Pre-Quaternary Rocks in the Sun River Canyon Area, Northwestern Montana

GEOLOGICAL SURVEY PROFESSIONAL PAPER 663-A

PRE-QUATERNARY ROCKS IN THE SUN RIVER CANYON AREA, NORTHWESTERN MONTANA

Sun River Canyon area, northwestern Montana. The forks of the North Fork Sun River join at the west end of Gibson Reservoir (light area near center of drawing). The river flows east from the reservoir.

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By MELVILLE R. MUDGE

GEOLOGY OF THE SUN RIVER CANYON AREA, NORTHWESTERN MONTANA

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A comprehensive restudy of a classic area of stratigraphy and thrust faulting in the northern Rocky Mountains

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1972

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

W. A. Radlinski, *Acting Director*

Library of Congress catalog-card No. 79–180657

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock Number 2401–1135

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PRE-QUATERNARY ROCKS IN THE SUN RIVER CANYON AREA, NORTHWESTERN MONTANA

By Melville R. Mudge

ABSTRACT

The Sun River Canyon area is in the southern part of the northern disturbed belt in northwestern Montana. Most of the area is in the Sawtooth Range; the extreme western part is in the Lewis and Clark Range.

The outcropping rocks have an aggregate thickness of about 19,000 feet. The sedimentary rocks are Precambrian, Paleozoic, and Mesozoic; the igneous rocks include diorite sills of late Precambrian age and trachyandesite sills of very Late Cretaceous or early Tertiary age.

Rocks of the Belt Supergroup of Precambrian age crop out only in the western part of the area, where they have been thrust onto Paleozoic and Mesozoic rocks. The Precambrian rocks, as much as 7,100 feet thick and more than 1,000 million years old, include the Spokane and Empire Formations (undifferentiated), Helena Dolomite, Snowslip Formation, Shepard Formation, Mount Shields Formation, Bonner Quartzite, and McNamara Formation. The sequence is mostly clastic, but the Helena is largely dolomite, and dolomite is common in the lower part of the Shepard. The clastic rocks consist mostly of reddish-brown siltstone and sandstone. Lentils of glauconitic sandstone are abundant in the upper part of the Shepard, lowermost Mount Shields, and upper part of the McNamara. Salt-crystal casts are widespread in the upper member of the Mount Shields.

The Cambrian rocks, about 1,700 feet thick, are divided into eight formations: Flathead Sandstone, Gordon Shale, Damnation Limestone, Dearborn Limestone, Pagoda Limestone, Steamboat Limestone, Switchback Shale, and Devils Glen Dolomite. They are Middle and Upper Cambrian, the boundary between the two series being in the Switchback Shale. The Damnation, Dearborn, Pagoda, and Steamboat Limestones contain relatively thin calcareous mudstone in the lower part and thick cliff-forming limestone in the upper part.

The Devonian rocks range in thickness from 950 to 1,500 feet and are divided into the Maywood, Jefferson, and Three Forks Formations. Mudstone is present in the lower part of the Maywood and in the upper part of the Three Forks. The bulk of the Devonian rocks, however, is dolomite, calcitic dolomite, and dolomitic limestone. Intraformational breccias (evaporite solution breccias) are especially persistent and thick in the Three Forks. The Devonian sequence embraces six faunal zones and beds which here are named the *Allanaria* zone, *Eleutherokomma* cf. *E. reidfordi* zone, *Pachyphyllum* zone, stromatoporoid beds, *Cyrtospirifer* zone, and Famennian brachiopod beds.

Mississippian carbonate rocks of the Madison Group dominate the landscape. They range in thickness from 900 to 1,700 feet and are divided into two formations: the Allan Mountain Limestone and the Castle Reef Dolomite. The Allan Mountain is made up mostly of thin beds of dark-gray limestone, whereas the Castle Reef is mostly thick beds of light-gray dolomite.

The Mesozoic sedimentary rocks, about 7,000 feet thick, belong to the Jurassic and Cretaceous Systems. The Jurassic rocks range in thickness from 485 to 1,175 feet. They comprise the marine Sawtooth, Rierdon, and Swift Formations of the Ellis Group, and the nonmarine Morrison Formation. The Sawtooth and Swift Formations consist mostly of sandstone, and the Rierdon is mostly calcareous gray mudstone. The Morrison changes facies from east to west. The eastern facies is mainly gray-green tuffaceous mudstone. The western facies ranges from dominantly sandstone to dominantly mudstone.

The Cretaceous rocks are a clastic sequence as much as 5,600 feet thick that is divided into six formations. The oldest is the Kootenai, which consists of nonmarine mudstone and sandstone. The overlying Colorado Group consists of the Blackleaf Formation and the Marias River Shale. The Blackleaf Formation consists of marine mudstone and sandstone overlain by nonmarine mudstone. The marine Marias River Shale is dominantly dark-gray mudstone.

The overlying Montana Group is divided into five formations in western Montana, and the lower three crop out in the Sun River Canyon area. They are the marine Telegraph Creek

Formation and the Virgelle Sandstone and the nonmarine Two Medicine Formation. The Telegraph Creek consists of alternate beds of sandstone and sandy mudstone and grades into the light-gray sandstone of the Virgelle. The Two Medicine is mainly mudstone with much volcanic-rich sandstone in the lower part.

INTRODUCTION

The Sun River Canyon project was started in 1957 and completed in 1967. The purpose of the project was to obtain a more detailed knowledge of the geology of the Montana Disturbed Belt, of which the Sun River Canyon area is a representative segment.

The Sun River Canyon area is bounded by lat 47°30′ and 47°45′ N. and long 112°37′30″ and 113°00′ W. The area extends from the high plains east of the mountains westward almost to the Continental Divide and embraces six 7½-minute quadrangles (figs. 1 and 2). Geologic data were plotted in the field on 1:24,000 preliminary topographic maps that were later enlarged to a scale of 1:20,000. The geology of these quadrangles, at a scale of 1:24,000, has been published as individual U.S. Geological Survey geologic quadrangle maps, and a separate surficial geologic map has been published of one—Sawtooth Ridge (Mudge, 1965; 1966a, b, c; 1967a, b; and 1968a). The bedrock maps were reduced to a scale of 1:48,000, combined, and somewhat generalized to make plate 1 of this report. Fossils abound in many of the rock units that crop out in the Sun River Canyon area. Thousands of specimens were collected from 436 localities. Fossil collections in the tables and measured sections are identified by the prefix F (pl. 2); some field numbers are followed by a U.S. National Museum number. Some of the museum numbers are followed by CO (Cambrian-Ordovician) or SD (Silurian-Devonian). Over 1,200 rock specimens were obtained, and these are identified by the prefix HS or CH, the latter collected mainly for geochemical analyses.

The thickness of lithologic units was measured partly by the Jacob's staff–Abney level method (Robinson, 1959) and partly by direct measurements with a tape. Carbonate rocks were classified in the field as limestone, dolomitic limestone, or dolomite by means of dilute hydrochloric acid. This classification was elaborated to that of Pettijohn (1949, p. 313) for a few units that were studied in the laboratory. The Pettijohn carbonate classification was adapted to the molar ratio method (Guerrero and Kenner, 1955, p. 48). Grain-size classification is based on the Wentworth scale for clastic rocks and on resolution by a 10-power hand lens for crystalline carbonate rocks. The mudstone classification is that of Twenhofel (1939) and of Pettijohn (1949, p. 269). Terminology of stratification is mostly that of McKee and Weir (1953). Where applicable, the color of the rocks was determined by use of the "Rock Color Chart" of the Geological Society of America (Goddard and others, 1948). Table 1 summarizes the lithologies and thicknesses of the formations exposed in the Sun River Canyon area.

PREVIOUS WORK

Reconnaissance geologic mapping and stratigraphic studies have been conducted in the Sun River Canyon area at various times since 1900. These are discussed by Deiss (1943a, p. 209–211) and by Mudge (1959, p. 18) and will be only summarized here. The earliest studies in the area were very likely those of Chapman (1900, p. 153–156), who described and mapped the Lewis and Clark and Sawtooth Ranges in a reconnaissance manner. Willis (1902) undoubtedly investigated parts of the area in conjunction with his studies in Glacier National Park. To the south and west of the Sun River Canyon area, Walcott (1906, 1908, 1915) studied the Precambrian and Cambrian rocks. A short report describing some of the rocks and fauna at damsites on the upper Sun River was published by Powers and Shimer (1914). Later, Stebinger (1918) published reconnaissance geologic studies of the area east of the mountain front. The structure of the Sawtooth Range was described by Bevan (1929, p. 446–449) and later by Clapp (1932).

Deiss (1933; 1938; 1939; 1943a, b) published descriptions of the stratigraphy and structure. His reconnaissance geologic maps of the Ovando, Coopers Lake, Saypo, and Silvertip quadrangles (scale 1:125,000) have never been published, but file copies were available to me.

Since Deiss' mapping, only stratigraphic studies have been made in the area. The Mississippian and Devonian rocks were studied by Sloss and Laird (1945 and 1946). The Mississippian rocks were also studied by Mudge, Sando, and Dutro (1962), and the Devonian rocks by Wilson (1955). Similar studies were made on the Jurassic rocks by Cobban (1945) and by Imlay, Gardner, Rogers, and Hadley (1948). University theses have been completed in the Gibson Reservoir area by Cobb (1941) and south of the Sun River Canyon area by Viele (1960), Knapp (1963), and Merrill (1965), and west of the area by Sommers (1966). In addition, the Precambrian rocks southwest of the area have been studied in detail by McGill and Sommers (1967) and in a

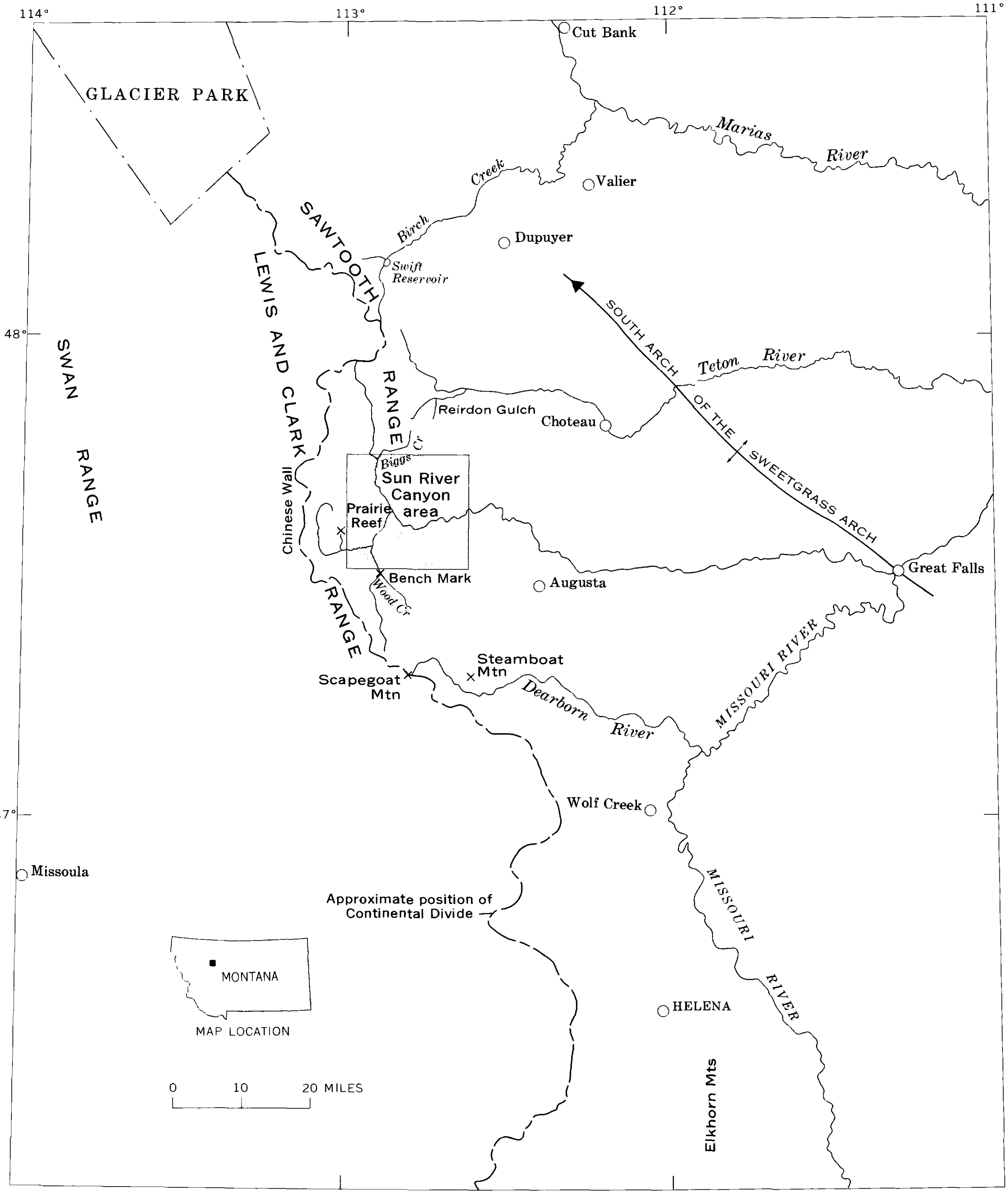


FIGURE 1.—Sun River Canyon and adjacent areas, northwest Montana.

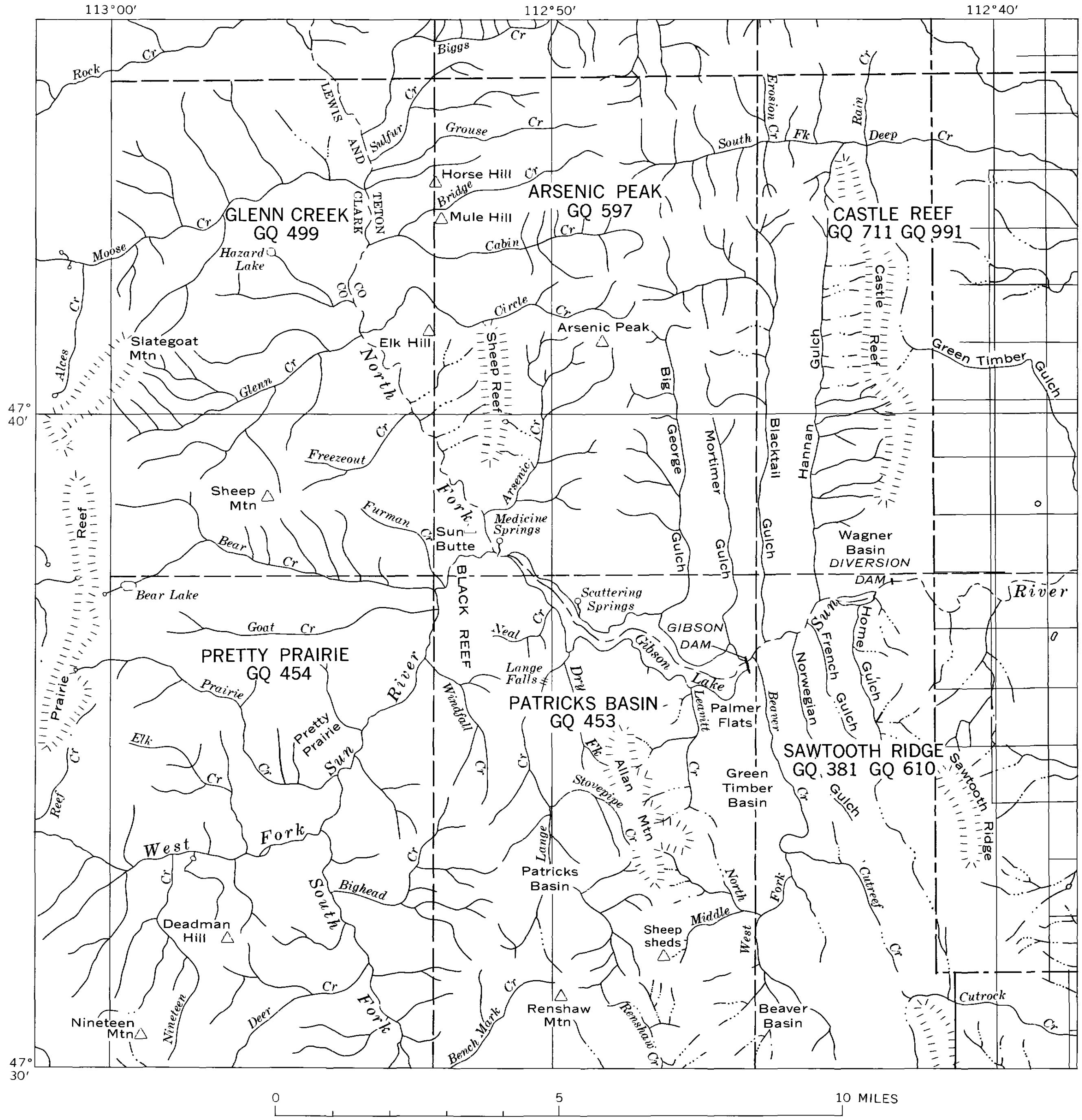


FIGURE 2.—Index map of the Sun River Canyon area. Names in bold type are U.S. Geological Survey topographic quadrangle maps; numbers in bold type are published U.S. Geological Survey geologic quadrangle (GQ) maps.

reconnaissance by Mudge, Erickson, and Kleinkopf (1968).

ACKNOWLEDGMENTS

Many persons throughout the years contributed freely of their time, ideas, and information, which greatly benefited this study. R. W. Lemke was largely responsible for inaugurating the project and for my being assigned to it. I am indebted for stimulating discussions in the field to G. O. Bachman, A. B. Campbell, P. E. Cloud, Jr., W. A. Cobban, D. R. Crandell, J. T. Dutro, Jr., E. B. Eckel, C. E. Erdmann, R. L. Erickson, James Gilluly, Ralph Imlay, M. R. Klepper, R. W. Lemke, G. M. Richmond, A. E. Roberts, G. D. Robinson, W. J. Sando, R. G. Schmidt, H. W. Smedes, and J. D. Wells, all of the U.S. Geological Survey; Prof. G. E. McGill of the University of Massachusetts; Prof. H. D. Pflug, of the University of Liebig, Germany; Paul Sartenaer, Institut royal des Sciences naturelles, Belgium; Prof. R. C. Gutschick, University of Notre Dame; T. C. Hoering, Carnegie Institution of Washington; Hans Frebold, Geological Survey of Canada; and J. E. Christopher, Department of Mineral Resources, Province of Saskatchewan, Canada.

Many other U.S. Geological Survey colleagues aided in the office and laboratories, and their help is acknowledged at appropriate places in the text. In particular I wish to acknowledge the assistance of K. L. Shropshire in the petrologic aspects of the project.

R. A. Price and A. Mac S. Stalker of the Geological Survey of Canada were most helpful in showing me the geology of the Crowsnest-Frank, Alberta, areas in Canada, for comparison.

The fieldwork was facilitated by the cooperation and help of the local residents and ranchers. In particular I thank Mr. and Mrs. Will Stecker, Mr. and Mrs. F. T. Slater, Mr. and Mrs. Bruce Neal, Mr. and Mrs. Glen Roberts, and Mr. and Mrs. Dan Neal. Special appreciation is due my sons R. M. Mudge and R. J. Mudge who gave freely of their time and energy helping during fieldwork from 1964 to 1966.

The following served as field assistants. They are listed below according to the summers they assisted me.

1956	John Halbert, E. B. McKee III, and Maynard Slaughter.
1957	R. E. Eggleton and Alan Swanson.
1958	M. W. Reynolds and Alan Swanson.
1959	M. W. Reynolds.
1960	R. A. Sheppard.
1961–62	Dale Snow.
1963	T. W. Chamberlin, Jr.

GEOGRAPHY

The Sun River Canyon area is mostly in the Northern Rocky Mountains physiographic province; the eastern part is in the High Plains section of the Great Plains province. The area is in the Sawtooth Range except for the extreme western part, which is in the Lewis and Clark Range. Much of the western part is in the Bob Marshall Wilderness Area.

The landscape is mainly a series of narrow north-trending mountain ridges of carbonate rock separated by narrow valleys underlain by mudstone and sandstone (frontispiece and pl. 1). The total relief is about 4,470 feet, from 4,280 feet along the Sun River to 8,752 feet at Slategoat Mountain; most of the peaks and ridges rise above 7,000 feet. The North Fork of the Sun River is in a relatively broad intermontane valley.

The easterly flowing Sun River and its tributaries are structurally controlled and have fault-trellis drainage (Mudge, 1959, p. 18). The river is joint controlled, especially where it flows through the resistant carbonates, and it is incised along an easterly trending flexure formed by a change in trend of fault blocks.

GENERAL STRATIGRAPHIC FEATURES

The bedrock that crops out in the Sun River Canyon area consists of consolidated sedimentary rocks of Precambrian, Paleozoic, and Mesozoic ages (pl. 1 and table 1). The aggregate thickness of these sedimentary rocks is about 19,000 feet.

Precambrian rocks crop out only in the western part of the area, where they form the sole of a major low-angle thrust fault which marks the east edge of the Lewis and Clark Range. They are overlain by Cambrian rocks (pl. 1). The upper part of the Cambrian sequence also crops out in the central part of the Sawtooth Range (pl. 1). Devonian, Mississippian, Jurassic, and Cretaceous rocks are well exposed in much of the Sawtooth Range. The Devonian and Mississippian rocks are also in some of the mountain ridges west and southwest of the Sun River Canyon area. The sills crop out only in the western part.

The sedimentary rocks are marine except for some Jurassic and Cretaceous rocks, which are continental. Clastic rocks are prevalent in the Precambrian and Mesozoic sequences, whereas carbonate rocks dominate the Paleozoic sequence. Most of the Phanerozoic marine rocks contain abundant well-preserved fossils, whereas the nonmarine rocks yield few fossils. In many of the units, local and, in some units, regional faunal zones are recognized.

PRECAMBRIAN BELT SUPERGROUP

As much as 7,100 feet of unmetamorphosed Precambrian sedimentary rocks crop out in the western parts of the Pretty Prairie and Glenn Creek quadrangles. These rocks have been thrust onto Paleozoic and Mesozoic rocks, some as young and Early Cretaceous.

Adequate geologic mapping in northwestern Montana now supports correlation of the Helena Dolomite, Cayuse Limestone, Wallace Formation, and Siyeh Limestone as stratigraphic equivalents (Smith and Barnes, 1966; McGill and Sommers, 1967; and unpub-

TABLE 1.—*Stratigraphy of the Sun River Canyon area*

Era	System	Series	Group	Formation	Member	Thickness (feet)	Description
Mesozoic	Cretaceous	Upper Cretaceous	Montana	Two Medicine Formation		1,000+	Gray to green mudstone interbedded with sandstone; some tuffaceous beds; carbonaceous shale in lower part.
Mesozoic	Cretaceous	Upper Cretaceous	Montana	Virgelle Sandstone		150-200	Light-gray sandstone; massive with some thin beds and crossbedding; some iron-stained zones.
Mesozoic	Cretaceous	Upper Cretaceous	Montana	Telegraph Creek Formation	Upper member	80	Light-gray calcareous poorly indurated beds of sandstone (about 4 ft thick) interbedded with gray calcareous sandy shale of equal thickness.
Mesozoic	Cretaceous	Upper Cretaceous	Montana	Telegraph Creek Formation	Middle member	90	Dark-gray calcareous hard dense sandstone (up to 1.0 ft thick); locally crossbedded and ripple marked; some mudstone.
Mesozoic	Cretaceous	Upper Cretaceous	Montana	Telegraph Creek Formation	Lower member	170	Dark-gray calcareous fine-grained sandstone and sandy shale in beds 1-3 in. thick; some ripple marks, crossbedding and minute laminae.
Mesozoic	Cretaceous	Upper Cretaceous	Colorado	Marias River Shale	Kevin Shale Member	850-1,050±	Dark-gray calcareous mudstone with many thin bentonite beds and zones of limestone and ferruginous limestone concretions; some thin beds of sandstone.
Mesozoic	Cretaceous	Upper Cretaceous	Colorado	Marias River Shale	Ferdig Shale Member	200-350	Gray noncalcareous mudstone with many iron-stained lenses of siltstone and sandstone; western part of area includes the sandstone member with thin nodular sandstone beds.
Mesozoic	Cretaceous	Upper Cretaceous	Colorado	Marias River Shale	Cone Calcareous Member	100	Gray shale with platy calcareous claystone and siltstone in upper part, which contains a thick bentonite bed and abundant *Inoceramus labiatus*.
Mesozoic	Cretaceous	Upper Cretaceous	Colorado	Marias River Shale	Floweree Shale Member	30	Dark-gray noncalcareous fissile shale with thin beds of siltstone in lower part that contains one or more beds of chert-pebble conglomerate. ——UNCONFORMITY——
Mesozoic	Cretaceous	Lower Cretaceous	Colorado	Blackleaf Formation	Vaughn Member	300-500	Thin beds of greenish-gray mudstone, sandstone, bentonitic shale, and thin beds of bentonite; locally thin conglomerates at base of sandstones.
Mesozoic	Cretaceous	Lower Cretaceous	Colorado	Blackleaf Formation	Taft Hill Member	225-600	Gray mudstone with many units of thin-bedded sandstone, locally crossbedded; some thin bentonite beds.
Mesozoic	Cretaceous	Lower Cretaceous	Colorado	Blackleaf Formation	Flood Shale Member	150-550	Dark-gray fissile shale with metallic luster on bedding planes; thin-bedded sandstone units at top and bottom. ——UNCONFORMITY(?)——
Mesozoic	Cretaceous	Lower Cretaceous		Kootenai Formation		650-800	Maroon and gray-green mudstone with lenticular greenish-gray interbeds of sandstone; some brown, iron-stained nodules and lentils of sandy limestone. ——UNCONFORMITY(?)——
Mesozoic	Jurassic	Upper Jurassic		Morrison Formation		200-550	Eastern facies, tuffaceous gray to olive-drab mudstone with some thin sandstone beds; western facies, poorly sorted crossbedded conglomeratic gray sandstone and red-brown mudstone.
Mesozoic	Jurassic	Upper Jurassic	Ellis	Swift Formation	Sandstone member	60-97	Gray to gray-brown fine to very fine grained thin-bedded sandstone with some crossbedding, ripple marks, and wood and clay fragments.
Mesozoic	Jurassic	Upper Jurassic	Ellis	Swift Formation	Shale member	22-58	Dark-gray to olive-drab sandy claystone with many thin beds of sandstone; basal bed is a thin poorly indurated glauconitic sandstone with waterworn fossils. ——UNCONFORMITY——
Mesozoic	Jurassic	Upper Jurassic	Ellis	Rierdon Formation		120-350	Dark-gray to brownish-gray calcareous mudstone with many thin argillaceous limestone beds; small barite nodules common in upper part. ——UNCONFORMITY(?)——
Mesozoic	Jurassic	Middle Jurassic	Ellis	Sawtooth Formation	Siltstone member	23-44	Grayish-brown to yellowish-brown thin-bedded calcareous siltstone
Mesozoic	Jurassic	Middle Jurassic	Ellis	Sawtooth Formation	Shale member	3-85	Dark-gray silty to clayey fissile shale with local thin beds of sandstone and conglomerate.
Mesozoic	Jurassic	Middle Jurassic	Ellis	Sawtooth Formation	Sandstone member	0-20	Gray fine-grained, noncalcareous sandstone, locally with dark-gray thin-bedded shale; in most places basal bed is a conglomerate of rounded pebbles and cobbles of limestone and chert. ——UNCONFORMITY——

TABLE 1.—*Stratigraphy of the Sun River Canyon area*—Continued

Era	System	Series	Group	Formation	Member	Thickness (feet)	Description
Paleozoic	Carboniferous: Mississippian	Upper Mississippian	Madison	Castle Reef Dolomite	Sun River Member	0–450	Light-gray fine- to medium-crystalline dolomite, locally with dolomitic thick-bedded limestone; some nodules and lentils of smoky-gray chert.
		Lower Mississippian			Lower Member	250–475	Medium- to light-gray dolomite, calcitic dolomite, dolomitic limestone, and magnesian limestone; thin to thick bedded; some chert lenses and nodules.
				Allan Mountain Limestone	Upper member	200–350	Medium- to dark-gray limestone with some dolomitic and magnesian limestone; thin to thick bedded; local dark-gray chert lenses and nodules.
					Middle member	150–200	Dark-gray fine-grained limestone, locally with dolomitic limestone; in beds 1–2 ft thick; dark-gray chert lenses and nodules abundant and spaced at intervals 6–10 in.
					Lower member	160–225	Dark-gray limestone and dolomitic limestone with many thin mudstones in lower part; very thin bedded; thicker beds of limestone in lower 50 ft.
							UNCONFORMITY
	Devonian	Upper Devonian		Three Forks Formation		50–589	Intraformational breccia that in places is overlain by grayish-brown limestone; locally upper part contains siltstone, carbonaceous shale, and green mudstone.
				Jefferson Formation	Birdbear Member	150–235	Dolomite, calcitic dolomite, and limestone, light-grayish-brown; thin bedded with thin pinch-and-swell type bedding in lower part.
					Lower member	300–650	Dolomite with thin beds of limestone and calcitic dolomite in lower part; grayish-brown with some light-gray beds; fetid odor; local intraformational breccia.
				Maywood Formation	Upper member	49–159	Dark-gray to gray-brown thinly bedded dolomite, calcitic dolomite, and limestone with distinctive yellowish-gray mottling.
		Middle Devonian			Lower member	26–229	Greenish-gray mudstone with some reddish-gray mudstone beds in western part; some thin beds of yellowish-gray dolomite.
							UNCONFORMITY
	Cambrian	Upper Cambrian		Devils Glen Dolomite		100–400	Very light gray fine- to medium-crystalline massive dolomite.
		Middle Cambrian		Switchback Shale		70–253	Mostly greenish-gray shale with some thin beds of dolomite, sandstone, and conglomeratic dolomite in upper part; locally some maroonish-gray beds.
				Steamboat Limestone		229–239	Mainly thin-bedded limestone and dolomite with some interbedded greenish-gray dolomitic mudstone; gray brown, distinctively mottled yellowish gray to gray orange.
				Pagoda Limestone		250–360	Gray-brown thin- to thick-bedded dolomitic limestone in upper part and grayish-green shale and argillaceous limestone in lower part.
				Dearborn Limestone		92–396	Limestone with some interbedded grayish-green shale in lower part; yellowish gray to grayish brown, mottled grayish orange; thin bedded.
				Damnation Limestone		272–363	Limestone, medium- to dark-gray; mottled light orange tan in lower part; some thin-bedded finely micaceous sandstone in irregularities between beds.
				Gordon Shale		197–252	Gray noncalcareous fissile shale with some thin beds of glauconitic limestone in middle part and thin beds of sandstone in lower part.
				Flathead Sandstone		70–115	Light-gray poorly indurated poorly sorted quartz sandstone, locally with thin gray and maroon shale partings and conglomeratic sandstone.
							UNCONFORMITY
Precambrian		Belt Supergroup	Missoula	McNamara Formation		0–575	Greenish-gray and gray sandy mudstone with many thin beds of sandstone and glauconitic sandstone; some maroon beds; load casts and salt casts.
				Bonner Quartzite		400–1,100	Moderately well sorted fine-grained sandstone; locally well indurated; moderate red to pinkish gray, some mottled grayish orange; thin to thick bedded; crossbedded.
				Mount Shields Formation	Red siltstone member	800–1,000	Pale-reddish-brown siltstone with some thin beds of sandstone; some mottled yellowish gray; upper part contains some gray beds and some salt casts.
					Red sandstone member	600–1,100	Dark-reddish-brown sandstone with some thin siltstone beds, especially in lower part; abundant minute structures; glauconitic sandstone in lower part.
				Shepard Formation		225–825	Dolomitic siltstone with much interbedded sandstone, especially in upper part; medium gray to grayish yellow; some thin dolomite beds in lower part; glauconite in upper part.
				Snowslip Formation		300–700	Red-brown, grayish-green, and yellowish-gray siltstone with some thin sandstone beds in upper part.
				Helena Dolomite		350–625	Gray dolomite, dolomitic limestone with some limestone in upper part; numerous beds of stromatolites, edgewise conglomerate, and oolite in upper part; argillite in lower part.
			Ravalli	Empire and Spokane Formations		1,200+	Pale-red, green, and gray argillite and siltite with some thin beds of quartzite, and locally with a few thin beds of dolomite.

lished studies of many workers), and therefore the Piegan Group is here abandoned. All Belt rocks above that stratigraphic level are considered to be within the Missoula Group (fig. 3). Rocks between the Prichard Formation and its stratigraphic equivalents and the base of the Helena and its equivalents are considered to be in the Ravalli Group.

The correlations of the Belt rocks in the Sun River Canyon area with the sections at Helena (Belt Mountains), and Glacier National Park are shown in figure 3. Walcott (1906, p. 10) extended the nomenclature of the Helena section to Lewis and Clark Pass (about 50 miles southeast of the Sun River Canyon section), which was the first step toward reasonable correlation of the two sections. Ross (1963, p. 12) extended the Helena nomenclature to the Dearborn River section, about 25 miles southwest of the Sun River Canyon area. It was then traced into the Sun River area by Mudge (1966b). At the same time, McGill and Sommers (1967, p. 348–349) adapted to the Wood Canyon area some of the nomenclature of the Glacier National Park and Missoula areas. Their work corrected a mistake made by Deiss (1935, p. 96) when he correlated beds now called the Spokane and Empire Formations with the Miller Peak Argillite of the Missoula section. This miscorrelation led Deiss to establish a new set of names for the Saypo quadrangle Belt rocks (fig. 3), which remained in use until abandoned by McGill and Sommers (1967, p. 348). Smith and Barnes (1966) showed that many early workers correctly correlated the Helena section with the Glacier National Park section (fig. 3). The correlation of the Glacier National Park rocks with Belt rocks in Alberta, Canada, and with those in Montana was also discussed by them.

In this report the nomenclature of the Belt rocks is partly that of McGill and Sommers (1967, table 1) and partly that of Mudge (1966b), which is, in ascending order: The Spokane and Empire Formations (undifferentiated), Helena Dolomite, Snowslip Formation, Shepard Formation, Mount Shields Formation, Bonner Quartzite, and McNamara Formation. The nomenclature of Deiss previously used in the Sun River Canyon area for Precambrian rocks (Cayuse Limestone, Hoadley Formation, and Ahorn Quartzite) is hereby abandoned (fig. 3, col. 4).

Radiometric ages of 1020–1135 m.y. (million years) have been determined by potassium-argon and rubidium-strontium methods on the Precambrian rocks in the Sun River Canyon area by Obradovich and Peterman (1968). Twenty-two samples were selected from these rocks, of which 10 glauconite samples are from the Spokane and Empire, Shepard, Mount Shields and McNamara Formations and 12 whole-rock samples are from the Spokane and Empire Formations, Helena Dolomite, and Snowslip, Shepard, and McNamara Formations. The glauconite samples and their apparent ages are listed in table 2, and ages of the whole-rock samples are plotted in figure 4; these ages are in accord with radiometric ages published for correlative rocks north of the Sun River by Gulbrandsen, Goldich, and Thomas (1963). The difference of age between the oldest and youngest samples is within the overall analytical precision of the methods (Z. E. Peterman, written commun., 1966). These data may indicate that the rocks are about the same age, especially as the oldest ages are from samples from the youngest formation, the McNamara.

TABLE 2.—*Dated glauconite samples from Precambrian rocks in the Sun River Canyon area*

Rock unit	Sample	Field No.	Age (m. y.)	
			Potassium-argon	Rubidium-strontium
McNamara Formation	484G	HS742	1070±55	1130±55
Do	483G	HS487	1130±55	1135±55
Do	517G	HS739	1060±55	1090±55
Do	516G	HS730	1080±55	----------
Mount Shields Formation	379G	HS411d	1110	1020±50
Shepard Formation	380G	HS411b1	----------	1130±55
Do	380G	HS411	----------	1070±55
Do	377G	HS411a4	1120±55	1085±55
Do	515	HS411a	----------	1055±50
Empire and Spokane Formations	482G	HS481	1040±50	1100±55

The Precambrian rocks of the Sun River Canyon area are mainly clastic rocks that were deposited in a very shallow shelf environment on the east side of a slowly subsiding geosyncline. Although these rocks do not change markedly in lithology to the northwest or southeast, they thicken in these directions. The greatest variation in thickness was noted between fault blocks, with a general thickening toward the west (Walcott, 1906; McGill and Sommers, 1967). The Belt rocks of the Sun River Canyon area contain more sand than those to the north and south, which suggests that they were formed closer to the strand line.

The original eastern edge of the Belt rocks is unknown. The present erosional edge is east of the Sun River Canyon area, probably near the trough of the

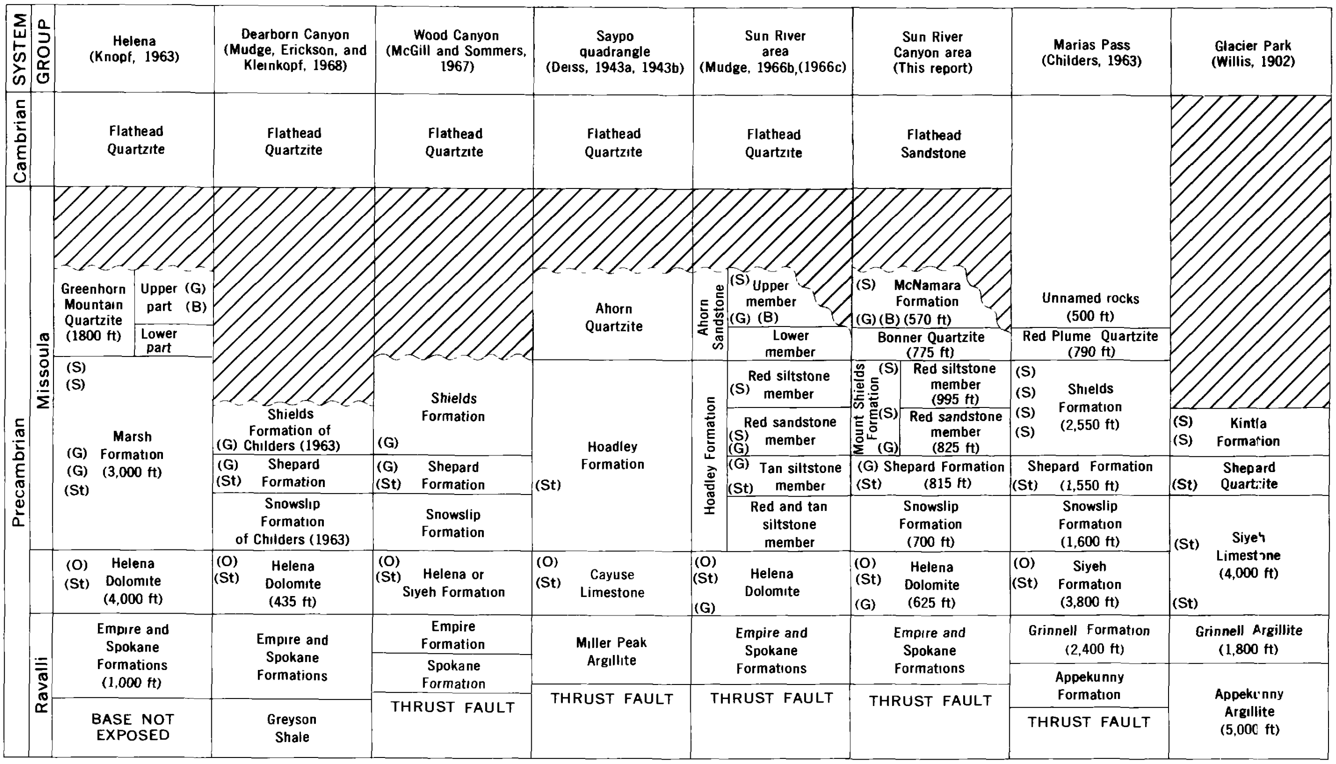


FIGURE 3.—Correlation of Precambrian rocks in the eastern outcrop area of northwestern Montana. (S), salt-crystal casts; (G), glauconite; (B), barite; (St), stomatolite; (O), oolites.

synclinorium (Stebinger, 1918, pl. 24) which lies between the mountain front and the Sweetgrass Arch (fig. 1). This postulated edge may nearly coincide with the eastern edge of the disturbed belt, which is about 6 miles east of the Sun River Canyon and about 20 miles east of the thrust-fault block containing the easternmost exposures of Belt rocks and about 19 miles northeast of similar exposures in Dearborn Canyon. Well logs in the Sweetgrass Arch show rocks as young as Devonian resting on Precambrian crystalline rocks (Alpha, 1955a, p. 135). The Sweetgrass Arch is a broad regional element that was structurally high in Precambrian time. Belt rocks, however, may have covered the arch before Middle Cambrian uplift and erosion (Alpha, 1955b, p. 129; Sloss, 1950, p. 430), for exposed Belt rocks to the west lack shoreline facies. In addition, the many sections shown in figure 13 clearly indicate that the base of the Flathead (Middle Cambrian) Sandstone is an angular unconformity. If this trend continued eastward, then the postulated edge of the Belt rocks is likely due to erosion rather than nondeposition.

SPOKANE AND EMPIRE FORMATIONS

The Spokane and Empire Formations, mainly argillite and siltite, crop out along the South Fork of the Sun River, in the vicinity of Benchmark and along the west side of the Glenn Creek quadrangle (pl. 1). In most places they bottom the sole of a major thrust fault. These rocks are poorly exposed along the west side of the South Fork of the Sun River between Deer Creek and Benchmark, and it is impractical to separate them. Along the Dearborn River there are about 100 feet of rocks of Empire lithology and about 1,000 feet of rocks of Spokane lithology (Mudge and others, 1968). Here the Spokane rests in gradational contact on the Greyson Formation. Only about 1,200 feet of the Spokane and Empire Formations are preserved in the Sun River Canyon area, and they contain many thrust faults and folds.

The Spokane and Empire Formations, undifferentiated, are mainly very thinly bedded pale-red, maroon,

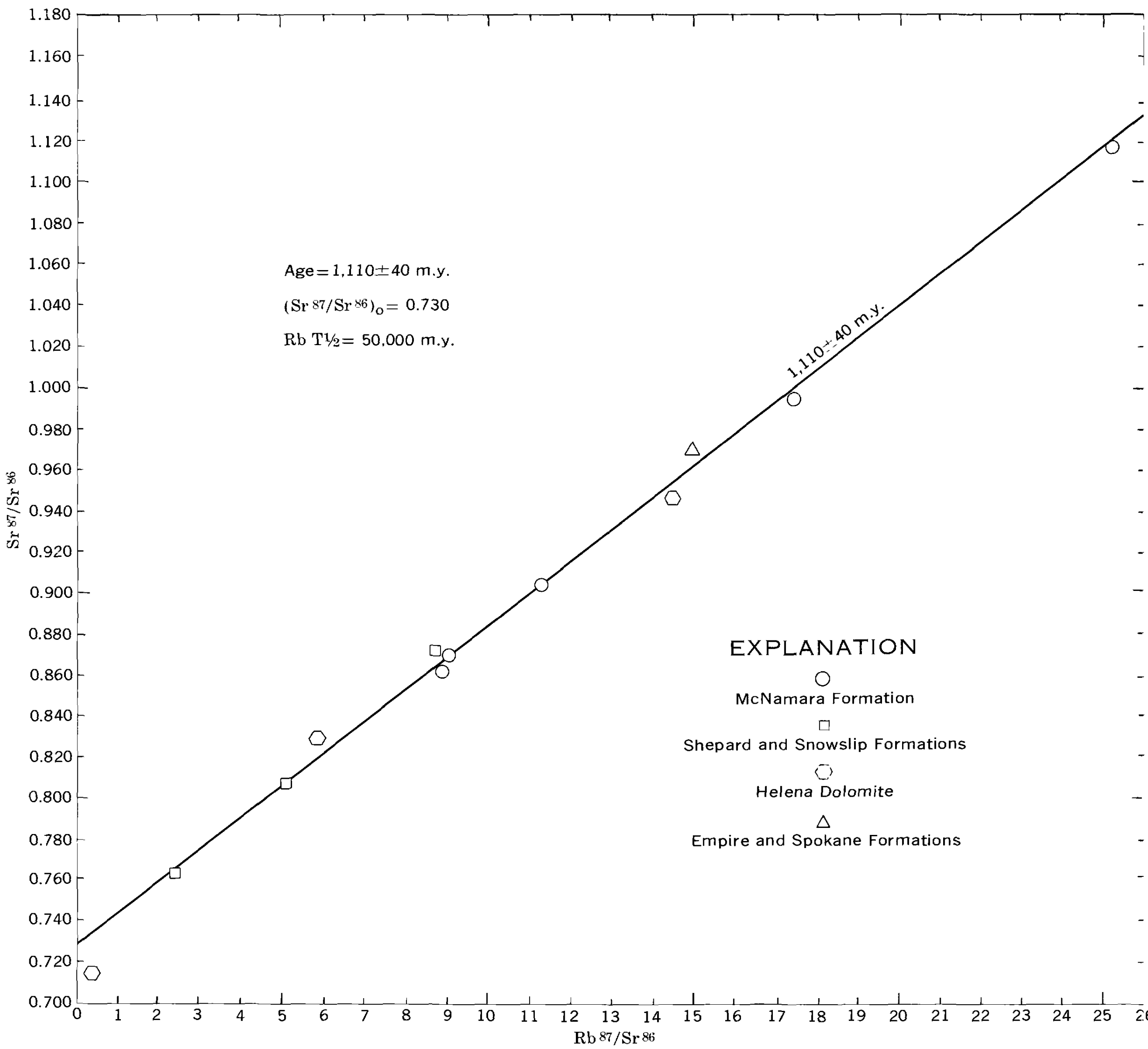


FIGURE 4.—Isochron of rubidium-strontium isotopic ages of whole-rock samples from the Belt rocks of the Sun River Canyon area, by Z. E. Peterman.

green, and gray siliceous argillite and siltite. Locally there are very thin beds of poorly sorted finely micaceous fine-grained feldspathic subgraywacke with ripple marks, minute cross-laminations and load casts. The upper part of Spokane and Empire includes a few thin yellowish-gray dolomite beds. About 1 mile northeast of Deadman Hill a 2-inch-thick bed of fine-grained sandstone near the top of Spokane and Empire contains lentils of glauconitic sand (HS481, table 2).

HELENA DOLOMITE

The Helena Dolomite was originally named the Helena Limestone by Walcott (1899, p. 207). Knopf (1963) pointed out that the formation is largely dolomite in the type locality and designated it Helena Dolomite. In the Sun River Canyon area this formation is best exposed on a ridge (elev 6,463 ft) about half a mile north of Deer Creek and about three-fourths mile west of the South Fork of the North Fork of the Sun River at station 158 and measured section 1 (pl. 2). This section contains a minor thrust fault in the lower part that repeats the lowermost part of the Helena and the uppermost beds of the undifferentiated Spokane and Empire Formations. The Helena Dolomite is about 625 feet thick at Deer Creek but thins both north and south to about 350 feet. It is about 570 feet thick along the Dearborn River.

About 50 feet of rock above the Empire is interbedded gray sandy shale, red argillite, dolomite and sandstone included here in the Helena. The basal beds of the Helena as so defined are a few feet of thin beds of sandstone. These beds contain lead and zinc in the Wood Creek–Deer Creek area (Mudge and others, 1968). In Wood Creek Canyon, McGill and Sommers (1967, fig. 2a) placed this 50 feet of gradational rocks in the upper part of the Empire Formation. Some of the carbonate beds contain irregular-sized flakes and vertical stringers of carbonate that form the "molar tooth" structure (fig. 5) referred to by Daly (1912, p. 74) and by Deiss (1943a, p. 216).

The middle part of the Helena consists mainly of thin beds of dolomitic mudstone with many interbeds of thick-bedded dolomite. The argillaceous beds are finely crystalline, dark gray, minutely micaceous, and massive, and they weather yellowish gray with a hackly fracture. They form a slope similar to that of a shale. The thick-bedded dolomite beds are finely crystalline and dark gray and form small ledges. Some contain coarse-grained oolites, edgewise (intraformational) conglomerates of broken stromatolites, and massive colonies of unbroken stromatolites.

The upper half of the Helena, consists mainly of beds of dolomite, calcitic dolomite, and dolomitic limestone that form a prominent hillside bench with many small jutting ledges. They are generally dark gray, very finely crystalline, and massive. In much of this unit there are cyclic sequences of beds (fig. 6), which are, in ascending order: (1) Thinly bedded dolomite or dolomitic limestone, (2) massive stromatolite colonies, (3) edgewise conglomerate with oolites, and (4) oolite beds (fig. 5). Although these are repeated many times, they differ locally by the absence of the edgewise conglomerate bed. The oolite bed generally contains some small angular to subrounded fragments of carbonate (fig. 5). An interpretation of this sequence is shown in figure 6.

The stromatolites are tentatively correlated with the genus *Collenia* described in these rocks in the Glacier National Park area by Rezak (1957, p. 133). The colony is largely cylindroidal and strongly convex, and it expands upward so that the next youngest layer drapes over part of the colony (fig. 7). The colonies join to form thick widespread biostromes. The size of this convex mass is quite variable, it ranges from 6 to 24 inches across and is as much as 3.6 feet high. Each colony consists of thinly laminated dark-gray dolomite or dolomitic limestone (fig. 7). Locally, the stromatolite beds are iron impregnated, and they form a siliceous iron-carbonate deposit at station 172, plate 2. The iron-impregnated beds are as much as 8 feet thick and 75 feet long.

The upper few inches of some colonies of stromatolites were broken shortly after deposition and formed

FIGURE 5.—Dolomite bed above a stromatolite colony in the upper part of the Helena Dolomite along the Dearborn River. Below head of pick are "molar tooth" structures; adjacent to the pick is an edgewise conglomerate with oolites; and above the pick are oolites with some small fragments of stromatolites.

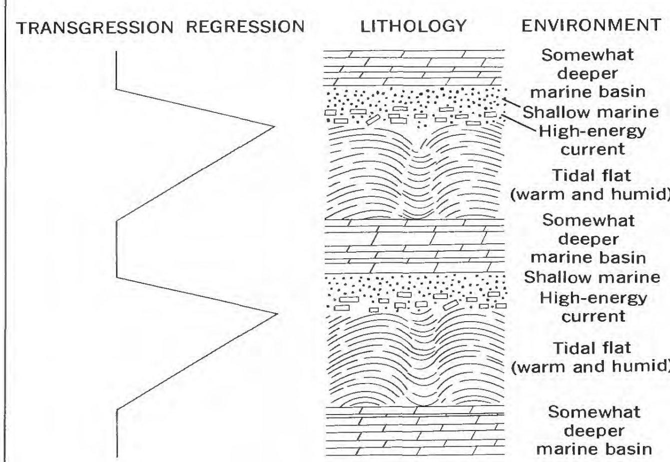


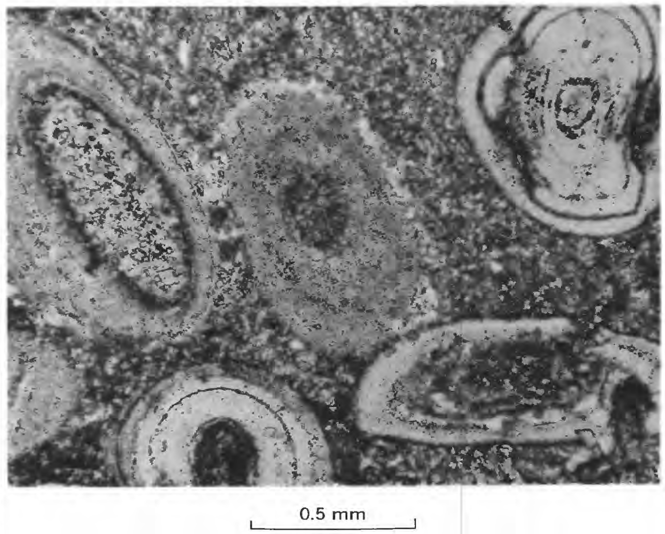
FIGURE 6.—Schematic diagram of the cyclical nature of much of the upper part of the Helena Dolomite in the Deer Creek exposure (sta. 158 and measured section 1, pl. 2). Small dots are oolites; angular fragments are edgewise conglomerates; and wavy lines are stromatolites.

an edgewise (intraformational) conglomerate, thus indicating that current or wave action occurred. Some fragments are roughly parallel to bedding, whereas others are imbricated. Interbedded with the conglomerates are abundant medium-sand-size oolites (figs. 5 and 8*A*) and some slightly larger rounded to oblong stromatolite colonies.

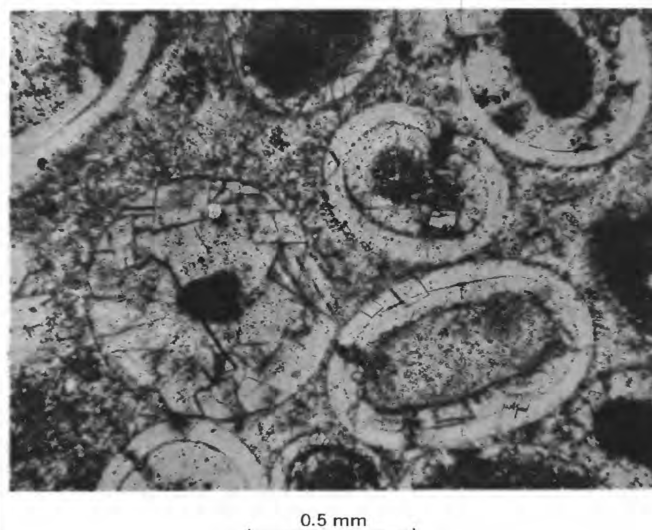
In any cyclic unit, the oolite bed is gradational with the underlying edgewise conglomerate (fig. 5). Most oolites are spherical, but some are oblong and a few are multiple spheroids. Thin concentric rings of carbonate or silica encase a core of sparry carbonate or silica. The rind of many is partially or completely replaced by extremely fine grained silica. Later the silica rind was partially replaced by dolomite rhombs; a few oolites are now sparry dolomites with the relic structure preserved (fig. 8*A* and *B*). In some, however, the core has retained its original calcium carbonate nucleus.

SNOWSLIP FORMATION

The Snowslip Formation was named by Childers in 1963. He designated the exposures on a ridge between Snowslip Mountain and Mount Shields at lat 48°16′30″ N. and long 113°31′ W. as the type section. The formation is siltstone and claystone with some interbedded sandstone. In most of the Sun River Canyon area these beds were metamorphosed during the intrusion of a diorite sill in late Precambrian time. The Snowslip rests with a sharp and distinct contact on the Helena.



A



B

FIGURE 8.—Photomicrographs of oolites in the upper part of the Helena Dolomite. *A*, Oolitic dolomite. Very light gray banded oolites are silica, some with calcite centers (dark speckled gray) that are partly replaced by dolomite (medium speckled gray). The oolite in upper center is completely replaced by sparry dolomite; all are in a sparry dolomite matrix. East of station 154 in Burned Creek (HS413). *B*, The centers of the oolites consist of a carbonate micrite nucleus encased by a silica shell. Here dolomite rhombs partly replaced the silica. On the ridge just north of Deer Creek near station 158 (measured section 1; HS677).

FIGURE 7.—Stromatolites in the upper part of the Helena Dolomite along the Dearborn River.

The Snowslip Formation ranges in thickness from 300 feet in the southwestern part of the Glenn Creek quadrangle to over 700 feet near Nineteen Mountain. East of Nineteen Mountain, near Benchmark, it is 350 feet thick. The variation of thickness is attributed to surface irregularities near the edge of the shelf at the time of deposition. The apparent rapid thickening to the west, noted here and by McGill and Sommers (1967, p. 348–349), very likely reflects deepening of the geosyncline.

Unmetamorphosed beds of the Snowslip are exposed on a northeast-trending spur of Slategoat Mountain and on both sides of Moose Creek to the north. Here the formation consists mostly of beds of moderate-red siltstone and claystone; some beds are green and yellowish-gray. Thin beds of fine-grained sandstone and quartzite are common, especially in the upper half. They are ripple marked and minutely cross-laminated and contain many load casts.

The metamorphosed rocks are dominantly beds of grayish-green to green argillite and siltite with some beds of calc-hornfels and quartzite. The beds range in thickness from 1 to 12 inches and form resistant ledges above and below a sill. Actinolite crystals are abundant on many of the bedding planes near the sill. Many beds contain symmetrical ripple marks, load casts, and minute laminae and crossbedding; others contain angular intraformational breccias.

SHEPARD FORMATION

The Shepard Formation is mainly gray siltstone. It is easily distinguished from the other Precambrian formations, as it forms a distinctive grayish-yellow slope beneath ledges of the reddish-brown sandstone member of the Mount Shields Formation. In the southern part of the area the Shepard contrasts markedly with the underlying gray-green metamorphosed ledge forming rocks of the Snowslip Formation. To the north, reddish-brown rocks of the Snowslip Formation underlie the Shepard.

The Shepard Formation ranges in thickness from about 815 feet in the southwestern part of the area to about 225 feet just northeast of Slategoat Mountain. (See measured section 2.)

The Shepard contains many thinly laminated beds of siltstone with some very thin beds of sandstone, orthoquartzite, and dolomite (measured section 2). The formation is mostly gray to medium gray with some beds of pale reddish brown in the middle and upper parts; they weather a yellowish gray to a light olive gray. The siltstone is composed mainly of angular to subrounded quartz and feldspar grains. Muscovite and biotite (up to 1 mm long) are abundantly aligned on bedding planes. Some of the beds are cemented with calcite, others with dolomite. The petrographic descriptions of these rocks are listed in table 3. As shown in this table, plagioclase and potassium feldspar occur in about equal amounts. In addition the beds contain more carbonate than other Precambrian rocks above the Helena Dolomite.

The beds of sandstone and orthoquartzites are very fine grained, hard, medium gray, and thinly bedded. Ripple marks are abundant and most are symmetrical; the amplitude rarely exceeds 1 inch, and the wavelength 3 inches. Minute cross-lamination, load casts and filled mud cracks are also common structures. A few thin beds contain possible raindrop depressions.

Glauconite is widespread in thin sandstone lentils in the upper half of the Shepard and in the lower part of the overlying Mount Shields Formation. This mineral has been recorded previously in Belt rocks, but it has not been described. Glauconitic sandstones occur at the same stratigraphic position in the Dearborn Canyon and Helena areas (fig. 3). The glauconite occurs as light- to dark-olive-green rounded, fine- to medium-grained pellets. Many form minute crossbeds, and some partly fill troughs of ripple marks. Hand-picked light and dark pellets from two samples were analyzed by X-ray by A. J. Gude III (written commun., 1962), who found them to be partially ordered glauconite, in the classification of Burst (1958, p. 487–488). Microscopically, the glauconite has replaced feldspars and some altered grains. Altered grains are listed as rock fragments in table 3, and they are the same size and shape as the glauconite grains. The altered grains are possibly clay pellets, although origins such as micritic limestone, altered feldspar, or chert cannot be discounted. Some of them have a chertlike texture. In addition, some biotite may have been replaced by glauconite. In most grains a later stage of replacement is evident. The glauconite pellets are partially or wholly replaced by carbonate, as figure 9 shows. Also in a few thin sections carbonate has partially replaced quartz and feldspar grains.

The beds of dolomite and magnesian limestone are in the lower half of the formation, and they form resistant ledges 1–2 feet thick. At and near the base of the formation these beds are mostly of angular fragments of broken stromatolites, forming edgewise conglomerates. In places these fragments are within a few inches of their point of dislodgement from the stromatolite colony. These beds are widespread and are diagnostic of the lower part of this formation. They were observed also in these rocks in the Dearborn Canyon and Helena areas (fig. 3).

TABLE 3.—*Quantitative petrographic description of some Precambrian sedimentary rocks in the Sun River Canyon area*

[Analyses, in percent, by K. L. Shropshire. Tr., trace]

Rock type	Sample HS–	Plagio-clase	Potassium feldspar	Quartz	Carbon-ate	Glauco-nite	Rock fragments	Accessory minerals [1]
McNamara Formation								
Siliceous glauconite	487	Tr.	Tr.	6		56		35 Ch; M; B; Mu; H; Cl; N
Feldspathic graywacke siltite	741			25	7	10	5	10 F; M; B; 35 Ma 3 B; S; Sa
Feldspathic graywacke	736	12	8	25	5	5		2 M; H; Ch; 1 Mu; B
Cherty glauconite sandstone	735			6	1	59	6	1 F; B; M; 3H; 23 Ch
Graywacke	734	8	7	22	24	18		M; Ch; Z; 14 Ma; H; Sa; Cl; 2 Mi; N
Siltite	733	11	7	31	15	<1		1 M; Z; A; 21 Ch; 5 S; 1 Mi; Sa; Z
Glauconite arkosic sandstone	732			20	3	50		10 F; M; Mi; 6 H; S; Sa; 6 Ch
Do	731			30	2	20		20 F; Mi; M; Cl; 20 Ch; S; Sa
Do	730	2.2	2.6	14.6	5.8	48.8		19.4 Ch; Mi; M; H; S; Z; 2.2 Ma
Glauconite sandstone	728			6	7	59		2 F; 8 Ch; H; M; Z; A; S; Sa; Mi
Bonner Quartzite								
Quartzite (top)	716	10	19	44	11	Tr.	3	6 F; 2 Ma; 1 H; S; Sa; M; Mi; Ch; Z; A; Cl
Subarkose (near top)	486	1	8	86			2	3 Ch; M; H; L; Cl; Mu; B; Ho
Subarkose (middle)	485	4	8	85			1	M; H; L; Ch; Mu; B; S
Subarkose (⅓ above base)	484	4	12	78			3	1 Ch; S; Mu; B; L; M
Arkose (near base)	483	4	28	59			4	2 Ch; 2 Cl; Mu; B; H; S; L; Ho
Mount Shields Formation								
Dolomicrite	714			3	96			1 F; M; Mi; Sa
Arkosic sandstone	712	13	14	47	4		15	Ma; M; A; Mi; Z; S; Sa; Ce
Siltstone	531	4	11	30			1	Mu; B; M; Sa; Ce; H; Ch; S; Cl; N
Do	512	3	31	53				2 M; 5 Cl; H; Ce; Sa; N
Sandstone	713	12	10	35	30	2	5	1 M; 1 Mi; H
Shepard Formation								
Silty dolostone	709	6	4	25	51	1	9	M; Z; 3 Mi; Ch
Quartzite	704	13	11	59	4	1	7	1 Ch; Mu; B; M; Z; Sp; A; Cl
Siltstone	702	10	10	60	12	<1	+1	H; B; M; Ch; T; Z; Mu; Ho; Ce
Quartzose dolostone	701			20	65			10 F; M; B; Z; Cl; 1 Ch; Ma; 1 Mu; H; G
Sandstone	700	20	10	40	15	2	Tr.	2 Mi; Ce; H; Ch; M; Z; 10 Ma; Sa
Arkosic sandstone	699	12.6	12.2	52.8	7.4	1.6	3.6	M; 1 B; Ce; Sa; 3 Ma; Z; A; T; Mu
Siltstone	698			45	10	2	Tr.	25 F; Mi; M; Ch; Z; H; 15 Ma
Do	697	10	10	60	15	Tr.	Tr.	1 Mi; 1 M; A; Z; T; L; S; Ma
Do	695	13	9	44	30			1 M; Mi; Z; T; A; Sp; S; Ma
Do	665			50	30		10	5 F; 3 Mi; M; Z; H; S; L; Sa; N
Do	661	2	6	52	26		7	2 Mu; 1 B; M; Z; H; S; L; 3 Ma; N
Sandy limestone	659			24.5	18.9			1.7 Ch; M; H; 54.8 Ma (micrite)
Subarkose	411a–4	6	8	46	7	24	3	M; Mi; Z; 2 Ma; 2 H; Sa; S
Feldspathic graywacke	411A			20	25	20		10 F; M; Mi; Z; Ch; 20 Ma; S; H; Sa; N
Glauconitic arkose	411	7	16	34	3	32	4	1 Ch; 1 Cl; M; H; L; A; Z; E
Snowslip Formation								
Graywacke silstone	418			44			Tr.	9 F; 46 Cl; M; H; L; E; Z
Arkosic siltite	416	3	21	60			2	13 Cl; M; H; L; Z; Ch
Siltite	414	8	22	48			Tr.	19 Cl; M; H; L; Z; T; Sp
Helena Dolomite								
Oolitic dolomite	413			5	60			35 Ma (micrite and sparrite)
Dolomite	650			3	45			52 Ma (micrite and sparrite)
Siliceous oolitic dolomite	677			1	70			30 Silica; M; H; Cl
Dolomite	674			2	75			22 Ma (micrite and sparry cement); H; Cl; Ch

[1] Ch, chert; M, magnetite; B, biotite, Mu, muscovite; Cl, clay; N, nontronite; F, feldspar undifferentiated; Ma, matrix; S, sericite; Sa, saussurite; H, hematite; Z, zircon; Mi, micas; A, apatite; L, leucoxene; Ce, chlorite; Sp, sphene; T, tourmaline; E, epidote, Ho, hornblende; G, garnet.

The Shepard is gradational with the underlying Snowslip Formation. The boundary between the two formations was arbitrarily selected at the top of a group of sandstone and siltstone beds that commonly form a small hillside ledge. In the Sun River Canyon area thin stromatolite-bearing dolomite beds are generally the lowermost strata in the Shepard. (See measured section 2.)

MOUNT SHIELDS FORMATION

The Mount Shields Formation consists mainly of red sandstone in the lower part and red siltstone in the upper part. It was named Shields Formation by Childers (1963, p. 147) for those rocks near Mount Shields between the Shepard Formation below and the Red Plume Quartzite above (fig. 3). The type section is on a ridge between Mount Shields and Blacktail Mountain, lat 48°17′ N., long 113°29′ W. The name Shields is preoccupied by a Precambrian formation in Tennessee. Therefore, the full name Mount Shields Formation is adopted in this report (table 1). In the Sun River Canyon area the formation is divisible into a lower, red sandstone member and an upper, red siltstone member

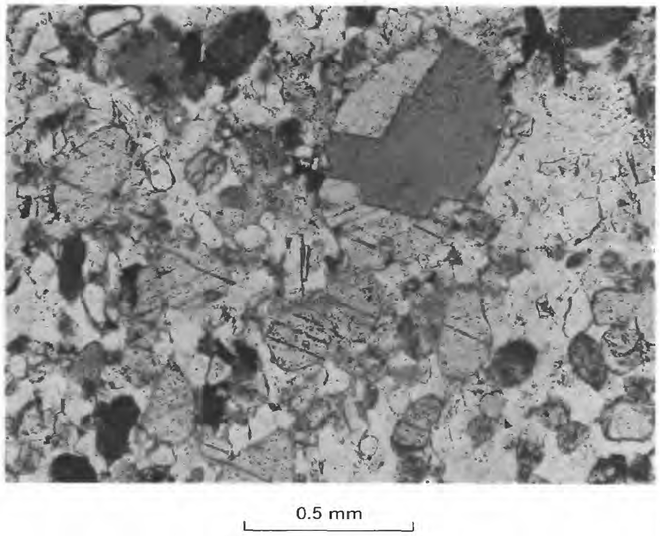


FIGURE 9.—Photomicrograph of glauconitic sandstone (HS 411a4) in the Shepard Formation on a ridge 1½ miles northwest of Benchmark guard station (measured section 2). Rounded glauconite grains (medium gray) are partially to completely replaced by sparry carbonate (lined) in a white silica cement with white quartz grains. Black spots are hematite stains.

which were formerly listed as members of the Hoadley Formation by Mudge (1966b, c) following Deiss (1943a). The Mount Shields is about 1,700 feet thick in the western part of the area.

RED SANDSTONE MEMBER

The red sandstone member is the more conspicuous member in the Mount Shields Formation, as it forms a prominent red hillside ledge. It is gradational with the underlying Shepard Formation through a transition zone, as much as 100 feet thick, of interbedded yellowish-gray siltstone and red sandstone. The red sandstone member thins uniformly toward the north. It ranges in thickness from about 1,100 feet in the southeast corner of the Pretty Prairie quadrangle to 600 feet in the west-central part of the Glenn Creek quadrangle.

The member contains many thin beds of dark-reddish-brown fine to very fine grained micaceous arkosic sandstone. Arkosic siltstone and silty dolomicrite are interbedded in the lower part. In the vicinity of Deadman Hill, a few of the thin beds are medium grained. At various horizons the beds are distinctively mottled with gray to light yellowish gray or pale yellowish green and yellow.

The beds of sandstone and siltstone are very similar in composition; they are mainly quartz and feldspar (table 3). In the transition zone, some of the feldspars are partially to wholly replaced by glauconite. Here the grains are colored a dark red brown by hematite.

The red sandstone member contains more well-preserved primary structures than any other Precambrian unit. Symmetrical ripple marks are more abundant than asymmetrical ones. Other beds with ripple marks show superimposed cross ripples that are at right or oblique angles to the previous set. A few show minor ripples, which were formed on a truncated ripple, both with the same current direction. In addition some are cross ripple marks similar to those described by McKee (1957, p. 1737, 1742) for tidal flats at Sonora, Mexico. Dendritic and lobate rill marks are in a few of the beds. Another common feature is the presence of numerous very fine grained sandstone beds with various sizes and shapes of load casts; some of the casts are as much as 12 inches high. Mud cracks are very abundant; locally they are superimposed on ripple marks. Other primary features include minute raindrop impressions, flute casts, and low-angle cross-lamination. Salt-crystal casts were observed in the upper part of this member in the Deer Creek section.

Another characteristic feature of the sandstone member, and of the overlying red siltstone member as well, is the abundance of angular unoriented fragments of mudstone or clay. These fragments have a lustrous surface and are generally very dark red brown, much darker than their matrix. They very likely were formed by wave or current action dislodging the curled edges of mud cracks during the inundation of a mudflat.

RED SILTSTONE MEMBER

The uppermost member of the Mount Shields is red siltstone. It is poorly exposed; the best exposures occur along crests of divides, especially on the northeast-trending ridges adjacent to Nineteen and Deer Creeks. The member averages about 1,000 feet thick in the western part of the Pretty Prairie quadrangle but thins northward to about 800 feet just north of Slategoat Mountain.

The red siltstone member is mostly dark-reddish-brown to grayish-red very thin bedded finely micaceous siltstone and claystone. The lower and upper parts contain many interbeds of yellowish-gray to grayish-olive platy limy siltstone with some thin lenses of red fine-grained sandstone. Many of the sandstone beds contain ripple marks, minute cross-laminae, mud cracks, and some load casts. Angular fragments of mudstone are locally in the lower part of the member.

Salt-crystal casts are abundant and widespread in the upper part (fig. 10). These characteristic cubes are as much as 2 cm in size. They occur abundantly on bedding planes about 50–100 feet beneath the top of the formation. Salt-crystal casts have been recorded in the Kintla Formation of Glacier Park (Willis, 1902;

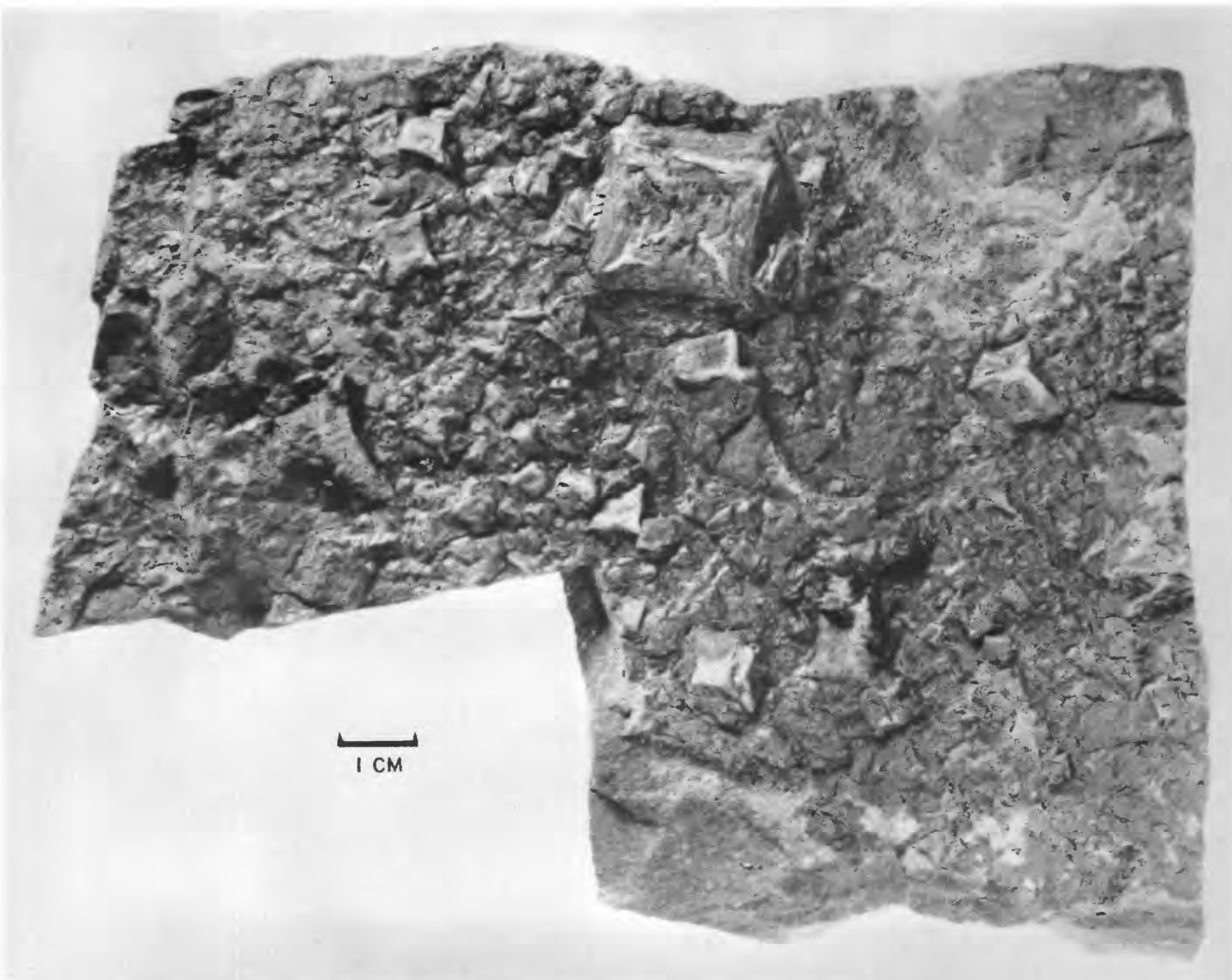


FIGURE 10.—Salt-crystal casts from upper beds of the red siltstone member of the Mount Shields Formation along abandoned horse trail on east side of Deadman Hill. This salt-crystal-cast zone is widespread in northwestern Montana.

Fenton and Fenton, 1937, p. 1901); this formation is laterally equivalent to the Mount Shields Formation (fig. 3). Smith and Barnes (1966, p. 1421) noted in the Glacier Park area that these casts occur in an interval up to 3,000 feet thick directly above the Shepard Formation. Similarly, salt-crystal casts have been recorded in the Mount Shields Formation at Marias Pass by Childers (1960) and in the upper part of the Marsh Formation in the Helena area by Knopf (1963). The upper part of the Marsh correlates with the red siltstone member of the Mount Shields Formation (fig. 3).

BONNER QUARTZITE

In the Sun River Canyon area the Bonner Quartzite is well exposed in the western and southwestern parts of the Pretty Prairie quadrangle and along the west side of the Glenn Creek quadrangle (pl. 1). The correlation of this formation and previous usage is shown in figure 3.

The Bonner changes considerably in thickness from south to north. In the southwestern part of the Pretty Prairie quadrangle it is only 700 feet thick, but in the northwest corner of the quadrangle it is 1,100 feet thick. Northeast of Slategoat Mountain it is only 400 feet thick; here, part of the formation was removed by pre-Middle Cambrian erosion.

The Bonner is easily recognized in the field. It forms a smoothly rounded, very pronounced high knob on the ridges that extend east and northeast from the cliff-forming Cambrian rocks. The Bonner is composed entirely of many thin to thick beds of sandstone, some of which is now orthoquartzite. Most beds range from moderate pink to light pale red; a few are pinkish gray. Some of the darker beds are distinctively mottled light grayish orange, whereas some of the light-colored beds are mottled pale reddish brown. The lowermost beds, in particular, are cross bedded with numerous foresets, indicating a southwest to westerly source direction. Some of those beds contain festoon crossbedding. The sandstone beds weather to rounded ledges with a slightly pitted surface, whereas the orthoquartzite beds form resistant, more angular ledges without a pitted surface.

Most of the beds are moderately well indurated arkosic to subarkosic sandstone (table 3). They are chiefly well-rounded poorly sorted fine to medium grains of clear to slightly frosted quartz and lesser quantities of feldspar. Most of the beds are cemented with silica, but a few are cemented with dolomite. Feldspar generally represents less than 30 percent of the rock (table 3). Unlike the underlying formations, plagioclase comprises only a small proportion of the feldspars. Fragments of older sedimentary and metamorphic rocks are more common in the Bonner than in the older formations.

The contact between the Bonner Quartzite and underlying Mount Shields Formation is sharp and is here regarded as a minor disconformity.

