AN ABSTRACT OF THE THESIS OF

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(Name) (Degree) (Major)

Date thesis is presented ______________________

Title STRATIGRAPHY AND STRUCTURE OF PART OF THE SOUTHERN MADISON RANGE, MADISON AND GALLATIN COUNTIES, MONTANA

Abstract approved [redacted]
(Major professor)

The thesis area consists of 42 square miles located in Madison and Gallatin counties, Montana, in the southern part of the Madison Range. The strata exposed in the area range in age from Precambrian to Quaternary and have an aggregate thickness of more than 7,600 feet.

The Paleozoic rocks, about 3,900 feet thick, are mainly carbonates but include sandstones, shales, and cherts of marine origin. Ordovician and Silurian formations are absent.

The Mesozoic rocks consist mainly of sandstones, shales, calcareous claystones, and argillaceous limestones of marine and continental origin. All Mesozoic periods are represented in this 3700 foot thick sequence of sedimentary rocks.

The Cenozoic rocks and sediments include welded tuff, glacial deposits, and alluvium. Quaternary landslides cover about one-quarter of the thesis area.

The structures are Late Cretaceous to Early Tertiary

(Laramide) and Late Cenozoic in age. The Laramide structures are northwest-trending, asymmetrical (steeper to the northeast) folds and high angle reverse faults. The Late Cenozoic structures are normal faults that displace Upper Cretaceous strata.

STRATIGRAPHY AND STRUCTURE OF PART OF THE SOUTHERN MADISON RANGE, MADISON AND GALLATIN COUNTIES, MONTANA

by

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A THESIS

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1967

APPROVED:

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Typed by Trudie Vallier

ACKNOWLEDGEMENTS

I would like to express appreciation to Dr. William B. Hall for suggestions leading to the selection of the thesis area and for assistance and friendship during the summer of investigation.

Special thanks go to Dr. David Bostwick, my major professor, for the critical reading of the manuscript and for his helpful suggestions during its writing.

I am also indebted to Drs. Keith F. Oles, William C. Barnes, Harold E. Enlows, and Paul T. Robinson for their critical reading of the manuscript and helpful suggestions.

I am thankful to the Goodrich family of the 320 Ranch for their friendship and help in packing us into the mountains of the thesis area.

To my wife goes my deepest appreciation for her companionship in the field, help during the writing, and continued encouragement throughout the project.

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INTRODUCTION

Location and Access

The thesis area comprises 42 square miles in Madison and Gallatin counties, Montana, between 45°00' and 45°05' north latitude and 111°17' and 111°26' west longitude. The entire area lies within the Beaverhead National Forest east of the Continental Divide (Plate 1).

The area is five miles by gravel and dirt road from U.S. Highway 191, which connects Boseman and West Yellowstone, Montana. Access within the area is provided by dirt roads and by Forest Service trails. The trails afford access to within one mile of any location and may be traveled nearly all summer.

Elevations within the area range from a low of 6,922 feet in the northeastern part to a high of 10,823 feet near the western margin. The topography ranges from low foothills in the east-central and northern part to rugged mountains in the west. These mountains are developed in the Paleozoic rocks. Drainage within the area is generally easterly.

The exposures are directly proportional to the steepness of the topography. The Paleozoic formations in the

