CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1930

PART II. MINERAL FUELS

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GEOLOGY AND MINERAL RESOURCES OF PARTS OF CARBON, BIG HORN, YELLOWSTONE, AND STILLWATER COUNTIES, MONTANA

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INTRODUCTION

LOCATION

The area described in this paper consists of about 1,050 square miles in central southern Montana, embracing parts of Carbon, Big Horn, Yellowstone, and Stillwater Counties. (See key map on pl. 1.) This area lies north of the Big Horn Basin of Wyoming. It is largely a broad lowland crossed by prominent northwestward-trending ridges and lies between the Beartooth Range of the Rocky Mountains on the west and the Big Horn and Pryor Ranges on the east.

The Big Horn River drains most of the Big Horn Basin in Wyoming but turns northeastward at the Montana-Wyoming line to follow a course through the Big Horn Mountains. The Pryor Mountains lie near and parallel with the Big Horn Mountains northwest of the river. The Yellowstone River flows eastward across the northern part of the area here described and receives the water of Clark Fork, which flows in a northerly direction across the area.

PRESENT INVESTIGATION

The present investigation was undertaken primarily to procure data for classifying the public lands. The coal resources of part of the area and also the possibilities of obtaining oil and gas were studied.

Field work of both authors occupied the second half of June, all of July and August, and the first half of September, 1922, and Moulton, the junior author, remained in the field until October 1. During July and August Homer H. Charles served as field assistant. Throughout the season work was carried on independently, the junior author mapping the northeastern part of the area and the senior author the southern and western parts. Frequent conferences were held, but by using the triangulation system of mapping the work was practically done by two separate parties.

No base map was available, and it was accordingly necessary to construct such a map with the aid of plane-table surveys as the geologic studies were carried forward. Little difficulty was experienced with the compass in the operation of the plane tables except in the areas where the Lance and Judith River formations are exposed. There the magnetite grains in the tuffaceous beds of these formations deflected the compass as much as 7°.

A press statement by the junior author concerning the northeastern portion of the area was issued in 1923.[1] The faults in a portion of the area have also been described by him.[2] Further study of the field data during the writing of the present report has involved some revision of the results as given in these publications. The present report, which was completed in 1926, has been written almost entirely by the senior author, although its results are based on the field studies of both authors.

ACKNOWLEDGMENTS

The project was supervised by K. C. Heald, who offered many suggestions during the field work and spent four days in field conferences. W. T. Thom, jr., spent three days in a reconnaissance of the area and furnished initial altitudes for the survey. J. B. Reeside, jr., identified the invertebrate fossils and checked their horizons, and F. H. Knowlton identified the plant fossils. H. D. Miser offered much help and many valuable suggestions in the preparation of the report. C. Max Bauer, who was chief geologist of the Mid-Northern Oil Co. at the time of the investigation, supplied several logs and much other information. Numerous residents of the area freely offered help and information.

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[1] Oil and gas possibilities north of the Pryor Mountains, Mont.: U. S. Geol. Survey Press Memo., Sept. 18, 1923.

[2] Moulton, G. F., Faulting south of Billings, Mont.: Jour. Geology, vol. 32, pp. 511–523, 1924.

EARLIER WORK

The coal resources of the area have been described in part by Darton[3] and Washburne,[4] who have reported on the coal of the Eagle formation near Joliet, Fromberg, and Bridger. Campbell[5] has mapped the geology of a strip along the Northern Pacific Railway. The area is also included in the reconnaissance of central and eastern Montana made by Clapp, Bevan, and Lambert.[6]

Although Darton's report on the Big Horn Mountains[7] describes an area considerably south of this one, the subdivisions and nomenclature of the pre-Cretaceous rocks in the area that he studied seem to be applicable to rocks of the same age in the area here described, and they are therefore used in this report.

Adjoining areas that have been described in previous reports are the Lake Basin area[8] to the north, the Huntley field[9] on the northeast, and the Crow Indian Reservation[10] on the east. Calvert's report on the Upper Stillwater Basin[11] covers an area only a few miles south and west of the area described in the present report.

GEOGRAPHY

SURFACE FEATURES

The area here described is a part of the broad depression in Montana and Wyoming lying between the Rocky Mountains on the west and a series of outlying ranges to the east, of which the Big Horn, Pryor, and Big Snowy Mountains are the better known.

Along the southeast side of the area West Pryor Mountain rises with smooth dip slopes of limestone to an altitude of more than 7,000 feet. An automobile can be driven without difficulty on these slopes between the box canyons that have been cut by a few streams flowing radially from the mountain summit.

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[3] Darton, N. H., Coals of Carbon County, Mont.: U. S. Geol. Survey Bull. 316, pp. 174–193, 1907.

[4] Washburne, C. W., Coal fields of the northeast side of the Big Horn Basin, Wyo., and of Bridger, Mont.: U. S. Geol. Survey Bull. 341, pp. 187–199, 1909.

[5] Campbell, M. R., Guidebook of the western United States, Part A, The Northern Pacific Route: U. S. Geol. Survey Bull. 611, pp. 79–84, 1915.

[6] Clapp, C. H., Bevan, Arthur, and Lambert, G. S., Geology and oil and gas prospects of central and eastern Montana: Montana Univ. Bull., Mines and Met. Ser., No. 4, 89 pp., 1921.

[7] Darton, N. H., Geology of the Big Horn Mountains: U. S. Geol. Survey Prof. Paper 51, 129 pp., 1906.

[8] Hancock, E. T., Geology and oil and gas prospects of the Lake Basin field, Mont.: U. S. Geol. Survey Bull. 691, pp. 101–147, 1918.

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

[10] Thom, W. T., jr., Oil and gas prospects in and near the Crow Indian Reservation, Mont.: U. S. Geol. Survey Bull. 736, pp. 35–53, 1922.

[11] Calvert, W. R., Geology of the Upper Stillwater Basin, Stillwater and Carbon Counties, Mont.; U. S. Geol. Survey Bull. 641, pp. 199–214, 1917.

FIGURE 1.—Pliocene(?) erosion surface on northwest flank of Pryor Mountains, Carbon County, Mont.

A well-marked gravel-capped plain forms the upland near the Pryor Mountains at an altitude of about 5,000 feet. Figure 1 shows the plain beveling all the formations from the Amsden (Carboniferous) to the Thermopolis (Cretaceous) on the northwest flank of the mountains, in T. 5 S., R. 24 E. Near Clark Fork and the Yellowstone River this plain has been destroyed, and it was not traced in the Lance and Fort Union belt west of the area here described. This erosion surface is probably the equivalent of the gravel-capped ridges of the eastern Crow Indian Reservation, which Alden[12] has correlated with the Flaxville gravel, of Miocene or Pliocene age.

Below the erosion plain the area consists chiefly of a series of roughly parallel lowlands and cuestas, whose escarpments face the Pryor Mountains. The cuestas are made by resistant formations of sandstone and limestone, and the lowlands and steep scarps are chiefly underlain by soft clay or shale. The cuestas lie half a mile to 2 miles apart, rise from 100 to 500 feet above the lowlands, and slope at angles of 5° to 10° to the respective succeeding valleys. In the northern part of the area the dips are usually gentler, and the well-marked cuestas are replaced by more gentle slopes or mesas, with irregular, ragged, mountain-facing escarpments and gently rolling uplands, each gradually descending toward the next higher scarp. Of these less definite cuestas the most prominent is popularly known as the "rim rock" of the Billings Basin. It is the outcrop of the Eagle sandstone, of Upper Cretaceous age. It forms a scarp 100 to 300 feet high, with a vertical face of 50 to 100 feet at the top, and extends from a point southeast of Billings along the north side of the Yellowstone Valley to Park City.

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[12] Alden, W. C., Physiographic development of the northern Great Plains: Geol. Soc. America Bull., vol. 35, pp. 74–75, 1924.

The drainage on the erosion surface referred to above was independent of the underlying structure, and on renewal of erosion streams incised their courses with a general northeasterly trend. Subsequent streams have developed along many of the clay or shale belts and by piracy are producing a trellised drainage, but in many places the master stream still runs athwart the structure in a valley marked by repeated narrows. In several places, the dry subsequent valley is nearly at the level of the main stream, and its diversion may be expected shortly.

Aside from the concentric cuestas and their associated valleys which sweep around the Pryor Mountains, the only other conspicuous topographic features are the broad, alluvial valleys of Clark Fork and the Yellowstone River. The flood plains range from a few hundred feet to a mile in width. Above them, at a height of 15 to 40 feet, terraces of silt-covered gravel extend for 1 to 3 miles from the rivers. These gravel benches contain the rich agricultural land of the valleys, and most of the irrigation of the region is confined to them.

Within the area mapped, the highest point located was on the flank of West Pryor Mountain at an altitude of 5,965 feet above sea level, and the lowest point is on the Yellowstone River in the northeast corner of the field, where the altitude is about 3,090 feet.

DRAINAGE

The Yellowstone River and its tributaries drain the entire area. The Yellowstone is joined near Laurel by Clark Fork, which drains all the southern portion of the area. The Stillwater River, which drains an area southwest of the territory treated in this report, reaches the Yellowstone at Columbus. Other tributaries are of less size, although Bluewater, Rock, Canyon, Valley, Hensley, and Keyser Creeks are all perennial streams. Most of the remaining streams are intermittent. They receive abundant water during the melting of the winter's snow and the early spring rains. Much of this water is absorbed by porous sandstone and escapes slowly to the streams during early summer. Several large springs supply Bluewater Creek with an abundant perennial flow, but the other streams depend upon storm and seepage waters.

Most of the smaller tributaries of the main streams have developed along the soft shales, and many of the intermittent streams follow meandering courses through broad, mature valleys, whereas the master stream follows a valley of rapidly alternating width and varying stage of development.

Some marsh land exists in the Yellowstone and Clark Fork bottoms as a result of the meandering of those streams. Two small ponds lie on the Bearpaw shale in T. 1 S., R. 21 E. They are similar to the numerous ponds of the Lake Basin and represent its southern continuation. The origin of these ponds is unknown. The depressions in which they lie may be the result of wind erosion of the soft Bearpaw shale or may indicate very recent deformation of the area.

POPULATION

Billings, the principal city of the area, had a population of 15,100 in 1920. It is an important railroad center and has extensive wholesale trade, sugar refining, and manufacturing industries. Laurel had a population of 2,239 in 1920. Columbus, Bridger, Fromberg, and Joliet each had less than 1,000 inhabitants. Outside the cities and towns the principal industries are farming, grazing, and coal mining. Dry farming has been extensively carried on in the uplands. The flood plains of the larger streams are irrigated and yield large crops of alfalfa, sugar beets, and small grains. Coal mining is the leading industry of Bridger, Fromberg, and Joliet. Smaller mines are located between these points and northeast of Columbus.

TRANSPORTATION

The main line of the Northern Pacific Railway crosses the area from Billings to Columbus. The Billings-Denver line of the Chicago, Burlington & Quincy Railroad runs north through the area, and the Billings-Great Falls-Shelby line of the Great Northern Railway provides a connection with the Northwest. A branch of the Northern Pacific extends from Laurel southwest to the coal-mining town of Red Lodge, outside the area described, and the Montana, Wyoming & Southern Railroad connects Bear Creek with the Northern Pacific Railway at Bridger.

The Yellowstone Park Trail follows the Yellowstone River. The Billings-Cody Highway leaves the Yellowstone Park Trail at Laurel, follows the Northern Pacific Railway to Bridger, and then turns southeastward toward Frannie. Another road runs south from Bridger along the west side of Clark Fork. Fair to good dirt roads connect all parts of the area. Cars can be driven over most of the shale land during the dry season, and the flat-lying sandstone formations of the northern part of the area provide good facilities for cross-country travel, except near the edges of the escarpments. Because of the cuesta type of topography, few of the upland roads follow section lines, except near Billings and Edgar.

PUBLIC-LAND SURVEYS

All of the area has been surveyed for or by the General Land Office. Some of the maps of the early contract surveys north of the

Yellowstone River are inaccurate, especially in the tuffaceous areas of Judith River and Lance beds, where compass deviations were extreme, but the more recent surveys south of the river are good. All the land surveys are well marked.

WATER SUPPLIES

Water may be obtained not only from the streams but also from wells that penetrate the water-bearing sandstones underlying the area. Wells properly located will flow, and some of the flowing wells are used for irrigation. Shallow wells usually have a low yield, unless they are located in stream alluvium and can draw on the underflow. Where streams of water from the alluvium are not available, water must be hauled, or else a well may be drilled to the first sandstone below stream level.

STRATIGRAPHY

GENERAL FEATURES

All the rocks exposed in this area are sedimentary. Presumably the pre-Cambrian crystalline rocks underlie the region at a depth of 2,000 feet or more below the top of the Madison limestone, the lowest exposed formation, as they do 40 miles to the southeast, in the Big Horn Mountains.[13] More recent igneous rocks are present in the Crazy and Beartooth Mountains, to the west, and tuffaceous material occurs in the Cloverly, Thermopolis, Judith River, Bearpaw, and Lance formations of this area.

The outcropping sedimentary rocks are of many ages—Mississippian, Pennsylvanian, Permian(?), Triassic, Jurassic, Cretaceous, Tertiary(?), and Quaternary—although deposition was repeatedly interrupted. The following table indicates the age, general lithology, thickness, and relations of the formations. Their areal distribution is shown on Plate 1. A total thickness of 5,970 feet is shown between the lowest exposed beds of the Madison and the base of the Lance. Most of this thickness consists of shale or clay, sandstone constituting roughly 20 per cent and limestone only 2 per cent of the column. The amounts of conglomerate, gypsum, and coal are quantitatively negligible.

Plate 2 presents a general correlation table, which has been prepared by the United States Geological Survey to show the relations between the formations and the varying usages of the formation names in the Rocky Mountain States.

[13] Darton, N. H., Geology of the Big Horn Mountains: U. S. Geol. Survey Prof. Paper 51, pls. 6, 38, 1906.

Formations exposed in southern Yellowstone, western Big Horn, southern Stillwater, and northern Carbon Counties, Mont.

Period	Epoch	Group and formation		Thickness (feet)		Character
				Extreme	Average	
Quaternary.	Recent and Pleistocene.					Gravel, sand, and clay.
Tertiary.	Pliocene (?).			0–5		Gravel and white or buff sand.
Tertiary (?).	Eocene (?).	Lance formation.		Not measured.		Dark andesitic continental sandstone and green, yellow, and black clay.
Cretaceous.	Upper Cretaceous.	Montana group.	Lennep sandstone.	129–310	170	Chiefly dark continental andesitic sandstone interbedded with yellow, green, and gray clay.
			Bearpaw shale.	250–425	400	Dark-gray marine clay and clay shale, with one andesitic sandstone.
			Judith River formation.	500–605	575	Interbedded dark continental andesitic sandstone and yellow, green, and gray clay.
			Claggett formation.	550–675	625	Dark-gray sandy marine clay with interbedded sandstones and massive mudstone. Parkman sandstone member, 286 to 310 feet thick, at top.
			Eagle sandstone.	200–250	210	Light-gray sandstone and shale, weathering buff to yellow. Prominent cliff former; carries coal.
			Telegraph Creek formation.	150–171	160	Yellow-buff sandy shale and sandstone.
		Colorado group.	Niobrara and Carlile shales.	1,060–1,230	1,100	Black fissile shale with minor sandy beds and many siderite concretions.
			Frontier formation.	395–420	410	Black fissile shale with thin sandstone (Peay sandstone member) below and massive yellow sandstone (Torchlight sandstone member) at top.
			Mowry shale.	180–325	225	Black fissile shale with numerous bentonite zones and some sandstone members.
				300–450	350	Black fissile shale, with rare bentonite beds.

			Thermopolis shale.	0–30	10	Black coarse stream-laid sandstone with much organic débris; "Muddy sand" of drillers.
						Slight unconformity
				270–290	280	Black fissile shale, with some rusty sandy beds in lower portion.
			Gradational contact			
	Lower Cretaceous.	Cloverly formation.	Greybull sandstone member.	50–60	60	Rusty thin-bedded sandstone and sandy shale.
			Gradational contact			
				90–240	180	Bright variegated clay, volcanic ash, and shale.
				20–90	45	Black chert conglomerate and yellow sandstone.
		Sharply channeled erosional unconformity				
Cretaceous (?).	(?)	Morrison formation.		160–254	210	Yellow clay and shale and soft sandstone.
		Slight erosional unconformity				
Jurassic.	Upper Jurassic.	Sundance formation.		387–498	450	Varicolored shale, clay, and limestone below; olive-brown clay and sandstone above.
		Slight erosional unconformity				
Triassic.		Chugwater formation.		375–450	410	Red shale, red clay, and red fine-grained sandstone. Much interbedded gypsum including, near the top, one bed 15 to 40 feet thick.
		Erosional unconformity of slight relief				
Carboniferous.	Permian (?).	Embar (?) limestone.		10–15	12	Porous thin-bedded gray limestone.
		Apparently conformable				
	Pennsylvanian.	Tensleep sandstone.		40–105	70	Sandstone, medium to coarse grained, buff to cream-colored; eolian cross-bedding below; calcite cement above.
		Marked erosional unconformity				
		Amsden formation.		65–156	140	Red and purple shales, buff chalky limestone, and discontinuous thin pink quartzites.
		Marked erosional unconformity				
	Mississippian.	Madison limestone.		1,000±		Dark-blue or gray dense, fine-grained limestone with some quartzite and chert.
		Erosional unconformity				

OLDER PALEOZOIC ROCKS

No rocks older than Mississippian crop out in the area here considered. Cambrian rocks having a thickness of 800 to 900 feet occur to the southeast, in the Big Horn Mountains,[14] to the north, in the Little Rocky Mountains,[15] and to the west, near Three Forks.[16]

The Upper Ordovician Bighorn dolomite has a thickness of 300 feet[17] about 40 miles southwest of the area described in this report. In the Little Rocky Mountains this formation is about 350 feet thick.[18] A buff, finely crystalline dolomite crops out near the mouth of Pryor Gorge, 5 miles east of the area treated herein. This rock is probably the Bighorn dolomite. It is not exposed in the area here described.

Devonian beds with a thickness of 350 feet occur in the Little Rocky Mountains, and Peale found 775 feet of these beds near Three Forks. They were not found in the Big Horn Mountains. From the areal distribution of these formations it seems probable that 800 or 900 feet of Cambrian beds and about 300 feet of Ordovician dolomite underlie this area, but the Devonian appears to be missing.

MISSISSIPPIAN ROCKS

MADISON LIMESTONE

The oldest formation exposed in this area is the Madison limestone, of early Mississippian age. It was named from outcrops in the Madison River Valley, south of Three Forks, Mont.[19] In the area here described the limestone is gray or dark blue, dense, very hard, fine to cryptocrystalline, heavy bedded, and uniform in character, both horizontally and vertically. It weathers light gray to dirty white and contains chert in amounts as large as 5 per cent of the total. Shaly partings develop on some beds after long weathering. The limestone is nonmagnesian and almost entirely free from identifiable organic remains. Quartzite is present in beds 3 feet or less in thickness and constitutes about 15 per cent of the upper 100 feet of the formation. The sand content decreases greatly below this upper zone.

Dip slopes of the Madison form the west flank of the Pryor Mountains and lie east of the Crow Indian Reservation boundary. The slopes are smooth, but several streams have cut box canyons 150 to 250 feet deep into the structural surface. (See pl. 3, *B*.) Not

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[14] Darton, N. H., op. cit., p. 23.

[15] Peale, A. C., Paleozoic section in the vicinity of Three Forks, Mont.: U. S. Geol. Survey Bull. 110, pl. 4, 1893.

[16] 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.

[17] Darton, N. H., op. cit., p. 26.

[18] Collier, A. J., and Cathcart, S. H., op. cit., p. 173.

[19] Peale, A. C., The Paleozoic section in the vicinity of Three Forks, Mont.: U. S. Geol. Survey Bull. 110, p. 15, 1893.

over 300 feet of the Madison is exposed in the area studied, but 40 miles to the southeast Darton [20] observed a thickness of 900 to 1,000 feet where the entire section is exposed. On Pryor Creek, several miles east of the area considered in this report, more than 600 feet of Madison limestone crops out. The total thickness was not measured and may easily reach 1,000 feet. Probably a similar thickness underlies this entire area.

