale | Shut down at 970 feet. |
| 7 | Cat Creek Consolidated. | 29 | 16 | 28 | Oiltana dome | 3,061 | 1,175 | 1920 | Show of oil | 1,175 | do | Large flow of water in First Cat Creek sand. |
| 7-A | Hardrock No. 1 | 33 | 16 | 28 | Brush Creek dome | | 1,315 | 1925 | Dry | | Kootenai | Water in all sands. |
| 8 | Montana Oil Syndicate. | 28 | 16 | 28 | Oiltana dome | 3,050? | 2,100 | 1922 | Shows of oil | In Kootenai and Ellis. | Quadrant | Large flows of water in Kootenai. |
| 8-A | Western Petroleum Producers No. 1. | 33 | 16 | 28 | Brush Creek dome | | 1,468 | 1924 | Dry | | Kootenai | Water in all sands. |
| 9 | E. G. Lewis Development. | 15 | 16 | 28 | Cottonwood Creek | (?) | 1,280 | 1920 | do | | Bearpaw | |
| 10 | Schwartz | 22 | 15 | 26 | McDonald Creek dome. | (?) | 1,720 | 1923 | do | | Top of Quadrant? | Water in First Cat Creek sand. |
| 10-A | Gordon Campbell No. 1. | 25 | 15 | 24 | do | | 1,200 | 1925 | do | | Kootenai | Water in all sands. |
| 11 | A. M. Z | 14 | 14 | 25 | Elk Creek | (?) | 1,735? | 1923 | do | | Top of Quadrant | Do. |
| 11-A | Winnett Syndicate No. 1. | 25 | 15 | 25 | McDonald Creek dome. | | 1,100 | 1926 | | | Kootenai | Shut down at 1,100 feet. |
| 12 | Oregon Montana | 20 | 14 | 26 | Elk Creek | 3,187 | 2,472 | 1921 | Show of oil | In top of Quadrant. | Quadrant | Water in Kootenai and Quadrant sands. |
| 12-A | Flatwillow-Elk Creek Basin Oil. | 24 | 14 | 25 | do | | 850 | 1926 | | | Kootenai | Drilling. |
| 13 | Whaley Oil | 30 | 14 | 26 | do | 3,092 | 1,100 | 1923 | Dry | | Quadrant | |
| 14 | E. G. Lewis Development. | 10 | 13 | 25 | Yellow Water | 3,200 | 1,490 | 1920 | do | | Ellis | Water in Kootenai sands. |