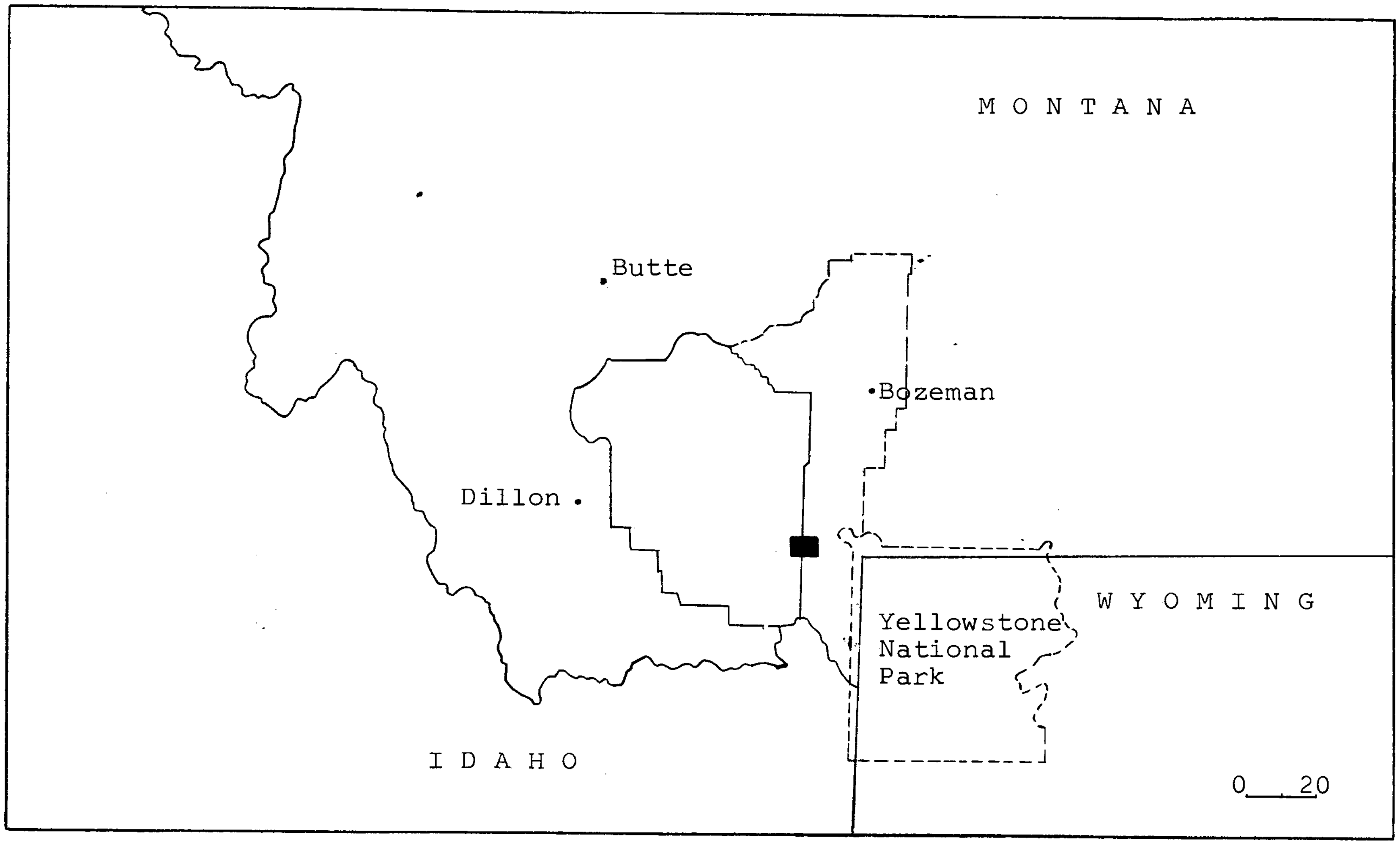

Plate 1. Index map showing location of thesis area.

western one-third of the area are generally well exposed. Outcrops do not occur on the low rolling hills of nonresistant Cretaceous rocks in the central and north-central areas except along stream banks.

Climate and Vegetation

The nearest weather station is at West Yellowstone, Montana (elevation 6,667 feet) about 35 miles south of the area. The climate in the thesis area is assumed to be similar to that at West Yellowstone. In the summer months (June to September) the temperature rarely goes above 85°F. and is usually in the 70's. Summer thunderstorms are frequent. In the winter months (October to May) the average temperature in West Yellowstone is 25°F. although it often drops to 30° below zero. Snowfall in the winter is the greatest source of the 30-inch average annual precipitation.

The vegetation varies with elevation. Scattered pine and sagebrush are common at lower elevations but give way to Lodgepole pine, Engelmann spruce, subalpine fir, Douglas fir, and lesser amounts of Whitebark pine at higher elevations. Aspens appear at all elevations in areas of moist soil, and wild flowers of many varieties occur throughout the thesis area.

Previous Work

The first geologic investigation of the Three Forks, Montana area was carried out by F.V. Hayden as a member of the Raynold expedition of 1860 (Berry, 1943).

