1967

Geology of Ford Creek area Sawtooth Range Montana

Peter Michael Langfield

The University of Montana

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GEOLOGY OF FORD CREEK AREA
SAWTOOTH RANGE, MONTANA

by

Peter M. Langfield
B. A. University of Montana, 1962

Presented in partial fulfillment of
the requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA
1967

[Signatures]

Chairman, Board of Examiners

Dean, Graduate School

OCT 10 1967
Date
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ABSTRACT

The Ford Creek area is located in the Sawtooth Range, 20 miles southwest of Augusta, Montana, and covers an area of about 38 square miles. Exposed sedimentary formation total about 5,860 feet in thickness and are mainly Precambrian to Cretaceous in age. Igneous rocks of probable pre-Laramide age are represented by a quartz diorite sill in Precambrian rocks in the northwestern part of the map area, and by a quartz diorite to diabase sill in Devonian rocks in the southcentral part of the map area.

The oldest rocks exposed belong to the Ahorn Formation of the late Precambrian Belt Supergroup. They consist of thin-bedded red argillite, and have an exposed thickness of about 400 feet. Approximately 1,800 feet of Middle and Upper Cambrian rocks, consisting of a basal sand, shale and thin to massively-bedded carbonates disconformably overlie the Ahorn Formation. The Devonian System consists of about 1,000 feet of carbonate rocks that disconformably overlie the Cambrian System. The Madison Group of Mississippian age is about 1,300 feet thick and consists of a lower limestone unit and an upper dolomite unit. Three hundred and twenty feet of marine Middle and Upper Jurassic rocks of the Ellis Group, and 195 feet of non-marine Upper Jurassic rocks of the Morrison Formation are overlain by 900 to 1,000 feet of non-marine Lower Cretaceous rocks of the Kootenai Formation. Quarternary glacial and stream deposits occur in valleys occupied by major drainages.
Normal and thrust faults are the major geologic structures in the map area. All faults trend northwest and dip to the southwest. Based on the intensity of deformation, the area of present study is divided into a southwestern area, a central closely folded area and a northeastern area. The southwestern area lies west of the Lewis thrust, and is characterized by broad, gentle and nearly symmetrical folds in Precambrian and Paleozoic rocks, and by thrust faults. The Lewis thrust and a thrust fault in Precambrian rocks in the extreme southwest corner of the map area dip between 45 and 50 degrees to the southwest, and have stratigraphic throws which exceed 5,000 feet.

The central closely folded area lies between the Lewis thrust and the North Fork of Ford Creek. This area is characterized by westward-dipping normal and thrust faults, and by tight, overturned and doubly plunging folds in Cretaceous and Jurassic rocks. Four thrust faults and two normal faults occur in this area. The thrusts in Devonian and Mississippian rocks dip between 38 and 50 degrees to the southwest, and have stratigraphic throws of about 2,800 feet. A thrust in Mesozoic rocks dips between 50 and 60 degrees to the southwest and has a stratigraphic throw of about 700 feet. Normal faults near the North Fork of Ford Creek and at Wood Lake dip between 50 and 60 degrees to the southwest, and have dip slips of 500 and 1,500 feet respectively.

The northeastern area lies east of the North Fork of Ford Creek, and is characterized by low-angle thrust faults and by gentle to overturned folds. Two thrust faults in Mississippian rocks dip 35 and 41 degrees to the southwest and have stratigraphic throws of about 2,800 feet.
Three phases of Laramide deformation are recognized in the map area:
(1) an early compressional phase which first produced folding, followed
by imbricate thrusting as compression continued, (2) a phase of relaxa-
tion of compressive forces which resulted in normal faulting, and (3) a
renewed compressional phase which produced thrusts that overrode earlier
developed structures.
INTRODUCTION

Location and Accessibility

The area mapped embraces approximately 38 square miles and is located near the eastern front of the Sawtooth Range, approximately 20 miles southwest of Augusta, Montana (Figures 1 and 2). The eastern map boundary coincides with the Lewis and Clark National Forest Boundary.

The Ford Creek area is accessible via the Willow Creek Road, Smith Creek Road and Bench Mark Road from Augusta, but only the latter traverses the mapped area. The section of the Bench Mark Road within the Lewis and Clark National Forest is maintained during the spring, summer and early fall, but is impassible during the winter months due to snow conditions. Forest Service trails, which follow major drainages, provide access to the more remote parts of the area.

Previous Work

The first significant study in the Sawtooth Range was by Stebinger (1918), who mapped the Birch Creek-Sun River area to determine the oil and gas prospects. Bevan (1929) described the structure of the Sawtooth Range as a zone of overthrust blocks that resemble the structure of the Scottish Highlands. Deiss
Figure 1 - Index map showing location of map area (shaded) in Montana
Figure 2 - Index map showing area of study and physiographic features
(1933, 1935, 1936, 1938, 1939, 1943a,b) published papers on the structure, stratigraphy and Cambrian trilobites of the Flathead, Lewis and Clark, and Sawtooth Ranges (Figure 3), and mapped most of his area of study, but the maps were never published. Clapp (1932-1933) and Deiss (1933) mapped most of the Coopers Lake quadrangle and carried the mapping north into the Saypo quadrangle (Figure 3). Clapp (1932) published a geologic map of northwestern Montana on the scale of 1:500,000. Sloss and Laird (1945, 1947) published papers on Devonian and Mississippian stratigraphy of northwestern Montana. Sloss (1946, 1950) published a paper on Devonian stratigraphy of western Montana and a paper on Paleozoic sedimentation in the Montana area. Andrichuk (1955) studied Carboniferous stratigraphy in northwestern Montana and southwestern Alberta. Mudge (1959) published a brief summary of the geology of the Sun River area and Mudge, et al. (1962) mapped and described Mississippian rocks in the Sun River Canyon area. Cobban (1945) studied Jurassic stratigraphy in Montana, and designated areas in the Sawtooth Range as type localities for the formations of the Ellis Group.

Present Study

Approximately 50 days were spent in the field between June and August of 1963. Geologic data were plotted on U.S. Forest Service aerial photographs at scale 1:20,000, flown in 1956 and on U.S.
Figure 3 - Map showing location of (1) Saypo, (2) Silvertip, (3) Ovando, and (4) Coopers Lake quadrangles; Sawtooth Range (shaded), Lewis and Clark and Flathead Ranges. Ford Creek area is shown in solid black.
Forest Service planimetric maps at a scale of 2 inches to the mile. Photo data were later transferred to the planimetric maps by inspection. The Coopers Lake quadrangle sheet was used for elevation control in constructing cross sections. Except for two traverses by saddle horse to the extreme southwest corner of the area, the area was traversed on foot to determine the geology.

Laboratory investigations include the examination of rock samples under a binocular microscope and the study of 20 thin sections. The rock classification used is that of Pettijohn (1959). Rock colors were determined from a Rock Color Chart (Goddard, et al. 1951) on dry cut surfaces.

Acknowledgements

I am grateful to Dr. R.M. Weidman for suggestions made during the period of field work, and for his critical reading of this manuscript. Thanks are also extended to Dr. D. Winston for his assistance with the sedimentary petrography. Comments and suggestions by Dr. J.P. Wehrenberg have greatly aided in completion of the work.
The Sawtooth Range is a series of closely spaced, northwest trending parallel ridges that stand 2,000 to 3,000 feet above the plains to the east. It is 2 to 13 miles in width, 85 miles in length, and is slightly convex toward the plains. The map area is located near the eastern front of the range, and is approximately 15 miles north of its southern terminus (Figure 3).

Crown and Cyanide Mountains are the highest points in the map area, having elevations of 8,400 feet and 7,800 feet respectively; most of the other ridges and intervening valleys range between elevations of 6,000 and 7,000 feet. The lowest elevation, 4,950 feet, is located where Ford Creek leaves the map area on the east.

The northwest-southeast drainages in the map area are structurally controlled, having patterns of the fault-trellis type. The major structural features trend northwest, and these structures had a marked effect on the development of subsequent drainage patterns. Ridges between tributaries of the major drainages are composed mainly of limestone of the Madison Group whereas the intervening valleys are underlain by less resistant mudstones and sandstones of Jurassic and early Cretaceous age.

The northwesterly flowing streams follow the strike of the strata and occupy relatively broad valleys which are the result of
differential erosion along faults or along soft non-resistant beds. The course of Straight Creek is controlled by differential resistance of Cambrian carbonates whereas Wood Creek occupies a fault-line valley (Figure 8), which is also a strike valley (Thornbury, 1961, p.114). Crown Creek follows the axis of a breached anticline for several miles and drains into Straight Creek west of the map area.

