THRUST FAULTING AND OIL POSSIBILITIES IN THE PLAINS ADJACENT TO THE HIGHWOOD MOUNTAINS, MONTANA

By Frank Reeves

INTRODUCTION

Scope of paper.—During May and June, 1926, the writer made a brief study of the geology in the plains adjacent to the Highwood Mountains, in north-central Montana, the main purpose of which was the collection of data that would throw light on the origin of the thrust faults that nearly encircle the Bearpaw Mountains—an isolated group about 60 miles northeast of the Highwood Mountains. In this investigation it was discovered that thrust faults similar to those adjacent to the Bearpaw Mountains are present north and east of the Highwood Mountains. In the regional study of these faults it became evident that the strata are undisturbed except within a narrow belt, commonly 600 to 700 feet wide, on the upthrown side of the faults, and additional data were obtained in support of the writer's belief that the thrust faulting typical of the region affects only the upper half of the Colorado shale and overlying formations.

The principal purpose of this paper is to describe these two features of the faulting, inasmuch as they have an important bearing on the oil and gas possibilities of the area and, to judge from past drilling, have not been recognized by the geologists who have directed the drilling. Consequently, the report will be confined mainly to a description of the formations exposed and penetrated by the drill in the area, a description of the surface expression of the thrust faults, and presentation of the evidence that the thrust faulting does not include the lower half of the Colorado shale and underlying formations, where oil is generally looked for in the region.

Other phases of the geology of the region, especially its igneous rocks and Pleistocene history, have been the subjects of earlier investigations.[1] The result of the regional study of the thrust faulting will be presented later in a Geological Survey publication.

[1] Weed, W. H., U. S. Geol. Survey Geol. Atlas, Fort Benton folio (No. 55), 1899. Pirsson, L. V., Petrography and geology of the igneous rocks of the Highwood Mountains, Mont.: U. S. Geol. Survey Bull. 237, 1905. Calhoun, F. H. H., The Montana lobe of the Keewatin ice sheet: U. S. Geol. Survey Prof. Paper 50, 1906.

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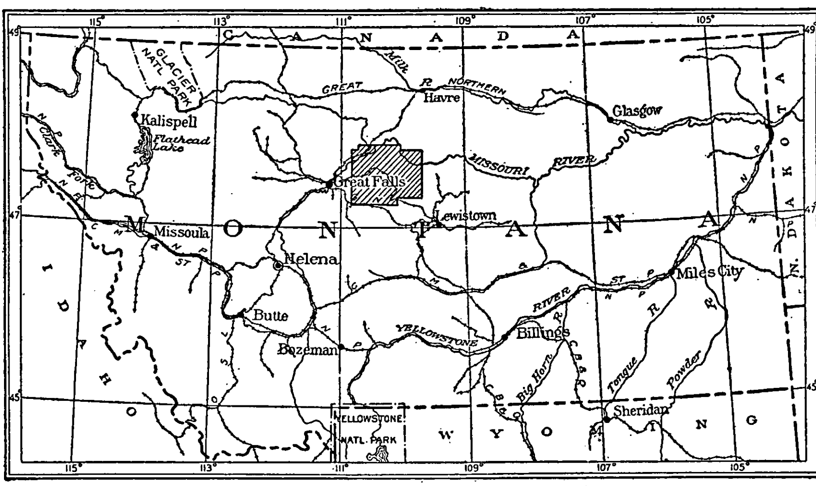
Field work.—The writer was ably assisted in the field work by R. H. Haseltine. Most of the mapping was done with an 18 by 24 inch plane table and an explorer's telescopic alidade. The United States land surveys, plotted to a scale of 1 mile to the inch on the plane-table sheets, were used as a base for the location of a few primary triangulation points, after which mapping proceeded by triangulation methods, altitudes being obtained by vertical-angle determinations and based upon altitudes of railroad stations.

Owing to the reconnaissance character of the investigation, which necessitated the mapping on an average of a township a day, some of the formational boundaries in localities of rugged topography and in glaciated areas are generalized or inferred. An effort was made, however, to map the faults and all significant features of the structure with exactness. More detailed work will undoubtedly show slight errors in the mapping of faults in inaccessible areas and may reveal a few faults not found by the writer. In the mapping of the geology along the "breaks" of Missouri and Marias Rivers a small boat was used. In all other areas the field work was done with the use of a ¾-ton Dodge truck.



INDEX MAP

FIGURE 13.—Index map of Montana, showing location of area mapped adjacent to the Highwood Mountains

Map data.—The base for Plate 44, which shows the areal and structural geology of the area, was compiled in part from maps of the General Land Office and in part from the United States Geological Survey's map of Montana, 1923, roads being added from county surveyors' maps. The geology of the Highwood Mountains is taken from the geologic folio by Weed,[2] with a few minor additions by the

[2] Weed, W. H., op. cit.

writer. The boundary between the Colorado shale and Kootenai formation in the southwestern part of the area is taken largely from Fisher's map of the Great Falls coal field.[3] The boundary between the Eagle sandstone and Colorado shale in T. 25 N., Rs. 8 and 9 E., was mapped by A. J. Collier in 1923.

TOPOGRAPHY

In the glaciated area north and northeast of the Highwood Mountains the plains consist of a rolling, uneven surface, into which the major streams have eroded deep branching valleys having the features of rugged bad lands. In the unglaciated areas west and south of the mountains the plains consist of remnants of flat gravel benches that form ridges between wide valleys. To the southeast of the mountains Arrow Creek and its tributaries flow through deep, narrow valleys that have a striking bad land topography, bordered by level gravel terraces. Rising boldly above these dissected plains is the cluster of volcanic peaks that form the Highwood Mountains. The highest of these peaks reach an altitude of 4,000 feet above the plains, or 7,800 feet above sea level. At the east end of the mountains two isolated masses of igneous rocks, of laccolithic origin, rise abruptly 1,500 to 2,000 feet above the plains, forming striking features of the landscape.

SEDIMENTARY ROCKS

GEOLOGIC SECTION

The sedimentary rocks exposed and underlying the surface within the reach of the drill in this area consist of about 7,000 feet of strata ranging in age from Cambrian to Recent. These are underlain by an unknown thickness of pre-Cambrian rocks. The sedimentary rocks exposed in the area, except the late Tertiary surficial deposits that conceal the older rocks in much of the area, are of Cretaceous age, except possibly the rocks designated Morrison (?) formation, which may be Jurassic. Knowledge of the rocks that underlie the Cretaceous rocks in the area has been obtained from Weed's study of them at their outcrop in the Little Belt Mountains and also from the examination of logs of wells drilled in the area. In the appended table the sequence and characteristic features of these rocks are presented. Further descriptions of them follow the table but are confined mainly to the presentation of data that will aid the oil geologist in recognizing them at their outcrops and identifying them in well logs.

[3] Fisher, C. A., Geology of the Great Falls coal field: U. S. Geol. Survey Bull. 356, pl. 1, 1909.

Sedimentary formations exposed and underlying the surface in the plains adjacent to the Highwood Mountains [a]

Geologic age	Group and formation	Thickness (feet)	Character	Occurrence
Recent.	Alluvium.	10–100	Flood-plain, alluvial-fan, and dune sand, clay, and gravel.	Occupies stream bottoms, valley slopes, and high bluffs.
Pleistocene.	Glacial drift.	1–100	Glacial till, gravel, sand, and boulders of granite, etc.	Covers most of the surface north of the mountains.
	Lower terrace gravel.	100±	Gravel and boulders derived from adjacent mountains.	Forms level benches around the mountains.
Pliocene or Miocene.	Higher terrace gravel.	50±	Gravel and boulders.	Present on the higher benches southeast of the mountains.
Upper Cretaceous.	Judith River formation.	500	Fresh and brackish water deposits consisting of irregularly and thin-bedded sandstone and sandy clay.	Occurs in T. 21 N., R. 15 E., and underlies the volcanic rocks in some localities in the mountains.
	Claggett shale.	500	Brownish-black marine shale containing yellow calcareous concretionary beds, bentonite, and a tan-colored shaly sandstone at its top containing *Tancredia americana*.	Occurs in eastern part of the area and in down-faulted blocks in Tps. 18 and 19 N., R. 11 E. Also present beneath some of the volcanic rocks in the mountains.
	Eagle sandstone.	250	A top member of soft yellow thin-bedded sandstone, a middle member of lignitic sandy clay, and a lower member of massive grayish-white sandstone (Virgelle sandstone member).	Forms conspicuous sandstone bluffs along Arrow Creek and the "castle gardens" in T. 24 N., R. 11 E., and underlies some of the volcanic rocks in the mountains.
	Colorado shale.	1,850–1,880	Upper two-thirds consists of grayish-blue marine shale containing beds of sandy shale, bentonite, and gray and reddish calcareous concretions. Lower third contains several sandstone members; one occurring at the base of the formation is representative of the First Cat Creek sand.	Exposed at the surface or immediately underlying the surficial deposits of glacial till and terrace gravel.
Lower Cretaceous.	Kootenai and Morrison (?) formations.	500–600	A series of red, green, and gray shales containing lenticular beds of limestone and sandstone and in some localities a commercial bed of coal about 400 feet below the top. Lower part may represent the Morrison formation, of Cretaceous (?) age.	Top part exposed along Belt and Little Belt Creeks in southwestern part of the area. The whole series was penetrated in wells 1, 3, 5, 7, 10. (See pl. 44.)
Jurassic.	Ellis formation	100–200	Calcareous sandstone, fossiliferous limestone, and blue and black shale.	Crops out on the north flank of the Little Belt Mountains south of the area. Penetrated in wells 1, 3, 5, 7, 10.

[a] Descriptions of pre-Carboniferous rocks are those given by Weed in the Fort Benton folio (No. 55) and the Little Belt Mountains folio (No. 56).

Sedimentary formations exposed and underlying the surface in the plains adjacent to the Highwood Mountains—Continued

Geologic age	Group and formation	Thickness (feet)	Character	Occurrence
Carboniferous.			(The Quadrant formation, consisting of variegated shale with thin beds of sandstone, limestone, and gypsum, may be represented in the area south of the Highwood Mountains by a few hundred feet of beds, as it crops out on the northeast flank of the Little Belt Mountains, south of the area.)	
	Madison limestone.	1,300	Massive white and light-gray limestone, containing reddish and sandy limestone beds in some localities, underlain by thin-bedded dark-gray and blue-gray limestone.	Crops out in the Little Belt Mountains. Top part penetrated in wells 1, 3, and 10.
Devonian.	Monarch formation.	130	Chocolate-brown and black saccharoidal limestone.	Exposed in the Little Belt Mountains.
Cambrian.	Barker formation.	750	Gray limestone, greenish micaceous shale with interbedded layers of limestone, and conglomerate of limestone pebbles; also sandstone and quartzite.	Exposed in the Little Belt Mountains.
Pre-Cambrian.	Gneiss and schist.	(?)	Gneiss carrying pink, red, and white feldspars; amphibolite; and schist.	Exposed in the highest of the Little Belt Mountains.

SURFICIAL DEPOSITS

The surficial deposits consist of glacial drift, terrace gravel, alluvium, and wind-blown material. The glacial deposits are confined to the areas north of the Highwood Mountains, where they practically conceal all the underlying Cretaceous rocks except in a belt along the base of the mountains and along Missouri, Marias, and Teton Rivers and a few of their major tributaries. Even where the streams have eroded deep channels in the Cretaceous formations, however, the strata are in many places concealed by wash and landslides of the overlying glacial till, and consequently the Cretaceous rocks are not exposed in continuous outcrops along the rivers. Along minor streams, such as Shonkin, Flat, and Stinking Creeks and Rowe and Crowe Coulees, the exposures are limited to freshly cut banks and are only sufficient to reveal approximately the regional distribution of the Cretaceous formations under the cover of glacial drift.