The Madison was exposed to prolonged erosion before the overlying Amsden formation, of late Mississippian and early Pennsylvanian age, was deposited. The surface of the Madison has the characteristic pitting and etching of a deeply weathered limestone. A relief of 2 to 5 feet in a horizontal distance of 20 feet is not uncommon, and along joint planes the red clay of the overlying formation extends several feet farther below the surface. Probably the red clay represents a residual soil derived from the weathered Madison. Chert nodules and weathered quartzite pebbles are also characteristic of the basal Amsden. On Soap Creek [21] low-grade oil has been found in the rotten weathered zone of the Madison beneath the Amsden formation.

MISSISSIPPIAN AND PENNSYLVANIAN ROCKS

AMSDEN FORMATION

Unconformably above the Madison limestone lies the Amsden formation, of late Mississippian and early Pennsylvanian age. Darton [22] named the formation from its outcrop along Amsden Creek, on the east flank of the Big Horn Mountains.

In the area here considered the Amsden consists of beds of red and purple shale below and beds of soft and sandy limestone and discontinuous, thin, pink quartzites above. Much less sand is present than on the east side of the Pryor Mountains or at the type section farther southeast. The formation is easily eroded and is quickly stripped from the Madison slopes after the overlying Tensleep sandstone has been removed. Good exposures are obtainable along the walls of the box canyons cut by the radial streams that flow from the Pryor summit. Because of its easy erosion the surface covered by the Amsden forms a narrow strip below the cuesta of the Tensleep sandstone. Outcrops are limited to the west flank of the Pryor Mountains, between the Madison and Tensleep formations.

The following section illustrates the general character of the formation. Other sections in the same general region do not differ

[20] Darton, N. H., op. cit., p. 30.

[21] Thom, W. T., jr., Oil and gas prospects in and near the Crow Indian Reservation, Mont.: U. S. Geol. Survey Bull. 736, p. 42, 1922.

[22] Darton, N. H., Comparison of the stratigraphy of the Black Hills, Big Horn Mountains, and Rocky Mountain Front Range: Geol. Soc. America Bull., vol. 15, p. 396, 1904.

materially in character, although measured thicknesses range from 65 to 156 feet, and average 140 feet.

Section of Amsden formation in canyon in SE. ¼ sec. 7, T. 6 S., R. 25 E.

	Feet
Tensleep sandstone.	
Evident erosional unconformity; beds above and below are parallel.	
Amsden formation:	
Limestone, soft, or chalky mud, cream-colored, porous, soft, fine grained, thin-bedded, uniform in composition, weathering to yellow clay; the rock is decidedly argillaceous, but contains little separate clay or shale	103
Limestone, very soft, like unit above, with minor amounts of red, purple, and green shale interbedded; deep-red shale reaches a thickness of 15 inches in two beds	22
Clay shale, red to purple, sandy, very soft; some buff to cream-colored chalky limestone interbedded; bedding poor, and material would be considered Mississippian residual soil if thin cream-colored or buff limestone were not present	18
Covered	4
Conglomerate; limestone, chert, and quartzite pebbles in red clay matrix; all material is characteristic of underlying Madison and is a residual soil product, only slightly sorted	1
Total thickness of Amsden formation	148
Erosional unconformity, with relief of 2 in 10 feet, horizontally.	
Madison limestone.	

The formation thickens southeastward in the Big Horn Mountains to 350 feet.[23] Similar beds are found in the Lewistown district,[24] where they form the base of the Quadrant formation.

The Amsden is separated from the Madison limestone below by an unconformity resulting from prolonged weathering. A distinct erosional unconformity exists also at the contact with the overlying Tensleep sandstone, but evidence of extensive weathering was not found at this horizon. In this area there is no evidence that either unconformity is angular, but on the East Fork of Pryor Creek the Madison limestone shows gentle flexing beneath the undistorted Amsden.[25]

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[23] Darton, N. H., Geology of the Big Horn Mountains: U. S. Geol. Survey Prof. Paper 51, p. 32, 1906.

[24] Calvert, W. R., Geology of the Lewistown coal field, Mont.: U. S. Geol. Survey Bull. 390, p. 6, 1909.

[25] Thom, W. T., jr., personal communication.

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.	Yellowstone, Stillwater, Big Horn, and Carbon Counties, Montana	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	Quaternary
Tertiary	Miocene(?)				Bishop conglomerate												Pliocene (?)			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						?
				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	Fort Union			Paskapoo
Tertiary (?)				Absent	"Laramie"		Lance	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	Pierre: Fox Hills	Pierre: Fox Hills	Lewis	Fox Hills	Meeteetse	Meeteetse	Mesaverde	Mesaverde	Bearpaw	Montana: Lennep	Bearpaw	Bearpaw	Bearpaw	Horsethief	
				?													Montana: Bearpaw				Bearpaw	Bearpaw
				Adaville	Mesaverde	Mesaverde	Mesaverde: Teapot	Pierre: Teapot			Pierre	Gebo	Mesaverde			Judith River	Montana: Judith River	Parkman	Judith River	Judith River	Two Medicine	Belly River
							Mesaverde: Parkman	Pierre: Parkman	Pierre: Parkman	Mesaverde: Parkman						Claggett	Montana: Claggett; Parkman	Claggett	Claggett	Claggett		
							Steele: Shannon	Pierre: Shannon	Pierre: Shannon	Steele: Shannon						Eagle	Montana: Eagle	Eagle	Eagle	Eagle	Virgelle	
													Cody	Cody	Cody		Montana: Telegraph Creek	Telegraph Cr.				
		Niobrara	Niobrara	Hilliard	Baxter	Mancos	Niobrara	Niobrara	Niobrara	Niobrara	Niobrara	Colorado				Niobrara	Colorado: Niobrara	Niobrara	Colorado	Colorado	Colorado	Colorado
		Benton	Carlile				Carlile				Carlile					Carlile	Colorado: Carlile	Carlile				
			Greenhorn	Frontier	Frontier		Frontier: Wall Creek	Benton: Wall Creek	Benton: Wall Creek	Benton: Wall Creek	Greenhorn		Frontier	Frontier: Torchlight	Frontier: Torchlight	Frontier	Colorado: Frontier: Torchlight	Frontier				
							Frontier: Peay							Frontier: Peay	Frontier: Peay		Colorado: Frontier: Peay					
			Graneros	Aspen	Aspen		Mowry	Benton: Mowry	Benton: Mowry	Benton: Mowry	Graneros: Mowry		Mowry	Mowry	Mowry	Mowry	Mowry	Mowry				
							Thermopolis						Thermopolis	Thermopolis	Thermopolis	Thermopolis		Thermopolis				
				Bear River	Dakota	Dakota	Dakota				Dakota				Cloverly: Greybull	Cloverly: Greybull	Greybull		?	?	?	?
	Lower Cretaceous	Dakota	Dakota	Absent	[?]	Lower Cretaceous	Lower Cretaceous	Cloverly	Cloverly	Cloverly	Fuson	Cloverly	Cloverly	Cloverly	Cloverly	Cloverly	Cloverly	Cloverly	Kootenai	Kootenai	Kootenai	Kootenai
											Lakota											
Cretaceous (?)		Morrison	Morrison	? Beckwith	? Morrison	Morrison	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	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	Chugwater (red beds)	Absent	Absent	Absent	[?]
Carboniferous	Permian	Lykins	Absent	Park City	Park City	Embar	Embar	Embar	Forelle (?), Satanka (?), Casper	Embar	Opeche	Embar	Embar	Embar	Embar	Embar	Embar (?)					Upper Banff shale
	Pennsylvanian	Lyons		Weber	Weber	Tensleep	Tensleep	Tensleep		Tensleep	Minnelusa	Tensleep	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	Amsden				Lower Banff shale
	Mississippian	Absent	Millsap	Madison	Mississippian	Madison	Madison	Madison		Madison	Pahasapa	Madison	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	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	Absent	Silurian
Ordovician	Upper	Absent	Fremont	Upper Ordovician	Absent (?)	Bighorn	Bighorn	Absent	Absent	Bighorn	Absent	Bighorn	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	No evidence	Absent	Absent	Absent	Absent	
	Lower	Absent	Manitou	Absent (?)	Absent (?)	Absent (?)	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	No evidence	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	Deadwood	Upper Cambrian
	Middle	Absent	Absent	Absent	Absent (?)	Gros Ventre	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	No evidence	Absent	Middle Cambrian	?	Middle Cambrian	Middle Cambrian
	Lower	Absent	Absent	Absent		Flathead; Absent (?)	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	No evidence	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.	No evidence	Granite, etc.	Limy shales, etc.	Schist	Granite, etc.	Granite, etc.

[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 is not fully established.

FORMATIONS PRESENT IN THE AREA SHOWN ON PLATE 1

PENNSYLVANIAN ROCKS

TENSLEEP SANDSTONE

The Tensleep sandstone, of Pennsylvanian age, overlies the Amsden formation. It was originally described from exposures in Tensleep Canyon,[26] on the west side of the southern Big Horn Mountains.

In the area described the Tensleep is a buff to cream-colored sandstone, at some places slightly calcareous and argillaceous. Though not a hard sandstone, it is more resistant to erosion than the adjacent beds and accordingly makes a small hogback or cuesta between the prominent ridge of the Chugwater formation and the Pryor Mountains. Straight, steeply inclined cross beds are common in this formation, together with the uniform size of grains, they suggest an eolian origin for the lower part of the sandstone. The higher part is more impure, and its calcareous character suggests, although it does not prove, marine deposition or reworking.

The following section illustrates the general character of the formation. The thickness is greater here than the 50 feet reported by Darton,[26] or the 75-foot maximum found east of the Pryor Mountains.[27] The average of three sections measured in this area is 70 feet.

Section of the Tensleep sandstone in the SE. ¼ sec. 7, T. 6 S., R. 25 E.

Embar (?) limestone.	
Tensleep sandstone:	Feet
Sandstone, cream-colored to buff, argillaceous, slightly calcareous, easily eroded	21
Sandstone, buff, 1 to 2 millimeter grains, beds 2 to 6 feet thick, straight cross beds dipping 25° or more, resistant to erosion and weathering; makes main Tensleep hogback and forms narrow box canyons	84
Total thickness of Tensleep sandstone	105
Erosional unconformity.	
Amsden formation.	

No fossils were found in the Tensleep in this area, but it has been correlated on the basis of its lithologic character and stratigraphic position with the Tensleep formation of the Big Horn Mountains and the upper part of the Quadrant of the Yellowstone Park area. A distinct erosional but not angular unconformity separates it from the Amsden below. Although it does not grade into the Embar(?)

[26] Darton, N. H., Comparison of the stratigraphy of the Black Hills, Big Horn Mountains, and Rocky Mountain Front Range: Geol. Soc. America Bull., vol. 15, p. 397, 1904.

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

above, there is no evidence in this area that the Embar(?)-Tensleep contact is not conformable.

PERMIAN (?) AND TRIASSIC ROCKS

EMBAR (?) LIMESTONE

Overlying the Tensleep sandstone a thin limestone occurs at three exposures. This rock has been tentatively referred to the Embar. It is gray-white and very porous and has irregular, wavy beds, ranging from 0.1 to 1 inch in thickness. It has many characteristics of chemically precipitated limestone, such as occur in basins of salt lakes. No trace of organic remains was found. The rock is resistant to weathering and makes a small hogback 15 to 20 feet high. The limestone is commonly missing at the top of the Tensleep, because of either nondeposition or erosion. The thicknesses measured ranged from 10 to 15 feet. The limestone is tentatively considered the northern extension of the Embar because of its stratigraphic position, but possibly it represents a salt-water precipitate of early Chugwater time, or indeed it may belong to the Tensleep.

CHUGWATER FORMATION

The Chugwater formation was named by Darton [28] from its extensive exposures along Chugwater Creek, in southeastern Wyoming. Typical bright to dark red sandy shale and sandstone of this formation flank the Pryor Mountains. The brilliant red contrasts sharply with the browns and grays of the associated strata, and except where covered by alluvium from other formations the Chugwater can be readily traced by its flaming outcrops and soils. Sandy shales with three thick beds of sandstone constitute most of the formation. Pure granular gypsum forms a bed 15 to 40 feet thick near the top, and gypsum in veinlets or disseminated crystals is abundant in the lower 100 feet. At many places a few feet of green, pink, and rose-colored clay is interbedded with normal deep-red clay near the top and bottom of the formation. In the main body of the formation only two beds of gray or light-brown shaly sandstone interrupt the uniform sequence of red beds. Even these beds are usually colored deep red by slope wash, and the lighter color appears only on fresh exposures.

Limestone, which possibly corresponds to the Minnekahta of the Black Hills, occurs in the upper part of the formation in the Big Horn Mountains. The limestone decreases steadily in amount northward. It has a thickness of only 4 feet on the east side of the Pryor Mountains,[29] but is entirely missing in this area.

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[28] Darton, N. H., Comparison of the stratigraphy of the Black Hills, Big Horn Mountains, and Rocky Mountain Front Range: Geol. Soc. America Bull., vol. 15, p. 397, 1904.

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

The Chugwater occupies a broad valley of greatly varying width along the north and west sides of the Pryor Mountains and forms a conspicuous escarpment on the outside or north and west sides of the red lowland. Only the Sundance and Eagle formations have developed higher and more continuous ridges. In the southern part of the area, where the strata dip 10° to 12° away from the mountains, the soft basal shales have been stripped from the Tensleep slope and the formation covers a strip about a quarter of a mile wide, but farther north, where the dip is gentler, the lowland, escarpment, and westward dip slope of the Chugwater together are 2 to 4 miles wide. Faulting has reduced the normal outcrop along the north end of the Pryor Mountains to a minimum of less than 200 feet. In addition to the main cuesta formed by the upper and middle sandstones, the lower sandstone forms a subordinate cuesta in the east-central part of T. 6 S., R. 24 E.

In the Big Horn Mountains the formation decreases in thickness from east to west and from south to north. West of Sheridan it is 1,100 feet thick, but 60 miles to the northwest only about 600 feet occurs along the Big Horn River. Along the west flank of the Pryor Mountains only 400 to 450 feet crops out, and the formation thins out and entirely disappears between this area and the Big Snowy Mountains, 85 miles to the north. Outcrops are not known north of the Pryor Mountains. Although this thinning is probably due to overlap, the available evidence does not exclude the possibility that pre-Sundance erosion caused the reduction in thickness. The following section is typical of the Chugwater in the area here considered.

Section of Chugwater formation in the SW. ¼ sec. 36, T. 6 S., R. 24 E.

Sundance formation (clays).	
Erosional unconformity of very slight relief.	
Chugwater formation:	Feet
Clay, red, shading to pink and rose color, with much gypsum, disseminated or in veinlets and interlaminated in beds as much as half an inch thick	34
Gypsum, massive, pure white in upper 20 feet; basal portion contains some red clay; this bed has been quarried for a plaster of Paris plant in sec. 18, T. 7 S., R. 24 E	30
Sandstone, 0.5 to 1 millimeter grains, in regular beds, cemented, veined, and interlaminated with gypsum; color varies from dark to bright red; this is the upper sandstone and forms the Chugwater cuesta or hogback	55
Clay and sandstone, interbedded regularly, brown to olive-green but normally appear red because of staining by slope wash; contain no gypsum	20

	Feet
Chugwater formation—Continued.	
Sandstone, gypsiferous, red-brown, thin bedded and not resistant to erosion, showing shallow-water wave ripples and cross beds	17
Clay, sandy, bright red, poorly laminated except for numerous well-bedded thin sandstones; not resistant to erosion and makes a gentle slope above the scarp of the underlying middle sandstone	71
Sandstone, bright red, well laminated or bedded in strata from half an inch to 8 inches thick, containing much red clay in sandstone and a smaller quantity interlaminated; gypsum present in veinlets and to less extent in $\frac{1}{16}$-inch laminations; sandstone shows wave ripples and short, curved cross beds, not over 1 foot long; this is the prominent middle sandstone	50
Clay, gypsiferous, and sandstone, olive-brown	½
Sandstone, gray to brown, argillaceous, nonresistant and makes reentrant in cliff face; appears red because of slope wash	12
Clay, red, massive; not laminated and not at all indurated	23
Sandstone, brick-red, 0.05 to 0.3 millimeter grains; well laminated and containing a few gypsum laminæ; combines with underlying 29 feet to form the resistant cliff-forming lower sandstone	5
Clay, red, unindurated, nonresistant; well laminated, an unusual characteristic in clays of this formation	11
Sandstone, brick-red, fine grained	2
Clay, bright red, laminated and containing a few ¼-inch beds of green shale	3
Sandstone, dark brick-red, fine grained, wave rippled	13
Clay, bright red to brick-red, poorly laminated to massive; gypsum disseminated in lower portion and in veinlets throughout; irregular vertical or steeply inclined joints, slickensided by settling movements; green spots half an inch or less in diameter with rare black material at center, probably an organic remnant that has reduced iron in the surrounding clay	64
Gypsum, white, marble-like, coarse grained	¼
Clay, brick-red	4
Clay, green, with gypsum interlaminated, perhaps as much as 10 per cent, in beds 5 inches or less in thickness; this zone has been considerably crumpled, apparently by compacting or possibly flowing under the load of the escarpment above	13
Gypsum, granular, white	⅔
Clay, green, with gypsum lamination as much as half an an inch thick	8
Total thickness of Chugwater formation	436

Unconformity with wavy, irregular surface; relief amounts to 3 in 25 feet horizontally.

Tensleep sandstone (calcareous).

No fossils were obtained from the Chugwater in this area. Its age is usually stated as Triassic, but Condit[30] has shown that the lower portion of the Chugwater (red beds) of some areas is equivalent to most of the Permian Embar.

As indicated in the detailed section, unconformities of moderate relief separate the Chugwater from the underlying Tensleep and the superjacent Sundance formation. No field evidence of angular unconformity was found, and probably any discordance which exists is very small.

JURASSIC ROCKS

SUNDANCE FORMATION

The Sundance formation was named for the town of Sundance, Wyo.,[31] in the northern part of the Black Hills uplift. It is more predominantly marine than any other formation between the Madison and the Colorado group. The basal 175 feet of the formation consists of very regular interbedded olive-brown clay and shale, pink and rose-colored clay, thin, commonly microcrystalline limestone, and a few thin beds of gypsum. The limestones are very persistent, and two beds of poor lithographic stone, one 12 inches thick and the other 8 inches thick, separated by 18 inches of clay, have been traced continuously by Hares from the Wyoming boundary to this area and except where interrupted by faulting have been followed around the north end of the Pryor Mountains into the Crow Indian Reservation. Erosion etches the soft alkaline clays into miniature badlands, in which scattered plants maintain a precarious existence. Above the lithographic limestone, which forms a cuesta, the strata appear to record uninterrupted deposition. About 200 feet of olive-brown clay, with subordinate sandy layers, is succeeded by 50 to 100 feet of sandstone and sandy clay. This upper 250 to 300 feet of beds weathers to a characteristic olive-brown or green-gray-brown, but where fresh the rock is normally gray. Fossils are more abundant in this zone than in any other formation of the area. On weathered slopes one or more Gryphaeas or Belemnites are crushed at every step. Very few species are represented in spite of the great abundance of the fossils. The number of fossils in the clay may be easily overestimated, however, for the shells accumulate on the surface as the soft clay is removed by slope wash.

A prominent escarpment, in many places so steep as to be unscalable for horizontal distances of 1,000 feet or more, is formed by the

[30] Condit, D. D., Relations of the Embar and Chugwater formations in central Wyoming: U. S. Geol. Survey Prof. Paper 98, pp. 263–270, 1917.

[31] Darton, N. H., Comparison of the stratigraphy of the Black Hills, Big Horn Mountains, and Rocky Mountain Front Range: Geol. Soc. America Bull., vol. 15, p. 398, 1904.

thick, usually well-bedded sandy limestone at the top of the formation. Normally this limestone is flat bedded with laminations less than an inch thick and is not very fossiliferous. At several places it has the characteristic of an alongshore bar, is strikingly cross-bedded, and occurs in thick, nearly massive strata, and at these places *Gryphaea* shells are very abundant. With this exception all the upper 250 to 300 feet of the formation has apparently been deposited beyond the littoral zone. Although very prominent topographically, the limestone is rather soft and appears hard only by contrast with the very soft sand and clay above and below. Analyses of specimens show that the rock contains about 50 per cent of carbonates and an equal amount of sand and clay.

The cuesta formed by the upper sandstone rises 250 to 400 feet above the lowland on the mountainward side and is the most prominent ridge of the whole area here described except the rim of the Eagle sandstone. Below a 30 to 75 foot vertical cliff of sandstone the eroded surface of the underlying clay slopes steeply at first and then more gently down to the back slope of the Chugwater cuesta. The regular curve of the clay slopes is interrupted by a prominent cuesta produced by the lithographic limestone and at some places by minor ridges resulting from discontinuous sandstone lenses.