McNAMARA FORMATION

The McNamara Formation, the youngest Precambrian sedimentary rock exposed in the Sun River Canyon area (table 1), is mostly gray siltstone. It forms a saddle just west of the resistant rounded knobs of the Bonner Quartzite and just east of the prominent cliffs formed by the Cambrian rocks (fig. 11). The McNamara is exposed on the ridge east of Nineteen Mountain (pl. 1) and in the upper reaches of Reef Creek, just south of the high point on Prairie Reef (figs. 2 and 11).

The thickness of the McNamara ranges from 0 to 575 feet, partly depending on the extent of pre-Middle

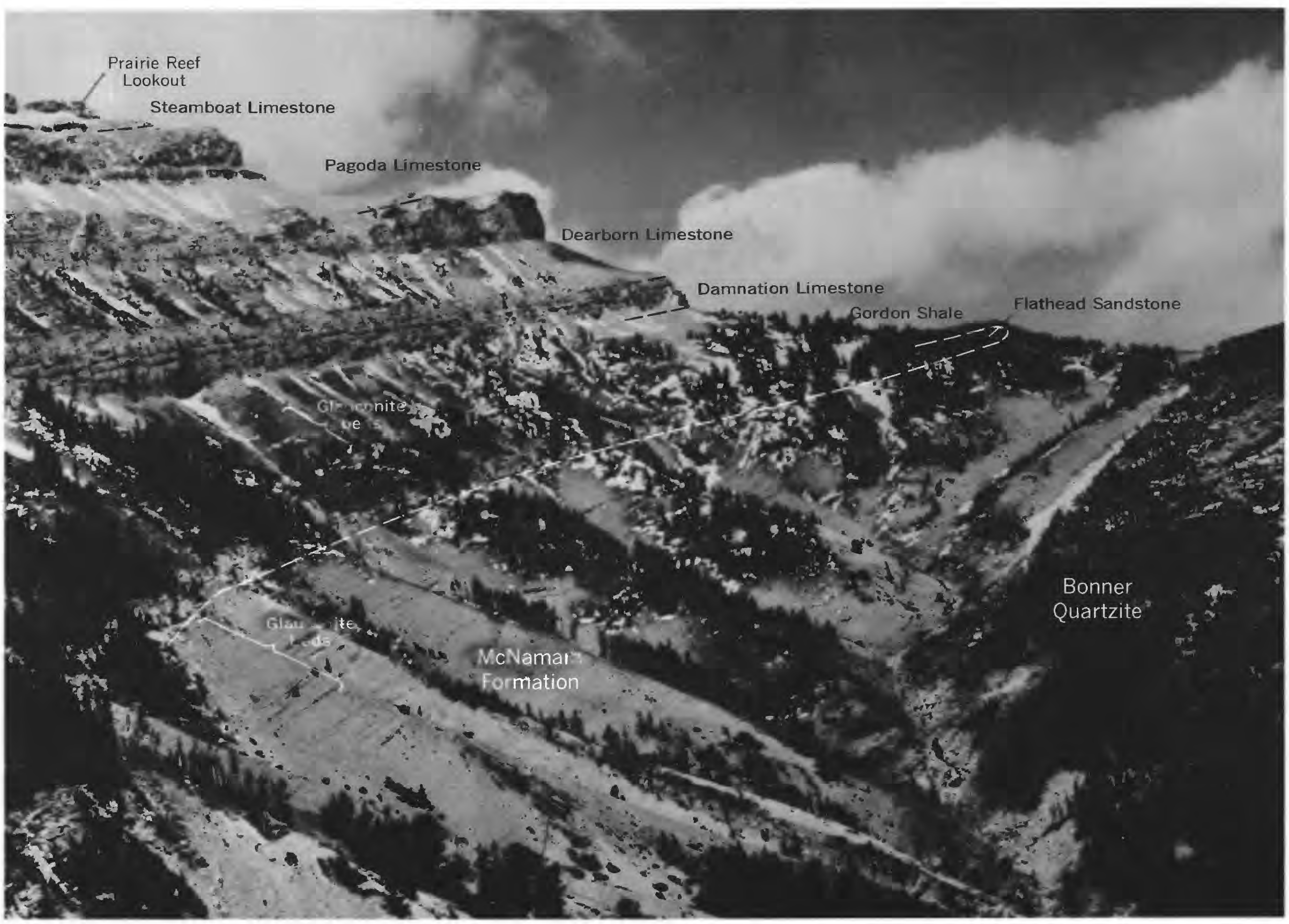


FIGURE 11.—Precambrian and Cambrian rocks in the upper reaches of Reef Creek at Prairie Reef. View looking north.

Cambrian erosion. The formation is absent in the Glenn Creek quadrangle, where the Flathead rests unconformably on the middle beds of the Bonner Quartzite. The maximum thickness of the McNamara is along Reef Creek, just south of the high point and lookout on Prairie Reef (figs. 2 and 11). The formation is about 400 feet thick in the southwest corner of the Pretty Prairie quadrangle, but south of that quadrangle it is absent owing to pre-Flathead erosion.

The McNamara consists mostly of thin beds of siltstone with many interbeds of sandy siltstone, claystone, arkosic sandstone, and orthoquartzite. These beds are gray green and gray with some thin interbeds of maroon, and they weather to a gray to grayish-green slope (fig. 11). The lithologies are described in detail in measured section 3. Common primary structures include mud cracks; mud flakes, some of them shingled; small symmetrical ripple marks; load casts; minute low-angle cross-laminae; and small salt-crystal casts.

A shale sample (741) from the upper part of the McNamara was studied by X-ray analyses and petrographically by H. A. Tourtelot (written commun., 1966), who reported: "The clay fraction consists of about 95 percent illite and 5 percent chlorite. The illite is the 1md polymorph and contains very few expandable layers."

The beds of sandstone are mainly quartz and feldspar, except for a few which are mostly glauconite (table 3). The matrix is mostly chert and altered clay minerals with some barite, hematite, sericite, and locally carbonate.

Barite is characteristically abundant in the McNamara Formation. It occurs as a pink, red, gray and grayish-green cement in many sandstone and siltstone beds in the upper part, and, in addition, it partly fills small cavities. Locally the barite has been replaced by or is associated with silica. The barite weathers in nodules and small plates, which litter the exposed surface of the formation.

Fine-grained glauconite is a common constituent of many of the sandstone beds in the upper part of the McNamara (figs. 11 and 12; table 3; and measured section 3). Its occurrence is essentially the same as in the Shepard Formation, as are its origin and the post diagenetic introduction of carbonate.

In the southwestern part of the Pretty Prairie quadrangle the McNamara rests in sharp contact on the Bonner. Farther north, in the vicinity of Prairie Reef (fig. 11), however, the contact is transitional. Here the contact was placed at the base of the lowest maroon sandstone bed. (See measured section 3.)

PRECAMBRIAN-CAMBRIAN UNCONFORMITY

In the Sun River Canyon area the unconformity at the base of the Flathead Sandstone of Middle Cambrian age represents an interval of about 550 million years. This unconformity was first noted by Peale (1893), later evaluated by Walcott (1899, 1906), and frequently discussed thereafter. (See Deiss (1935, p. 99–104) for summary.) Deiss (1933, p. 33–34) estimated that 18,000–19,000 feet of Belt rocks was removed in northwestern Montana during the time represented by this unconformity.

Deiss (1935, pl. 8) noted that the Flathead Sandstone in northwestern Montana was deposited on an erosional surface beneath which successively older strata had been truncated to the east. This easterly truncation is well illustrated in the Belt exposures south of the Sun River Canyon area (fig. 13). A line through sections 4, 9, and 10 in figure 13 shows the Flathead on progressively older Belt units to the east. In section 10 at least 8,500 feet of Belt rocks was eroded prior to the deposition of the Flathead. On a similar line through sections 4, 5, and 6, the unconformity cuts out about 5,000 feet of Belt strata. Along strike, however, as on a north-south line through sections 1, 2, 7, 6, 8, and 9, the unconformity cuts out only 1,500 feet of Belt rocks.

The discordance between the Flathead and the Belt rocks at locality 2 is approximately 12° along the strike and 3° along the dip (Deiss, 1938, p. 1077).

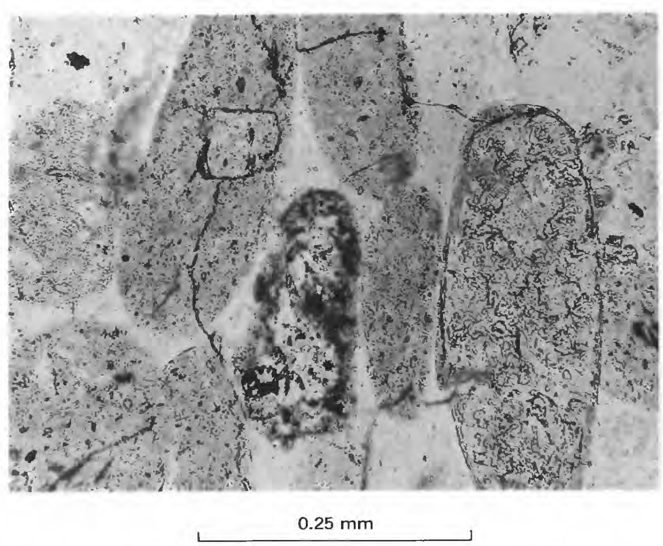


FIGURE 12.—Photomicrograph of glauconitic sandstone (HS730) in the McNamara Formation exposed in Reef Creek at Prairie Reef (measured section 3 and fig. 11). The rounded glauconite pellets (fibrous texture) are alined parallel to bedding, which is normal to this view. The dark chalcedony grain in the center is heavily impregnated with iron. In the upper left the glauconite grain is partly replaced by a carbonate rhomb. The chalcedony grain on the right is partly replaced by glauconite, which forms the rind.

The total amount of Belt strata that was present in the Sun River Canyon and adjacent areas prior to pre-Middle Cambrian erosion can only be roughly estimated. In doing so, one must recognize that the Belt rocks thin markedly to the east from one fault block to another (McGill and Sommers, 1967). The now-missing younger Belt rocks also were very likely thinner than their counterparts further west. By applying a hypothesis on the depth and control of sills by Mudge (1968b), the thickness of strata that were eroded prior to deposition of the Flathead can be inferred. In the Sun River Canyon area, diorite sills (750 m.y. old) intruded Belt strata at various horizons that now are 1,650–4,085 feet beneath the unconformity. Mudge (1968b) noted that many sills in the United States are intruded into flat-lying rocks at depths of 3,000–7,500 feet and hypothesized that this is true of sills in general. If so, a minimum of 1,350 feet and a maximum of 3,400 feet of strata has been removed in Reef Creek at Prairie Reef (figs. 11 and 13, loc. 2). However, this thickness accounts only for half of the interval represented by the unconformity; therefore, the history from 550 m.y. to 750 m.y. remains unknown. Rocks equivalent to the Windermere Series of British Columbia, Canada, and eastern Washington which were deposited within that interval (Alberta Soc. Petroleum Geologists, 1964) may have been laid down here and then eroded.

PALEOZOIC ROCKS

The Paleozoic sequence, mainly of carbonate rock, is about 4,000 feet thick. The Cambrian, Devonian, and Mississippian Systems are represented (table 1). The missing systems are probably represented by widespread low-angle unconformities.

The earliest workers recognized the Paleozoic age of some of the rocks in and adjacent to the Sun River Canyon area. Systemic boundaries were established by Clapp and Deiss (1931) and Deiss (1935, 1939, and 1943a). Sections of the Cambrian rocks in the Lewis and Clark Range were described by Deiss (1939), who correlated them with the Paleozoic sections of southwestern Montana. Sections of the Devonian and Mississippian rocks in the Sun River Canyon area were described by Sloss and Laird (1945 and 1946), who correlated them with sections in Canada. Later, detailed stratigraphic and paleontologic studies were conducted on the Mississippian rocks by Mudge, Sando, and Dutro (1962), who established the nomenclature used in this report.

In the Sun River Canyon area each of the three systems in the Paleozoic has similarities that suggest major cycles of deposition. The lower part of each system contains transgressive shallow-water marine mudstone or argillaceous limestone overlain by deep-water marine limestone. The deep-water limestone is in turn overlain by shallow-water marine regressive dolomite. During the Devonian Period, restricted marine environments resulted in deposition of evaporite. Similar conditions prevailed at the close of the Cambrian and Mississippian Periods.

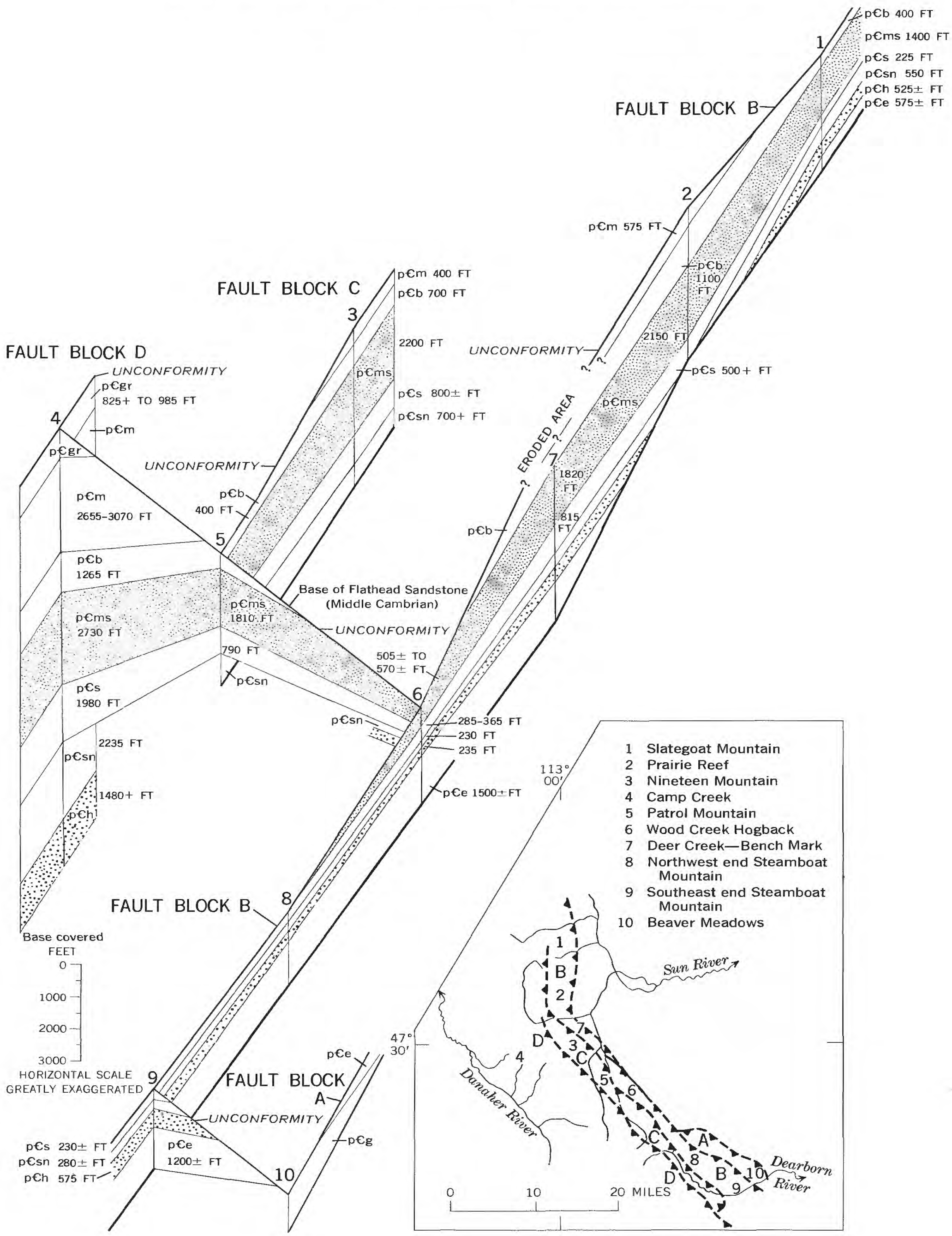
CAMBRIAN

The Cambrian rocks in the Lewis and Clark Range have been thoroughly described and discussed by Deiss (1939 and 1943a), and consequently, are only cursorily treated here. Deiss divided them into nine formations: Flathead Sandstone (bottom), Gordon Shale, Damnation Limestone, Dearborn Limestone, Pagoda Limestone, Pentagon Shale, Steamboat Limestone, Switchback Shale, and Devils Glen Dolomite (top). The Pentagon Shale, as Deiss recognized (1939, p. 42–43), is of local extent and is not present in the Sun River Canyon area. The correlation of these formations with those of the Cambrian sequence at Logan, Mont., shown in figure 14, is modified only slightly from that by Deiss (1939, p. 54).

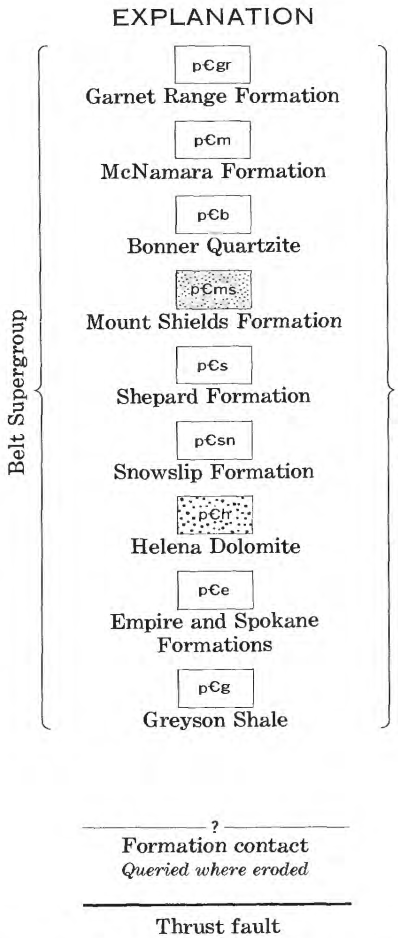
Cambrian rocks are exposed at Nineteen Mountain; in the cliff on the east side of Prairie Reef (figs. 2 and 11), which extends north through the west side of Glenn Creek quadrangle; along the east face of the ridge containing Allan Mountain and Arsenic Peak; and along the west side of Mortimer Gulch and Palmer Flats in the vicinity of Gibson Reservoir (pl. 1).

The sandstones of the Cambrian differ from those of the Precambrian in that they are composed mostly of quartz with only minor amounts of feldspar, mica, and unaltered micrite grains.

In the Prairie Reef and Nineteen Mountain sections, in the eastern outcrop area, most of the limestone formations contain mudstone sequences in their lower part (fig. 11). But mudstone apparently grades into limestone to the west and southwest. This is evident in a correlation diagram by Deiss (1939, p. 52) that depicts relations from the Prairie Reef section west to Haystack Mountain and Pagoda Mountain and southwest to Nannie Basin in the Swan Range. In each formation there is an increase in carbonate and a decrease in mudstone to the west. There is also an appreciable increase in the thickness of the formations in the Nannie Basin section. The easterly increase of mudstone to limestone is well illustrated by the Steamboat Limestone. In the Allan Mountain–Big George Gulch area this formation is half mudstone, but to the southwest at Nineteen Mountain it is 95 percent limestone and 5 percent mudstone.



p€b 400 FT
p€ms 1400 FT
p€s 225 FT
p€sn 550 FT
p€h 525± FT
p€e 575± FT
1
FAULT BLOCK B
2
p€m 575 FT
p€b 1100 FT
2150 FT
UNCONFORMITY
p€s 500+ FT
p€ms
ERODED AREA
7
1820 FT
815 FT
p€b
FAULT BLOCK C
3
p€m 400 FT
p€b 700 FT
2200 FT
p€ms
p€s 800± FT
p€sn 700+ FT
FAULT BLOCK D
UNCONFORMITY
p€gr
825+ TO 985 FT
4
p€m
p€gr
UNCONFORMITY
p€m
2655–3070 FT
p€b
400 FT
5
p€b
1265 FT
p€ms
2730 FT
p€ms
1810 FT
Base of Flathead Sandstone
(Middle Cambrian)
UNCONFORMITY
790 FT
p€sn
505± TO
570± FT
6
p€s
1980 FT
p€sn
285–365 FT
230 FT
235 FT
2235 FT
p€sn
1480+ FT
p€h
p€e 1500± FT
FAULT BLOCK B
8
Base covered
FEET
0
1000
2000
3000
HORIZONTAL SCALE
GREATLY EXAGGERATED
9
p€e
FAULT BLOCK
A
UNCONFORMITY
p€g
p€s 230± FT
p€sn 280± FT
p€h 575 FT
p€e
1200± FT
10
113°
00′
47°
30′
1 Slategoat Mountain
2 Prairie Reef
3 Nineteen Mountain
4 Camp Creek
5 Patrol Mountain
6 Wood Creek Hogback
7 Deer Creek—Bench Mark
8 Northwest end Steamboat Mountain
9 Southeast end Steamboat Mountain
10 Beaver Meadows
Sun River
Danaher River
Dearborn River
A
B
C
D
0
10
20 MILES



Unit thicknesses for sections 4, 5, and 6 from McGill and Sommers (1967); those for section 9 from Mudge, Erickson, and Kleinkopf (1968) and interpreted from Walcott (1906)

FIGURE 13.—Relationship of the unconformity at the base of the Middle Cambrian rocks to Precambrian rocks exposed in four thrust-fault blocks in southeastern part of the Lewis and Clark Range, Montana. Angle of unconformity exaggerated.

Two types of intraformational conglomerates are found in the Pagoda and Steamboat Limestones: edgewise conglomerate with angular fragments shingled or parallel to bedding, and angular to subrounded flat-pebble conglomerate. Origin of such conglomerates is discussed by Robinson (1963, p. 20), who suggests that nonshingled flat-pebble conglomerate may form in response to differing rates of lithification in thin-bedded strata far from shore and on a horizontal sea bottom, but that the edgewise conglomerates form in the presence of strong currents or waves.

The thicknesses of the Cambrian rocks at many sections in the Lewis and Clark Range are listed by Deiss (1939): Prairie Reef, 1,752 feet; Ford Creek–Straight Creek, 1,801 feet; Scapegoat Mountain, 1,723 feet; and Dearborn River, 2,233 feet. The Prairie Reef and Dearborn sections are in the same fault block (fig. 13), which indicates thickening to the southeast. The Scapegoat Mountain section is in three fault blocks to the west of the Dearborn section, which suggests that in this area the section thins to the west.

FLATHEAD SANDSTONE

The Flathead Sandstone, of Middle Cambrian age, is the oldest Paleozoic unit in the report area (table 1). This formation is exposed only at Nineteen Mountain and near the base of the ridge extending from Prairie Reef north to Slategoat Mountain (fig. 11 and pl. 1). In these areas, except at Slategoat Mountain itself, this sandstone forms a distinct light-gray ledge between the mudstone of the McNamara Formation and the shale of the Gordon Shale (fig. 11). At Slategoat Mountain the Flathead rests on the lower part of the Bonner Quartzite.

The Flathead Sandstone is 70–110 feet of noncalcareous, thin- to thick-bedded sandstone that locally contains a few beds of mudstone. The beds of sandstone are yellowish gray and consist of poorly sorted poorly indurated fine to very coarse grained quartz sand and scattered quartz pebbles (table 1). The sand grains are subangular to well rounded. The beds contain minor amounts of feldspar, biotite, muscovite, zircon, chert, hematite, and clay minerals. A characteristic speckled appearance of weathered surfaces is due to disseminated hematite. Low-angle (10°–25°) crossbedding is abundant and indicates that the current direction was to the northeast or east.

Mudstone interbeds were observed only in the vicinity of Prairie Reef. Here they are in beds from a fraction of an inch to as much as 4 feet thick. Those in the lower part are gray, but those higher in the section are purple or maroon. The beds are very finely micaceous sandy shale with some small load casts and organic trails and burrows. (See measured section 3.)

The beds of the Flathead generally weather with an exfoliated rounded surface. In many exposures the weathered rim is so poorly indurated that it readily crumbles when struck with a hammer.

GORDON SHALE

The Gordon Shale forms a broad slope between the Flathead Sandstone and the Damnation Limestone (fig. 11). This shale correlates with the upper part of the Flathead Sandstone and the lower part of the Wolsey Shale of central Montana and probably is essentially equivalent to the Cathedral Dolomite in Alberta, Canada (Deiss, 1939, p. 54).

In the Sun River Canyon area the Gordon crops out at Nineteen Mountain (pl. 1) and near the east base of

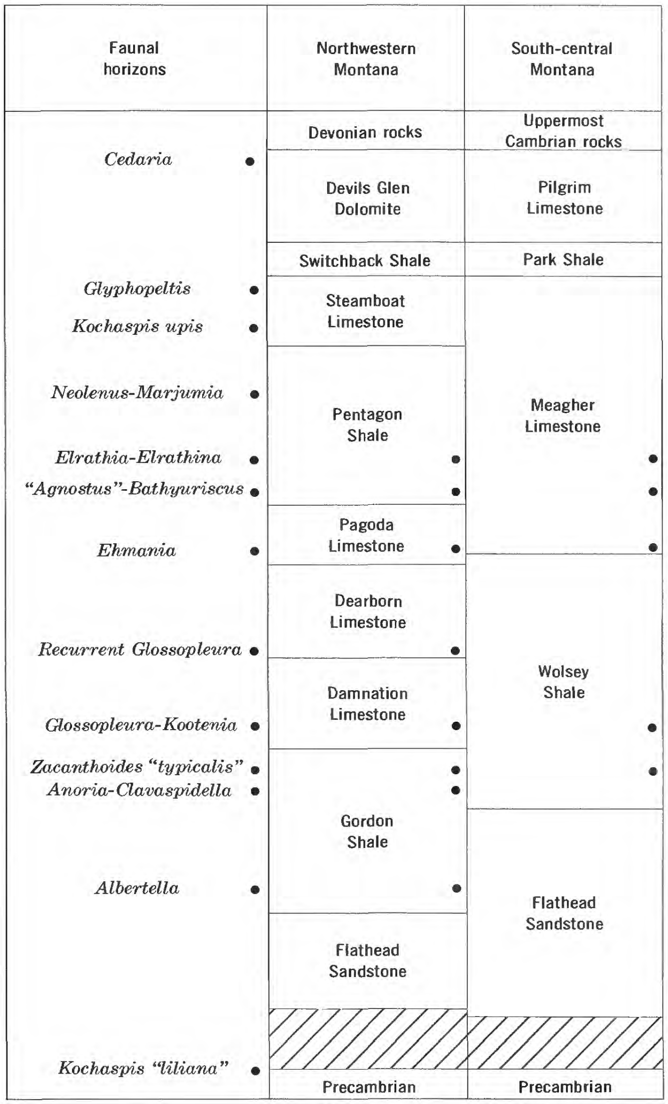


FIGURE 14.—Faunal horizons and correlation of the Cambrian rocks in the Sun River Canyon area in northwestern Montana with those at Logan in South-Central Montana. Modified from Deiss (1939, p. 54).

the ridge from Prairie Reef (fig. 11) to Slategoat Mountain (pl. 1).

Thickening toward the south, the Gordon is about 197 feet thick in the vicinity of Bear Lake (Deiss, 1939, p. 28), 252 feet thick, 1 mile south of Prairie Reef lookout (measured section 3), and 221 feet thick in the Lewis and Clark Range (Deiss, 1939, p. 38).

The Gordon is mainly dark-gray to gray-brown noncalcareous very thinly laminated clay shale, but it has many thin beds of sandstone and a few of limestone. (See measured section 3.) The sandstone, which is mainly in the lower part of the Gordon, is gray to yellowish gray, thin bedded, very fine to medium grained, and ripple marked and contains abundant organic trails and burrows. The sandstone has moderately well sorted angular to rounded grains composed mostly of quartz with minor amounts of feldspar, chert, glauconite (fig. 15), biotite, and fossil fragments. The glauconite is bright green mostly rounded lobate pellets from 0.1 to 1.0 mm across (fig. 15). In some grains, glauconite has partially or wholly replaced elongate (up to 2.0 mm) altered flakes of biotite (fig. 16), whereas in others it has replaced saussuritized feldspar. Many of the pellets encase quartz grains, and some have been replaced by dolomite.

The limestone, in beds about 1 foot thick, occurs mainly in the middle part of the formation. The beds are gray-brown massive sandy biosparrudites or biomicrudite. They contain large fragments of fossils, reworked limestone, glauconite grains, quartz, and hematite. Some of the glauconite has partially replaced algal deposits which are 2 mm in diameter (fig. 17).

The contact between the Flathead Sandstone and the Gordon Shale is everywhere gradational in northwestern Montana (Deiss, 1939, p. 53).

Algal deposits and fossil fragments were the only fossils I noted in the Gordon. Deiss (1939, p. 38) found many trilobites, an *Albertella* fauna in the lower part, and *Anoria* and *Zacanthoides* zones in the upper part.

DAMNATION LIMESTONE

The Damnation Limestone forms the first massive cliff above the Gordon Shale (fig. 11). This limestone is laterally equivalent to the middle part of the Wolsey Shale of south-central Montana (fig. 14) and the lower part of the Stephen Formation of Alberta, Canada

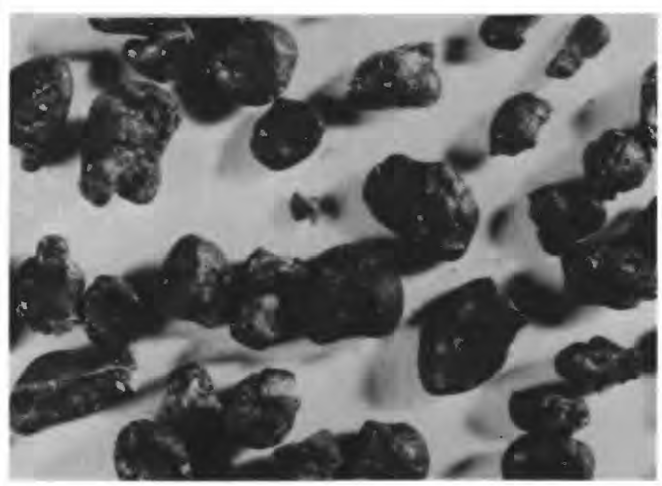


FIGURE 15.—Glauconite pellets from limestone beds in the Gordon Shale. Pellets are more irregularly shaped than those in the Precambrian rocks.

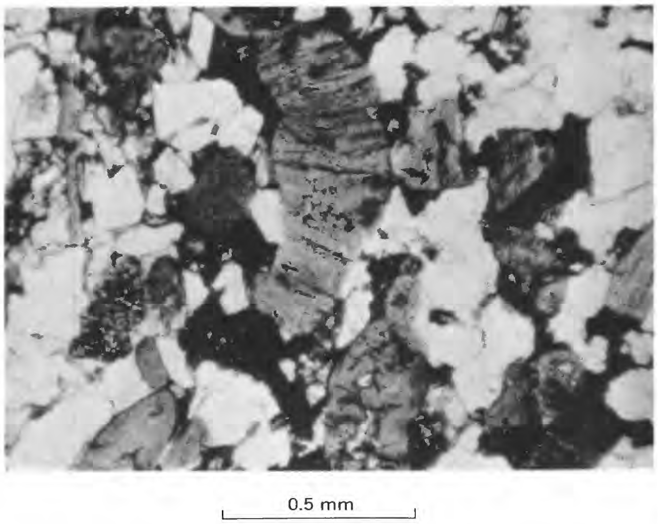


FIGURE 16.—Photomicrograph of glauconitic sandstone (HS752) from the Gordon Shale in the upper reaches of Reef Creek at Prairie Reef. Glauconite (medium gray) has replaced biotite (irregularly shaped grains with lines); white, quartz; black, hematite stains. Some of the glauconite grains contain quartz inclusions. The white shadow at the edge of some of the grains is quartz that has partially replaced glauconite.

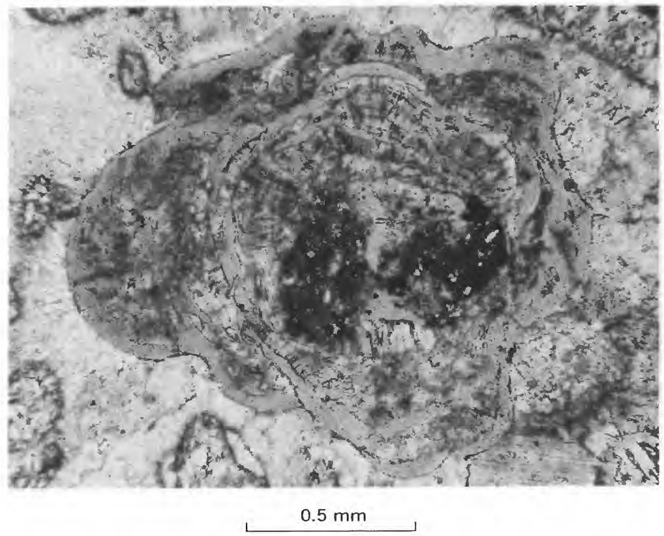


FIGURE 17.—Photomicrograph of algal structure in a dolomitic, glauconitic biomicrudite (HS755) at the same location and section shown in figure 11. The fine-grained segments of the structure are glauconite; the fibrous areas are carbonate. In this specimen the order of replacement is uncertain. Elsewhere carbonate has replaced rock fragments and similar algal structures.

(Deiss, 1939, p. 54). The Damnation is well exposed at Nineteen Mountain on the east face of the ridge from Prairie Reef to Slategoat Mountain (pl. 1). It is about 145 feet thick along the west side of Pretty Prairie quadrangle. Elsewhere it ranges in thickness from 100 to 225 feet (Deiss, 1939, p. 39).

The Damnation grades upward from dolomitic limestone into limestone. (See measured section 4.) Most of the beds are finely crystalline, medium to dark gray, and distinctively mottled light grayish orange to pale yellowish orange, especially in the lower half of the formation. The beds are very thin bedded and separated by laminae of grayish-orange to yellowish-gray micaceous siltstone. These laminae thicken and thin, and on a bedding surface they fill organic trails and burrows, imparting an appearance of ripple marks. The upper part of the formation forms a massive cliff with many nodular-weathering beds. Deiss (1939, p. 39) described the Damnation as being coarsely oolitic. Oolites were observed in this formation along the east face of Nineteen Mountain, but they are rare in exposures at Prairie Reef. This formation conformably overlies the Gordon Shale. This contact is distinctly sharp and very likely represents a minor hiatus. I found no identifiable fossils in the Damnation, but Deiss (1939, p. 39) reported the *Glossopleura-Kootenia* trilobite fauna in the lower 10 feet.

DEARBORN LIMESTONE

The Dearborn Limestone comprises mudstone (lower) and limestone (upper) members (fig. 11 and table 1). Both are well exposed on the east side of Nineteen Mountain and on the east face of the ridge from Prairie Reef (fig. 11) to Slategoat Mountain. Only the limestone member is exposed in the upper reaches of Big George Gulch in the Arsenic Peak quadrangle (pl. 1). The Dearborn ranges in thickness from 272 to 363 feet and averages about 298 feet in thickness (Deiss, 1939, p. 40). At its type locality, on the Dearborn River, Deiss (1939, p. 33) listed it as 354 feet. It is about 295 feet thick at Prairie Reef.

The mudstone member contains about 150 feet of calcareous shale and many thin limestone beds. It rests in sharp contact on the limestone beds of the Damnation. The lower part of this member is mainly gray-green clay shale, whereas the upper part is gray, olive-gray, and green sandy shale. Limestone beds occur mainly in the middle and upper parts. They are finely crystalline and gray to pale yellowish brown and contain thin pinch-and-swell beds that weather nodular.

The upper member is about 145 feet of finely crystalline pale-yellowish-brown very thin irregularly bedded limestone. Bright-orange-brown siliceous clay flakes are common. A thin grayish-green shale bed occurs near the base. This member forms a prominent massive vertical cliff.

PAGODA LIMESTONE

The Pagoda Limestone contains two distinct thick members: a lower shale and an upper limestone (fig. 11). The formation is well exposed at Nineteen Mountain, at its type locality at Prairie Reef, and at Slategoat Mountain. The upper member is also exposed in a fault block on the west side of the north end of Big George Gulch. The Pagoda ranges in thickness from 92 to 396 feet; at Prairie Reef it is 364 feet thick (Deiss, 1939, p. 28, 40–41).

The lower member is about 160 feet thick and forms a broad bench above the Dearborn Limestone (fig. 11). It consists of beds of grayish-green thinly laminated to nodular clay shale, yellowish- to gray-brown limestone, and, in the lower part, sandstone. The beds of limestone are mostly very thin and fine grained, and some are glauconitic.

The upper member everywhere forms a prominent massive rounded cliff, about 220 feet thick, with two or more thin indentations. It is noticeably thicker than the limestone members of the adjacent formations (fig. 11). This member consists of finely crystalline pale-yellowish-brown very thin bedded limestone in the lower part and yellowish-gray to light-yellowish-brown thin- to thick-bedded dolomitic limestone and some dolomite in the upper part. Locally in the middle of the member there is an intraformational breccia composed of angular elongate randomly oriented dolomite fragments in a dolomite matrix.

In the Nineteen Montain area the upper member contains a variety of lithologies. Some are minutely laminated, whereas others are crossbedded. In places there are dark-grayish-brown chert nodules and lentils 2–4 feet long and 2 inches thick. (See measured section 5.)

In the Sun River Canyon area the Pagoda conformably overlies, with a distinct contact, the Dearborn Limestone. In other places the contact between these formations is gradational (Deiss, 1939, p. 40).

STEAMBOAT LIMESTONE

The Steamboat Limestone forms the uppermost ledge at Nineteen Mountain (pl. 1) and at Prairie Reef (fig. 11). Its type locality is on the crest of Prairie Reef (Deiss, 1939, p. 43). It is exposed on the east face of Allan Mountain, along the west side of Big George Gulch, and in the upper reaches of Blacktail Gulch, Cabin Creek, and Deep Creek. This formation correlates with the upper part of the Meagher Limestone of south-central Montana (fig. 14). The Steamboat resembles the Meagher, but the strata below it, which also correlate with the Meagher, do not. The Steamboat Limestone is 239 feet thick at Prairie Reef (Deiss, 1938, p. 1079) and 219 feet at Nineteen Mountain. (See measured section 5.)

The Steamboat consists mostly of very thin to thin beds of limestone and dolomitic limestone. In the western part of the Sun River Canyon area it has thin mudstone units in the lower part, and in the central part of the area mudstone comprises about half of the formation. The limestone beds are nodular, hard, dark yellowish brown, and finely crystalline; many are lithographic. Between the nodules are irregular lentils of grayish-orange to dark-yellowish-orange quartz silt that are generally elongate with the bedding. Some appear to be organic trails and burrows, whereas others are filled mud cracks and troughs of remnant ripple marks. Thin beds of intraformational conglomerate are present locally. (See measured section 5.)

The mudstone is mainly grayish-green papery noncalcareous clay shale with many interbeds of calcareous siltstone and claystone.

A comformable contact was inferred between the Steamboat Limestone and the Pagoda Limestone by Deiss (1938, 1939, and 1943a). North of the Sun River Canyon area, the relationship of the Pentagon Shale to these formations is not clear. Deiss (1939, p. 43) stated that the Pentagon appears to be a conformable wedge which grades vertically and laterally into the Steamboat.

Abundant trilobites and some brachiopods occur in limestone lenses within the shale and in some of the upper limestone beds. Fossil collections were identified and discussed by A. R. Palmer (written commun., 1958, 1959, and 1961):

1. Collection F247. East face of Allan Mountain, lat 47°33′ N. long 112°47′ W. *Glyphaspis*, probably *G. dearbornensis* Deiss. A characteristic trilobite of the Steamboat.
2. Collection F246a, b, same locality as above only stratigraphically lower. *Ehmania* fauna. The fauna is like that which Deiss (1939, p. 44) assigned to the Pentagon Shale. This collaborates his (1939) observation that the Pentagon Shale grades laterally into the lower part of the Steamboat Limestone.
3. Collection F202. Stratigraphically equivalent to collection F246a, b. *Ehmania* fauna.
4. Collection F260. West side of Big George Gulch. *Glyphopeltis* from upper part of Steamboat Limestone.
5. Collection F297. Big Geoge Gulch. The assemblage is probably correlative with Deiss' collection 30.3 (Deiss, 1939, p. 67) from the Steamboat Limestone on Cliff Mountain. It contains *Glossocoryphus* cf. *G. typus* Deiss, *Kochaspis* cf. *K. upis* (Walcott),

and an undeterminable simple ptychoparioid similar to *Ehmania.*

6. Collection F298. West side of Big George Gulch. Abundant *Glyphaspis* cf. *G. dearbornensis.* Essentially same horizon as collection F247.
7. Collection F139. West side of Big George Gulch. *Glyphopeltis primus* Deiss.
8. Collection F354 (3736–CO). From the basal mudstone unit of the Steamboat Limestone near the crest of Nineteen Mountain. *Kochaspis upis* (Walcott), *Glossocoryphus cliffensis* Deiss, and *Coelaspis prima.* Deiss.
9. Collection F356 (3737–CO). From about 100 feet above base of Steamboat Limestone near the crest of Nineteen Mountain. Indeterminate species of *Glyphaspis.*

The exceedingly abundant trilobite in collection 7 is present only in nodules of calcium carbonate that formed in place around the fossils, perfectly preserving them. The nodules with trilobites were not observed elsewhere in the Sun River Canyon area.

SWITCHBACK SHALE

The Switchback Shale is the uppermost shale unit in the Cambrian sequence. It is equivalent to the Park Shale of the south-central Montana section (fig. 14) and very likely correlates with the lower division of the Lynx Formation in Alberta as described by Aitken (1966, p. 10). The boundary between the Middle and Upper Cambrian is within the Switchback Shale (Deiss, 1943a, p. 223), probably at the base of the conglomerate beds exposed at the north end of Allan Mountain and at Nineteen Mountain (measured sections 6 and 5). In northwest Montana the Switchback Shale ranges unsystematically in thickness from 70 to 253 feet (Deiss, 1939, p. 46). It is 254 feet thick at Nineteen Mountain, 75 feet at Prairie Reef, and about 270 feet near Arsenic Peak. Some of this variation may be due to minor faulting and folding or to unconformities within the Switchback. (See measured sections 5 and 6.)

The Switchback Shale crops out on the west side of Nineteen Mountain (pl. 1) and on Prairie Reef. It is also exposed in a few places along the east side of the ridge that contains Allan Mountain and Arsenic Peak, at the heads of Blacktail Gulch, Cabin Creek, Grouse Creek, and Deep Creek. In most exposures this shale forms a saddle.

The Switchback is mostly noncalcareous greenish-gray thinly laminated clay shale with local thin interbeds of dolomite, limestone, sandstone, and conglomerate. The dolomites are very finely crystalline, light gray, and very thin bedded. In the Allan Mountain area, a thin limestone bed in the upper part of the formation is silty and conglomeratic and contains well-rounded dolomite pebbles (up to 3 in. across). Another thin conglomerate beneath it contains well-rounded pebbles and cobbles (up to 6 in. across) of oolitic limestone and laminated siltstone in a sandy limestone matrix. This conglomerate bed, about 35 feet below the top, may mark the base of the Upper Cambrian in this section. Collection F328 from this conglomerate contains brachiopods like the genus *Ceratreta,* which is known only from middle Upper Cambrian (A. R. Palmer, written commun., 1959). At Nineteen Mountain, three conglomerate beds are described in the Switchback in measured section 5. The lower one contains fragments of linguloid and acrotretid brachiopods and poor molds of a *Hyolithes* and a *Helcionella* (A. R. Palmer, written commun., 1961, collection F357 [USGS 3739–CO]). Palmer noted fragments of trilobites in the matrix and pebbles. The conglomerate, about 47 feet below the top, very likely marks the base of the Upper Cambrian in this section. The Switchback Shale rests conformably on the Steamboat Limestone. This contact is very sharp and distinct.

DEVILS GLEN DOLOMITE

The Devils Glen Dolomite is the youngest Cambrian formation in northwestern Montana. The Devils Glen correlates with the Pilgrim Limestone of the south-central Montana section (fig. 14). Deiss (1939, p. 54) correlated the Devils Glen with the Eldon Dolomite in Alberta. It may also be equivalent to part of the upper division of the Lynx Formation in Alberta described by Aitken (1966, p. 11).

In the Sun River Canyon area the Devils Glen Dolomite crops out in the same places as the Switchback Shale. The Devils Glen is also exposed in the eastern part of the Gibson Reservoir area along the west side of Mortimer Gulch (measured section 8) and Palmer Flats (pl. 1).

In northwestern Montana the Devils Glen ranges in thickness from 179 to 565 feet (Deiss, 1939, p. 46). In the Sun River Canyon area it is about 330 feet thick at Prairie Reef (Deiss, 1933, p. 26). Along the west side of the Big George Gulch it ranges in thickness from 100 to about 350 feet and averages about 200 feet (measured section 7). At Nineteen Mountain it is about 400 feet thick (measured section 5). The reason for the variation in thickness is not known. The formation very likely thins eastward toward the Sweetgrass Arch, which was structurally high in Cambrian time.

Everywhere, the Devils Glen is a distinctive thick-bedded dolomite that forms light-gray massive ledges (fig. 18). The rock is finely to very finely crystalline and light gray to light yellowish gray. Faint laminae

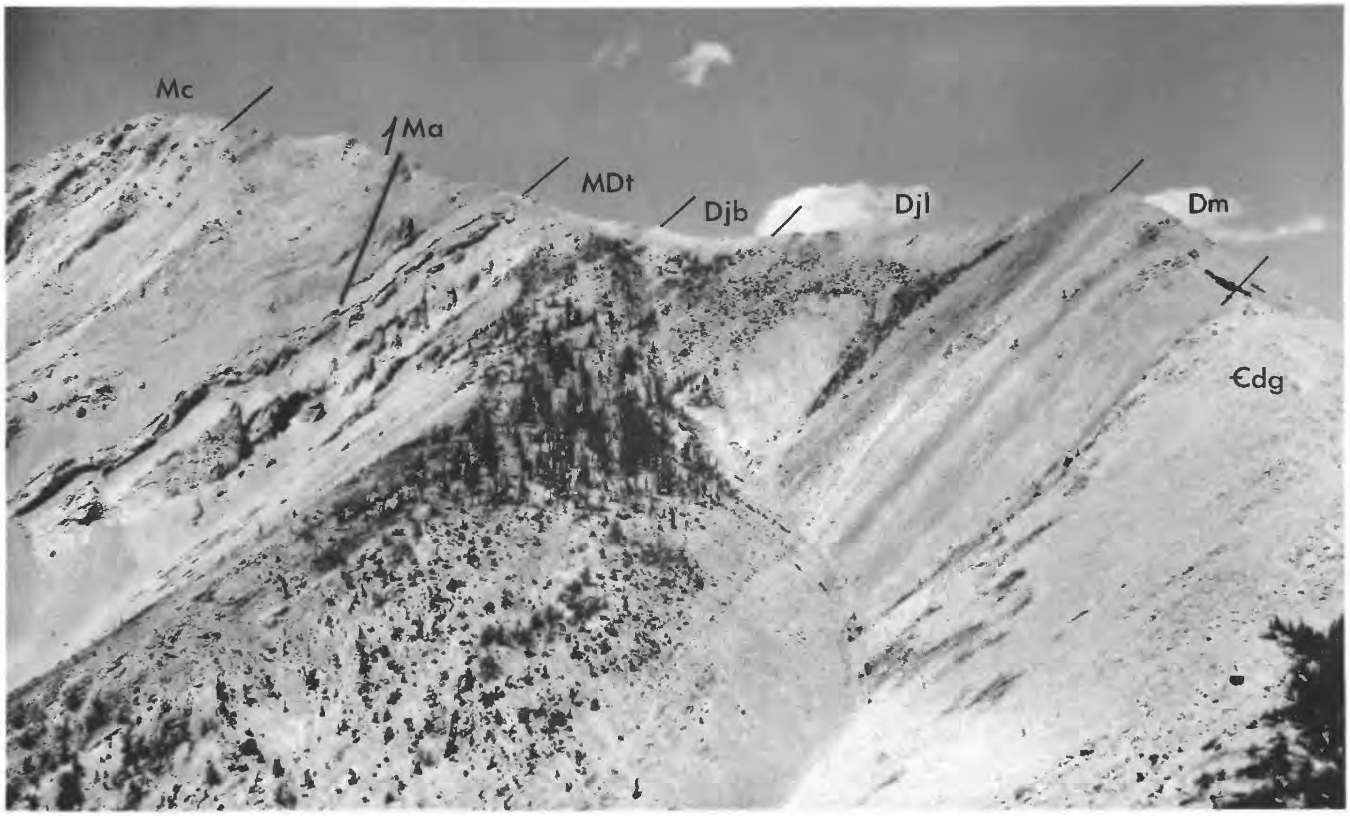


FIGURE 18.—Cambrian, Devonian, and Mississippian rocks exposed on the south side of Arsenic Peak (high peak). €dg, Devils Glen Dolomite; Dm, Maywood Formation; Djl, lower member of Jefferson Formation; Djb, Birdbear Member of Jefferson Formation; MDt, Three Forks Formation; Ma, Allan Mountain Limestone; Mc, Castle Reef Dolomite. A small thrust fault (arrow) repeats part of the Allan Mountain Limestone.

and crossbedding are apparent on the roughly etched weathered surfaces of some of the beds. Locally, concentric structures, similar to algal deposits, are visible on the weathered surface. In places in the eastern outcrop area thin beds of intraformational breccia occur at the top of the formation and about 10 feet below the top. These may be evaporite solution breccias. The Devils Glen rests in sharp and conformable contact on the Switchback Shale.

On the west side of Mortimer Gulch, near Gibson Reservoir, the Devils Glen contains salt-crystal casts. These fill fractures and voids in a 3-inch-thick bed about 2.5 feet beneath the top of the formation. They may be laterally equivalent to the breccias in the formation, or salt may have been deposited in these openings during the first advance of the next (Devonian) sea.

The only fossils observed in the Devils Glen Dolomite in the Sun River Canyon area or in northwestern Montana are trilobites from thin beds of limestone in the upper 20 feet on the west side of Mortimer Gulch, just north of Gibson Reservoir in the NE¼NW¼SW¼ sec. 4, T. 31 N., R. 9 W. In collection F301, A. R. Palmer (written commun., 1959) identified the following Late Cambrian forms:

Cedaria cf. *C. milleri* Resser
Kormagnostus? sp.
Talbotina? sp.

CAMBRIAN-DEVONIAN UNCONFORMITY

The unconformity at the base of the Devonian rocks represents more than 100 million years, from Late Cambrian to Middle Devonian. It is exposed at many places in the middle part of the Patricks Basin and Arsenic Peak quadrangles (pl. 1).

In most of the Sun River Canyon area this break is hard to recognize, for it is between a bed of light grayish-orange platy silty or sandy dolomite of the Maywood Formation, and thick light gray dolomite beds of the Devils Glen Dolomite (fig. 18). North of the ridge east of Arsenic Peak, the basal Devonian, a sandy dolomite, is in angular discordance with the underlying Devils Glen. Locally the dolomite fills channels with as much as 20 feet of relief in a lateral distance of 100 feet (fig. 19). The fine-grained sand of the Devonian also filled joints in the Devils Glen to a depth of 3 feet.

FIGURE 19.—Devonian and Cambrian rocks in the upper reaches of Cabin Creek. Light-gray dolomite beds of the Cambrian Devils Glen Dolomite (€dg) are overlain disconformably by the gray-brown carbonate and mudstone of the Devonian Maywood Formation (Dm). The irregularities at the base of the Devonian rocks are small channels as much as 20 feet deep.

From Arsenic Peak northward along the unconformity, many dark-brown irregularly-shaped iron nodules fill small cavities at the top of the Devils Glen.

DEVONIAN

The Devonian rocks in the Sun River Canyon area are divided into three formations, which are, in ascending order: Maywood, Jefferson, and Three Forks (table 1 and pl. 3). Deiss (1943a, p. 224) and Sloss and Laird (1945, 1946, and 1947) recognized that the rocks here called Jefferson and Three Forks are laterally equivalent to these formations in south-central Montana (Peale, 1893, p. 27–32), but believed that data were insufficient either to assign these names or to establish new names. Later work by Sandberg and Hammond (1958, p. 2320) made practicable extension of the south-central Montana nomenclature into the Sun River Canyon area, mainly through their recognition and definition of the Birdbear Member of the Jefferson Formation. Figure 20 compares the nomenclature used in the present report with that used in reports on other areas in Montana and Alberta, Canada.

In the Sun River Canyon area, the Devonian rocks are mainly grayish brown in the lower part and yellowish gray in the upper part. They contrast with the underlying light-gray Upper Cambrian rocks and with the overlying dark- to medium-gray Mississippian rocks (fig. 18).

Evaporite solution breccias occur at various horizons in the Devonian rocks, mostly in the Three Forks Formation (pl. 3). Sloss and Laird (1947, p. 1423) noted that these breccias contain fragments of Mississippian rocks; therefore, they believed the solution of the evaporite occurred after Early Mississippian time, during early Laramide (very Late Cretaceous or very early Tertiary). Christopher (1961, p. 67) believed that the removal of the salt from Middle Devonian beds in southern Saskatchewan was accelerated during Late Mississippian to pre-Middle Jurassic time. Definitive evidence is lacking in the Sun River Canyon area, but I

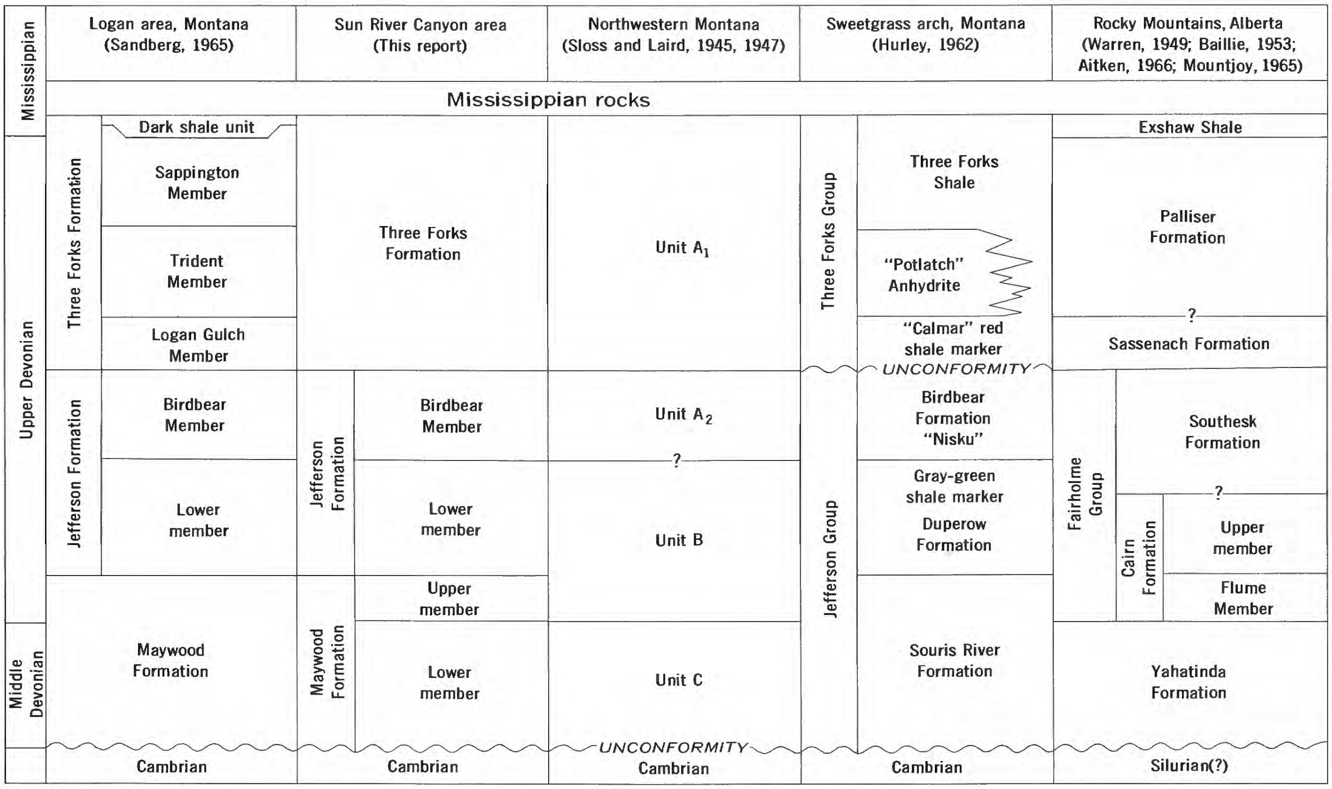


Figure 20.—Correlation chart of Devonian rocks in northwestern Montana and Canada.

prefer Christopher's interpretation. The age of the breccia formation in the Devonian may be within the period from late Early Mississippian to Early Pennsylvanian (Robinson, 1963, p. 44).

The breccias, according to Sloss and Laird (1945), are laterally equivalent to evaporite beds in the subsurface of the Sweetgrass Arch area. In Sloss and Laird's (1945) sections and in a section by Belyea (1957), evaporite beds occur at various horizons in the Devonian section from the upper part of the lower member of the Maywood Formation up through the carbonate facies of the Three Forks Formation, as do beds of breccia in the exposed Devonian sequence in the Sun River Canyon area (pl. 3).

The presence of evaporites in the Devonian sequence may be related to the formation of dolomite in these rocks (pl. 3) by the process of seepage refluxion, as explained by Adams and Rhodes (1960, p. 1919):

> Following this restriction of circulation the salinity of the brines increased and evaporites formed. The hypersaline brine eventually became heavy enough to displace the connate waters and seep slowly downward through the slightly permeable carbonates of the lagoon floor. During this seepage, the magnesium replaced part of the calcium, and metastable aragonites and high magnesium calcite recrystallized as dolomites.

Six faunal zones and beds are recognized in the Devonian rocks in the Sun River Canyon area (pl. 3). These were identified by J. T. Dutro, Jr. (written commun., 1968), and are, in descending order:

Famennian brachiopod beds in the Three Forks Formation.

Cyrtospirifer zone in the Birdbear Member of the Jefferson Formation.

Pachyphyllum zone and stromatoporoid beds in the lower member of the Jefferson Formation.

Eleutherokomma cf. *E. reidfordi* zone in the lower part of the lower member of the Jefferson Formation.

Allanaria zone in the upper member of the Maywood Formation.

These zones are in each section and exposure, except the Famennian brachiopod beds (pl. 3). However, these beds are present in the upper limestone member of the Three Forks in many exposures in the southern half of the area (Sawtooth Ridge and Patricks Basin quadrangles). In the northern half of the area, including Slategoat Mountain, this limestone is absent, owing to either pre-Mississippian erosion or incorporation in the collapsed breccia that constitutes the Three Forks Formation of that area. Each faunal zone and bed and its age is discussed under the formation in which it occurs.

Warren (1949, p. 566) listed five faunal zones and beds for the Upper Devonian rocks in Alberta. Of these, only the *Cyrtospirifer* zone and the stromatoporoid beds occur in the Sun River Canyon area. These zones and beds, however, do permit a more accurate correlation of the Sun River Devonian rocks with the Rocky Mountain Devonian sequence in Alberta. For western Alberta, Warren and Stelck (1956, p. 7) listed a somewhat different faunal succession with *Allanaria allani* fauna as the lowest. There the *Allanaria* fauna is overlain by the *Eleutherokomma* zone.

The Devonian rocks range in thickness from 950 feet in the eastern outcrop area to about 1,500 feet in the western part. As shown on plate 3, the Three Forks Formation, the Birdbear Member of the Jefferson Formation, and the Maywood Formation thicken westward; in contrast, the lower member of the Jefferson thins.

MAYWOOD FORMATION

The Maywood Formation of Middle and Late Devonian age is well exposed above the Devils Glen Dolomite and beneath the Jefferson Formation. It is divided into two members: a lower, mudstone member (Middle Devonian) and an upper, limestone member (Upper Devonian). The formation crops out along the east side of Allan Mountain and along that ridge northward to Arsenic Peak (fig. 18) and the head of Cabin and Deep Creeks and on the southwest end of Slategoat Mountain (fig. 21).

The Maywood was first defined by Emmons and Calkins (1913, p. 64–65) as part of the Silurian, but the age was later amended to Devonian by Lochman (1950, p. 2213–2217). She (1950, p. 2213) noted that the Maywood Formation is correlative with the Devonian unit C of northwestern Montana as described by Sloss and Laird (1947, p. 1418) and recommended that the name be applied for this unit in central and northwestern Montana. The definition of the Maywood Formation in this report follows that of Robinson (1963, p. 24–25) for the Three Forks area. Previously, in the Sun River Canyon area, the Maywood was regarded as Late(?) Devonian by Mudge (1966a). Correlation of the Maywood in the Sun River Canyon area with other areas in Montana and Alberta is shown in figure 20. Additional data are necessary to verify the correlation of the Maywood with the Yahatinda Formation in Alberta. The Yahatinda includes strata that were formerly part of the Ghost River Formation (Aitkin 1966, p. 4).

FIGURE 21.—Cambrian and Devonian rocks at the southwest end of Slategoat Mountain at the head of the North Fork of Glenn Creek. Ꞓdg, Devils Glen Dolomite; Dm, Maywood Formation; Djl, lower member of the Jefferson Formation.

LOWER MEMBER

The lower member is mostly greenish-gray dolomitic mudstone that forms a gentle slope above the steep ledges of the Cambrian Devils Glen Dolomite (fig. 21, and measured sections 7–9). In the eastern outcrop area the mudstones are dominantly greenish gray, but in the western outcrop area they are greenish gray with some maroon beds in the upper part of the member. Thin beds of finely crystalline yellowish-gray to olive-gray dolomite and dolomitic limestone are common in the middle and lower parts of the member. The middle of the member also contains widespread dolomite beds with lenses of breccia. In the eastern exposures the basal bed is a thin-bedded light-grayish-orange sandy siltstone that grades northward into a conglomeratic coarse-grained sandstone.

The lower member thickens westward from 26 to 207 feet (pl. 3 and fig. 21). The variation in thickness is very likely depositional and not structural. (See measured sections 7–9.)

The only fossils observed are from a dolomite bed about 24 feet above the base. (See measured section 9, unit 17). Charophytes were first recognized in this material by A. R. Palmer while he was examining it for possible Cambrian fossils. The charophytes were identified by R. E. Peck, University of Missouri (written commun., 1966). His identification and discussion follow:

Choranella burgessi Peck and Eyer. Common in the Slave Point and Watt Mountain Formations of Alberta and the copper limestone facies of the Callaway Formation of Missouri. Also known from Devonian of Nevada. Middle Devonian in age.

?*Eochara wickendi* Choquette. Middle Devonian—Alberta.

The lower, mudstone member is therefore assigned a Middle Devonian age.

The conodont *Icriodus* sp. was identified by John Huddle from near the base of the Big George Gulch section (F303, USGS 5379–SD), as reported by J. T. Dutro, Jr. (written commun., 1959).

In central and southern Montana, similar beds contain brachiopods, echinoids, conodonts, ostracodes, and trochiliscids; others contain fragmentary fish and plant remains (Sandberg and McMannis, 1964, p. C52–C53).

UPPER MEMBER

The upper member of the Maywood is mainly thin-bedded finely crystalline limestone and dolomitic limestone that form many small ledges in the basal part of the cliff and ridge formed by the resistant beds of the lower member of the Jefferson Formation (fig. 21). Locally, a thin evaporite solution breccia is present in the lower part of the member. The beds of this member are dark grayish brown to pale yellowish brown and weather light gray and yellowish gray (fig. 18). Most beds have a mottled appearance owing to distinctive pale-yellowish-orange to yellowish-gray stringers to ovoid inclusions of silty limestone or dolomitic limestone.

The upper member thickens eastward from about 70 feet in the western outcrop area to 159 feet in the eastern area. (See measured sections 7–9.)

Allanaria is abundant in thin zones in the lower half of the member, the lowest Devonian faunal zone in the area. Other fossils present are listed in table 4.

J. T. Dutro, Jr. (written commun., 1958), noted about the fauna of the member:

> The spiriferoid brachiopod *Allanaria* is common in the upper member of the Maywood Formation in each of the three sections, where it is associated with a sparse assemblage that includes productellid brachiopods, *Tenticospirifer*? sp., a finely costate *Atrypa*, and a small species of *Spinatrypa*.
>
> This zone has been recognized in the Maywood Formation of southwestern Montana and is common in the Flume Formation of Alberta, where it is considered the oldest Late Devonian fauna (basal Frasnian).

JEFFERSON FORMATION

The Jefferson Formation is mainly dark dolomite of Frasnian age (early Late Devonian). It consists of two members: an unnamed lower member and the Birdbear Member (Sandberg, 1965, p. N4–N7). The formation ranges in thickness from about 625 feet in the west to about 810 feet in the east (pl. 3). Nearly all the variation in thickness is in the lower member.

The Jefferson is well exposed in Wagner Basin, Home Gulch, west side of Mortimer Gulch, Palmer Flats, in the West Fork of Beaver Creek, on the east face of Allan Mountain, on that ridge extending north through Arsenic Peak (fig. 18) to the head of Grouse Creek, and on the southwest end of Slategoat Mountain.

LOWER MEMBER

The lower member of the Jefferson Formation contains beds considered typical of the Jefferson as defined by Peale (1893, p. 27–29) in the type locality around Three Forks and as described by Sandberg (1962, p. 48–50; 1965, p. N4–N5) near Logan. The member attains a maxmium thickness of about 650 feet in the central part of the Sawtooth Range. Thinning both east and west, it is about 390 feet thick at Slategoat Mountain and about 420 feet thick along the west side of Mortimer Gulch. At the localities shown on plate 3 where it is thin, it is mainly limestone; but where it is thick, it is mainly dolomite. (See measured sections 7–9.)

TABLE 4.—*Distribution of megafossils in the Devonian rocks in the Sun River Canyon area, Montana*

[Brachiopods identified by J. T. Dutro, Jr.; corals and algae, by W. A. Oliver, Jr.; conodont, by John Huddle; and charophytes, by R. E. Peck. Query indicates doubtful identification]

	MAYWOOD FORMATION												JEFFERSON FORMATION																																		Three Forks Formation		Collections not in measured sections						
	Lower member		Upper member										Lower member																														Birdbear Member												
	HS563	F303 (5379)	F400 (8131)	F304 (5380)	F305 (5381)	F306 (5382)	F280 (5405)	F281 (5406)	F279 (5404)	F92 (5092)	F93 (5091)	F94 (5090)	F401 (8132)	F402 (8133)	F403 (8134)	F404 (8135)	F405 (8136)	F406 (8137)	F407 (6571)	F408 (6572)	F307 (5383)	F309 (5385)	F310 (5386)	F311 (5387)	F308 (5384)	F312 (5388)	F314 (5390)	F315 (5391)	F316 (5392)	F317 (5393)	F318 (5394)	F319 (5395)	F320 (5396)	F321 (5397)	F322 (5398)	F323 (5399)	F95	F96 (8138)	F98 (5077, 5089)	F97 (8139)	F185 (5087)	F186 (5086)	F409 (8140)	F324 (5400)	F325 (5401)	F187 (5082)	F410 (6573)	F146 (5089)	F249 (5079)	F288 (5378)	F289 (5377)	F250 (5080)	F2 (5083, 5084)	F183 (5085)	F329 (5003)
Icriodus sp.		X																																																					
Solenopora sp.																																																				X			
algae, indet.						X				?						?		X						?		?				X																			?		?	?			
Chovanella burgessi Peck and Eyer	X																																																						
?*Eochara wickendi* Choquette	X																																																						
Amphipora sp.																																									X	?					?		?						
Actinostroma sp.																																						X																	
Gerronostroma sp.												X													?					X																						X			
Idiostroma sp.																									X														?																
Stachyodes sp.																																																				X			
Stromatopora sp.																																								X															
Synthetostroma sp.																																								X															
Massive stromatoporoids, indet.																											X	X											X		X														
Stromatoporoids, indet.														X				X			X			X		?			X	X	X				X		X																		
Alveolites cf. *A. rockfordensis* Hall and Whitfield																																							X																
Alveolites sp.												?													X				X	X																						X			
Thamnopora sp.												X								X				X	X						X					X					X											X			
Auloporoid, indet.																																																						X	
Ramose tabulates, indet.																															X	?	?	?					X																
Amplexiphyllum? sp.												X																																											
Breviphyllum? sp.																																																				X			
Disphyllum? sp.																															X				X																				
Macgeea sp.																			X																																				
Tabulophyllum sp.																			X						?						?								?													X			
Pachyphyllum cf. *P. levatum* Webster and Fenter																																							X		?														
Phacellophyllum sp.																													?																										
Horn corals, indet.																									X						X										X	X				X								X	
Schizophoria sp. (large)																						X																																	
Douvillina? sp.																						X																																	
Nervostrophia? sp.																													X																										
Productella sp.													X				X	X				X																																	
Productellid, indet.									X					X																															X										
"*Pugnoides*" *minutus* Warren																																																X							
"*Leiorhynchus*" cf. "*L.*" *walcotti* Merriam																																																X							
Paurorhyncha utahensis (Kindle)																																																							X
Trifidorostellum? sp.																																																							X
Sinotectirostrum? sp.																																																X							
Allanaria sp.			X		X		X		?	X	X	X																																					X						
Tenticospirifer sp.					?	?		?			?	?										X																																	
Eleutherokomma cf. *E. reidfordi* Crickmay															X	X	X					X	X																																
Cyrtospirifer sp.														X															X																X	?		X					X		X
Cyrtiopsis? sp.																																																X							
Theodossia? sp.																																																					X		
Spinatrypa sp. (small)											X		X																																X										
Spinatrypa sp. (large)															X	X	X					X	X																																
Atrypa sp. (fine costae)				X									X	X																													X												
Atrypa spp.														X															X	X	X								X		X			X									X		
Cyrtina cf. *C. iowaensis* Fenton and Fenton																																							X																
Cyrtina? sp.													X		X																																			X					
Cranaena? sp. cf. *C.*? *vera* (Belanski)																																							X																

NOTE.—In boxheads, numbers prefixed with "F" or "H" are field numbers; numbers in parentheses are USGS locality SD numbers.

In the eastern part of the Sun River Canyon area this member is dolomite with some limestone and calcitic dolomite. In the western outcrop area, however, this member consists mainly of limestone, magnesian limestone, and dolomitic limestone; dolomite and calcitic dolomite are lesser components. The beds are mostly about 1 foot thick and finely crystalline, in places sandy. They are distinctively grayish brown except for a few light-gray-brown beds in the middle and upper parts of the member which form distinct light bands in outcrop (figs. 18 and 21). The rock characteristically has a fetid odor; locally, oil stains are present.

One or more thin beds of evaporite solution breccia are common in the lower part (pl. 3). They consist of angular blocks of limestone, dolomitic limestone, and dolomite in a limestone matrix. The breccia may correlate with evaporite beds that are in the lower part of the Jefferson in the subsurface to the east.

The lower member contains many beds that have saccharoidal or sucrose texture. According to Murray (1960, p. 69–73), this texture is a result of filling of space once occupied by cryptocrystalline calcite by randomly oriented dolomite rhombs. Calcite matrix remaining between the rhombs has been dissolved to produce voids, thus accounting for the high porosity and permeability of the beds. Murray and Lucia (1967, p. 29) stated that porosity can be formed and maintained if the sediment being dolomitized is the only source of carbonate.

Dark-gray chert lenses and nodules are common in the lower part of this member in the eastern outcrop area but are absent in the western exposures.

A grayish-green dolomitic mudstone is near the top of this member only in exposures along the west side of Mortimer Gulch. This mudstone may be laterally equivalent to the gray-green shale marker at the top of the Duperow Formation as recorded from the subsurface in the Sweetgrass Arch area by Hurley (1962, p. 24).

The lower member forms cliffs. Many beds are sufficiently resistant to form small overhanging ledges. In most places the lower member of the Jefferson grades into the member of the Maywood Formation.

Fossils common in the lower member are listed in table 4. A remarkably greater variety and number of fossils are in this member than in the other units of the Devonian; elsewhere in western Montana the lower member of the Jefferson is relatively unfossiliferous. In the Sun River Canyon area the two faunal zones in the member—*Pachyphyllum* and *Eleutherokomma* cf. *E. reidfordi*—are widely recognizable and aid in stratigraphic correlation and interpretation (pl. 3). The stromatoporoid beds, in the lower and middle parts of the member, are characteristic of the Duperow Formation of western Montana (Wilson, 1955; Hurley, 1962, p. 31), of the Fh_b unit of the Fairholme Formation or Woodbend Group of the southern Alberta plains (Belyea, 1957 and 1958), of the lower part of the Fairholme Formation in the Rocky Mountains of Alberta, and of the middle part of the member at the type locality of the Jefferson at Logan, Mont. (Wilson, 1955; Sandberg, 1962, p. 49).

Massive stromatoporoids are widespread in the lower part of the member (pl. 3). In the easternmost measured section (8) they occur as small individual masses from 125 to 240 feet above the base of the member, whereas, in the central measured section (7) they form biostromes as much as 3 feet thick from 200 to 275 feet above the base of the member. Here they resemble colonies of stromatolites in the Precambrian Helena Dolomite. Although present in the western measured section (9), the masses are smaller and less abundant than in the other sections. Stromatoporoids are thought to indicate a rough-water environment at or just below the low-tide level and well above wave base (R. S. Boardman, written commun., 1956).

In the Sun River Canyon area, *Amphipora* occurs as widespread biostromes in the upper part of the lower member of the Jefferson (pl. 3). Locally, *Amphipora* are also in the middle and lower parts of the member but not as biostromes. *Amphipora* beds are commonly referred to as "spaghetti beds" or "spaghetti coral." Helen Duncan (in Robinson, 1963, p. 28) pointed out: "The general prevalance of *Amphipora* in calcareous facies of the Devonian all over the world makes this one of the more useful fossils in stratigraphic work." *Amphipora* is commonly recorded in the most recent descriptions of the Jefferson Formation in Montana (Wilson, 1955, cross sections; Sandberg, 1962, p. 48–50; Robinson, 1963, p. 26–29; and many other workers in Montana).

Eleutherokomma cf. *E. reidfordi* is a common spiriferoid in the lower part of the member in the Big George Gulch (measured section 7) and Mortimer Gulch (measured section 8) sections, according to J. T. Dutro, Jr. (written commun., 1968). Dutro further stated:

> *Eleutherokomma* ranges from 55 to 110 feet above the base of the lower member in Big George Gulch and from 65 to 75 feet above the base in Slategoat Mountain. The assemblage found with this species includes *Schizophoria* sp. (large), *Douvillina?* sp., *Productella* sp., *Spinatrypa* (large), *Tenticospirifer* sp., and *Crytina?* sp.
>
> A similar faunal assemblage has been reported from the Maligne Formation in Alberta, the next youngest rock unit above the Flume, and from the lower member of the Hay River Formation in the district of Mackenzie.

The *Pachyphyllum* zone consists of rugose corals of Frasnian age that occur at several levels in the Jefferson Formation. Pertaining to the corals J. T. Dutro, Jr. (written commun., 1968), stated:

Pachyphyllum cf. *P. levatum* Webster and Fenton was identified by W. A. Oliver, Jr., from the Mortimer Gulch section at 140 feet above the base of the lower member. Other fossils at this level include *Alveolites* cf. *A. rockfordensis* Hall and Whitfield, *Tabulophyllum*? sp., ramose favositoids, *Atrypa* sp., *Cyrtina* cf. *C. iowaensis* Fenton and Fenton, and *Cranaena*? cf. *C.*? *vera* (Belanski). Similar *Alveolites* occur also in the Big George Gulch section from 215 to 230 feet above the base of the lower member. In the latter collection are also found *Nervostrophia*?, *Cyrtospirifer* sp., and *Atrypa* sp. *Macgeea* and *Tabulophyllum* occur at 290 feet above the base of the Slategoat Mountain section.

These coral-rich beds, together with the massive stromatoporoid-bearing strata, can probably be compared with the coralline members of the Southesk Formation of Alberta. They are probably middle or late Frasnian age.

BIRDBEAR MEMBER

The Birdbear Member was originally defined as a formation by Sandberg and Hammond (1958, p. 2318), who applied the name to the light-colored dolomite and limestone beds that overlie the Duperow Formation (called the lower member of the Jefferson Formation in this report) and underlie the Three Forks Formation. Even though the type section is in the subsurface in Dunn County, N. Dak., the Birdbear is recognized as an outcropping unit over much of Montana (Hurley, 1962, p. 24; Sandberg, 1962, p. 48 (listed as upper member of Jefferson Formation), and 1965, p. N7). Although the Birdbear is still considered a formation in the Williston basin, it is used as a member of the Jefferson Formation (Mudge, 1965, 1966a) in the Sun River Canyon area. This member generally forms a light-yellowish-gray slope above the dark-grayish-brown cliffs of the lower member of the Jefferson Formation (fig. 18). The Birdbear ranges in thickness from 150 to about 235 feet (pl. 3). Its maximum thickness is in the westernmost exposure, at Slategoat Mountain, and its minimum thickness is in an eastern exposure, at Mortimer Gulch. (See measured sections 7–9.)

The Birdbear Member is mostly thin beds of very fine to finely crystalline dolomite. (See measured sections 7–9.) The lower part contains many distinctive thin pale-yellowish-brown to brownish-gray beds that pinch and swell. The upper part of the member is thin, platy light- to medium-gray, pale-yellowish-brown, and light-brownish-gray beds. A thin evaporite solution breccia occurs in the lower part of the Birdbear in the Slategoat Mountain section. (See unit 45, measured section 9.)