South of the area generally covered by glacial drift the Cretaceous rocks are concealed in many localities by deposits of gravel and boulders that form level benches between stream valleys. Near the Highwood Mountains these deposits are composed of rock material derived from the mountains. To the south and southeast of the mountains, except within 5 to 8 miles of their base, the deposits consist largely of limestone pebbles washed out from the Belt Mountains. Alluvium is common as outwash along valleys; wind-blown material forms a fringe of dunes at the tops of high bluffs.

CRETACEOUS FORMATIONS

The Cretaceous formations present in the area are the Judith River formation, Claggett shale, Eagle sandstone, Colorado shale, and Kootenai formation. The Morrison formation, of Cretaceous (?) age, may also possibly be represented. These formations have approximately the same lithology as in the faulted belt south of the Bearpaw Mountains and will be considered only briefly here.

Judith River formation.—The lower part of the Judith River formation is present in T. 21 N., R. 15 E., in the eastern part of the area. In some localities in the southern part of the Highwood Mountains the volcanic rocks rest on a floor of sandstone and sandy shale which probably belong to the Judith River formation, although this identification could not be definitely substantiated because of the lack of good exposures and the alteration of the rocks.

Claggett shale.—The Claggett shale is present in the eastern part of the area mapped and also beneath the volcanic rocks in the Highwood Mountains and in down-faulted areas southeast of the mountains in Tps. 18 and 19 N., R. 11 E. In these down-faulted blocks it can be identified by its brownish color and the yellow slablike concretions in its upper half. Its differentiation from the Colorado shale can also be definitely established by fossil forms that are common to the Claggett shale and not present in the Colorado shale, such as *Baculites compressus*, *Baculites ovatus*, and *Tancredia americana*, the last species being widely present in the tan-colored shaly sandstone at the top of the formation.

Eagle sandstone.—The Eagle sandstone is exposed along a wide belt in the western part of the area and is present also around the base of the Highwood Mountains and in down-faulted blocks at several localities southeast of the mountains. It is easily recognizable by the white massive Virgelle sandstone member at its base and by black polished pebbles in its top member. In many localities there is a fossil bed in its upper part. A collection from this bed, made by the writer in sec. 24, T. 21 N., R. 13 E., contained, according to J. B. Reeside, jr., the following species:

Ostrea glabra Meek and Hayden.
Cardium speciosum Meek and Hayden.
Corbula perundata Meek and Hayden.
Corbula subtrigonalis Meek and Hayden.
Goniobasis? sp. indet.

Near the mountains the Eagle sandstone is usually associated with sills or laccolithic intrusions of igneous rocks, which commonly occupy stratification planes in the basal part of the sandstone. Along Arrow Creek and its tributaries the white basal Virgelle sandstone member of the Eagle is prominently exposed, forming precipitous bluffs. In the area drained by the headwaters of Rowe Coulee there are striking "castle gardens" formed by wind erosion of the Virgelle sandstone. The Eagle sandstone commonly contains water, and where it underlies the surface at depths of less than 500 feet the ranchers commonly use windmills in pumping water from it. The following section is representative of the Eagle sandstone in this region:

Section of the Eagle sandstone on the west bank of Arrow Creek in lot 8, sec. 19, T. 21 N., R. 15 E.

	Feet
Soft thin-bedded yellow sandstone with partings of dark shale and pebble beds at top	100
Soft dark lignitic sandy clay with a lignite bed at its base	45
White well-indurated sandstone, fairly well bedded in its upper part and massive in lower part (Virgelle sandstone member)	95
	240

Colorado shale.—Although widely concealed by glacial till and terrace gravel, the Colorado shale crops out in a wide belt entirely around the Highwood Mountains. It can be readily recognized by its light grayish-blue or bluish-black color, by the distinctive character of its several members, and by its fossil forms, among the most common of which, according to Stanton,[4] are *Inoceramus labiatus*, *I. umbonatus*, *I. exogyroides*, *Scaphites warreni*, *S. ventricosus*, *Pholadomya papyracea*, and *Baculites asper*. Although the formation is preponderantly shale, it contains many beds of bentonite, calcareous concretions, sandy shale, and sandstone. The bentonite and concretionary beds are the most numerous in the upper two-thirds of the formation, and the sandstone beds in the lower third. At the top there is commonly 100 to 150 feet of sandy shale, which in some localities contains a sandstone member 10 to 30 feet thick, about 50 feet below the top of the formation. Sandy shale is also common throughout the formation. The sandstone beds in the lower third of the formation are exposed south and west of the Highwood Mountains, where they form prominent escarpments and ridges. These sandstones are evidently the thickest and most persistent in the southwestern part of the area, for they were not encountered in some of the wells drilled north and east of the mountains. The following section of the Colorado shale was compiled from measurements of parts of it at several localities around the Highwood Mountains. The

[4] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, p. 11, 1905.

thickness of this section is 1,820 feet, but calculations of the thickness of the formation based on well logs and measured sections give a thickness of 1,850 to 1,880 feet.

Section of the Colorado shale at localities around the Highwood Mountains

	Feet
1. Light grayish-blue sandy shale with sandstone layers, commonly less than 1 foot in thickness	175
2. Light-gray to bluish-black shale containing several bentonite beds 1 to 2 feet thick	300
3. Brown calcareous bed with small black pebbles in top part, commonly one-fourth to one-half inch in diameter	5
4. Bluish-black clay shale with a few gray limestone concretions bearing fossils	35
5. Bluish-black clay containing scattered dark-red ferruginous concretions bearing *Inoceramus exogyroides*. Upper red-chip zone	25
6. Bluish-black to purple shale containing several bentonite beds 1 to 3 feet thick and layers of sand 1 to 4 inches thick	260
7. Bluish-black clay containing dark-red ferruginous concretions which weather into small chips. Lower red-chip zone	25
8. Bluish-black shale containing a 2-foot bed of bentonite in its middle part and another at the base	60
9. Shaly sandstone with yellow calcareous sandstone at top containing numerous fossil oysters (Mosby sandstone member)	12
10. Bluish-black shale with sandy partings in upper part	30
11. Persistent bed of soft bentonite	3
12. Soft blue shale	15
13. Gray calcareous concretionary bed	2
14. Soft blue shale, partly concealed	18
15. Thin-bedded coarse-grained pebbly sandstone, weathering into conspicuous bench	10
16. Blue shale, partly concealed	40
17. Hard massive sandstone consisting principally of dark minerals and containing fish teeth	1
18. Soft gray shale containing a few sandy partings and beds of bentonite 1 to 2 feet thick at intervals of 10 to 20 feet	45
19. Persistent bed of soft bentonite	2
20. Gray sandy shale containing numerous fish scales; bentonite beds near top and base (Mowry shale member)	55
21. Sandy grayish-blue shale, not well exposed	45
22. Thin-bedded fine to coarse-grained sandstone containing a 2-foot bed of bentonite	7
23. Bluish-black shale with a 2-foot bed of ripple-marked sandstone in its middle part	40
24. Thin-bedded sandstone, weathering into prominent escarpments along Highwood Creek below Highwood station, in T. 21 N., R. 17 E	30

		Feet
25.	Sandy gray shale, not well exposed	45
26.	Hard grayish-white well-bedded sandstone with a 3 to 5 foot conglomerate at top, consisting of polished black rounded pebbles attaining a maximum diameter of 1 inch. Weathers into prominent escarpments along the north bank of Willow Creek, in T. 20 N., R. 7 E	20
27.	Gray sandy shale, partly concealed. Volcanic ash is present in the top part of the shale south and southwest of the Highwood Mountains	180
28.	Bentonite	3
29.	Lenticular bed of lignite	2
30.	Medium-grained clayey sandstone, 10 to 40 feet thick, in some localities weathering as a soft white massive sandstone and in others as a hard gray thin-bedded sandstone forming conspicuous escarpments between Belt and Geyser. Occurs at about the horizon of the Muddy sand of Wyoming	25
31.	Bluish-black shale, containing a few sandy beds and lenses of sandstone. A lenticular sandstone at the base is representative of the First Cat Creek sand	305
		1,820

In the above section Nos. 3, 5, 7, 9, 13, 20, 24, 26, and 30 are most useful as key beds. The different parts of the Colorado shale are well exposed in the following localities: Beds 1 to 5, NW. ¼ sec. 25, T. 20 N., R. 13 E; 5 to 7, Pownal station, NE. ¼ sec. 16, T. 19 N., R. 12 E; 7 to 24, Highwood station, sec. 12, T. 21 N., R. 7 E; 24 to 31, sec. 32, T. 21 N., R. 7 E.

Kootenai and Morrison (?) formations.—Between the Colorado shale and Ellis formation there is 500 to 600 feet of red and gray shale containing lenses of sandstone and thin limestone. The upper three-fourths of these strata belong to the Kootenai formation, but the lower part may represent the Morrison formation. Inasmuch as these rocks are very similar in character, they are here considered together. The top of the Kootenai can readily be recognized in well logs by the presence of the red shales, which are the first red beds to be encountered in drilling in the region. Beneath these red beds, which make up the greater part of the upper 200 feet of the series, there is variegated shale containing thin beds of limestone and lenses of sandstone and in some localities a commercial bed of coal. The upper part of this series of rocks is exposed along Belt and Little Belt Creeks in the southwestern part of the area. Most of the wells drilled north and northeast of the mountains penetrate these rocks and commonly encounter large flows of water in the sandstones.

PRE-CRETACEOUS FORMATIONS

No rocks older than Cretaceous are exposed in or adjacent to the Highwood Mountains, but some of the wells drilled north and east of the mountains penetrate the Madison limestone, of early Carboniferous (Mississippian) age, and it would be possible to penetrate all the sedimentary formations by drilling to a depth of 3,500 feet in the southwestern part of the area mapped. The first of these pre-Cretaceous formations to be encountered is the Ellis, which at its outcrop consists of calcareous sandstone and sandy limestone and where penetrated in wells, to judge from the logs, contains also blue and black shale. Strata commonly referred to the Quadrant formation may be present in parts of the area between the Ellis formation and the Madison limestone. Just south of the area, on the north flank of the Little Belt Mountains, the Quadrant is represented by several hundred feet of variegated shale, thin limestone, and sandstone, but a short distance farther northwest it is entirely absent. Of the three wells (Nos. 1, 3, and 10, pl. 44) that have penetrated strata older than the Ellis formation, Nos. 1 and 10 clearly did not encounter any Quadrant beds. Although reddish sandy limestone such as occurs in the series of strata encountered in well No. 3 between depths of 2,360 and 2,970 feet is characteristic of the Quadrant formation in the region, the writer has assigned the series to the Madison limestone, primarily because the Quadrant formation nowhere in the region contains so great a thickness of limestone, whereas the Madison consists almost entirely of limestone. This identification is somewhat strengthened by the fact that Mr. Ray Lebkicher [5] reports that pink and red limestones were encountered in the Madison limestone in the California Co.'s well on the northeast side of the Bearpaw Mountains, recently completed, and that he has observed similar red limestone and shale in the Madison limestone at its outcrop in the Little Rocky Mountains, which were also noted by A. J. Collier.[6]

IGNEOUS ROCKS

The Highwood Mountains are widely known among geologists for their unusual types of igneous rocks and the striking exposures of laccoliths, dikes, and sills. These have been described by Lindgren,[7] Davis,[8] Weed,[9] and Pirsson,[9] [10] and statements made herein regarding

[5] Letter to the Geological Survey.