The Sundance ranges in thickness from 387 to 498 feet. The variation is due largely to erosion of its upper surface before Morrison deposition and to variation in amount of the thick central clay.

The following section was measured at a place where the formation was unusually well exposed. Most of its members are recognizable at other exposures, for the different zones in the Sundance are unusually regular.

Section of the Sundance formation in sec. 19, T. 7 S., R. 24 E.

Morrison formation.	
Erosional unconformity of slight relief.	
Sundance formation:	Feet
Limestone, sandy, or calcareous sandstone, gray when fresh, olive-brown to greenish buff on weathering, dense, moderately hard; sand grains range from 0.5 to 2 millimeters in diameter; thick bedded above, but thin bedded below; beds in the upper part 3 to 4 feet thick, with straight cross beds at many places, dipping 10° to 18°, and 10 to 20 feet long; moderately fossiliferous	70
Clay, very sandy, gray when fresh, weathering olive-brown to greenish-gray brown, poorly bedded to massive; forms gentle slope where erosion is retarded; very fossiliferous	20

Sundance formation—Continued.	Feet
Sandstone, argillaceous, of the usual color, soft but more resistant than inclosing clays, and so forming small cuesta; sand grains, 0.2 to 0.8 millimeter in diameter; bedding poorly marked, cross-bedded; not fossiliferous	5
Clay, sandy in some zones, of usual Sundance colors, very soft; bedding obscure or absent, Belemnites and *Gryphaea* very abundant; steep slope below cliff, becoming more gentle and forming flat lowland, which rises gently mountainward to the lithographic limestone; in this section the thickness is increased by faulting, but the zone is generally about	230
Limestone, very sandy, like top of formation but not cross-bedded and rather easily weathered	4
Limestone, lithographic, pearl-gray, weathering white; very dense, hard, forming a single bed; nonfossiliferous; very regular and traceable for many miles; bare stone has normal outcrop width of 25 feet; this and the lower bed of lithographic limestone form a minor cuesta	1
Clay, buff, calcareous, soft; quickly removed from limestone below	1½
Limestone, lithographic, like bed above	⅔
Clay, pink to rose-colored, very soft, not bedded, disseminated gypsum, not sandy	37
Shale, blue, hard, thinly laminated, fissile; makes subordinate terrace, not sandy	¼
Clay, pink and rose-colored, very soft, not bedded, gypsiferous, not sandy	67
Gypsum, white, coarse grained, resistant to erosion	1
Clay and shale, interbedded pink, red, and blue, rapidly alternating in color and in resistance to weather; uniformly argillaceous, with much disseminated gypsum	29
Clay, bright red, with interlaminated gypsum; resembles in lithology the Chugwater formation	4
Shale, blue, as above	1
Limestone, olive-brown to black, crowded with pelecypods	⅔
Shale, blue-gray to olive-brown, well laminated, moderately resistant to erosion	5
Limestone, blue, weathering buff, dense, poorly bedded; 70 per cent evident shell fragments; along strike becomes sandy and less massive	3
Shale, olive-drab and blue, poorly exposed, with discontinuous thin limestones containing abundant pelecypods; this member is missing or not recognized at exposures north and east	18
Total thickness of Sundance formation	498

Erosional unconformity.
Chugwater formation.

The formation is here 150 feet thicker than it is in the average Big Horn Mountain section and is 60 feet thicker than the maximum in the Lewistown coal field,[32] to the north. In the Soap Creek field [33] wells have penetrated as much as 680 feet of the Sundance. The unusual thickness in this area may suggest that this was the site of a delta in Sundance time, but the unconformity above this formation makes very questionable any inference drawn from thickness alone.

Like the underlying formations, the Sundance occupies a zone along the west side and north end of the Pryor Mountains, ranging in width from 1 to 3 miles, depending on the dip and the thoroughness of the stripping of the soft clay from the dip slopes of the Chugwater and Sundance cuestas.

The following fossils were collected from the lower 100 feet of the formation and were identified by J. B. Reeside, jr.:

Camptonectes sp.
Dosinia jurassica Whitfield.
Lima? sp.
Mytilus cf. M. whitei Whitfield.
Ostrea sp. undet.
Serpula? sp.
Tancredia inornata Whitfield.

From the upper two-thirds of the formation the following forms were procured and have been identified by Mr. Reeside:

Belemnites densus Meek and Hayden.
Camptonectes bellistriatus Meek and Hayden.
Eumicrotis curta Hall.
Gryphaea nebrascensis Meek and Hayden.
Lima occidentalis Hall and Whitfield.
Ostrea sp.
Trigona sp.

The Sundance is of Upper Jurassic age, as shown by its fossil content. It is correlated with the Sundance of the type locality of the formation in the Black Hills and with the Ellis formation of central and northern Montana. It lies between two continental formations, is bounded by unconformities, and represents the invasion of the sea from the northwest in late Jurassic time.

CRETACEOUS (?) ROCKS

MORRISON FORMATION

The Morrison formation is a distinctive series of fresh-water and continental sandstones, shales, and clays that extends at least from the Lewistown coal field southward beyond the type section at Morrison, near Denver, Colo.[34]

In the area here under consideration the Morrison is distinguished by its light-colored but not bright clay and shale and yellow sandstone. Tints of red, yellow, green, and rarely purple are charac-

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[32] Calvert, W. R., Geology of the Lewistown coal field, Mont.: U. S. Geol. Survey Bull. 390, p. 21, 1909.
[33] Thom, W. T., jr., op. cit., p. 40.
[34] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Pikes Peak folio (No. 7), p. 2, 1894.

teristic. In general, the formation here consists of two beds of sandstone separating three beds of clay or very soft shale. The upper and lower beds of clay are normally light yellow to yellow buff; the middle clay is varicolored, light green, purple, salmon, and light red. Soft yellow or white sandstones are interbedded with the clays and form the two prominent members that normally separate the formation into five parts. Pre-Cloverly erosion removed the upper shale in many places and even cut deeply into the upper sandstone, so that one or both of these members may be thin or absent. Probably the Morrison was deposited on a series of broad, coalescing flood plains or, less probably, it is of marsh and delta origin.

The absence of marine fossils and the presence of numerous pieces of petrified wood, bone fragments, and polished stones, which have been interpreted by some geologists as stomach stones of dinosaurs, indicate a continental origin for these sediments. The regular appearance of the two sandstones and three clays noted above, the approximately plane contacts between these members, their fine grain, and the rarity and shallowness of channels indicate widely meandering, sluggish streams if the sediments are not standing-water deposits. Current ripples and current cross-bedding, the absence of wave ripples, the presence of broad, shallow channels, and the poor development or absence of lamination in the clays are all characteristic of alluvial materials.

The sandstone at the top of the Sundance formation changes—gradually at some places, sharply at others—from the typical olive-brown sandstone of the Sundance to the normal light-yellow or yellow-buff sandy clay of the Morrison. This clay is poorly bedded or massive, contains a considerable amount of sand in grains as much as 0.3 millimeter in diameter, and ranges in thickness from 35 to 75 feet.

Above the clay is the lower sandstone, whose thickness ranges from 12 to 30 feet. Stream cross beds dipping as much as 18° at the top curve gently to tangency with horizontal bedding. The sand grains range from 0.1 to 1 millimeter in diameter, the cementing material is poor or lacking, and the rock is little harder than the adjacent clays.

Soft, unconsolidated variegated sandy clay that ranges in thickness from 30 to 50 feet forms the middle member. Sand is abundant and forms discontinuous beds or lenses 4 feet or less in thickness. In contrast with the brilliant hues of the red Chugwater formation below and the variegated tints of the Cloverly clays above, the Morrison colors are pale and subdued. Yellow predominates, but tints of pink and salmon are common and light green and blue appear in many places. Deep red, purple, and black are absent. Bedding is poorly developed, as is common in alluvial deposits. Some stream channels have been identified in the middle clay.

Where fully developed the upper sandstone of the Morrison is from 15 to 90 feet thick and averages 70 feet. Except for greater induration it is similar to the lower sandstone. Current cross-bedding is better developed than in any other member, and a fluvial origin seems practically certain. A clay parting divides this member at many places so that it forms two sandstones, each 10 to 15 feet thick, separated by a clay that has a maximum thickness of 20 feet.

The upper clay is similar to the soft yellow lower clay and has a maximum thickness of 60 feet. Like the lower clay, it contains some light-green and pale-red sandy clays, but these colors are largely confined to the middle member. As in the other Morrison clays, bedding is obscure, induration is slight, and exposures poor except where erosion is rapid.

The Morrison forms a rolling lowland on the back slope of the Sundance and produces sharp bluffs under the overlying conglomerate member of the Cloverly formation. Where not included in such a scarp both main sandstone beds develop low ridges or benches, the upper member forming the more prominent feature. As in the Sundance, the sandstone is hard only by comparison with the associated clays so that the Morrison topography is distinctly undulating but not rough.

The thickness of the formation ranges from 160 to 254 feet in this area, which is about the average range in thickness in adjacent areas. The following section, which was measured at a locality just east of the area shown on Plate 1, is typical for this region.

Section of the Morrison formation in north bank of Poplar Creek, in NE. ¼ sec. 25, T. 4 S., R. 25 E.

	Feet
Cloverly formation.	
Distinctly channeled erosional unconformity.	
Morrison formation:	
Upper clay and sandstone missing.	
Clay or soft shale, yellow-buff, grading to red above; indefinite bedding	25
Sandstone, yellow-buff, weathering brown, distinctly stream cross-bedded; largest grains 1.5 millimeters in diameter; resistant below, grading to softer pink sandy shale in upper 1 foot	5
Clay, with lenses of sandstone, both yellow, weathering gray-white; poor bedding, incoherent (middle clay)	30
Sandstone, buff, weathering gray-white, fine grained; steep stream cross beds, with much intercalated yellow clay (lower sandstone)	30

	Feet
Morrison formation—Continued.	
Clay, yellow, pale red, blue, green, and dull purple, with very minor amounts of interbedded thin yellow-buff sandstone (lower clay)	70
Contact covered.	
Total thickness of Morrison formation	160
Sundance formation (olive-brown sandstone).	

Like the lower formations, the Morrison crops out along the west and north sides of the Pryor Mountains. Because of its thinness and softness the outcrop is narrow, ranging from 200 feet to half a mile in width. Some of the beds lie on the back slope of the Sundance cuesta, but most of them occupy a narrow lowland in front of the Cloverly scarp and the lower slopes of the scarp itself.

This formation is tentatively classified by the United States Geological Survey as Cretaceous (?), but it was formerly referred to the Jurassic, and many paleontologists now believe that its large vertebrate fauna is more closely related to Jurassic than to Cretaceous faunas. A distinct erosional unconformity of low relief marks the contact with the Sundance, and one of sharp relief was developed by the pre-Cloverly erosion.

CRETACEOUS ROCKS

CLOVERLY FORMATION

Name and character.—Darton [35] proposed the name Cloverly for a series of coarse sandstones and variegated clays that occur near Cloverly, Wyo., on the west side of the Big Horn Mountains. This formation has been traced into the area considered in this report, where it maintains the general character that it has in the type locality but is thicker and contains coarser material.

In this area three distinct members appear, comprising at the base a thick irregular mass of black chert conglomerate and tawny yellow sandstone; in the middle a series of brilliant variegated clays and mudstones, including much andesitic agglomerate and a very lenticular coarse brown sandstone; and at the top the Greybull sandstone member, named by Hewett and Lupton.[36] The Greybull member consists of about 60 feet of rusty fine-grained sandstone and sandy shale and constitutes the expansion of a few feet of sandstone at the top of Darton's type Cloverly.

Darton suggested the correlation of the lower conglomerate zone with the Lakota sandstone of the Black Hills, the bright clays with the Fuson formation of the same region, and possibly the upper

[35] Darton, N. H., Comparison of the stratigraphy of the Black Hills, Big Horn Mountains, and Rocky Mountain Front Range: Geol. Soc. America Bull., vol. 15, p. 398, 1904

[36] Hewett, D. F., and Lupton, C. T., Anticlines in the southern part of the Big Horn Basin, Wyo.: U. S. Geol. Survey Bull. 656, p. 19, 1917.

sandstone with the Black Hills Dakota sandstone, but because there was nothing in the section strictly comparable with the Dakota, although that formation was believed to be represented, it seemed necessary to treat the sediments as a single formation under the name Cloverly. In the area here described the Greybull is sharply distinct from the underlying clays. It is partly of fluvial origin, but the upper bench-forming sandstones are wave ripple-marked and very regular and indicate the definite establishment of marine conditions, which were continued uninterruptedly in the succeeding black shale. The Greybull is here separately mapped. (See pl. 1.) The shale that lies above the conglomerate of the Cloverly is as distinct from the conglomerate as it is from the Greybull, and it was mapped as an independent unit, but the introduction of a new name for it is not now deemed advisable.

The basal Cloverly consists of fluvial conglomerate and yellow sandstone. A study of 600 pebbles from the basal conglomerate showed 94 per cent of black chert, 2 per cent of limestone, 3 per cent of blue-gray quartzite, and 1 per cent of granite, pegmatite, and orthoclase. Except for the igneous material, the pebbles are all from the Madison or Amsden formation. These pebbles are set in a matrix of tawny-yellow sandstone. Similar sandstone is interbedded with the conglomerate and probably constitutes 65 per cent of the member. Most of the pebbles are less than an inch in diameter, but on the bottom of several channels 4-inch boulders occur. That the basal conglomerate was deposited by vigorous streams is indicated by the torrential cross-bedding, the occurrence of well-defined channels cut into the upper part of the Morrison, the contemporaneous channeling of the conglomerate, which was then a gravel, and the rapid lateral gradation into coarse sandstone. The cross beds in this formation in most places dip eastward, and the amount of gravel decreases rapidly both north and south from this area. Probably this conglomerate zone indicates a land mass to the west in Cloverly time and perhaps marks the general course of an eastward-flowing, fan-building stream.

Above the coarse sand and gravel bright red, green, purple, blue, yellow, and dull-black clays were deposited. These clays present the most brilliant and also the most varied colors to be seen in the area. They are normally sandy, rarely laminated, and repeatedly channeled, so that they can not be traced horizontally or correlated. None of the black clays contain coal, although coal has been found at this horizon both in the Big Horn Basin in Wyoming and to the northwest, near Great Falls.[37] Most of the argillaceous material is clay

[37] Fisher, C. A., Southern extension of the Kootenai coal-bearing formation: Econ. Geology, vol. 3, pp. 77–99, 1908.

or mudstone, and very little is properly called shale. Much of the clay swells like bentonite when wet and forms a gumbo mud, which is porous and collapses under pressure after drying. Lenses of dark-green andesitic sand and thin layers of bentonite, a thoroughly weathered volcanic ash, appear in some sections as evidence of early Cretaceous volcanic activity. Highly polished, well-rounded stones, which some geologists hold are gastroliths, are so amazingly abundant that if they are actually stomach stones either many thousand reptiles died per square mile or the animals were in the habit of disgorging and changing their digestive equipment. If each set of stones marks the death of an animal, accumulation of the clays must have been very slow. Bone fragments, although present, are not common in these beds. Most of the stones are pink and white quartzite, unknown in place or in the Cloverly gravel in this area; black chert is much less common. According to T. W. Stanton these facts suggest that these stones are probably not stomach stones, but that they were transported and polished in some other way as yet unexplained.

A very lenticular, coarse, soft brown sandstone is present at many places about 30 feet below the top of the clay. This sandstone ranges from a feather edge to 60 feet in distances of 1,000 feet. It would make an excellent oil reservoir, but because of its irregularity many wells would not encounter it.

Topographic expression.—The conglomerate and sandstone are very resistant, forming bare rock ledges or hogbacks, facing the Morrison lowland below. (See pl. 3, *A*.) With the underlying clay and sand, these hogbacks rise sharply 75 to 150 feet. Erosion quickly strips the typical clay from the hogbacks and forms badlands on the long back slope toward the Greybull scarp. The lenticular sandstone forms cliffs along the headwaters of Fivemile and Cottonwood Creeks, in Tps. 4 and 5 S., Rs. 24 and 25 E. Because the conglomerate is the most resistant rock in the entire area, large blocks have slumped down and rest in diverse attitudes on the Morrison and Sundance formations, in some places more than a quarter of a mile from the present formation boundaries. At many places the Morrison slope beneath the Cloverly is literally covered with masses of conglomerate.

Thickness and section.—The conglomerate-sandstone member ranges from 20 to 95 feet in thickness but averages about 45 feet. The clay member ranges from 90 to 240 feet and averages 180 feet. Complete sections are rarely exposed because of the rapid slumping of the clays. The following section illustrates the general character of the member, but because of the rapid lateral variation of these continental clays a section measured within a mile of this point is radically different.

Section of the clay member of the Cloverly formation in the SE. ¼ sec. 31, T. 4 S., R. 25 E.

	Feet
Greybull sandstone member.	
Clay member, contact covered:	
Covered; apparently variegated sandy clay	22
Clay, brown, weathering black, with manganese grains, and rusty	19
Clay, light gray	21
Clay, brownish-red to brick-red; covered with alkaline efflorescence	16
Clay, gray to white; not well exposed	10
Clay, red to red-brown; badlands develop on erosion	16
Clay, gray; not well exposed	3
Covered to top of conglomerate	80
	187

All the clay in the above section is massive and structureless, soft, and easily eroded, and most of it shrinks greatly on drying, forming large deep cracks in the surface.

Greybull sandstone member.—The Greybull sandstone member was named from its occurrence at Greybull, Wyo., about 50 miles south of this area. The Greybull member was deposited during the transition from continental to marine conditions in this area, and thus includes the first marine strata above the Sundance. Its exact time equivalence is difficult to determine, for its contains no fossils except worm trails, but its stratigraphic position suggests that it may be the approximate time equivalent of the so-called Dakota sandstone of the Black Hills.

The Greybull consists of interlaminated brown quartz sandstone and sandy shale. Its sand grains are 0.4 millimeter or less in diameter. Except near the base cross bedding and channeling are not found, but wave ripple marks and uniform lamination occur throughout the formation. Because of its fine grain and clay content, the rock is not very porous and is probably not a very favorable reservoir for oil and gas, as compared with the Cloverly sand below or the Frontier and Montana sands above.

Although the sandstone is thin bedded and shaly, it is fairly well cemented with limonite and makes a distinct escarpment by protecting the underlying clay member. This bench is rarely 200 feet high and is only a minor interruption in the long slope from the conglomerate member of the Cloverly to the imposing Mowry ridge farther west or north.

The thickness that should be assigned to the Greybull is a matter of uncertainty, for it grades into the overlying black shale. Its top is drawn at the base of the first black shale, a horizon which also marks the top of the escarpment. According to this definition the thickness of the Greybull is 50 to 60 feet.

Areal distribution.—The Cloverly formation crops out, as shown on the geologic map, in a band half a mile to 3 miles wide along the west and north sides of the Pryor Mountains.

Age and relations.—As already indicated, the Cloverly formation is classified as Lower Cretaceous, though it may include some early Upper Cretaceous beds at the top. A deeply channeled erosional unconformity separates it from the Morrison, but it apparently passes without interruption into the overlying Thermopolis shale.

COLORADO GROUP

The Cloverly formation is overlain by about 2,400 feet of dark marine shale and sandstone of Colorado age. In central Wyoming the Colorado group contains numerous sandstones and is readily differentiated into the Thermopolis, Mowry, Frontier, Carlile, and Niobrara formations. The amount of sand decreases to the north, and the group there consists predominantly of black shale. Even within the small area considered in this report a marked decrease in the thickness and porosity of the sand is apparent as the beds are traced northward. Unlike the underlying systems and the overlying Montana group, the Colorado strata indicate practically uninterrupted marine conditions, and accordingly continental sediments and contemporaneous subaerial erosional results are absent, except in the thin sandstone in the Thermopolis shale.

THERMOPOLIS SHALE

Lower shale member of Thermopolis shale.—The Greybull sandstone member of the Cloverly formation passes imperceptibly upward into rusty sandy shale and interbedded black shale. On a weathered exposure the rusty beds are prominent, but fresh surfaces show that the less resistant black shale predominates. The sandy shale passes upward into a uniform body of regular, thin-bedded, fissile carbonaceous shale, which is identical in appearance and character with the upper shale member of the Thermopolis above and joins with it in the long slope back of the Greybull escarpment. In a few places a sandstone makes a minor hogback with the lower shale member, forming the scarp below, but in general the shale forms the lowland between the Greybull and Mowry bluffs. The thickness of the lower member is uniform, ranging from 260 to 280 feet wherever measured in this area and in the Crow Reservation to the east.[38]

[38] Thom, W. T., jr., unpublished notes.