The easterly flowing Willow, Ford, Petty and Smith Creeks follow courses transverse to geologic structures and form deep canyons in the massive Madison fault blocks. Similar drainage patterns are found elsewhere on the east flank of the Sawtooth Range; Mudge (1959, p.18) states that the Sun River Canyon is joint controlled and is incised along a zone of weakness.

Glaciation

Evidence of Pleistocene glaciation occurs in the map area, and studies by Alden (1932) indicate that the Sawtooth Range and the plains adjacent to the range front have been glaciated. He has shown that north-trending moraines located approximately 5 miles east of the map area (Figure 4) were deposited by the large Sun River Piedmont Glacier that covered an area of more than 200 square miles. Glaciers occupied east-west trending canyons in the range, spread out onto the plains, and coalesced into the piedmont glacier.

Valley glaciers occupied headwater branches of Smith, Petty and
Figure 4 - Map showing direction of ice flow in the map area. Glacial geology east of map area after Alden, 1932.
Willow Creeks and overrode the tops of lower mountains, producing U-shaped canyons that widen abruptly at the range front. In the lower reaches of these canyons, postglacial streams cut 100 to 150 foot deep V-shaped notches in the canyon floors. The Ford Creek drainage was glaciated in its upper reaches where it leaves Alpine Lake, and along its northwesterly course. The creek leaves Alpine Lake, a cirque lake, through a hanging valley and flows northwesterly for about a mile in a tight valley. It then swings sharply to the east and enters a deeply incised V-shaped canyon on its southeasterly flow to the plains (Figure 4). This part of the drainage has not been modified by glaciers. Approximately one mile east of the map boundary and out on the plains, Ford Creek occupies a broad U-shaped channel that has been scoured by ice tongues advancing east from drainages to the north and south (Figure 4).

Small cirques are present near the summit on the east and west sides of Crown Mountain and on the northwest side of Cyanide Mountain. Poorly preserved morainal and terrace deposits consisting of till, silts and gravels were noticed on the north bank of Petty Creek and along the Willow Creek Road. Erratics consisting of Madison limestone and Kootenai sandstone were noticed in the vicinity of Nilon Lake.

The exact time in the Pleistocene when the first glaciation occurred in the Sawtooth Range is not known, but Alden (1932) infers that at least two stages of glaciation had occurred. This inference is made on the basis of an outer and inner moraine present on the plains west of Augusta.
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<th>THICKNESS FT</th>
<th>LITHOLOGY</th>
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</thead>
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<tr>
<td>Quaternary</td>
<td>Recent</td>
<td>Alluvium</td>
<td></td>
<td>Silts, Sand and gravel restricted to valley bottoms and plains east of the mountain front; Not differentiated from glacial drift.</td>
</tr>
<tr>
<td>Pleist.</td>
<td>Glacial drift</td>
<td></td>
<td></td>
<td>Unconsolidated fluvi-glacial sand and gravel, poorly preserved morainal deposits along east-draining streams; Not differentiated from alluvium.</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>Lower</td>
<td>Kootenai</td>
<td>900-1000</td>
<td>Lower part consists of light brownish gray, fine to medium grained sandstone interbedded with reddish brown silty limestones and mudstones, overlying grayish brown clay and calcareous sandstone interbedded with green shales. In middle a 15 to 20 foot unit of chert pebble conglomerate is interbedded with the shales. Upper interbeds of gray, coarse-grained, cross-bedded sandstone.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Unconformity</strong></td>
</tr>
<tr>
<td></td>
<td>Upper</td>
<td>Morrison</td>
<td>195</td>
<td>Alternating mudstones and lenticular beds of light olive green thin-bedded sandstones. Lower part consists of greenish gray, nodular weathering argillaceous limestone in beds 6 inches to 1 foot thick. Nonmarine invertebrate fragments.</td>
</tr>
<tr>
<td>Jurassic</td>
<td></td>
<td>Swift</td>
<td>115</td>
<td>Medium light gray, silty and calcareous, slightly micaceous shales in the lower part overlain by light brownish gray, fine-grained, slightly calcareous, limy sandstone, water-worn relicts in lower part.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rierdon</td>
<td>150</td>
<td>Medium light gray, fissile and chunky calcareous shales that weather grayish orange from 4 to 8 inch thick beds of medium gray, nodular limestone that contains abundant fossils, especially Gryphaea.</td>
</tr>
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<td>Middle</td>
<td></td>
<td>Sawtooth</td>
<td>55</td>
<td>Light brownish gray, fine-grained, limy limestone. Calcereous sandstone in the lower part overlain by alternating medium light gray, fissile and sandy, silty and clayey shales, some of which are calcareous. Upper part consists of light gray, thin-bedded calcereous siltstones.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Unconformity</strong></td>
</tr>
<tr>
<td>Mississippian</td>
<td>Group</td>
<td>Castle Reef</td>
<td>1200-1300</td>
<td>Light brownish gray to medium gray, thick and thin reded, fine to medium grained limestone and dolomitic limestone. Abundance of irregular lenses and nodules of bedded chert; Fossiliferous.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Allan Mtn.</td>
<td>1000</td>
<td>Upper part consists of interbedded yellowish gray, fine to medium grained limestone, and pinkish gray poorly fossiliferous dolomite. Middle part consists of yellowish gray, fine grained limestone and olive gray dolomites. Lower part consists of pale red dolomitic shales and mudstones interbedded with argillaceous dolomite.</td>
</tr>
<tr>
<td>Devonian</td>
<td>Upper</td>
<td>Undifferentiated</td>
<td>350</td>
<td>Pale red, light brown and very pale orange fine to medium grained limestone and dolomite. Middle part is massive, upper and lower parts thin reded with beds less than 2 feet thick.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Devills Glen</td>
<td>85</td>
<td>Green and gray fissile and nodular shales, locally calcareous and silty interbedded with thin beds of gray dolomite that weathers pale red.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Devills Glen</td>
<td>275</td>
<td>Yellowish brown, massively reded and banded fine grained limestone, slightly noduled light brown by clay partings interbedded with grayish orange pink, fine to medium grained, massively reded dolomite. Upper part consists of yellowish gray, fine to medium grained, thin reded dolomitic limestone.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pageda</td>
<td>300</td>
<td>Light olive gray, fissile and nodular shales overlain by light brownish gray fossiliferous limestone in lower part, and light gray, dolitic, fossiliferous, massively reded limestone in upper part; weathers very light gray.</td>
</tr>
<tr>
<td>Cambrian</td>
<td>Middle</td>
<td>Dearborn</td>
<td>275</td>
<td>Grayish green, fissile, micaceous and calcareous shales interbedded with light gray thin-reded limestone in lower part, and greenish gray, fine to medium grained fossiliferous limestone in upper part; upper part massively reded.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Damnation</td>
<td>100</td>
<td>Pale blue and grayish blue, irregularly and thin-reded limestone in the lower part, and pale yellowish brown limestone in the upper part; light brown clay partings conspicuous throughout formation.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gordon</td>
<td>220</td>
<td>Greenish gray fissile and micaceous shales interbedded with greenish gray sandstone lenses in lower part overlain by pinkish gray, fine to medium grained cross-reded sandstones. Upper part consists of olive gray fissile shales interbedded with thin reded, fossiliferous limestone.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flathead</td>
<td>113</td>
<td>Pinkish gray to pale red purple, coarse-grained, poorly sorted, cross-reded, silica cemented sandstone; contains well rounded quartz pebbles up to one-half inch in diameter.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ahorn</td>
<td>400</td>
<td>Grayish red and greenish gray thin-and thick-reded argillites in the lower part, that grade upward to very thin-reded grayish red argillites, interbedded with 1 to 2 inch thick beds of medium to coarse grained, poorly sorted reddish sandstones. Base not exposed.</td>
</tr>
</tbody>
</table>

**Table 1.** STRATIGRAPHY

**Ford Creek Area**
STRATIGRAPHY

General Statement

Sedimentary rocks of late Precambrian, Paleozoic and Mesozoic ages are exposed in the map area. A quartz diorite sill and a diabase sill occur in the western part of the map area. The Precambrian rocks exposed belong to the Belt Supergroup, and consist of approximately 400 feet of thin-bedded argillites that occur in the southwestern part of the area on the northeast limb of Crown Mountain Syncline.

Overlying the Belt rocks are about 1,800 feet of Middle and Upper Cambrian shale and limestone, and approximately 1,000 feet of Upper Devonian limestone and dolomite. Approximately 1,300 feet of Mississippian carbonate rocks are exposed in the central and northeastern parts of the area. They have been thrust over Mesozoic rocks, and form a series of north to northwest-trending parallel ridges. Middle and Upper Jurassic marine rocks 320 feet thick, and 195 feet of Upper Jurassic nonmarine rocks are exposed in the central and northeastern part of the map area. Approximately 900 to 1,000 feet of nonmarine Lower Cretaceous rocks overlie the Jurassic rocks. Glacial debris and alluvium occupy drainage bottoms throughout the area.
Precambrian (Belt Supergroup)

Ahorn Formation: The Ahorn formation is approximately 2,100 feet thick in the western part of the Saypo quadrangle where it was originally described by Deiss (1943, p. 217), but only the upper 400 feet are exposed on the northeast flank of Crown Mountain syncline in the southwestern part of the map area (Figure 5).