[6] Personal communication.

[7] Lindgren, Waldemar, Eruptive rocks of Montana: Tenth Census U. S., vol. 15, pp. 724–730, 1886; Eruptive rocks of Montana: California Acad. Sci. Proc., 2d ser., vol. 3, pp. 39–57, 1891; A sodalite syenite and other rocks from Montana: Am. Jour. Sci., 3d ser., vol. 45, pp. 286–297, 1893.

[8] Davis, W. M., Relation of the coal of Montana to the older rocks: Tenth Census U. S., vol. 15, pp. 709–710, 1886.

[9] Weed, W. H., U. S. Geol. Survey Geol. Atlas, Fort Benton folio (No. 55), 1899. Weed, W. H., and Pirsson, L. V., Highwood Mountains of Montana: Geol. Soc. America Bull., vol. 6, pp. 389–422, 1895; Missourite, a new leucite rock from the Highwood Mountains of Montana: Am. Jour. Sci., 4th ser., vol. 2, pp. 315–323, 1896; Geology of the Shonkin Sag and Palisade Butte laccoliths in the Highwood Mountains of Montana: Am. Jour. Sci., 4th ser., vol. 12, pp. 1–17, 1901.

[10] Pirsson, L. V., Petrography and geology of the igneous rocks of the Highwood Mountains, Mont.: U. S. Geol. Survey Bull. 237, 1905.

the igneous rocks are based largely on data obtained from these geologists' studies.

The Highwood Mountains consist of a highly dissected mass of basaltic and trachyandesitic breccia, tuff, and lava flows resting on a dissected floor of Cretaceous shale and sandstone crosscut by several intrusive stocks consisting of monzonite, shonkinite, and syenite, with occurrences of the rare types missourite and fergusite. The sedimentary strata for a considerable distance around these intrusive rocks are highly altered, and both they and the overlying extrusive rocks are cut by numerous dikes, most of which are analcite and leucite basalts and minettes. These dikes extend into the surrounding plains for a distance of at least 5 to 10 miles. On the northeast side of the mountains the dikes are very numerous and may be continuous some distance beneath the glacial drift. Sills are also common on the northeast side of the mountains, and some of them thicken into laccoliths. The best examples of these laccoliths are the Square Butte, Palisade Butte, and Shonkin Sag laccoliths, which consist of masses of shonkinite capped by syenite. The laccoliths and most of the sills were intruded along stratification planes in the Eagle sandstone. The dikes are commonly 8 to 10 feet thick and are in places markedly jointed. In the plains the strata in immediate contact with the dikes are commonly hardened, but those beyond a distance of 3 to 5 feet show no alteration.

STRUCTURE

REGIONAL CHARACTER

The Cretaceous formations in the Highwood Mountain region, as shown in Plate 44, have a regional northeastward dip that is a continuation in a gradually decreasing amount of the tilt on the northeast flank of the Little Belt Mountains, which lie 15 to 20 miles south of the Highwood Mountains. In the southwestern part of the area mapped this dip commonly ranges from 1° to 2°, whereas in the northeastern part it averages about one-third of a degree, or approximately 30 feet to the mile. This northeastward dip persists to the Bearpaw Mountains, which are about 60 miles northeast of the Highwood Mountains. It is locally interrupted by faulting and tilting of the strata, both in the plains and in the Highwood Mountain area.

STRUCTURE OF THE HIGHWOOD MOUNTAINS

The northeastward dip of the strata in the plains around the Highwood Mountains persists without marked modification in the mountains. The formations immediately underlying the volcanic rocks are the Eagle sandstone, Claggett shale, and Judith River formation. In most localities the volcanic rocks probably rest on the Judith River formation. These formations crop out along stream valleys, in the mountains, and in the rough country that is encountered in ascending from the fairly level plains to the volcanic rocks, the base of which is 500 to 1,000 feet above the general level of the surrounding country. Although no attempt was made to map in detail the structure of the mountain area, the brief field work done showed that although the formations underlying the volcanic rocks are locally faulted and tilted by intrusive bodies, the mountain area is not domed like the other mountain groups of the region and has not subsided like the Bearpaw Mountains. As far as could be determined, the faulting in the Highwood Mountains is all of the normal type, and the tilting observed was probably that accompanying normal faulting and intrusive activity.

STRUCTURE IN THE ADJACENT PLAINS

In the plains around the Highwood Mountains the regional northeastward dip of the strata is interrupted by normal and thrust faulting. Although the presence of domes at several localities has been reported, and oil journals have published structural maps showing circular domes of considerable closure, the writer places another interpretation on the structure of the areas where the domes are said to occur. In certain places there is some basis for the assumption that a dome exists, because the tilted strata along the thrust faults where the exposures are few simulate the steeply dipping limb of an asymmetric fold of the Cat Creek type. But in other places domes have been reported to exist where the writer believes there was no reasonable basis for inferring their presence and where no exact data are obtainable for the construction of contour maps. The only structure suggesting a dome observed by the writer was that of the small plunging folds marking the termination of thrust faults, which will be described in a later paragraph.

NORMAL FAULTS

Normal faults of small throw and horizontal extent were observed on the southwest side of the mountains and, according to Fisher,[11] are fairly common in the Kootenai coal field, farther southwest. Normal faults were also noted on the northeast side of the mountains in the rugged country bordering the outer margin of the areas of volcanic rocks. The Cretaceous rocks here, however, are so widely concealed by glacial till and bench gravel that it was difficult to determine the extent of the faulting, but in most places it probably

[11] Fisher, C. A., op. cit., p. 49.

is associated with down-faulted blocks. The most conspicuous examples of normal faults observed are on the southeast side of the mountains, bordering narrow down-faulted blocks of Claggett shale and Eagle sandstone. Three of these down-faulted blocks were mapped in Tps. 18 and 19 N., R. 11 E., and there are possibly more in this locality. The down-faulted blocks mapped have a northwesterly trend and are commonly about a quarter of a mile wide and several miles long. Their entire length could not be determined, because toward the northwest they are obscured by deposits of bench gravel. To the southeast they terminate on the left bank of Arrow Creek, approximately where the Mosby sandstone member (No. 9 of the section on p. 162) of the Colorado shale crops out. The dip of the fault planes along the margins of these down-faulted blocks was not determined. The vertical displacement or throw is commonly about 1,000 feet but varies between 500 and 1,200 feet. The structure in these down-faulted blocks is obscure because of the poor exposures, but it is evident that in some places the strata are fairly flat-lying, whereas in others they are tilted and broken by subsidiary faults. The strata adjacent to the down-faulted blocks commonly show little disturbance, but in some localities they appear to be flexed above their normal regional position. Because of the narrowness of these blocks and the fact that they end where the Mosby sandstone and older strata appear at the surface, the writer believes that no beds much lower than the Eagle sandstone are involved in the down faulting. To the east of these down-faulted areas small blocks of the Eagle sandstone are found below the normal level of the formation occupying tilted positions on the downthrown side of the thrust faults in T. 19 N., Rs. 12 and 13 E., and T. 20 N., R. 13 E. Whether this structure is due to down faulting or underthrusting, the writer has not determined.

THRUST FAULTS

AREAL EXTENT AND TREND

The principal deformation of the strata in the plains adjacent to the Highwood Mountains is produced by thrust faulting of the type occurring in the plains adjacent to the Bearpaw Mountains and previously described by the writer.[12] Such faults are present on the north and east sides of the Highwood Mountains but were not

[12] Reeves, Frank, Geology of northern Fergus County, Mont.: U. S. Geol. Survey Press Bull., 1922; Geology and possible oil and gas resources of the faulted areas south of the Bearpaw Mountains, Mont.: U. S. Geol. Survey Bull. 751, pp. 71–114, 1924; Structure of the Bearpaw Mountains, Mont.: Am. Jour. Sci., 5th ser., vol. 8, pp. 296–311, 1924; Shallow folding and faulting around the Bearpaw Mountains: Am. Jour. Sci., 5th ser., vol. 10, pp. 187–200, 1925.

observed on the south and west sides, although careful search was made for them, especially on the southwest side, where the sandstone members of the lower half of the Colorado shale are exposed in unbroken outcrop along northwestward-flowing streams. Undoubtedly there are more thrust faults north and east of the mountains than are shown on the map, because, as previously stated, glacial drift conceals the Cretaceous rocks in much of this area. In fact, nearly all the faults mapped pass beneath glacial till and have a greater length than that shown on the map. A greater number of faults was observed on the east side of the mountains than elsewhere, possibly because in this part of the plains the Cretaceous strata are well exposed in the deep valleys cut by Arrow Creek and its tributaries.

The most southeasterly faults are about 32 miles distant from the mountains. Northeast of the mountains few faults were observed, probably because the exposures are few and limited to small outcrops on ridges and in freshly cut stream channels. Thrust faults persist in this direction as far as the Bearpaw Mountains. On the north side of the Highwood Mountains thrust faults were observed near the mountains along the Shonkin Sag and farther north along Missouri River and tributaries of Teton and Marias Rivers. Between the Shonkin Sag and Missouri River the only exposures are those along Shonkin Creek. These, however, are not continuous enough to make it certain whether or not the Cretaceous rocks are faulted in this part of the plains. The last fault observed northwest of the mountains is about 25 miles from the base of the mountains, and it is probable that this is the most northerly thrust fault, because Marias River was traversed for 12 to 15 miles farther north, and although the exposures are practically continuous, no faults were observed. The most northwesterly fault observed lies about 8 miles west of Fort Benton. Although the exposures are too few in this locality to determine whether or not there are other faults farther west, the probability is that there are none. At least none were observed along Missouri River west of Fort Benton, where the Colorado shale is continuously exposed. From the observations made the writer is of the opinion that the thrust faulting adjacent to the Highwood Mountains occurs only in the area lying northeast of a northwest-southeast line drawn through the center of the mountains.

The writer believes the most of these faults are concentric or nearly concentric to the Highwood Mountains in trend, the only conspicuous exception being the long northeastward-trending fault that is strikingly exposed along Arrow Creek. This fault intersects the faults of concentric trend at right angles, and along it some of the concentric faults appear to be offset.

