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.

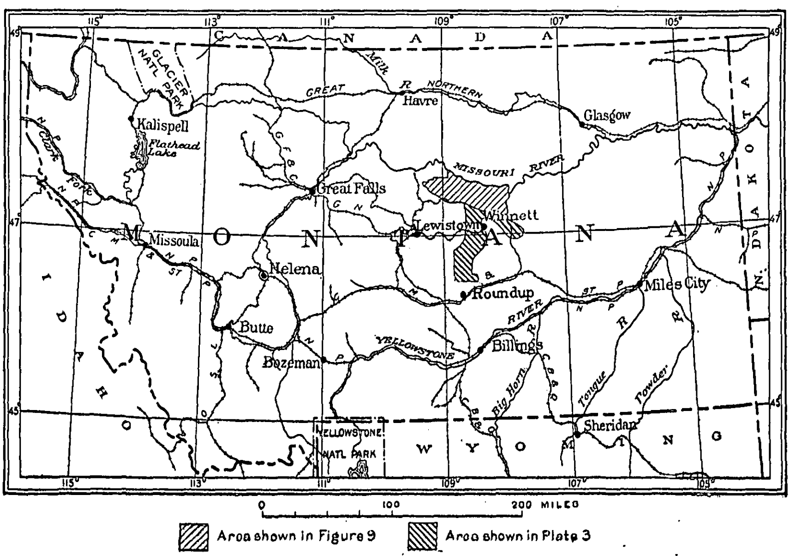

Figure 6.—Index map of Montana, showing location of area including Cat Creek and Devils Basin oil fields

(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	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. / Mississippian.		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

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[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

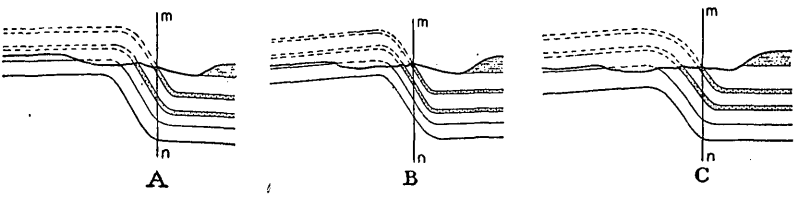


FIGURE 7.—Three possible interpretations of the structure along the margin of the Cat Creek-Devils Basin uplift, Mont.: A, Concentric type; B, similar type; C, combination of concentric and similar types

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

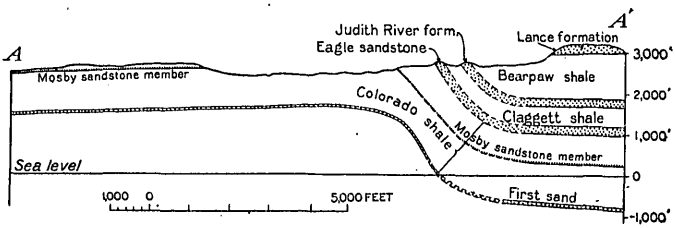


FIGURE 8.—Restoration of structure across Mosby dome, Mont., along line *A–A'*, Plate 3

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.