*Summary of wells drilled in the area outside of the Cat Creek field*—Continued

| No. on map | Company | Location | | | | Altitude of well (feet) | Total depth (feet) | Date of completion | Results | Depth of sand (feet) | Lowest formation penetrated | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sec. | T. N. | R. E. | Dome or locality | | | | | | | |
| 15 | Wayne Petroleum No. 1. | 28 | 13 | 25 | Pike Creek | (?) | 1, 550 | 1920 | do | | Quadrant | Water in Kootenai sand. |
| 16 | Wayne Petroleum No. 2. | 34 | 13 | 25 | do | (?) | 960 | 1921 | do | | Top of Kootenai | Water in First Cat Creek sand. |
| 17 | Monarch No. 3 | 5 | 11 | 24 | Devils Basin | 4, 004 | 200 | 1921 | | | Kootenai | |
| 18 | Monarch No. 2 | 4 | 11 | 24 | do | 3, 930 | 545 | 1921 | | | do | |
| 19 | Absaroka | 9 | 11 | 24 | do | | 2, 086 | 1923 | Dry | | Madison | Sulphur water many horizons. |
| 20 | Spokane Roundup | 9 | 11 | 25 | do | 3, 769 | 1, 950? | | do | | Kootenai | |
| 21 | Monarch No. 1 | 16 | 11 | 24 | do | 3, 921 | 1, 325 | 1921 | Show of oil | 1, 160 | Quadrant | |
| 22 | Roundup Oil Gas | 14 | 11 | 24 | do | 3, 827 | 1, 235 | 1921 | do | 1, 123 to 1, 137 | do | Water flowed from well |
| 23 | Montil Oil | 14 | 11 | 24 | do | 3, 852 | 1, 175 | | Little oil | 1, 159 to 1, 164 | do | Little sulphur gas at 810. |
| 24 | "56" Petroleum | 14 | 11 | 24 | do | | 2, 505 | 1923 | Dry | | Madison | Sulphur water at many horizons. |
| 25 | Devils Dome | 18 | 11 | 25 | do | 3, 857 | 1, 525 | 1921 | do | | Quadrant | |
| 26 | Tri-City Oil | 23 | 11 | 24 | do | 3, 903 | 1, 236 | 1921 | Little oil | 1, 165 to 1, 195 | do | Abandoned. |
| 27 | Highland Oil | 23 | 11 | 24 | do | 3, 800 | 1, 250 | 1921 | Dry | | do | |
| 28 | Van Dusen No. 1 | 24 | 11 | 24 | do | 3, 822 | 1, 845 | 1920 | Oil 25 barrels daily | 1,175 | do | Oil shows at 1,650, 1,665, and 1,770. |
| 29 | Addams No. 1 | 24 | 11 | 24 | do | 3, 812 | 1, 193 | 1921 | Little oil | (?) | do | Abandoned. |
| 30 | Addams No. 2 | 24 | 11 | 24 | do | 3, 911 | 1, 400 | 1921 | Dry | | Kootenai | |
| 31 | A. B. C. No. 2 | 26 | 11 | 24 | do | 3, 906 | 1, 758 | 1921 | do | | Quadrant | |
| 32 | A. B. C. No. 1 | 25 | 11 | 24 | do | 3, 911 | 1, 205 | 1920 | 100 barrels oil | 1,173 | do | Oil used as fuel. |
| 32-A | Aerolite No. 1 | 25 | 11 | 24 | do | | 100 | 1926 | | | Kootenai | Drilling. |
| 33 | Calgary Montana | 25 | 11 | 24 | do | 3, 883 | 1, 315 | 1921 | Dry | | Quadrant | No show. |
| 33-A | Lincoln Oil | 25 | 11 | 24 | do | | 1, 193 | 1926 | Oil 30 barrels daily | 1,146 | do | Oil used as fuel. |
| 34 | Roundup drillers | 30 | 11 | 25 | do | 3, 669 | 450 | 1920 | do | | Kootenai | |
| 35 | Great American | 30 | 11 | 25 | do | 3, 671 | 1, 585 | 1921 | do | | Quadrant | |
| 36 | Allied Oil | 30 | 11 | 25 | do | 3, 641 | 830 | 1921 | do | | Kootenai | |
| 37 | Washington Montana. | 6 | 10 | 25 | do | 3, 570 | 900 | 1921 | do | | do | Show at 650 feet. |
| 38 | Montana Central | 8 | 10 | 25 | do | (?) | 1, 015 | 1921 | do | | Colorado | |

The following are the logs of the deepest wells drilled in different parts of the area, with the writer's interpretation of the formations penetrated. All these are drillers' logs except that of the Absaroka Oil Development Co.'s well in Devils Basin, which was compiled by A. A. Hammer from drill cuttings.

