Geology of the Bighorn Canyon-Hardin area, Montana and Wyoming

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Geology of the Bighorn Canyon-Hardin area, Montana and Wyoming

By PAUL W. RICHARDS

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A description of the geography, stratigraphy, structure, geomorphology, and mineral resources of the area

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GEOLOGY OF THE BIGHORN CANYON-HARDIN AREA, MONTANA AND WYOMING

By Paul W. Richards

ABSTRACT

This report describes the geology of an area of about 1,300 square miles in south-central Montana extending from Hardin, Mont., southward across part of the Great Plains to the Bighorn Mountains and thence southwestward through the mountains along Bighorn Canyon to the Bighorn Basin. The area is mostly within the Crow Indian Reservation in southwestern Big Horn County, Mont., but it includes parts of Carbon County, Mont., and Big Horn County, Wyo., and less than 10 square miles of the southeast part of Yellowstone County, Mont.

The only incorporated town within the area is Hardin, the county seat of Big Horn County, Mont., and the only other settlement is St. Xavier, Mont. The region is drained by the Bighorn River and its tributaries. The main valleys are cultivated. The proposed Yellowtail dam, in the canyon of the Bighorn River near the east edge of the Bighorn Mountains, would create a reservoir 70 miles long and provide irrigation water for extensive terrace lands along the Bighorn River.

About 9,000 feet of sedimentary rocks, ranging in age from Cambrian to Late Cretaceous, are exposed in the area. Pre-Cambrian granites and metamorphic rocks, which form the central parts of the Bighorn Mountains and are separated from the overlying sedimentary rocks by an erosional unconformity, do not crop out in the area. In the deepest part of Bighorn Canyon approximately the upper 700 feet of about 1,000 feet of shale and thin-bedded limestone that make up the Cambrian Gros Ventre formation and Gallatin limestone is exposed. Resistant limestone and dolomite which overlie the Gallatin comprise 400 feet of Bighorn dolomite of Ordovician age, 200 feet of undivided Jefferson limestone and Three Forks shale of Late Devonian age, and 700 feet of Madison limestone of Mississippian age.

The overlying rocks belong to the Amsden formation, which is intergradational from the Mississippian(?) to the Pennsylvanian and the Tensleep sandstone of Pennsylvanian age. The Amsden formation lies unconformably on the Madison limestone, consists of red shales and siltstones, gray limestones and sandstones, and ranges from 230 to 280 feet in thickness. The Tensleep sandstone, which is as much as 120 feet thick but is missing locally, consists of gray to yellowish-gray sandstone and a few thin beds of dolomite and chert. Overlying the Tensleep sandstone and separated from it by an erosional unconformity are the Permian Embar formation and the Triassic Chugwater formation. The Embar and Chugwater formations were mapped separately only in the southwestern part of the area where the Embar consists of 100 feet of dolomite, limestone, and red siltstone and sandstone. Elsewhere, a zone of redbeds, gypsum, and thin beds of limestone is seemingly the Embar equivalent, but the zone is too thin to

map as a formation and was included in the base of the Chugwater formation. The Chugwater formation consists of 350 to 500 feet of red sandstone and siltstone and gypsum.

About 150 feet of red siltstone and sandstone, limestone, and gypsum belonging to the Piper formation of Middle Jurassic age overlies the Chugwater formation. In central Montana the Piper is separated from rocks as old as Mississippian by an extensive unconformity, but in the area adjacent to the Bighorn Mountains the Piper is seemingly conformable above the Chugwater. About 300 feet of light olive-gray to olive-brown calcareous shale belonging to the Upper Jurassic Rierdon formation overlies the Piper, and nearly 200 feet of yellowish-gray to grayish-green sandstone and siltstone and light olive-gray shale of the Upper Jurassic Swift formation overlie the Rierdon. Glauconite-bearing marine beds of the Swift formation grade upward into continental sandstones and siltstones of the overlying Upper Jurassic Morrison formation. The upper part of the Morrison is largely variegated shales which are commonly concealed, and the total thickness of the formation ranges from less than 100 feet to about 250 feet.

The Lower Cretaceous Cloverly formation is 400 feet or less thick. It contains a basal lenticular member named the Pryor conglomerate member, a middle zone of variegated beds, and an upper zone of interbedded siltstones, shales, and sandstones. Where the Pryor member is missing, variegated beds in the upper part of the Morrison cannot be distinguished from beds of similar lithology in the Cloverly, and the two formations were mapped together.

The Lower Cretaceous Thermopolis shale, which is about 450 feet thick, consists of dark-gray shale and interbedded bentonite. A zone of gray sandstone dikes about 150 feet above the base is correlated with the Newcastle sandstone of the Powder River Basin and the Muddy sandstone in the Bighorn Basin. Overlying the Thermopolis shale is the Mowry shale which is characterized by abundant fish scales and numerous layers of siliceous shale and siltstone. The Mowry is 325 to 400 feet in thickness and contains several beds of bentonite. It is the uppermost formation in the Lower Cretaceous series.

A conformable sequence above the Mowry shale of about 4,000 feet of shales, siltstones, and sandstones underlies the Great Plains region. Included in this sequence are the Frontier formation, Cody shale, Parkman sandstone, and Bearpaw shale, all of Late Cretaceous age. These formations belong to the Colorado and Montana groups. The basal few feet of the nonmarine Hell Creek formation, which is equivalent to the Lance formation and younger than the Montana group, occurs in the northeast corner of the mapped area.

The Frontier formation, about 250 feet thick, comprises dark-gray partly sandy shale and interbedded bentonite. Overlying the Frontier is the Cody shale which consists of 2,600 feet of dark-gray concretionary partly sandy shale and interbedded bentonite. It has been divided into 7 members, the lower 4 belonging to the Colorado group and the upper 3 to the Montana group. From base to top, the members of the Cody shale are (a) an unnamed member 200 feet thick; (b) the Greenhorn calcareous member 60 to 100 feet thick; (c) the Carlile shale member about 280 feet thick; (d) the Niobrara shale member 400 feet thick; (e) the Telegraph Creek member 750 feet to 850 feet thick; (f) a shale member equivalent in age to the Eagle sandstone about 375 feet thick; and (g) the Claggett shale member about 350 feet thick. Above the Cody shale is the Parkman sandstone which comprises 100 feet of silty and sandy shale overlain by 150 feet of massive and thick-bedded yellowish-gray and greenish-gray sandstone. The Bearpaw shale, which is the uppermost formation of the Montana group, is exposed only in the northeastern corner of the area. It is composed of dark-gray shale 850 feet thick that has many beds of bentonite in the middle.

A few feet of greenish sandstone, siltstone, and shale belonging to the Hell Creek formation overlie the Bearpaw in the northeastern corner of the area.

Six well-developed stream terraces, the highest two of which may be late Tertiary in age, extend along the Bighorn River. These and correlative terraces in tributary stream valleys have a 25-foot thick veneer of limestone and volcanic rock gravel. Several surfaces, which were mapped as pediments, in the southwestern part of the area slope rather steeply away from the Pryor Mountains and are covered with limestone gravel and boulders washed from the Pryor Mountains. Several erosional surfaces in the Great Plains area have little covering other than reworked shale and gravel washed from nearby terraces, and these surfaces were mapped as undifferentiated Quaternary surfaces.

The folding and main deformation of the mountains occurred during early Tertiary time after the deposition of all the sedimentary formations of the area. The domes and anticlines in the plains region may have formed during this same period of orogeny as they trend parallel to the northern end of the Bighorn Mountains which is itself the northward plunging end of a long anticline. Structural closure on the domes is small except for Soap Creek dome, and faults are simple and of relatively small displacement except for the Sykes Springs fault zone near the southern tip of the Pryor Mountains.

Black oil has been produced from the Soap Creek oil field, which was first drilled in 1921, and gas for the town of Hardin is supplied from the Hardin gas field. Thick beds of bentonite in the Cretaceous formations and limestone in the Carboniferous strata may some day be of economic importance.

INTRODUCTION

LOCATION AND EXTENT OF AREA

This report and the accompanying maps describe the geology of an area of about 1,300 square miles which is mainly within southwestern Big Horn County, Mont., but extends into the southeastern part of Carbon County, Mont., and the north-central part of Big Horn County, Wyo. The location of the area is shown by the index map on plate 1. About 1,125 square miles, or nearly one-third of the Crow Indian Reservation is included. Nearly 70 miles of the Bighorn River from Crooked Creek in northern Wyoming to a point 5 miles below the mouth of the Little Bighorn River in Montana, including the site of the proposed Yellowtail dam are shown. The maps cover the south half of the Fort Custer and the north half of the St. Xavier 30-minute quadrangles (published in 1894 and 1901 respectively) and an irregularly shaped area along Bighorn Canyon from the Bighorn Basin through the Bighorn Mountains.

PURPOSE OF REPORT

This report was prepared as part of the Interior Department program for development of the Missouri River basin. The fourfold purpose of the investigation was (1) to map and study the terraces below the mouth of Bighorn Canyon in order to provide information as to the type of aggregate available for construction of the proposed Yellowtail dam and show the distribution of terraces, some of which would be irrigated by water diverted from the Bighorn River by the dam; (2) to map the geology of Bighorn Canyon and show formations that would be covered in part by the Yellowtail reservoir; (3) to locate and describe mineral deposits of possible economic importance; and (4) to map and describe the rock formations, some of which contain known or potential oil-bearing strata elsewhere in Montana and Wyoming. These formations are exposed for detailed study in and near the Bighorn Mountains. A map and brief text have been published describing the geology and geologic structure of part of the area (Richards and Rogers, 1951).

LEGAL STATUS OF LAND

The Crow Indian Reservation, which includes about 2,250,000 acres of land, is made up of four classes of land ownership. Trust allotted lands, comprising 78 percent of the reservation, have been apportioned to individual members of the tribe with the title to the land held in trust by the United States Government. Tribal lands, making up about 12 percent of the reservation, are owned by the Crow tribe. Fee, or alienated lands, include about 10 percent of the reservation and have been patented to members of the tribe or to persons outside the tribe. Land owned by the United States Government makes up an almost negligible percentage of the reservation. Most of the land surrounding the Crow Indian Reservation is held in fee.

FIELD WORK AND ACKNOWLEDGMENTS

Field work was done during the months of June to October in 1947 and 1948. The project was under the direction of C. P. Rogers, Jr. until November 1947 when the writer assumed charge and completed the work. Assistants were E. C. Beaumont and Z. S. Altschuler in 1947 and Linn Hoover, Jr., W. J. Mapel, A. A. Meyerhoff, and G. E. Prichard in 1948. Members of the field parties worked alone much of the time, but each man worked in several areas and no index was made to show the parts of the area mapped individually.

Geologic and topographic features were drawn in the field on aerial photographs, both contact prints and enlargements, and were transferred to subsequently prepared base maps by the use of a vertical Sketchmaster for the plains area where the topographic relief is low, and by the use of a Kail plotter for the Bighorn Canyon area where the relief is high. The base map of the plains area (pl. 1) was compiled from General Land Office plats on a plane table and telescopic alidade triangulation net prepared by the writer. Vertical control for structure contouring was carried by plane table triangulation from Coast and Geodetic Survey benchmarks along the Chicago, Burlington & Quincy Railroad. The base map of the Bighorn Canyon area (pl. 1) was taken from a topographic map of the Yellowtail reservoir site prepared for the Bureau of Reclamation by Fairchild Aerial Surveys, Inc. This topographic map was compiled by stereophotographic methods, the triangulation net having been established by ground survey.

W. A. Cobban of the Geological Survey furnished several stratigraphic sections of Cretaceous formations measured and described by him that have appeared in generalized form (Knechtel and Patterson, 1952, pl. 1). Assistance in several ways was extended members of the party by offices of the Bureau of Reclamation and the Big Horn County Agricultural Conservation Association at Hardin, Mont. The Tribal Council of the Crow Indians granted permission to map within the reservation. Phillips Petroleum Co. kindly provided samples and the electric log of the Soap Creek oil field (the Inland Empire Refineries well 52–34, Crow tribal); and H. H. Perrigo, district engineer of the Geological Survey at Billings, Mont., supplied recorded data on wells. The writer expresses for himself and members of the party appreciation for the many courtesies given by residents of the area.

PREVIOUS WORK AND PUBLICATIONS

The Bighorn Mountains were mapped by Darton (1906a) between 1901 and 1905. Thom and Moulton (1921) made a report and structure contour map of Soak Creek dome, and Thom (1922) made a report on Soap Creek dome and other domes and anticlines in the area adjacent to the Bighorn Mountains. Thom later (Thom and others, 1935) completed the unpublished reports of several field projects in the Crow Indian Reservation, Montana. The Hardin gas field was described by Perry (1937). Geology of the Pryor Mountains was described by Blackstone (1940). Several stratigraphic sections were measured along the flanks of the Bighorn Mountains by L. S. Gardner and others (1946).

GEOGRAPHY

SURFACE FEATURES AND RELIEF

The Bighorn Canyon-Hardin area lies along the border of the Great Plains and Middle Rocky Mountain provinces (Fenneman, 1931, p. 160). The Bighorn Mountains trend northwestward about 150 miles from north-central Wyoming into south-central Montana. Their width decreases from about 30 miles in Wyoming to a point where they die out north of Bighorn Canyon in Montana. In the high central part of the mountains, glaciated peaks are as much as 13,000 feet above sea level, but the crest of the range declines steadily northward to 8,000 feet at the Montana-Wyoming border, 6,000 feet just south of Bighorn Canyon, and less than 4,500 feet at Grapevine dome at the northern tip of the Bighorns.

In Montana the Bighorn Mountains have been untouched by glaciation; so there are no peaks. A relatively smooth upland surface, which has been deeply incised by streams, slopes from the crest to steep flanks. Although the streams are now in deep canyons, the intercanyon areas have been dissected so little that much of the surface can be crossed by auto. Cattle, sheep, and buffalo that belong to the Crow Indians graze on the higher slopes.

As the Bighorn Mountains decline in altitude northward, they take the outline of one's thumb and forefinger—the forefinger on the east and pointed northward. The western flank of the range—represented by the thumb—ends in Porcupine Creek anticline, almost on the Montana-Wyoming border, and the eastern flank—represented by the forefinger—runs a little more than 25 miles into Montana. The Pryor Mountains start just north of the west flank of the Bighorns and continue 30 miles northwestward into Montana. West of the Bighorn and Pryor Mountains is the Bighorn Basin, and east of the Bighorn Mountains is the Powder River Basin. These basins, which are roughly elliptical in outline and trend northward to northwestward, are more than 100 miles long.

A smaller basin lies between the Pryor Mountains and the two northern prongs of the Bighorn Mountains. This basin is bisected by Bighorn Canyon; the area south of the canyon is called Garvin Basin, whereas the area north of the canyon is herein referred to as the Dry Head Creek area.

Bighorn Canyon ranges from 200 feet to more than 1,000 feet in depth across the Garvin Basin-Dry Head Creek area. The canyon is narrow, and the walls are nearly vertical for most of the canyon's length. Livestock can cross the canyon and ford the river at only one locality, which is south of the mouth of Camp Creek in T. 8 S., R. 29 E.

As the Bighorn River crosses the axis of the northern projection of the mountains, Bighorn Canyon changes from a 1,000-foot deep box canyon to a 2,200-foot deep gorge. The canyon declines steadily in depth from the axis of the mountains to the mouth, where the canyon walls are only a few feet high. There, the Bighorn flows onto the Great Plains and meanders through a broad valley to join the Yellowstone River about 60 miles north of the mouth of Bighorn Canyon. Stream terraces in the Bighorn valley are as much as 700 feet above the river.

CLIMATE AND VEGETATION

The climate of most of the region is semiarid, the average annual precipitation at Hardin from 1940 to 1947 being a little less than 15 inches. The average annual precipitation is higher toward the mountains, and at the Campbell farm camp, which is about 600 feet higher than Hardin, the average precipitation was 19 inches from 1942 to 1947. Precipitation in the mountains is undoubtedly much higher. May and June are the wettest months, and July and August are the hottest. Temperatures as low as −46° F. and as high as 110° F. were recorded at Crow Agency between 1897 and 1930. Climatological data for the area are summarized in table 1.

Rain and melted snow support a good growth of grass in meadows of the Bighorn Mountains and on high terraced lands of the plains region. Pine forests grow on the Bighorn Mountains, scattered groves of pines mark the outcrops of sandstone along the flanks of the mountains, and cottonwood and boxelder trees flourish in the valleys of perennial streams. Sagebrush, greasewood, small varieties of cacti, and sparse grass grow on thin soil that covers the dark shales of the plains and the gravels of the lower terraces.

DRAINAGE AND WATER SUPPLY

The Bighorn River, master stream of the area, originates at the southern edge of the Bighorn Basin, Wyo., as a continuation of the Wind River. The Wind River crosses the western part of the Wind River Basin, Wyo., and then flows northward across the Owl Creek Mountains through Wind River Canyon. At the mouth of this canyon the stream changes in name from the Wind River to the Bighorn River, which crosses the Bighorn Basin, the northern end of the Bighorn Mountains, Mont., and finally part of the Great Plains to the Yellowstone River about 30 miles north of Hardin, Mont. The average rate of discharge of the Bighorn River is about 3,500 cubic feet per second (cfs) at a point just downstream from the mouth of Bighorn Cayon and more than 4,000 cfs at Hardin. A high flow of 37,400 cfs and a low of 228 cfs have been recorded at the gauge near the mouth of Bighorn Canyon.

The Little Bighorn River, which joins the Bighorn near Hardin, is the chief tributary stream within the area. A dozen smaller permanent streams, all of which head in the Bighorn and Pryor Mountains, enter the Bighorn River. A summary of stream discharges is shown in table 2.

Irrigation water for the Bighorn River valley between the Bighorn Mountains and Hardin is carried in two canals. The Bighorn canal, with its headgate at the mouth of Bighorn Canyon, supplies water for the valley above Two Leggin Bridge about 8 miles south of

TABLE 1.—*Climatological data for Hardin and the surrounding area in Big Horn County, Mont.*

[From U. S. Weather Bureau reports]

Station	Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Average monthly and annual precipitation at Weather Bureau stations at and near Hardin (inches)														
Campbell farm camp	1940–47	0.59	0.61	0.93	1.96	2.45	4.60	0.78	1.08	2.60	1.40	1.06	0.63	18.69
Crow Agency [1]	1881–90	.91	.45	.59	1.13	1.75	2.57	.87	1.02	.95	92	.39	.67	12.00
Do.[1]	1891–1900	[2] .74	[2] .46	[2] .82	[2] 1.73	[2] 2.33	[2] 3.08	[2] 1.68	[2] .72	.81	1.57	[2] 1.15	[3] .34	[4] 16.07
Do.[1]	1901–10	.58	.85	1.47	1.33	2.88	2.48	.98	1.02	1.18	.93	.88	.97	15.55
Do.[1]	1911–20 [5]	[4] 1.05	[4] .72	[4] .77	[4] 1.23	[4] 2.26	[4] 2.27	[3] 1.52	[3] .69	[3] 1.59	[3] 1.72	[3] .83	[3] .60	[4] 15.68
Do.[1]	1921–30	.99	.84	1.12	1.38	2.74	2.01	1.81	.64	1.62	1.49	1.23	.87	16.74
Do.[1]	1931–40	.66	.79	1.56	1.61	2.03	1.79	.99	.90	1.09	1.37	.66	.79	14.22
Do.[1]	1941–47	.58	.41	1.01	1.65	1.93	4.16	.61	1.07	2.37	1.36	.85	.87	16.86
Hardin	1942–47	.51	.41	.82	.84	1.90	3.93	.65	1.19	1.89	.98	.59	.59	14.30
Average monthly and annual temperature (° F.)														
Campbell farm camp	1940–47	26.3	28.4	34.9	47.3	54.7	60.8	72.5	70.8	60.4	51.5	35.6	30.4	47.8
Crow Agency [1]	47 years [6]	18.9	21.8	33.6	46.4	54.7	65.1	72.4	69.0	58.7	47.4	33.6	23.6	45.4
Do	1931–47	[3] 22.0	[2] 24.3	[2] 32.6	[2] 44.3	[3] 56.5	[3] 64.6	[2] 68.7	[2] 69.8	[2] 59.2	[2] 48.8	[2] 33.8	[2] 25.7	[4] 46.7
Hardin	1942–47	23.4	26.6	34.6	48.9	55.1	61.5	71.7	69.4	59.7	50.2	34.5	26.2	46.9
Average monthly and annual maximum temperatures (° F.)														
Crow Agency [1]	47 years [6]	31.6	34.6	46.4	60.5	68.2	80.4	89.7	86.4	75.4	62.5	47.1	35.5	59.9
Average monthly and annual minimum temperatures (° F).														
Crow Agency [1]	47 years [6]	6.2	9.0	20.9	32.2	41.2	49.8	55.1	51.5	42.0	32.3	20.1	11.7	31.0

[1] Record from 1881 to October 1897, inclusive, for old Fort Custer, about 9 miles northwest of Crow Agency.
[2] One year's record missing.
[3] Two years' records missing.
[4] Three years' records missing.
[5] No record for 1915–16.
[6] Through 1930.

TABLE 2.—*Stream discharges*

[Data in cubic feet per second for water years ending September 30. Sources: U. S. Geol. Survey, 1943 and 1947, Water Supply Papers 917 and 1036; and unpublished records of the Water Resources Division, Billings, Mont.]

Stream	Location of gaging station	Period	Discharge				
			Average	Maximum		Minimum	
				Amount	Date	Amount	Date
Bighorn River	Kane, Wyo	1928–45	2,319	25,200	June 16, 1935	179	June 22, 1934.
Do	22 miles southwest of St. Xavier, Mont	1934–45	3,556	37,400	June 16, 1935	228	Dec. 9, 1937.
Do	One-half mile above mouth of Little Bighorn River near Hardin, Mont.	1917–24	4,941				
		1929–32	4,055				
Little Bighorn River	Near Crow Agency, Mont	1928–29	434	8,200	July 23, 1923	None	July 28–Aug. 6, 1921.
		1930–31	153				
		1931–32	301				
		1938–46	285	3,980	June 6, 1944	2	Aug. 4–6, 1939.
Rotten Grass Creek	Near St. Xavier, Mont	1914–17	31				
Soap Creek	10 miles southwest of St. Xavier, Mont	1939–47	33	1,060	May 13, 1942	5	Jan. 18–19, 1940.

Hardin. Two Leggin canal, with its headgate at the bridge, supplies the valley between Two Leggin Bridge and Hardin. Between the canyon and the bridge the river flows along the western edge of the valley, but it crosses to the eastern side below the bridge and flows northward past Hardin on the east edge of the valley. A reservoir impounded by the proposed Yellowtail dam would reach up the Bighorn River to near Kane, Wyo., on the west side of the Bighorn Mountains about 11 miles south of the Montana border. It would provide water to irrigate the terrace, now farmed by dry-land methods, 125 feet above the Bighorn River on the west side of the valley below Bighorn Canyon.

INDUSTRY, SETTLEMENT, AND TRANSPORTATION

Ranching and farming are the principal industries in the area. Wheat is grown on the terraces, and cattle and sheep graze the grasslands. Sugar beets, which are refined at Hardin, and hay are the chief crops of irrigated lands. Some oil has been produced from the Soap Creek field, and gas from the Hardin gas field supplies the town of Hardin and nearby ranches.

Hardin, the county seat of Big Horn County, Mont., and the only incorporated town in the area, had a population of 1,886 in 1940. Most of the inhabitants of the area live on farms in the river valleys and on the lower terraces. Crow Agency, headquarters of the Crow Indian Reservation, is in the valley of the Little Bighorn River about 12 miles southeast of Hardin.

Hardin is on the Chicago, Burlington & Quincy Railroad between Billings, Mont., and Sheridan, Wyo. U. S. Highway 87 is generally parallel to the railroad. The only other paved road in the area is between Hardin and St. Xavier. The history of exploration and early settlement of the area has been described by Thom (Thom and others, 1935, p. 5–7).

STRATIGRAPHY

GENERAL FEATURES

About 9,000 feet of sedimentary rocks, predominantly of marine origin, is exposed within the area. Lying in a nearly conformable sequence, they represent every system from Cambrian to Cretaceous except the Silurian. Rocks older than the Upper Jurassic Morrison formation crop out only between and on the flanks of the Bighorn and Pryor Mountains. Morrison and younger rocks are exposed in the plains region east and north of the Bighorn and Pryor Mountains.

Pre-Cambrian crystalline rocks and the lowermost Cambrian strata are not exposed within the area, and the only exposure of pre-Cambrian rocks in the Montana part of the Bighorn Mountains is at Point Lookout, about 16 miles south of the mouth of Bighorn Canyon (Darton, 1906a, pl. 47). The pre-Cambrian crystalline rocks, which form the core of the Bighorn Mountains, are mostly moderately coarse-grained red granite and fine-grained gray granite which are transitional into each other (Darton, 1906a, p. 15–17). Some schist and gneiss are exposed in the core of the mountain, and many dikes of basic rock intrude the granite. All are truncated by an unconformity at the base of the Cambrian system (Darton, 1906a, pl. 6).

Characteristics of the formations exposed in the area are summarized in plate 2. Thicknesses of the formations were obtained from surface sections and from records of wells drilled in the area. The formations, particularly those of the Paleozoic era, are traced westward into formations underlying the Bighorn Basin in plate 4.

CAMBRIAN SYSTEM

GROS VENTRE FORMATION AND GALLATIN LIMESTONE

The basal 300 feet of Cambrian strata are not exposed in the area, but as much as 700 feet of limestones and shales of Cambrian age crop out in the deepest part of Bighorn Canyon at the anticlinal axis of the Bighorn Mountains. Steep talus-covered slopes on these rocks rise from the river to the cliff-forming Bighorn dolomite of Ordovician age, and the Cambrian rocks can be seen only in isolated exposures.

Darton included all Cambrian strata of the Bighorn Mountains in the Deadwood formation, a name which he had earlier given to Cambrian rocks of the Black Hills area (Darton, 1901, p. 505). He described the Deadwood of the Bighorn Mountains as being about 900 feet thick and consisting of a basal 10- to 200-foot zone of coarse-grained reddish-brown conglomeratic sandstone, an overlying 200-foot zone of sandy shale and thin-bedded sandstone which merges upward into 400 feet or more of soft greenish-gray shale with a few limestone and sandstone beds, and an uppermost zone, 125 to 200 feet thick, of gray slabby limestone, sandstone, and flat-pebble limestone conglomerate (Darton, 1906a, p. 23–26).

A two-fold division of the Cambrian strata into an upper predominantly limestone formation and a lower predominantly shale and limestone unit leads to a correlation of these strata in the northern end of the Bighorn Mountains with the Gros Ventre formation and Gallatin limestone of more westerly areas. The use of these names is to be preferred over using the Deadwood formation which was applied to beds in the Black Hills about 200 miles southeast of Bighorn Canyon. A correlation of the Cambrian strata across Bighorn Basin and the north end of the Bighorn Mountains is shown in plate 4.

The uppermost 40 feet of the Gallatin in Bighorn Canyon consists of thin-bedded gray limestone, thin-bedded mud-cracked, somewhat silty, grayish-green shale, thin stringers of sand, and thin beds of rather inconspicuous flat-pebble limestone conglomerate. The underlying beds are mostly poorly exposed interbedded shale and flat-pebble or edgewise conglomerate.

Cambrian strata, about 1,050 feet thick, in the Inland Empire Refineries well 52–34, Crow tribal, at Soap Creek dome are divisible into a lower 850 feet of what is predominantly shale and an upper 200 feet of limestone. The lithology, based upon a study of cuttings from the well by G. E. Prichard, is shown in plate 3. The lower unit, which is probably the Gros Ventre formation, is made up of two main lithologic units, a lower 600 feet or more of dark-gray and dark-green shale, phyllitic in the basal part and variably silty, sandy, and calcareous throughout, and an upper 235-foot unit composed of micaceous, fissile gray to green calcareous shale. The topmost 200 feet of limestone is considered to be the Gallatin limestone. Some fragments of dark-green shale occur in the samples from this upper unit, but shale seems to be less abundant in the subsurface samples from the Gallatin than in the outcrop. The lower member of Darton's Deadwood formation, a conglomeratic sandstone, does not occur in the Inland Empire Refineries well, and the sandstone may be missing in the nearby mountains.