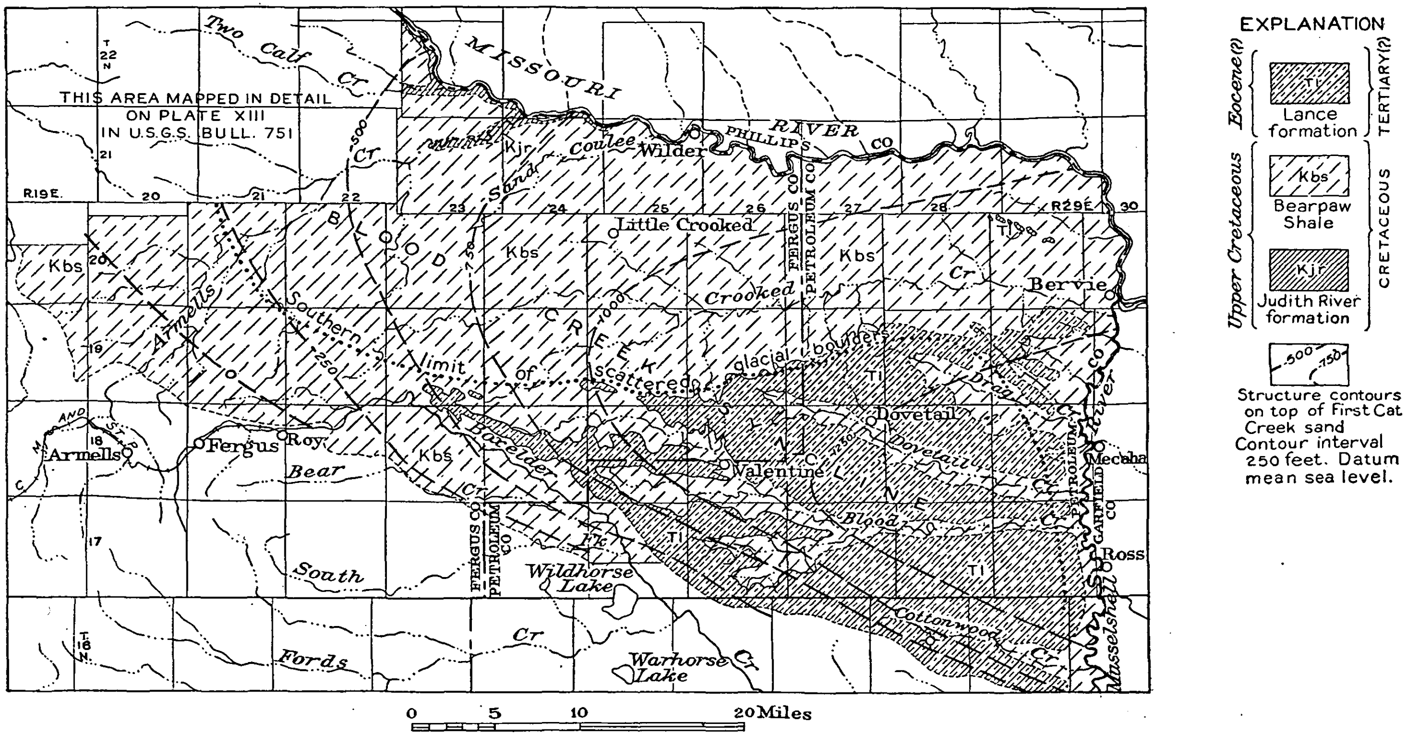
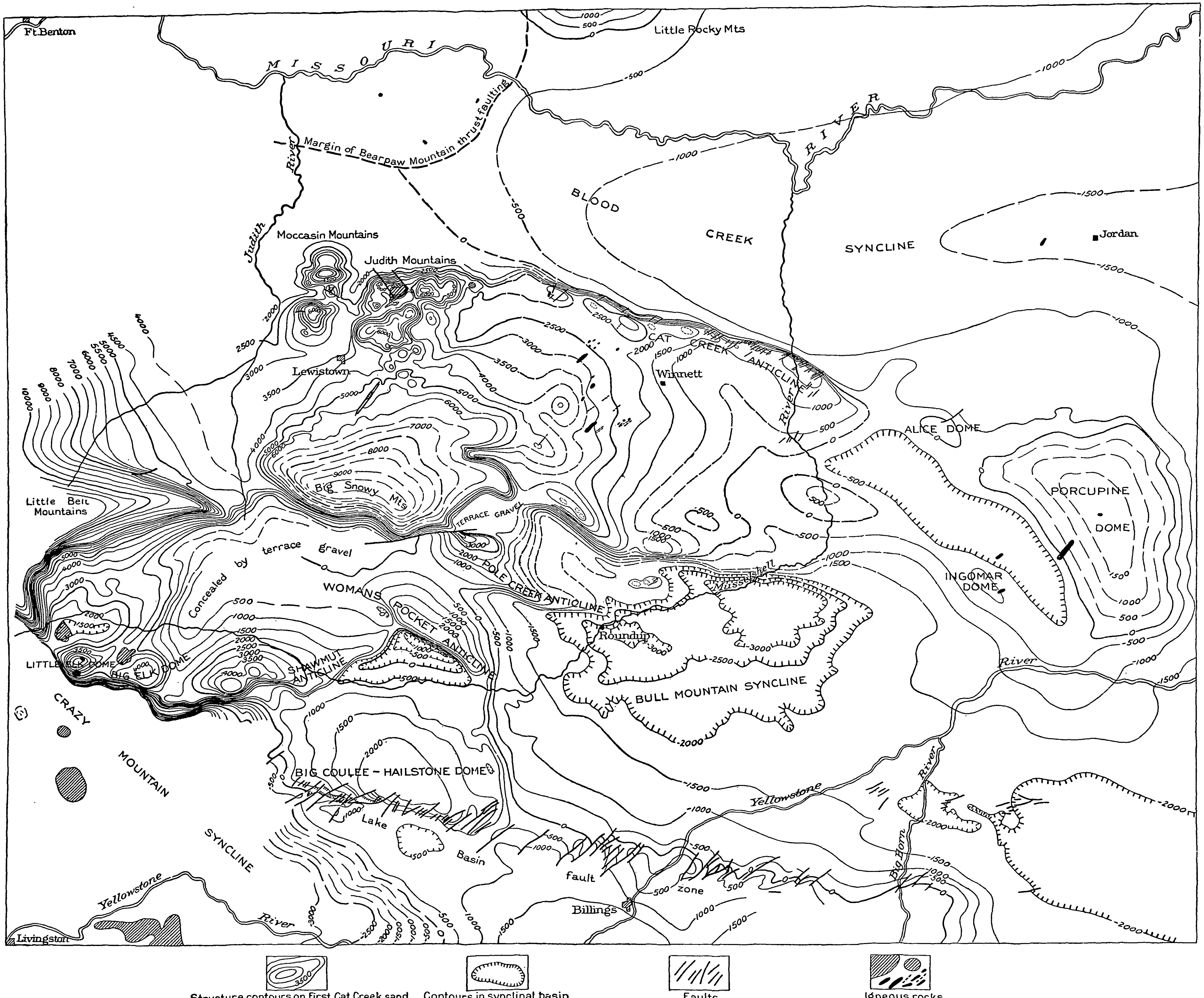