Because of its softness no detailed section could be measured, but the following generalized section indicates the essential characteristics:

Generalized section of lower shale member of Thermopolis shale

	Ft.	in.
Thermopolis shale:		
Sandstone member ("Muddy sand" of drillers).		
Lower shale member:		
Black, fissile shale, marine, with here and there half-inch layers of sandstone and two very thin layers of bentonite	170	
Interbedded black fissile shale, as above, and rusty sandy shale in beds as much as 2 inches thick	40	
Marcasite concretions, chiefly replaced by calcium phosphate		2
Rusty sandy shale, thin sandstone, and subordinate amounts of hard black shale	30	
Rusty thin-bedded, wave-rippled sandstone making very small hogback	3	
Rusty sandy shale, thin sandstone, and subordinate amounts of hard black shale; the lower 100 feet of this section has been commonly called "the rusty beds"	27	
Total thickness of lower shale member of Thermopolis	270	

As indicated above, the lower member of the Thermopolis shale occupies a strip from 500 to 2,500 feet wide on the back slope of the cuesta of the Greybull sandstone and in the lowland in front of the escarpment of the Mowry and Thermopolis formations. It is conformable with the underlying Greybull sandstone, which grades almost imperceptibly into it. The overlying sandstone (so-called "Muddy sand" of the drillers) is stream or current laid in channels cut in the top of the shale and spread over the general shale surface. The erosion interval separating the two is probably very short.

Sandstone member of Thermopolis shale.—Above the lower shale member a persistent thin fluvial or current-deposited sandstone occurs, which is correlated by some geologists with the "Muddy sand" of the drillers in Wyoming oil fields. The sandstone is normally coarse grained to pebbly, differs greatly in thickness within short distances, and contains much organic débris in the form of plant fragments, fish teeth, and bits of bone and turtle shell. The coarser and thicker portions of the member lie in steep-sided channels cut 10 to 30 feet into the top of the underlying shale. The uniform occurrence of the sandstone as a thin sheet over the surface between the channels suggests that the sand was deposited on a barely submerged mud flat over which streams of considerable size meandered.

The sandstone makes a low bench or terrace in front of the Mowry escarpment, which is very persistent. This terrace has been traced through the western part of the Crow Reservation and in the northern part of the area described in this report, but is missing in some of the southern part. The thickness of the sandstone ranges from a few inches to 30 feet, and detailed sections are accordingly of little value. Rapid lateral change in the stream deposits makes it impossible to trace individual beds for a distance as far as 50 feet.

Lee [39] has expressed the opinion that a corresponding sand in Wyoming, known as the "Muddy sand," is the upper member of the Dakota. This is also the opinion of the present writers.

Upper shale member of Thermopolis shale.—The Thermopolis shale is the oldest of the series of marine black shales and associated sandstones which here constitute the Colorado group of the Upper Cretaceous. The deposits of Benton (lower Colorado) age in this area are subdivided into the Thermopolis, Mowry, Frontier, and Carlile formations. The type section of the Thermopolis is near the town of that name in Wyoming, 120 miles south of this area.

Black or dark blue-gray shales constitute the bulk of the upper member of the Thermopolis in the area here considered. At the top the member becomes more sandy and grades into the Mowry shale. Several persistent beds of greenish-yellow bentonite are present and are excellent key beds for detailed geologic mapping. Most of the clayey material forms well-laminated shale, but beds of gray alkaline clay are numerous in the central portion. This clay swells on wetting and shrinks greatly on drying, and partly because this contraction exposes plant roots little vegetation grows on these beds. Although the clay is especially barren, the formation as a whole does not support abundant vegetation, probably because of the general alkalinity and imperviousness of the strata.

In general the outcrop area of the Thermopolis shale forms a lowland beginning on the back slope of the Greybull cuesta, and the upper part of the formation is exposed in the steep 300 to 400 foot bluff beneath the outcrop of the overlying Mowry shale.

The thickness of the upper member of the formation within this area ranges from 400 to 460 feet. The following section indicates its character. As it is a widespread quiet-water deposit, some beds of the section can be identified many miles from this locality.

[39] Lee, W. T., Continuity of some oil-bearing sands of Colorado and Wyoming: U. S. Geol. Survey Bull. 751, pp. 1–22, 1923.

Section of the upper member of the Thermopolis shale in secs. 30 and 31, T. 6 S., R. 24 E.

	Feet
Mowry shale.	
Thermopolis shale:	
Shale, black	18
Sandstone, buff; makes small bench	1
Shale, black, sandy; weathers buff	25
Bentonite	1
Sandstone, brown, shaly	2
Shale, black, and buff shaly sandstone, interbedded; not well exposed	109
Shale, black, with scattered manganiferous siderite-calcite concretions	20
Bentonite	1
Shale, black, with siderite concretions	38
Shale, gray and black, separated by 12 persistent beds containing siderite concretions	68
Shale, black, with four interbedded bentonite beds, each of which makes a small terrace	78
Shale, sandy, gray to black; weathers buff; has many interbedded layers of concretions	21
Clay, gray, with three bentonite beds, one 14 inches thick	25
Total thickness of upper member of Thermopolis shale	407
Sandstone member of Thermopolis shale.	

MOWRY SHALE

A group of sandstones and shales that weather gray or buff, in the lower part of what was then called Benton shale, was designated Mowry by Darton.[40] The outcrop of this group is so striking in topography and color and the beds contain fish scales so unfailingly that they constitute one of the best-known and most reliable horizon markers in the northern Great Plains. The Mowry consists of interbedded black shale and gray sandstone and sandy shale. On weathering the sandstone bleaches to a distinctive silver-gray and the sandy shale becomes gray or buff. Fragments of the sandstone and sandy shale, which accumulate as the less resistant shale is removed by rain and wind, cover dip slopes and crown an escarpment that is a veritable landmark for the geologist. In southern Montana about 5 feet of the sandstone has been thoroughly cemented to quartzite, and at many places this stratum projects as an overhanging ledge along the Mowry escarpment. The amount of shale is usually underestimated, because fresh exposures are not common, and weathering and erosion leave a residue of sandstone or quartzite on the surface.

[40] Darton, N. H., Comparison of the stratigraphy of the Black Hills, Big Horn Mountains, and Rocky Mountain Front Range: Geol. Soc. America Bull., vol. 15, p. 400, 1904.

Almost invariably the Mowry is found as the cap rock of a cuesta, forming the crest of its scarp 200 to 400 feet above a lowland and making a smooth back slope with sandy soil. Where streams cut through the quartzite, however, they develop box canyons that in some places have overhanging walls. Between Bridger and the mouth of Cottonwood Creek several streams, which were originally established on the Tertiary(?) erosion surface, described on page 4, have maintained a course diagonally down the dip and have eroded characteristic steep-walled, narrow canyons in the Mowry slope.

The contact with the underlying Thermopolis shale is gradational and is taken at the horizon where the black shale of the Thermopolis becomes predominantly gray or drab. Probably in different regions this contact has been placed at somewhat different horizons, depending on the exposure and the judgment of the geologist. Thicknesses measured range from 180 to 325 feet, which is about the same as reported from the Eastern Crow Reservation and about the maximum reported in the Big Horn Mountains. For mapping the heavy quartzite in the Mowry is easier to take as a base, and some geologists have used this bed.[41] The advantages from the point of view of the field man are obvious, but this assigns to the Thermopolis some beds that are faunally and lithologically similar to the Mowry.

The following section was compiled from measurements in sec. 31, T. 6 S., R. 24 E. At no place is the formation completely exposed within a short horizontal distance.

Section of the Mowry shale in sec. 31, T. 6 S., R. 24 E.

	Feet
Frontier formation, Peay sandstone member.	
Mowry shale:	
Clay, gray, soft, largely covered	10
Clay, black, gummy, similar to bentonite; alkaline springs are common	11
Sandstone, drab or gray, quartzitic, and black shale, repeatedly alternating	35
Quartzite, drab, thin bedded; weathers silver-gray to dirty white; this is the scarp-forming member	4–5
Shale, sandy, drab, and black shale, interbedded; not more than 25 per cent of black shale	205
Total thickness of Mowry shale	266
Thermopolis shale.	

The Mowry is exposed in an irregular strip from half a mile to many miles wide that stretches northeastward across the area here described.

[41] Bauer, C. M., and Robinson, E. G., Comparative stratigraphy in Montana: Am. Assoc. Petroleum Geologists Bull., vol. 7, p. 170, 1923.

Fish scales that range from 0.25 to 1.5 inches in diameter and a few fish teeth are found in the sandy shale of this member throughout the northern Great Plains. The Mowry is about middle Graneros (lower Benton) in age and grades vertically into the adjoining formations, the Thermopolis below and the Frontier above.

FRONTIER FORMATION

The type section of the Frontier [42] is near the town of that name, in southwestern Wyoming, where the formation includes over 2,000 feet of sandstone, shale, and coal. In the area here considered the formation is definitely marine, and most of it is very fine grained, but the term has been generally applied to strata at this horizon and will be used here for beds of upper Graneros and Greenhorn age.

Black shale, brown sandy shale, and heavy sandstone compose the formation in this area. In the southern part the thin Peay sandstone member lies near the base and the heavy yellow-brown Torchlight sandstone member, resembling the Virgelle sandstone member of the Eagle, marks the top. To the north the lower sandstone thins out and completely disappears in the region south of the Yellowstone River. In the area to the north the Torchlight member also is thinner and less prominent topographically, but it can be traced into the Crow Reservation southeast of Billings. Farther east the Frontier and Carlile are so similar that they have not been positively separated.

In the southern part of the area the outcrop of the Peay sandstone member forms a small hogback in the lowland between the high scarps of the Mowry and the massive Torchlight member. Part of the intervening shales underlie the lowland, and the remainder form the steep slope below the cliff of the Torchlight sandstone member. In this region the Torchlight sandstone forms a solid vertical wall that is unscalable at many places. Northeast of Silesia the alluvium of Clark Fork and the Yellowstone River conceals the Frontier formation, but farther east the formation reappears as a scarp former, though the cliffs are not so high as those in the southern part of the area.

About 420 feet of the Frontier formation is present in the southern part of the area, as compared with 410 feet in the eastern part of the Crow Reservation and 450 to 550 feet in the Elk Basin,[43] to the south.

The following section is fairly representative of the southern part of the area, but, as already noted, much less sand occurs in the formation in the northeastern part of the area.

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[42] Knight, W. C., Coal fields of southern Uinta County, Wyo.: Geol. Soc. America Bull., vol. 13, p. 543, 1903.

[43] Hares, C. J., unpublished notes.

Section of the Frontier formation in secs. 35 and 36, T. 6 S., R. 23 E., and the SW. ¼ sec. 31, T. 6 S., R. 24 E.

	Feet
Carlile shale.	
Frontier formation:	
Sand, buff to rusty, coarse, poorly cemented, basal 40 feet makes vertical cliff, upper part less resistant, all lithologically similar to the Virgelle sandstone member of the Eagle; concretions of sandstone with calcite cement, 6 inches to 3 feet in diameter in base of sandstone (Torchlight sandstone member)	76
Clay, sandy, gray-buff, rapidly eroded	24
Shale, sandy, buff, and argillaceous black shale, with thin sandstone beds in some places	180
Sandstone, gray-buff, grains 0.5 to 1 millimeter in diameter, resistant, ledge former	½
Shale, carbonaceous, black, almost lignitic, with several 1 or 2 inch sandstone laminae and abundant thin flat gypsum plates 1 inch square	48
Sandstone, gray-buff, coarse, persistent through southern part of area here described	3
Shale, sandy, light brown	21
Sandstone, yellow-brown, lenticular; single bed	2
Shale, sandy, light brown to buff	17
Shale, blue-gray, argillaceous	3
Clay, dark gray, bentonitic	1
Shale, gray-black, slightly sandy, including 2-inch black chert-pebble conglomerate as in Peay sandstone member below	14
Clay, dark gray, bentonitic	6
Bentonite, yellow-gray	½
Clay, ash-gray, with much biotite, apparently volcanic ash	1
Clay, dark gray, gummy; swells when wet; cracks deeply on drying	10
Sandstone, gray, with black chert pebbles scattered in the sand; pebbles lithologically similar to but better rounded than those at the top of the Eagle sandstone; this is the Peay sandstone member and forms a minor bench about 25 feet high	11
Total thickness of Frontier formation	418
Mowry shale.	

A few fragments of fish skeletons were found in the sandy shale. Abundant specimens of *Inoceramus fragilis* Hall and Meek were identified by Mr. Reeside from the base of the Torchlight sandstone member. From its stratigraphic position the Frontier is known to include the equivalents of the upper part of the Graneros shale, the Greenhorn limestone, and possibly part of the Carlile shale, all of which are of Benton age. Both inclosing formations are conformable, marine, and lithologically somewhat similar but finer grained.

CARLILE AND NIOBRARA SHALES

The Carlile and Niobrara shales are represented in southern Montana by black shale that contains a little sandy shale and numerous persistent layers of black siderite concretions. The shale of the two formations could not be distinguished by the authors. Because of the nonresistant and uniform character of the beds they form a broad, low, gently rolling valley between the escarpments of the Telegraph Creek formation and the Torchlight sandstone member of the Frontier formation. Where the sandstones of the Frontier are wanting, dark or black shale occupies the interval between the ridges of the Mowry and Telegraph Creek formations, and the separate formations have not been distinguished.

Two measurements of the formations as exposed at the surface give thicknesses of 1,060 and 1,140 feet, though the measurements are not altogether satisfactory, owing to poor exposures. In the Rock Creek well of the Hoosier Oil Co., in sec. 8, T. 4 S., R. 23 E., the thickness is apparently 1,180 feet, and the Dry Creek well of the Empire Co., in sec. 14, T. 7 S., R. 22 E., shows 1,230 feet.

The following partial section indicates the character of these formations:

Section of the Carlile and Niobrara shales in Tps. 1 and 2 S., R. 27 E.

	Feet
Telegraph Creek formation.	
Niobrara and Carlile shales:	
Shale, dark, soft; not well exposed	645
Sandstone, red, hard, calcareous; forms chips	¼
Shale, dark, carbonaceous	3
Sandstone, like that above	¼
Shale, dark, carbonaceous	9¼
Limestone, yellow, hard	1
Shale, carbonaceous, dark	20
Bentonite	4
Shale, dark	30
Shale, dark, poorly exposed	380
Shale, dark	21
Shale, dark, containing yellow calcareous concretions	5
Shale, dark, carbonaceous	15
Total thickness of Niobrara and Carlile shales	1,140
Frontier (?) formation (sandy zone, probably represents Torchlight sandstone member).	

MONTANA GROUP

The Montana group records a time of oscillating shore lines, when deposition occurred alternately under marine and continental conditions. Of the several formations in the group the Telegraph Creek, Claggett, and Bearpaw formations are nearly or entirely marine; the Eagle sandstone is partly marine but largely continental; the Lennep sandstone is chiefly shallow water or fluviatile; and the Judith River formation consists of fresh-water and brackish-water deposits.

TELEGRAPH CREEK FORMATION

At the base of the Montana group beds of yellow sandy shale and sandstone carrying a mixed Montana and Colorado fauna constitute the Telegraph Creek formation, which is typically developed 10 miles southeast of Billings.[44]

The formation is exposed in an irregular belt that is less than a mile wide at most places. A hard sandstone, here mapped as the base of the formation, makes a well-marked terrace in front of the towering escarpment of the Eagle sandstone. This escarpment has been given the local name "rim rock." The upper softer shales of the Telegraph Creek form the lower part of the Eagle escarpment and are usually hidden by talus and slide rock.

The interval from the base of the heavy sandstone (which Thom described as the middle of the Telegraph Creek formation) to the base of the Eagle is fairly uniform, all measurements giving results between 150 and 171 feet. Hancock[45] reports 115 feet at one point in the Lake Basin area, to the north and 169 feet on Canyon Creek. Thom[46] gives a thickness of 320 feet to the formation, including about 160 feet of the beds underlying the sandstone. The indefiniteness of this base in the area described in this report—for there is no lithologic change, and fossils are very rare in this area—led the present writers to map the base of the heavy sandstone as the bottom of the formation.

Thom[47] separated the Telegraph Creek from the adjacent formations above and below because it contains a fauna comprising both Montana and Colorado elements. Hancock[48] had earlier collected unidentified forms from it that were reported as probably of Colorado age.

The following fossils collected from the Telegraph Creek formation in the SW. ¼ sec. 30, T. 1 S., R. 24 E., during the present study were identified by J. B. Reeside, jr.:

Inoceramus aff. I. lobatus Goldfuss.
Lucina, n. sp.
Baculites ovatus Say var.
Inoceramus sp.?, thick shelled.
Baculites, sp. undet.

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

[45] Hancock, E. T., Geology and oil and gas prospects of the Lake Basin field, Mont.: U. S. Geol. Survey Bull. 691, p. 113, 1918.

[46] Thom, W. T., jr., op. cit.

[47] Thom, W. T., jr., op. cit., p. 38.

[48] Hancock, E. T., Geology and oil and gas prospects of the Lake Basin field, Mont.: U. S. Geol. Survey Bull. 691, p. 113, 1918.

Baculites ovatus Say var. was also collected in the NW. ¼ sec. 31, T. 5 S., R. 23 E., about 5 feet below the main sandstone. Reeside states: "These forms are of Montana age. The form *Inoceramus* aff. *I. lobatus* Goldfuss is known only from the Telegraph Creek."

So far as paleontologic evidence is available the formation is transitional between Colorado and Montana in age, and it is here placed in the Montana because of its close lithologic affiliation with the overlying Eagle sandstone. The Telegraph Creek marks the arrival in the sea of the sand which was later to come in much greater quantity and form the coastal plain during Eagle time.

The Telegraph Creek is conformable with the Niobrara shale below and the Eagle sandstone above and grades into each of them.

EAGLE SANDSTONE

Weed [49] described and named the Eagle sandstone from its exposures along the Missouri River near Eagle Creek, in Chouteau County, Mont. In southern Montana the Eagle consists of thick, massive sandstone above and below, with an intermediate zone of sandy shale and soft sandstone. The most valuable coal of this area occurs in the upper part of the shaly member. Massive light-gray or buff sandstone forms the lower sandstone and is so characteristic from Wyoming to the Canadian line that it has been separately designated the Virgelle sandstone member [50] of the Eagle sandstone, from the town of Virgelle, Mont., 10 miles northwest of the type section of the Eagle. In the area described in the present report the Virgelle has a thickness ranging from 60 to 140 feet and is a very prominent topographic feature.

The last and most conspicuous of the cuestas formed by the moderately dipping sediments surrounding the Pryor Mountains marks the outcrop of the Eagle sandstone. Benches develop on the harder members of the higher formations, but distinct cuestas do not appear, in some places because the stratigraphic distance to the next overlying resistant layer is small and the back slope is only cleared for a short distance and in other places because the resistant formation consists of alternating hard and soft strata, forming rough, irregular hills but not having the distinct scarp and plane upland of a cuesta. Beneath the Eagle the relatively soft Telegraph Creek formation and the shales of the Colorado group produce an imposing scarp and wide valley, whereas above the sandstone the Claggett beds are readily eroded. An abrupt cliff results, in which the Virgelle sandstone member towers 100 feet or more in vertical

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[49] Weed, W. H., U. S. Geol. Survey Geol. Atlas, Fort Benton folio (No. 55), p. 2, 1899.

[50] Bowen, C. F., The stratigraphy of the Montana group, with special reference to the position and age of the Judith River formation in north-central Montana: U. S. Geol. Survey Prof. Paper 90, p. 97, 1915. Also quoted by Stebinger, Eugene, idem, p. 62.

bluffs of pale yellow-brown sandstone above the lowlands of the Yellowstone River and Clark Fork. The "rim rock" is the popular designation for this scarp, which partly surrounds Billings, Park City, and the intermediate area. The shaly central member of the Eagle formation interrupts the bluff, and the upper part, formed by the top sandstone, is set back, step fashion, behind the cliff of the Virgelle sandstone. Along most of their length, the scarps of the Eagle are unscalable, and at many other places they can be climbed only with difficulty.

Within this area the thickness of the Eagle sandstone ranges from 200 to 250 feet and averages about 210 feet. Individual members differ considerably from place to place, but inversely, so that a nearly uniform total is maintained. In the southern area the Virgelle sandstone member is not over 60 feet thick, and correspondingly the middle shaly zone increases to about 170 feet; in the northeastern area the shale amounts to less than 30 feet and the Virgelle member expands to 140 feet.

