GEOLOGY AND POSSIBLE OIL AND GAS RESOURCES OF THE FAULTED AREA SOUTH OF THE BEARPAW MOUNTAINS, MONTANA.

By FRANK REEVES.

INTRODUCTION.

Scope of paper.—The field work on which this report is based was undertaken in part as an investigation of the oil and gas resources of the area and in part as a study of the faults, which are unique in extent and character. The possibility of obtaining oil and gas in the area is discussed here. A more detailed discussion of the character and origin of the faults will be given in a later publication.

Field work.—The map of the area shown on Plate XIII is a compilation of the work of several geologists. The area south of the Missouri and west of Judith River was mapped during the autumn of 1914 by E. Russell Lloyd, assisted by W. T. Thom, jr., W. B. Wilson, and R. H. Gilroy. The area between Winifred and Judith River was examined in part by Eugene Stebinger, assisted by W. P. Woodring and J. D. Sears, in 1915, and in part by M. N. Bramlette and James Gilluly in August, 1921. The area lying south of Missouri River and east of Winifred was mapped by the writer with the assistance of J. B. Eby in July and August, 1921, and the area north of the Missouri by the writer with the assistance of M. N. Bramlette in the summer of 1922. During the later part of the field season of 1922 M. I. Goldman assisted in making stratigraphic studies of the Mesozoic and Paleozoic rocks of the area. The geologists received from the inhabitants of the area much kindly assistance and hospitality.

The area considered is confined to the southern half of the zone of faults surrounding the Bearpaw Mountains, in north-central Montana. The location of the area is shown in Figure 13.

In mapping the geology 18 by 24 inch plane-table boards and telescopic alidades were used for the greater part of the area. 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, and mapping then proceeded by triangulation methods, a stadia rod being used for detailed work in areas of complex structure.

The study is admittedly of a reconnaissance nature, and it is therefore to be expected that detailed work in areas of complex structure may reveal errors in mapping that will demand modification of the interpretation of the geology made by the writer and his associates.

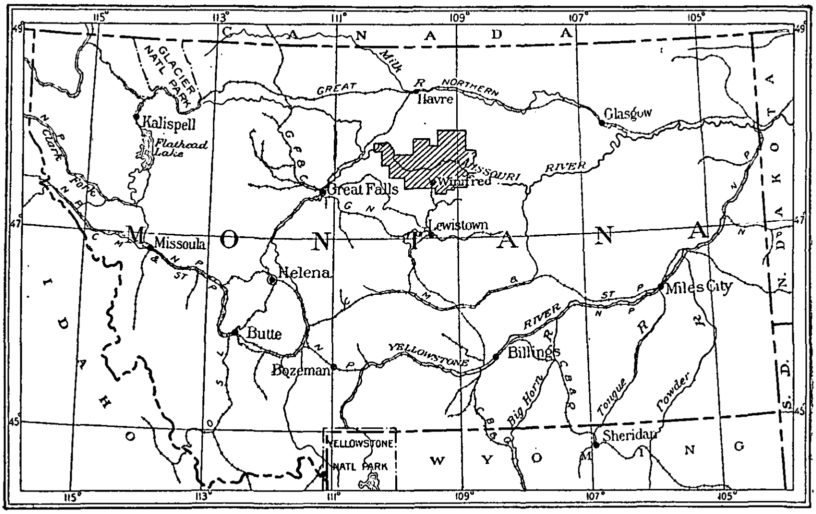

FIGURE 13.—Index map of Montana showing location of faulted area south of the Bearpaw Mountains.

TOPOGRAPHY.

The area is a part of the Missouri Plateau, a subdivision of the Great Plains province, which extends eastward from the Rocky Mountains to the Central Lowlands of the Mississippi River valley. This plateau is an old peneplain surface glaciated in the northern part and eroded locally into badlands in the southern part. A number of isolated mountains of more or less circular outline rise 3,000 to 5,000 feet above these plains. As shown on Plate XII, five such mountain groups lie near the area mapped. When viewed from a distance these mountains rise above the level stretches of the plains in a dim ragged profile. Nearer at hand their rugged, timbered slopes present a striking contrast to the level, sagebrush-covered plains. Within the area here considered the most striking features of the topography are the badlands along Missouri River and the lower courses of its larger tributaries. As a result of being forced by the continental ice sheet in Pleistocene time to seek a new channel, the Missouri here has cut a canyon 600 to 800 feet deep. This intrenchment has given

AGE		Boulder, Colo.	Florence, Colo.	Spring Valley and Labarge, Wyo.	Rock Springs, Wyo.	Lander, Wyo.	Central Wyoming	Big Muddy, Wyo.	Douglas, Wyo.	Salt Creek and Powder River, Wyo.	Moorcroft and Newcastle, Wyo.	Shoshone River, Wyo.	Grass Creek, Oregon Basin, and other anticlines, Wyo.	Basin, Wyo.	Greybull, Wyo.	Elk Basin, Wyo.	Crow Indian Reservation, Mont.	Cat Creek, Mont.	Bearpaw Mountains, Mont.	Sweetgrass Arch, Mont.	Alberta, Canada
Quaternary		Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary
Tertiary	Miocene(?)				Bishop conglomerate														Late Tertiary		
	Oligocene				Absent		White River	White River	White River										Oligocene(?)		Oligocene
	Eocene				Bridger																
				Green River	Green River																----?----
				Wasatch	Wasatch	Wind River	Wind River			Wasatch		Wasatch	Wasatch			Wasatch					Paskapoo
				Evanston	Post-"Laramie" a	Absent or concealed	Fort Union		Fort Union	Fort Union		Fort Union	Fort Union	Fort Union and Lance undifferentiated		Fort Union	Fort Union	Fort Union			
Tertiary (?)				Absent	"Laramie"		Lance	Lance	Lance	Lance		Lance	Lance		Lance	Lance	Lance	Lance	Lance	Willow Creek St. Mary River	Edmonton and St. Mary River
Cretaceous	Upper Cretaceous	Laramie b Fox Hills Pierre, with Hygiene sandstone member	Vermejo Trinidad Pierre	Absent ?	Lewis	Absent	Lewis	Fox Hills	Fox Hills	Lewis	Fox Hills	Meeteetse	Meeteetse	Mesaverde	Mesaverde	Bearpaw	Bearpaw	Bearpaw	Bearpaw	Horsethief Bearpaw	Bearpaw
				Adaville	Mesaverde	Mesaverde	Mesaverde: Teapot, Parkman	Pierre: Teapot, Parkman	Pierre: Parkman	Mesaverde: Parkman	Pierre	Gebo	Mesaverde			Judith River	Parkman	Judith River	Judith River	Two Medicine	Belly River
																Claggett	Claggett	Claggett	Claggett		
					Blair		Steele: Shannon	Shannon	Shannon	Steele: Shannon						Eagle	Eagle	Eagle	Eagle	Virgelle	
				Hilliard	Baxter												Telegraph Cr.				
		Niobrara	Niobrara		(Not exposed		Niobrara	Niobrara	Niobrara	Niobrara	Niobrara		Cody	Cody	Cody	Niobrara	Niobrara				
							Carlile				Carlile					Carlile	Carlile				
		Benton	Carlile Greenhorn Graneros	Frontier	Frontier	Mancos	Frontier: Wall Creek, Peay	Benton: Wall Creek	Benton: Wall Creek	Benton: Wall Creek	Greenhorn	Colorado	Frontier	Frontier: Torchlight, Peay	Frontier: Torchlight, Peay	Frontier	Frontier	Colorado	Colorado	Colorado	Colorado
				Aspen	Aspen		Mowry	Mowry	Mowry	Mowry	Graneros: Mowry		Mowry	Mowry	Mowry	Mowry	Mowry				
							Thermopolis						Thermopolis	Thermopolis	Thermopolis	Thermopolis	Thermopolis				
	Lower Cretaceous	Dakota	Dakota	Bear River Absent ?	Absent ? ?	Dakota Lower Cretaceous	Dakota Lower Cretaceous	Cloverly	Cloverly	Cloverly	Dakota Fuson Lakota	Cloverly	Cloverly	Cloverly	Cloverly: Greybull	Cloverly: Greybull	Cloverly	? Kootenai	? Kootenai	? Kootenai	? Kootenai
Cretaceous (?)		Morrison	Morrison	Beckwith	Beckwith	Morrison	Morrison	Morrison	Morrison	Morrison	Morrison	Morrison	Morrison	Morrison	Morrison	Morrison	Morrison	Morrison(?)	?	Morrison (?)	[?]
Jurassic c		Absent	Absent	Twin Creek Nugget	Twin Creek Nugget	Sundance	Sundance	Sundance	Sundance	Sundance	Sundance	Sundance	Sundance	Sundance	Sundance	Sundance	Sundance	Ellis	Ellis	Ellis	Fernie
Triassic		Absent	Absent	Ankareh Thaynes Woodside	Ankareh Thaynes Woodside	Chugwater	Chugwater	Chugwater	Chugwater	Chugwater	Spearfish - Minnekahta	Chugwater	Chugwater	Chugwater	Chugwater	Chugwater	Chugwater (red beds)	Absent	Absent	Absent	[?]
Carboniferous	Permian	Lykins	Absent	Park City	Park City	Embar	Embar	Embar	Forelle (?)	Ember	Opeche	Embar	Embar	Embar	Embar	Embar					Upper Banff shale
	Pennsylvanian	Lyons		Weber	Weber	Tensleep	Tensleep	Tensleep	Satanka (?) Casper	Tensleep	Minnelusa	Tensleep	Tensleep	Tensleep	Tensleep	Tensleep	Tensleep	Quadrant	Absent	Absent	Upper Banff limestone
		Fountain	Fountain	Older Pennsylvanian	Older Pennsylvanian	Amsden	Amsden	Amsden		Amsden	?	Amsden	Amsden	Amsden	Amsden	Amsden	Amsden				Lower Banff shale
	Mississippian	Absent	Millsap	Madison	Mississippian	Madison	Madison	Madison		Madison	Pahasapa	Madison	Madison	Madison	Madison	Madison	Madison	Madison	Madison	Madison	Lower Banff limestone
Devonian		Absent	Absent	Jefferson	Devonian(?)	Devonian	Absent (?)	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Probably absent	?	Jefferson	Devonian	Devonian
Silurian		Absent	Absent	Absent (?)	Absent (?)	Absent (?)	Absent (?)	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Silurian
Ordovician	Upper	Absent	Fremont	Upper Ordovician	Absent (?)	Bighorn	Bighorn	Absent	Absent	Bighorn	Absent	Bighorn	Bighorn	Bighorn	Bighorn	Bighorn	Bighorn	?	Bighorn	Bighorn	Ordovician
	Middle	Absent	Harding	Absent (?)	Absent (?)	Absent (?)	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	
	Lower	Absent	Manitou	Absent (?)	Absent (?)	Absent (?)	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	
Cambrian	Upper	Absent	Upper Cambrian	Upper Cambrian	Cambrian	Gallatin	Deadwood	Deadwood	Deadwood	Deadwood	Deadwood	Deadwood	Deadwood	Deadwood	Deadwood	Deadwood	Deadwood	?	Deadwood	Deadwood	Upper Cambrian
	Middle	Absent	Absent	Absent	Absent (?)	Gros Ventre Flathead	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Middle Cambrian	?	Middle Cambrian	Middle Cambrian
	Lower	Absent	Absent	Absent		Absent (?)	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent (?)	?	Absent (?)	Lower Cambrian
Pre-Cambrian		Quartzite, granite, etc.	Granite, etc.	Granite, etc.	Granite, etc.	Granite, etc.	Granite, etc.	Granite, etc.	Granite, etc.	Granite, etc.	Granite, etc.	Granite, etc.	Granite, etc.	Granite, etc.	Granite, etc.	Granite, etc.	Granite, etc.	Limy shales, etc.	Schist	Granite, etc.	Granite, etc.

FORMATIONS PRESENT IN THE FAULTED AREA SOUTH OF THE BEARPAW MOUNTAINS, MONT., AND THEIR APPROXIMATE EQUIVALENTS IN THE ROCKY MOUNTAIN REGION.

Table compiled by U. S. Geological Survey from published reports, slightly modified to accord with later information. a Includes rocks older than Lance and may all be pre-Lance. b Laramie placed here for convenience. It is of unquestioned Cretaceous age and younger than Fox Hills or Lewis. c Twin Creek and Ellis may include rocks older than Sundance; correlation of the Nugget not fully established.

a steep gradient to all its tributaries, and they also have cut deep channels in their lower courses, producing a much dissected region, in which the highly folded and faulted strata are strikingly exposed. Adjacent to these badland areas the surface of the country is a rough but fairly flat plain cut by deep, narrow canyons and broken by sandstone ridges and hogbacks which are topographic expressions of folds and faults present in the area. The altitude of this plain is 3,000 to 3,200 feet above sea level along the Missouri River bluffs and 3,400 to 3,600 feet at the base of the mountains. Adjacent to the Bearpaw and Little Rocky mountains are a number of gravel terraces of varying altitude and extent, whose level, even surfaces are a pronounced feature of the landscape. The highest of these terraces form flat-topped table-lands, mesas, and long, narrow ridges; the lower terraces are slightly trenched alluvial fans. Northwest of Birch Creek the country has been glaciated and presents a younger and less varied type of topography. Here the gravel terraces and sandstone ridges have been eroded and covered up by glacial action, and the streams, except along Missouri River, are but slightly intrenched. The weathering of small masses of igneous rocks intruded into the sediments of the plains has produced a scattered array of high buttes, pinnacles, and long, narrow rock walls, and in places circular depressions.

SEDIMENTARY ROCKS.

GENERAL SECTIONS.

The sedimentary rocks of this general region consist of about 8,300 feet of strata ranging in age from Recent to Cambrian. About 4,500 feet of strata, principally of Cretaceous age, crop out in the area mapped, the oldest rock exposed being the Kootenai formation (Lower Cretaceous). The rest of the stratigraphic section, consisting chiefly of rocks of Paleozoic age, is exposed in the Little Rocky Mountains. The oldest rock exposed in the Bearpaw Mountains is the upper part of the Madison limestone, of lower Mississippian age. The sequence and character of the sedimentary strata of the region are given on pages 74–75. Their equivalents in many areas in Colorado, Wyoming, Montana, and Alberta are shown in Plate X. In describing the sedimentary rocks the writer has discussed the post-Paleozoic formations in detail, because it appears desirable not only to present information that will be of aid to the oil geologist in judging the possibility of obtaining oil in the area and in recognizing the formations in the areas of complex structure, but also to place on record some of the data which the study of the sedimentary rocks furnishes as to the geologic history of the region.

Post-Paleozoic formations exposed on the south flank of the Bearpaw Mountains, Mont.