The lower two thirds of the exposed sequence consists of grayish red (5R 4/2) and greenish gray (5GY 6/1) thin-bedded to fissile argillites that grade upward to very thin-bedded grayish red argillites. Sun cracks and ripple marks occur throughout this sequence. The upper third consists of reddish gray fissile argillites with several 1 to 6 inch thick beds of medium to coarse grained, poorly sorted, light brownish gray (5YR 6/1) and grayish red sandstones. The base of the formation is not exposed.

A thin section from the lower part of the formation shows the rock is an argillite. It is composed of 50 percent angular and poorly sorted quartz grains in a clay and dolomite matrix. The quartz grains range from 0.06 millimeters to 0.25 millimeters in diameter but average size is about 0.125 millimeters. In general, they are clear with straight to slightly undulose extinction, and numerous grains were observed to contain vacoules and inclusions of platy minerals. Platy biotite 0.3 millimeters in length is present in amounts up to 10 percent and is oriented parallel to bedding. Minor constituents include varying amounts of apatite, sericite,
plagioclase, orthoclase, hematite and detrital magnetite.

A thin section from the upper part shows the rock is a calcite and dolomite cemented sandstone. It is composed of approximately 70 percent quartz grains that range in size from 0.05 millimeters to 1.0 millimeters. Average grain size is about 0.40 millimeters. The grains are subangular to subrounded, moderately sorted and are clear with straight to strongly unulose extinction. The calcite and dolomite grains are anhedral to euhedral and average 0.20 millimeters in diameter. Other constituents are 2 percent plagioclase feldspar, less than 1 percent microcline, and minor amounts of magnetite, chert, hematite and limonite.

Figure 5. View looking west showing Precambrian red argillites exposed at the base of Crown Mountain syncline, approximately 2 miles east of Wood Lake.
CAMBRIAN

The first significant study of Cambrian stratigraphy in northwestern Montana was by Walcott (1908) who published a measured section for the North Fork of the Dearborn River. Deiss (1939) measured and described 12 sections in the Sawtooth and Lewis and Clark Ranges which he divided into nine formations.

The Ford-Straight Creek section described by Deiss (1939, p.28-31) occurs in the map area, S.W.1/4, Sec.8, T.19N., R.9W., and consists of approximately 1,800 feet of Middle and Upper Cambrian strata, consisting mostly of limestone, dolomite and shale. Deiss assigned the rocks to eight formations, which are in ascending order, the Flathead, Gordon, Damnation, Dearborn, Pagoda, Steamboat, Switchback and Devils Glen.

For this report, the Cambrian formations are combined into three cartographic units. These units are represented as C1, C2, and C3 on the geologic map. C1 consists of the Flathead Sandstone and the Gordon Shale, C2 consists of the Damnation Limestone, Dearborn Limestone and the Pagoda Limestone and C3 consists of the Steamboat Limestone, Switchback Shale and the Devils Glen Dolomite. Formation thicknesses given below are from Deiss's Ford-Straight Creek section, but formation descriptions are those of the writer.

**Flathead Sandstone:** The Middle Cambrian Flathead Sandstone (Peale, 1933) was named for exposures at Flathead Pass, in the northeast corner of the Three Forks quadrangle, Montana. In the Ford Creek
area it unconformably overlies the Belt Ahorn Formation and is 113 feet thick. Deiss (1939, p.31) recorded a discordance of 8 to 11 degrees between the two systems at the measured section located in S.W.1/4, Sec.8, T.19N., R.9W., but the writer did not observe the truncation on the northeastern flank of the Crown Mountain syncline where the entire Cambrian section is exposed.

The Flathead Sandstone is pinkish gray (5YR 8/1) to pale red purple (5RP 6/2). It is coarse-grained, poorly sorted and indurated, cleanly washed and silica-cemented. It contains approximately 20 percent of well rounded tan and white quartz pebbles up to one half inch in diameter. The sandstone is cross-bedded throughout and shows red purple banding, especially in the lower part. The entire sequence is characterized by rusty-buff limonite stains.

The lower part is massively bedded, some beds are greater than 4 feet thick. The upper third of the formation is more thinly bedded and contains numerous beds 1 to 2 inches thick of micaceous argillaceous shales that resemble the lithology of the overlying Gordon Shale.

A thin section of typical Flathead Sandstone consists of subangular to subrounded quartz grains cemented by silica. The grains are highly fractured, poorly sorted, equidimensional and range from 0.25 millimeters to 3.0 millimeters in diameter, with an average size of about 0.6 millimeters. Approximately 5 percent of the quartz grains have overgrowths on well rounded nuclei. The grains are clear with straight to slightly undulose extinction. Orthoclase feldspar is present in an amount of approximately 5 percent. Minor constituents include microcline,
plagioclase, chert and limonite.

**Gordon Shale**: The Middle Cambrian Gordon Shale (Walcott, 1917) was named from Gordon Creek in the Ovando quadrangle, Montana. The formation is 222 feet thick and forms a rather gentle slope between the Damnation limestone above and the Flathead sandstone below. The middle third of the formation is exposed topographically as a slight rib (Figure 5).

The lower third consists of greenish gray (5GY 6/1) fissile to slightly nodular and micaceous shales interbedded with several 1 to 2 foot thick beds of greenish gray sandstones that contain varying amounts of green detrital biotite, and are limonite stained.

The middle third consists of pinkish gray (5YR 8/1) fine-to medium-grained, moderately sorted, cross-bedded sandstones which are slightly banded by concentrations of limonite on bedding surfaces.

The upper third of the formation consists essentially of olive gray (5Y 4/1) fissile and micaceous shales with numerous 4 to 6 inch thick beds of medium gray (N5) buff weathering, dense, argillaceous limestones that contain abundant trilobite fossil material. These upper shales contain less mica and are more distinctly gray than the shales below.

**Damnation Limestone**: The Middle Cambrian Damnation Limestone (Deiss, 1933, p.135) was named from Damnation Creek on the southwest side of Pagoda Mountain for a 140 foot sequence of carbonate rocks that overlie the Gordon shale. In the map area, the Damnation is 100 feet thick. The lower 25 to 30 feet consist of pale blue (5PB 7/2)
and grayish blue (5PB 5/2) limestone in irregular beds approximately one inch thick. The upper 70 to 75 feet consists of pale yellowish brown (10YR 6/2) limestone in beds 4 inches to 3 feet thick. Conspicuous throughout the limestone are light brown weathering limonitic clay partings, which are the distinguishing features of the formation.

Under the binocular microscope, the rocks are fine-to medium-grained, moderately sorted, spine-bearing limestones. They contain small spar-filled patches and irregular laminae. Dolomite rhombs are conspicuous on acid etched surfaces.

A thin section from the Damnation Limestone shows that the rock was originally a lime mud that has been partially replaced by calcite. Some crystals are up to 0.5 millimeters in diameter, but on the average they are 0.15 millimeters in diameter. Approximately 10 percent of the rock has been replaced by anhedral and subhedral calcite. Spar-filled patches up to 2.0 millimeters in diameter are conspicuous in thin section. Dolomite rhombs are present in an amount of about 2 percent. No microstructures or fossil fragments were seen.

**Dearborn Limestone:** The Dearborn Limestone is Middle Cambrian in age and was named by Deiss (1933, p.36) from the North Fork of Dearborn River in the Sawtooth Range. The formation is 296 feet thick, of which the lower 35 feet are composed of grayish green (10GY 5/2) fissile, micaceous and calcareous shale interbedded with several 1 to 3 inch thick beds of medium light gray (N6) fine-grained limestone.

The upper interval is a greenish gray (5GY 6/1) to light brownish gray (5YR 6/1) fine-to medium-grained fossiliferous limestone. In
general, the beds are 4 to 6 inches thick near the base of this interval but become more massive toward the top. Irregular bedding and green sandy clay partings occur throughout the interval. The formation weathers yellowish gray and forms a steep cliff above its lower shaly unit.

In thin section, the Dearborn Limestone is characterized by the abundance of trilobite fossil fragments in a lime mud matrix that is partially replaced by calcite. Approximately 10 percent of the mud has been replaced by anhedral and euhedral calcite crystals that average 0.1 millimeters in diameter. Trilobite spines and other elongate fragments are randomly oriented and loosely packed. Fossil fragments constitute about 20 to 30 percent of the rock. Angular, silt-sized detrital quartz grains are present in an amount less than 2 percent and a few finely divided mica flakes were noticed.