SURFACE EXPRESSION

Although the thrust faults around the Highwood Mountains are of the same type as those adjacent to the Bearpaw Mountains, they have a different surface expression, owing to the fact that the regional erosion of the northeastward-dipping strata has exposed the faults at lower stratigraphic levels. In most localities in this area all the formations above the Colorado shale are eroded, and as older formations do not appear among the upthrust beds the surface expression of the faults is confined to the Colorado shale. The faults are therefore not as conspicuous features here as in the Bear-

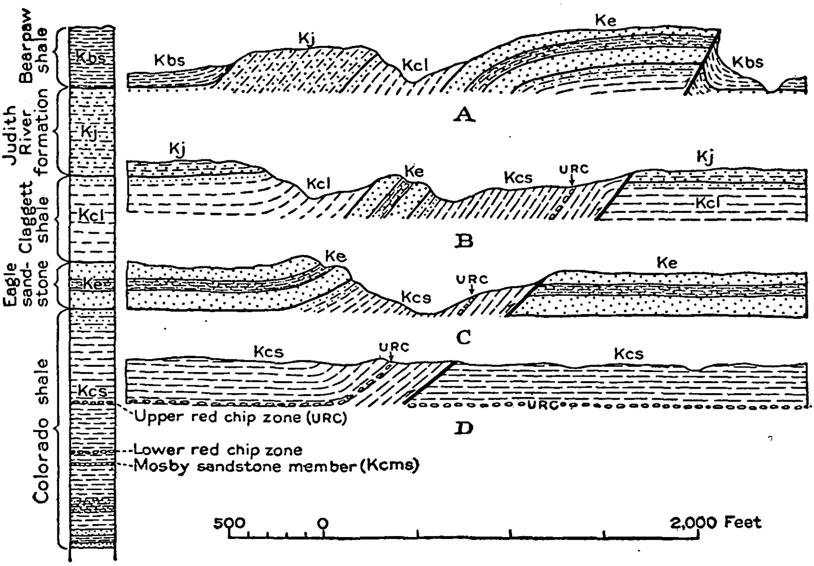


FIGURE 14.—Diagrammatic cross sections showing surface relations of formations adjacent to thrust faults around the Bearpaw and Highwood Mountains, Mont., as dependent on the amount of erosion. A, B, and C are characteristic of many faults lying, respectively, southeast, south, and southwest of the Bearpaw Mountains; D, of most of the faults adjacent to the Highwood Mountains

paw faulted area, where either the Eagle sandstone or the Judith River formation or both form prominent hogbacks in the tilted belts on the upthrown side of the faults, and the juxtaposition of formations of different lithology along the faults renders their presence easily recognizable. (See fig. 14.) The only evidence that faults occur in areas immediately underlain by the Colorado shale is afforded by the belts of tilted shale on the upthrown side of the faults. These belts are commonly only 600 to 700 feet wide but range between 500 and 1,500 feet in the area mapped, their width depending on the stratigraphic depth to which the faults are eroded, the tilted belt being the narrowest where erosion has reached the lowest horizon, as is shown in Figure 14. In the plains southeast of the Bearpaw Mountains, where the regional erosion has exposed the faults only to shallow depths, the tilted belts are commonly 3,000 to 4,000 feet wide.

The dip of the strata in the tilted belts adjacent to the faults near the Highwood Mountains is commonly 30° to 40°, being practically the same as the dip of the fault plane in the 10 localities where fault-plane dips were determined. Beyond the limits of these narrow tilted belts the strata occupy their regional nearly horizontal position. The structure most typical of the strata along the faults in the area mapped is shown in Figure 14, D. In only a few places are the strata on the downthrown side of the fault turned upward along the fault plane, and in others they are bent downward. Although the fault planes are commonly not visible, their outcrops can be closely located, because they usually mark the boundary between tilted and flat-lying strata and also because the regional study of the faults around the Highwood Mountains has shown that the upper red-chip zone (No. 5 of the Colorado shale in section on p. 162) occupies a tilted position near the faults. In fact, during the progress of the work it was recognized that if this red-chip zone were found in a tilted position above its normal regional altitude it would indicate the presence of a thrust fault.

The fault planes observed commonly appear as clear-cut fractures unaccompanied by gouge, fault breccia, or shear zones. There is some evidence that below the Eagle sandstone the fault planes split into two or more fractures, resulting in the repetition in the outcrop of beds in the Colorado shale. Along the strike a fault commonly persists for several miles, terminating abruptly in a sharp plunging fold (see fig. 15) or in a slightly offsetting fault. The thrusting along a second fracture is commonly a reversal in the direction of the upthrown and downthrown sides of the fault. The downthrow is on the mountainward side of some of the faults and on the plainsward side of others. In the faults farthest from the mountains, however, the downthrow is usually on the plainsward side. The dips of the fault planes are commonly between 25° and 45°, usually about the same as the dip of the strata along the upthrown side of the faults. The strike of the faults is parallel to the strike of the tilted strata except near the termination of the faults. (See fig. 15.) The displacement or vertical throw of the strata on the faults can seldom be determined in the Highwood Mountain region, because here, as a result of regional erosion, the upthrust ends of even the lowest formation exposed are eroded. In most places the throw is evidently more than 500 feet, and, to judge from the amount of displacement in faults of the same type in the Bearpaw region, it probably attains a maximum of 1,500 feet.

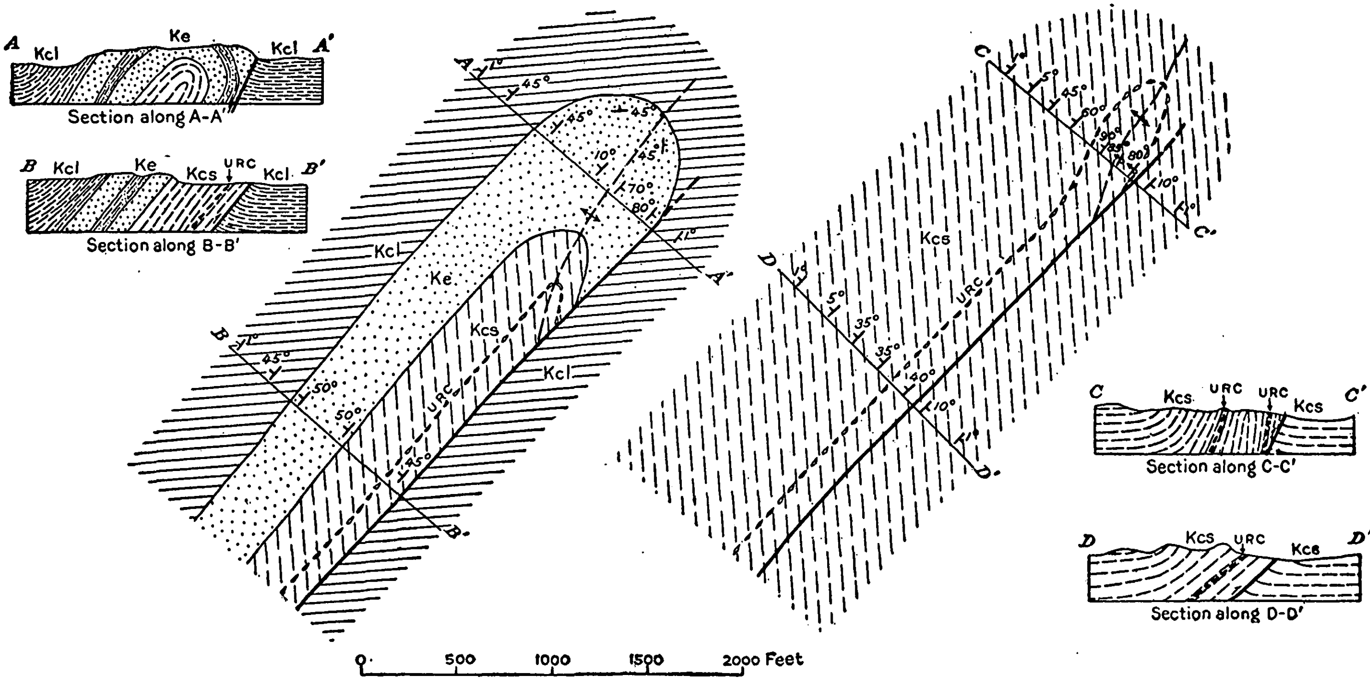


FIGURE 15.—Diagrammatic map and sections showing thrust faults ending in plunging folds. For explanation of symbols see Figure 14

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DEPTH OF FAULTING

While the writer was engaged in mapping the faults on the south side of the Bearpaw Mountains in the summer of 1922 he was impressed with the probability that the thrust faulting in the region was confined to the Upper Cretaceous and early Tertiary strata. But the hypothesis of such a large-scale shallow deformation of the earth's crust appeared theoretically impossible under the prevalent conceptions of the manner in which the crust of the earth is deformed, and the writer at that time could offer no special explanation of the phenomenon. Consequently his belief that the potential oil-bearing sands in the lower half of the Colorado shale and underlying formation were not included in the deformation accompanying the thrust faulting was not presented in the published report.[13] Field work in the region since that report was written, however, has revealed more evidence of the shallow depth to which the faulting extends and has furnished data that make it possible to offer an apparently adequate explanation of the shallow faulting. This explanation is briefly as follows:

The superficial part of the earth's crust composed of the weak Upper Cretaceous and early Tertiary strata in the Bearpaw and Highwood Mountains, being covered by an enormous load of extrusive rocks and subjected to violent and frequent earthquake shocks during the middle Tertiary volcanic eruptions, slipped plainsward on plastic beds such as those of clay or bentonite, producing the thrust faults in the areas toward which there was a plainsward dip. The evidence in support of this explanation of the cause of the thrust faulting, together with a discussion of the mechanics involved, will be presented in a later Geological Survey publication.

The evidence here to be offered, indicating that the faulting is shallow, will be confined to the presentation of data that involve no theoretical considerations such as the writer set forth in a former publication.[14] This evidence is based on observation as to the lowest strata exposed along the faults, the attitude of these strata, the curvature of the fault planes, and the data furnished in the drilling of wells in the region.

Lowest beds exposed along the faults.—The most obvious evidence that the faulting is shallow is the fact that although certain beds in the upper half of the Colorado shale are almost universally exposed along the faults, no lower beds have been observed along any fault. It can be safely stated that along 75 miles of the 85 miles of thrust faults mapped adjacent to the Highwood Mountains the basal part

[13] 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, pp. 71–144, 1924.
[14] Am. Jour. Sci., 5th ser., vol. 10, pp. 187–200, 1925.

of the exposed upthrust strata belong stratigraphically somewhere between the upper red-chip zone and the Mosby sandstone member and hence occupy horizons in the Colorado shale 600 to 900 feet below its top. At no place was the Mowry shale member, which lies about 1,050 feet below the top of the Colorado formation, found along the fault, yet in many localities of thrust faulting it normally lies only 300 to 400 feet below the surface and consequently, if upthrust like the overlying beds, should be exposed at the surface, inasmuch as the vertical throw in the thrust faults farther northeast, where determinable, is commonly 500 to 1,600 feet. At any rate, the beds but 200 or 300 feet above the Mowry shale are almost universally encountered along the faults, even in the eastern part of the area, where such beds in their normal regional position lie at depths of 700 to 1,000 feet. Farther northeast, in the faulted area south of the Bearpaw Mountains, where the regional dip carries these beds 1,200 to 1,500 feet beneath the surface, they are exposed along some of the major faults. The widespread appearance of certain beds along the faults, despite the difference in depth of about 1,500 feet to which the faults have been eroded, together with the fact that nowhere in the 750 miles of thrust faults mapped were lower beds found along the faults, furnishes good ground for the inference that lower beds are not included in the faulting.