*Logs of deep wells in Devils Basin-Cat Creek area*

**Frantz Corporation's well on Mosby dome, in the NE. ¼ SW. ¼ sec. 27, T. 15 N., R. 29 E., Garfield County**

| | Feet |
|---|---|
| Surface soil | 0–18 |
| Quicksand and gravel | 18–25 |
| Black shale | 25–800 |
| Gritty shale | 800–910 |
| Sand; water | 910–935 |
| White shale | 935–1, 020 |
| Sand; show of oil | 1, 020–1, 025 |
| White shale | 1, 025–1, 040 |
| Red shale | 1, 040–1, 075 |
| Pink shale | 1, 075–1, 100 |
| Black shale | 1, 100–1, 110 |
| Hard sand | 1, 110–1, 112 |
| White shale | 1, 112–1, 120 |
| Sand | 1, 120–1, 124 |
| Green shale | 1, 124–1, 130 |
| Sand; show of oil, some water | 1, 130–1, 160 |
| Pink shale | 1, 160–1, 235 |
| Sand; 10,000 barrels of water | 1, 235–1, 325 |
| Blue shale | 1, 325–1, 335 |
| Sandy lime | 1, 335–1, 355 |
| Blue shale | 1, 355–1, 435 |
| Sand | 1, 435–1, 455 |
| Blue shale | 1, 455–1, 535 |
| Sandy shale | 1, 535–1, 590 |
| Gray shale | 1, 590–1, 850 |
| Red shale | 1, 850–1, 900 |
| Gray shale | 1, 900–1, 920 |
| Yellow sand; show of oil | 1, 920–1, 955 |
| Gray shale | 1, 955–2, 005 |
| Red shale | 2, 005–2, 030 |
| Black shale | 2, 030–2, 090 |
| White lime | 2, 090–2, 104 |
| Lime shells and shale | 2, 104–2, 120 |
| White lime | 2, 120–2, 132 |
| Red shale | 2, 132–2, 144 |
| White lime | 2, 144–2, 166 |
| Red shale | 2, 166–2, 186 |
| Black lime | 2, 186–2, 192 |
| Red shale | 2, 192–2, 200 |
| White lime | 2, 200–2, 212 |
| Black shale | 2, 212–2, 230 |
| White lime | 2, 230–2, 243 |
| Brown shale | 2, 243–2, 250 |
| Red shale | 2, 250–2, 340 |
| Gray shale | 2, 340–2, 385 |
| Black shale | 2, 385–2, 395 |
| White shale | 2, 395–2, 398 |
| Black shale; iron pyrites | 2, 398–2, 445 |
| Blue shale | 2, 445–2, 495 |
| Gray shale; iron pyrites | 2, 495–2, 535 |
| Black shale | 2, 535–2, 600 |
| Black shale and shells | 2, 600–2, 625 |
| Gray shale | 2, 625–2, 650 |
| Dark-gray shale | 2, 650–2, 672 |
| White soft shale | 2, 672–2, 685 |
| Dark shale | 2, 685–2, 700 |
| White shale | 2, 700–2, 745 |
| Hard shell | 2, 745–2, 749 |
| Black shale | 2, 749–2, 760 |
| White shale | 2, 760–2, 785 |
| Black shale | 2, 785–2, 790 |
| White shale | 2, 790–2, 815 |
| Brown lime | 2, 815–2, 825 |
| Talc and lime | 2, 825–2, 860 |
| Green shale | 2, 860–2, 880 |
| White shale | 2, 880–2, 895 |
| Hard lime | 2, 895–2, 899 |
| Green shale, sandy | 2, 899–2, 920 |
| Blue shale | 2, 920–2, 925 |
| Green shale | 2, 925–2, 940 |
| Lime | 2, 940–2, 945 |
| White shale | 2, 945–2, 950 |
| Gray shale | 2, 950–2, 980 |
| Gray lime | 2, 980–2, 992 |
| Dark shale | 2, 992–3, 015 |
| Gray lime | 3, 015–3, 025 |
| Gray sandy shale | 3, 025–3, 050 |
| Brown sandy shale | 3, 050–3, 075 |
| White talc or gypsum | 3, 075–3, 105 |
| Author's interpretation: | |
| Colorado shale | 0–935 |
| Kootenai and Morrison (?) formations | 935–1, 535 |
| Ellis formation | 1, 535–1, 590 |
| Quadrant formation | 1, 590–3, 105 |

**Thermopolis Cat Creek Syndicate's Miller No. 2, on West dome, in the SW. 1/4 SW. 1/4 sec. 11, T. 15 N., R. 29 E., Fergus County**

| | Feet. |
|---|---|
| Black shale | 0–245 |
| Mosby sand; shows some gas | 245–250 |
| Colorado shale | 250–1, 385 |
| Oil sand (First sand) | 1, 385–1, 480 |
| Red shale | 1, 480–1, 500 |
| Oil sand | 1, 500–1, 540 |
| Red shale | 1, 540–1, 590 |
| Lime; oil show | 1, 590–1, 638 |
| Gray sand; oil show (Second sand?) | 1, 638–1, 640 |
| Hard red shale | 1, 640–1, 695 |
| Sandy gray shale | 1, 695–1, 705 |
| Pink shale | 1, 705–1, 720 |
| Pink sandy shale; 1,735–1,740 hard | 1, 720–1, 740 |
| White sand; water at 1,747 feet | 1, 740–1, 747 |
| Sand; heavy water at 1,755 feet (Third sand) | 1, 747–1, 798 |
| Red shale | 1, 798–1, 800 |
| Sand | 1, 800–1, 837 |
| Black shale | 1, 837–1, 838 |
| Sand | 1, 838–1, 842 |
| Gray shale | 1, 842–1, 845 |
| Sand; water | 1, 845–1, 857 |
| Coal | 1, 857–1, 864 |
| Black sand | 1, 864–1, 865 |
| Black shale | 1, 865–1, 899 |
| Blue shale; shows slight oil saturation | 1, 899–1, 900 |
| Shale | 1, 900–1, 910 |
| Sandy lime | 1, 910–1, 925 |
| Lime | 1, 925–1, 940 |
| Sand; water | 1, 940–1, 976 |
| Hard blue shale | 1, 976–1, 992 |
| Gray shale | 1, 992–2, 002 |
| Coarse sand | 2, 002–2, 005 |
| Gray and red shale | 2, 005–2, 058 |
| Dark lime | 2, 058–2, 095 |
| Blue shale | 2, 095–2, 098 |
| Gray lime sand | 2, 098–2, 118 |
| Bluish-gray sticky shale | 2, 118–2, 200 |
| Gray shale, some sand | 2, 200–2, 275 |
| Soft white lime | 2, 275–2, 280 |
| Gray shale, mixed white on tools | 2, 280–2, 428 |
| Brownish-red shale, sandy, mixed pink on tools | 2, 428–2, 485 |
| Light-gray fine lime | 2, 485–2, 495 |
| Dark-gray shale, hard white lime | 2, 495–2, 576 |
| Brown shale, some grit | 2, 576–2, 595 |
| Yellow clay shale, some grit | 2, 596–2, 630 |
| Gray shale; shows a little pink on tools | 2, 630–2, 640 |
| Dark shale | 2, 640–2, 685 |
| Author's interpretation: | |
| Colorado shale | 0–1, 480 |
| Kootenai and Morrison(?) formations | 1, 480–2, 098 |
| Ellis formation | 2, 098–2, 428 |
| Quadrant formation | 2, 428–2, 685 |