The following section illustrates the character of the Eagle in the southern part of the area:

Section of the Eagle sandstone in SE. ¼ sec. 15, T. 7 S., R. 23 E.

Claggett formation.	
Eagle sandstone:	Feet
Sandstone, buff, grains 0.3 to 0.7 millimeter in diameter; weathers dark brown	8
Clay, gray and carbonaceous, interbedded, sandy	15
Sandstone, buff-brown, fairly well bedded	10
Shale, carbonaceous, with several thin sandstone beds	18
Coal, good quality, bituminous	1⅔
Shale, carbonaceous, sandy	46⅓
Sand, buff, coarse, soft and easily eroded	10
Clay, carbonaceous and gray, interbedded; not well exposed	82
Sandstone, gray-white, fresh, light rusty yellow weathered, deep brown on joint planes, massive; forms cliff from which lower part breaks out, making caves; the Virgelle sandstone member	58
Thickness of Eagle sandstone	249
Telegraph Creek formation, carbonaceous sandy shale.	

North of the Yellowstone River, in T. 1 S., R. 23 E., black chert pebbles occur in a thin sandstone at the top of the Eagle. Hancock [51] noted that these pebbles do not form a gravel bed but are embedded in a sand matrix and that they are commonly flattened in one direction. In an effort to determine the origin of this form the junior

[51] Hancock, E. T., Geology and oil and gas prospects of the Lake Basin field, Mont.: U. S. Geol. Survey Bull. 691, p. 115, 1918.

author cut several pebbles at right angles to the flat faces, polished the fresh surface, and searched for joint planes or other structures parallel to the large faces. In no pebble was any such structure found, and although the absence of joint planes does not prove that such surfaces did not originally bound the pebble, it suggests that these pebbles were ground flat, as they lay on the bottom of a coastal body of water, by currents washing sand back and forth, cutting the exposed surface, much as wind-blown sand cuts boulders in desert areas (dreikanters). If a storm disturbed the relations, the pebbles would come to rest with the flat side down, the center of gravity so being lowest, and the opposite side of the pebble would then be ground. Whether or not this suggested explanation of the flattened faces is true, it seems probable that storm waves embedded the pebbles in the sand, for streams would have segregated them as gravel. The conditions here postulated are in harmony with the sedimentary history of the Eagle, for in this area it contains coal as evidence of clear water in places, marine fossils, wave ripple marks, and cross-bedding and grades into marine shale immediately above the pebbly zone.

Outcrops of the Eagle occupy an area half a mile to 3 miles wide, extending northward from Jack Creek. Although the outcrop is interrupted by alluvium along Clark Fork and also by faulting, it follows the west side of Clark Fork northward from a point 3 miles south of Bridger to Fromberg and continues northward, crosses the Yellowstone River west of Park City, swings around the north side of the Billings Basin, and crosses the river once more just east of Billings, where the Eagle lies on the northeast side of the Pryor anticline.

In this study only one fossil has been found in the Eagle, and this has been identified by Mr. Reeside as *Cardium speciosum* Meek and Hayden, a Montana form. The Eagle and Telegraph Creek are the basal formations of the Montana group. The Claggett formation, next to be described, was deposited upon the sand without interruption of sedimentation.

CLAGGETT FORMATION

The type locality of the Claggett formation is about 140 miles north of the area here described, near Judith, at the site of old Fort Claggett.[52] The Eagle and Judith River formations are chiefly coarse, fresh or brackish water delta deposits and may be considered wedges or tongues that project eastward and pass into Pierre shale. The beds of shale in the Telegraph Creek, Claggett, and Bearpaw

[52] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, p. 13, 1905.

formations are therefore the western marine extensions of the Pierre. As the Eagle and Judith River formations and the three other formations just mentioned are traced westward, continental or littoral sediments progressively replace the beds of marine shale, and the Claggett and Bearpaw wedge out westward and entirely disappear where the tuffaceous Livingston formation replaces the entire Montana group west of the Crazy Mountains. This relation makes very difficult the drawing of satisfactory formational boundaries over large areas. In the present study the base of the Claggett is taken at the contact between a soft gray shale and the underlying heavy buff sandstone which covers the coal bed in the upper part of the Eagle. The Claggett-Judith River boundary is taken at the base of a heavy, bench-forming gray to white sandstone, which shows beach cross-bedding and stream channels and above which no marine fossils were found, except in the Bearpaw. This sandstone was also taken by Hancock [53] as basal Judith River in the Lake Basin field, and Hares [54] made the same correlation in the area south of that here considered.

Although the Claggett formation in Montana is often described as a series of dark shales, in the area here under consideration the argillaceous material is a very soft shale and commonly a clay, of light to medium gray color. Light-gray or white sandstone composes 20 to 40 per cent of the formation in different exposures. Hancock [55] has noted the marked increase in sand content from northeast to southwest in the Lake Basin. In the area here studied the formation crops out along a generally northward-trending line, so that westward increase in sand is not shown, but southward the beds of sandstone increase in number until west of Fromberg 40 per cent of the Claggett consists of sandstone, whose ledges tower above the Virgelle sandstone and by comparison make it appear a minor ledge in the high bluffs. Farther south the percentage of sand decreases, and the beds are more characteristic of the typical Claggett. In addition to the massive soft sandstone at the base, the upper part of the formation is very sandy and is correlated, on the basis of stratigraphic position and lithologic character, with the Parkman sandstone. Shale predominates in the central part of the formation.

The soft gray sandstone is easily weathered and removed by erosive processes, and the shale is little more resistant than clay. Exposure tends to develop a gently rolling lowland, which slopes back from the Eagle outcrop to the conspicuous low range of hills at the Judith River boundary. As a rule, the surface of the Clag-

[53] Hancock, E. T., Geology and oil and gas prospects of the Lake Basin field, Mont.; U. S. Geol. Survey Bull. 691, p. 117, 1918.

[54] Hares, C. J., unpublished notes.

[55] Hancock, E. T., op. cit., p. 116.

gett formation is subdued and is very similar to that of the Bearpaw. Where erosion is rapid, however, the clay is removed much faster than the sandstone, and prominent ridges are produced. High bluffs, many of them unscalable, occur west of Bridger and Joliet and along the Yellowstone River southwest of Park City, where the formation is more arenaceous and where undercutting of the slope has developed cliffs.

The soft sandstones weather into smooth, rounded forms and afford a satisfactory means of distinguishing this formation from the Bearpaw, in which the sandstones are andesitic, hard, and dark green and produce sharp, flat-surfaced benches with bare clay slopes below. Where rapid erosion of the clay of the Claggett occurs, the overlying sandstones form bluffs 20 to 200 feet high. The upper sandstone normally weathers light gray to tan. (See pl. 4, *B*.) Along these cliffs the massive unjointed sandstone breaks along curved fractures, forming conspicuous and characteristic recesses or alcoves with roofs resembling gothic arches.

Sections measured in this area range from 550 to 675 feet, and the average is 625 feet. The following section is typical of the formation south of the Yellowstone River:

Section of the Claggett formation 2 miles southwest of Bridger, in sec. 32, T. 6 S., R. 23 E.

	Feet
Judith River formation.	
Claggett formation:	
Parkman sandstone member:	
Sandstone, shaly, soft, gray, with interbedded gray shale; not well exposed	280
Sandstone, gray, thin bedded; weathers yellow-brown to buff; forms beehive-shaped buttes	30
Thickness of Parkman sandstone member	310
Shale, sandy, gray; not well exposed	15
Sandstone, shaly, gray, soft	22
Shale, gray, sandy, with interbedded carbonaceous dark shale, but not lignitic	28
Sandstone, gray; weathers gray, in smooth, rounded forms; massive, with almost no trace of bedding	110
Shale, gray, soft	15
Sandstone, buff, with 20 per cent of shale interbedded	23
Shale, gray, fresh; weathers buff; sandy at some horizons, in many places so soft that it is only clay	129
Total thickness of Claggett formation	652
Eagle sandstone.	

Another section, measured along the Yellowstone River, is incomplete, but exposures are better and give more detail about the beds that are present.

Section of the Claggett formation in sec. 34, T. 2 S., R. 22 E.

	Feet
Erosion surface.	
Claggett formation:	
Parkman sandstone member:	
Sandstone, massive, light buff, soft, medium to fine grained, with cross-bedding of the beach type; upper 150 feet not exposed here	58
Sandstone, thin bedded, brown, hard; makes slight bench	2
Sandstone, massive, cross-bedded, buff, soft	60
Unexposed; apparently sandy	16
Approximate thickness of Parkman sandstone member	286+
Sandstone, massive, cross-bedded, light buff, hard; makes slight bench	1½
Shale, sandy, gray	3
Sandstone, thin and evenly bedded, light buff	2
Shale, sandy	2½
Sandstone, massive, even bedded; parted near middle by thin band of shale	6
Shale, dark, fine	3
Sandstone, light buff, even bedded	3
Shale, dark	2
Sandstone and interbedded shaly sandstone	30
Covered; probably shale or sandy shale	33
Sandstone, even bedded, hard, brown, medium grained, makes a minor bench	1
Shale	4
Thin sandstone and interbedded carbonaceous shale	8
Covered; probably drab shale	28
Sandstone, massive, light colored, rarely cross-bedded	45
Sandstone, thin bedded and interbedded with some shale	16
Shale, sandy	55
Sandstone, soft below but with a hard layer that forms a minor bench near the top	16
Covered; seems to be mostly sandstone and sandy shale	48
Covered; lowest 30 feet seems to be very sandy	55
Total partial thickness of Claggett formation	498
Top of Eagle sandstone.	

The Claggett is exposed in an irregular belt from half a mile to almost 4 miles in width between the Eagle scarp and the irregular, ragged front of the Judith River area, extending northward along the west side of Clark Fork and swinging east around the Billings Basin outside the present area.

The following fossils collected from the Claggett during the writers' field work have been determined by John B. Reeside, jr.:

Baculites compressus Say.
Baculites sp. undet.
Inoceramus sp.
Lucina occidentalis Morton.
Mactra formosa Meek and Hayden.
Modiola attenuata Meek and Hayden.
Scaphites nodosus Owen.
Tubes of a boring mollusk, undetermined.

The Claggett is a formation of the Montana group, and the fauna listed above consists of Pierre species, as is to be expected.

Associated with the marine fauna, the following plants, identified by F. H. Knowlton, were collected from the upper shales of the Claggett formation in the SE. 1/4 SW. 1/4 sec. 30, T. 5 S., R. 23 E.:

Sequoia reichenbachi (Geinitz) Heer.
Cunninghamites elegans (Corda) Endlicher.
Dammara acicularis Knowlton.
Ficus trinervis Knowlton.
Castalia stantoni Knowlton.

The occurrence of these land plants with the marine fauna probably indicates the burial in a near-shore sand bar of drift material from the land. The gradational relation of the Claggett to the Judith River, referred to above, is further emphasized by the association of the fossils. Regarding these forms Knowlton wrote:

> I am able to identify five species of plants with absolute certainty, and they are all known from the Judith River, several of them never having been reported previously at any other horizon. I do not recall any flora from the Claggett. The Claggett, being marine, is not likely to contain the remains of a land flora, though it is possible that in the extreme upper part conditions of sedimentation similar to those of the Judith River might be inaugurated. How ever, without any positive data to the contrary, I am constrained to refer these plants to the Judith River.

Although the Claggett is chiefly marine and the formations above and below are largely of fresh or brackish water origin, there is no evidence of intervening erosion. Deposition was probably continuous in this area from Eagle to Judith River time.

JUDITH RIVER FORMATION

The Judith River was originally named by Hayden,[56] who used the term "Judith group" for a series of chiefly continental sediments occurring in the "Judith Basin" on the Missouri River, near the mouth of the Judith River. In the type locality these beds are characterized by a large content of plant fragments, leaves, lignite beds, fresh and brackish water shells, and an unusual reptilian fauna.

In the area considered in this report the formation consists of alternating beds of sandstone and sandy clay or, more rarely, shale. Plant material is abundant, and one coal seam is mined at several points north of the Yellowstone River, in Tps. 1 and 2 S., R. 21 E.

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[56] Hayden, F. V., Geology of the Missouri Valley: U. S. Geol. Survey Terr. Fourth Ann. Rept., p. 97, 1871.

Volcanic material is abundant as fresh nonbentonitic ash that is included and interbedded in the clays and also as tuffaceous sandstone. Beds of eolian ash of notable size are rare, and most of the volcanic products have been distributed here by streams. Igneous material is common throughout the formation in the southern part of the area but is largely confined to the upper half in the northern part. The Judith River formation, with its content of volcanic material, thus contrasts sharply with the underlying Claggett formation, which contains no volcanic material, in the southern part of the area just west of Fromberg and Bridger. Still farther north Hancock[57] found not only that sand and clay typical of the Claggett were deposited in early Judith River time, but he considered that marine conditions persisted for some time after the close of the Claggett. In that area Hancock mapped the volcanic material as Bearpaw. The Judith River-Bearpaw contact of Hancock is therefore appreciably lower than the contact adopted by the present authors, who placed their boundary at the lowest marine fossils they discovered.

An interesting feature of the coal bed in the Judith River formation is the occurrence immediately above the coal of a layer of fresh unweathered volcanic ash 4 to 8 inches thick that carries lenses of coaly material. The lenses range from 8 to 24 inches in width and from one-fourth to three-fourths inch in thickness and appear to be greatly compressed tree trunks. The ratio between the width and thickness of the lenses ranges from 30 to 1 to 50 to 1. This relation, combined with the fact that the ash laminae are not contorted, indicates that if compression occurred without spreading of the trunk 30 to 50 inches of woody material yielded an inch of subbituminous coal.

The Judith River sediments are well bedded, in view of their continental origin, and the persistent sandstone or sandstone zones are commonly traceable for a mile or more. (See pl. 4, *A*.) In the nonvolcanic areas the sandstones are soft and are gray or white; the beds that have considerable volcanic material are cemented with iron, rusty brown, and in many places sufficiently magnetic to deflect the compass needle. These brown sandstones are very resistant to erosion. Similarly the volcanic contribution to the interbedded clays colored them yellow or yellow green instead of the normal light gray.

The sandstone beds of the Judith River are hard and form definite benches, but because they are numerous and not separated by thick beds of shale or clay, most of them join in producing a rough, steep escarpment, which has the appearance of a range of hills, rising

[57] Hancock, E. T., op. cit., p. 117.

above the exposed surface of the Claggett formation. Within the area where the Judith River formation is exposed the surface is commonly moderately rugged, but locally beds of sandstone form prominent benches, small plateaus, and flat-topped buttes or mesas.

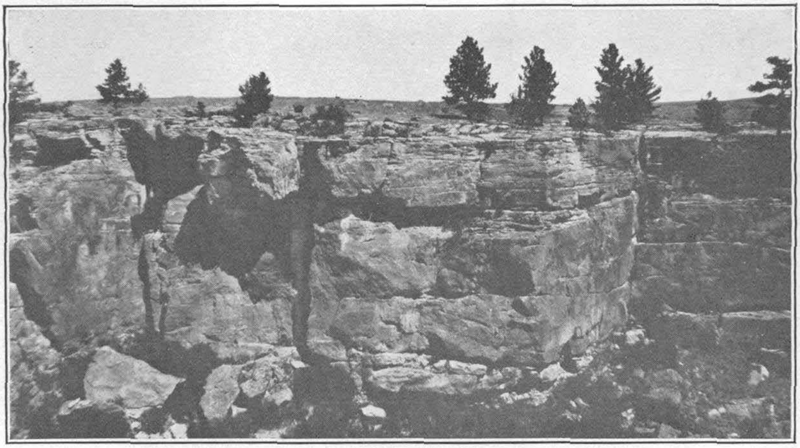
At no place is the entire thickness of the formation exposed, but measurements of 550 and 605 feet were made. The range is probably greater than that indicated by these sections. Hancock found more than 395 feet in the area to the north [58] and 500 feet 6 miles east of Billings.[59] The following section was measured along the north side of the Yellowstone River and indicates the character of the formation. As shown, the section was measured in two parts, which represent the continental, fresh-water division below and the fresh-water volcanic division above.

Section of the Judith River formation north of Yellowstone River in Tps. 1 and 2 S., Rs. 21 and 22 E.

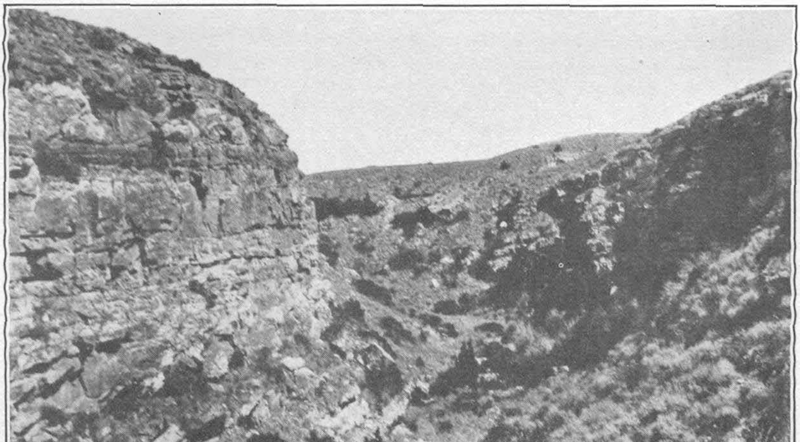
	Feet
Bearpaw shale.	
Judith River formation:	
Sandstone, thin bedded, yellow-gray; interbedded with softer material; makes a long dip slope	40
Shale, sandy	10
Sandstone, tuffaceous; contains numerous dark fragments of volcanic material, probably andesite	1
Shale, dark, carbonaceous	8
Unexposed	23
Sandstone, tuffaceous	2
Shale, dark, carbonaceous; weathers dark	3
Sandstone, tuffaceous, interbedded with light shale	2
Shale, dark; weathers dark	½
Shale, dark, carbonaceous; weathers light	5
Poorly exposed; seems to be mainly light shale and green to brown tuffaceous lenses	20
Sandstone, light gray, soft, cross-bedded	10
Not exposed	12
Sandstone, irregular, coarse, gray	3
Shale, soft, yellow, sandy	1
Shale, dark, carbonaceous; plant fossils	10
Sandstone, soft, gray	5
Unexposed	8
Sandstone, fine grained, green when fresh; weathers chocolate-brown	⅔
Shale	2
Sandstone, coarse and fine; shows channeling and filling; weathers light yellow except at top, where it is brown	11
Not exposed; apparently in part carbonaceous shale	19

[58] Hancock, E. T., op. cit. (Bull. 691), p. 118.

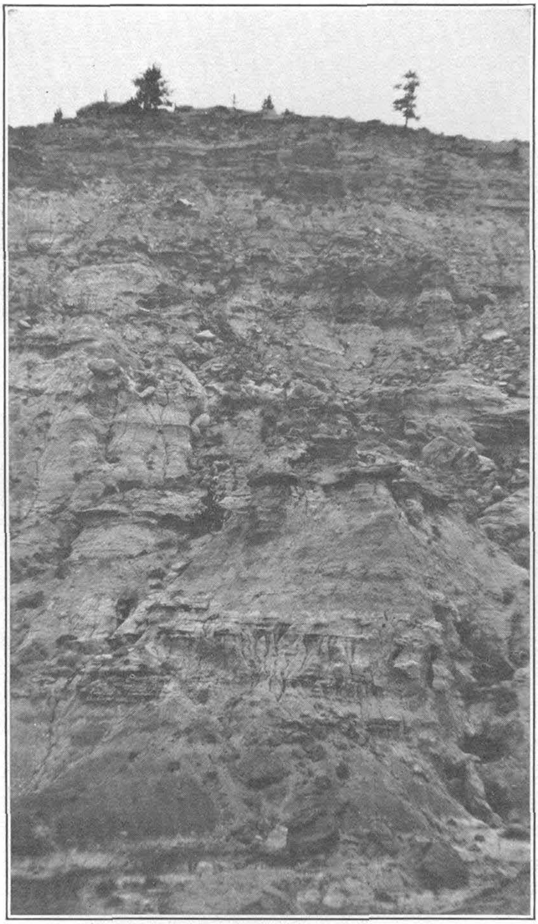
[59] Hancock, E. T., Geology and oil and gas prospects of the Huntley field, Mont.: U. S. Geol. Survey Bull. 711, p. 123, 1920.