**Pagoda Limestone:** The Pagoda Limestone is Middle Cambrian in age and is named after Pagoda Mountain, which lies 13 miles northwest of the type locality at Prairie Reef (Deiss, 1939, p. 41). The formation is 300 feet thick at the Ford-Straight Creek section.

The lower part of the formation consists of light olive gray (5Y 5/2) and grayish olive (10Y 4/2) fissile and nodular shales overlain by light brownish gray (5YR 6/1) fossiliferous limestone in beds 3 to 5 inches thick.

The upper part is composed of light gray (N7), oolitic and fossiliferous limestone, massively bedded in the middle but thinly-bedded in the lower and upper parts. The formation forms a steep
cliff and weathers very light gray.

A thin section from the upper part of the formation shows the rock consists of lime mud that is partially replaced by calcite into an irregular pattern. The calcite crystals average 0.2 millimeters in diameter but a few grains exceed 0.5 millimeters. In general, most grains are anhedral to euhedral and are clear. Characteristic constituents are pellets and superficial oolites that are partially replaced by calcite, and constitute approximately 10 percent of the rock. The pellets and oolites average 0.25 millimeters in diameter. Intraclasts with enclosed fossil fragments are up to 3.0 millimeters in diameter and are present in an amount of less than 5 percent. Fossil fragments are present in an amount estimated to be 10 percent.

Steamboat Limestone: The type section for the Middle Cambrian Steamboat Limestone is just below the crest of Prairie Reef, and the formation takes its name from Steamboat Mountain, which is north of Dearborn River (Deiss, 1939, p.45). The Steamboat Limestone is 239 feet thick at the type section but has a thickness of 276 feet at the measured section in the map area.

The lower third of the formation is a moderate yellowish brown (10YR 5/4) fine-grained limestone, which weathers to massive outcrops but is banded in beds up to 4 inches thick. It is mottled light brown by clay partings. The middle third consists of grayish orange pink (5YR 7/2) dolomite, fine-to medium-grained, massively bedded in units 5 feet thick or more and is characterized by numerous vugs
throughout the sequence.

The upper third consists of yellowish gray (5Y 8/1) fine to medium grained dolomite and dolomitic limestone. It is thin-bedded (4 to 6 inches) and weathers very light gray.

Two thin sections from the lower and upper part of the formation were examined. The lower sample is a limestone in which the lime mud has almost been completely replaced by anhedral and euhedral calcite crystals that average 0.2 millimeters in diameter. Intraclasts composed of lime mud are only partially replaced by calcite grains that are less than 0.2 millimeters in diameter. The intraclasts are subspherical to slightly elongate and average 30 millimeters in diameter.

The upper sample is a dolomitic limestone in which 30 to 40 percent of the lime mud has been replaced by euhedral dolomite crystals that range from 0.05 millimeters to 0.10 millimeters in diameter. Scattered throughout are circular spar-filled patches 0.5 millimeters to 1.0 millimeters in diameter.

Switchback Shale: The type section for the Upper Cambrian Switchback Shale is on the ridge east of Kidd Mountain, and takes its name from Switchback Pass, located approximately 2 miles southeast of Pentagon Mountain (Deiss, 1933, p. 5, 39).

The formation is 85 feet thick, and forms a depression between the overlying Devils Glen Dolomite and the underlying Steamboat Limestone. The formation consists of green, slightly calcareous and silty, nodular weathering shales in the upper and lower part. In the middle are several 4 inch thick beds of light brownish gray (5YR 6/1) fine-to
medium-grained dolomite that weather pale red, and form a low rib in the depression.

Devils Glen Dolomite: The type section of the Upper Cambrian Devils Glen Dolomite is on the northern spur of Monitor Mountain, south of the North Fork of Dearborn River, and takes its name from Devils Glen, a tight narrow canyon along the North Fork of the Dearborn River (Deiss, 1933, p. 40).

The Devils Glen Dolomite is approximately 350 feet thick and consists of pale red (10R 6/2), light brown (5YR 6/4) and very pale orange (10YR 8/2) fine-to medium-grained limestone and dolomite. Conspicuous throughout the formation are pellets and oolites, which are most highly concentrated in the upper and lower part of the formation. The Middle part is massive, consisting of beds greater than 4 feet thick while the lower and upper part is thin-bedded, with beds less than 2 feet thick. The formation weathers to a light gray sugary surface and forms a prominent ridge below the softer overlying Devonian limestone and dolomite.

Three samples taken at approximately 100 foot intervals from the formation were studied in thin section. A representative sample from the lower interval is an oolitic and pelletal limestone made up of approximately 70 percent pellets and oolites in a mud matrix which has been partially replaced by dolomite and calcite grains averaging 0.1 millimeters in diameter. The oolites average 0.25 millimeters in diameter, are subspherical to spherical and show concentric internal structure; the pellets are ovoid and structureless.
A sample representing the middle internal is a limestone composed of 20 to 30 percent oolites and pellets in a lime mud matrix that is partially replaced by dolomite grains; these range from 0.05 millimeters to 0.25 millimeters in diameter, but their average size is about 0.10 millimeters. The pellets and oolites average 0.20 millimeters in diameter.

A thin section from the upper interval consists of approximately 60 percent pellets in a lime mud matrix that has been partially replaced by calcite and dolomite. The pellets range from 0.05 millimeters to 0.25 millimeters in diameter with average size of about 0.10 millimeters. Intraclasts up to 1.0 millimeters in diameter and superficial oolites are present in an amount less than 10 percent. The dolomite rhombs average 0.05 millimeters in diameter and the calcite grains average 0.25 millimeters in diameter. The calcite crystals are euhehedral and clear.
DEVPONIAN

The earliest work on the Devonian system in central and northwestern Montana is that of Deiss (1933) who described seven sections in the Sawtooth and Lewis and Clark Ranges, and divided the rocks into five formations. These formations in ascending order were: White Ridge, Glen Creek, Coopers Lake, Lone Butte and Spotted Bear. Later, Deiss (1943, p.226) described an additional section at Allan Mountain in the Saypo quadrangle, just south of Gibson Dam on the Sun River.

The study of the Devonian system in central and northwestern Montana by Sloss and Laird (1947, p.1404-1430) resulted in the first attempt to describe and incorporate these strata into a regional setting. They did not use Deiss's formation names, but assigned units A, B and C to the Devonian system. Sloss and Laird (1947, p.1426) correlated the units of northwestern Montana with the Devonian system in the Three Forks area, central Montana, Alberta mountain front and the southern Alberta plains.

The Devonian system in the map area is represented by an estimated thickness of 1,000 feet of strata, consisting mostly of limestone and dolomite, that disconformably overlie the Upper Cambrian Devils Glen Dolomite. The writer did not attempt to subdivide the Devonian rocks into either the formations proposed by Deiss or to the units of Sloss and Laird, because subdivision of the system would have required a detailed stratigraphic study. Consequently the Devonian rocks were
mapped as a single undifferentiated unit.

The lower third consists of pale red (10R 6/2) and pale yellowish brown (10YR 6/2) dolomitic shales and mudstones interbedded with pale reddish brown (10R 5/4) argillaceous and arenaceous dolomites containing occasional 1 to 4 inch irregular beds of yellowish gray (5Y 7/2) fine-grained dolomite.

The middle third consists of yellowish gray (5Y 8/1) fine-grained limestone and light olive gray (5Y 6/1) fine-grained dolomite interbedded with pinkish gray (5YR 8/1) saccharoidal dolomite in beds 1 to 2 feet thick.

The upper third consists of interbedded yellowish gray (5Y 7/2) fine to medium grained limestone and pinkish gray (5YR 8/1) poorly sorted, fossiliferous medium grained dolomite in 1 to 2 foot thick beds.

The Devonian rocks weather light brown to moderate orange pink and are in sharp contrast to the very light gray weathering of the overlying Madison Group and the underlying Devils Glen Dolomite.

Samples taken from the Devonian section are believed to be representative of the rock types. Two thin sections taken approximately 300 and 600 feet above the base of the system show that the rocks are dolomites. The lower of the two thin sections shows that the rock consists of lime mud which is almost completely replaced by dolomite. Except for a few fossil ghosts, the original texture and structures have been obliterated. The ghosts show straight extinction and are up to 1 millimeter in length and 0.4 millimeters in width. Dolomite rhombs range from 0.1 millimeters to 0.15 milli-
meters and form a porous network of euhedral and anhedral crystals. Approximately 70 percent of the lime mud has been replaced by dolomite. Pore space is estimated to be about 10 percent. Minor silicifications were also noted. The upper sample shows the rock consists of approximately 80 to 90 percent dolomite rhombs in a lime mud matrix. The rhombs range from 0.08 millimeters to 0.10 millimeters in diameter and form a mosaic of tightly interlocking anhedral and subhedral crystals. The rock is homogeneous with fewer ghosts than in the previous section. Few silicifications are present, and pore space is estimated at less than 5 percent.