**Well of Neudigate Estate (Inc.), on Kootenai dome, in the NE. 1/4 sec. 28, T. 16 N., R. 26 E., Fergus County**

| | Feet |
|---|---|
| Gumbo shale | 0–9 |
| First sand | 9–52 |
| Yellow clay | 52–57 |
| Blue shale | 57–62 |
| Gray shale | 62–67 |
| Pink shale | 67–80 |
| Gray sandy shale | 80–86 |
| Red beds | 86–101 |
| Gray hard rock | 101–140 |
| Red beds | 140–170 |
| Gray sandstone; water | 170–172 |
| Red beds | 172–195 |
| Gray lime shells | 195–197 |
| Red shale | 197–203 |
| Gray shale | 203–210 |
| Coarse sand (Second) | 210–225 |
| Red beds | 225–275 |
| Hard sand shells | 275–280 |
| Red beds | 280–288 |
| Sand (Third) | 288–317 |
| Reds beds | 317–329 |
| Limestone | 329–336 |
| Gray sand, medium | 336–341 |
| Gray sand, fine | 341–344 |
| Lime | 344–352 |
| Coarse sand | 352–361 |
| Hard sand, fine | 361–380 |
| White | 380–392 |
| Coal showing gray | 392–403 |
| Dark-gray sand | 403–425 |

| | Feet |
|---|---|
| Black sandy coal | 425–441 |
| Gray sand; water | 441–443 |
| Dark-gray sand | 443–485 |
| Coal bed | 485–490 |
| Hard sandrock | 490–500 |
| Black shale | 500–510 |
| Dark-blue shale (hole 10 feet short; casing set 491 feet) | 510–521 |
| Gray shale | 521–533 |
| Hard gray sand | 533–537 |
| Black shale | 537–540 |
| White shale | 540–550 |
| Red beds (rock) | 550–560 |
| Blue shale | 560–565 |
| Lime shells | 565–570 |
| Blue shale | 570–600 |
| Gray shale | 600–625 |
| White lime shells | 625–627 |
| Gray-blue shale | 627–665 |
| Hard lime shells | 665–680 |
| White talc | 680–685 |
| Blue shale | 685–700 |
| Hard sand | 700–705 |
| Blue sandy shale | 705–730 |
| Water sand; 80,000 cubic feet of gas | 730–740 |
| Blue lime | 740–750 |
| Blue shale | 750–800 |
| White lime | 800–808 |
| White chalk and lime | 808–871 |
| Blue clay | 871–916 |
| Gray lime | 916–921 |
| White clay | 921–933 |
| Gray lime | 933–936 |
| White clay | 936–966 |
| Gray shale | 966–991 |
| Red beds | 991–1, 020 |
| Blue shale | 1, 020–1, 038 |
| Brown lime | 1, 038–1, 050 |
| White lime | 1, 050–1, 060 |
| Gray lime | 1, 060–1, 080 |
| Muddy lime | 1, 080–1, 095 |
| Yellow sand | 1, 095–1, 100 |
| Blue shale | 1, 100–1, 105 |
| Yellow lime | 1, 105–1, 115 |
| Gray lime | 1, 115–1, 118 |
| Brown lime | 1, 118–1, 135 |
| Yellow clay | 1, 135–1, 143 |
| Blue lime | 1, 143–1, 145 |
| Brown shale | 1, 145–1, 164 |