Darton (1906a, p. 26) considered the Deadwood formation in the Bighorn Mountains to be Middle Cambrian, but Meyerhoff and Lochman (1938, p. 285) have found Upper Cambrian strata there, too. The Gros Ventre formation and the Gallatin limestone west of the Bighorn Basin are Middle Cambrian and Upper Cambrian respectively (Wilmarth, 1938, p. 883 and 793).

Poor exposures of Cambrian strata in Bighorn Canyon and the absence of faunal data have led to mapping the two formations as one unit. The contact between the Gallatin limestone and the Gros Ventre formation in Soap Creek dome is based upon lithologic similarities with those formations west of Bighorn Basin (Leatherock, 1950). As no fossils have been collected in the one area, part or all the 235 feet of calcareous shale at the top of the Gros Ventre formation in the Inland Empire Refineries well may be Late Cambrian in age.

ORDOVICIAN SYSTEM

BIGHORN DOLOMITE

The Bighorn dolomite ranges in thickness from about 205 feet in Black Canyon to 390 feet in Bighorn Canyon and 480 feet in Soap Creek dome. Within this area the Bighorn consists of a lower massive dolomitic limestone member and an upper thin-bedded dolomite and limestone member. The massive member is exposed in high cliffs which led Darton (1906a, p. 26) to say that the Bighorn is perhaps the most conspicuous sedimentary formation in the Bighorn Mountains.

In the section near the mouth of Big Bull Elk Creek in Bighorn Canyon, a description of which follows, the lower member of the Bighorn dolomite is light yellowish-gray dolomitic limestone that forms a smooth vertical cliff 180 feet high above a steep slope on the Cambrian strata. Weathering along a bedding plane about 45 feet below the top has made the only break in the cliff. Above this massive member, which forms the cliff, are thin beds of light-gray to white dolomite and dolomitic limestone, which form alternate slopes and ledges. A similar, though thinner section was measured by Gardner and Rogers (Gardner and others, 1946, p. 90–91) at Black Canyon, about 9 miles southeast of the Bighorn Canyon section.

Section of Bighorn dolomite on north side of Bighorn River about 2 miles west of mouth of Big Bull Elk Creek in N½ sec. 5, T. 7 S., R. 30 E. (unsurveyed), Big Horn County, Mont.

[Units are numbered as shown in plate 4, section 4]

	Feet
Jefferson limestone and Three Forks shale undifferentiated:	
Limestone, light-brown, dolomitic, thick-bedded	23
Bighorn dolomite:	
12. Limestone, light-gray, dolomitic, thin-bedded	22
Limestone, white, dolomitic, very finely crystalline, medium-bedded; forms prominent cliff	80
Limestone, white, in part dolomitic, thin-bedded; forms slopes	65
13. Dolomite, white, very finely crystalline, thick-bedded; forms small cliffs locally but is generally concealed	40
14. Limestone, yellowish-gray, dolomitic, finely crystalline, massive; forms cliff with underlying unit	35
Limestone, similar to overlying unit; forms vertical cliff	145
Total, Bighorn dolomite	387
Gros Ventre formation and Gallatin limestone undifferentiated:	
Limestone and shale: gray thin-bedded ripple-marked finely crystalline limestone and green silty mud-cracked shale in very thin beds and laminae; few thin beds of flat-pebble limestone conglomerate and a few streaks of sand	40

The Bighorn dolomite is fairly uniform in thickness along Bighorn Canyon, but, as shown in plate 4, it is thicker to the west beneath the Bighorn Basin and to the east in Soap Creek dome. This range in thickness may be due to an unconformity at the base of the Devonian system, but the amount is questionable because of the uncertainty in distinguishing Ordovician from Devonian strata.[1] Bedding in the upper part of the Cambrian strata seems to be parallel with the base of the Bighorn dolomite, or nearly so, but exposures of the contact are poor, and the exact relation between the Bighorn and Cambrian strata was not determined.

[1] The occurrence of Silurian rocks in the subsurface at Soap Creek dome was suggested shortly before this report went to the printer. In the pre-Permian correlation chart of the Billings Geological Society's Fifth Annual Field Conference Guidebook (1954) the rocks between 2,905 and 3,050 feet depth in the Inland Empire Refineries well at Soap Creek dome are called Silurian(?)

All Ordovician strata of the Bighorn Mountains were included in the Bighorn dolomite by Darton (1906a). The two members of the Bighorn dolomite within the area are correlated with the Upper Ordovician beds described in the central latitudes of the Bighorn Mountains by Darton (1906a, p. 28–29). At least 2 and probably 3 units of the Bighorn dolomite in the Bighorn Mountains in Wyoming do not occur or are poorly represented along Bighorn Canyon. These are (1) a sandy dolomite in the base of the lower massive member, which Kirk (1930, p. 460–465) correlates with the Lander sandstone (Miller, 1930), (2) the fine-grained white sandstone beneath the massive member, which Kirk (1930, p. 460–465) correlates with the Middle Ordovician Harding sandstone of Colorado, and (3) red shaly and silty beds at the top of the Bighorn, which was described briefly by Darton (1906a, p. 28) as "reddish clay, due to the weathering of the uppermost limestone." Whether these reddish silty beds are younger than the highest beds in Bighorn Canyon or whether they represent a lateral change in lithology of the highest beds in Bighorn Caynon is not now known. These 3 units are well exposed along the South Fork of Rock Creek, Johnson County, Wyo., about 90 miles south-southeast of the mouth of Bighorn Canyon.

DEVONIAN SYSTEM

JEFFERSON LIMESTONE AND THREE FORKS SHALE UNDIFFERENTIATED

Rocks of probable Devonian age, which are herein mapped as undifferentiated Jefferson limestone and Three Forks shale, crop out in Bighorn Canyon between Black Canyon and Dry Head Creek, in Black Canyon, and in Devils Canyon of Porcupine Creek. Darton (1906, p. 14) did not recognize any formation of Devonian age in the Bighorn Mountains. Both Stipp (1947, p. 122) and Thomas (1948, fig. 2), however, have indicated the possibility of Devonian rocks occurring in the northern part of the mountains, and earlier Wilson (1934) had mapped Devonian rocks along the west flank of the mountains a few miles east of Lovell in Big Horn County, Wyo.

The names Jefferson limestone and Three Forks shale were first given to Devonian strata in Jefferson and Gallatin Counties, Mont., about 200 miles west of Bighorn Canyon. These names are used in the Bighorn Canyon area for strata that are presumed to be at least in part the stratigraphic equivalents of the type Jefferson and Three Forks, even though the lithology of the beds along and near Bighorn Canyon is not wholly the same as the type formations. Further work, particularly subsurface studies of adjacent areas, may indicate that another name such as, perhaps, the Darby formation of Wyoming, is preferable.

Jefferson and Three Forks rocks are 395 feet thick in a section measured by W. G. Pierce and R. P. Bryson along Clarks Fork of the Yellowstone River in T. 56 N., R. 103 W., Park County, Wyo. (Leatherock, 1950). Two surface sections of the Devonian rocks were measured in the Bighorn Canyon area; one in Devils Canyon (fig. 1), where the formations are 180 feet thick, and the other in Bighorn Canyon near the mouth of Big Bull Elk Creek (fig. 2), where the formations are 220 feet thick. These two sections are described below. The Devonian rocks include a lower limestone and dolomite unit containing some greenish-gray shale, siltstone, and sand, and an upper very sandy limestone and dolomite unit. The sand grains are well rounded, commonly one millimeter in diameter, and occur in stringers and disseminated throughout the limestone and dolomite. The greenish-gray shale is in very thin layers; some is so dolomitic that it could be called argillaceous dolomite. Limestones in the upper part of the Devils Canyon area contain many calcite-filled vugs. These and the abundant sand grains are characteristic of the Darby formation of Wyoming (Thomas, 1948, p. 84).

Section of undifferentiated Jefferson limestone and Three Forks shale on north side of the Bighorn River about 2 miles east of mouth of Big Bull Elk Creek in N½ sec. 5, T. 7 S., R. 30 E. (unsurveyed), Big Horn County, Mont.

[Units are numbered as shown in plate 4, section 4]

	Feet
Madison limestone:	
Limestone, gray, finely crystalline, medium-bedded; lower few feet dolomitic and sandy; thin-bedded chert in upper 40 feet; irregular contact with underlying strata	84
Jefferson limestone and Three Forks shale undifferentiated:	
9. Limestone, yellowish-gray, finely crystalline, and interbedded greenish-gray sandy limestone in irregular beds; few inches at top consist of greenish-gray siltstone and sandstone with subrounded gray quartzite and limestone pebbles as much as 1-inch in diameter	96
Limestone, gray, finely crystalline, and laminated greenish-gray sandy limestone; a 3-foot bed of sandy limestone breccia about 10 feet below top; lower 15 feet mostly concealed	30
10. Limestone, brownish-gray, granular, cliff-forming	5
Concealed	10
Limestone, brownish-gray, thin-bedded, cliff-forming	13
11. Dolomite, gray, finely crystalline, hard; many vugs; thin zone of green shale at base	17
Dolomite, gray, finely crystalline; some irregular zones of reddish dolomite in upper part; lower 5 feet thin bedded and platy; upper part weathers very blocky; much of unit weathers to very sharp rough surface	25
Limestone, light brownish-gray, dolomitic, thick-bedded	23
	219
Bighorn dolomite:	
Limestone, dolomitic, light-gray, thin-bedded	22

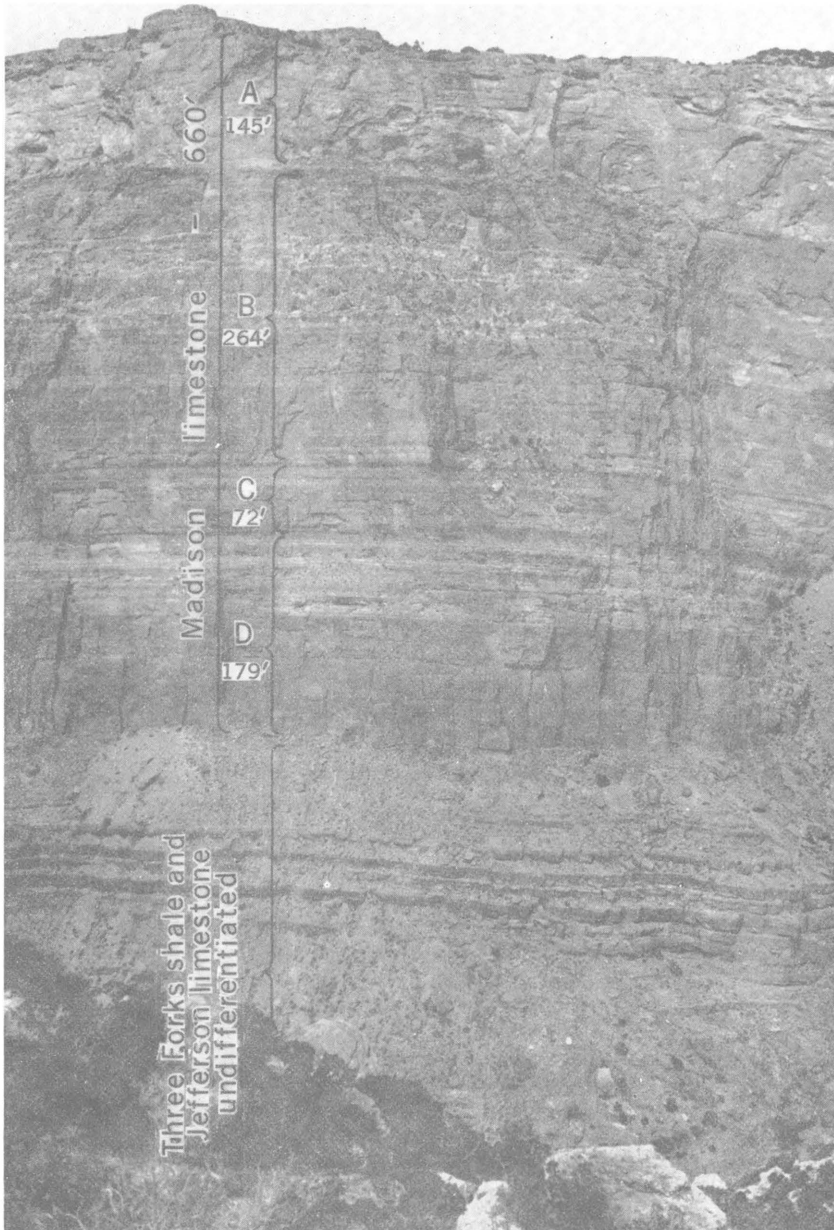

FIGURE 1.—Paleozoic strata in north wall of Devils Canyon of Porcupine Creek. Madison limestone and underlying beds of probable Devonian age crop out about one-third mile east of Bighorn Canyon. Porcupine Creek, which is just below the lowest rocks seen in photo, joins the Bighorn River in the southwest corner of Big Horn County, Mont.

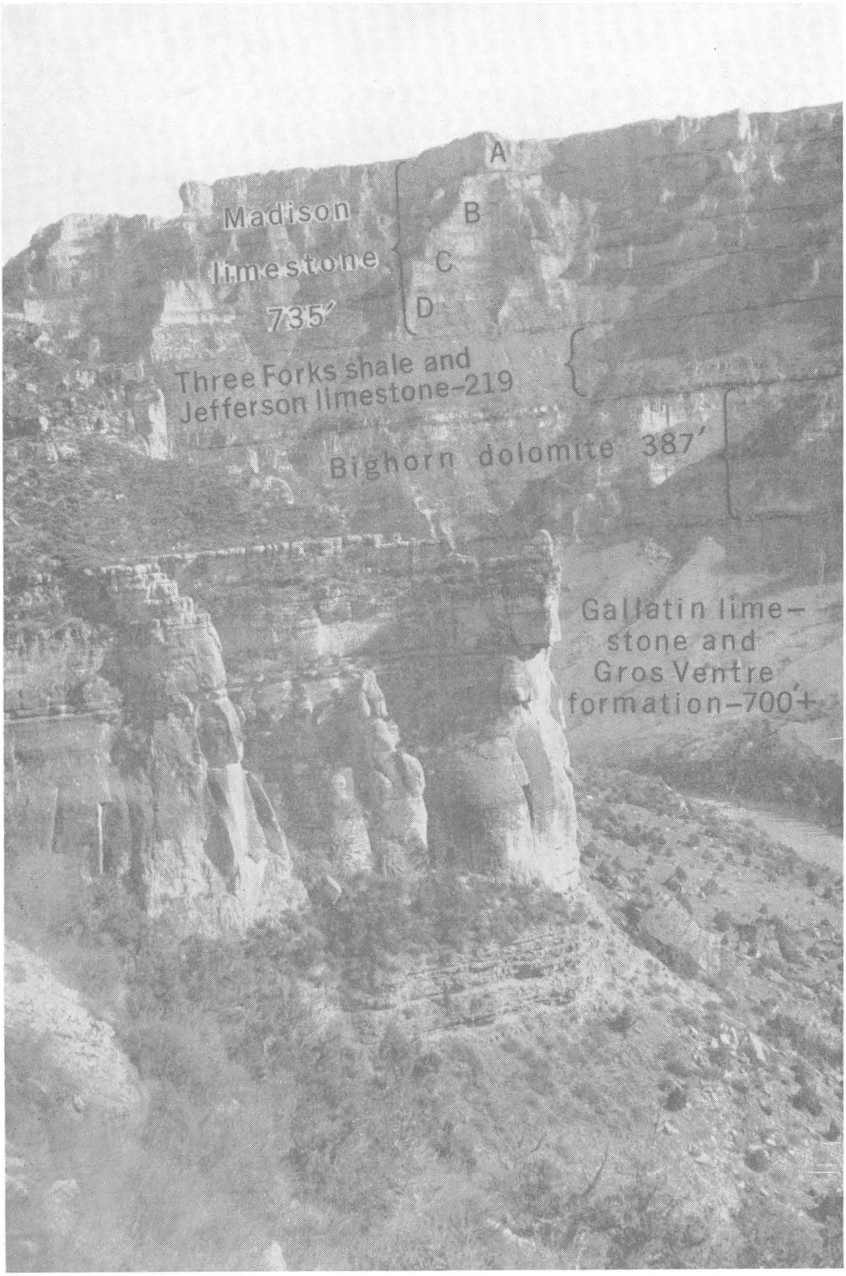

FIGURE 2.—Paleozoic strata in Bighorn Canyon near the crest of the Bighorn Mountains. View eastward across the Bighorn River from a point opposite the mouth of Big Bull Elk Creek. Paleozoic strata underlying the Amsden formation are seen in the far cliffs. The basal member of the Bighorn dolomite and the underlying Cambrian thin-bedded limestone and shales form the cliff in foreground. The thickness shown for each formation was measured on near side of river, starting at base of Bighorn dolomite in foreground.

Section of undifferentiated Jefferson limestone and Three Forks shale and upper part of Bighorn dolomite in Devils Canyon about one-half mile east of junction of Porcupine Creek and the Bighorn River in S½ sec. 25, T. 9 S., R. 28 E. (unsurveyed), Big Horn County, Mont.

[Units are numbered as shown in plate 4, section 3]

	Feet
Madison limestone:	
Limestone, light-gray, dolomitic, hard	9
Jefferson limestone and Three Forks shale undifferentiated:	
7. Dolomite, brownish-gray, sandy, hard; vugs in upper part filled by calcite	8
Dolomite, greenish-gray, very silty; contains few thin rusty-weathering sandy beds and beds of green shale; upper 6 inches somewhat brecciated, containing angular fragments of gray dolomite; lower 10 feet mostly concealed	18
Dolomite, light-brownish-gray, granular, partly silty	2
Siltstone and fine-grained sandstone, greenish-gray; weathers green and brown; several thin layers of sandstone composed of well-rounded frosted quartz sand as much as 1 millimeter in diameter	10
8. Limestone, gray, finely crystalline, medium-bedded; ledge former; weathers brownish gray	4
Dolomite, gray; bedding in lower 4 feet very irregular; weathers blocky	12
Dolomite, pale-brown, granular; at top is 3-inch bed of very porous limestone composed of calcite grains; ledge former	1
Siltstone and sandstone, greenish-gray; sandstone has coarse well-rounded quartz grains in fine matrix; thin bed of yellowish-brown dolomite 2 feet below top has calcite crystals in vugs	10
Dolomite, dense and earthy, and greenish-gray coarse-grained sandstone in which quartz grains are cemented	1
Limestone, light-brown, dolomitic; numerous vugs filled with calcite crystals; channeling in top of unit; upper 2 feet very porous	10
Shale, greenish-gray, dolomitic, hard, flaky; much sand in base	5
Limestone, light-gray, dense, thin-bedded	2
Limestone, brownish-gray, finely crystalline; ledge former	5
Dolomite, gray, sandy; vugs on surface	3
Sandstone, greenish-gray, shaly, mostly fine-grained and very fine grained; contains many 1-millimeter quartz grains	1
Dolomite, light-gray, granular, weathers light gray	2
Limestone, pale-yellowish-brown, very finely crystalline; ledge former	4
Limestone, light-gray, weathers to pitted surfaces	3
Limestone, gray; weathers brownish gray; ledge former	13
Dolomite, greenish-gray, silty; 1 inch of greenish-gray dolomitic shale at top	1
Limestone, light-gray, earthy, thin-bedded	2
Limestone, brownish-gray, dolomitic; this and overlying unit weather to very rough corrugated surfaces	2½
Dolomite, gray	2
Dolomite, greenish-gray, silty, soft; forms reentrant	½

Section of undifferentiated Jefferson limestone and Three Forks shale and upper part of Bighorn dolomite in Devils Canyon about one-half mile east of junction of Porcupine Creek and the Bighorn River in S½ sec. 25, T. 9 S., R. 28 E. (unsurveyed), Big Horn County, Mont.—Continued

	Feet
Jefferson limestone and Three Forks shale undifferentiated—Continued	
Limestone and dolomitic limestone, gray; ledge former; lower 4 to 5 feet pitted	10
Limestone and dolomite; dolomitic limestone at top and gray finely crystalline dolomite at base	4
Dolomite, silty and greenish-gray sandy dolomitic siltstone	8
Dolomite, gray, dense, hard, vuggy	5
Dolomite, gray, dense	4
Siltstone and shale, greenish-gray	3
Dolomite and limestone, gray, thin- to medium-bedded	7
Limestone, brownish-gray; ledge former	6
Limestone, sandy, thin-bedded	7
Dolomite and dolomitic limestone, gray, thin- to medium-bedded	8
Concealed	4
Total, Jefferson limestone and Three Forks shale, undifferentiated	188
Bighorn dolomite:	
9. Dolomite, light-gray; reddish brown in upper 10 feet; weathers brown and gray; sharp rough surfaces, finely crystalline; 2 or 3 ledges in unit	25
Dolomite, very light gray; weathers white; finely crystalline; gradational into underlying unit	8
Dolomite, light-gray to white; weathers to very sharp rough surface; caves develop at base and extend vertically, resulting in formation of pinnacles	15
Dolomite, light-gray, finely crystalline to dense, hard; forms small ledge	4
Dolomite, light-gray, dense; forms two ledges	36
Total, to level of Porcupine Creek	88

Devonian rocks are 210 feet thick in the Barnsdall well 2, Dorothy Fox, sec. 7, T. 57 N., R. 97 W., Big Horn County, Wyo., on Sage Creek dome in the Bighorn Basin. They are 185 feet thick in the Inland Empire Refineries well 52–34 Crow tribal, at Soap Creek dome, Big Horn County, Mont., just east of the Bighorn Mountains (pl. 3, and sec. 6, pl. 4).

The contact between the Bighorn dolomite and the overlying Devonian strata is difficult to recognize. In this report it is so placed in the doubtful zone that the Bighorn dolomite includes most of the light-gray to white dolomites and the Jefferson and Three Forks strata contain the gray to brown dolomites and slightly shaly and sandy limestones. Bedding in the Ordovician and Devonian strata is seemingly parallel and no erosional unconformity was seen in the field. Dorf (1934, p. 727) described an erosional unconformity between the Ordovician and Devonian rocks at Beartooth Butte on the Beartooth Mountains north of Clarks Fork. There, the Beartooth Butte formation was deposited during Early Devonian time in a deep channel cut into the Bighorn dolomite.

Several fossils were collected from the Devils Canyon section by R. J. Ross, Jr., R. P. Kunkel, and the writer. Brachiopods in USGS collection D2 (SD) from brownish-gray limestones about 60 feet below the Madison limestone have been described by A. J. Boucot of the Geological Survey (personal communication) as "finely ribbed brachiopods referable to the genus *Atrypa*. Similarly ornamented members of this genus occur elsewhere in the Middle and Upper Devonian beds of the west." Corals in USGS collection D4 (SD) were collected from silty limestones about 20 feet below the limestones that contained the above described brachiopods. These were examined by Jean M. Berdan of the Geological Survey who states (personal communication) that

> Collection D–4 contains broken and sheared tetracorals which may be part of a loosely phacelloid colony, scraps of cladoporoid corals, and stromatoporoids. As some sections of the tetracorals show dissepiments, and as cladoporoid corals are present, the collection may be dated as post-Ordovician. The presence of stromatoporoids suggests that it is pre-Mississippian. Although none of the fossils have been identified generically because of the poor preservation, the faunal assemblage suggests a Devonian age for the beds rather than Silurian, although on the basis of this collection the possibility of a Silurian age cannot be eliminated.

In Clarks Fork Canyon W. G. Pierce and R. P. Bryson collected fossils from beds about 150 feet above the base of a rock sequence believed to be comparable to the Devonian of the Bighorn Canyon area. These fossils were examined by Edwin Kirk, who stated that they are probably of Jefferson age (Leatherock, 1950) and identified a brachiopod as *Atrypa reticularis* Linnaeus. The pelecypod fragments were indeterminate. Corals in the same lot have been restudied by Helen Duncan and Jean Berdan, who report (personal communication) that

> The dolomitic samples contain poorly preserved fragments suggesting "*Favosites limitaris*" and indications of forms that are probably disphyllids. Another specimen in a limestone matrix, although incomplete, is much better preserved. This coral, which may be the form called *Amplexus* in the previous report, is apparently an undescribed genus. It has a large columella and other characters that suggest relationships with Carboniferous zaphrentoids. Inasmuch as corals comparable to this one have never been reported in the Devonian and the specimen occurs in a different lithology, derivation from higher beds is suggested.

M. T. Rader and J. K. Osmond of the Continental Oil Co. collected an *Atrypa* n. sp. and *Amplexiphyllum* n. sp. from 40 feet below the

Madison limestone and the same *Atrypa* n. sp. and *Theodossia* n. sp. from 63 feet below the Madison in Bighorn Canyon west of the mouth of Big Bull Elk Creek (personal communication from Rader). These fossils, which came from the same locality that was measured and described by the writer (pl. 4, section 4), were identified by Dr. B. J. Chronic of the University of Colorado for the Continental Oil Co. Mr. Rader states (personal communication) that forms similar to the *Atrypa* n. sp. were collected from Devonian strata at Beartooth Butte, Park County, Wyo., and in Montana from Shell Mountain in Park County, the Little Rocky Mountains, and the Rocky Mountain front east of Glacier National Park.

In plate 4, sections 1 to 6, the writer has shown a correlation of what he considers to be Devonian strata in Bighorn Canyon and Bighorn Basin with the Devonian strata exposed west of Bighorn Basin at Clarks Fork. Devonian strata extend northwestward from Clarks Fork around the Beartooth Mountains (Lovering, 1929, p. 27–28) and southward from Clarks Fork to Shoshone Canyon near Cody, Wyo. (Johnson, 1934, p. 817–818), thence into Wind River Basin, Wyoming (Thomas, 1948, p. 84).

CARBONIFEROUS SYSTEMS

MISSISSIPPIAN SYSTEM

MADISON LIMESTONE

The Madison limestone is 865 feet thick in the subsurface at Soap Creek dome, 735 feet in Bighorn Canyon, and 670 feet in Devils Canyon. Westward from Devils Canyon it thickens to about 800 feet in Sage Creek dome, Wyo., and nearly 1,000 feet at Clarks Fork of the Yellowstone River, Wyo. In the higher parts of Bighorn Canyon the formation forms a steplike series of cliffs with pinnacles and spires common on strata below the uppermost massive member. The Madison limestone has been divided, for convenience of description, into four lithologic units which are lettered *A* to *D*, from top to bottom. These units are easily recognized in exposures, and the thinnest, unit *C*, is a good marker in both surface and subsurface sections. They are shown in the photograph of Devils Canyon (fig. 1).

The lowest zone, unit *D*, is about 190 feet thick and consists chiefly of finely crystalline limestone and dolomite. A 40-foot zone of nodular chert 40 feet above the base of the Madison is well exposed in Bighorn Canyon, and is recognizable in the Soap Creek dome and Sage Creek dome wells. A much thinner bed of chert occurs at this horizon in Devils Canyon.

Unit *C*, which is about 75 feet thick in surface sections and somewhat thinner in the subsurface, is the most conspicuous and persistent lithologic marker in the formation. It is grayish-purple to reddish, partly silty, limestone that contains thin layers of broken remains of brachiopods, bryozoans, and crinoid stems. It is readily recognized by its reddish color in subsurface samples and by its purplish color in weathered outcrops.

Unit *B* is 265 feet thick at Devils Canyon, 310 feet near the mouth of Big Bull Elk Creek, and nearly 400 feet in the subsurface at Soap Creek dome. It is hard finely crystalline light-gray limestone and dolomite. Prominent pinnacles on the canyon walls are erosional remnants of beds in this unit. The upper 40 feet of the zone in the lower Bighorn Canyon area and the upper 120 feet in the Devils Canyon area are broken, possibly by collapse of solution caverns before deposition of the next younger unit in the Madison. This brecciated zone can be seen faintly in the walls of Bighorn Canyon near the mouth of Porcupine Creek.