Geologic age.	Group and formation.		Thickness (feet).	Character.	Remarks.
Recent.	Alluvium.		50±	Flood-plain and alluvial-fan deposits of clay, sand, and gravel.	
Pleistocene.	Glacial drift. Gravel terraces.		1-50 100±	Glacial till, gravel, sand, and boulders of granite, gneiss, basic igneous rocks, and limestone. Lower terrace deposits of gravel derived from adjacent mountains.	
Pliocene or Miocene.	Flaxville gravel.		50	Highest terrace deposits derived from adjacent mountains.	
Oligocene.	Conglomerate.		5-30	Well rounded and polished pebbles and boulders consisting principally of quartzite derived probably from the Algonkian Belt rocks of western Montana. Occurs at the base of the volcanic rocks in the Bearpaw Mountains.	
Tertiary (?) (Eocene?).	Lance formation.		500+	Massive gray to brown clayey sandstone, greenish to grayish yellow clay, thin sandy limestone, lignitic shale, and coal beds.	Contains coal in the Big Sandy coal field and on the flanks of the Bearpaw Mountains.
Upper Cretaceous.	Montana group.	Bearpaw shale.	900	Steel-gray to black marine shale containing a few grayish-white and dark-red concretions and beds of bentonite.	
	Montana group.	Judith River formation.	500	Fresh and brackish water deposits consisting of irregularly and thin-bedded gray clayey sandstone, lignitic clay, and coal beds.	Contains coal in the area mapped. Yields gas in the Baker anticline, in southeastern Montana.
	Montana group.	Claggett shale.	550	Dark to brownish-black marine shale containing persistent yellow calcareous concretionary beds. Bentonite and tan-colored sandstone in the upper part.	
	Montana group.	Eagle sandstone.	200±	Massive and thin-bedded buff to white sandstone, carbonaceous shale, and coal beds.	Contains coal in the area mapped. Yields gas near Havre and small amounts of oil and gas in the Lake Basin field, in south-central Montana.
	Colorado shale.		1,800	Bluish-black marine shale with a sandy transitional stage, 100 to 200 feet thick, at the top; a zone of calcareous concretionary beds, about 300 feet thick, in the middle of the formation overlying a series, 75 feet thick, of gray thinly laminated sandy shale bearing fish scales, representing the Mowry shale member; and below this 600 to 700 feet of dark-blue shale containing a conglomerate sandstone in the middle part and sandy shale with lenses of sandstone at the base.	Top part yields oil in a few localities in Wyoming and gas in southeastern Alberta. Beds equivalent to the concretionary zone contain the most productive oil sands of Wyoming. The sandstone at the base is the most productive sand in Cat Creek, Mont., and yields gas in Kevin, Mont., and in southeastern Alberta.

Post-Paleozoic formations exposed on the south flank of the Bearpaw Mountains, Mont.—Continued.

Geologic age.	Group and formation.	Thickness (feet).	Character.	Remarks.
Lower Cretaceous.	Kootenai formation.	260	Red and greenish shale at the top, lenses of sandstone and thin sandy limestone in the middle, and a massive sandstone underlain by a bed of carbonaceous shale in the lower part.	Yields oil in Wyoming and in the Cat Creek and Kevin fields, Mont. Contains coal in the Lewistown and Great Falls coal fields.
Upper Jurassic.	Ellis formation.	310	Buff and gray petroliferous and fossiliferous limy shale and thin beds of limestone with 75 feet of blue to black thin-bedded petroliferous and fossiliferous limestone at the base.	Contains oil in the Kevin-Sunburst field, Mont.

Paleozoic formations exposed in the Little Rocky Mountains and underlying the Mesozoic formations in the area of this report.[a]

Geologic age.	Group, formation, and member.		Thickness (feet).	Character.	Oil and gas in near-by field.
Mississippian	Madison group.	Mission Canyon limestone.	500	A massive white limestone of marine origin. Not so fossiliferous as the Lodgepole limestone.	Yields oil in the Soap Creek field.
		Lodgepole limestone.	800	Thin-bedded limestone and shale. Contains many fossils.	Contains albertite near Landusky.
Devonian.	Jefferson limestone.		350	Upper 250 feet massive dark limestone, lower 100 feet thin-bedded limestone. A few brachiopods, corals, and Stromatopora.	Fetid odor indicates the presence of disseminated oil. The Athabaska tar sand derives its oil from the Devonian.
Ordovician.	Bighorn limestone.		350	Light-colored massive sandy limestone. Fossils principally corals.	Fetid odor indicates presence of disseminated oil.
Cambrian.	Deadwood formation.		800±	Thin-bedded limestone, shale, sandstone, and intraformational conglomerate. Conglomerate or quartzite at base. Fragments of trilobites and a small brachiopod.	May be oil-bearing in favorable localities.
	Unconformity				
Pre-Cambrian.	Schist.			Mica, hornblende, and feldspar schists.	No possibilty of oil.

[a] Collier, A. J., and Cathcart, S. H., Possibility of finding oil in laccolithic domes south of the Little Rocky Mountains, Mont.: U. S. Geol. Survey Bull. 736, p. 173, 1922.

CENOZOIC STRATA.

The Cenozoic strata consist of surficial deposits of sand, clay, gravel, glacial till, and boulders ranging in age from Recent to probably Oligocene. In addition a series of sandstone and shale which are regarded as belonging to the Lance formation are tentatively classified as of Cenozoic (?) age.

RECENT DEPOSITS.

The flood-plain and alluvial-fan deposits occurring along the larger streams are of Recent origin and are composed of the sand, clay, and gravel derived from the adjacent outcropping rocks. Very little of such material occurs along Missouri River, because owing to its steep gradient it is constantly deepening its channel and carrying away the material that its tributaries deposit along its banks or that collects in its eddies. West of the mouth of Birch Creek there is a large area of bottom land about 100 feet above the river which is receiving the outwash of the high bluffs that surround it. These broad valleys may mark former courses of Missouri and Judith rivers.

GLACIAL DRIFT.

During Pleistocene time continental glaciers formed in Canada and advanced at five different periods southward across the northern part of the United States. The two of these great ice sheets that are known to have invaded Montana were obstructed by the Bearpaw and Little Rocky mountains, and consequently the area directly south of these mountains was not glaciated. The ice, however, at the earlier of these advances passed around the southwest flank of the Bearpaw Mountains and the southeast flank of the Little Rocky Mountains and extended south of the present course of Missouri River to about the position shown on Plate XII. The lobe that extended around the west end of the Bearpaw Mountains, according to Calhoun,[1] forced Missouri River, which formerly flowed around the north flank of these mountains, to seek a new outlet south of them. On melting the glaciers deposited the boulders and pebbles of granite, gneiss, and other crystalline rocks that they had carried from the Hudson Bay region, as well as the finer material produced by their grinding and reworking of the sedimentary rocks over which they passed. This material, 25 to 100 feet in thickness, conceals the sedimentary rocks except where streams have removed it. The lobe of the glacier that passed around the eastern flank of the Little Rocky Mountains may not have extended as far west and south as the boundary shown on the map, for most of the material there consists of glacial boulders, and these may have been transported by ice, floating outward on a body of water produced by the damming of streams by the glacier.

GRAVEL TERRACES.

On the southwest flank of the Little Rocky Mountains and the south flank of the Bearpaw Mountains there are a number of gravel terraces consisting of angular boulders, pebbles, and other unconsolidated and

[1] Calhoun, F. H. H. The Montana lobe of the Keewatin ice sheet: U. S. Geol. Survey Prof. Paper 50, pp. 34-36, 1906.

poorly sorted rock materials, which are the weathered products of the rocks that crop out in the adjacent mountain uplifts. These materials have been carried by streams down the slope of the mountains and deposited on the plain as alluvial fans. In the terraces adjoining the Little Rocky Mountains these deposits consist chiefly of limestone derived from the Paleozoic limestones that encircle the central laccolithic mass of granite porphyry. Adjacent to the Bearpaw Mountains the deposits are composed of fragments of the volcanic rocks that form the greater portion of the mountains.

The highest of these terraces, including the Joslin and Lone Tree benches, are correlated by W. C. Alden, of the United States Geological Survey, who is making a regional study of these benches, with the Flaxville gravel of northeastern Montana, which Collier and Thom[2] report to be of Miocene or Pliocene age. The terraces occurring at lower levels are probably of Pleistocene age.

Around the outer margin of the Bearpaw Mountains, underlying the volcanic rocks and resting on the eroded surface of the Bearpaw and Lance beds, is a conglomerate 10 to 30 feet thick which consists of well-rounded and polished pebbles and boulders, firmly cemented in a matrix of coarse sand. Many of the pebbles have been shattered and recemented in this matrix. In color they range from gray-white to green and red. Most of the pebbles are fine-grained quartzite, but argillite and metamorphosed limestone are also present. Apparently none of the materials are derived from rocks that crop out in the Bearpaw Mountains. Their resemblance to the Algonkian Belt rocks, which crop out in western Montana, suggests that they are derived from these rocks. They are very similiar also to the Cypress Hills bench gravels that occur in southern Canada, 100 miles north of the Bearpaw Mountains, which are now regarded as of Oligocene age.[3] It is possible that this conglomerate and the Cypress Hills gravel bench represent a remnant of a gravel bench which W. C. Alden[4] suggests may have had a widespread distribution over the plains of Montana and Wyoming.

CENOZOIC (?) STRATA.

Lance formation.—Beneath the volcanic rocks on the south flank of the Bearpaw Mountains and in down-faulted areas adjacent to the mountains there is a formation which consists of thick, massive gray and brown medium-grained sandstone, gray and greenish sandy shale, carbonaceous clay, thin sandy limestone, and one or two coal beds. It was not possible to make a detailed measurement and study of

[2] Collier, A. J., and Thom, W. T., The Flaxville gravel and its relation to the high terrace gravels of the northern Great Plains: U. S. Geol. Survey Prof. Paper 108, pp. 179-184, 1917.

[3] Lambe, L. M., A new species of *Hyracodon* (*H. priscidens*) from the Oligocene of the Cypress Hills, Assiniboia: Canada Roy. Soc. Proc. and Trans., 2d ser., vol. 2, sec. 4, pp. 37-42, 1906.

[4] Personal communication.

these beds, because they are so faulted and covered by bench-gravel material that their sequence and character could be determined only approximately. In some areas there is at the base a tan-colored sandstone 100 feet or more thick. This is overlain by a series of soft yellowish-gray to creamy-white sandstone, sandy shale, and carbonaceous clay, probably about 200 feet thick. Above this series is about 100 feet of greenish shale and thin calcareous sandstone containing an 11-foot bed of bituminous coal overlain by 10 feet of lavender-gray plant-bearing clay. This coal and the adjacent beds crop out in sec. 24, T. 26 N., R. 16 E. No higher beds were seen in the area, but in the northwestern part of the Bearpaw Mountains, in sec. 36, T. 29 N., R. 14 E., there are beds of similar character which contain a coal bed at about the same horizon, and above this coal there is several hundred feet of massive gray sandstone. The sedimentary floor on which the volcanic rocks rest on the outer edge of the mountains apparently also consists largely of these beds.

As described on page 80, between this formation and the underlying Bearpaw shale there are transitional beds which are similar to the beds occuring beneath the Lance at its nearest outcrop in the Blood Creek syncline, 75 miles to the southeast. Consequently there is apparently no reason why the beds overlying the Bearpaw in this region should not be called Lance, for although they are grayer and contain more sandy material and thicker coal beds than the Lance in the Blood Creek syncline, yet in many respects the formations are similar, for they both are sandstone formations and contain sandy limestone, green shale, and coal beds. The massive sandstone at the base of the formation in this area is also comparable to the massive sandstone which C. E. Dobbin,[5] of the United States Geological Survey, states is a very persistent member of the basal Lance in the Blood Creek syncline. The close similarity of these beds to the coal-bearing formation that overlie the Bearpaw shale in the Big Sandy field, at the west end of the Bearpaw Mountains, makes it appear very probable that those beds, which Pepperberg[6] and Bowen[7] called Fort Union on the basis of Knowlton's determinations of the fossil plants found in them, are also Lance.

Although the Lance is classified as of Tertiary (?) age by the United States Geological Survey, the gradual transition from the marine Bearpaw shale to the fresh-water Lance beds in central Montana indicates that there was no break in sedimentation at the end of Bearpaw time, an inference which tends to support Stanton's view[8] that the Lance is of Cretaceous age.

[5] Personal communication.
[6] Pepperberg, L. J., The Milk River coal field, Mont.: U. S. Geol. Survey Bull. 381, p. 87, 1910.
[7] Bowen, C. F., The Big Sandy coal field, Chouteau County, Mont.: U. S. Geol. Survey Bull. 541, p. 74, 1914.
[8] Stanton, T. W., Boundary between Cretaceous and Tertiary in North America as indicated by stratigraphy and invertebrate faunas: Geol. Soc. America Bull., vol. 25, pp. 341–344, 1914.

MESOZOIC STRATA.

GENERAL CHARACTER.

The 4,500 feet of Mesozoic strata present in the area include the rocks that are of most interest in connection with the subject of this report, for they form the outcropping strata over the greater part of the area and hold the best possibilities of oil. These strata consist of the Bearpaw shale, Judith River formation, Claggett shale, Eagle sandstone, Colorado shale, Kootenai formation, and Ellis formation. All except the Ellis, which is Upper Jurassic, are of Cretaceous age and form a conformable series of alternating marine and nonmarine formations. As a result of investigations by members of the United States Geological Survey and the Montana State Bureau of Mines, the extent and character of these beds throughout the greater part of Montana are well known. This information has been well summarized by Arthur Bevan.[9] Many of the Cretaceous formations show a marked change in lithology from west to east across Montana, and consequently they have been classified differently in different parts of the State, as is indicated in the following table:

Formations that crop out in the area south of the Bearpaw Mountains and their equivalents in southeastern and northwestern Montana.

<table>
<tr><th>Age.</th><th colspan="2">Southeastern Montana.</th><th colspan="2">Central Montana, including area herein described.</th><th colspan="2">Northwestern Montana.</th></tr>
<tr><td>Tertiary (?).</td><td colspan="2">Lance formation.</td><td colspan="2">Lance formation.</td><td colspan="2">Willow Creek formation.
St. Mary River formation.</td></tr>
<tr><td rowspan="8">Upper Cretaceous.</td><td rowspan="5">Montana group.</td><td>Fox Hills sandstone.</td><td rowspan="5">Montana group.</td><td rowspan="2">Bearpaw shale.</td><td rowspan="5">Montana group.</td><td>Horsethief sandstone.</td></tr>
<tr><td rowspan="4">Pierre shale.</td><td>Bearpaw shale.</td></tr>
<tr><td>Judith River formation.</td><td rowspan="2">Two Medicine formation.</td></tr>
<tr><td>Claggett shale.</td></tr>
<tr><td>Eagle sandstone.</td><td>Virgelle sandstone.</td></tr>
<tr><td rowspan="2">Colorado group</td><td>Niobrara formation.</td><td colspan="2" rowspan="2">Colorado shale.</td><td colspan="2" rowspan="2">Colorado shale.</td></tr>
<tr><td>Benton shale.</td></tr>
<tr><td colspan="2">Dakota sandstone.</td><td colspan="2">?</td><td colspan="2">?</td></tr>
<tr><td rowspan="2">Lower Cretaceous.</td><td colspan="2">Fuson formation.</td><td colspan="2" rowspan="2">Kootenai formation.</td><td colspan="2" rowspan="2">Kootenai formation.</td></tr>
<tr><td colspan="2">Lakota sandstone.</td></tr>
</table>

[9] Clapp, C. H., Bevan, Arthur, and Lambert, C. S., Geology and oil and gas prospects of central and eastern Montana: Montana Univ. Bull. 4, pp. 34-64, 1921.

The most marked change is seen in the Montana group, which in this area consists of the Bearpaw shale, Judith River formation, Claggett shale, and Eagle sandstone. Stebinger[10] and Bowen[11] have shown that the nonmarine Judith River formation and Eagle sandstone grade eastward into the marine Pierre shale, and Stebinger has also shown that the marine Claggett shale grades westward into the non-marine Two Medicine formation. These changes are obviously due to the fact that the land from which the materials were derived lay toward the west.

The formations belonging to the Montana group were first known from studies made by Meek and Hayden in 1854. As a result of further investigations by geologists in the region a controversy arose as to the age of the beds and lasted for nearly 50 years. The classification presented by Stanton and Hatcher[12] in 1905 is now generally accepted.

BEARPAW SHALE.

Underlying the beds here referred to the Lance formation is several hundred feet of shale, which Stanton and Hatcher[13] named the Bearpaw shale, because of its exposure in areas adjacent to the Bearpaw Mountains. This formation in the area mapped consists principally of steel-gray marine shale in which are many thin beds of bentonite and a few gray and dark-red calcareous concretions. At the top the shale grades upward into the Lance beds through 30 to 40 feet of dark shale and thin yellow sandstone. These beds are well exposed at the Heubchwellern ranch, on Sand Creek in sec. 5, T. 25 N., R. 17 E. At the base of the formation there is about 40 feet of bentonite and gypsiferous clay, which give the weathered surface of this part of the formation a grayish-white color.