| | Feet |
|---|---|
| Red shale | 1, 164–1, 184 |
| Yellow sand | 1, 184–1, 197 |
| Brown lime | 1, 197–1, 210 |
| Pink shale | 1, 210–1, 215 |
| Sandy red shale | 1, 215–1, 227 |
| Red shale | 1, 223–1, 237 |
| Pink lime | 1, 233–1, 298 |
| Gray lime | 1, 298–1, 325 |
| Pink shale | 1, 325–1, 460 |
| Yellow lime | 1, 460–1, 464 |
| Pink shale | 1, 464–1, 510 |
| Blue shale | 1, 510–1, 585 |
| Gray shale | 1, 585–1, 605 |
| Gray sandy shale | 1, 605–1, 655 |
| Blue shale | 1, 655–1, 670 |
| White lime; little water | 1, 670–1, 695 |
| Hard gray lime | 1, 695–1, 705 |
| Blue shale and white lime | 1, 705–1, 715 |
| Blue shale and lime streaks | 1, 715–1, 790 |
| Dark-blue shale | 1, 790–1, 890 |
| Light-blue shale | 1, 890–1, 920 |
| Soft gray shale | 1, 920–1, 940 |
| Black shale | 1, 940–1, 965 |
| Soft gray shale (cavey) | 1, 965–1, 995 |
| Dark-gray shale (min.) | 1, 995–2, 025 |
| Light-gray shale | 2, 025–2, 038 |
| Brown shell | 2, 038–2, 048 |
| Green-gray shale | 2, 048–2, 068 |
| White shale | 2, 068–2, 080 |
| Dark-gray and green shale mixed | 2, 080–2, 105 |
| Light-gray shale | 2, 105–2, 110 |
| Yellow and gray lime | 2, 110–2, 120 |
| White and brown lime | 2, 120–2, 125 |
| Gray lime and green shale | 2, 125–2, 160 |
| Greenish-gray lime | 2, 160–2, 175 |
| Dark-blue lime | 2, 175–2, 180 |
| Hard gray lime | 2, 180–2, 185 |
| Dark-blue lime | 2, 185–2, 200 |
| White and blue lime | 2, 200–2, 215 |
| Blue lime | 2, 215–2, 225 |
| Gray lime | 2, 225–2, 235 |
| Blue lime; streaks of blue shale | 2, 235–2, 245 |
| Gray lime | 2, 245–2, 252 |
| Gray shale | 2, 252–2, 265 |
| Blue lime | 2, 265–2, 270 |
| Blue shale | 2, 270–2, 290 |
| Gray lime | 2, 290–2, 300 |

| | Feet |
|---|---|
| Blue shale | 2, 300–2, 335 |
| Gray shale and slate | 2, 335–2, 373 |
| Gray lime | 2, 373–2, 380 |
| Sandy lime | 2, 380–2, 390 |
| Hard gray sand | 2, 390–2, 405 |
| Blue sandy shale | 2, 405–2, 410 |

| | Feet |
|---|---|
| Author's interpretation: | |
| Colorado shale | 0–67 |
| Kootenai and Morrison (?) formations | 67–700 |
| Ellis formation | 700–991 |
| Quadrant formation | 991–2, 410 |