Small irregularities in the upper surface of unit *B*, observed in two accessible but poorly exposed localities in the western end of Bighorn Canyon, are filled with limestone fragments which are lithologically similar to the limestone of the unit itself. These depressions, which are as much as a foot or two deep, are interpreted to be channels that have been filled by material eroded from the unit elsewhere and deposited in the channels. These channels seem to underlie and to be older than the breccias and redbeds in the overlying member of the Madison limestone. The breccia and the channel fills in unit *B* may be evidence of an unconformity above the unit, an unconformity that may follow in general but not in detail the contact of units *A* and *B*.

Solution cavities lined with calcite crystals have formed in the upper part of this unit. Several cavities large enough to permit entry of a man were intersected as much as 150 feet from the face of the canyon wall by tunnels at Yellowtail dam site. Although the cavities are undoubtedly the result of solution during a much later time than the solution that led to the brecciation of the upper part of unit *B*, their exact age has not been determined. Bureau of Reclamation geologists expect that a core-drilling program, which started late in 1952 during the writing of this report, will show whether the cavities follow bedding planes in the Madison limestone or whether they follow some nearly level horizon. If they coincide with bedding planes, the cavities presumably are pre-Laramide folding in age, but if they follow a nearly level plane, the cavities may have formed in post-Laramide time and have a genetic relationship to the Bighorn River when the river stood at some higher level now marked by terraces in the Great Plains.

The upper member of the Madison limestone, unit *A*, is about 145 feet thick along Bighorn Canyon, and it forms a sheer cliff at the upper rim of the canyons in the northern part of the Bighorn Mountains. Much of the member is finely crystalline thin-bedded pale yellowish-brown limestone. The unit is commonly thin bedded, although from a distance it appears to be massive. Numerous zones of breccia in the unit, particularly at the top and the base, contain limestone fragments in a matrix of red claystone and mudstone typical of the basal part of the overlying Amsden formation. Many caves have weathered into the basal breccia zone, and collapse structures are common in the brecciated limestone.

Although unit *A* is reasonably uniform in thickness along Bighorn Canyon, its boundaries were presumably determined by erosion and not by deposition. That is, this member includes by definition the brecciated beds at the top of the Madison limestone, and the breccia has been described as a product of cavern collapse following solution of the top of the Madison limestone in a time of weathering that preceded or coincided with early Amsden deposition (Thom and others, 1935, p. 37). If this theory of origin is correct, the top and base of unit *A* bear only incidental relation to bedding planes in the Madison limestone, and the age of the limestone strata in unit *A* would differ from place to place depending mainly upon the amount of folding of the Madison that preceded erosion. The outline of fillings of channels and sinkholes in the Madison limestone by red muds, much of which may have been soil on the karst topography, is illustrated by the cross section shown in plate 5. Judging from its appearance in outcrops along Bighorn Canyon, unit *A* is nearly parallel to the underlying Madison strata.

Unit *A* is correlated in plate 4 with the upper, brecciated member of the Madison limestone in the canyon of the Clarks Fork in Wyoming along the west edge of the Bighorn Basin (Leatherock, 1950). As has been pointed out in the preceding discussion, the uppermost beds in the Madison of the Bighorn Canyon and the Clarks Fork may not be the same age; so the brecciated unit along the Clarks Fork may be younger or older, than unit *A* along the Bighorn River.

The contacts of the Madison limestone with the underlying and overlying formations are well marked by changes in lithologic character and topography. Massive ledge-forming limestone at the base of the Madison rests on sandy or shaly limestone or dolomite at the top of the Devonian strata. The contact is at a definite break in topography; the Devonian strata have been eroded to steeply sloping surfaces, whereas the Mississippian limestones occur as ledges and cliffs. Bedding of the two formations appears to be parallel, but a thin layer of breccia at the contact in Bighorn Canyon marks what may be an erosional unconformity. Redbeds at the base of the Amsden formation have been eroded to smooth slopes above the Madison cliffs.

Thom (Thom and others, 1935, p. 34–35) referred the Madison limestone to the lower Mississippian. Additional paleontologic data may show the presence of upper Mississippian strata, too.

Section of Madison limestone on north side of Bighorn Canyon about 2 miles east of the mouth of Big Bull Elk Creek in S½ sec. 32, T. 6 S., R. 30 E. (unsurveyed), Big Horn County, Mont.

[Units are numbered as shown in plate 4, section 4]

	Feet
Amsden formation: Concealed, red soil.	
Unconformity.	
Madison limestone:	
Unit *A*:	
1. Limestone and breccia, light-brownish-gray, finely crystalline; hard thin-bedded limestone with a few thin layers of chert; breccia of limestone, red shale, and siltstone abundant near top and base; forms massive vertical to overhanging cliffs; contact with underlying unit is irregular	145
Unit *B*:	
2. Limestone, very light gray, finely crystalline, medium-bedded; somewhat brecciated near top; some channeling at top with solution cavities along bedding planes; erodes to pinnacles	85
3. Limestone, very light gray, dolomitic, finely crystalline to dense, hard, thin- to medium-bedded; small vugs in upper part; lower few feet very dolomitic; forms pinnacles	100
4. Dolomite and limestone; thin-bedded gray dolomite and thicker beds of gray limestone; red-shale partings at base	46
5. Limestone, gray and pale-brown, finely crystalline; forms pinnacled cliff with overlying unit	81
Unit *C*:	
6. Limestone, grayish-red to grayish-red-purple, dolomitic, silty, medium- and thick-bedded	45
Limestone, grayish-purple; crystalline, partly clastic; contains many red- and purple-silt stringers and thin layers of brachiopods, bryozoans, and crinoid stem fragments in lower part	38
Unit *D*:	
7. Limestone, light-brownish-gray, finely crystalline and dense, poorly bedded; forms ledges	29
Limestone, light-brownish-gray, finely crystalline; forms massive overhanging ledge	12
Limestone, light-gray, finely crystalline; weathers to yellowish and light-gray blocky surface	20
Limestone, light-gray and gray, finely crystalline, vuggy	50
8. Limestone, gray, crystalline, medium-bedded; lower few feet dolomitic and sandy; thin-bedded chert in upper 40 feet; irregular contact with underlying unit	84
Total, Madison limestone	735
Jefferson limestone and Three Forks shale undifferentiated:	
Limestone, yellowish-gray, finely crystalline, and interbedded greenish-gray sandy limestone in irregular beds; few inches at top consist of greenish-gray siltstone and sandstone with subrounded gray quartzite and limestone pebbles as much as 1 inch in diameter	96

Section of Madison limestone in Devils Canyon of Porcupine Creek in S½ sec. 25, T. 9 S., R. 28 E. (unsurveyed) Big Horn County, Mont.

[Units are numbered as shown in plate 4, section 3]

	Feet
Amsden formation: Shale and siltstone, red.	
Unconformity.	
Madison limestone:	
Unit *A*:	
1. Limestone, very light gray to light-brownish-gray, finely crystalline to granular, partly dolomitic, thin- to thick-bedded; fragmental and layered red and brown chert near top; basal 25 to 50 feet mostly breccia containing angular blocks and rounded pebbles of limestone in red shale, siltstone, and sandstone; collapse structures in limestone. Angular limestone blocks are imbedded in red siltstone and sandstone 20 to 40 feet below top of unit. The unit forms near vertical cliff in Bighorn and tributary canyons	145
Unit *B*:	
2. Limestone, light-gray, finely crystalline and dense; wavy and broken bedding; contains bedded and fragmental chert	120
Limestone, light-gray, finely crystalline, massive, ledge-forming	14
Limestone, light-gray, granular; fairly well bedded	6
3. Dolomite, gray to light-brownish-gray, dense, hard, medium-bedded; contains a few thin beds of dolomitic limestone	44
Dolomite, gray to light-brownish-gray; some beds are porous; thin beds of yellowish-gray chert in lower 3 feet	12
Dolomite, gray to light-brownish-gray; poorly preserved shells near top	32
Dolomite, gray to light-brownish-gray, dense to finely crystalline, medium-bedded; contains few thin beds of limestone	36
Unit *C*:	
4. Limestone and dolomite; lower 5 feet is mostly finely crystalline limestone, upper 12 feet is mostly dense gray dolomite with several red-shale partings; top 1½ feet is coarse-grained limestone	17
Limestone, gray and purplish-gray, partly dolomitic, medium-bedded, stylolitic, ledge-forming	18
Limestone, gray and purplish-gray; some interbedded gray dolomite contains red-shale stringers	8
Limestone, gray and purplish-gray; purplish zones contain many fragments of limestone and dolomite; numerous brachiopods	22
Limestone, gray and purplish-gray; thin, irregular bedding; forms base of overhanging ledge	3
Dolomite and limestone, light-gray; contains laminae of red silty material; many shell fragments; 1-inch layer of coarse silty red limestone with crinoid stem fragments at top	4
Unit *D*:	
5. Limestone, gray, hard, thin- to thick-bedded, ledge-forming	14
Limestone, gray and dark-gray, dense to finely crystalline, thin- and medium-bedded	16

Section of Madison limestone in Devils Canyon of Porcupine Creek in S½ sec. 25, T. 9 S., R. 28 E. (unsurveyed) Big Horn County, Mont.—Continued

	Feet
Madison limestone—Continued	
Unit *D*—Continued	
Limestone, gray (weathering bluish gray), dense, hard, thick-bedded	7
Limestone, gray, dense, thin-bedded	11
Limestone, brownish-gray (weathering black), dolomitic, granular, porous; upper 6 feet thin and medium bedded; has petroleum odor when freshly broken	20
Limestone and dolomitic limestone, brownish-gray (weathering brown), porous	16
Limestone, gray, dense	2
Limestone, brownish-gray, dolomitic, granular, porous	2
Limestone, gray, finely crystalline; lower 4 feet has splintery fracture	9
6. Limestone, gray, dolomitic, granular, porous; thin zone of gray chert nodules 27 feet above base	43
Limestone, gray, dolomitic, hard, massive	30
Limestone, light-gray, dolomitic, hard	9
Total Madison limestone	660
Unconformity.	
Jefferson limestone and Three Forks shale undifferentiated:	
Dolomite, brownish-gray, sandy; vugs in upper part filled with calcite	8
Dolomite, green, very silty.	

MISSISSIPPIAN AND PENNSYLVANIAN SYSTEMS

AMSDEN FORMATION

The Amsden formation, which ranges in thickness from 230 feet near the head of Bighorn Canyon to 280 feet on the eastern flank of the Bighorn Mountains, consists of interbedded sandstone, limestone, and red shale and siltstone. The Amsden is separated from the underlying Madison limestone by an erosional unconformity but is gradational into the overlying Tensleep sandstone.

The basal 50 feet of the Amsden is red shale and siltstone with intercalated limestone and dolomite resting upon channeled Madison limestone. A sequence of interbedded red shale, limestone, dolomite, and sandstone comprises the rest of the formation. Thin beds of gray or red chert and cherty limestone form ledges about in the middle of the formation. Inasmuch as the contact of the Amsden formation with overlying Tensleep sandstone is gradational by inter fingering, it was found expedient at some localities to map within the Amsden formation a few lenticular beds of sandstone similar to the Tensleep.

Preceding or accompanying early Amsden deposition the upper part of the Madison limestone underwent solution with resultant brecciation and filling by redbeds of the Amsden. There seems to be no divergence in bedding of the two formations however, except as noted by Thom at Shively Hill dome (Thom and others, 1935, p. 37). The nature of the complex contact between the Madison limestone and the Amsden formation and the size of the breccia masses in the upper member of the Madison are shown by plate 4.

Much of the Amsden formation in the northern end of the Bighorn Mountains is Pennsylvanian in age. L. G. Henbest of the Geological Survey collected and identified the following fossils from a 30-foot unit of cherty limestones about 100 feet above the base of the Amsden formation in the W½ sec. 35, T. 9 S., R. 28 E., Carbon County, Mont.

USGS collection f8009:

- Sponge spicules.
- Calcitornellids.
- *Climacammina* sp.
- *Bradyina* sp.
- *Tetrataxis* sp.
- *Pseudostaffella* sp.
- *Profusulinella* sp. (highly specialized form) or possibly a species of *Fusulinella*.

Henbest states (personal communication) that

> There is no record of these fusulinids in rocks that are known to be older than the Atoka; i. e., early middle Pennsylvanian. Occurrences in rocks known or thought to be of Atoka age are numerous and widespread. Restriction of these particular forms to Atoka time seems probable but range into early Des Moines time must be regarded as entirely possible.

About 100 feet of red shale and siltstone and several beds of dolomite lie beneath the fusulinid-bearing cherty limestones. No fossils were seen in these beds; so the age of approximately the lower one-third of the Amsden within this area is Pennsylvanian or Mississippian.

Section of Amsden formation in canyon near Kane, Wyo.,-Dry Head, Mont., road. Upper 35 feet measured in S½ sec. 34, T. 9 S., R. 28 E., lower 196 feet measured near Bighorn River, opposite mouth of Porcupine Creek in W½ sec. 35, T. 9 S., R. 28 E. Carbon County, Mont.

[Plate 4, section 3]

	Ft	in
Tensleep sandstone: Basal part covered in most areas; where exposed, 4 feet of ledge-forming dolomite with overlying sandstone.		
Amsden formation:		
Limestone, gray, sandy; 2 inches of red and purple shale at top		8
Breccia; a 2-foot bed of sandy limestone at top is broken and partly fragmented and many pieces are imbedded in underlying clayey limestone; about 100 yards along outcrop the sandy limestone is in very irregular beds, but is only slightly broken	2	8
Dolomite, red, silty		8
Shale and siltstone, red and purple; with a few thin beds of limestone	6	0
Sandstone, gray, and red shale	5	0
Dolomite, light-gray, and red shale; contains lenses of gray limestone, sandstone, and red chert	6	0
Limestone, irregularly bedded, ledge-forming	1	0
Breccia; fragments of thin-bedded limestone enclosed in red mudstone	4	0
Shale, red	3	0
Breccia, dolomite, and red shale; unit grades into clayey vuggy limestone	2	0
Sandstone interbedded with dolomite, light-gray	4	0
Shale, purple and red (weathering purplish); contains several lenses of white sand and, in lower 20 feet, 2 or 3 thin beds of dolomite	50	0
Sandstone, light-gray, fine-grained, calcareous, cross-bedded, ledge-forming	4	0
Sandy siltstone, yellowish-brown, calcareous, soft	3	0
Dolomite, gray, soft; mostly covered	4	0
Limestone and dolomite, light-gray, poorly bedded; contains some red shale; angular and nodular gray chert in upper part; middle mostly covered; Henbest collection, USGS f8009	31	0
Concealed	4	0
Dolomite, light-gray, dense	3	0
Limestone, light-gray	4	0
Dolomite, light-gray, partly brecciated, irregularly bedded	3	0
Concealed	10	0
Dolomite, gray, variably calcareous, ledge-forming; upper part siliceous, weathering to very sharp and irregular surface	9	0
Concealed	4	0
Dolomite, white, dense	1	0
Siltstone and silty shale, red, slightly calcareous; includes one thin bed of limestone	38	0
Limestone and dolomite, light-gray, dense; red-silt stringers at base	24	0
Concealed	4	0
Total, Amsden formation	231	0

Unconformity; a few beds at top of Madison limestone are beveled.

Section of Amsden formation about 3 miles south of Bighorn River canyon mouth in NE¼ sec. 33, T. 6 S., R. 31 E., Big Horn County, Mont.

[Plate 4, section 5. Measured by L. S. Gardner and C. P. Rogers, Jr.]

	Ft	*in*
Tensleep sandstone:		
Sandstone, white (weathering gray to yellowish gray), friable, massive cross-bedded	22	0
Quartzite, gray, fine-grained; capped by 8 inches of gray nodular sandstone of light lavender and greenish tints	3	0
Amsden formation:		
Shale, purplish-brown, calcareous, nonresistant		2
Sandstone, purplish-brown and white, quartzitic, locally cherty		10
Siltstone, dolomitic, light-purple, pink, and red; in thin laminations separated by partings of deep-red siltstone and platy shale	7	0
Siltstone and shale, purple, nonresistant, poorly exposed	5	0
Sandstone, white to gray (weathering brownish gray), calcareous, massive	3	0
Shale, dark-purple, calcareous		6
Sandstone, dark-red, fine-grained, massive, well-cemented to friable, nonresistant; has some gray streaks	6	6
Concealed	18	0
Sandstone, light-reddish-brown, very calcareous, medium- to fine-grained, massive, friable	11	0
Sandstone breccia, light-purple; contains many angular solution cavities as much as 2 inches across; composed of noncalcareous sandstone and purple shale; unit is nonresistant and becomes cavernous upon weathering	6	0
Concealed	27	0
Limestone, gray, massive, sandy-textured; contains gray to brown and reddish-brown lenses or layers of chert; bed of chert ½ to 2 inches thick is in middle of unit	11	0
Quartzite, gray, fine-grained, massive	1	6
Shale, siltstone, and claystone; dark-purple, calcareous, nonresistant; has some greenish-gray spots and irregular areas	1	6
Concealed	6	0
Chert, gray to light-purple, massive, brittle	5	0
Concealed	7	0
Chert, similar to next chert above	3	0
Concealed	63	0
Sandstone, red; made up of medium- to coarse-grained subangular poorly sorted and cemented quartz sand grains; has some irregular-shaped areas of yellow sandstone	23	0
Concealed; a 4-foot ledge of light-purplish-gray limestone similar to next bed below is exposed elsewhere at this horizon	20	0
Limestone, purplish-gray, weathers medium gray; forms single bed; resistant but not commonly well exposed because it and other beds are covered by slope wash	5	0
Concealed; residual soil is red silt, but it is mixed with coarse sandstone from above	50	0
Total, Amsden formation	281	0
Madison limestone:		
Limestone, gray, resistant, thin- to thick-bedded	20	0

PENNSYLVANIAN SYSTEM

TENSLEEP SANDSTONE

The Pennsylvanian Tensleep sandstone around the north end of the Bighorn Mountains has an average thickness of about 75 feet and consists of light-gray to yellowish-gray cross-bedded sandstone and a little interbedded limestone and dolomite. The sandstone contains well-rounded fine- and medium-grained quartz sand. Groves of pine trees mark outcrops of the Tensleep on the mountain slopes.

The Tensleep is 110 feet thick near the head of Bighorn Canyon in Carbon County, Mont., and about 90 feet thick near the mouth of Bighorn Canyon, but it is missing in a small area in the NE¼ sec. 4, T. 8 S., R. 32 E., about 12 miles southeast of the mouth of Bighorn Canyon. Although some of the variation in thickness is due to the gradational contact of the Tensleep with the Amsden formation, much is due to an erosional unconformity at the base of the Permian strata. This is shown by figure 3 which shows the unconformity in the area near the head of Soap Creek on the east side of the Bighorn Mountains. The uppermost 30 feet of a surface section near the Kane-Dryhead road (p. 31) was removed for a distance of a few hundred feet by erosion prior to the deposition of the Embar formation. The Tensleep sandstone thins to the north and is absent from most

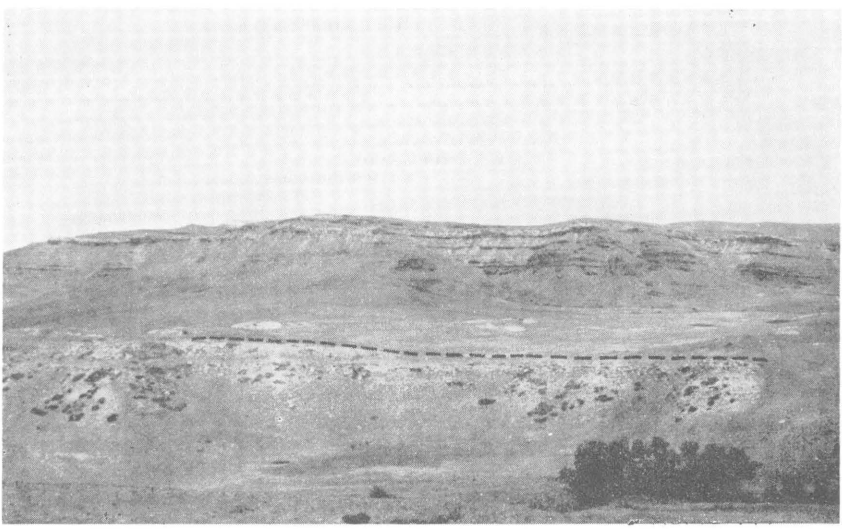

FIGURE 3.—Erosional unconformity at the base of the Chugwater formation. The view is northward from near the head of Soap Creek in the NE¼ sec. 33, T. 7 S., R. 32 E. The uppermost 20 feet of sandstone in the Tensleep present in the hill on the left is missing from the hill on the right. The dashed line inicates the unconformity. White areas on the slopes in the background are beds of gypsum in the lower part of the Chugwater formation. The ledge of limestone just below the skyline is in the upper part of the Chugwater formation and may be the Alcova limestone member.

of the area north of an east-west line through Billings, Mont., (Rogers and others 1945).

The age of the Tensleep sandstone is indicated by the following fusulinids collected by L. G. Henbest of the Geological Survey from a 10-foot unit of chert and limestone 40 to 50 feet below the top of the Tensleep sandstone near the southern tip of the Pryor Mountains (see stratigraphic section p. 32).

USGS collection f8008

Sponge spicules.
Calcitornellids.
Climacammina sp.
Bradyina sp.
Pseudostaffella sp.
Wedekindellina euthysepta (Henbest)
W. excentrica (Roth and Skinner)
Fusulina rockymontana? Roth and Skinner

According to Henbest (personal communication)

> These fossils are preserved in chert and though the shells have suffered some alteration their identity seems to be definitely determinable. Early or early middle Des Moines age is indicated. Similar forms are present in collections from the Tensleep formation further south in the Bighorn Mountains.
>
> This fauna is widely distributed in the Rocky Mountain and Mid-Continent regions, notably in the McCoy formation and middle part of the Hermosa formation of western Colorado, and in the lower part of Division III of the Hartville group in southeastern Wyoming.

Oil is obtained from the Tensleep sandstone in several oil fields in the Bighorn Basin. A few exposures of the Tensleep sandstone along the eastern side of the Bighorn Mountains contain asphalt, and Thom (Thom and others 1935, p. 38) reported "dead oil" in the Tensleep penetrated by wells at Soap Creek dome.

Section of Tensleep sandstone in canyon just east of Kane, Wyo.,-Dry Head, Mont., road in S½ sec. 34, T. 9 S., R. 28 E., Carbon County, Mont.

[Plate 4, sec. 3]

	Feet
Embar formation: Concealed; red soil.	
Unconformity; uppermost 30 feet of Tensleep sandstone is bevelled in one-quarter of a mile.	
Tensleep sandstone:	
Sandstone, yellowish-brown (weathering brown), calcareous, thin-bedded, ledge-forming; includes one bed of white sandstone and, in the upper part, thin lenses of calcite	14
Sandstone, white, fine-grained, porous, friable, cross-bedded, composed of clean well-rounded quartz grains; weathers light gray and nodular (nodules about one-half inch in diameter)	13
Sandstone, brown, medium-grained, calcareous, porous, slabby; a short distance to the north all overlying Tensleep rocks have been removed by erosion and the Embar formation lies on this unit	8

Section of Tensleep sandstone in canyon just east of Kane, Wyo.,-Dry Head, Mont., road in S½ sec. 34, T. 9 S., R. 28 E., Carbon County, Mont.—Continued

Tensleep sandstone—Continued	*Feet*
Dolomite, light-brown, finely crystalline, granular; interbedded gray nodular chert (Henbest collection, USGS f8008)	10
Limestone, sandy; laminated calcareous siltstone	3
Sandstone, white (weathering light gray), fine-grained, friable	4
Sandstone, brown, fine-grained, calcareous, thin-bedded	2
Sandstone, white to light-gray (weathering light gray), medium-bedded and crossbedded, nodular, ledge-forming	6
Sandstone, light-greenish-gray, calcareous, soft, platy; mostly covered	1
Sandstone, white (weathering gray), medium-grained, porous, crossbedded	3
Sandstone, light-brown and gray, fine-grained; upper part forms ledge, lower part mostly covered	6
Sandstone, light-gray (weathering brown), medium-grained, variably calcareous, locally quartzitic, ledge-forming	4
Sandstone and dolomite, gray, thin-bedded	6
Sandstone, light-gray (weathering gray), fine- and medium-grained, calcareous, thick-bedded, nodular	11
Sandstone, white (weathering gray), fine-grained, slightly calcareous, porous	5
Shale, green, very silty	1
Sandstone, white to light-gray (weathering brown), medium-grained, friable, crossbedded, ledge-forming; calcareous at top	5
Dolomite, light-gray, sandy	1
Sandstone, greenish-gray (weathering light brown), medium-grained, slightly calcareous; crossbedded and nodular in upper half	3
Dolomite, purple to purplish-gray; silty at base	2
Dolomite, light-purple (weathering brown), silty; is at base of prominent ledge-forming series of rock above the much less resistant Amsden formation; contact with Amsden formation covered in most places	2
Total Tensleep sandstone	110
Amsden formation: Limestone and limestone breccia about	4

PERMIAN SYSTEM

EMBAR FORMATION

The Permian Embar formation, which was mapped separately from the Chugwater formation only in the area between Crooked Creek in Wyoming and Porcupine Creek in Montana, is a sequence of limestones, dolomites, and red shales, siltstones, and sandstones which are as much as 100 feet thick.

Darton (1906b, p. 17–18) gave the name Embar to limestone, shale, and phosphatic rocks that are exposed on the north flanks of the Owl Creek Mountains at the southern edge of the Bighorn Basin. He thought the Embar was "neither a development of the basal portion of the Red Beds nor of the calcareous sandstone" at the top of the Tensleep sandstone (Darton, 1906a, p. 35). He did not recognize the formation north of No Wood, Wyo., west of the Bighorn Mountains or north of Barnum, east of the mountains.

In 1918 Blackwelder (p. 423–426) divided the Embar in western Wyoming into the Permian Park City formation (consisting predominantly of dolomite, shale, and phosphatic rock) and the Triassic Dinwoody formation (made up of greenish-gray shale and thin-bedded sandstone and dolomite). Since that time the term Park City formation has been replaced in northwestern Wyoming by the Phosphoria formation, which was named in a 1912 report by Richards and Mansfield (p. 687) for Permian strata in Idaho that are correlative with the upper part of the Park City formation. The great variations in the lithology of rocks near the boundary of the Permian and Triassic systems has resulted in conflicting conclusions by various geologists in tracing the beds from the type locality northeastward into the Bighorn Mountains.

Thomas in 1934 studied the stratigraphic relations of the Phosphoria and Dinwoody formations with the overlying and underlying formations from the Owl Creek Mountains southeastward into central Wyoming. He showed (1934, fig. 3) that the Phosphoria and Dinwoody formations, which are predominantly limestone and shale, interfinger southeastward with redbeds. The unit above the Tensleep sandstone and below the Chugwater formation in central Wyoming, thus, consists of redbeds and intercalated marine limestone and sandstone tongues of the Phosphoria and Dinwoody formations. Thomas calls this unit "Embar."

The name Embar has been used along the northeastern side of the Bighorn Basin and in the Pryor Mountains for a series of limestone, dolomite, and red shale and siltstone which lie unconformably on the Tensleep sandstone and are distinct in lithology from the overlying Chugwater formation. Knappen and Moulton (1930, p. 14) said that the "Embar(?)" in the area north of the Pryor Mountains consists of 10 to 15 feet of gray-white very porous thin- and wavy-bedded limestone. They found the limestone in only three localities and attributed its absence elsewhere to nondeposition or removal by pre-Chugwater erosion. According to Blackstone (1940, table 1) the "Embar(?)" of the Pryor Mountains is thickest on the southeastern flanks where it consists of 25 to 40 feet of white siliceous limestone underlain by 70 to 90 feet of red and yellow shales. Near the mouth of Shell Canyon, about 40 miles southeast of the mouth of Crooked Creek, Pierce (1948) measured about 180 feet of Embar, the basal part of which consists of 48 feet of maroon sandstone and siltstone with 2 to 5 feet of subangular chert conglomerate and sandstone and lies unconformably upon the Tensleep sandstone. This maroon sandstone and siltstone is succeeded by 61 feet of maroon siltstone and pure white gypsum, and in turn by 73 feet of soft salmon-red gypsiferous sandstone and gypsum with beds of dolomite at the base and top. The unit is conformable with the overlying Chugwater formation, the lower part of which contains thin beds of gypsum and dolomite similar to those in the Embar.