A sample from the upper third of the section shows the rock to be a fossiliferous limestone with a lime mud matrix. Fossil debris, mostly crinoid and brachiopod fragments are slightly silicified, and make up about 50 percent of the rock. Approximately 60 percent of the lime mud has been replaced by calcite crystals that average 0.05 millimeters in diameter. Dolomite rhombs ranging from 0.10 millimeters to 0.20 millimeters in diameter are a minor constituent. The calcite grains are generally clear and show well developed crystal outlines.
Mississippian

Madison Group

Rocks of Mississippian age in northwestern Montana have been referred to as the Hannan Limestone, Madison Limestone and Madison Group and are partly correlative with the type Madison Group in the Three Forks quadrangle and with the Brazer Limestone of northeastern Utah (Deiss, 1943, p. 228).

Deiss (1933) measured four sections in the Flathead and Lewis and Clark ranges and divided the Mississippian rocks into five units. He later (1943, p. 229) named the entire Mississippian section in the Sawtooth Range the Hannan Limestone and designated Hannan Gulch at Sun River the type locality. Sloss and Laird (1945) divided the Hannan Limestone into units MA, MB and MC in ascending order, and these units were later used by Andrichuk (1955) in studying Mississippian stratigraphy in northwestern Montana and southwestern Alberta.

Recently Mudge et al. (1962) measured sections in the Sun River Canyon area and divided the Madison Group into two formations, the lower Allan Mountain Limestone and the upper Castle Reef Dolomite. The Allan Mountain Limestone is 587.2 feet thick and the Castle Reef Dolomite is 640.1 feet thick at the Gibson Reservoir reference section (Mudge et al., 1962, p. 2005-2008).

The Madison Group is between 1,200 and 1,250 feet thick in the map area and is divided into two formations, bearing the names
proposed by Mudge et al. (1962). Because the Madison group has been
described in detail from the Sun River area, only general lithologic
characteristics of the formations are given here, based on data
obtained while mapping.

Allan Mountain Limestone: The Allan Mountain Limestone consists
of light brownish gray (5YR 6/1) and medium light to medium gray
(N6-N5) thin and thick-bedded fine-to medium-grained limestone and
dolomitic limestone. The lower part consists of limestone beds 1
to 4 feet thick interbedded with numerous 1 to 2 inch thick beds of
medium gray dolomitic limestone. The upper part consists of lime-
stone beds 1 to 3 feet thick and is characterized by an abundance of
irregular lenses and nodules of bedded chert 1 to 4 inches thick
separated by 6 to 8 inch intervals of limestone, and by beds con-
taining numerous crinoid fragments. The formation weathers light
gray. The base of the formation is not exposed.

Castle Reef Dolomite: The Castle Reef Dolomite consists of light
to very light gray (N7-N8) fine to coarse-grained massively-bedded
dolomite in the lower and upper parts and massively-bedded limestone
and dolomitic limestone in the middle part. The middle part contains
several zones of thinly-bedded dark-gray chert which produces distinct
banding in the light gray limestones. The coarsely-grained dolomites
contain an abundance of crinoid fragments, giving the rocks their
texture. The formation weathers very light gray.

A thin section from the upper part of the Allan Mountain Lime-
stone shows the rock is composed of lime mud that is partially rep-
laced by calcite. The calcite grains average 0.04 millimeters in diameter but few grains are up to 0.10 millimeters in diameter. Present are few patches several millimeters in length consisting of euhedral calcite grains larger than the average size. Fossil debris is absent in this particular section.

A thin section from the middle part of the Castle Reef Dolomite shows the rock is a fossiliferous limestone consisting of approximately 40 percent crinoid fragments in a mud matrix that is partially recrystallized to clear calcite. The grains range from 0.05 millimeters to 0.40 millimeters but average size is about 0.10 millimeters. Crinoid and other fossil fragments of various sizes are partially silicified. Pellets that average 0.20 millimeters in diameter, intraclasts up to 3.0 millimeters in diameter, dolomite rhombs and hematite are minor constituents.
JURASSIC

Ellis Group

The Ellis Formation (Peale 1893) was named for exposures near the site of Fort Ellis, a few miles southwest of Bozeman, Montana. Cobban et al. (1945, p.451) designated the north side of Rocky Creek Canyon, about 7 miles southeast of Bozeman, the type section for Middle and Upper Jurassic marine rocks. Later, Cobban, (1945, p.1268-1281) divided the Ellis into three formations, which are, in ascending order, Sawtooth, Rierdon and Swift. The Ellis Group is approximately 320 feet thick in the map area, and rests disconformably on the Madison Group.

Sawtooth Formation: The Sawtooth Formation (Cobban, 1945, p.1270) is named from the Sawtooth Range and Rierdon Gulch is designated the type section. The formation is approximately 55 feet thick; the lower part consists of light brownish gray (5YR 6/1) sandstone which is fine-grained, limonite stained and calcareous. It is overlain by alternating medium light gray (N6), fissile and chunky, silty and clayey shales, some of which are calcareous. The upper part consists mainly of light gray (N7) thin-bedded, calcareous siltstones. The Sawtooth Formation is poorly exposed in the map area.

Rierdon Formation: The Rierdon Formation (Cobban, 1945, p.1277) is named from Rierdon Gulch in the Sawtooth Range for a group of alternating shales and limestones. The formation is approximately
150 feet thick in the map area and consists of medium light gray (N6), fissile and chunky, calcareous shales that weather grayish orange pink (5YR 7/2). Many 4 to 8 inch thick beds of medium gray (N5) nodular, fossiliferous limestones are interbedded in the middle part of the formation. Water-worn Gryphaea are abundant in the thin-bedded limestones.

In thin section, a limestone sample from the Rierdon Formation is a recrystallized fossiliferous limestone that consists of about 25 percent fossil fragments and 75 percent grains that range from 0.06 millimeters to 0.10 millimeters in diameter but average size is about 0.07 millimeters. The original texture of the matrix has been obliterated by recrystallization to a mosaic consisting mainly of subhedral and anhedral calcite crystals. The calcite grains between fossil fragments are generally equidimensional, but are elongate and normal to the fossil fragment surfaces. The pelecypod shells are only partially recrystallized, and much of their original structure is preserved. The fragments range in size from 0.5 millimeters to 1 centimeter in length. Tiny gastropods are present in the amount of less than 2 percent and are almost entirely replaced by collophane. The fossil fragments are randomly oriented and loosely packed.

Swift Formation: The Swift Formation (Cobban, 1945, p.1281) takes its name from Swift Reservoir on Birch Creek in the Sawtooth Range. In the map area the formation is approximately 115 feet thick and consists of medium light gray (N6) silty and calcareous, slightly
micaceous shales in the lower part overlain by light brownish gray (5YR 6/1) fine to very fine-grained, slightly calcareous sandstone. The sandstone is limonite stained, thin-bedded and cross-bedded, and contains black chert grains, giving it a fine salt-and-pepper texture. The sandstone forms a slight ridge in the area. At the base there is a thin sandstone bed containing water-worn belemnites.

A thin section from the upper part of the Swift Formation shows that the rock is a calcite cemented sandstone. It consists of approximately 60 to 70 percent of subround to round, well sorted quartz grains that range from 0.1 millimeters to 0.5 millimeters in diameter but the average size is about 0.3 millimeters. The grains are clear, equidimensional with straight to slightly undulose extinction. Quartz overgrowth are present on about 1 percent of the grains. Orthoclase feldspar is present in the amount of approximately 10 percent and plagioclase feldspar is less than 1 percent. The feldspar grains are slightly weathered and show iron staining around their borders. Chert is present in the amount of about 5 percent and is generally more angular than the quartz grains. The calcite grains are subhedral to anhedral, cloudy and average 0.1 millimeters in diameter.

Morrison Formation

The Morrison Formation is Upper Jurassic and was named by Eldridge (1896, p.22, 60) for beds of varicolored shales, sandstones and fresh-
water limestones occurring near Morrison, Colorado. Imlay (1952, p.953-960) correlated the Jurassic formations in the western interior of the United States. In Montana, the Morrison Formation crops out in the central, south-central, southwestern and northwestern parts of the state and is present in the subsurface to the east.