The characteristic *Cyrtospirifer* zone is present in the lower beds of the Birdbear. According to J. T. Dutro, Jr. (written commun., 1958 and 1968), the *Cyrtospirifers* are sparsely distributed and occur with rather finely ornamented *Atrypa* and *Theodossia*?. He further stated that the zone is probably late Frasnian age, perhaps equivalent to the Ronde Member of the Southesk Formation in Alberta. In most places fossils are not abundant in this member even though it contains a varied assemblage of horn corals, bryozoans, brachiopods, and fish teeth. The fossil collections are listed in table 4.

In addition, fish teeth are in collections F2 and F183 (USGS loc. 5085–SD, 5082–SD, and 5083–SD) from the lower part of the member in the center of SE¼ sec. 35, T. 22 N. R. 9 W., Home Gulch, south side of Diversion Reservoir. Regarding these teeth, D. H. Dunkle (written commun., 1958) stated: "The teeth are the only part of the fish known. Such teeth are rather common in the more limy sediments of Middle and Late Devonian age around the world."

THREE FORKS FORMATION

The Three Forks Formation consists of rocks of Late Devonian age in the southern part of the Sun River Canyon area, but also contains rocks of Early Mississippian age in the northern part (table 1). Previous geologic maps by Mudge (1965; 1966a, b) erroneously referred to the upper few feet of beds of the Three Forks as Early Mississippian. Recent data indicate that all the Three Forks is Devonian except in the northern part of the area, where the uppermost 2–3 feet is Mississippian. At Slategoat Mountain the breccia of the Three Forks includes some lower Mississippian rocks. The Three Forks crop out in Wagner Basin, Home Gulch, west side of Mortimer Gulch, Palmer Flats, and the West Fork of Beaver Creek, along the east face of the ridge which extends north from Allan Mountain through the upper reaches of Grouse Creek; in the upper reaches of the South Fork of Deep Creek (pl. 1), and on the southwest end of Slategoat Mountain.

The thickness of the Three Forks Formation varies considerably. In most places in the northern outcrop area the formation is represented only by breccia (figs. 18 and 22). Locally the breccia thins to about 50 feet. On the west side of Big George Gulch, at Gibson Reservoir, it is about 200 feet thick, and is half breccia and half limestone. At the southwest end of Slategoat Mountain the Three Forks, entirely breccia, is 589 feet thick. All the breccia at Slategoat Mountain is mapped as Three Forks, though the upper half may contain Mississippian rocks equivalent to the lower member of the Allan Mountain Limestone. (See measured sections 7–10.)

There may be some sort of ratio between thickness of the existing breccia and original thickness or composition of the evaporite sequence. In many places, one or more zones of brecciated dolomite form rough irregular

FIGURE 22.—Vertical sinuous outcrop of the evaporite solution breccia in the Three Forks Formation near station 245 (pl. 2). Lower member of the Allan Mountain Limestone to the left and thrust-faulted Three Forks Formation on the right. Here, the boundary between the Mississippian and Devonian rocks is on top (left side) of the breccia. At the top of the ridge the breccia is about 30 feet thick.

massive ledges that thicken and thin along strike (figs. 18 and 22). In general, the breccias thicken to the north and especially to the northwest. In the southern part of the area, where breccias are thin, the normal sequence of beds persists; but in the north, where they are thick, the overlying beds are mostly absent. The thickest breccia is at Slategoat Mountain, where it includes rocks of Mississippian age (pl. 3). Stanton (1966, p. 845) pointed out that if the evaporite was originally gypsum, there would be a volume decrease of about 40 percent in the transformation of gypsum to anhydrite and the removal of water, provided additional $CaSO_4$ was not added. He believed the transformation would result in much subsidence and possible breakage without removal of gypsum or anhydrite. The absence of gypsum or anhydrite in the Sun River Canyon breccias indicates that they were completely removed, possibly at a later stage.

The breccia is composed of angular blocks of very fine to medium-crystalline pale-yellowish-brown dolomite and dolomitic limestone. Most of the fragments are less than 2 feet long, but some are tens of feet long (Sloss and Laird, 1945). In most places the breccia is firmly cemented with finely crystalline dolomite and dolomitic limestone. Locally, however, it is very porous and secondary calcium carbonate lines the pore spaces; some exposures contain large cavities. W. A. Oliver, Jr. (written commun., 1963, identified an amphiporoid stromatoporoid (probably *Amphipora* sp.) from these beds. (See F410, unit 49, measured section 9.)

A very thick bed of limestone overlies the breccia in the Patricks Basin and Sawtooth Ridge quadrangles. This limestone, about 100 feet thick on the ridge that forms the west side of Big George Gulch, just north of Gibson Reservoir (pl. 3), thins south and east to as little as 20 feet. The rock is grayish brown and very fine grained and contains lentils of porous gray-brown chert.

The limestone contains the Famennian brachiopod beds of the Devonian, which include the silicified "*Pugnoides*" *minutus* brachiopod faunule. In the southeasternmost outcrop "*P.*" *minutus* occurs with large poorly preserved gastropods. Pertaining to the age of the collection from this limestone, J. T. Dutro, Jr. (written commun., 1958), stated: "The association of "*Leiorhynchus*" cf. "*L.*" *walcotti* Merriam and "*Pugnoides*" *minutus* (Warren), together with cyrtospiriferids, in F146 is quite characteristic of Famennian assemblages in the northern Cordillera." The fossils collected from this part of the Three Forks Formation are listed in table 4.

Dutro (written commun., 1968) believed the beds are approximately equivalent to the Trident Member of the Three Forks Formation of southwestern Montana and the Costigan Member of the Palliser Formation of Alberta.

Seventeen feet of a grayish-green and black shale and yellowish-gray limestone overlie the *Pugnoides*-bearing limestone at the north end of the Sawtooth Ridge. Elsewhere in the area these strata are absent, owing to either pre-Madison erosion (Mudge and others, 1962, p. 2008), nondeposition, or incorporation in the breccia. The sequence at Sawtooth Ridge is described in measured section 10. Here the contact between the Mississippian and Devonian is between unit 7 and the overlying limestone with Mississippian corals and crinoids. The black shale (unit 5) was identified by R. C. Gutschick (written commun., 1962) as the lower black shale of the Sappington Member in Montana that is correlative with the Exshaw Shale in Alberta. The black shale rests disconformably on clay shale of the Three Forks Formation (Gutschick and others, 1962, p. 79, fig. 1). The underlying clay shale is iron-enriched and contains abundant brown iron nodules. The origin of the enrichment is not certain; it may represent a paleosol.

In the upper part of Deep Creek (sta. 246, pl. 2) 3 feet of black shale separates typical basal Allan Mountain Limestone from brecciated dolomite beds of the Three Forks. According to R. C. Gutschick (written commun., 1965), this shale does not have the conchostracans that are typical of the black shale (unit 5, measured section 10) on Sawtooth Ridge, and it may be the upper black shale of the Sappington Member as described by Gutschick, Suttner, and Switek (1962, p. 80) and Sandberg (1965, p. N16). If so, it is Mississippian. At station 245 (pl. 2), 1 mile north of station 246, there is a lag deposit containing thin (0.4 ft) iron-stained coquina at the unconformity at the base of the Allan Mountain. This coquina contains conodonts of Mississippian age (C. A. Sandberg, oral commun., 1967).

In the Sun River Canyon area the Three Forks Formation conformably overlies the Birdbear Member of the Jefferson Formation. In the Sweetgrass Arch area, Hurley (1962, p. 24 and 32) showed the Three Forks Formation as resting unconformably on the Birdbear, citing Deiss (1933) for evidence of a sandstone bed present above the Birdbear in the central Sawtooth Range but absent in the Sweetgrass Arch area. However, sandstone is not present at this position in the Sun River Canyon area. Related to this problem is the misconception by Deiss (1933, p. 46) of the Silvertip Conglomerate Member of the Madison as a basal conglomerate of the Mississippian sequence. Sloss and Laird (1947, p. 1420) showed, and I confirm, that the "Silvertip conglomerate" is the evaporite solution breccia of the Three Forks Formation, and, except at Slategoat Mountain it is Devonian. Conglomerate is not present at the base of the Mississippian sequence in the Sun River Canyon area.

DEVONIAN-MISSISSIPPIAN BOUNDARY

The position of the Devonian-Mississippian boundary is fairly accurately established in the Sun River Canyon area even though it remains a problem in many places in western Montana. The boundary is at a slight disconformity at the base of a limestone sequence of the Madison Group that contains crinoidal debris and Mississippian corals in the exposure at the north end of Sawtooth Ridge (sta. 57). In most of the northern outcrop area the uppermost beds of the Sawtooth Ridge section of the Three Forks Formation are absent, and beds of Mississippian limestone rest on the breccia unit of the Three Forks (fig. 22); so the systemic boundary is at the contact.

At Slategoat Mountain, both Devonian and Mississippian rocks seem to be incorporated in a great thickness of breccia within which the systemic boundary falls (pl. 3). Sloss and Laird (1945) recognized fragments of Mississippian limestone in this breccia. At Slategoat Mountain the overlying middle member of the Allan Mountain Limestone of the Madison Group rests directly on breccia. Therefore, the breccia includes from 160 to as much as 275 feet of Mississippian rocks, comprising all the lower member of the Allan Mountain Limestone. As shown on plate 3, the boundary between the Devonian and Mississippian rocks may be at the contact between the lower, dolomite breccia and the overlying dolomitic limestone breccia. Elsewhere in the Sun River Canyon area the lower member of the Allan Mountain Limestone is composed of beds of dolomitic limestone and limestone. Therefore, the upper 275 feet of the breccia at Slategoat Mountain is composed of Mississippian rocks. This thickness is reasonable when it is compared with the range in thickness of the lower member of Allan Mountain Limestone, and allowance is made for an expansion of volume of the section where it was brecciated. The amount of expansion ranges from 13 to 40 percent, if the range of thickness for the lower member is applicable.

MISSISSIPPIAN

MADISON GROUP

The most prominent rocks in the Sun River Canyon area are of Mississippian age. They form the many north-trending ridges that extend from the mouth of the canyon, at Diversion Dam, west to Sheep Mountain (pl. 1). Most of these ridges rise more than 1,000 feet above the Sun River. The east side of each ridge is a near-vertical cliff, whereas the west side slopes more gently. Although the Sun River Canyon area affords excellent exposures of the Madison Group, completely exposed sections are not common because thrust faults have cut out part of the sequence. However, complete sections are exposed in many places along the ridge that includes Allan Mountain and Arsenic Peak (fig. 18) and in the upper reaches of the South Fork of Deep Creek. The reference section of the Madison (in the Patricks Basin quadrangle, Sun River area), as well as all fossil collections, has been described in detail by Mudge, Sando, and Dutro (1962, p. 2005) and is not repeated in this report. The remaining sections illustrated by Mudge, Sando, and Dutro (1962, fig. 3) are included as measured sections 8, 11, and 12 in the present report.

The divisions of the Madison Group used in the southern part of the Sawtooth Range are the Allan Mountain Limestone and the Castle Reef Dolomite. The Allan Mountain is subdivided into three unnamed members, and the Castle Reef Dolomite is subdivided into a lower, unnamed member and the Sun River Member. The Allan Mountain is mostly thin beds of dark-gray limestone, and the Castle Reef is mostly thick beds of light-gray dolomite (Mudge and others, 1962, p. 2004–2009, and fig. 3).

The correlation of the Mississippian rocks of the Sun River Canyon area with those in the north-central Montana and Alberta, Canada, sequences is shown in figure 23. This figure also compares the units described by

Age	North-central Montana (Knechtel, 1959)	Sun River Canyon area: (Sloss and Laird, 1945)	Sun River Canyon area: (This report, Mudge and others, 1962)		Southern Alberta plains (Alberta Society of Petroleum Geologists, 1964)
Meramec		MA	Castle Reef Dolomite	Sun River Member	Mount Head Formation
Osage	Mission Canyon Limestone	? MB$_1$		Lower member	Livingstone Formation
	Lodgepole Limestone	? MB$_2$	Allan Mountain Limestone	Upper member	
Kinderhook		MC		Middle member	Banff Formation
				Lower member	
	Upper part of Three Forks Formation				Bakken Formation

FIGURE 23.—Correlation of Mississippian rocks in the report area with those in north-central Montana and Alberta, Canada.

Sloss and Laird (1945) with those of this report, which are the same as those described by Mudge, Sando, and Dutro (1962).

Faunal zones in the Madison, recognized by Sando and Dutro (1960), are applicable to the Sun River Canyon area (Mudge and others, 1962, p. 2009). These zones are based mainly on corals and are designated by letters. *Cyathaxonia*, characteristic of Zone A, is common in the lower few feet of Mississippian beds and occurs sparsely in the rest of the Allan Mountain Limestone. Zone B contains numerous brachiopods and small horn corals, mostly in the middle member. Zone C spans the upper member of the Allan Mountain Limestone and most of the Castle Reef Dolomite. This zone contains a large and varied fauna of brachiopods and corals (Mudge and others, 1962, p. 2013). Specimens of *Homalophyllites* are abundant in thin zones above and below the contact between the two formations; brachiopods appear to be more abundant in this part of the section than elsewhere in the Madison. Faunal Zone D spans the upper part of the Sun River Member of the Castle Reef Dolomite. *Perditocardinia*, *Faberophyllum*, and *Lithostrotion Siphonodendron*) characterize this faunal zone (Mudge and others, 1962, p. 2018). They are widespread and generally are silicified. The two most numerous and most noticeable corals throughout the Madison are *Syringopora* and *Vesiculophyllum*. The most abundant fossil remains, however, are the many beds of crinoidal debris, called encrinites.

Complete sections of the Madison Group are present on the ridge including Allan Mountain and Arsenic Peak (fig. 18) and also along the upper reaches of the South Fork of Deep Creek (fig. 24). Deiss (1943b, p. 1165) recorded 1,400 feet for the thickness of the Madison Group in the Sawtooth Range. To the north, near the head of Cabin Creek, Sloss and Laird (1945) showed this group as being about 1,700 feet thick. East of this section, in the Deep Creek area, the Madison Group is 900 feet thick. On the north shore of Gibson Reservoir it is about 1,250 feet thick (Mudge and others, 1962, p. 2008). About 4 miles to the south on Allan Mountain it is 1,230 feet thick (Sloss and Laird, 1945). Much of the variation in thickness is a result of pre-Jurassic erosion, which is discussed on page A42.

The origin of the dolomite in the upper half of the Mississippian sequence warrants discussion. Most of the fragmentary evidence indicates that dolomitization occurred shortly after burial:

1. The encrinites are highly porous.
2. They increase in number to the west.
3. They are more numerous in the Castle Reef Dolomite; the lowest occurrence is in the Allan Mountain Limestone.
4. Magnesium increases both upward in the section and to the west (Mudge and others, 1962, p. 2008, fig. 3), as do the encrinites.
5. All the fine-grained dolomites are exceptionally rich in magnesium. These beds may have been argillaceous limestones.
6. No data indicate that any of the dolomites are primary precipitates of dolomite.

The environment of deposition of warm shallow open marine waters in which life flourished under shoal conditions prevailed throughout much of Madison sedimentation. There are no data from in or near the Sun River Canyon area to suggest that restricted seas and evaporite deposition occurred during this time. However, younger Mississippian strata, containing evaporites, have been

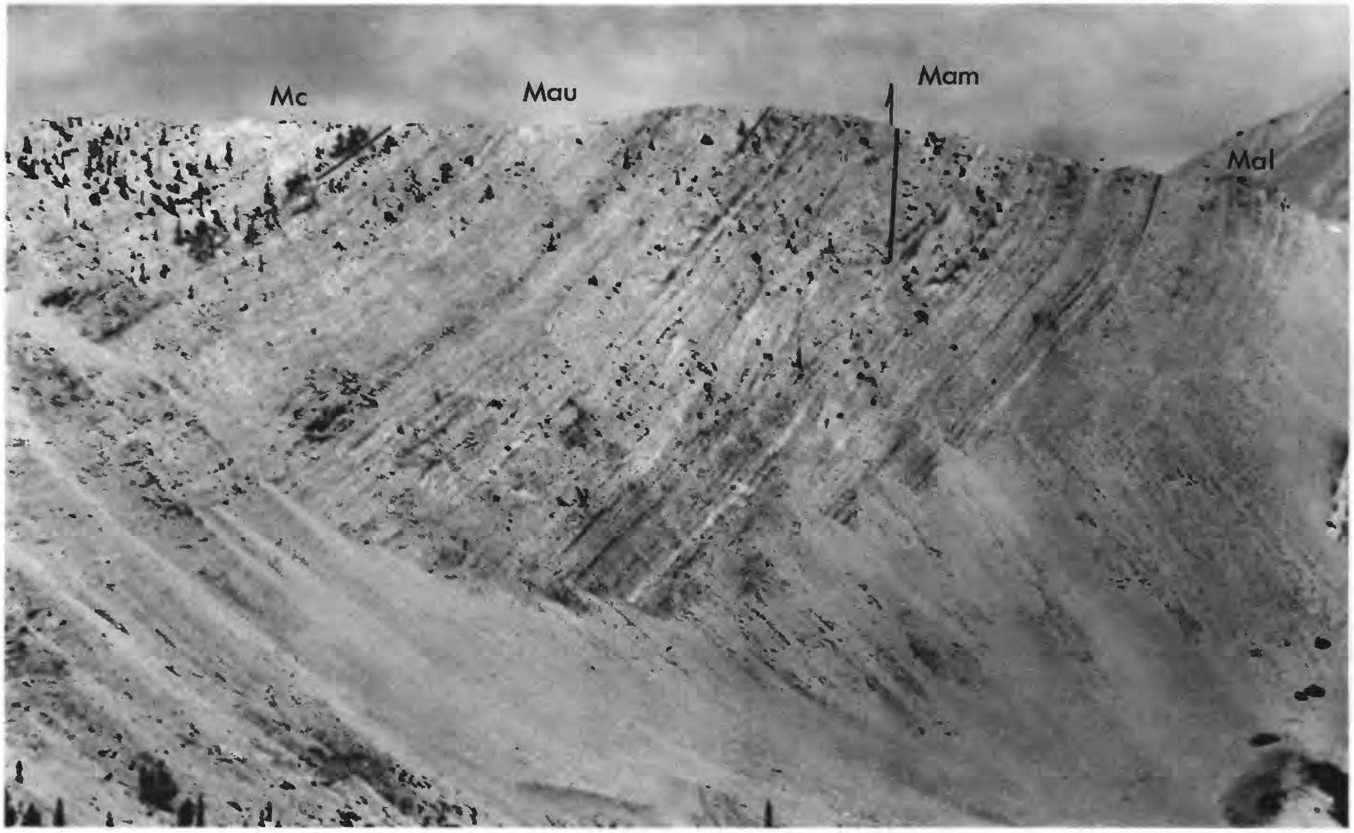


FIGURE 24.—Mississippian rocks exposed in a north tributary of the South Fork of Deep Creek near station 245 (pl. 2). Mal, lower member; Mam, middle member; and Mau, upper member of the Allan Mountain Limestone; Mc, Castle Reef Dolomite (lower member). The middle member of the Allan Mountain Limestone is repeated by a small thrust fault (arrow).

described in the subsurface in eastern Montana by Fish and Kinard (1959, p. 53–55). If they existed in the Sun River area, dolomitization may have resulted from a condition of seepage refluxion from hypersaline brines in a manner described by Adams and Rhodes (1960, p. 1919), who are quoted on page A28.

Some of the magnesium may be from the crinoidal debris. Twenhofel (1939, p. 331) stated: "Skeletons of modern echinoderma contain magnesium carbonate, and it may be supposed that fossil forms had the same characteristic. Crinoidal limestones may hence be expected to be slightly dolomitic." Also, Fairbridge (1957, p. 138–139) noted that the higher the environmental temperature within any class of organisms, the higher the magnesium, and the more primitive the plant or animal, the higher the magnesium. The washing and sorting of the crinoidal debris may have charged the waters with more calcium and magnesium than normal, and highly porous encrinites may have permitted seepage refluxion to the buried beds. The selectivity of the early dolomitized waters for the argillaceous beds was described by Murray and Lucia (1967, p. 28–29) for similar rocks in Alberta. In the Sun River Canyon area the very fine-grained beds (possibly argillaceous) show a gradual decrease in magnesium from the fine-grained part to the adjacent coarse-grained encrinites and limestones. In the Madison the amount of magnesium decreases downward, indicating the supply of magnesium was from above or the side, and occurred after the deposition of much if not all the sequence.

ALLAN MOUNTAIN LIMESTONE

The Allan Mountain Limestone was named by Mudge, Sando, and Dutro (1962, p. 2009) from excellent exposures high on the east side of Allan Mountain. At least part of this formation is present on nearly every ridge in the Sun River Canyon (pl. 1). The Allan Mountain Limestone ranges in thickness from 535 to 650 feet, thickening somewhat to the north. This formation is divided into three distinctive unnamed members.

LOWER MEMBER

The lower member is well exposed on the ridge containing Allan Mountain and at various places along this ridge north to the head of Grouse Creek (fig. 18). This member is also exposed on the north end of Sawtooth Ridge, at the head of Wagner Basin; on the west side of Beaver Creek, Green Timber Gulch, and Mortimer Gulch, and in the upper reaches of the South Fork of Deep Creek (fig. 24). On Allan Mountain it is about 160 feet thick, whereas at the type locality at Gibson Reservoir it is about 225 feet thick; at the latter locality minor deformation may account for the apparent increase in thickness.

The lower member is mostly dark-gray very thin bedded argillaceous dolomitic limestone with many shale partings. The lower 50 feet of the member contains gray dense limestone beds, 1–4 feet thick, interbedded with equally thick calcareous, gray-brown silty thin-bedded mudstones. In most places the member abounds in fossils (faunal Zone A), which were listed by Mudge, Sando, and Dutro (1962, p. 2012).

Middle Member

The middle member, about 150 feet thick, is well exposed in the same areas as the lower member. (See measured section 11.)

The middle member is thin-bedded dark-gray fine-grained limestone with some dolomitic limestone. It characteristically contains lenses and nodules of bedded gray chert throughout, 6–10 inches apart. In the lower part of the member the chert nodules are irregularly shaped (1–4 in. thick) and have a dark-gray core and a light-yellowish-gray concentric-layered weathered rind. In the middle of the member there are many even-bedded chert lenses 3–4 inches thick, but some are as much as 1.5 feet thick. The upper part of the member contains even-bedded lenses of fibrous-appearing chert with interstitial limestone. The chert weathers dark grayish brown and ¼–½ inch in relief on the surface.

The contact of the middle member with the lower member is distinct but gradational and is placed below the lowest limestone that contains bedded chert.

The middle member is sparsely fossiliferous; only a few fossils were listed by Mudge, Sando, and Dutro (1962, p. 2013).

Upper Member

The upper member, 200–300 feet thick, crops out widely in the Sun River Canyon area. It is especially well exposed at or just east of the crest of the high ridges in the Patricks Basin and Arsenic Peak quadrangles, and at Sawtooth Ridge (pl. 1). (See measured sections 11–13.)

The member consists of thin to very thick beds of limestone, magnesian limestone, and dolomitic limestone. They are fine grained and dark gray and weather light to medium gray. Nodules and lentils of gray to gray-brown chert are common and are not as abundant as in the middle member.

Some beds are coarsely crystalline porous encrinites, and others contain lenses of encrinite. In the eastern outcrop area the lowest stratigraphic position of encrinite is in the upper member, but at Slategoat Mountain encrinites occur as low as the lower part of the middle member. These coquinas very likely interfinger with beds of finely crystalline limestones, because their position differs considerably from one exposure to another, even though the coquinas mainly occur in the middle part of the member. The contact between the upper and middle members is gradational and in places is difficult to determine within an interval of 100 feet.

A large and varied fauna was listed by Mudge, Sando, and Dutro (1962, p. 2013) for the upper member. It is dominated by brachiopods and corals that are characteristic of faunal Zone C. The coral *Homalophyllites* is abundant especially about 100–130 feet beneath the top of the member.

CASTLE REEF DOLOMITE

The Castle Reef Dolomite was named by Mudge, Sando, and Dutro (1962, p. 2015) for Castle Reef Mountain. The excellent exposures of the type locality are on the south end of that mountain, just north of Diversion Lake and east of Hannan Gulch. Other complete exposures are on almost all the mountain ridges in the Sawtooth Range. In most places the formation forms the crests and the west dip slope.

The Castle Reef Dolomite ranges considerably in thickness in the Sun River Canyon area. (See measured sections 11–13.) In the eastern part it ranges in thickness from 730 to 815 feet. It is 650–800 feet thick in the Patricks Basin quadrangle and thickens westward to about 1,000 feet in the Pretty Prairie quadrangle. North of the Sun River, in the northern part of the Arsenic Peak quadrangle, it ranges in thickness from 950 feet in the west to 250 feet in the east. Here, the thinning is a result of pre-Jurassic erosion.

The Castle Reef Formation is divided into an unnamed lower member and the Run River Member.

Lower Member

The lower member of the Castle Reef generally forms the crest and the upper part of the west dip slope of the mountainous ridges in the Sun River Canyon area. In most places this member ranges in thickness from 375 to 475 feet. In the northern part of the Arsenic Peak quadrangle, however, it was reduced to a thickness of 250 feet by pre-Jurassic erosion. (See measured sections 11–13.)

The lower member of the Castle Reef Dolomite is thick-bedded fine- to coarse-crystalline light- to medium-gray dolomite, calcitic dolomite, dolomitic limestone, and limestone. The proportion of dolomite to limestone increases to the west (Mudge and others, 1962, p. 2008 and fig. 3), especially in the upper part of the member. The coarsely crystalline beds are composed almost entirely of crinoidal debris and occur at various positions in the member. Locally, the weathered surface of these beds shows crossbedding.

Lenses and nodules of gray chert are generally in the middle and upper parts of this member, and a widespread zone of thin-bedded dark-gray chert occurs about 100 feet above the base.

The boundary between the Allan Mountain Limestone and Castle Reef Dolomite is conformable. It is at the base of the lowest thin dolomite bed in the Madison Group (Mudge, and others, 1962, p. 2015). This very fine grained dolomite, 3–10 feet thick, characteristically fractures into small elongate vertical joint blocks that weather to small but very discernible reentrants in the cliff. Beneath it, the upper beds of the Allan Mountain Limestone form a broad light-gray massive band along the cliffs in the eastern and southern outcrop areas. In addition, the small solitary horn coral *Homalophyllites* occurs abundantly in thin zones within and just below these massive beds. This coral is also present, but not abundant, in the lower beds of the Castle Reef Dolomite. The chert zone described above is about 100 feet above the dolomite marker bed. This zone commonly forms a narrow dark band along a cliff face.

In the northern outcrop area the two formations of the Madison are distinctly different. The Allan Mountain Limestone is dark gray and thin bedded, whereas the Castle Reef Dolomite is light gray and thick bedded (figs. 18 and 24). These contrasts are more subtle in the southern and eastern outcrop areas.

The lower member of the Castle Reef Dolomite contains a large and varied fauna, especially in the lower part. This fauna, described by Mudge, Sando, and Dutro (1962, p. 2016–2017), is mostly brachiopods and corals comprising part of faunal Zone C. *Homalophyllites* sp., though not as abundant as in the upper member of the Allan Mountain Limestone, is locally present throughout much of the lower member of the Castle Reef Dolomite. *Vesiculophyllum* sp. and *Syringopora* sp. are very common, appearing to be more abundant in the upper part of the member.

Sun River Member

The name Sun River was first published by Chamberlin (1955, p. 78) for the uppermost formation, the Sun River Dolomite of the Madison Group. The stratigraphic rank of the Sun River was formally changed to member of the Castle Reef by Mudge, Sando, and Dutro (1962, p. 2017). The member correlates with the lower part of the Charles Formation in the subsurface of eastern Montana and with the upper part of the Mission Canyon Limestone in the Three Forks area, Montana.

The Sun River Member varies in thickness over much of the area, mainly because of pre-Jurassic erosion. Locally in the northeastern part of the Arsenic Peak quadrangle it has been completely removed. Elsewhere, the member ranges in thickness from 250 to 450 feet in the northwestern outcrop area.

The Sun River Member contains thin to thick beds of very fine to medium-crystalline dolomite and locally, some interbedded calcitic dolomite. (See measured sections 11–13.) These beds are light to medium gray and characteristically weather a very light gray. Many of the lower beds contain thick lenses of encrinite, some of which are coarsely crystalline. Even though these are pure dolomite, the relict structure of the crinoid columnals is preserved. Some of the dolomite beds contain well-preserved silicified corals and brachiopods, suggesting that dolomitization followed silicification. Light-gray to gray-brown chert nodules and quartz- and calcite-lined geodes are common, especially in the upper part. Locally on the east side of Hannan Gulch, about 4 miles north of the Sun River, the lower beds of the member are coarsely crystalline and contain some low-angle crossbeds.

In the Hannan Gulch section and on the south side of Bear Creek (just north of sta. 183), a lens 2 feet thick and 50 feet long of very fine grained crossbedded sandstone occurs about 20–40 feet beneath the top of the member. West of station 183 a similar lens is about 100 feet below the top of the Madison. This sandstone is petrographically similar to that of the overlying Jurassic Sawtooth Formation and is likely a Jurassic cave filling. On the south end of Diversion Ridge this sandstone fills joints to depths of 20 feet or more and occurs as sills along bedding planes for distances of 5 feet or more.

The Sun River Member is in transitional contact with the underlying lower member described by Mudge, Sando, and Dutro (1962, p. 2017). In the eastern outcrop area (measured section 11) this contact is more easily determined than in the western outcrop area. To the east the basal bed of the Sun River is a medium-crystalline light-gray dolomite that overlies the upper bed of the lower member, which is a coarsely crystalline encrinite of magnesian limestone. In the westernmost section, dolomite beds of the Sun River overlie dolomite beds of the lower member (Mudge and others, 1962, p. 2005–2006). Here, the basal dolomite of the Sun River is medium to coarsely crystalline, massive, and light gray, whereas the upper dolomite of the lower member is fine to medium crystalline, thin to medium bedded, and light gray.

The fauna of the Sun River Member was discussed by Mudge, Sando, and Dutro (1962, p. 2018). The moderately large fauna of Zone D consists mostly of corals. Mudge, Sando, and Dutro (1962, p. 2018) stated: "The presence of *Perditocardinia*, *Faberophyllum*, and *Lithostrotion* (*Siphonodendron*) in the Sun River fauna suggests that the member is at least partly of early Late Mississippian (Meramec) age." A similar conclusion as to the age was made earlier by Sloss and Laird (1945). In addition, this zone contains *Ankhelasma*, which is known elsewhere only from the Brazer Dolomite of northeast Utah (Sando, 1961). *Ankhelasma* sp. cf. *A. typicum* was collected at the type locality of the Castle Reef Dolomite and Sun River Member on the east side of Hannan Gulch (Sando, 1961, p. 70).

The fauna of the Sun River Member was observed mainly in the upper part of the member in each of the ridges containing Mississippian rocks, except in the northeastern part of the Arsenic Peak quadrangle, where this sequence was eroded prior to Jurassic deposition. In many places the fossils are silicified and randomly oriented.

Fossils of Mississippian age were collected from silicified boulders (fig. 25) in the basal conglomerate of the Jurassic Sawtooth Formation. The boulder (F181, USGS loc. 17472–PC) yielded the following forms, according to W. J. Sando and J. T. Dutro, Jr. (written commun., 1957):

Millerellid Foraminifera, undet.
Diphyllum sp.
Syringopora sp.
Horn corals, indet.
Fistuliporoid bryozoans, indet.
Fenestella, 3 spp.
Hemitrypa sp.
Cystiodictoya sp.
Rhynchonellid brachiopod, indet.

Much of this fauna, except for *Hemitrypa* sp., is characteristic of the Castle Reef Dolomite. *Hemitrypa* has not been reported from any of the other units, and abundant bryozoans are not characteristic of the other faunal horizons in the preserved Mississippian sequence.

MISSISSIPPIAN-JURASSIC UNCONFORMITY

The unconformity at the base of the Jurassic rocks represents a time span of about 130 million years from Late Mississippian to Middle Jurassic. Rocks representing the missing systems are present locally in Montana and in Alberta, Canada.

Younger Mississippian rocks were very likely deposited in the Sun River Canyon area prior to pre-

FIGURE 25.—Jurassic-Mississippian unconformity on the north side of Sun River Canyon at station 38 (pl. 2). The dark boulders are silicified carbonate rocks of the Castle Reef Dolomite that form the basal conglomerate of the Sawtooth Formation. Above the boulders are sandstone beds of the sandstone member of the Sawtooth Formation. Boulders of this size were observed elsewhere only at station 56.

Jurassic erosion, as just noted. Evaporite beds may have been interbedded in this missing sequence of Upper Mississippian rocks, as such beds are in the upper part of the Charles Formation, which overlies the Madison in the subsurface in eastern Montana (Fish and Kinard, 1959, p. 53–55). The former presence of evaporite beds in the missing sequence in the Sun River Canyon area might account for the magnesium necessary to form the dolomite in the upper part of the Madison, if seepage refluxion operated (Scruton, 1953, p. 2507; Adams and Rhodes, 1960, p. 1912–1919).

Concerning former deposition of Pennsylvanian and Permian sediments in the Sun River Canyon area, the evidence consists of the presence of such sediments over wide areas in southern, south-central, and western Montana (Sloss, 1950, figs. 10 and 11) as well as in western Alberta (Macauley and others, 1964, p. 98–100; and McGugan and others, 1964, fig. 8–1). The nearest exposures of these rocks are southeast of Wolf Creek, about 50 miles south of the Sun River Canyon area (G. D. Robinson, written commun., 1967).

Triassic and Lower Jurassic rocks in the northern Rocky Mountains are more limited. Triassic rocks are present in eastern Montana (McKee and others, 1959, pl. 5) and in western Alberta (Barss and others, 1964, fig. 9–8, 9–9). Lower Jurassic rocks have not been recorded in Montana (McKee, and others, 1956) but are present in western Alberta (Springer and others, 1964, fig. 10–5). It is doubtful that Triassic and Lower Jurassic rocks were ever present in the Sun River Canyon area.

The nature of the unconformity indicates that the Mississippian rocks were exposed for a long time before Middle Jurassic sedimentation. To the south, as in many areas in Montana, the upper surface of the Mississippian was very irregular and deeply weathered prior to deposition of Pennsylvanian rocks (Robinson, 1963, p. 47; Roberts, 1966, p. B20–B21). The weathered surface that must have existed in the Sun River Canyon area was completely removed. Karst topography, typical on the Mississippian rocks of south central Montana, is absent. Surface exposure is, however, shown by the fact that joints in the Mississippian rocks were widened by solution and filled with sand during Middle Jurassic sedimentation to depths of 20 feet or more, indicating that the surface was exposed for a relatively long period of time. Sand was also injected laterally along some bedding planes.

In many places in the eastern outcrop area the top of the Madison contains abundant small borings that are filled with fine-grained Jurassic sandstone (fig. 26). The borings are about one-half inch deep and about one-fourth inch across. The long axis is at right angles to the

FIGURE 26.—Borings of pelecypods in the uppermost bed of the Castle Reef Dolomite at station 38 in the lower reaches of Sun River Canyon. Borings are filled with resistant sandstone of the Sawtooth Formation. The basal sandstone and boulder conglomerate of the Sawtooth is in left part of photograph.

bedding. These borings were also observed on the top bed of the Madison in Wagner Basin, about 1 mile north of Diversion Lake.

The abundance, size, and symmetry of the borings indicate that they were made by clams similar to *Opertochasma* n. sp. identified in Cretaceous rocks by Cobban (p. A71). The borings are similar to those of *Gastrochaena* sp. in the Miocene rocks in southern Poland identified by Radwanski (1965, pl. 2).

The effect of the pre-Jurassic erosion on the Mississippian rocks can be partially appraised for the Sun River Canyon area. The measured sections in an east-west line are separated by many thrust faults, and therefore, the distance between sections has been greatly shortened. Most of the sections in a north-south direction, however, are in the same fault block. The datum for this evaluation is the base of the Castle Reef Dolomite. As near as can be determined, the variation in thickness of this formation is mostly a result of pre-Jurassic erosion rather than variation in sedimentation rate. The maximum thickness of the Castle Reef Dolomite, about 950 feet thick, is in the upper reaches of Cabin Creek. East of this section, in the upper reaches of the South Fork of Deep Creek, the Castle Reef is only 250 feet thick, suggesting at least 700 feet of pre-Jurassic erosion. On the same ridge south of the Cabin Creek section, at Gibson Reservoir and Allan Mountain, at least 250 feet of the Castle Reef was eroded (Mudge and others, 1962, p. 2017). A series of sections along the Sun River from the mountain front west to Gibson Reservoir shows that an additional 170 feet of rocks was eroded in the west (Mudge and others, 1962, p. 2017).

MESOZOIC ROCKS

Mesozoic sedimentary rocks are about 7,000 feet thick in the Sun River Canyon area and belong to the Jurassic and Cretaceous Systems. These rocks crop out mainly east of the mountain front, but some are present in each of the mountain valleys. The rocks are dominantly mudstone with some sandstone and from marine to nonmarine in origin. Unconformities occur not only at the base of each system but also within the systems.

JURASSIC

Middle and Upper Jurassic rocks crop out in each of the mountain valleys in the Sun River Canyon area as far west as the lower reaches of the West Fork of the Sun River and at Sheep Mountain (pl. 1). These rocks are divided into four formations: Sawtooth, Rierdon, Swift, and Morrison. The first three formations comprise the Ellis Group and are marine in origin (table 1). Deiss (1943a, p. 233) included in the Kootenai Formation the rocks now called the Swift and Morrison Formations. Cobban (1945, p. 1269–1303) recognized Morrison affinities above the Swift Formation and established the subdivision of the Ellis Group used in the present report.

The Jurassic rocks thicken from 485 feet in the eastern outcrop area to about 1,175 feet in the western outcrop area.

ELLIS GROUP

The Ellis Group and its fauna were well described by Imlay (1945; 1952 a, b; 1953; 1962) and by Imlay, Gardner, Rogers, and Hadley (1948). In the Sun River Canyon area this group thickens from 285 feet in the east to about 675 feet in the west.

SAWTOOTH FORMATION

In the Sun River Canyon area the Sawtooth Formation is poorly exposed along the east side of each of the north-trending valleys. Cobban (1945, p. 1272, 1273) divided the Sawtooth into three unnamed members, which are, in ascending order: sandstone, shale, and siltstone; these members are also recognized here. The Sawtooth Formation ranges in age from middle Bajocian through Bathonian (Imlay, 1962, p. C11), and in thickness from 50 to 225 feet; in most places it is between 65 and 150 feet thick. (See measured sections 13–16.) The geologic maps show locally abnormal thicknesses, which are a result of minor faulting and folding (Mudge, 1966a).

Sandstone Member

Exposures of the sandstone member are more abundant in the eastern outcrop area than in the western. In most places this member is a single bed that is conglomeratic at the base. Locally, it consists of two beds of sandstone separated by a bed of shale. Where this member comprises three units, as on the east side of Wagner Basin (station 88, pl. 2; measured sections 13–16) and on the north end of Sawtooth Ridge (sta. 52), the middle and upper parts of the upper sandstone bed contain lenses of conglomerate. The sandstone member ranges in thickness from 0 to 20 feet but in most places is 2–7 feet thick.

The member consists almost entirely of thin-bedded hard dense fine-grained noncalcareous light-gray sandstone. The sandstone weathers yellowish brown and contrasts with the very light gray underlying dolomite beds of the Madison (fig. 25). In Norwegian Gulch and in upper Hannan Gulch the sandstones are very thick bedded and contain some zones of friable sandstone. Minute laminae, crossbedding, and symmetrical ripple marks are apparent on some of the weathered surfaces. The beds are composed of clear fine-grained quartz and a little chert and pyrite.

Conglomerate, present at the base in most exposures, consists of light-gray well-rounded to subangular pebble- to boulder-size fragments of Mississippian carbonate and chert in a brownish-gray firmly cemented sandstone matrix that weathers in relief. The conglomerate ranges in thickness from a few inches to 2 feet. Large silicified boulders as much as 4.5 feet long were observed at stations 38 and 56 (fig. 25) and discussed before (p. A40). On Prairie Creek (sta. 180) the basal conglomerate contains, in addition to fragments of Madison, a few quartzite and siltstone pebbles from Cambrian(?) rocks. The quartzite pebbles are mostly of poorly sorted fine- to coarse-grained quartz resembling the Flathead Sandstone. The siltstone pebbles are light yellowish gray; they resemble the silty dolomite beds of the Steamboat Limestone. The very light gray fine-grained dolomite fragments may have been derived from the Devils Glen Dolomite (Cambrian). The most abundant constituent in this conglomerate is well-rounded pebble- to boulder-size fragments of Mississippian carbonate and chert. Some of the boulders are as much as 1 foot across.

The interbedded shale in the sandstone member is a few feet thick mostly silty, noncalcareous, dark gray, and laminated to thinly laminated. In places, as in Hannan Gulch, it is claystone, with a thin bed of impure limestone in the lower part, overlain by dark-gray silty calcareous thin-bedded shale and siltstone.

At the north end of Sawtooth Ridge (sta. 52, pl. 2) the Madison is overlain directly by 3 feet of dark gray shale. This shale is overlain by about 4 feet of conglomerate and fine-grained finely crossbedded sandstone that includes 2 feet of conglomerate in the lower part and a 0.5-foot-thick conglomerate at the top. The bed between the conglomerates contains 0.5-foot-thick coquina (F184–F188) of *Ostrea* sp. and *Meleagrinella ferniensis* (McLearn) (R. W. Imlay, written commun., 1957). Here, the shale and overlying conglomeratic sandstone comprise the upper two units of the sandstone member of the Sawtooth Formation.

Fossils in the sandstone member are listed in table 5; they are Bajocian (Imlay, 1962, p. C11).

Shale Member

In the Sun River Canyon area the shale member of the Sawtooth Formation is mainly a dark-gray silty to clayey thinly laminated shale. However, at the head of Hannan Gulch the lower part of this member consists of calcareous beds of claystone, silty shale, siltstone, and one thin bed of argillaceous limestone. These lithologies persist northward to Rierdon Gulch (Cobban, 1945, p. 1293) but are mostly absent elsewhere in the Sun River Canyon area.

Locally in the northern outcrop area there are thin beds of conglomeratic shale in the upper and lower parts of the member. In the upper reaches of Blacktail Gulch and the South Fork of Deep Creek, a heavily iron-impregnated dark-gray shale of this member rests unconformably on the Madison. The iron-impregnated zone ranges from a few inches thick in the upper reaches of Blacktail Gulch to over 4 feet thick along Biggs Creek.

The shale member, like the sandstone member, ranges in thickness. It is 3 feet thick at the north end of Sawtooth Ridge, about 34 feet in the upper part of Wagner Basin, 18 feet just south of Diversion Lake, 85 feet in upper reaches of Hannan Gulch, 30.8 feet in Green Timber Gulch, and 16.4 feet at head of Lime Gulch. It thickens northward to 66± feet in Rierdon Gulch and 133± feet farther north along the north shore of the Swift Reservoir (Cobban, 1945, p. 1293, 1295). (See measured sections 13–16.)

The shale member is in sharp but conformable contact with the underlying sandstone member. Locally the sandstone member is absent and its position is marked by an unconformity within the lower part of the shale member.

Locally fossils are abundant in zones in the lower part of the member. These fossils, listed in table 5, were identified by R. W. Imlay (written commun., 1958).

The shale member is considered to be of Bajocian age because its lower part at Swift Reservoir, west of Dupuyer, Mont., has furnished the ammonites (Imlay and others, 1948; and Imlay, 1967, p. 90).

Siltstone Member

In the Sun River Canyon area the siltstone member consists mainly of thin hard beds of siltstone with a few very thin beds of shale. This member thickens northward. It ranges in thickness from about 21 feet at Lime Gulch to about 44 feet at the head of Hannan Gulch. (See measured sections 13–16.) North of the Sun River Canyon area, at the head of Rierdon Gulch, Cobban (1945, p. 1293–1294) noted that it was 52 feet thick. Farther north, on Badger Creek, Imlay (1962, p. C9) recorded it as 170 feet thick.

The siltstone is calcareous and grayish brown to yellowish gray and characteristically weathers a dark yellowish orange to moderate yellow brown. The shale beds are mostly noncalcareous, silty, medium gray, and thinly laminated to laminated. In the upper reaches of Green Timber Gulch they are calcareous. Here, also, the lower part of the member contains the oldest bentonite bed (0.2 ft thick) observed in the area.

On Prairie Creek (sta. 180, pl. 2) the upper part of the siltstone member contains three zones of nodules

TABLE 5.—*Distribution of megafossils in the Sawtooth Formation in the Sun River Canyon area, Montana*

[Fossils identified by R. W. Imlay]

	Sandstone member					Shale member			Siltstone member																			
	F3	F184	F188	(19606) [1]	F55 (27037)	F55B (26282)	F223 (27043)	F221 (27044)	F222	(18324) [2]	(19608) [3]	F56 (26283)	F87 (26284)	F231 (27039)	F224 (27040)	F237 (27041)	F57 (27042)	F228 (27045)	F225 (27046)	F227 (27047)	F227 (27501)	F278 (27502)	F286b (27503)	F286a (27504)	F287 (27505)	F291 (27506)	F435 (29442)	F433 (29445)
Algal markings										×																		
Crinoid fragments																							×					
Echinoid spines					×																							
Terebratulid brachiopod																									×			
Gastropod fragments					×																		×					
Gastropod molds							×																					
Ostrea sp			×		×		×			×																	×	
Oxytoma cf. *O. mclearni* Warren	×																											×
Meleagrinella curta (Hall)		×	×	×	×					×							×								×		×	
sp						×																						
Camptonectes stygius White					×			×		×				×	×	×											×	×
sp				×					×		×	×	×										×					
Pleuromya subcompressa Meek							×	×		×	×				×	×				×	×					×	×	×
obtusiprorata McLearn												×	×															
sp					×													×										
Trigonia sp				×	×																							
Grammatodon? sp					×															×								
Quenstedtia? sp				×												×												
Astarte (*Coelastarte*) *morion* Crickmay							×																					
cf. *A. packardi* White										×																		
sp						×																						
cf. *Corbula munda* McLearn						×																						
sp												×																
Isocyprina? sp												×						×										
Pinna kingi Meek														×	×	×	×									×	×	
Modiolus rosii McLearn										×							×									×		
Cercomya punctata (Stanton)															×					×								
Protocardia sp																				×								
schucherti McLearn										×																		×
Pholadomya inaequiplicata Stanton																		×		×								
sp																		×										
Gryphaea sp																							×					×
Gervillia sp																							×					
Inoceramus sp																									×			
Pronoella cf. *P. iddingsi* (Stanton)																											×	
Tancredia sp																											×	
Placunopsis sp																												×
Praeconia? sp																		×										
Lytoceras sp																												×
Cobbanites sp																×				×	×						×	
Paracephalites sawtoothensis (Imlay)															×		×					×						×
cf. *P. glabrescens* Buckman																												×
sp											×			×					×	×	×			×				
?*saypoensis* Imlay										×																		
Ammonite fragments																		×					×			×		
Belemnite fragments							×											×				×						

[1] A collection from Wagner Basin by R. W. Imlay, Aug. 1945.
[2] A collection from head of Lime Gulch by Charles Deiss and R. M. Garrels, July 1940.
[3] A collection from Wagner Basin by R. W. Imlay.

NOTE.—In boxheads, numbers prefixed with "F" are field numbers. Those in parentheses are USGS Mesozoic locality numbers.

that were identified as phosphate by R. P. Sheldon (oral commun., 1963). The upper zone of nodules is about 2–3 feet below the top of the member. The other two zones are spaced at 2 foot intervals beneath. These nodules are rounded to angular and are as much as three-fourths of an inch across. The matrix of the nodules is of the same composition as the sand matrix of the enclosing bed, and many nodules have uneven borders with phosphate extending into the sand matrix, suggesting that the nodules formed in place.

In most places the siltstone member forms a small but not very prominent hillside bench. This bench is generally easily recognized because above it is a smooth gentle slope formed on the yellowish-gray shale of the overlying Rierdon (fig. 27). The soil on the siltstone member is generally a yellowish-brown silty loam, whereas that on the Rierdon is a dark-gray to gray clayey to silty loam.

The siltstone member rests gradationally on the shale member. The contact is placed at the lowest bed of yellowish-gray massive siltstone.

Fossils are locally abundant in the upper and lower parts of the member (table 5). *Pleuromya* is the most abundant fossil and generally occurs as perfect specimens with both valves attached. The distinctive ammonites are *Paracephalites* and *Cobbanites*. Of these, *Paracephalites* is known only from the siltstone member, but *Cobbanites* ranges higher (Imlay, 1962, p. C27). The siltstone member is correlated with the Bathonian Stage because of the close resemblance of *Paracephalites* to the Bathonian genus *Cranocephalites*, because the siltstone member underlies a succession of beds of early Callovian age, and because the member grades downward into beds of Bajocian age (Imlay and others, 1948; Imlay, 1962, p. C5–C10; Imlay, 1967, p. 59).

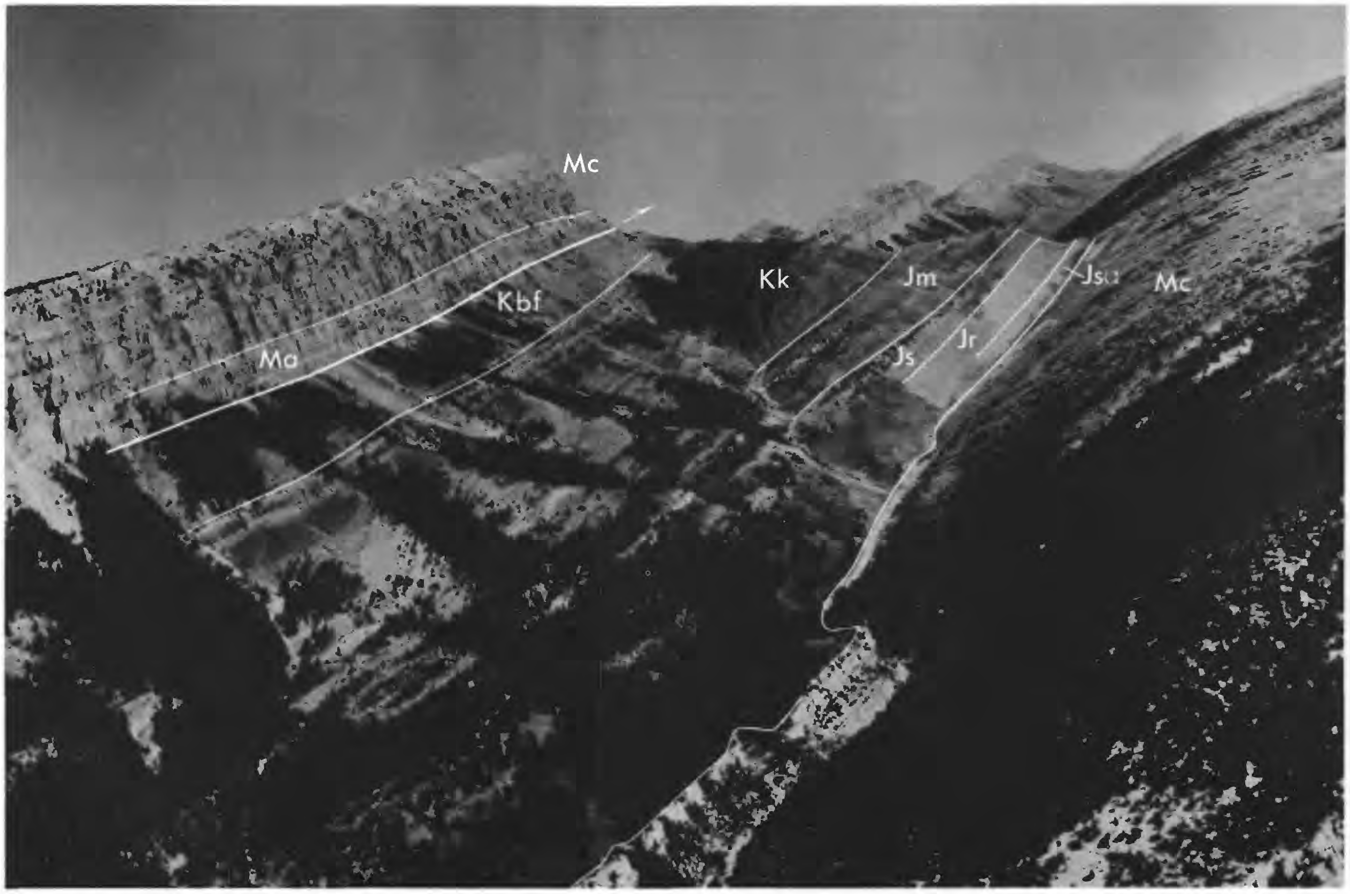


FIGURE 27.—Aerial view of the upper (north) tributary of Green Timber Gulch. Ma, Allan Mountain Limestone; Mc, Castle Reef Dolomite; Jsa, Sawtooth Formation; Jr, Rierdon Formation; Js, Swift Formation; Jm, Morrison Formation; Kk, Kootenai Formation; Kbf, Flood Shale Member of Blackleaf Formation. Arrow indicates position and movement of a thrust fault; arrow parallel to upper plate.

RIERDON FORMATION

The Rierdon Formation consists mostly of gray mudstone. The formation was named by Cobban (1945, p. 1277), and it is early Callovian in age (Imlay, 1953, table 2). The Rierdon Formation is relatively constant in thickness (Cobban, 1945, p. 1277–1279; Imlay, and others, 1948). The maximum thickness variation is in the eastern part of the canyon area, from about 121 feet just south of Diversion Lake (Cobban, 1945, p. 1296) to about 165 feet 1 mile farther south. Elsewhere the thickness ranges from 140 to 150 feet. (See measured sections 13–16.)

The Rierdon unconformably overlies the Sawtooth Formation and is overlain disconformably by the Swift Formation. The Rierdon forms a distinctive long gentle yellowish-gray weathered-shale slope between the hillside benches formed by more resistant beds above and below (fig. 27). The Rierdon characteristically weathers to a dark-gray to gray silty to clayey loam on which vegetation does not flourish. On the divide between Palmer Flats and Green Timber Basin (sta. 104), lupine and other flowering plants flourish on the weathered Swift Formation, but they are scanty on the Rierdon soil. Here the contact between the formations was drawn along the line of floral change.

The Rierdon Formation consists mostly of claystone, siltstone, and shale but includes many thin beds of limestone. The beds of siltstone and claystone are calcareous and dark gray brown, and most have a hackly fracture. Beds of calcareous silty dark-gray-brown laminated shale are common in the lower part of the formation. Barite nodules, noted by Cobban (1945, p. 1279), are commonly scattered in the middle and upper parts. A bentonite bed (0.2–0.3 ft thick) occurs near the middle of the formation in Lime Gulch and at the head of Green Timber Gulch.

The limestone beds are hard, dense, argillaceous, and dark gray to gray brown. They grade upward and downward into mudstone. Most of them are fossiliferous, and locally some are a coquina. The spacing of these beds varies within the formation, even though at a distance they appear to be about equally spaced in the thick mudstone sequence. The presence of these limestone beds and the general character of the formation distinguish it from all other rock units in the area.

The subtle unconformity at the base of the Rierdon was recognized only recently in the Sun River Canyon area; therefore it is not indicated on my maps published earlier. As noted by Imlay (1962, p. C9), north of the Sun River in the Northern Rocky Mountains the Rierdon is conformable on the Sawtooth. However, on the Sweetgrass Arch in southern Alberta and in southwestern Montana, Imlay (1962, p. C9) reported evidence of a minor unconformity at the base of the Rierdon. In most places in the Sun River Canyon area, the contact appears conformable, but a minor unconformity is suggested in two places. At the head of Gibson Reservoir the basal bed of the Rierdon is firmly cemented heavily iron stained pyritic sandy mudstone that lies on an irregularly eroded siltstone bed of the Sawtooth Formation. On the north side of the head of the West Fork of Beaver Creek, the basal bed of the Rierdon is a sandy calcarenite (1.5 ft thick) composed of quartz and fossil detritus, including waterworn but whole specimens of *Gryphaea* and *Pleuromya*. This unconformity very likely marks the Bathonian-Callovian boundary (Cobban, 1945, p. 1279 and Imlay, 1962, p. C9).

Fossils are common and well preserved in the limestone beds but less so in the mudstone beds; they are listed in table 6. In Montana the Rierdon has been subdivided by Imlay, Gardner, Rogers, and Hadley (1948) and Imlay (1953, p. 5–8; 1967, p. 29) into five ammonite zones, characterized by, respectively, in ascending order, (1) *Warrenoceras codyense*, (2) *Gowericeras costidensum*, (3) *G. subitum*, (4) a finely ribbed species of *Kepplerites* comparable with *K. tychonis* (Ravn), and (5) a more coarsely ribbed species of *Kepplerites* named *K. mclearni*. In the Sun River Canyon area, R. W. Imlay (written commun., 1958) subdivided the Rierdon into two relatively equal parts, each with a faunal zone. These zones are, in ascending order: (1) *Gryphaea impressimarginata* and *Warrenoceras* and (2) *Gryphaea nebrascensis* and *Cadoceras*. The latter zone is equivalent to the upper three zones described elsewhere in Montana by Imlay, Gardner, Rogers, and Hadley (1948). The *Cadoceras* zone is correlated with the *Gowericeras* zones described elsewhere in Montana by Imlay (1953, p. 7), although *Gowericeras* has not been found in the Sun River Canyon area. It has been found, however, within 8 feet of the top of the Rierdon Formation (Imlay, 1953, table 3) a few miles to the north, near the South Fork of the Teton River. The two zones of *Kepplerites* have been found only near Glacier National Park (Imlay, 1953, p. 7) and are probably absent in the Sun River Canyon and Teton River areas. The ammonite *Cadoceras* occurs throughout the formation, thus underlying as well as overlying the zone containing *Warrenoceras*. *Warrenoceras* appears to occur in greater numbers in the lower zone than *Cadoceras* does in the upper zone. In places the ratio may be as high as 10 to 1.

Intertwined organic burrows (tubes) were collected from the upper part of the Rierdon on the ridge about 1½ miles south of Diversion Dam (HS75). P. E. Cloud (written commun., 1959) said they were "made by serpulid worms such as the ones that veneer intertidal and shallow-water marine benches in Bermuda, Florida, and other tropical to subtropical areas today. Shallow, warm, marine waters are implied, possibly near shore, possibly even intertidal."

In addition to the invertebrate fossils listed in table 6, fragmental vertebrate bones were found in the upper part of the Rierdon at the south end of Diversion Ridge. Peter Vaughn (in D. H. Dunkle, written commun., 1958) reported them as undoubtedly reptilian and very likely of a plesiosaur. D. H. Dunkle (written commun., 1958) described a tooth (F329) collected from near the middle of the Rierdon at the head of Lime Gulch as that of the shark *Hybodus polyprion* Agassiz.

SWIFT FORMATION

The Swift Formation, half shale and half sandstone, is the youngest marine Jurassic unit in the Sun River Canyon area. Cobban (1945, p. 1281, 1283) named the Swift and divided it into a lower, shale member and an upper, sandstone member.

The Swift is well exposed in most of the tributary valleys of the Sun River. The upper, sandstone member is the most resistant unit in the Ellis Group and tends to form a prominent gray-brown ledge (fig. 27). Cobban (1945, p. 1283, 1284) noted that the Swift becomes more sandy and less shaly southeast of the Sun River.

The Swift is 115–120 feet thick in most of the Sun River Canyon area. A maximum thickness of about 140 feet was measured at the head of the Green Timber Gulch (fig. 27). (See sections 13–17.)

SHALE MEMBER

In most places in the Sun River Canyon area a poorly exposed shale member makes up about the lower half of the Swift. This member contains dark-gray shale and some sandstone. In the Sun River Canyon area the shale member averages about 50 feet thick. It is only 22 feet thick in Lime Gulch, but here some of the sandstone beds included in the overlying sandstone member may be laterally equivalent to the upper part of the shale member in the eastern outcrop area.

TABLE 6.—*Distribution of megafossils in the Rierdon Formation in the Sun River Canyon area, Montana*

[Fossils identified by R. W. Imlay]

	F362	F69	F70	F258	F283	18325 [1]	18326 [1]	18327 [1]	18329 [1]	18610 [1]	F58 (26285)	F59 (26286)	F60 (26287)	F61 (26288)	F62 (26289)	F43 (26290)	F63 (26291)	F65 (26292)	F66 (26293)	F67 (26294)	F68 (26295)	F71 (26296)	F72 (26297)	F240 (27038)	F226 (27048)	F232 (27049)	F238 (27050)	F241 (27051)	F220 (27052)	F229 (27053)	F245 (27054)	F64 (27055)	F230 (27056)	F136 (27057)	F63 (27060)	F230 (27494)	F284 (27495)	F285 (27496)	F292 (27497)	F293 (27498)	F294 (27499)	F330 (27500)	F434 (29438)	F434 (29439)
Hamulus? sp																					X																							
?*subquadratum* Meek and Hayden							X																																					
Serpula sp									X																																			
Boring sponge resembling *Cliona*						X																																						
Foraminifera, possibly a rodosarian							X																																					
Trigonoceia sp. (bryozoan identified by R. S. Bassler)									X																																			
Bryozoan undetermined																																									X			
Rhynchonellid brachiopods							X																																					
Lingula sp								X																																				
Coquina of gastropods *Camptonectes* and *Astarte*																								X																				
Bittium? sp							X																																					
Astarte (*Coelastarte*) *morion* Crickmay		X																																										
Astarte meeki Stanton															X																													
cf. *A. packardi* White							X	X	X																																			
sp																	X	X	X		X																							
Thracia cf. *T. weedi* Stanton								X																																				
Thracia? sp																	X																											
Gryphaea impressimarginata McLearn						X				X	X		X	X																													X	X
nebrascensis Meek and Hayden							X		X													X	X		X															X				
sp												X				X																X												
Pleuromya obtusiprorata McLearn													X			X			X																									
subcompressa Meek							X	X	X	X																																		
sp																				X		X																						
Trigonia montanensis Meek																			X																									
sp												X																																
Camptonectes stygius White						X																																						
sp							X	X	X			X				X			X	X	X																				X			
Corbula munda McLearn							X					X																																
Modiolus rosii McLearn																X																												
sp									X									X																										
Grammatodon sp								X								X		X			X																							
Grammatodon? sp									X																																			
Protocardia schucherti McLearn							X																																					
sp																X		X				X										X												
Tancredia sp																				X																								
Inoceramus? sp							X																																					
Lima cf. *L. cinnabarensis* Stanton							X																																					
Nucula sp								X																																				
Nuculana sp								X																																				
Ostrea sp								X																																				
Pinna sp									X																																			
Meleagrinella curta (Hall)									X																																			
Unicardium? sp									X																																			
Isocyprina? sp									X																X																			
Myopholas? sp	X																																											
Lopha sp																																								X				
Plicatula sp																																								X				
Chlamys sp																																											X	
Oyster fragments																																			X									
Cadoceras tetonense Imlay									X																									X										
shoshonense Imlay																									X								X											
cf. *C. shoshonense* Imlay																																								X				
cf. *C. tetonense* Imlay																									X																			
sp					X																	X														X					X		X	
Pachyteuthis sp						X																																						
Warrenoceras sp										X																X	X	X	X	X	X		X				X	X	X			X		
rierdonense (Imlay)	X																																										X	X
codyense (Imlay)																																				X						X		
Eutrephoceras sp	X																																											
Cobbanites sp																									X				X				X											
sp																																					X		X					
Ammonite fragments				X														X														X												
Macrocephalitid ammonite												X			X																													
Belemnite-bearing worm tube (much weathered)																																			X									

[1] Mesozoic collections 18325, 18326, 18327, 18329, and 18610 collected by Deiss and Garrels, 1940.

NOTE.—In boxheads, numbers prefixed with "F" are field numbers; those in parentheses are USGS Mesozoic locality numbers.

In the Sun River Canyon area a thin but rarely exposed bed of poorly indurated fine- to coarse-grained dark-yellowish-green glauconitic sandstone is at the base of the member. This is the only bed in the area that is composed almost entirely of glauconite grains. In addition to glauconite, the sandstone also contains water-worn belemnites identified by R. W. Imlay (written commun., 1958) as *Pachyteuthis "densus"* (Meek and Hayden). This sandstone rests disconformably on the Rierdon Formation. The disconformity represents the upper half of Callovian and much of Oxfordian time (R. W. Imlay, written commun., 1958).

At the south end of Diversion Ridge, the basal sandstone is thicker than elsewhere and contains more fossils. In addition to the belemnites, the pelecypod *Buchia concentrica* (Sowerby) was found by James Gilluly (USGS Mesozoic loc. 27058). Its importance was stated by R. W. Imlay (written commun., 1967):

> The presence of *Buchia* at the base of the Swift Formation is of considerable stratigraphic significance, as the genus did not appear until late Oxfordian time and, in northwest Europe, has not been found below the zone of *Perisphinctes plicatilis*. The particular species *B. concentrica* (Sowerby), that is present at the base of the Swift Formation has been found in many parts of the world and is the earliest representative of the genus. Its range is late Oxfordian to middle Kimmeridgian. Consequently, in the Sun River Canyon area evidence exists that deposition of the Swift Formation did not begin before late Oxfordian time. In contrast, ammonite evidence from central Montana (Imlay and others, 1948, p. 17) indicates that deposition of the Swift Formation began in the Williston basin area in latest Callovian time and gradually overlapped the marginal areas during Oxfordian time.

At the head of Wagner Basin the basal sandstone contains a 0.5-foot-thick conglomerate (unit 71, measured section 13). It is poorly indurated and composed of subangular fragments of sandstone as much as 2 inches across. These fragments and waterworn belemnites are in a glauconitic sandstone matrix. In this conglomerate Cobban (1945, p. 1283) noted rare occurrences of black chert pebbles as much as half an inch across.

The shale is mainly silty slightly calcareous dark-gray to dark-olive-gray claystone grading upward into very fine grained finely micaceous sandstone. Locally the sandstone is ripple marked and contains organic trails and burrows. Some ripple marks are standing-wave types, suggesting a shallow-water environment.

In places in the middle of the shale member there is a very hard dense dark-gray nodular concretionary limestone that fractures conchoidally and weathers yellowish orange. Elsewhere, Cobban (1945, p. 1283) reported similar brown-weathering calcareous concretions throughout the member.

Sandstone Member

The sandstone member makes up approximately the upper half of the Swift Formation. This member is equally divided into two units. The lower unit is generally covered by talus, and the upper unit forms a prominent hillside ledge. At a distance this ledge appears as the first thick resistant unit above the Madison (fig. 27). This member ranges in thickness from 60 to 97 feet. Its maximum thickness is in Lime Gulch, where some of the lower beds are very likely equivalent to the siltstone and sandstone beds in the upper part of the shale member in the eastern outcrop area.

The lower unit of the sandstone member is the transitional zone between the shale member below and the sandstone beds above. This unit consists of noncalcareous gray very fine-grained sandstone. Individual beds thicken and thin from 0.1 to 0.4 foot. Most of the beds are separated by very thin finely micaceous shale lentils that are a metallic blue gray. This color is also characteristic of the lower part of the upper sandstone unit of the Flood Shale Member of the Blackleaf Formation. (See p. A57.) The lower unit of the sandstone member of the Swift contains some crossbedding, ripple marks, many organic burrows and trails, and some small sandstone nodules. Locally it contains load casts, truncated ripple marks, and raindrop impressions. (See unit 11, section 15.)

The upper unit consists entirely of thin-bedded moderately indurated gray to gray-brown sandstone. The sandstone is composed of fine to very fine quartz and chert grains. Locally, some beds contain rounded fragments of mudstone, abundant ripple marks, and minute cross-laminations. Just west of station 249, on Deep Creek, this unit has low-angle festoon crossbedding. In many places the unit forms an overhanging cliff that weathers platy and yellowish brown and is marked by small pits and cavities.

Conglomerate is present in the lower part of the upper member at station 229 in the upper reaches of Blacktail Gulch. This conglomerate, about 10 feet thick, consists of well-rounded pebbles of siltstone and limestone in a medium-grained poorly sorted sand matrix. The fragments of siltstone resemble the siltstone of the Sawtooth Formation, and the fragments of limestone are like the carbonates of the Madison. This conglomerate indicates that a local positive area existed at this time, very likely to the northwest.

In the Sun River Canyon area the sandstone member of the Swift Formation is relatively barren of fossils. Except for abundant organic trails and burrows and wood fragments, fossils were observed only in two places. At station 171 (pl. 2) there is a coquina, 1.5 feet thick, of white pelecypods in brown sandstone at the base of the member. The pelecypods are imbricated in a manner that indicates a current flow toward the east. They were identified by R. W. Imlay (written commun., 1960) as of the genus *Corbicellopis* or *Tancredia*. This coquina bed is widespread, for Marvin Kauffman (oral commun., 1960) observed it in the Bearmouth area, 60 miles to the south. At the same horizon along the Rocky Mountain front, Cobban (1945, p. 1283) reported conglomerate containing belemnites, fish teeth, and comminuted pelecypod shells.

MORRISON FORMATION

The Morrison Formation is a nonmarine mudstone with some sandstone. This formation was first recognized in the northern Rocky Mountains area by Cobban (1945, p. 1269–1270, 1290), who stated that it conformably overlies the Swift Formation (table 1). Prior to 1945, these rocks were included in the Ellis Group (Peale, 1893, pl. 1; Stebinger, 1918, p. 155; Deiss, 1943a, p. 231).

In the Sun River Canyon area the Morrison contains two distinct facies referred to here as the eastern and western facies (figs. 28 and 29). The eastern facies is mainly gray-green siltstone with interbedded lenticular sandstone similar to the type Morrison in Colorado. (See measured sections 17 and 18.) The western facies is mainly bright-reddish-brown mudstone with thick channel-type sandstone. The sinuous gradational boundary between these facies is shown in figure 29. The facies change is best seen in the upper reaches of Big George Gulch. Here, in a very short distance the mudstone beds grade laterally from grayish-green (eastern facies) to bright moderate reddish brown (western facies). The upper lenticular sandstones of the eastern facies grade laterally into thick coarse-grained poorly sorted highly crossbedded (channel type) sandstones of the western facies, and the lowermost sandstone beds of the eastern facies grade laterally into thick sandstone beds of the western facies. The most widespread beds of the western facies are those that occur in the upper part of the Morrison, especially the sandstone units.

The western facies of the Morrison in the Sun River Canyon area is similar to the Morrison of the Three Forks area (Robinson, 1963, p. 57) and of many places elsewhere in western Montana.

The thickness of the Morrison changes markedly with the facies. The eastern facies is about 200 feet thick, whereas the western facies is about 550 feet thick.

EASTERN FACIES

The eastern facies consists mainly of grayish-green tuffaceous siltstone with interbedded sandstone, limestone, and some siderite (fig. 28). In most places medium-gray shale makes up the lowermost 20–30 feet of the eastern facies. However, at Mortimer Gulch (measured section 17), in the upper Blacktail Gulch (sta. 228, pl. 2), and across the Norwegian Gulch (sta. 40), the lower beds are dark-gray shale with many very thin in-

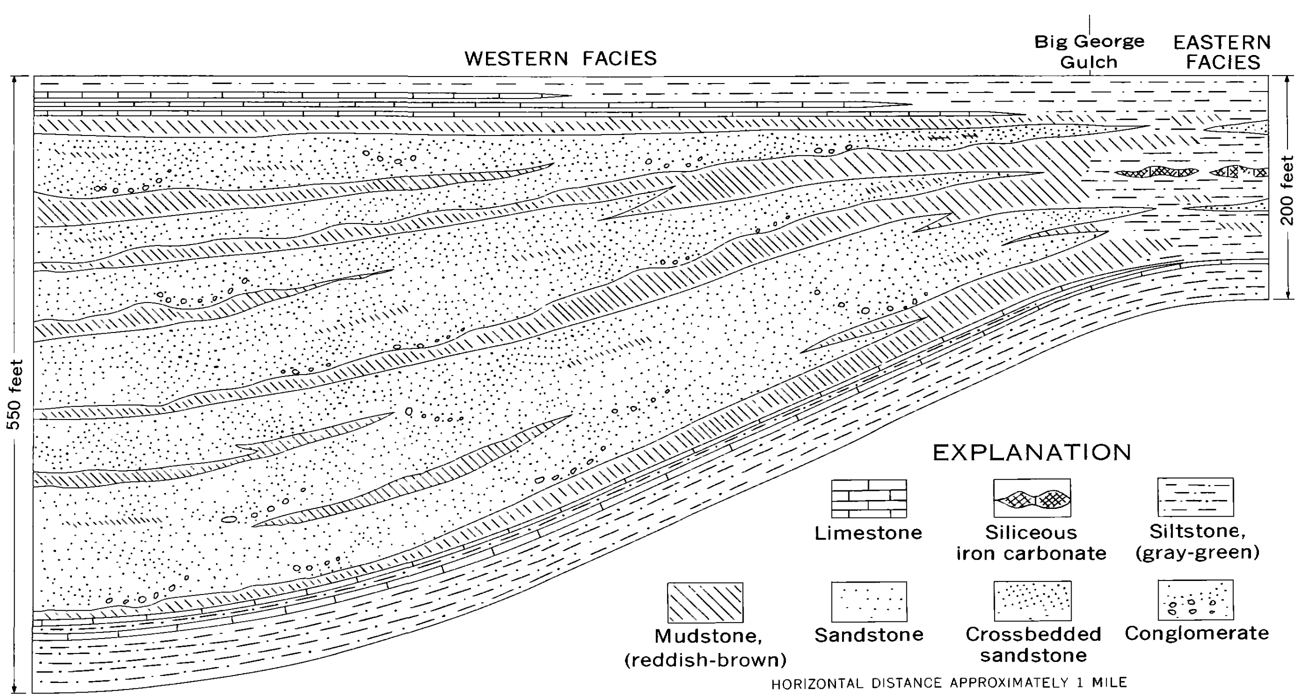


FIGURE 28.—Schematic diagram of the facies of the Morrison Formation in the Sun River Canyon area.

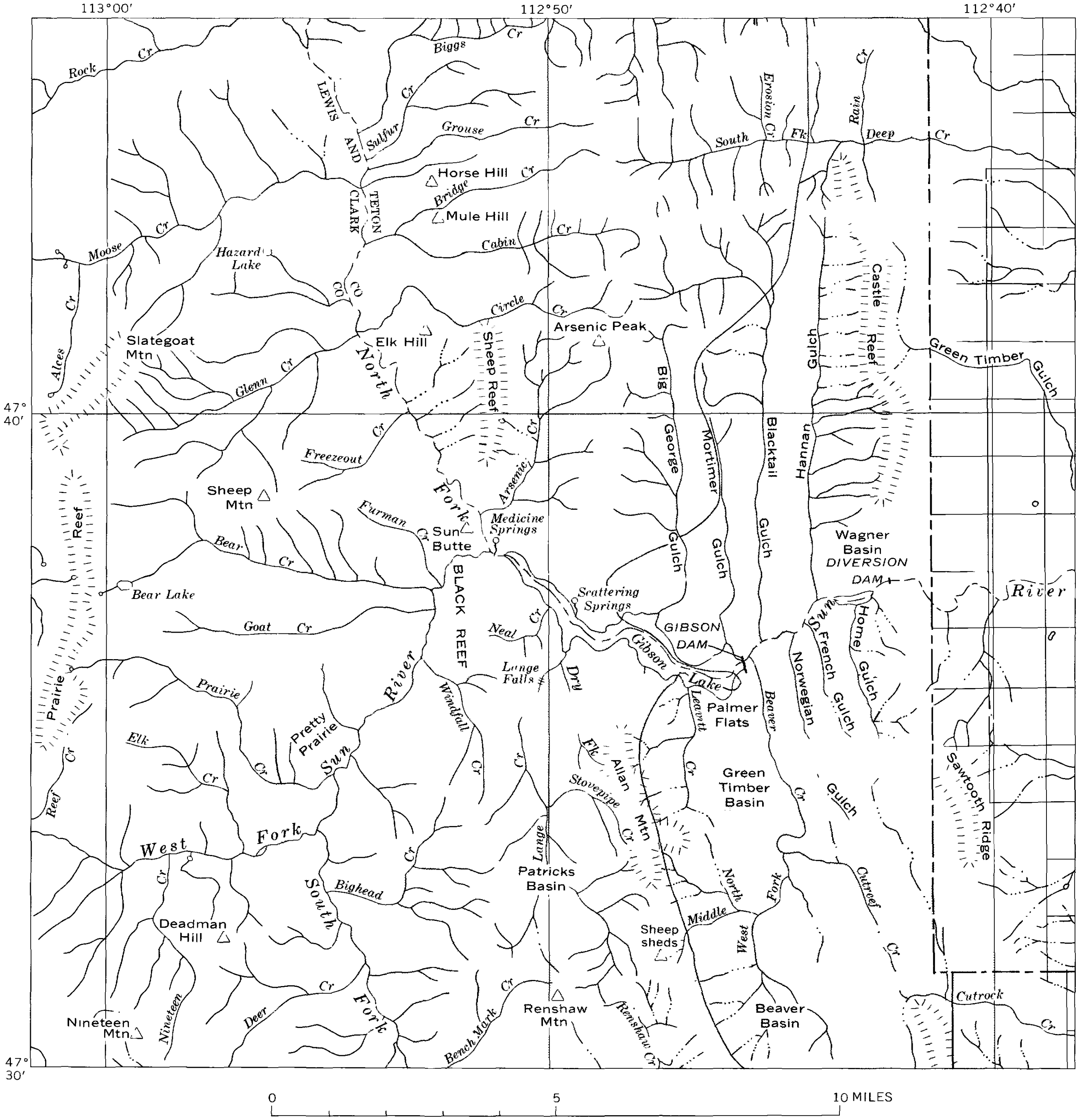


FIGURE 29.—Boundary between the eastern and western facies of the Morrison Formation (stippled) in the Sun River Canyon area, Montana.

terbeds of siltstone. This sequence resembles the lower member of the Swift Formation. According to Hans Frebold (oral commun., July 1960), this unit is called the "passage beds" in Canada, being transitional from the Swift Formation.