FIGURE 9.—Areal and structural geology of the Blood Creek syncline, north of the Cat Creek field, Montana



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.

[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.

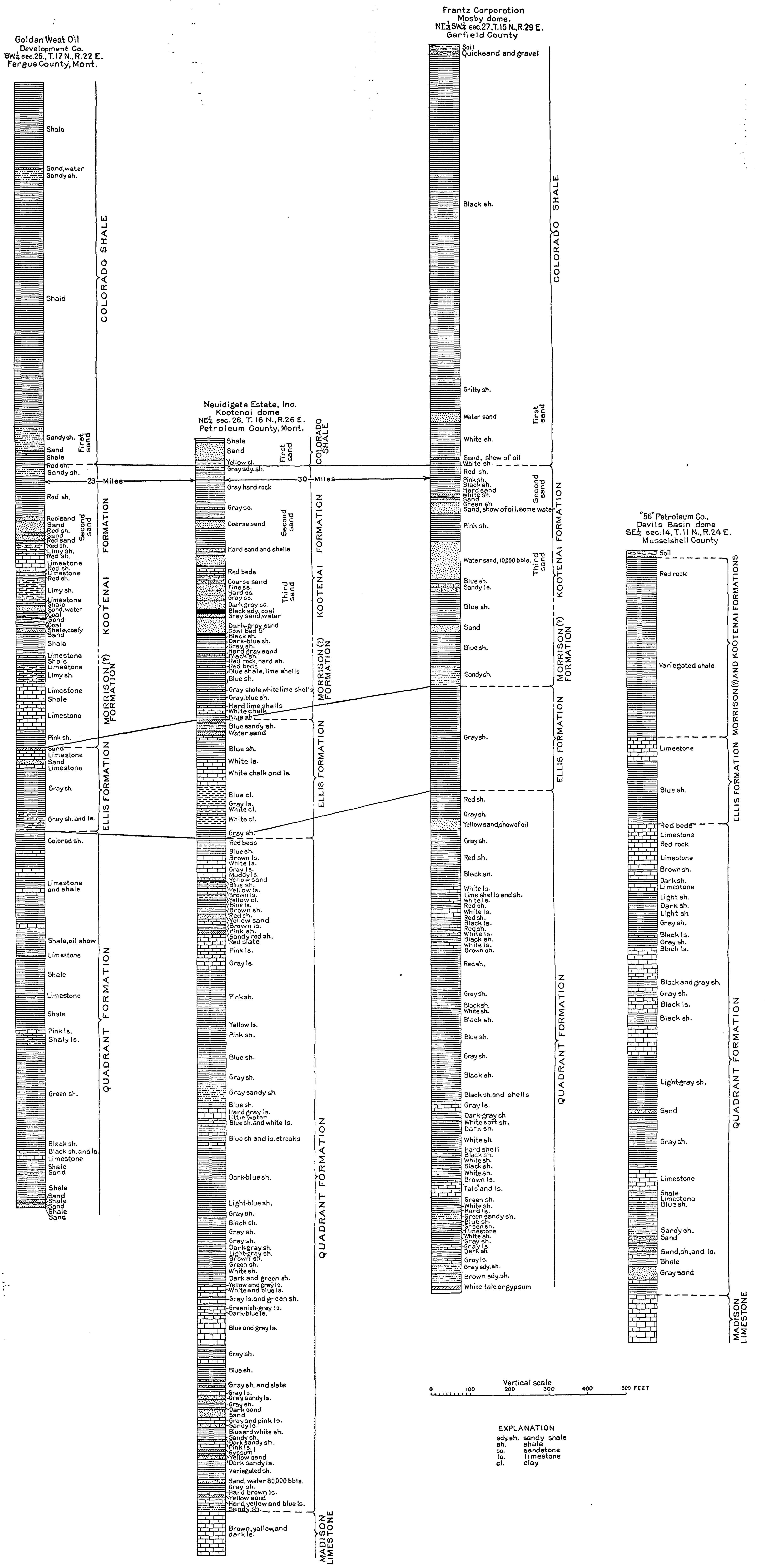
The origin of these heavy Carboniferous oils of the Rocky Mountain fields is a problem of considerable geologic interest. The Cretaceous oils in the region are practically all light-gravity oils. The fact that these Cretaceous oils are closely associated with black shale and the Carboniferous oils with 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