In the years 1883 to 1889, Peale did considerable reconnaissance mapping in the Three Forks area and to the south. He was the first to describe many of the Paleozoic formations of western Montana.

Condit, Finch, and Pardee (1916) did extensive work on the Permian rocks in the Madison, Gravelly, and Centennial Ranges.

J.A. Wilsey (1947-1948), mapped for Phillips Petroleum Corporation southeast of the thesis area. A resume' of his work has been published in the 1960 Billings Geological Society Guidebook.

William B. Hall, in 1961, mapped an area in the southern Madison Range for his doctoral thesis that included the eastern one-third of the thesis area.

STRATIGRAPHY

Rocks ranging in age from Precambrian to Recent crop out in the thesis area and total about 7,600 feet in thickness (Table 1).

The Paleozoic rocks, about 3,900 feet in thickness, are mainly carbonates but include minor sandstones and shales. Ordovician and Silurian formations are absent.

The Mesozoic rocks consist mainly of sandstones, shales, calcareous claystones, and argillaceous limestones, and are about 3,700 feet thick. All Mesozoic periods are represented in these sedimentary rocks.

The Cenozoic Era is represented by welded tuff, glacial deposits, alluvium, and landslides.

Precambrian Rocks

The Precambrian rocks of Montana are divided into three groups or series on the basis of different lithologies and degrees of metamorphism. They are, from oldest to youngest, the Pony Series, the Cherry Creek Group, and the Belt Series (Perry, 1962).

The relationship of the Pony Series to the Cherry Creek Group is not certain, because of conflicting evidence. Early investigation showed that the Pony Series is overlain by the Cherry Creek Group, but recent work in the northern Tobacco Root Range (Klepper, 1950) has shown

Table 1. Summary of Stratigraphic Units.

Age	Formation	Lithology	Thickness
Quaternary		alluvial valley fill	0-30'
	Unconformity		
Quaternary		gravel and clay	0-200'
	Unconformity		
Quaternary		glacial gravel and clay	0-100'
	Unconformity		
Quaternary		glacial gravel and clay	0-100'
	Unconformity		
Tertiary		acid igneous volcanics	0-80'
	Unconformity		
Cretaceous	Unit Three	interbedded sandstones and shales	1600+'
Cretaceous	Unit Two	tuffs and tuffaceous mudstones	80'
Cretaceous	Unit One	black shale and sandstones	100'
	Unconformity		
Cretaceous	Albino Formation	sandstones, sandy tuffs,and siliceous mudstones	255'
	Unconformity		
Cretaceous	Muddy Member; Thermopolis Formation	salt-and-pepper, cross-laminated, calcareous sandstones	110'

Table 1. (Continued)

Age	Formation	Lithology	Thickness
Cretaceous	Thermopolis Formation	black shale	180'
Cretaceous	Kootenai Formation	limonitic quartz arenites, calcareous mudstones, argillaceous limestones, and chert conglomerates	407'
	Disconformity		
Jurassic	Morrison Formation	buff quartzose sandstones and calcareous mudstones	305'
Jurassic	Swift Formation	dark gray glauconitic sandstones and conglomeratic sandstones	35'
Jurassic	Rierdon Formation	oolitic and argillaceous limestones	195'
	Disconformity		
Triassic	Woodside Formation	red siltstones and very fine-grained sandstones	105'
Triassic	Dinwoody Formation	brown, very fine-grained sandstones, siltstones, and limestones	242'
	Disconformity		
Permian	Phosphoria Formation	calcareous sandstones, bedded cherts, and silty limestone	230'
	Disconformity		
Pennsylvanian	Quadrant Formation	cross-bedded, calcareous quartz arenites	220'

Table 1. (Continued)