This conclusion is further supported by the fact that no thrust faults have been found in areas where beds below the Mosby sandstone crop out. Although these beds are not exposed anywhere in the areas of thrust faulting northeast of the Highwood Mountains or adjacent to the Bearpaw Mountains, they crop out on the south and west sides of the Highwood Mountains and are there undeformed except by a few small normal faults and the tilting associated with the Little Belt Mountain uplift. Although the absence of thrust faulting of these beds in these localities can not be used as conclusive evidence that the faulting is shallow, because it is not assumed that the overlying, now eroded formations were generally faulted in these areas in which the strata dip toward and not away from the mountains, nevertheless the fact that the thrust faulting disappears to the northwest and southwest of the mountains, approximately where these older beds rise to the surface, is significant evidence. The only exposures northwest of the mountains that are continuous enough to show the western limits of the faulting are those along Missouri River and the Shonkin Sag, an old bed of the Missouri through which the Chicago, Milwaukee & St. Paul Railway runs between Square Butte and Highwood stations. The westernmost thrust fault exposed along Missouri River lies about 7 miles east of the point where the Mosby sandstone rises above water level. For a distance of about 100 miles farther down the river, along which the

Cretaceous strata overlying the Mosby sandstone are strikingly exposed, a thrust fault may be seen on an average every 3 miles. Along the Shonkin Sag thrust faulting is fairly persistent to a point within 4 miles of the outcrop of the Mosby sandstone. Farther southwest, where the rocks below the Mosby sandstone are well exposed along Highwood Creek and Belt Creek and its tributaries, thrust faulting nowhere appears. Southeast of the mountains good evidence that the faulting does not include rocks below the Mosby sandstone is afforded by the fact that the long fault that begins near the mouth of Arrow Creek persists for 25 miles southwestward and ends where the Mosby sandstone and underlying beds rise above the surface in the Arrow Creek valley. More positive evidence than this that the faulting does not include these lower beds would be available only if a fault crossed a valley in which both the beds below and above the Mosby sandstone were exposed. These conditions, unfortunately, are not present in the region but would be so if the channel of Surprise Creek were slightly deeper where it crosses the thrust fault in sec. 28, T. 19 N., R. 12 E.

Attitude of upthrust strata.—The attitude of the beds in the upthrust side of the faults also strongly supports the hypothesis of shallow faulting. Manifestly, if the beds exposed along the fault are the lowest beds involved in the faulting, they must have approximately the same inclination as the fault plane. Many of the exposures fail to reveal the dip of the fault planes. In several localities, however, as in the badlands along Arrow Creek, the fault planes are strikingly exposed, revealing dips of 25° to 50°, which invariably are within 5° of the dip of the adjacent upthrust strata. The average determination of the dips of the fault planes is 36°—the same as the average of all the great number of dip determinations made of the upthrust strata. The same parallelism in the dip of the faults and the upthrust strata is present in the faults adjacent to the Bearpaw Mountains, except in those eroded to the shallowest stratigraphic levels, where the terminal part of the upthrust series had not been eroded. In such faults the beds lying above the basal strata—the Eagle sandstone and overlying formations—although having the same dip as the fault planes throughout the greater part of their upthrust portions, show a marked flexure over to the fault, giving the appearance of a sharp anticline with one limb displaced by a thrust fault. (See fig. 19.) Such flexures are probably characteristic of the terminal part of an overthrust series of strata, for it is evident that in order for any bed except the basal bed to remain in contact with the fault plane, it must be flexed over all the underlying strata that are involved in the upthrusting. The width of such a flexure in any given bed, therefore, will but slightly exceed the thickness of the strata between that bed and the base of the upthrust series. Thus it is evident why the structure along the thrust faults south of the Bearpaw Mountains so closely simulates that of faulted anticlines, and also why, in the southwestward direction toward the Highwood Mountains and, consequently, in the direction in which the faults are exposed to lower and lower stratigraphic levels, the disturbed belts become narrower and have less the appearance of faulted anticlines. (See fig. 14.) Inasmuch as in the field work south of the Bearpaw Mountains it was impossible in some localities to determine whether the beds were faulted or steeply inclined, the simplest interpretation was placed on the structure, and it was mapped as anticlinal. Thus, before the true character of the structure was realized, the writer was of the impression that unfaulted and partly faulted anticlines were present. But in reviewing all the data the writer now believes that practically all the structure can be accounted for by thrust faulting. The only places where anticlinal structure appears are where the faults end on the flank of a steeply plunging fold, such as is shown in Figure 15. In the most deeply eroded plunging folds the basal beds are commonly those belonging stratigraphically immediately below the upper red-chip zone, and practically everywhere these beds have a vertical or overturned attitude, forming a closed fold such as is shown in the cross section C–C′ in Figure 15.

Curvature of fault planes.—The fault planes are apparently curved surfaces, for in the eastern part of the faulted belt south of the Bearpaw Mountains they commonly have dips of 60° to 70°, whereas in the Highwood region, where erosion has exposed them to lower stratigraphic levels, the dips are commonly about 35° and in the most deeply eroded faults only 25°. Thus the field data are consistent with the assumption that the faults gradually flatten and merge with the stratigraphic plane on which the surficial slipping supposedly took place.

Data furnished by wells drilled for oil.—Of the 16 wells drilled for oil in and immediately adjacent to the area mapped, 10 were located near thrust faults. The other six (Nos. 3, 4, 10, 11, 12, and 12A in the appended table), so far as the writer could determine from brief field examination, were drilled in areas in which there is no marked interruption of the regional northeastward inclination of the strata, and this conclusion was confirmed by the fact that the subsurface formations were not encountered above their regional nearly horizontal position. Of the 10 wells drilled adjacent to thrust faults, 6 (Nos. 2, 6, 7, 8, 9, and 13) were drilled on the downthrown side at distances of 100 to 6,000 feet from the outcrop of the fault. Inasmuch as these wells start in undisturbed surface strata, the writer would not expect them to encounter disturbed strata, and this assumption is corroborated by the fact that in the five wells

(Nos. 2, 7, 8, 9, and 13) that penetrated the Kootenai red beds—the first strata that can be recognized beyond a reasonable doubt in well logs—these strata were encountered in their normal regional attitude.

The reason that so many wells were drilled in the downthrown sides of faults presumably was because the presence of the near-by fault was not recognized, and the belt of tilted strata adjacent to it was mistaken for the highly inclined limb of an asymmetric fold, and the flat-lying strata at the well site for the crest of such a fold. But no matter what opinions were held as to the structure when the drilling began, it is quite probable that these were changed when the Kootenai red beds were penetrated, because these beds were never encountered at as shallow depths as the assumptions of folding implied that they should be. Four wells, Nos. 1, 5, 14, and 15, were drilled on the upthrown sides of faults. Well 1 is 3,000 feet north of the outcrop of the nearest fault and consequently starts in the flat-lying strata back of the tilted belt, which is here but 600 to 700 feet wide. Inasmuch as the well does not start on the surface upthrust strata, the writer would not expect it to encounter upthrust strata below the surface, because the marked decrease in width of the tilted belt with increasing stratigraphic depth is definitely opposed to the assumption that the tilted belt in the deeper strata lies outside of the tilted belt in the surface strata. However, as this fact may not be entirely evident to those who have not made a regional study of the faults, the evidence furnished in the drilling of the well is presented in Figure 16, which shows a cross section of the structure between the two wells drilled in the locality and transverse to the fault that crops out about midway between the wells. This cross section, which is based on an accurate stadia traverse and the logs of wells 1 and 2, taken in conjunction with the data used in the compilation of the structure contours, demonstrates that the Kootenai and other underlying formations were not involved in the thrust faulting, at least at the positions where they were penetrated by the drill. Because of their position at considerable distances from the faults, the data furnished by these wells obviously do not exclude the possibility that the Kootenai is upthrust in an intervening position. Well 5, however, is excellently situated to test this possibility, for it is on the tilted belt about 1,000 feet from a thrust fault and consequently at about the right position to encounter the Kootenai formation on the upthrust side of the fault if it were included in the faulting. Although the well starts in the Colorado shale at a horizon about 300 feet below its top, where these beds are thrust approximately 500 feet above their normal position, the Kootenai formation was encountered at its regional, nearly flat-lying position. This fact

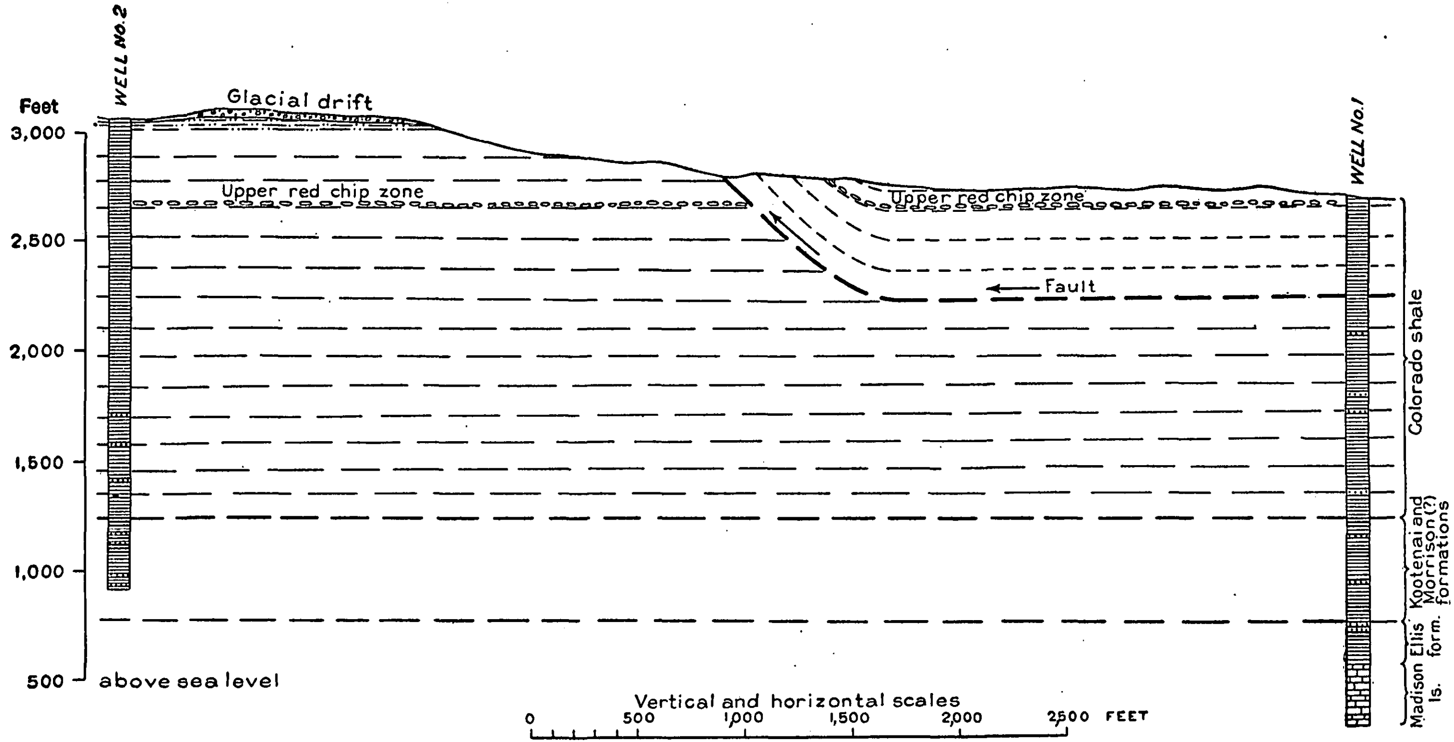

FIGURE 16.—Interpretation of the subsurface structure between wells 1 and 2 on Vimy Ridge, T. 25 N., R. 9 E., Mont. The Kootenai formation where penetrated in the wells has not been faulted or bowed above its normal regional position

is indicated by the abnormal thickness of the Colorado shale, which is 500 feet above the average of 1,850 feet. (See appended table and the cross section in fig. 17.)