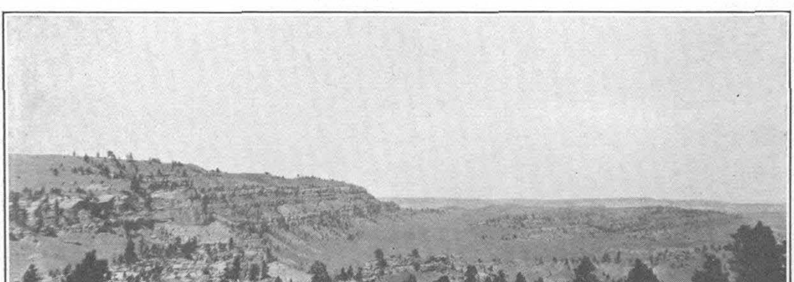
A. OUTCROP OF BASAL CONGLOMERATE OF CLOVERLY FORMATION



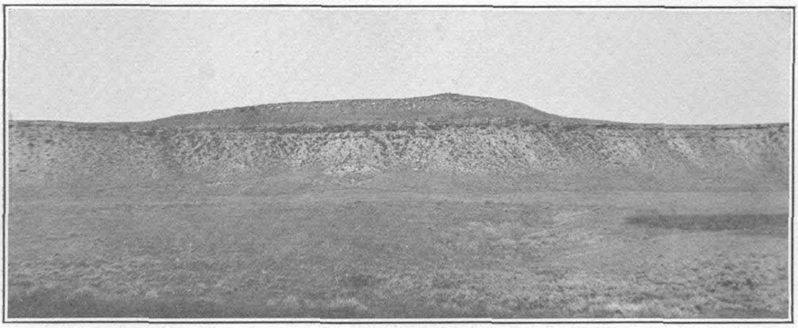
B. BOX CANYON IN MADISON LIMESTONE



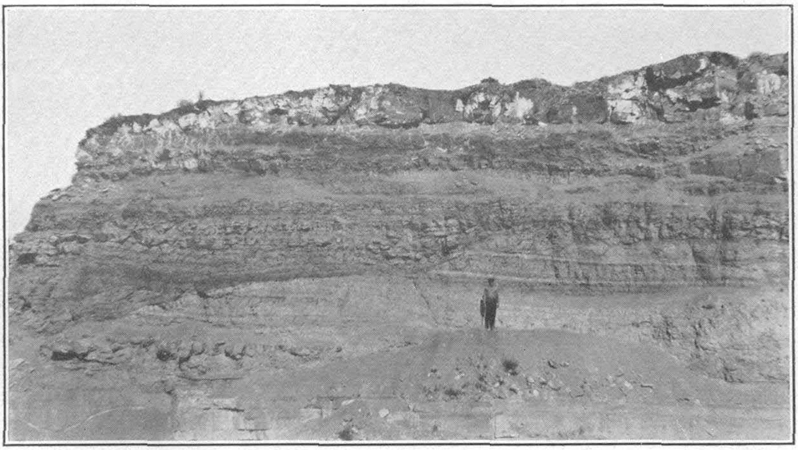
A. CLAYS AND SANDSTONES OF JUDITH RIVER FORMATION



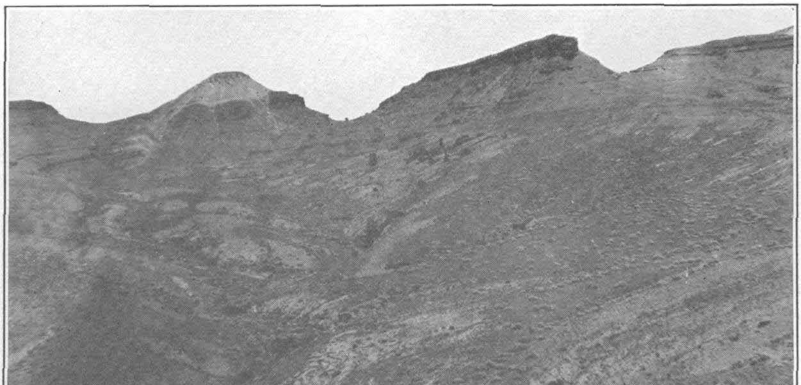
B. EAGLE, CLAGGETT, AND PARKMAN OUTCROPS



A. BEARPAW SHALE AND LENNEP SANDSTONE



B. CHANNELS AT BEARPAW-LENNEP CONTACT AND IN LENNEP



C. BLEACHED CHUGWATER SANDS ON RED DOME, CARBON COUNTY, MONT.

Judith River formation—Continued.	Feet
Sandstone, yellow, coarse, lenticular; plant fossils	2
Sandstone, soft, carbonaceous	1
Sandstone, green when fresh; weathers gray; hard, tuffaceous	1
Shale, dark, carbonaceous; plant fossils	8
Shale, light colored	2
Shale, dark, carbonaceous; plant fossils	1
Shale, light colored	6
Shale and sandstone, soft; plant fossils; poorly exposed	39
Sandstone, tuffaceous, massive	3
Shale and sandstone, soft, interbedded; plant fossils; not well exposed	24
Shale, chocolate-brown when fresh; light colored when weathered; slightly tuffaceous; contains abundant plant fossils	11
Bentonitic material	1½
Shale, sandy, tuffaceous; olive-gray when fresh; weathers white	1
Sandstone, green when fresh; chocolate-colored when weathered; hard, fine, tuffaceous; plant fossils	1
Shale, sandy, tuffaceous; olive-gray when fresh; weathers white; numerous black plant fossils	21
	319

Bottom of one part of the section. The following section, measured near Rapids, on the north side of the river, begins approximately with the basal beds of the foregoing section. Accurate correlation was impossible.

	Feet
Sandstone, coarse, yellow, cross-bedded	25
Not well exposed; contains a thin tuffaceous bed that shows current ripple marks	7
Sandstone, massive, cross-bedded	8
Shale, carbonaceous at top	3
Sandstone, coarse, massive, light colored	2
Shale, light colored	41
Sandstone, yellow; lower half fine and massive; upper half coarse and cross-bedded	6
Shale and sandy shale, not well exposed	30
Sandstone, greenish, tuffaceous; plant fossils	2
Sandstone, massive, yellow	23
Shale, carbonaceous, not well exposed	2
Sandstone, thin bedded, with some shaly layers, tuffaceous; contains plant fossils at the top	5
Shale, sandy	7
Sandstone, massive, yellow	5
Sandstone, very soft	2
Sandstone, thin bedded, coarse, yellow	4
Shale, yellow, sandy	11
Sandstone, massive, tuffaceous; plant fossils	1

Judith River formation—Continued.	Feet
Shale, light yellow, gray when fresh	6
Sandstone, thin bedded; plant fossils	7
Shale	9
Sandstone, massive	1
Shale, yellow, sandy	10
Sandstone, massive	1
Shale, yellow, sandy	10
Sandstone, yellow, cross-bedded to massive, upper part is massive and contains plant fossils	25
Shale, sandy, yellow	7
Sandstone, greenish yellow; plant fossils	1
Shale	8
Sandstone, soft	3
Shale, sandy	8
Shale, soft, sandy	18
Sandstone, irregular bedding; some tuffaceous material; plant fossils	6
Shale	25
Sandstone, thin bedded	15
	605

The Judith River formation is of upper Montana age and is composed of continental sediments that are intercalated without erosion or apparent interruption of deposition between the marine Claggett formation below and the marine Bearpaw shale above. The Judith River of this area is an eastern continuation of a part of the tuffaceous Livingston formation and is in every way similar in character to the Lance as developed in this area.

BEARPAW SHALE

Beds of soft gray marine shale or clay, including several thin beds of hard sandstone and a thin conglomeratic limestone, constitute the Bearpaw shale, overlying the Judith River formation. Like the Claggett, the Bearpaw was named by Stanton and Hatcher[60] from north-central Montana, the formation being typically developed on the south side of the Bearpaw Mountains.

The shale of the Bearpaw is similar to the shale in the Claggett formation, but the beds of sandstone of the two formations are strikingly different. In the Claggett beds of soft gray quartz sandstone are abundant, but in the Bearpaw the sandstone beds are hard, well-cemented, brown-weathering andesitic tuffs that are similar to the hard sandstone of the Judith River but are commonly concretionary and rarely show strong cross-bedding.

[60] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, p. 13, 1905.

The beds of shale weather quickly and are readily eroded, forming badlands at some places and a gently rolling plain at others. Where beds of sandstone are present they form prominent benches, with steep faces of bare clay. A persistent zone of sandstone above the middle of the formation divides the outcrop into two similar parts. The upper Bearpaw forms a rolling plain, with steep scarp rising to the overlying Lennep sandstone. (See pl. 5, *A*.) Accordingly, the Bearpaw occupies a lowland between the Judith River hills and the sharp bluff escarpment of the Lennep and Lance. North of the Yellowstone River the Bearpaw outcrop has a prominent, persistent terrace 130 feet below the top of the formation.

Because of its softness good exposures of the Bearpaw are rare and none gives a complete section. Several calculations from available field data near the Yellowstone River give thicknesses that range from 360 to 425 feet and average practically 400 feet, though in the area west of Bridger the thickness is about 250 feet.

The following incomplete section indicates the character of the formation:

Section of Bearpaw shale, in sec. 3, T. 1 S., R. 21 E., and sec. 33, T. 1 N., R. 21 E.

	Feet
Lennep sandstone.	
Bearpaw shale:	
Shale and clay, light to medium gray, soft; poorly exposed, measured in sec. 3, T. 1 S., R. 21 E	128
Sandstone, coarse, well cemented, tuffaceous, with much ash, mica, and feldspar; plant fragments common; forms bench 1 to 2 miles wide throughout area north of the Yellowstone River	15
Shale and clay, gray, soft, gypsiferous; in face of bluff	81
Same, on gently rolling plain, not well exposed	35
Sandstone, coarse, gray, little volcanic matter; makes small bench	5
Covered; scattered exposures of normal gray shale	107
Limestone, with thin pebble conglomerate of igneous gravel at top; pebbles 1 inch or less in diameter	½
Shale, blue-gray, normal, with many thin interbedded laminae of calcareous shale, well jointed	22
	392

The Bearpaw covers a broad area in the headwater portions of the Valley Creek and Hensley Creek drainage basins, in Tps. 1 and 2 S., R. 21 E. It is also exposed in the southern Keyser Creek Valley and in a narrow band that stretches southeastward from Columbus to Bridger.

In the course of the field work numerous Baculites and Scaphites were noted in the soft clays of this formation. A suite of specimens collected in the SW. ¼ sec. 13, T. 2 S., R. 20 E., contained the following forms, as identified by J. B. Reeside, jr.:

Nucula planimarginata Meek and Hayden.
Inoceramus barabini Morton.
Pteria linguaeformis Evans and Shumard.
Lucina occidentalis Morton.
Lucina subundata Hall and Meek.
Baculites compressus Say.
Scaphites nodosus Owen.
Scaphites? halli Meek.

These forms are middle and upper Pierre species.

The Bearpaw shale is the youngest wholly marine formation of the area. Its deposition began when the open ocean overflowed the Judith River delta swamps and was ended by the deposition of the volcanic sand of the Lennep on land and in shallow ocean water or coastal swamps. Accordingly, the Bearpaw is conformable with both of its inclosing formations. As noted earlier, the present writers placed the Bearpaw-Judith River boundary at the horizon of the lowest marine fossils they collected above the Claggett. This boundary corresponds to a marked development of even-bedded soft gray shale. The writers regard it as marking the change from continental or brackish-water deposition to marine conditions. This boundary is fully 200 feet higher than that used by Hancock in the Lake Basin area, to the north.

LENNEP SANDSTONE

The Lennep formation is composed of dark green-brown beds of lenticular sandstone and clay. The sandstone is lithologically identical with two members of the Bearpaw below, and much of the Lennep clay is dark gray, nonlaminated, and very soft, like most of the underlying Bearpaw. The formations are separated on the basis of preponderant marine gray clay in the Bearpaw, whereas the Lennep is chiefly a shallow-water or fluviatile sandstone. Northwest of the area here described, in the western Lake Basin, the Lennep carries some thin coal beds. In the area treated in this report no coal is exposed, although thin beds of carbonaceous clay are abundant. Like the Judith River, the Lennep contains much volcanic material and is an eastward extension of a part of the tuffaceous Livingston formation.

The andesitic sandstones of the Lennep are fairly well cemented by limonite and form a sharp escarpment overlooking the soft Bearpaw shale. Although a similar escarpment is produced by andesitic sandstone near the center of the Bearpaw, the Lennep outcrop can be distinguished by its greater height, greater thickness of sandstone, and absence of a well-defined back slope, for no large amount of clay separates the Lennep from the overlying Lance.

The thickness of the Lennep varies inversely with that of the Bearpaw, and probably the one formation replaces the other, the Lennep becoming thicker as it is traced southward. Hancock also reports an increase of thickness northwestward, to 275 feet in sec. 29, T. 2 N., R. 20 E. In the area here under consideration the sections measured range from 129 feet near the Montana base line to 310 feet west of Bridger.

The following section indicates the general character of the formation, although its members can not be correlated throughout the area.

Section of the Lennep sandstone in the SW. ¼ sec. 8, T. 1 N., R. 21 E.

	Feet
Lance formation.	
Lennep sandstone.	
Sandstone, hard, brown, andesitic	4
Clay, sandy, and argillaceous sandstone, olive-brown, gray, and green	42
Sandstone, as above	8
Clay shale and clay, soft, green, olive-brown, and gray; contains several thin sandstone lenses	66
Sandstone, hard, brown, andesitic, stream cross-bedded and lenticular	14
Total thickness of Lennep sandstone	134
Bearpaw shale.	

The Lennep crops out for distances of a quarter of a mile to a mile east of the Lance and so occupies a narrow, irregular, ribbon-shaped area along the western border of the area described in this report.

Plant fragments and carbonaceous clays are numerous in the Lennep, but no well-preserved specimens were collected in this area. The typical exposures of the formation in the Musselshell Valley have yielded brackish-water and marine invertebrates related to the Bearpaw fauna. It includes accordingly the highest known marine Cretaceous sediments of the region. The basal beds of the Lennep sandstone occupy channels in the upper part of the Bearpaw, but no angular discordance in bedding is recognizable. The unconformity is duplicated at many places within the Lennep and probably is only incidental to the change from marine to continental deposition, without indicating any notable interruption in sedimentation. (See pl. 5, *B*.) The contact with the Lance is usually covered, but the sandstones of the two formations are parallel, and there was probably uninterrupted continental deposition during the passage from Lennep to Lance time.

TERTIARY (?) ROCKS

LANCE FORMATION

The western boundary of the area here described is near the contact of the Lennep and Lance formations. The Lance was therefore not studied in detail. It consists, in general, of repeatedly alternating andesitic and yellow sandstones separated by beds of yellow, buff, and dark-green clay all containing much volcanic matter. The thickness of the formation was not determined but is certainly several thousand feet. After Lennep time all deposition in this area appears to have been of continental character.

TERTIARY DEPOSITS

PLIOCENE (?) GRAVEL

Thin coatings of gravel and white or buff sand cover portions of the Pliocene (?) erosion surface that flanks the Pryor Mountains. The deposits are rarely 5 feet thick, are unconsolidated, and yielded no fossils, so that their age is doubtfully determined by physiographic evidence. Similar deposits of gravel are found at many places on the escarpment of the Mowry shale east of Clark Fork, between Bridger and Silesia, and probably are of the same age as those on the Pryor Mountains.

QUATERNARY ALLUVIUM

Probably during the Pleistocene epoch the Yellowstone River, Clark Fork, and Rock Creek filled their valleys with gravel to a height of 40 to 100 feet above the present stream levels. This gravel is derived chiefly from igneous rocks of the Beartooth and western mountain ranges, is well sorted and rounded, and in its finer facies is widely stratified. Most of the material is less than an inch in diameter, but perhaps 15 per cent is coarser, and the largest pebbles are 3 inches in diameter. About half of the gravel that originally stood above present stream level has been removed, leaving high prominent benches which are farmed where water is available for irrigation.

Numerous lower benches have been developed by the meandering streams as they removed the gravel, but no periods of rest in the process of down-cutting were identified. Alluvium of the lower benches and of the present flood plains contains much sand and clay from the neighboring sediments, which have been contributed by the smaller tributaries during the postglacial period of erosion and reworking of the gravel.

STRUCTURE

GENERAL FEATURES

The area here described lies on the northwestward-plunging anticline of the Pryor Mountains, a fold that is parallel with and near the fold of the Big Horn Mountains. The area embraces exposures of late Paleozoic and Mesozoic formations whose belts form a semicircle around the northwest end of the Pryor Mountains. Owing to the general structure, these formations crop out in a series of steep mountain-facing scarps and long, gentle dip slopes extending away from the sandstone cliffs down to the lowland valleys, which are eroded in the shales that are interbedded with the escarpment-forming sandstones.

The structure contours on the map (pl. 1) indicate the attitude of the Greybull sandstone, the top member of the Cloverly formation. The dips range from 7° to 10° W. on the immediate flank of the Pryor Mountains and from 1° to 3° NW. or N. along the mountain axis and west of the steep mountain flank. This general structure is interrupted at many places by faulting and warping, which in some places produces dips of 20°. About 50 faults have been mapped in the region under consideration. Many more faults have been omitted because they have only slight displacements and their inclusion would serve only to complicate the map. For instance, on the northeast side of Red Dome, in secs. 16 and 17, T. 7 S., R. 24 E., five faults that have not been mapped displace the basal conglomerate of the Cloverly formation by amounts ranging from 20 to 75 feet. All the faults represented on Plate 1 are mapped on the basis of field observations and are not inferred from differences in altitude of formations. The semiarid character of the region provides good exposures of the resistant formations, which produce prominent scarps that can be traced continuously through the area, except where they are overlain by the alluvium of the Yellowstone River and Clark Fork. Faults conspicuously interrupt these escarpments, and the amount of horizontal and vertical displacement is readily determinable at most places. In many places the fault plane is itself visible or its position is marked by brecciation of the sandstones and some crumpling of the adjacent beds of shale. None of the faults are of the thrust variety, although several are apparently due to compression, which has resulted in horizontal shear along nearly vertical planes without overriding of one mass of rock by another.

FAULTS AND FOLDS

Three types of faults are clearly distinguishable—namely, those whose strike is practically due west, those which strike N. 45° E., and those striking approximately due north. There is no evidence to show that these different fault systems have originated in different periods. Apparently they are all the result of one post-Cretaceous deformation, although the northerly faults are probably slightly later than the others.

Near the southern border of the area mapped there is an east-west fault that extends from sec. 15, T. 7 S., R. 23 E., to sec. 15, T.

7 S., R. 24 E. It is named the Bowler fault from the near-by post office. Within the present area the strata south of the fault have been relatively uplifted about 500 feet through most of the length of the fault. In addition there has been crumpling of the strata, which resulted in the development of Red Dome and the formation of several faults on its flanks. East of the dome the beds rise gradually toward the Pryor Mountains, whereas the beds north of the fault rise more rapidly, so that at the eastern border of the area mapped the beds on opposite sides of the fault lie at nearly the same altitude. The area immediately north of the Bowler fault has been slightly folded west of Jack Creek and again south of Bridger Creek, so that the beds in each locality dip northward for about half a mile and then resume their normal western dip. These northward dips are due to drag folding during the movement along the fault plane. North of the fault two minor parallel faults are shown in the conglomerate of the Cloverly formation and also in the Greybull sandstone member of the Cloverly. Although the movement in the conglomerate has amounted to as much as 200 feet, the soft beds of clay above and below have absorbed the strain, and the adjacent formations have not been appreciably affected.

A second east-west fault in secs. 34 to 36, T. 5 S., R. 24 E., and secs. 31 and 32, T. 5 S., R. 25 E., cuts the sharp monocline of the Pryor Mountains, along which dips as steep as 22° have been measured. From its position this fault is named the North Pryor. On the accompanying map the fault is indicated as probably continuing eastward to join the fault which has been mapped by Thom [61] along the north side of the mountains, east of Pryor Creek, about 10 miles east of this area. The North Pryor fault plane is not well exposed. Along much of the fault the beds dip steeply and the displacement is less than 100 feet. In a few places the actual break is visible and short sections of various Lower Cretaceous formations are missing along the central part of the fault line. A well-marked half dome with a northward trend occurs on the north side of the fault in T. 5 S., R. 25 E. Thom [61] shows in his map of the Crow Indian Reservation a syncline immediately east of this half dome. On the west the North Pryor fault merges with or is cut off by a northeastward-trending fault that runs through the northern part of T. 6 S., R. 24 E., and into the adjacent townships to the north and northeast. Although the two fault planes are recognizable within 200 feet of their junction, there is no evidence that one displaced the other.