Age	Formation	Lithology	Thickness
	Disconformity		
Mississippian	Amsden Formation	red siltstones	43'
	Disconformity		
Mississippian	Mission Canyon Formation	limestone breccia, massive oolitic limestone	852'
Mississippian	Lodgepole Formation	dark, thin-bedded, highly fossiliferous limestone and black calcareous shale	615'
Devonian	Three Forks Formation	dolomitic limestone, breccia, and varicolored shale	182'
Devonian	Jefferson Formation	brown dolomite and limy dolomite	339'
	Disconformity		
Cambrian	Park Formation	varicolored shale	100'
Cambrian	Meagher Formation	mottled limestone	413'
Cambrian	Wolsey Formation	limestone and green and gray shale	69'
Cambrian	Flathead Formation	quartzitic sandstone and green shale	20+'
	Angular Unconformity		
Precambrian		gneiss and scattered schist	not measured

that the Cherry Creek Group is overlain by the Pony Series. This contradiction has led Klepper (1960) to the theory that these two metamorphic units are a thick sequence of metamorphic rocks that differ somewhat in lithology in separated areas.

The Cherry Creek Group of schist, gneiss, marble, and quartzite was first named and described for exposures along Cherry Creek about 20 miles south of Ennis, Montana. The Pony Series of schist and gneiss was named for exposures near Pony, Montana (Perry, 1960).

The Belt Series is a thick sequence of gently folded limestones, argillites, quartzites, and shales. It has widespread exposures in western Montana but does not crop out in the Madison Range.

The Precambrian gneisses and schists exposed within the thesis area seem similar lithologically to those of the Pony Series. However, the small area of outcrop is insufficient to justify assigning these rocks to the Pony Series. They are very resistant and form steep cliffs. Many of the highest mountains in the Madison Range are made up of these rocks. From a distance the gneisses and schists appear black and structureless, but, on closer examination, foliation and color variations are evident.

The Precambrian rocks are best exposed in the southwest corner of sec. 36, T. 9 S., R. 2 E.

Lithology

Most of the rocks are gneisses with a wide range in lithology. The most distinctive gneiss is pink, the result of a high orthoclase content. The orthoclase embays the surrounding microcline, occurs in quartz mosaics, is found in large crystals between masses of microcline, and is generally well-crystallized. It is most abundant in long stringers of biotite and comprises 45 percent of the rock. The orthoclase shows incipient alteration,but the microcline is fresh. The microcline is well crystallized and comprises about 35 percent of the rock. Quartz forms medium- to fine-grained mosaics, but the individual grains do not have sutured contacts. Quartz makes up about 15 percent of the rock. Thin stringers of biotite elongated in the direction of banding (foliation) make up five percent of the rock.

Another distinctive gneiss is dark and, upon close examination, shows banding. The banding is the result of alignment of mica, pyroxene, and plagioclase. The main constituents are oligoclase (60 percent), biotite (15 percent) and quartz (12 percent). The minor constituents are augite (8 percent), microcline (5 percent), pyrite, zircon, and green hornblende. The oligoclase, microcline, and some quartz are in rounded crystals ranging from 0.6 to 2 millimeters in diameter. These crystals are surrounded by the biotite and pyroxene (augite) and smaller crystals (0.1 to 0.5 millimeters) of quartz and oligoclase.

The above two rock types grade into each other laterally and combine to form gneisses of different compositions. The prevailing direction of banding could not be determined because of the folding of these metamorphic rocks.

Cambrian System

Cambrian formations exposed in the thesis area are the Flathead Sandstone, Wolsey Shale, Meagher Limestone, and Park Shale. The lithologies and thicknesses of these formations are similar to those reported at other localities in Montana. In this report the Flathead Sandstone and the Wolsey Shale are grouped as the Wolsey Formation in order to obtain a mappable unit large enough to be expressed on the geologic map (see Plate 2).

Flathead Formation

The Flathead Formation in the thesis area is equivalent to Peale's Flathead Quartzite (Peale, 1893). Weed (1900) referred to the Flathead as a quartzite that is somewhat fissile, impure, and shaly in the middle. He stated that it is the oldest Cambrian deposit in the area and assigned to it a Middle Cambrian age.

The Flathead Formation in the area consists of 20 feet of buff, maroon, green, and pink sandstones and intercalcated green shales.

At most localities the Flathead Formation is covered by limestone talus from overlying formations. In the northeast corner of sec. T. 9 S., R. 2 E., it forms a nine-foot high weathered sandstone ledge. The basal contact is unconformable; the sandstone of the Flathead lies on a regolith developed on the Precambrian gneisses. The regolith is about two feet thick and consists of abundant red clay with quartz and feldspar grains.