The sea in which the Bearpaw shale was deposited marked the last and probably the most widespread transgression of the Cretaceous sea in western Montana. The calcareous concretions contain an abundant invertebrate marine fauna. Among the most common forms are *Baculites compressus*, *Baculites ovatus*, *Protocardia subquadrata*, and *Placenticeras*. Fossils of large marine reptiles are also found in the shale. A number of vertebrae found in Black Coulee, in sec. 16, T. 25 N., R. 18 E., by J. W. Foy, of Riedel, were studied by J.W. Gidley, of the United States National Museum, who states that they are the caudal vertebrae of a large species of plesiosaur. The fossils of the Bearpaw shale do not differ conspicuously from those

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

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

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

[13] Idem, p. 72.

of the Claggett shale, to which the Bearpaw is so similar lithologically as to be often mistaken for it in areas of complex structure. These shales, however, have slight differences in character which make it possible to distinguish between them. A discussion of these differences is given on pages 82–83.

The Bearpaw shale is exposed at the surface in the tracts of flat-lying rocks in the eastern half of the area mapped and in the region extending for 50 to 75 miles southeast of it. Where it is not dissected by streams it forms a sagebrush-covered plain with a gumbo soil. Adjacent to streams it weathers rapidly into badlands, in which the fresh shale is exposed in loose crumbly surfaces. In the western part of the area mapped and for 100 miles farther west the Bearpaw shale has been removed by erosion. In the eastern part of the area only the lower few hundred feet is present. The entire formation occurs only in the down-dropped fault blocks along the south flank of the Bearpaw Mountains, where its exact thickness could not be measured. But it is probably about 900 feet, if, as is reasonable to believe, the thickness is intermediate between measurements of 1,100 feet made 75 miles to the southeast and 750 feet made 100 miles to the northwest.

JUDITH RIVER FORMATION.

The Judith River formation consists of approximately 500 feet of grayish-white sandstone and gray to dark-colored sandy shale and clay. The sandstone is fine grained, contains much clayey material, and is lenticular and thin bedded. The shale and clay are carbonaceous and in places contain lenses of minable coal. Near the top of the formation in all but the southeastern part of the area there is a shell breccia which contains a brackish-water fauna made up largely of *Ostrea subtrigonalis*.

The upper 150 feet of the formation in the eastern part of the area has a rusty appearance somewhat like that of the somber beds of the Lance in the Blood Creek syncline. The rest of the formation is gray or grayish white and contains fewer lignitic beds and thicker sandstones. The Judith River formation is exposed at the surface in the tracts of flat-lying rocks in the western and extreme northeastern parts of the area, in the badlands of Missouri River and its tributaries, and in the anticline and fault-scarp ridges throughout the greater part of the area.

The formation was named by Hayden from exposures near the mouth of Judith River. The fauna of the Judith River formation is fairly well known and includes both vertebrate and invertebrate forms. Dinosaurs are conspicuous among the vertebrates, and the genera *Trachodon, Ceratops, Monoclonius, Deinodon, Palaeoscincus, Ischyrotherium, Trionyx, Emys, Crocodilus, Lepidotus, Myledaphus,* and others have been described. The invertebrate fauna consist largely of fresh-water genera, among the most common of which are *Unio*, *Anodonta*, *Sphaerium*, *Physa*, *Planorbis*, and *Goniobasis*. The oyster marl at the top is composed largely of the brackish-water form *Ostrea subtrigonalis*.

The sandstone and clay of the Judith River formation, though soft, tend to weather into hard barren surfaces, and consequently this formation produces a more pronounced badland topography than any of the others. This characteristic, together with the banded appearance of its outcrop and the abundance of carbonaceous beds and light-colored clays, makes it in most places readily distinguishable from the Lance formation and the Eagle sandstone, with which it has been sometimes confused. Its invertebrate fauna is also unlike the Eagle, as the Eagle contains few fresh-water forms. Although the Lance may contain somewhat similar forms, yet fewer fossils are found in the Lance than in the Judith River formation.

CLAGGETT SHALE.

The Claggett shale, so named by Stanton and Hatcher[14] from its exposures near old Fort Claggett, near the mouth of Judith River, consists of about 550 feet of black to brownish-gray marine shale which contains numerous beds of bentonite and a number of yellow persistent calcareous concretionary beds. At the top there is a transitional series of dark shale and thin brown sandstone, ending with a massive tan-colored sandstone 10 to 40 feet thick that contains marine fossils. At the base throughout the region there is a triple bed of bentonite. The sandstone at the top of the formation, sometimes called the *Tancredia*-bearing sandstone because of the occurrence in it of the bivalve *Tancredia americana*, was mapped with the Judith River formation, as it constitutes with that formation a topographic unit distinct from the rest of the Claggett. The thickness of the formation, including the *Tancredia*-bearing sandstone member, appears to range in this area from 450 to 650 feet, but as most of these measurements were made in localities of steeply dipping strata the variation is probably due to the flow of these beds under compression. In some places the beds are almost entirely squeezed out, and it is probable that in some parts of the folds they have been thickened, so that it seems reasonable to consider 550 feet their average thickness. In the complex faulted area it is difficult to distinguish between the Claggett and Bearpaw shales and therefore difficult to determine the structure. The shales, however, have slight differences in character, which makes it possible in most places to distinguish between them. These differences are as follows: The Bearpaw shale, where well exposed, has commonly a steel-gray color, whereas the Claggett shale has a brownish

[14] Op. cit., p. 62.

cast. The most marked distinction is in their concretions. Those in the Bearpaw are not confined to definite beds, are gray and dark red, and on weathering crumble into small fragments; those in the Claggett are persistent beds 1 to 2 feet thick, occurring at intervals of approximately 50 feet in the upper part of the formation, are brownish yellow, and weather out in large slabs or boulders. In the absence of concretions in the lower part of the Claggett the triple-bedded zone of bentonite at its base furnishes a means of distinguishing this part of the formation from the basal Bearpaw, which contains only a single bed of bentonite. The Bearpaw also has a greater content of gypsum and weathers into a gumbo soil to a greater extent than the Claggett shale. The vegetation supported by the two formations is consequently different. Greasewood is more common on the Bearpaw than on the Claggett, and a small reddish weed 2 to 3 inches high, commonly known as ink weed, entirely covers many gumbo areas in the Bearpaw but is seldom seen in the Claggett. Outcrops of the Claggett are found in areas of flat-lying rocks west of Judith River and Ship Creek and east of these streams where the strata have been highly folded and faulted. In such places its weathered outcrop forms an area of low relief.

EAGLE SANDSTONE.

The Eagle sandstone, so named by Weed[15] from its outcrops along Missouri River at the mouth of Eagle Creek, consists of 220 to 300 feet of medium-grained white and yellow sandstone. The lower part is a hard massive bed; the upper part is usually much softer and contains in many places in the western part of the area sandy and carbonaceous shales and minable beds of coal. The lower part weathers into prominent sandstone ridges and vertical cliffs along Missouri River in the western part of the area and forms the "rock walls" noted by Lewis and Clark in their exploration of the sources of Missouri River in 1806. Its prominent exposures near Virgelle, in the western part of the area, led Bowen[16] to name it the Virgelle sandstone member. In that locality this lower member has a milky-white color. East of Judith River and Birch Creek it is brownish yellow, and the upper bed, which is grayish yellow farther west, has a grayish-white color. The white color of the upper member and buff color of the lower member continue eastward to Cat Creek. The upper part of the Eagle in all areas where it was examined, except on the southwest flank of the Little Rocky Mountains, contains conglomerate beds from 1 to 2 feet thick, consisting of highly polished pebbles that range in size

[15] Weed, W. H., U. S. Geol. Survey Geol. Atlas, Fort Benton folio (No. 55), p. 97, 1899.

[16] Bowen, C. F., The stratigraphy of the Montana group: U. S. Geol. Survey Prof. Paper 90, p. 97, 1914.

from small granules to pebbles 1 inch or more in diameter, the larger ones occurring in the western part of the area. In shape these pebbles are round to oval and and somewhat flattened. They occur in a matrix of fine clay and also scattered along bedding planes of the sandstone. In some areas they were found in the lower part of the overlying Claggett shale. The pebbles are composed largely of quartzite and chert and are black, blue, light brown, and green. They may be derived from the Belt rocks of western Montana. These pebbles in the Eagle sandstone have a widespread distribution in Montana, having been noted by Stebinger as far north as Milk River and by Hancock as far south as the Hailstone Basin. Wherever present they are a useful means of identifying the Eagle, for in areas of poor exposures these pebbles can be seen in the sandy soil into which the formation weathers. The Eagle sandstone is exposed for many miles along Missouri River west of the mouth of Arrow Creek and farther east in areas where the strata are highly folded and faulted. In such areas it forms sandstone ridges and narrow hogbacks. No sharp line can be drawn between the Eagle sandstone and the underlying Colorado shale, for the Colorado grades up into the Eagle through a transitional series of sandstone and shale 100 to 200 feet thick, indicating that the change from shale to sand deposition was gradual. The boundary between the two formations was drawn at the top of this transitional zone, as this horizon marks the most abrupt change in lithology and is also at the boundary between two topographic units. The massive sandstone at the base of the Eagle is probably of marine origin in the eastern part of the area, but toward the west it is probably of fresh or brackish water origin. The beds in the upper part of the formation were probably deposited near the shore of a shallow sea, as they consist of intercalated marine and fresh-water deposits.

The following sections of the Eagle give in more detail the character of the beds in various parts of the area:

Sections of the Eagle sandstone.

Two Calf Creek, sec. 34, T. 22 N., R. 21 E.

	Feet.
Shale and bentonite (Claggett shale).	
Sandstone, grayish white, well bedded, the beds about 10 feet thick and showing a slight irregularity in bedding	70
Shale, carbonaceous	3
Sandstone, massive, medium grained, yellowish at base, grading upward into a white sandstone	80
Shale, carbonaceous	1
Sandstone, dirty yellow, medium grained	10
Clay, blue	1
Sandstone, dirty yellow, with zones of brownish-yellow ferruginous concretions	35
Shale, blue, sandy (Colorado shale.)	
	200

Cow Creek, sec. 4, T. 25 N., R. 21 E.

	Feet.
Shale and bentonite (Claggett shale).	
Clay, dark blue, sandy, containing in its upper part scattered black shiny pebbles one-fourth to one-half inch in diameter...	40
Sandstone, hard, flaggy, coarse grained, with numerous plant impressions	1
Sandstone, argillaceous, bluish gray, regular to cross-bedded, with fine laminations of dark sandy carbonaceous shale, weathering yellow	30
Sandstone, massive, grayish white, cliff forming	90
Sandstone, carbonaceous and ferruginous	1
Sandstone, massive, buff	10
Sandstone, massive, buff, with a few ferruginous concretions and thin lentils of coal	20
Sandstone, buff, interbedded with ferruginous beds and thin laminations of dark-blue sandy shale	30
Shale, bluish gray, sandy (Colorado shale).	
	222

Birch Creek, sec. 6, T. 24 N., R. 16 E.

	Feet.
Sandstone, thin bedded, shaly, with black pebbles and cone-in-cone structure	10
Sandstone, dirty yellow, thin bedded, with channel lenses 1 to 1½ feet thick and 10 feet long; contains thin streaks of coal and few scattered pebbles	12
Sandstone and clay, thin, regularly interlaminated beds 2 to 10 inches thick, with scattered black pebbles in upper part	10
Sandstone, dirty yellow	10
Clay, sandy and carbonaceous	1
Sandstone, yellow, finely laminated, laminations irregular to cross-bedded	12
Sandstone, yellowish, carbonaceous	5
Sandstone, dirty yellow, well bedded; beds 2 to 12 inches thick, interbedded with thin layers of carbonaceous shale 1 to 2 inches thick	10
Shale, sandy, carbonaceous	10
Clay, sandy, gypsiferous, containing ferruginous concretions	10
Sandstone, soft, coarse grained, grayish yellow	10
Shale, carbonaceous	3
Sandstone, yellow, carbonaceous	4
Sandstone, massive, cliff forming, yellowish gray, uniformly angular, medium grained; contains numerous dark minerals	40
Shale, carbonaceous	1
Sandstone, interbedded with dark clayey shale; sandstone beds dirty yellow, 2 to 6 feet thick, and finely laminated	20
Sandstone and shale, about half and half, beds finely laminated and 6 to 12 inches thick	20
Sandstone and shale, interbedded with thin laminations of dark shale	20
Shale and sandstone (Colorado shale).	
	208

Missouri River, sec. 24, T. 24 N., R. 13 E.

	Feet.
Claggett shale.	
Clay, sandy and carbonaceous, containing pebbles	20
Sandstone, soft, dirty yellow	8
Shale, carbonaceous	4
Coal	2
Shale, carbonaceous	1
Sandstone, massive white, cliff forming	100
Blue sandy shale (Colorado shale).	
	135

COLORADO SHALE.

Below the Eagle sandstone there is about 1,800 feet of dark-blue marine shale, which contains many persistent beds of concretions, sandstone, limestone, and bentonite. This formation is the Colorado shale. The top part consists of a series of 100 to 200 feet of bluish-gray shale and thin beds of sandstone, marking a transition between the deposition of the marine shale and that of the overlying Eagle sandstone. Below this series there is about 550 feet of shale in which occur thick beds of bentonite and a sandy zone about 15 feet thick near the middle. These beds overlie a concretionary series about 300 feet thick, beneath which is the Mowry shale member, consisting of 75 feet of thin-bedded fine-grained sandstone and shale, containing fish scales. Below the Mowry there is 600 to 700 feet of dark-blue shale, which near the middle contains a conglomeratic sandstone and at the base 30 to 40 feet of sandy shale. The sandy shale is underlain by the red shale that forms a widespread feature of the upper part of the Kootenai formation of the region.

The lower part of the Colorado shale is not exposed in the area mapped but crops out on the flanks of the Little Rocky Mountains and in the east end of the Bearpaw Mountains. Small exposures of the upper part of the formation occur in the complex folded and faulted areas and in the flat-lying rocks along Missouri River west of the mouth of Arrow Creek. The outcrops of the shale differ in appearance from the Bearpaw and Claggett by their dark-blue color and their tendency to weather with hard surfaces, unlike the loose crumbling surfaces of the Bearpaw and Claggett outcrops. The concretions of the Colorado also are unlike those of the other shale formations, as they contain a greater variety of colors. Paleontologically, the Colorado can be readily distinguished from the shales of the Montana group. According to Stanton,[17] some of the most common species of the Colorado invertebrate fauna are *Inoceramus labiatus, I. umbonatus, I. exogyroides, Scaphites warreni, Pholadomya papyracea, Scaphites ventricosus,* and *Baculites asper.*

The Colorado shale was deposited during the first widespread incursion of the Cretaceous sea in the region, and apparently similar con-

[17] Stanton, T. W., and Hatcher, J. B., op. cit., p. 11.

ditions of deposition existed throughout most of Montana, for the formation does not vary much in character and thickness over the entire region. No evidence that there was a shoaling of the lower Colorado sea in central Montana, as Billingsley[18] has suggested, was observed in this area. Many of the members and concretion beds are apparently continuous as far south as Wyoming and serve as useful key beds to the oil geologist and as horizon markers to the stratigrapher in correlating the different parts of the Colorado with their equivalents in Wyoming.

The following section, measured in the southeast corner of T. 25 N., R. 23 E., gives the character and sequence of the beds of the Colorado shale in detail and is probably characteristic of the Colorado in the entire area mapped:

Section of the Colorado shale on the southwest flank of the Little Rocky Mountains, in T. 25 N., R. 23 E.