It is reported that well 14 is 300 feet east of well 13. The location and structural position of this well were not determined by the writer, but if the report is correct this well also is located on the tilted belt on the upthrown side of a thrust fault 100 to 200 feet from the outcrop of the fault. The strata at the well site are those occurring 500 to 600 feet below the top of the Colorado shale and are upthrust about 500 feet above their normal position. Although no log of this well could be obtained, oil journals state that it encountered the Kootenai at a depth of 1,800 feet. Inasmuch as the altitude of the well

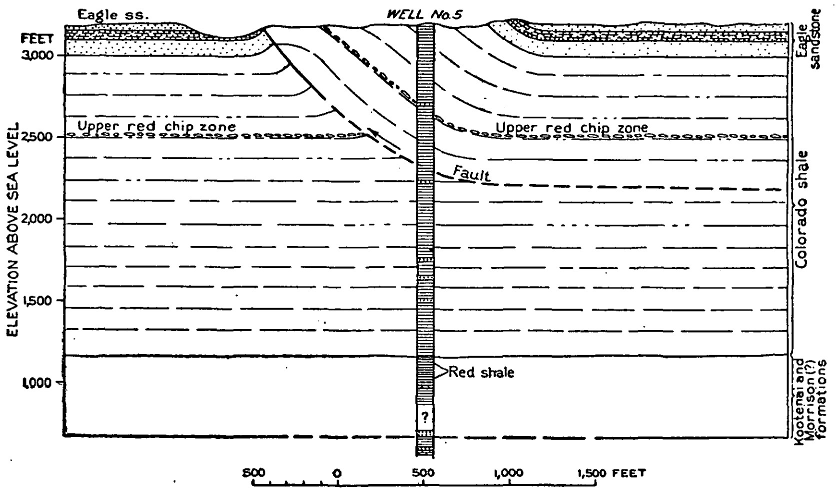

FIGURE 17.—Interpretation of subsurface structure transverse to the thrust fault at well 5, T. 22 N., R. 13 E., Mont. The Kootenai formation where penetrated in the wells has not been faulted or bowed above its normal regional position

is about 50 feet below the altitude of the top of the Colorado shale in areas outside of the tilted belt, it is evident that the Kootenai formation, where penetrated, occupies its normal nearly flat-lying position. The writer has not visited well 15, but it is reported to be located on a tilted belt of Colorado shale bordering a thrust fault. The log of the well, however, shows that the Kootenai formation was not encountered above its regional nearly horizontal position.

From the data above set forth it is evident that although nine deep wells have been drilled on and off the tilted belts adjacent to the thrust faults in the area under consideration, the Kootenai formation has in no well been encountered above its nearly horizontal regional attitude. The evidence by these wells as to the undisturbed attitude of the Kootenai formation is assembled in Figure 18.

This cross section shows the surface expression characteristic of a thrust fault eroded to the same level as the one shown in Figure 17, on which is projected the exact structural and stratigraphic positions of the wells.

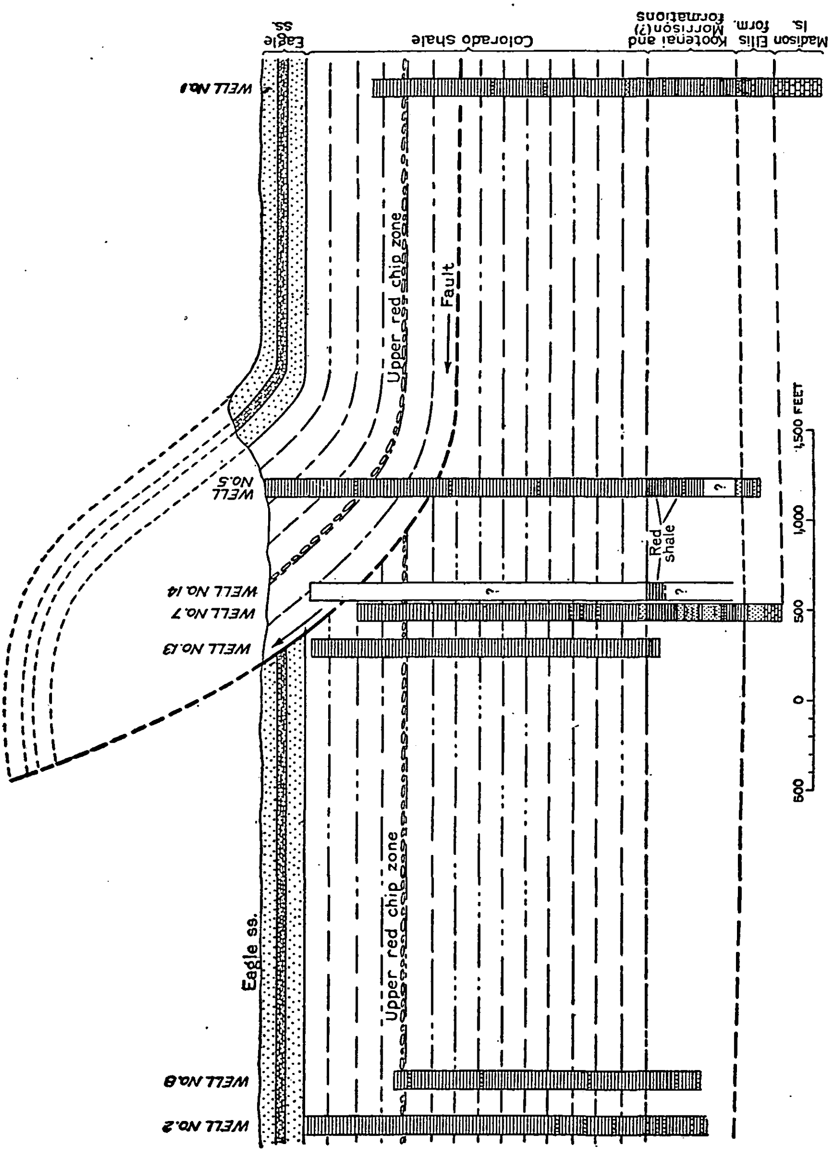

FIGURE 18.—Composite cross section showing the undisturbed attitude of the Kootenai formation where it has been penetrated by wells drilled adjacent to thrust faults near the Highwood Mountains, Mont.

Summary of wells drilled adjacent to the Highwood Mountains, Mont.

Map No.	Company	Location	Total depth (feet)	Formations penetrated		Approximate altitude of well mouth (feet)	Vertical distance between base of Eagle sandstone and Kootenai formation (feet)	Structural position of well	Remarks
				Start in	Stop in				
1	Twenty Dollar Bill Syndicate.	SE. ¼ sec. 9, T. 25 N., R. 9 E., Chouteau County.	2,378	Colorado shale, 415 feet below top.	Madison limestone.	2,647	1,850	3,000 feet from thrust fault on upthrown side.	Show of gas in Colorado shale.
2	Hager Stevenson	SE. ¼ sec. 16, T. 25 N., R. 9 E., Chouteau County.	2,130	Colorado shale, 35 feet below top.	Kootenai formation.	3,032	1,850	3,000 feet from thrust fault on downthrown side.	Dry.
3	Transcontinental Oil Co.	NE. ¼ sec. 8, T. 23 N., R. 9 E., Chouteau County.	2,970	Colorado shale, 200 feet below top.	Madison limestone.	3,200	1,865	No local deformation of strata.	Do.
4	Hager Stevenson	NE. ¼ sec. 1, T. 23 N., R. 11 E., Chouteau County.	200-300	Near top of Eagle sandstone.	(?)	3,270		do	
5	do	NE. ¼ sec. 23, T. 22 N., R. 13 E., Chouteau County.	2,659	Colorado shale, 300 feet below top.	Ellis formation.	3,200	2,350	1,000 feet from thrust fault on upthrown side.	Show of gas in Colorado shale.
6	Mid States Oil Co.	SW. ¼ sec. 29, T. 21 N., R. 14 E., Chouteau County.	1,150	Eagle sandstone	Colorado shale	3,423		2,200 feet from thrust fault on downthrown side.	Dry.
7	Continental Oil Producing Co.	SW. ¼ sec. 24, T. 20 N., R. 12 E., Chouteau County.	2,278	Colorado shale, 300 feet below top.	Ellis formation.	3,395	1,880	200 to 300 feet from thrust fault on downthrown side.	Do.
8	Arrow Creek Development Co., No. 2.	NE. ¼ sec. 27, T. 20 N., R. 13 E., Chouteau County.	1,655	Colorado shale, 500 feet below top.	Kootenai formation.	2,929	1,880	2,900 feet from thrust fault on downthrown side.	Showings of oil and gas.
9	Arrow Creek Development Co. No. 1.	NW. ¼ sec. 25, T. 20 N., R. 13 E., Fergus County.	1,710	Colorado shale, 450 feet below top.	do	2,957	1,880	6,000 feet from thrust fault on downthrown side.	Small gas well and showing of oil.
10	Hager Stevenson	SE. ¼ sec. 33, T. 19 N., R. 7 E., Cascade County.	1,275	Kootenai formation	Madison limestone.	4,086		No local deformation of strata.	Dry.
11	Chicago, Milwaukee & St. Paul Ry.	Sec. 16, T. 19 N., R. 12 E., Fergus County.	975	Colorado shale, 800 feet below top.	Colorado shale	3,145		do	Showing of oil and some gas.
12	Wm. MacKenzie No. 1.	NE. ¼ sec. 22, T. 19 N., R. 13 E., Fergus County.	680	Colorado shale, near top	do	3,630		do	Small gas well.
12A	Wm. MacKenzie No. 2.	NW. ¼ sec. 22, T. 19 N., R. 13 E., Fergus County.	2,265	do	Ellis formation.	3,630	1,850	do	Showings of oil and gas.

13	Montana Drilling Equipment Co.	NE. ¼ sec. 12, T. 18 N., R. 15 E., Fergus County.	1,875	Colorado shale, 50 feet below top.	Kootenai (?)	3,555	([a])	100 to 200 feet from thrust fault on downthrown side.	Showing of oil and gas.
14	Eugene Oil Syndicate	NE. ¼ sec. 12, T. 18 N., R. 15 E., Fergus County.	2,285	Colorado shale, 500 to 600 feet below top.	do	3,550	([a])	100 to 200 feet from thrust fault on upthrown side.	Dry.
15	Claggett Independent Co.	NE. ¼ SE. ¼ sec. 27, T. 22 N., R. 15 E., Fergus County.	2,660	Colorado shale	do	(?)		On upthrown side of thrust fault.	Water in several sands.

[a] Log not obtained.