[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. ¼ NW. ¼ 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. ¼ NE. ¼ 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. ¼ 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

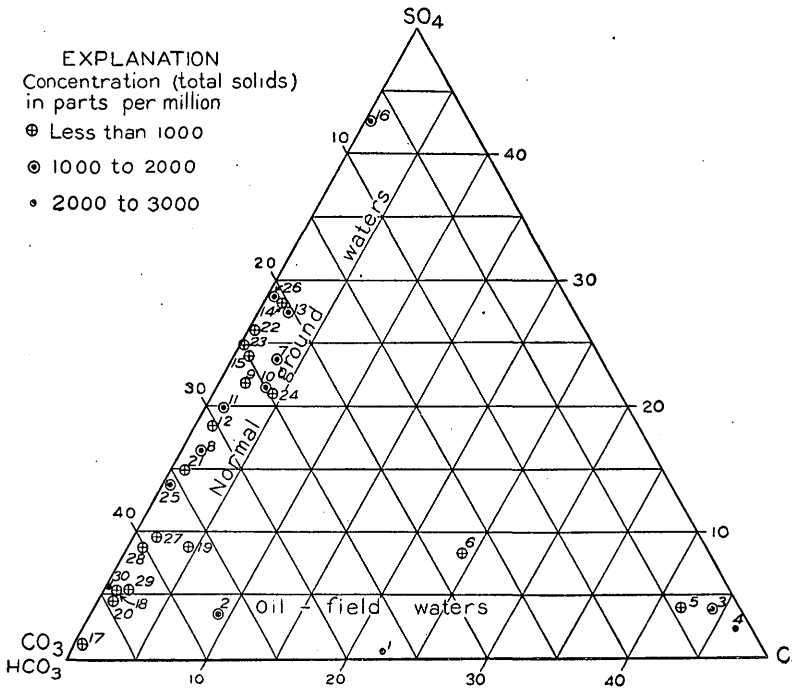


FIGURE 11.—Proportions of sulphate (SO_4), carbonate and bicarbonate (CO_3 and HCO_3), and chloride (Cl) in ground waters of Fergus County, Mont., plotted in terms of percentage reacting values. Numbers refer to table on p. 80.

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.

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

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

[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. ¼ SW. ¼ 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:

	Feet
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. ¼ 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
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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