		Feet.
1.	Transitional beds consisting of interbedded and finely laminated blue sandy shale and shaly sandstone	100
2.	Shale, blue, sandy at top; contains bentonite beds	115
3.	Limestone, sandy; weathers into small shelly fragments	5
4.	Bentonite; forms a hogback with yellow soil	10
5.	Shale, bluish black	200
6.	Sandy concretionary zone containing thin beds of coarse-grained sandstone and gray calcareous concretions interbedded with blue shale	20
7.	Shale, blue-black	310
8.	Gray concretionary zone; blue shale containing two or three gray concretionary beds	40
9.	Bentonite	10
10.	Yellow concretionary zone; blue shale, with sulphur laminations and three yellow concretionary beds 1 to 2 feet thick	60
11.	Red concretionary zone; clay containing red ferruginous concretions	10
12.	Shale, blue	30
13.	Sandstone, thin bedded, calcareous and fossiliferous; weathers in small yellow fragments	15
14.	Bentonite	5
15.	Sandstone, thin bedded and calcareous, with fossil marl 1 foot thick at base, containing *Exogyra columbella*, *Callistra orbiculata*, *Pseudomelania*, and *Inoceramus labiatus* (Mosby sandstone member)	10
16.	Shale, bluish black	65
17.	Concretionary zone; bluish-black fissile shale containing two thin yellow concretionary beds, a bed of bentonite, and a 2-foot bed of coarse-grained sandstone	50
18.	Shale, bluish black	25
19.	Black concretionary zone; black clay containing black rounded concretions 3 to 4 inches in diameter	15

[18] Kemp, J. F., and Billingsley, Paul, Sweet Grass Hills, Mont.: Geol. Soc. America Bull., vol. 32, pp. 471–476, 1921.

		Feet.
20.	Shale, gray, papery, containing numerous fossil fish scales and one or two beds of bentonite and low-grade oil shale (Mowry shale member)	75
21.	Shale, bluish black	310
22.	Sandstone; the upper 5 feet coarse grained and ripple marked, containing plant impressions and markings that resemble worm tracks, overlying a 5-foot bed consisting largely of black smoothly rounded to flat pebbles, ranging from the size of a wheat grain to half an inch in diameter. Lower part consists of 15 feet of shaly, irregularly bedded sandstone containing thin partings of shale and sandy shale. Occurs at about the horizon of the Muddy sand of Wyoming	25
23.	Shale, bluish black	230
24.	Shale, black, containing thin partings of sandstone with black shiny ripple-marked surfaces on which are markings resembling worm tracks	40
		1,770

In the above section the Mosby sandstone (No. 15) and the Mowry shale (No. 20) are the most conspicuous members, lithologically and topographically. The Mosby sandstone member, so named by Lupton[19] because it forms prominent outcrops near Mosby post office, in the Cat Creek anticline, can be identified in most areas in central Montana by the shell breccia occurring at its base, composed almost entirely of *Exogyra columbella*, *Callistra orbiculata*, and *Pseudomelania*. In many areas in the eastern part of the Bearpaw Mountains the upper part of the member contains many fossils of *Inoceramus labiatus*, a common form of the Greenhorn limestone of the Black Hills region. The Mosby member is present in many of the anticlinal areas of central Montana, where it is the first prominent ridge-making bed within the Eagle sandstone escarpment. In most areas it is a very calcareous sandstone, but in the east end of the Bearpaw Mountains it is a petroliferous limestone.

The Mowry shale is readily recognizable because it weathers into conspicuous grayish-white surfaces and because it contains many fish scales. Where the writer has seen it the Mowry in central Montana consists principally of very fine grained sandstone interlaminated with thin partings of dark shale ranging from one-sixteenth of an inch to an inch in thickness. In certain zones, especially near the top and bottom of the member, the sandy material predominates and 5 to 10 foot beds of clayey sandstone are present; in other zones the clay material predominates and shale, some of it low-grade oil shale, occurs. A bentonite bed also occurs near the top of the member. The Mowry shale member is found at about the same horizon in the

[19] 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, p. 263, 1921.

Colorado shale throughout Montana, Wyoming, and parts of Colorado and retains in this entire area more or less the same characteristics. The minerals in the sandy phases consist principally of fine-grained quartz and feldspar, having an average diameter of 0.05 millimeter. Small amounts of biotite and other dark minerals are also present. The quartz and feldspar grains are very angular, showing almost no rounding. The abundance of quartz and the absence of glassy material indicate that the bed is not an accumulation of volcanic ash blown seaward, as its widespread extent suggests. The presence of fine laminae of shale and of fish scales and the unvarying fineness of its material, both vertically and laterally, indicate that it is not a near-shore deposit of a transgressive sea, but that it represents the deposition of materials probably washed into a shallow sea and widely distributed by wave and current action. The angularity of the grains in materials that have been transported for such long distances can be attributed to their small size, which is below the limits at which water-borne sediments are rounded.[20] The question why the conditions which brought about the accumulation of such deposits prevailed for a period and then disappeared is more difficult to answer and will not be considered here.

Other good horizon markers are the red concretionary zone (No. 11) about 60 feet above the Mosby and the conglomeratic sandstone (No. 22) about 300 feet below the Mowry. The red conglomeratic zone usually weathers into low hogbacks that are covered with lumps and small fragments of the red concretions, whose color distinguishes them from any other concretions in the Colorado shale. The sandstone in the lower part of the Colorado shale is easily recognized because it is the only sandstone occurring in a series of 600 feet of shales and it contains pebbles in its upper part very similar to those of the Eagle sandstone except for their smaller size. This sandstone is widely distributed throughout Montana and occurs at about the horizon of the Muddy sand of Wyoming.

There are other easily recognizable beds in the Colorado shale, which, though individually persistent, are repeated at a number of horizons and are therefore harder to identify. The numerous concretionary layers in the series of 400 feet of shale overlying the Mowry present an interesting example of persistency of individual beds and wide variation of form and color among the beds. They range from beds in which the concretionary tendency can scarcely be detected to typical concretionary masses occurring in clay strata. In color they range from light gray to brownish yellow, brick-red, and bluish black. The thickness of the individual beds is rarely greater than 2 feet,

[20] References to the literature on the subject of the limits in size at which grains of different minerals are not rounded by water and wind are given by M. I. Goldman (The origin of the Catahoula sandstone of Texas: Am. Jour. Sci., 4th ser., vol. 39, pp. 271-273, March, 1915).

although Nos. 11 and 19 of the section on page 87 occupy zones 10 and 15 feet thick. The concretions of these zones are also exceptions to the usual yellow and gray colors. Furthermore, they contain less calcite than the others, which are composed almost entirely of calcite. Many of these gray and yellow beds show a fibrous and cone-in-cone structure in their upper parts. Some of them weather out in hollow masses in which the cavities are partly filled with black and light-yellow calcite. The persistency of these concretionary beds along definite zones and the fact that they are interbedded with and grade into thin calcareous sediments such as members Nos. 3 and 15 in the stratigraphic section make it appear probable that all the concretionary beds are of syngenetic origin—that is, they were formed during the deposition of the sediments and are not due to growth by the segregation of material from the rocks after their deposition. Tarr[21] thinks that such concretions may be the result of a precipitation of the calcium carbonate present in the sea in which the sediments were deposited, the precipitation occurring at a slower rate than when limestone beds are formed. The different colors in the concretions may be due to the presence of varying amounts of iron hydroxide.

As commonly used in Montana, the term Colorado shale includes the dark marine shale lying between the Virgelle sandstone and the red shale occurring at the top of the Kootenai formation. This series has been regarded as equivalent to the Niobrara, Carlile, Greenhorn, and Graneros of the Black Hills region and to the Niobrara, Carlile, Frontier, Mowry, and Thermopolis of northern Wyoming. In the adjoining Little Rocky Mountains area Collier[22] subdivided these shales into the Warm Springs, Mowry, and Thermopolis formations, including in the Warm Springs all the beds between the Mowry and the Virgelle sandstone. It is probable that with a few more paleontologic data the Colorado shale in central Montana can be subdivided into the units recognized in the Wyoming section. But it is doubtful if any but arbitrary boundaries can be drawn between these subdivisions, or if such boundaries would be useful in mapping the beds.

In Plate XI a series of sections of the Colorado is shown extending southward across central Montana and correlated with the Soap Creek stratigraphic section, which W. T. Thom, jr., has correlated tentatively with the typical section of northern Wyoming. The members used in correlating the central Montana sections with the Soap Creek section are the topmost concretionary bed, the red concretionary beds, and the Mowry shale. The Mosby sand of the central Montana section appears to have an equivalent in the Soap Creek section which con-

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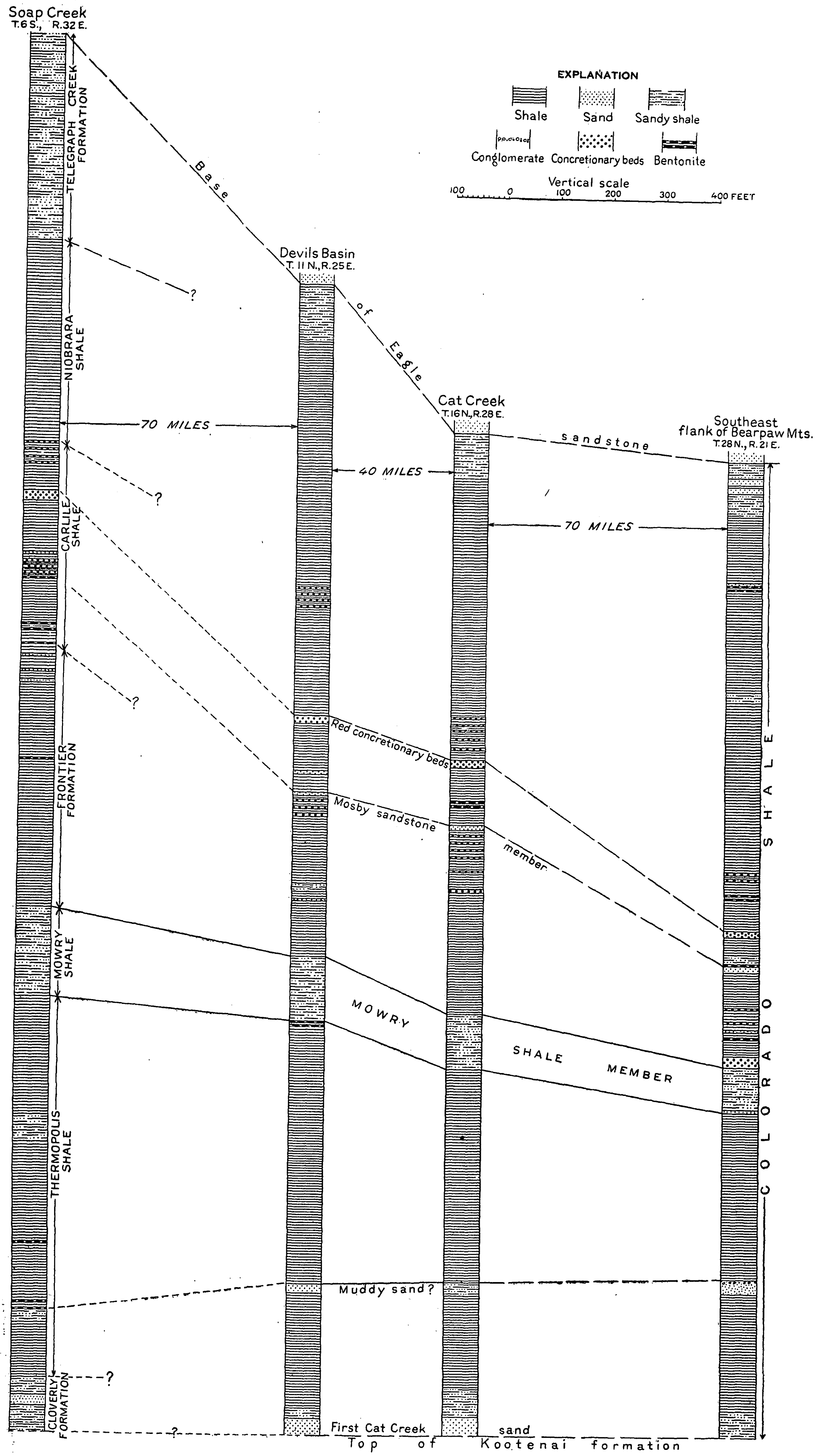
[21] Tarr, W. A., Syngenetic origin of concretions in shale: Geol. Soc. America Bull., vol. 32, pp. 373–384, 1911.

[22] Collier, A. J., and Cathcart, S. H., Possibility of finding oil in laccolithic domes south of the Little Rocky Mountains, Mont.: U. S. Geol. Survey Bull. 736, p. 172, 1922.



THE COLORADO SHALE IN NORTHERN AND CENTRAL MONTANA AND EQUIVALENT BEDS IN SOUTHERN MONTANA.

tains a fauna similar to that of the Greenhorn limestone of the Black Hills region. The abundance of *Inoceramus labiatus* in the Mosby in the area mapped is a further indication that this is the proper correlation, because that species is also common in the Greenhorn limestone.

According to this correlation the beds in central Montana between the Eagle sandstone and the top of the concretionary zone are equivalent to the Telegraph Creek and Niobrara formations of the Soap Creek section, and all the concretionary beds above the Mosby sand are equivalent to the Carlile, and the beds between the Mosby and the Mowry shale are equivalent to the Frontier formation. The beds designated Mowry member in the several sections are probably equivalent, but the beds below the Mowry, generally referred to the Colorado in central Montana, probably include more than the Thermopolis of the Soap Creek area, because in that area the sandy shale and sandstone in the top part of the Cloverly are very similar in character to the sand occurring at the base of the Colorado shale in the Cat Creek field and other areas in central Montana, and as both overlie red shales, it is very probable that they represent equivalent beds.

Some geologists have included this sand (the first Cat Creek sand) in the Kootenai formation, but Fisher,[23] Calvert,[24] and Barnett[25] in their work in central Montana placed the top of the Kootenai at the top of the red shales that are of widespread occurrence in Montana and at the bottom of a rusty-colored thin-bedded shaly sandstone which is undoubtedly the equivalent of the first Cat Creek sand, for it has the same peculiar characteristics as that sand and, like it, overlies a series of 100 to 200 feet of red shale.

Thus, if the usage of the earlier workers in the field is followed, the first Cat Creek sand is to be included in the Colorado shale. Good reasons for not including it in the Kootenai were obtained by the writer in his studies of the Colorado shale on the southeast flank of the Bearpaw Mountains, for there the equivalent of the first Cat Creek sand is represented by a series about 40 feet thick consisting of lenses of sandstone, 5 to 10 inches thick, interbedded with bluish-black shale that is identical in appearance with the overlying Colorado shale and entirely dissimilar to the underlying Kootenai red and green shales. The sandy material is also very unlike the sandstone of the Kootenai and similar to the sandstone occurring 250 feet above it, which has the same ripple-marked and fucoidal surfaces that are everywhere characteristic of the first Cat Creek sand.

As the first Cat Creek sand, therefore, has been commonly included in the Colorado shale in central Montana, it follows that the Colorado

[23] Fisher, C. A., Geology of the Great Falls coal field, Mont.: U. S. Geol. Survey Bull. 356, p. 32, 1909.
[24] Calvert, W. R., Geology of the Lewistown coal field, Mont.: U. S. Geol. Survey Bull. 390, p. 29, 1909.
[25] Barnett, V. H., Geology of the Hound Creek district of the Great Falls coal field, Cascade County, Mont.: U. S. Geol. Survey Bull. 641, p. 223, 1917.

shale as delimited in that area contains at its base beds that are very probably equivalent in part to the Dakota sandstone of the Black Hills region, for the character and stratigraphic position of the sandstone at the top of the Cloverly in the Soap Creek field indicate that it is equivalent both to the first Cat Creek sand of central Montana and to the Dakota sandstone of the Black Hills region, and the logs of wells drilled between Cat Creek and the Black Hills region indicate that the Dakota is continuous across that area. It is possible that the conglomeratic sandstone occurring about midway between the Mowry shale and the first Cat Creek sand, together with the shale beneath it, may also prove to be Dakota, for this sandstone is very widespread and in its stratigraphic position and character is similar to the Muddy and Newcastle sands of Wyoming, and these Stanton[26] thinks are equivalent to the upper Dakota of central Wyoming.