Of the 30 or more wells drilled in the faulted area adjacent to the Bearpaw Mountains, only 7 have penetrated to any appreciable depths below the Eagle sandstone. The two wells drilled by the Franz

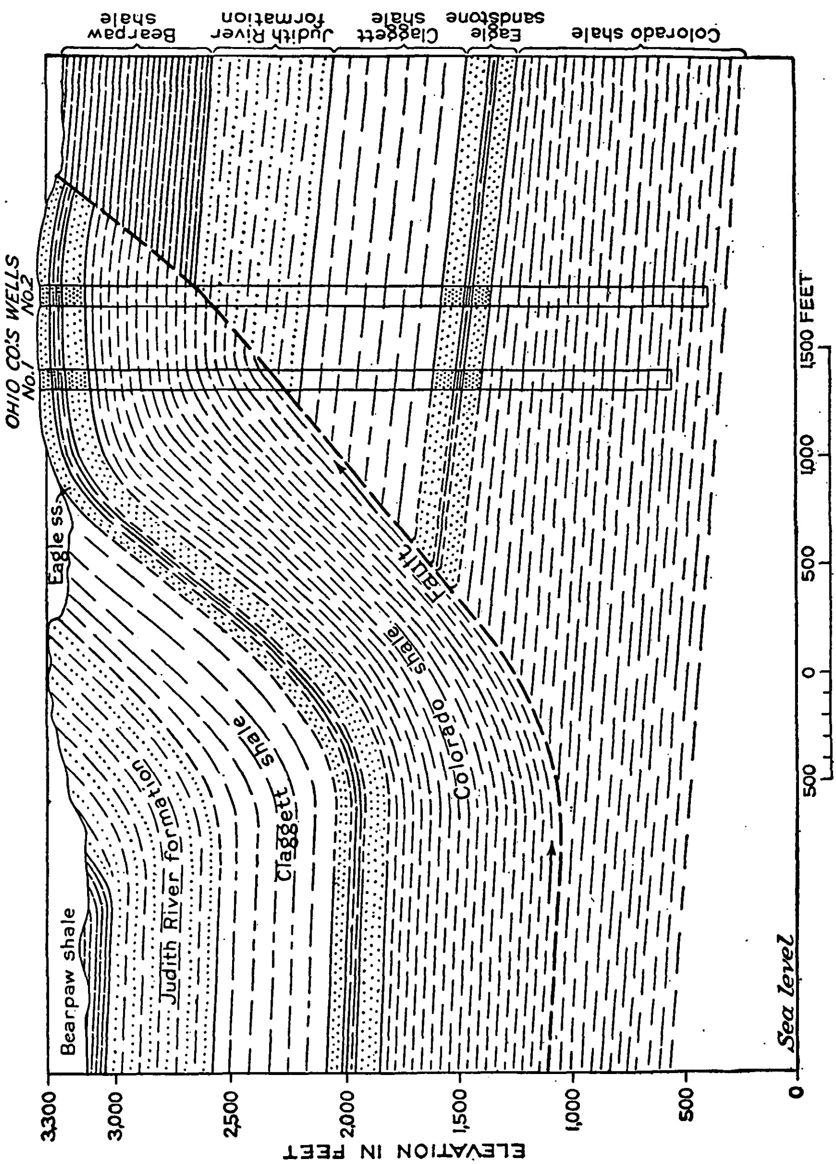

FIGURE 19.—Interpretation of subsurface structure transverse to the thrust fault at the Ohio Oil Co.'s wells on Sand Coulee, T. 25 N., R. 17 E., Mont.

Corporation and the California Co. (see appended table) passed entirely through the Colorado shale, revealing an approximate normal thickness for that formation. The Franz well, however, is on a faulted dome, probably of igneous origin, and the California well started in the flat-lying strata on the downthrown side of a thrust fault and encountered undisturbed strata throughout its depth. At the Kremlin Petroleum Co.'s well the surface strata are not exposed sufficiently to reveal the structure, but inasmuch as the Claggett shale, Eagle sandstone, and Colorado shale were encountered above their normal position in the locality, it is probable that the well is on the upthrown side of a thrust fault. A thickness of 400 feet above the normal for the Colorado shale was penetrated without the base of the formation being reached. Hence the Kootenai formation beneath the well location can not be appreciably deflected above its normal position. The Ohio Co.'s wells in Sand Coulee started in the Eagle sandstone on the upthrown side of a thrust fault and within 1,000 and 700 feet of the outcrop of the fault. Both wells evidently passed through the fault plane at about the depths equal to the distance of each well from the fault. At any rate, Kootenai red beds were not penetrated in either well, although depths of 2,765 and 2,893 feet were attained. (See fig. 19.) The Kansas-Montana Co.'s well near Winifred started in the Judith River formation on the upthrown side of a thrust fault, within about 700 feet of the outcrop of the fault. Because of the nearness of the well to the fault the drill evidently passed through the fault plane at a depth of 600 to 800 feet and encountered the Eagle sandstone and Colorado shale where they occupied their normal regional position on the downthrown side of the fault.

Summary of deep wells drilled in the faulted area adjacent to the Bearpaw Mountains

Company	Location	Total depth (feet)	Formations penetrated		Approximate altitude of well mouth (feet)	Vertical distance between base of Eagle sandstone and Kootenai formation (feet)	Structural position of well	Remarks
			Started in	Stopped in				
California Co.	NE. ¼ NE. ¼ sec. 9, T. 31 N., R. 19 E., Blaine County.	4,400	Judith River formation	Madison limestone.	3,143	1,922	On crest of a dome	Large flow of gas in Eagle sandstone.
Franz Corporation.	NW. ¼ SW. ¼ sec. 31, T. 34 N., R. 14 E., Hill County.	3,306	Near base of Judith River formation.	Kootenai	2,685	1,872	On downthrown side of thrust fault.	Show of gas in Eagle sandstone.
Kremlin Petroleum Co.	NW. ¼ SE. ¼ sec. 28, T. 33 N., R. 12 E., Hill County.	3,131	do	Colorado shale	2,958	2,269+	Probably on upthrown side of thrust fault.	Little gas in Colorado shale.
Ohio Oil Co. No. 1.	NE. ¼ NE. ¼ sec. 17, T. 25 N., R. 17 E., Chouteau County.	2,765	Top of Eagle sandstone	do	3,330	[a] 2,565+	On upthrown side of thrust fault.	Large flow of gas in Eagle sandstone.
Ohio Oil Co. No. 2.	NW. ¼ NW. ¼ sec. 16, T. 25 N., R. 17 E., Chouteau County.	2,983	do	do	3,325	[a] 2,733+	do	Do.
Kansas Montana Oil Co.	SW. ¼ NW. ¼ sec. 18, T. 21 N., R. 19 E., Fergus County.	3,182	Near top of Judith River formation.	do	3,290	[a] 1,802+	do	Shows of oil and gas.
Melton Corporation.	SW. ¼ sec. 24, T. 21 N., R. 17 E., Fergus County.	2,390 (April, 1928)	600 feet below top of Colorado shale.	Drilling in Colorado shale.	(?)	2,990+	On upthrown side of thrust fault, 350 feet from fault.	Showings of oil.

[a] Well ends in the Colorado shale; hence its total thickness is not known.

The Melton Corporation, which is drilling a well a few miles west of Winifred, has had the same experience as other companies that have drilled wells in the region on the tilted strata bordering the upthrown sides of the thrust faults. This well starts in the Colorado shale about 600 feet below the top of the formation and should have encountered the Kootenai red beds at approximately 1,300 feet if they had been involved in the deformation accompanying the faulting. In April, 1928, however, the well was still drilling in the Colorado shale at a depth of 2,390 feet.

Thus, of the 15 wells in the region that have penetrated the lower part of the Colorado shale or underlying formations adjacent to the thrust faults, none have encountered the Kootenai formation faulted or bowed above its normal position. Whether beds in the lower part of the Colorado shale are similarly undisturbed can not be definitely determined, because the Kootenai red beds are the first strata below the top of the Colorado shale whose exact stratigraphic position can be recognized beyond a reasonable doubt in well logs. These data, taken in connection with the widespread appearance of certain beds along faults that have been eroded to markedly different stratigraphic levels, the absence of lower beds along the faults, the parallelism in the dip of the beds and the fault planes, the decrease in the amount of dip of the fault planes in the most deeply eroded faults, and the disappearance of the faults where the lower half of the Colorado shale appears at the surface, justify the conclusion that the thrust faulting does not include the lower half of the Colorado shale or older formations. The writer formerly considered that it was possible that the lower formations were included in the thrust movement, responding to it in such a manner as to allow crustal shortening without the formation of folds or large-scale thrust faults.[15] This hypothesis, however, was only tentatively held and, when critically examined, was abandoned because mechanically it appeared impossible and was also not consistent with the known facts.

POSSIBILITY OF OBTAINING OIL AND GAS IN COMMERCIAL VOLUME

Oil and gas should be found in commercial volume in the area adjacent to the Highwood Mountains if suitable structural conditions have been present for its accumulation and retention, because the Colorado shale and the Ellis formation are undoubtedly rich in the organic deposits that yield hydrocarbons, and there are porous sandstones in practically all the formations that would furnish suitable reservoirs for the accumulation of these hydrocarbons. The

[15] Reeves, Frank, Shallow folding and faulting around the Bearpaw Mountains: Am. Jour. Sci., 5th ser., vol. 10, pp. 199–200, 1925.

most common type of structure in the area is, however, that produced by thrust faulting. Structure of this type is not considered favorable for the accumulation of oil and gas in this area, because there is good evidence that the sandstones in the lower part of the Colorado shale and in the underlying Kootenai and Ellis formations are not involved in the faulting, and the sandstones in the overlying formations are either eroded or too near the surface to retain hydrocarbons in appreciable volumes. This conclusion is supported by the results obtained in the 10 wells drilled adjacent to thrust faults in the area mapped, for in none were commercial volumes of oil or gas obtained, although good showings were encountered in some of the wells. These shows of oil and pockets of gas, however, are widely encountered in the Rocky Mountain region and can not be considered proofs of the presence of near-by commercial pools of oil or gas.

The other type of structure noted in the area—the down faulting near the mountains—although offering more favorable conditions for the accumulation of oil and gas than the thrust faulting, is not considered sufficiently favorable to justify the drilling of wells at the present time.

The dikes that are present in parts of the plains probably do not form barriers behind which oil and gas might accumulate in commercial volume, because they are commonly so jointed that they probably do not prevent a free movement of water, even in the few dikes whose trend diverges sufficiently from the regional dip of the strata to offer any obstruction to the movement of the water, which probably is in the direction of the regional dip.

In the writer's opinion, therefore, the possibility of finding oil and gas in the area is not sufficiently attractive to justify further drilling at the present time.

WELL LOGS

The following are the logs of the deepest wells drilled in the area, with the writer's interpretation of the formations penetrated:

Log of Twenty-Dollar Bill Syndicate's well in SE. ¼ sec. 9, T. 25 N., R. 9 E., Chouteau County, Mont., drilled in 1922–23 (No. 1 on map)

	Feet
Surface rock	0–35
Blue shale; shows of gas at 190 and 220 feet	35–570
Gray shale	570–600
Blue shale	600–685
Sandy blue shale; showing of gas	685–690
Blue shale	690–963
Water sand	963–986
Blue shale	986–1,150
Gray shale; water at 1,305 feet	1,150–1,305
Water sand	1,305–1,335
Gray shale	1,335–1,435
Red shale	1,435–1,460
Gray shale	1,460–1,485
Blue shale	1,485–1,500
Sand	1,500–1,505

	Feet
Blue shale	1, 505–1, 545
Gray shale	1, 545–1, 565
Red shale	1, 565–1, 585
Blue shale	1, 585–1, 595
Shell	1, 595–1, 602
Blue shale	1, 602–1, 675
Limestone	1, 675–1, 680
Blue shale	1, 680–1, 705
Sandy shale	1, 705–1, 717
Water sand	1, 717–1, 719
Black shale	1, 719–1, 741
Shell	1, 741–1, 742
Blue shale	1, 742–1, 813
Hard shell	1, 813–1, 815
Red shale	1, 815–1, 850
Blue shale	1, 850–1, 900
Hard shell	1, 900–1, 902
Blue shale	1, 902–1, 907
Sand	1, 907–1, 922
Blue shale	1, 922–1, 930
Sand	1, 930–1, 945
Red shale	1, 945–1, 965
Blue shale	1, 965–1, 977
Limestone	1, 977–1, 990
Blue shale	1, 990–2, 055
Black shale	2, 055–2, 062
Blue shale	2, 062–2, 090
Sand; water flowing 9,000 barrels daily at 2,095 feet	2, 090–2, 095
White limestone	2, 095–2, 378

Writer's interpretation (well starts about 100 feet above upper red-chip zone):

	Feet
Colorado shale	0–1, 435
Kootenai and Morrison (?) formations	1, 435–1, 907 (?)
Ellis formation	1, 907 (?)–2, 095
Madison limestone	2, 095–2, 738

Casing: 12½-inch, 110 feet; 10-inch, 986 feet; 8¼ inch, 1,780 feet.