One or more beds of limestone overlie the lowermost unit in both the eastern and the western facies. In much of the eastern outcrop area there is only one massive bed of limestone, 1–2 feet thick; it is dark gray brown and very fine grained and weathers nodular. Locally the limestone contains white fresh-water gastropods. Above this bed is 5–10 feet of gray to olive-green siltstone and sandy siltstone containing many calcareous nodules.

The rest of the eastern facies of the Morrison ranges from tuffaceous claystone to siltstone that are interbedded with fine-grained dirty-appearing sandstone.

The fine-grained rocks are mostly grayish green, olive green and olive gray; pink or maroon tones occur here and there. At the head of Home Gulch and in Norwegian Gulch, the Morrison is brightly variegated in tones of red, green, and yellow.

Abundant polished pebbles as much as 3 inches across are characteristic of the Morrison locally. Polished pebbles are scattered in the lower part of the formation just west of the Sheep Sheds at the head of the West Fork of Beaver Creek and near station 235 south of Green Timber Gulch. They are in the upper part of the Morrison, about 50 feet from the top, in the South Fork of Deep Creek (sta. 232 and 233, pl. 2). The pebbles appear to be more abundant in the northeastern part of the area. They are mostly well-rounded to subrounded pink, red, and gray quartzite, jasper, black and brown chert, and quartz. Most of the pebbles are polished or semipolished on all sides, indicating polishing during or before deposition. In places the pebbles are coated with a film of clay that conceals the polished surface. The pebbles were likely transported by streams, in which they obtained their shape, and were deposited in a tuffaceous silt. When agitated by currents, the silt may have served as a fine abrasive and produced the polish on the pebbles. The pebbles seem far too abundant to be gastroliths.

The sandstone beds are thin and medium to light brownish gray. They are composed mainly of fine to very fine grained fragments of light-brownish-gray siliceous tuff, quartz, chert, and clay minerals. The tuff fragments range from extremely fine grained to almost amorphous; some are chert formed from recrystallization of the tuff. The quartz grains are subangular to rounded and have overgrowths, many of which have been abraded. Some beds are crossbedded, and locally they contain symmetrical ripple marks.

Sandstone lenses, some as much as 75 feet thick, appear to be thicker, more widespread, and more prominent in the upper part of the formation, which is also characteristic of the western facies.

Siliceous siderite lenses and nodules are common about 115 feet above the base. They are medium gray but weather dark brownish gray. At a prospect (sta. 40) north of Norwegian Gulch, siderite lenses are as much as 1.5 feet thick. On the east side of Big George Gulch and at the low-level mark of Gibson Reservoir, siderite beds are 5–7 feet thick.

Fossils are rare in the eastern facies and occur mainly in the lower limestone and mudstone beds. Collections listed below were identified by J. B. Reeside (written commun., 1956) and include fresh-water, probably fluviatile, forms.

From F76, 77, 78 (USGS Mesozoic loc. 26300), lower part of Morrison Formation in lower part of Beaver Creek:

Amplovalvata scabrida (Meek and Hayden)
Tropidina jurassica (Branson)
Ostracodes indet.
Plant frag. indet.
Fragments of bone, probably reptilian.

From F87 (USGS Mesozoic loc. 26299) unit 4, sec. 17, beds above lower limestone, Mortimer Gulch:

Unio mucalis Meek and Hayden?
Unio felchi White
Amplovalvata scabrida (Meek and Hayden)
Atopochara?

The gastropod *A. scabrida* is a widespread Morrison species.

WESTERN FACIES

The western facies of the Morrison ranges from a dominantly sandstone sequence with interbedded bright-reddish-brown mudstone to a dominantly reddish-brown mudstone sequence with some sandstone. The red mudstone of the Morrison somewhat resembles that of the overlying Kootenai but is brighter in tone.

Distinctive limestone beds are present in the lowermost and uppermost parts of the western facies, and they aid in determining the upper and lower contacts of the formation. A lower limestone bed 1–2 feet thick and the underlying siltstone persist not only in the western but also in the eastern facies (fig. 28). The limestone is dark gray brown and very fine grained and weathers to nodular blocks. Locally it contains small white pelecypods and gastropods. Less persistent beds 1–2 feet thick, of impure light-gray limestone occur up section.

The limestone beds in the upper part are not as widespread as those in the lower (fig. 28). They are thin bedded and nodular. In places, they attain a thickness of as much as 30 feet. The limestone is very fine grained and dark gray and weathers light gray; locally it is mottled gray brown. Locally, the beds contain gastropods and pelecypods.

Between the two limestone sequences are thick units of sandstone and mudstone. The thickest and most widespread sandstone unit occurs in the lower part of the western facies. It forms a prominent hillside ledge 50–100 feet above that of the upper member of the Swift Formation. The proportion of sandstone to mudstone differs from one exposure to another. Sandstone is more abundant in the southern outcrop area, whereas mudstone is more abundant in the northern part. Most sandstone beds fill channels. In places multiple channels are partly superimposed. The beds are thin crossbedded poorly sorted fine to very coarse grained gray sandstone with numerous lenses of conglomerate. The sandstone is mainly rounded to subrounded grains of quartz and chert, with some feldspar and, locally, fragments of red mudstone, coal, and wood. In many places the beds are heavily iron stained and contain disseminated nodules of ironstone. They are also stained red from the overlying red mudstones. The sandstone unit ranges in thickness from about 15 feet to 100 feet.

Thin conglomerate lenses are common in the basal part of the channel fill. They are indurated and poorly sorted and are composed mostly of rounded to subangular granules and pebbles of chert and limestone, with some gray and red quartzite, quartz, siltstone, and ironstone.

The interbedded red mudstone ranges from siltstone to claystone. Mudstone is more prevalent in the upper part of the western facies but makes up most of this facies in the northern outcrop area. These beds are mainly a bright moderate reddish brown (10*R* 4/6) and weather to a bright moderate reddish orange (10*R* 6/6). In places there are some thin beds of gray mudstone that have red-stained surfaces. Locally these red-stained mudstones extend eastward into the eastern facies of the Morrison.

JURASSIC-CRETACEOUS UNCONFORMITY

In the Sun River Canyon area the contact between the Jurassic and Cretaceous rocks is an unconformity of extremely low relief. The disconformable relationship between these two systems is best illustrated on the northwest flank of the Sweetgrass Arch (Cobban, 1955, p. 107). Here Cobban (1955, p. 107) noted that there was a marked erosional unconformity characterized by a conglomerate and conglomeratic sandstone at the base of the Cut Bank sand, an informal name of economic usage. He also noted that in the Cut Bank oil and gas field this basal sand of the Kootenai Formation rests on bevelled edges of the marine Rierdon and Swift Formations. Further south in the Livingston, Mont., area, the Pryor Conglomerate Member of the Kootenai rests unconformably on the Morrison (Roberts, 1965, p. B55). Elsewhere in Montana a disconformity has been noted at the base of the Kootenai. (See discussion in Robinson, 1963, p. 57.)

In the Sun River Canyon area the Cut Bank sand is absent and the younger Sunburst sand, also an informal name of economic usage, is the basal unit of the Kootenai. Locally in the Sun River Canyon area and Sweetgrass Arch area, this sandstone overlies a bright-yellow mudstone of the Morrison (Cobban, 1955, p. 107), which Perry (1929, p. 15) believed represents a paleosol.

CRETACEOUS

Cretaceous rocks are exposed in the plains east of the mountains and in each of the mountain valleys (pl. 1). The sequence, as much as 5,600 feet thick, is composed mainly of mudstone but includes much interbedded sandstone. The complete sequence of Cretaceous rocks in northwestern Montana is about 8,000 feet thick (Cobban, 1955, p. 107). Cobban noted that on the west flank of the Sweetgrass Arch two-thirds of these rocks are nonmarine and one-third is marine.

KOOTENAI FORMATION

The Kootenai Formation, mainly variegated mudstones and sandstones, is the oldest Cretaceous unit in the Sun River Canyon area. It is exposed in each of the mountain valleys, and it is partially exposed east of the mountains in and adjacent to the Sun River in sec. 32, T. 22 N., R. 8 W. (pl. 1). The Kootenai ranges in thickness from 650 to 800 feet. In places map measurements indicate that it is as much as 1,000 feet thick. Such a thickness, however, is very likely in error, as the Kootenai is faulted and folded in most places. These structures are not easily detected because of poor exposures and lack of key beds. (See measured sections 17–19.)

The formation is easily recognized by its variegated mudstones and sandstones. The only other formation containing variegated beds is the western facies of the Morrison.

At the base of the Kootenai is a widespread and distinctive ledge-forming sandstone unit known informally as the Sunburst sand in the subsurface nearby (Cobban, 1945, p. 1269–1270; 1955, p. 108). It consists of a basal sandstone overlain by sandy shale and clayey shale. The Sunburst ranges in thickness from a few feet to 70 feet. The lower sandstone bed of the Sunburst ranges in thickness from 0 to about 50 feet. It is absent in the southern part of the Patricks Basin quadrangle, in the general vicinity of the head of Gibson Reservoir, and at station 43 in French Gulch. The sandstone is 3–5 feet thick in the southwest corner of the area and attains a maximum thickness of 50 feet in the vicinity of Green Timber Gulch. In general this sandstone is best developed in the eastern part of the area.

The lower sandstone of the Sunburst consists of many thin beds of hard noncalcareous indurated very light gray sandstone, composed of poorly sorted rounded to subangular grains of clear quartz and a few scattered grains of chert and feldspar. In most places it is very fine- to fine-grained; locally it is coarse grained. In some exposures the matrix is a white clay with some small white clay nodules. The beds are locally crossbedded and characteristically weather in small elongate blocks 4–8 inches long. In the upper part of Hannan Gulch, crossbeds indicate current flow to the northeast.

Overlying the lower sandstone is 20–40 feet of beds of mudstone that Cobban (1945, p. 1269) included in the Sunburst. In most places these beds are yellowish-gray, gray, and olive-drab thin-bedded siltstone. Limestone interbeds occur in the southern outcrop area, where they form a sequence 2–25 feet thick about 10–20 feet above the base. They are thin bedded, dense, and gray to light gray, and contain many thin gray shale partings. At station 114 these beds contain charophytes, gastropods, pelecypods, and vertebrate bones.

Above the Sunburst, the remaining 90 percent of the Kootenai consists of thick beds of varicolored mudstone and lenses of greenish-gray sandstone. The proportion of sandstone to mudstone varies considerably. In Hannan Gulch, for example, the formation is 65 percent sandstone and 35 percent shale. In many places, however, sandstone comprises less than 25 percent.

The most noticeable colors in the Kootenai are grayish green and a dull dark reddish brown (10 *R* 3/4). The formation also contains gray, olive-gray, yellowish-gray, and purple thin beds. Locally grayish-green beds comprise much, if not all, of the formation. Most of the mudstones are siltstones that locally are sandy. In addition, at station 230 there is a thin (0.3 ft) bed of bentonitic shale in the lower part.

The mudstone, especially in the lower half of the formation, contains numerous heavily iron stained spheroidal nodules and lentils of dark-grayish-red sandy limestone. All sizes and shapes of nodules are generally within a single exposure. These nodules are as much as 3 feet across; most of them, however, are 2–5 inches across.

The sandstone beds fill channels; a few attain thicknesses of 160 feet and weather to cliffs 50 feet high. Within 2 miles, most of the sandstone lenses out or grades laterally into sandy mudstone.

The first sandstone unit above the Sunburst beds is relatively distinctive and easily recognized. It is massive and generally forms a small hillside bench. The distinguishing feature of this sandstone is its abundant magnetite. In the South Fork of Deep Creek (HS829), this bed has many thin (up to one-fourth inch) lenses composed almost entirely of coarse-grained magnetite, which impart a banded appearance to the rock. Elsewhere the magnetite is dispersed throughout the beds, and it may be confused with black chert.

A sandstone bed 50–100 feet below the top of the formation is the thickest and most widespread of the sandstones. It generally forms a prominent hillside bench. In places it represents a channel fill as much as 160 feet thick. In the area north of the Sun River Canyon the basal part is locally conglomeratic.

Almost all the sandstone beds are of a similar composition. They are made up mainly of well-rounded to subangular grains of quartz and chert, which impart a salt-and-pepper appearance to the bed. Mica and feldspar occur in varying amounts. In most places the sandstones are fine to medium grained, noncalcareous, poorly sorted, and poorly indurated. Locally within a channel they are coarse grained and interbedded with conglomerate. Common in all of the sandstones are varying amounts of chlorite and magnetite. The chlorite occurs both as a detrital mineral and as part of the cement. A few of the grains are heavily coated with hematite. Magnetite is in almost all the beds, ranging from a few sparsely scattered grains to abundant fragments. In many places it is sufficiently concentrated to have an effect on a magnetic compass. The sandstones are very thin to thin bedded and commonly crossbedded. A carbonaceous shale lens (0.5 ft thick) is at the base of one of the sandstone units at station 115.

The conglomerates in the Kootenai of the Sun River Canyon area have been described by Mudge and Sheppard (1968) and will be discussed only briefly here. These conglomerates occur at the base of the uppermost and lowermost sandstone units and are generally deposits filling channels cut into the underlying beds. These channels represent at least two local unconformities within the Kootenai, and there are very likely others. (See measured section 8.) The conglomerates at the base of the lower sandstone bed is exposed locally in the southern outcrop area (sta. 110 and 150, pl. 2). It consists of rounded to subrounded pebble and smaller sizes of quartzite, quartz, chert, and igneous rocks. This conglomerate at station 150 is thicker and contains larger fragments and more igneous rocks than the conglomerate at station 110. The crossbedding at station 150 indicates a current direction to the northeast. The bulk of the fragments are black chert from the Paleozoic rocks. Most of the quartzite fragments were derived from Precambrian rocks, and some may be from the Flathead Sandstone (Cambrian).

The conglomerates in the upper sandstone unit crop out in the northern part of the Sun River Canyon area in the vicinity of Goat Creek (sta. 187, pl. 2), Sheep Mountain (sta. 196, pl. 2 and west), and in No Business Creek (sta. 251, pl. 2). At each of these locations this conglomerate has a similar lithology, but in the No Business Creek area it is thicker and contains coarser fragments. There it also contains a higher percentage of igneous-rock fragments than at the other localities.

In No Business Creek, this conglomerate consists mainly of well-rounded pebbles (½–1½ in. across) but includes cobbles of igneous rocks 3–6½ inches across. The rock fragments are mainly chert, quartz, quartzite, silicified limestone, and an abundance of extrusive and shallow intrusive igneous types; all were derived from a nearby westerly source (Mudge and Sheppard, 1968). These are in a coarse-grained matrix, mostly of angular to subangular fragments of quartz, chert, and feldspar. The igneous rocks described by Mudge and Sheppard (1968) are granite, quartz monzonite, granodiorite, and quartz diorite as well as silicic lavas and tuff. The extrusive rocks are similar to the igneous pebbles in the Cretaceous McDougall-Segur conglomerate in the southeastern Canadian Cordillera (Norris and others, 1965, p. 9–11). Interbedded with the conglomerates are lenses of coarse-grained sandstone containing wood and coal fragments. The lower part of the channel fill is heavily iron-stained with abundant limonite and hematite along fracture planes. The sandstones and conglomerates fill a channel about 50 deep and 600 feet long that trends southeastward. On this trend in the next fault block southeast, the same conglomerate, with igneous debris, is exposed in the upper reaches of Battle Creek.

In most places in the Sun River Canyon area a distinctive coquinoid limestone unit occurs at or near the top of the Kootenai. This unit, commonly called the gastropod limestone, persists over much of western Montana (Klepper and others, 1957, p. 25; Freeman, 1954, p. 10–14; Scholten and others, 1955, p. 356; Robinson, 1963, p. 59; Childers, 1960, p. 74; and Cobban, 1955, p. 107).

In the Sun River Canyon area this limestone is widespread only in the central and western outcrop areas, west of Mortimer Gulch and Green Timber Basin and south and west of the upper reaches of Home Gulch. In most places it occurs from 2 to 15 feet below the top of the formation, but in the area between Circle and Cabin Creeks it is the topmost bed. This unit is a single bed, except locally where there are two or more beds of limestone. At Sheep Mountain there are five relatively thick beds of coquinoid limestone that are separated by gray silty coquinoid beds of shale (see measured section 19), much as in the section near the south border of Glacier National Park (Cobban, 1955, p. 107–108).

This coquinoid limestone unit is characteristically hard, dense, massive, and moderate brown to moderate yellowish brown. In places in the Patricks Basin quadrangle it is thick and dark gray and weathers a bluish gray to gray brown. Everywhere it contains one or more coquinoid lenses of white pelecypods, gastropods, and some fish teeth and scales. In places, however, the whole bed is composed of fossil fragments. These coquinas form distinctive white bands or zones in the brown limestone. In the western part of the Sun River Canyon area this unit generally forms a small but prominent ledge near the top of the Kootenai and ranges in thickness from 1 to 40 feet; its maximum thickness is at Sheep Mountain. In the central part of the area it ranges in thickness from 1 to 20 feet, averaging about 6 feet. In general it thickens toward the southern part of the Patricks Basin and southeastern part of the Pretty Prairie quadrangles.

Fossils are relatively rare in the Kootenai Formation except in the upper limestone unit. Locally, sparse minute invertebrates are in the lower mudstone units, whereas vertebrate bone fragments are in some of the limestone concretions. The fossils from the lower mudstone beds exposed in Beaver Creek were identified by J. B. Reeside, Jr. (written commun., 1956), and are as follows.

F81 (USGS Mesozoic locality n. 26304), and F82 (USGS Mesozoic locality n. 26305):

?*Unio farri* Stanton
?*Eupera onestae* (McLearn)
?*Gyraulus* sp.
Protelliptio douglassi (Stanton)
Mesoneritina sp.
Liaplacodes sp.

The lower part of the Kootenai is exposed in an irrigation ditch in the NW¼SE¼ sec. 32, T. 22 N., R. 8 W. Here, poorly preserved fragments of gastropods and pelecypods were collected from argillaceous limestone beds, and one of the gastropods was identified by Cobban (written commun., 1956) as *Neritina* sp. He stated that this was a fresh-water form. At this same location but higher in the Kootenai, another argillaceous limestone bed contained fragments of a vertebrate, possibly a fish (F197).

F349 is from beds above the gastropod limestone at station 167, southwest of Windfall Creek, and was identified by W. A. Cobban (written commun., 1960) as *Eupera*? sp.

Collections from the upper limestone unit in measured section 19 at Sheep Mountain were examined by W. A. Cobban (written commun., 1961), who reported the following forms.

F364. Unit 20, measured section 19:
Unio sp.
Eupera onestae (McLearn)
Stantonogyra sp.

F365. Unit 24, measured section 19:
Unio sp.
Stantonogyra? sp.

F366. Unit 25 and 26, measured section 19:
Protelliptio douglassi (Stanton)
Eupera onestae (McLearn)
Stantonogyra silberlingi (Stanton)?

F367. Unit 29, measured section 19:
Stantonogyra silberlingi (Stanton)?

Vertebrate fragments from the upper limestone bed of the Kootenai were studied by F. C. Whitmore, Jr. (written commun., 1960), who reported:

F337. Scales of holostean fish and the teeth of two species of Hybodont sharks: *Hybondus polyprion* Agassiz and *Acrodus* sp., cf. *A. anningei* Agassiz.

F343. From station 161 on Bighead Creek, a dermal plate of small crocodilian, indicating fresh or slightly brackish water.

F344. From station 163 on the South Fork of the Sun River, an anterior tooth of a medium-sized crocodile.

COLORADO GROUP

In the Sun River Canyon area the Colorado Group comprises as much as 3,000 feet of rocks of Early and Late Cretaceous age (table 1). These rocks were formerly called the Colorado Shale by Stebinger (1918, p. 157). Later they were designated the Colorado Group and divided into two formations, the Blackleaf Formation and the Marias River Shale (Cobban and others, 1959a, p. 89; 1959b, p. 2787). The age and faunal zones of these units as well as their correlation with the sequences in Alberta, Canada, northeastern Wyoming, and western Kansas were discussed by Cobban, Erdman, Lemke, and Maughan (1959b, p. 2792, fig. 3).

Both formations are well exposed in the Sun River and Deep Creek drainages east of the mountains, and in the North Fork and lower reaches of the South Fork of the Sun River within the mountains (pl. 1). Parts of the Blackleaf Formation are also exposed in each of the mountain valleys tributary to the Sun River (pl. 1).

BLACKLEAF FORMATION

The Blackleaf Formation is mudstone and sandstone that was originally defined by Stebinger (1918, p. 158–160) as the Blackleaf Sandy Member of the Colorado Shale. Later this member was given formation status by Cobban, Erdmann, Lemke, and Maughan (1959a, p. 89; 1959b, p. 2787), who divided it into four members: Flood, Taft Hill Glauconitic, Vaughn Bentonitic, and Bootlegger. All but the Bootlegger Member are present in the Sun River Canyon area (table 1). As Cobban, Erdmann, Lemke, and Maughan (1959b, p. 2793) noted, the Bootlegger thins to the west from the Sweetgrass Arch and is absent along the mountain front, owing either to thickening of water-laid volcanics of Vaughn lithology or to pre-Marias River Shale erosion. The nomenclature of the three outcropping members was modified slightly when it was adapted to the Sun River Canyon area by Mudge (1965). As used in the present report, the three members are Flood Shale, Taft Hill, and Vaughn (table 1). The lithic designations were dropped from the Taft Hill and Vaughn because they do not apply here.

The soils on the shales of the Flood and Taft Hill Members are generally well developed and adapted to grasses. In contrast, the soil on the Vaughn is poorly developed and sparsely covered with grass. Limber pine thrives on the sandstone units of the three members; it is absent on the shales, except for those of the Vaughn.

The Blackleaf Formation ranges in thickness from about 665 feet east of the mountains to about 1,600 feet in the western outcrop area. Each member thickens westward.

Flood Shale Member

The Flood Shale Member consists of two thin sandstone units separated by a relatively thick shale unit (table 1). It is equivalent to the "lower black shale unit" in the Elkhorn Mountain area (Klepper and others, 1957, p. 26–27). It is also correlative with the Fall River Formation of northeastern Wyoming (Cobban and others, 1959b, p. 2792).

In the Sun River Canyon area the Flood is exposed east of the mountain front as well as in each of the mountain valleys as far west as Sheep Mountain (pl. 1). It is locally exposed along the west side of each valley beneath thrust faults. The member ranges in thickness from 150 feet just east of the mouth of the Sun River Canyon to 550 feet at Sheep Mountain in the western part of the area. It also thickens southwestward to 345 feet in Lime Gulch and 390 feet at the head of Dry Fork in the Patricks Basin quadrangle. Some of the rock fragments in the sandstone are from metamorphic, volcanic, and tuffaceous rocks. Most of the sand, however, was derived from older sedimentary rocks. (See measured sections 18–21.)

The lower sandstone unit is a distinctive sequence of thin even-bedded gray sandstone, some of which is quartzitic. The beds weather yellowish gray with some reddish-brown hematite stains. Locally some beds display mud cracks, minute laminae, crossbedding, load casts, and penecontemporaneous folds. Ripple marks are common, and both symmetrical and asymmetrical ripples are present. The crossbedding is generally tabular and low angle, except at station 156 (pl. 2), where it is similar to the festoon type.

The beds are composed mostly of clear rounded grains of quartz with scattered grains of black chert. In most places they are well sorted and fine grained; locally, some beds are poorly sorted and very fine to coarse grained. Their composition is listed in table 7. Most of the grains are angular; a few are rounded. The unit contains fragments of altered volcanic tuff and other rock types in the upper reaches of Hannan Gulch, in Mortimer Gulch, and in Green Timber Basin (HS49 and 174, table 7).

At station 138 (pl. 2), at the head of Reclamation Flats, there is a thin conglomerate near the base of the

TABLE 7.—*Quantitative petrographic description of some Cretaceous rocks in the Sun River Canyon area*

[Analyses, in percent, by K. L. Shropshire. Tr., trace]

Rock type	Sample HS-	Plagioclase	Potassium feldspar	Quartz	Carbonate	Chert	Rock fragments	Matrix	Clay	Accessory minerals [1]
Two Medicine Formation										
Sandstone [2]	24									
Tuffaceous graywacke	23	19		3	10		31	35		2 Ce; M; A; S; Sa; H
Feldspathic subgraywacke	22	14	16	22	5	5	25	6		M; 1 H; L; A; R; T; Sa; N; Ce; Li
Calcareous subgraywacke	18	[3] 8	9	35	9	7	15	12		B; Mu; M; P; Sp; Z; A; T; Sa; N; S; L; Si
Subgraywacke	634	4	3	31	20	5	18	7		2 B; 3 Ce; 1 Mu; M; A; Sp; Z; S; Sa; N ; E; 1 H
Arkose [4]	635									
Silicified tuff	636	[5] 4	Tr.	Tr.		Tr.		94	Tr.	B; Ho; H; L; glass and tuff
Do. [6]	637									
Virgelle Sandstone										
Silicified arkose	17	7	13	26	24	2	7	5		M; T; A; Mu; B; Ho; 2 Ce; Sa; H; L; N; S
Telegraph Creek Formation										
Silicified graywacke	16	6	7	18	34	3	1	10		Z; B; M; Ce; H; L; N; S
Kevin Shale Member of Marias River Shale										
Silicified sandstone	25	23	10	2	18		Tr.	4	Tr.	Z; A; 4 Ce; 5 N; S; Sa; H; 14 P; 10 F
Vaughn Member of Blackleaf Formation										
Silicified arkose	97	6	11	25	21	26	6			M; H; Li; L; Mu; B; S; Am; Gl; A; Z
Siltstone	96	Tr.	1	5	25	4			65	M; H; Li; A
Chert	95		1	2	Tr.	90			3	M; H; Li; B; A; L
Subgraywacke	119	7	15	20	1	9	48		Tr.	M; H; L; B; A
Feldspathic graywacke	78	8	12	16		4	9	43		M; L; H; S; B; Ce; Z; G
Volcanic graywacke	77	3	18	10	Tr.	7	33	20		B; Ce; S; Sp; M; Li; A; G
Subgraywacke	12	12	11	18	2	2	36	15		M; H; Ce; Mu; G; Z
Arkose	11	23	5	10	24	2	26	3		M; H; Li; S; Ce; Z; R; T; Gl
Subgraywacke	10	5	11	15	13	4	46	1		M; H; Li; G; T; Ce; Mu
Graywacke	9	8	8	17	4	4	38	18		M; H; Li; Ce; S; B; E; G; Gl
Subgraywacke	8	2	6	25	24	5	32	1		M; H; L; S; G; Ce; B; Z
Volcanic graywacke	74	9	23	15		4	31	14		M; S; B; E; O; Ce; Z; H
Feldspathic subgraywacke	7	2	9	12	Tr.	12	53		6	2 M; H; L; Ce
Arkose	84	10	33	8	5		1	3		10B; M; H; L; P; Z; A
Taft Hill Member of Blackleaf Formation										
Feldspathic subgraywacke	26	9	6	35	10	8	18		2	M; L; Ce; E; G; Am; Gl
Do	6	5	9	11	3	4	54		7	M; H; Ce; Z
Subgraywacke	5	3	5	26	35	5	16	8		M; H; I; L; Li; S; Ce; B; P; Gl; Z; Sp
Graywacke	4	1	5	28	17	6	14	23		H; Li; M; L; Ce; A; Gl; O; P
Subgraywacke	3	Tr.	7	32	35	7	8	5		Ce; S; H; M; I; L; A; G; Z; B; Mu
Graywacke	1	Tr.	7	34	1	14	18		7	M; H; Li; I; L; Mu; B; S; Ce; Z
Subgraywacke	2	3	7	56	2	14	15	1		M; H; I; L; Li; S; Ce; P; Z; A; Gl; B
Flood Shale Member of Blackleaf Formation										
Feldspathic graywacke	524	1	6	39	13	15	5		14	H; Li; M; L; B; Mu; Ce; S; A; Mu; Gl; Z
Subgraywacke	14	2	3	50	14	5		18	1	M; H; Li; Gl; S; B; Z
Arkose	218	Tr.	20	51		7		13		M; H; Li; L; Z; O; Ce; Mu; S
Subgraywacke	51	2	6	56		7	11		14	M; L; H; Mu; S; Z; T
Protoquartzite	13	Tr.	1	79		5	11			M; L; Z; B
Subgraywacke	523	Tr.	4	29	35	15	1		9	H; M; Gl; B; Mu; S; Am; T
Do	525	2	8	40	20	14	4		9	2 Ce; S; H; L; M; Mu; Gl; G
Arkose	526	3	10	38	6	19	12		9	M; H; Mu; Gl; Ce; Py; Sd; T
Calcarenite	332		Tr.	1	93			2		2 H; M
Sandy calcarenite	22	Tr.	2	20	65	3	1		2	H; M; Ce; B; Mu; Z
Protoquartzite	50	1	1	73		1	4			M; 2 H; L; Mu; Z; Sp
Subgraywacke	174	12	14	21	Tr.	4	32		12	M; H; Li; L; B; Mu; S; E; Sp; A; Ce; Z
Orthoquartzite	407	Tr.	Tr.	94		1			1	S; Ce; M; A; Am
Graywacke	49	1	7	35		3	10		25	M; H; Li; Mu; B; S; Z; P; Sp; Gl; E; L
Protoquartzite	276		2	69		3	4	15		M; H; L; Mu; S; Z; H; T: Sp
Do	497			78		3	1	15	Tr.	Mu; B; H; Z; H; Ce
Do	220		4	81	Tr.	3	2		3	M; H; Li; L; Mu; Gl; T; G; Z
Orthoquartzite	419		3	86		5	1			M; H; S; Mu; B; Z; T
Protoquartzite	521		1	88		3	2	5		M; H; B; Ce; Z; Mu; T
Do	287B	Tr.		86	4	3	Tr.		4	M; Li; L; H; B; Z; Sp; Sd
Do	284	Tr.	2	76		4	13	1		M; Li; Z: T

[1] Ce, chlorite; M, magnetite; A, apatite; S, sericite; Sa, saussurite; H, hematite; L, leucoxene; R, rutile; T, tourmaline; N, nontronite; B, biotite; Mu, muscovite; P, pyrite; Sp, sphene; Z, zircon; Si, silica; E, epidote; Ho, hornblende; Li, limonite; Gl, glauconite; G, garnet; O, olivine; I, ilmenite; Py, pyroxene; Am, amphibole; Sd, siderite.

[2] Same as HS23 but has larger fragments of tuffaceous rock.

[3] Oligoclase.

[4] Like HS18 and HS22 except contains more feldspar.

[5] Oligoclase.

[6] Same as HS636 but has mcre plagioclase phenocrysts.

lower sandstone, and it is composed of subrounded to rounded granules and small pebbles of chert and quartzite in a poorly sorted coarse sand matrix.

The thickness of the basal sandstone unit is variable. The sandstone is absent east of Diversion Dam and along No Business Creek, but elsewhere it ranges in thickness from 2.5 to about 26 feet. In most places it forms a small distinct hillside ledge.

The medial shale, 100–195 feet thick, makes up most of the Flood. This shale is distinctive, as it is the only very dark gray thick thinly laminated shale in the lower part of the Colorado Group. Generally it is clayey and noncalcareous and weathers into small fragments that have a metallic-gray luster. In most places the contact between this shale and the underlying sandstone is sharp and distinct, but in a few places it is gradational.

The southwesternmost outcrop of the shale unit contains numerous coarsely crystalline phosphatic nodules up to 4 inches across. Most are rounded with a globular surface; some are flattened elongate to the bedding. X-ray analyses by R. A. Sheppard (oral commun., 1967) show that the nodules are composed of carbonate-fluorapatite and quartz and that fractures are filled with kaolinite. The nodules are a dense dark-gray silt with no structures. The nodular surface is minutely pitted. Similar nodules have been described from stratigraphically equivalent shale in the Bearpaw Mountains by Pecora, Hearn, and Milton (1962, p. B31–B32). The nodules differ from those in the Bearpaw Mountains by the absence of spherulitic structure. Pecora, Hearn, and Milton (1962, p. B33–B34) believed that the nodules formed by precipitation of microcrystalline carbonate-fluorapatite from sea water transgressing a broad shelf.

The middle part of the shale contains some thin beds of dark-gray sandstone and thick lentils and nodules of limestone and claystone. The sandstone is mainly very fine grained quartz, chert, and feldspar (table 7) colored by carbonaceous material. The limestone and claystone are dark gray and very fine grained and have a conchoidal fracture.

The upper part of the shale unit is transitional into the overlying sandstone (fig. 30), which consists of alternating thin beds of yellowish-gray sandstone (HS 523 and 524, table 7) and sandy shale. The beds contain a film of bluish-gray clay on the bedding planes. The sandstone beds are very irregular (pinch and swell) in thickness; some contain wood fragments.

In the southeastern part of the Sawtooth quadrangle there is 72 feet of shale between the transitional sandstones and the upper sandstone unit of the Flood. This shale is similar in lithology to the middle part of the Flood in that it is dark gray and thinly laminated to laminated. The amount of sand also increases to the north, as can be seen at No Business Creek, where the

FIGURE 30.—Upper sandstone unit of the Flood Shale Member of the Blackleaf Formation along the Pishkun irrigation canal in sec. 28, T. 21 N., R. 8 W., Teton County (measured section 20). The beds grade from dark-gray mudstone below to light-gray sandstone above. Rock shown in figure 31 was obtained from the lower sandstone beds exposed here.

upper one-third of the Flood is mostly sandstone beds that form three prominent ledges.

The upper sandstone unit consists of thin distinct units of very thin bedded to thin-bedded sandstone (fig. 31). Locally these beds are crossbedded and contain fragments of wood and coal. Most of the rocks are calcareous subgraywacke; some are arkose and protoquartzite (table 7). They are mostly very fine grained well-sorted angular to subrounded quartz with some chert and feldspar in a calcareous cement.

In the eastern part of the area the middle of this unit contains a thin zone of heavily iron stained sandstone which forms a dark-brown band on the cliff face. Locally, large nodules of sandstone are in the upper part.

The upper sandstone unit ranges in thickness from 4 to about 30 feet. In most places it forms the most distinct hillside bench of the Colorado Group and a vertical cliff 20–30 feet high (fig. 30).

The Flood Shale Member rests disconformably on the Kootenai. The disconformity is subtle and of low relief, no more than 15 feet.

Fossils are rare in the Flood Member, except for organic trails and burrows, which are particularly abundant in the upper part of the shale unit (fig. 31), where they serve as criteria for identifying the unit. Trails and burrows also occur sparsely in the sandstone units. The burrows are randomly arranged on the upper surfaces of individual beds and look much like coprolites.

FIGURE 31.—Organic trails and burrows on the upper surface of a sandstone bed in the Flood Shale Member of the Blackleaf Formation along the Pishkun irrigation canal in sec. 28, T. 21 N., R. 8 W., Teton County (measured section 20); same outcrop as figure 30. The dark material is blue-gray clay that partly coats the organic burrows and trails.

Locally in the shale member are bluish-gray fragments of bones. Those in sample F296 were collected from a ridge just west of NW. cor. sec. 30, T. 22 N., R. 8 W., Castle Reef quadrangle, and were examined by Nicholas Hotton III (written commun., 1965), who reported a skull plate, similar to that of crocodilians, and fragments of a dinosaur.

A collection of pelecypods (F350, USGS Mesozoic loc. D2614) was obtained from the upper sandstone unit at station 168 (pl. 2), west of Windfall Creek (table 8). In it, W. A. Cobban (written commun., 1960) identified *Pleurobema* cf. *P. dowlingi* (McLearn), which he believed to have been a fresh-water form. Poorly preserved pelecypods (F425, USGS Mesozoic loc. D4562) from the upper sandstone unit of the Flood near the head of the South Fork of Deep Creek (table 8) were also identified as *Pleurobema* by Cobban (written commun., 1964).

TAFT HILL MEMBER

The Taft Hill Member consists mainly of gray sandy shale and sandstone (table 1). It is well exposed along the Sun River east of the mountains and in many valleys as far west as Sheep and Slategoat Mountains. A section (measured section 23) is in the north bank of the Sun River about half a mile east of Diversion Dam (fig. 32). In the Sweetgrass Arch area the Taft Hill contains beds of glauconitic sandstone and was called the Taft Hill Glauconitic Member by Cobban, Erdmann, Lemke, and Maughan (1959b, p. 2790). In the Sun River Canyon area, however, glauconite is present only as minor constituent (table 8).

The Taft Hill Member ranges in thickness from 225 to 600 feet. Its minimum thickness is along the Sun River east of the mountains. It thickens southwestward to 360 feet in the head of Beaver Creek and westward

TABLE 8.—*Distribution of megafossils in the Blackleaf Formation of the Sun River Canyon area, Montana*

[Invertebrates identified by W. A. Cobban. Plants identified by R. W. Brown]

	Flood Shale Member			Taft Hill Member																																										Vaughn Member										
	F296	F350 (D2614)	F425 (D4562)	F5	F8	F10	F28	F29	F30	F33	F35	F38	F83	F135	F422	F22 (D1119)	F25 (D1120)	F27 (D1121)	F26 (D1122)	F45 (D1123)	F46 (D1124)	F47 (D1125)	F34 (D1131)	F36 (D1132)	F37 (D1133)	F39 (D1134)	F40 (D1135)	F41 (D1136)	F42 (D1137)	F43 (D1138)	F4 (D1139)	F6 (D1140)	F7 (D1141)	F9 (D1142)	F11 (D1143)	F12 (D1144)	F13 (D1145)	F84 (D1146)	F134 (D1489)	F135A (D1490)	F218 (D1770)	F242 (D1771)	F236 (D1772)	F326 (D2219)	F324 (D2608)	F413 (D3804)	F31	F32	F44	F119	F120	F138	F140	F141	F196	F398	F30
Invertebrates																																																									
Helminthoides?														X																										X																	
Lingula subspatulata Hall and Meek																X					X	X	X	X													X	X	X																		
Inoceramus sp.						X							X												X	X					X																										
bellvuensis Reeside				X										X					X								X		X	X		X											X														
comancheanus Cragin											X							X			X	X	X										X																								
Ostrea sp.				X								X		X												X																															
anomioides Meek						X		X									X			X	X	X	X											X	X	X	X	X																			
larimerensis Reeside					X	X	X			X								X	X			X	X				X	X		X	X		X	X				X																			
noctuensis Reeside																			X		X										X																										
Cardium kansasense Meek					X														X					X											X		X																				
Pleurobema cf. *P. dowlingi* (McLearn)		X																																							X																
n. sp.																																										X															
?sp.			X																																																						
Corbula sp.															X													X																	X												
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Arctica? sp.																																												X		X											
Nuculana? sp.																				X																																					
Phelopteria sp.																				X																																					
salinaensis White																							X								X			X																							
Callistina? belviderensis (Cragin)																						X													X	X	X	X																			
Modiolus sp.																								X																																	
Thracia? sp.																								X																																	
Pteria sp.																									X																																
Pinna sp.																												X																													
Brachidontes sp.																																													X												
Gyrodes sp.					X														X																																						
Anchura kiowana Cragin					X														X				X																																		
Plants																																																									
Sphenolepis kurriana (Dunker) Schenk																																															X		X			X					
Pseudocycas steenstrupi (Heer) Nathorst (?-*Cycadites unjiga* Dawson)																																																	X								
Podozamites lanceolatus (Lindley and Hutton) Brown																																																	X								
?*Araucarites* sp.																																																	X								
Brachyphyllum crassicaule Fontaine																																																	X			X					
Sassafras cretaceum Newberry																																																	X								
Cephalotaxopis magnifolia Fontaine																																																	X								
Cinnamomum sp.																																																	X			X					
Sequoia sp.																																																					X	X			
Tempskya sp.																																																								X	
Fragments of dicotyledonous leaves									X																																						X		X	X	X	X	X	X			X
Fragments of ferns																																																X		X	X						
Fragments of coniferous																																																		X	X				X		
Cone scales (not identified)																																																X									

NOTE.—In boxheads, numbers prefixed by "F" are filed numbers; these in parentheses are USGS Mesozoic locality numbers.

to 600 feet thick at Sheep Mountain. (See measured sections 22, 23, 25, and 26.)

The Taft Hill rests sharply and conformably on the Flood. In the eastern outcrop area the basal beds of the Taft Hill are brackish water to marine sandy shale, whereas in the westernmost outcrop they are nonmarine carbonaceous shale with coal lentils.

The interbedded shale and sandstone of the Taft Hill seems to represent cyclic sedimentation (figs. 32 and 33). A cycle is as follows: Gray fossiliferous shale, gray shale with bentonite beds, transitional beds of siltstone, claystone, sandy shale, and sandstone, and thin-bedded fossiliferous sandstone. Five of these cycles are recognized in the Taft Hill, and the 10 units are believed to be widespread in the area.

Mudstone composes units A, C, E, G, and I (figs. 32 and 33). It is mostly gray noncalcareous silty shale in the lower units but includes claystone and siltstone in the upper units. Also in some of these units are thin beds of sandstone and bentonite. The proportion of sandstone on the mudstone units increases to the northwest. Locally, iron-stained limestone concretions are in the upper part of each of the units. On the east side of Sheep Mountain a 1-foot-thick carbonaceous bed with lentils of coal occurs at the base of the Taft Hill.

The sandstone units of the Taft Hill are distinctive and not readily confused with other Cretaceous sandstones. They are gray, very fine grained, finely micaceous, and moderately well sorted, and they generally

FIGURE 32.—Taft Hill Member of the Blackleaf Formation exposed in the north bank of the Sun River about half a mile east of Diversion Dam (measured section 23). The base is not exposed. The uppermost unit (J) is at the top of the exposure. The units (C–J) and their fauna are shown in figure 33.

weather grayish brown. They consist of angular to well-rounded quartz, chert, feldspar, rock fragments, and carbonate (table 7). Statistically, these sandstones contain less quartz and more rock fragments than those in the Flood. Quartz decreases upward in the Taft Hill, whereas feldspars and rock fragments increase. The rock fragments are a variety of volcanic, metamorphic, plutonic, and sedimentary rocks. In some beds, carbonate occurs both as calcite cement and as detrital grains, whereas in other beds it occurs as dolomite rhombs and as a replacement of quartz. Pyrite crystals occur in some of the lower sandstone units. The accessory minerals of these sandstones are listed in table 7.

The sandstone units are mostly very thin bedded, but a few are laminated (fig. 34). Most of the sandstone units have low-angle crossbedding, especially unit J.

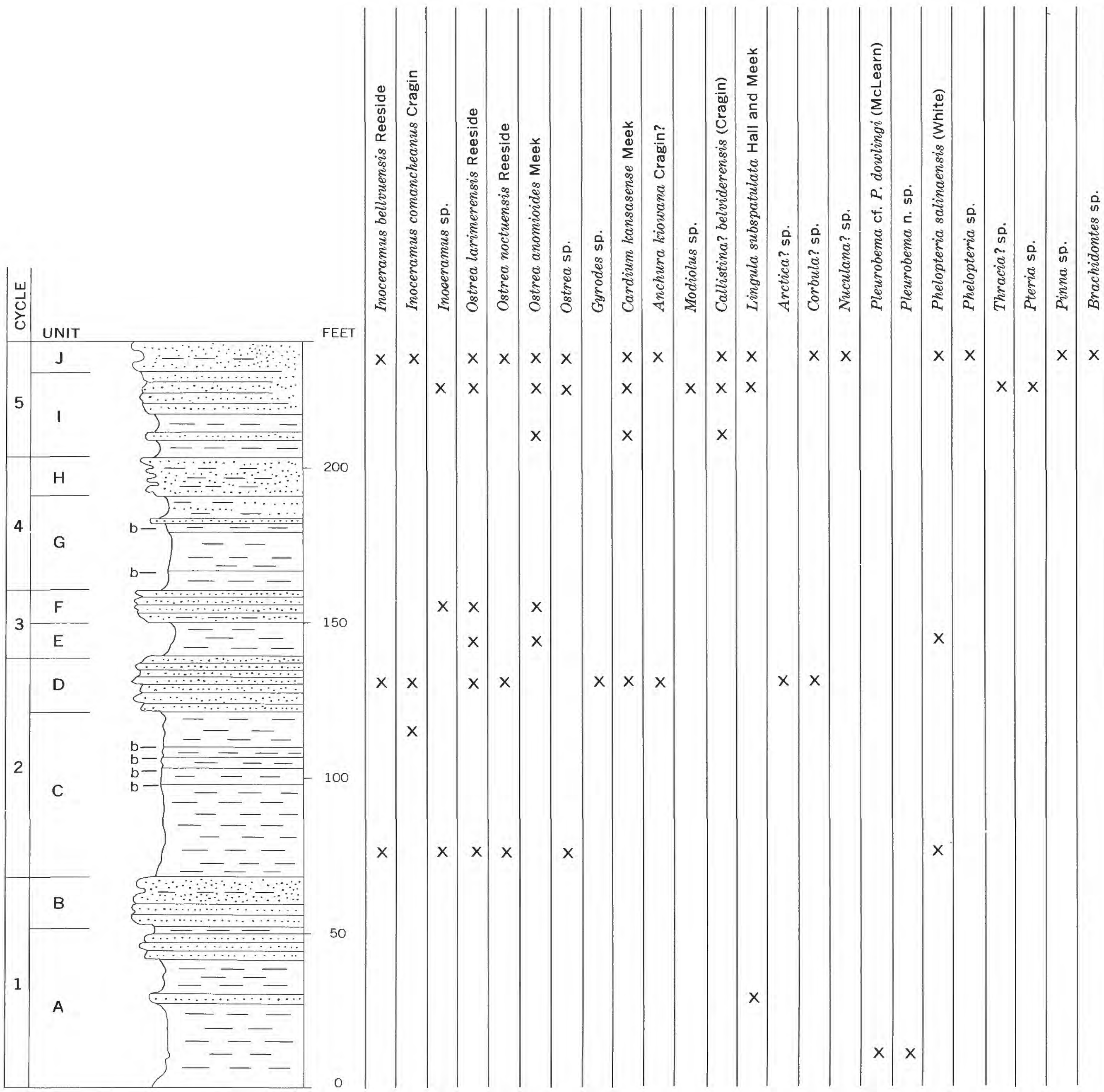

FIGURE 33.—Subdivisions and fauna of the Taft Hill Member of the Blackleaf Formation in the Sun River Canyon area. b, thin bentonite bed.

FIGURE 34.—Uppermost sandstone unit (J) of the Taft Hill Member of the Blackleaf Formation along the Pishkun irrigation canal in the NE¼ sec. 31, T. 22 N., R. 8 W., Teton County. The contorted fine-grained sandstone bed is characteristic of the lower part of this unit. L, *Lingula subspatulata* zone; O, *Ostrea anomioides* zone.

The lowermost sandstone unit (B) contains many ripple marks. In No Business Creek the lower sandstone units contain abundant angular fragments of mud chips that were not observed elsewhere. In measured section 23, east of Diversion Dam, lentils of coal are in the sandy shale underlying unit J. Units D and J form hillside benches that are generally covered with brown weathered plates. Unit J forms the thickest and most prominent of these ledges (fig. 34). In much of the area unit J overlies a widespread thick bed of very fine grained sandstone with penecontemporaneous folds (fig. 34).

Unlike the rest of the Blackleaf Formation, the Taft Hill contains many fossils, especially pelecypods (table 8). Fossils are more common in the eastern outcrop area than in the western. As indicated in figure 33, fossils are more numerous in units D and J; they were not found in units B, G, and H. The Taft Hill contains the oldest occurrence of *Inoceramus*, and both *Inoceramus comancheanus* Cragin and *I. bellvuensis* Reeside are restricted to it. According to W. A. Cobban (written commun., 1957), *I. comancheanus* is a guide fossil that also occurs in the Kiowa Shale in Kansas and in the Skull Creek Shale of the Black Hills. *Ostrea anomioides* Meek, *Gyrodes* sp., and *Anchura kiowana* Cragin? are restricted to the Taft Hill Member in the Sun River Canyon area (table 8). *O. anomioides* Meek is found only in the upper beds, and is most abundant in the J sandstone unit. Of *O. anomioides* Meek, W. A. Cobban (written commun., 1956) said: "This is a common species in western Montana in an area extending from the vicinity of Three Forks northwestward nearly to Birch Creek west of Dupuyer. The species seems to be confined to rocks of Early Cretaceous age equivalent to the

[Taft Hill] glauconitic sandstone members of the Colorado Shale of the Sweetgrass Arch." He also noted that the Taft Hill has abundant oysters and many fragmented shells, which suggests shallow nearshore marine deposition in waters of normal salinity. The fragmental shells indicate turbulence.

Lingula subspatulata Hall and Meek, also found in the lower shale unit, occurs abundantly in the upper beds of unit J (figs. 33 and 34). It is mostly in thin zones 1–2 feet above the *Ostrea anomioides* zone.

About 1 foot below the top of unit D is a 0.3-foot-thick coquina of the pelecypods *Ostrea larimerensis* Reeside and *Cardium kansasense* Meek and the gastropods *Gyrodes* sp. and *Anchura kiowana* Cragin?. This coquina is relatively widespread east of the mountains and in most of the valleys tributary to the Sun River southeast of Grouse Creek.

Organic trails and burrows are common in many of the sandstone beds. In places unit J contains a single type of burrow that has a distinctive symmetrical U-shape and is parallel to the bedding. The burrows are about three-fourths of an inch long, 1 inch wide and about one-sixteenth of an inch in diameter. W. A. Cobban (written commun., 1957) said of them: "The U-shaped markings of dark shale in the sandstone may be detached pieces of a problematical fossil commonly known in Europe as *Helminthoides*. These markings have been interpreted as the work of worms by some authors and of gastropods by other writers." These markings were also examined by P. E. Cloud, Jr. (written commun., 1959), who stated that the U-shaped tubes do not show scratches that would be made by a crustacean, and that they were probably feeding burrows of a polychaete worm.

In the upper reaches of Beaver Creek, the pelecypods *Pleurobema* cf. *P. dowlingi* (McLearn) and *Pleurobema* n. sp. occur in a thin bed in the lower part of unit A (F218, USGS Mesozoic loc. D1770; F242, USGS Mesozoic loc. D1771) (table 8), according to W. A. Cobban (written commun., 1958), who stated: "*Pleurobema dowlingi*, from the Dunvegan Formation of Alberta (Cenomanian) is believed to be a fresh-water shell." Also in unit A is *Lingula subspatulata* Hall and Meek.

At station 140 on the west side of Leavitt Creek, and on the northeast flank of Allan Mountain, unit D contains a coquina (F326, USGS Mesozoic loc. D2219) in which W. A. Cobban (written commun., 1959) identified the pelecypods *Arctica*? sp. and *Corbula*? sp. that represent a very shallow water marine or brackish-water environment. At station 160 on the divided between Bighead and Lange Creeks, collection F342 (USGS Mesozoic loc. D2608) from unit J contains the pelecypods *Brachidontes* sp. and *Corbula* sp., which are also a brackish-water fauna (W. A. Cobban, written commun., 1960).

Leaf fragments and carbon-coated wood fragments are present about 1.7 feet above the base of unit J in an irrigation ditch in the SE¼SW¼ sec. 31, T. 22 N., R. 8 W. R. W. Brown (written commun., 1956) referred to them as unidentifiable fagments of dicotyledonous leaves. Wood fragments are also present at approximately the same horizon at station 97 (pl. 2). These fragments were examined by R. A. Scott (written commun., 1958), who reported them to be conifers, possibly belonging to the Cupressaceae.

Vaughn Member

The Vaughn Member is typically made up of beds of alternating gray to olive-drab mudstones and bentonitic mudstone with many thin interbeds of very light gray sandstone. It is nonmarine and is the upper member of the Blackleaf Formation in the Sun River Canyon area (table 1). The upper part of the Vaughn in the Sun River Canyon area may be the nonmarine equivalent to the Bootlegger Member of the Blackleaf of the Sweetgrass Arch (Cobban and others, 1959b, p. 2793). A thin bed of carbonaceous shale (unit 49, measured section 24) that occurs about 160 feet above the base of the Vaughn may be equivalent to the uppermost bed of the Vaughn on the Sweetgrass Arch described by Cobban, Erdmann, Lemke, and Maughan (1959b, p. 2791). It is possible that some of the Vaughn may be marine, although all present evidence suggests a nonmarine origin. The Vaughn is laterally equivalent to the Newcastle Sandstone of the Black Hills (Cobban and others, 1959b, p. 2792).

This member is well exposed in many places east of the mountains, but in the mountains it is present only along the east side of the North Fork of the Sun River and in the vicinity of Windfall Creek. The lower half is exposed in a west-facing stream bank of the Sun River about three-fourths of a mile east of Diversion Dam (measured section 24). The upper part is exposed in a bank of a tributary of the Sun River in the NW¼SW¼ sec. 6, T. 21 N., R. 8 W. (measured section 28).

The thickness of the Vaughn Member is not easily ascertained, as in most places the member is complexly faulted and folded. In the eastern outcrop area the Vaughn is about 300 feet thick. To the west, on the east side of the North Fork of the Sun River, the thickness of this member determined by measuring on a map is about 500 feet. (See measured sections 24–28.)

The mudstone is mainly thin beds of noncalcareous tuffaceous claystone and siltstone that are mostly gray but weather olive gray to olive green. Locally there are zones of carbonaceous shale. Many beds are hard and firmly cemented with silica or carbonate. Along streams they form small ledges with a pitted weathered surface.

Interbedded with the siltstone and claystone are thin beds of bentonitic shale and a few of bentonite. The bentonite beds are rarely more than half a foot thick, and most are but 1–2 inches thick. Beds of bentonite and bentonitic shale are not as thick or numerous here as they are in the Sweetgrass Arch area. In places minute red specks and streaks (heulandite?) are in the mudstone. These are characteristic of the Vaughn in the Sweetgrass Arch area (Cobban and others, 1959b, 2790), and they compose the "red speck" zone in the subsurface of the arch area.

Beds of sandstone are thicker and more numerous in the lower part of the Vaughn than in the upper part. They are generally of poorly sorted fine- to coarse-grained gray to light-gray micaceous poorly indurated graywacke to arkose. The coarse grains are subrounded to rounded, whereas the fine grains are generally angular to rounded. The variation in the composition of these sandstones is shown in table 8. Quartz is less abundant in this member than in the sandstones of the underlying Taft Hill (table 8), whereas feldspar and rock fragments are more abundant. The rock fragments are of metasediments, altered volcanic (lavas and tuffs), and metamorphic and sedimentary rocks. Many of the feldspars have been albitized and sericitized, and some are partly replaced by calcite or dolomite. Biotite is altered and deformed. In many beds the matrix appears to be tuffaceous clay.

Angular to subrounded fragments of tuff, up to half an inch long, are in a sandstone bed in the lower part of the Vaughn at station 28, south of the Sun River (HS74, table 8).

In the upper half of the Vaughn there are a few beds of very fine grained light-gray chert and clay, which are very likely silicified and altered ash. Some of these are porcellanite with considerable tuffaceous debris. Beneath these beds is stratified fine-grained tuff (unit 5, measured section 28) with thin zones of accretionary lapilli (fig. 35). The lapilli are oblate spheroids that are elongate parallel to the bedding and are various sizes up to 5 mm long and 3 mm high. The core is light-gray very fine grained ash, enclosed by a rim of dark-gray very fine grained ash. The core is readily eroded, imparting a porous appearance to the weathered rock. The lapilli in the Vaughn are essentially identical with those described by Moore and Peck (1962, p. 184–191), who concluded that such lapilli "formed by accretion of moist ash in eruptive clouds and fell as mud-pellet rains."

A thick distinctive and widespread sandstone unit occurs in the middle of the Vaughn. It ranges in thickness from 15 to 30 feet, and it is poorly indurated, noncalcareous, and light gray. The beds are massive in the lower part but extensively crossbedded in the middle and upper parts. Sample HS12 in table 7 represents this unit. The main constituents are angular to rounded fine- to coarse-grained rock fragments derived from basic igneous rock, tuff, and metasediment. Chert is rare, far less common than in the sandstone beds in the other members of the Blackleaf Formation.

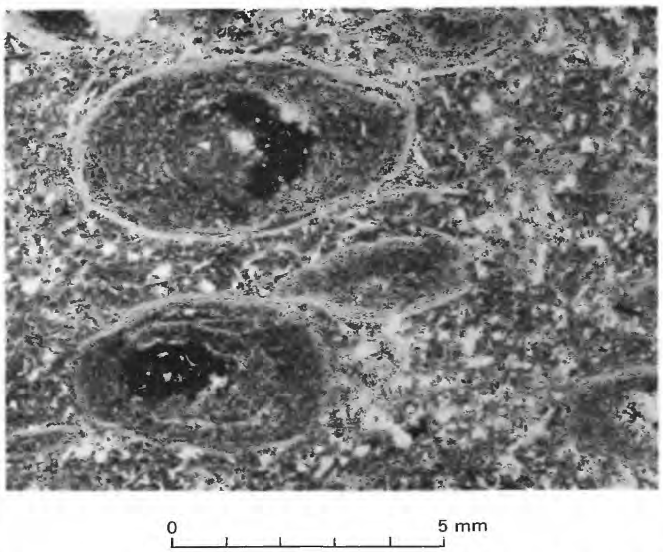

FIGURE 35.—Photomicrograph of accretionary lapilli in a tuff from the Vaughn Member of the Blackleaf Formation (HS 73) in a tributary south of the Sun River above station 27 at measured section 28. The lapilli are alined with the bedding.

Pebble and cobble conglomerate, filling small channels, is common at two horizons in the Vaughn. That in the lower part is exposed at stations 64 and 73 and at and near station 78 (pl. 2). The thickest and most widespread conglomerate occurs at the base of the prominent middle sandstone unit L of the Vaughn. The conglomerate is well exposed in the center of the NE¼ sec. 31, T. 22 N., R. 8 W. (measured section 26), and in the center of the SE¼ sec. 29, T. 22 N., R. 8 W. Elsewhere in the eastern part of the area it is at stations 17, 80, 97, 99, 243, 254, and 257, and at and near stations 25 and 92. The width of the channel was determined only at station 243, where it is less than 3,000 feet wide, and at station 92, where it is about 150 feet wide. All the channels trend in an easterly direction, and some can be traced due east from one fault block to another.

The channel fill consists of well-rounded pebbles and cobbles of quartz, chert, quartzite, and silicified carbonate. Although the maximum cobble size is about 4 inches across, the average pebble size is 1–2 inches across. The stratigraphic units from which these were derived are as follows: The quartzite fragments are mainly from the Mount Shields and Bonner Formations of Precambrian age; the quartz pebbles are very likely from the Flathead Sandstone (Middle Cambrian); and the chert and most of the carbonate fragments are from the Madison Group (Mississippian), and possibly from the Helena Dolomite (Precambrian).

Abundant pebbles of igneous rock, in addition to the sedimentary rocks mentioned above, are in a conglomerate exposed at station 243. This conglomerate was described by Mudge and Sheppard (1968) and is not described further here except to note that it includes many pebbles and cobbles, some as much as 6 inches across, of rhyolitic welded tuffs and dacite lavas.

Unit L of the Vaughn generally forms a moderately prominent rounded hillside bench containing beds of light-gray crossbedded sandstone. In most places it is the first bench above the prominent ledge of the uppermost sandstone unit (J) of the Taft Hill. A thin poorly developed soil, typical of Vaughn exposures, is light yellowish gray, gray, and grayish green. The surface of the Vaughn is generally pitted with many depressions a few inches deep and wide. Generally, this surface is mostly covered with many small irregular-shaped blocks of light-gray to yellowish-gray sandstone that are partly stained moderate reddish brown to moderate reddish orange. When damp, the soil is spongy, but when wet it is slick. Soil creep and, in places, small landslides are typical on hillside slopes of this member. Also characteristic are growths of limber pine and a lack of a good grass cover.

The contact of the Vaughn with the underlying Taft Hill is sharp and distinct but comformable. It very likely represents an abrupt change from marine to nonmarine environment, possibly a period of nondeposition and nonerosion. Evidence of weathering in this interval comes from the southeastern part of the Sawtooth Ridge quadrangle, especially the SW¼SE¼ sec. 21, T. 21 N., R 8 W., where a remnant of paleosol on the uppermost sandstone bed of the Taft Hill is exposed. The upper 1–3 inches of this bed is heavily stained with limonite. White vertical veinlets, the fossilized roots of woody plants, extend down as much as 3 inches into the sandstone. Numerous fragments of petrified wood on top of this bed were identified by R. A. Scott (written commun., 1957) as coniferous. These fragments represent complete segments of a tree limb or trunk that was as much as 3 inches across.

The only other fossils noted in the Vaughn are wood fragments and leaves. Samples of wood from the lower beds of the Vaughn (F196 and F207) were examined by R. A. Scott (written commun., 1957 and 1958), who identified them as conifers. Another specimen, F398, from the upper part of the Vaughn, is part of the "trunk" of a tree fern. It was found in an upright position at right angles to bedding. According to R. A. Scott (written commun., 1962):

> This specimen is from the basal part of the "trunk" of a bizarre, extinct tree fern—*Tempskya*. The "trunk" of this plant was composed of numerous separate stems surrounded by an intermingled mass of small roots. The whole unit united to give the appearance of a single trunk. As the plant grew, the basal stems died and were superseded by higher stems which maintained contact with the soil through the mass of roots in the lower part. Your specimen is from the basal part of the "trunk," for it consists entirely of roots.

He further stated that modern tree ferns occur only in tropical and subtropical regions and that the evolution of the "tree" habit among ferns was limited to warmer regions. Present knowledge indicates that *Tempskya* grew only as a terrestrial plant.

Leaves are locally common in the lower part of the Vaughn. Well preserved leaves were collected (F44 on table 8) from a stream bank exposure along the Sun River in the SW¼SE¼NE¼ sec. 36, T. 22 N., R. 9 W. Those listed in table 8 were examined by R. W. Brown (written commun., 1956 and 1957). Regarding environment he said: "Judging from the cycads present, the climate was probably warm. There was sufficient moisture to support the broad-leaved trees; hence, the environment was not arid."

MARIAS RIVER SHALE

The Marias River Shale is mostly dark-gray mudstone (table 1). It is the uppermost formation in the Colorado Group in this area according to Cobban, Erdmann, Lemke, and Maughan (1959b, p. 2793). They regarded it as equivalent to the Greenhorn Formation, Carlile Shale, and Niobrara Formation of the Black Hills area. In the Sun River Canyon area the Marias River Shale is exposed east of the mountains and in the valleys of the North and South Forks of the Sun River (pl. 1). A partial section is exposed in the north streambank of the Sun River in the center of the NE¼ NW¼ sec. 32, T. 22 N., R. 8 W. This formation was subdivided into four members by Cobban, Erdmann, Lemke, and Maughan (1959b, p. 2793): Floweree Shale, Cone Calcareous, Ferdig Shale, and Kevin Shale. (See measured sections 28–36.)

A slight disconformity separates the Marias River Shale from the Blackleaf Formation. In the Sun River Canyon area the lower half of the Floweree Shale Member of the Marias River Formation and all the Bootlegger Member of the Blackleaf Formation are absent. These units are present about 60 miles to the east on the Sweetgrass Arch. W. A. Cobban (oral commun., 1957) believed that the Bootlegger possibly wedges out east of the Sun River area owing to nondeposition. If this is true, than the amount of erosion represented by the unconformity is negligible. The break is thought to represent the transition from Lower to Upper Cretaceous.

The Marias River Shale is about 1,200 feet thick in the eastern outcrop area. It thickens westward to about 1,300 feet.

Floweree Shale Member

The Floweree Shale Member, about 30 feet thick, is characteristically very dark gray noncalcareous nonfossiliferous shale. A basal siltstone unit locally contains lenses of chert-pebble conglomerate (table 1). The shale ranges from very thin bedded to thinly laminated. The weathered surfaces of chips and beds have a distinct metallic luster, resembling that of the Flood Shale Member of the Blackleaf Formation. Locally a bed of bentonite 1–2 inches thick occurs at or near the top of the Floweree. (See measured sections 28 and 29.)

The lower unit of the Floweree ranges in thickness from 0 to 5 feet. It is a noncalcareous gray-brown siltstone with many thin interbeds of silty shale; it characteristically weathers platy. In the eastern part of the area, mainly from the Sun River north to Green Timber Gulch, this unit contains a thin chert-pebble conglomerate. In places there are as many as five thin very lenticular conglomeratic beds.

The conglomerate near the base and fractures and bedding planes in the rest of the member are stained a distinctive yellowish brown, perhaps by hydrous iron sulfate. This staining, not observed in other units, is characteristic of the Floweree elsewhere in Montana (W. A. Cobban, oral commun., 1957).

Cone Calcareous Member

The Cone Calcareous Member, about 100 feet thick, is a widespread and distinctive unit in the Sun River Canyon area. This member is shale, siltstone, and claystone. It is partly exposed in many places east of the mountains (Mudge, 1965, 1968a). The lower part is exposed in the north stream bank of the Sun River in the center of the NE¼NW¼ sec. 32, T. 22 N., R. 8 W. (measured section 29). The upper beds are exposed farther downstream in the SE¼NE¼NE¼ sec. 32, T. 22 N., R. 8 W. (measured section 31). The upper part is also exposed in an anticline in the South Fork of the Sun River, about 2,000 feet north of Windfall Creek (Mudge, 1966b).

The Cone Member is correlative with the Greenhorn Formation of the Black Hills and with the Greenhorn Limestone of western Kansas and eastern Colorado (Cobban and others, 1959b, p. 2792). In these areas, as well as the Sun River Canyon area, these rocks characteristically contains the pelecypod *Inoceramus labiatus*. In northwestern Montana, *I. labiatus* is restricted to the Cone. (See measured sections 29–31, 33.)

The lower half of the Cone consists of about 40 feet of clayey, mostly noncalcareous medium-gray very thin-bedded shale. A bentonite bed 0.4 foot thick occurs about 25 feet above the base. The lowermost 4 feet of beds is calcareous dark-gray-brown thin-bedded silty shale that contains *Inoceramus labiatus* (Schlotheim) and fish scales. A zone of septarian concretions, with minute white specks, is at the top of this silty shale.

The upper half consists of about 50 feet of very thin bedded medium-gray calcareous siltstone, claystone, and some bentonite (fig. 36). It generally forms a small bench covered by dirty gray plates, many with fragments of *Inoceramus labiatus* and blue scales of the fish *Ichtyodectes*.

Figure 36.—Uppermost beds of the Cone Calcareous Member of the Marias River Shale in the north bank of the Sun River in the SE¼NE¼ sec. 32, T. 22 N., R. 8 W., Teton County (measured section 31).

Thin beds of calcarenite are common, especially in the upper 15 feet of the Cone. These beds are composed mostly of poorly preserved specimens of *Globigerina* that give a sandy appearance to the beds. These fossils were identified as *Globigerina cretacea*(?) d'Orbigny by Ruth Todd (written commun., Nov., 1957), who regarded *Globigerina* as a deep-water form because "among Recent sediments, there are no verified occurrences of *Globigerina* oozes on beaches or at shallow depths." According to W. A. Cobban (oral communication, 1957), globigerinid beds are common in the Cone of the plains region of Montana and Wyoming and in the Greenhorn Limestone of Kansas.

Freshly broken rock from the upper beds has a kerosene odor. Stebinger (1918, p. 162) reported that distillation tests made on five samples yielded the equivalent of 1–2 gallons of oil per ton.

The thickest bed of bentonite, as much as 7 feet thick, occurs near the base of the upper part. It is well exposed only in a bank of the South Fork of the Sun River about half a mile southwest of Furman Creek. Where it is present but covered, its position is indicated by small landslides and seeps.

Fossils, other than those mentioned above, were collected from the upper beds of the Cone (table 9). Most abundant are thin-shelled *Inoceramus labiatus* (Schlotheim). Also present, but rare, are faint impressions of a coiled cephalopod, *Watinoceras reesidei* Warren. The impressions of this fossil are best observed on wet bedding planes illuminated by reflected light. These were identified by W. A. Cobban (written commun., 1961 and 1957) in collections F122 (USGS Mesozoic loc. D1481), F124, and F395 (USGS Mesozoic loc. D3171). Associated with these fossils are *Ostrea* n. sp., fish teeth, and *Isurus* cf. *I. appendiculata* (Agassiz) identified by Cobban in collections F125 (USGS Mesozoic loc. D1482) and F126 (USGS Mesozoic loc. D1483). *Ichthyodectes* and a vertebrae of enchodontid were identified by D. H. Dunkle (written commun., 1957). The collections represent moderately shallow marine environments of normal salinity (W. A. Cobban, written commun., 1957).

Ferdig Shale Member

The Ferdig Shale Member is mostly siltstone and shale in the lower and upper parts and siltstone with sandstone in the middle part. The middle and upper parts grade into sandstone to the west. This threefold subdivision of the Ferdig was first recognized in the Sweetgrass Arch area by Cobban, Erdmann, Lemke, and Maughan (1959b, p. 2794). The Ferdig ranges in thickness from about 200 feet in the east to 350 feet in the northwest. (See measured sections 30–34.)

The lower beds of siltstone and shale are dark gray and laminated to thinly laminated. Locally they contain ironstone nodules and one or more very thin beds of bentonite. The beds of the Ferdig, unlike those of the underlying Cone Member, are distinctively iron-stained and noncalcareous.

The upper half of the Ferdig in the eastern outcrop area is silty noncalcareous shale with many lenses of very fine grained micaceous sandstone. The beds of sandstone are especially abundant in the lower part, and they weather into many iron-stained plates which litter the outcrop. A very thin poorly indurated chert-pebble conglomerate is locally in the lower part, and it may correlate with bed N in the Kevin Sunburst area as described by Erdmann, Gist, Nordquist, and Beer (1947).

In the western outcrop area the Ferdig is mostly sandstone and contains some siltstone in the lower part. The sandstone part of this member was referred to as the sandstone member of the Marias River Shale by Mudge (1966a, b, c; and 1967a). In the Wolf Creek-Holter Lake area, these beds of sandstone were referred to as the Holter Sandstone of the Marias River Shale by Groff (1963) upon the suggestion of C. E. Erdmann, but this sandstone has not been formally described, and the name was not used by Schmidt (1963) or by Schmidt, Swanson, and Zubovic (1964). Much, if not all, of this sandstone is correlative with the Cardium Formation of Southern Alberta.

The sandstone beds in the Ferdig in the western part of the Sun River Canyon area are now considered by me as a facies of the middle and upper units of the Ferdig exposed east of the mountains. In the eastern part of the Glenn Creek quadrangle, these sandstone beds grade laterally northward into somewhat sandy, but otherwise typical, middle and upper units of the Ferdig. In addition, the lower contact of the sandstone grades into the lower unit of the Ferdig. (See measured section 33.) Such a relationship has been noted for the Cardium Formation in Alberta (Stott, 1963, p. 55).

In Alberta the Cardium consists mainly of marine strata but includes nonmarine beds (Stott, 1963, p. 58–59). In the Sun River Canyon area all the sandstone beds are regarded as marine, but some very thir beds may be nonmarine.

The sandstone of the western outcrop of the Ferdig consists of a nodular sandstone and sandy shale unit in the lower part; a very thinly even bedded sandstone unit in the middle part; and a thick-bedded calcareous light-gray sandstone unit in the upper part. Of these, only the lower, nodular beds extend as far north as Circle Creek. On the west side of the North Fork of the Sun River, the three units persist northward to the north edge of the Glenn Creek quadrangle. (See sandstone member and Ferdig Shale Member of Mudge, 1966b and c.) The above units are described in measured sections 33 and 34 and are not repeated here.

A very thin sandstone dike cuts diagonally across a nodular sandstone bed of the lower unit at station 204 (pl. 2). The sharp and straight contact of this dike indicates that it filled an open joint during the deposition of the overlying bed.

The fossils differ between the eastern and western outcrop areas. Organic trails and burrows are very abundant in the Ferdig, especially in the sandstone beds of the middle part in the eastern area and the lower sandstone unit in the western area. Most cannot be related to specific organisms. In the eastern area one track, distinctive of the Ferdig, looks like that of a centipede; it has many hairlike depressions that extend from about 1/8 to 1/4 inch laterally on each side of a central depression. P. E. Cloud, Jr. (written commun., 1959), believed that it was made by something like an eunicid worm.

The other fossils collected from the Ferdig in the eastern area are a scaphite, and small rib markings of that fossil. In collection F203 (USGS Mesozoic loc. D1773) at station 89 in the NW1/4SE1/4NW1/4 sec. 4, T. 20 N., R. 8 W., W. A. Cobban (written commun., 1958) identified *Scaphites whitfieldi* Cobban. He stated that this species characterizes the middle part of the Carlile Shale of the Black Hills and that the collections represent a very shallow water marine environment of normal salinity. The rib markings of a scaphite are probably molds of bounce marks made by dead but buoyant shells, according to P. E. Cloud, Jr. (written commun., 1958 and 1959).

A variety of fossils was collected from the beds of sandstone in the western outcrop area. In the lower unit, organic trails and burrows are very abundant, and some cut diagonally across beds. The largest burrow is almost cylindrical and is as much as 4 inches across and at least 4 feet long. Wood fragments are scattered throughout much of this unit. Numerous relatively large (2–3 in. across) conifer cones were collected from this unit (sta. 216, pl. 2; F421, USGS paleobotany loc. 9936). These are *Araucarites* sp. according Jack Wolfe (written commun., 1963). These cones were deposited on a bedding surface, and subsequent laminae draped over them, indicating deposition in relatively quiet waters.

The other fossils collected from the lower unit as well as those from the other units in the beds of sandstone in the western exposures of the Ferdig are listed in table 9. Collections D2611 and D2612 are from the lower unit, F421 from the middle unit, and D3160, D3172, and D3802 from the upper unit. The specimens of *Cardium* recorded in the upper unit are larger than

TABLE 9.—*Distribution of megafossils in the Marias River*

[Fossils identified

	Cone Calcareous Member						Ferdig Shale Member									Kevin Shale Member														
	F123	F124	F122 (D1481)	F125 (D1482)	F126 (D1483)	F395 (D3171)	F421	F144 (D1493)	F203 (D1773)	F346 (D2610)	F347 (D2611)	F348 (D2612)	F374 (D3160)	F374B (D3172)	F399 (D3802)	F85	F86	F117	F131	F137	F165	F167	F168	F198	F327	F379	F380	F385A	F386	F387
Serpula sp																														
Inoceramus deformis Meek																													X	
sp							X				X			X								X	X		X	X	X			
labiatus (Schlotheim)	X	X	X	X	X	X																								
involutus Sowerby																														
stantoni Sokolow																														
pontoni McLearn																														
cf. *I. deformis* Meek																														
cf. *I. lesginensis* Dobrov and Pavlova																	X													
Veniella goniophora Meek																														
Ostrea congesta Conrad																						X	X	X						
sp		X											X											X				X		
n. sp				X	X																									
cf. *O. sannionis* White										X																				
Cardium pauperculum Meek													X																	
sp							X								X															
? sp																														
Opertochasma, n. sp																														
Pteria cf. *P. nebrascana* (Evans and Shumard)																		X												
Lucina? sp																				X										
Protodonax sp										X																				
Crassatella sp															X															
Turritella sp															X															
Tessarolax hitzii White																														
Scaphites preventricosus Cobban																									X			X		
sp								X			X								X	X		X								X
ventricosus Meek and Hayden																														
cf. *S. ventricosus* Meek and Hayden																														
binneyi Reeside																														
whitfieldi Cobban									X																					
Clioscaphites vermiformis (Meek and Hayden)																	X													
montanensis Cobban																	X													
sp																														
Watinoceras reesidei Warren	X	X	X			X																								
Prionocyclus cf. *P. wyomingensis* Meek												X																		
Placenticeras sp														X																
Actinocamax sp																														
Baculites codyensis Reeside																X					X									
sp																						X								
asper Morton																														
sweetgrassensis Cobban																														
mariasensis Cobban																														

NOTE. In boxheads, numbers prefixed by "F" are field numbers; those in parentheses are USGS Mesozoic locality numbers.

any known from the Ferdig or Holter (W. A. Cobban, written commun., 1961).

Kevin Shale Member

The Kevin Shale Member is the youngest and thickest member of the Marias River Shale. It is mainly dark-gray noncalcareous shale, siltstone, and claystone. Characteristic of this member are numerous beds of bentonite and concretions of limestone (fig. 37). More than 100 bentonite beds occur in the Kevin. The upper half also contains many very thin beds of fine-grained sandstone. In the eastern outcrop area most of the Kevin is well exposed along the Sun River near the center of the N½NW¼, sec. 33, T. 22 N., R. 8 W. (measured section 35). The uppermost beds are excellently exposed along an irrigation ditch at station 76 in the center of the NW¼ sec. 28, T. 22 N., R. 8 W. In the western part of the area the Kevin is well exposed along the South Fork of the Sun River from Bear Creek to a point about three-fourths mile south of that creek. The lower beds are completely exposed just north of station 166 along the Sun River (measured section 34). (See measured sections 34–36.) The Kevin, being soft mudstone, is exposed mainly in streambanks. East of Sawtooth Ridge it forms a thick dark-gray residual soil that generally maintains a growth of grass but rarely trees. The soft Kevin is hard to measure because it is generally poorly exposed and much deformed. In the eastern outcrop area it is about 850 feet thick. In the western outcrop area it is estimated to be about 1,050± feet thick. The estimated thicknesses for the Sun River Canyon area are compatible with the regional pattern.