KOOTENAI FORMATION.

The Kootenai formation in this area, as elsewhere in Montana, consists mainly of a series of variegated shales and lenticular sandstones with some thin beds of siliceous limestone and a coaly shale. The following section measured on the southeastern flank of the Bearpaw Mountains gives the character of the Kootenai in detail:

Section of Kootenai formation at the head of Suction Creek, in sec. 1, T. 28 N., R. 20 E.

	Feet.
Sandstone, thin bedded, shaly, gray to black, and ferruginous.	15
Shale, red and green, with thin beds of sandy shale	50
Shale, red, with lenses of sandstone	85
Limestone, fine grained, sandy	3
Sandstone, gray (approximate horizon of second Cat Creek sand).	5
Limestone, black, petroliferous, containing fragments of small pelecypod shells	4
Shale, gray to green	10
Limestone, light gray, specked with brown spots and full of fossil fragments; weathers in small pieces with milky-white surfaces.	10
Shale, dark, and thin beds of sandstone	10
Sandstone, coarse grained (approximate horizon of third Cat Creek sand)	25
Shale, dark	20
Sandstone, thin bedded and ferruginous	10
Shale, dark and carbonaceous	3
Unexposed	10
	260

This section, although thinner, is similar to those of the Kootenai formation in other areas of central Montana in that it has red shale in the upper part and coarse-grained sandstones in the lower part,

[26] Stanton, T. W., Some problems connected with the Dakota sandstone: Geol. Soc. America Bull., vol. 33, pp. 265–266, 1922.

overlying a carbonaceous shale. These sandstones are approximately equivalent to the second and third Cat Creek sands, and the dark shale probably represents the horizon at which the coal occurs in the Lewistown and Great Falls coal fields. About 10 feet beneath this shale typical Ellis fossils were found. In some localities 100 to 200 feet of variegated shale and sandstone are present between this coal bed and the top of the Ellis. These beds have been doubtfully correlated with the Morrison formation. The variation in the thickness of these beds in the region in general and their absence in this locality suggest that there is an unconformity between the Kootenai and Ellis.

ELLIS FORMATION.

About 310 feet of beds belonging to the Ellis formation, of Upper Jurassic age, underlie the Kootenai in the east end of the Bearpaw Mountains. The upper two-thirds of the formation consists of black and brown limy petroliferous shale and the lower 75 feet of hard thin-bedded blue to black fossiliferous and petroliferous limestone. The limy shale at the outcrop forms conspicuous gray to brown barren surfaces, over which are strewn many fossils of *Gryphaea calceola,* an oyster-like form with a curved beak, and *Belemnites densus,* a cigar-shaped shell. These fossils are characteristic of the Ellis throughout Montana. The lower limestone bed, being harder than the overlying limy shale, weathers into more pronounced topographic forms, forming precipitous bluffs and narrow canyons. From a collection made from this basal limestone, the following forms were identified by T. W. Stanton:

Ostrea strigilecula White.
Camptonectes pertenuistriatus Hall and Whitfield.
Gervillia? sp.
Astarte sp.
Cerithium? sp.

The following section of the Ellis formation measured on the southeastern flank of the Bearpaw Mountains shows the character of the Ellis in detail. The numerous sills of igneous rock 10 to 40 feet thick that are intruded into the beds are excluded from the section.

Section of Ellis formation at the head of Birch Creek, in sec. 1, T. 28 N., R. 20 E.

	Feet.
Shale, brown, limy	50
Limestone, dark, shaly	18
Shale, drab, limy, petroliferous	20
Limestone, drab, thin bedded, shaly	10
Shale, limy, petroliferous, with thin beds of limestone. Beds weather into grayish-white barren outcrops on which occur many fossils of *Gryphaea calceola* and *Belemnites densus*	90
Shale, yellowish gray, limy	30

	Feet.
Limestone, brownish gray; contains numerous fossils of *Gryphaea* and *Belemnites*	10
Shale, brownish gray	10
Limestone, hard, black, finely laminated, lamination wavy and crenulated, probably of algal origin	2
Limestone, hard, blue to black, petroliferous, thin bedded, beds 6 inches to 6 feet thick; top part has a slight reddish tinge and is slightly siliceous, with ripple-marked surfaces. Limestone very fossiliferous	70
	310

PALEOZOIC STRATA.

In the Little Rocky Mountains an intrusion of igneous rocks in the form of a laccolith has lifted the strata 10,000 feet above their position in the surrounding plains, and as a result of erosion the formations of Carboniferous, Devonian, Ordovician, and Cambrian age, which lie several thousand feet below the surface in the plains, are exposed as steeply dipping beds surrounding a central body of porphyry. The thickest of these formations is the Madison limestone, of lower Mississippian age. It consists of 1,300 feet of massive to thin-bedded gray crystalline limestone, which forms the reef rocks that encircle the mountains. This limestone has a widespread occurrence in the Rocky Mountains, and because of its resistance to weathering its outcrop forms many of the mountain ridges. The upper 75 feet of the Madison is exposed in the southeastern part of the Bearpaw Mountains in sec. 1, T. 28 N., R. 20 E., in a tilted block adjacent to an intrusive mass. Here and in the Little Rocky Mountains it is overlain unconformably by the Ellis formation, of Upper Jurassic age. The unconformity between the Madison and the Ellis represents an interval that in southwestern Montana is occupied by several hundred feet of Triassic, Permian, and Pennsylvanian strata. The absence of the Chugwater formation, mainly of Triassic age in this region, is probably due to nondeposition, for these beds appear to thin toward the northeast across Wyoming and are absent in the mountain uplifts of central Montana, but the absence of beds of Permian and Pennsylvanian age is probably due to erosion, for such beds are present in the mountains of central Montana, are of marine origin, and show no marked thinning toward the northeast. The strata between the Ellis and Madison in the Big Snowy, Judith, and South Moccasin mountains have been called the Quadrant formation. They are very similar lithologically to the Tensleep sandstone (Pennsylvanian) and Amsden formation (Pennsylvanian and Mississippian) of the Big Horn Mountains, but it is not yet definitely known whether the Quadrant includes representatives of these formations.

It is not known how far the Quadrant beds extend into the plains north of the Judith and South Moccasin mountains, but they may be present in the southern part of the area here considered. If present they probably consist of red and green shales, petroliferous limestone, and sandstone.

The following beds occur at the unconformity between the Madison and Ellis in sec. 1, T. 28 N., R. 20 E., on the southeastern flank of the Bearpaw Mountains.

	Ft.	in.
1. Brown laminated sandy clay		3
2. Soft sandy and limy clay	2	
3. Angular chert and limestone breccia	2	

M. I. Goldman has studied these materials and furnishes the following statement as to their character:

Bed 2, which rests on an angular limestone conglomerate at the top of the Madison limestone, appears in hand specimens as a gray argillaceous chalky limestone; as I remember it in the field some of it was quite unindurated. Under the microscope this appears as a meal of very fine angular quartz sand (about 0.08 millimeter in average diameter), disseminated through a finely granular calcite matrix in which were also disseminated minute spherules or grains, apparently of limonitic material, presumably derived from the decomposition of syngenetic sulphides.

Bed 1 consists of a peculiar dark-brown granular material with rather coarse grit grains in the lower part. Under the microscope this layer is found to be surprisingly like bed 2, differing mainly in the great amount of limonitic material disseminated all through it, to which it owes its color. Most of it seems to contain, however, instead of a fine calcite matrix, large shells or fragments of shells with angular quartz grains slightly larger than those in bed 2 (0.1–0.12 millimeter), scantily disseminated between them. In places the limonitic grains have distinctly the form of cross sections of pyritohedrons, so that the derivation of all the limonite from sulphides is pretty certain.

Bed 3 has close affinities to basal glauconite beds in that it has coarse shells and shell fragments with relatively few detrital quartz grains lying between them, and an abundance of an iron salt presumably precipitated by decaying organic matter. A large amount of sulphide is generally an associate of basal glauconite beds. The factors that made one or the other prevail are, I think, not yet known.[27] The presence of a small amount of phosphate, as indicated by a wet test, is also a point in common with glauconite beds, the phosphate being, like the sulphide or glauconite, a common product of accumulation rich in decaying organic matter.

Like basal glauconite beds, therefore, this deposit indicates an accumulation of shells and bodies of dead organisms with relatively little detrital material.

The formations beneath the Madison are chiefly of limestone material, though there is at the base a quartzite conglomerate of Cambrian age. These limestones have a fetid odor and may be regarded as a possible source of oil. They are generally dense and crystalline, but fissuring and solution channels in them may act as reservoirs for oil.

[27] See Goldman, M. I., Petrograhy and genesis of the sediments of the Upper Cretaceous of Maryland: Maryland Geol. Survey, Upper Cretaceous, pp. 171, 177–178, 1916; Basal glauconite and phosphate beds: Science, Aug. 11, 1922, pp. 171–173.

The sequence and character of all the Paleozoic rocks are shown in the table on page 75.

IGNEOUS ROCKS.

Numerous small outcrops of igneous rocks occur within the area mapped, most commonly near the Bearpaw Mountains and in the western part of the area. All these rocks are intrusive and of Tertiary age. It is probable that they were intruded into the strata before the faulting and folding took place, because most of the exposures are in the areas of flat-lying strata, and it is thought that if the intrusions had occurred during or after the faulting the igneous material would have been injected into the fractured and folded strata. The most common types of intrusions are dikes and volcanic necks. Chonoliths and sills are also common, and two small laccoliths occur near the Bearpaw Mountains. No detailed petrographic study of these rocks has yet been made, but most of them are black and appear to consist of the same minerals, in which biotite appears to be the most abundant. They range in texture from fine-grained to coarsely crystalline rocks, and the latter consist largely of flakes of biotite. These rocks resemble minettes in the Highwood Mountains described by Weed and Pirsson and those in the Sweet Grass Hills described by Kemp. Because of the close similarity of the rocks and for other reasons, it is thought that they were derived from the magma which formed the intrusive bodies in the central part of the Bearpaw Mountains. In the faulted area only the larger intrusive masses have produced any noticeable metamorphism of the intruded strata, and the metamorphism of the strata around these is very slight. Within the mountains, however, the metamorphic action of the intrusive bodies is much more pronounced, the sedimentary rocks having been altered and hardened for considerable distances.

The dikes are usually from 2 to 4 feet in thickness and vary greatly in length, some of them being several miles long. The longest occur near the Bearpaw Mountains and radiate from them. The volcanic necks are circular bodies, 50 to 100 feet in diameter, some composed of fine-grained rock and others of granular material. Both textural types are rich in biotite. The fine-grained rocks weather as rock pinnacles, which form prominent landmarks, and the coarse-grained rocks weather to circular depressions. No extrusive rocks were seen around the necks, but as the extrusives of the Bearpaw Mountains are known to weather very rapidly, any that may have been poured out have probably been removed by erosion. Another intrusive form common in the area is one that might properly be called a chonolith. These are very irregular in shape and range from small masses a few feet in diameter to some several hundred feet thick. The strata into which they are intruded do not appear to be thrust aside but are partly included within the magma as broken fragments. Sills are common in the western part of the area near Eagle Butte and were noted at a few places in the northern part of the area. Farther north, within the mountains, they occur in great numbers where the sedimentary strata are exposed beneath the extrusives. Two sills that have laccolithic proportions were mapped in sec. 23, T. 27 N., R. 20 E., and in secs. 7 and 8, T. 25 N., R. 18 E. In the eastern part of the area, in sec. 21, T. 25 N., R. 23 E., and secs. 3 and 10, T. 24 N., R. 23 E., there are two circular domes which were probably produced by laccolithic offshoots of the Little Rocky Mountain intrusive mass. In the western part of the area, about midway between the Bearpaw and Highwood mountains, the sedimentary strata are intruded by numerous dikes and sills and other large intrusive bodies. Some of these form high buttes, which are prominent features of the landscape. The largest of these buttes, known as Eagle Butte, in sec. 13, T. 24 N., R. 13 E., consists principally of a black rock with a fine-grained groundmass in which are large phenocrysts of biotite and olivine. In the upper part of the butte there is a fine-grained grayish-white syenitic rock. The character of the intrusive bodies forming these buttes was not definitely determined. They have the appearance of stocks, but they may be small laccoliths. The larger intrusive bodies in this area are shown on the map, but no attempt was made to map all the numerous dikes and sills.

STRUCTURE.

THE FAULTED BELT SURROUNDING THE BEARPAW MOUNTAINS.

EXTENT AND TREND OF THE FAULTS.

The area considered in this report comprises the southern half of a belt of thrust faults which appears to surround or nearly surround the Bearpaw Mountains. The outer margin of this belt is 25 to 30 miles distant from the flanks of the mountains and about 48 miles from the center of the mountains. Most of the faults, however, are confined to the outer 20 miles of the belt. It is not possible to determine whether these faults entirely surround the mountains, because the mantle of glacial drift east and west of the mountains covers the Cretaceous beds and conceals the faults if they are present. North of the mountains, however, faults similar to those on the south side have been mapped by Pepperberg[28] and Stebinger[29] in areas where Milk River and its tributaries have removed the covering of glacial till. Plate XII shows all the faults that have been mapped in the

[28] Pepperberg, L.J., The Milk River coal field, Mont.: U. S. Geol. Survey Bull. 381, pp. 60-82, 1910.

[29] Stebinger, Eugene, Possibilities of oil and gas in north-central Montana: U. S. Geol. Survey Bull. 641, pp. 49-91, 1916.

region. It will be noted that both the outer margin of the faulted belt and most of the faults themselves are distinctly circumferential in their relations to the Bearpaw Mountains.

STRUCTURE ADJACENT TO THE FAULTS.

In the areas south of the mountains, where there is little glacial drift to conceal the strata, the character of the structure is fairly evident. All the major faults in the main faulted belt are probably of the thrust type. The dip, however, of most of the fault planes is steep, being 60° to 70°, but dips as low as 15° were observed. The faults vary in longitudinal extent and displacement, ranging from those a few hundred feet long with throws of a few feet to those 20 to 30 miles long with throws of 1,200 to 1,500 feet. Most of the faults are several miles long and have throws of 1,000 to 1,600 feet. The downthrow occurs on the mountainward side of some of the the faults and the plainsward side of others, but in most of the major faults it is on the plainsward side, especially in the major faults on the outer margin of the belt. As stated previously, most of the faults are concentric to the mountains and are therefore parallel to one another. (See Pls. XII and XIII.) Some faults, however, have a trend radial to the mountains, thus intersecting the faults of concentric trend at right angles, and many of them offset the concentric faults. There are also minor auxiliary faults that meet the major faults at acute angles. Near the Bearpaw Mountains there are normal faults along which down-dropped blocks of Lance beds occur.

A noteworthy feature of the faulted belt is the flat-lying attitude of the Cretaceous strata. The regional attitude of the beds apparently has not been disturbed by the pronounced upward folding of narrow zones along the faults nor by crustal movement in the adjoining mountains except for a tilting of 1° or 2° away from the mountains. The belt of upturned strata along most of the faults is 2,000 to 3,000 feet wide and is confined commonly to the upthrown side. Figure 14, A, shows the characteristic structure along most of the faults. The dip of the beds, which is very slight near the fault, increases rapidly away from it on the upthrown side, attaining 60° to 80° at distances of 2,000 to 3,000 feet, and in some of the faults assumes an overturned position. On the downthrown side of most of the faults the strata occupy their regional position and maintain a flat-lying attitude. In places, however, they appear to be slightly dragged up along the fault plane. Rarely, except near the mountains, are the beds dropped below their regional elevation. Plate XIV shows the flat-lying attitude of the beds and the extent to which they are disturbed along the faults.