**Whaley Oil Co.'s well on Elk Creek, in sec. 30, T. 14 N., R. 26 E., Fergus County**

| | Feet |
|---|---|
| Gumbo | 0–10 |
| Gravel; little water | 10–20 |
| Blue shale | 20–50 |
| Black sandy shale; water; probably Mowry; set 60 feet 20-inch pipe | 50–57 |
| Colorado shale, dark | 57–528 |
| Colorado shale, lighter | 528–700 |
| Sandy shale | 700–720 |
| Dark shale shot with sand | 720–735 |
| Sand | 735–780 |
| Lime shell | 780–785 |
| Sand carrying a little water; set 15½-inch casing | 785–818 |
| Kootenai mixed shale | 818–833 |
| Pink shale; clamped 15½-inch casing at 866 feet 6 inches | 833–840 |
| Blue shale | 840–867 |
| Sand; small showing of oil | 867–890 |
| Red and pink shale | 890–925 |
| Lime shell | 925–928 |
| Red beds | 928–955 |
| Broken sandy lime cased 12½-inch at 960 feet | 955–965 |
| Red beds, thin streak of bentonite | 965–976 |
| Sand; showing of oil and gas | 976–1, 035 |
| Red shale | 1, 035–1, 060 |
| Sand; showing of oil and gas | 1, 060–1, 080 |
| Red beds | 1, 080–1, 135 |
| Sand; water 300 barrels | 1, 135–1, 155 |
| Blue shale | 1, 155–1, 160 |
| Sandy lime | 1, 160–1, 167 |
| Blue shale | 1, 167–1, 198 |
| Sand; water 300 barrels | 1, 198–1, 214 |
| Coal | 1, 214–1, 215 |
| Blue shale; clamped 12½-inch casing at 1,218 feet | 1, 215–1, 230 |
| Sandy lime shell | 1, 230–1, 232 |
| Sandy shale; steel-line measurement at this level shows total depth to be 1,278 feet | 1, 232–1, 267 |
| Sandy lime shell, iron, hard | 1, 278–1, 286 |
| Mixed lime sand, iron; water 300 barrels | 1, 286–1, 365 |
| Sandy lime | 1, 365–1, 380 |
| Pink lime | 1, 380–1, 395 |
| Lime | 1, 395–1, 405 |
| Blue sandy shale | 1, 405–1, 585 |
| Gray shale | 1, 585–1, 678 |
| Brown lime | 1, 678–1, 683 |
| Broken lime | 1, 683–1, 705 |
| Limestone | 1, 705–1, 716 |
| Lime, reddish | 1, 716–1, 725 |
| Lime, pebbly with crystals; 300 barrels water | 1, 725–1, 734 |
| Lime | 1, 734–1, 737 |
| Black and white lime | 1, 737–1, 739 |
| Light lime | 1, 739–1, 744 |
| Pink lime, light | 1, 744–1, 749 |
| White lime, 1,750 feet base of Ellis | 1, 749–1, 754 |
| Red shale | 1, 754–1, 765 |
| Lime, brownish | 1, 756–1, 759 |
| Lime, white, cherty | 1, 759–1, 775 |
| Lime, light | 1, 775–1, 787 |
| Red shale | 1, 787–1, 789 |
| Black shale | 1, 789–1, 815 |
| Lighter shale, very cavey | 1, 815–1, 827 |
| Lime | 1, 827–1, 862 |
| Shale | 1, 862–1, 865 |
| Lime | 1, 865–1, 898 |

| | Feet |
|---|---|
| Shale | 1, 898–1, 907 |
| Lime | 1, 907–1, 914 |
| Shale and bentonite | 1, 914–2, 000 |

Casing: 60 feet 20-inch, 866 feet 15½-inch, 1,248 feet 12½-inch, 1,468 feet 10-inch, 1,848 feet 8¼-inch.

| Author's interpretation: | Feet |
|---|---|
| Colorado shale | 0–818 |
| Kootenai and Morrison (?) formations | 818–1, 395 |
| Ellis formation | 1, 395–1, 716 |
| Quadrant formation | 1, 716–2, 000 |