The lowest unit of the Kevin is a dark-gray mostly noncalcareous siltstone that locally is laminated and finely micaceous. It is exposed in the eastern outcrop area in the SE¼ sec. 6, T. 21 N., R. 8 W., and in the western outcrop area in the west bank of the South Fork of the Sun River just north of station 166. The unit is about 100 feet thick in the eastern outcrop area and thickens westward to about 300 feet. It contains

Shale in the Sun River Canyon area, Montana

by W. A. Cobban]

Kevin Shale Member—Continued

F388	F389	F390	F392	F393	F394	F23 (D1129)	F24 (D1130)	F115 (D1474)	F116 (D1475)	F163 (D1476)	F164 (D1477)	F166 (D1478)	F118 (D1479)	F121 (D1480)	F128 (D1484)	F129 (D1485)	F130 (D1486)	F132 (D1487)	F133 (D1488)	F142 (D1491)	F143 (D1492)	F127 (D1774)	F345 (D2609)	F368 (D3155)	F369 (D3156)	F370 (D3157)	F371 (D3158)	F372A (D3159)	F375 (D3161)	F376 (D3162)	F377 (D3163)	F378 (D3164)	F381 (D3165)	F382 (D3166)	F383 (D3167)	F384 (D3168)	F385 (D3169)	F391 (D3170)
																																X						
	X	X	X											X			X		X	X	X		X	X	X		X			X	X	X	X	X	X	X		X
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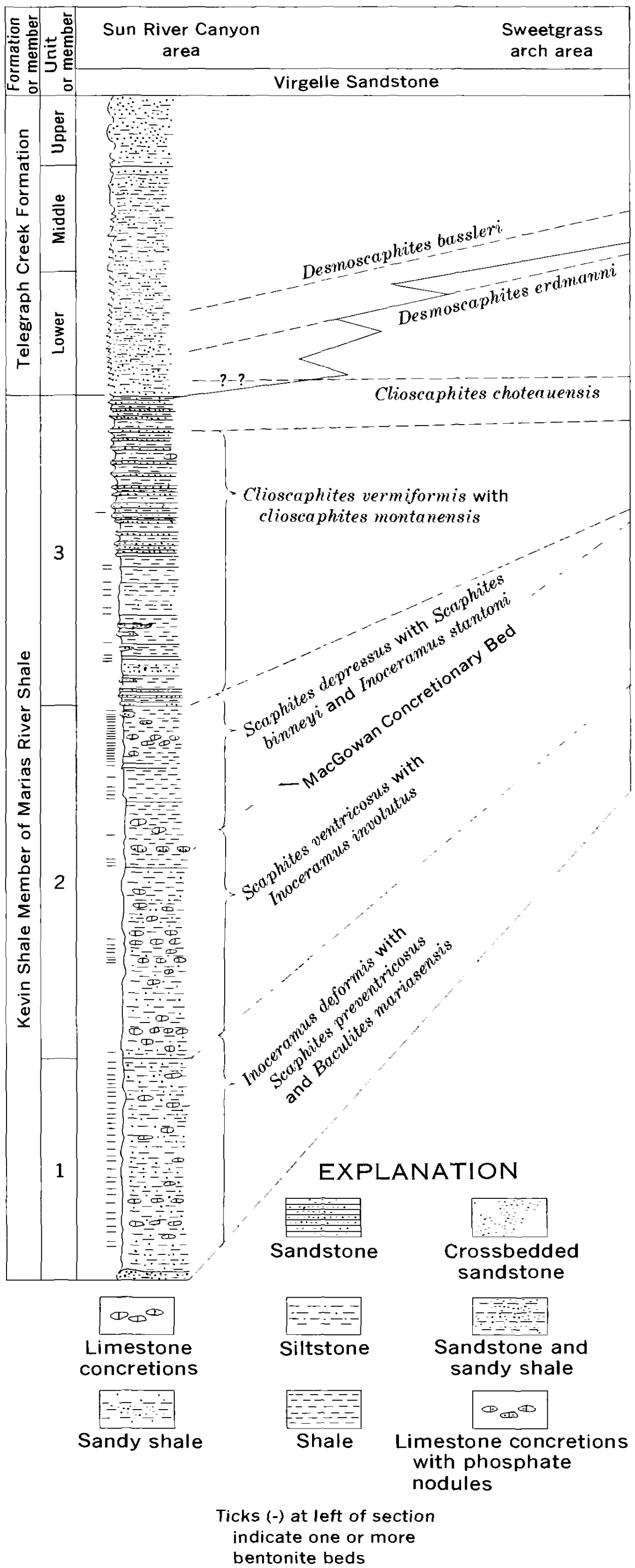

FIGURE 37.—Stratigraphic sequence and faunal zones in the Kevin Shale Member of the Marias River Shale and in the Telegraph Creek Formation in the Sun River Canyon area. Faunal zones from Cobban (1955) and Cobban and others (1959a, b).

many bentonite beds less than 6 inches thick and a few thicker ones; these are typically soft, light gray, and micaceous. The unit contains many nodules and concretions of hard, dense, medium-gray limestone, and some are associated with well-developed cone-in-cone structures, whereas others are associated with bentonite beds (fig. 37).

The basal beds of the Kevin range in lithology from the eastern to the western outcrop areas. In the eastern area the contact between the Kevin and underlying Ferdig is arbitrarily placed at the base of a zone of yellowish-brown concretionary limestone. The beds beneath this limestone are more typical of the iron-stained gray, noncalcareous, silty shale of the Ferdig that is void of bentonite. The beds above the limestone contain the lower faunal zone of the Kevin. In the western area the basal beds of the Kevin lie disconformably on massive light-gray sandstone beds of the Ferdig. (See measured section 34.)

Unit 2, about 400 feet thick, consists mostly of gray siltstone in the lower part and gray claystone in the upper part. Characteristic of it are many zones of reddish-brown to yellowish-brown limestone concretions. The widespread MacGowan Concretionary Bed (Erdmann and others, 1947) is near the middle of this unit (Cobban and others, 1959b, p. 2795) and indicated in figure 37. This bed is concretionary limestone with small grayish-brown phosphatic nodules. Thin light-gray beds of micaceous bentonite are scattered within this unit, especially in the upper part. The thicker beds (as much as 1.5 ft. thick) are somewhat sandy and generally contain limestone concretions and or cone-in-cone structures. Many of them are loci for seeps and springs.

Unit 3, about 360 feet thick, is mostly noncalcareous medium-gray silty shale and siltstone in the lower part and dark-gray siltstone and sandstone in the upper part (fig. 37). The lower part contains many thin beds of very fine grained sandstone and some thin beds of bentonite.

The beds of sandstone are very fine grained, finely cross-laminated, and minutely micaceous and are generally more resistant and a lighter shade of gray than the interbedded siltstone.

Five faunal zones are in the Kevin in the Sun River Canyon area, and these are listed in figure 37. These zones, plus another, are in this member on the Sweetgrass Arch (Cobban and others, 1959b, p. 2795–2796). In the Sun River Canyon area the *Desmoscaphites erdmanni* faunal zone is in the lower part of the Telegraph Creek Formation. The *Clioscaphites choteauensis* zone was not observed in the area, but it too may occur in the formation. The occurrence of these faunas in beds of Telegraph Creek lithology indicates a change in the upper part of the Kevin from mudstone with some sandstone in the east to sandstone in the west.

Almost all the fossils listed in table 9 are preserved on or within the concretions; a few are scattered throughout the mudstones. The large specimens of *Inoceramus platinus* (12–15 in. long) are more common in the upper part and are generally seen only in cross section, where they are parallel to the bedding. Some scales of *Ichthyodectes* sp. and small organic trails and burrows are in some of the sandstone beds in unit 2.

One collection contained a fragment of wood more than 2 feet long and 4 inches wide. The wood was filled with boring pelecypods (F128, USGS Mesozoic loc. D1484) which were identified by W. A. Cobban (written commun., 1957) as *Opertochasma* n. sp. Most of the wood structure had been removed by the boring clams. The basal part of the wood contained some bituminous coal.

MONTANA GROUP

The youngest Upper Cretaceous rocks exposed in the Sun River Canyon area are part of the Montana Group. Present are the Telegraph Creek Formation, Virgelle Sandstone, and Two Medicine Formation (table 1). The youngest units of the Montana Group, the Bearpaw, Horsethief and St. Mary River Formations crop out east of the Sun River Canyon area. The Montana Group in this region is estimated to be about 3,700 feet thick.

TELEGRAPH CREEK FORMATION

The Telegraph Creek Formation contains the transitional beds between the underlying Marias River Shale and the overlying Virgelle Sandstone (table 1). The Telegraph Creek is mainly made up of beds of sandstone and some sandy shale. It is well exposed along the Sun River east of the mountains and partly exposed in the mountains along the North Fork of the Sun River, about 1 mile north of Circle Creek (pl. 1). This formation is correlated with the Wapiabi Formation of southern Alberta (Billings Geological Society, 1959, p. 17).

The Telegraph Creek Formation thickens to the west (fig. 37). In the Kevin-Sunburst dome area the Telegraph Creek ranges in thickness from 120 to 170 feet (Cobban, 1955, p. 113). In the eastern outcrop of the Sun River Canyon area it is 340 feet thick. In the western outcrop area it is about 550 feet thick (Mudge, 1966c), but there the lower part includes sandstone beds that grade laterally into mudstone and sandstone of the upper part of the Kevin Shale Member to the east. (See measured sections 36 and 37.)

In the eastern part of the Sun River Canyon area the Telegraph Creek Formation is divisible into lower, middle and upper members.

Lower Member

The lower member, about 170 feet thick, consists of very thin bedded gray very fine grained calcareous sandstone with many partings of sandy to silty shale. Some of the beds are minutely cross-laminated and contain ripple marks. Carbon stains, wood fragments and organic trails and burrows are common. (See sections 36 and 37.)

In the western outcrop area the lower member is mainly alternating thick beds of very fine grained sandstone and dark-gray sandy shale. Typical of this unit are crossbeds, asymmetrical ripple marks, and mud cracks. The uppermost sandstone bed contains load casts about 7 feet thick.

In the eastern outcrop area fossils were observed only in the lower half of this member. They compose the *Desmoscaphites bassleri* faunal zone common in the Telegraph Creek Formation of the Sweetgrass Arch area (Cobban and others, 1959b, p. 2792). The following collections from measured section 37, exposed in a stream bank in the SE¼SW¼ sec. 28, T. 22 N., R. 8 W., were identified by W. A. Cobban (written commun., 1956 and 1957) as follows.

F88. From 26.1 feet below top of unit 1:
- *Pteria* cf. *P.* (*Oxytoma*) *nebrascana* (Evans and Shumard)
- *Ostrea congesta* Conrad
- *Anomia* sp.
- *Cardium* sp.
- *Goniobasis*? *subtortuosa* Meek and Hayden
- *Baculites* sp.
- *Baculites* cf. *B. aquilaensis* Reeside

F89. (USGS Mesozoic loc. D1128) From 64.8 feet below top of unit 1:
- *Inoceramus* sp.
- *Ostrea congesta* Conrad
- *Baculites haresi* Reeside?
- *Desmoscaphites bassleri* Reeside?

Cobban regards all these forms as representing a shallow marine environment except for the nonmarine gastropod *Goniobasis*? which was probably washed in.

The only Telegraph Creek fossils from the western part of the Sun River Canyon area were obtained from the lower member. Collection F412 (USGS Mesozoic loc. D3803) is from exposures in the North Fork of the Sun River about 1 mile north of Circle Creek. It represents the *Desmoscaphites erdmanni* faunal zone (see p. A70), according to W. A. Cobban (written commun., 1962), who identified:

- *Inoceramus* cf. *I. lesginensis* Dobrov & Pavlova
- *Inoceramus* cf. *I cordiformis* Woods
- *Pteria* cf. *P. linguaeformis* (Evans & Shumard)

Ostrea sp.
Laternula sp.
Cymbophora sp.
Gyrodes sp.
Baculites thomi Reeside
Clioscaphites montanense Cobban?
Desmoscaphites? sp.
Placenticeras sp.

Middle Member

The middle member, about 90 feet thick, consists of sandstone interbedded with sandy shale and siltstone (fig. 38). The sandstone beds are generally thicker than those in the lower member, ranging in thickness from 0.3 to 1.0 foot. They are calcareous, hard, dense, very fine grained, and dark gray and weather blocky to platy. Ripple marks, mud cracks, and minute cross-laminations are common. The siltstone and sandy shale beds are dispersed at various horizons throughout the member (fig. 38). These beds range in thickness from 1 inch to as much as 2.8 feet. Sandstone concretions are locally in the lower part of the member. The uppermost sandstone in measured section 37 contains conglomeratic lenses composed of rounded sandstone pebbles up to 3 inches across. (See measured sections 36 and 37.)

FIGURE 38.—The middle and upper members of the Telegraph Creek Formation exposed in the east flank of an anticline in the north bank of the Sun River in the SW¼SE¼ sec. 28, T. 22 N., R. 8 W., Teton County (measured section 37).

As seen in one thin section (HS16), the sandstone is mainly very fine well-sorted angular to subrounded quartz, feldspar, and carbonate. The minor accessories are rock fragments, chert, magnetite, biotite, and zircon. The matrix, feldspar, and biotite are much weathered. Hematite coats and cements many grains.

The middle member commonly contains organic trails and burrows as well as carbon and wood fragments.

Upper Member

The upper member, about 80 feet thick, differs from the other members in having thicker beds (as much as 4 ft thick) of sandstone alternating with equally thick beds of sandy shale (fig. 39). The sandstone is light gray, calcareous, and in most places poorly indurated. Commonly the beds are ripple marked and crossbedded and contain some organic trails and burrows. (See measured section 37.)

FIGURE 39.—Uppermost beds of the Telegraph Creek Formation (Kt), the Virgelle Sandstone (Kv), and lowermost beds of the Two Medicine Formation (Ktm) exposed in the east flank of an anticline in the north bank of the Sun River in the SW¼SE¼ sec. 28, T. 22 N., R. 8 W., Teton County (measured section 37). The dark bands and nodules in the Virgelle are iron-impregnated sandstone.

The only fossil found in this member (F14) was identified by W. A. Cobban (written commun., 1956) as *Inoceramus* sp.

VIRGELLE SANDSTONE

The Virgelle Sandstone consists of many moderately thick light-gray poorly indurated beds of sandstone. This distinctive cliff-forming unit is well exposed in the north bank of the Sun River in the SW¼SE¼ sec. 28, T. 22 N., R. 8 W., Castle Reef quadrangle (measured section 37). Elsewhere in the eastern outcrop area, good exposures are only along streams (pl. 1). In the western outcrop area the Virgelle is exposed at numerous places along the North Fork of the Sun River and along Biggs Creek (Mudge, 1966c). In the eastern outcrop area the Virgelle is 150 feet thick. (See measured section 37.) It thickens westward to about 200 feet.

The Virgelle Sandstone is a member of the Eagle

Sandstone on the east side of the Sweetgrass Arch (Cobban, 1955, p. 108).

The sandstone is well sorted, fine grained, calcareous, micaceous, and arkose. Colorless quartz and altered feldspar are the main constituents. Minor constituents are chert, magnetite, tourmaline, apatite, muscovite, and biotite. There is considerable clay in the matrix. The upper beds are thinner and more crossbedded than the lower beds.

Some beds are heavily impregnated with iron (fig. 39) and are relatively resistant to weathering. In places, iron-rich beds weather into caps on small pedestals of less resistant sandstone, a mode of weathering characteristic of the Virgelle. The zones impregnated with iron may be laterally equivalent to the titaniferous magnetite sandstone lenses in the Virgelle in the Choteau-Valier area described by Cobban (1955, p. 115). There, the Virgelle escarpment is capped by a dark-brown band of titaniferous magnetite sandstone, which was discussed by Wimmler (1946). The only titaniferous sandstone in the Virgelle near the Sun River Canyon area crops out to the east in an irrigation ditch in the SW¼SW¼ sec. 14, T. 22 N., R. 8 W., Split Rock Lake quadrangle.

The Virgelle in the western outcrop area is a little coarser grained and slightly thicker than in the east and contains less iron-impregnated sandstone.

Only patches of soil and a short creeping juniper are on the outcrop of the Virgelle Sandstone. Apparently, the well-drained condition of this sandstone is not suitable for grasses and pine but is suitable for juniper.

Fossils are scarce in the Virgelle, both in number and variety. The following collections were identified by W. A. Cobban (written commun., 1956):

F15. From 110 feet above the base of the Virgelle in the SE¼SW¼ sec. 28, T. 22 N., R. 8 W., *Ostrea coalvillensis* Meek. This species has been found in the Virgelle at several localities on the west flank of the Sweetgrass Arch.

F16. (USGS Mesozoic loc. D1127) Same locality as above; collected from 80 feet above base. *Corbula* aff. *C chacoensis* Stanton, a brackish-water form. It has been found in the Virgelle and the lower part of the Two Medicine Formation at many localities on the west flank of the Sweetgrass Arch and along the disturbed belt from Glacier National Park to Wolf Creek.

A little petrified wood is in the upper part of the Virgelle. Two collections have been studied by R. A. Scott (written commun., 1958):

F204. From a hill in the SW¼SE¼ sec. 21, T. 22 N., R. 8 W., 2 specimens of conifer, one possibly Cupressaceae and the other possibly Podocarpaceae.

F205. From a hill in the NE¼ sec. 28, T. 22 N., R. 8 W., part of a dicotyledonous root. The Podocarpaceae family of conifers is now mostly limited to the Southern Hemisphere and is uncommon in the North American fossil record.

TWO MEDICINE FORMATION

The Two Medicine Formation is the youngest Upper Cretaceous unit exposed in the Sun River Canyon area (table 1 and pl. 1). It consists of nonmarine shale and sandstone. Almost all the Two Medicine is present in the eastern part of the Glenn Creek quadrangle, whereas only the lower part of the formation crops out in the eastern part of the Sawtooth Ridge and Castle Reef quadrangles (pl. 1). East of these quadrangles, however, the rest of the formation is exposed. A total thickness of the Two Medicine was not obtained in the Sun River Canyon area but is 2,125 feet near a well about 11 miles northwest of Dupuyer (Cobban, 1955, p. 115).

The Two Medicine is equivalent to the upper member of the Eagle Sandstone, the Claggett Shale, and the Judith River Formation in the area east of the Sweetgrass Arch (Cobban, 1955, p. 108).

In the eastern part of the Sun River Canyon area, the lower 550 feet of the Two Medicine consists of sandy to clayey shale with many interbeds of sandstone. (See measured section 37.) Dark-gray to black carbonaceous shale commonly occurs at the base of the formation and at other horizons in the lower 250 feet. These shale beds range in thickness from a few inches to as much as 5 feet. Other shale beds are gray and olive drab to gray green; purple beds appear about 550 feet above the base.

The sandstone interbeds range in thickness from 1 foot to 80 feet. The thickest is about 160 feet above the base and resembles the Virgelle Sandstone.

Most of the sandstone beds are massive, but some are thin bedded and many are crossbedded. The sandstone beds are poorly indurated; some form only small hillside ridges. The beds of sandstone vary in composition and grain size. Most of them are gray to light gray and fine to medium grained and are composed mainly of colorless quartz. Like many of the nonmarine sandstones in the Cretaceous, these beds contain bright-red hematite-coated grains, chlorite grains, and fragments. The minor constituents of the sandstones are biotite, magnetite, hematite, limonite, apatite, rutile, tourmaline, pyrite, sphene, and zircon. The rock fragments, which constitute as much as 25 percent of the sandstone, are mainly olive-green siliceous mudstone, chert, carbonate, and silicified tuff. The matrix ranges from carbonate to silica with much altered clay.

A unique sandstone unit about 30 feet thick occurs about 400 feet above the base (unit 58 of measured section 37). It consists of lenses of greenish-gray sandstone with sandy shale partings. The upper part contains thin lenses of conglomeratic sandstone. The sandstone beds are composed of subrounded to rounded fine to medium grained chloritized volcanic rock fragments and some grains of quartz and feldspar. The conglomerate is composed of rounded to subrounded pebbles of gray, greenish-gray, and reddish-brown dacite and andesite (Mudge and Sheppard, 1968). Thin sections of the sandstone were examined by Lee Shropshire (writen commun., 1965), who stated that the original source rock for most of the grains was a tuffaceous or pyroclastic rock with an andesitic composition, a glassy matrix, and phenocrysts of feldspar, pyroxene, and other minerals; that the rock was subjected to mild metamorphism, as most of the grains are altered; that the rock was then broken, transported, and redeposited with a few rounded grains of quartz and feldspar from a different source; and that, somehow, a warm gel was deposited in and around the grains, developed desiccation cracks on cooling, and eventually crystallized with some degree of anisotropy. The gel is probably subkaolinitic in composition.

The volcanic-rock fragments are very similar to those in the lower member of the Big Skunk Formation in the Dearborn River area described by Viele and Harris (1965, p. 386–387). These authors noted a widespread disconformity at the base of the volcanic-rich Big Skunk Formation about 500–650 feet above the base of the Two Medicine. The lower member of the Big Skunk is mostly grayish-red, maroon-weathering volcanic-rich sandy mudstone and grayish-red to olive-gray volcanic-rich sedimentary breccia interbedded with dark-gray to black volcanic-rich sandstone and greenish-gray chloritic shaly mudstone (Viele and Harris, 1965, p. 387). Very likely, the volcanic-rich sandstone and conglomerate in the Sun River Canyon area are a northern facies of part of the lower member of the Big Skunk Formation of Viele and Harris (1965).

East of the Sun River Canyon area the rest of the Two Medicine has had only a cursory examination. It mainly consists of greenish-gray mudstone and some thin beds of nodular sandstone. Some beds contain fragments of vertebrate bones. Much of this part of the section is very likely rich in volcanic debris.

In the western part of the area the Two Medicine is rarely exposed. Perhaps only the lower and middle parts are present. The lower part of the formation seems to be composed mainly of gray sandstone interbedded with gray and grayish-green mudstone. Carbonaceous shale is present at the base. In addition, there are many beds of reddish-gray, maroonish-gray, purple, and gray-green mudstone.

At station 210 (pl. 2), on the North Fork of the Sun River, two relatively thick beds of light greenish-gray and light-red silicified tuff are exposed near the middle of the formation. Oligoclase and biotite phenocrysts up to 3 mm long are in a dense aphanitic matrix of quartz and feldspar. Other constituents are quartz, chert, biotite, hornblende, clay, hematite, leucoxene, glass, and fragments of tuff.

Beneath the beds of tuff are thin beds of poorly indurated fine - to medium-grained greenish - gray sandstone interbedded with maroon, purple, and light-gray nodular mudstone. Also interbedded are one or more thin beds of dense hematite-stained finely crystalline fresh-water(?) limestone. The sandstones are volcanic-rich altered lithic subgraywackes. They are mainly composed of quartz, feldspar, volcanic rock fragments and chert.

In a streambank at station 209 (pl. 2), on the North Fork of the Sun River, the middle part of the formation contains variegated beds of gray, green, and red mudstone with interbedded sandstone. A volcanic-rich conglomerate underlies one of the sandstone beds. A similar conglomerate is exposed to the north on the east side of the Sun River about 1,000 feet northeast of the junction of Moose Creek with the Sun River. Both of the beds of conglomerate are described by Mudge and Sheppard (1968).

The contact of the Two Medicine with the underlying Virgelle is distinct. The sandstone beds of the Virgelle form a prominent ridge, whereas the basal sandy shale of the Two Medicine forms a low slope.

Fossils are scarce in the Two Medicine; most are petrified wood. In measured section 37 a fragment of a large petrified log and stump was collected from the lower part of the formation (F17), and R. A. Scott (written commun., 1957) identified as *Cupressinoxylon*. A collection of invertebrate fossil (F199) was obtained from basal beds at station 77, in the SW¼ SE¼SW¼, sec. 34, T. 21 N., R. 8 W. W. A. Cobban (written commun., 1958) identified the pelecypods *Ostrea* sp., *Corbula* n.sp., and *Anomia* sp. and the gastropod *Melania? whiteavesi* Stanton and Hatcher and regarded the collection as a brackish-water fauna.

IGNEOUS ROCKS

Sills of late Precambrian and of very Late Cretaceous or early Tertiary age crop out in the western part of the Sun River Canyon area. Deiss (1943a, p. 245–248) recognized these sills but dated them all as probably of Late Cretaceous age. Radiometric dates show that all sills that intruded Precambrian rocks are late Precambrian in age.

SILLS OF LATE PRECAMBRIAN AGE

Sills of diorite, with minor diorite-gabbro, gabbro and monzonite facies, intruded the Precambrian rocks in the western part of the Pretty Prairie and Glenn Creek quadrangles (pl. 1). Similar sills are common in these rocks elsewhere in northwestern Montana. In the Sun River Canyon and adjacent areas these sills have been dated by potassium-argon methods as 750±25 m.y. old by J. D. Obradovich (oral commun., 1966). At Logan Pass, in Glacier Park, a similar sill has been dated as 1,073–1,110 m.y. old by Hunt (1962, p. 438).

In the Sun River Canyon area, diorite sills intruded various stratigraphic horizons in the Belt rocks. In the western part of the Pretty Prairie quadrangle they are in the Snowslip Formation, but east of Prairie Reef they are in the Mount Shields Formation, the youngest Belt formation intruded. East of Deadman hill a thin basalt sill is in the upper part of the Helena Dolomite. In the western part of the Glenn Creek quadrangle the sills are mostly in the red sandstone member of the Mount Shields Formation, but locally they are in the Empire and Spokane Formations. South of the Sun River Canyon area the sills are mainly in the Empire and Spokane rocks. The sills are mostly diorite but locally are gabbro and monzonite. The thin sills are fine to medium-crystalline, whereas the thick ones are coarsely crystalline. Magnetite in the sills appears to be a late magmatic stage mineral in that it melted its way into interstitial areas and locally is concentrated in thin bands. Similar sills in the Wood Creek area to the south were described by Knapp (1963).

In the Deer Creek area a dark-gray andesite-basalt sill (less than 1 ft. thick) is exposed in the upper part of the Helena Dolomite for a distance of about 1 mile. It is concordant with a bedding plane for a short distance but inflects up a few feet along joints to another bedding plane. The sharp corners of the joints were not rounded during intrusion, and there has been very little detectable wallrock alteration.

The sills are distinctive and easily recognized in hillside exposures, as they weather to a moderate-brown (5YR 4/4) to yellowish-brown (10YR 5/4) sandy soil which contrasts with the yellowish-gray soils of the adjacent sedimentary rocks.

The sedimentary rocks adjacent to the sills are slightly altered to hornfels for a distance of as much as 200 feet. The altered strata are greenish-gray and gray-brown hornfels that has a purple tint and many thin interbeds of yellowish-gray quartzite. Actinolite crystals are abundant on many bedding planes.

The sills are as much as 600 feet thick. Most of them are tabular, but one is shaped like a laccolith and thickens and thins along the strike. A sill noted by Deiss (1943a, p. 247) in the southwestern part of the Pretty Prairie quadrangle terminated abruptly with a blunt end about 200 feet thick. Elsewhere the terminal ends of the sills are covered by Quaternary deposits.

SILLS OF VERY LATE CRETACEOUS OR EARLY TERTIARY AGE

A trachyandesite sill intruded Lower Cretaceous rocks in the western outcrop area (pl. 1). This sill is exposed in the western parts of the Patricks Basin and Arsenic Peak quadrangles, in the northeastern Pretty Prairie quadrangle, and in the central part of the Glenn Creek quadrangle (pl. 1). In these areas the sill and Cretaceous rocks were folded and faulted during the Laramide orogeny. The sill is mostly in the lower sandstone unit of the Flood Shale Member of the Blackleaf Formation; however, along strike it is in younger units.

The sill is as much as 600 feet thick. In most places it is 300–400 feet thick. The segment that extends 20 miles across Patricks Basin and Arsenic Peak quadrangles is about 600 feet thick in the vicinity of Circle Creek and south of the South Fork of the Sun River; it thins both to the north and south.

In the southwestern part of the area there is only one sill, which has been folded and faulted. Deiss (1943a, p. 245) believed there are three sills in the Patricks Basin quadrangle. In the adjacent Pretty Prairie quadrangle there is one sill, which has been repeated by folding and thrust faulting (Mudge, 1966a, b). Lenticular sills are in the Kootenai Formation in the central part of the Glenn Creek quadrangle. These poorly exposed sills may represent the eroded remains of a single sill complicated by deformation. Two sills in the western part of the Arsenic Peak quadrangle are believed by Mudge (1967a) to join at depth to form one sill.

The sill forms distinct dark-grayish-brown cliffs and ridges. The most prominent exposure of the sill is in the ridge that forms Black Reef in the Patricks Basin quadrangle and Sun Butte and Sheep Reef in the Arsenic Peak quadrangle (pl. 1). The sill-formed ridge extends northward 20 miles from the southern part of the Patricks Basin quadrangle, through Arsenic Peak quadrangle, to a point north of Headquarters Creek (Deiss, 1943b, p. 1145).

The sill is a trachyandesite with some local syenite in the middle part. The phenocrysts are plagioclase, potassium feldspar, pyroxene, and quartz. The feldspars, in nearly equal proportions, constitute about two-thirds of the phenocrysts. Quartz is mostly less than 5 percent. Most of the plagioclase is albite. The pyroxene is augite with a extinction angle of 41° to 56°. The groundmass is extremely fine grained felted feldspar and clay minerals.

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In places the basal 10 feet of the sill is distinctly banded in tones of gray. Characteristically, the bands are narrowest and most closely spaced near the edge and are progressively thicker and farther apart toward the center. For example, at station 169 (pl. 2) they are about one-eighth inch thick and one-eighth inch apart 3 feet above the base, and 1 inch thick and about 6 inches apart 10 feet above the base. The bands have essentially the same composition as the sill. The bands are rhyolite, and they are finer grained and contain slightly more quartz than the sill. Nontronite occurs in elongate masses or stringers parallel to the bands. The thicker bands have more quartz and less plagioclase than the thinner ones. Similar banding structure was discussed by Grout (1918), who believed that these structures developed while the rock was still molten or, at most, only partly crystalline.

In most places the sill intruded the middle of the lower sandstone unit of the Flood Shale Member of the Blackleaf Formation. The sandstone unit, almost 20 feet thick, consists of widespread beds 2–5 inches thick that are separated by even, clearly defined bedding planes. Along strike in the western part of the Patricks Basin and Arsenic Peak quadrangles the sill is concordant to a bedding plane for 1–2 miles, then inflects upward, in a stair-step manner, for a vertical distance of 2–5 feet (fig. 40), but remains in the sandstone unit for a horizontal distance of about 10 miles. The intruded magma did not damage the sharp edges of the jointed beds. From a point south of Circle Creek and extending north, the sill has stepped upward into beds of the Flood Shale, Taft Hill, and Vaughn Members. In this 20 miles of exposure this sill remains within a stratigraphic interval of about 1,200 feet.

FIGURE 40.—Upper contact of sill with basal sandstone beds of the Flood Shale Member (adjacent to pick) of the Blackleaf Formation exposed northeast of station 146 in the upper reaches of Windfall Creek. The sill transgressed the section by following along joints in the sandstone unit.

In the vicinity of Circle Creek there are many variations along the upper contact of the sill that were not seen elsewhere. These variations are very likely related to an early stage of the fold that formed during the Laramide orogeny. South of Circle Creek along Sheep Reef, the sill deflected at a low angle upward across beds. At, and just north of Circle Creek, the sill stoped the overlying beds, in places along joints and in other places diagonally across beds. Here, it stoped most of the Flood Shale Member and part of the Taft Hill Member (pl. 1), and in places foundered blocks (as much as 10 ft. long) of this member are completely encased in the sill. Near Circle Creek, apophyses of the sill occur only across the fold axis (pl. 1), suggesting that the sill was injected during folding. Extending north from this fold there are two sills. As shown in a cross section by Mudge (1967a, cross section C–C'), the sill at the fold north of Circle Creek very likely bifurcated during injection and folding, and the bulk of the magma intruded younger rocks in the syncline. The lower part of the melt, however, continued to follow the original bedding plane.

The sill in the Sun River Canyon area intruded along a well-defined bedding plane with a fluid barrier above the host rocks and at a depth of 5,500–6,000 feet beneath the surface; all are the necessary conditions for the emplacement of sills as postulated by Mudge (1968b). In most places the thinly laminated clay shale unit of the Flood Shale Member overlies the host bed. Elsewhere, the shale beds of the Vaughn Member or of the Kootenai Formation overlie the host bed.

The range of the amount of overburden can be computed, even though the age of intrusion is not accurately determined. If the sill intruded shortly after the cessation of the deposition of the St. Mary River Formation, about 5,500 feet of rocks would have overlain the intruded bed. If the time of intrusion was at the close of the Cretaceous, then the overburden would have totaled about 6,000 feet. Rocks of Late Cretaceous and very early Tertiary age are not present in this or nearby areas. The above postulated thicknesses are within the range of thickness of 3,000–7,500 feet of overburden determined by Mudge (1968b) as necessary for the emplacement of concordant igneous masses in nearly flat-lying sedimentary rocks.

The age of the sill is Late Cretaceous or possibly early Tertiary. It intruded Lower Cretaceous rocks during folding and before thrust faulting of the Laramide orogeny. Deiss (1943a, p. 248) concluded that the sill was "intruded before the earliest faulting in the area, probably late in the Cretaceous, and that the folding of the sills may have preceded the faulting."

As noted previously, the sill at and near the folds on Circle Creek moved up section and stoped some of the strata (pl. 1). Here the sill intruded at the early stage of folding. Similar sills in the Elkhorn Mountains area intruded the same rocks, and Klepper, Weeks, and Ruppel (1957, p. 44) stated: "It does seem likely, however, that intrusion may have coincided with the early stage of folding * * * ." In the Boulder batholith area, folding and thrust faulting occurred at various times during the Late Cretaceous and probably early Tertiary (G. D. Robinson, oral commun., 1967). In northwestern Montana and southern Alberta rocks as young as the St. Mary River and Willow Creek Formations were folded and faulted during the Laramide (Stebinger, 1915, pl. 15). An Eocene age was assigned to this orogeny by Russell (1951, p. 47) on the basis of changes in the strata and fauna in Alberta, Canada. Therefore the age of the sills in the Sun River Canyon area is Willow Creek or younger, either very Late Cretaceous or early Tertiary.

MEASURED SECTIONS

All outcropping units except the Dearborn and Pagoda Limestones were measured at one or more locations. These two formations along with other Cambrian units were measured nearby by Deiss (1933 and 1939). A reference section of the Madison Group was published by Mudge, Sando, and Dutro (1962, p. 2004–2008) and is not repeated here. However, other partial sections of the Madison, shown in their figure 3, are described herein.

1. *Helena Dolomite (part) measured on an east-trending ridge (elev 6,463 ft) about one-half mile north of Deer Creek and about three-fourths mile west of the South Fork of the Sun River, southern Pretty Prairie quadrangle, Montana*

[Measured by M. R. Mudge and Dale Snow]

Top not well exposed; talus covers basal contact of the Snowslip Formation, which is at or near saddle and in small tributary.

Helena Dolomite (part):	*Thickness (feet)*
24. Dolomite, calcitic, fine-grained dark-gray; large massive stromatolite structures; weathers into irregular plates; siliceous fragments in upper part; interbedded oolite beds and edgewise conglomerates; some iron stains. HS689 (Ca, 18.2 percent; Mg, 4.8 percent; molar ratio, 2.24) at 7.0 ft above base	50±
23. Dolomite, calcitic, dense, dark-gray, iron-stained; massive, 2.0-ft-thick oolite bed at top underlain by stromatolite bed; minute laminae. HS688 (Ca, 33.7 percent; Mg, 1.2 percent; molar ratio, 1.82) for middle part	4.7
22. Mudstone, dolomitic, mostly covered, dark-gray, thick-bedded; weathers platy and shaly. HS687 (Ca, 9.3 percent; Mg, 2.5 percent; molar ratio, 4.67) from middle part	10.0

Helena Dolomite—Continued	*Thickness (feet)*
21. Dolomite, dark-gray, finely laminated; contains calcitic stromatolite bed overlain by oolite bed, HS686 (Ca, 16.0 percent; Mg, 7.5 percent; molar ratio, 1.39) from middle part	12.8
20. Sill, of late Precambrian age; porphyritic andesite-basalt, dense, dark-gray, very fine grained, massive; vertical joints, which follow jointing in adjacent rocks. HS417	0–1.0
19. Limestone, dolomitic, dense, gray; one bed; stromatolite at top and in middle; in many places edgewise conglomerate composed of stromatolite fragments; lentils of dense limestone. HS685 (Ca, 30.8 percent; Mg, 1.4 percent; molar ratio, 12.13) from middle	4.8
18. Mudstone, dolomitic, dark-gray; thin dolomite lenses in upper part; unit weathers yellowish gray and platy. HS684 (Ca, 3.6 percent; Mg, 2.9 percent; molar ratio, 0.78) from middle	15.5
17. Dolomite, argillaceous in lower part, very finely crystalline, dark-gray; weathers yellowish gray; one bed; weathers blocky; 2-in.-thick oolitic dolomitic limestone bed at top overlying thin edgewise conglomerate of stromatolite fragments. HS683 (Ca, 24.2 percent; Mg, 2.5 percent; molar ratio, 5.76) from top bed; HS682 (Ca, 11.7 percent; Mg, 6.0 percent; molar ratio, 1.15) from lower part	2.5
16. Limestone, magnesian, fine-grained, medium-gray; at 9.3–11 ft above base, 1.7-ft-thick stromatolite bed with oolites in upper part; at 7.3 ft, 2.0-ft-thick platy dolomite; edgewise conglomerate at top; thick stromatolite bed overlies basal foot of platy limestone; minute laminae and iron stains throughout. HS681 (Ca, 12.4 percent; Mg, 0.8 percent; molar ratio, 1.33) at 7.5 ft above base; HS680 (Ca, 32.0 percent; Mg, 0.8 percent; molar ratio, 24.27) at 4.0 ft above base	11.0
15. Limestone, dolomitic, fine-grained, dark-gray; at 15.6–18.0 ft above base, oolite bed with angular stromatolite fragments; at 14–15.6 ft, thick stromatolite bed with iron-stained laminae; many thin beds with stromatolites in lower 10 ft that weather platy. HS679 (Ca, 28.8 percent; Mg, 1.3 percent; molar ratio, 15.17) from upper bed	18.0
14. Limestone, dolomitic, dark-gray; weathers yellowish gray; 2 ft of oolitic limestone at top underlain by 7 ft of iron-stained stromatolite and 4 ft of argillaceous limestone. HS678 (Ca, 28.8 percent; Mg, 2.8 percent; molar ratio, 6.06) at 10 ft above base	13.0
13. Limestone, dolomitic, fine-grained, dark-gray; sequence of beds of dense oolitic limestone, algal limestone, and oolitic limestone repeated three times. Thickest oolite bed (2.5 ft) at top; oolite-bearing beds composed mostly of rounded medium-sand-sized oolites with some scattered coarse sand sized ones, rounded to subrounded and frosted quartz grains and include angular fragments and lentils of stromatolites. HS677 at top; HS676	

Helena Dolomite—Continued — Thickness (feet)

(Ca, 23.2 percent; Mg, 5.0 percent; molar ratio, 2.85) at 15 ft above base; HS675 (Ca, 25.6 percent; Mg, 2.6 percent; molar ratio, 6.06) at 2.0 ft above base — 20.8

12. Limestone, dolomitic, medium-crystalline, gray; weathers yellowish gray; edgewise conglomerate and oolites in upper part; almost all fragments are less than ¼ in. long; oolites are medium sand size with scattered frosted quartz grains; thick stromatolite bed in lower part — 7.0

11. Limestone, dolomitic; like unit 12. HS674 Ca, 29.9 percent; Mg, 3.0 percent; molar ratio, 6.06) from top bed — 25.0

10. Dolomite, argillaceous, very finely crystalline, dark-gray, thick-bedded; weathers yellowish gray; at 11.0 ft above base, 3.6-ft-thick bed of large stromatolites with edgewise conglomerate at top. HS673 (Ca, 15.8 percent; Mg, 8.1 percent; molar ratio, 1.21) from middle — 14.6

9. Partly covered. Dolomite, argillaceous, with many thin interbeds of very finely crystalline dolomite; argillaceous beds are very thick and dark gray and weather yellowish gray, blocky, and platy; hackly fracture; thin dolomite beds are very hard, very finely crystalline, and medium dark gray and fracture semiconchoidally. HS672 (Ca, 11.4 percent; Mg, 5.9 percent; molar ratio, 1.15) from near top; HS671 from 10 ft above base — 82.3

8. Dolomite, finely crystalline, dark-gray, thick-bedded; weathers yellowish gray; some minute laminae; weathers blocky; 4.0-ft-thick stromatolite bed 30.0 ft above base with edgewise conglomerate and oolites in upper part; 1.0-ft-thick stromatolite bed at 24.7 ft; 1.0-ft-thick dolomitic sandstone bed at 15.0 ft. F416 from 24.7 ft above base. HS670 (Ca, 16.4 percent; Mg, 9.1 percent; molar ratio, 1.09) from 18 ft above base; HS669 from sandstone; HS668 from basal bed — 35.0

7. Mudstone, dolomitic, and argillaceous dolomite, very fine grained, dark-gray, thin- to nodular-bedded; lowest 4 ft mostly mudstone. HS657 (Ca, 4.5 percent; Mg, 5.3 percent; molar ratio, 0.048) from lower part — 12.8

6. Dolomite, argillaceous, with interbedded dolomitic mudstone, very finely crystalline, dark-gray; weathers grayish orange to grayish yellow; upper part thick bedded; lower part thin bedded with some thin silicified laminae; stromatolite beds in upper and lower part. HS656 (Ca, 5.7 percent; Mg, 3.5 percent; molar ratio, 0.97) from top bed; HS655 (Ca, 4.4 percent; Mg, 3.2 percent; molar ratio, 0.84) from middle; HS654 (Ca, 14.3 percent; Mg, 7.8 percent; molar ratio, 1.09) and F415 from near base — 40.0

Helena Dolomite—Continued — Thickness (feet)

5. Dolomite, argillaceous, dark-gray, thick-bedded; weathers grayish yellow; weathers platy and shaly; nodular bed in upper part. HS653 (Ca, 14.6 percent; Mg, 8.6 percent; molar ratio, 1.03) from 2.0 ft below top — 14.8

4. Dolomite and argillaceous dolomite, very finely crystalline, medium-gray; weathers grayish yellow; in beds 2–3 ft thick; argillaceous dolomite is in minutely micaceous beds 1–2 ft thick; minute laminae; 1.0-ft-thick stromatolite bed in upper part; 1.0-ft-thick edgewise conglomerate in middle. F414 from upper part; HS652 (Ca, 15.1 percent; Mg, 8.7 percent; molar ratio, 1.03) from lower part — 12.8

3. Dolomite, argillaceous, very finely crystalline, dark-gray, thick-bedded; weathers platy and shaly; some interbeds 6–8 in. thick; local edgewise conglomerate in upper part. HS651 (Ca, 14.0 percent; Mg, 8.8 percent; molar ratio, 0.97) from near middle — 10.8

2. Dolomite, very finely crystalline, dark-gray, weathers grayish yellow; in 3.5-ft-thick beds with interbedded argillaceous dolomite 2.0 ft thick; weathers with hackly fracture; at top, 1.3 ft of coarse oolites, many concentrically laminated. HS650 (Ca, 19.0 percent; Mg, 10.8 percent; molar ratio, 1.09) from top bed; HS649 (Ca, 18.0 percent, Mg, 10.7 percent; molar ratio, 1.03) from middle; HS648 (Ca, 16.8 percent; Mg, 9.7 percent; molar ratio, 1.03 from base — 9.5

1. Mostly covered. Dolomite, very finely crystalline, dark-gray, thin-bedded; weathers yellowish gray; weathers blocky and platy; minute laminae. HS647 (Ca, 15.6 percent; Mg, 9.6 percent; molar ratio, 0.97) from near top; HS646 (Ca, 17.7 percent; Mg, 9.6 percent; molar ratio, 1.15) from near base — 23.0

Total measured Helena Dolomite and of sill of late Precambrian age — 462.7±–463.7±

Base of section covered. Underlying sequence mostly pale-red argillite and brown siltite of lower part of Helena Dolomite.

2. *Shepard Formation measured along an eastward-trending ridge (elev about 6,000 ft), about one-half mile west of the South Fork of the Sun River, south edge of Pretty Prairie quadrangle*

[Measured by M. R. Mudge and Dale Snow]

Thickness (feet)

Transitional zone; top of Shepard Formation arbitrarily selected as top of relatively thick siltstone sequence that is overlain by reddish-brown and yellowish-gray sandstone with interbedded siltstone assigned to Mount Shields Formation.

Shepard Formation:

27. Siltstone, very finely micaceous, pale-reddish-brown, thin-bedded; weathers shaly and into small irregular fragments; lentils 1–2 in. thick of very fine grained sandstone that are ripple marked; claystone on some bedding planes. HS711 at 15 ft above base — 23.8

Shepard Formation—Continued	*Thickness (feet)*
26. Siltstone, finely micaceous, dolomitic, light-gray, thin-bedded; some thin grayish-red beds; weathers grayish orange to light gray; very fine grained sandstone lenses 2–4 in. thick; ripple marks, load casts, and minute low-angle cross-lamination; fine- to medium-grain sand-size glauconite pellets at two horizons. HS710 from 30 ft above base; HS411b1 from 27.5 ft above base; HS411b from 24 ft above base; HS709 from near base	40.0
25. Siltstone, like unit 26, finely micaceous, alternating gray and grayish-red, thin-bedded; weather yellowish gray. HS708 from middle	10.0
24. Sandstone, with siltstone in middle part, very fine grained, finely micaceous pale-yellowish-brown to dark-yellow-brown, very thin bedded to thin-bedded; symmetrical ripple marks. HS707 from 5 feet above base; HS706 from base	12.5
23. Siltstone, with some thin quartzite beds, gray, thin-bedded to very thin bedded; weathers grayish yellow; load casts; ripple marks; quartzite beds, 0.1–0.3 in. thick, are very fine-grained and pale red to grayish pink and weather to dark yellowish orange, mainly because of heavy iron staining. HS705 (Ca, 9.2 percent, Mg, 6.0 percent; molar ratio, 0.91) from 20 ft above base; HS704 from base	30.5
22. Mostly covered; soil and float indicate red and yellowish-gray siltstone	25.0
21. Siltstone, with interbedded quartzite, dolomitic, finely micaceous, medium-gray, laminated to thinly bedded; weathers grayish organge to light gray; load casts and ripple marks; quartzite is very fine grained clear quartz. HS703 from 25 ft above base; HS702 from 20 ft above base; HS701 from 10 ft above base	35.0
20. Sandstone with thin quartzite beds (poorly exposed), finely micaceous, very fine grained, dolomitic, gray to grayish-yellow, laminated to very thin bedded; locally mottled pale reddish brown; weathers grayish orange to light brown; load casts; ripple marks; very low angle minute cross-lamination. Glauconite-bearing sandstone lenses 25 ft above base, HS411a6, and near base, HS411a5; HS700 from 35 ft above base; HS699 from basal bed	95.0
19. Mostly covered; float and scattered exposures indicate sandstone and thin quartzite beds, laminated, very fine grained, dolomitic, finely micaceous, medium-gray to light-gray; some thin beds of moderate red to pale red; some beds have green tint; weathers light brown to grayish orange; some laminae form small low-angle crossbeds and contain small rounded clay balls. Glauconite-bearing sandstone lenses 65.0 ft above base HS411a4; 51.0 ft above base, HS411a3; and 30 ft above base, HS411a2; HS698 from 60.0 ft above base	80.0
18. Sandstone with thin quartzite beds, very fine grained, finely micaceous, yellowish-gray to medium-gray; weathers grayish orange; very thin bedded with minute laminae; load casts common; ripple marks. Glauconite sample HS411a1 from near top in many thin laminae that are fine to medium grained (0.125–0.50 mm); rock sample HS697 from middle of unit	16.5
17. Siltstone with lentils of sandstone and quartzite, dolomitic, finely micaceous, medium-gray, very thinly bedded, weathers pale yellowish brown to moderate yellowish brown; sandstone in beds 2–3 in. thick; load casts; ripple marks. Glauconite, HS411a, in laminae and lentils up to ¾ in. thick, some of which are in low-angle crossbeds, fine- to medium-grained. HS696 (Ca, 6.0 precent; Mg, 3.3 percent; molar ratio, 1.09) from middle part; HS695 from 4.0 ft above base	49.0
16. Limestone, magnesian, very fine grained, medium-gray to light-olive-gray; weathers yellowish gray; one bed; weathers blocky; stromatolite biostrome and debris in limestone matrix; upper part of biostrome is partly fragmented. HS694 (Ca, 29.3 percent; Mg, 0.80 percent; molar ratio, 21.23)	1.0
15. Siltite, dolomitic, very finely crystalline, medium-gray, very thinly bedded; weathers moderate yellowish brown; weathers platy. HS693 from middle part	9.5
14. Dolomite, siliceous, very finely crystalline, mostly dark gray with some medium-gray; contains nontransported stromatolite fragments; weathers medium gray to grayish orange; one bed. HS692 (Ca, 6.0 percent; Mg, 5.1 percent; molar ratio, 1.82)	1.5
13. Siltstone, calcitic dolomite cement, very finely micaceous, thin-bedded, medium-gray to light gray; weathers moderate yellowish brown and pale yellowish brown. HS691 (Ca, 7.0 percent; Mg, 4.5 percent, molar ratio, 0.97) from 10 ft below top of unit; HS690 (Ca, 6.8 percent; Mg, 3.2 percent; molar ratio 1.33) from base	39.5
12. Covered. Float of thin-bedded argillaceous sandstone and siltstone	64.0±
11. Siltstone, calcitic dolomite cement, very finely micaceous, light-olive-gray, thin-bedded, weathers pale yellowish brown; weathers platy; ripple marks. HS667 (Ca, 8.3 percent; Mg, 3.8 percent; molar ratio, 1.33) from middle	12.0
10. Sill of late Precambrian age; microcrystalline quartz diorite dark-gray; weathers dark to moderate yellowish brown and to a brown soil; weathers blocky. HS666 from middle	30.0
9. Conglomerate, medium-gray; magnesian limestone matrix encloses mixture of poorly sorted sand to flat pebbles of siltstone and limestone; sand consists of rounded to subrounded quartz and feldspar with some clay balls; abundant oolites, some of which are	

Shepard Formation—Continued — *Thickness (feet)*

squashed and broken; glauconite; weathers pale yellowish brown and light gray; one bed; weathers blocky with many fragments etched in relief. HS665 (Ca, 26.4 percent; Mg, 0.73 percent; molar ratio, 21.23) — 0.7

8. Argillite, finely micaceous, medium-light-gray, thin-bedded; weathers grayish green; weathers platy and shaly; lenses of thin slightly calcareous very micaceous very fine grained sandstone; symmetrical ripple marks; minutely cross-laminated; load casts and mud cracks. HS664 from middle part — 79.5
7. Dolomite, finely micaceous, medium-gray; weathers light brown; thin bedded with minute laminate; weathers platy; some dolomitic siltstone. HS663 from base — 11.5
6. Siltstone with some very thin beds of sandstone calcareous, medium-gray; weathers brownish gray; shaly and platy; mud cracks and ripple marks; sandstone is very fine grained, minutely laminated, and slightly recrystallized. HS662 from about 30–40 ft above base — 95.0
5. Sandstone (poorly exposed), calcareous, finely micaceous, very fine grained, medium gray, laminated to very thin bedded; weathers moderate yellowish brown; weathers platy; ripple marks. HS661 from 10 ft above base — 19.7
4. Limestone, stromatolite, dolomitic, very fine grained, dark-gray, iron-stained, thinly laminated; weathers gray with light-gray blotches; weathers blocky. HS695 (Ca, 27.7 percent; Mg, 1.0 percent; molar ratio, 15.17) and F417 — 2.5
3. Siltite, calcareous, light-medium-gray, olive-gray, thin-bedded; ripple marks — 14.4
2. Dolomite, calcitic, very finely crystalline stromatolites; dark-gray, laminated; weathers light olive gray; one bed; some laminae are broken and silicified, many weather in relief. HS658 (Ca, 15.9 percent; Mg, 9.6 percent; molar ratio, 1.03) — 2.0
1. Covered. Mostly thin bedded slightly recrystallized siltite — 14.7

Total Shepard Formation including sill of late Precambrian age — 814.8±

Snowslip Formation, recrystallized sandstone and siltite.

3. *Gordon Shale, Flathead Sandstone, and McNamara Formation on west side of upper reaches of Reef Creek about 1 mile south of Prairie Reef lookout*

[Measured by M. R. Mudge and Dale Snow]

Damnation Limestone.

Gordon Shale: — *Thickness (feet)*

41. Shale, clayey, noncalcareous, gray to gray-green, locally maroon-tinted, thinly laminated; many thin gray micaceous sandstone lentils. HS755 from very thin bed of gray limestone with coarse glauconite 23.0 ft above base; HS754 from bed of limestone with algal deposits and coarse glanconite 9.5 ft above base — 94.0

Gordon Shale—Continued — *Thickness (feet)*

40. Limestone, medium-crystalline, dark-gray-brown; algal deposits abundant — 1.0
39. Shale, clayey, noncalcareous, dark-gray, thinly laminated; many thin lenses of very fine grained sandstone — 10.0
38. Limestone, as in unit 36; algal deposits — 1.0
37. Shale, clayey, noncalcareous, dark- to medium-gray, thinly laminated; very thin bed of limestone in middle with abundant fossil fragments, possibly algal deposits. F418 — 4.4
36. Limestone, sandy, gray-brown, massive, glauconitic; fragments of limestone pebbles in upper part. HS753 — .7
35. Shale, silty to clayey, very micaceous, noncalcareous, dark- to medium-gray-brown, laminated; many thin lenses of brown sandstone; glauconitic sandstones abundant in upper half; organic trails and burrows abundant on bottom of beds. HS752 (composite) — 82.4
34. Sandstone with interbedded shale, very fine grained, noncalcareous, finely micaceous, very thin bedded, gray to yellowish-gray; maroon bed at 20 ft above base; ripple marks; organic trails and burrows abundant. HS751 (composite) — 34.5
33. Shale, clayey, noncalareous, finely micaceous, dark-gray-brown, maroon-tinted, thinly laminated; very thin lenses of fine-grained sandstone, lowermost lens coarse grained; sandstone beds form small ledges; organic trails and burrows on base of beds. HS750 (composite) — 24.5

Total Gordon Shale — 252.5

Flathead Sandstone:

32. Sandstone, fine- to medium-grained, noncalcareous, yellowish-gray, crossbedded, iron-stained; mostly in beds 2–6 in. thick, some thicker beds in upper part; organic trails and burrows. HS749 from 4 ft above base. HS743 from 3 ft above base — 24.0
31. Sandstone, poorly sorted, medium- to coarse-grained, yellowish-gray, iron-stained, thin- to thick-bedded; vertical light-gray veinlets in upper beds; organic trails and burrows. HS747 (composite) — 12.5
30. Sandstone, same as unit 31 but in beds 6 in.–1.5 ft thick, crossbedded; thin gray shale bed; organic trails and burrows. HS746 (composite) — 7.0
29. Sandstone, same as unit 27 — 10.0
28. Sandstone, same as unit 26 — 1.0
27. Shale and sandy shale, very fine grained, very finely micaceous, maroon, laminated — 4.0
26. Sandstone, fine- to medium-grained, poorly indurated, light-yellowish-gray, massive; low-angle crossbedding dips 25° SW — 1.3
25. Shale, sandy, very fine grained, very finely micaceous, maroon, laminated; minute load casts; organic trails and burrows. HS745 — 3.7
24. Sandstone, same as unit 23, poorly sorted and indurated, very thin bedded; mud cracks; organic trails and burrows in upper bed. HS744 — 12.5

Flathead Sandstone—Continued	Thickness (feet)
23. Sandstone, poorly sorted and indurated, yellowish-gray, massive; maroon lenses and stains in upper part; lower bed mainly quartz pebble conglomerate (3–6 in.) in sand matrix; weathers blocky with rounded edges; thinly laminated with low-angle crossbeds dipping 10° W.; some zones coarse-grained, two very thin gray beds of shale at 10.0 and 4.5 ft above base. HS743 (composite)	30.0
Total Flathead Sandstone	106.0

McNamara Formation:	Thickness (feet)
22. Shale, sandy, minutely micaceous, laminated, iron-stained, greenish-gray; maroon and light-yellowish-gray lenses; some greenish-gray beds of siltstone; thin beds of glauconitic sandstone at 23.0 ft above base in a very thin bedded sandstone bed. HS742 (composite)	36.0
21. Sandstone, with interbedded sandy shale and shale, very fine grained, very finely micaceous, yellowish-gray and gray, very thin bedded; weathers brown; weathers platy. HS741 (composite)	8.5
20. Shale, sandy, noncalcareous, gray, thinly laminated; thin maroon bed in upper part. HS740 (composite)	13.5
19. Siltstone with sandstone, minutely micaceous, gray, thin bedded; maroon lenses; very thin beds of glauconitic sandstone at 2 ft above base. HS739	5.5
18. Sandstone and sandy shale, very fine grained, finely micaceous, noncalcareous, greenish-gray and yellowish-gray, laminated to thin bedded; weathers brown; weathers blocky to platy; scattered shale fragments; mud cracks; glauconite grains; many small ledges. HS738 (composite)	8.0
17. Shale, sandy, with some interbeds of sandstone, gray-green, laminated; maroon lenses; minute load casts in upper part. Sandstones are very thin and very fine grained. HS737 (composite)	29.5
16. Sandstone, very fine grained, very finely micaceous, medium-gray, very thin bedded; weathers yellowish brown; weathers blocky and platy; symmetrical ripple marks in lower part; load casts; minute cross-lamination; salt casts; many thin poorly indurated lenses of green sandstone in lower part; some glauconite grains. HS736 from lower part	5.5
15. Sandstone, with sandy shale, noncalcareous, very fine grained, gray-brown, massive, laminated; thin maroon bed in upper part; weathers brown; weathers platy; abundant fine mica; glauconitic beds in upper and middle parts; some clayey gray and gray-green thin-bedded shale beds. HS735 (composite)	18.5
14. Siltstone, with thin sandstone, very fine grained, very micaceous, noncalcareous, greenish-gray, laminated; weathers yellowish brown; thin reddish-brown sandstone in upper part; glauconite grains. HS734	6.0

McNamara Formation—Continued	Thickness (feet)
13. Siltstone, very fine grained, very micaceous, slightly calcareous, medium-gray, very thin bedded; weathers brown to gray brown; load casts in upper part. HS733	4.5
12. Sandstone, very fine grained, minutely micaceous, gray, cross-laminated; thin bedded, maroon and mottling of maroon; symmetrical ripple marks; load cases; unit forms prominent ledges; glauconite abundant in many beds. HS729 (composite); HS732 at 74 ft above base; HS731 at 58 ft above base; HS730 at 28 ft above base	75.0
11. Claystone, minutely micaceous, light-gray-green, thinly laminated; gray-green glauconitic and feldspathic sandstone at top. HS728	23.0
10. Shale, clayey, light-gray-green, thinly laminated; weathers light gray. HS727	0.6
9. Sandstone with sandy shale, very fine grained, finely micaceous, and grayish-green to green, very thin-bedded; salt casts and mud cracks; granules and pebbles of grayish-green mudstone and grayish-orange siltstone; numerous cavities filled with barite in lower part. HS726 (composite)	88.0
8. Sandstone with sandy shale, same as unit 9, with much sandy mudstone; many mud-cracked surfaces with chips (¼ in. across) of mudstone in a very fine grained sandstone matrix; some chalcedony-filled geodes; thin sandstone forms resistant ledges. HS725 (composite)	55.0
7. Quartzite, with sandy shale, very fine grained, finely micaceous, glauconitic, mainly green, very thin-bedded; some maroon lenses; some gray-green rounded mudstone fragments (up to ¼ in.); thin lens filled with barite. HS724 (composite)	60.0
6. Quartzite, very fine grained, minutely micaceous, pale-brown; weathers brown. HS723	1.0
5. Siltstone, sandy, finely micaceous, very fine grained, mainly green, laminated; thin maroon lenses 2–4 in. thick; some biotite; local low-angle crossbedding; load casts near middle; flat round dark-gray-green mudstone pebbles, up to ½ in. across, aligned with bedding. HS722 (composite)	50.0
4. Siltstone, sandy, very fine grained, slightly calcareous, yellowish-gray; very thin bedded in upper part; small flat rounded green mud chips parallel to bedding, some are siliceous; glauconite. HS721	1.5
3. Sandstone, alternating with sandy shale, very fine grained, very finely micaceous, yellowish-gray to grayish-green, thin-bedded; maroon beds; low-angle crossbedding; some biotite; mud cracks; green siliceous mud chips (up to ¾ in.) abundant; unit forms resistant ledges. HS720 (composite)	46.5
2. Sandstone, silty, very thin bedded, very fine grained, finely micaceous, noncalcareous; maroon beds mottled with green; yellowish-gray sandstone lenses locally; green mud chips. HS719 (composite)	31.0

McNamara Formation—Continued

	Thickness (feet)
1. Sandstone, very fine grained, noncalcareous, maroon, very thin bedded; mottled with green; some yellowish-gray lenses; low-angle crossbedding. HS718	10.0
Total McNamara Formation	577.1

Bonner Quartzite, uppermost clear quartz sandstone.

4. *Damnation Limestone on west side of upper reaches of Reef Creek about 1¼ miles south of Prairie Reef lookout*

[Measured by M. R. Mudge and Dale Snow]

Dearborn Limestone.

Damnation Limestone:

	Thickness (feet)
3. Limestone, finely crystalline, hard, medium-gray; bedding very thin and indistinct; yellowish-gray silt in irregularities between beds; weathers massive, forms uppermost cliff with rounded surface; organic trails and burrows abundant at and near top. HS760 from 20 ft below top; HS759 (Ca, 40.2 percent; Mg, 0.15 percent; molar ratio, 97.10) from basal bed	46.0
2. Limestone, like unit 1, but in thin beds forming massive unit; weathers nodular	14.0
1. Limestone, dolomitic, finely crystalline with coarsely crystalline zones, dark-gray, mottled light-orange-gray and yellowish-gray; beds 1–2 in. thick separated by irregular fillings of silt and very fine grained sand in troughs of ripple marks and in organic trails and burrows; boring ¼ in. across; coarsely crystalline beds form light-gray bands on cliff; fossil fragments scattered throughout. HS758 (Ca, 35.4 percent; Mg, 1.1 percent; molar ratio, 21.23) from 65 ft above base; HS757 (Ca, 33.8 percent; Mg, 1.7 percent; molar ratio, 12.13) from 20 ft above base; HS756 (Ca, 32.8 percent; Mg, 1.6 percent; molar ratio, 12.13) from 12 ft above base	85.0
Total Damnation Limestone	145.0

Gordon Shale.

5. *Upper part of Devils Glen Dolomite, Switchback Shale, Steamboat Limestone, and upper part of Pagoda Limestone, measured on north face of Nineteen Mountain and extending to saddle and knob, just northwest of Nineteen Mountain, Pretty Prairie quadrangle*

[Measured by M. R. Mudge and Dale Snow]

Fault, Precambrian rocks on Upper Cambrian Devils Glen Dolomite

Devils Glen Dolomite:

	Thickness (feet)
41. Dolomite, very finely crystalline, very light gray; in beds 6 in.–2 ft thick. HS479 from top; HS478 from 10 ft above base	34.0
40. Dolomite, very finely crystalline, very light gray; in beds 2–10 in. thick. HS477 from 6.5 ft above base	10.0
39. Dolomite, like unit 40 but thick bedded. HS476 from 21 ft above base; HS475 from 8.5 ft above base	33.8

Devils Glen Dolomite—Continued

	Thickness (feet)
38. Dolomite, finely crystalline, crossbedded, very light gray; many beds 4–12 in. thick; many minute laminae; algallike structures. HS474 from 21 ft above base	32.0
37. Dolomite, finely crystalline, very light gray; in beds 6–12 in. thick; minute laminae apparent in upper and lower parts; algallike structures. HS473 from near top; HS472 from 5 ft above base	48.5
36. Dolomite, finely crystalline, light-yellowish-gray, thick-bedded. HS471 from near top	8.5
35. Dolomite, finely crystalline, light-gray, thick-bedded; many minute laminae; minute pores; algallike structures. HS470 from top; HS469 from near base	29 5
34. Dolomite, very finely crystalline, light-gray, thick-bedded; faint crossbedding. HS468 from center	12.7
33. Dolomite, very finely crystalline, light-yellowish-gray, thin- bedded to very thin bedded; minute laminae. HS467 from 10 ft above base	11.7
32. Dolomite, finely crystalline, light-gray, thin to thick-bedded. HS466 from 8 ft below top; HS465 from center	46.0
31. Dolomite, finely crystalline, light-gray, massive; in beds 2–4 ft thick; faint crossbedding in upper part; possible bedding-plane fault. HS464 from near top; HS463 from near base	60.0
30. Dolomite, very finely crystalline, light-gray; one bed with faint thin lamination and crossbedding. HS462	4.2
28. Dolomite, coarsely crystalline, light-brownish-gray; thick-bedded; disseminated green stains. HS461 from middle	7.5
27. Dolomite, silty, finely crystalline, pale-yellowish-brown, thick-bedded; weathers grayish-orange; faint lamination. HS460 from 2 ft below top; HS459 from 10 ft above base	38.5
Total Devils Glen Dolomite east of fault	376.9

Switchback Shale:

	Thickness (feet)
26. Shale, dark-gray, thinly laminated; grades up into brown laminated shale; a few very fine grained sandstone beds 3–12 in. thick; a thin conglomerate is in the sandstone beds; organic trails and burrows; badly sheared. HS457 (shale); HS458 (sandstone)	35.0
Small fault; measurement continued on same bed on other side of fault.	
25. Shale, clayey, noncalcareous, greenish-gray; some plates have purple tint; thinly laminated thin yellowish-gray limestone 165 ft above base; thin conglomerate at top (HS455 and 456); thin zone of very fine grained slightly calcareous platy brown-weathering sandstone occurs beneath limestone; small ripple marks; organic trails and burrows. F358 from limestone. HS454 from shale at 15 ft above base	177.0

Switchback Shale—Continued *Thickness (feet)*

24. Limestone, finely crystalline. thin-bedded, grayish-brown; mottled with dark-gray-orange. Upper part, HS452, contains small calcite- and iron-filled pores; conglomerate, HS453, at top consists of small chert pebbles and some fossil fragments, F357 (USGS loc. 3739–CO) ------- 6.0
23. Shale, noncalcareous, clayey, gray, thinly laminated; thin limestone bed 8.5 ft above base. HS451 ------- 36.5

Total Switchback Shale ------- 254.5

Steamboat Limestone:

22. Limestone, like unit 18 ------- 1.5
21. Limestone, dolomitic, gray; weathers pale yellowish brown; has intraformational breccia composed of angular splinters as much as 5 in. long; many are shingled, dipping 30° from bedding. HS449 ------- .5
20. Limestone, finely crystalline, gray; weathers pale yellowish brown; sandy appearance; minute lamination in upper part. HS448 ------- 1.1
19. Limestone. dolomitic, finely to medium crystalline, gray, thin-bedded, oolitic; fossil fragments. HS450 ------- 6.5
18. Dolomite, finely crystalline, dark-yellowish-brown, thin-bedded; mottled with dark gray orange. HS447 ------- 7.0
17. Limestone, slightly dolomitic, finely crystalline, gray to gray-brown; in beds 6–12 in. thick; brown lenses in upper part; mottled in lower part. HS446 from upper part; HS445 from lower part ------- 28.0
16. Limestone, slightly dolomitic, finely crystalline, dark-yellowish-brown, thin-bedded; mottled gray orange; unit forms top ledge of northeast face of Nineteen Mountain. HS444 from 3.0 ft above base ------- 30.5
15. Limestone, dark-yellowish-brown, nodular; laminated with shale partings ------- 1.1
14. Limestone, finely crystalline. dark-yellowish-brown; one bed; forms small ledge. HS443 ------- 1.7
13. Limestone, slightly dolomitic, finely crystalline, dark-yellowish-brown; mottled yellowish gray; in beds ½–2 in. thick; weathers nodular. HS442 ------- 2.2
12. Limestone, finely crystalline, dark-yellowish-brown; mottled light yellowish gray; one bed; weathers blocky to nodular; forms narrow band on cliff face ------- 1.4
11. Limestone with gray calcareous shale partings, yellowish-gray; 1–3 in. beds; weathers platy; organic trails and burrows; trilobites in lower part. F356 (USGS loc. 3737–CO). HS440 ------- 14.5
10. Limestone, dolomitic, very finely crystalline, dark-yellowish-brown, very thin bedded; with many small areas mottled in yellowish gray and dark yellow orange; many mottled areas more coarsely crystalline than matrix; in cross section they resemble filled troughs of small

Steamboat Limestone—Continued *Thickness (feet)*

ripple marks; many organic trails and burrows. HS439 from 40 ft above base; HS438 and F355 from 3 ft above base ------- 90.0

9. Shale, noncalcareous, clayey, dark-grayish-green, thinly laminated; weathers yellowish gray; thin nodular fine-grained limestone in lower part with trilobites; dolomitic limestone nodules scattered throughout. (F354, USGS loc. 3736–CO). HS437 from lower part ------- 16.5
8. Dolomite, finely crystalline, dark-yellowish-brown, thick-bedded; mottled light gray and yellowish gray; weathers nodular to blocky; calcite-filled pores; organic trails and burrows HS436 from top ------- 11.5
7. Shale, clayey, noncalcareous, grayish-brown, thinly laminated. HS435 ------- 5.0

Total Steamboat Limestone ------- 219.0

Pagoda Limestone (upper part):

6. Limestone, dolomitic, very finely crystalline, hard, pale-yellowish-brown, thick-bedded, oolitic; weathers blocky; organic trails and burrows, forms prominent cliff. HS510 from top; HS509 from 6 ft above base ------- 43.0
5. Limestone, dolomitic, finely crystalline, light-yellowish-brown, oolitic, thick-bedded; weathers platy; many minute laminations; some crossbedding; in lower part are porous gray-brown chert lentils 2–4 ft long and 2 in. thick; thin lenses of silty limestone; forms small identation in cliff. HS508 from top; HS507 from 18 ft above base ------- 45.0
4. Dolomite, finely crystalline, hard, gray-brown, thick-bedded; weathers platy; some nodular wavy beds have algal appearance; dark-gray-brown chert nodules scattered throughout, organic trails and burrows. HS506 and F353 from 9 ft. above base ------- 17.5
3. Limestone, dolomitic, finely crystalline, hard, gray-brown, thick-bedded, nodular; weathers block or slabby; nodular, algal appearance on upper surface; oolites and coarse crystals which may be fossil fragments. HS505 from 3 ft. below top ------- 9.5
2. Dolomite, finely crystalline, pale-yellowish-brown, thick-bedded, oolitic, weathers blocky; minute laminae; some angular breccia that weathers lighter than matrix. HS504 from top ------- 7.0
1. Limestone, finely crystalline, yellowish-gray; dark mottled areas; in beds 2–3 feet thick; minute lamination. HS503 from center ------- 9.5

Total upper part of Pagoda Limestone ------- 131.5

Lower beds are inaccessible on cliff.

6. *Switchback Shale (part) measured at northeast end of Allan Mountain just northeast of peak 7426, Patricks Basin quadrangle*

[Measured by M. R. Mudge and M. W. Reynolds]

Devils Glen Dolomite.

Switchback Shale:

	Thickness (feet)
10. Shale, noncalcareous, grayish-green, thinly bedded; weathers yellowish gray; heavily iron stained at base. HS319	4.0
9. Dolomite, very finely crystalline, gray iron-stained; many beds 2–3 in. thick; weathers blocky. HS320 (Ca, 22.0 percent; Mg, 12.3 percent; molar ratio, 1.085)	11.5
8. Shale, noncalcareous, greenish-gray, thin-bedded; weathers papery; iron stained at top. HS321	5.0
7. Dolomite, calcitic, yellowish-gray; one bed; weathers blocky; lower 5 in. contains conglomerate with well-rounded pebbles of dolomite; numerous small en echelon normal faults. HS322 (Ca, 22.5 percent; Mg, 9.7 percent; molar ratio, 1.407)	2.5
6. Shale, greenish-gray, thin-bedded, badly sheared; weathers grayish orange	.5
5. Dolomite, calcitic, gray; weathers light brownish gray; irregular beds ¼–2 in. thick; weathers nodular; load casts at top. HS324 from top; HS323 (Ca, 15.8 percent; Mg, 6.5 percent; molar ratio, 1.475)	2.5
4. Shale, noncalcareous, thinly laminated; greenish gray grading to dark gray in lower part. HS325	14.0
3. Conglomerate, lenticular; well-rounded carbonate pebbles and cobbles up to 6 in. across. F328 and HS326	0–0.8
2. Siltstone, calcareous, greenish-gray, thin-bedded; many calcite nodules. HS327	14.7
1. Shale, noncalcareous, dark-gray, thinly laminated; iron-stained plates. HS328	3.0
Total partial Switchback Shale measured	57.5–58.3

Fault. Switchback Shale as exposed here consists mostly of thinly laminated dark-greenish-gray and dark-grayish-red shale that is finely micaceous and contains some very fine grained sandstone lenses with organic trails and burrows.

7. *Three Forks, Jefferson and Maywood Formations, and Devils Glen Dolomite along ridge on west side of Big George Gulch extending almost to Gibson Reservoir in SW¼ sec. 31, T. 22 N., R. 9 W., and in areas adjacent to reservoir*

[Units 1–33 measured on knob just north of reservoir. Measured by M. R. Mudge, R. M. Mudge, and R. J. Mudge]

Mississippian Allan Mountain limestone.