The foregoing description outlines the general character of the faults of the region, which have been observed and commented upon by a number of geologists. In fact, the faults are so conspicuous a feature of the structure that at first they seem to indicate that all the deformation of the strata should be attributed to movements along the fault planes. A critical examination of the structure, however, leads to the conclusion that its major features are due to folding produced by horizontal compression. As shown on the map (Pl. XIII), the faults are paralleled in some localities by unfaulted anticlines in which the tilting of the strata is of the same character and is confined to belts as narrow as those along the faults, and these anticlines themselves

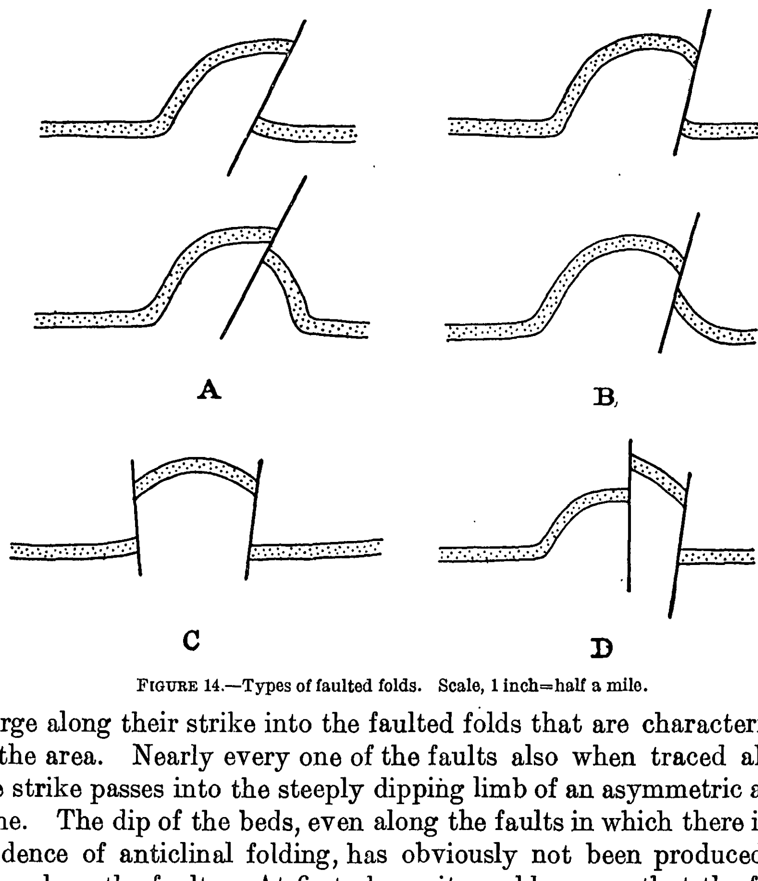


FIGURE 14.—Types of faulted folds. Scale, 1 inch=half a mile.

merge along their strike into the faulted folds that are characteristic of the area. Nearly every one of the faults also when traced along the strike passes into the steeply dipping limb of an asymmetric anticline. The dip of the beds, even along the faults in which there is no evidence of anticlinal folding, has obviously not been produced by drag along the faults. At first glance it would appear that the folds which are characterized by an inclination of the strata away from the fault on the upthrown side have been disrupted by faults along their axes, one limb seemingly having been entirely faulted down. Data to be published later will show that this does not entirely explain the feature. Some of the folds appear to be faulted along one limb, as is shown in Figure 14, B. Many of the anticlines have more complex faulted relations than those outlined above, and for further discussion of these relations it will be convenient to speak of the faults that occur along the axes of folds as axial faults, and of those along the flanks as limb faults. Some anticlines appear to be faulted along both limbs, as is illustrated in Figure 14, C, and others are cut by both axial and limb faults, as is shown in Figure 14, D. Many faults appear to change along their strike from axial to limb faults and then back to axial faults, with the result that anticlinal axes appear and disappear along the faults. This feature is illustrated in Figure 15 and typically in the field by the anticline in the central part of T. 25 N.,

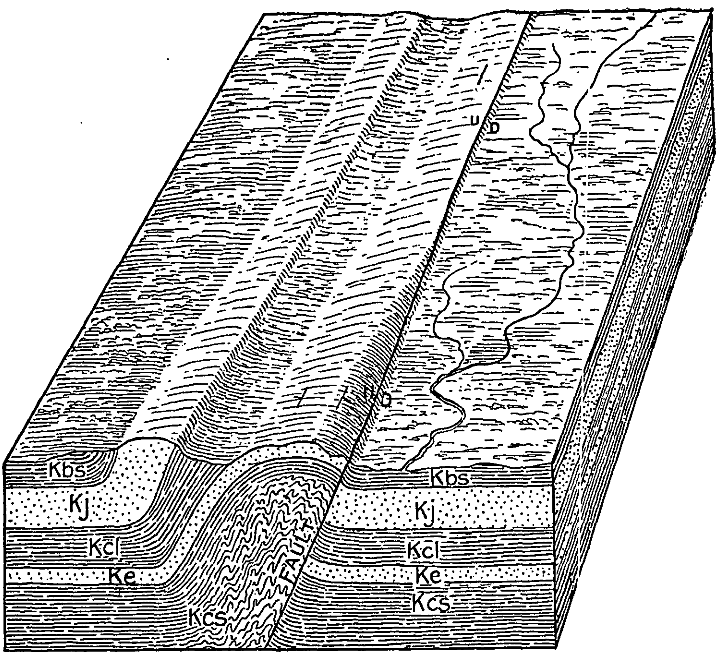
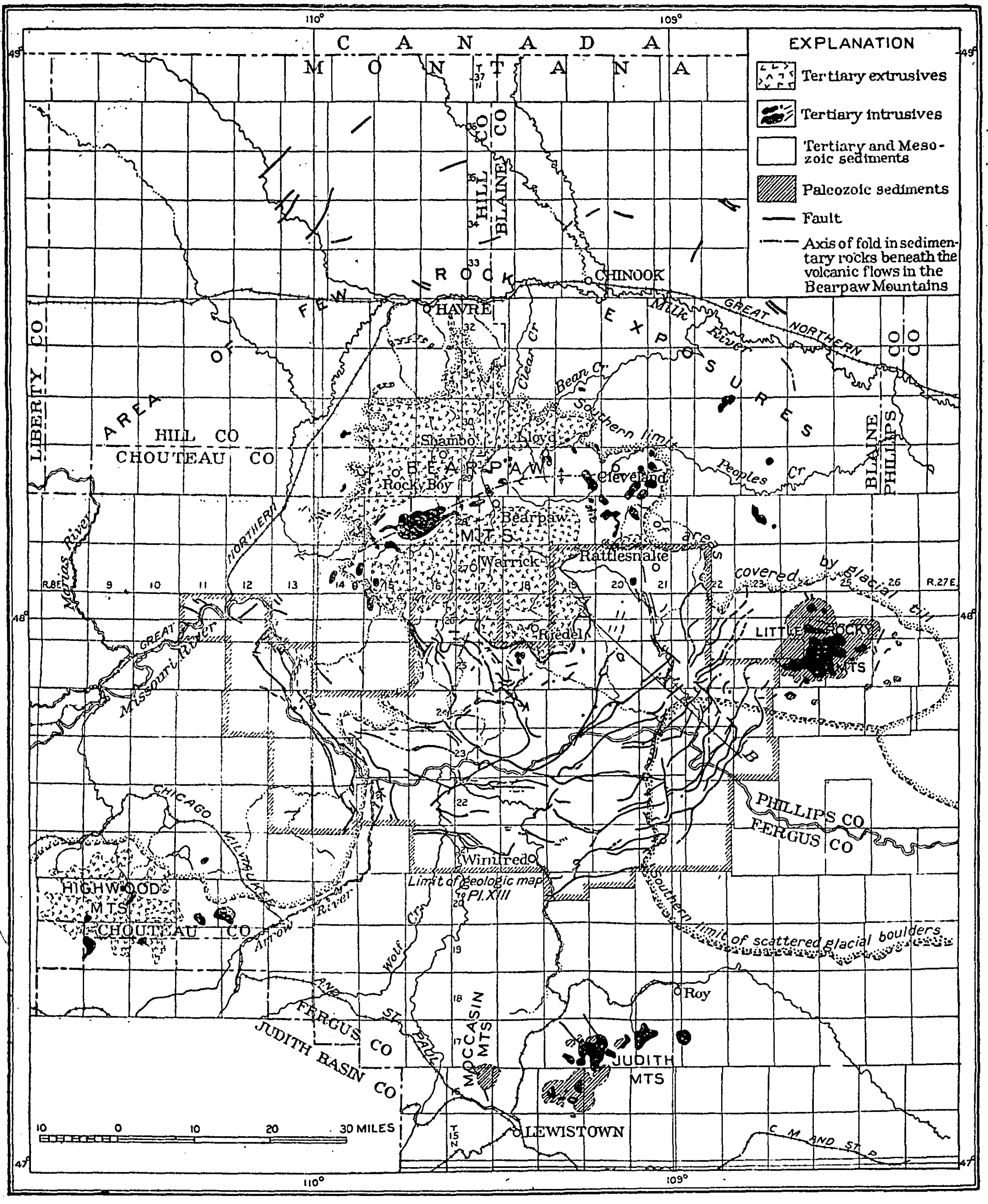


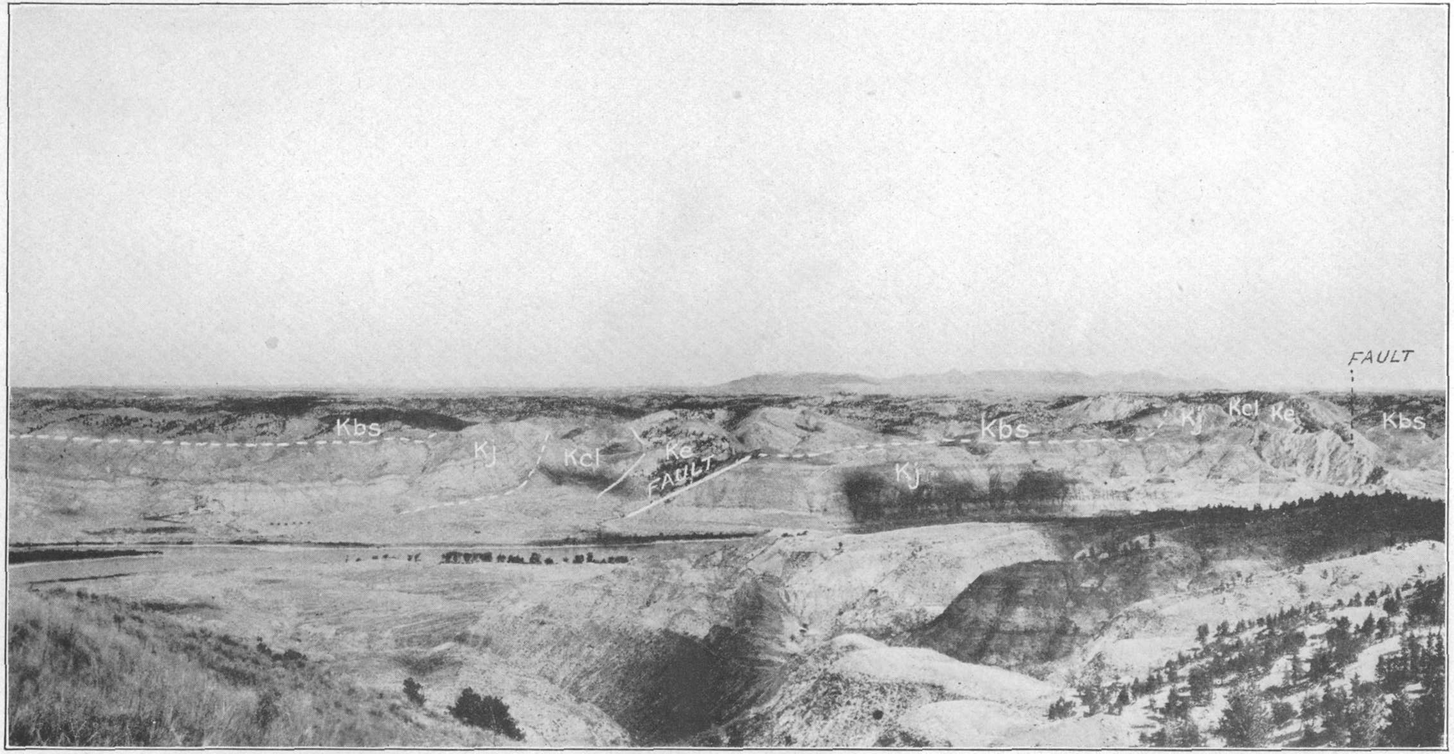
FIGURE 15.—Sketch showing the manner in which an anticlinal axis merges along the strike into a fault. For explanation of symbols see Plate XIII.

R. 17 E., and the anticlines crossing Missouri River in T. 23 N., R. 22 E.

Although most of the folds have had one or both limbs cut off by faults, yet some of the folds are almost unfaulted, being pronounced upward flexures lying between belts of regionally unfolded and unfaulted strata. (See fig. 16.) Many of these unfaulted anticlines have a width of less than 3,000 feet and a length of 5 to 10 miles, and some of them have distinctively curving axes. Few of the folds are more than a mile wide. All the flat-lying beds between the narrow anticlines may be regarded as forming synclines, but these synclines have no definite axes and are not troughs. The upward flexures in



MAP SHOWING THE EXTENT AND TREND OF THE FAULTS SURROUNDING THE BEARPAW MOUNTAINS, MONT., AND OTHER GEOLOGIC FEATURES OF THE REGION.



VIEW SHOWING TILTING OF STRATA ALONG FAULTS.

For explanation of symbols see Plate XIII.

most of the folds begin abruptly, the flat-lying strata being bent upward at sharp angles, in many places approaching vertical and overturned positions. Along the crests of the folds, on the other hand, the beds are usually inclined at angles of only a few degrees. However, the manner in which the beds have been folded varies with the character of the beds. In the soft and relatively incompetent beds of the Judith River formation the cross section of a fold shows curved lines, about as described above. In the massive and more competent Eagle sandstone the cross section of a fold commonly shows broken lines. This manner of folding along one line has resulted in the fracturing of the rock along this line, with the consequent development of faults. As a result the Eagle sandstone may be faulted where the Judith River beds in the same anticline are but sharply folded. Many of the sharp angular flexures in the Eagle sandstone also merge along the strike into faults.

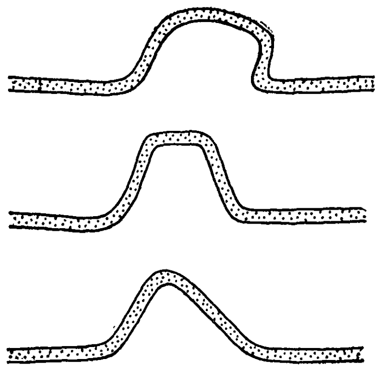


FIGURE 16.—Types of unfaulted folds. Scale, 1 inch=half a mile.

TOPOGRAPHIC EXPRESSION OF FAULTS AND FOLDS.

In the eastern part of the region mapped the Bearpaw shale overlies the Judith River formation in the areas of flat-lying strata and, being softer than the sandstone formations in the disturbed belts, is eroded more rapidly, so that the sandstones usually form ridges. If both the Eagle and Judith River formations crop out along a fault, they weather into parallel hogbacks separated by a belt of low relief, in which the Claggett shale is exposed. In the western half of the area, where sandstones of the Judith River formation are exposed in the areas of flat-lying beds and the Claggett and Colorado shales are the principal strata exposed in the faulted belts, these belts do not stand out as prominent ridges, although the Eagle sandstone there may form hogbacks.