**Absaroka Oil Development Co.'s well in Devils Basin, in sec. 9, T. 11 N., R. 24 E., Musselshell County**

| | Feet |
|---|---|
| Light-gray to white sand, rounded quartz grains | 270–290 |
| Fine gray sand | 290–300 |
| Gray shale, sandy | 300–310 |
| Grayish-white plastic shale | 310–330 |
| Gray plastic shale | 330–340 |
| Gray sandy lime | 340–350 |
| Red and gray shale | 350–360 |
| Blue sticky shale | 360–370 |
| Gray limestone | 370–380 |
| Shaly lime, dark | 380–390 |
| Dark shale | 390–400 |
| Gray limestone | 400–410 |
| Hard gray compact sand | 410–420 |
| Sandstone, light gray to white | 420–430 |
| Gray sandy shale | 430–440 |
| Blue sandy shale | 440–450 |
| Dark-gray sandy lime | 450–460 |
| Gray sandy lime, some maroon particles | 460–470 |
| Gray to light sand | 470–480 |
| Gray limestone, some sand | 480–490 |
| Light hard sandstone | 490–500 |
| Sandy lime | 500–520 |
| Lime, gray | 520–543 |
| Shale, blue | 543–556 |
| Shale, gray | 556–570 |
| Shale, limy, dark gray | 570–595 |
| Sandy lime | 595–600 |
| Shaly lime | 600–625 |
| Siliceous lime, dark gray | 625–630 |
| Sandy lime and red shale | 630–635 |
| Sand, lime, and red shale | 635–640 |
| Shale, dark red | 640–645 |
| Lime, siliceous, white and green particles | 645–650 |
| White limestone | 650–655 |
| Limestone, white, with some pink and brown particles | 655–680 |
| Lime, gray, with pink and purple particles | 680–690 |
| Lime, gray to red, and brilliant red shale | 690–694 |
| Lime, white to purple, some dark particles | 694–700 |
| Lime, white to gray | 700–712 |
| Lime, white and gray, streaks of red shale | 712–733 |
| Shale, white, gray, and red | 733–739 |
| Hard rock and lime shell | 739–743 |
| Shale, blue | 743–755 |
| Sandy lime, gray | 755–765 |
| Shale, blue | 765–783 |
| Shale, gray | 783–805 |
| Lime, gray | 805–810 |
| Shale, black; water at 812 feet in shale, filled 160 feet in 15½-inch hole in 1 hour | 810–816 |
| Sandy shale, black | 816–819 |
| Lime, gray | 819–832 |
| Shale, white | 832–840 |
| Lime, gray; water at 850 feet, 10 barrels per hour | 840–850 |
| Shale, gray | 850–855 |
| Shale, blue | 855–865 |
| Shale, gray | 865–872 |
| Sandy lime, gray | 872–895 |
| Lime and shale, gray | 895–900 |
| Sandy lime, gray | 900–910 |
| Lime and shale, gray | 910–920 |
| Shale, brown | 920–925 |
| Lime and shale, gray | 925–930 |
| Shaly limestone, gray | 930–935 |
| Shale, limy, gray | 935–940 |
| Lime, gray | 940–955 |
| Shale, gray | 955–965 |
| Lime, gray | 965–980 |
| Shale | 980–985 |
| Lime, gray | 985–1, 000 |