The Morrison Formation is 195 feet thick in the Sun River area (Mudge, 1959, p.20), and is estimated to have the same thickness in the map area. It consists of grayish olive (10Y 4/2) mudstones interbedded with light olive green (5Y 5/2) thin-bedded, fine-grained friable sandstones. The middle part contains several greenish gray (5GY 6/1), nodular weathering argillaceous limestone beds 6 inches to 1 foot thick and contains few nonmarine invertebrate fragments. The formation weathers to form a shallow depression between the more resistant sandstones of the overlying Kootenai and the underlying Swift formations.
CRETACEOUS

Kootenai Formation

The Lower Cretaceous rocks in the Rocky Mountains north of the 49th Parallel were originally named the Kootanie Group by Dawson (1885) for beds containing a remarkable Jurassic-Cretaceous flora. Fisher (1909, p.28-35) assigned a 475 foot thick sequence of coal-bearing shales and sandstones in the Great Falls, Montana area to the Kootenai Formation, which he believed to be equivalent to the Kootenay Formation of southwestern Alberta. Berry (1929, p.241) has shown the Kootenai of Montana to be at least in part equivalent to the Jurassic-Cretaceous Kootenay and the Lower Cretaceous Blairmore formations of Alberta. Childers (1963, p.152) stated..."The Kootenai Formation is at least partly equivalent to the Blairmore Formation and may be equivalent to both the Blairmore and Kootenay of Canada."

The Kootenai Formation is 650 feet thick in the Sun River area (Mudge, 1959, p.20) and is approximately 900 feet thick in the southwest corner of the Saypo quadrangle (Deiss, 1943, p.236). Cobban (1955, p.107) states that the formation thickens southwestward from about 350 feet near the Sweetgrass Hills to more than 1,300 feet in the Disturbed Belt. In the map area, the formation is estimated to be between 900 and 1,000 feet thick, and conformably overlies the Morrison Formation. The top of the formation is not exposed. Because
the Kootenai rocks are tightly folded and faulted, an orderly stratigraphic succession could not be determined.

The lower 200 to 300 feet of the Kootenai Formation that overlies the Morrison Formation consists of a basal sandstone overlain by finer clastics. The lower part consists of light brownish gray (5YR 6/1) fine to medium-grained, thick-bedded sandstone. It is cross-bedded, noncalcareous and limonite stained throughout. The upper part consists of moderate reddish brown (10R 4/6) siltstone, mudstones and fine to medium-grained, thin-bedded sandstones.

An estimated 600 to 700 foot thick sequence of sandstones, shales, mudstones and limestones occur in the central folded area (Figure 6). It is bounded on the east by the North Fork Fault and on the west by the Red Creek Fault (Section B-B'). A sequence of shale, sandstone and limestone form the base of this sequence. The shales are medium gray and gray green, chunky to poorly fissile and slightly micaceous. The sandstones are grayish green (10G 4/2), fine to medium-grained, and contain varying amounts of limonite and black chert. Cross bedding is prominent in most beds. A nonfossiliferous limestone bed 5 to 8 feet thick marks the top of this sequence. The limestone is medium dark gray (N4), dense, and weathers light to pinkish gray.

The next overlying unit consists of interbedded sandstone, shale and mudstones similar to the rocks described above. Near the top of this sequence, just east of Red Creek Fault, is a 15 to 20 foot thick conglomerate bed composed of chert pebbles one-half to one inch in diameter. The bed weathers a very prominent reddish brown color.
A thin section from the lower sandstone bed of the Kootenai Formation shows the rock is a silica cemented, chert bearing quartz sandstone. The grains are subangular to subrounded and moderately sorted. The grains range from 0.25 millimeters to 0.75 millimeters in diameter, but average grain size is about 0.40 millimeters. Approximately 50 percent of the quartz grains have overgrowths on well rounded nuclei, resulting in a mosaic of equidimensional interlocking grains. Extinction is slightly to strongly undulose, and a few grains are composite. In general, the quartz grains are cloudy and contain vacoules and inclusions of platy minerals. The rock contains approximately 5 percent orthoclase and 20 to 25 percent angular to subangular chert grains, which give the rock a salt and pepper appearance.

Figure 6. View looking northeast showing the central folded area, and the dip-slope of a Madison thrust in background.
Unconsolidated pleistocene fluvio-glacial sand and gravel, and Recent alluvium have been recognized in the map area and out on the plains east of the mountain front, but these deposits were mapped as a single undifferentiated unit Qg. With the exception of Straight, Wood and Ford Creeks, most of the valleys contain little Pleistocene or Recent deposits. Streams have removed most of the material since the retreat of the valley glaciers, and are actively cutting down in the U-shaped valleys. Most of the sediments in the unglaciated valleys is alluvium consisting of silt, sand and well-rounded gravel. In the northwest corner of the map area are two small lakes in which fine silts are now accumulating.
IGNEOUS ROCKS

Igneous rocks of probable pre-Laramide in age are represented by a quartz diorite sill in the Wood Lake area, and by a quartz diorite to diabase sill in the Petty Creek area.

The sill in the Wood Lake area is approximately 1500 feet thick at the western map boundary, but decreases in thickness southeastward. The sill is medium grey, medium crystalline, and composed mainly of white to pink colored plagioclase, hornblende and quartz. A study of a thin section reveals the rock to consist of about 40 percent zoned plagioclase, 18 percent quartz, 35 percent hornblende, 7 percent biotite and minor amount of pigeonite and apatite. The plagioclase is considerably sericitized. The rock is relatively fresh appearing, the alterations noticed being the formation of chlorite at the expense of biotite and hornblende.

The upper contact of this sill is intrusive into the Ahorn argillite and its basal contact is the Lewis thrust. The age of intrusion cannot be determined specifically from field evidence. ¹

The sill in the Petty Creek area is approximately 500 feet thick at the southern map boundary, but is cut out at the surface by the Lewis thrust in a saddle just east of Crown Mountain. Under a binocular scope, the rock is green to greenish-black and appears to consist of about 70

¹ This sill has been traced 6 miles northward by McGill and Sommers (Geol. Soc. of America Bull. Vol. 78, 1967) into a sill mapped as Precambrian by Mudge (Pretty Prairie quadrangle, U.S. Geological Survey Map GQ - 454).
percent white mineral, mainly feldspar in rather stubby laths, and about 30 percent dark mineral not identifiable on a sawed surface. A study of a thin section reveals the rock to consist of about 30 percent brown hornblende, 5 percent ore mineral, 55 percent altered plagioclase and 10 percent micrographic quartz and possibly orthoclase. Grain size averages about 1 millimeter. The sill is sheared and slickensided, weathers reddish-brown, and forms a topographic high.

The original upper (western) contact of the Petty Creek sill is obscured by faulting. Although the lower contact with Devonian strata was not found exposed, a prospect pit near the contact (sample locality 257) reveals quartz veins in the carbonate suggestive of an intrusive contact. Because of this mineralization and because of certain differences in texture and composition between the two random samples from the sills at Wood Lake and Petty Creek, the sill at the latter locality is interpreted to be intrusive into Devonian rocks, an assumption which leads to the least involved structural relations. The age of this sill is probably Cretaceous. Deiss (1943a, p. 248) stated that the sills in the Kootenai Formation and in the younger rocks of the Colorado Group in the Sawtooth Range were intruded prior to folding. He also stated that the sills were intruded before the earliest faulting, probably late in the Cretaceous, and that the folding of the sills may have preceded the faulting.
The Sawtooth Range, which forms the front of the Northern Rocky Mountains, extends from Glacier National Park for 85 miles south to the Dearborn River (Figure 4). The range is separated structurally from the Lewis and Clark Range on the west by the Lewis thrust, which brought Precambrian rocks eastward over Paleozoic rocks of the present Sawtooth Range. The eastern front consists of abrupt escarpments of Mississippian rocks standing above the plains.

Based on the intensity of deformation, the area of present study is divided into three parts: a southwestern area, a central closely folded area and a northeastern area. The southwestern area lies west of the Lewis thrust and is characterized by broad, gentle and nearly symmetrical folds in Paleozoic rocks. The central closely folded area lies between the Lewis thrust and the North Fork of Ford Creek. This area is characterized by westward-dipping normal and thrust faults, and by intensely folded Cretaceous and Jurassic strata. The northeastern area lies east of the North Fork of Ford Creek, and is characterized by west-dipping thrust faults and by minor folds.

The structural divisions used in the map area lie in extensions Deiss's western and eastern structural provinces of the Southwest Saypo quadrangle (Deiss, 1943a). The central closely folded area and the northeastern area coincide with Mudge's western area in the Sun River area (Mudge, 1959).
Figure 7. View showing Mississippian thrust slices forming the front of the Sawtooth Range.