In some localities where the fault occurs between two shale formations it has no topographic expression, and its presence can be detected only by recognizing that two formations are present and determining the line of their contact. The position of such a fault may be indicated by the presence of a sandy streak in the shale or by narrow blocks of steeply inclined sandstone strata. The faults are not accompanied by minor fractures, joints, or vein material, which in some regions occur along faults and are useful criteria for their recognition.

REGIONAL STRUCTURE.

The area under discussion lies within an extensive region of generally flat-lying Cretaceous beds, which show a slight tilting to the east. The structure of these beds apparently has not been affected by the movements in the adjacent mountain uplift except possibly for a slight inclination of less than 1° away from the mountains. Two of these mountain groups, the Judith and Little Rocky mountains, are of laccolithic origin and represent circular areas of uplift, respectively 10 and 15 miles in diameter, in the center of which igneous rocks are exposed. The Highwood and Bearpaw mountains do not have a markedly domal structure but consist principally of volcanic rocks.

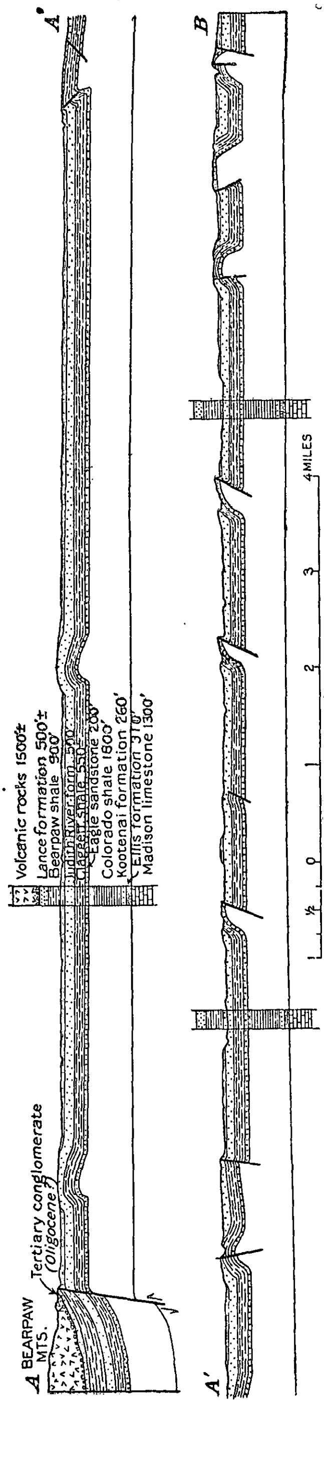


FIGURE 17.—Section showing structure of faulted belt along line *A–B*, Plate XIII.

ORIGIN OF THE FAULTS AND FOLDS.

The presence of thrust faults and pronounced anticlinal folds in the strata surrounding the Bearpaw Mountains indicates that the beds have been subjected to horizontal compression, and their definite relation to these mountains in extent and trend suggests that this force was transmitted outward from the mountains, for it is difficult to conceive that a circular area such as this could have been subjected to compression from all directions from without, and besides the strata surrounding the region apparently could not have transmitted such forces without being themselves folded or faulted. It may be suggested that the area was compressed during the formation of the adjacent mountain uplifts. But these mountains, being due either to laccolithic intrusion or to volcanic extrusion, were not produced by horizontal compression, and consequently it seems improbable that their formation could have resulted in compressing the strata adjacent to them. At any rate, to the north and southeast there are no mountain masses to have produced such forces. The compression apparently originated in the Bearpaw Mountains, but these mountains in their outward aspect do not appear capable of furnishing such a force, for they consist of a mass of volcanic rocks resting on a floor eroded across a broad dome affecting the Cretaceous strata. Yet in the manner outlined below they may have produced such a force.

If, owing to the overload of volcanic material added to the crust during the volcanic period, the Bearpaw Mountain area subsided, it is possible that the strata in the mountains, which were arched into a broad, low dome prior to the volcanic period and lengthened by the intrusion of dikes into tensional fissures, would during such subsidence themselves buckle or buckle the strata in the plains region roundabout the mountain arch. Inasmuch as the beds in the mountain area were hardened and reinforced by the widespread intrusion of dikes and sills and overlain by several thousand feet of basaltic flows, they were probably more rigid than the strata in the plains. Thus it is conceivable that the buckling stresses in this flattening arch may have been transmitted to the strata in the plains and produced the folds and faults observed there. In a later publication, which will deal with the geology of the Bearpaw Mountains, the character and origin of the structure in the faulted belt will be considered further. For the purpose of the present paper, in which the oil possibilities of the area are considered, a detailed discussion of the origin of the faults is not thought necessary.

OIL AND GAS POSSIBILITIES.

RESULTS OF DRILLING.

Four wells have been drilled for oil in the area. The following table gives their location and other information concerning them:

Wells drilled in faulted area south of Bearpaw Mountains, Mont.

Company.	Location.	When drilled.	Total depth (feet).	Remarks.
Home Oil Co	Sec. 22, T. 21 N., R. 20 E	1917–18	860	Show of gas.
Kansas Montana Oil & Gas Co	Sec. 18, T. 21 N., R. 19 E	1920–1923	3,182	Show of gas and oil.
Ohio Oil Co	Sec. 17, T. 25 N., R. 17 E	1923	2,765	Gas.
Do	Sec. 16, T. 25 N., R. 17 E	1923	2,983	Gas.

The Home Oil Co.'s well was drilled to a depth of only 860 feet and can not be considered an adequate test. A show of gas was encountered at a depth of 840 feet. The Kansas-Montana well encountered showings of oil and gas at three horizons and a considerable volume of salt water also at three horizons. The last water encountered flowed out of the well mouth and offered so great an obstacle to further drilling that the well was abandoned. The well started near the top of the Judith River formation and ended in the Colorado shale. The showings of oil and gas were obtained in the *Tancredia*-bearing sandstone member of the Claggett shale, in the Eagle sandstone, and in a sandstone about 1,400 feet below the top of the Colorado shale.

Salt water was encountered in the Eagle sandstone and in sands in the Colorado shale occurring at depths of 2,855 to 2,865 feet and 3,177 to 3,182 feet. Samples of the waters from the Colorado shale sands were collected by W. T. Brown, manager of the Kansas-Montana Oil & Gas Co., and analyzed by C. S. Howard, of the United States Geological Survey. These analyses are discussed on pages 110–111. The results obtained by this test, though somewhat discouraging to the company, should not prevent further drilling in the area, for the chemical character of the waters encountered, as later pointed out, and the good showing of oil and gas may be regarded as favorable evidence as to the possibility of encountering commercial pools of oil in the area. A better test would have been afforded if the well had been located a short distance south of the axis of the fold and drilled a few hundred feet deeper.

The following is a log of the well:

Log of Kansas-Montana Oil & Gas Co.'s well in sec. 18, T. 21 N., R. 19 E., Fergus County, Mont.

	Feet.
Earth	0–20
Soft granite (?)	20–70
Brown shale	70–90
White sand	90–110
Dark shale	110–150
Chocolate-colored shale	159–160
White sand	160–185
Brown shale	185–200
Dark-gray sand	200–300
Gray shale	300–335
Muddy shale	386–410
Gumbo shale	410–600
Sand rock, soft; showing of oil and gas; burns steady	600–650
Shale, very cavey	650–875
Muddy shale; heavy flow of water	875–890
Cavey and muddy; water	890–1,200
Soapstone	1,200–1,210
Sandy shale	1,210–1,270
Sand and water (salt); gas and oil showing	1,270–1,275
Sand and shale	1,275–1,290
Light shale	1,290–1,350
Sand and water	1,350–1,380
Muddy blue shale	1,380–1,400
Shells and shale	1,400–1,410
Lime	1,410–1,416
Sand and water	1,416–1,428
Lime	1,428–1,560
Shale and lime shells	1,560–1,660
Brown shale	1,660–1,820
Dark shale	1,820–1,930
Light shale	1,920–1,985
Shell	1,985–1.987
Light shale	1,987–2,000
Brown shale, dark	2,000–2,055
Lime	2,055–2,079
Shale	2,079–2,126
Lime	2,126–2,148
Shale	2,148–2,171
Lime	2,171–2,192
Shale	2,192–2,223
Brown shale	2,223–2,240
Dark shale and shells	2,240–2,265
Shells and shale	2,265–2,273
Black shale	2,273–2,313
Brown dry sand, fine	2,313–2,323
Light shale	2,323–2,353
Sandy shale	2,353–2,365

	Feet.
Hard shell	2, 365–2, 368
Hard black shale	2, 368–2, 385
Blue shale and soapstone	2, 385–2, 390
Brown sandy shale and small shells	2, 390–2, 420
Gray shale	2, 420–2, 428
Brown sandy shale	2, 428–2, 433
Gray shale	2, 433–2, 439
Hard shell	2, 439–2, 440
Brown soft shale, cavey	2, 440–2, 443
Shell	2, 443–2, 444
Brown shale and small shells	2, 444–2, 470
Dark-gray shale and soapstone	2, 470–2, 480
Sandy brown shale	2, 480–2, 495
Sandy brown shale and soapstone	2, 495–2, 500
Brownshale, smallshells, and soapstone	2, 500–2, 520
Soapstone	2, 520–2, 523
Brown shale, coarse	2, 523–2, 530
Sandy brown shale	2, 530–2, 545
Brown shale	2, 545–2, 585
Gray shale and soapstone	2, 585–2, 595
Very dark brown shale	2, 595–2, 607
Hard gray fine sandy shale, turning darker	2, 607–2, 612
Black slate, very cavey	2, 612–2, 652
Broken gray sand shells	2, 652–2, 674
Black slate	2, 674–2, 688
Gray sand	2, 688–2, 697
Black shale	2, 697–2, 702
Dark-gray sand shell	2, 702–2, 704
Dark-gray sandy shale	2, 704–2, 71
Black shale	2, 710–2, 715
Gray sand	2, 715–2, 723
Gray sand and shell	2, 723–2, 727
Black shale with gravel and sand	2, 727–2, 736
Gray sand	2, 736–2, 741
Light-blue shale, turning darker	2, 741–2, 770
Black shale mixed with sand	2, 770–2, 777
Blue shale	2, 777–2, 783
Gray coarse sand, trace of oil	2, 783–2, 834
Black shale	2, 834–2, 838
Dark-brown sandy shale	2, 838–2, 855
Gray water sand; filled casing within 100 feet of top	2, 855–2, 865
Gray sandy hard slate	2, 865–2, 885
Blue gumbo or shale, very cavey	2, 885–2, 957
Gray sandstone shell	2, 857–2, 960
Blue-black shale with thin shells	2, 960–3, 100
Blue-black sandy shale, shells more frequent	3, 100–3, 160
Shale turning lighter and more sandy	3, 160–3, 165
Gray sandy slate	3, 165–3, 177
Water sand; water flowed out of well	3, 177–3, 182

Writer's interpretation of formations penetrated:

Judith River formation and Claggett shale	0–1, 210
Eagle sandstone	1, 210–1, 380
Colorado shale	1, 380–3, 182

Casing:

$15\frac{1}{2}$-inch, 20 feet.
$12\frac{1}{2}$-inch, 230 feet.
10-inch, 1, 023 feet.
$8\frac{1}{4}$-inch, 2, 366$\frac{1}{2}$ feet, cemented in.
$6\frac{5}{8}$-inch, 2, 875 feet.
$5\frac{3}{16}$-inch, hanging free at 3, 175 feet.

The Ohio Oil Co.'s wells are on a pronounced anticlinal fold in which the Eagle sandstone crops out. Drilling started in this formation and ended in the Colorado shale. In the first well flows of gas were encountered at depths of 1,050 and 1,750 feet, estimated at 3,000,000 and 20,000,000 cubic feet a day, respectively. In the second well, which is 500 feet east of the first, small volumes of gas were encountered at a number of horizons in sandstones occurring at depths of 725 to 1,130 feet and also from the top of a sandstone series occurring at depths of 1,735 to 1,930 feet. The log of the first well is shown on the following page. The log of the second well is like the first, with the exception that in the second well a sandstone series was encountered from 725 to 1,130 feet, while in the first well a similar sandstone series was encountered from 995 to 1,105 feet. Both wells encountered about 200 feet of sandstone at depths approximately 1,750 to 1,950 feet. The writer is of the opinion that this lower sandstone is the Eagle, that the 500 feet of shale above it is the Claggett shale, and that the overlying sandstone series represents the basal part of the Judith River formation. Such an interpretation of the logs can be explained, if it is assumed that the fault which cuts off the northeast limb of the dome has an inclination to the southwest of 45°. The wells, on this assumption, would cut across the fault plane at a depth about equal to their distance from the outcrop of the fault, which for well No. 1 is about 1,000 feet and for well No. 2 is about 700 feet. On the downthrown side of the fault the basal part of the Judith River formation would first be penetrated and at greater depths the Eagle sandstone. Such an interpretation of the structure of the dome agrees with the known facts as to the character of the faults in the region and also explains the presence of the thick sandstone series encountered in the wells, which is inexplicable if it is assumed that the wells penetrated a normal sequence of strata. Such an assumption would make it necessary to infer that the sandstones belong to the Colorado shale, inasmuch as it is evident that the wells never reached the Kootenai formation underlying the Colorado. That sandstone of such thickness occurs in the Colorado shale is very improbable, for at no other place in the region where the Colorado shale crops out or has been penetrated by the drill does it have such a character.

Log of Ohio Oil Co.'s well in sec. 17, T. 25 N., R. 17 E., Chouteau County, Mont.

	Feet.
Gray broken sand	0–100
Shale and coal	100–110
Gray sand	110–160
Light-blue shale	160–180
Gray sand; water	180–200
Gray shale	200–995
Dark hard sand	995–1,002
Gray sand; 3,000,000 cubic feet of gas	1,002–1,050
Dark shale	1,050–1,070
Sand	1,070–1,105
Sandy shale	1,105–1,140
Gray shale	1,140–1,180
Gray sandy shale	1,180–1,240
Sand	1,240–1,255
Sandy shell	1,255–1,260
Blue shale	1,260–1,400
Shell	1,400–1,420
Soft shale	1,420–1,450
Dark shale	1,450–1,750
Sand; 20,000,000 cubic feet of gas	1,750–1,775
Dark shale	1,775–1,790
Sand	1,790–1,956
Sandy shale	1,956–2,250
Dark shale	2,250–2,765

Writer's interpretation of formations penetrated:

Eagle sandstone	0–200
Colorado shale	200–995
[Fault.]	
Judith River formation	995–1,260
Claggett strata	1,260–1,750
Eagle sandstone	1,750–1,956
Colorado shale	1,956–2,765

The results obtained from the drilling of these two wells demonstrate that the folds of the faulted belt have acted as reservoirs for the accumulation of commercial bodies of gas, and it is reasonable to assume that they also may have been effective in the accumulation of commercial pools of oil.

REASONS FOR BELIEVING THAT OIL OCCURS IN THE AREA.

In spite of the narrowness of the folds and the unsuccessful results obtained by the wells drilled in this area the writer is inclined to believe that the area contains oil in commercial quantities. The reasons for believing that oil occurs in the known folded strata are summarized below:

The strata contain an abundance of organic material of the proper kind to yield oil.

There has been sufficient but not too much regional alteration of the sediments to convert the organic material into oil.

There are porous strata in the proper relation to act as oil reservoirs.

The structure is favorable for the accumulation of the oil.

The oil has not escaped along faults or been flushed out of the sands by circulating ground water.

The character of the water from the Kansas-Montana Oil & Gas Co.'s well is favorable to the existence of oil in the area.

Gas in commercial quantity has been obtained in the area and in folds of similar character north of the Bearpaw Mountains.

That the strata contain an abundance of organic material of the proper kind to yield oil is indicated by the bituminous character of the Colorado shale, chemical tests of which show the presence of both free oil and pyrobitumens. Some of the beds, such as the Mowry, contain low-grade oil shale. The fact that most of the oil in Wyoming, Montana, and Alberta occurs in the Colorado shale indicates that these beds, which appear petroliferous, are the probable source of the oil occurring in them.