| | Feet |
|---|---|
| Sandy lime, gray | 1, 000–1, 005 |
| Sandy shale, gray | 1, 005–1, 018 |
| Sand, fine, gray | 1, 018–1, 030 |
| Lime, shaly, dark | 1, 030–1, 035 |
| Sand, fine white, with shale; may be cavings | 1, 035–1, 052 |
| Lime, shaly, dark gray | 1, 052–1, 086 |
| Sandy lime, dark, with an abundance of pyrite | 1, 086–1, 088 |
| Shale, gray | 1, 088–1, 090 |
| Shale, black | 1, 090–1, 092 |
| Sandy shale, gray | 1, 092–1, 094 |
| Shale, dark | 1, 094–1, 096 |
| Shale and lime, dark | 1, 096–1, 110 |
| Shale, dark, with white particles | 1, 110–1, 120 |
| Lime and shale, dark | 1, 120–1, 130 |
| Shale, black | 1, 130–1, 145 |
| Lime, a little shaly, black; sulphur water at 1,145 feet, filled 1,120 feet in 12½-inch hole in 2 hours | 1, 145–1, 170 |
| Sandy lime, black, with a white mixture and gypsum | 1, 170–1, 190 |
| Lime, black | 1, 190–1, 192 |
| Sandy shale, black | 1, 192–1, 194 |
| Lime and black shale | 1, 194–1, 200 |
| Lime, gray | 1, 200–1, 209 |
| Shale, gray | 1, 209–1, 216 |
| Shale, sandy, gray | 1, 216–1, 235 |
| Shaly lime | 1, 235–1, 255 |
| Shale and lime | 1, 255–1, 265 |
| Shale, dark gray | 1, 265–1, 290 |
| Lime, gray | 1, 290–1, 295 |
| Lime and shale, gray | 1, 295–1, 312 |
| Shale, gray | 1, 312–1, 325 |
| Lime, gray | 1, 325–1, 336 |
| Shale, gray | 1, 336–1, 345 |
| Lime and shale, some sand, much pyrite | 1, 345–1, 350 |
| Lime and shale | 1, 350–1, 360 |
| Lime and black shale, much pyrite | 1, 360–1, 362 |
| Lime, gray | 1, 362–1, 365 |
| Lime and shale, gray | 1, 365–1, 370 |
| Shale, light gray, and lime | 1, 370–1, 400 |
| Lime, gray | 1, 400–1, 405 |
| Shale, gray | 1, 405–1, 420 |
| Lime and shale, gray | 1, 420–1, 435 |
| Shale, light gray and green | 1, 435–1, 455 |
| Shaly lime | 1, 455–1, 458 |
| Lime, light gray | 1, 458–1, 466 |
| Lime and shale | 1, 466–1, 480 |
| Lime and shale, green | 1, 480–1, 485 |
| Shale and lime, black and green | 1, 485–1, 495 |
| Lime shells 1 to 2 inches thick with light-green shales between | 1, 495–1, 515 |
| Lime and dark shale | 1, 515–1, 550 |
| Shale and lime, gray | 1, 550–1, 565 |
| Shale and lime shell, gray | 1, 565–1, 580 |
| No record; hole caving | 1, 580–1, 585 |
| Sandy lime or limy sand; hole filled with water 800 feet in 4 hours | 1, 585–1, 595 |
| Sandy and shaly lime | 1, 595–1, 600 |
| Sandy shale, gray | 1, 600–1, 610 |
| Shaly lime; some quartz grains | 1, 610–1, 620 |
| Sandy shale, gray | 1, 620–1, 640 |
| Limy shale, gray | 1, 640–1, 645 |
| Lime and shale, green and gray; some quartz | 1, 645–1, 670 |
| Lime and shale, some quartz | 1, 670–1, 680 |
| Lime, greenish, with some white gypsum | 1, 680–1, 685 |
| Shaly lime | 1, 685–1, 700 |
| Lime and shale, gray; some gypsum | 1, 700–1, 710 |
| Shale and lime, gray; some quartz | 1, 710–1, 715 |
| Sandy shale, gray | 1, 715–1, 720 |
| Lime, sandy, gray | 1, 720–1, 735 |
| Sand, fine white; water at 1,735 feet over top of casing | 1, 735–1, 775 |
| Limy sand | 1, 775–1, 780 |
| Shale and sand, limy | 1, 780–1, 790 |
| Sand, fine, light, yellow and gray | 1, 790–1, 800 |
| Shale, red, a little limy | 1, 800–1, 808 |
| Sand, gray | 1, 808–1, 815 |
| Sand, fine, gray, and limy shale, red | 1, 815–1, 820 |
| Red shale with sand | 1, 820–1, 830 |
| Limy shale, red | 1, 830–1, 845 |

| | Feet |
|---|---|
| Limy and shaly sand, reddish brown | 1, 845–1, 860 |
| Limy shale, red with some white shale particles | 1, 860–1, 890 |
| Shaly lime, reddish brown | 1, 890–1, 895 |
| Limy shale, brownish red | 1, 895–1, 900 |
| Lime, green | 1, 900–1, 905 |
| Red shale, limy, with white gypsum | 1, 905–1, 910 |
| Red shale, limy, with tan and green shale lime | 1, 910–1, 920 |
| Red limy shale with gray lime and some green shale | 1, 920–1, 945 |
| Lime, gray, with some light gray; red and green shale and limestone (cavings) | 1, 945–1, 950 |
| Lime, gray | 1, 950–1, 955 |
| Lime, gray, a little shaly | 1, 955–1, 960 |
| Gray shaly lime with black particles | 1, 960–1, 970 |
| Lime, gray | 1, 970–1, 980 |
| Lime, brown | 1, 980–1, 995 |
| Lime, gray | 1, 995–2, 015 |
| Lime, gray, and white gypsum | 2, 015–2, 020 |
| Shaly lime, gray | 2, 020–2, 030 |
| Lime, dark gray and light gray with some white | 2, 030–2, 040 |
| Lime, gray, with a few white particles (gypsum) | 2, 040–2, 045 |
| Lime, gray, and white gypsum | 2, 045–2, 053 |
| No samples | 2, 053–2, 057 |
| Lime, gray, and white gypsum | 2, 057–2, 065 |
| Lime, gray; warm sulphur water over top; strong flow | 2, 065–2, 086 |

Casing record: 15½-inch, 835 feet; 12½-inch, 1,229 feet; 10-inch, 1,461 feet; 8¼-inch, 1,743 feet; 6⅝-inch, 1,966 feet.

Author's interpretation:

| | |
|---|---|
| Kootenai and Morrison (?) formations | 0–460 |
| Ellis formation | 460–635 |
| Quadrant formation | 635–1, 950 |
| Madison limestone | 1, 950–2, 086 |

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