Lithology and Thickness

A six inch bed of sandstone at the base is buff-colored and contains rounded quartzite pebbles. The sandstones above are thin-bedded (2 inches to 6 inches) and range in color from maroon to green. Locally some of the sandstones are cross-bedded. The grain size of the sandstones increases upward from very fine- to medium-grained.

Quartz grains typically make up 90 to 95 percent of the sandstones. These grains are subangular to subrounded, a result of quartz overgrowths on the originally rounded grains. Many overgrowth contacts are sutured and all grains are tightly packed. Other constituents include quartzite, chert, microcline, plagioclase, and glauconite. Locally the glauconite is sufficiently abundant to define the bedding and to impart a green color to the sandstone. Hematite cement, which is very common, stains the detrital grains maroon to red.

Small interbeds of green shale occur near the base and increase in thickness and number upward, becoming dominant near the top. The shale is micaceous and green owing to the presence of chlorite.

Fossils and Age

No fossils have been found in the Flathead Formation in Montana. One inarticulate brachiopod was found in Wyoming, but it was useless for age determination (Miller, 1936). The Wolsey Formation contains abundant fossils of Middle Cambrian age and because the Flathead Formation grades upward into the Wolsey Formation in southwestern Montana, the Flathead is considered to be Middle Cambrian in age (Hanson, 1952).

Regional Correlation

The Flathead Formation is widespread in Montana and in northwestern Wyoming and maintains a very uniform lithology over its area of outcrop (Hanson, 1952). The formation exhibits regional thickness variations because of irregularities on the floor of deposition and the lateral tonguing of the Flathead Sandstone into Wolsey Shale. South of Dillon, Montana, the Flathead Formation is about 125 feet thick and consists of sandstones and a few thin shales. At Townsend, Montana, the formation contains nearly 170 feet of quartzites and very minor shales (Hanson, 1952).

Lochman (1957) states that the Flathead Formation becomes younger and thinner to the east in Montana, a circumstance that reflects deposition in an eastward transgressing sea.

Wolsey Formation

The Wolsey Shale was defined by Weed (1900) for exposures in the Little Belt Mountains and consists of about 150 feet of dark-gray or greenish shale overlying the Flathead Quartzite. He noted that it is commonly micaseous and contains small oval limestone concretions. The Flathead shale is mentioned by Peale (1893) as equivalent to Weed's Wolsey Shale.

In the mapped area the Wolsey Formation consists of a lower 22 foot limestone unit and an upper 45 foot shale and limestone unit. At the measured section the lower limestone unit forms a rubbly ledge, and the overlying shales and limestones form steep covered slopes. The Wolsey Formation is usually covered by limestone rubble from the overlying Meagher Formation but is best exposed in the northeast corner of sec. 25, T. 9 S., R. 2 E. However, everywhere in the area the basal contact is covered.

Lithology and Thickness

The lower limestone unit is mottled dark-brown and gray, is thin- to thick-bedded (1 inch to 3 feet), and has wavy bedding planes. Toward the top of the unit the limestone contains thin (1 to 2 inches) interbeds of green shale.

The limestone is made of calcareous pellets (25 percent), quartz and quartzite grains (6 percent), about 15 percent dolomite rhombs, all surrounded by medium to coarsely crystalline carbonate matrix. The pellets are calcareous, show no structure, and range in size from one-quarter to one millimeter in diameter. The siliceous grains are fine-grained and angular to subrounded. The dolomite rhombs (about 1/6 millimeter in diameter) partly replace both the calcium carbonate matrix and the pellets.

The lower 25 feet of the upper unit is predominantly green chloritic shale that contains a few thin limestone interbeds. About 20 feet of green to gray shales and interbedded thin (2 to 4 inch) gray limestones compose the upper beds of the unit. The limestone interbeds increase in thickness and relative abundance toward the top of the unit, and the shale changes in color from predominantly green to gray. The contact of the shale at the top of the Wolsey Formation with the overlying thin-bedded limestones of the Meagher Formation is well exposed in the mountains south of Taylor Fork where the stratigraphic column was measured (see measured sections), and the two formations appear to be conformable.