As White[30] has pointed out, the fixed-carbon content of coal is a gage of the degree of the alteration of the organic material that yields oil. The coals in this area have a fixed-carbon content of 52 to 59 per cent, which indicates that the organic matter present in the region has been altered sufficiently to yield a good grade of oil. Although it is regarded as probable that the sediments adjacent to the Bearpaw Mountains have been altered more than those in the outer margins of the faulted zone, owing to the closer proximity of the main intrusive mass, it is not thought that the alteration has progressed so far as to lessen the oil possibilities of the areas near the mountains.

[30] White, David, Some relations in origin between coal and petroleum: Washington Acad. Sci. Jour., vol. 5, No. 6, 1916.

The condition of porous strata occurring in the proper relation to furnish oil reservoirs is fulfilled in many folds by the presence of the Eagle sandstone under considerable cover and in all the folds by sandstone members in the Colorado shale and Kootenai formation.

Although it appears that there is in the rocks of this area an abundance of organic matter from which oil could be produced, that this organic matter has been altered sufficiently to be converted into oil, and that there are sands of sufficient porosity to act as reservoirs for the oil, it must be recognized that oil in commercial amounts is to be expected only where structural conditions are suitable. The most uncertain thing in this area is whether or not the narrow faulted anticlines furnish conditions suitable for the accumulation of oil. Some geologists would hold that such folds have an insufficient gathering ground for the accumulation of oil in commercial pools. The narrowness of the tilted belts, however, can be regarded as an unfavorable feature only if it is assumed that the accumulation of oil is a result merely of gravitational adjustments between the oil and water under static conditions, for then the gathering ground would probably be limited to the deformed areas where there has been sufficient tilting of the beds to cause the lighter liquid—the oil—to accumulate in the arched portions of the sands. But the consensus of opinion among oil geologists is that the hydraulic circulation of water in the sands has played a greater part in segregating the oil than the mere buoyancy of the oil.[31] This appears to be the most important factor in the accumulation of the oil pools in the Rocky Mountain oil fields, where the regional deformation of the strata is on so large a scale as to produce an active circulation of ground water, as is shown by the large volumes of fresh water encountered in the sands in the areas adjoining the oil pools and even in many of the anticlines, where apparently the circulation has been so active as to flush the oil out of the sands. If this theory of accumulation is applied to the area under discussion it can be assumed that the gathering ground is not limited to the faulted folds but includes large areas of the flat-lying strata through which the water has moved. As to the effect of the faults in impeding the free circulation of water and preventing the segregation of the oil at the crest of the anticline: They undoubtedly have hindered the development of a rapid regional circulation of ground water through the sands, and in some places where both limbs of a fold are cut off by faults, as is shown in Figure 14, A, the anticline may be locally shut off from the circulating ground water, and hence no oil could be segregated in it except that which is obtained from the small area between the two faults. But as these limb faults merge along the strike into highly inclined and partly torn strata, they prob-

[31] See Rich, J. L., Moving underground water as a primary cause of the migration and accumulation of oil and gas: Econ. Geology, vol. 16, No. 6, pp. 347-371, 1921.

ably do not prevent the circulating ground water from reaching the anticlinal crests. As to the effect of the faults in destroying the closure of a fold, it is probable that the closure is as great in the faulted as in the unfaulted anticlines, for the preponderance of shale in the stratigraphic section makes it highly probable that the faulted ends of the oil sands have been moved against impermeable shale beds.

Although it seems probable that suitable structural conditions are present in the area for the accumulation of oil, the possibility remains that this oil has escaped along the faults or has been flushed out by the circulation of water in the sands. There seem, however, to be good reasons for believing that no appreciable quantity of oil has escaped along the fault planes, for no seeps of oil or bituminous residues were observed along the faults, and only one gas seep was noted in the area. This one, which was called to the writer's attention by William R. Bandy, a cadastral engineer of the General Land Office, occurs in a spring issuing from an exposure of the Eagle sandstone in the SE. ¼ sec. 15, T. 24 N., R. 20 E. The flow of gas, though steady, is small, being scarcely of sufficient volume to ignite where there is the slightest wind. Small flows of gas have also been encountered in shallow water wells in T. 24 N., R. 14 E.

The absence of seeps or oil veins of solid bitumen along the faults might be cited as a reason for believing that no oil has accumulated in the area. However, in the Cat Creek field there are no seeps or bituminous material in the numerous faults that cut the oil-producing sands, in spite of the fact that some of the sands lie within 700 feet of the surface. Consequently the absence of these materials along the faults in the area under discussion does not prove that oil is not present. In fact, when it is considered that the faults are apparently thrust faults and in most places several hundred feet of soft shale overlies the possible oil-bearing sand, it would be expected that the faults would be sealed. Apparently the fault planes are not channels even for the escape of water from shallow depths, for no vein material is noticeable along the faults, and the few springs issuing at the faults occur mostly in outcrops of the Eagle and Judith River sandstones and apparently derive their water from these beds. The relation between faults and oil pools in the many fields where faults have been recognized furnishes no reason for a belief that this area may have lost its oil by seepage along the fault planes. In fact, many oil geologists now believe that faulted anticlines are more suitable for the accumulation of oil than unfaulted anticlines, and Mills [32] has advanced the theory that the escape of gas and water along fault planes has resulted in the migration and segregation of the oil in the areas of the

[32] Mills, R. V. A., Natural gas as a factor in oil migration and accumulation in the vicinity of faults: Am. Assoc. Petroleum Geologists Bull., vol. 7, No.1, pp. 14-24, 1923.

sand immediately adjacent to the fault. The writer is inclined to believe that the occurrence of oil along faults is in most places due to the fact that the fault has acted as a barrier to the free circulation of ground water and prevented the oil from being flushed out of the sands. This explanation as to the part that faults play in the accumulation of oil offers what is probably the best reason for assuming that oil is present in the area here considered, for it is thought that the numerous faults have hindered a rapid regional circulation of ground water and prevented the oil from being flushed out of the sands, as it apparently has in the many anticlines surrounding the Big Snowy Mountains, where the proximity of the outcrops of the sands and the greater regional folding have resulted in a more rapid circulation.

Probably the occurrence of oil in the Cat Creek dome and its apparent absence in the sands at the same horizon in the Brush Creek, Kootenai, Box Elder, and Bear Creek domes, all of which occur along the same anticlinal fold, is to be explained by the fact that in the Cat Creek dome, owing to the larger number of faults and the greater distance from the outcrops of the sands, the ground-water circulation is not as active as in the other domes, where large volumes of fresh water are encountered in the sands that yield oil in the Cat Creek field. The likelihood that the circulation of ground water in the area under discussion is less active than in the barren anticlines around the Big Snowy Mountains is indicated theoretically by the faults, the synclinal nature of the regional structure, the remoteness of the outcrops of the sands that may contain oil, and practically by the analyses of waters from sands in the lower part of the Colorado shale in the Kansas-Montana well, in sec. 18, T. 21 N., R. 19 E. Two samples of this water were found to contain 3,200 and 4,395 parts of dissolved solids per million parts of water, in contrast to waters obtained from the Colorado and Kootenai sands in the Bear Creek, Kootenai, and Brush Creek domes, which contain less than 1,000 parts per million of dissolved solids.

The character of the water encountered in the Kansas-Montana well indicates that oil is present. The analyses of these waters given below indicate that the solid dissolved constituents are nearly all salts of sodium and also that there is almost a total lack of sulphates. This absence of sulphates is characteristic of most of the oil-field waters of the world and according to Rogers [33] is attributable to chemical reaction between the sulphate and the oil and gas, in which the sulphate is presumably reduced to sulphide or hydrogen sulphide, which either escapes as gas or undergoes oxidation to free sulphur and is precipitated. These waters are very similar to the waters encountered in the Cat Creek oil field.

[33] 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. 56-66, 1919.

Analyses of water from test well of Kansas-Montana Oil Co., sec. 18, T. 21 N., R. 19 E., Winifred, Mont.

[C. S. Howard, analyst. Parts per million.]

	1	2
Silica (SiO_2)	3.0	14
Iron (Fe)	1.1	5.3
Calcium (Ca)	3.0	9.6
Magnesium (Mg)	1.4	2.4
Sodium (Na) (calculated)	1,723	1,280
Potassium (K)	17	6.8
Carbonate radicle (CO_3)	58	9.6
Bicarbonate radicle (HCO_3)	781	1,375
Sulphate radicle (SO_4)	66	4.6
Chloride radicle (Cl)	2,110	1,190
Nitrate radicle (NO_3)	......	......
Total dissolved solids at 180° C	4,395	3,200
Total hardness as $CaCO_3$ (calculated)	13	34

1. Collected September 22, 1922, from water-bearing sand at depth of 2,855 to 2,865 feet. Water rose within 100 feet of the well mouth.
2. Collected January 4, 1923, from water-bearing sand at 3,177 to 3,182 feet. Water flowed out of well mouth.

The presence of gas in commercial volumes encountered in the Ohio Co.'s wells in secs. 16 and 17, T. 25 N., R. 17 E., and in the faulted belt north of the Bearpaw Mountains in the vicinity of Havre demonstrates that the type of structure occurring in this belt is suitable for the accumulation and retention of gas, and it apparently should also present favorable conditions for the accumulation of oil. The gas in the area north of the mountains is found in the Eagle sandstone at a depth of about 1,000 feet. None of the wells have been drilled deep enough to reach the sands in the lower part of the Colorado shale.

RECOMMENDATIONS FOR DRILLING.

From all theoretical considerations it would appear that oil and gas should occur in this area in commercial quantities. It must be recognized, however, that oil is not always found where the geologic conditions seem to be ideally suitable for its occurrence. Therefore, in view of the fact that the structure in this area is unlike that of the other oil fields of the world, no one should invest money in the drilling of wells here unless he can afford to lose it. It must also be remembered that the discovery of a new oil field is usually preceded by many discouraging results, sometimes many wells being drilled before oil is obtained. As the structure of this area is unusually complex a number of test wells may be required to prove whether or not it contains commercial pools of oil. Unfaulted or partly faulted anticlines of the type shown in Figure 14, B, are believed by the writer to furnish the best chances for obtaining oil in the area. Wells should be drilled along the axes of the anticlines except on a fold that is pronouncedly asymmetric, where they should be 100 to 200 feet off the axis, toward the side with the lesser dip. More specific advice as to the distance the wells should be offset would be given if it were not thought that the thinning of the shale formations on the steeper flank of the fold makes it improbable that the axial plane is inclined pronouncedly toward the limb of lesser dip. If oil is obtained from folds of these types, then the types represented by Figure 14, A, should be tested by wells located on the upthrown side and at a sufficient distance from the fault to avoid drilling through the fault plane. Folds of the type shown in Figure 14, C and D, are not considered as favorable for the accumulation of oil as the other types, but still they may contain oil in commercial quantities. It is quite improbable that oil occurs in the areas of flat-lying rocks.

The beds in which oil is most likely to be encountered are the porous layers occurring in the Colorado shale—that is, the Mosby sandstone, Mowry shale, Muddy (?) sand, and first Cat Creek sand. The sandstones in the Kootenai and Ellis formations may also yield oil. Though the Eagle sandstone may yield oil, experience in drilling in the area north of the Bearpaw Mountains indicates that it is a more probable source of gas than of oil. The sands in which oil may be looked for, and the approximate depth at which they may be encountered in a well beginning at the top of Judith River formation, are the Eagle sandstone, at 1,000 to 1,200 feet; the Mosby sandstone, 2,000 feet; the Mowry shale, 2,300 to 2,400 feet; the Muddy (?) sand, 2,700 to 2,800 feet; the first Cat Creek sand, 3,000 to 3,100 feet; the second Cat Creek sand, 3,200 to 3,300 feet; the third Cat Creek sand, 3,300 to 3,400 feet; and the Ellis sand, 3,500 to 3,700 feet. As a result of the squeezing of the shales in the process of folding, however, the depths at which the beds are actually encountered may vary considerably from those given.

In deciding on locations for the drilling of oil wells in the area it should be borne in mind that most of the geologic mapping on Plate XIII is the result of rapid reconnaissance work, in which an average of two townships a week were mapped by the writer working with one assistant, and therefore that in many areas more detailed work will be necessary. All locations, in fact, should be made only with the advice of a competent geologist. During the drilling of wells care should be taken to keep an accurate log of the strata penetrated and to collect samples of drill cuttings and of any water, oil, and gas that may be encountered. All such data will be of considerable value to the geologist who may be asked to advise the oil operator.

ACCESSIBILITY AND OPERATING CONDITIONS.

In undertaking development in the area many things have to be considered in addition to the favorable character of the folds. Among these are the nearness of railroads, the cost of making roads to the well sites, and the availability of sufficient water and fuel with which to drill the wells. The following information is furnished for guidance to those who are unacquainted with the region.

Culture.—The area is sparsely inhabited. Winifred, with a population of about 350 people, is the only town. It is in the southern part of the area, at the northern terminus of the Lewistown and Winifred branch of the Chicago, Milwaukee & St. Paul Railway. The Great Falls and Havre branch of the Great Northern Railway touches the western part of the area. In the vicinity of Winifred, on Lone Tree Bench, and in the areas west of Birch and Arrow creeks most of the Government land has been taken up by homesteaders who have been attempting, without much success, to raise grain by dry-farming methods. Elsewhere the country is almost entirely uninhabited, except for a few horse, cattle, and sheep ranchers along the larger streams and on the flanks of the mountains. Ranchers living north of Missouri River freight most of their supplies from Big Sandy and Chinook stations on the Great Northern Railway, 30 to 60 miles north and northwest of the area. There are few improved roads, and all except those on the gravel terraces are nearly impassable for automobiles during wet weather. There are a number of trails, however, by which it is possible during the summer and fall to reach by automobile all parts of the area except a few isolated districts along Missouri River, some of which can now be reached only on horseback or afoot. The main trails extending across Missouri River and leading northward and westward out of the region are shown on Plate XIII as solid lines. The general courses of the principal subordinate trails are shown as double-dotted lines. Where, owing to the grade, a car can go in only one direction, that direction is indicated on the map by an arrow.

Water, fuel, and timber resources.—Missouri River, which rises in the Rocky Mountains, flows eastward across the area and contains an abundance of running water even during the driest summers. Its tributaries rise in the adjacent mountain uplifts, where, owing to the greater amount of rainfall, they are running streams during most of the year. At short distances from the points where they enter the plains, however, the water is lost by evaporation, and they are consequently dry except during rainy periods. Water for domestic use in most of the area is obtained from springs occurring along fault planes. Water is rarely obtained from shallow wells except in gravel terraces, where wells 10 to 50 feet deep obtain good supplies of drinkable water. Water for drilling could probably be provided in most localities by building a reservoir in which the run-off from a small area during the winter and spring could be impounded. It is probable also that good supplies of water could be obtained from wells drilled to depths of 200 feet or more in areas where the Eagle sandstone could be reached at such depths. Fuel for drilling could be obtained from local coal mines, the locations of some of which are shown on Plate XIII. Some timber suitable for building is available along the Missouri River bluffs. A large supply of good pine and fir timber is obtainable from the Jefferson National Forest, in the Little Rocky Mountains, and from the Rocky Boy Indian Reservation, in the Bearpaw Mountains.

Climate.—The region is subject to great extremes in temperature, from a maximum of 110° F. in summer to 60° F. below zero in winter. In summer there is often a range of 60° to 70° in temperature from the chilly night to the heat of noonday, and in winter a temperature of 30° to 40° below zero may be quickly changed by a chinook wind to a temperature above freezing. In spite of these extremes, chiefly because of the lack of moisture, the climate is healthful and not disagreeable. During the summer there are sometimes hot winds that will destroy grain crops in a few hours. The average annual rainfall ranges from 12 to 14 inches, and most of it occurs during the winter and spring.