Three Forks Formation:

	Thickness (feet)
48. Covered	17.5
47. Limestone, very fine grained, grayish-brown, very thick bedded; weathers gray; weathers block; stringers of porous chert locally in upper part; brachiopod fragments. F146 (USGS loc. 5081–SD) from upper 10 ft. HS350 (Ca, 38.3 percent; Mg, 0.4 percent; molar ratio, 58.10)	98.0

Three Forks Formation—Continued

	Thickness (feet)
46. Evaporite-solution breccia containing fragments of limestone and magnesian limestone, finely crystalline, light-yellowish-brown, massive; weathers gray; weathers to irregular blocks; large unoriented angular blocks as much as 6 ft across, most are 2 ft or less with smaller fragments in lower part; some fragments of silty limestone and dolomitic limestone; iron specks; forms prominent ledge. HS349 (Ca, 28.1 percent; Mg. 6.4 percent; molar ratio, 26.64) from upper part; HS348 (Ca, 26.2 percent; Mg, 8.9 percent; molar ratio, 17.86) from basal part	85.0
Total Three Forks Formation	200.5

Jefferson Formation:

Birdbear Member:

45. Covered by talus; much is probably like unit 44	33.0
44. Dolomite, very finely crystalline, light-gray, very thin bedded; lighter than unit 43; weathers blocky with minute laminations. HS318 (Ca, 22.0 percent; Mg, 12.5 percent; molar ratio, 1.068)	4.0
43. Limestone, dolomitic, very finely crystalline, very pale orange, very thin bedded; some very thin interbeds; forms ledge. HS347 (Ca, 19.7 percent; Mg, 7.5 percent; molar ratio, 15.93)	35.0
42. Dolomite, very finely to finely crystalline, pale-yellowish-brown, very thin bedded; weathers platy. HS346 (Ca, 23.0 percent; Mg, 11.9 percent; molar ratio, 1.172)	20.0
41. Dolomite, finely crystalline, thin to very thin bedded; grades from gray in upper part to light brownish gray in lower part; weathers yellowish gray; weathers blocky. HS317 (Ca, 22.6 percent; Mg, 12.3 percent; molar ratio, 1.115)	20.0
40. Dolomite, calcitic, very finely crystalline, light-brownish-gray, very thin bedded; weathers platy; some minute laminae apparent on weathered surfaces. HS316 (Ca, 25.3 percent; Mg, 10.0 percent; molar ratio, 1.535)	30.0
39. Dolomite, very finely crystalline, medium-gray; in even beds 5–10 in. thick. HS315 (Ca, 19.6 percent; Mg, 11.3 percent; molar ratio, 1.052)	7.0
38. Dolomite, very finely crystalline, pale-yellowish-brown to brownish-gray; upper part mottled with grayish orange; nodular irregular beds 2–4 in. thick; weathers nodular. F325 (USGS 5401–SD) from 20 ft below top; F324 (USGS 5400–SD) from 10 ft above base. HS345 (Ca, 21.8 percent; Mg, 12.0 percent; molar ratio, 1.102) from near top; HS344 (Ca, 21.4 percent; Mg, 11.6 percent; molar ratio, 1.119) near base	72.0
Total Birdbear Member	221.0

Jefferson Formation—Continued *Thickness (feet)*

Lower member:

37. Dolomite, finely crystalline, dark-yellowish-brown, thin-bedded; weathers yellowish gray to grayish brown; weathers nodular; evaporite-solution breccia contains fragments up to 8 in. long in upper and lower parts; calcite-lined pits and pores. HS343 (Ca, 22.8 percent; Mg, 11.8 percent; molar ratio, 1.172) ---- 18.0
36. Dolomite, calcite, finely crystalline, mostly brownish-gray, thin-bedded; some beds yellowish gray; weathers blocky to platy; lighter colored beds show minute undulated laminae. HS314 (Ca, 25.5 percent; Mg, 10.4 percent; molar ratio, 1.487) ---- 27.0
35. Dolomite, finely crystalline, pale-yellowish-brown; light-gray dolomite at base; weathers light gray brown and in places yellowish gray; thin nodular bedding; iron specks. F323 (USGS 5399–SD) (corals 2 ft above base). HS342 (Ca, 21.2 percent; Mg, 11.9 percent; molar ratio, 1.081) ---- 17.0
34. Dolomite, with calcitic dolomite in lower part, finely crystalline, light-brownish-gray; in beds 1–2 feet thick; fetid odor. F322 (USGS 5398–SD) (solitary corals) 30 ft above base; *Amphipora* bed 25 ft above base; F321 (USGS 5397–SD) (*Amphipora*) 20 ft above base. HS341 (Ca, 21.8 percent; Mg, 12.5 percent; molar ratio, 1.058) near top; HS340 (Ca, 23.8 percent; Mg, 11.5 percent; molar ratio, 1.2556) near base ---- 53.0
33. Dolomite, very finely crystalline, gray, thin-bedded; weathers yellowish gray; weathers platy; highest light-gray bed in Jefferson Formation. HS313 (Ca, 22.0 percent; Mg, 12.6 percent; molar ratio, 1.059) ---- 13.0
32. Dolomite, dark-grayish-brown; in beds up to 1.0 ft thick; weathers platy and flaggy. *Amphipora* coquina, F320 (USGS 5396–SD), throughout except for about 2 ft of beds about 5 ft below top. HS312 (Ca, 21.8 percent; Mg, 12.4 percent; molar ratio, 1.066) ---- 17.0
31. Dolomite, with magnesian limestone in lower part, very finely crystalline, porous, dark-grayish-brown; light-yellowish-gray bed in lower part; in beds 1–2 ft thick; weathers blocky with deeply etched surface; fetid odor. F319 (USGS 5395–SD) from a 2-ft-thick coquina of *Amphipora* 6 ft below top; F318, 35 ft above base. HS311 (Ca, 22.7 percent; Mg, 12.3 percent; molar ratio, 1.119); HS338 (Ca, 29.2 percent; Mg, 7.1 percent; molar ratio, 24.95) ---- 51.0
30. Dolomite, very finely crystalline, brownish-gray, thin-bedded; weathers yellowish gray; weathers platy; this unit and part of underlying unit form yellowish-gray band on ridge. HS779 (Ca, 21.3 percent; Mg, 12.0 percent; molar ratio, 1.09) ---- 6.0

Jefferson Formation—Continued *Thickness (feet)*

Lower member—Continued

29. Dolomite, very finely crystalline, brownish-gray, thick-bedded, minutely porous; some brownish-gray siliceous masses; weathers blocky; calcite-filled cavities. HS339 (Ca, 21.9 percent; Mg, 12.7 percent; molar ratio, 1.046) ---- 16.0
28. Dolomite, dark-brownish-gray, thick-bedded; weathers blocky; weathered lower part shows minute laminae; forms top ledge along ridge; poorly preserved brachiopod and coral fragments at top. HS310 (Ca, 22.7 percent; Mg, 12.5 percent; molar ratio, 1.1019) ---- 30.0
27. Limestone, very finely crystalline, yellowish- to brownish-gray, thin-bedded; some medium-gray beds; weathers platy. HS778 (Ca, 38.8 percent; Mg, 0.29 percent; molar ratio, 79.89) ---- 42.0
26. Limestone, with dolomite in lower part, dark gray, massive; weathers light gray; weathers blocky except lower part which weathers platy; forms upper gray band on cliff on west side of Big George Gulch; black chert lentils in middle and lower parts; lower beds darker in color. F317 (USGS 5393–SD) massive stromatoporoid beds about 10 ft below top; F316, massive stromatoporoid beds 10–12 ft above base, some brachiopods. HS309 (Ca, 39.5 percent; Mg, 0.33 percent; molar ratio, 72.63) 15 ft below top; HS777 (Ca, 35.6 percent; Mg, 2.0 percent; molar ratio, 1.09) near base ---- 64.0
25. Dolomite, calcitic, finely crystalline, pale-yellowish-brown, thin- to thick-bedded; weathers blocky with rounded edges. Massive stromatoporoid biostrome with silicified colonies up to 15 in. thick, some 3 ft thick, F315 (USGS 5391–SD); fossils weathered in relief to lighter color than matrix. HS337 (Ca, 25.6 percent; Mg, 10.2 percent; molar ratio, 1.552) ---- 10.0
24. Dolomite, very finely crystalline; dark-brownish gray zone near middle weathers yellowish gray; many beds 3 in.–1 ft thick; weathers blocky to platy; calcite-filled small cavities; forms many small ledges. F314 (USGS 5390–SD), *Amphipora* and massive stromatoporoids, from 6 ft below top; F313, *Amphipora*, 25 ft above base. HS308 (Ca, 23.1 percent; Mg, 11.8 percent; molar ratio, 1.187) ---- 53.0
23. Dolomite, very finely crystalline, dark-brownish-gray, thin-bedded; weathers platy; minute lamination; evaporite-solution breccia in upper 1 ft. HS776 (Ca, 21.2 percent; Mg, 12.3 percent; molar ratio, 1.03) from middle of bed ---- 6.0

Jefferson Formation—Continued Lower member—Continued	Thickness (feet)
22. Dolomite, very finely crystalline, dark-brownish-gray, thin-bedded; weathers blocky; in beds 1–2 ft thick; many calcite-lined cavities and pits; weathered surface deeply etched; fetid odor; forms ledge. F312 (USGS 5388–SD) from 14 ft above base. HS307 (Ca, 23.2 percent; Mg, 12.1 percent; molar ratio, 1.164)	26.0
21. Evaporite-solution breccia with fragments of dolomitic limestone, very finely crystalline, pale-yellowish-brown, thin-bedded; weathers light gray; weathers blocky with rounded surface; voids cemented with $CaCO_3$; this unit and upper part of unit 20 form lowest light-gray band on cliff. HS306 (Ca, 35.8 percent; Mg, 3.0 percent; molar ratio, 7.241)	12.0
20. Limestone, dark-yellowish-brown, thin-bedded; mottled light gray in upper part and with light-gray beds in lower part; weathers into small blocks with hackly fracture. F311 (USGS 5387–SD) from 50 ft above base; F310 (USGS 5386–SD) from 43 ft above base; F309 from 35 ft above base; F308, *Amphipora*. HS305 (Ca, 38.8 percent; Mg, 0.48 percent; molar ratio, 49.05)	69.0
19. Dolomite, very finely crystalline, gray; in beds 3–4 in. thick. HS304 (Ca, 22.4 percent; Mg, 12.0 percent; molar ratio, 1.132)	2.0
nae; a few brachiopods. HS303 (Ca, 27.4	
18. Dolomite, very finely crystalline, hard, pale-yellowish-brown; very thin bedded in upper part, thin bedded and porous in lower part. HS772 (Ca, 21.3 percent; Mg, 12.2 percent; molar ratio, 1.03)	12.5
17. Limestone, dolomitic, resembles unit 16 but is mostly an evaporite-solution breccia, very finely crystalline, very pale orange, iron-stained; grayish-brown fragments. F307 (USGS 5383–SD) (stromatoporoids?) from near top. HS771 (Ca, 35.4 percent; Mg, 2.8 percent; molar ratio, 9.10) from middle	22.0
16. Dolomite, calcitic, finely crystalline, brownish-gray, thin-bedded; weathers blocky to platy; etched surface shows minute laminae; a few brachiopods. HS303 (Ca, 27.4 percent; Mg, 7.5 percent; molar ratio, 2.216)	11.0
Total lower member	577.5
Total Jefferson Formation	798.5
Maywood Formation:	
Upper member:	
15. Dolomite, calcitic, very finely crystalline, pale-yellowish-brown, very thin bedded; weathers yellowish gray. Coquina of brachiopods (*Allanaria*) at top, F306 (USGS 5382–SD). HS770 (Ca, 24.0 percent; Mg, 5.2 percent; molar ratio, 2.79)	2.5

Maywood Formation—Continued Upper member—Continued	Thickness (feet)
14. Limestone, magnesian, very finely crystalline, brownish-gray thin-bedded; distinctly mottled with stringers and nodules of yellowish gray; weathers slabby and platy. HS302 (Ca, 32.1 percent; Mg, 0.69 percent molar ratio, 28.229)	22.0
13. Limestone, dolomitic, with calcitic dolomite in upper part, very finely crystalline, dark-gray to grayish-brown, thin-bedded. One-ft thick coquina zone, F305, of platy beds 7.0 ft above base; F304 (USGS 5380–SD) from base. HS769 from top (Ca, 25.1 percent; Mg, 9.5 percent; molar ratio, 1.57); HS768 from 6 ft above base (Ca, 34.6 percent; Mg, 2.4 percent; molar ratio, 9.10)	22.0
12. Dolomite, very finely crystalline, pale-yellowish-brown, very thin bedded to thin-bedded; weathers blocky; evaporite-solution breccia 5.0 ft below top; iron stains. HS773 (Ca, 23.7 percent; Mg, 11.2 percent; molar ratio, 1.27)	31.0
Total upper member	77.5
Lower member:	
11. Mudstone, dolomitic, gray to greenish-gray thin-bedded, weathers olive green; iron-stained in upper part. HS782 (Ca, 11.5 percent; Mg, 7.6 percent; molar ratio, 0.91)	7.0
10. Limestone, dolomitic, like unit 6, but very finely crystalline and grayish-brown	1.5
9. Mudstone, dolomitic, greenish-gray; weathers light grayish green; 1.0-ft-thick platy limestone in upper and lower parts; hackly fracture	9.0
8. Limestone, like unit 6	.5
7. Mudstone, dolomitic, dark-grayish-green; weathers olive green; hackly fracture	5.0
6. Limestone, dolomitic, finely crystalline, yellowish-gray, thick-bedded, porous; weathers blocky; evaporite-solution breccia at top and in middle	12.0
5. Claystone, like unit 3, but with many interbeds of yellowish-gray laminated siltstone and darker greenish gray	3.5
4. Limestone, dolomitic, finely crystalline, dark-olive-gray, thick-bedded, porous; weathers blocky; finely laminated in upper part. HS300 (Ca, 36.7 percent; Mg 2.0 percent; molar ratio, 11.134)	5.5
3. Claystone, dolomitic, light-greenish-gray, thin-bedded; hackly fracture	10.0
2. Dolomite, sandy (some coarse grains), light-grayish-orange, very thin bedded; weathers platy. F303 (USGS 5379–SD) near base, fossil fragments. HS299 (Ca, 19.2 percent; Mg, 10.8 percent; molar ratio, 1.078)	5.0
Total lower member	59.0
Total Maywood Formation	136.5

Unconformity.

Devils Glen Dolomite (part):

	Thickness (feet)
1. Dolomite, light-yellowish-gray, thick-bedded; weathers light gray; finely crystalline in upper part grades to medium crystalline in lower part; weathers to large irregular blocks; minute crossbedding apparent on weathered surface; intraformational breccia locally at top and about 10 ft below top; upper part more porous than rest of unit; forms prominent ledge. HS295 from top; HS294 (Ca, 22.3 percent; Mg, 12.9 percent; molar ratio, 1.041) from 40 ft below top; HS293 (Ca, 22.3 percent; Mg, 13.0 percent; molar ratio, 1.040) from middle; HS292 (Ca, 22.5 percent; Mg, 12.8 percent; molar ratio, 1.066) from about 40 ft above base; HS291 (Ca, 22.4 percent; Mg, 12.9 percent; molar ratio, 1.053) from base	155. 0
Total exposed Devils Glen Dolomite	155. 0

8. *Three Forks, Jefferson, and Maywood Formations exposed on west side of Mortimer Gulch, north of Gibson Reservoir, NE¼NW¼SW¼ sec. 4, T. 21 N., R. 9 W.*

[Measured by M. R. Mudge, J. J. Halbert, and E. B. McKee III]

Three Forks Formation:

	Thickness (feet)
38. Limestone and evaporite-solution breccia composed of angular fragments of limestone, as much as 2 ft across, in limestone matrix. Limestone is dark gray with gray-brown tint and weathers medium gray. Lower part of breccia contains fragments of underlying Devonian limestone and weathers blocky	46. 0
37. Evaporite-solution breccia, partly covered; thin-bedded to platy limestone in lower 5 ft. Breccia is yellowish gray and platy, is composed of angular fragments of very fine grained sandy dolomite, dolomite, and dolomitic limestone and small clay fragments, less than 2 in. across, weathers to small fragments, and forms in a slope similar to shale; lower part locally stained red; oil stains. HS152 (Ca, 18.7 percent; Mg, 6.8 percent; molar ratio, 1.668)	85. 0
Total exposed Three Forks Formation	131. 0

Jefferson Formation:

Birdbear Member:

	Thickness (feet)
36. Limestone with thin evaporite-solution breccia (poorly exposed) that may contain shale partings, very fine grained, dense, gray to yellowish-gray, massive; weathers light gray to yellowish gray; weathers to small irregular fragments; forms rounded ledge on hillside; oil stains. HS151 from upper part; HS150 from middle; HS149 (Ca, 37.4 percent; Mg, 0.50 percent; molar ratio, 45.38)	82. 0

Jefferson Formation—Continued

Birdbear Member—Continued

	Thickness (feet)
35. Dolomite and dolomitic limestone, very finely crystalline, with some dolomitic shale, yellowish-gray, thin-bedded; most beds not more than 2 ft thick; weathers to small irregular plates and fragments and to a slope similar to shale; oil stains. HS147 from middle (Ca, 18.8 percent; Mg, 10.8 percent; molar ratio, 1.05); HS148 from lower part (Ca, 29.7 percent; Mg, 5.7 percent; molar ratio, 3.16); F187 (USGS Mus. Loc. 5082–SD)	69. 5
Total Birdbear Member	151. 5

Lower member:

	Thickness (feet)
34. Dolomite, very finely crystalline, yellowish-gray, thin-bedded; weathers to small blocks; in places, minute laminae apparent; somewhat brecciated; prominent ledges in valley. HS145 from upper part (Ca, 19.6 percent; Mg, 11.9 percent; molar ratio, 0.99); HS146 from below HS145 (Ca, 20.8 percent; Mg, 12.0 percent; molar ratio, 1.05)	12. 5
33. Dolomite, very fine grained, dense, gray, thin-bedded; weathers yellowish gray; weathers blocky to platy. HS434 (Ca, 25.0 percent; Mg, 10.4 percent; molar ratio, 1.45)	11. 0±
32. Shale, dolomitic (covered in lower part); yellowish gray in upper part, becoming gray downward; laminated, weathers slabby to platy. HS144	9. 0
31. Limestone (covered in lower part), finely crystalline, yellowish-gray, thin-bedded; some very fine green quartz grains; weathers blocky; in places has evaporite-solution breccia	10. 0
30. Dolomite, very finely crystalline, dense, light-gray to gray-brown; in places very argillaceous and dark; weathers platy to blocky; forms part of saddle at head of small valley. HS143 from top (Ca, 22.5 percent; Mg, 12.5 percent; molar ratio, 1.08)	39. 0
29. Dolomite, finely sandy, finely crystalline, gray-brown; many thin beds, none exceeding 1.0 ft. most are 5 in.; weathers blocky in lower part; oil stains. HS429 from middle (Ca, 22.1 percent; Mg, 12.3 percent; molar ratio, 1.09). F186 (USGS Mus. loc. 5086–SD) corals	55. 2
28. Partly covered. Thin dolomitic limestone, medium-hard; grades downward to thinly bedded dolomite in lower part. Dolomitic limestone is finely crystalline, gray-brown, and massive and weathers blocky and to small irregular plates. Dolomite is very finely crystalline and light gray and weathers platy. HS430 from top (Ca, 22.4 percent; Mg, 12.7 percent; molar ratio, 1.07)	29. 0

Jefferson Formation—Continued Lower member—Continued	Thickness (feet)
27. Dolomite, sandy, very finely crystalline, dark-gray-brown, massive, very porous, thinly cross-laminated; weathers blocky; minute laminae. HS142 (Ca. 21.6 percent; Mg, 12.73 percent; molar ratio, 1.03)	3.5
26. Dolomite, gray-brown and gray, finely crystalline, very thin bedded; grades downward to yellowish gray; silt sized in places; weathers platy; abundant minute laminae. HS431 from near top (Ca, 21.8 percent; Mg, 13.1 percent; molar ratio, 1.009)	6.0
25. Dolomite, finely crystalline, gray-brown, thin-bedded; weathers gray brown to gray; weathers blocky; very thin beds in lower part; small geodes HS432 from near top (Ca, 21.9 percent; Mg, 12.9 percent; molar ratio, 1.03). F185 (USGS Mus. loc. 5087–SD)	5.0
24. Dolomite, finely crystalline, gray-brown, thin-bedded, porous; weathers to small irregular-shaped nodules and blocks; geodes; bedding distorted, possibly penecontemporaneously with deposition; stromatoporoids. HS433 from near top (Ca, 22.3 percent; Mg, 12.5 percent; molar ratio, 1.08)	10.0
23. Dolomite, finely crystalline, gray-brown; thin beds, less than 1 ft thick; weathers blocky and porous; geodes	6.0
22. Dolomite; evaporite-solution breccia in lower 6.5 ft consisting of angular to subangular fragments, some as large as 6 in., of dolomite, dolomitic limestone, and chert; faint laminae locally apparent. Dolomite is finely crystalline, gray brown, thin bedded, and porous and weathers to irregular blocks; small geodes; fetad odor; fossil fragments. HS141 from top (Ca, 22.61 percent; Mg, 12.28 percent; molar ratio, 1.12); HS140 from middle (Ca, 22.36 percent; Mg, 12.59 percent; molar ratio, 1.08)	52.0
21. Limestone, fine-grained, medium-hard, dark-gray-brown; weathers gray; generally very thin bedded with some very thin zones; weathers platy; beds less than 3 in. thick; scattered chert nodules; 1.0-ft-thick shale bed near top; stromatoporoid zone 10.0 ft above base; organic burrows(?) in upper thin beds. F97, fragments of brachiopods in talus from upper platy beds. HS139 from platy beds (Ca, 38.6 percent; Mg, 0.51 percent; molar ratio, 45.9)	27.1
20. Limestone, dolomitic, gray, finely crystalline, thin-bedded; weathers yellowish gray; weathers blocky; black chert lentils in lower part. F98, USGS Mus. loc. 5077 and 5089–SD, from upper part; F96 from 15.0 ft above base. HS138 from base (Ca, 23.9 percent; Mg, 10.9 percent; molar ratio, 1.33)	24.3
19. Limestone, dolomitic, medium-gray, thin-bedded; weathers light gray; weathers to small irregular blocks; many small rounded calcite-lined cavities; somewhat brecciated; elongate masses of banded chert in upper part, HS136, dolomitic limestone (Ca, 24.9 percent; Mg, 10.4 percent; molar ratio, 1.45); HS137 from calcite-lined geodes. F95 from upper part	5.4
18. Limestone, dolomitic, finely crystalline, gray-brown, thin-bedded; weathers gray; upper one-third weathers into large blocks; lower two-thirds weathers into smaller irregular blocks; some chert nodules but less common than in underlying units. HS135 from 1.5 ft below top (Ca, 23.8 percent; Mg, 11.0 percent; molar ratio, 1.31)	25.0
17. Limestone, dolomitic, hard, dark-gray; weathers gray to gray brown; many thin beds, none more than 1.0 ft thick, most not more than 2 in.; many scattered chert nodules, similar to above. HS428 from 5 ft above base (Ca, 26.2 percent; Mg, 9.7 percent; molar ratio, 1.638)	10.4
16. Limestone, dolomitic, and finely crystalline dolomite, medium-gray, thin-bedded; weathers light gray to yellowish gray; weathers into irregular blocks; fractures into vertical elongate plates; upper 2.9 ft contains chert nodules that are dark gray with medium- to light-gray core; nodules appear to be more abundant in the lower part; fetid odor. HS427 from top (Ca, 29.8 percent; Mg, 6.6 percent; molar ratio, 2.739); HS60 from near top (Ca, 28.0 percent; Mg, 7.0 percent; molar ratio, 1.89); HS133 from base (Ca, 22.8 percent; Mg, 11.9 percent; molar ratio, 1.16)	20.4
15. Limestone; dolomitic in lower one-third; grades into silty dolomite. Dolomitic limestone is medium-hard, thin-bedded, and gray and weathers light gray; silty dolomite is finely crystalline. HS132 (Ca, 22.9 percent; Mg, 12.1 percent; molar ratio, 1.14)	5.0
14. Dolomite and evaporite-solution breccia, medium-gray, porous, thin-bedded; weathers light gray; weathers blocky; breccia contains angular to subangular fragments, some as large as 6 in., of sandy dolomite, dolomitic limestone, and limestone; in places grades into overlying unit; lower contact very distinct. HS134 from top (Ca, 23.8 percent; Mg, 11.3 percent; molar ratio, 1.27)	4.1–5.6
13. Dolomite, sandy, silty to very fine grained, dark-gray-brown, thin-bedded; weathers blocky; forms rounded resistant ledge. HS426 from about 5 ft below top (Ca,	

Jefferson Formation—Continued — Thickness (feet)

Lower member—Continued

21.8 percent; Mg, 12.5 percent; molar ratio, 1.05) — 27.4

12. Evaporite-solution breccia, gray; composed of unoriented angular to subangular fragments of dolomite and dolomitic limestone in a dolomite matrix; weathers light gray; very thin sandy limestone beds; darkest fragments are 5 in. by 3 in.; most are less than 1 in.; irregular upper contact: large masses of limestone locally in upper part. HS425 (Ca, 22.2 percent; Mg, 12.3 percent; molar ratio, 1.09) — 7.7
11. Dolomite with some limestone, finely crystalline, thin-bedded, gray to dark-gray; talus; weathers slabby and into irregular fragments; weathers light gray; upper 10 ft forms ledge, uppermost 1–2 ft being most resistant — 15.6

Total lower member — 420.6±–422.1±

Total Jefferson Formation — 572.1±–573.6±

Maywood Formation:

Upper member:

10. Limestone, dolomitic, finely crystalline, dark-gray, thin-bedded; light-yellowish-gray mottled beds in upper and lower parts; in units as much as 3 ft thick; weathers into irregular globular fragments. In middle part 2–3-ft-thick zone of platy silty limestone; above, beds are more massive. F94 (USGS Mus. loc. 5091–SD) from uppermost beds; F93 (USGS Mus. loc. 5091–SD) collected 86.7 above base. HS129 from upper part (Ca, 31.4 percent; Mg, 3.9 percent; molar ratio, 4.85); HS131 from bed above HS130 (Ca, 22.4 percent; Mg, 11.2 percent; molar ratio, 1.21); HS130 from lower part (Ca, 22.2 percent; Mg. 10.0 percent; molar ratio, 1.34) — 95.4
9. Limestone, dolomitic, medium-hard, very fine grained, yellowish-gray, thin-bedded; weathers platy and flaggy. HS128 (Ca, 29.6 percent; Mg, 6.5 percent; molar ratio, 2.76) — 3.6
8. Limestone, dolomitic, medium-hard, massive; gray in upper half, yellowish gray to dark gray in lower half; weathers into thin plates; lower part poorly exposed; 23.4 ft below top, evaporite-solution breccia with angular to subangular fragments, as much as 8 ft long, of limestone, dolomite, and very fine grained sandstone; beneath breccia is very fine grained thin-bedded sandstone, 1.0 ft thick, in alternating yellowish-gray and yellow layers. HS127 from upper part (Ca, 21.0 percent; Mg, 8.6 percent; molar ratio, 1.48); HS126 from lower part (Ca, 29.8 percent; Mg, 6.5 percent; molar ratio, 2.78). Upper part contains abundant fossil fragments, F92 (USGS Mus. loc. 5092–SD) — 50.0±

Total upper member — 149.0±

Lower member:

7. Claystone, noncalcareous, silty; yellowish gray in upper part, gray to olive green below; weathers to irregular fragments; grades into overlying unit. HS125 — 2.0
6. Dolomite and shale, poorly exposed in places, containing interbedded claystone, clayey, noncalcareous, olive-green to yellowish-gray, thin-bedded. Shale is dolomitic, medium hard, fine grained, and and yellowish brown; four beds about 3 in. thick. HS123 (Ca, 21.8 percent; Mg, 13.5 percent; molar ratio, 0.979); HS124 (Ca, 23.7 percent; Mg, 11.1 percent; molar ratio, 1.295) — 10.0
5. Limestone, dolomitic, and silty interbedded shale; mostly shale in lower part. Shale is light olive green; limestone is yellowish gray, and blocky, weathers gray, and locally forms ledge. HS122 — 5.5
4. Limestone, dolomitic, very fine grained, hard, yellowish-gray, very thin bedded; weathers gray, weathers blocky; conchoidal fracture; areas of pink, coarsely crystalline dolomite. HS120 (Ca, 39.3 percent; Mg, 0.19 percent; molar ratio, 12.55); HS121 (Ca, 23.9 percent; Mg, 11.1 percent; molar ratio, 1.306) — 2.0
3. Shale, partly covered, clayey, noncalcareous, olive-green, laminated to thinly laminated, iron-stained; weathers light olive green and yellowish gray — 6.2

Total lower member — 25.7

Total Maywood Formation — 174.7±

Devils Glen Dolomite:

2. Limestone, fine- to medium-crystalline, light-yellowish-gray to gray; thick bedded in lower half, thin bedded in upper half; porous in many places. HS297 from upper part (Ca, 40.0 percent; Mg, 0.32 percent; molar ratio, 75.85). F301 from 15 ft below top — 72.8
1. Dolomite with many shale partings in lower part. Dolomite is hard, very fine grained, dark gray brown, and thin to thick bedded and weathers yellowish gray and blocky. Shale is silty, finely micaceous, olive, and laminated and contains fossil fragments — 45.0

Total Devils Glen Dolomite present — 117.8

Thrust fault.

9. *Three Forks, Jefferson, and Maywood Formations exposed on southwest end of Slategoat Mountain*

[Measured by M. R. Mudge and Dale Snow]

	Thickness (feet)
Mississippian rocks.	
Three Forks Formation:	
52. Evaporite-solution breccia (contains rock fragments of Mississippian age) with angular fragments of dolomitic limestone and calcitic dolomite, finely to very finely crystalline, sandy, pale-yellowish-brown to grayish-orange, very thick bedded, heavily iron stained. HS632 (Ca, 25.6 percent; Mg, 10.2 percent; molar ratio, 1.52) from near top; HS631 (Ca, 33.2 percent; Mg, 4.4 percent; molar ratio, 4.55) from middle	265.0
51. Evaporite-solution breccia (rock fragments in upper part may be Mississippian in age) with interbedded calcite dolomite, fine- to medium-crystalline, yellowish-gray, heavily iron stained; breccia is very thick bedded; dolomite is thin bedded in units about 10 ft thick; geodes near top. HS630 from dolomite beds (Ca, 22.3 percent; Mg, 12.4 percent; molar ratio, 1.09)	219.0
50. Dolomite, calcitic, finely crystalline, pale-yellowish-brown, thin-bedded, heavily iron stained; weathers platy; evaporite-solution breccia 13–15 ft above base; *Amphipora* biostrome at top	25.0
49. Dolomite, calcitic, finely crystalline, medium-dark-yellowish-brown, thin-bedded, porous; fillings of calcite; forms small ledges. HS628 (Ca, 24.1 percent; Mg, 11.9 percent; molar ratio, 1.21) from near top. *Amphipora* bed, F410 (USGS) loc. 6573–SD), 5 ft above base, is porous, medium crystalline, and sugary appearing	40.0
48. Evaporite-solution breccia, with small angular fragments of dolomite, finely crystalline pale-yellowish-brown, very thick bedded. HS627 (Ca, 22.2 percent; Mg, 12.6 percent; molar ratio, 1.09) from upper part; HS626 (Ca, 21.7 percent; Mg, 12.4 percent; molar ratio, 1.09) from lower part	40.0
Total Three Forks Formation	589.0
Jefferson Formation:	
Birdbear Member:	
47. Dolomite, finely crystalline, pale-yellowish-brown, thinly bedded; pinch-and-swell beds; weathers nodular; upper part more thickly bedded; minute lamination. HS625 (Ca, 22.1 percent; Mg, 11.8 percent; molar ratio, 1.15) from 72 feet above base; HS624 (Ca, 21.6 percent; Mg, 12.6 percent; molar ratio, 1.03) from near base	103.0
46. Dolomite, finely crystalline, light-yellowish-brown, thin-bedded; weathers platy. HS623 (Ca, 19.5 percent; Mg, 11.7 percent; molar ratio, 1.03) from lower part	10.0
45. Dolomite, very finely crystalline, sugary-appearing, very pale orange, thin-bedded, porous; light-gray dolomitic limestone at base; weathers nodular with pinch-and-swell beds, especially in upper part; locally brecciated in lower part. *Cyrtospirifer* in upper part, F409. HS622 (Ca, 21.0 percent; Mg, 12.7 percent; molar ratio, 1.03) from upper part; HS620 (Ca, 36.9 percent; Mg, 1.5 percent; molar ratio, 1.09) from 10 ft above base	65.0
44. Dolomite with dolomitic limestone in upper part, hard, very finely crystalline, dark-yellowish-brown to very pale orange; thin pinch-and-swell beds; symmetrical ripple marks. HS619 (Ca, 33.0 percent; Mg, 4.6 percent; molar ratio, 4.37) from near top; HS618 (Ca, 21.3 percent; Mg, 12.3 percent; molar ratio, 1.03) from middle; HS617 (Ca, 12.7 percent; Mg, 7.5 percent; molar ratio, 1.03) from 9 ft above base	14.0
43. Dolomite, calcitic, medium-crystalline, sugary-appearing, light-grayish-orange, porous; one bed. HS616 (Ca, 24.2 percent; Mg, 10.9 percent; molar ratio, 1.33)	1.0
42. Dolomite, very finely crystalline, hard, light-olive-gray; thin pinch-and-swell beds; weathers platy to nodular and yellowish gray. HS615 (Ca, 20.0 percent; Mg, 11.4 percent; molar ratio, 1.09) from 5 ft above base	40.0
Total Birdbear Member	233.0
Lower member:	
41. Dolomite, very finely crystalline, pale-yellowish-brown, thin-bedded, porous; darker in lower part; very light gray bed at top; forms top of ridge spur. F408 (USGS loc. 6572–SD). HS614 (Ca, 21.9 percent; Mg 12.5 percent; molar ratio, 1.09) from top bed; HS613 (Ca, 21.7 percent; Mg, 12.5 percent; molar ratio, 1.03) from 2 ft below top; HS612 (Ca, 21.6 percent; Mg 12.3 percent; molar ratio, 1.09) from 4 ft above base	28.7
40. Dolomite, very finely crystalline, light-yellowish-gray, heavily iron stained, porous; one bed; weathers nodular; some cavities partly filled with white calcite; forms light-gray band on cliff. HS611 (Ca, 21.7 percent; Mg 12.5 percent; molar ratio, 1.09)	8.0
39. Dolomite, finely crystalline, sugary-appearing, pale-yellowish-brown, thick-bedded, minutely porous; etched surface; forms large vertical cliff; *Amphipora* biostrome in upper part. HS610 (Ca, 23.0 percent; Mg, 12.4 percent; molar ratio, 1.15) from middle	16.5

Jefferson Formation—Continued — *Thickness (feet)*

Lower member—Continued

38. Dolomite, finely crystalline, sandy-appearing, thick-bedded, porous; pale yellowish brown alternating with dark yellowish brown; minute lamination and cross-lamination; 1.0-ft-thick very light gray limestone 18 ft above base; forms ledge; *Amphipora* in uppermost bed. HS609 from top; HS608 (Ca, 29.9 percent; Mg, 0.20 percent; molar ratio, 91.02) from 18 ft above base; HS607 (Ca, 22.5 percent, Mg, 12.0 percent; molar ratio, 1.15) from 6 ft above base; HS606 (Ca, 22.0 percent; Mg, 12.3 percent; molar ratio, 1.09) from lower part ---- 28.5
37. Dolomite, fine- to medium-crystalline, sugary-appearing, very pale orange to pale-yellowish-brown, thick-bedded, porous; weathers blocky; evaporite-solution breccia; *Amphipora* in places that are lighter than matrix, HS605 (Ca, 22.0 percent; Mg, 12.0 percent; molar ratio, 1.15) from near top; HS604 (Ca, 22.2 percent; Mg, 12.3 percent; molar ratio, 1.09) from near base ---- 13.3
36. Limestone, magnesian, very fine grained, pale-yellowish-brown to dark-yellow-brown, thin-bedded; forms small ledges. F407 (USGS loc. 6571–SD) at 9.5 ft from base. HS603 from near top, HS602 (Ca, 38.0 percent; Mg, 1.0 percent; molar ratio, 23.06) from near base ---- 11.0
35. Dolomite, calcitic very finely crystalline, dense, dark-yellowish-brown, thin-bedded; minute lamination; forms ledge; scattered *Amphipora* biostromes. HS601 (Ca, 29.3 percent; Mg, 7.1 percent; molar ratio, 2.49) from near top ---- 4.5
34. Limestone, magnesian, very fine grained, dense, dark-yellowish-brown; one bed; minute lamination and some crossbeds. HS600 (Ca, 38.6 percent; Mg, 0.85 percent; molar ratio, 27.31) from middle ---- 3.1
33. Dolomite, calcitic, very finely crystalline, dark-yellowish-brown, thin-bedded; weathers blocky. HS599 (Ca, 27.2 percent; Mg, 8.1 percent; molar ratio, 2.06) from middle ---- 13.2
32. Limestone, dolomitic, very finely crystalline, dense, dark-yellowish-brown, thin-bedded; weathers blocky; forms vertical cliff with columnar joints. Fossils, F406, (USGS 8137–SD), from upper part. HS598 (Ca, 32.0 percent; Mg, 3.8 percent; molar ratio, 5.10) from top; HS597 (Ca, 36.8 percent; Mg, 1.6 percent; molar ratio, 13.96) from base ---- 22.0
31. Limestone, very finely crystalline, dense, dark-brownish-gray, thin bedded; weathers blocky and platy; many minute laminations; load casts 8–10 ft above base; upper beds form ledges; streaks of calcite; semiconchoidal fracture; minute fossil fragments. HS596 (Ca, 36.9 percent; Mg, 0.96 percent; molar ratio, 25.06) from 44 ft above base; HS595 (Ca, 38.1 percent; Mg, 0.34 percent; molar ratio, 66.75) from 5 ft above base ---- 64.5
30. Limestone, with calcitic dolomite in lower part, very finely crystalline, light-olive-gray, thin-bedded; weathers into thin irregular plates; minute breccia on some bedding planes; brecciated in lower 3 ft; forms small ledges; calcite-lined pores in lower part. HS594 (Ca, 37.3 percent; Mg, 0.54 percent; molar ratio, 42.48) from 5 ft below top; HS593 (Ca, 38.7 percent; Mg, 0.43 percent; molar ratio, 54.61) from 17 ft above base; HS592 (Ca, 27.5 percent; Mg, 7.1 percent; molar ratio, 2.36) from 5 ft above base ---- 46.0
29. Limestone, magnesian to dolomitic, very finely crystalline, olive-gray, thin-bedded; mottled very pale orange in upper part; weathers into small blocks; some thin platy beds and partings; calcite-lined pores and fractures; stromatoporoid zone 7.0 ft above base. F405 (USGS 8136–SD) collected at 18.5–21.0 ft above base. HS591 (Ca, 36.5 percent; Mg, 1.2 percent; molar ratio, 18.20) from 5 ft below top; HS590 (Ca, 32.9 percent; Mg, 4.4 percent; molar ratio, 4.55) from 10 ft above base ---- 28.5
28. Limestone, very finely crystalline, dark-yellowish-brown, thin-bedded; mottled very pale orange; minute laminations; upper part forms massive ledge; lower part locally contains evaporite-solution breccia, which weathers cavernous. HS589 (Ca, 39.2 percent; Mg, 0.34 percent; molar ratio, 69.78) from 4 ft below top ---- 10.0
27. Limestone, magnesian to dolomitic, very finely crystalline, thin-bedded, dark-yellowish-brown; mottled with yellowish gray; weathers platy; lower part contains some very dense dark-gray-brown areas; forms small ledges; fossiliferous; stromatoporoid zone, 1.5 ft thick, 44 ft above base, overlain by fossiliferous bed. F404 (USGS 8135–SD) from 34.7 ft above base; F403 (USGS 8134–SD) from 17 ft above base. HS588 (Ca, 34.1 percent; Mg, 3.7 percent; molar ratio. 5.58) from 45 ft above base; HS587 (Ca, 33.7 percent; Mg, 2.6 percent; molar ratio, 7.89) from 20 ft above base; HS586 (Ca. 36.1 percent; Mg, 0.63 percent; molar ratio, 34.59) from 5 ft above base ---- 47.8
26. Evaporite-solution breccia, finely crystalline, very pale orange; fragments of dolomitic limestone up to 6 in. across; forms indentation in cliff. HS585 (Ca, 33.3 percent; Mg, 4.4 percent; molar ratio, 4.61) from middle ---- 13.0
25. Limestone, dolomitic, finely to very finely crystalline, dark-yellowish-brown, thin-

	Thickness (feet)
Jefferson Formation—Continued	
Lower member—Continued	
bedded; weathers into irregular blocks; minute calcite-lined fractures; forms cliff. Stromatoporoids and pelecypods, F402 (USGS 8133–SD). HS584 (Ca, 34.6 percent; Mg, 3.4 percent; molar ratio, 6.07) from 3 ft below top; HS583 (Ca, 34.7 percent; Mg, 2.6 percent; molar ratio, 7.89) from 5 ft above base	12.0
24. Limestone, dolomitic, very finely crystalline, dark-yellowish-brown, thin-bedded, weathers platy. F401 (USGS 8132–SD) from near top. HS582 (Ca, 32.7 percent; Mg, 3.8 percent; molar ratio, 5.22) from 3 ft below top; HS581 (Ca, 33.0 percent; Mg, 3.5 percent; molar ratio, 5.70) from 5 ft above base	19.5
Total lower member	390.1
Total Jefferson Formation	623.1
Maywood Formation:	
Upper member:	
23. Limestone, dolomitic, very finely crystalline, dense, pale- to dark-yellowish-brown, thin-bedded; distinctively mottled very pale orange to grayish-orange; weathers flaggy with very irregular etched surfaces; forms ledge. HS580 (Ca, 34.8 percent; Mg, 1.4 percent; molar ratio, 15.17) from 5 ft below top; HS579 (Ca, 31.4 percent; Mg, 1.9 percent; molar ratio, 10.32) from 5 ft above base	21.5
22. Limestone, very finely crystalline, dense, dark-yellowish-brown, thin-bedded. HS578 (Ca, 39.1 percent; Mg, 0.43 percent; molar ratio, 54.61) from near top	5.4
21. Dolomite, calcitic, fine- to medium-crystalline, pale-yellowish-brown, thin-bedded; weathers platy; *Allanaria*. HS577 (Ca, 29.5 percent; Mg, 6.8 percent; molar ratio, 2.61) from near base	5.0
20. Limestone, dolomitic, very fine crystalline with coarse-crystalline zones, dense, pale-yellowish-brown; distinctive light-yellowish-gray to grayish-orange mottling; thin uneven beds; weathers platy. HS576 (Ca, 32.2 percent; Mg, 3.1 percent; molar ratio, 6.07) from 5 ft above base	9.5
19. Limestone, very finely crystalline, pale-yellowish-brown; in beds 1–2 ft thick; hackly fracture; calcite-lined fractures; forms massive cliff. *Allanaria* zone in lower part, F400 (USGS 8131–SD). HS575 (Ca, 37.3 percent; Mg, 0.47 percent; molar ratio, 48.54)	5.0
18. Dolomite, very fine grained, yellowish-gray; in beds 1–3 in. thick, weathers blocky with slightly rounded edges; semiconchoidal fracture; forms indentation in cliff. HS574 (Ca, 19.2 percent; Mg, 10.2 percent, molar ratio, 1.15) from middle	5.2
Maywood Formation—Continued	
Upper member—Continued	
17. Limestone with calcitic dolomite, finely crystalline, light-yellowish-brown, thin-bedded; mottled pale yellowish gray; minute lamination; breccia near top; thin-bedded mudstone in lower part. HS573 (Ca, 38.9 percent; Mg, 0.48 percent; molar ratio, 48.54) from top; HS572 (Ca, 27.6 percent; Mg, 8.2 percent; molar ratio, 2.00) from near base	16.0
16. Dolomite, finely crystalline, yellowish-gray; one bed. HS571 (Ca, 22.5 percent; Mg, 11.8 percent; molar ratio, 1.15)	2.5
Total upper member	70.1
Lower member:	
15. Mudstone, partly covered, greenish-gray; thin limestone in lower part	70.5
14. Dolomite, calcitic, very finely crystalline but coarser than underlying beds, pale-yellowish-brown, thin-bedded, porous; weathers blocky with rounded edges; forms small ledge. HS570 (Ca, 23.6 percent; Mg, 11.3 percent; molar ratio, 1.27)	13.9
13. Mudstone, dolomitic, finely sandy; alternating greenish gray and dusky red; with thin limestone lentils; evaporite-solution breccia in middle part. HS569 (Ca, 14.4 percent; Mg, 9.0 percent; molar ratio, 0.97) from near top	55.5
12. Dolomite, very finely crystalline, yellowish-gray; one bed, weathers blocky with rounded edges. HS568 (Ca, 19.4 percent; Mg, 10.5 percent; molar ratio, 1.09)	1.6
11. Mudstone, dolomitic, dark-greenish-gray; dusky-red stained areas and streaks; dusky-red bed in middle; thin limestone lenses. HS567 (Ca, 6.8 percent; Mg, 5.1 percent; molar ratio, 0.79)	10.0
10. Dolomite, very finely crystalline, dense; yellowish-gray, very thin bedded to thin-bedded; light-gray lenses; weathers platy and into small blocks; some minute laminae; forms small ledge. HS566 (Ca, 20.1 percent; Mg, 11.3 percent; molar ratio, 1.09)	7.3
9. Siltstone, mostly covered, dolomitic, light-olive. HS565 (Ca, 11.5 percent; Mg, 7.5 percent; molar ratio, 0.91)	11.0
8. Dolomite, calcitic, finely crystalline, light-grayish-orange, thin-bedded; fine laminae in places; calcite-lined cavities in upper 2 ft; forms ledge. HS564 (Ca, 24.8 percent; Mg, 9.8 percent; molar ratio, 1.46	11.5
7. Dolomite, calcitic, very finely crystalline, yellowish-gray; one bed, weathers blocky with nodular surface; forms small indentation; trilobite fragment and spinelike objects. HS563 (Ca, 20.6 percent; Mg, 9.2 percent; molar ratio, 1.33)	2.4

Maywood Formation—Continued

Lower member—Continued

	Thickness (feet)
6. Dolomite, calcitic, very finely crystalline, pale-yellowish-brown, thinly laminated, one bed; some laminae have algal appearance; weathers platy; minute low-angle crossbedding. HS 562 (Ca, 21.6 percent; Mg, 9.8 percent; Molar ratio, 1.33)	2.8
5. Dolomite, calcitic, very finely crystalline, yellowish-gray; one bed; conchoidal fracture. HS561 (Ca, 20.5 percent; Mg, 9.9 percent; molar ratio, 1.27)	1.6
4. Dolomite, calcitic, finely crystalline, very pale orange; pale-yellowish-brown lenses; one bed; crossbedded with edgewise conglomerate. HS560 (Ca, 27.7 percent; Mg, 7.8 percent; molar ratio, 2.18)	2.0
3. Siltstone, dolomitic, grayish-orange; one bed, weathers slabby	2.5
2. Shale, clayey, dolomitic, pale-olive. HS559 (Ca, 0.75 percent; Mg, 1.4 percent; molar ratio, 0.30)	1.0
1. Siltstone, dolomitic, grayish-orange, very thin bedded; weathers platy. F431 and F432 from lower part. HS558 (Ca, 11.5 percent; Mg, 6.0 percent; molar ratio, 1.15)	14.1
Total lower member	207.7
Total Maywood Formation	277.8

Devils Glen Dolomite.

10. *Uppermost beds of Three Forks Formation on north end of Sawtooth Ridge, station 57*

[Measured by R. C. Gutschick, R. L. Erickson, and M. R. Mudge]

Mississippian limestone, containing corals and crinoidal debris.

Three Forks Formation:

	Thickness (feet)
8. Claystone, noncalcareous, dusky-yellow, massive, conodont-bearing; glauconite? CH124a	0.2
7. Siltstone, noncalcareous, hard, moderate-olive-brown, blocky; iron stains on joints; *Syringothyris* in upper part. CH124b	.5
6. Shale, noncalcareous, olive-gray, papery to flaggy. CH124c	.2
5. Shale, noncalcareous, black, glossy and contorted; crumbly in upper part; slickensided fractures; yellow film (sulfur?) on fractures. CH124d, upper half, CH124e, lower half	1.3
4. Clay, noncalcareous, dark-reddish-brown, thinly laminated. CH124f	.1
3. Siltstone, dark-reddish-brown; iron nodules. CH124f	.1
2. Clay, noncalcareous, dark-reddish-brown, thinly laminated; thin streaks of gray clay at base. CH124h	.1
1. Limestone, hard, fine-grained, yellowish-gray; gray brown in lower part; one bed, weathers blocky and porous in upper part; pyrite crystals on top; pyritic nodular zones in middle; limonitic zones more abundant in upper half. CH124i in uppermost 0.3 ft; CH124j, limonite nodules; CH124k, limonite nodules; CH124l, lower limestone. Contains brachiopods, crinoid fragments, and *Leiorhynchus* sp. (R. C. Gutschick, written commun., 1962)	2.6
Total exposed Three Forks Formation	5.1

Base mostly covered. (About 12 ft of partly exposed grayish-green mudstone is present between the above limestone and the *Pugnoides*-bearing limestone below.)

11. *Madison Group in Hannan Gulch*

[Measurement begins along horse trail, near the east gate on the north side of Diversion Lake and the Sun River, on the ridge between Hannan Gulch and Wagner Basin. Measured by M. R. Mudge and M. W. Reynolds]

Castle Reef Dolomite:

Sun River Member:

	Thickness (feet)
26. Dolomite, medium to finely crystalline, light-yellowish-gray, thick-bedded; weathers light-yellowish gray in lower part to almost white in upper part; weathers blocky with pitted surfaces that show minute cross-lamination; smoky-gray chert lentils and nodules in lower part; chert nodules also abundant 100 ft above base; some have minute laminae; thin lentils of fine-grained sandstone locally in uppermost beds, upper beds badly sheared into vertical elongate blocks; some geodes in upper part, fossil fragments are alined to laminae. Silicified Meramec fauna abundant in interval 154.5–164–5 ft above base, F256–257 (USGS loc. 18006–PC, 19543–PC, 19544–PC), F256 (USGS loc. 18005–PC) 10 ft below top. HS254 (Ca, 20.8 percent; Mg, 12.4 percent; molar ratio, 1.017) 2.0 ft below top; HS252 (Ca, 22.13 percent; Mg, 12.82 percent; molar ratio 1.047) 40.0 ft above base; HS251 (Ca, 22.0 percent; Mg, 12.5 percent; molar ratio, 1.068) 20.0 ft above base	253.0
Total Sun River Member	253.0

Lower member:

	Thickness (feet)
25. Limestone, coarsely crystalline encrinite, light-gray, thin- to thick-bedded; weathers medium gray; weathers into large blocks with rounded edges. HS250 (Ca, 38.51 percent; Mg, 1.06 percent; molar ratio, 32.039) from middle part	23.7
24. Dolomite with thin interbedded limestone, gray, thin-bedded; all contacts within unit are gradational; weathers yellowish-gray; weathers into irregular blocks; two chert lentils in upper part, fossil fragments abundant in limestone beds. HS249c (top) (Ca, 33.0 percent; Mg, 4.8 percent; molar ratio, 4.171); HS249b below 249c (Ca, 23.0 per-	

Castle Reef Dolomite—Continued — *Thickness (feet)*
Lower member—Continued

cent; Mg, 11.1 percent; molar ratio, 1.257); HS249a basal bed (Ca, 23.6 percent; Mg, 10.8 percent; molar ratio, 1.326) — 4.7

23. Limestone, encrinite, mostly coarsely crystalline, light-gray, thin- to thick-bedded; grades upward to finely crystalline; weathers blocky with rounded surfaces. HS248 near top (Ca, 37.1 percent; Mg, 1.9 percent; molar ratio, 11.848); HS247 near base (Ca, 39.31 percent; Mg, 0.42 percent; molar ratio, 56.77) — 46.2

22. Limestone, dolomitic, finely crystalline, yellowish-gray, thin- to thick-bedded; weathers yellowish gray; weathers in small blocks; many thin fibrous chert bands, brachiopods and bryozoans, strike N. 20° W., dip 30° SW. HS246 near base (Ca, 32.8 percent; Mg, 1.4 percent; molar ratio, 14.316) — 31.4

21. Limestone, finely crystalline, light-yellowish-gray, thin-bedded; weathers same and darker than overlying unit; fractures into small blocks; calcite-lined geodes in upper part; grades up into encrinite, strike N. 20° W., dip 12° W — 14.8

20. Dolomite with blotches of limestone and thin limestone bed in upper part, finely crystalline, brownish-gray, thin-bedded, weathers yellowish gray; weathers into irregular blocks; calcite-lined geodes abundant; encrinite in upper part; strike N. 20° W., dip 43° W. HS245, 5 ft above base (Ca, 26.6 percent; Mg, 10.0 percent; molar ratio, 1.614) — 10.7

19. Limestone, fine-grained, medium-gray, thin-bedded; weathers gray to yellowish gray; weathers blocky; thin breccia zone in lower part with secondary calcite cement; calcite-lined geodes; locally encrinite. HS244, 5 ft above base (Ca, 38.63 percent; Mg, 0.87 percent; molar ratio, 26.92) — 6.8

18. Limestone with areas of dolomitic limestone in lower part, gray, thin- to thick-bedded; coarsely crystalline except in dolomitic areas which are finely crystalline; weathers yellowish gray; weathers blocky; chert nodules; mostly crinoidal debris, some bryozoans. Spirifer zone with *Vesiculophyllum* 34–36 ft above base. F255 (USGS loc. 18004–PC); corals (mostly silicified) abundant at about 20 ft above base, F254 (USGS loc. 18003–PC). HS243 from top bed (Ca, 38.9 percent; Mg, 0.98 percent; molar ratio, 24.086); HS242, 35 ft above base (Ca, 25.55 percent; Mg, 9.96 percent; molar ratio, 1.553); HS241b above 241a (Ca, 28.1 percent; Mg, 7.9 percent; molar ratio, 2.158); HS241a near base (Ca, 31.9 percent; Mg, 4.5 percent; molar ratio, 4.301) — 111.3

Castle Reef Dolomite—Continued — *Thickness (feet)*
Lower member—Continued

17. Limestone, dark-gray; similar to unit 16 but weathers into smaller blocks and has less chert; in beds 0.2–1.0 ft thick; weathers medium gray — 23.4

16. Limestone, coarsely crystalline, interbedded with finely crystalline limestone, medium-gray, thinly bedded; weathers blocky; many very thin chert lentils, some containing minute black bands; fetid odor. HS240 near top (Ca, 37.58 percent; Mg, 1.48 percent; molar ratio, 15.416) — 31.6

15. Limestone, encrinite, medium-crystalline, medium-hard, gray, thin-bedded; weathers light gray; many platy beds, especially in lower part; strike N .20° W., dip 34° SW — 11.1

14. Limestone, finely crystalline, medium-gray, thin- to thick-bedded; weathers blocky with semirounded edges, almost entirely an encrinite — 14.3

13. Limestone, dolomitic, finely crystalline to medium-crystalline, hard, medium-gray; thin zones of yellowish-gray dolomitic limestone alternating gradationally with dark-gray limestone; fractures into narrow vertical blocks, some with conchoidal surfaces; brachiopods and crinoidal debris in less dolomitic parts. HS239d (top) (Ca, 25.0 percent; Mg, 9.7 percent; molar ratio, 1.563); HS239c below 239d (Ca, 28.7 percent; Mg, 7.5 percent; molar ratio, 2.322); HS239b below 239c (Ca, 22.6 percent; Mg, 10.2 percent; molar ratio, 1.344); HS239a (base) (Ca, 24.7 percent; Mg, 9.4 percent; molar ratio, 1.594) — 5.8

12. Limestone, medium-hard, gray, thin- to thick-bedded; weathers light gray; weathers blocky with rounded pitted rough surfaces; milky-gray chert nodules in lower part; composed almost entirely of crinoidal debris. HS238 from near top (Ca, 39.02 percent; Mg, 0.25 percent; molar ratio, 94.26) — 32.9

11. Limestone, hard, dense, dark-gray, thin-bedded; weathers into small blocks; many chert lenses and nodules which are medium gray and dense and have smoothly rounded upper and lower surfaces; fossils very abundant in chert, less so in limestone matrix; bryozoans very abundant in some chert lenses; brachiopods; a little crinoidal debris. HS391 from middle (Ca, 39.2 percent; Mg, 0.29 percent; molar ratio, 82.020) — 18.1

10. Limestone, fine-grained, hard, dark-gray, thin- to thick-bedded; weathers gray to yellowish gray; weathers blocky; dark-gray to milky-gray chert nodules with some distinct lamination; crinoidal debris abundant, solitary corals, brachiopods. F335 (USGS loc. 19541–PC) near top. HS237 from upper part (Ca, 39.45 percent; Mg, 0.25 percent; molar

	Thickness (feet)
Castle Reef Dolomite—Continued	
Lower member—Continued	
ratio, 95.75); HS236 from middle (Ca, 40.2 percent; Mg, 2.8 percent; molar ratio, 8.495); HS235 from lower part (Ca, 38.04 percent; Mg, 0.32 percent; molar ratio, 72.057)	79.3
9. Dolomite, finely crystalline, dense, brittle gray; weathers yellowish gray; weathers with hackly fracture and into irregular blocks; forms small indentation in cliff. HS233 (Ca, 27.2 percent; Mg, 8.5 percent; molar ratio, 1.941) and HS233a (Ca, 19.48 percent; Mg, 9.15 percent; molar ratio, 1.2865)	2.1
Total lower member	468.2
Total Castle Reef Dolomite	721.2
Allan Mountain Limestone:	
Upper member:	
8. Limestone, like unit 10 but slightly darker; weathers yellowish gray and into small irregular blocks; milky-white chert in upper part; grades into overlying unit. Syringoporoid, F253 (USGS loc. 18002–PC). HS234 from upper bed (Ca, 30.60 percent; Mg, 6.04 percent; molar ratio, 3.074)	15.0
7. Limestone, hard, fine-grained, massive; weathers gray mottled with yellowish gray; surface with small secondary calcium carbonate pimples; gray chert nodules in upper part; less crinoidal debris than in unit 6; syringoporoid. HS232 from middle (Ca. 39.6 percent; Mg, 0.28 percent; molar ratio, 85.818)	23.3
6. Limestone, medium-hard, dark-gray to medium-gray, massive; weathers yellowish gray and in places gray; weathers blocky with rounded pitted rough surfaces; blue-gray chert nodules on upper surface. Encrinite, brachiopods near top, F252 (USGS loc. 18001–PC). HS231 near base (Ca, 39.24 percent; Mg, 0.25 percent; molar ratio, 95.24)	58.7
5. Limestone, medium-hard, medium-gray, thin- to thick-bedded; weathers yellow and in places gray; weathers into rounded pitted rough surfaces; few scattered fibrous chert nodules; encrinite with a few corals and brachiopods. F334 (USGS loc. 19540–PC) near middle. HS230 near top (Ca, 37.27 percent; Mg, 0.51 percent; molar ratio, 44.344)	42.7
4. Limestone, medium-hard, yellowish-gray very thick bedded; weathers with rounded pitted surfaces; fibrous chert lentil near top; strike N. 25° E., dip 37° NW. Corals abundant (*Homalophyllites*) with brachiopod fragments 11.8 ft above base, F333 (USGS loc. 19539–PC). HS390 from middle (Ca, 38.3 percent; Mg. 0.58 percent; molar ratio, 40.069)	21.5
Allan Mountain Limestone—Continued	
Upper member—Continued	
3. Limestone, hard, dark-gray; weathers light yellowish gray; like overlying unit but is in three thinner massive units, each 5–10 ft thick, platy at base; chert lentil in lower part: weathers blocky; mostly crinoidal debris, some small solitary corals. F332 near top (USGS loc. 19538–PC). HS389 near base (Ca, 36.1 percent; Mg. 0.47 percent; molar ratio, 46.60)	25.6
2. Limestone, hard, dark-gray, very thick bedded; weathers light yellowish gray; weathers blocky and to smoothly rounded surfaces; composed almost entirely of crinoidal debris, some corals; forms steep cliff, on which red pictographs have been drawn; strike N. 40° E., dip 47° NW. HS229 near upper part (Ca, 37.9 percent; Mg, 0.33 percent; molar ratio, 69.690)	22.8
Total upper member	209.6
Middle member:	
1. Limestone, with many lenses, lentils, and nodules of dark-blue-gray banded chert. Limestone is finely crystalline and dark-gray and weathers medium gray; in many thin beds not exceeding 1.5 ft Chert-bearing zones, about 1.0 ft thick, occur at horizons 0.5–1.0 ft apart; few lentils within a zone exceed 0.3 ft, most are 0.1 ft chert weathers yellowish gray, which accentuates the banding. Limestone weathers platy, is minutely pitted and some has petroliferous odor; three small caves with cemented breccia. Brachiopods, bryozoans, and small corals, F251 (USGS loc. 18000–PC). HS388 from 5 ft from top (Ca, 37.2 percent; Mg, 0.46 percent; molar ratio, 49.07); HS228 from base (Ca, 17.5 percent; Mg, 0.66 percent; molar ratio, 16.089). Base covered with talus	187.0
Total exposed middle member	187.0
Total exposed Allan Mountain Limestone	396.6

12. *Madison Group at Gibson Dam*

[Measurement begins at base of lowest exposure adjacent to center of dump on north side of the Sun River and east of spillway of Gibson Dam at bend in river. Strike N., dip 73° W. Units 7–24 measured along horse trail. Measured by M. R. Mudge, R. M. Mudge, and R. J. Mudge]

	Thickness (feet)
Top covered. Sawtooth Formation exposed only at low water mark of Gibson Reservoir.	
Castle Reef Dolomite:	
Sun River Member:	
24. Dolomite, finely crystalline, medium-gray; weathers light to medium gray; two or three beds weather to small blocks; bedding planes pitted. HS274 (Ca, 20.8 percent; Mg, 12.0 percent; molar ratio, 1.0518) near top	5.0

Castle Reef Dolomite—Continued
Sun River Member—Continued

	Thickness (feet)
23. Dolomite, very fine grained, blue-gray, thin-bedded; weathers yellowish gray; weathers platy with conchoidal fracture. HS 273 (Ca, 14.0 percent; Mg, 8.1 percent; molar ratio, 1.0488) near middle	12.0
22. Dolomite, finely crystalline, light-gray, thin- to thick-bedded; weathers light and dark gray; badly fractured; chert nodules at and near top. *Syringopora, Vesiculophyllum* at 60 ft above base, F277 (USGS loc. 19016–PC). HS272 (Ca, 22.0 percent; Mg, 12.9 percent; molar ratio, 0.0348) from middle	64.0
21. Dolomite, very fine grained, dense, hard, very light gray, thick-bedded; weathers same to yellowish gray; weathers blocky; semiconchoidal fracture; many irregular gray to gray-brown chert nodules. Silicified brachiopods and corals, F276 (USGS loc. 19015–PC). HS271 (Ca, 23.0 percent; Mg, 12.5 percent; molar ratio, 1.116) from middle	32.0
20. Dolomite, very fine grained, very light gray, thick-bedded; some medium-gray zones; weathers light gray to yellowish gray; weathers in small blocks; conchoidal fracture in dense areas. Silicified fossils, mostly brachiopods, about 5 ft above base, F275 (USGS loc. 19014–PC). HS270 (Ca, 21.1 percent; Mg, 12.3 percent; molar ratio, 1.0409) from middle	18.0
19. Dolomite, finely crystalline, hard, light-gray, thick-bedded, porous; some zones coarsely crystalline; weathers medium gray; weathers blocky and platy; abundant light-gray chert lentils and nodules, weather gray brown; gray chert beds, 6–10 in. thick, at base and in lower part. Two samples of HS269 (Ca, 22.1 percent; Mg, 12.9 percent; molar ratio, 1.0395) from middle	32.0
18. Dolomite, finely crystalline, light-gray, thick-bedded; weathers into irregular blocks. HS268 (Ca, 22.2 percent; Mg, 12.9 percent; molar ratio, 1.0442) from middle	25.5
17. Dolomite, fine, hard, medium- to light-gray, thick-bedded; some medium-crystalline zones; weathers light gray with some bands of dark gray; weathers blocky; dark-gray chert lenses; iron-stained stylolites; many fossil fragments, zones of crinoidal debris. HS267 (Ca, 24.8 percent; Mg, 10.0 percent; molar ratio, 1.5048) middle part	60.0
Total Sun River Member	248.5

Castle Reef Dolomite—Continued
Lower member:

	Thickness (feet)
16. Limestone, dolomitic, hard, medium-gray, thin- to thick-bedded; finely to medium crystalline in upper part, coarsely crystalline in lower part; weathers light gray; weathers blocky with rounded edges; in upper part, many light-gray chert lentils and lenses with some bryozoans; some lenses as thick as 8 in.; fossils from middle part, brachiopods, fish teeth and bone. F274 (USGS loc. 19013–PC). HS266 (Ca, 36.2 percent; Mg, 2.5 percent; molar ratio, 8.786) from middle	55.0
15. Dolomite, very fine grained, light-gray; fractures into elongate irregular plates at right angles to bedding; forms indentatation along outcrop; steps from dam to horse trail are in this indentation. HS265 (Ca, 38.3 percent; Mg, 1.4 percent; molar ratio, 16.600) from middle	4.0
14. Limestone, medium-hard, coarse-, medium-, and fine-crystalline zones, medium-gray, thin- to thick-bedded; some crystalline zones show graded bedding; weathers into irregular blocks; locally encrinite; solitary corals and brachiopods. HS264 Ca, 36.7 percent; Mg, 2.1 percent; molar ratio, 10.604) from middle	14.0
13. Dolomite, with some dolomitic limestone, dense, very fine grained, light-gray, thick-bedded; fractures into long thin plates at right angles to bedding; forms small indentation on horse trail; fossil fragments in dolomitic limestone. HS263 (Ca, 24.5 percent; Mg, 10.2 percent; molar ratio, 1.4575) from middle	6.0
12. Limestone, coarsely crystalline, encrinite, dark-gray, thin- to thick-bedded; weathers medium gray; fractures into long thin blocks at right angles to bedding; yellow stains on some bedding planes; corals. F273 (USGS loc. 19012–PC). HS262 (Ca, 39.0 percent; Mg, 0.66 percent; molar ratio, 35.856) from middle	35.0
11. Dolomite, with 5-ft-thick limestone interbed. Dolomite is very finely crystalline and dark gray and weathers yellowish gray and in small chips. Limestone is medium crystalline and dark gray and weathers blocky. Dolomite beds form small indentation on hillside above horse trail and near spillway. HS261 (Ca, 24.1 percent; Mg, 11.4 percent; molar ratio, 1.2828) from upper dolomite	10.0
10. Limestone, coarsely crystalline, light-gray, weathers medium gray; one bed with rounded shoulders, pitted surface; brown chert nodules; solitary corals in lower part; unit forms roof of spillway outlet.	

Castle Reef Dolomite—Continued
Lower member—Continued

	Thickness (feet)
F272 (USGS loc. 19011–PC) from upper part. HS260 (Ca, 39.2 percent; Mg, 0.66 percent; molar ratio, 36.040) from middle	80.0
9. Limestone, finely crystalline, dark-gray, thick-bedded; weathers yellowish gray; weathers blocky with rounded edges and pitted surface; irregular white chert nodules. *Homalophyllites* abundant 21 and 12 ft above base, F271 (USGS loc. 19010–PC). HS259 (Ca, 25.1 percent; Mg, 9.5 percent; molar ratio, 1.1165) from middle	27.0
8. Limestone, very dense, finely crystalline to medium-crystalline, encrinite, dark-gray, thin- to thick-bedded; weathers yellowish gray; weathers blocky and also slabby; conchoidal fracture; many medium- to light-gray chert lenses, 1–2 in. thick; forms the uppermost southern part of the abutment of the dam on south side of river. F270 (USGS loc. 19009–PC) middle part. HS258 (Ca, 28.4 percent; Mg, 6.3 percent; molar ratio, 2.735) from middle part	86.0
7. Limestone, alternating bands of coarse and finely crystalline, dark-gray, thick-bedded; weathers dark and medium gray; weathers blocky; 1–2-in.-thick lentils and nodules of light-gray chert in upper part; minute laminae with some cross-lamination; coarsely crystalline part is encrinite; brachiopods and corals, especially in encrinite. F269 (USGS loc. 19008–PC) middle. HS257 (Ca, 38.6 percent; Mg, 0.86 percent; molar ratio, 27.035) from middle	34.5
6. Limestone, medium-crystalline, medium-gray, thick-bedded; similar to underlying unit but contains less chert in lower part. HS256 (Ca, 39.3 percent; Mg, 0.35 percent; molar ratio, 68.135) about 20 ft above base	49.0
5. Limestone, medium to coarsely crystalline, medium-gray, thin- to thick-bedded; medium to dark gray; pitted rounded surface; many dark-brown chert lenses and nodules, as much as 6 in. thick; upper part contains 2-in.-thick dark-gray fibrous band resembling algal remains. F268 (USGS loc. 19007–PC) from base. HS398 (Ca, 38.7 percent; Mg, 0.35 percent; molar ratio, 67.085) from middle; HS397 (Ca, 31.3 percent; Mg, 5.6 percent; molar ratio, 3.391) from base	40.0
4. Dolomite, finely crystalline, dark- to medium-gray, thin-bedded; weathers to small yellowish-gray chips; forms small indentation in cliff. HS396 (Ca, 22.4 percent; Mg, 10.7 percent; molar ratio, 1.270) from middle	2.2
Total lower member	442.7
Total Castle Reef Dolomite	601.2

Allan Mountain Limestone:
Upper member:

	Thickness (feet)
3. Limestone, finely crystalline, dark-gray; in beds 1.5–3 ft thick; weathers to rectangular slabs; many milky-gray chert lenses and nodules, some as much as 6 in. thick; corals. HS395 (Ca, 29.5 percent; Mg, 6.3 percent; molar ratio, 2.841) from middle	19.0
2. Limestone, coarsely crystalline, encrinite, medium- to light-gray, thin- to thick-bedded; weathers into light- to medium-gray blocks with rounded edges; corals and brachiopods. F267 (USGS loc. 19006–PC) middle. HS394 (Ca, 34.5 percent; Mg, 3.0 percent; molar ratio 6.978) from upper part; HS393 (Ca, 38.0 percent; Mg, 1.1 percent; molar ratio, 20.96) from lower part	98±
1. Limestone, mostly coarsely crystalline, medium- to dark-gray, thin- to thick-bedded; weathers into irregular medium-gray blocks; many fibrous chert lentils and nodules, encrinite in coarsely crystalline parts. Corals and brachiopods in lower part, F266 (USGS loc. 19005–PC). HS392 (Ca, 38.4 percent; Mg, 0.63 percent; molar ratio, 14.655) from middle	47.0
Total upper member	164.0±
Total Allan Mountain Limestone exposed	164.0±

Base covered by dump.

13. *Ellis and Madison Groups just north of Diversion Dam in SW¼SW¼ sec. 25, T. 22 N., R. 9 W.*

[Section begins at east end of Canyon just northeast of Diversion Dam, continues west at right angles to the dip slope of the Madison, and then extends up into the northeastern part of Wagner Basin. Measured by M. R. Mudge, J. J. Halbert, and E. B. McKee III]

Ellis Group:
Swift Formation:
Sandstone member:

	Thickness (feet)
69. Sandstone, fine-grained to very fine grained, slightly calcareous, medium-gray, very thinly bedded and minutely cross-laminated, massive; weathers yellowish gray to yellowish brown; weathers platy; ripple marks abundant; forms bluff along hillside with small overhanging cliff; weathered surface has many small cavities and friable appearance; wood and some leaf fragments from top. HS38, HS163 from top	58.0

Ellis Group—Continued
Swift Formation—Continued
Sandstone member—Continued

	Thickness (feet)
68. Sandstone, with many interbedded sandy shale beds, noncalcareous, gray, heavily iron stained; weathers gray brown to brown; upper surfaces particularly are stained a distinctive metallic gray blue; beds have very irregular surfaces, which may represent ripple marks; many small nodules; small organic burrows	32.0
Total sandstone member	70.0
Shale member:	
67. Shale, silty with many siltstone lenses, slightly calcareous, dark-olive-gray to gray, very thin bedded; belemnites 11 ft above base; grades into overlying unit. F75	22.0
66. Limestone, very hard, dense, dark-gray, concretionary; weathers brown to yellowish gray; weathers blocky to nodular; fractures conchoidally	0.3–1.5
65. Shale, silty, slightly calcareous, dark-gray to olive-gray, laminated; some thin beds of siltstone	9.2
64. Sandstone, very fine grained with many sandy and silty shale partings, calcareous, yellowish-gray to olive-gray, very thinly bedded; weathers yellow to gray; weathers platy; sandy shale is gray, weathers yellowish gray. F74	5.3
63. Shale, silty with thin siltstone beds in middle, calcareous, dark-gray-brown-thin-bedded	5.6
62. Sandstone, very glauconitic, poorly indurated, dark-green, thin-bedded. HS37	.5
61. Conglomerate, poorly indurated, very glauconitic; contains subangular fragments of sandstone up to 2 in. across, iron stains. Belemnites abundant, F73 (USGS Mesozoic loc. 26298)	.5
Total shale member	43.4–44.6
Total Swift Formation	about 113.4–114.6

Unconformity
Rierdon Formation:

	Thickness (feet)
60. Limestone, argillaceous, dark-gray; weathers yellowish gray to very light gray; weathers blocky; some iron stains. F72 (USGS Mesozoic loc. 26297), *Gryphaea nebrascensis*	.6
59. Shale, silty, calcareous, with argillaceous limestone beds in middle and upper parts, dark-gray-brown, thin-bedded; beds of limestone are thin bedded and weather blocky	4.8
58. Limestone, argillaceous, dark-gray-brown; weathers yellowish gray; weathers blocky. F71 (USGS Mesozoic loc. 26296)	.7

Ellis Group—Continued
Rierdon Formation—Continued

	Thickness (feet)
57. Shale, calcareous, silty, gray-brown, thin-bedded; very calcareous bed about 4 ft above base; some fossil fragments	10.5
56. Limestone, hard, argillaceous, dark-gray; weathers yellow; weathers blocky; conchoidal fracture. F70, *Cadoceras*	0.5
55. Shale, silty, very calcareous, dark-gray-brown, thin-bedded	3.5
54. Limestone, argillaceous, dark-gray-brown; weathers yellowish gray; weathers in thin irregular-shaped blocks with a hackly fracture; sparsely fossiliferous. F69	.5
53. Shale, silty, very calcareous, dark-gray-brown, laminated to thinly laminated; thin nodular claystone 32.0 ft above base; barite nodules. *Gryphae nebrascensis* and *Cadoceras*	36.5
52. Limestone coquina, gray; composed entirely of gastropods and pelecypods; weathers yellowish gray and blocky. F68 (USGS Mesozoic loc. 26295) *Gryphaea nebrascensis*. HS162	.5
51. Claystone, silty, very calcareous, dark-gray-brown, thick-bedded; weathers gray; hackly fracture; upper part weathers shaly; barite nodules at about 3.0 ft below top; pelecypod fragments. HS161 from top bed	32.0
50. Siltstone, calcareous, dark-gray-brown; weathers yellowish gray; weathers in elongate fragments; strike N. 10° E., dip 15° W. F67 (USGS Mesozoic loc. 26294)	0.7
49. Claystone, silty, very calcareous, dark-brown; weathers gray; blocky to nodular; thin bedded at top; barite nodules in middle	5.8
48. Limestone, argillaceous, gray; weathers yellowish gray; weathers in small blocks and plates; fossiliferous; grades into underlying and overlying unit. F66 (USGS Mesozoic loc. 26293)	.6
47. Shale, silty, slightly calcareous, dark-gray-brown, very thin bedded; weathers gray	2.0
46. Limestone, argillaceous, dark-gray-brown; weathers yellowish gray; weathers nodular to blocky. F65 (USGS Mesozoic loc. 26292)	.4
45. Shale, silty, calcareous, mainly dark gray, locally olive green; iron stains in lower part; limestone concretions. F220 (USGS Mesozoic loc. 27056). HS160	5.9
44. Limestone, argillaceous, dark-gray-brown; weathers yellowish gray;	

Ellis Group—Continued
Rierdon Formation—Continued

	Thickness (feet)
weathers nodular to blocky. Pelecypods, F64 (USGS Mesozoic loc. 26290)	.9
43. Shale, same as unit 40 except for a nodular argillaceous limestone lens at base. HS159	6.1
42. Limestone, argillaceous, dark-gray-brown; weathers blocky to nodular. F63 (USGS Mesozoic loc. 26291)	.6
41. Claystone, grading up into clayey shale, calcareous, dark-gray-brown, thick-bedded; grades up into dark gray; weathers blocky; shale is laminated to thinly laminated; chitinous fossil fragments. HS158	5.5
40. Limestone, argillaceous, dark-gray-brown; weathers yellowish gray; weathers in irregular blocks; chitinous fossils; grades into overlying unit. F62 (USGS Mesozoic loc. 26289)	3.3
39. Claystone, silty, calcareous, dark-gray-brown, thick-bedded; grades up into darker gray; weathers blocky to nodular; chitinous fossils. HS157. F60 (USGS Mesozoic loc. 26287) from lower shale, 8.0 ft thick; F61 (USGS Mesozoic loc. 26288), *Gryphaea impressimarginata* from 17.0 ft above base	17.0
38. Mudstone, calcareous, dark-gray-brown, thin-bedded; weathers gray; shale in middle part grades up into mudstone. F58 (USGS Mesozoic loc. 26285), *Gryphaea impressimarginata* from lower mudstone and shale; small resistant bed forms small bench. F59 (USGS Mesozoic loc. 26286) from upper part	10.0
Total Rierdon Formation	148.9

Unconformity (?)
Sawtooth Formation:
Siltstone member:

	Thickness (feet)
37. Siltstone, calcareous, gray-brown, thin-bedded; weathers yellowish brown; weathers in small plates in lower part; blocky in upper part; forms hillside bench. F57 (USGS Mesozoic loc. 26284)	12.2
36. Shale with very thin siltstone lenses, silty, calcareous, dark-gray-brown, laminated to thinly laminated	2.7
35. Siltstone, calcareous, dark-gray-brown; weathers yellowish gray; weathers blocky; fossil fragments; organic burrows	.9

Ellis Group—Continued
Sawtooth Formation—Continued
Siltstone member—Continued

	Thickness (feet)
34. Siltstone, calcareous, dark-gray-brown, shaly to blocky; weathers yellowish gray	1.4
33. Siltstone, calcareous, gray-brown; weathers yellowish gray; weathers in irregular blocks. F56 (USGS Mesozoic loc. 26283)	1.3
32. Shale with thin siltstone layers, silty, calcareous, dark-gray-brown, thin-bedded; weathers yellowish gray; weathers platy	3.0
Total siltstone member	21.5

Shale member:

	Thickness (feet)
31. Shale, black, mostly covered; contains a very thick fossiliferous siltstone bed at top. HS164 from middle	35.5
Total shale member	35.5

Sandstone member:

	Thickness (feet)
30. Sandstone, very fine grained, slightly calcareous, very light-gray, thin-bedded; composed of well sorted clean quartz; weathers blocky and brown; very minute laminae and some crossbedding abundant at 1.0 ft from top; very fossiliferous in upper part 0.5 ft thick, 1.0 ft below top, small lenses of limestone pebble conglomerate in the upper part, limestone pebbles from Madison group; pebbles rounded to subangular, 1–2 in. across. F55 (USGS Mesozoic loc. 26282), upper part. HS36, near top	6.5
29. Shale, silty to clayey with sandstone in upper part, noncalcareous, thinly laminated, dark-gray, waterworn belemnites, pelecypods, gastropods, and echinoid spines in lower part. HS165, upper part	3.2
28. Conglomerate, unsorted pebbles and cobbles of Madison Group, brown; some chert in a matrix of fine-grained clear quartz sandstone; pebbles are well rounded to subangular; pebbles badly fractured; iron-stained, HS35	0.5–1.3
Total sandstone member	10.2–11.0
Total Sawtooth Formation	67.2–68.0
Total Ellis Group	329.5–331.5

Unconformity.