Fossils and Age

In the mapped area only casts of worm burrows (?) were found in the Wolsey Formation.

The Glossopleura-Kootenai marine invertebrate fauna characteristic of the Wolsey Shale in western Montana indicates an early Middle Cambrian age (Lochman, 1957).

Regional Correlation

Throughout western Montana and Wyoming the Wolsey shales are uniform in lithology and thickness. In northwestern Montana the shales are called the Gordon Formation; in central and southern Montana, the Wolsey; and in western Wyoming, the Lower Shale Member of the Gros Ventre Formation (Lochman, 1957). Like the Flathead Formation, the Wolsey Formation becomes progressively younger toward the east (Hanson, 1952).

Because the thesis area lies on the geosyncline-foreland axis developed during the Paleozoic, the Wolsey Formation generally increases in thickness to the west and northwest toward the geosyncline.

Meagher Formation

This formation was named by Weed (1900) for exposures in the Little Belt Mountains. Weed described it as a pure gray limestone, mottled with patches of buff-colored, arenaceous, clayey material, and characterized by thin, irregular bedding. He noted that the upper beds are spotted with green glauconite grains and numerous fossil fragments. Deiss (1936) emended Weed's original definition to read thick- and thin-bedded gray and tan limestones which contain thin shale partings. Deiss also located a typical section for the Meagher Formation in the Little Belt Mountains.

The Meagher Formation in the thesis area is a 413 foot thick sequence of gray and brown limestones. They are thin-, medium-, and thick-bedded and become oolitic and glauconitic near the top. The resistant limestones of the formation form high, nearly vertical, cliffs. The limestone weathers to a light-gray to buff color (Figure 1).

The basal contact was selected as the lowest limestone above the last shale interbed of the Wolsey. The contact is conformable and the contact surface is a gently undulating plane.

Lithology and Thickness

The lower 65 feet of the Meagher Formation in the

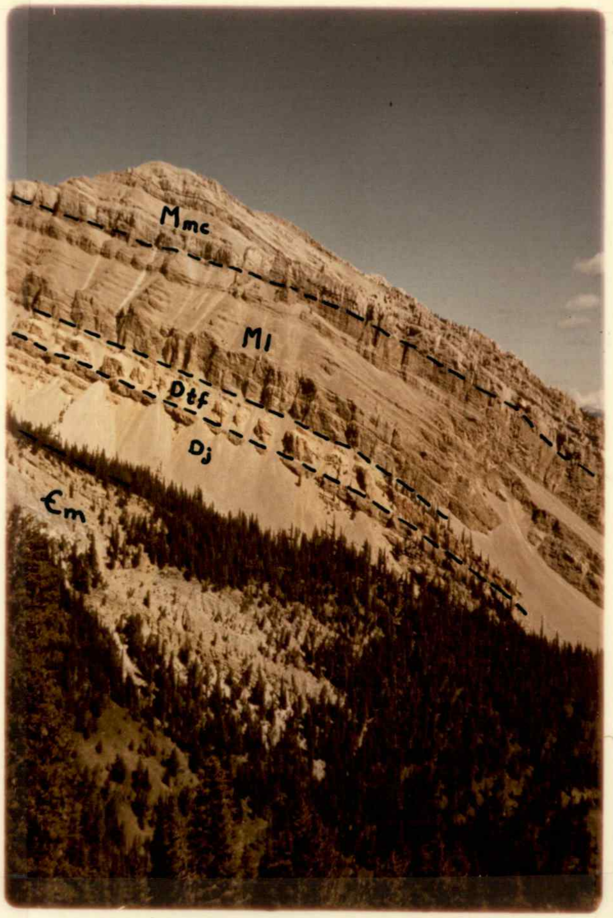

Figure 1. Excellent exposures of Cambrian through Mississippian rocks in the mountains in the western part of the area immediately north of Taylor Fork. Formations from bottom to top are the Meagher (€m), Jefferson (Dj), Three Forks (Dtf), Lodgepole (Ml), and Mission Canyon (Mmc). Located in section 24, T. 9 S., R. 2 E.

thesis area is thin-bedded, mottled light-brown and light grayish-brown, and has wavy bedding surfaces. These surfaces are rough with about one-half inch relief and are pitted. The limestone is micritic, dark, and contains a small amount of fossil debris, including sponge spicules, brachiopod and gastropod shells, and bryozoan (?) fragments. In the coarser parts of the limestone, dolomite rhombs replace the calcite.