Between Crooked Creek and the mouth of Porcupine Creek the upper dolomite or limestone beds in the Embar form bare white dip slopes, and basal beds of red siltstone lie on the eroded Tensleep. Units of the formation thin a short distance north of Porcupine Creek, and in the area between Layout Creek and Dry Head Creek the upper limestone is only 5 to 10 feet thick and the underlying red siltstone and sandstone about 25 feet thick. The limestone thins in places almost to zero eastward from Dry Head Creek to Grapevine Creek. North of sec. 26, T. 9 S., R. 28 E., opposite the mouth of Porcupine Creek, the limestone and underlying red shale and sandstone were included in the Chugwater formation in mapping, but a line representing the top of the limestone was drawn wherever the limestone is exposed. The eastward thinning of the Embar formation within the area may be due to decreased deposition inasmuch as both the dolomite and underlying siltstone unit are thinner east of the Bighorn Mountains than at the south end of the Pryor Mountains. The limestone and red siltstone and sandstone beds mapped as the lower part of the Chugwater formation north of Crooked Creek probably also belong to the Embar formation.

Section of Embar formation between Bighorn River and Sykes Mountain in N½ sec. 7, T. 57 N., R. 94 W., Big Horn County, Wyo.

[Plate 3, sec. 3]

	Feet
Chugwater formation: Red gypsiferous siltstone.	
Embar formation:	
Dolomite, light-gray (weathering very light gray), dense to finely crystalline; has variable porosity, nodular gray chert in basal 5 feet; 20 feet of dolomite overlying chert is very gypsiferous; upper and lower beds form ledges; uppermost bed forms a dip slope and supports a growth of juniper trees	65
Concealed; red shales at same interval in nearby area	15
Dolomite, porous, gray (weathering light gray); hard at top, nonresistant at base	3
Sandstone, siltstone, and red shale; lower part is covered	12
Limestone, gray and pink, dolomitic; has some interbedded red chert	4
Concealed; green silty dolomitic limestone found by digging	6
Total Embar formation	105
Unconformity.	
Tensleep sandstone: Gray sandstone.	

PERMIAN AND TRIASSIC SYSTEMS

CHUGWATER FORMATION

The Chugwater formation, which forms red bluffs facing toward and encircling the Bighorn and Pryor Mountains, consists largely of red sandstone. The formation ranges in thickness from about 450 feet along Bighorn Canyon to more than 650 feet near the head of Soap Creek. The sandstone is mostly fine to very fine grained and moderate to dark red. Red siltstone and shale, in much smaller amount, are interbedded with the sandstone. In the Chugwater gypsum commonly forms stringers and veinlets throughout, and thin beds occur in the basal part of the formation. The thickest beds of gypsum are in the vicinity of the head of Soap Creek. Thin green streaks along small fractures in the Chugwater south of Crooked Creek, Big Horn County, Wyo., are undoubtedly due to chemical reduction of ferric oxide (bleaching) in the rock adjacent to the fractures. Moulton (1926, p. 304–312) has attributed similar bleaching along the crests of minor folds and on the flanks of mountain folds to the reducing action of hydrogen sulfide upon the ferric oxide which coats sand and silt grains and gives the rock its red color.

A 5- to 10-foot bed of limestone which is from 90 feet to 200 feet below the top of the Chugwater, is persistent throughout the area north and east of the Bighorn Mountains but is missing south of the Pryor Mountains. The limestone is light gray with purple streaks, and forms conspicuous but narrow white ledges. It may be equivalent to the Alcova limestone member in the Bighorn Basin and Wind River Basin of Wyoming first described by Lee (1927, p. 14) from exposures in the southern part of the Bighorn Basin. Limestone and dolomite also occur in a few thin beds in the lower part of the Chugwater formation.

Section of Chugwater formation between Bighorn River and Sykes Mountain in N½ sec. 7, T. 57 N., R. 94 W., Big Horn County, Wyo.

[Plate 4, sec. 3]

Gypsum Spring formation: Thick white gypsum.	
Chugwater formation:	*Feet*
Siltstone, red; red fine-grained sandstone	61
Sandstone, red, very fine grained; some red siltstone	192
Sandstone, red, very fine grained, thin- and medium-bedded; contains numerous porous leached zones	85
Sandstone, red, fine-grained and very fine grained, thin- and medium-bedded; some red siltstone and shale	76
Gypsum, gray and pink, wavy- and thin-bedded	3
Sandstone, red, predominantly very fine grained; red siltstone	4
Dolomite, gray, platy	1
Siltstone, red, gypsiferous	25
Total Chugwater formation	447
Embar formation: Thick gray dolomite.	

Section of Chugwater formation south of Soap Creek in NE¼ sec. 4, T. 8 S., R. 32 E., and SW¼ sec. 34, T. 7 S., R. 32 E., Big Horn County, Mont.

[Measured by W. J. Mapel and A. A. Meyerhoff]

	Feet
Piper formation:	
Gypsum, white, granular, irregularly bedded; forms three ledges	10
Chugwater formation:	
Sandstone and siltstone, red, shaly and silty; siltstone at top grades down into fine-grained silty sandstone	65
Sandstone, moderate-red, mostly fine-grained, locally crossbedded; forms three ledges	25
Siltstone and fine-grained sandstone, moderate-red; lower third is mostly sandstone; forms ledges	70
Sandstone, moderate-red, fine-grained, thick-bedded, ledge-forming	22
Siltstone, red, thin-bedded; interbedded moderate-red fine-grained ripple-marked sandstone; unit forms slopes	11
Limestone, white, hard, slabby; has closely spaced red laminations and shale partings; forms prominent ledge. Unit may be equivalent to the Alcova limestone member	5
Siltstone, moderate-red, nodular; contains 1 or 2 beds of fine-grained sandstone; forms reentrant	3
Sandstone, red, medium-grained, friable, thick-bedded, ledge-forming, somewhat cavernous	24
Sandstone, moderate-red, fine-grained, platy; interbedded red thin-bedded siltstone; forms slope	71
Sandstone, moderate-red, fine-grained; lower 35 feet massive, upper one third ripple-marked; unit forms massive ledge	50
Siltstone, maroon, well-cemented, thin-bedded, nodular; middle 7 feet is fine-grained thin-bedded red sandstone	16
Sandstone and siltstone. Sandstone is red, fine grained, thin to medium, interbedded with red thin-bedded siltstone	34
Sandstone, red, fine-grained; silty in lower part becoming less silty towards top; beds of red fine- to medium-grained thin-bedded resistant sandstone in upper 10 feet	48
Siltstone, red; very fine grained thin-bedded red sandstone; numerous layers and stringers of white crystalline gypsum as much as 1 inch thick; unit slightly calcareous; forms slope	51
Gypsum, white with closely spaced pink laminations, thin-bedded; lower 4 feet forms ledge; upper 3 feet is soft and impure with thin lenses of red siltstone	7
Siltstone, red, and fine-grained red sandstone; contains stringers and thin beds of gypsum	9
Covered; probably all red beds	46
Gypsum, white, granular, thick-bedded; a 5-foot interval about 13 feet above base has interbedded red siltstone and forms small ledge	38
Covered; few exposures of red shaly siltstone	28
Gypsum, white, granular, medium- to thick-bedded	8
Siltstone, red, thin-bedded, fine-grained calcareous red sandstone	10
Covered; elsewhere the lower 2 or 3 feet is red sandstone and siltstone containing numerous angular chert fragments as much as 2 inches in diameter	5

Section of Chugwater formation south of Soap Creek in NE¼ sec. 4, T. 8 S., R. 32 E. and SW¼ sec. 34, T. 7 S., R. 32 E., Big Horn County, Mont.—Continued

	Feet
Chugwater formation—Continued	
Sandstone, white, locally stained red and purple, mostly fine-grained, partly leached and brecciated, locally cavernous; has red and gray chert fragments in upper 3 feet. This unit is placed at base of Chugwater formation and is considered to be locally reworked sand of the Tensleep. A feather edge of Tensleep sandstone crops out nearby at about this horizon	28
Total Chugwater formation	674
Unconformity.	
Amsden formation:	
Shale and silty shale, red and purple, thin-bedded; top 2 feet dolomitic; mostly covered	13

A widespread erosional unconformity separates the Chugwater formation from the Tensleep sandstone, but the bedding in the lower part of the Chugwater closely parallels the bedding of the Tensleep sandstone. Thin beds of chert-pebble conglomerate are common in the basal part of the Chugwater in areas where the Chugwater overlies the Tensleep sandstone. L. G. Henbest collected a Pennsylvanian fauna from gray chert pebbles in a basal conglomeratic sandstone along Grapevine Creek; the chert presumably was eroded from Tensleep sandstone or possibly Amsden formation during early Chugwater time.

Although the Chugwater in this area is seemingly conformable with the overlying Middle Jurassic Piper formation, an unconformity at the base of the Jurassic strata has removed the Chugwater in central Montana, and the Chugwater is only about 200 feet thick under the Hardin area (Rogers, Gardner, and Hadley, 1945). It was almost completely removed prior to Jurassic deposition north of the Yellowstone River in central Montana (Rogers, Gardner, and Hadley, 1945).

The thin limestone, gypsum, and redbed series at the base of the Chugwater east of the Pryor Mountains is very likely equivalent to the Embar formation and was included in the Chugwater because it is too thin to map separately. Thus the Chugwater in the vicinity of Bighorn Canyon includes rock of Triassic and probably Permian ages.

JURASSIC SYSTEM

The Jurassic system includes four formations, of which three, the Middle Jurassic Piper and the Upper Jurassic Rierdon and Swift, constitute the Ellis group (Imlay and others, 1948). The Morrison formation overlies the Ellis group.

The grayish-green and olive-gray sandstones and shales of the Rierdon and Swift formations and the redbeds and limestones which make up the Piper formation formerly were called the Ellis formation in central and north-central Montana. The Piper is, at least in part, equivalent to the Gypsum Spring formation of Wyoming. Thom (Thom and others, 1935, p. 39–40) placed all known Jurassic strata below the Morrison formation in the Sundance formation which included the upper one-half of the Piper formation and the Rierdon and Swift formations. Figure 4 has been taken from the nomenclature and correlation table prepared by Imlay and others (1948).

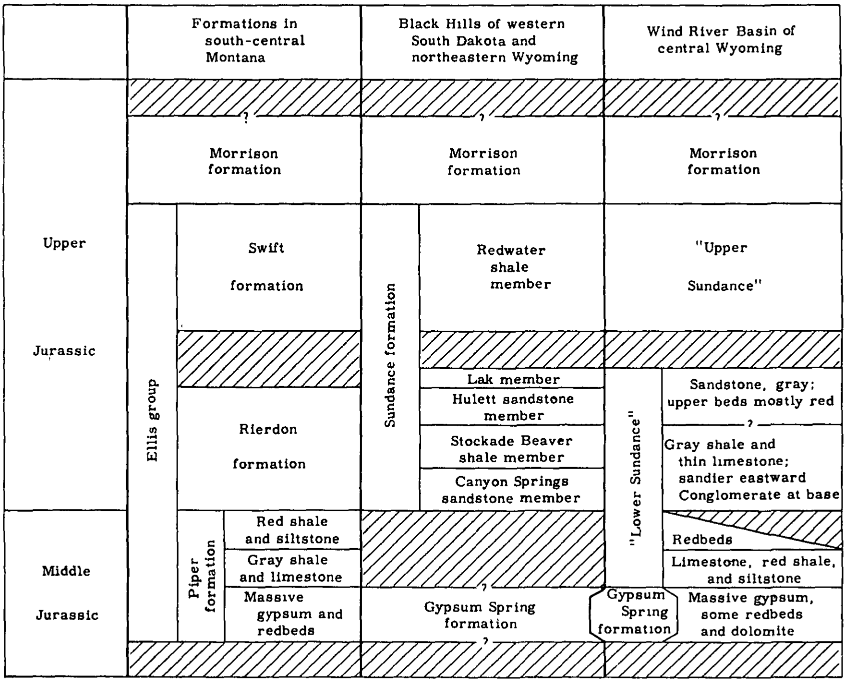

FIGURE 4.—Correlation of Jurassic formations of south-central Montana with Upper and Middle Jurassic formations of other areas.

MIDDLE JURASSIC SERIES

PIPER FORMATION

The Piper formation consists of red sandstone and siltstone, gray limestone, and gypsum, and it is 150 feet thick or more in outcrops along the Bighorn Mountains. It was named by Imlay in 1948 for exposures near Piper, Fergus County, Mont. The formation was defined to include all redbeds, gypsum, and associated normal marine beds of Middle Jurassic age in Montana east of the Sweetgrass-Big Belt uplift. Some of the Piper is equivalent in age to, and the remainder is younger than, the Gypsum Spring formation of Wyoming.

A section typical of Piper in south-central Montana is exposed along the north side of Grapevine Creek where the Piper is 150 feet thick and consists of three principal units. The lower unit consists of 45 feet of thick-bedded gypsum and thin layers of red and green shale. This gypsum is the base of the Piper formation throughout the area covered by this report. The middle unit, the bottom of which was mapped as the base of the Sundance formation in this area by Thom (Thom and others, 1935, p. 39–40), is gray argillaceous limestone with intercalated green and red shale. It erodes to form prominent light-gray ledges, below which stand bright-red bluffs of Piper and Chugwater strata. The upper unit of the Piper consists of red shale and siltstone but is covered at most localities by debris on a dip slope above the limestone of the middle unit. The contact of the Piper with the overlying Rierdon formation commonly is concealed in strike valleys.

The Piper formation is about 200 feet thick at the eastern foot of Sykes Mountain a short distance south of Crooked Creek, Big Horn County, Wyo.; 175 feet thick near the head of Soap Creek about 14 miles southeast of the Grapevine Creek section; and 90 feet thick at Shively dome in T. 5 S., R. 27 E. north of the Pryor Mountains, Big Horn County, Mont., (Imlay and others, 1948). Imlay explained the wide variation in thickness of the Piper in Montana as being due to deposition upon an irregular surface. In central and north-central Montana, the Piper rests on a pre-Jurassic erosion surface which cuts across the Madison limestone, Amsden formation, Tensleep sandstone, and the Big Snowy group, all of Carboniferous age.

Section of Piper formation east of Grapevine Creek in center of sec. 6, T. 6 S., R. 31 E., Big Horn County, Mont.

[Plate 4, section 5]

Rierdon formation: Lower part covered by valley fill.

Piper formation:

	Feet
Siltstone and sandstone, red; unit is mostly covered and contact with Rierdon formation is concealed in strike valley, about	20
Limestone, light-gray, finely crystalline, thin-bedded, moderately resistant; caps some ridges; contains a few poorly preserved molds of fossils	8
Shale, red and green, mostly covered	8
Limestone, gray, argillaceous; abundant molds of small pelecypods; thin streaks of green calcite along fracture planes	3
Limestone, argillaceous; red and gray shale	10
Limestone, gray, argillaceous, ledge-forming; red shale streaks in lower 3 feet and thin dolomite bed at base; in 4- to 6-inch beds	13
Limestone, light-gray, argillaceous; a few beds of red shale 3 to 12 inches thick; 10 inches of brown shale at top; this and overlying limestone beds form ledges where dips are gentle and ridges where dips are steep	8

Section of Piper formation east of Grapevine Creek in center of sec. 6, T. 6 S., R. 31 E., Big Horn County, Mont.—Continued

	Feet
Piper formation—Continued	
Shale, red; gray thin-bedded limestone	6
Shale, red; siltstone near base; contains numerous gypsum stringers; mostly covered	27
Gypsum, white, granular; in 2- to 4-foot beds separating ¼- to 4-inch beds of red shale or thin gray dolomitic shale	47
Total Piper formation	150
Chugwater formation:	
Sandstone, red, silty and red gypsiferous siltstone	26

UPPER JURASSIC SERIES

RIERDON AND SWIFT FORMATIONS

The Rierdon and Swift formations consist of Upper Jurassic marine fossiliferous grayish-green and olive-gray sandstones and shales that lie between the redbeds of the Piper formation and the continental sandstones and shales of the Morrison formation. Total thickness of the Rierdon and Swift formations is about 500 feet along the eastern side of the Bighorn Mountains, but their band of outcrop is narrow because dips are steep, and the two formations have been mapped as one unit.

The Rierdon formation consists of nonresistant calcareous olive-gray shale as much as 300 feet thick north of Grapevine Creek but much thinner south of the Bighorn River. The shale weathers readily and is commonly covered by several inches of residual soil which contains many *Belemnites* and *Gryphaea* shells. At the top of the Rierdon is a 5- to 10-foot bed of sandy "oolitic" fossiliferous ledge-forming limestone that overlies 5 to 10 feet of highly calcareous yellowish-gray very fine grained sandstone. This sandy unit forms long low ledges on an otherwise fairly smooth steep slope cut on the Rierdon and Swift formations. During a visit to the area in 1947, Imlay stated that the sandy unit is correlative with the Hulett sandstone member of the Sundance formation of the Black Hills area.

The Swift formation consists of grayish-green sandstone, siltstone, and shale which together range from about 180 feet to a little more than 250 feet thick along the east front of the Bighorn Mountains. The sandstone contains glauconite, small chert pebbles, and layers of fossil shells. There are lenticular fossiliferous sandstones near the top of the Swift, which are overlain by nonmarine beds of the Morrison formation. The contact of the two formations was drawn above the highest bed that contains marine Jurassic fossils.

Imlay (Imlay and others, 1948) has described an angular unconformity between the Rierdon and Swift formations in north-central Montana with the Swift overlapping the Rierdon and Piper formations and resting on Paleozoic strata. However, within this area the Rierdon and Swift are seemingly conformable.

Section of Rierdon and Swift formations exposed north of mouth of Bighorn Canyon in sec. 6, T. 6 S., R. 31 E., Big Horn County, Mont.

[Plate 4, section 5]

	Feet
Morrison formation: Concealed; some green siltstone exposed.	
Swift formation:	
Sandstone, greenish-gray and brown, fine- and medium-grained, poorly exposed; contains few fossils; thin ledge of glauconitic coarse-grained sandstone at top	25
Limestone, greenish-gray, sandy, crossbedded, very fossiliferous, ledge-forming	15
Concealed; probably largely shale	63
Concealed; some discontinuous exposures of calcareous light-brown shale and gray siltstone near middle; light-brown shale at top	64
Total, Swift formation	167
Rierdon formation:	
Limestone, oolitic, very sandy, very fossiliferous; ledge forming, weathers dark brown	9
Sandstone, light-brownish-gray, weathering tan; fine grained, calcareous. Similar sandstone may be concealed at top of underlying unit	9
Concealed; a few exposures of soft light-brown to light-greenish-brown calcareous clay shale; numerous *Belemnites*, fragments of star-shaped crinoid stems, and *Gryphaea* shells in soil; base concealed beneath alluvium in valley bottom, about	300
Total Rierdon formation	318
Piper formation: Concealed, probably mostly redbeds.	

MORRISON FORMATION

The Upper Jurassic Morrison formation consists of grayish-green siltstone and sandstone and variegated shale. Locally, as in the center of Soap Creek dome, the variegated shales are conspicuous, but at most localities along the mountain front the Morrison is grayish-green sandstone and siltstone. Some of the lower beds that are crossbedded and calcareous are not easily distinguished from beds in the Swift formation.

The Morrison ranges in thickness between 140 and 280 feet in the area. This pronounced change in thickness is due largely to gradation and interfingering downward into the Swift formation and upward into continental deposits in the lower part of the Cloverly formation. The Morrison and Cloverly formations are mapped as units wherever a basal conglomeratic sandstone occurs in the Cloverly formation. Elsewhere the Morrison cannot be differentiated from the Cloverly and the two are mapped as one unit.

Section of Morrison formation along Lime Kiln Creek in NW¼ sec. 21, T. 7 S R. 31 E., Big Horn County, Mont.

[Plate 4, section 5. Measured by L. S. Gardner and C. P. Rogers, Jr.]

	Feet
Cloverly formation:	
Conglomerate, gray to light-brown, massive; made up of pebbles of sandstone, quartz, and chert as much as 2 inches in diameter in a matrix of fairly well cemented medium-grained quartz sand	22
Morrison formation:	
Siltstone, greenish-gray, clayey, highly calcareous, platy, friable, poorly exposed	38
Sandstone, white, calcareous, friable, massive, nonresistant	14
Siltstone, medium-gray (weathering light greenish gray), poorly exposed; contains some platy gray shale	28
Limestone or calcareous siltstone, light-gray, silty, clayey, nonresistant	1
Siltstone and shale, gray. Siltstone grades into fine-grained sandstone	92
Concealed	89
Siltstone and claystone, yellowish-brown, friable, nonresistant	5
Sandstone, dark-gray, highly calcareous, platy, nonresistant	1
Siltstone or claystone, yellowish-brown, friable, nonresistant	15
Total, Morrison formation	283
Swift formation:	
Sandstone, greenish-gray, very calcareous, massive, crossbedded; contains layers of shells near top	7

CRETACEOUS SYSTEM

LOWER CRETACEOUS SERIES

CLOVERLY FORMATION

The Cloverly formation, exposed along the northern and eastern sides of the Bighorn Mountains and around Soap Creek dome, generally consists of a discontinuous basal conglomeratic sandstone member, a middle variegated shale member, and an upper shale, siltstone, and sandstone member. The formation ranges somewhat in thickness, but its average thickness is between 300 and 400 feet.

The Pryor conglomerate member at the base of the Cloverly is composed of resistant sandstones, commonly with chert-pebble-bearing conglomerates in the lower part. The Pryor member ranges in thickness from about 30 feet at Soap Creek dome, where it is not conglomeratic, to 150 feet south of the mouth of Bighorn Canyon, except in the area from sec. 7, T. 7 S., R. 31 E. southeastward to Rotten Grass Creek where the member is missing. The Pryor reappears south of Rotten Grass Creek in sec. 8, T. 8 S., R. 33 E. and thickens considerably within a few hundred feet southward. Prominent hogbacks held up by the Pryor conglomerate member have formed in the belt of steeply dipping strata along the eastern side of the mountains. Differences in thickness of the Pryor conglomerate member account for much of the range in thickness of the Cloverly formation.

Poorly exposed red and gray shales, and some interbedded siltstones, constitute the middle unit of the Cloverly. This member ranges from a few feet to about 50 feet in thickness except in the area north of Rotten Grass Creek where 140 feet of variegated shale, bentonite, and bentonitic shale, which are exposed in sec. 1, T. 8 S., R. 32 E., represents the middle and basal Cloverly units and, perhaps, the upper part of the Morrison formation. Red shales at this outcrop contain numerous gastroliths and thin beds of light-gray to light-red limestone and chert.

The upper part of the Cloverly formation is about 250 feet thick along the east side of the Bighorn Mountains. The unit consists of interbedded siltstones, dark-gray shales, and thin-bedded "flaggy" sandstones. The siltstones weather brown, and thin ironstone layers, most of which are in the lower part, have a pronounced rusty weathered color. Numerous dahllite concretions (McConnell, 1935, p. 693–698) occur about 125 feet below the top of the formation along the mountain flank, but none were seen at Soap Creek dome.

The Birdhead sandstone, which was tentatively correlated with the Newcastle sandstone of the Black Hills and Powder River Basin areas and the Muddy sandstone of the Bighorn Basin and included in the Thermopolis shale by Thom (Thom and others, 1935, p. 47; also Richards and Rogers, 1951), is the top of the Cloverly formation as herein described. The Birdhead sandstone member is mostly fine-grained sandstone and is in part silty and argillaceous. It is not sharply set off from the underlying beds and is commonly 10 or 15 feet thick. Locally, a thin brown-weathering limestone at the top of the Birdhead member makes ledges. Overlying the Birdhead is a zone of black shale with hard ironstone concretions. This shale is the basal unit of the Thermopolis shale. A few feet of shale and siltstone which occurs locally between the Birdhead and the black shale is included in the Cloverly formation.

The Cloverly formation was named by Darton (1904, p. 398–399) for exposures on the east side of the Bighorn Basin, Wyoming. In his report on the Bighorn Mountains, Darton (1906a, p. 50–51) described the Cloverly as consisting of a conglomeratic sandstone member and an overlying clay member, a few feet of massive sandstone occuring locally above the clay. Darton (1906a, p. 53) thought the Cloverly to be equivalent to the Lakota sandstone, Fuson forma-

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tion, and Dakota sandstone (now Fall River sandstone) of the Black Hills region, but he noted that the Dakota member is either not well developed or is represented by transition shales and thin sandstones at the top of the Cloverly. The section of the Cloverly formation in its type area as described by Darton (1906a, p. 52) follows.

Section of Cloverly formation 1½ miles west of Cloverly, Wyo.

	Feet
Light-buff sandstone (overlain by Benton shale)	10
Tan-colored sandstone	10
Maroon clay	4
Reddish and tan-colored sandy clay	10
Drab sandy clay	10
Deep-maroon sandy-clay	20
Hard tan-colored sandstone	3
Deep-maroon to purple variegated clay	12
Lenses of maroon sandstone	3
Deep-maroon sandy clay	20
Olive-green, soft, cross-bedded sandstone, with hard layers (lying on maroon and drab-gray Morrison shale)	11
Total	113

Lupton (1916, p. 168) called the 20 feet of sandstone at the top of Darton's type Cloverly formation the Greybull sand, a name which originated as a driller's term and was reported by Hintze in 1915 (Wilmarth, 1938, p. 878). Since then the Greybull sandstone has been a member of the Cloverly formation but not always the top member. Overlying the Greybull sandstone member in the Bighorn Basin is a unit of shales and rusty-weathering sandstones which Darton (1906a, p. 54–55) called the "rusty series" and "rusty beds." Near the former post office of Cloverly, Wyo., which was 9 miles north-northwest of the present town of Shell, Wyo., the basal part of the Colorado formation, now the Thermopolis shale, was described by Darton (1906a, p. 55) as consisting of

> about 100 feet of dark-gray to black shales with layers of thin brown sandstone weathering to a rusty color. The shales usually begin abruptly on top of the Cloverly sandstone, but without sign of unconformity. The characteristic globular [dahllite] concretions averaging an inch in diameter occur in a few feet of the lower shales about 60 feet above their base. Above this "rusty" series are about 200 feet of black fissile shales . . .

The so-called "rusty beds" are a poorly defined stratigraphic unit, but "rusty beds" were placed at the base of the Thermopolis shale, which overlies the Cloverly formation, by Washburne (1908, p. 350), Hewett and Lupton (1917, p. 19), and Knappen and Moulton (1930, p. 27–28). "Rusty beds" were included in the Greybull sandstone member of the Cloverly formation by Lee (1927, p. 64), and a thinner unit of "rusty beds" was placed above the Greybull sandstone but at the top of the Cloverly by Pierce (1948) and Rogers and others (1948). "Rusty beds" have also been placed near the top of the Cloverly formation east of the Bighorn Mountains in Wyoming (Mapel, 1954).

In localities east of the Bighorn Basin, such as Soap Creek dome, it is not wholly clear which beds represent the "rusty beds" and the Greybull sandstone of the basin. The black shale at the base of the Thermopolis shale in the Bighorn Canyon-Hardin area is considered by W. A. Cobban (personal communication) of the Geological Survey to be the stratigraphic equivalent of the Skull Creek shale of the Black Hills region. As the Skull Creek shale overlies the Fall River sandstone near the Black Hills, the Cloverly formation in the Bighorn Canyon-Hardin area represents the Lakota sandstone, Fuson shale, and Fall River sandstone of the Black Hills region—the formations that Darton thought were equivalent to the type Cloverly formation. However, if the Cloverly formation from the Birdhead sandstone member down to the variegated beds is correlative with Darton's "rusty beds," the Cloverly in the Bighorn Canyon-Hardin area includes strata younger than the type Cloverly formation.