	Thickness (feet)
Madison Group:	
Castle Reef Dolomite:	
Sun River Member:	
27. Limestone, dolomitic, finely crystalline, medium-gray, thick-bedded; slightly brown tint; weathers light gray; weathers blocky and yellowish-gray; upper part porous and fractured; some fractures and bedding planes filled with very fine grained brown quartz sand of the Sawtooth Formation. HS156 from the top bed	65.0
26. Dolomite, finely crystalline, medium-gray, thick-bedded, extremely porous; pores filled with black oil residue; exposures at lake level show many encrustations of fine-grained quartz sand along bedding planes; strike N. 5° W., dip 22° W. F54	22.0
25. Dolomite, finely crystalline, light-gray, thin-bedded; weathers nearly white at top; weathers in large blocks; upper part fractures in small blocks; small scattered chert nodules. F159 (USGS loc. 17469), *Syringopora*, in the middle part	59.0
24. Dolomite, finely crystalline, light-medium-gray, thick-bedded; weathers in large blocks; minute laminae and crossbedding apparent on weathered surfaces; calcite-filled cavities; syringoporoid colonial corals and *Vesiculophyllum;* forms massive bluff	36.0
23. Dolomite, very fine crystalline to medium-crystalline, medium-gray, thick-bedded; weathers in large blocks; minute laminae apparent on weathered surfaces; in lower part dark chert lentils; in stringers, similar to but not so abundant as those in unit 3. Corals, at 46 ft, F52; syringoporoids and horn corals, F53, (USGS loc 17445). Upper half is a zone of abundant large horn corals (*Vesiculophyllum?*) and some syringoporoid colonial corals. Many small geodes filled with calcite	99.0
22. Dolomite, finely crystalline, light-gray, thick-bedded; weathers light gray; weathers blocky; banded chert in thin lenses, nodules, and lentils; porous on weathered surface; chert is dark gray and weathers in relief and gray brown	36.0
Total Sun River Member	317.0
Lower member:	
21. Limestone, very dolomitic, finely crystalline, medium-gray; weathers in small thin blocks; weathered surface contains many thin cross-laminations and involute structures; grades into underlying and overlying units. HS34	2.1
20. Limestone with interbedded slightly dolomitic limestone and dolomite, finely crystalline, light- to medium-gray, thin- to thick-bedded; medium- to light-gray bands; weathers blocky with finely crystalline irregular blocks; chert stringers; fossil fragment, brachiopods. HS33 (CaO, 29.8 percent; MgO, 20.5 percent; $CaCO_3$, 42.9 percent)	21.0
19. Limestone, with many irregular masses of finely crystalline dolomitic limestone or dolomite, coarsely crystalline, yellowish-gray; weathers blocky; fossil fragments	21.0
18. Limestone, slightly dolomitic, with interbedded dolomite; limestone coarsely crystalline, dolomite finely crystalline; limestone is thick bedded and weathers in large blocks; dolomite weathers in small irregular blocks; dark-gray chert occurs as nodules and as nodular lenses; chert is badly fractured and banded with light and dark layers; calcite-filled cavities; fossil fragments like those in unit 14	12.0
17. Limestone, coarsely crystalline, light-gray, massive; weathers in large blocks; encrinite. HS32	37.0
16. Limestone with many interbeds of dolomitic limestone. Limestone is coarsely crystalline, light gray, brown tinted, and thick bedded and weathers blocky. Dolomitic limestone (or dolomite?) is fine to medium crystalline and medium gray and characteristically fractures in narrow vertical blocks, different from the limestone; chert lenses 0.5 ft thick are common in middle part; chert is dark gray and dense. Fossil fragments, especially of crinoids, are abundant in limestone and locally in dolomitic limestone, as in unit 14. Contact between limestone and dolomite is gradational	89.0±
15. Limestone, slightly dolomitic, finely crystalline with coarsely crystalline limestone interbedded, gray to light-gray; weathers in small irregular blocks; crystalline limestone weathers to coarse sand appearance (encrinite); contains many chert lentils that have a weathered crust of tripoli; fossiliferous, especially in	

Madison Group—Continued
Castle Reef Dolomite—Continued
Lower member—Continued *Thickness (feet)*

chert lenses; fenestrate bryozoans predominant; various brachipods and pelecypods. F51 (USGS loc. 17444) ---- 45.0±

14. Limestone, dolomitic with thick limestone in upper and lower parts that is very coarsely crystalline and light gray and weathers to a sandy appearance. Dolomitic limestone is medium gray and fine to coarsely crystalline and weathers light gray; texture depends on quantity of fossils. Fossils, concentrated in zones and masses, are recrystallized and stand in relief on weathered surface. Dolomitic zones weather in irregular blocks, whereas coarsely crystalline zones exfoliate ---- 32.0

13. Limestone with alternating dolomitic limestone, very finely crystalline, light- to medium-gray; weathers light gray; massive with some thin beds (1.0± ft thick); badly fractured; contains calcite-filled pores; fossils less common than in underlying units ---- 37.0

12. Limestone, dolomitic, finely crystalline, medium-gray; weathers in thin beds and in irregular blocks; forms vertical cliff; fossils sparse; corals ---- 2.9

11. Limestone, fine- to medium-crystalline, medium-gray; dark-gray dolomite lenses, 0.6–0.8 ft thick, at base; thinner dolomite lentils are in lower 15 ft; most beds are encrinite; limestone is massive and weathers blocky; coquinas are exfoliated. F158 (USGS loc. 17468) lower part; H531 from limestone ---- 51.0

10. Limestone, finely crystalline with some coarsely crystalline, medium-gray, massive; weathers light gray; in beds about 2.0 ft thick; weathers exfoliated, in places shaly; weathered surface shows faint crossbedding; fossil fragments, especially crinoid columnals and corals ---- 19.0

9. Limestone, coarse to finely crystalline, medium-gray, massive; local zones of dark gray; mostly weathers blocky, some zones weather in thin irregular plates; lower part contains thin zones of black chert nodules. Fragments and whole specimens of brachiopods and corals (horn and colonial) abundant, F48 (USGS loc. 17442) ---- 31.0

8. Limestone, fine- to coarse-crystalline, light- to medium-gray, thick-bedded; some relatively thin beds in uppermost part; chert nodules locally throughout; black chert lenses in upper part; fossil fragments abundant, particularly of brachiopods and crinoids ---- 62.0

7. Limestone, with dolomitic limestone bed (1.5 ft thick in middle part, grades up and down into limestone), fine- to coarse-crystalline, mostly thick-bedded, partly thin-bedded; scattered chert nodules in middle; lower part has nodules of porous and dense dark-gray chert, weathering brown; forms bluff and small bench; fossil fragments abundant. Brachiopods and corals, F50 (USGS loc. 16543) at 20.0 ft from base ---- 20.0

Total lower member ---- 482.0

Total Castle Reef Dolomite ---- 709.0

Allan Mountain Limestone:
Upper member:

6. Limestone, coarsely to finely crystalline, medium-gray, thick-bedded; brown tint; weathers blocky with bedding planes locally apparent; corals 8.0 ft above base; fossil fragments include abundant crinoid columnals ---- 88.0

5. Limestone, coarsely crystalline, medium- to light-gray, thin-bedded; weathers light gray; fractures in large blocks in lower part; lentils and nodules of massive chert in zones; chert differs from underlying and overlying units in that it is more massive and lighter gray and does not contain interstitial limestone; at 2.5 ft below the top, many thin dark-gray dense chert beds. Fossil fragments and fossils are abundant in the lowest 4 ft, F49 (USGS loc. 16542) ---- 14.0

4. Limestone, coarsely crystalline, light-gray grading up into dark-gray, thin-bedded; some thin elongate nodules of black chert that weather brown and in slight relief; fossil fragments, especially crinoid columnals, are abundant and weather white; contains less well-bedded chert than overlying and underlying units; top forms ledge ---- 11.0

3. Limestone with many bands of chert with interstitial limestone, finely crystalline, medium-gray, thick-bed-

Madison Group—Continued
Allan Mountain Limestone—Continued
Upper member—Continued

	Thickness (feet)
ded; brown tint; weathers blocky; fracture in very small irregular blocks; weathered surface is rough and irregular. Chert is dark gray, hard, and brittle and occurs mainly in lenses 1–2 ft thick, each lens having about an equal amount of limestone; chert nodules. 0.2–0.5 ft thick, are scattered throughout but are most common in lower part. Chert weathers brown and in relief, whereas the limestone weathers light gray; weathered exposures of chert and limestone lenses look fibrous; a few lenses and nodules are nearly at right angles to bedding. Minute fossil fragments abundant in lower 15–20 ft; some coarse fossil debris; large fossils weather lighter than matrix. F157 (USGS loc. 17467) from upper part	90.0
2. Limestone; finely crystalline, medium-gray, thin-bedded; badly fractured and locally sheared in upper part; many elongate chert nodules and lentils are slightly darker than matrix and considerably thinner than those in overlying unit; chert weathers in slight relief; elongate nodules are parallel to beds except along fractures; minute fossil fragments abundant, including crinoid columnals, echinoid plates, and spines; fossils are lighter gray than matrix and weather medium mottled gray	12.2
1. Limestone, (fault breccia) finely crystalline, medium-gray, massive, brecciated; slight brown tint; weathers to a rounded irregular surface; extremely brittle; contact with overlying unit apparently conformable but sheared; upper part forms overhanging cliff	36.0
Total upper member	251.2
Total Allan Mountain Limestone	251.2
Total Madison Group present	1,050.2

Thrust fault in covered interval (talus of Madison). Colorado Group. Bottom unit is a 15-ft-thick fine-grained noncalcareous, light-gray to gray, thin-bedded sandstone that is badly distorted in upper part. It is bed L of the Vaughn Member of the Blackleaf Formation.

14. *Ellis Group measured near east saddle at head at Hannan Gulch*

[Measured by M. R. Mudge and M. W. Reynolds]

Morrison Formation.
Ellis Group:
Swift Formation:
Sandstone member:

	Thickness (feet)
35. Sandstone, fine-grained, well-sorted, calcareous, medium- to light-gray; clear quartz with some chert; chert more abundant in middle and lower parts; weathers yellowish-gray; minute laminae in beds 0.2–1.5 ft thick; thicker beds in lower part, most are 0.3–0.5 ft; locally crossbedded; upper beds form hillside ledge. HS210 from near middle; HS209 from near base	58.4
34. Sandstone, with thin interbedded shale, fine-grained, noncalcareous, yellowish-gray, iron-stained; blue-gray clay on some surfaces; beds very thin, pinch and swell; sandstone is rounded clear quartz with some chert fragments; organic trails and burrows; fish teeth. HS208	3.5
Total sandstone member	61.9
Shale member:	
33. Claystone, silty, noncalcareous, dark-gray, very thin bedded; blue-gray clay on surfaces; many thin siltstone lenses; some very fine grained sandstone lenses, more abundant toward the top; pinch-and-swell beds; organic trails and burrows in upper part	50.0
32. Covered; green glauconitic sandstone at base	4.2
Total shale member	54.2
Total Swift Formation	116.1
Unconformity.	
Rierdon Formation:	
31. Mudstone, very calcareous, medium-gray; *Pleuromya; Gryphaea nebrascensis* coquina about 10 ft above base. F226 from near top	93.2
30. Mudstone, very calcareous, gray; *Pleuromya*	2.4
29. Mudstone, like unit 25 below but more massive; forms ledge; *Gryphaea nebrascensis*	.9
28. Shale, like unit 25	8.0
27. Mudstone, like unit 25; forms three-tiered ridge	4.4
26. Mudstone, like unit 25 but less resistant	.4
25. Mudstone, calcareous, gray, massive; forms small ridge	.9
24. Shale, slightly calcareous, brownish-gray, thinly laminated	6.4
23. Mudstone, calcareous, grayish-brown; *Gryphaea impressimaginata*	11.4

Ellis Group—Continued
Rierdon Formation—Continued

	Thickness (feet)
22. Shale, very calcareous, light-gray; weathers platy	7.2
21. Shale, calcareous, dark-gray; hackly fracture	4.4
Total Rierdon Formation	139.6

Unconformity (?)
Sawtooth Formation:
Siltstone member:

	Thickness (feet)
20. Siltstone, vary calcareous, yellowish-gray, massive; upper part a lighter shade; each siltstone unit in this member forms small ledge	4.9
19. Shale, noncalcareous with some siltstone lentils, medium-gray, thin-bedded to thinly laminated	6.8
18. Siltstone, like unit 20 above	6.6
17. Shale, like unit 19 above	3.5
16. Siltstone, like unit 20; ammonite, F225 (USGS Mesozoic loc. 27046)	2.6
15. Shale, like unit 19	4.6
14. Siltstone, like unit 20, very fossiliferous; ammonite. F224	3.6
13. Shale, like unit 19 with siltstone lenses	6.5
12. Siltstone, like unit 20	1.3
11. Shale, noncalcareous, silty, medium-gray, thin-bedded to thinly laminated	1.0
10. Siltstone, very calcareous, yellowish-gray, iron-stained; massive in upper part, nodular in lower part; *Pleuromya, Camptonectes, Gryphaea impressimarginata*	2.3
Total siltstone member	43.7

Shale member:

	Thickness (feet)
9. Shale, clayey to silty, dark-gray; thinly laminated in lower part grading up into silty thin beds	2.6
8. Siltstone, very calcareous, yellowish-gray; hackly fracture; scattered limestone pebbles; *Camptonectes, Gryphaea impressimarginata, Pleuromya*	1.1
7. Shale, silty, calcareous, yellowish-gray, thin-bedded; many clayey noncalcareous thinly laminated lenses; calcareous nodules 5.3 ft and 1.0 ft above base; limestone pebbles; fossils in lower part. F223 (USGS Mesozoic loc. 27043)	15.2
6. Shale, clayey, noncalcareous, minutely micaceous; light gray grades down to dark gray; calcareous claystone with thin siltstone at top; hackly fracture; fossil fragments including belemnites	37.4
5. Siltstone, very calcareous, yellowish-gray; grades into very fine grained sandstone; massive in upper part, nodular in lower part; thinly cross-laminated; sandstone is a lighter shade of yellowish-gray; *Pleuromya* and wood fragments	4.7

Ellis Group—Continued
Sawtooth Formation—Continued
Shale member—Continued

	Thickness (feet)
4. Shale, silty, calcareous, medium- to dark-gray, very thin bedded; weathers yellowish gray; thin siltstone lenses in upper part; gradational with overlying unit	18.2
3. Limestone, argillaceous, hard, dense, brittle, dark-gray; weathers yellowish-gray and blocky; minute pyrite crystals	.7
2. Claystone, silty, calcareous, dark-gray; weathers light gray and blocky; 0.1-ft-thick very fine grained yellowish-gray sandstone in middle; iron stains on fractures; Gradational with overlying unit	5.1
Total shale member	85.0

Sandstone member:

	Thickness (feet)
1. Sandstone, very fine grained, well-rounded and sorted, noncalcareous hard, medium-gray, thin-bedded, finely laminated; weathers yellowish gray to pale yellowish brown; clear quartz; symmetrical ripple marks; heavily iron stained; conglomerate, 0.5 ft thick at base, composed of well-rounded to sub-angular pebbles of Mississippian limestone and chert. HS207	19.5
Total sandstone member	19.5
Total Sawtooth Formation	148.2

Unconformity.
Madison Group.

15. *Ellis Group at head of Green Timber Gulch just south of the divide with No Business Creek.*

[Measured by M. R. Mudge and M. W. Reynolds]

Morrison Formation.
Ellis Group:
Swift Formation:
Sandstone member:

	Thickness (feet)
13. Sandstone, fine-grained, calcareous, yellowish-gray, thin- to thick-bedded; mainly quartz with some chert; abundant crossbedding	55.0±
12. Sandstone with interbeds of sandy shale, fine-grained, yellowish-gray, thin-bedded; thin blue-gray clay on bedding planes; organic trails and burrows	11.0
11. Sandstone, fine-grained, dark-yellowish-brown, thin-bedded, thinly cross-laminated; flow casts; eroded ripple marks and raindrop impressions in lower part of bed. HS283	8.8
Total sandstone member	74.8±

Ellis Group—Continued

Swift Formation—Continued — *Thickness (feet)*

Shale member:

10. Shale with interbedded sandy shale, calcareous, micaceous, fine-grained, yellowish-gray, very thin bedded; bluish-gray clay on bedding planes; grades into sandyshale beds in upper 6.0 ft; organic trails and burrows. F295 (USGS Mesozoic loc. 27493) — 45.0

Total shale member — 45.0

Total Swift Formation — 119.8±

Unconformity.

Rierdon Formation:

9. Shale, like unit 8 below but contains many very calcareous zones and ammonites; *Gryphaea, Gryphaea nebrascensis, Cadoceras, Camptonectes* bryozoans(?) in upper part; *Gryphaea* very abundant in top bed. F294 (USGS Mesozoic loc. 27499), 22.5 ft below top; F292 (USGS Mesozoic loc. 27498), *Warrenoceras*, 27.5 ft below top; F293 (USGS Mesozoic loc. 27498), ammonite, 6 ft below top — 27.5
8. Shale, silty, calcareous, light-olive-gray, thin-bedded; barite nodules in lower 4 ft — 24.0
7. Siltstone, calcareous, light-olive-gray, thin-bedded; weathers gray to yellowish-gray; bentonite lens about 1.0 ft below top; *Warrenoceras* 15 ft above base; *Gryphaea impressimarginata* — 21.0
6. Shale, with argillaceous limestone beds. Shale is noncalcareous, dark gray to brownish gray, and thin bedded — 20.0
5. Claystone and shale with interbedded thin yellowish-gray dense limestone, gray; barite nodules 17.0 ft above base; *Camptonectes, Gryphaea impressimarginata;* limestone beds form small ledges — 19.0

Total Rierdon Formation — 111.5

Unconformity (?)

Sawtooth Formation:

Siltstone member:

4. Siltstone, yellowish-gray, shaly, calcareous, with many interbeds of shale; weathers nodular and platy; forms small ledges. Shale is dark gray, calcareous, and thinly laminated; 0.2-ft-thick bentonite lens about 2.0 ft above base. *Camptonectes, Pleuromya,* F291 (USGS Mesozoic loc. 27506) — 29.1

Ellis Group—Continued

Sawtooth Formation—Continued — *Thickness (feet)*

Siltstone member—Continued

3. Siltstone, calcareous, shaly, weathers nodular and platy; many well-rounded chert pebbles — .6

Total siltstone member — 29.7

Shale member:

2. Shale, calcareous, dark-gray, laminated to thinly laminated; many fine-grained limestone nodules; nodular silty limestone near top — 30.8

Total shale member — 30.8

Sandstone member:

1. Sandstone, fine-grained, moderate-yellowish-brown to light-gray; thin cross-lamination; conglomerate, lens at top consists of rounded pebbles of chert and limestone — 2.5

Total sandstone member — 2.5

Total Sawtooth Formation — 63.0

Unconformity.

Madison Group.

16. *Ellis Group measured near saddle at head of Lime Gulch, Sawtooth Ridge quadrangle*

[Measured by M. W. Reynolds]

Thickness (feet)

Ellis Group:

Swift Formation (not described):

Sandstone member — 96.7

Shale member — 22.5

Total Swift Formation — 119.2

Rierdon Formation:

27. Covered — 14.9
26. Shale, like unit 24 — 18.8
25. Shale, like unit 24, but thinly laminated; 0.2-ft-thick nodular limestone at top; weathers grayish orange — 4.8
24. Shale, calcareous, moderate-yellowish-brown; weathers yellowish gray; mainly platy; thinly laminated in upper part; 0.6-ft-thick nodular limestone at top that contains *Gryphaea* — 12.1
23. Claystone, like unit 19; 0.7-ft-thick nodular limestone at top with *Warrenoceras.* F241 (USGS Mesozoic loc. 27051) — 5.2
22. Shale, like unit 21, 0.3-ft-thick limestone at top with coquina of *Camptonectes* and gastropods. F240 (USGS Mesozoic loc. 27038) — 1.7

Ellis Group—Continued
Rierdon Formation—Continued

	Thickness (feet)
21. Shale, calcareous, brownish-gray, iron-stained; thinly laminated to platy; 0.5–0.8-ft-thick nodular limestone at top	17.4
20. Shale, like unit 18; with blocky siltstone 4.2–5 ft above base; nodular limestone 0.5 ft thick at top	7.4
19. Claystone, calcareous, brownish-gray, iron-stained; weathers light gray; mostly platy, papery in upper part; 0.8-ft-thick blocky gray limestone at top; forms small ledge	5.8
18. Shale, calcareous, brownish-gray, weathers light gray; nonswelling bentonite bed 1.5 ft above base; 0.5-ft-thick nodular limestone at top; *Gryphaea* in limestone and in shale beneath bentonite. HS215	4.3
17. Claystone, calcareous, brownish-gray	1.5
16. Shale, like unit 13; 0.8-ft-thick nodular limestone at top; weathers grayish-orange; forms ledge; *Gryphaea impressimarginata*, *Camptonectes*, rhychonellid brachiopod, fish tooth. F239	5.3
15. Shale, like unit 13 but softer in upper part; 0.8-ft-thick nodular limestone at top with *Warrenoceras;* forms ledge. F238 (USGS Mesozoic loc. 27050)	4.8
14. Shale, like unit 13 but more thinly laminated; 0.8–0.9-ft-thick nodular limestone at top	3.4
13. Shale, calcareous, dark-gray-brown, gray, platy; nodular limestone bed (3–4 in.); fragments of *Camptonectes*; forms ledge	3.0
12. Claystone, silty, like unit 10	2.2
11. Shale, like unit 9	2.6
10. Claystone, silty, calcareous, brownish-gray; weathers grayish orange; hackly fracture	7.4
9. Shale, like unit 2, but softer and more thinly laminated	2.9
8. Claystone, silty, calcareous, grayish brown; weathers grayish orange; softer in upper part	4.9
7. Shale calcareous, grayish-brown; weathers light gray; hackly fracture; *Pleuromya*	2.5
6. Shale, like unit 2	2.7
5. Siltstone, calcareous, grayish-brown; weathers light grayish brown mottled with orange; chunky fracture; forms ledge	1.4
4. Claystone, very calcareous, grayish-brown platy; weathers light gray	2.0
3. Claystone, calcareous, grayish-brown; weathers yellowish gray; platy in lower part grading up into hackly fracture in upper and middle parts; forms small ledge; *Gryphaea impressimarginata* at base	2.5
2. Shale, slightly calcareous, olive-gray; weathers medium gray; thinly laminated zone, 0.1 ft. thick, of claystone concretions at top	1.6
1. Claystone, calcareous, dark-gray, platy	.9
Total Rierdon Formation	144.0
Unconformity (?)	
Sawtooth Formation (not described):	
Siltstone member	25.1
Shale member	16.4
Sandstone member	5.0
Total Sawtooth Formation	46.5

Unconformity. Sawtooth-Madison contact is concealed in this gulch. Contact located for measurements on basis of break in slope and change in vegetation—grass and flowers are dense on the Sawtooth, scant on the Madison.

17. *Kootenai (lower part), Morrison, and Swift (sandstone member) Formations, north shore of Gibson Reservoir on the west side of Mortimer Gulch, center SW¼ sec. 4, T. 21 N., R. 9 W.*

[Most of the units measured are exposed only during low water stage of Gibson Reservoir. Measured by M. R. Mudge, J. J. Halbert, and E. B. McKee III]

	Thickness (feet)
Kootenai Formation (Sunburst sand of economic usage):	
23. Sandstone, noncalcareous, fine to very fine grained, part medium-grained, very light gray, massive; mainly quartz, feldspar, some chert; weathers yellowish gray to light gray; weathers blocky and into thin beds, especially in lower part; forms a prominent ridge. HS59 from middle part	32.1
Unconformity (?)	
Morrison Formation:	
22. Siltstone, with many interbedded fine grained sandstone lenses, as in unit 21, noncalcareous, thick-bedded; siltstone is very dark red, with some gray green and locally mottled gray green; upper few feet mainly yellowish gray; weathers blocky to shaly	27.4
21. Sandstone, very fine grained, noncalcareous, very light gray, massive; quartz, some feldspar, and fine mica; weathers yellowish gray; weathers blocky; gradational lower contact	3.1
20. Siltstone, highly sheared, noncalcareous gray-brown to yellowish-gray; mottled with very dark red and purple in middle part; red and green chert scattered in upper part; weathers blocky; thin sandstone lenses in lower part are light gray, stained yellowish gray; quartz	44.9
19. Covered, possibly faulted	42.0
18. Siltstone, sandy, noncalcareous, gray thick-bedded; weathers olive gray; weathers blocky; many wood fragments	9.0

Morrison Formation—Continued	Thickness (feet)
17. Sandstone, calcareous, very fine grained, gray, thin-bedded; mostly chert and quartz; weathers olive gray; weathers blocky; some limestone nodules	3.0
16. Siltstone, very calcareous, massive; not as resistant as unit 15; fine grained chert; olive gray with some dark-green areas in upper part; weathers blocky; shaly in lower part	9.2
15. Siltstone, very calcareous, gray, iron-stained; mottled with olive gray; weathers blocky; many minute pores	2.4
14. Siltstone, calcareous, light-olive-gray; fractures hackly; limestone nodules in middle part that are heavily iron stained; iron stains common on fracture	6.0
13. Claystone, calcareous, gray to olive-gray; weathers platy; some heavily iron stained zones; blocky siltstone at top; middle part is finely micaceous platy siltstone; minute carbonaceous material	16.7
12. Limestone; dark-gray, weathers yellowish gray; nodular and lenticular; light-olive-green siltstone in lower part	2.3–3.3
11. Siltstone, slightly calcareous, carbonaceous, olive-green with gray-brown areas; weathers blocky except in gray-brown areas, which weather shaly; small chert pebbles and fossil fragments in upper part; contains calcareous nodules in mid-part overlain by thin gray clayey shale; many small calcareous iron-stained nodules, carbonaceous	20.0
10. Sandstone, slightly calcareous, micaceous, very fine grained, light-olive-gray; weathers blocky with some thin plates; heavily iron stained; some laminae. F299, pelecypods and bone fragments	.9
9. Siltstone, noncalcareous, with thin beds of of sandstone. Siltstone is light and dark-olive-green mottled with gray. Sandstone is very fine grained, poorly indurated, and yellowish gray; contains many small siliceous nodules and weathers blocky	7.7
8. Sandstone, hard, calcareous, very fine grained, gray, massive; mostly quartz and chert; weathers yellowish gray; weathers blocky; some iron stains	1.9
7. Siltstone, noncalcareous, light-olive-green mottled with gray; slight purple tint; weathers blocky; many calcareous nodules	12.4
6. Covered	29.0
5. Sandstone, hard, calcareous, very fine grained, slightly micaceous, gray-brown, thin-bedded; mostly chert, quartz, and feldspar; weathers yellowish gray; weathers platy in upper part, blocky in lower part; some iron stains; some shaly lentils in upper part; thinly cross-laminated	7.7
4. Siltstone, calcareous, mostly gray (olive-gray in upper and lower parts); has purple tint; few scattered quartz grains; weathers blocky; many small calcareous and limonite nodules; some carbon stains and wood fragments; strike, N. 5° W.; dip, 85° W. Fossils, F87 (26299), fresh-water pelecypods	18.8
3. Limestone, very lenticular, dark-gray mottled with light-olive-green, massive; weathers gray brown with a heavily iron stained surface; weathers blocky to nodular with nodular upper surface	0.0–1.0
2. Shale, noncalcareous, dark-gray, thin-bedded; weathers gray with many siltstone lentils that are yellow and heavily iron stained; alternating dark- and light-yellowish-gray beds grade up into light-olive-green ones	29.2
Total Morrison Formation	325.7–327.7
Swift Formation:	
Sandstone member:	
1. Sandstone, noncalcareous, gray, thin-bedded, fine to very fine grained; upper part calcareous; mainly quartz and chert fragments; weathers yellowish gray; most beds are less than 1 ft thick; weathers blocky; upper and lower surfaces of beds are highly irregular and ripple marked; in places thinly laminated and thinly cross-laminated; many beds, especially in lower part, have very thin rounded clay fragments, which weather out leaving elongate voids; 6.0 ft below top are thin elongate limestone nodules that are dark gray and weather yellowish gray, lighter than the matrix; some iron stains on bedding planes and exposed surfaces; organic burrows and wood fragments locally abundant; petroleum residue; strike, N. 5° W.; dip, 65° W	60.6
Total sandstone member of Swift Formation	60.6

18. *Blackleaf (Flood Shale Member), Kootenai, and Morrison Formations exposed on west side of upper reaches of Hannan Gulch, SW¼ sec. 26 and NW¼ sec. 35, T. 23 N., R. 9 W.*

[Measured by M. R. Mudge, J. J. Halbert, and E. B. McKee III]

Blackleaf Formation:	Thickness (feet)
Flood Shale Member:	
47. Sandstone, very fine grained, noncalcareous, finely micaceous, light-gray; mostly chert, quartz, and feldspar; weathers yellowish gray with red iron stains; thin	

	Thickness (feet)
Blackleaf Formation—Continued	
Flood Shale Member—Continued	
bedded in upper part, grades downward into very thin beds; thrust faults very likely are in the upper and lower parts of this unit; forms a very prominent ridge that is distinctive from the other units in the section by its thin beds; unit "B"; correlates with unit 11, section 20	30.0
46. Sandstone, noncalcareous, very fine grained, very thin bedded; mostly quartz, chert, and feldspar; gray with greenish-gray tint; bedding planes are stained bluish gray; thin sandy shale beds; locally thin lenses of light-gray sandstone; weathers blocky to nodular; limestone concretion in lower part; correlated with units 8–10, section 20	29.0
45. Shale, with many thin sandstone lenses in middle part, noncalcareous, black, very thinbedded; grades up into overlying unit; upper part is calcareous, micaceous, minutely cross-laminated; organic burrows; upper sandstones correlate with units 1–7, section 20. F30	128.0
44. Sandstone with thin shale partings in upper and lower parts, very fine grained, crossbedded, hard, noncalcareous, very light gray; clear quartz and some chert grains; weathers yellowish gray to very light gray; heavily iron stained surface; very thin-bedded, weathers blocky. Shales are clayey, dark gray, and laminated with flow casts at top. HS50	12.6
43. Sandstone, noncalcareous, very fine grained, crossbedded, gray; many lentils of very coarse sandstone, some of granule size; mainly quartz, feldspar, and chert; many granules of claystone; very thin shale partings in lower part; weathers yellowish gray; ripple marks; unit "A". HS49	6.9
Total Flood Shale Member of Blackleaf Formation	206.5
Unconformity (?)	
Kootenai Formation:	
42. Siltstone, sandy, noncalcareous, finely micaceous, grayish-green; weather olive gray and blocky; nodules and lentils of gray silty limestone; thin very dark red lentils of siltstone in upper part	12.5
41. Sandstone, poorly indurated, fine to very fine grained, noncalcareous, light-grayish-green, very thick bedded; quartz, feldspar, some chert, and some pink and green grains with large grains of feldspar; weathers into thin plates and blocks; possibly a fault at the base	85.0

	Thickness (feet)
Kootenai Formation—Continued	
40. Sandstone, with conglomerate (up to 1.2 ft thick) at base; sandstone is very fine to medium grained, slightly micaceous, and noncalcareous, contains quartz, feldspar, and chert in almost equal quantities, and has a salt-and-pepper appearance. Upper half of unit is hard thick beds of very fine grained noncalcareous light-grayish-green sandstone that weathers olive gray and blocky. Lower half is light gray, massive, and minutely cross-laminated, weathers gray with an olive-green tint, and contains wood fragments in zones. Conglomerate is composed of mainly granules and pebbles (most are about 0.5 in. across) of chert and fragments of the underlying sandstone. Unit form hillside bench with overhanging cliff and is heavily iron stained. HS48 from upper part; HS47	81.0
Disconformity.	
39. Sandstone,, noncalcareous, poorly indurated, very fine grained to fine-grained, grayish-green, thick-bedded; quartz, feldspar, chert, and some unidentified red and green grains; weathers light olive green; weathers blocky; nodular masses, as much as 3 ft across, in upper part	39.0
38. Sandstone, noncalcareous, very fine grained, gray; quartz, chert, feldspar, and some pink and green grains; weathers to olive-gray tint; upper part has many thin beds with sandy shale partings; middle part is thinly bedded and crossbedded	24.0
37. Siltstone, with thin sandstone lens in lower part, noncalcareous, dark-olive-green, iron-stained; weathers light olive green and blocky	7.3
36. Claystone, noncalcareous, dark olive green mottled dusky red; weathers blocky; limonite nodules	3.6
35. Sandstone, fine-grained to very fine grained, thin-bedded, medium-hard, slightly calcareous, gray; mainly quartz, chert, feldspar, with scattered green, pink, and red grains; weathers light olive gray; weathers blocky, platy, and nodular; locally crossbedded; locally heavily iron-stained; forms small hillside bench. HS46	49.0
34. Siltstone, noncalcareous; very dark red with some beds of alternate green and olive gray in upper part, mostly very dark red in lower part with interbedded green; weathers blocky; limestone concretions; heavily iron stained in upper part	39.0

Kootenai Formation—Continued	Thickness (feet)
33. Sandstone grading down into siltstone, noncalcareous, very fine grained, same as unit 31 but more chert grains, light-grayish-green; yellowish gray in upper part; iron-stained calcareous sandstone nodules in middle part; weathers blocky	3.9
32. Siltstone, noncalcareous, very dark red; weathers blocky; thin light-grayish-green sandstone lentils in lower part	6.3
31. Sandstone, very fine grained, light-grayish-green, medium-hard; mostly quartz and feldspar and some green and pink grains and chert; weathers into small irregular blocks	1.6
30. Siltstone with poorly indurated sandstone lenses, noncalcareous, very dark red; sandstone, light-gray-green, similar to unit 29; thin silty shale lentils; weathers blocky to shaly; iron-stained limestone concretions	16.5
29. Sandstone, mostly poorly indurated, fine to very fine grained, similar to units 21 and 23, light-grayish-green	9.4
28. Siltstone with interbedded silty shale and sandstone in upper part, noncalcareous, very dark red; some gray-green lentils; weathers blocky to shaly; many iron-stained limestone nodules and lentils, some with calcite-filled concretions; some lentils have elongate tubular structures that may be organic	46.0
27. Sandstone, noncalcareous, mostly very fine grained, hard, micaceous, green, thin-bedded; mainly quartz, feldspar, and some chert grains; weathers grayish-green; weathers blocky and locally into very thin plates; small iron-stained limestone concretions; iron strains on weathered surfaces. HS45	25.2
Minor disconformity.	
26. Siltstone, noncalcareous, light- and dark-maroon; thin interbedded grayish-green sandstone layer in upper part; weathers into small blocks; iron-stained limestone lentils and nodules	35.0
25. Sandstone, moderately well indurated, calcareous, very fine grained, very thin bedded, same as underlying unit, light-gray with green tint; weathers into blocks; very thin lentils of dark-red- and green-mottled sandy siltstone; iron-stained limestone lenses and concretions	11.8
24. Siltstone with shale and sandstone, noncalcareous, very dark red; local areas of light red in upper part; thin light-green lenses. Sandstone is light gray with green tint, very fine grained, similar to unit 21, and thinly bedded, weathers shaly, and contains iron-stained limestone lenses and concretions	36.0

Kootenai Formation—Continued	Thickness (feet)
23. Sandstone, poorly indurated in lower part, very fine grained, noncalcareous, same as unit 31, gray weathers gray; weathers blocky; minute laminae locally apparent; locally heavily iron stained and calcareous; elongate limestone concretions. HS44	1.5
22. Siltstone, noncalcareous, very dark red; locally mottled with green; weathers blocky to shaly; iron-stained limestone lentils and nodules	1.8
21. Sandstone, poorly indurated, fine-grained, noncalcareous, gray, finely micaeous; quartz, chert, and feldspar; green and moderate-orange-pink grains; weathers gray with green tint; grades up into siltstone, which is mottled green and very dark red; locally minutely cross-laminated; iron-stained limestone concretions as much as 1 ft across. HS43	2.2
20. Siltstone with a thin green sandy shale lens in upper part, noncalcareous, thick-bedded; very dark red with green lentils; weathers blocky to shaly; iron-stained limestone nodules; thin sandstone lentils in upper part	15.1
19. Sandstone, fine-grained with some medium-size grains, noncalcareous, moderate-green, thin-bedded; mainly quartz, magnetite and feldspar with some chert; some chert grains are larger than the others; weathers grayish-green; weathers blocky; some faint crossbedding; thin elongate clay nodules in middle and lower parts; forms a small resistent ledge. HS42	32.0
18. Sandstone (Sunburst sand of economic usage), poorly indurated, noncalcareous, fine-grained, poorly sorted, gray, iron-stained; quartz, feldspar, and some larger grains of chert; weathers yellowish gray; weathers platy	4.5
17. Siltstone in upper part with thin claystone (Sunburst sand of economic usage), grading down into claystone and clayey shale, noncalcareous, gray; grayish-olive-green tint; weathers blocky in upper part and shaly in lower part; small limonite nodules; wood fragments	15.0
16. Sandstone (Sunburst sand of economic usage), noncalcareous, fine-grained with some medium grains, poorly sorted, rounded to subangular, thin-bedded; mainly quartz with a few scattered chert grains; light gray in upper part, and yellowish gray in lower part; weathers blocky; heavily iron stained; locally weathers very light gray, especially in upper part; minute laminae and cross-laminations; 4.0-ft.-thick zone in middle part is distinctly crossbedded; current	

Kootenai Formation—Continued — Thickness (feet)

direction from southwest; local mudstone nodules as much as 2 in. across; white clay nodules and cement; forms first high ridge west of Swift Formation. HS41 — 52.0±

Total Kootenai Formation — 656.2±

Unconformity (?)

Morrison Formation:

	Thickness (feet)
15. Claystone, noncalcareous, dusky, blocky	2.3
14. Claystone, noncalcareous, gray, iron-stained; weathers into small vertical blocks; forms small resistant ledge	1.5
13. Siltstone with some silty shale, poorly exposed; yellowish gray grades up into olive gray; weathers blocky	19.8
12. Sandstone, noncalcareous, fine to very fine-grained, gray; mainly quartz with some chert; weathers light gray; weathers blocky; minute cross-laminations on weathered surfaces; some iron stains	3.4
11. Siltstone and very fine grained sandstone, noncalcareous, olive-gray; weathers blocky; at 6–8 ft above base, heavily iron stained siltstone lens which is slightly calcareous and medium gray	48.2
10. Sandstone, very fine grained, noncalcareous, light-olive-gray; mostly quartz and chert with some iron-stained voids; weathers blocky; minute laminae on weathered surfaces	3.2
9. Claystone with thin-bedded siltstone, poorly exposed. Claystone is noncalcareous, gray, and heavily iron stained and weathers medium blue gray and moderate brown; siltstone is calcareous and olive-gray and weathers blocky to shaly. HS40 collected at 22.5 ft above base	31.8
8. Sandstone with limestone lentils and masses, very calcareous, very fine grained, medium-gray; limestone, very dark gray; sandstone composed of quartz, some chert, and unidentified yellow grains; finely cross-laminated	2.3
7. Mostly covered; some siltstones and shales; small limestone nodules	15.6
6. Siltstone grading up into claystone, poorly exposed, calcareous, blocky, dark olive gray mottled with dark gray	6.0±
5. Sandstone, noncalcareous, very fine grained, massive, gray; olive-gray tint; weathers blocky; fractures into elongate vertical blocks; heavily iron stained; locally crossbedded; thickens and thins within short distance	1.2–6.1
4. Siltstone, sandy, noncalcareous, olive-gray, massive; many fine-grained quartz, chert, and some red grains; weathers blocky; small lime nodules; thin limestone lentil in upper part; fossil fragments	4.2

Morrison Formation—Continued

	Thickness (feet)
3. Limestone, hard, dense, gray, massive; weathers blocky; weathered surface rough and nodular; stained brown to gray brown; grades laterally into a sandy limestone	1.6
2. Siltstone, sandy, noncalcareous; grains of chert and quartz; gray grades to olive gray in lower part; weathers blocky; many calcite nodules; thin sandstone at base; lower part covered	10.0
1. Mostly covered; some dark-olive-green siltstone and shale exposed in lower part	44.0
Total Morrison Formation	195.1±

Swift Formation (Ellis Group). Beds strike north, dip 40° W.

19. *Flood Shale Member of the Blackleaf Formation and the upper part of the Kootenai Formation exposed in a gulch just southeast of the east end of Sheep Mountain*

[Measured by M. R. Mudge and Dale Snow]

Blackleaf Formation:

Flood Shale Member:

	Thickness (feet)
45. Sandstone ("B" bed), fine-grained, finely micaceous, yellowish-gray, thin-bedded, crossbedded, heavily iron stained; conchoidal fracture; minute laminae; wood fragments. HS526 about 5 ft below top; HS525 about 3 ft above base	28.0
44. Sandstone and sandy shale, noncalcareous, mainly dark gray; blue-gray zones; heavily iron stained; wood fragments	14.5
43. Shale, noncalcareous, gray, thin-bedded; many thin fine-grained standstone lenses in upper part	17.5
42. Sandstone, very thin bedded, like unit 38; lower beds transitional to shale	5.0
41. Shale, like unit 40	25.5
40. Shale, with many sandstone lenses, silty, noncalcareous, gray, thin-bedded; sandstone is very fine grained and nodular	8.8
39. Shale, like unit 32	10.0
38. Standstone with shale partings, very fine grained, gray, very thin bedded, weathers yellowish gray; weathers platy; some cross-bedding; heavily iron-stained. HS524 from upper part	24.0
37. Shale with interbedded sandstone, very fine grained, slightly calcareous, gray, iron-stained; in beds 4–6 in. thick separated by silty noncalcareous thin bed of shale; thick sandstone bed near base (HS523); some minute cross-laminations; wood fragments	26.5
36. Shale, like unit 32	27.0
35. Sandstone, very fine grained, slightly calcareous, gray; weathers yellowish gray; one bed; weathers blocky. HS522	.6
34. Shale, like unit 32 but with fewer iron nodules; thinly bedded siltstone in middle part; some iron nodules are silicified	199.5

Blackleaf Formation—Continued
Flood Shale Member—Continued

	Thickness (feet)
33. Siltstone, calcareous, yellowish gray, iron-stained; one bed, weathers platy	1.2
32. Shale, noncalcareous, very dark gray; lower 4 ft is claystone; weathers papery and with hacky fracture; numerous iron-stained fracture planes and micaceous ironstone nodules	87.0
31. Sandstone ("A" bed), fine-grained; in beds up to 2.5 ft thick; heavily iron-stained in upper 1 ft. HS521 from middle	19.0
Total Flood Shale Member of Blackleaf Formation	494.1

Unconformity.

Kootenai Formation:

	Thickness (feet)
30. Claystone, noncalcareous, dark-gray; weathers blocky	4.8
29. Sandstone, very fine grained, finely micaceous, medium gray; in beds as much as 2.0 ft thick, most are 6–12 in., with calcareous shale partings 0.2–0.5 ft thick; minute cross-lamination; ripple marked; locally nodular; heavily iron stained; numerous wood and leaf fragments. HS520 from 3.0 ft above base. F367 (USGS Mesozoic loc. D3154) from 2.8 ft above base	45.0
28. Siltstone, calcareous, dark-gray-brown, very thick bedded; hackly fracture; grades into overlying bed	8.2
27. Shale, silty dark-gray, thin-bedded; thin limestone lenses in lower part; fossils very abundant in thin zones	15.5
26. Limestone, medium-hard, dark-gray; one bed, weathers blocky to shaly. Coquinoid F366 (USGS Mesozoic loc. D1353) (also from unit below)	4.0
25. Shale, silty, calcareous, dusky-brown, thin-bedded; zones of coquina, thickest zones at top; grades into overlying bed. F366	8.5
24. Limestone, hard, with shaly zone at base; one bed; coarsely crystalline; fossil fragments. F365	3.5
23. Limestone, finely crystalline, grayish-brown, very thick bedded; weathers blocky; composed almost entirely of minute fossil fragments. HS519	5.5
22. Shale, contorted, very calcareous, dark-gray; weathers yellowish gray; very thin bedded to nodular	.4
21. Limestone, gray-brown; weathers yellowish gray and blocky; one bed, thickens and thins; stylolites very abundant; vertebrate fragment	1.0
20. Limestone, argillaceous with very calcareous shale in upper part, dark-gray; one bed of white pelecypod and gastropod coquina. F364	1.5

Kootenai Formation—Continued

	Thickness (feet)
19. Siltstone, grades upward into poorly indurated sandstone, noncalcareous, greenish-yellow, very thick bedded; weathers blocky and into small chips; heavily iron stained at top	23.5
18. Claystone, noncalcareous, greenish-gray; mottled with purple in lower part	3.5
17. Claystone, noncalcareous, grayish-red, very thick bedded; weathers blocky	12.0
16. Claystone, noncalcareous, greenish-gray, very thick bedded; weathers blocky; sandstone lenses in upper part and lower part	28.5
15. Claystone, noncalcareous, grayish-red, very thick bedded; weathers blocky; nodular resistant zone in lower part	13.0
14. Sandstone, like unit 12, crossbedded. HS518	21.5
13. Claystone, noncalcareous, grayish-red, very thick bedded; greenish-gray lenses; weathers blocky	29.0
12. Sandstone, noncalcareous, poorly indurated, grayish-green; one bed	2.0
11. Claystone, noncalcareous, grayish-red, very thick bedded; greenish-gray lenses	33.0
10. Sandstone, poorly indurated, noncalcareous, very fine grained, finely micaceous, greenish-gray; iron stains	5.0
9. Siltstone, noncalcareous, greenish-gray; grayish-red lenses in upper and lower parts; heavily iron stained	14.0
8. Claystone, silty in lower part, noncalcareous, grayish-red, very thick bedded; weathers nodular	9.0
7. Sandstone, calcareous, poorly indurated, grayish-green, massive; heavily iron stained at top and base; iron-stained sandstone nodules. HS517	4.5
6. Claystone, noncalcareous, very thick bedded; grayish red in upper part, grayish-green in lower part; weathers blocky	10.0
5. Siltstone, noncalcareous, finely micaceous, very thick bedded	9.0
4. Claystone, noncalcareous, grayish-green; weathers light green; one bed; grades laterally into sandy shale	0.6–2.0
3. Claystone, noncalcareous, grayish-red, very thick bedded; weathers nodular	13.0
2. Siltstone, calcareous, gray, green-tinted, laminated; calcareous and siliceous nodules; grades laterally into green sandy shale with calcareous sandstone nodules	9.0
1. Claystone, badly sheared, slightly calcareous, grayish-red, very thick bedded; hackly fracture; 1.0-ft-thick gray bed near middle, nodular limestone at base; grades into overlying bed	46.0
Total measured Kootenai Formation	384.0–358.4

Fold axis.

20. *Flood Shale Member of the Blackleaf Formation, north side of irrigation canal in center NE¼NE¼ sec. 31, T. 22 N., R. 8 W., Teton County*

[Measured by M. R. Mudge, J. J. Halbert, and E. B. McKee III]

	Thickness (feet)
Blackleaf Formation:	
Flood Shale Member:	
11. Sandstone with many shale partings in lower part, fine- to very fine-grained, noncalcareous; mainly clear quartz, some chert grains; light gray in upper part; dark gray in lower part; uppermost 2.0 ft is dark gray; 2-ft-thick sandstone bed, beneath upper bed, composed of clear rounded quartz grains with a few chert grains and carbonaceous material; sandstone weathers into 0.3–1.0 ft thick beds in lower half; blue-gray staining on bedding planes; sandy shale bed near the top of unit; nodules up to 2.0 ft across locally in the upper half; plant fragments; carbon stains and worm burrows in uppermost 2.0 ft and lower part; sandstone forms a massive hillside bench with vertical cliff	22.5
10. Sandstone, very fine grained with many silty and sandy shale partings, noncalcareous, dark-gray; lenticular and nodular beds as much as 1.0 ft thick. Shale is dark gray and laminated to thinly laminated; some parts weather shaly; iron stains on exposed surfaces; worm burrows	18.0
9. Shale, sandy, micaceous noncalcareous, yellowish-gray, laminated to thinly laminated; some of lower part olive gray drab	.2
8. Shale, sandy and clayey in upper part and clayey in lower part, noncalcareous, dark-gray, laminated to thinly laminated; thin sandstone lenses and nodules; sandy parts are slightly micaceous; calcareous claystone concretions	35.4
7. Sandstone, very fine grained, calcareous, dark-gray; blue tint on broken surfaces; weathers blocky; small organic burrows(?) locally abundant	.6
6. Shale with several lenses and nodules of sandstone, clayey, noncalcareous, dark-gray to black, thinly laminated; several lenses and nodules of very fine grained sandstone, especially in the upper 6 ft	23.0
5. Limestone, silty, grading up into very fine grained sandstone, hard, dense, dark-gray; weathers to moderate brown; platy in upper part; massive in lower part with conchoidal fracture	0.3–0.7
Blackleaf Formation—Continued	
Flood Shale Member—Continued	
4. Shale, clayey, noncalcareous, dark-gray to black, thinly laminated; thin lens of claystone with some concretions which commonly are iron stained; plant fragments in lower part	9.4
3. Sandstone, very fine grained, calcareous, massive, dark-gray; weathers to brownish gray; upper part weathers platy, lower part weathers blocky; wood fragments in upper part	.2–.7
2. Shale, clayey, noncalcareous, dark-gray to black, thinly laminated; badly fractured and distorted; limestone concretions; some limestone lentils. Sandstone lenses, at 16.8 ft above base, are very fine grained, dark gray, calcareous, and 0.5 ft thick	21.3
1. Covered; base, exposed by digging, consists of black thinly laminated shale	10.0±
Total Flood Shale Member	140.9–141.8

Unconformity(?)

Kootenai Formation is olive-drab-gray and very dark red very fine grained sandstone and siltstone (not measured).

21. *Flood Shale Member of the Blackleaf Formantion on the west side of the saddle between Dry Fork and Stovepipe Creek, Patricks Basin quadrangle*

[Measured by M. R. Mudge and M. W. Reynolds]

	Thickness (feet)
Blackleaf Formation:	
Flood Shale Member (top not exposed):	
4. Sandstone with sandy shale interbeds, very fine grained, yellowish-gray; mostly quartz; two very thick beds with sandy shale between; asymmetrical ripple marks trending southeast; organic burrows very abundant on top of same beds	13.5
3. Shale, dark-gray, thinly laminated; lenses of very fine grained sandstone; a little marl; ironstone concretions; organic trails and burrows. HS331 (marl); HS332 (shale)	325.0
2. Shale, sandy, grading up into thin-bedded sandstone, gray. Sandstone beds are very fine grained to fine-grained quartz sand and black chert. Minutely crossbedded; ripple marks; brown iron-stained surface; organic trails and burrows abundant; forms prominent ledge	42.3
1. Sandstone, fine- to medium-grained, gray, thinly laminated; mostly quartz; weathers yellowish gray; asymmetrical ripple marks trending north	6.0
Total exposed Flood Shale Member	386.8

Unconformity(?)

Kootenai Formation.

22. *Taft Hill Member (lower part) of Blackleaf Formation in hillside exposure at Station 22 in SE¼SE¼ sec. 5, T. 21 N., R. 8 W., Lewis and Clark County*

[Measured by M. R. Mudge, R. M. Mudge, and R. J. Mudge]

	Thickness (feet)
Blackleaf Formation:	
Taft Hill Member (base of "D" bed):	
4. Sandstone, calcareous, fine-grained, gray; mainly chert and quartz with some feldspar; mottled with yellowish gray; thin bedded in upper part grading down into thin (0.2–0.4 ft) wavy-bedded sandstone with blue-gray streaks; upper beds thicken northward; vertical organic burrows	4.5
3. Shale, silty, noncalcareous, dark-gray, very thin bedded	12.2
2. Sandstone, very fine grained, noncalcareous, gray; weathers yellowish gray with a green tint; massive calcareous beds in upper part, which thicken and thin. *Lingula*, F134 (USGS Mesozoic loc. D1489), in lower part	2.9
1. Claystone, grading up into sandstone, silty, noncalcareous, dark-gray; weathers shaly	26.0
Total exposed Taft Hill Member	45.6
Flood Shale Member.	

23. *Taft Hill Member of the Blackleaf Formation in the north bank of the Sun River in the center of the N½NE¼ sec. 36, T. 22 N., R. 9 W.*

[Measured by M. R. Mudge, J. J. Halbert, and E. B. McKee III]

	Thickness (feet)
Blackleaf Formation:	
Taft Hill Member:	
40. Sandstone, noncalcareous, fine-grained, gray, very thin bedded; chert, quartz, and feldspar; weathers yellowish gray; weathers platy; some crossbedding; carbon stains; wood fragments. F13 (USGS Mesozoic loc. D1145) (unit J)	4.9
39. Shale, sandy, poorly indurated, noncalcareous, fine-grained, yellowish-gray, laminated; locally grading up into carbonaceous shale with thin lentils of coal, none exceeding 0.1 ft (unit J)	1.0
38. Sandstone, fine-grained, glauconitic, calcareous; some chert; thin bedded in lower part, very thin bedded in upper two-thirds; weathers platy; small wood fragments (unit J)	4.7
37. Sandstone, fine-grained, slightly calcareous, gray; many chert grains; weathers gray with grayish-green tint; very thin bedded with thin shale beds in upper part; densely fractured with some distortion; spheroidal weathering; some carbon stains; in eastern part of exposure there is thin 1.2-ft-thick sandstone bed in middle of this unit which is gray, dense, hard, fine grained, iron stained, slightly calcareous, and fossiliferous. F12, (USGS Mesozoic loc. D1144, unit J)	14.5
36. Shale, clayey, noncalcareous, dark-gray, thin-bedded; two thinly bedded sandstones in upper and lower parts	6.7
35. Sandstones, hard, calcareous, fine to very fine grained, iron-stained; blocky in the lower two-thirds, platy in the upper part. Fossils abundant in the lower 1–2 in., F11 (USGS Mesozoic loc. D1143)	1.2–2.0
34. Shale, silty, noncalcareous, gray, laminated; thin sandstone lens in upper and lower part; sandstone is fine grained and glauconitic	6.5
33. Sandstone with much shale. Sandstone is very fine grained, yellowish gray and very thin bedded, weathers platy, and many fractures trending N. 75° E. Shale is dark gray, weathers in irregular-shaped blocks, and has carbon stains and wood fragments. Sandstone forms a small ledge (unit H)	18.8
32. Shale with thin sandstone lenses, calcareous, sandy, dark gray, laminated; calcite-filled fractures extend diagonally across beds at point of measurement	7.5
31. Sandstone, very fine grained, light-gray, very thin bedded, iron-stained; weathers platy; shale parting in the middle; some very minute laminations and cross-bedding; wood fragments and worm burrows	1.8
30. Claystone, noncalcareous, gray to olive-gray	3.0
29. Bentonite, yellowish-gray	.1
28. Shale, badly fractured, silty, noncalcareous, dark-gray, laminated; fractures hackly; grades into splintered mudstone; a thin resistant siltstone about 13 ft above base	14.9
27. Bentonite, gray to light-yellowish-gray, iron-stained	.4
26. Mudstone, noncalcareous, dark gray; badly fractured in elongate slivers; structureless	4.6
25. Sandstone, very fine grained, light-gray; weathers yellowish gray in the upper and lowermost beds; generally massive, but middle beds are very thin and weather platy; shale partings; massive parts show fine laminae and crossbedding throughout, especially in middle part; forms prominent bluff with many overhanging ledges; sandstone differs from underlying sandstone (unit 23) by massive bedding and lack of shale. Many fossils, F10 (USGS Mesozoic loc. D1142, unit F)	7.5
24. Shale with thin sandstone lenses, noncalcareous; shale alternately light gray silty and dark gray clayey	4±

Blackleaf Formation—Continued
Taft Hill Member—Continued

	Thickness (feet)
23. Sandstone, very fine grained, gray, very thin bedded and minutely crossbedded; weathers in very thin plates	1.3
22. Shale, noncalcareous, dark-gray, laminated to thinly laminated; zone, 0.8 ft thick, of many thin 0.1–0.2 ft lenses of very fine grained sandstone to siltstone 7.6 ft above base; laminated beds are crossbedded; local carbon stains in shale beds; limestone concretions; some iron stains; F9 (USGS Mesozoic loc. D1142) collected about 3 ft below top	11.2
21. Sandstone with shale partings, fine to very fine grained, medium gray, very thin bedded, finely micaceous; some black chert grains; weathers shaly to platy; lowermost bed 0.2–1.0 ft thick; locally massive and dense; surfaces heavily ironed stained; uppermost sandstone is 1.4 ft thick with some very thin beds; some crossbedding; coquina is 0.3 ft below base of uppermost bed. F8 (USGS Mesozoic loc. D1141); F6 (USGS Mesozoic loc. D1140) from basal bed; F7 (USGS Mesozoic loc. D1141) collected 8.3 ft above base unit D)	17.3
20. Shale with many thin sandstone lenses. Shale is silty, noncalcareous, dark gray. Sandstone is very fine grained, gray, tinted olive gray, and minutely crossbedded, tends to weather platy with iron-stained surfaces, contains minute worm burrows. Both sandstone and shale are finely micaceous; wood fragments	7.3
19. Claystone with siltstone lenses, noncalcareous, dark-gray; weathers hackly; siltstone weathers platy; uppermost siltstone contains minute worm burrows	5.0
18. Sandstone, very fine grained, gray, massive; weathers blocky	.6
17. Shale, same as unit 13	2.2
16. Bentonite and bentonitic clay	.3
15. Shale, same as unit 13	2.6
14. Bentonite, light-yellowish-gray	.2
13. Shale, sandy, very fine grained, noncalcareous, dark-gray, structureless; fractures hackly	4.2
12. Bentonite, silty, yellowish-gray	.1
11. Shale, noncalcareous, silty, gray, laminated; fragments of *Inoceramus* at 2.2 ft from base	4.4
10. Shale, locally nodular, silty, noncalcareous, dark-gray, blocky, badly fractured; slightly calcareous upsection. Pelecypod fragments rare, F5 (USGS Mesozoic loc. D1139)	1.1
9. Bentonite, clayey, light-gray; weathers yellowish gray because of limonite staining	.1
8. Shale, noncalcareous, silty, dark-gray, laminated, badly fractured; some small ironstone concretions. At 2.4 ft above base, fossil zone 0.5 ft thick, F4 (USGS Mesozoic loc. D1139)	29.9
7. Sandstone, fine to very fine grained, noncalcareous, gray; very thin bedded in lower half; shale lentil in middle part; massive sandstone in upper half; heavily iron stained; upper part weathers in elongate blocks (unit B)	3.3
6. Shale, clayey, noncalcareous, dark gray, thinly laminated	.5
5. Sandstone, fine to very fine grained, yellowish-gray to light-gray, noncalcareous; weathers same; many thin beds; none exceeding 8 in. in thickness, most are 3–5 in.; beds are separated by sandy shale partings, most are heavily carbon stained; sandstone forms cliff with thin beds, weathering somewhat rounded; sandstone composed mainly of quartz, glauconite, and some red specks; some fine crossbedding (unit B)	7.2
4. Sandstone, poorly indurated, fine-grained; thin lenses gray to olive gray; wood fragments (unit B)	3.8
3. Shale, slightly carbonaceous, sandy, noncalcareous, dark-olive-gray, laminated to thinly laminated	3.3
2. Sandstone with shale parting at base and middle, fine to very fine grained, massive noncalcareous; smoky quartz grains; weathers in small irregular shaped blocks and plates; upper part weathers platy; wood fragments	1.6
1. Sandstone, fine grained to very fine grained, slightly glauconitic, noncalcareous, gray, massive; gray-green tint; weathers yellowish gray; vertical fractures very abundant; iron stains abundant along fractures; sandstone weathers in small elongate blocks due to fracturing; argillaceous zone in middle part; forms cliff	6.5
Total exposed Taft Hill Member	207.5–208.3

Base of section, water level of the Sun River.

24. *Vaughn Member of the Blackleaf Formation in east streambank along the Sun River in the center of the N½NE¼ sec. 36, T. 22 N., R. 9 W.*

[Measured by M. R. Mudge, J. J. Halbert, and E. B. McKee III]

	Thickness (feet)
Blackleaf Formation:	
Vaughn Member:	
Top covered	
56. Mudstone, green to gray-green; hackly	10.0±
55. Sandstone, unit L, arkosic, poorly indurated, fine-grained, noncalcareous, gray, thin-bedded, medium-hard; rounded chert and quartz grains; weathers yellowish gray; weathers in small blocks and spalls in small plates. (The description of this unit is continued from an exposure in a roadcut about 100 yards South of point measured.) Sandstone medium-hard to soft, light-gray; fine-grained quartz with some chert and feldspar; weathers yellowish gray; upper 1–2 ft heavily iron-stained; nodular upper surface that weathers blocky; below it for the next 8 ft is a relatively soft poorly indurated sandstone that is thin bedded, extremely crossbedded, and locally nodular; lower 2–3 ft composed of medium hard sandstone; weathers blocky; wood fragments. The upper and lower massive units are calcareous	13.0±
54. Shale with thin sandstone lenses in upper part, sandy, noncalcareous, very fine grained, gray, thin-bedded; weathers light gray	2.3
53. Claystone, noncalcareous, dark-gray, massive; weathers gray with light-olive-green tint; fractures into irregular-shaped blocks in lower part and into splinters in upper part; surfaces iron stained; forms small overhanging ledge	2.0
52. Shale, bentonitic, clayey, noncalcareous, laminated; lower half light gray grading up into dark gray; wood fragments in upper part	3.0
51. Siltstone grading up into claystone, noncalcareous, dark-gray; upper part fractured hackly, lower part fractures into small blocks; coal fragments common	3.5
50. Claystone, dense, hard, noncalcareous, dark-gray, nodular; wood fragments in lower part; grades into overlying unit	.5
49. Shale, very carbonaceous, dark-gray, laminated; carbon-stained wood fragments very abundant	.7
48. Bentonite, white, iron-stained	.5
47. Siltstone, noncalcareous; light yellowish gray grading up into dark gray; weathers blocky	1.5
46. Sandstone, very fine grained, noncalcareous, gray; composed mainly of quartz, feldspar and chert; well-rounded; hard, grading up into medium hard to soft; weathers light olive gray; lower part massive; weathers blocky in upper part and hackly; badly fractured	2.5
45. Claystone with 0.5-ft-thick shale in middle part, noncalcareous, dark-olive-gray to gray; upper 2.5 ft very resistant and forms small overhanging ledge	7.0
44. Sandstone with 0.4 ft claystone in lower part, noncalcareous, gray, massive; fine to very fine grained quartz, feldspar and chert; weathers gray with olive-gray tint; weathers blocky	1.9
43. Shale, sandy with thin sandstone lens and nodules in middle part, noncalcareous, light-gray; weathers yellowish gray	1.7
42. Sandstone with thin sandy shale interbedded, medium-hard, noncalcareous, gray; fine- to medium-grained rounded to subangular quartz, feldspar, and chert; small clay-ball granules; weathers yellowish gray; spalling on weathered surfaces. Sandstone beds are arkosic, lenticular and massive, weather blocky, and grade up into overlying unit	2.0
41. Claystone, noncalcareous, dark-gray, massive; fractures into elongate splinters	2.5
40. Shale with thin bentonite lens at base, carboniferous, slightly petroliferous laminated; yellowish gray in lower part becoming dark yellowish gray in upper part part	.5
39. Claystone, hard, noncalcareous, dark-gray, massive, lenticular; weathers light olive gray; weathers blocky	.8
38. Shale, silty, noncalcareous, dark-gray, laminated; carbon-stained wood fragments abundant	3.0
37. Sandstone, very fine grained, noncalcareous, gray, massive; chert grains not common; weathers yellowish gray with olive-gray tint; fractures hackly; iron specks and limonite stains common	.8±
36. Shale, sandy, gray, laminated	3.0
35. Siltstone to very fine grained sandstone, noncalcareous, hard, dark-grayish-green; weathers light yellowish gray; fractures hackly	2.5
34. Shale, yellowish-gray, laminated; thin olive-gray claystone in middle part	2.0
33. Bentonitic clay, yellowish-gray	.2
32. Claystone, noncalcareous, olive-gray; fractures hackly	1.2
31. Shale, with thin claystone lentil in middle, silty, noncalcareous, medium-gray, thin-bedded; olive-gray tint	5.0
30. Claystone, noncalcareous, grayish-green; fractured hackly	1.5

Blackleaf Formation—Continued Vaughn Member—Continued	Thickness (feet)
29. Bentonitic clay, light-yellowish-gray	.1
28. Shale, noncalcareous, dark-gray; fractures in very small splinters	2.5
27. Shale with thin siltstone at top, sandy, noncalcareous, light-grayish-green, laminated	.8
26. Siltstone to very fine grained sandstone, noncalcareous, gray, blocky; fractures in elongate splinters	2.5
25. Sandstone, arkosic, fine- to coarse-grained, rounded to subangular, gray, massive, lenticular; poorly sorted quartz, chert and glauconite(?); some rounded clay-balls 0.2 ft in diameter; olive-gray tint; weathers blocky; forms small overhanging ledge	4.7
24. Claystone, noncalcareous, dark-gray; weathers in blocks and fractures in elongate splinters and blocks; some iron-stained lenses	3.2
23. Bentonite and bentonitic clay, light-yellow-gray	.2
22. Shale, sandy to silty, slightly micaceous, noncalcareous, yellowish-gray; grayish-green siltstone in lower part and dark-gray claystone lentils at top	7.9
21. Siltstone, noncalcareous, light-grayish-green; blocky; calcite-filled fractures	1.5
20. Shale, bentonitic, light-gray	.2
19. Shale, noncalcareous, gray, laminated, carbon-stained, badly fractured	.8
18. Sandstone, soft, grading into siltstone, very fine grained, gray, massive; green tint; carbon-stained wood fragments	1.6
17. Shale, silty, yellowish-gray, very thin bedded, carbon-stained; rare wood fragments	2.2
16. Claystone, with thin shale partings and siltstone lentils, gray; weathers light gray to olive gray; claystone fractures into elongate splinters; siltstone fractures into small plates and blocks	10.6
15. Sandstone (unit J), arkosic, poorly indurated, fine to very fine grained, noncalcareous, massive; white smoky quartz, some chert; weathers blocky with smooth rounded edges and in a slope similar to shale	4.5
14. Siltstone with lenses of sandstone. Siltstone is noncalcareous and gray to dark gray, weathers gray to olive gray, and is highly fractured into elongate splinters. At 11.0 ft above base is conglomeratic sandstone lentil composed of rounded granules of gray and olive-gray claystone that do not exceed 0.5 in. in diameter. Sandstone is very lenticular, fine grained, massive, and carbon stained, contains mainly quartz with some chert, is more resistant than siltstone, and forms small ledges; wood fragments are common. Uppermost bed (4.0 ft±) is composed of siltstone and claystone that is very dense, hard, and more resistant to weathering than the other beds. (Section continued southeast of two small normal faults and a small fold.)	37.7
13. Shale with many interbedded sandstone lenses. Shale is noncalcareous, dark-gray and very thin bedded and grades up into claystone; claystone and shale badly fractured. Sandstone is very lenticular, fine-grained quartz and chert and gray, weathers brown, and lenses out toward north end of exposure; uppermost sandstone bed is glauconitic and about 2 ft thick, and wedges out toward the north	9.7±
12. Claystone grades into shale at very top, noncalcareous, dark-gray; fractures into elongate splinters; contains two very fine-grained sandstone lentils	2.2
11. Shale, silty, noncalcareous, gray, very thin bedded; grades up into dark gray	6.9
10. Sandstone, medium- to coarse-grained, noncalcareous, gray, massive; composed mainly of rounded subangular fragments of quartz and chert; conglomeratic in lower 0.5 ft with pebbles of gray-green shale and sandstone that have a maximum diameter of 3 in.; fragments of wood, some of which have been transformed into coal; shale lentils in conglomerate; fragments of bone(?); pebbles of claystone scattered throughout; weathers blocky; calcite-filled fractures (unit I)	2.8
9. Siltstone, conglomeratic, noncalcareous, dark-gray; weathers blocky; contains rounded fragments of light-grayish-green mudstone that do not exceed 0.2 ft in diameter	.8
8. Shale, clayey, noncalcareous, light-olive-gray, laminated; weathers to small blocks	1.9
7. Claystone, noncalcareous, dark-gray; some bright red streaks (heulandite?) in lower part	1.0
6. Shale, clayey, noncalcareous, olive-gray, very thin-bedded; grades up into dark gray; blocky in upper part	2.3
5. Sandstone, very fine grained, noncalcareous, gray; weathers gray with an olive-gray tint	0.7
4. Claystone, noncalcareous, gray, iron-stained; weathers blocky	1.8
3. Bentonite, light-gray	.4

Blackleaf Formation—Continued
Vaughn Member—Continued

	Thickness (feet)
2. Shale, silty, noncalcareous, very dark gray to black; 0.2-ft-thick yellowish-gray silty shale bed at 2.2 ft above base; weathers to thin laminae	3.0
1. Claystone, noncalcareous, dark-gray; weathers light gray; fractures hackly	4.0
Total exposed Vaughn Member	193.6

Top of Taft Hill Member.

25. *Parts of Vaughn and Taft Hill Members of the Blackleaf Formation, south side of irrigation ditch in the SW¼ SW¼ sec. 31, T. 22 N., R. 8 W.*

[Measured by M. R. Mudge, J. J. Halbert, and E. B. McKee III]

Blackleaf Formation:
Vaughn Member:

	Thickness (feet)
80. Shale, sandy with thin sandstone lenses, very fine grained, noncalcareous. Sandstone is similar to that in unit 79. Shale is thin bedded and ranges from gray near base to grayish green in upper part; lower part is bentonitic; upper contact covered	4.0±
79. Sandstone, fine to very fine grained, noncalcareous, gray, massive; quartz, chert, and phlogopite(?); weathers gray brown; weathers blocky; some thin laminae	1.1
78. Siltstone with silty shale partings, noncalcareous, hard, dark-gray, massive; weathers blocky. Leaf and wood fragments, F32	1.9
77. Siltstone, sandy, noncalcareous, gray to dark-gray, thin-bedded; bentonite stringer at top; carbonaceous in lower part	2.6
76. Claystone, hard, resistant, brittle, somewhat silty, noncalcareous, dark-gray, massive, iron-stained; weathers blocky; conchoidal fracture; some thin silty shale lentils	1.7
75. Shale, with many sandstone beds, sandy, yellowish-gray, noncalcareous, very fine grained. Sandstone is gray and iron-stained and weathers blocky and fractures hackly; thickest bed at base	4.8
74. Shale, sandy. Beds of poorly indurated noncalcareous fine-grained sandstone; argillaceous in upper part; sandstone lentils in middle part. Lentils of very carbonaceous shale and coaly shale in lower part	3.3
73. Sandstone, fine to very fine grained, noncalcareous, gray, massive; mainly quartz, some chert; weathers grayish brown; many very thin laminations; weathers blocky; many wood fragments	.7
72. Shale, silty, noncalcareous, light-gray to yellowish-gray grading up into dark-gray-brown, laminated; very carbonaceous at the top	1.5

Blackleaf Formation—Continued
Vaughn Member—Continued

	Thickness (feet)
71. Bentonite, light-gray	.4
70. Shale, sandy; thin siltstone beds in upper and middle parts. Upper siltstone is dark gray, blocky; wood fragments. Shale and lower siltstone are yellowish gray and very thin bedded	2.2
69. Sandstone, very fine grained, noncalcareous, dark-gray, massive; weathers gray; weathers blocky; poorly indurated at base	2.0
68. Bentonitic shale with stringers of siltstone, noncalcareous, dark-gray	.9
67. Siltstone, noncalcareous, dark-gray, massive; weathers shaly to blocky; more resistant in lower part; some wood fragments	3.8
66. Bentonitic shale, light-grayish-green, thin-bentonite content decreases downward	2.9
65. Bentonite, light-gray, thin-bedded	.8
64. Shale, silty, noncalcareous, dark-grayish-green to green, thin-bedded	2.2
63. Claystone, hard, noncalcareous, dark-gray to dark-gray-green; weathers to small blocks; wood fragments	3.6
62. Bentonite with bentonitic shale at top, yellowish-gray	.7
61. Bentonitic shale, yellowish-gray; 0.2-ft-thick lentil of siltstone in upper part	1.3
60. Claystone, hard, dark-gray, massive, weathers blocky, and light gray	.9
59. Shale, sandy, with sandstone lentils, noncalcareous, yellowish-gray, very thin bedded; thin bentonitic shale in upper and middle parts	1.9
58. Bentonitic shale, noncalcareous, medium-gray, thin-bedded	.7
57. Bentonite, light-gray, thin-bedded	.6
56. Claystone, noncalcareous, dark-grayish-green; weathers blocky; iron-stained fractures	2.8
55. Shale, silty, bentonitic, noncalcareous, light-gray, very thin bedded	1.0
54. Claystone, noncalcareous, hard, dark-grayish-green; weathers to small irregular blocks	1.2
53. Shale, slightly bentonitic, silty, noncalcareous, light-gray, thin-bedded	1.0
52. Siltstone, hard, brittle, noncalcareous, dark-grayish-green mottled with gray, massive; many shaly zones; hackly fracture; upper part very fine grained and micaceous and contains green grains; weathers blocky	8.4
51. Shale sandy, noncalcareous; gray grades up into olive gray with a purple tint in upper 0.6 ft, which is bentonitic and very thin bedded	3.3
50. Shale, bentonitic, light-gray, very thin bedded	.4

Blackleaf Formation—Continued Vaughn Member—Continued	Thickness (feet)
49. Sandstone, with sandy shale partings, noncalcareous, gray with olive-gray tint, massive; weathers in small blocks and chips; many light-gray organic burrows(?); uppermost beds fractured	3.6
48. Shale, bentonitic, grades up into silty shale, dark-grayish-green and light-grayish-green	2.9
47. Siltstone, noncalcareous, dark-grayish-green, massive; weathers blocky; upper part porous and contains many light-gray organic burrows(?)	1.9
46. Shale, sandy, noncalcareous, dark-grayish-green, very thin bedded, possibly bentonitic	1.3
45. Sandstone, very fine grained, noncalcareous, gray, massive; grayish-green tint; weathers blocky; upper surface nodular; iron-stained fractures	1.6
44. Shale, with many thin bentonite lenses in upper part, bentonitic, noncalcareous, light-gray, very thin bedded; interbedded thin grayish-green siltstone	5.1
43. Shale, sandy with many thin beds of sandstone in lower part grading up into siltstone, noncalcareous, dark-grayish-green; unit weathers light grayish green with mottled areas; uppermost bed contains fillings of light-gray chalcedony resembling petrified wood	3.0
42. Sandstone with sandy shale partings, slightly calcareous, light-gray, massive; firmly cemented in upper part, more friable in lower part; mainly white quartz with some chert; minute laminae; weathers blocky; iron-stained fractures. HS28	9.6
41. Shale, sandy, very fine grained, slightly calcareous, friable, yellowish-gray; green tint	1.8
40. Siltstone with very fine grained sandstone and sandy shale lenses, very hard, dark-gray, massive; weathers grayish brown; weathers blocky, locally nodular; wood fragments	5.9
39. Bentonite and sandy shale, light-gray to gray, thinly laminated	.8
38. Siltstone, noncalcareous, hard, brittle, dark-gray, massive, porous; weathers grayish green; weathers nodular; fractured upper surface	1.0
37. Shale, bentonitic, light-gray, laminated	.9
36. Siltstone, noncalcareous, dark-gray, nodular; carbon stains	.8
35. Shale, silty with bentonitic shale stringers, noncalcareous, dark-gray	.9
34. Siltstone, sandy, noncalcareous, dark-gray, massive; green tint; weathers blocky to nodular; iron stains in fractures and on weathered surface	2.2

Blackleaf Formation—Continued Vaughn Member—Continued	Thickness (feet)
33. Shale, sandy, upper and lower parts bentonitic, noncalcareous; sandy shale is dark-green; bentonitic shale is gray, locally white	2.0
32. Claystone, noncalcareous, dark-grayish-green, massive, iron-stained; weathers nodular and to small blocks	2.8
31. Shale, bentonitic, with thin bentonite bed, light-gray, iron-stained; green tint; weathers white; limonite pellets	1.1
30. Shale, sandy, slightly calcareous, dark-olive-green, thin-bedded	.9
29. Sandstone, very fine grained, noncalcareous, iron-stained, massive, dark-grayish-green to gray; weathers light grayish green; weathers nodular and in irregular blocks	1.8
28. Shale; upper half is grayish green, massive, and noncalcareous; lower half is bentonitic, sandy, slightly calcareous, and green and grades up into grayish green	4.0
27. Sandstone, very fine grained, and silty shale grading up into siltstone, noncalcareous, gray, green tint; weathers blocky to nodular in upper part. Siltstone is greener and contains many small organic burrows	4.7
26. Sandstone, very fine grained, gray, massive; quartz and chert; grayish-green tint; weathers blocky; upper surface nodular; weathered surface has limonite specks and stains	1.9
25. Siltstone, sandy, noncalcareous, gray, massive; gray-green tint; weathers blocky to nodular; shaly in upper part; many iron stains	3.2
24. Shale, sandy, poorly indurated sandstone at base, slightly calcareous, gray; green tint; some wood fragments	2.1
23. Sandstone, noncalcareous, very fine grained, gray, massive; quartz and chert; grayish-green tint; upper surface weathers nodular; iron stains	1.4
22. Shale, sandy, noncalcareous; grayish-green at base, grades upward into poorly indurated gray sandstone that is laminated to thinly laminated	2.3
21. Claystone, with sandstone beds in upper and lower part. Claystone is hard, brittle, slightly calcareous, dark gray and massive, and contains many wood fragments, and weathers blocky to nodular. Sandstone is medium gray, medium to fine grained, noncalcareous, and massive, and weathers yellowish gray and blocky; upper sandstone has grayish-green tint, and its upper surface is nodular and porous	9.3

Blackleaf Formation—Continued Vaughn Member—Continued	Thickness (feet)
20. Shale with bentonite stringers in upper part, sandy, noncalcareous, gray; weathers nodular; abundant fractures	3.9
19. Sandstone, calcareous, fine-grained, gray massive; poorly sorted quartz, chert and glauconite(?), weathers yellowish gray with greenish tint; weathers blocky and with fine cross-laminations; faint ripple marks; many sandy shale lentils in uppermost beds; lower part has sandy shale lentils and nodular claystone; wood fragments; thrust fault at base	15.4
18. Siltstone grading up into claystone in middle part overlain by 0.3-ft.-thick shale bed, hard, brittle, noncalcareous, dark-gray, massive; weathers nodular to blocky, and shaly in upper part; wood fragments abundant. F31 from claystone	6.2
17. Shale, sandy with many sandstone lenses, grades up into massive friable sandstone overlain by sandy shale, fine to very fine grained, noncalcareous, gray; weathers grayish green. Sandstone lenses are nodular; uppermost sandstone is friable. Less resistant than the overlying unit	13.3
16. Sandstone, fine-grained, noncalcareous, gray, massive; chert and quartz; weathers yellowish gray; many sandy shale partings that grade into sandstone; many sandy shale and claystone inclusions and lentils parallel to the bedding; weathers blocky; very thin bedded and faintly crossbedded on weathered surfaces; grades into overlying unit; lenticularity apparently results from shearing at base	7.1
15. Shale, sandy with sandstone lentils, fine to very fine grained, noncalcareous, grayish-green, laminated; quartz, chert, and green grains; thin dark-gray lentils scattered throughout; carbon stains on bedding planes; in upper part of cut, this unit is cut out by thrust fault	2.5
14. Sandstone, fine- to medium-grained, poorly sorted, noncalcareous, massive; mostly quartz; lower part contains chert, quartz, and claystone granules; weathers blocky and locally platy; minute laminae apparent on weathered surface; wood fragments; fault plane at base dips 55° W., strikes N. 10° W	5.1
13. Sandstone with thin sandy shale lenses in upper half, noncalcareous, gray; weathers grayish green; iron-stained surface; upper sandstone weathers nodular to thin bedded; wood fragments; much jointing; lower sandstone, massive; weathers nodular to blocky; shale weathers thin bedded; in the north end of this cut units 9–13 are cut out by a high-angle reverse fault at the base of unit 14	1.7
12. Claystone, noncalcareous, olive-gray to gray; fractures blocky and shaly	2.0
11. Bentonite, yellowish-gray	.1
10. Claystone, noncalcareous, dark-gray, massive; weathers blocky; locally nodular; wood fragments abundant; grades into carbonaceous shale, 1.0 ft thick, at top; weathers thinly laminated	3.8
9. Sandstone, noncalcareous, friable, fine-grained, light-olive-brown; mostly quartz, with some chert; weathers shaly	.6
Total exposed Vaughn Member	207.1
Taft Hill Member:	
8. Sandstone, noncalcareous, gray; fine to medium grained in upper 14.7 ft; fine to very fine grained in lower 6.0 ft; colorless quartz, chert, and glauconite(?). Zone of very dark gray claystone nodules occurs 6.0 ft above base; scattered claystone nodules occur in upper part; weathers yellowish gray; iron stained in upper part. Carbon stains on bedding planes with large wood fragments in upper part; 0.1-ft-thick shale partings in lower part. HS26	20.7
7. Sandstone, very fine grained, calcareous; gray, massive; weathers brown as a result of iron staining; weathers platy to blocky; shaly in upper part; locally nodular; colorless quartz, chert, and glauconite(?); finely micaceous; carbon-coated wood fragments. F29 from platy fossil zone 1.7 ft above base; F30 from 1.2 ft above base	9.2
6. Sandstone, very fine grained, with silty shale beds in lower part. Upper sandstone is noncalcareous, gray, and massive, weathers gray and grayish green, thin bedded, and somewhat nodular, and contains some wood fragments; upper bed is very carbonaceous and grades laterally from sandstone to siltstone. Lower sandstone bed is 0.8 ft thick, thin bedded, and locally crossbedded and locally contains coquina, F28	6.4
5. Shale, bentonitic, slightly calcareous, light-gray, laminated; minute carbon specks	.7
4. Sandstone, very fine grained, slightly calcareous, dark-gray, massive; weathers medium gray with grayish-green tint; weathers thinly laminated	2.3

Blackleaf Formation—Continued
Taft Hill Member—Continued

	Thickness (feet)
3. Sandstone, very hard, very fine grained, noncalcareous, slightly glauconitic, dark-gray, massive; mainly colorless quartz and chert; weathers grayish brown with iron-stained surface; weathers blocky and locally piaty in upper part; organic burrows on lower surfaces; wood fragments; grades into overlying unit	.7
2. Shale, silty, slightly calcareous, with many thin sandstone lenses. Sandstone is very fine grained, slightly calcareous, and gray with grayish-green tint. Shale is dark gray, laminated, and locally nodular; wood fragments and carbon stains	22.1
1. Covered	10.0±
Total exposed Taft Hill Member	72.1±
Total exposed Blackleaf Formation	279.1±

26. *Vaughn Member of Blackleaf Formation in streambank along the Sun River in the center of NE¼ sec. 31, T. 22 N., R. 8 W.*

[Measured by M. R. Mudge, J. J. Halbert, and E. B. McKee III]

Blackleaf Formation:
Vaughn Member:

	Thickness (feet)
39. Sandstone (unit L), medium- to fine-grained slightly calcareous; mainly quartz and chert grains with some feldspar(?). Lower 7.9 ft is massive, weathers blocky and some beds weather platy, contains interbedded zones of crossbedded sandstone, and forms hillside ledge with underlying conglomerate. Rest of unit is mostly sandstone that is less indurated and harder than that in lower one-third, is highly crossbedded, and weathers platy	25.5
38. Conglomerate, pebbles and some cobbles of quartzite and chert in a sandstone matrix; some Belt quartzite; maximum size 0.3 ft; well-rounded. At upper end of exposure is thin (0.6–2.0 ft) lens of sandstone; at lower end of exposure, lower conglomerate and sandstone are absent at base of exposure. Upper conglomerate is as much as 3.2 ft thick and rests conformably on shale. Intervening unsorted massive sandstone bed contains lenses with pebbles of chert and quartzite. Upper contact of conglomerate with overlying sandstone is flat and distinct	3.2–7.9

Unconformity.