A third eastward-trending fault approximately 6 miles in length passes a mile north of Columbus and is here called the Columbus fault. Horizontal slickensides indicate some lateral movement along

[61] Thom, W. T., jr., unpublished notes.

the fault plane. A downthrow of more than 100 feet has taken place on the south side at a locality 1 mile northeast of Columbus, but near the ends of the fault the downthrow is on the north side of the plane. The character of the warping of the strata near the fault is indicated by the structure contours on Plate 1. A minor fault with a northwest trend has broken the strata north of the fault at the place of greatest vertical displacement. Its downthrow is on the east side.

The northeasterly faults all have their downthrow on the northwest side, with the exception of the Bluewater fault, which has a downthrow on the northwest along one portion and on the southeast along other portions. Horizontal shearing is not shown along these faults, and folding and crumpling did not take place except for very minor flexing.

The longest northeasterly fault has been named by the junior author[62] the Fromberg fault, from the town of Fromberg, near which it passes. The fault zone extends from the southwest corner of the area almost to the northeast corner, where it is no longer a distinct fault, although there are marked irregularities in the structure contours as far as the alluvium of the Yellowstone River. West of Clark Fork the fault is a single, normal displacement, with the northwest side downthrown about 1,000 feet at the westernmost point mapped. The throw decreases to 500 feet near Fromberg, where the fault disappears under the alluvium of Clark Fork. A parallel fault appears near the mouth of Fivemile Creek and extends to T. 2 S., R. 26 E. The two faults through this distance inclose a dropped block (graben) which ranges from 0.5 to 1.5 miles in width and which in R. 25 E. has been dropped as much as 400 feet. In the block the rock strata are not crumpled or folded but are broken by numerous small faults and joints. It was impracticable to map the position of formations within the dropped block. No extensive folding accompanied this faulting, but a slight downward bending toward the fault is shown on the northern block 2 miles northeast of Edgar and again near Duck Creek. Several minor north-south faults branch from the main fault, practically all with a downthrow on the east. Toward the northeast the downthrow of the block decreases in amount and is expressed in moderate warping of the beds and in three roughly parallel faults, all with a northeast trend. The easternmost fault of the three lies chiefly in sec. 36, T. 1 S., R. 26 E., and sec. 2, T. 2 S., R. 26 E. Its displacement is greater than that of the other two faults. The beds on both sides of the fault dip toward it.

A parallel and similar dropped block occurs southwest of Bridger. It strikingly displaces the Claggett, Bearpaw, and Lennep forma-

[62] Moulton, G. F., Faulting south of Billings, Mont.: Jour. Geology, vol. 32, pp. 511–523, 1924.

tions, the maximum displacement being 450 feet, but to the east the amount of displacement decreases, and none can be recognized in the Eagle sandstone. This variation takes place in a distance of 3 miles. There is no evidence of shearing along this block.

Another northeastward-trending fault, almost 3 miles long, runs northeast from Bluewater Creek, in the northwest corner of T. 6 S., R. 24 E. It has a downthrow of 300 feet on the northwest, but the downthrow diminishes to zero at each end of the fault. A fourth northeasterly fault, called the Bluewater, is joined by one of the faults that cuts the north end of the Pryor Mountains. The strata on the north side have been domed near the southwest end of the fault, but a very conspicuous terrace surmounted by a dome of about 50 feet closure lies on the south side of the fault at its southwest end. The fault is doubtfully continued to a junction with a northerly fault that lies along the west sides of Tps. 4 and 5 S., R. 25 E., where the downthrown side lies on the west. A fifth northeasterly fault, 5 miles long, cuts across the head of Bluewater Creek in what is locally known as Frosty Jack Canyon, in sec. 26, T. 6 S., R. 24 E. It displaces all the belts of outcrop by a mile or more. Near its middle the strata have dropped about 400 feet on the northwest side, but the displacement decreases toward each end. Nine minor faults of this same system lie between Frosty Jack Canyon and the Bowler fault. They all have downthrows on the northwest that range from 20 to 100 feet. A sixth long northeasterly fault, 6 miles in length, lies about 2½ miles southeast of the Fromberg fault zone, in the northwestern part of T. 4 S., R. 25 E., and the south-central part of T. 3 S., R. 25 E. Like the other faults of this set, it has the downthrown side on the northwest. The relative movement amounts to nearly 200 feet near the middle of the fault but decreases to zero along the strike in each direction.

The northerly faults have a downthrow on their west sides. Several of them branch from the northeasterly faults, and they in turn have numerous small branches that generally trend northeast. Only one fault has a displacement of more than 125 feet.

The northerly faults are not accompanied by folding. They are represented by at least 10 faults immediately north of the Pryor Mountains, by nine faults that branch from the Fromberg fault zone, by seven faults lying south of the Bowler fault zone, and by three lying between the town of Bridger and the Pryor Mountains. The fault that has the greatest displacement is in secs. 12 to 25, T. 6 S., R. 23 E., where the throw reaches a maximum of 450 feet. All these faults are normal and show no evidence of horizontal movement.

The folds of the area consist of the plunging anticline of the Pryor Mountains and minor warpings which are, with two exceptions, intimately connected with the faulting. A closed fold, which is a dome or anticline, lies 3 miles east of Columbus; another one lies on Bluewater Creek 6 miles northeast of Bridger; and a third lies 4½ miles west of Bowler. In addition to these closed folds a half dome or partial anticline that is bounded on one side by faults lies 2 miles northeast of Columbus, another one extends along the north boundary of T. 6 S., R. 24 E., and a third rises in T. 5 S., R. 25 E. Besides the folds noted, all of which are contiguous to faults, there are two closed folds which are not near faults. In the center of T. 1 S., R. 21 E., a dome with gentle dips that has a closure of 65 feet lies between two well-marked troughs on the slope of the general regional dip, and another fold carrying two domes lies along the boundary between Tps. 1 and 2 S., R. 27 E. In each of these three domes the closure is less than 150 feet, and the closed area is less than 2 square miles. Obviously, the structural contours do not indicate the total closed area, for the lowest altitude on the rim of the dome is not on a contour line.

MINERAL RESOURCES

OIL AND GAS

Necessary conditions.—In order to produce oil and gas it is necessary that the rocks of a region shall contain an adequate source of petroleum, suitable reservoir rocks, a favorable structural feature in which oil and gas may accumulate, an impervious cover for this feature, a considerable area from which the oil and gas may be gathered, and some cause to bring about the migration of the oil and gas.

In the region described in this report an adequate source of oil and gas occurs. The Carboniferous limestones consist primarily of organic material, and much of the rock contains enough hydrocarbons to give the characteristic petroleum odor when freshly broken. Dark organic shales are abundant. In order to produce oil it seems to be necessary for the source rock to be formed in the ocean. In this area there are marine sediments that contain much organic matter in the Sundance, in the black shales that are the predominant rocks in the Colorado group, including the Thermopolis, Mowry, Frontier, Carlile, and Niobrara, and in the Montana group in the shales of the Telegraph Creek, Claggett, and Bearpaw formations. There is, then, in this region an abundance of source material from which oil and gas might be produced.

Reservoir rocks are similarly abundant. Coarse, porous, loosely cemented sandstones are present in the Amsden, Tensleep, Chugwater, Sundance, Morrison, Cloverly (Greybull member), upper part of the Thermopolis ("Muddy sand" of drillers), Frontier (Peay and Torchlight sandstone members), Telegraph Creek, Eagle, Claggett, and Judith River formations. Each of these sandstones is sufficiently open to furnish an excellent reservoir rock if other conditions for an accumulation of oil and gas are favorable. In near-by areas in Wyoming and Montana oil has been found in considerable quantities in the Madison, Amsden, Tensleep, Chugwater, Sundance, Morrison, Cloverly (Greybull member), Thermopolis ("Muddy sand"), Frontier (Peay and Torchlight members), and Eagle formations, and it is entirely probable that some of these formations are petroliferous in the present area if the necessary conditions are fulfilled.

The doubtful factor in the situation is the question of the presence of favorable structure. As shown in the preceding section nearly all the structural features in this area are either closed by or else closely related to faults, but faults do not necessarily condemn a structural feature, as is attested by the occurrence of many oil fields on areas of faulted structure. In this area the faulting was accompanied by much shattering of the wall rocks, which makes it probable that the faults have not obstructed the movement of oil and gas or retained them in the formations below. The Fromberg fault cuts off the entire northwestern part of the area from the Pryor Mountains, and if it forms an impervious barrier to upward migration of oil and gas, considerable deposits should have accumulated against it. So also the Bluewater fault and the parallel fault in the northwest corner of the same township (T. 6 S., R. 24 E.) provide excellent opportunities for the accumulation of oil and gas if they are sufficiently impervious to cause accumulation. The only known folds in the area which are not closely associated with faults are the dome in the center of T. 1 S., R. 21 E., and the two small domes near the boundary of Tps. 1 and 2 S., R. 27 E. A large gathering area is provided for the monocline that is bounded by the Fromberg fault. Certainly several hundred square miles of beds slope gently upward to this fault and might readily be sources of abundant petroleum. The Bluewater and near-by faults are not favored by a large collecting area, although it seems probable that they might draw from 40 to 50 square miles of territory. The half dome in T. 5 S., R. 25 E., possibly drains as much as 150 square miles, but a number of faults occur on its flanks, and possibly these either have permitted the escape of migrating oil and gas or else have trapped them and prevented them from reaching the top of the dome.

Three causes of probable migration have affected this area. In the first place, the settling of the great thicknesses of shale must have squeezed tremendous quantities of water and any accompanying oil and gas out of the compacting shales into the adjacent sandstones. Presumably the beds of sandstone were originally filled with water, and therefore this great supply of fluids must have caused a strong circulation through the sandstone beds with excellent opportunities for accumulation of the hydrocarbons wherever conditions were favorable. Second, the folding of the region has resulted from a thrust from the west, which has bent and in many places broken the rocks. This folding has presumably been accompanied by considerable compression of the softer sediments and again a resulting movement of fluids through the porous rocks. Third, there is at present a steady and extensive artesian circulation through several of the sandstone formations. Large quantities of water are absorbed by sandstone where streams cross the sandstone outcrops. Numerous streams running down the flanks of the Pryor Mountains dwindle and disappear as they cross the upturned edges of the sandstone formations. Some of this water reappears at the surface within the region in the form of springs, such as the great lime spring in sec. 14, T. 6 S., R. 24 E., and the Blue Springs, which give Bluewater Creek its name and are located in sec. 9 of the same township. Numerous deep wells have obtained abundant supplies of fresh artesian water, and under most of the territory adjacent to the mountains there is probably a steady circulation of fresh water. Movement of this water through the sandstone beds naturally tends to displace oil and gas and cause them to accumulate in the higher portions of any structural features that may be present, if these features are sufficiently pronounced and the sand is thick and unbroken by shale layers, so that water may circulate beneath the oil already collected. Where the sands are thin or the water circulates rapidly, the water will tend to flush the oil through to be accumulated in more distant structural features or even to be swept out and lost at the point of escape of the water. The amount of this artesian circulation is suggested by the 56 Petroleum Co.'s well in T. 5 S., R. 29 E., which was flowing approximately 1,000,000 gallons of fresh water a day when visited in 1922. So far as is known, no wells have encountered salt water within the present area. The absence of salt water indicates a thorough washing of the marine sands by this artesian circulation, and the writers believe that unless such original marine waters—that is, salt waters—have been trapped in some structural features of the area, there is little chance of finding notable quantities of oil and gas in the region. A thorough washing of the sands must almost inevitably have caused an equally thorough removal of the oil and gas from the rocks, except where the structure is very favorable. The best opportunity for the persistence of oil in spite of this artesian circulation will be found where the sands are thick and the folds well marked, so that the water could circulate freely beneath the oil.

Evidences of petroleum.—The rocks of this area have contained oil and still contain small quantities at least. The Chugwater sandstone on top of Red Dome in secs. 17 and 18, T. 7 S., R. 24 E., and adjacent areas has been bleached along the top by the accumulation of hydrocarbons against the overlying impervious shales of the Sundance formation. The rock has lost its normal red color and has become gray through reduction of the original hematite. This bleaching is observed not only in the upper layers of the formation on the crest of the dome but also along joint planes for distances as great as 200 feet beneath the top of the formation, indicating that the oil migrated up along these joints, bleaching the rocks on each side and finally accumulating as stated. (See pl. 5, *C*.) Most of this oil has, of course, escaped, for erosion has stripped away the cover from the dome. Much of the sandstone still contains enough oil to stain the fingers with a sticky, black, viscous residue of partly evaporated petroleum. This is the only known place within the area where oil actually appears at the surface. Wells that have been drilled for oil near Red Dome have obtained water carrying much free hydrogen sulphide. An analysis of this water is given on pages 68–69. The presence of hydrogen sulphide does not prove the presence of petroleum, but oil and gas have commonly exerted a reducing effect upon calcium-sulphate waters, and accordingly the occurrence of hydrogen sulphide at least suggests that some oil or gas or both are present beneath this area. On the other hand, the water flows freely from these wells and carries neither oil nor identifiable amounts of methane, so that if hydrocarbons are present beneath the surface they are not necessarily abundant.

It has already been noted that the Madison limestone has the typical petroliferous odor of a rock rich in hydrocarbons. In no place has oil been noted in this formation in the area here studied, but the same limestone produces oil on the Soap Creek fold northeast of the Big Horn Mountains, in T. 7 S., R. 32 E.

No wells in the area are known to have produced enough oil or gas to justify the expectation that they would be of commercial value, but showings of oil have been reported as follows: Mosser well, sec. 23, T. 3 S., R. 24 E., in the "Muddy sand" and other beds of the Thermopolis shale and in the Greybull sandstone member of the Cloverly formation; Hoosier Oil Co. well, in the NE. ¼ sec. 8, T. 4 S., R. 23 E., in a sandstone in the Morrison formation; Harrison Oil Co. well, in the SE. ¼ sec. 22, T. 1 S., R. 21 E., in the Judith River; and Columbus Oil & Gas Co. well, in the NW. ¼ sec. 30, T. 2 S., R. 21 E., in Claggett shale and Virgelle sandstone member of the Eagle. Gas has been reported in the Harrison well in the Eagle and in a sandstone that is possibly in the Mowry; in the Columbus well in a sandstone in the Claggett, and lower, in a shale in the Claggett; in the Hoosier well in the Greybull sandstone; in the Bitter Creek well, drilled by C. B. McMenamin and others in the SE. ¼ sec. 2, T. 2 S., R. 26 E., in the Thermopolis shale; in the well of B. F. Hoyte and others, in the SE. ¼ sec. 7, T. 2 S., R. 24 E., in shales near the top of the Frontier formation and in a sandstone in the Mowry; and in the Empire Gas & Fuel Co. well, in the NW. ¼ sec. 14, T. 7 S., R. 22 E., a flow of 200,000 cubic feet a day is reported from shale in the Claggett.

Although some of these reports are not well authenticated it seems clear that oil and gas have been present in this region and that small amounts, at least, still remain underground in favorable locations.

Development.—By the end of 1924 at least 22 wells had been drilled within the area mapped. Of these wells many were not properly located, and others were not carried to a sufficient depth to prove the presence or absence of oil and gas.

For instance, the well in sec. 14, T. 7 S., R. 22 E., was carried to a depth of 4,500 feet and thoroughly tested the formations only to the base of the Frontier. Similarly, a deep test hole was drilled in sec. 8, T. 4 S., R. 23 E., to a depth of 2,670 feet on the steadily westward-dipping Cretaceous rocks. It reached the basal part of the Sundance without giving hope of commercial production. A near-by well in sec. 28, T. 3 S., R. 23 E., was similarly located and reached approximately the horizon of the quartzite in the Mowry before it was abandoned at 1,680 feet. Three wells are reported in a group northwest of Laurel, in secs. 6 and 7, T. 2 S., R. 24 E., and sec. 12, T. 2 S., R. 23 E. The area is covered by the alluvium of the Yellowstone River, and the reason for locating on an apparent uninterrupted northwesterly dip is not known to the authors. The well in sec. 7 was abandoned after passing about 50 feet through the Greybull sandstone.

Two wells have been drilled in the dropped block of the Fromberg fault zone. One in sec. 34, T. 2 S., R. 25 E., is reported dry at 1,100 feet, with no information about the water encountered. The other well, 4 miles to the southwest, in the SW. ¼ NE. ¼ sec. 18, T. 3 S., R. 25 E., found artesian water at 640 feet, which is about the horizon of the Greybull sandstone. The presence of artesian water on the northwest, basinward side of the dropped block is evidence that the faulted zone is not impervious and accordingly has not caused accumulation of notable amounts of oil and gas, by cutting across the northwestern part of the Pryor anticline.

The area northwest of the Fromberg fault has been tested by five wells within a mile of the fault and by one other 2.5 miles down the dip, in Rs. 24 and 25 E., as shown on Plate 1. Four of the wells close to the fault certainly reached the Greybull sandstone, and two of them found abundant water in that sand. No information is available about conditions in the others. In sec. 27, T. 2 S., R. 25 E., the Carter Duck Creek dry hole continued to the middle beds of the Chugwater formation. This well was properly located to test thoroughly the formations above the Carboniferous. A 1,900-foot dry hole is reported in sec. 29, T. 3 S., R. 24 E., which should have penetrated the upper sands of the Chugwater but was too far northwest of the Fromberg fault zone to condemn the lower beds entirely. In addition to these wells northeast of Clark Fork, a well in the southwest corner of sec. 25, T. 5 S., R. 22 E., was drilled through all the lower Montana beds and abandoned in the Niobrara or the Carlile shale at 1,904 feet.

On Bitter Creek a well in sec. 2, T. 2 S., R. 26 E., was located close to a fault and was unsuccessful. The Mid-Northern Oil Co. drilled a well in the NW. ¼ NW. ¼ sec. 4, T. 2 S., R. 27 E., which was properly located to test the small dome shown on Plate 1. The total depth is 2,532 feet, and the well penetrated the Madison limestone at least 30 feet. The Amsden-Madison contact is not clearly defined in the log, and it is possible that the well extended 86 feet into the Madison. Artesian water flowed over the casing from the upper part of the Sundance formation, and a little gas was found in the same formation. Warm sulphur water is reported in the basal part of the Amsden or upper part of the Madison, but no oil was encountered. From all these results it appears that the Fromberg fault zone has been thoroughly tested.

Red Dome has been drilled at four places. The first well was located in sec. 16, T. 7 S., R. 24 E., in the crushed zone of the Bowler fault. At 1,134 feet it encountered fresh water, which has flowed steadily for 15 years and is used for irrigation. This water is probably from the Tensleep sandstone. Near by, in sec. 17, a well was abandoned at 400 feet after encountering a strong flow of water containing hydrogen sulphide. In the SW. ¼ sec. 20 a well that was flowing about 17,000 gallons of water a day in 1922 has been abandoned. Water rising inside the 12-inch casing was saturated with hydrogen sulphide, whereas the water from the 8-inch casing was potable, indicating, as on the north side of the dome, that the hydrogen sulphide comes from a comparatively shallow depth. A well in the SE. ¼ sec. 20 was the only test located high on the dome. As it started near the top of the Chugwater, it should have reached the Madison, at about 600 feet and at 700 feet it would have penetrated all probable petroliferous beds and would have definitely proved or condemned the dome. Whether it was completed to this depth is not known.

The Black Butte dome, in sec. 35, T. 7 S., R. 24 E., is 2 miles south of the area mapped. It is a prominent dome with Tensleep beds exposed on top. A well on this feature has been abandoned at 1,100 feet, which is about 900 feet below the top of the Madison limestone.

A rig in sec. 6, T. 5 S., R. 25 E., is located on a fault block about half a mile wide, lying between two northward-trending faults. The north end of this block is cut off by a northeastward-trending fault. So far as known, no actual drilling has been done at this location.

In sec. 18, T. 6 S., R. 24 E., a rig was properly located to test a dome of about 65 feet closure that lies at the west side of a large terrace shown on the structure map. Since the field work was done it is reported that this well was drilled to a depth of 1,600 feet, found artesian water, and has been abandoned. The log is not available but this depth would indicate that the well penetrated 300 feet into the Madison formation.