Folds

The southwestern area, which lies west of the Lewis thrust fault, contains a pair of broad, gentle folds that trend N.35°W. These are the Crown Mountain syncline and the Straight Creek anticline. The syncline is nearly symmetrical, with dips on the northeast limb from 20 to 40 degrees, and dips on the southwest limb from 18 to 30 degrees. To the southwest, the adjoining anticline is nearly symmetrical, with dips on the southwest limb from 33 to 44 degrees. Precambrian, Cambrian and...
Devonian rocks forming these folds were thrust from the west over rocks of Devonian and Cretaceous age (Section C-C').

The central closely folded area, which is about two and one-half miles wide, lies between the Lewis thrust and the North Fork of Ford Creek. Here the Cretaceous and Jurassic rocks were deformed into a continuous complex of anticlines and synclines that trend N.30°W. Folds vary from open and nearly symmetrical to isoclinal and overturned. The folds between Cyanide Mountain and the Red Creek fault are nearly symmetrical in the vicinity of Ford Creek (Section B-B'), but are overturned to the northeast when traced northwest, where axial planes dip approximately 40 degrees to the southwest (Section A-A'). On the west side of the Red Creek fault, a three mile long doubly plunging anticline in Jurassic rocks was thrust over a smaller doubly plunging anticline in Cretaceous rocks on the east side of the fault.

Between the North Fork of Ford Creek and the Red Creek fault, Mesozoic rocks from a complex of asymmetrical and overturned anticlines and synclines that can be traced from the northern boundary southeast for a distance of approximately 5 miles to the eastern boundary. Folds in the Mesozoic rocks are nearly symmetrical near the northern boundary (Section A-A'), but, with the exception of one back-folded anticline, are overturned to the northeast near Ford Creek (Section B-B'). At Ford Creek, the axial planes of the overturned folds dip between 35 and 40 degrees to the southwest. Along Ford Creek, between the Red Creek fault and the North Fork of Ford Creek, numerous irregular folds too small to map were seen in the incompetent shales and mudstones of the Kootenai Formation. Folds near the eastern map boundary are only slightly asymmetrical (Section C-C').
In the northeastern area, which lies east of the North Fork of Ford Creek, Cretaceous and Jurassic rocks are little deformed in the northern part of the area, but are gently folded along the north side of Ford Creek. South of Ford Creek, Cretaceous rocks are deformed into a complex of south-plunging, overturned and isoclinal anticlines and synclines. These folds are not characteristic of the northeastern area, and appear to belong to the Disturbed Belt structure.
FAULTS

Normal Faults

Two normal faults were mapped in the central closely folded area. These are the North Fork fault and the Wood Lake fault. The North Fork fault is located near the eastern boundary of the closely folded area, and parallels the west branch of the North Fork of Ford Creek for approximately two miles and then continues north and south beyond the map area. The trace of the fault is well defined along the west branch of the North Fork of Ford Creek and north beyond the map boundary, but it loses its definite character when traced beyond the eastern map boundary. Along its northerly trace, a south-plunging anticline in Jurassic strata strikes into and is truncated at the fault. South of Ford Creek, the strata on the west side of the fault strike essentially parallel to its trace, but on the east side, Cretaceous rocks were deformed into a series of folds too small to map that are oblique to the strike of the fault. These folds trend N.10°E and are truncated at the fault (Section C-C').

The North Fork fault strikes approximately N.40°W, and based on its trace, dips about 60 degrees to the southwest. Dip separation, and also dip-slip, appear not to exceed 500 feet.

The Wood Lake fault is a high-angle, west-dipping normal fault located northeast of Wood Lake in the northwest corner of the map area. The fault trace terminates approximately one mile southeast of Wood Lake where it is truncated by a southwest-dipping, high-angle thrust fault; it reappears three and one-half miles to the southeast in the Petty Creek area. It strikes N.40°W and is essentially parallel to the strike of the strata.
The west block was downthrown relative to the east block, bringing rocks of Jurassic age in contact with Devonian rocks. North of the Township line near Wood Lake, the Sawtooth Formation is in contact with Devonian rocks, but south of the Township line, the Sawtooth Formation is faulted out and rocks of the Rierdon Formation are in contact with Devonian rocks.

In the Petty Creek area, the fault dropped rocks of Jurassic age into contact with a sill intruded into Devonian rocks. This sill apparently does not extend much farther to the north or if present there, it may lie at depth in the core of an overturned anticline.

The maximum stratigraphic throw is estimated to be 1,500 feet. From the relationship of its trace to topography, the fault is estimated to dip between 50 and 60 degrees to the southwest.

**Thrust Faults**

Southwest-dipping thrust faults are the major geologic structures in the Ford Creek area, where slices of Paleozoic strata form an imbricate series of northwest-trending ridges characteristic of the Sawtooth Range. Based on fault traces and topography, and on rare exposures of fault planes, four faults are estimated to dip between 30 and 40 degrees and four dip between 45 and 60 degrees. There is no correlation between the amount of dip of the faults and their geographic distribution in the map area. In general, the stratigraphic throw on most faults is greater than 2,000 feet.

The first thrust fault west of the eastern map boundary marks the front of the Sawtooth Range and the western edge of the Disturbed Belt.
This fault brought Mississippian rocks over Kootenai rocks along a plane that dips about 35 degrees to the southwest. The fault is continuous to the north beyond the map boundary, but at Ford Creek its trace swings sharply to the southwest, cuts up-section into the Kootenai and disappears beneath the next thrust slice to the west. The trace is strongly convex toward the east; at the north it trends N.45°W, but at Ford Creek it trends N.25°E.

The next thrust to the west brought Mississippian rocks over Kootenai rocks along a plane that dips 41 degrees to the southwest, where the fault surface is exposed in Ford Creek. North of Ford Creek, the Jurassic and Cretaceous rocks on the footwall are not appreciably deformed (Section A-A'). At the exposed fault surface, no conspicuous drag or gouge was seen. Near the eastern boundary, the fault trace cuts up-section in the hanging wall block due to a strike change in the bedding, placing Kootenai rocks in fault contact with one another. Maximum stratigraphic throw north of Ford Creek is estimated at 2,800 feet.

The next thrust to the southwest is the Red Creek thrust which closely parallels Red Creek and extends northwest and southeast beyond the map boundaries. Here a doubly plunging asymmetrical anticline in Jurassic and Cretaceous rocks was upthrust over a back-folded, doubly plunging anticline in Cretaceous rocks (Section A-A'). The relationship of its surface trace to topography suggests a dip of between 50 and 60 degrees for the fault surface. The stratigraphic throw probably does not exceed 300 feet.

The geologic structure at Cyanide Mountain and its topographic extension southeast of Ford Creek is a combination of two thrusts. The eastern thrust brought Mississippian rocks that form the summit of Cyanide
Mountain over Kootenai rocks along a plane estimated to dip about 38 degrees to the southwest. The stratigraphic throw is estimated to be 2,800 feet. Kootenai rocks below the thrust near the northern map boundary were dragged into overturned and isoclinal folds (Section A-A'). In the vicinity of Petty Creek, Kootenai folds are nearly symmetrical (Section C-C'). Some gouge and breccia were noticed along the fault zone near Ford Creek.

In the area just west of the summit of Cyanide Mountain, the western thrust brought Devonian rocks over Mississippian rocks along a plane estimated to dip about 50 degrees to the southwest. Near the Cyanide Mountain summit and further southeast, Devonian rocks were deformed into folds, producing a strongly sheared zone (Sections A-A' & C-C'). The underlying Mississippian rocks at the fault contact were deformed into a series of drag folds with amplitudes of approximately 5 feet, exposed on the northeast side of Cyanide Mountain. The stratigraphic throw is approximately 2,800 feet.

A thrust fault just west of Wood Lake brought a slice of Devonian rocks over Kootenai rocks along a plane estimated to dip between 40 and 50 degrees to the southwest. The fault continues to the northwest for about a mile beyond the map boundary, but is concealed by alluvium near its southern terminus, where map relations indicate that it truncates the Wood Lake normal fault. Structural and stratigraphic relationships suggest the fault continues southeast for about 2 miles, where it is truncated by the other thrust.
The Lewis thrust\(^1\), a major fault with a stratigraphic throw that exceeds 5,000 feet, brought a sill, Precambrian and Cambrian rocks over Devonian, Jurassic and Cretaceous rocks. The fault trace trends approximately N\(45^\circ\)W north of Section B-B', and parallels upper Ford and Wood Creeks for a distance of about three miles. The sole of the thrust is in the sill along its northwestern trace, but cuts up section into Precambrian and Cambrian rocks south of Ford Creek. Along its trace in a southeasterly direction, the sill and Precambrian rocks are in contact with Devonian rocks, and Cambrian rocks are in contact with a younger sill and with Jurassic and Cretaceous rocks that were down-faulted along the Wood Lake fault (Section C-C'). Because of its arcuate trace, the thrust truncates the Wood Lake fault and its extension in the Petty Creek area. Based on surface trace and topography, the thrust plane is estimated to dip between 45 and 50 degrees to the southwest at Petty Creek.