Blackleaf Formation—Continued
Vaughn Member—Continued

	Thickness (feet)
37. Siltstone and silty shale, slightly calcareous, dark-gray, thinly laminated to blocky	1.5±
36. Covered	4.0±
35. Claystone, noncalcareous, gray; fractures hackly; fragments of wood	2.0
34. Shale, sandy with sandstone lenses. Sandstone is very fine grained, and slightly calcareous, and contains quartz and chert grains. Shale is noncalcareous, yellowish gray, and thin bedded	1.2
33. Claystone, noncalcareous, gray, blocky; olive-gray tint; some carbon-stained wood fragments	2.3
32. Bentonite, crumbly, light-yellowish-gray	0 2–0.4
31. Claystone, noncalcareous, dark-olive-gray, blocky; 0.2-ft-thick dark-gray thinly laminated shale near top; more resistant than underlying unit	2.8
30. Shale, silty, noncalcareous, light yellowish-gray, thin-bedded	2.0
29. Claystone, noncalcareous, massive; weathers blocky; iron stains on fracture planes	.6
28. Shale, possibly bentonitic, silty, noncalcareous; light yellowish gray in lower part; laminated to thinly laminated	1.4
27. Sandstone, noncalcareous, hard, fine grained, gray, massive; composed of chert and quartz; weathers brown because of iron stains; weathered surface has olive-gray tint; weathers blocky; shale lentils in lower part	2.2
26. Siltstone, calcareous, dark gray; weathers shaly; badly fractured	.6
25. Siltstone grading up into sandstone, slightly calcareous, dark-gray; weathers gray. Sandstone is very fine grained, weathers shaly to blocky	2.8
24. Sandstone, fine to very fine grained, slightly calcareous, gray; massive; composed of chert and quartz grains; weathers grayish-brown; minute bedding planes; shale partings in upper part; wood fragments	1.0
23. Siltstone, slightly calcareous, dark-gray; weathers blocky to shaly and nodular	.9
22. Shale, with a very thin bentonite bed at base, silty, noncalcareous, dark-gray	.6
21. Mostly covered, but some siltstone, noncalcareous, dark grayish-green, blocky	7.8
20. Bentonite, light-gray	.2
19. Claystone and siltstone (mostly covered), grayish-green; some shale	15.2
18. Sandstone, fine grained, gray; mostly quartz and chert with some green grains; weathers gray to olive gray; upper part heavily iron stained	1.5
17. Claystone, same as unit 15	.3

Blackleaf Formation—Continued
Vaughn Member—Continued

	Thickness (feet)
16. Sandstone, fine grained, slightly calcareous; weathers blocky to thin bedded	.4
15. Claystone, noncalcareous, dark gray; weathers blocky to nodular with shaly appearance; badly fractured	.5
14. Siltstone with very fine grained sandstone grading up into claystone, which grades laterally into sandstone, slightly calcareous, dark-gray, blocky; weathers grayish brown; at 1.1 ft above base, weathers shaly and wedges out laterally into sandstone. Where unit is all sandstone, it is massive and contains sandstone nodules	4.0
13. Siltstone grading up into very fine grained sandstone, slightly calcareous, gray; weathers blocky in upper part, shaly in middle and lower parts; forms small indentation on cliff	2.5
12. Claystone with thin sandstone lenses, noncalcareous, dark-gray; weathers blocky	3.4
11. Shale, silty, noncalcareous, dark-grayish-brown; weathers thin bedded	1.2
10. Claystone, noncalcareous, dark-gray; olive-gray tint; weathers grayish-green and blocky	1.0
9. Shale, sandy, noncalcareous, dark-olive-gray, thin-bedded	.7
8. Claystone, noncalcareous, dark-gray; weathers blocky	1.0
7. Shale, silty, noncalcareous, gray; weathers yellowish gray; weathers laminated to thinly laminated	1.4
6. Claystone, noncalcareous, dark-gray; weathers blocky; badly fractured	1.5
5. Sandstone, fine to very fine grained, noncalcareous, dark-gray; guartz and chert grains; weathers yellowish gray; upper surface weathers nodular, rest weathers blocky	2.3
4. Shale, silty, noncalcareous, dark-gray, laminated; many carbon-stained wood fragments	1.3
3. Sandstone, fine-grained, noncalcareous, dark-gray; quartz and chert; weathers blocky and with greenish-gray tint	1.2
2. Covered	38.7
Total Vaughn Member exposed	140.9–145.8±

Taft Hill Member:

	Thickness (feet)
1. Sandstone (unit J) with sandy shale partings, fine- to medium-grained, slightly calcareous gray, very thin bedded; composed mainly of colorless chert; scattered grains of green glauconite(?); locally massive; weathers platy to blocky in lower part; local zones crossbedded; uppermost bed massive, hard, somewhat darker; upper surface nodular and irregular, tinted gray; forms prominent hillside bench	20.7
Total Taft Hill Member measured	20.7

Lower beds of Taft Hill Member (not measured).

27. *Part of Vaughn Member of Blackleaf Formation, north bank of the Sun River, NW¼SW¼ sec. 31, T. 22 N., R. 8 W.*

[Measured by M. R. Mudge and M. W. Reynolds]

Blackleaf Formation:
Vaughn Member:

	Thickness (feet)
17. Sandstone, very fine grained, micaeous, noncalcareous, gray; weathers yellowish gray; fractures into vertical rectangular blocks; iron stains on upper surface; plant fossils; strike N. 25° W., dip 38° SW. HS78	3.0
16. Shale, bentonitic, noncalcareous, gray, laminated	2.0
15. Siltstone, with very fine grained sandstone in middle part, noncalcareous, gray-olive-gray; hackly fracture; forms three small ledges	5.7
14. Siltstone, slightly sandy and micaceous, noncalcareous, olive-gray; weathers with hackly fracture	2.2
13. Shale, noncalcareous, slightly bentonitic, gray, laminated	.6
12. Claystone, noncalcareous, olive-gray, massive; weathers light grayish green; weathers shaly and with hackly fracture	.6
11. Shale, bentonitic, noncalcareous, dark-olive-gray, thin-bedded; weathers light gray	.7
10. Claystone, massive; finely micaceous with brown mica, olive gray grading up into gray; hackly fracture; strike N. 25° W., dip 38° SW	7.5
9. Shale, finely micaceous, bentonitic, light-grayish-green, laminated; weathers yellowish gray	1.2
8. Claystone, noncalcareous, green, massive; weathers blocky; minute fractures stained light gray	1.5
7. Sandstone, poorly indurated, noncalcareous, gray, massive; fine-grained quartz, feldspar, and some chert; weathers light gray with a green tint; irregular blebs of secondary chalcedony in upper part; strike N. 20° W., dip 50° SW. HS77	9.2
6. Claystone, noncalcareous, olive-gray, massive; weathers somewhat lighter gray; hackly fracture; iron stains on upper surface	2.7
5. Shale, noncalcareous, clayey, gray, laminated; grades up into bentonite; weathers light gray; strike N. 25° W., dip 58° SW	1.8

Blackleaf Formation—Continued
Vaughn Member—Continued *Thickness (feet)*

4. Claystone with some fine-grained sandstone, noncalcareous, olive-gray, porous; weathers blocky; forms small resistant ledge ---- 0.5
3. Siltstone, noncalcareous, dusky-yellow-brown; mottled with green and gray; weathers blocky ---- 2.8
2. Shale, noncalcareous, bentonitic, light-gray, laminated; weathers yellowish gray ---- 1.5
1. Mudstone, noncalcareous, light-grayish-green, massive; mottled with gray; weathers blocky; many minute fractures stained light gray; some iron stains; some mottlings of reddish brown; lower part (1.9 ft) forms small resistant ledge ---- 3.1

Total exposed Vaughn Member ---- 46.6

Total exposed Blackleaf Formation ---- 46.6

Top of "L" bed of Vaughn Member.

28. *Lower part of Floweree Shale Member of Marias River Shale and part of Vaughn Member of Blackleaf Formation in streambank in NW¼SW¼ sec. 6, T. 21 N., R. 8 W.*

[Measured by M. R. Mudge, R. M. Mudge, and R. J. Mudge]

Marias River Shale:
Floweree Shale Member: *Thickness (feet)*

57. Shale, noncalcareous, dark-gray, thinly laminated; fractures into minute splinters; many iron-stained beds; platy fine-grained sandstone, 0.5 ft thick, 4.5 ft above base; claystone bed 11 ft above base; 0.2-ft-thick bentonite 5.5 ft above base; iron stains abundant on fracture planes; basal contact is sharp but irregular ---- 15.0±

Unconformity.

Blackleaf Formation:
Vaughn Member:

56. Sandstone, fine-grained, gray, thinly laminated; quartz, feldspar, and chert in equal amounts; weathers light gray and yellowish brown; more massive beds in lower part; locally less friable; iron stains common in upper part; locally crossbedded; locally shaly in lower part; beds thicken and thin; stringers of coal. HS97; wood fragments, F141 ---- 5.3
55. Claystone, noncalcareous, dark-gray; blocky in upper part, hackly fracture throughout; nodular bed at top is as much as 0.6 ft thick; local iron-stained zone. Leaf collection from nodular bed, F140 ---- 4.5
54. Shale, bentonitic, noncalcareous, grayish-brown, laminated, iron-stained ---- 1.5
53. Siltstone, noncalcareous, dark-gray, porous; weathers blocky; forms ledge. HS96 ---- .7

Blackleaf Formation—Continued
Vaughn Member—Continued *Thickness (feet)*

52. Shale, bentonitic, noncalcareous, light-gray, heavily iron stained, laminated; less bentonitic in upper part ---- 1.1
51. Claystone, noncalcareous, dark-gray; weathers grayish green; weathers blocky to shaly ---- 2.2
50. Claystone, noncalcareous, gray, massive; weathers blocky and with hackly fracture; forms distinct ledge ---- .7
49. Siltstone, noncalcareous, light-grayish-green, iron-stained; hackly fracture; grades up into gray claystone ---- 1.3
48. Shale, bentonitic, noncalcareous, light-gray, laminated ---- 0.9
47. Claystone, like unit 45, iron-stained. HS195 ---- 6.0
46. Shale, silty, noncalcareous, medium-gray, laminated; hackly fracture ---- 1.2
45. Claystone, sandy, finely micaceous, noncalcareous, massive, resistsant; hackly fracture; iron-stained zones; porous bed in lower part ---- 4.8
44. Shale, bentonitic, noncalcareous, light-gray, laminated; iron stains on fractures ---- 1.0
43. Siltstone, noncalcareous, dark-gray, porous; blocky to hackly fracture; forms ledge; irregular basal contact ---- .7
42. Shale, noncalcareous, slightly bentonitic, dark-gray, laminated; grayish-green claystone 0.3 ft above base ---- 1.0
41. Shale, very bentonitic, finely micaceous, noncalcareous, light-gray, laminated; iron stained in upper part ---- 1.4
40. Siltstone, noncalcareous, gray, grayish-green tint; hackly fracture; more resistant in upper part ---- 1.5
39. Siltstone, tuffaceous, noncalcareous, gray, blocky; weathers light grayish green; forms small ledge ---- 0.4
38. Siltstone, tuffaceous, noncalcareous, grayish-green; lighter in upper part; three small ledges ---- 5.3
37. Claystone, slightly calcareous, dark-gray; hackly fracture; sandy in upper part. HS194 ---- 4.0
36. Siltstone, noncalcareous, medium-gray; weathers blocky ---- .8
35. Shale, bentonitic, noncalcareous, light-gray, laminated ---- .8
34. Siltstone, tuffaceous, poorly indurated, locally very dense, especially in lower part, noncalcareous, grayish-green and light-gray; weathers blocky to slabby; thinly cross-laminated ---- 4.7
3. Claystone, noncalcareous, gray; thin-bedded in upper part; hackly fracture in lower part ---- 1.5-2.8

Blackleaf Formation—Continued
Vaughn Member—Continued — *Thickness (feet)*

32. Sandstone, tuffaceous, poorly indurated in places, noncalcareous, very fine grained, yellowish-gray, very thin bedded, lenticular; dark-gray-green bed at top; some thin tuffaceous beds; fills small channel. HS95 — .4–2.5
31. Claystone, noncalcareous, dark-gray, grades down into grayish green; hackly fracture. HS193 — 7.5
30. Bentonite; light-gray, laminated — .2
29. Siltstone, noncalcareous, dark-gray, massive; weathers blocky — 3.0
28. Sandstone, noncalcareous, poorly indurated, bentonitic, light-gray, very thin bedded — .6
27. Siltstone, slightly calcareous, dark-gray; hackly fracture — 2.0
26. Covered (measurements continued upstream) — 7.0
25. Sandstone, very fine grained, noncalcareous, dark-gray, massive; weathers light gray; weathers blocky; iron stains; wood fragments. HS94 — 2.5
24. Shale, clayey, noncalcareous, dark-grayish-brown; weathers into small blocks — .9
23. Siltstone, noncalcareous, very fine grained with coarse-grained lentils, gray; composed of detrital shale in upper part; grades down into grayish green; mottled dark gray in upper part — 1.3
22. Siltstone, noncalcareous, gray to grayish-brown; hackly fracture — 4.6
21. Siltstone, micaceous, noncalcareous, dark-grayish-green; hackly fracture; iron-stained zone at top — .7
20. Claystone, noncalcareous, dark-gray; hackly fracture — .9
19. Siltstone, like unit 21; forms small ledge; weathers nodular — 1.0
18. Siltstone, like unit 21 — 1.1
17. Shale, very bentonitic, noncalcareous, gray, laminated — .4
16. Siltstone, noncalcareous, dark-gray, blocky — 3.6
15. Siltstone, finely sandy, noncalcareous, micaceous, dark-gray, blocky; weathers gray — .8
14. Siltstone, noncalcareous, poorly indurated, dark-grayish-brown; hackly fracture — 1.4
13. Shale, bentonitic, noncalcareous, gray, blocky to laminated — .6
12. Claystone, noncalcareous, dark-grayish-brown, blocky — .8
11. Shale, with 0.2 ft thick claystone in middle, clayey, noncalcareous, dark-gray, blocky — .9
10. Shale, like unit 11 but yellowish-gray — 0.5
9. Claystone, noncalcareous, dark-gray, blocky — .7
8. Covered — 54.5

Blackleaf Formation—Continued
Vaughn Member—Continued — *Thickness (feet)*

7. Claystone, noncalcareous, dark-gray, massive; weathers dark gray; weathers blocky with hackly fracture; local white porous zones — 1.5
6. Shale, bentonitic, noncalcareous, light-gray, laminated — 2.8
5. Tuff, micaceous, light-gray, massive; yellowish gray in lower part; weathers platy and with hackly fracture; zones with many small white rounded accretionary lapilli; forms small ridge. HS73 — 7.2
4. Siltstone, noncalcareous, blocky; dark grayish brown mottled with stringers of gray — .5
3. Shale, clayey, noncalcareous, olive-gray, blocky — .3
2. Siltstone, sandy, noncalcareous; grayish green mottled with light green; hackly fracture; porous in places — 13.0
1. Shale and mudstone, distorted; contains thin lenses of grayish-green sandstone. HS72 — 25.5

Total exposed Vaughn Member — 205.4±–272.0±

29. *Lower part of Cone Calcareous Member and Floweree Shale Member of Marias River Shale, north bank of the Sun River, center NE¼NW¼ sec. 32, T. 22 N., R. 8 W.*

[Measured by M. R. Mudge and M. W. Reynolds]

Fault.
Marias River Shale:
Cone Calcareous Member (lower part): — *Thickness (feet)*

7. Shale, noncalcareous, clayey, dark-gray, laminated to thinly laminated; iron stains on bedding planes; somewhat contorted at top. HS187, composite of units 5, 6, and 7 — 15.3
6. Bentonite, noncalcareous, medium- to light-gray; iron-stained in upper and lower parts — .4
5. Shale, clayey, noncalcareous, dark-gray, laminated; iron stains on fracture and bedding planes; somewhat contorted in lower part — 20.0
4. Shale, silty, calcareous, dark-grayish-brown, very thin bedded to laminated; iron stains on bedding planes; at top are hard gray limestone concretions with white specks that weather brown; calcite-filled fractures; heavily iron stained at base; *Inoceramus* at top; fish scales. HS188 — 3.7

Total exposed Cone Calcareous Member — 39.4

Floweree Shale Member:

3. Shale, noncalcareous, silty, dark-gray, thin-bedded to thinly laminated; weathers gray with metallic luster; yellow and brown iron stains common; platy iron-stained siltstone in lower 16.0 ft; 0.1-ft-thick bentonite 0.2 ft above base. HS189 — 28.8

Marias River Shale—Continued
Floweree Shale Member—Continued

	Thickness (feet)
2. Siltstone, noncalcareous, gray-brown, laminated; weathers into small blocks; heavily iron stained; yellow stains (iron sulfates?) common on bedding planes	.7
1. Conglomerate; rounded to subangular pebbles of chert, mostly less than 1 in. across; some are as large as 2 in. in a fine sandstone matrix; rests disconformably on sandstone (unit 56 in measured section 28) of upper part of Vaugh Member. HS65 and HS68	.5
Total Floweree Shale Member	30.0
Total exposed Marias River Shale	69.4

30. *Part of Ferdig Shale and Cone Calcareous Members of Marias River Shale, north bank of the Sun River, SE¼ NE¼NE¼ sec. 32, T. 22 N., R. 8 W.*

[Measured by M. R. Mudge, J. J. Halbert, and E. B. McKee III]

Marias River Shale:

	Thickness (feet)
Ferdig Shale Member:	
10. Shale, noncalcareous, dark-gray, thinly laminated; top covered	4.0±
Cone Calcareous Member:	
9. Bentonite, like unit 7	.2
8. Siltstone, sandy, calcareous, micaceous, medium gray; flakes larger than those in unit 6; grades upward to yellowish gray and iron stained; uppermost part very limonitic. Fish scales and teeth, F125	.6
7. Bentonite, light-gray, heavily iron stained; weathers to minute chips	.7
6. Sandstone, very fine grained, calcareous, finely micaceous, massive, medium-gray; weathers light gray; weathers blocky	.2–.7
5. Shale, calcareous, dark-gray; weathers medium gray; weathers slabby to shaly; ¼-in.-thick iron-stained zone in middle	1.3
4. Siltstone, calcareous, medium-gray, massive; weathers light gray; weathers blocky	0.3
3. Shale, with massive siltstone bed in the middle, calcareous, dark-gray; weathers medium gray; shale, laminated to thinly laminated; siltstone fractures into elongate splinters; unit forms small knob	9.1
2. Shale, sandy, with interbedded thin sandstone and silty shale, calcareous, finely micaceous, very fine grained, medium- to dark-gray, flaggy to platy; weathers light gray. Four sandstones beds, of which two form top and base of unit, are 0.2–0.5 ft thick; thickest bed is in upper part; bedding irregular, some crossbedding; massive, weathers platy to blocky; forms very small ledges; 0.6-ft-thick light-gray iron-stained bentonite occurs 0.4 ft above base; petroliferous odor. *Inoceramus*, fish scales; *Ostrea*, worm burrows. F126 (USGS Mesozoic loc. D1483)	3.2±
1. Claystone, grading up into laminated siltstone, calcareous, dark-gray; weathers medium gray; siltstone, massive; fractures into elongate splinters; gradational upper contact; petroliferous odor	14.2±
Total exposed Cone Calcareous Member	29.8±–30.3±
Total exposed Marias River Shale	33.8±–34.3±

Base covered.

31. *Parts of Ferdig Shale and Cone Calcareous Members of the Marias River Shale, north bank of the Sun River, SE¼ NE¼NE¼ sec. 32, T. 22 N., R. 8 W.*

[Measured by M. R. Mudge and M. W. Reynolds]

Marias River Shale:

	Thickness (feet)
Ferdig Shale Member:	
9. Bentonite (top of section)	0.2
8. Shale, clayey, noncalcareous, dark-gray, laminated to thinly laminated, thin, micaceous, silty; weathers light gray; bentonite seams in upper and middle parts; iron stains abundant on bedding and fracture planes	9.3
7. Bentonite, light-gray to white, massive; weathers blocky; some iron stains	.2
6. Shale, silty, noncalcareous, dark-bluish-gray, laminated; weathers dark gray; weathers into small chips; bedding and fracture planes heavily iron stained in upper part	1.0
Total exposed Ferdig Shale Member	10.7
Cone Calcareous Member:	
5. Shale, very soft, silty, calcareous, dark-grayish-brown, laminated; weathers yellowish gray; weathers papery	.5
4. Bentonite, finely micaceous, light-gray, laminated; heavily iron stained	0.6
3. Shale, silty, calcareous, dark-gray, laminated to thinly laminated; weathers medium gray, weathers papery; thin bentonite stringers in upper part; many thin very fine grained sandstone lenses in 1.4-ft-thick zone at base (HS197); very resistant; forms ledge in waterfall; *Inoceramus labiatus* very abundant, F124	7.4
2. Bentonite, finely micaceous, light-gray, massive; weathers blocky; heavily iron stained	1.1
1. Shale, calcareous, dark-gray, petroliferous laminated to thinly laminated; weathers medium gray; many papery-weathering beds; two thin iron-stained zones in upper part; possibly bentonitic; bentonite stringer 6.5 ft above base. Thin very fine	

Marias River Shale—Continued
Cone Calcareous Member—Continued

	Thickness (feet)
grained sandstone beds common in upper part. Fossils very abundant; F123 from 10 ft above base; F122 (USGS Mesozoic loc. D1481) from 2.0 ft above base	10.5
Total exposed Cone Calcareous Member	20.1
Total exposed Marias River Shale	30.8

Botton of section.

32. *Part of Ferdig Shale Member of the Marias River Shale, north bank of the Sun River SE¼NE¼NE¼ sec. 32, T. 22 N., R. 8 W.*

[Measured by M. R. Mudge and M. W. Reynolds]

Marias River Shale:
Ferdig Shale Member:

	Thickness (feet)
6. Covered. Cone Calcareous Member faulted against Floweree Shale Member; fault possibly in the Ferdig	40.0
5. Same as unit 1	18.0
4. Conglomerate, gray; poorly indurated as result of weathering; rounded-pebbles of chert, mainly ⅛–¼ in., some as large as ¾ in. HS76	.2
3. Shale, silty, noncalcareous, dark-bluish-gray; many thin lenses of very fine grained micaceous sandstone; weathers dark bluish gray to medium gray; laminated with many thin plates; iron stains very abundant on bedding and fracture planes; iron-stained platy beds distinguish this unit from underlying unit; sandstone beds are less than 2 in. thick; organic burrows. HS191	35.0
2. Concretionary zone, iron-stained, with claystone concretions	0.0–0.5
1. Shale, with scattered sandstone lenses, noncalcareous, dark-gray, laminated, very fine grained; weathers to small fragments, generally not more than ¼ in. across; some thin beds; iron stains abundant on sandstone lenses and on some bedding and fracture planes; iron-stained concretions in upper part; small organic burrows in sandstone lenses	100.0
Total exposed Ferdig Shale Member	193.2–193.7
Total exposed Marias River Shale	193.2–193.7

33. *Ferdig Shale Member and part of Cone Calcareous Member of the Marias River Shale in the east and west streambanks of the South Fork of the Sun River, three-fourths of a mile southwest of junction of Bear Creek with South Fork, about 750 feet north of axial trace of anticline*

[Measured by M. R. Mudge and Dale Snow]

Marias River Shale:
Ferdig Shale Member:

	Thickness (feet)
About 15 ft of beds seem to be covered between this section and measured section 34 on the west side.	
36. Sandstone with many shale partings. Sandstone is calcareous, yellowish gray, very fine grained, finely micaceous; weathers platy. Shale is noncalcareous, dark gray, granular	6.5
35. Siltstone (poorly exposed), noncalcareous, medium-gray; one bed; weathers granular	3.5
34. Sandstone, calcareous, fine-grained, moderately well sorted, gray; two massive beds separted by laminated sandy shale; clear quartz and chert; weathers blocky to platy; weathers yellowish gray HS537	1.5
33. Sandstone, noncalcareous, very fine grained, very thin bedded, gray with some bluish gray; very thin bedded; weathers yellowish gray; platy to granular; heavily iron stained; organic trails and burrows	25.2
32. Sandstone, slightly calcareous, very fine grained, yellowish-gray; some dark-gray to bluish-gray surfaces; beds 1–5 in. thick; ripple marks	6.2
31. Sandstone, slightly calcareous, fine-grained, iron-stained, well-sorted, gray, massive, mostly clear quartz with some chert; weathers blocky to platy; forms protruding ledge near stream. HS536	1.6
30. Siltstone with many thin sandstone beds, noncalcareous, dark-gray, very thick bedded; weathers granular to slabby. Sandstone is very fine grained, finely micaceous, and very thinly bedded; weathers platy; heavily iron stained; weathers yellowish gray; small resistant ledges; organic trails and burrows	15.0
29. Sandstone, noncalcareous, very fine grained, finely micaceous, yellowish-gray, heavily iron stained; one bed with thin laminae apparent on fresh surface; weathers platy; carbon fragments; upper surface ripple marked; thin dark-gray clay laminae in lower part	0.8

Marias River Shale—Continued
Ferdig Shale Member—Continued

	Thickness (feet)
28. Shale, noncalcareous, silty; medium-gray; mottled with dark gray; many very thin fine grained sandstone beds; shale weathers yellowish gray; heavily iron stained; some sandstone beds weather platy, others granular; some small ironstone concretions; organic trails and burrows	14.1
27. Bentonite, sandy, micaceous, light-gray, heavily iron stained	0.1–0.2
26. Claystone, with many very thin sandstone lenses, noncalcareous, dark-gray; blue tinge, weathers yellowish gray. Sandstone is very fine grained, micaceous, heavily iron stained; ripple marks and wood fragments. Claystone weathers to granules and chips; sandstone weathers platy; organic trails and burrows	9.8
25. Sandstone, noncalcareous, very fine grained, dark-gray, thin-bedded; most beds thicken and thin; ripple marks; crossbedding; uppermost bed is thinly laminated and weathers platy; upper part has shaly partings; ramdomly spaced limonite concretionary zones; organic trails and burrows	14.8
24. Sandstone, noncalcareous, medium-gray, very fine grained, finely micaceous, thinly laminated; two ½-in.-thick limonitic sandstone concretionary zones in middle, a similar zone about 1 ft below top; carbon fragments; lower beds and some upper beds ripple marked	8.8
23. Covered by talus; interval exposed on bottom of the stream, where it is sandstone similar to overlying unit	15.8
22. Sandstone, noncalcareous, light-gray, fine-grained; mostly quartz, but contains more chert than do underlying beds; one bed; ripple marked at top; weathered surface shows minute lamination. HS535	1.0
21. Sandstone, noncalcareous, medium-gray, fine-grained; mostly quartz, some chert, and scattered green grains; in beds 2–4 in. thick that form small indentations; ripple marked	.7
20. Sandstone, noncalcareous, very hard, medium-gray, fine-grained; mostly clear quartz; one bed; upper surface ripple marked; forms rapids. HS534	.8
(Measurements continued 1,000 ft to the south on west side of South Fork and at the top of very thick beds in the trees.)	
19. Sandstone, noncalcareous, very fine grained, finely micaceous, gray; some scattered coarse grains of mica and dirty-appearing quartz; weathers yellowish gray with an olive-gray tint; in very irregular beds 3–6 in. thick; one 1-ft-thick bed is 2 ft below top; iron stains very abundant; organic trails and burrows very abundant on base of beds; bluish-gray clay coating in areas with organic trails; some burrows extended diagonally across beds; burrows are cylindrical, as much as 4 in. across and 4 ft long; concretionary zone (limonite?) 9.3 ft beneath top. Unit forms uppermost exposure south of anticline. F347 (USGS Mesozoic loc. D2611); F346 (USGS Mesozoic loc. D2610), HS533	28.0
18. Sandstone, slightly calcareous, medium-gray; very fine grained quartz with some chert; weathers yellowish gray to gray; nodular; abundant scattered ironstone concretions; lentils of quartzite; minute organic trails and burrows	10.4
17. Sandstone with interbedded siltstone; many very thin nodular sandstone beds that are slightly calcareous, a few are quartzite; medium gray (lighter than underlying beds); weathers with hackly fracture; more nodular and irregularly bedded in upper part; iron stains abundant, mostly yellowish brown. This is a transitional unit	8.0
16. Siltstone, noncalcareous, finely micaceous, medium-grayish-brown to medium-gray, very thick bedded; weathers into small irregular blocks; thin lenses of very fine grained sandstone at top; ironstone concretionary zone in middle with many concretions parallel to bedding, some as much as 3 in. thick and 12 in. long; iron stains very abundant	20.8
15. Siltstone, noncalcareous, medium- to dark-gray, massive; weathers granular and into thin hackly fragments; zone of ironstone concretions 1.0 ft from base; concretions are as much as 3 in. thick and 18 in. long, all parallel to bedding; two ½-in.-thick bentonite seams, one 6 in. below top, the other 4 ft below top	19.8
14. Siltstone, noncalcareous, medium-gray; one bed, weathers granular; very fine grained micaceous sandstone lentils; abundant iron stains and a few yellow stains; 1-in.-thick ledge of sandstone at top	2.4
13. Siltstone, noncalcareous, medium-gray, very thick bedded to thinly laminated; weathers granular; many interbedded lenses and lentils of sandstone and siltstone; some persist to form thin narrow bands along face of exposure; iron stains very abundant	15.0
12. Bentonite, wet, light-gray; heavily iron stained at top and bottom	.6
11. Siltstone, noncalcareous, finely micaceous, medium-gray, massive; contains many very thin very fine grained clear quartz sandstone beds and lenses that form small	

Marias River Shale—Continued
Ferdig Shale Member—Continued *Thickness (feet)*

ledges; siltstone more heavily iron stained at base where there may be a thin bentonite; one bentonite bed, near middle, is as much as 0.3 ft thick	16.2
Total Ferdig Shale Member	247.4–247.5

Cone Calcareous Member:

10. Siltstone, very calcareous, dark-gray, very thick bedded; fine-grained mica; fractures into large irregular fragments or plates; petroliferous odor; forms upper part of exposed apex of anticline; black fish scales	17.8
9. Limestone, clayey, dark-gray thinly laminated; weathers yellowish gray; iron stains in upper part; forms small ledge; blue fish scales	.4
8. Limestone, clayey, silty, dark-gray; weathers lighter gray; one bed weathers thin bedded with hackly fracture; contains two 0.1-ft-thick bentonite beds in lower 1 ft; petroliferous odor; *Ostrea*, and black fish scales	5.2
7. Bentonite, crumbly, light-gray, heavily iron stained	.4
6. Siltstone, dark-gray, thick-bedded; weathers platy and into small elongate fragments; laminated in middle; seven bentonite beds, thickest is 0.1 ft; thin calcite seams; forms resistant ledges; *Inoceramus labiatus* and small black fish scales	7.4
5. Bentonite, light-gray; one bed, breaks into very small blocks; heavily iron stained	1.5
4. Siltstone, calcareous, very dark gray, thick-bedded; fractures into small elongate fragments and thin beds. Eleven thin bentonite beds, none thicker than 0.1 ft; light gray; each is iron stained on top and bottom and contains minute calcite crystals; petroliferous odor; black fish scales	9.3
3. Siltstone, very calcareous, dark-gray, thick-bedded; fractures into small plates and irregular fragments; scattered calcite-filled fractures; petroliferous odor; limestone concretions as much as 18 in. long in lower part; *Inoceramus labiatus*	5.5
2. Bentonite, silty, white, iron-stained; one bed	.1
1. Siltstone, very calcareous, dark-gray, massive, badly sheared; weathers into small elongate fragments and chips; some hackly fracture; limestone concretionary zone 13.5 ft above base, some concretions as much as 3 ft across and 4 in. thick; petroliferous odor. *Inoceramus labiatus*, *Ostrea congesta*; blue fish scales; F395 (USGS Mesozoic loc. D3171) from 1.0 ft above base	17.7

Marias River Shale—Continued
Cone Calcareous Member—Continued *Thickness (feet)*

Measurements began at low water level, just south of the apex of the anticline which contains a small normal fault (north side down, trending northwest) with 6–8 ft displacement. The section measured has a dip of 55° NW.

Total exposed Cone Calcareous Member	65.3
Total exposed Marias River Shale	312.7–312.8

34. *Lower part of Kevin Shale Member and upper part of Ferdig Shale Member of the Marias River Shale, measured about 750 feet north of station 166 in west bank of South Fork of the Sun River*

[Measured by C. E. Erdmann, Aug. 1961]

Marias River Shale:
Kevin Shale Member: *Thickness (feet)*

128. Bentonite, yellowish-gray to light-yellowish-gray, soft, weathered. (Bed dislocated by fault with throw of about 6 ft. Measurement terminated at this feature because of its easy recognition.)	0.3
127. Siltstone, dark-gray, soft, very thick bedded	16.0
126. Bentonite, as in unit 128	.3
125. Siltstone, as in unit 127	11.0
124. Bentonite, yellowish-gray, weathered, granular	.3
123. Siltstone, dark-gray	1.0
122. Limestone, dark-gray, hard, compact; smoothly rounded oval masses up to 12 by 8 by 6 in. are flattened parallel to bedding, making a fairly continuous bed	.5
121. Siltstone, dark-gray, similar to underlying beds	10.0
120. Bentonite	.3
119. Siltstone, dark-gray, as in unit 91. F394 from base	5.6
118. Bentonite, medium-light-gray, granular	1.0
117. Siltstone, dark-gray, as in unit 91	6.2
116. Siltstone, dark-gray. F393 from top of bed	2.0
115. Bentonite, light-yellowish-gray to dark-yellowish-orange	.7
114. Siltstone, dark-gray	6.1
113. Bentonite	.4
112. Siltstone, dark-gray	3.6
111. Bentonite	.1
110. Siltstone, dark-gray	4.5
109. Bentonite	1.0
108. Siltstone, dark-gray, massive, as in unit 91; film of light-gray sandstone on top	1.0
107. Bentonite, light-gray, granular	1.7
106. Sandstone, light-gray	.2
105. Siltstone, dark-gray, as in unit 91	5.5
104. Siltstone, dark-gray. F392 from top	2.3

Marias River Shale—Continued
Kevin Shale Member—Continued

	Thickness (feet)
103. Limestone, dark-gray, concretionary; separate ovoid masses up to 16 by 14 by 6 in.; large specimens of *Inoceramus deformis*	.5
102. Siltstone, dark-gray	.7
101. Bentonite	.3
100. Siltstone, dark-gray	.8
99. Sandstone, light-gray, fine-grained	.1
98. Siltstone, dark-gray, as in unit 91	1.0
97. Bentonite, soft; weathers rusty	.9
96. Sandstone, gray, fine-grained	.1
95. Siltstone, dark-gray, as in unit 91; in beds about 1 ft thick. F391 from base of lowest bed (USGS Mesozoic loc. D3170)	6.5
94. Bentonite	.3
93. Siltstone, dark-gray	1.5
92. Bentonite, weathering rusty	.5
91. Siltstone, dark-gray; in beds up to 1 ft thick	2.9
90. Sandstone, light-gray, fine-grained	.2
89. Siltstone, dark-gray, as in unit 81. F390 from just below top	.8
88. Bentonite, light-gray	1.2
87. Siltstone, dark-gray	.6
86. Bentonite, light-gray	.3
85. Sandstone, light-gray, fine-grained	.1
84. Siltstone, dark-gray, as in unit 81	.3
83. Bentonite; weathers rusty	.4
82. Siltstone, dark-gray; top covered with a film of light-yellowish-gray fine-grained sandstone	1.8
81. Siltstone, dark-gray, F389 from about 7 in. above base	2.9
80. Siltstone, dark-gray, as in unit 52	1.7
79. Siltstone, dark-gray; at top ⅛-in.-thick laminae of light-gray sandstone; *Inoceramus* cast about 3 in. below top	1.6
78. Concealed. Probably occupied in part by bentonite	1.6
77. Sandstone, light-gray, fine-grained	.1
76. Siltstone, dark-gray, as in unit 52	1.2
75. Bentonite	.2
74. Siltstone, dark-gray. F387	1.5
73. Bentonite, light-gray	.2
72. Limestone, light-gray, sandy, hard, compact; in small flat discrete oval masses surrounded by bentonite	.2
71. Siltstone, dark-gray as in unit 52	1.6
70. Limestone, medium-gray, clayey; gnarly irregular bedding; slump blocks apparently from same layer contain abundant well-developed cone-in-cone structures up to 2 in. long	0.4–0.8
69. Siltstone, dark-gray, as in unit 52	2.6
68. Concealed by finely granular siltstone talus	3.9
67. Siltstone, dark-gray; laminae of sandstone on top	1.8
66. Bentonite, light-gray, as in unit 64	.2
65. Sandstone, light-gray, calcareous, thinly laminated	.2
64. Bentonite, light-gray, finely granular	.2
63. Siltstone, dark-gray, as in unit 52; single lamina of light-gray fine-grained sandstone on top	2.3
62. Siltstone, dark-gray, as in unit 52; *Inoceramus* cast 1.3 ft below top. F386 from top	9.7
61. Siltstone, dark-gray, as in unit 52; weathers light-gray with efflorescent stain; *Inoceramus* cast at top	1.0
60. Bentonite; weathers rusty	.1
59. Siltstone, dark-gray, as in unit 52; scaphite in float on top of bed. F385a	3.2
58. Bentonite, light-gray, soft, poorly exposed	2.4
57. Limestone, medium-gray, concretionary, hard, compact; discrete nodules. F385 (USGS Mesozoic loc. D3169)	.2
56. Siltstone, as in unit 52	2.8
55. Bentonite, medium-yellowish-orange, weathered	.6
54. Siltstone, dark-gray, very thick bedded	9.5
53. Siltstone, as in unit 52. F384 from top (USGS Mesozoic loc. D3168)	11.6
52. Siltstone, dark-gray; very thick bedded as in unit 50, but somewhat more clayey and with fewer thin layers of hard sandstone; weathers to finely granular talus. F383 from top (USGS Mesozoic loc. D3167) includes scaphite cast in float	14.5
51. Bentonite, light-gray; weathers medium yellowish orange	.2
50. Siltstone, dark-gray; in thin layers that break with subconchoidal fracture; *Inoceramus* prism 1.2 ft below top	6.6
49. Siltstone, as in unit 50; *Inoceramus* cast 10 in. above base. F382 from top (USGS Mesozoic loc. D3166)	8.7
48. Bentonite, medium-gray; upper half weathers light yellowish orange; granular	.8
47. Siltstone, dark-gray, as in unit 44	4.0
46. Siltstone, as in unit 44; *Inoceramus* cast at top	2.9
45. Siltstone, as in unit 44. F381 from top of unit (USGS Mesozoic loc. D3165)	2.8
44. Siltstone, dark-gray; contains fine-grained brown mica (phlogopite?); one bed; breaks with hackly fracture. F380 from top	3.3
43. Siltstone, dark-gray, noncalcareous, very thin bedded; fine-grained gray sandstone at intervals of 3–4 ft; thin limestone concentrations; *Inoceramus* cast 1 ft above base. F379 from top	9.8
42. Siltstone, dark-gray, as in unit 33	.7
41. Bentonite, soft; weathers rusty	.1
40. Siltstone, dark-gray, as in unit 33	.3

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Marias River Shale—Continued Kevin Shale Member—Continued	*Thickness (feet)*
39. Bentonite, soft; weathers rusty	.2
38. Limestone, concretionary, as in unit 36	.2
37. Siltstone, dark-gray as in unit 33	1.3
36. Limestone, dark-gray; in hard compact concretions averaging about 5 by 4 by 1½ in. F378 (USGS Mesozoic loc. D3164)	.2
35. Siltstone, dark-gray, as in unit 33	2.2
34. Bentonite, soft; weathers rusty	.2
33. Siltstone, dark-gray, noncalcareous, chunky; lentils of fine-grained gray sandstone and limestone nodules	3.2
32. Siltstone, dark-gray; light-gray efflorescent stain on edges of beds. F377 from top (USGS Mesozoic loc. D3163)	1.5
31. Siltstone, dark-gray, massive, thinly and irregularly bedded	5.7
30. Siltstone, medium-dark-gray, as in unit 26. F376 from top (USGS Mesozoic loc. D3162)	.6
29. Siltstone, dark-gray, soft	.2
28. Bentonite, light-gray, finely granular; contains small oval calcareous nodules	.2
27. Sandstone, bentonitic, light-gray	.1
26. Siltstone, medium-gray, soft, noncalcareous; weathers down into small granular fragments	10.0
25. Sandstone, medium-gray, fine-grained, firm, compact, thinly laminated, calcareous; upper surface slightly irregular	.2
24. Concealed by slump down to water	6.9
23. Sandstone, medium-gray, fine-grained	.1
22. Siltstone, medium-dark-gray; weathers into small grains. F388 from float at river edge appears to be from upper part	6.0
21. Bentonite, light-yellowish-gray, weathered	.1
20. Siltstone, medium-dark-gray, as in unit 16	1.8
19. Sandstone, medium-dark-gray, platy; float shows sole marks	.1
18. Siltstone, as in unit 16. F375 (*Scaphites* sp.? (USGS Mesozoic loc. D3161) from middle of bed	.5
17. Sandstone, medium-dark-gray, fine-grained, platy	.1
16. Siltstone, medium-dark-gray, finely micaceous; bedding marked by partings of very fine grained dark-gray sandstone	3.0
15. Concealed; covered strata probably similar to enclosing beds	10.2
14. Siltstone, as in unit 13, but without pebbles	2.0
13. Siltstone, medium-dark-olive-gray, thinly and evenly laminated; one chunky bed, breaking with subconchoidal fracture; smoothly rounded isolated pebbles of black chert up to ¾ in. long	.5
12. Conglomerate; rounded black chert pebbles in matrix of fine- to medium-grained subangular olive-gray hard compact cherty sand; sparse pebbles of light-gray translucent quartz, soft light-olive-gray siltstone, and fragments of *Inoceramus* prisms; in the basal 1 in., thin flat pellets of soft dark-gray claystone and irregular laminae of medium-dark-gray siltstone with thin mud cracks filled with sand	0.2–0.4
11. Sandstone, light-olive-gray, fine-grained, laminated, soft, friable; salt-and-pepper appearance; sprinkling of fine brown mica (phlogopite?)	.3
10. Sandstone, as in unit 11, but more homogeneous and harder; contains thin pellets of medium-gray siltstone at base	.1
9. Siltstone, medium-dark-gray, soft, crumbly; in laminae ⅛–¼ in. thick; partings of harder lighter gray fine-grained sandstone, white efflorescence on edges of beds	1.3
8. Sandstone, medium-gray, very fine grained, hard, firm; thin ledge	.2
7. Siltstone, medium-dark-olive-gray, soft, finely micaceous, slightly calcareous	2.0
Total measured lower part of Kevin Shale Member	285.0–285.6
Disconformity(?)	
Ferdig Shale Member:	
6. Sandstone, light-olive-gray, fine-grained, subangular, cherty, compact, calcareous; *Cardium pauperculum, Ostrea sannionis* (?). F374 (USGS Mesozoic loc. D3160); F348 (USGS Mesozoic loc. D2612)	0.3–0.4
5. Sandstone, as in unit 6, but nonfossiliferous; beds in upper half are about 2 in. thick; those in lower half are ¼ in. thick	0.7–0.8
4. Sandstone, medium-light-olive-gray, fine-grained, calcareous; upper surface conglomeratic, with scattered flat pebbles of yellowish-gray fine-grained quartzite; base of bed irregular filling local relief on underlying unit	0.6–1.0
3. Sandstone, medium-light-olive-gray, fine-grained, angular to subangular, homogeneous and well-sorted, calcareous; about 20 percent dark grains; carbonized wood; firm beds 1 ft thick or more; equally thick assemblages of soft friable crossbedded ¼–½-in.-thick layers grading into one another horizontally, the whole making a conspicuous ledge	12.5
2. Sandstone, light-olive-gray; in ½–1-in.-thick layers; forms thick ledge	6.0

Marias River Shale—Continued
Ferdig Shale Member—Continued

	Thickness (feet)
1. Sandstone, light-olive-gray; in very thin flaggy layers; largely in bed of river. Base concealed, but total thickness probably not more than 15 ft	8.7±
Total measured Ferdig Shale Member	28.8–29.4
Total measured Marias River Shale	313.8–315.0

Base of sandstone (unit 1) is about 15 ft below unit 36 of measured section 33, which begins across the river.

35. Kevin Shale Member of the Marias River Shale in the south streambank of the Sun River, center N½NW¼ sec. 33, T. 22 N., R. 8 W.

[Measured by M. R. Mudge, J. J. Halbert, E. M. McKee III, and M. W. Reynolds]

Marias River Shale:
Kevin Shale Member:

	Thickness (feet)
26. Shale, with thin sandstone lenses and calcareous nodules, silty, calcareous, sandy, micaceous, dark-gray, finely cross-laminated. *Inoceramus platinus* 37 ft. above base, *Inoceramus labiatus* and *Scaphites* 26 feet above base, F86	29.8
25. Shale, silty with many thin sandstone beds, very fine grained; fault breccia zone in lower part, composed of shale and sandstone with baculites, F85	20.0
24. Shale, silty, slightly calcareous, dark-gray to medium-black, laminated to thinly laminated; limestone bed, 0.1—0.2 ft thick, 4.6 ft below top; concretionary zone with fossils 6.0 ft below top; a 0.1–0.2 ft bentonite bed 7.6 ft below top; badly fractured limestone concretions (0.4 ft or less across), some calcite filled, scattered throughout. F23 (USGS Mesozoic loc. D1129), 10.2 ft below top; fossil zone F24 (USGS Mesozoic loc. D1130) about 30 ft below top; *Inoceramus platinus* in shale, F24, near top and 11.0 ft below top	44.5
23. Shale, silty, with many siltstsone and very fine grained sandstone lenses in upper part, calcareous, dark-gray; weathers flaggy to platy; shale weathers flaggy to papery; sandstone and siltstones laminated; some cross-laminations; gastropod fragments in uppermost bed; *Inoceramus platinus*	24.0
22. Siltstone, noncalcareous, bentonitic, dark-gray to black, massive; weathers thin bedded to massive; bentonite beds 0.2 foot thick, 47.9 ft above base, 0.2 ft thick 24.2 ft above base, 0.4 ft thick 33.1 ft above base, and 0.2 ft thick 35.9 ft above base; contains a few thin fine-grained sandstone lenses, and limestone concretions	53.7

Marias River Shale—Continued
Kevin Shale Member—Continued

	Thickness (feet)
21. Bentonite, soapy, light-gray; many minute brown specks; blocky	1,2
20. Siltstone, noncalcareous, dark-gray; weathers flaggy to blocky; limestone concretions; organic burrows; bentonite bed 0.3 ft thick 6.5 ft above base; nodular limestone beds 7.5 ft and 11.5 ft above base; at 20.6 ft above base there is a zone of structurally deformed beds 11.6 ft thick; except for this zone, the unit is the same as unit 22	80.7
19. Sandstone, in three beds separated by siltstone; sandstone is calcareous; upper sandstone bed is bentonitic and 1.0 ft thick; lower bed is 0.6 ft thick, middle one is 0.2 ft thick; very fine grained; altered mica and white quartz; light gray; weathers blocky. Siltstone is noncalcareous and dark gray and weathers blocky. Bentonite, 0.3 ft thick, overlies lower sandstone unit. HS25	3.4
18. Same as unit 20, but much deformation of beds; two argillaceous nodular zones; 0.2-ft-thick iron-stained zone at top	17.8
17. Shale, silty, slightly calcareous, dark-gray, laminated to thinly laminated; siltstone and sandstone lentils are very thinly bedded with thin cross-lamination; *Inoceramus platinus*	16.0
(Note: Section continued on north side of S fold)	
16. Sandstone with interbeds of siltstone and silty shale, calcareous, gray; weathers yellowish gray; many 0.1–0..3-ft-thick beds of sandstone separated by sandy and silty shale; thicker silty shale zone in middle; thin distinct laminae; thin cross-lamination in some beds. Sandstone is very fine grained, micaceous; lentils of vitreous coal in upper part, as much as 4 in. long. Forms two resistant ledges separated by small indentation due to shale beds. This is lower part of *Clioscaphites vermiformus* zone	20.3
15. Shale, silty, grading down into siltstone, noncalcareous, gray, laminated; weathers medium gray; contains some 0.2–0.3-ft-thick sandstsone lentils; bentonite lenses, 0.1–0.3 ft thick, at 0.3, 1.4, 2.4, 2.8, 3.5, 6.5, 8.7, 15.9 and 21.0 ft above base; this unit is top of *Scaphites binneyi* and *Inoceramus stantoni* zone	28.8
14. Bentonite, noncalcareous, slightly sandy micaceous in lower part, yellowish-gray; weathers blocky; limestsone concretions and thin stringers of cone-in-cone secondary calcite; *Inoceramus* sp. fragments in concretions	1.4

Marias River Shale—Continued
Kevin Shale Member—Continued

	Thickness (feet)
13. Shale, silty and sandy, noncalcareous, finely micaceous, medium-gray; bentonite layers, 0.1 ft thick, at 6.5, 6.8, 7.2, 10.1, 11.1 ft above base; many limestone concretions; some cone-in-cone structure, 0.0–0.3 ft thick, in lower part; limestone concretions at 8.5 ft above base. F163 (USGS Mesozoic loc. D1476) from concretions	14.5
12. Sandstone, poorly indurated, calcareous, very fine grained, light-gray; mostly quartz; weathers yellowish gray	0.2–0.4
11. Shale, slightly calcareous, dark-gray, laminated; weathers medium gray; thin limestone concretions at 15.8 ft above base; thin bentonite beds at 5.6, 7.2, 8.8, 9.7, 10.6, 12.1, 12.3, 12.7, and 14.0 ft above base	16.4
10. Same as unit 11 (fault zone)	8.5
9. Shale, with thin sandstone lenses in upper part, calcareous, dark-gray, laminated; two 0.3 ft thick sandy, micaceous, bentonite beds in upper part; thin sandstone lenses and bentonite in lower half; bentonite beds are at 7.3 and 18.6 and 27.7 ft above base. F164 (USGS Mesozoic loc. D1477) at 25 ft above base; F165 at 27.0 ft above base	33.9
8. Fault zone; many folds and fractures; bentonite overlain by siltstone, noncalcareous; part of the underlying unit may be repeated by thrust fault	2.4
7. Shale, micaceous with micaceous bentonitic sandstone at top overlying thin sandstone lentils in upper part, noncalcareous, dark-gray, laminated; weathers medium gray. HS84 from top	1.5
6. Sandstone, bentonitic, micaceous, calcareous, very fine grained, light gray, very thin bedded; weathers yellowish gray; heavily iron stained in upper and lower parts	.8
5. Claystone, noncalcareous, dark-gray, massive; weathers medium gray; weathers shaly; fractures hackly; iron-stained limestone concretions and 0.1-ft-thick bentonite bed at base; concretions as much as 3 by 2 ft across; bentonite bed, 1.5 ft thick, 41.2 ft above base; limestone concretions 23.3 and 32.3 ft above base. F166 (USGS Mesozoic loc. D1478) collected at 33.7 ft above base	42.8
4. Shale, silty with many thin lenses of siltstone that form many small ledges, noncalcareous; small limestone concretions throughout; one concretion contains small phosphatic pebbles. This is MacGowan Concretionary Bed (bed f) and is the *Scaphites ventricosus* and *Inoceramus involutus* zone. F167 from 5.9 and 11.9 ft above base	25.2
3. Bentonite, micaceous, calcareous, light gray	1.0
2. Siltstone, slightly sandy in middle part, thin bentonitic beds in upper part, noncalcareous, dark-gray, massive; weathers medium gray; weathers with hackly fracture; septarian concretions throughout but more common in lower part. F168	45.0
1. Siltstone, finely micaceous, noncalcareous, dark-gray, massive; weathers medium gray; hackly fracture; limestone concretions, as much as 4 ft long, at top with secondary porous boxwork structure; bentonite seams 0.1 ft thick above and below concretions. Five bentonite seams in upper part; bentonite bed 0.3 ft thick, at base. Many small cobble-size concretions, some heavily iron stained; concretions weather dark yellowish orange; some light-brown bentonite zones are micaceous; iron-stained limestone concretions in lower half; large limestone concretions 30 ft above base (F116, USGS Mes. loc. D1475, collected from these). (F115, collected 101.4 ft above base.) Many minor flexures throughout the section. At 81.0 ft above base, iron-stained limestone concretionary zone containing secondary boxwork zone. At 112 ft above base is concretionary zone with bentonite bed 0.1 ft thick	134.7
Total measured Kevin Shale Member	668.5–668.7

End of section; distorted beds of lower part of Kevin Shale Member.

36. *Lower part of Telegraph Creek Formation and upper part of Kevin Shale Member of Marias River Shale as exposed at station 76 in a deep cut for the Pishkun irrigation canal in center of NW1/4 sec. 28 T. 22 N., R. 8 W., Castle Reef quadrangle*

[Section begins at east end of cut at a high-angle thrust fault which has placed the middle member of Telegraph Creek Formation against the Virgelle Sandstone. Measured by M. R. Mudge, R. M. Mudge, and R. J. Mudge]

Virgelle Sandstone.
Thrust fault.
Telegraph Creek Formation:
Middle member:

	Thickness (feet)
19. Sandstone with some siltstone, very fine grained, dense, hard, calcareous, dark-gray; weathers yellowish gray; in beds 0.3–1.0 ft thick; weathers slabby to platy; organic burrows and trails. HS113 from basal bed	141.1
Total remaining middle member	141.1

Telegraph Creek Formation—Continued *Thickness (feet)*

Lower member:

18. Sandstone, like unit 16 but with less siltstone; in beds 0.3–1.0 ft thick; correlates with unit 4 of section 37 — 16.8
17. Sandstone, like unit 16; beds somewhat lenticular; carbon specks and wood fragments — 38.2
16. Sandstone, and thin siltstone lenses, fine- to very fine grained, calcareous, dark-gray, very thin bedded, thinly cross-laminated; coarser grained and thicker bedded than underlying unit; carbon specks. HS112 from 4.9 ft above base — 52.3
15. Sandstone, with fewer siltstone interbeds than underlying unit, calcareous, dark-gray, very thin bedded; weathers yellowish gray; thicker bedded than underlying unit; forms small ledges; carbonaceous debris — 37.5
14. Sandstone, and interbedded siltstone, very fine grained, calcareous, very micaceous, dark-gray; siltstone beds are darker than sandstone beds and weather yellowish gray; very thinly bedded; thinly cross-laminated; minute wood fragments; transitional lower contact — 25.1

Total lower member — 169.9

Total exposed Telegraph Creek Formation — 311.0

Marias River Shale:

Kevin Shale Member:

13. Siltstone with many thin interbeds of very fine grained sandstone, like unit 11; limestone nodules 59.7 ft above base; abundant minute spines and *Ostrea* sp. HS115 from shale 80 ft above base. F198 from 76.7 above base; F197a, *Ostrea congesta* Conrad — 121.8
12. Bentonite, very light gray — .3
11. Sandstone, with interbedded siltstone, very fine grained, calcareous, minutely micaceous, hard, dense, alternating light- and dark-gray, very thin bedded, thinly cross-laminated; more resistant than adjacent units — 24.2
10. Shale with many siltstone lenses, silty, noncalcareous, dark-gray with olive-gray zones, thin-bedded; 0.1–0.2-ft-thick bentonite beds at 25.6, 20.4 and 16.1 ft above base — 35.3
9. Bentonite, calcareous, like unit 7 — .9
8. Siltstone, like unit 6; 0.4-ft-thick bentonite bed 14.5 ft above base — 17.1
7. Bentonite, very light gray, very thin bedded; iron stained in lower part — 1.2
6. Shale, with many slightly calcareous siltstone lentils. Shale is silty, noncalcareous, dark gray, and thin bedded and weathers to

Marias River Shale—Continued *Thickness (feet)*

Kevin Shale Member—Continued

medium gray. Bentonite beds 0.1–0.3 ft thi·k at 29.1, 22.4, 7.5, and 5.8 ft above ba··; five thinner bentonite beds at otl·er horizons. HS116 from shale 12 ft above base — 36.7

5. Sandstone, very bentonitic, micaceous (phlogopite?), very fine grained, light-gray; weathers very light gray and granular; stringer of petroliferous dark-gray claystone 1.4 ft above base — 1.8
4. Shale, with thin very fine grained sandstone and siltstone lentils that weather platy, silty, noncalcareous, dark-gray; some siltstone lentils are calcareous; laminated limestone nodules 24.2 ft above base — 29.1
3. Bentonite, shaly, calcareous, dark- to me-dium-gray, granular — 1.1
2. Shale, silty, noncalcareous, dark-gray, lari-nated; some 1/2-in.-thick beds of very fi·e grained sandstone; minor normal fault 1[illegible].9 ft above base — 16.0
1. Three bentonitic sandstone beds separated by siltstone. Sandstone is very bentonitic, micaceous (phlogopite?), very fine grained, and light gray and iron stains and secondary calcite occur in lowest sandstone b·d (HS109). HS110 from middle sandstor·. Siltstone is noncalcareous, dark-gray, ma·s-sive and fractures hackly. To the west tl is set of beds is repeated six times by high-angle normal faults; correlates with ur·it 19 of section 35 — 4.3

Total measured Kevin Shale Member — 289.8

Total measured Marias River Shale — 289.8

37. *Two Medicine Formation, Virgelle Sandstone, and Telegraph Creek Formation in the north streambank of the Sun River, SE1/4SW1/4 sec. 28, T. 22 N., R. 8 W*

[Measured by M. R. Mudge, J. J. Halbert, and E. B. McKee III]

Two Medicine Formation: *Thickness (feet)*

63. Shale, purple and gray-green; some green sandstone lenses in lower part — 10.0±
62. Sandstone, fine to very fine grained, calcareous, medium-hard to soft; mostly quartz and chert; middle part is especially soft; yellowish gray with grayish-green tint; weathers yellowish gray; massive to thin bedded with some shale partings; some crossbedding; weathers platy to loose sand; shale nodules in upper part; carbon-stained wood fragments and carbon stains in upper part; upper and lower parts form ledges. HS807 from near top; HS806 from near base — 74.0
61. Shale, sandy, noncalcareous, grayish-green, thin-bedded to laminated — 5.0

Two Medicine Formation—Continued	Thickness (feet)
60. Sandstone, very fine grained, medium-hard to soft, green grains, noncalcareous, grayish-green, massive; interbeds of sandy shale; weathers platy to loose sand. HS805 from near top	14.7
59. Mostly covered, but present in the middle part is a dark-gray-brown noncalcareous massive mudstone with many fragments of carbonized wood	43.0
58. Sandstone with sandy shale (partly covered). Sandstone is fine to medium grained, soft, thin bedded, slightly calcareous, and green and contains abundant green grains. Conglomerate at 23 ft contains dacite and andesite pebbles; most fragments are granule of green and red quartzite and green argillite from Belt Supergroup. Sandstone weathers blocky to loose sand and is locally platy. HS23 from conglomerate; HS24 from sandstone	30.0
57. Sandstone, very fine grained, hard, slightly calcareous, dark-gray, massive; weathers blocky and platy	1.0
56. Shale, clayey, noncalcareous, dark-gray, laminated	3.2
55. Sandstone, very fine grained, slightly calcareous, hard, gray, massive; weathers blocky and grayish brown	1.3
54. Shale, silty, noncalcareous, gray, laminated	1.2
53. Bentonite, light-yellowish-gray, thin-bedded; iron stained at top	.3
52. Shale, sandy with sandstone lenses in lower part grading up into silty shale, noncalcareous, light-gray-green, laminated; slightly calcareous in lower part; sandstone weathers blocky; uppermost shale bed is 0.5 ft thick, clayey, and somewhat bentonitic. HS804 from sandstone	14.3
51. Sandstone, very fine grained, slightly calcareous, light-gray, massive; weathers yellowish gray; many minute laminae; weathers blocky to platy; iron-stained surface. This unit and underlying sandstone form small cliff on both sides of river and a small waterfall in river	4.4
50. Shale, sandy with sandstone lenses, calcareous, fine to very fine grained, gray; weathers yellowish gray. Shale is laminated to thinly laminated and contains a carbon-stained zone. Sandstone is massive to very thin bedded. Sandy shale contains elongate slivers of clayey shale that leave small cavities when weathered	2.8
49. Sandstone, fine grained, calcareous, light-gray; composed of colorless quartz, chert, and feldspar; weathers yellowish gray; massive with very fine laminae; weathers blocky to platy; finely crossbedded; nodular in lower part; contains thin elongate fragments of shale that weather out imparting a porous appearance. HS803 from near base	13.5
48. Upper two-thirds mostly covered but contains some fine grained thin-bedded sandstone; lower one-third is shale, clayey, noncalcareous, gray to olive-gray, laminated	75.0
47. Shale, silty, slightly carbonaceous, noncalcareous, laminated; dark-gray-green lenses	3.0
46. Shale, silty, noncalcareous, yellowish-gray; heavily iron stained in upper and lower parts	2.5
45. Sandstone, soft, fine grained, light-gray, thin-bedded; composed of rounded to subangular quartz, feldspar, chert, and some greenish-gray grains; weathers light gray except in upper part which weathers yellowish gray; some crossbedding; upper part contains 0.5-ft-thick zones of sandy shale spaced 3–4 ft apart; contains two thin zones in lower part with fragments of gray clayey shale; forms small bluff on south side of river, but not apparent in smooth slope on north side of river. HS802 from 2 ft below top	15.0
44. Shale, clayey, noncalcareous, dark-gray; weathers thin bedded to blocky	6.5
43. Sandstone, very fine grained, noncalcareous, dark-grayish-green; weathers light grayish green; weathers blocky; prominent only on south side of river	2.1
42. Sandstone with many sandy shale partings especially in lower two thirds, slightly calcareous, fine grained to very fine grained, light- to medium-gray, thin bedded; some medium-hard to soft sandstone nodules; weathers platy to blocky; in places minutely crossbedded; grades into overlying unit	11.2
41. Sandstone, poorly indurated, fine grained, light-gray, thinly bedded; some medium grains; mostly quartz and feldspar, some black chert and greenish-gray grains, well rounded to subangular; weathers yellowish gray; very crossbedded; some sandstone nodules; some iron-stained lenses and nodules; some carbon-stained zones; small wood fragments; resembles Virgelle Sandstone; forms a prominent bluff and ridge on south side of river, but is less prominent on north side; grades into overlying unit. HS22	78.0
40. Sandstone with interbedded shale, slightly calcareous, very fine grained, light-gray, platy; some organic burrows(?)	9.0

	Thickness (feet)
Two Medicine Formation—Continued	
39. Covered; probably shale with thin sandstone lenses	38.5
38. Sandstone, fine-grained, calcareous, thin-bedded, crossbedded; mainly colorless quartz, some feldspar, and chert; local zones are heavily iron stained; large concretion 3.0 ft in diameter in lower part. F17, in lower part, petrified log 2.8 ft in diameter at base. HS18	33.2
37. Shale, clayey, calcareous, olive-gray to grayish-green; laminated; contains limestone concretions stained brown in upper 2 in.; five carbonaceous zones, 0.5–1.0 ft thick, spaced about 2–3 ft apart; carbonaceous shale is thinly laminated	21.5
36. Shale, petroliferous, carbonaceous, dark-gray to black, laminated to thinly laminated	5.0
35. Shale, clayey, noncalcareous, olive-gray, thin-bedded; lenses of dark gray; weathers blocky	3.0
34. Partly covered; sandstone at top and base. Upper sandstone is fine grained, calcareous, and stained brown and weathers blocky; basal sandstone is fine grained, calcareous, light gray, and thin bedded	12.0
33. Sand, poorly indurated; contains thin platy lentils of fine-grained yellowish-gray sandstone	1.0
32. Shale, carbonaceous, noncalcareous, dark-gray, laminated	.5
31. Partly covered. Upper 5.0 ft contains fine-grained sandstone composed of colorless quartz with some black chert and is noncalcareous, thin bedded and crossbedded. Similar to unit 28 at base	10.0
30. Shale, carbonaceous, with clayey shale in middle part, noncalcareous, dark-gray to black, thinly laminated	1.8
29. Covered. Top of covered interval contains very fine grained noncalcareous, grayish-green to olive-gray, nodular, iron-stained sandstone	10.0
28. Shale, slightly petroliferous, very carbonaceous, noncalcareous, dark-gray to black, thinly laminated	1.6
27. Sandstone, soft, fine-grained, calcareous, light-gray, thin-bedded, crossbedded; mostly colorless, quartz, chert, and green translucent grains; forms small bench	7.5
26. Shale (mostly covered), sandy	8.9
25. Shale with sandstone lenses, sandy, calcareous, fine-grained, light-gray, laminated; weathers light gray with yellow tint. Sandstone is ripple marked and thin bedded	5.0
Total Two Medicine Formation exposed	580.5

	Thickness (feet)
Virgelle Sandstone:	
24. Sandstone, fine-grained, calcareous, light-gray, crossbedded, thin-bedded; composed of colorless quartz and some chert, locally very micaceous, some green grains of glauconite(?); contains many sandstone concretions and nodules, some are heavily iron stained and more resistant to erosion, and leave pedestal-type erosional remnants. In uppermost bed are rounded clay balls and local carbon stains. Sandstone forms prominent bluff. Fossiliferous bed 110 ft above base, 4 ft thick, F15; at 80 ft above base a coquina zone about 2 ft thick, F16 (USGS Mesozoic loc. D1127)	149.0
Total Virgelle Sandstone	149.0
Telegraph Creek Formation:	
Upper member:	
23. Sandstone with many beds of sandy shale, fine-grained, calcareous, soft, light-gray, very thin bedded; weathers platy; crossbedded and ripple-marked; spheroidal weathering; dark thinly laminated shale in lower part. F14 at 38 ft above base	74.0
22. Sandstone, fine-grained, light-gray, calcareous; and colorless quartz, weathers yellowish gray; upper 2 ft contains sandy shale and thin sandstone beds; massive in lower 2 ft, which is ripple marked; organic burrows	4.1
Total upper member	78.1
Middle member:	
21. Sandstone, platy with sandy shale partings, fine-grained, calcareous, light-gray; many thin laminae; weathers platy in lower part and shaly in upper part; base forms overhanging ledge and contains organic burrows and carbon stains; thin zone in middle contains rounded pebbles of yellowish-gray sandstone, none exceeds 0.3 ft across; lower sandstone is conglomeratic	6.5
20. Sandstone and nodular shale, calcareous, fine-grained, gray; colorless quartz and fragments of chert; weathers yellowish gray; weathers blocky and nodular; organic burrows; sandstone is thinly bedded	14.6
19. Sandstone, fine-grained, calcareous, dark-gray; weathers yellowish gray; massive with some nodular beds; wood fragments; organic burrows	4.7
18. Sandstone with many sandy shale partings, very thin bedded, calcareous, nodu-	

Telegraph Creek Formation—Continued

Middle member—Continued

	Thickness (feet)
lar, very fine grained, lenticular; beds less than 0.3 ft thick. Upper 3 ft is somewhat coarser grained, and massive, weathers shaly, and forms indentation in hillside; carbon and organic burrows abundant	12.5
17. Sandstone with many thin beds of sandy shale and partings of siltstone, calcareous, fine-grained, gray, thin-bedded; weathers blocky; organic burrows, carbon stains, and wood fragments abundant	12.9
16. Sandstone, hard, calcareous, fine-grained, very micaceous in upper part, gray, massive; weathers platy; upper surface contains abundant organic burrows, some extending vertically	1.2
15. Sandstone with many shale partings, calcareous, dark-gray. Sandstone is thin-bedded, weathers slabby to nodular, and contains abundant carbon-stained wood fragments and organic burrows; uppermost bed ripple marked	4.7
14. Shale, silty, calcareous, dark-gray, massive. fine-grained sandstone lenses which are partly nodular occur in upper part. Unit weathers blocky in upper part, is thin bedded in lower part, and contains vertical organic burrows throughout	2.8
13. Sandstone, very fine grained, calcareous, gray; massive with many laminae apparent; weathers blocky	.5
12. Sandstone, argillaceous, very fine grained, calcareous, dark-gray; upper part weathers thinly bedded, lower part massive and nodular	1.2
11. Sandstone with silty shale partings, calcareous, gray; shale darker gray; sandstone weathers blocky to platy; sandstone nodular in middle part; carbon stains abundant; some organic burrows	4.9
10. Sandstone, very hard, very fine grained, calcareous, dark-gray; massive with minute laminae apparent on weathered surface; weathers blocky; iron-stained surface; some carbon stains	1.0
9. Siltstone with argillaceous sandstone, calcareous, thinly laminated, dark-gray; in lower part nodular sandstone with abundant concretions, some 1.0 ft across; upper part weathers shaly; lower part weathers blocky; carbon stains abundant	2.6
8. Sandstone, calcareous, very fine grained, gray; very thin laminae apparent on weathered surface; weathers blocky; iron stains on exposed surface	.3
7. Sandstone, argillaceous, with sandy shale partings and interbedded sandstone, fine-grained, calcareous, dark-gray; weathers blocky to slabby; sandstone beds less than 0.5 ft thick, nodular, and thin bedded; carbon stains and wood fragments common	7.1
6. Sandstone, very fine grained, calcareous, gray; massive with many thin laminae apparent on weathered surface; upper part fractures hackly with argillaceous appearance; lower part weathers platy; many calcareous nodules in upper part	1.5
5. Siltstone to very fine grained sandstone, calcareous, dark-gray; fractures hackly; thin nodular sandstone lenses near top; shale between upper sandstone and overlying unit, wedges out toward east end of cut; large concretions in lower part	5.9
Total middle member	84.9
Lower member:	
4. Sandstone, calcareous, very fine grained, slightly micaceous, gray to yellowish-gray, massive; fractures hackly; nodules	2.5
3. Sandstone with many sandy shale partings, similar to sandstone in unit 1, dark-gray, thinly laminated; weathers platy; locally massive bed at base; iron stains on fractures; some carbon stains and wood fragments	3.8
2. Sandstone, very fine grained, slightly calcareous, dark-gray, massive; weathers blocky; badly fractured; some sandstone nodules and lenses that weather to form indentation along cut	3.2
1. Shale, sandy, with many thin interbeds of sandstone less than 1.0 ft thick and averaging 0.1–0.3 ft thick, calcareous, very fine grained, dark-gray, laminated to thinly laminated; sandstone mostly weathers in very thin plates; some minute crossbedding; some sandstone nodules; carbon-stained wood fragments and carbon stains abundant; Thin bentonite bed 87.5 ft from top. Lower 8.5 ft measured was exposed by digging; base covered. F88, 26.1 ft from top; F89 (USGS Mesozoic loc. D1128), 64.8 ft from top	93.5
Total exposed lower member	103.0
Total exposed Telegraph Creek Formation	272.0

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U. S. GOVERNMENT PRINTING OFFICE : 1972 O - 426-778