The inclusion of "rusty beds" in the Cloverly formation in this and other areas constitutes a redefinition of the Cloverly described by Darton. Such a redefinition is justifiable because Darton's upper unit of the Cloverly, the Greybull sandstone member, is not readily separated in many localities from the overlying "rusty beds." The top of the Cloverly formation—if it is to occur at a lithologic break of considerable areal extent—should be placed either below the Greybull sandstone member and above the variegated beds or below the black Skull Creek shale (or its stratigraphic equivalent) and above the so-called "rusty beds." Inasmuch as Darton considered the upper part of the Cloverly to be a correlative of the Fall River sandstone, the top of the Cloverly as described is as close as practical to its originally defined position.

THERMOPOLIS SHALE

The Thermopolis shale is about 425 feet thick and consists largely of dark-gray shale with many beds of bentonite and ironstone concretions. Three or four beds of bentonite near the middle of the formation are 2 to 4 feet thick. A basal unit of dark-gray to black shale, about 150 feet thick, is part of the black shale widely distributed in Montana that is the stratigraphic equivalent of the Skull Creek shale of the Black Hills area (Cobban, 1951, p. 2175–2179). Overlying the black shale is dark-gray shale 50 feet or more thick that is cut by gray sandstone dikes. The sandstone dikes range from 1 to 8 inches in thickness and from 5 to 15 feet or more in length. Many of the dikes are nearly perpendicular to bedding planes in the shale, but others deviate several degrees therefrom. The sandstone is fine grained, noncalcareous, and in part crossbedded with respect to the walls of the dikes. Sand for the dikes may have been derived from thin layers of sand in and above the zone of the sandstone dikes prior to the consolidation of the beds. The dikes, judging from the presence of sandstone in strata adjacent to the dikes and from the crossbedded nature of the sand in the dikes, seemingly represent filling of fissures in the shale.

Section of Thermopolis shale on east side of Soap Creek dome in SW¼ sec. 35, T 6 S., R. 32 E., Big Horn County, Mont.

[Plate 4, section 7. Measured by C. P. Rogers, Jr. and P. W. Richards]

	Feet
Mowry shale:	
Bentonite, gray; few inches of dark-gray shale with fish scales at base	3
Thermopolis shale:	
Shale, dark-gray; contains few thin siltstone layers and thin beds of bentonite	65
Bentonite	1
Shale, dark-gray	57
Bentonite, gray	1
Shale, dark-gray	28
Shale, dark-gray; contains layers of thin-bedded brown siltstone and two thin beds of bentonite	31
Bentonite	2
Shale, dark-gray; contains a few thin beds of gray sandstone and manganiferous-stained concretionary siltstone beds in lower half	21
Bentonite	3
Shale, dark-gray; contains several thin layers of concretionary manganiferous-stained siltstone and gray sandstone; fine-grained gray sandstone dikes cut nearly perpendicularly across the unit	58
Bentonite and shale	5
Shale, dark-gray; contains thin beds of rusty-weathering siltstone	6
Bentonite	4
Shale, dark-gray; contains numerous thin beds of siltstone, some sandstone, a few thin beds of bentonite, and scattered ironstone concretions	143
Total, Thermopolis shale	425
Cloverly formation: Sandstone and siltstone, the Birdhead sandstone member, overlain by a few feet of silty shale.	

The contact between the Thermopolis shale and the overlying Mowry shale is gradational. Although close to the base of the lowest occurrence of abundant fish scale impressions and siliceous shale and siltstone of the Mowry shale, the contact has been mapped at the base of a 2- to 4-foot bed of bentonite below about 50 feet of dark-gray shale typical of the Thermopolis shale. This bentonite bed is near the middle of the steep, nearly bare slopes beneath escarpments held up by the Mowry shale.

The Thermopolis shale is now known to be of Early Cretaceous age (Cobban and Reeside, 1951, p. 1892–1893). The Birdhead sandstone member, which is at or just below the top of the Cloverly formation as herein described, is not a correlative of the Newcastle sandstone as thought by Thom (Thom and others, 1935, p. 47), but the zone of sandstone dikes is about the stratigraphic equivalent of the Newcastle sandstone (W. A. Cobban, personal communication). This correlation is based upon the lithologic similarity of the black shale beneath the zone of sandstone dikes with the Skull Creek shale of the Black Hills area and the similarity of the sandstone dikes with dikes which occur locally in a stratigraphic zone where the Newcastle sandstone is either thin or missing in the Black Hills region.

MOWRY SHALE

The Mowry shale is the most conspicuous formation of the Cretaceous system because of the cuesta-like escarpments that have formed of it. The Mowry is exposed in an almost continuous cuesta extending along the eastern edge of the Bighorn Mountains from Rotten Grass Creek at the northeast corner of T. 8 S., R. 32 E. northward to sec. 7, T. 6 S., R. 32 E. south of the Bighorn River and from Muddy Creek in the north-central part of T. 5 S., R. 30 E. northward to the South Fork of Woody Creek in the northeast corner of T. 4 S., R. 29 E.

The Mowry is 350 to 400 feet thick and consists of dark-gray shale and light-gray siltstone and sandstone. Some of the shale and much of the siltstone in the formation is hard and resistant to erosion because it is siliceous (Rubey, 1929). The more siliceous beds characteristically weather light gray and light bluish gray. Many beds contain abundant fish scale impressions which are particularly characteristic of the Mowry shale. The base of the Mowry shale is a 4-foot bed of bentonite at the bottom of 50 feet of dark-gray-weathering shale that commonly forms a band almost barren of vegetative cover about midway in the escarpment slopes of the Mowry cuestas.

Ridges or hogbacks common on the Mowry shale are supported by thin beds of sandstone about 150 feet below the top of the formation. Similar beds of sandstone about 50 to 60 feet below the top of the formation are exposed in the SE¼ sec. 28, T. 3 S., R. 31 E., next to a fault which transects Woody Creek dome. The Clay Spur bentonite bed marks the top of the Mowry and is a source of commercial-grade bentonite in northeastern Wyoming (Rubey, 1930, p. 4). The contact of the Mowry shale and the overlying Frontier formation is commonly at the foot of long dip slopes held up by the upper beds of the Mowry shale.

The Mowry shale has long been considered to be Late Cretaceous in age, but accumulating knowledge now indicates that the Mowry fauna is Early Cretaceous (Cobban and Reeside, 1951 and 1952, chart 10b).

Section of Mowry shale south of the South Fork of Woody Creek in W½ sec. 2, T. 4 S., R. 29 E., Big Horn County, Mont.

	Feet
Frontier formation:	
Shale, dark-gray, fissile; containing 4 or 5 beds of ironstone concretions	28
Mowry shale:	
Bentonite, greenish-gray. This is the Clay Spur bentonite bed	2
Shale, dark-gray; containing a few very thin sandstone beds with mud-cracked shale partings	16
Shale, gray, siliceous; with numerous ripple-marked sandstone stringers; silty in upper few feet; mostly covered	32
Bentonite, gray	3
Sandstone; gray with "salt-and-pepper" appearance; mostly fine-grained, thin-bedded, crossbedded, hard; forms ledges and ridges	3
Covered; shale and siltstone float	5
Bentonite, gray	1
Siltstone, gray and gray siliceous shale; contains some fine-grained sandstone	47
Siltstone, gray, platy	4
Shale, gray, siliceous	5
Shale and siltstone, gray, siliceous in part, hard, platy; weathers to light bluish gray or silvery gray	10
Shale, gray, chippy, poorly exposed	17
Sandstone, gray, fine- to medium-grained, shaly and silty, thin-bedded; locally forms top of prominent hogback; elsewhere the top of the hogback is an overlying unit and this sandstone forms a small ledge	1
Covered; siliceous shale and siltstone in float	14
Bentonite, gray; probably very impure	1½
Sandstone, gray, fine-grained, silty; contains shale partings	2
Siltstone, silty shale, and fine-grained thin-bedded sandstone; a 6-inch bed of green bentonite is 10 feet below top; upper part of unit mostly covered	95
Bentonite, green	1
Siltstone and shale, gray (weathering bluish gray); small ledges form at top of unit	19
Siltstone, gray, sandy; weathers bluish gray, forms small ledge, contains numerous fish scales	2
Bentonite, light-gray; upper 6 inches shaly	3
Shale, dark-gray; sandy in upper part, forms steep slope devoid of vegetation	49
Bentonite, gray; forms small shoulder	2
Shale, gray, hard; weathers bluish gray	2
Bentonite, gray	1½
Shale, dark-gray	4
Bentonite, yellow-green; rather granular	1
Total Mowry shale	343
Thermopolis shale:	
Shale, gray; contains a few thin beds of ironstone and sandstone	88

UPPER CRETACEOUS SERIES

FRONTIER FORMATION

The Frontier formation, about 260 feet thick, forms a much wider outcrop belt around the Bighorn and Pryor Mountains than do the underlying formations. Although the Frontier contains a few lenses of sandstone, some of which are mostly composed of small black chert pebbles similar to those that characterize the Frontier sandstone in the Bighorn Basin, the formation consists predominantly of dark-gray concretionary, sandy shale with interbedded bentonite. It is, in fact, very similar to the lower part of the overlying Cody shale.

The basal 70 feet of the Frontier contains several beds of bentonite and ferruginous concretions in dark-gray partly bentonitic shale. At least one of these bentonite beds in each exposure is stained red from a layer of limonite. Where this basal unit has not been protected by vegetation, it has eroded to badland topography.

The white-weathering Soap Creek bentonite bed (Knechtel and Patterson, 1952, pl. 1), the topmost unit of the Frontier of this report, is from 5 to 10 feet or more thick over much of the area. Brown calcareous concretions, locally as much as 8 feet in diameter, are very common in the shale beneath the Soap Creek bed, and the association of the thick bed of bentonite and exceptionally large concretions provides an easily mapped horizon. The top of the Frontier formation might be difficult to recognize in subsurface and it probably would be placed at the top of the highest sandstone or sandy shale in wells which penetrate the Frontier. Inasmuch as lenses of sandstone and sandy shale are locally common in the lower part of the overlying Cody shale, the contact as selected in the subsurface might range somewhat up or down in the stratigraphic section from well to well.

Section of the Frontier formation on the north flank of Rotten Grass dome in the N½ sec. 29, T. 7 S., R. 33 E., Big Horn County, Mont.

[Measured by S. H. Patterson and P. W. Richards]

	Feet
Cody shale: Shale, gray, sandy	
Frontier formation:	
Bentonite, olive-green, waxy: Soap Creek bentonite bed	8
Shale, gray, partly sandy; mostly covered	62
Bentonite, greenish-gray, waxy	½
Sandstone and shale; consists predominantly of gray poorly consolidated sandstone in upper 25 feet and gray shale in lower 45 feet	70
Bentonite, green, waxy	2
Shale, dark-gray, sandy; has 2 thin beds of bentonite near the middle	45
Shale, dark-gray; weathers gray; sandy in upper 10 feet, bentonitic in lower part; has bed of ferruginous and manganiferous siltstone at top and at base	60
Bentonite, greenish-gray, waxy; mostly stained a rusty color	1½
Shale, dark-gray	2

Section of the Frontier formation on the north flank of Rotten Grass dome in the N½ sec. 29, T. 7 S., R. 33 E., Big Horn County, Mont.—Continued

	Feet
Frontier formation—Continued	
Bentonite, dark-gray, waxy; has rusty weathered streak in middle from interbedded ferruginous material	½
Shale, dark-gray	1½
Bentonite, dark greenish-gray	1
Shale, dark-gray; sandy in lower half; 8- to 12-inch bed of gray claystone concretions near middle	6
Total Frontier formation	260

CODY SHALE

The Cody shale includes 2,600 feet of dark-gray partly sandy shale which underlies much of the plains region in south-central Montana. The Cody is conformable above the Frontier formation and under the Parkman sandstone and includes rocks of the Colorado and Montana groups. Several members of the Cody shale were mapped by Thom (Thom and others, 1935, p. 49–58) as formations.

The Cody shale is a thick, mappable formation composed of seven members. Although lithologic characteristics of the members enable the mapping of individual units in much of the area, the differences in lithology are commonly too little to make possible the distinction of individual members where the shale is not well exposed east of the Bighorn River. The lower members of the Cody shale in the Colorado group are an unnamed basal member, the Greenhorn calcareous member, and the combined Carlile and Niobrara shale members, the total thickness being about 1,000 feet. Members of the Cody shale which belong to the Montana group are the Telegraph Creek member, a shale unit equivalent to the Eagle sandstone, and the Claggett shale member. Rocks in the Montana group part of the Cody shale are about 1,600 feet thick.

Inasmuch as the dark-gray shale of the Cody shale is relatively homogeneous in composition and uniform in its resistance to erosion, low rounded hills are typical of Cody outcrops in the Hardin area. Some high topographic relief has resulted on the plains, however, where terrace gravels in high-elevation remnants have preserved the underlying shale from erosion. Very little vegetation grows on the Cody shale except where silt has been deposited on it by streams or wind.

The Cody shale was measured and fossils collected and identified by W. A. Cobban. Fossils have been previously collected by W. T. Thom, Jr., and identified by J. B. Reeside, Jr. (Thom and others, 1935, p. 50–58).

Lower member of the Cody shale.—The lower member of the Cody shale consists of concretionary dark-gray shale and has several thin lenticular beds of sandstone in its lower part. The member is about

200 feet thick in the southern part of the area and is somewhat thicker in Woody Creek valley. On the east side of Soap Creek dome an 8-foot bed of bentonite occurs about 60 feet above the base of the formation, but in Woody Creek valley the interval between the Soap Creek bentonite bed at the top of the Frontier formation and the next higher bentonite layer is only 30 feet. The concretions found throughout the Cody shale commonly are septarian, calcareous, and brown to gray in color. This member and the underlying Frontier formation are equivalent to the Belle Fourche shale in the Black Hills region.

Section of lower member of Cody shale on east flank of Soap Creek dome in SW¼ sec. 36, T. 6 S., R. 32 E. Big Horn County, Mont.

[Plate 4, Section 7. Measured by W. A. Cobban]

	Feet
Cody shale:	
Greenhorn calcareous member:	
Shale, calcareous, dark-gray; weathering bluish-white	38
Bentonite, gray, limonitic	1
Lower member:	
Shale, dark-gray	10
Bentonite, gray, impure	3
Shale, dark-gray	19
Shale, dark-gray; contains three beds of light gray- and buff-weathering calcareous concretions with dark-brown calcite septarian veinlets	20
Shale, dark-gray	37
Shale, dark-gray; contains calcareous septarian concretions in upper foot	29
Shale, gray, bentonitic	18
Bentonite, gray; contains brown-weathering fibrous aragonite 21 inches above base; weathers to gray bare gumbo ridge	8½
Shale, dark-gray; contains very fine sandy streaks; contains calcareous septarian concretions at base, commonly 1½ by 3 feet with white to pale-yellow calcite veins at top	21
Shale, dark-gray; contains fine sandy streaks and a few thin beds of sandstone with black chert pebbles; has thin bed of friable coarse-grained sandstone locally at base; contains *Acanthoceras*? sp. (loc. 24059)	40
Total, lower member, Cody shale	205½
Frontier formation: Soap Creek bentonite bed.	

Greenhorn calcareous member.—The Greenhorn calcareous member of the Cody shale ranges in thickness from about 60 feet on the north side of Woody Creek valley to nearly 100 feet on the east flank of Soap Creek dome. It is composed of dark-gray very calcareous shale which weathers to nearly white soil that is conspicuous on dry sunny days. Its base is marked by a bed of gray limonitic bentonite and its top by a change from calcareous chunky shale in the Greenhorn member to noncalcareous fissile shale in the Carlile shale member.

Thom (Thom and others, 1935, p. 49–51) collected several forms of the ammonite genus *Vascoceras* from concretions 40 feet above the base of the Greenhorn east of Soap Creek dome. Reeside (1925, p. 25–33) identified them as the only specimens of the genus found in North America outside the State of Coahuila, Mexico.

Section of Greenhorn calcareous member on east flank of Soap Creek dome in SW¼ sec. 36, T. 6 S., R. 32 E. Big Horn County, Mont.

[Plate 4, sec. 7. Measured by W. A. Cobban.]

	Feet
Cody shale:	
Carlile shale member:	
Shale, dark-gray; contains very fine sandy streaks	56
Greenhorn calcareous member:	
Shale, dark-gray, calcareous; weathers bluish gray to white; contains a few limestone concretions 5 feet above base	28
Shale, dark-gray, calcareous; contains light-gray to buff calcareous concretions	1
Shale, dark-gray, calcareous; weathers bluish gray to white	28
Shale, dark-gray, calcareous; contains light-gray to buff limestone concretions commonly 9 by 12 inches with calcite crystal-lined cavities; contains *Inoceramus labiatus* (Schlotheim), *Inoceramus* sp., *Ostrea* n. sp., *Plicatula*? sp., gastropod indet., *Allocrioceras pariense* (White)?, *Pseudaspidoceras* sp., *Pseudotissotia* (*Choffaticeras*) sp.?, *Scaphites delicatulus* Warren var., *Vascoceras moultoni* Reeside, *Vascoceras stantoni* Reeside, *Vascoceras thomi* Reeside, *Watinoceras reesidei* Warren, fish bones (locs. 10755, 10890, 20935)	1
Shale, dark-gray, calcareous; weathers bluish gray to white	38
Bentonite, gray, limonitic	1
Total, Greenhorn calcareous member	97
Lower member:	
Shale, dark-gray	10

Carlile shale member.—The Carlile shale member is about 280 feet thick and consists chiefly of dark-gray shale, which is sandy in the lower part. Two zones of concretions, one about 75 to 100 feet above the base, and one about 90 feet below the top, crop out widely within the area. Concretions of the lower zone occur in thin beds in a stratigraphic interval of about 25 feet. They are thin, very hard, gray on fresh surfaces, red to brown on weathered surfaces, and soluble in hot hydrochloric acid. This zone is an easily recognized stratigraphic horizon because the "rusty" concretions are the only ones of their kind below the Telegraph Creek member and are conspicuous on the shale surfaces.

The upper concretionary zone contains light-brown to grayish-orange septarian concretions and is well exposed near the top of the hill in the SW¼ sec. 36, T. 6 S., R. 32 E. Elsewhere in the area the zone forms small ledges. This horizon was mapped by Thom (Thom and others, 1935, p. 52) as the base of the Niobrara shale, but Cobban, after examining the fauna he collected, placed the contact nearly 100 feet above the zone of concretions.

Composite section of Carlile shale member of Cody shale, Big Horn County, Mont.

[Plate 4, sec. 7. Measured by W. A. Cobban. Upper 95 feet measured on east side of Bighorn valley in NW¼SW¼SW¼ sec. 15 and SE¼SE¼ sec. 16, T. 3 S., R. 33 E. and in SW¼SW¼ sec. 26, T. 2 S., R. 33 E.; the lower 185 feet measured on east flank of Soap Creek dome in SW¼ sec. 36, T. 6 S., R. 32 E.]

	Ft	in
Cody shale:		
Niobrara shale member:		
Shale, dark-gray, sandy; bed of concretions in bentonitic shale at base	10	0
Carlile shale member:		
Shale, dark-gray; contains septarian concretions at base	5	6
Shale, dark-gray	8	0
Shale, dark-gray; contains numerous fragments of large thin-shelled *Inoceramus* encrusted with *Ostrea congesta* Conrad	3	6
Shale, dark-gray; contains calcareous septarian concretions which weather light gray to yellow tan	3	6
Shale, dark-gray; weathers light gray; contains fragments of large *Inoceramus* encrusted with *Ostrea congesta* Conrad (loc. 20945)	10	6
Shale, dark-gray; contains *Ostrea congesta* Conrad	4	6
Shale, dark-gray; contains large calcareous septarian concretions which weather light gray or buff and contain thin yellow calcite veinlets	5	0
Shale, dark-gray; contains thin sandy partings in middle and few gray calcareous septarian concretions; fossils are rare; contains *Inoceramus* sp., *Ostrea* sp., *Veniella* sp	39	0
Shale, dark-gray; contains distantly spaced gray calcareous septarian concretions at base; fossils scarce; contains *Inoceramus* sp., *Prionocyclus* sp. (loc. 20944)	1	6
Shale, dark-gray; gray calcareous septarian concretions in middle; fossils scarce; contains *Veniella* cf. *V. goniophora* Meek, *Placenticeras stantoni* Hyatt (loc. 20943)	14	3
(Underlying beds measured east of Soap Creek dome)		
Shale, dark-gray, weathers buff; large gray calcareous concretions at top weather yellow tan, and smaller septarian concretions weather light gray or buff; fossiliferous; contains "*Corbula*" n. sp., *Crassatellites* cf. *C. reesidei* Sidwell, *Inoceramus altus* Meek and Hayden?, *Inoceramus* n. sp., *Veniella* cf. *V. goniophora* Meek, *Tritonium*? cf. *T. kanabense* Stanton, *Baculites* cf. *B. besairiei* Collignon, *Placenticeras stantoni* Hyatt, *Scaphites corvensis* Cobban, *Scaphites corvensis* var. *bighornensis* Cobban (loc. 20939)	5	0
Shale, dark-gray; contains gray-weathering septarian concretions, many of which are fossiliferous; dark-gray calcareous concretions at base; shale contains *Membraniporina* sp., *Inoceramus* cf. *I. flaccidus* White, *Inoceramus* n. sp., *Nucula* sp., *Ostrea* sp., *Baculites* cf. *B. besairiei* Collignon, *Prionocyclus wyomingensis* Meek, *Scaphites corvensis* var. *bighornensis* Cabban (loc. 20938)	16	6

Composite section of Carlile shale member of Cody shale, Big Horn County, Mont.—Continued

	Ft	in
Cody shale—Continued		
Carlile shale member—Continued		
Shale, dark-gray; contains gray-weathering calcareous septarian concretions with dark-brown calcite veins; contains *Inoceramus* sp., *Prionocyclus wyomingensis* Meek, *Scaphites nigricollensis* var. *meeki* Cobban (loc. 20937)	12	0
Shale, dark-gray; with thin sandy streaks; weathers to gray soft soil	30	0
Conglomerate; very light gray-weathering pebbles of clayey siltstone commonly one-half inch in length but as much as 3 inches in length in a matrix of dark shale; or forms a band of pebbles through the middle of calcareous concretions which weather yellowish tan		4
Shale, dark-gray; contains some streaks of sand and at least 10 layers of very hard gray ironstones weathering bright orange-rust and dark maroon-brown which average 12 to 15 inches by 2 to 3 inches and contain bright tan weathering claystone nodules; contains *Inoceramus* sp., *Scaphites* sp. (loc. 20936)	25	0
Shale, dark-gray; contains sandy streaks	6	6
Bentonite, gray		6
Shale, dark-gray; contains sandy streaks	25	6
Bentonite, gray with base olive, nonswelling	3	0
Sandstone and shale alternating in thin beds	3	9
Bentonite, greenish-gray, nonswelling	2	6
Shale, dark-gray; contains very thin streaks of sand and contains *Inoceramus* sp., *Prionocyclus* sp	55	0
Total Carlile shale member	280	10
Greenhorn calcareous member:		
Shale, dark-gray, calcareous; weathers bluish then white; contains a few limestone concretions 5 feet above base	28	0

Niobrara shale member.—The Niobrara shale member, which is a little more than 400 feet thick where measured by Cobban on the east side of the Bighorn River south of Hardin, crops out along the northern and eastern edge of the area. It consists of dark-gray shale, many thin beds of bentonite, and several beds of septarian concretions. A 10-foot bed of calcareous shale about 90 feet above the base of the member weathers to form a band of yellowish-colored soil extending along the east side of the Bighorn valley from near Two Leggin Bridge southward past St. Xavier into the Rotten Grass Creek valley. This same bed forms a thin band of white soil south of Beauvais Creek and east of the airplane beacon in sec. 30, T. 4 S., R. 31 E., where it looks very much like the Greenhorn calcareous member. As the zone can be traced throughout most of the area, it was mapped wherever possible.

Unless exposures are good, the Carlile and Niobrara shale members are hard to distinguish so the two members were mapped together. The contact of the Niobrara shale member with the overlying Telegraph Creek member is gradational between shale in the Niobrara and sandy shale in the Telegraph Creek member. The contact is concealed in much of the area, but can be mapped because the sandy shale of the Telegraph Creek member forms yellow soil, whereas the Niobrara shale member forms gray soil.

Section of Niobrara shale member of Cody shale in bluffs on east bank of Bighorn River

[Plate 4, section 8. Measured by W. A. Cobban. Measured from point in E½NE¼SE¼ sec. 15, T. 2 S. R. 33 E. to a point in NE¼NE¼ sec. 25, T. 1 S., R. 33 E., 1 mile southeast of Hardin, Big Horn County, Mont.]

	Ft	in
Cody shale:		
Telegraph Creek member:		
Shale, dark-gray, sandy.		
Niobrara shale member:		
Shale, dark-gray; contains some very thin streaks of sand and some gray-weathering calcareous concretions; few fossils; contains *Inoceramus* n. sp., *Ostrea* sp., *Pteria* aff. *P. nebrascana* (Evans and Shumard), *Baculites codyensis*, Reeside, *Clioscaphites vermiformis* (Meek and Hayden) (loc. 20953)	32	
Shale, dark-gray; contains small gray-weathering calcareous concretions and four thin bentonite beds	18	0
Bentonite, gray		4
Shale, dark-gray	2	0
Shale, dark-gray; contains small rusty ironstone concretions	1	0
Shale, dark-gray	10	7
Shale, dark-gray; contains three 1½-inch beds of bentonite and a bed of calcareous concretions	7	9
Shale, dark-gray; contains nearly a dozen very thin layers of bentonite, commonly with aragonite	31	8
Bentonite, gray, streaked with yellow		4
Shale, dark-gray; contains two very thin layers of bentonite	13	6
Shale, dark-gray; contains some crushed fossils	18	6
Shale, dark-gray, and four 1- to 3-inch layers of bentonite	20	7
Shale, dark-gray; contains a few crushed fossils including *Inoceramus* sp., *Baculites codyensis* Reeside, *Clioscaphites vermiformis* (Meek and Hayden) (loc. 20952)	9	6
Bentonite and aragonite, gray		4
Shale, dark-gray; contains a few layers of ripple-marked sand in lower part	19	0
Bentonite, gray; widely spaced calcareous concretions commonly 4 by 36 inches are developed along the bed		1
Shale, dark-gray; contains calcareous widely spaced gray-weathering concretions, commonly 6 by 18 inches at base	7	3
Shale, dark-gray	7	9
Bentonite, gray		9
Shale, dark-gray	23	3
Bentonite, gray, finely micaceous	2	0

Section of Niobrara shale member of Cody shale in bluffs on east bank of Bighorn River—Continued

	Ft	in
Cody shale—Continued		
Niobrara shale member—Continued		
Shale, dark-gray and interbedded bentonite in thin beds	17	6
Shale, dark-gray; contains six thin beds of bentonite; calcareous concretions that weather light gray at base contain *Anomia* n. sp., *Inoceramus* sp., *Ostrea* sp. *Baculites* sp. (loc. 20951)	21	10
Shale, dark-gray, slightly calcareous; contains crushed fossils; a zone of calcareous widely spaced concretions that weather light gray and are commonly 1 by 2 feet at base; shale contains *Inoceramus* sp., *Ostrea* n. sp., *Baculites codyensis* Reeside, *Baculites* sp., pelecypods indet. (loc. 20950)	10	0
Bentonite, gray, finely micaceous	1	0
Shale, dark-gray, slightly calcareous; contains light-gray weathering calcareous septarian concretions at base	11	0
Shale, dark-gray; lower part slightly calcareous; contains crushed fossils; contains *Inoceramus* sp., *Ostrea congesta* Conrad, *Baculites* sp., fish scales	29	0
Bentonite, gray, micaceous		6
Shale, dark-gray, calcareous; contains crushed fossils; forms conspicuous yellowish-cream soil supporting greasewood east of Bighorn River from near Hardin and south at least as far as Rotten Grass Creek; contains *Inoceramus* sp., *Ostrea congesta* Conrad, *Veniella* sp., *Baculites* sp., *Scaphites* sp., fish scales (loc. 20949)	9	2
Shale, dark-gray, slightly calcareous; includes two 1-inch bentonite layers	7	8
Shale, dark-gray, and thin beds of bentonite	28	10
Shale, dark-gray; contains scattered biotite flakes	11	0
Bentonite, gray to greenish-gray, finely micaceous; contains long light-gray, buff-weathering limestone concretions	1	6
Shale, dark-gray, and thin beds of bentonite; bed of light-gray weathering calcareous concretions as large as 1½ by 2 feet at base; concretions contain *Inoceramus deformis* Meek, *Ostrea* n. sp., *Baculites mariasensis* Cobban, *Baculites sweetgrassensis* Cobban, *Scaphites* sp., nautiloid indet., gastropod indet. (loc. 20948)	12	11
Shale, dark-gray; contains sandy streaks in middle and fossiliferous calcareous concretions at base; concretions contain *Inoceramus deformis* Meek, *Inoceramus* n. sp., *Baculites mariasensis* Cobban, echinoid spines (loc. 20947)	10	9
Shale, dark-gray; contains very thin streaks of sand; at base a 15-inch micaceous bentonite bed along which are developed light-gray calcareous buff-weathering concretions containing *Inoceramus deformis* Meek, *Scaphites impendicostatus* Cobban, *Baculites mariasensis* Cobban (loc. 20946)	10	0
Total, Niobrara shale member	408	10
Carlile shale member:		
Shale, dark-gray.		