In the extreme southwest corner of the map area, a thrust fault brought Precambrian Ahorn argillite over Devonian strata on the southwest limb of the Straight Creek anticline (Section C-C'). The fault contact is well defined because of the sharp contrast between red Belt argillite and underlying light gray Devonian rocks. The fault strikes N\(50^\circ\)W and is essentially parallel to the strike of the Devonian rocks. The Devonian

\(^1\) The name applied to this fault by Deiss (1943a, P.214) at a location 6 miles northwest of Wood Lake, and also used by Alpha (1955, P.130). On the recently published geologic map of the Pretty Prairie quadrangle, Mudge has designated this structure the South Fork Thrust Zone (U.S. Geological Survey Map GQ - 454).
rocks are not appreciably brecciated at the fault zone, but float from the Belt argillite was found to be slickensided. Based on topography and its surface trace, the fault is estimated to dip about 45 degrees to the southwest. The stratigraphic throw is probably greater than 5,000 feet.

Figure 8. View looking northwest along a fault-line valley. Precambrian, Cambrian and Devonian rocks on left thrust over Devonian rocks on right. Viewed from south slope of Cyanide Mountain.
Sequence of Geologic Events

The Cordilleran Geosyncline and the Sweetgrass Arch are broad regional elements which were established early in the earth's history and have remained in their relative positions since Precambrian time. The Cordilleran Geosyncline in Western Montana received approximately 40,000 feet of Precambrian Beltian sediments, but none are known on the Sweetgrass Arch. There is no evidence for intense deformation in the area prior to the Laramide Orogeny, although a slight unconformity between the Precambrian and Cambrian systems is indicative of some crustal warping and erosion prior to Middle Cambrian time (Deiss, 1939, P.31).

Paleozoic sedimentation in Western Montana began with the transgression and deposition of sediments from Middle Cambrian to Lower Ordovician time. In the map area, the Flathead Sandstone overlaps truncated Beltian strata. In the Sweetgrass Arch area, the Flathead rests on the basement complex (Alpha, 1955, P.31). This sedimentation cycle was closed by regional uplift and erosion of lower Ordovician and part of the Upper Cambrian strata from portions of Western Montana and from the Sweetgrass Arch area. The next depositional cycle began with transgression and deposition of sediments from late Devonian to late Mississippian time. Pennsylvanian and probably also Permian sediments were deposited in the map area, but were later removed by erosion. There are no Mesozoic sediments within the mapped area of pre-Middle Jurassic age.

Middle Jurassic deposition commenced with transgression and deposition of the Ellis Group on a well-developed Madison erosional surface. During late Jurassic and early Cretaceous time, the area was a low-lying
land area in which muds accumulated. During middle and late Cretaceous time, the area probably received sediments that were removed by erosion following Laramide deformation.

Three phases of Laramide deformation are recognized in the map area: (1) an early compressional phase which produced folds followed by imbricate thrusting, (2) a phase of relaxation of compressive forces which produced normal faults and (3) a later compressional phase which produced overthrusting.

The early compressional phase produced the imbricate structure east of the Wood Lake normal fault. In the northeastern area, the second thrust fault west of the eastern map boundary is younger than the first thrust because it truncates the arcuate trace of the first fault on its south end and at the north end beyond the map boundary.

A tensional phase is inferred to explain the high-angle North Fork and Wood Lake normal faults. The North Fork fault truncates folds in Jurassic rocks north of Ford Creek. The west block was downthrown relative to the east block, having a stratigraphic throw of approximately 500 feet. The west block of the Wood Lake fault was downthrown relative to the east block, truncating southwest-dipping Jurassic rocks north of Wood Lake. South of Wood Lake, the fault trace disappears beneath a thrust slice in Devonian rocks. The fault reappears in the Petty Creek area where it brought rocks of Jurassic age in contact with a sill.

The later compressional phase first brought a thin slice of Devonian rocks over Cretaceous rocks along a fault that parallels Wood Lake on the southwest side. This fault truncates the Wood Lake normal fault just southeast of Wood Lake. This event was followed by thrusting on the
Lewis fault, which brought a sill and Precambrian rocks over Devonian rocks and Cambrian rocks over Cretaceous rocks on the downthrown side of the Wood Lake fault near Petty Creek. The Lewis thrust truncates the preceding thrust fault just south of Ford Creek and is the youngest datable structure in the southwestern area. The thrust fault in the extreme southwest corner of the map area cannot be dated from map evidence. The final event of the Laramide Orogeny, which is not represented in the map area, was the development of major high-angle normal faults which offset the Lewis thrust in the Marias Pass area (Childer, 1963, P.159), and displaced earlier low-angle normal faults and underlying thrust faults in the Saypo quadrangle (Deiss, 1943a, p.257).

The occurrence of a brief tensioanl phase between periods of compression is here recognized in a small part of the Sawtooth Range. Previous geological investigations in Western Montana have not yielded a similar sequence of events during the Laramide orogeny. Based on stratigraphic relationships and on the premise that thrust faults put older rocks onto younger, the most logical explanation for the occurrence of Jurassic rocks on Devonian rocks just northeast of Wood Lake is through normal faulting.

The sequence and mechanics of deformation in the Sawtooth Range is open to controversy. Deiss (1943, P.249) stated that the oldest faults in the Sawtooth Range are in the east, suggesting an east to west development of the Sawtooth structure. Deiss (1943, P.25b) also stated that

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Examination of geologic maps of the Pretty Prairie and Park's Basin quadrangles recently published by Mudge (U.S. Geological Survey Maps GQ 454 and GQ 453) support the interpretation of tensional faulting which followed an episode of thrusting and was in turn followed by renewed thrusting.
the Lewis thrust in the Saypo quadrangle truncates the westernmost high-angle thrust, and concluded that the thrust is younger than the Sawtooth structure. Alpha (1955, p.136) elaborated by stating... "it is postulated that the Sawtooth Range existed first and that the range was too high structurally and topographically to be overridden." He explained that the Marias Pass transverse fault and the Scapegoat-Bannatyne Trend (Dobbin and Erdmann, 1955), a transverse fault zone south of the map area, facilitated the eastward movement of the Lewis thrust north and south of the Sawtooth Range. However, Ross (1956, p.100) and Childers (1963, p.160) concluded that the Marias Pass transverse fault does not exist.

Childers (1963, p.160) notes that the structures in the part of the Sawtooth Range mapped by Deiss are parallel to the structures west of the Lewis overthrust, but near Marias Pass there is a significant discordance. He interprets the Sawtooth Range structure as a salient which, at its north end, plunges beneath the south end of the Clarke Range salient. He also stated that the north end of the Sawtooth Range salient reflects differential movement because of varying amounts of counter-clockwise rotation of the Paleozoic and Mesozoic rocks within the north end. Because of parallelism between the structures east and west of the discordant north end of the Sawtooth Range salient, Childers interprets a stage of concordant deformation throughout the area before the Sawtooth Range salient developed.

Regional evidence suggests a west-to-east development of the Sawtooth structure. Hume (1957, p.401) stated that the order of development of the foothills structure in southern Alberta was from west to east. He interprets the Lewis overthrust as not overriding the foothills structure; rather the foothills structure developed below the Lewis thrust in slices
that moved upward and outward from under the Lewis thrust. He concluded that thrusting began in the west with older thrust sheets moving eastward on younger thrust sheets.

Childers (1963, p.162) has shown by diagram a hypothetical structure section of incipient faults in the stratified rocks of northwestern Montana when deformation began (Figure 9). In the Sawtooth Range, he believes that movement began on la and continued on Ib, lc, ld and le, but movements on 2, 3 and 4 are increased southeastward to a maximum near the middle of the range. Also, the Paleozoic rocks may be folded due to differential movement on any of the main branch faults.

It is believed that the thrust faults in the Ford Creek area east of Wood Lake developed first and are represented hypothetically in Figure 9 by faults 2, 3 and 4, although it is not possible to relate specific faults in the map area to numbered faults in the diagram or to state their sequential order of development (except that the easternmost thrust is older than the next thrust to the west). Following a period of normal faulting, renewed compression produced the Lewis thrust and the thrust immediately east of it near Wood Lake. The thrust in Devonian rocks near Wood Lake may hypothetically be represented by fault lc and the Lewis thrust by lb on Figure 9, and they developed in that order.
Figure 9. Hypothetical pattern in vertical section of incipient faults in the stratified rocks of northwestern Montana when deformation began. (After Childers, 1963, p. 161).
REFERENCES CITED


## APPENDIX

### Petrographic Thin Sections

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