Log of Transcontinental Oil Co.'s well in NE. ¼ sec. 8, T. 23 N., R. 9 E., Chouteau County, Mont., drilled in 1921–22 (*No. 3 on map*)

	Feet
Soil	0–10
Dark-blue shale	10–690
Blue shale, hard, shelly	690–875
Water sand; six bailers an hour	875–885
Blue shale, shelly	885–1, 040
Gray shale; caving at 1,060 feet	1, 040–1, 090
Blue shale	1, 090–1, 095
Water sand; four bailers an hour	1, 095–1, 100
Blue shale	1, 100–1, 150
Blue shale, shelly	1, 150–1, 360
Blue shale, sandy	1, 360–1, 385
Blue shale	1, 385–1, 480
Blue shale, shelly	1, 480–1, 510
Blue shale, light, sandy	1, 510–1, 585
Blue shale	1, 585–1, 665
Red shale, caving badly	1, 665–1, 710
Blue shale, caving	1, 710–1, 730
Blue shale, hard, shelly	1, 730–1, 770
Blue shale	1, 770–1, 810
Water sand; hole full of water, flowing	1, 810–1, 880
Yellow lime, hard	1, 880–1, 885
Blue shale; water broke through; casing collapsed	1, 885–1, 935
Broken lime, light	1, 935–1, 945
Gray sandy lime	1, 945–1, 950
Blue shale	1, 950–1, 953
Red shale	1, 953–1, 955
Blue shale; bailing water	1, 955–1, 975
Blue shale, shelly, caving	1, 975–2, 010
Sandy brown shale; showing of oil	2, 010–2, 055
Sand	2, 055–2, 065
Hard lime	2, 065–2, 077
Water sand; hole full of water	2, 077–2, 125
Hard white lime	2, 125–2, 130
Hard lime	2, 130–2, 138
Broken lime; artesian flow of water, 7,000 barrels daily	2, 138–2, 155
Sand and shelly lime; flowing water	2, 155–2, 175
Gray lime	2, 175–2, 280
Sandy lime	2, 280–2, 345
Water sand	2, 345–2, 360

	Feet
Shelly lime	2,360–2,370
Gray lime	2,370–2,380
Water sand, soft	2,380–2,410
Gray lime, hard	2,410–2,425
Sandy lime	2,425–2,450
Hard lime; flowing water over casing, 7,600 barrels a day	2,450–2,465
Sandy lime	2,465–2,480
Fine yellow sand	2,480–2,500
Soft gray lime; hard shells	2,500–2,545
Hard lime	2,545–2,580
Hard red sand	2,580–2,585
Hard red sandy lime	2,585–2,630
Pinkish hard lime	2,630–2,685
Reddish lime with streaks of yellowish shale	2,685–2,710
Sandy gray limestone	2,710–2,775
Brown sand	2,775–2,805
Gray limestone	2,805–2,915
Pinkish limestone	2,915–2,925
Hard gray limestone	2,925–2,970

Writer's interpretation (well starts in Colorado shale about 200 feet below top of formation):

	Feet
Colorado shale	0–1,665
Kootenai and Morrison(?) formations	1,665–2,125(?)
Ellis formation	2,125(?)–2,360
Madison limestone	2,360–2,970

Casing: 12½-inch, 1,007 feet; 10-inch, 1,720 feet; 8¼-inch, 2,205 feet; 6⅝-inch, 2,278 feet.

Log of Hager-Stevenson Co.'s well in NE. ¼ sec. 23, T. 22 N., R. 13 E., Chouteau County, Mont., drilled in 1923–24 (No. 5 on map)

	Feet
Drift	0–50
Blue shale	50–977
Hard sandy blue shale, carrying some gas	977–981
Blue shale	981–1,455
Water sand	1,455–1,465
Blue shale	1,465–1,571
Sandy gray shale	1,571–1,587
Blue shale	1,587–1,690
Gray shale	1,690–1,730
Sandy gray shale; showing of gas	1,730–1,750
Blue shale	1,750–1,769
Shell	1,769–1,773
Blue shale	7,773–1,820
Gray shale	1,820–1,860
Blue shale	1,860–2,050
Red shale	2,050–2,145
Blue shale	2,145–2,155
Red shale	2,155–2,160
Brown shale	2,160–2,165
Sandy greenish-gray shale	2,165–2,185
Red shale; caving	2,185–2,236
Shell	2,236–2,240
Dry sand	2,240–2,245
Gray shale	2,245–2,305
Shell	2,305–2,307
Gray shale	2,307–2,342
Water sand	2,342–2,345
Missing	2,345–2,505
Gray shale	2,505–2,518
Sand	2,518–2,540
Missing	2,540–2,552
Hard lime	2,552–2,583
Blue lime	2,583–2,596
Lime shale	2,596–2,622
Sand	2,622–2,654
Lime; water at 2,658 feet	2,654–2,659

Writer's interpretation (well starts in Colorado shale about 300 feet below top of formation):

	Feet
Colorado shale	0–2,050
Kootenai and Morrison (?) formations	2,050–2,553(?)
Ellis formation	2,553(?)–2,659

Casing: 12½-inch, 1,475 feet; 10-inch, 1,769 feet; 8¼-inch, 2,515 feet.

Log of Continental Oil Producing Co.'s well in SW. ¼ sec. 24, T. 20 N., R. 12 E., Chouteau County, Mont., drilled in 1923–24 (No. 7 on map)

	Feet
Surface rock	0–18
Blue shale	18–190
Black shale	190–200
Blue shale	200–390
Brown shale	390–430
Blue shale	430–485
Coarse sand	485–490
Blue shale	490–1,075
Hard shell	1,075–1,085
Blue shale and shell	1,085–1,140
Sand; hole filled with water	1,140–1,165
Blue shale	1,165–1,185
Sand; hole filled 800 feet with water	1,185–1,195
Blue shale	1,195–1,285
Sandy shale; hole full of water	1,285–1,295
Blue shale	1,295–1,545
Gray sand; water at 1,565 feet	1,545–1,582
Red shale	1,582–1,720
Gray shale	1,720–1,725
Hard red shale	1,725–1,737
Gray sand	1,737–1,775
Blue lime, hard	1,775–1,780
Gray sand	1,780–1,800
Blue shale; hole filled with water	1,800–1,810
Gray sand; hole filled with water	1,810–1,840
Blue shale; more water	1,840–1,845
Gray sand, very hard	1,845–1,880
Red shale	1,880–1,885
Blue shale	1,885–1,895
White and gray lime	1,895–1,905
Gray sand; hole full of water from 1,905 to 1,913 feet	1,905–1,980
Blue shale	1,980–1,985
Dark-gray lime	1,985–1,990
Hard gray sandy lime	1,990–1,993
Gray sandy lime; black sulphur water at 2,000 feet	1,993–2,005
Hard gray sand	2,005–2,010
Gray sandy lime	2,010–2,014
Blue shale	2,014–2,020
Blue sandy shale	2,020–2,026
Blue shale	2,026–2,032
Red shale	2,032–2,036
Blue shale	2,036–2,066
Gray sand	2,066–2,075
Blue shale	2,075–2,088
Gray sand; hole full of water at 2,105 feet	2,088–2,207
Sandy gray lime	2,207–2,237
White lime	2,237–2,247
Gray and white lime	2,247–2,268
Gray water sand	2,268–2,275
White lime	2,275–2,278

Writer's interpretation (well starts in Colorado shale about 300 feet below top of formation):

	Feet
Colorado shale	0–1,582
Kootenai and Morrison (?) formations	1,582–2,088 (?)
Ellis formation	2,088 (?)–2,278

Casing: 20-inch, 39 feet; 12½-inch, 1,024 feet; 10-inch, 1,584 feet; 8¼-inch, 1,987 feet.

Log of Arrow Creek Development Co.'s No. 1 well, NW. ¼ sec. 25, T. 20 N., R. 13 E., Fergus County, Mont., drilled in 1920–21 (No. 9 on map)

	Feet
Alluvium	0–50
Soft blue clayey shale	50–100
Sandy blue shale	100–250
Gray to black shale	250–300
Black shale; water at 350 feet	300–350
Gray shale; gas encountered at 375 feet	350–375

	Feet
Gray to black shale; showings of oil	375–575
Gray to black shale; sandy with sandy shells. A little more gas at 575 feet. Drilling continued to 690 feet, where 10-inch casing was set and gas manifolded between the casings and used to fire boiler, stove, and bit forge	575–690
Blue to black shale	690–1,020
Sand; artesian water at 1,035 feet	1,020–1,065
Blue shale	1,065–1,150
Blue shale concretions	1,150–1,170
Gray shale	1,170–1,285
Blue shale; showings of red in last 20 feet	1,285–1,450
Maroon shale	1,450–1,555
Sandy gray-green shale	1,555–1,630
Maroon calcareous sandstone; showing of oil	1,630–1,650
Sandy maroon shale; strong show of heavy oil	1,650–1,678
Gray sandstone; struck artesian water; oil comes up from 1,678 feet in small heavy drops	1,678–1,710

Writer's interpretation (well starts in Colorado shale about 450 feet below top of formation):

	Feet
Colorado shale	0–1,430
Kootenai formation	1,430–1,710

Casing: 12½-inch, 375 feet(?); 10-inch, 690 feet; 6⅝-inch, 1,710 feet.

Log of Hager Stevenson Co.'s well in SE. ¼ sec. 33, T. 19 N., R. 7 E., Cascade County, Mont., drilled in 1925 (*No. 10 on map*)

	Feet
Yellow earth	0–30
Gray sandy shale	30–48
Red shale	48–73
Gray shale	73–85
Red shale	85–110
Gray shale	110–150
Light-gray shale	150–170
Gray shale	170–180
Hard limestone	180–190
Red shale	190–210
Blue shale	210–220
Sandy gray shale	220–280
Gray sand	280–290
Sandy gray shale	290–305
Red shale	305–340
Hard gray shale	340–350
Red shale	350–373
Dark sandy shale	373–395
Red shale	395–410
Gray shale	410–425
Coal; water at 440 feet	425–440
Shale and coal	440–450
Black shale	450–460
Sandy limestone; water	460–500
Sandy gray shale	500–555
Red shale	555–565
Gray shale	565–580
Pink shale	580–590
Gray limestone	590–615
Gray shale	615–660
Sandy shale	660–725
Sandy shale and limestone	725–815
Gray and white sandy limestone	815–1,275

Writer's interpretation (well starts at base of Colorado shale):

	Feet
Kootenai and Morrison (?) formations	0–590
Ellis formation	590–815
Madison limestone	815–1,275

INDEX

A

B

C

D

E

F

G

H

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