Telegraph Creek member.—The Telegraph Creek member crops out along the northern and eastern edges of the area. It was first named the Telegraph Creek formation by Thom (1922, p. 38), who stated that the formation consists of 320 feet of light-colored sandy shales that crop out in T. 2 S., Rs. 28 and 29 E. between the top of the Niobrara shale and the base of the Virgelle sandstone member of the Eagle sandstone. The writer and members of his party measured a total thickness of 785 feet of what is considered to be an equivalent unit, as follows: the upper 440 feet in sec. 6, T. 2 S., R. 29 E., the middle 140 feet along the drainage divide in sec. 17, T. 2 S., R. 29 E., and the lower 205 feet in the east-central part of T. 1 S., R. 30 E. The Telegraph Creek member is 850 feet thick where measured by Cobban east of Little Bighorn River in T. 2 S., R. 34 E.

Throughout the vicinity of Hardin, the Telegraph Creek member is sandy shale that contains a few thin beds of sandstone and calcareous concretions. Most of the sand occurs in laminae and thin stringers in the shale; some of it is calcareous. Weathered surfaces on the Telegraph Creek member are yellowish gray, and they contrast moderately with the weathered gray shale of the Niobrara. However, the contact of the two members in the shale bluffs along the Bighorn River east of Hardin is not discernible from a distance, because the basal part of the Telegraph Creek is neither sufficiently sandy nor sufficiently weathered to have a color different from that of the underlying shale.

The Telegraph Creek member was described by Reeside (Thom and others, 1935, p. 54) as containing a mixed Eagle and Niobrara fauna; nevertheless the Telegraph Creek is considered to be the basal part of the Montana group. Cephalopods from the Telegraph Creek have been described and figured by Reeside (1927).

Section of Telegraph Creek member of Cody shale extending from east bank of Little Bighorn River in center of sec. 2 southeastward one and a half miles across the S½ sec. 1, T. 2 S., R. 34 E., Big Horn County, Mont.

[Plate 4, Section 8. Measured by W. A. Cobban]

	Feet
Cody shale:	
Shale member equivalent to Eagle sandstone:	
Shale, weathers gray; contains rusty-colored ironstone concretions.	
Telegraph Creek member:	
Shale, dark-gray, light-gray weathering; contains gray calcareous concretions; bed of calcareous yellowish-tan weathering concretions at base contains *Baculites* sp., *Scaphites hippocrepis* (DeKay) var. *tenuis* Reeside (loc. 21201)	122
Concealed: buff-colored sandy soil; contains calcareous tan- to orange-weathering concretions at base; concretions contain *Ostrea* sp., *Baculites* sp	90

Section of Telegraph Creek member of Cody shale extending from east bank of Little Bighorn River in center of sec. 2 southeastward one and a half miles across the S½ sec. 1, T. 2 S., R. 34 E., Big Horn County, Mont.—Continued

	Feet
Cody shale—Continued	
Telegraph Creek member—Continued	
Sandstone and shale, interlaminated and interbedded gray, buff-weathering; sandstones are very fine grained, commonly ripple marked, and occur in layers less than 1 foot thick	96
Sandstone and shale, interlaminated and interbedded gray, buff-weathering; sandstones are very fine grained, non-resistant, and are in layers less than one-half inch thick	68
Sandstone, gray, very fine-grained, shaly, hard, tan-weathering; ledge forming	1
Sandstone and shale; similar to second unit above; lower 60 feet exposed in river bluff	490
Total Telegraph Creek member	867
Niobrara shale member:	
Shale, dark-gray; thin beds of bentonite; 10 feet below top are calcareous concretions which weather light gray	11

Shale member equivalent to the Eagle sandstone.—The Eagle sandstone forms prominent ledges and cliffs north of U. S. Highway 87 in T. 1 S., R. 29 E., but it grades eastward into shale and becomes inconspicuous east of the Bighorn River in T. 1 N., R. 33 E. A unit of shale at a corresponding stratigraphic horizon north of the Little Bighorn River and east of the Bighorn River contains fossils considered by Cobban to be typical of the Eagle fauna. This unit has been mapped as a distinct member of the Cody shale north of the Little Bighorn River, but it could not be mapped separately south of the Little Bighorn.

The shale member is 375 feet thick where measured by Cobban in sec. 13, T. 1 N., R. 34 E. It consists of three units; 50 feet of dark-gray shale at the base with several beds of ironstone concretions generally similar in appearance to those in the Carlile shale member, 215 feet of yellowish gray-weathering silty shale with many ironstone concretions in the middle, and 90 feet of dark-gray shale, which weathers brownish gray and contains some septarian and ironstone concretions. A 20-foot zone of bentonite and bentonitic shale at the top of the middle unit forms a gray band across the surface. A thin sandy zone, which makes small ledges about 160 feet above the base, is a good horizon marker in the area north of the Little Bighorn River and has been shown on the geologic map.

Section of shale member equivalent to Eagle sandstone south of Dry Creek in the north-central part of sec. 13, T. 1 S., R. 34 E., Big Horn County, Mont.

[Plate 4, section 8. Measured by W. A. Cobban]

	Ft	in
Cody shale:		
Claggett shale member:		
Bentonite, yellow	1	6
Shale member equivalent to Eagle sandstone:		
Shale, dark-gray, brownish-weathering; contains brown- and gray-weathering calcareous concretions; contains *Inoceramus* cf. *I. barabini* Morton, *Inoceramus* sp., *Baculites aquilaensis* Reeside, *Baculites aquilaensis* var. *separatus* Reeside, *Baculites haresi* Reeside, *Baculites minerensis* Landes, *Placenticeras* sp. (loc. 21210)	27	6
Shale, dark-gray; weathers to brownish soil; contains calcareous rusty-, brown-, and reddish-weathering ironstone concretions	15	0
Shale, dark-gray; weathers brownish gray; contains some brown-weathering calcareous concretions with yellow calcite veins; contains *Goniochasma crockfordi* Warren, *Inoceramus barabini* Morton, *Inoceramus saskatchewanensis* Warren, *Inoceramus subdepressus* Meek and Hayden, *Inoceramus* n. sp., *Pholadomya* aff. *P. subventricosa* Meek and Hayden, *Baculties* sp., *Placenticeras planum* Hyatt (loc. 21209)	46	0
Bentonite, yellowish-gray grading upward into brownish-gray; contains much white aragonite	3	0
Shale, dark bluish-gray, silicified	1	6
Bentonite, creamy-yellow grading upward into brownish-gray	5	0
Shale, dark bluish-gray, silicified	1	0
Shale, gray, bentonitic	5	0
Bentonite, yellowish-cream grading upward into gray; forms gray bare gumbo soil	6	0
Shale, dark-gray; weathers to light-gray soil with bluish bands; middle part contains numerous small calcerous concretions which weather bluish gray to buff; contains *Baculites aquilaensis* var. *separatus* Reeside, *Baculites haresi* Reeside, reptilian bones (loc. 21208)	45	0
Shale, dark-gray; weathers lighter gray; contains very fine sandy partings and about 25 beds of closely spaced ironstone concretions which weather rusty to dark maroon; contains *Baculites haresi* Reeside (loc. 21207). Bed of gray calcareous and ferruginous silty ledge-forming concretions at base	51	0

Section of shale member equivalent to Eagle sandstone south of Dry Creek in the north-central part of sec. 13, T. 1 S., R. 34 E., Big Horn County, Mont.—Con.

	Ft	in
Cody shale—Continued		
Shale member equivalent to Eagle sandstone—Continued		
Shale, gray, sandy; contains a few gray silty calcareous concretions and locally crossbedded sandstone concretions. Includes a bed of calcareous gray-weathering concretions that are fairly closely spaced and commonly septarian with thin veins of white calcite; some concretions carry a prolific Eagle fauna, *Anomia* sp., "*Callista*" cf. *C. pellucida* Meek and Hayden, "*Callista*" sp., *Cardium* (*Ethmocardium*) *whitei* Dall, *Corbulamella* cf. *C. gregaria* Meek and Hayden, *Crenella* cf. *C. elengantula* Meek and Hayden, *Cymbophora*? sp., *Cymella montanensis* Henderson, *Inoceramus barabini* Morton, *Leptosolen* cf. *L. conradi* Meek, *Lima* n. sp., *Lithophaga* n. sp., *Pinna* cf. *P. dolosoniensis* McLearn, *Syncyclonema halli* (Gabb) *Tellina* cf. *T. scitula* Meek and Hayden, *Velsella* n. sp. aff. *V. meeki* Evans and Shumard, *Capulus*? aff. *C.*? *microstriatus* Stephenson, *Drepanochilus* aff. *D. evansi* Cossman, *Spironema* aff. *S. tenuilineata* Meek and Hayden, other gastropods indet., *Baculites aquilaensis* Reeside, *B. aquilaensis* var. *separatus* Reeside, *Baculites haresi* Reeside, *B. haresi* var. (corrugated venter), *Baculites thomi* Reeside, *Hamites novimexicanus* Reeside, *Helicoceras rubeyi* Reeside, *Placenticeras meeki* Boehm, *Scaphites aquilaensis* Reeside, *S. aquilaensis* var. *costatus* Reeside, *S. aquilaensis* var. *nanus* Reeside, *Scaphites hippocrepis* (DeKay), *S. hippocrepis* var. *crassus* Reeside, *S. hippocrepis* var. *pusillus* Reeside, *S. hippocrepis* var. *tenuis* Reeside, *Scaphites stantoni* Reeside, *Scaphites* n. sp., *Scaphites* sp., crustacean remains, fish scales (loc. 21206)	6	
Shale, dark-gray, silty; weathers buff gray; contains a few ferruginous tan-weathering calcareous concretions	42	0
Shale, dark-gray, silty; weathers light gray; contains a few brown-weathering calcareous ironstone concretions as long as 4 feet	72	0
Bentonite, gray and yellow	1	6
Shale, dark-gray; contains ironstone concretions	17	0
Bentonite, yellowish-cream; contains much aragonite	1	0
Shale, dark-gray, somewhat silty; contains many layers of ironstone concretions which weather rusty, brown, and dark maroon	29	0
Total, shale member equivalent to Eagle sandstone	374	6
Telegraph Creek member:		
Shale, gray, sandy; contains gray-weathering calcareous concretions especially in lower 5 feet, where they are septarian with orange calcite veins	65	0

Claggett shale member.—The Claggett, topmost member of the Cody shale, is about 350 feet thick north of the Little Bighorn River in the only part of the Bighorn Canyon-Hardin area in which it was mapped as a separate unit. It also crops out south of the Little Bighorn River, but there much of it is concealed and it cannot be separated from the underlying shale. The Claggett consists of dark-gray shale that is bentonitic in the lower part and concretionary throughout. Two beds of grayish-yellow bentonite at the base are overlain by nearly 70 feet of shale, which weathers to a lighter color than the underlying shale and which contains several thin beds of bentonite. The shale above the bentonite zone contains a number of calcareous septarian concretions.

Large forms of *Baculites* and *Inoceramus* occur in reddish-brown septarian concretions near the top of the member at some localities. The contact between the Claggett shale member and the overlying Parkman sandstone is the base of sandy shales in the Parkman.

Section of Claggett shale member of Cody shale along drainage divide south of Sarpy road in NE¼ sec. 13, T. 1 S., R. 34 E. and NW¼ sec. 18, T. 1 S., R. 35 E., Big Horn County, Mont.

[Plate 4, section 8. Measured by W. A. Cobban]

	Ft	*in*
Parkman sandstone:		
Shale, buff-weathering; transitional upward from silty shale into very sandy shale; contain 5 or 6 beds of silty calcareous concretions that weather gray, yellowish tan, or brown	109	0
Cody shale:		
Claggett shale member:		
Shale, dark-gray; crops out as dark soft flaky shale which contrasts strongly with overlying light sandy unit; contains fossiliferous brown-weathering calcareous septarian concretions with yellow calcite and white barite; base marked by yellow-tan to brown-weathering calcareous concretions which are quite fossiliferous, closely spaced, and septarian with thin pale-yellow calcite veins, commonly 10 by 18 inches to 15 inches by 3 feet but as much as 2 by 6 feet; concretions contain *Caprinella coraloidea* Hall and Meek, *Inoceramus barabini* var. *inflatiformis* Douglas, *Inoceramus barabini* var. *magniumbonatus* Douglas, *Inoceramus* cf. *I. sagensis* Owen, *Inoceramus saskatchewanensis* Warren, *Pteria* cf. *P. notukeuensis* Warren, *Inoceramus vanuxemi* Meek and Hayden. "*Yoldia*" sp., *Acanthoscaphites* aff. *A. brevis* Meek, *Baculites asperiformis* Meek (loc. 21214)	17	6
Shale, dark-gray; contains a bed of calcareous septarian concretions 28 feet below top; concretions at base are calcareous, very closely spaced; concretions weather rusty brown, tan, and reddish and are septarian with thin veins of pale-yellow calcite	43	0

Section of Claggett shale member of Cody shale along drainage divide south of Sarpy road in NE¼ sec. 13, T. 1 S., R. 34 E. and NW¼ sec. 18, T. 1 S., R. 35 E, Big Horn County, Mont.—Continued

	Ft	In
Cody shale—Continued		
Claggett shale member—Continued		
Shale, dark-gray; contains a few brown-weathering calcareous concretions; septarian with yellow calcite; crops out as dark soft flaky shale in contrast with underlying gray-weathering shale; contains *Baculites* cf. *B. aquilaensis* Reeside (loc. 21213). Concretions at base are brown weathering, calcareous, very closely spaced, septarian with brown or white calcite veins; contain *Baculites haresi* Reeside (loc. 21212)	41	6
Shale, dark-gray, gray-weathering; forms grass covered slopes; contains at least 8 beds of brown-weathering calcareous concretions that are septarian with yellow or brown calcite veins	156	0
Shale, dark-gray; weathers to gray bare gumbo soil; contains a few small gray calcareous concretions; contains *Baculites aquilaensis* var. *separatus* Reeside, *Baculites haresi* Reeside (loc. 21211)	40	0
Bentonite and concretions. Two beds of gray calcareous concretions, weathering light gray and brown, separated by about 3 feet of gray bentonite and bentonitic shale. Concretions are very closely spaced and somewhat septarian with veins of pale-yellow to brown calcite and, rarely, bluish chalcedony	4	6
Shale, dark-gray; with bentonitic beds; weathers lighter gray with gumbo bands	30	0
Bentonite, yellow	3	0
Shale, dark-gray, bentonitic; weathers lighter gray	24	6
Bentonite, yellow; forms gray bare gumbo	3	0
Shale, dark-gray; contains gray-weathering calareous concretions at base	3	0
Bentonite, yellow	1	6
Total, Claggett shale member	367	6
Shale member equivalent to Eagle sandstone:		
Shale, dark-gray, brownish-weathering; contains gray- and brown-weathering calcareous concretions	27	6

PARKMAN SANDSTONE

The Parkman sandstone consists of about 250 feet of sandy shale and sandstone. The only completely exposed section in the area is north of the Little Bighorn River, where it is made up of a lower 110-foot unit of shale (which is silty in the lower part and sandy in the upper part) and an upper 140-foot unit of massive grayish-yellow to olive sandstone (which contains many hard limonitic nodules).

Darton (1906a, p. 58–59) named the Parkman sandstone after the town of Parkman, Sheridan County, Wyo., where he found about 350 feet of buff-colored massive nonresistant sandstone with hard dark concretionary portions. The base of the formation is sharply delineated in some areas and transitional in others. Fossils collected from the Parkman by Darton were identified by T. W. Stanton as being marine forms of Late Cretaceous age.

Thom (Thom and others, 1935, p. 59) states that in the area of Pine Ridge, in T. 1 N., Rs. 31 and 32 E. northwest of Hardin, the beds above the basal sandstone of the Parkman resemble the Judith River formation and are a continuation of the fresh-water and brackish-water beds in the Judith River formation that occur in the Huntley field (Hancock, 1920, p. 121–124).

BEARPAW SHALE

Overlying the massive sandstone of the Parkman sandstone is about 850 feet of dark-gray marine shale which constitutes the Bearpaw shale. Cobban has divided the formation into three members, a lower 300 feet of dark-gray concretionary shale, a middle 250 feet of dark-gray concretionary shale with numerous beds of bentonite, and an upper 300 feet of dark-gray concretionary shale which is sandy in the upper few feet. The formation is exposed only in the Ninemile area where it forms saddles and small valleys between ridges of Parkman sandstone and pine covered hills of the Hell Creek formation. The Bearpaw is the uppermost formation of the Montana group in the Hardin area and is, according to Thom (Thom and others, 1935, p. 61) apparently conformable with the overlying Hell Creek formation, the base of which is largely greenish-gray shale, siltstone, and sandstone that supports a growth of pine trees in the Ninemile area.

Section of Bearpaw shale along the Sarpy road between the center of the SW¼ sec. 8 and the SW¼ sec. 10, T. 1 S., R. 35 E, Big Horn County, Mont.

[Plate 4, section 8. Measured by W. A. Cobban]

	Ft	in
Hell Creek formation: Sandstone at base.		
Bearpaw shale:		
Upper member:		
Shale, gray, sandy; interlaminated very fine grained soft sandstone	10	0
Shale, dark-gray; bed of dark-brown weathering calcareous concretions at base contains *Nucula planimarginata* Meek and Hayden (loc. 21228)	26	0
Shale, dark-gray; fossiliferous dark-brown weathering calcareous concretions at base; contains *Protocardia subquadrata* Evans and Shumard, "*Yoldia*" *evansi* Meek and Hayden, *Baculites grandis* Hall and Meed (loc. 21227)	9	0
Shale, dark-gray; dark-brown weathering calcareous concretions developed along greenish-gray bentonite at base	21	8
Shale, dark-gray	25	0
Shale, dark-gray, largely concealed; exposed along Bighorn River bluffs near old Nine Mile bridge where the following fossils were collected: *Lucina* sp., *Acanthoscaphites nodosus* (Owen), *Baculites compressus* Say, *Placenticeras meeki* Boehm, *Placenticeras planum* Hyatt (loc. 21363). A bed of small gray-weathering hard, nodular calcareous concretions and large cavernous masses of "tepee butte" limestone containing abundant *Lucina occidentalis* (Morton) at base; concretions and limestone contain *Chlamys nebrascensis* Meek and Hayden, *Inoceramus barabini* var. *inflatiformis* Douglas, *Inoceramus* sp., *Lucina occidentalis* (Morton), *Lucina subundata* Hall and Meek, *Ostrea* sp., *Pteria linguaeformais* (Evans and Shumard), *Polinices* aff. *P. concinna* (Hall and Meek), *Baculites compressus* Say, *Discoscaphites* aff. *D. nicolletii* (Morton) (loc. 21226)	155	0
Shale, dark-gray; a few calcareous concretions	15	0
Shale, dark-gray; contains calcareous, more or less ferruginous, concretions; contains *Baculites compressus* Say	35	0
Shale, dark-gray; contains calcareous concretions and *Cymbophora* cf. *C. gracilis* (Meek and Hayden), *Inoceramus altus* Meek, *Baculites compressus* Say, *Placenticeras meeki* Boehm (loc. 21225)	18	0
Bentonitic member:		
Shale, dark-gray, poorly exposed; contains a few thin beds of olive-green bentonite and some calcareous concretions	28	0
Bentonite, olive-green	1	0
Shale, dark-gray	6	6
Bentonite, greenish-gray	1	0
Shale, dark-gray; a few calcareous concretions; a bed of calcareous concretions at base weathers brown or gray; some concretions are fossiliferous	3	6

Section of Bearpaw shale along the Sarpy road between the center of the SW¼ sec. 8 and the SW¼ sec. 10, T. 1 S., R. 35 E., Big Horn County, Mont.—Con.

	Ft	In
Bearpaw shale—Continued		
Bentonitic member—Continued		
Shale, dark-gray; contains two thin beds of bentonite; calcareous widely spaced concretions at base weather bright brown; smaller grayish-brown weathering calcareous concretions are highly fossiliferous and contain *Cuspidaria* aff. *C. moreauensis* (Meek and Hayden), *Cuspidaria ventricosa* (Meek and Hayden), *Cymbophora gracilis* (Meek and Hayden), *Cymella meeki* Whitfield, *Gervillia recta* Meek and Hayden, *Inoceramus tenuilineatus* Hall and Meek, *Inoceramus* sp., *Lucina subundata* Hall and Meek, *Ostrea* cf. *C. subalata* Meek, *Pteria* cf. *P. parkensis* White, *Syncyclonema halli* (Gabb), "*Yoldia*" *evansi* Meek and Hayden, "*Yoldia*" aff. *Y. ventricosa* Hall and Meek, *Acmaea? occidentalis* (Hall and Meek), *Drepanochilus evansi* Cossmann, *Drepanochilus nebrascensis* (Evans and Shumard), *Fasciolaria* aff. *F. gracilenta* Meek, *Ellipsoscapha occidentalis* (Meek and Hayden), *Ellipsoscapha subcylindrica* (Meek and Hayden), *Polinices* aff. *P. concinna* Hall and Meek, *Dentalium pauperculum* Meek and Hayden, *Acanthoscaphites brevis* (Meek), *Acanthoscaphites nodosus* (Owen), *Acanthoscaphites quadrangularis* (Meek and Hayden), *Baculites compressus* Say, *Placenticeras intercalare* Meek, *Placenticeras meeki* Boehm (loc. 21224)	5	6
Bentonite, cream-colored	1	0
Shale, dark-gray	10	0
Bentonite, olive-yellow to gray	1	6
Shale, dark-gray	2	6
Bentonite, olive-green to grayish-green; bed of calcareous brown and gray weathering closely spaced concretions at base; contains *Inoceramus vanuxemi* Meek and Hayden, *Acanthoscaphites nodosus* (Owen), *Baculites compressus* Say (loc. 21223)	2	6
Shale, dark-gray; contains calcareous concretions in middle	10	9
Bentonite, olive-green		6
Shale, dark-gray	3	0
Bentonite, olive-green	1	6
Shale, dark-gray; contains calcareous concretions near middle; concretions contain *Cymbophora gracilis* (Meek and Hayden) (loc. 21222)	12	6
Bentonite, yellow, grades upward into gray	1	6
Shale, dark-gray, somewhat sandy	2	6
Bentonite, yellow to yellowish-green	1	0
Shale, dark-gray, partly sandy and bentonitic	2	0
Bentonite, green, grading upward into gray; locally contains large gray calcareous concretions; forms conspicuous light-gray bare gumbo soil	5	0
Shale, dark-gray; contains gray sandy calcareous concretions with silicified pelecypods; concretions contain *Cymbophora gracilis* (Meek and Hayden), *Inoceramus* sp. (loc. 21221)		6

Section of Bearpaw shale along the Sarpy road between the center of the SW¼ sec. 8 and the SW¼ sec. 10, T. 1 S., R. 35 E., Big Horn County, Mont.—Con.

	Ft	In
Bearpaw shale—Continued		
Bentonitic member—Continued		
Bentonite, light-green, grading upward into dark-green	2	0
Shale, dark-gray, bentonitic; lower 9 feet sandy; contains bed of calcareous, sandy, ferruginous closley spaced concretions that weather dark brown and purplish at base; concretions contain *Cymbophora gracilis* (Meek and Hayden), *Inoceramus* sp., *Baculites compressus* Say, *Placenticeras* sp. (loc. 21220)	23	0
Shale, dark-gray, somewhat sandy, nonresistant; contains calcareous concretions 8 feet above base; concretions contain *Lucina* sp., *Acanthoscaphites* sp., *Baculites compressus* Say, *Placenticeras* sp. (loc. 21219)	20	0
Shale, gray, bentonitic; contains a few gray calcareous concretions	35	0
Shale, gray, very bentonitic; weathers to gray gumbo soil	13	0
Shale, gray, bentonitic, poorly exposed; interbedded with darker colored fissile shale	42	0
Bentonite, olive-green	3	0
Lower member:		
Shale, dark-gray; contains brown- and gray-weathering septarian calcareous concretions 8 feet and 22 feet below top	53	0
Shale, dark-gray; contains several beds of calcareous brown-weathering ferruginous concretions	20	0
Shale, dark-gray; contains a few calcareous concretions; contains *Inoceramus* sp., *Placenticeras meeki* Boehm (loc. 21218) includes bed of calcareous brown-weathering concretions that are septarian with yellow calcite veins, commonly 1½ by 3 feet but as large as 2 by 10 feet at base	46	6
Shale, dark-gray; contains a few brown-weathering calcareous concretions	63	0
Shale, dark-gray; contains many brown-weathering calcareous concretions more or less septarian with yellow calcite veins; contains *Inoceramus* cf. *I. palliseri* Douglas, *Inoceramus sagensis* Owen?, *Inoceramus saskatchewanensis* Warren, *Inoceramus tenuilineatus* Hall and Meek, *Ostrea* sp., "*Yoldia*" sp. *Baculites compressus* Say (loc. 21217)	37	0
Shale, dark-gray; contains a few small gray calcareous concretions; contains *Inoceramus* sp., *Lucina* sp. (loc. 21216)	20	0
Shale, dark-gray; contains some bentonitic beds and a few calcareous concretions; at base a bed of calcareous closely spaced concretions that weather buff and brown; concretions contain *Inoceramus barabini* var. *inflatiformis* Douglas, *Emperoceras simplicostatum* (Whitfield) (loc. 21215)	54	6
Shale, dark-gray	15	0
Total, Bearpaw shale	865	5
Parkman sandstone: Sandstone, buff, brownish, and olive-green; forms hills.		

TERTIARY(?) AND QUATERNARY SYSTEMS

TERRACE GRAVELS

Extensive gravel deposits of Quaternary and in part, perhaps, of Tertiary age lie adjacent to the larger streams east of the Bighorn Mountains. These terrace deposits, which occur as high as 650 feet above the Bighorn River, are about 25 feet thick and contain a variety of rock material derived from the nearby Bighorn Mountains and from the Absaroka Mountains on the west side of the Bighorn Basin. A description of the gravel deposits and the correlation of surfaces is discussed under "Geomorphology" on pages 78–82.