The Harrison well in sec. 22, T. 1 S., R. 21 E., was properly located to test a dome of about 75 feet closure and was carried to a depth of 3,212 feet, at which it was abandoned in the sandstone in the Mowry shale. It found in that formation an abundant flow of slightly saline water with some gas. An analysis of the water is given on page 69. The next possible oil-bearing bed is about 800 feet lower. Between 800 and 1,100 feet below the bottom of this well, or at a total depth of 4,000 to 4,300 feet, the hole should penetrate the producing sands of the Lake Basin pool, which is about 10 miles north. This dome is one of the few that are not accompanied by faulting, but its small size is unfavorable, and the great thickness of shale lying underneath may have absorbed the stress, so that although the overlying sandstones were folded, the potential reservoir rocks may not have been sufficiently deformed to furnish adequate traps for any oil and gas that may have been present.

A well drilled in the NW. ¼ sec. 30, T. 2 S., R. 21 E., penetrated the Eagle sandstone and was abandoned in that formation at a depth of 1,125 feet. It was properly located to test a small dome, having a closure of at least 85 feet, which is located on an anticlinal nose and which can be identified across the southern part of that township. Small showings of oil and gas were obtained at three horizons. The failure of this well indicates that oil and gas may not be expected in this dome unless the well should be continued to the Torchlight sandstone, at a probable additional depth of 1,250 feet. The Lake Basin sand may be expected to lie at a total depth of 3,900 to 4,200 feet. The drainage area of this dome is small, and like that of the dome in the center of T. 1 S., R. 21 E., there is no certainty that the deep-lying sands have been deformed to the same extent as the surface beds. The risk involved is great, but the location should be tested to the conglomerate member of the Cloverly when prices for petroleum justify the speculation.

The following list includes wells that have been drilled deeper and abandoned since 1924 or that have been drilled altogether since that date:

L. C. Neudigate, SE. ¼ NW. ¼ sec. 25, T. 1 S., R. 21 E.; abandoned at 4,105 feet.
California Co., SW. ¼ NE. ¼ sec. 20, T. 1 S., R. 25 E.; abandoned at 3,212 feet.
American Indian Oil Co., SE. ¼ SE. ¼ sec. 6, T. 2 S., R. 24 E.; abandoned at 2,400 feet.
Walker Bros., NE. ¼ SE. ¼ sec. 13, T. 2 S., R. 25 E.; abandoned at 1,325 feet.
McMenamin, sec. 4, T. 2 S., R. 25 E.; drilling at 1,055 feet (May, 1928).
Rose-Altamont Oil Co., SW. ¼ SE. ¼ sec. 17, T. 3 S., R. 23 E.; abandoned at 2,020 feet.
Euclid Oil Co., SW. ¼ SE. ¼ sec. 23, T. 3 S., R. 24 E.; abandoned at 1,005 feet.
Murray Bros., SW. ¼ NW. ¼ sec. 27, T. 3 S., R. 24 E.; abandoned at 1,500 feet.
Hoosier Oil Co., NE. ¼ sec. 8, T. 4 S., R. 23 E.; abandoned at 4,025 feet.
Record Petroleum Co., NE. ¼ sec. 21, T. 5 S., R. 25 E.; abandoned at 1,105 feet.
Texas-Montana Production Co., SW. ¼ SE. ¼ sec. 21, T. 6 S., R. 25 E.; drilling at 1,125 feet (June, 1928).
Atlantic Oil Co. No. 3, SE. ¼ NE. ¼ sec. 20, T. 7 S., R. 24 E.; drilling at 1,669 feet in May, 1928.
Atlantic Oil Co. No. 1, NW. ¼ SW. ¼ sec. 21, T. 7 S., R. 24 E.; abandoned at 1,387 feet.

Drilling recommendations.—Most of the domes and anticlines in this area have already been tested, or at least locations have been made on them, as indicated in the preceding pages. The most promising sites for further drilling are the dome in sec. 22, T. 1 S., R. 21 E., and the similar one in sec. 30, T. 2 S., R. 21 E. In each dome the depth to which the drilling must be carried in order to reach the productive sands of the Lake Basin has been indicated, and although the risk is high, the possibilities lead the writers to believe that deeper drilling will be wise when market conditions are favorable to the operator.

The half anticline that occupies most of T. 5 S., R. 25 E., is a large fold that lies north of the North Pryor fault and has extensive northward-trending faults on both sides. The heavy cover of gravel that overlies most of secs. 33, 34, and 35 conceals a possible eastward extension of the North Pryor fault along the south side of the township. Even if the fault is present, there is no assurance that it serves as a barrier against artesian circulation. Probably the fold is barren, but the uncertainties are so great that it should not be positively condemned. A well drilled at the northeast corner of sec. 33 would test all possible horizons, including the upper part of the Madison, in a depth of 1,300 feet. The small cost of such a well may justify the risk involved when the price for petroleum permits.

Another area of closed structure is located on the anticlinal flexure that runs approximately N. 80° E. along the boundary between Tps. 1 and 2 S., R. 27 E. On this upwarp there are two small domes. The eastern dome, with its center practically at the southeast corner of sec. 32, has recently been drilled, without the discovery of oil, as described on page 60, according to trade journals. A second dome on this same flexure has its center approximately on the line between sec. 6, T. 2 S., R. 27 E., and sec. 1 of the next township west, about 2,000 feet south of the northwest corner of sec. 6. This dome is less favorable than the one just described, because the amount of closure directly between it and the mountains is less than that of the eastern dome. As the eastern dome has been thoroughly tested and proved barren, it is improbable that the western dome will be of value. So far as known, faulting is not extensive in the vicinity of either dome, although the Fromberg fault zone lies about a mile west of the western dome.

COAL

EAGLE SANDSTONE

Most of the coal mined in this area has come from the Eagle formation, where a persistent bed occurs 55 to 60 feet below the Claggett formation. Washburne [63] has mapped and described this coal in this district. As indicated on the geologic map (pl. 1) this coal crops out along an approximately north-south line in Tps. 4, 5, and 6 S., near the boundary between Rs. 22 and 23 E. Although the coal extends north of Joliet, at no place north of Rock Creek does it have a thickness greater than 8 inches, and it is of no value, so far as now exposed. South of Joliet the coal thickens and extends beyond the southern boundary of the area here described, without interruption except where faulting has displaced the bed or flood plains have concealed it. In sec. 36, T. 4 S., R. 22 E., the coal is not over 10 inches thick, and in sec. 13 of the same township the coal is chiefly bone. At all other exposures south of Joliet at least 12 inches of coal is present.

Along the outcrop the coal zone shows great differences in number and thickness of both coal and bone or dirt members within short distances, but it generally contains three coals separated by bone or less commonly by shale. The commercially productive zone ranges from 45 to 65 inches in total thickness, the total coal from 23 to 46 inches, and the amount of coal in the zone from 46 to 82 per cent. The average of 10 sections gives a thickness of 32½ inches of coal; the total thickness of the zone is 49 inches, and the coal forms 66 per cent of the zone.

Little information is available about the western extension of the coal. The log of a well drilled by the Empire Gas & Fuel Co. in sec. 14, T. 7 S., R. 22 E., shows a thickness of 7 feet, which includes all the bone and partings, but because of drilling conditions it can

[63] Washburne, C. W., Coal fields of the northeast side of the Big Horn Basin, Wyo., and of Bridger, Mont.: U. S. Geol. Survey Bull. 341, pp. 187–199, 1909.

not be regarded as very accurate. A predecessor of the Anaconda Copper Co. sank a 900-foot shaft near Boyd, in T. 4 S., R. 22 E., to the coal, but found its ash content high and two thick partings within the main coal bed. This mine was accordingly considered unprofitable and was abandoned in 1901.

Although the good coal contains only a moderate amount of ash, unless great care is used to sort out bone and dirt the product as shipped will contain an excessive amount of ash. The coal is a subbituminous coal of good grade, can be stored fairly well, and is the principal source of supply for the local market, where its chief competitor is Fort Union coal from the Red Lodge-Bear Creek district.

In 1922 wagon mines were shipping coal from secs. 24 and 25, T. 4 S., R. 22 E. This coal was hauled chiefly to Joliet, where some was shipped by rail. The Burgin mine, in sec. 26, formerly produced 25 to 50 tons daily from workings that extended 1,200 feet down the dip. Trouble with water and shipping costs led to the abandonment of the mine when it reached a depth of 75 feet below the level of Elbow Creek. It has not been operated since 1913. A small mine in the NW. ¼ sec. 23 has been occasionally operated for the supply of the landowner and his neighbors.

Farther south, west of Fromberg, there has been considerable mining of the Eagle coal, locally known as Fromberg coal. The Gebo mine, in the NW. ¼ sec. 18, T. 5 S., R. 23 E., had a railroad connection through Fromberg and once supported the company town of Coalville. Transfer of company interests to thicker and better beds in Wyoming is said to have caused the abandonment of the mine and the town. Two mines were being operated in 1922 in sec. 18, T. 5 S., R. 23 E., and their product was shipped chiefly by rail. A switch track from Fromberg served both mines, which together averaged about one car a day during the fall and winter.

The Bridger mine of the Bridger Coal & Improvement Co., in the SE. ¼ sec. 17, T. 6 S., R. 23 E., was the largest producing mine in the district in 1922. It has employed 90 to 100 men and has produced 200 tons a day, but before the strike in 1922 only 15 men were working, and the output was 30 to 35 tons a day. The main entry is 3,900 feet long, extending S. 70° W., with five cross entries ranging from 300 to 1,800 feet in length. Mining is carried on by the long-wall method, roof pressure being utilized to break down the coal after undercutting. Electric haulage is used inside the mine and to pull the cars to the tipple, about 4,000 feet from the mouth of the mine. Gas does not occur in the mine, and open-flame lamps are in use. About 2,000 gallons of water is pumped daily. The following section is reported by the company to be typical of the mine, although the quality improves northwestward by thinning of the lower break, and southwestward the upper coal becomes more bony.

Section in the Bridger mine, at point 3,000 feet from the mine entry in sec. 17, T. 6 S., R. 23 E.

	Ft.	in.
Roof, sandy shale.		
Coal		6
Shale, sandy, soft		10
Coal	1	6
Bone	1	
Coal	2	2
Clay floor.		
Total coal	4	2

Several prospect pits have been opened in T. 6 S., south of the Bridger mine, but only one mine was working in 1922—the Pioneer mine, in sec. 32, which was employing five to seven men and producing 10 to 12 tons of coal daily. It had no rail connection. A roof of soft sandy shale, together with much bone, made operation expensive. At the extreme southeastern outcrop of the coal, north of Clark Fork, the coal has burned back from the surface for 150 to 300 feet.

East or south of Clark Fork coal is known within the area here under consideration only in sec. 15, T. 7 S., R. 23 E. Because of the Bowler fault it occurs fully a mile east of its normal position. Two prospect pits have been opened, but no coal has been shipped.

JUDITH RIVER FORMATION

In the Judith River formation about 75 feet below the Bearpaw shale there is a coal bed that has been worked by several wagon mines in Tps. 1 and 2 S., R. 21 E., as shown on the geologic map. The following section of the coal illustrates its character, but because of rapid lateral variation the section may not be valid at as short a distance as 500 feet.

Section of coal in Judith River formation in sec. 33, T. 1 N., R. 21 E.

	Ft.	in.
Sandstone, heavy bedded to massive, weathering to thin laminations	5	
Clay, carbonaceous	2	
Coal, black, jointed; slacks greatly on exposure		3
Bone		3
Coal, as above		8
Shale, blue-gray, carbonaceous in zones and carrying many plant fossils	7	
Total coal		11

A similar section was measured at a mine in sec. 26, T. 1 S., R. 21 E., and illustrates the repeated occurrence of volcanic ash with the Judith River coal.

Section of coal in Judith River formation in sec. 26, T. 1 S., R. 21 E.

	Ft.	in.
Clay, carbonaceous		6
Coal		1
Bone		3
Clay, carbonaceous, with coal seams a fraction of an inch thick	1	6
Volcanic ash (unaltered), with leaves, stems, and thin coal lenses representing buried tree trunks		5
Clay, carbonaceous, or bone		3
Coal, good quality		2
Bone		5
Coal, good quality	1	8
Shale, sandy, yellow-brown.		
Total coal	1	11
Coal mined	1	8

The ash content of the coal is high, and unless care is used in sorting out waste much bone and shale are included in the coal as shipped. Southward this bed thins out, and it disappears entirely south of T. 2 S. and was not located south of the Yellowstone River.

The following analysis was made by the Bureau of Mines on a sample of coal collected by the authors. The sample was taken in the usual manner by channeling across the working face of the mine and rejecting a bone bed that is normally picked out in mining.

Analysis of coal from Judith River formation in NW. ¼ sec. 26, T. 1 S., R. 21 E.

[H. M. Cooper, analyst]

	Air dried	As received	Moisture free	Moisture and ash free
Moisture	10.7	12.5		
Volatile matter	31.7	31.1	35.5	44.4
Fixed carbon	39.6	38.7	44.3	55.6
Ash	18.0	17.7	20.2	
Sulphur	.6	.6	.7	.9
Calories	4,739	4,639	5,300	6,639
British thermal units	8,530	8,350	9,450	11,950

This coal bed is the one referred by Hancock [64] to the Bearpaw shale in the Lake Basin field. It is possible that exposures at the mine in sec. 29, T. 2 N., R. 20 E., have been considerably improved since the Lake Basin work was done. At present the channeled

[64] Hancock, E. T., Geology and oil and gas prospects of the Lake Basin field, Mont.: U. S. Geol. Survey Bull. 691, p. 121, 1918.

character of the top of the coal and its position between stream-deposited volcanic ash beds of the Judith River are both very clear. The coal lies at the base of a Judith River hill, and a dip of 6° SW. would be required to carry the coal over the hill. Actually, the dip is about 2° SE., as Hancock correctly indicated. Hancock's structure contours, together with differences in altitude, indicate that the bed lies 550 to 600 feet below the base of the Lennep. The present authors estimate the distance at 525 feet. As the Bearpaw is only 400 feet thick, the coal must be of Judith River age.

Three small wagon mines were operating on this coal bed within the area described in this report in 1922. None had a main entry over 75 feet long, and the output of each was less than 10 tons a day. These mines supply a local trade in the surrounding agricultural district, where the haul from the mine is shorter than that from the nearest railroad town.

Although the Cloverly shales and the Lennep formation have produced coal in neighboring areas, they contain only carbonaceous clays in this area. No coal beds, even though small, are known here outside the Eagle and Judith River formations.

GYPSUM

The heavy bed of gypsum that occurs near or at the top of the Chugwater formation, depending on the amount of pre-Sundance erosion, ranges from 15 to 35 feet in thickness. The upper 20 feet is characteristically a white granular gypsum that shows no impurities in the hand specimen. A plaster of Paris mill was operated from 1897 to 1904 on this bed in sec. 18, T. 7 S., R. 24 E., but distance from fuel and transportation made the enterprise unprofitable. The Casper-Billings line of the Chicago, Burlington & Quincy Railroad now renders the gypsum readily available. A large reserve, averaging 15 to 20 feet in thickness, underlies the Sundance formation in T. 7 S., R. 24 E., both northeast and southwest of Bridger Canyon.

UNDERGROUND WATER

In this area water supplies are of great importance. Surface supplies are almost entirely confined to the larger valleys. Much of the upland could be made more habitable by drilling artesian wells. In most places the amount of water would probably not provide for extensive irrigation but would supply domestic and livestock needs. An indication of the large amounts of water available is offered by a well of the 56 Petroleum Co., drilled on the northeast flank of the Pryor Mountains, which was flowing at a roughly gaged rate of 1,000,000 gallons of fresh water a day in July, 1922.

Structurally the whole region is a northwestward-plunging anticline composed of alternate porous and impervious beds. Much of the precipitation on the Pryor Mountains runs into the porous sandstones and fails to reach the lowland valleys. Some of this water escapes to the surface in springs, such as the beautiful Blue Springs on upper Bluewater Creek, in sec. 9, T. 6 S., R. 24 E., where several springs occur along a fault line. The largest spring in the area issues from the Chugwater formation in sec. 22, T. 6 S., R. 24 E., where a daily flow of 800,000 to 1,000,000 gallons was gaged. Much calcium carbonate is deposited by the water, which has built a mound of tufa 82 feet high that blocks the valley and extends 350 feet along it. This spring is utilized for irrigating a considerable area up the valley, where the ponded stream has built a small park.

Artesian water from wells drilled for oil irrigates small tracts in secs. 16 and 17, T. 7 S., R. 24 E. The well in sec. 16 is 1,184 feet deep and probably produces water from the Tensleep sandstone. Its flow has remained constant for 15 years. In the northwest corner of sec. 17 a 500-foot well produces a hydrogen sulphide water that probably comes from the upper part of the Chugwater formation. Faulting makes the identification of the horizon doubtful. This water is satisfactorily used for irrigation.

In sec. 20 of the same township a well drilled to a reported depth of 400 feet produces water from the upper, oil-saturated Chugwater formation. This well is located on the southwest flank of Red Dome. Chugwater strata have been deeply eroded on top of the dome, where the oil saturation bleached the normal red color to gray. Some of the sandstone still contains enough oil to stain the hands and to yield a distinctly petroliferous odor when freshly broken. The flank well produces water that contains hydrogen sulphide from the upper beds of the Chugwater, where possibly gypsum is being reduced by the oil, with resulting liberation of hydrogen sulphide. The inner casing of the well extends 200 feet or more into the Chugwater, and a water containing calcium sulphate is obtained from the lower horizon.

The following analysis of water obtained from the higher horizon was made by J. G. Fairchild, of the United States Geological Survey.

Analysis of water in upper part of Chugwater formation from well in sec. 20, T. 7 S., R. 24 E.

	Parts per million
HCO_3	1,044
SO_4	2,015
Cl	Trace.

	Parts per million
SH	[a] 95
Ca	639
Mg	169
Ba	None.
Sr	18
Na	345
K	27
Li	Faint trace.
SiO_2 and $(Al, Fe)_2O_3$	Trace.
Total solids at 180° C	3, 320

The Harrison Oil & Gas Co. drilled a 3,212-foot well to a sand that is probably the quartzite in the Mowry shale, in sec. 22, T. 1 S., R. 21 E. Fresh, potable water stood within 3 feet of the top of the casing, which was said to extend 650 feet below the surface. There is no evidence as to the formation that supplies the water, and it is probably a mixed water from Montana and Colorado sands. A sample of this water was analyzed by Mr. Fairchild, whose report is given below.

Analysis of water from the Harrison Oil & Gas Co. well in sec. 22, T. 1 S., R. 21 E.

HCO_3	2, 364
SO_4	Trace.
Cl	658
SH	None.
Ca	13
Mg	3
Ba	None.
Sr	None.
Na	1, 298
K	16
Li	0. 3
SiO_2 and $(Al, Fe)_2O_3$	9
Total solids at 180° C	3, 190

Lithium was determined by the spectroscopic method. The HCO_3 ion was determined by actual titration with standard acid.

Although this water contains considerable sodium chloride, it had no bad effect on vegetation when bailed from the well and could probably be used for irrigation, if it were occasionally used freely enough to wash away the residues of evaporation.

A well in the southwest corner of sec. 25, T. 5 S., R. 22 E., was drilled into the Niobrara shale and abandoned at a depth of 1,904 feet. Water stands 16 feet below the surface and is pumped for

[a] The SH could not be determined directly because of the small sample supplied but is approximated from the difference in ionic ratios of acids and bases. Lithium was determined by the spectroscope; HCO_3 by titration with standard acid.

domestic use and for irrigating a small tract. It is reported that continuous pumping does not affect the water level.

In addition to the wells seen during this study, the wells mentioned below are said to have flowed over the casing while they were being drilled. In the SE. ¼ sec. 7, T. 2 S., R. 24 E., water flowed in large quantity from sandstone in the Frontier formation when the hole was 960 feet deep. In the "Muddy sand" artesian water was also found, but the flow was of small volume. This bed was 1,700 feet below the surface. The well in the northeast corner of sec. 8, T. 4 S., R. 23 E., encountered artesian water at 960 feet in the lower part of the Frontier or in a sandstone in the upper part of the Mowry shale. Although the pressure was sufficient to make the water flow from the well, the volume was small, and bailing lowered the water level almost to the bottom of the well. In the SW. ¼ NE. ¼ sec. 18, T. 3 S., R. 25 E., artesian water was struck at 640 feet in the "Muddy sand" or else in a fault zone.

It appears from these observations that artesian wells can be obtained in nearly all parts of the area; that the well may flow, if located near the mountains or in upland valleys; that the water will be within pumping distance of the surface through practically the whole area; and that potable waters may be expected at one or more horizons, even very deep below the surface.