QUATERNARY SYSTEM

LANDSLIDE MATERIAL

Several small landslides, each as much as one-fourth square mile in area, occur near the head of Soap Creek and along the high divide east of Rotten Grass Creek. Landslides, some of very recent date, result from headward erosion by small streams into shale that is covered by protective layers of terrace gravel. The slides always occur in the Cody shale and take place irrespective of the attitude of the bedding. Slides continue to develop in an area until the protective covering of gravel on the stream divides is destroyed and oversteepening is no longer possible.

ALLUVIUM

Alluvium on the flood plains which border each stream consists of silt, sand, and gravel. In the Bighorn River valley the alluvium shown on the geologic map includes only the present day flood plain, but in all other valleys the alluvium includes the flood plain, and the lowest terrace level, which generally is 5 to 20 feet above the flood plain. Alluvial flats in the valleys of Bighorn River, Little Bighorn River, Rotten Grass Creek, and Soap Creek are occupied by irrigated farms.

STRUCTURE

GENERAL FEATURES

The area covered by this report includes the northern end of the Bighorn Mountains—an anticlinal uplift which exposes rock formations of Paleozoic age—and the adjacent foothills and plains, on which are exposed Mesozoic strata that dip at low degrees away from the mountains. Geologic structures in the area are simple folds that are little affected by faults, and the chief visible difference between the north end of the Bighorn Mountain anticline and the anticlines in the adjacent plains area is in size.

FIGURE 5.—Aerial view of Bighorn Canyon. The view is southwestward toward the Pryor Mountains which make the distant skyline. The light-colored cliff near the rim of the canyon is the uppermost member of the Madison limestone, and the slopes above it are on the Amsden formation. Trees in the left center grow on a dip slope of the Tensleep sandstone. A hogback on the Pryor conglomerate member of the Cloverly formation is visible in left foreground.

The structural relief between the vicinity of Hardin and the crest of the Bighorn Mountain anticline, where the anticline is breached by Bighorn Canyon, is about 6,000 feet. Between Hardin and Soap Creek dome, which is the highest structural point east of the mountains, the structural relief is about 2,000 feet.

BIGHORN MOUNTAINS

The northern end of the Bighorn Mountains is a northward plunging anticline with a rather broad top and steep limbs. These features are seen in figure 5. The crest is near the western limb, and surface strata, which are the uppermost beds of the Madison limestone and the lower beds of the Amsden formation, dip about 5° eastward across the top of the fold and then steepen to 40° on the eastern limb. An eastward view down Bighorn Canyon and a view of the western limb of the mountains are shown in figures 6 and 7. Westward from the crest, the same strata dip at a low angle across the top of the fold to the western limb where they steepen abruptly to about 50° and flatten just as abruptly 1,500 feet lower.

The area between the Pryor and Bighorn Mountains is a structural and topographic basin, elliptical in outline and trending northeastward. There are two geographic divisions, Garvin Basin south of the Bighorn River and the Dry Head Creek area north of the river. Garvin Basin is bordered on the east and south by the Bighorn Mountains and on the west by Porcupine Creek anticline, which is a northward-plunging fold that forms the northernmost part of the western flank of the Bighorn Mountains. Porcupine Creek anticline dies out just north of the Bighorn River at faults which mark the southern end of the Pryor Mountains. The Dry Head Creek area is bordered on the west by the Pryor Mountains, on the east by the northernmost tip of the Bighorns, and on the north by a ridge of Triassic and Jurassic rock that connects the Pryor and Bighorn Mountains. Although the Garvin Basin-Dry Head Creek area is structurally much lower than the surrounding mountains, the top of the Madison limestone is about 4,700 feet higher than it is in the subsurface at Hardin. The Pennsylvanian Amsden formation forms most of the surface in the Garvin Basin-Dry Head area.

Fort Smith anticline, which is centered in secs. 3 and 11, T. 7 S., R. 31 E., occupies a unique position on the east flank of the Bighorn Mountain anticline. Its eastern limb coincides with the eastern limb of the Bighorn Mountains, but it is separated from the broad Bighorn Mountain anticline to the west by a northward-plunging syncline. The Fort Smith anticline is unfaulted and has more than 200 feet of structural closure. The resistant Tensleep sandstone and the uppermost part of the Amdsden formation are at the surface

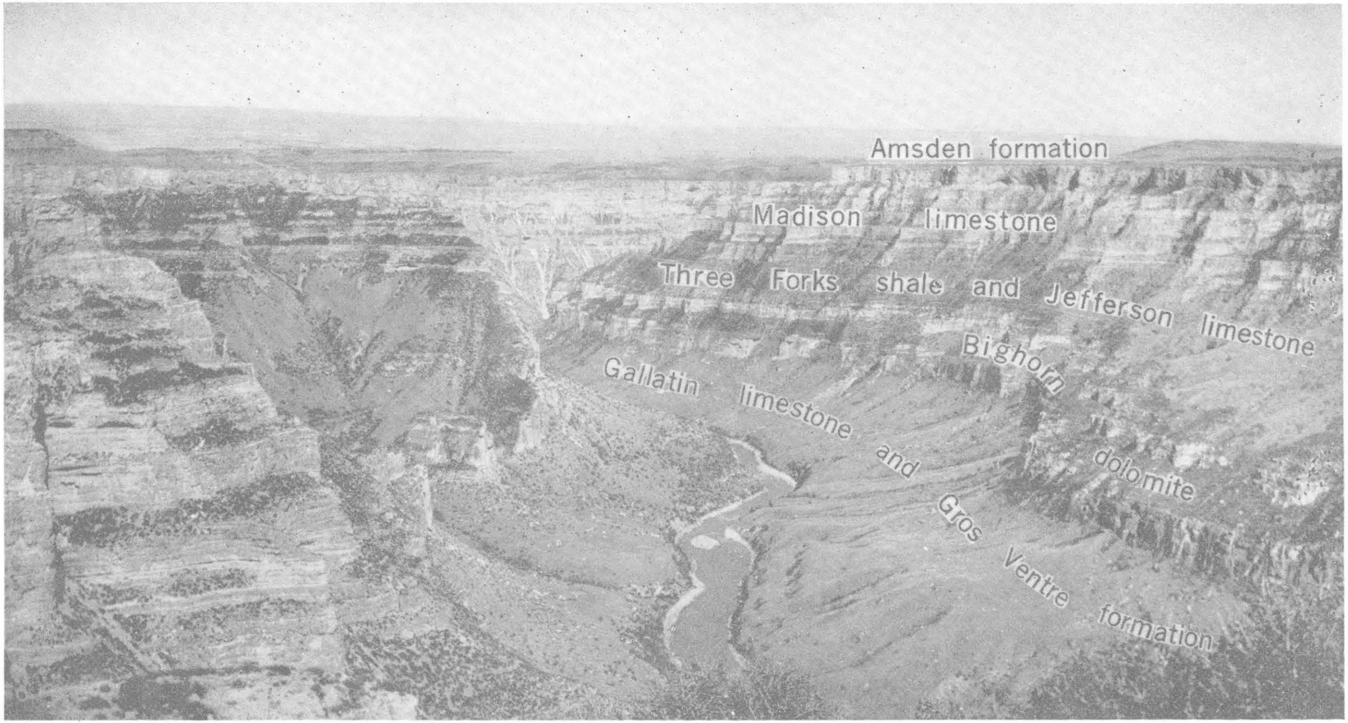

FIGURE 6.—View eastward down Bighorn Canyon from near the crest of the Bighorn Mountains. Fort Smith anticline forms the skyline at the right. Photograph by G. E. Prichard.

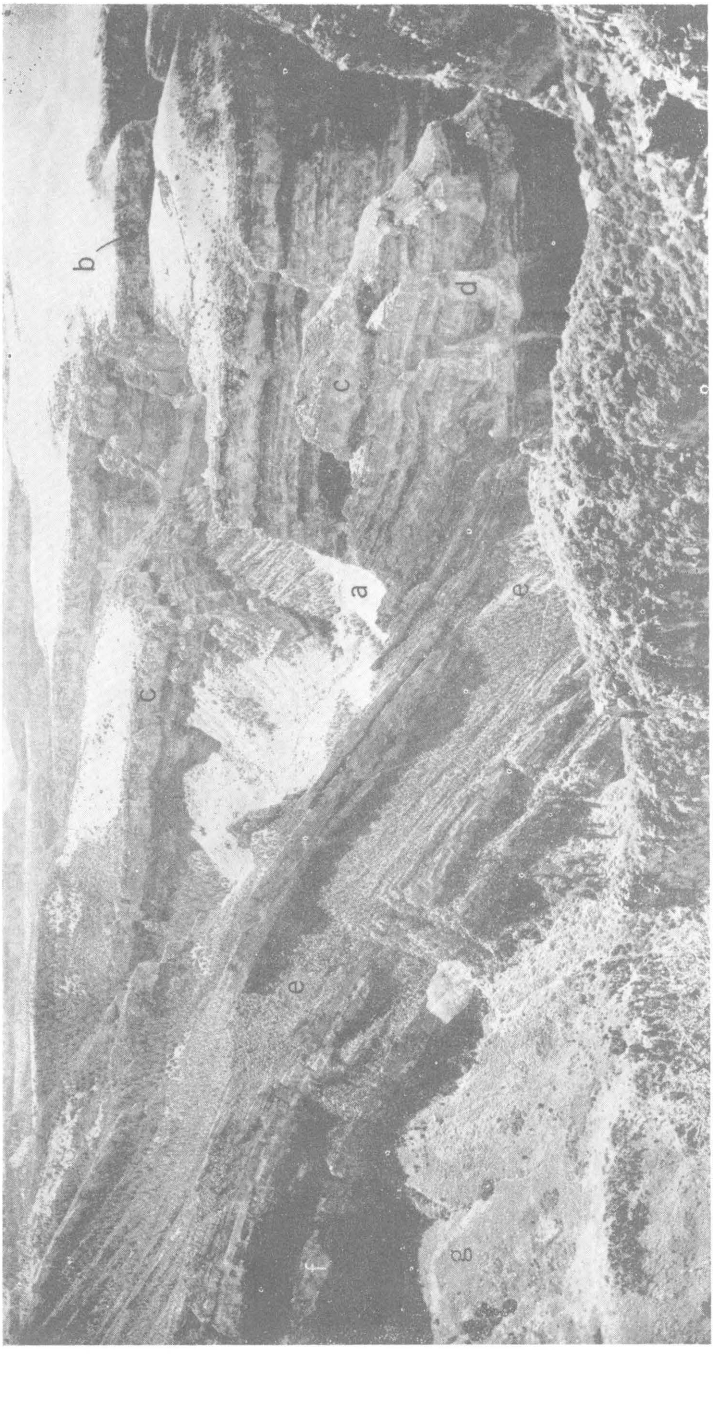

FIGURE 7.—Steep western flank of the Bighorn Mountains near the junction of the Bighorn River and Dry Head Creek. The view is southwestward, upstream, showing (*a*) Bighorn River, (*b*) canyon of Dry Head Creek, (*c*) uppermost member of the Madison limestone, (*d*) Madison limestone, (*e*) Three Forks shale and Jefferson limestone, (*f*) Bighorn dolomite, and (*g*) Gallatin limestone and Gros Ventre formation. Photograph by G. E. Prichard.

and thus the topographic form of the fold reflects closely the structural form.

Triassic and Jurassic formations near the eastern limb of the Bighorn mountains dip even more steeply eastward than does the Pennsylvanian Tensleep sandstone on the mountain flank. The dip of strata in the Ellis group south of the mouth of Bighorn Canyon is as much as 70° eastward, but within a mile to the east the dip has flattened to 10° or less in the shales of Late Cretaceous age. Throughout the plains portion of the Bighorn Canyon-Hardin area these shales dip about 2° away from the mountains, except locally where they are folded into anticlines and domes. The relation between the folds of the plains area and the axis of the Bighorn Mountains is shown by plate 6.

ANTICLINES AND DOMES

Soap Creek anticline.—Soap Creek anticline extends from Rotten Grass Creek in the southern part of T. 7 S., R. 33 E. northwestward to the Bighorn River in sec. 25, T. 5 S., R. 31 E., north of which it is concealed by extensive deposits of terrace gravel. Rotten Grass dome is near the south end of the anticline and Soap Creek dome near the middle.

Soap Creek dome.—Soap Creek dome, which is the only oil-producing structure in the area, was first described by Thom and Moulton (1921). The dome is elongate and the axis trends northward across sec. 34, T. 6 S., R. 32 E. The Morrison formation is exposed along Soap Creek at the highest structural point on the dome, which has more than 500 feet of structural closure at the surface. Formations above the Morrison are well exposed on the steeply dipping east flank of the dome, but they are concealed beneath terrace deposits on the gently dipping west flank. The history of drilling and of oil production in the Soap Creek field is discussed under "Economic Geology" on pages 82–83.

Rotten Grass dome.—Rotten Grass dome, in the SE¼ sec. 29, T. 7 S., R. 33 E., has a structural closure at the surface of less than 200 feet. Rocks exposed in and around the dome range from the top of the Mowry shale to the Greenhorn calcareous member of the Cody shale. The asymmetry of the dome is opposite to that of Soap Creek dome, and beds which dip less than 5° on the east side of the dome dip as much as 25° on the west side. The Western States Oil and Land Co's. well No. 1, in the SW¼SW¼ sec. 28, T. 7. S., R. 33 E., was drilled in 1921 to the Morrison formation and abandoned as a dry hole. It encountered water in the Cloverly formation.

Reed dome.—Reed dome is in the SW¼ sec. 35, T. 7 S., R. 32 E. and the NW¼ sec. 2, T. 8 S., R. 32 E. It is west of Rotten Grass dome and is at the eastern edge of the Bighorn Mountains. Rocks from the

Chugwater formation to the Morrison formation are exposed in the uplift, and although the dip of beds on the flanks is steep, the structural closure is less than 200 feet at the surface. A well described only as being in sec. 2, T. 7 S., R. 32 E., was drilled to a depth of 100 feet and abandoned as a dry hole.

Woody Creek dome.—Woody Creek dome is centered in the N½ sec. 33, T. 3 S., R. 31 E., south of Woody Creek. The dome is cut by a northeast-trending fault and has about 200 feet of closure on the southeast side and a little more than 100 feet of closure on the northwest side of the fault. Mowry shale is exposed along the fault, and the Frontier formation and the lower part of the Cody shale crop out around the dome. The axis of the anticline on which the dome is located continues southeastward and disappears under extensive terraces near the Bighorn River. This axis, however, is not in line with that of the Soap Creek anticline, the north end of which is also concealed beneath the terraces. A northward continuation of the axis from the Woody Creek dome forms the Two Leggin uplift. Wells which have been drilled at Woody Creek are described on page 83.

Beauvais Creek uplift.—The Beauvais Creek uplift, which is north of Grapevine dome, represents the northernmost recognized structural feature of the northward-plunging Bighorn Mountain anticline. It is traversed by the eastward-flowing Beauvais Creek and outlined on the northern and eastern sides by Mowry shale hogbacks. Reversals of the general northward dip in the area have made several small domes. Of these, Point Creek dome, in NW¼ sec. 29, T. 4 S., R. 30 E., has structural closure of less than 100 feet. Another small dome, south of Point Creek, also has less than 100 feet of surface closure. Several wells drilled in T. 4 S., Rs. 29–30 E. encountered water in the Tensleep sandstone and were abandoned as dry holes. These are discussed under "Economic Geology" on pages 83 and 86.

Hardin gas field.—The Hardin gas field, in and around the town of Hardin, yields dry gas from sandy shale at an average depth of about 725 feet in what has been called the Frontier formation. The sandy shale, however, probably is somewhat higher stratigraphically than the top of the Frontier formation as mapped in this report. Elevations on the top of the producing zone in the wells indicate a low northward dip, similar to dips observed in shale outcrops east and west of Hardin. The surface formation, the Cody shale, is concealed by terrace gravels at most places other than in river bluffs, but no faults that might have caused a trap for the gas were found in or near Hardin. The reservoir probably is a stratigraphic trap caused by sandy shale changing to shale or pinching out in the updip, southerly, direction.

Ninemile and Hardin areas.—The Ninemile area lies along Dry Creek and Nine Mile Coulee north of the Little Bighorn River and east of the Bighorn River. The steeply dipping faulted Parkman sandstone extends from the Little Bighorn River northward along the eastern edge of sec. 12, T. 1 S., R. 34 E. to sec. 35, T. 1 N., R. 34 E. and thence westward to the Bighorn River in sec. 23, T. 1 N., R. 33 E.; it marks in general the northern and eastern boundary of the Ninemile area. The Ninemile area lies mainly on a poorly defined anticlinal nose that plunges northward east of Hardin. North of the Little Bighorn River there are no anticlines with surface closure of 100 feet or more.

The Hardin gas field is centered in the town of Hardin, about 6 miles south of the mouth of Nine Mile Coulee. The area surrounding Hardin, including the gas field, is called loosly the Hardin area, and there is no well-defined border between the Ninemile and Hardin areas. The Marcus Snyder field was named upon the discovery of oil during 1952 in the G. J. Greer No. 2 Kendrick well just east of the Parkman sandstone in the NE¼NW¼NW¼ sec. 6, T. 1 S., R. 35 E. No distinct boundary separates this field from the Ninemile and Hardin areas. An area of about 6 or 7 square miles within the 1,800-foot structure contour lies about 5 miles southeast of Hardin and along the Little Bighorn River. This small anticlinal structure is on the broad anticlinal nose that strikes northward from the Little Bighorn River in the south-central part of T. 1 S., R. 34 E. through the Ninemile area, and southwestward from the Little Bighorn River toward Soap Creek anticline.

The Parkman sandstone around the northern and eastern flanks of the Ninemile area dips locally as much as 20° northward and eastward. Steeper dips are common along faults. These steep dips persist along the outcrop of the Parkman sandstone just east of the mapped area. Westward dips in the Cody shale are low along the western flank of the anticlinal nose that plunges northward through the Hardin and Ninemile areas, commonly less than 3°. There are no closed anticlines in the Ninemile area and only one small closed anticline in the Hardin area along the Little Bighorn River. Northward thinning of the Chugwater formation may increase the closure on the top of the Tensleep sandstone or Madison limestone in the Little Bighorn River area. This thinning is at a rate of about 10 feet per mile from the latitude of Bighorn Canyon northward to the H. L. Hunt No. 1 Kendrick Cattle Co. well in the SE¼SE¼ sec. 24, T. 1 N., R. 34 E., Big Horn County, Mont.

FAULTS

The faults in the Bighorn Canyon-Hardin area are simple and have small displacement except for two fault zones, the Lake Basin-Huntley zone northeast of Hardin and the Sykes Spring zone at the south end of the Pryor Mountains. In the plains area north and northeast of the Bighorn Mountains, isolated small faults were found only because they are visible on aerial photos.

Sykes Spring fault zone.—The Sykes Spring fault zone, named by Blackstone (1940, p. 603) for the springs which rise along the faults, extends southward from East Pryor Mountain, through secs. 27 and 34, T. 9 S., R. 28 E., Carbon County, Mont., and secs. 23 and 26, T. 58 N., R. 95 W., Big Horn County, Wyo., to Sykes Mountain south of Crooked Creek. The zone is about 5 miles long and not over one-quarter mile wide and consists of two or three northward-striking faults with associated shorter in echelon faults. The Sykes Spring faults transect rocks from the Madison limestone in East Pryor Mountain to the Cloverly formation in Sykes Mountain.

Blackstone (1940, p. 612), describing the Sykes Spring faults, states that they may be controlled by a zone of structural weakness in the basement rocks that is common to the Sykes Spring faults and the Dry Head fault which lies along the east flank of East Pryor Mountain and north of the Sykes Spring fault zone. The Sykes Spring faults formed as part of the Pryor Mountain structures, but their origin seems to have been associated with, or is in part a result of, the forming of Porcupine Creek anticline which is an unfaulted north-westward-plunging extension of the western flank of the Bighorn Mountains. Porcupine Creek anticline abuts the Pryor Mountains opposite the mouth of Porcupine Creek.

Bighorn Canyon area.—A near-vertical fault at least 6 miles long strikes eastward across Bighorn Canyon through T. 8 S., Rs. 28 and 29 E. The fault, which has a downthrow of about 225 feet on the south where it crosses Bighorn Canyon, is shown in figure 8. This is the only fault that was observed to cross Bighorn Canyon. Bedding plane faults may occur in steeply dipping beds of the west flank of the Bighorns along the eastern edge of T. 7 S., R. 29 E.

Grapevine Creek area.—An easterly trending fault, in secs. 24 and 25, T. 5 S., R. 29 E. and secs. 20 and 30, T. 5 S., R. 30 E., cuts the north and northeast sides of Grapevine dome. Chugwater strata that dip about 30 degrees eastward are offset 1,100 feet to the east on the south side of the fault, and the Chugwater formation is thinned considerably on the north side of the dome. A short fault trends northward across the outcrop of the basal sandstone of the Cloverly formation in the southeastern part of sec. 6 to the basal part of the Chugwater formation in sec. 7, T. 6 S., R. 31 E., a short distance north of the mouth of Bighorn Canyon. Both of these faults in the Grapevine Creek area are near lines of change in strike and dip of the strata on the edge of the Bighorn Mountains, and they undoubtedly

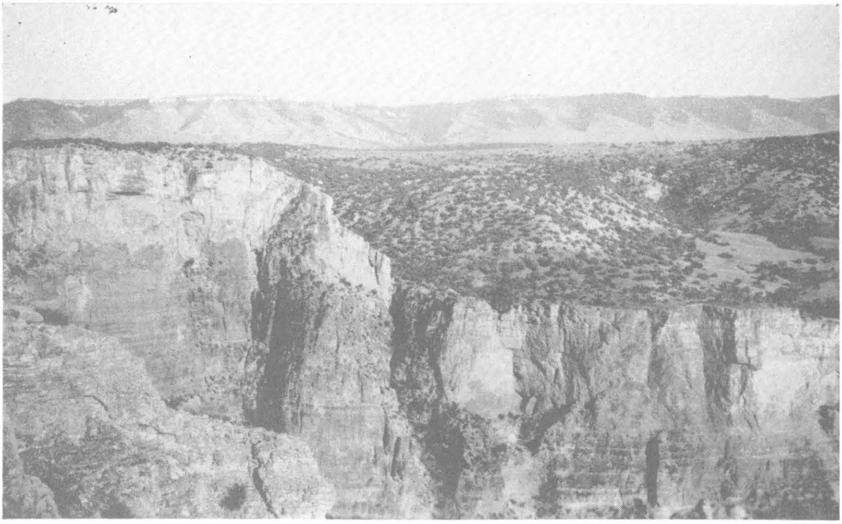

FIGURE 8.—Fault in Bighorn Canyon. View eastward from near mouth of Camp Creek in T. 8 S., R. 29 E. showing a nearly vertical fault that brings the lower part of the Amsden formation on the right opposite the uppermost part of the Madison limestone. The west flank of the Bighorn Mountains appears in the background.

were formed during the deformation that created the mountain structure.

Woody Creek dome.—A near-vertical fault crosses Woody Creek dome, trending from sec. 33, T. 3 S., R. 31 E. into sec. 11. This fault dies out in a very short distance in the Cody shale south of the dome and has a maximum vertical displacement of about 100 feet. A similar fault in secs. 3 and 9, west of the anticlinal axis extending northward from Woody Creek dome, has prominent surface expression, as on the north side of Woody Creek valley it displaces the white-weathering Greenhorn calcareous shale member of the Cody shale nearly 100 feet. Several other smaller faults on the north side of the valley are en echelon to the Woody Creek dome fault, and they occur in a belt parallel to the axis of the northward-plunging Two Leggin uplift. Structural closure along the faults is less than 100 feet.

Ninemile area.—Ten faults ranging from one-half mile to 2½ miles in length cross the Parkman sandstone in secs. 23, 24, and 25, T. 1 N., R. 33 E. and the southwestern part of T. 1 N., R. 34 E. These faults generally trend perpendicular to the strike of the Parkman sandstone, and the faults die out shortly after entering the shales that overlie and underlie the sandstone. The maximum horizontal displacement of the Parkman sandstone is about 3,000 feet. These faults are at the eastern end of the Lake Basin-Huntley fault zone, a narrow belt of northeastward-trending faults extending for about 100 miles northwestward through the town of Huntley and north of Billings to the Lake Basin area in Golden Valley County (Hancock, 1918, 1920).

As the trend of most of the faults in the Ninemile area is perpendicular to, rather than parallel to, the strike of the formations, there is little or no structural closure along the faults. There seems to be a definite association of these faults with the Parkman sandstone, and it seems probable that the faults follow the Parkman sandstone downdip and continue to die out in the shale above and below the sandstone. If the deforming forces broke the sandstone beds and deformed the shale plastically, other sandstones—such as the Pennsylvanian Tensleep sandstone—which are stratigraphically lower than the Parkman may be cut by an entirely different set of faults than is seen in the surface formations.

AGE OF DEFORMATION

All formations in the Bighorn Canyon-Hardin area are older than the Laramide mountain-making deformation of the region, so the deformational history must be determined from other parts of the Bighorn Mountains and the adjacent Bighorn Basin. Ample evidence in the Bighorn Basin (Hewett, 1926, p. 68; Rogers and others, 1948) shows that slight folding preceded deposition of the oldest Tertiary strata, which belong to the Paleocene Fort Union formation, and that more intense folding preceded deposition of the next younger strata of the Willwood (Wasatch) formation.

Along the eastern edge of the Bighorn Mountains, the deformation continued well into Eocene time. In Sheridan and Johnson Counties, Wyo., the Kingsbury conglomerate (Darton, 1906a, p. 60–62; Brown, 1948. See bibliography of latter paper) is separated from underlying Mesozoic and Paleozoic rocks by a pronounced angular unconformity and from the overlying Moncrief gravel (Sharp, 1948, p. 1–15) of probable Eocene age, by another angular unconformity.

Darton's Kingsbury conglomerate is composed mainly of limestone boulders derived from the Paleozoic limestones in the Bighorn Mountains, whereas the Moncrief gravel (of Sharp) is composed mainly of boulders derived from the pre-Cambrian crystalline core of the mountains. Stratigraphic and structural relations of the Kingsbury conglomerate and Moncrief gravel to older formations led Sharp (1948, p. 14) to conclude that at least three episodes of Laramide orogeny are recorded: Uplift and attendant erosion which led to the deposition of the Kingsbury conglomerate, uplift and deformation of the Kingsbury and erosion which resulted in the deposition of the Moncrief gravel, and the action of compressional forces which thrust the Paleozoic limestones onto the Moncrief gravel along the present east front of the Bighorn Mountains. These episodes of deformation

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were preceded in the Bighorn Mountain area by at least one other, folding, during pre-Fort Union time.

According to Mackin (1937, p. 819, 824, 892; 1947, p. 103–120) the Bighorn Basin remained near sea level during the Laramide uplift of the mountains, but the basin and adjacent mountains were elevated approximately to their present position during a regional uplift which was initiated in middle Tertiary time. The course of the Bighorn River across the northern end of the Bighorn Mountains rather than out of the open north end of the Bighorn Basin a few miles to the northwest has been cited as evidence (Fenneman, 1931, p. 166; Mackin, 1937, p. 821) that the river was superimposed from a surface on Tertiary formations in the Bighorn Basin that was at least partly continuous with the Tertiary cover of the Great Plains region (Mackin, 1937, p. 821).

Post-Laramide uplift in the region is thought by Thom (Thom and others, 1935, p. 84) to have continued through late Tertiary and Quaternary time in "more or less periodic upwarping or upbowing of the Big Horn arch and the adjacent region, attended by downcutting and terrace development." Mackin, in considering the problem of regional uplift in the Bighorn Basin, notes that stream terraces formed during pauses in downcutting of the stream need not be explained solely by regional uplift of the area. He points out (Mackin, 1937, p. 887) that fluctuations of sea level in late Tertiary and Pleistocene time and the changes in the course of the Missouri River during the Pleistocene undoubtedly affected the length and declivity, and, consequently, the load and volume of the Missouri, Yellowstone, and Bighorn River systems. These factors as well as the possibility of regional uplift must be considered when seeking an explanation of the origin of the Bighorn River terraces.

GEOMORPHOLOGY

GENERAL FEATURES

The Bighorn Canyon-Hardin area lies athwart the boundary of the Middle Rocky Mountains and the Great Plains provinces (Fenneman, 1931, p. 160), and much of its geomorphic history is reflected in surface features associated with or directly caused by the Bighorn River, the master stream of the area. The Bighorn River meanders across Bighorn Basin in a broad, shallow terraced valley cut into nonresistant Cretaceous and Tertiary formations, but it crosses the Bighorn Mountains in meanders incised to canyon depth in resistant, slightly folded Paleozoic limestones. The canyon ranges between 200 feet to a little more than 1,000 feet deep from Porcupine Creek anticline at the southern tip of the Pryor Mountains eastward across Garvin Basin and the Dry Head Creek area of the Bighorn Mountains to the northern end of the anticlinal arch of the Bighorn Mountains. The top of the Madison limestone generally forms the edge of the canyon and the overlying nonresistant redbeds in the Amsden formation have been stripped back from the Madison limestone. As shown by figure 7, meander spurs in the canyon have not been greatly reduced, even where the canyon is 1,000 feet deep.

The Paleozoic limestones rise steeply, and abruptly, up the west flank of the Bighorn Mountain anticline a short distance east of the mouth of Dry Head Creek. Where the river meets the flank of this great fold, it leaves a canyon one-quarter mile wide and 1,100 feet deep to enter a gorge five times as wide and twice as deep. In the axial part of the anticline the Bighorn River has exposed Cambrian shales and thin limestones that are much less resistant than the overlying massive limestones, and for 6 miles in this part of the canyon the river has no incised meanders. Steep talus-covered slopes cut on nonresistant Cambrian strata rise as much as 750 feet from the river's edge to nearly vertical limestone cliffs that are as much as 1,300 feet high. East of the mountain crest, however, the eastward dip of the strata is greater than the gradient of the river, and the canyon again narrows about 4 miles northeast of the axis, and the river flows to the mouth of Bighorn Canyon in incised meanders that show little regard for the bedrock structure.

The Bighorn River thus flows through incised meanders except across the axial part of the Bighorn Mountains where it follows a straight course in shale of Cambrian age. Undoubtedly, incised meanders existed when the river was cutting in limestone of Paleozoic age at higher levels, but as the river reached shale of Cambrian age, its meanders were able to migrate downstream, thereby undercutting and removing meander spurs. Evidence of former meanders has been destroyed as the cross-sectional profile of the valley widened above stream level to the angle of repose of the shale. There is no valley floor, other than the stream channel, and there is no sign of former stream deposits on the valley walls, because weathering and rill wash are constantly eroding the shale of the valley sides. Incision of the meanders may have started at a level considerably higher than the Madison limestone in the Dry Creek-Garvin Basin area, but owing to the alternately resistant and nonresistant character of the strata overlying the Madison limestone these beds have been largely stripped off or weathered back from the edge of the Madison cliffs. Terrace gravels have been almost completely removed from the same area.

The Bighorn River flows northeastward from the mountains along the west edge of its valley to Two Leggin Creek where it crosses the valley and continues northward past Hardin. Through this part of its course the river cuts at the base of nearly vertical shale bluffs 125 feet high, first on the west side of the valley, then on the east. The shale bluff is overlain by terrace gravels. Between Rotten Grass Creek and Hardin, the Bighorn flows parallel to the strike of the shale of Late Cretaceous age. The stream divide to the east is a westward-facing cuesta that is gradually shifting eastward. Numerous small valleys on the east slopes of the cuesta have been beheaded during the eastward migration of the divide.

The Little Bighorn River and Rotten Grass Creek rise on the east slopes of the Bighorn Mountains and flow eastward onto the plains, where they turn northward parallel to the strike of the bedrock. This pattern may have developed at a higher level as subsequent streams in the Cretaceous shales worked headward and captured streams flowing eastward from the mountains. Stream piracy in more recent times is well exemplified by the capture of the headwaters of Hay Creek by Muddy Creek. This capture, which occurred in the NW¼ sec. 23, T. 4 S., R. 30 E., left Hay Creek valley with virtually no stream. Typical reversed streams at the head of Hay Creek join Muddy Creek at the elbow of capture.

TERRACES

Six principal terrace levels and a few intermediate ones that are cut on beveled strata along the Bighorn River and its tributary streams may be recognized east of the Bighorn Mountains. The most extensive terraces were made by the Bighorn and Little Bighorn Rivers. The terraces along Bighorn River, which range from 10 to 650 feet or more in elevation above the river, are designated by numbers from 1 (the lowest and youngest) to 6. Terraces of tributary streams have been correlated with them at points as close as possible to the junctions of the streams.

The terraces are underlain by generally unconsolidated silt, sand, and gravel, which total about 25 feet thick on the lower levels. The gravel is composed of limestone, basalt, andesite, and a subordinate amount of sandstone, quartzite, granite, gneiss, and chert. Near the mouth of Bighorn Canyon the coarser aggregate in terrace Qt1 ranges from 2 to 40 inches in diameter, and is predominantly limestone, whereas material smaller than 2 inches in diameter is chiefly volcanic rock. Near Hardin, however, limestone is subordinate to the volcanic rocks in all sizes of aggregate. Characteristics and correlations of the terraces are summarized in table 3. Distribution of terrace gravels is shown on plate 7.

The lowest terrace, designated Qt1, covers most of the valley floors in the area. Its forward edge is about 10 feet above the narrow flood plain in Bighorn River valley, but the two surfaces merge locally.

TABLE 3.—*Bighorn River terraces below the Yellowtail dam site*

[Symbols: Qal, Quaternary alluvium; Qt, Quaternary terrace; Tt, Tertiary terrace

Symbo	Average height above river (feet)	Maximum diameter of gravel (inches)	Average diameter of gravel (inches)	Correlation: Thom [1]	Correlation: Alden [2]	Rock types of aggregate (most abundant named first)
Tt6	650	10	3	Flaxville (?) or no. 1.	Flaxville gravel.	Limestone, sandstone, basalt, andesite, chert, granite, and quartzite.[3]
Tt5	550	12	4			
Qt4	350	12	4	No. 2 and no. 3.	No. 2(?)	
Qt3	250	13	3			
Qt2	[4] 120–140	16	3		No. 2	
Qt1	20–90	[5] 40	5	Qal [6]	Qal	
Qal	0–15	----------	5	Qal	Qal	

[1] U. S. Geol. Survey Bull. 856, plate 3.
[2] U. S. Geol. Survey Prof. Paper 174, plate 1.
[3] Volcanic rock is most abundant in Qt1 and Qal gravel north of Two Leggin Creek and in gravel of 1 to 3-inch diameter in almost all terraces.
[4] 120 feet above river near mouth of Bighorn Canyon; downstream the interval increases.
[5] Near the mouth of Bighorn Canyon.
[6] Except near the mouth of Bighorn Canyon where it is included in nos 2 and 3.

Although Qt1 is mapped as a separate surface in the Bighorn River valley, it is included in the alluvium, Qal, in all other valleys. The Qt1 is a composite surface of many small terraces left by streams that swung laterally as they cut downward. It has a pronounced riverward slope that is accentuated by alluvial fan material deposited on its outer edge by intermittent tributary streams that do not reach the main stream.

Terrace number Qt2 caps the 125-foot bluffs along the Bighorn River and is one of the most prominent terraces in the area. It is well preserved on the northwest side of the Bighorn River, but it has been largely destroyed on the southeast side. Terraces Qt3, about 250 feet above the river, and Qt4, about 100 feet higher, are well preserved on the west side of the Bighorn River west of St. Xavier but are represented elsewhere only by small remnants.

The fifth terrace, Tt5, forms high benches southwest of Hardin and northeast of the mouth of Bighorn Canyon. It is about 550 feet above the river and is perhaps the most conspicuous terrace in the area. The highest terrace, Tt6, which is about 650 feet above Bighorn River is represented by a few remnants north of the mouth of Bighorn Canyon. A few remants of high terraces on the Bighorn-Little Bighorn River divide that are marked "Tt" represent Tt6 or perhaps an even higher level.

No fossils were found in the terrace deposits, and no glaciers extended from the Bighorn Mountains into this area to leave deposits that would aid in dating the terraces. The two highest terraces, Tt6 and Tt5, were tentatively correlated by Alden (1932, p. 28) with the Flaxville gravel of northern Montana, which Collier and Thom (1918, p. 179–184) considered to be upper Miocene or Pliocene in age. The lower terraces are Quaternary in age.

PEDIMENTS AND UNDIFFERENTIATED SURFACES

Several pediments in the Dry Head Creek area slope away from the Pryor Mountains toward Bighorn River and Dry Head Creek. These surfaces occur at more than one level and are covered by poorly sorted boulders and smaller debris, mostly limestone, derived from the Pryor Mountains. The pediments slope as much as 3° riverward within the area mapped.

A number of surfaces that bevel shale and are covered by reworked shale have been mapped as part of the shale bedrock formation in the Plains area. Elsewhere, as in the area between Little Bighorn and Bighorn Rivers in T. 1 S., R. 34 E., terraces have been partially or wholly destroyed and their gravels redistributed on a younger poorly developed surface. All such surfaces are identified on the geologic map as "Qu."

ECONOMIC GEOLOGY

OIL AND GAS

Small quantities of oil and gas have been found in the area. Oil has been produced periodically from the Soap Creek field and sufficient gas for the town of Hardin is obtained from the Hardin gas field. Oil was discovered during the latter part of 1952 in the Ninemile area. Exploratory drilling in several other areas has failed to find commercial amounts of oil or gas. Significant wells in the Hardin area are listed and described in table 4.

Hardin gas field.—Gas was discovered near Hardin in 1913 and was first piped into Hardin in 1929 (Perry, 1937, p. 55). The gas, which is mostly methane, comes from depths of from 675 to 825 feet. Although 103 wells had been drilled by June 1, 1949, only 50 were in production on that date, and most of these were in T. 1 S., Rs. 33 and 34 E. A check of the records of 90 wells in T. 1 S., Rs. 32–34 E. shows that about 70 percent had initial daily production of 30,000 to 80,000 cubic feet, and that the maximum daily production was about 180,000 cubic feet. Rock pressure in most wells now producing is between 120 and 140 pounds.

The Daniels Petroleum Corp.'s No. 1 May, in Hardin was started in 1935 and abandoned as a dry hole at total depth of 4,195 feet. Oil showings were reported in the upper part of the Madison limestone, which, depending upon interpretation of the driller's log, was penetrated as much as 250 feet but not more than 600 feet.

Soap Creek field.—Oil was discovered in Soap Creek dome in February 1921 (Thom and Moulton, 1921). Seven of 16 wells drilled on the dome have yielded oil. These were located close to the axis of the dome in secs. 27 and 34, T. 6 S., R. 32 E. Oil and water were recovered from the Amsden formation in 5 wells, and from the upper part of the Madison limestone in 2 wells. Initial tests of the Inland Empire Refineries well 52–34, Crow tribal, which was drilled in 1948, recovered oil with no water from the interval between 120 and 140 feet below the top of the Madison limestone. The gravity of Amsden oil is about 19° and Madison oil is 20°. Total production of the field as of July 1, 1948 was nearly 150,000 barrels.

Records of the Soap Creek wells are tabulated in table 4. Driller's logs of several wells have been published by Thom (Thom and others, 1935, p. 111–119). A log of the lower formations penetrated by the Inland Empire Refineries well 52–34 (pl. 3) was made by G. E. Prichard from a study of chip samples of cores and cuttings.

Woody Creek dome.—Two wells have been drilled on Woody Creek dome, one on each side of the fault that strikes northward through the dome. The Haskell and others well 1, Crow allotted, in the SE¼SE¼ sec. 29, T. 3 S., R. 31 E., west of the fault, reached the Chugwater formation and was abandoned as a dry hole at total depth of 2,000 feet but was later completed as a flowing water well. The Mid-Northern Oil Co.'s. well 1, Crow tribal, in the NE¼NE¼ sec. 33, T. 3 S., R. 31 E. was drilled on the east side of the fault to a total depth of 2,755 feet, stopping in the Madison limestone. It obtained no oil and was completed as a flowing water well. Both wells were drilled in 1923 and presently provide a small flow of water.

A driller's log of the Mid-Northern Oil Co.'s well 1, Crow tribal, indicates the top of the Morrison is at a depth of 1,270 feet, the top of the Tensleep sandstone at 2,332 feet, and the Madison limestone at 2,704 feet.

Beauvais Creek uplift—Four wells have been drilled in T. 4 S., Rs. 28–29 E. on the Beauvais Creek uplift. All were drilled in 1922 and were abandoned as dry holes. They started near the top of the Cloverly formation and penetrated not more than 100 feet into the Amsden formation. All found water in the upper 15 feet of the Tensleep sandstone and, with the possible exception of the T. S. Hogan well 1, all found water in the upper part of the Amsden formation. Driller's logs of the "56" Petroleum Co.'s well 1, NW¼SW¼NE¼ sec. 28 and well 2, SE¼NW¼ sec. 9, T. 4 S., R. 29 E., were published by Thom (Thom and others, 1935, p. 109–110). The only well which lies within the area of the accompanying geologic map is the T. S. Hogan well 1, Crow tribal. Formation contacts have been indicated by the writer in the driller's log of the well, as given on page 86.

TABLE 4.—*Selected oil and gas wells and dry holes*

[Land status: P, Patented (lessee of patented land in parentheses). Location: Townships marked with (*) indicate north, all others south; all ranges are east. Remarks: IDP, initial daily production; M, thousand cubic feet; RP, rock pressure of gas wells in pounds per square inch.]

No. on pl. 1	Operator	Well no.	Land status	Location				Drilling ceased	Total depth	Lowest formation reached	Remarks
				Fraction	Section	T.	R.				
1	Mackinnie Oil & Drilling Co.	1	P—(Douglas)	SW¼NE¼	32	*1	34	1946	1,046		Trace of gas at 720 feet.
2	Superior Oil & Coal Co.	1	P	SW¼SE¼NE¼	33	*1	34	1922	2,504	Cloverly(?)	
3	E. A. Lammers	1	P—(E. A. Lammers)	SE¼SW¼NW¼	14	1	32	1936	750	Frontier	IDP 135M gas.
4	Marcus Snyder	5	P—(Buzzetti-Corkin)	NE¼NE¼	16	1	32	1946	800	do	IDP 60M gas.
5	H. I. Crowe	1	P—(Snyder-Reed)	SE¼SE¼NW¼	23	1	32	1950	4,000	Madison	Top of Madison 3,489 ft. Abandoned.
6	Marcus Snyder	1	P—(E. Kelly)	Center, lot 3	24	1	32	1945	663	Frontier	IDP 40M gas.
7	Warren & Sons	3	P—(Warren & Sons)	NW¼SE¼SW¼	8	1	33	1940	830	do	IDP 30M gas, RP 60.
8	Yellowstone Oil & Gas Co.	3	P—(Sikenga)	NW¼	8	1	33	1938	850	do	Water and some gas.
9	Hardin Gas & Fuel Co	1	P—(Fearis)	SE¼NW¼	9	1	33	1925	800	do	Show of gas.
10	Yellowstone Oil & Gas Co.	1	P—(Grand Junction Sugar Co.).	SW¼	10	1	33	1913	2,210	Cloverly	
11	Big Horn Oil & Gas Development Co.	4	P—(McKay)	SW¼NW¼SE¼	11	1	33	1928	780	Frontier	IDP 105M gas.
12	Daniels Petroleum Corp.	1	P—(A. May)	NW¼SE¼SE¼	13	1	33	1938	4,195	Madison(?)	
13	Big Horn Oil & Gas Development Co.	6	P—(L. Mead)	NE¼NE¼SW¼	14	1	33	1929	730	Frontier	IDP 50M gas.
14	do	15	P—(Ottun)	Lot 7	15	1	33	1930	720	do	IDP 143M gas.
15	do	41	State of Montana	E½NE¼SW¼	16	1	33	1939	765	do	IDP 68M gas, RP 120.
16	do	45	P—(Cox)	N½NE¼SW¼	20	1	33	1942	690	do	IDP 60M gas.
17	do	17	P—(Big Horn County Bank).	N½NE¼NE¼	21	1	33	1930	693	do	IDP 161M gas.
18	do	19	P—(Houghton)	Lot 6	22	1	33	1931	642	do	IDP 115M gas, RP 120.
19	do	23	P—(Luther)	NE¼NE¼SE¼	22	1	33	1935	676	do	IDP 150M gas, RP 135.
20	Ursulla Zelka	1	P—(U. Zelka)	Lot 2, block 16, Old Town, Hardin.	23	1	33	1936	692	do	IDP 40M gas.
21	Big Horn Oil & Gas Development Co.	24	P—(Peck)	NW¼NE¼NE¼	26	1	33	1935	750	do	Show of gas.
22	Yellowstone Oil & Gas Co.	2	P—(Newkirk)	NE¼NE¼	27	1	33	1915	1,190	do	Do.
23	Mackinnie Oil & Drilling Co.	4	P—(Douglas)	NE¼NE¼	3	1	34	1946	428	do	Dry hole.
24	do	5	do	NW¼NW¼	3	1	34	1946	2,982	Ellis	Do.
25	do	2	do	NW¼SW¼	4	1	34	1946	882	Frontier	Do.
26	Big Horn Oil & Gas Development Co.	49	P—(Eckroy)	E½SE¼SW¼	17	1	34	1945	761	do	IDP 92M gas, RP 132.
27	do	51	do	NE¼NW¼SW¼	17	1	34	1945	805	do	IDP 122M gas, RP 132.
28	C. H. Butler	1	P—(C. H. Butler)	SW¼SW¼SE¼	18	1	34	1937	721	do	IDP 42M gas.
29	Warren & Sons	1	P—(Warren & Sons)	NW¼NW¼SE¼	19	1	34	1937	727	do	IDP 40M gas, RP 135.
30	Big Horn Oil & Gas Development Co.	56	P—(Warren)	NW¼	21	1	34	1946	845	do	IDP 53M gas, RP 134.

31	Massey Oil & Gas Co	1	P—(Massey Oil & Gas Co.)	SE¼SW¼SE¼	11	2	31	1940	2,150	Cloverly	Flowing water, 1,900–1,943 ft.
32	Haskell and others	1	Crow allotted	W½SE¼SE¼	29	3	31	1923	2,000	Chugwater	Completed as water well.
33	Mid-Northern Oil Co	1	Crow tribal	NW¼NE¼NE¼	33	3	31	1923	2,755	Madison	Do.
34	T. S. Hogan	1	do	SW¼SW¼NW¼	19	4	30	1922	1,435	Amsden	Water from Tensleep, 1,270–1,283 ft; flowing water well.
35	B. E. La Dow & Co	1	do	SW¼NE¼SE¼	16	6	32	1922	2,260	do	Fresh water in Amsden.
36	Winnie & Richards	1	do	SE¼SW¼	21	6	32	1922	2,030	Madison	Water in Tensleep.
37	Detroit-Wyoming Oil Co	1	Crow allotted	SW¼SW¼SW¼	26	6	32	1922	1,200	Chugwater	
38	Mule Creek Oil Co	6	P—(P. R. Krone)	E½SW¼NW¼	27	6	32	1922	1,970	Madison	IDP 28 bbl, Amsden.
39	Phillips Petroleum Co	3	Crow allotted	W½SE¼SW¼	27	6	32	1921	1,964	do	IDP 200 bbl, Madison.
40	do	1	Crow tribal	SW¼SW¼SE¼	27	6	32	1944	1,826	do	Shut in.
41	do	1	do	SW¼SW¼NE¼	34	6	32	1921	1,966	do	IDP 400 bbl, Amsden.
42	do	4	do	SW¼NE¼	34	6	32	1921	1,656	Amsden	IDP, 1,000 bbl, Amsden.
43	Western States Oil & Land Co	7	Crow allotted	NW¼SW¼	34	6	32	1922	2,115	Madison	Water in Madison.
44	Phillips Petroleum Co	2	do	SE¼SE¼NW¼	34	6	32	1922	1,652	Amsden(?)	IDP 1,500 bbl, Amsden.
45	do	3-8	Crow tribal	NW¼SW¼NE¼	34	6	32	1934	1,658	do	IDP 65 bbl oil, 650 bbl water.
46	Inland Empire Refineries, Inc	52-34	do	NW¼NE¼	34	6	32	1948	4,470	pre-Cambrian	102 bbl oil, no water pumped in 6 hr from 1,990–2,010 ft, Madison.
47	Dox Oil Co	1	P—(C. E. Wolf)	NW¼NW¼NW¼	2	7	32	1921	2,168	Amsden	Show of oil in Amsden.
48	Thermopolis-Cat Creek Oil Co	1	do	N½NE¼SW¼	2	7	32	1922	2,017	Chugwater	Water in Cloverly, 550–575 ft.
49	Rice-Hoffman	1	Crow tribal	NE¼NE¼	4	7	32	1922	2,345	Amsden	Show of oil in Tensleep.
50	Western States Oil & Land Co	1	do	SW¼SW¼SW¼	28	7	33	1922(?)	2,615	Chugwater	Water in Cloverly, 1,575–1,705 ft.
51	G. J. Greer, trustee	1	P—(Ottun)	SW¼NE¼	32	*1	34	1952	5,727	Cambrian	Abandoned.
52	do	1	P—(Kendrick)	SE¼SE¼SW¼	34	*1	34	1952	2,700	Morrison	Do.
53	do	2	do	NE¼NW¼NW¼	6	1	35	1952	4,588	Tensleep	Discovery of low-gravity oil in Tensleep.

Note.—Hardin gas field:
Producing wells: 50 on June 1, 1949.
Wells drilled: 103 to June 1, 1949.
Soap Creek oil field:
Production:
127,500 bbl, 1921-38.
20,400 bbl, 1947–July 1, 1948.
No production on June 1, 1949.

T. S. Hogan well 1, Crow tribal, Beauvais Creek uplift, SW¼SW¼NW¼ sec. 19, T. 4 S., R. 30 E., Big Horn County, Mont.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Unclassified:			Unclassified—Continued		
No record	400	400	Limestone, sandy	11	1,254
Sandstone	10	410	Shale, red	16	1,270
Sandstone; water	10	420	Tensleep sandstone:		
Shale, blue	100	520	Sandstone; 200 barrels of water	13	1,283
Limestone; water	20	540	Sandstone; finer toward bottom, water	77	1,360
Shale, light-blue	20	560	Amsden formation:		
Lime shell	9	569	Limestone, shell	15	1,375
Shale, blue, red, and pink	306	875	Limestone	7	1,382
Limestone, blue	23	898	Sandstone, white, soft	5	1,387
Shale and shells, red	113	1,011	Limestone, white, hard	48	1,435
Sandstone	14	1,025			
Redbeds	218	1,243			

The small structural closure of the domes in the Beauvais Creek area and the proximity of outcrops of all underlying sedimentary formations minimize the likelihood of a well obtaining oil in the Beauvais Creek area.

Two Leggin uplift.—One well has been drilled on the Two Leggin uplift, the northward-plunging anticline that is a continuation of Woody Creek dome. This well, the Massey Oil and Gas Co. well 1, SE¼SW¼SE¼ sec. 11, T. 2 S., R. 31 E., Big Horn County, Mont., started drilling at about the concretion zone at the base of the Niobrara shale as defined by Thom (Thom and others, 1935, p. 52) and was abandoned as a dry hole when it reached a total depth of 2,150 feet. The top of the Morrison formation is at a depth of 1,943 feet, judging from the driller's log.

Ninemile area and Marcus Snyder field.—Discovery of oil just east of the Ninemile area came during 1952 when low gravity oil was recovered from the Tensleep sandstone at a depth of 4,556 feet. The discovery well, the G. J. Greer, No. 2 Kendrick, is in the NE¼NW¼NW¼ sec. 6, T. 1 S., R. 35 E., in the newly named Marcus Snyder field. Several older shallow wells have been drilled in the Ninemile area; none of them reached formations below the Ellis group. Records for four of these wells are listed in table 4. The G. J. Greer, No. 1 Ottun well, in the SW¼NE¼ sec. 32, T. 1 N., R. 34 E., Big Horn County, Mont., which was drilled late in 1952, was dry and abandoned.[2]

[2] The Carter No. 1 Rides Bear, which was drilled during 1953 in the middle of NE¼SE¼ sec. 27, T. 1 S., R. 34 E. on the small structural closure shown on plate 1, was also dry and abandoned. No oil or gas shows were reported for this well which reached Cambrian strata. Sulfur water reportedly flowed from the Tensleep sandstone. A second Carter test, the Carter Oil No. 1 Crow tribal in the NE¼NE¼SW¼ sec. 7, T. 1 S., R. 35 E., was abandoned in 1954 reaching the Tensleep sandstone, where "dead oil" was encountered.

MINERAL DEPOSITS

Bentonite.—Numerous beds of bentonite, ranging in thickness from less than 1 inch to nearly 20 feet, occur in shale of Cretaceous age. The bentonite is of the swelling variety, and its color ranges from light gray to yellowish and greenish gray. Several thick beds are well exposed in sec. 35, T. 6 S., R. 32 E. on the east flank of Soap Creek dome. Here the Clay Spur bentonite bed at the top of the Mowry shale is 7 feet thick; the Soap Creek bentonite bed at the top of the Frontier formation is about 10 feet thick, and a bed in the lower part of the Cody shale is 8 feet thick. These beds are much thinner along Woody Creek, but the Soap Creek bed is locally more than 10 feet thick south of Soap Creek dome.

A bed of bentonite in the upper part of the Cody shale is 14 or more feet thick where exposed along the drainage divide east of Rotten Grass Creek between sec. 18, T. 5 S., R. 34 E. and sec. 4, T. 6 S., R. 34 E. Two thick beds at the base of the Claggett shale member and a thick zone of bentonite about 100 feet below the top of the shale member equivalent to the Eagle sandstone are well exposed south of Dry Creek in the S½ sec. 12, T. 1 S., R. 34 E. A thick lenticular zone of bentonite and bentonitic shale in the undifferentiated Cloverly and Morrison formations is exposed north of Rotten Grass Creek in the central part of sec. 1, T. 8 S., R. 32 E.

The thicker and more extensive beds of bentonite have been mapped and studied in detail by M. M. Knechtel and S. H. Patterson of the Geological Survey, and the results of their investigations have been published separately (Knechtel and Patterson, 1952).

Gypsum.—Deposits of gypsum in the basal part of the Piper formation are well exposed in many scarps that face toward the Bighorn Mountains. Along the north side of Grapevine Creek, north of the Bighorn River, and in the northern part of T. 6 S., R. 30 E. and in the northwestern part of T. 6 S., R. 31 E., the gypsum is about 50 feet thick and occurs in beds about 4 feet thick separated by 2 or 3 inches of red or green shale. Gypsum also occurs commonly in the lower part of the Chugwater formation. The thickest beds are in the area near the head of Soap Creek, in the south-central part of T. 7 S., R. 32 E. and the north-central part of T. 8 S., R. 32 E., where several beds are from 5 to 40 feet thick. Many of them contain thin seams of red shale.

Limestone.—The Madison limestone, which is well exposed in Bighorn Canyon and in several smaller canyons on the flanks of the Bighorn Mountains, is a huge deposit of limestone. The uppermost 150 feet is brecciated and contains zones of red shale mixed with blocks of limestone. Many of the beds in the Madison, particularly in the lower part, are notably dolomitic.

Limestone deposits in the upper part of the Piper formation are in several beds that range from nearly pure to very clayey limestone. They are well exposed along the north side of Grapevine Creek. A 5-foot bed of hard and slabby limestone about 100 feet below the top of the Chugwater formation has been quarried in Lime Kiln Creek in sec. 21, T. 6 S., R. 31 E.

Shale and clay.—An inexhaustible source of clay rock is the Cretaceous dark-gray shales, most of which are noncalcareous, and which are exposed over hundreds of square miles east of the Bighorn Mountains. The clay shales in the Rierdon formation are highly calcareous, and claystones and shales in the Cloverly and Morrison formations are thin or very lenticular.

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