The overlying 240 feet is a sequence of thin- (1 to 2 inches) to thick- (1 to 2 feet) bedded limestone. There is no orderly interbedding of the thin and thick beds, although the thick-bedded limestones are more abundant. The color is mottled light- to dark-brown, except where iron oxides stain the limestone yellow to brown. Calcite veins and circular calcite blebs are numerous in the limestones. Most of the limestone sequence is micritic, but contains scattered unidentifiable fossil fragments.

The upper 108 feet of the formation consist mostly of medium to coarsely crystalline, thin- (1 to 4 inches) bedded limestones and a few thick beds (1½ feet) of limestone. The limestones of this upper part are oolitic and contain glauconite. The oolites are solid calcite, are coated by limonite stain, and average one-third millimeter in diameter. Fossil debris, quartz silt, and oolites occur together in the medium-crystalline limestones. The round, broken glauconite grains are somewhat larger than the oolites, and are partly altered to iron oxide. Some of these grains reach one-quarter inch in diameter.

Fossils and Age

No identifiable fossils were found in the Meagher Formation in the thesis area. The age span of the Meagher Formation varies considerably owing to the transgressive nature of the conformable Wolsey and Park Formations. The known fauna indicates a Middle Cambrian age and consists of impressions of soft-bodied animals, calcareous algae, gastropods, and many trilobites and brachiopods (Lochman, 1957).

Regional Correlation

The lithology and thickness of the Meagher Formation vary throughout western Montana. Westward from the Madison River the Meagher Formation becomes increasingly dolomitic and is entirely dolomite at Whitehall, Montana (Hanson, 1952). The Meagher Formation is known as the Death Canyon Member of the Gros Ventre Formation in western Wyoming where the lithology is nearly the same as in southwestern Montana, but farther east the formation becomes dominantly shale. In northwestern Montana the Meagher is partly correlative with the thicker Pentagon Shale and the Steamboat Limestone (Deiss, 1939).

Park Formation

Weed (1900) first named the Park Formation for exposures in the Little Belt Mountains. He described the formation as gray or greenish shales in the lower part and shales and intercalcated limestone beds in the upper part. Deiss (1936) described a typical section for this formation in the Little Belt Mountains and emended Weed's description to say there are thin limestone beds throughout the shale.

The Park Formation in the thesis area is a nonresistant unit which forms conspicuous saddles in the mountainous areas. The Park Formation is usually covered either by a thin soil layer or by limestone and dolomite talus from overlying formations. The best exposure of the Park Formation is in the N½SE¼ sec. 36, T. 9 S., R. 2 E.

Consideration of sections measured by Hanson (1952) and the author's field observations lead to the conclusion that the contact between the Park Formation and the underlying Meagher Formation is conformable. The contact with the overlying Devonian Jefferson Formation is not exposed in the thesis area because of talus from the Jefferson.

In the thesis area the Park Formation is a green, buff, and reddish to purple gray shale. Throughout the formation the shale is micaceous and very thin-bedded.

It is usually covered in the mapped area and therefore was not measured, but the thickness is estimated at 100 feet.

Fossils and Age

Although no fossils were found in the Park Formation in the mapped area, they have been found in outcrops elsewhere in southwestern Montana. According to Hanson (1952) the formation contains a well-developed trilobite and brachiopod fauna and exhibits occasional impressions of soft-bodied animals. At Three Forks, Montana the fauna indicates a late Middle Cambrian age but in western Wyoming the Park Formation equivalent has been dated as early Late Cambrian in age.

Regional Correlation

The name Park Formation is used in central and southern Montana (Deiss, 1939). The lithology and regional extent of the Park Formation is very similar to that of the Wolsey Formation. In northwestern Wyoming the Park Formation is known as the Upper Shale Member of the Gros Ventre Formation and has the same lithology as in southwestern Montana (Hanson, 1952).

In the Lewis and Clark Range of northwestern Montana the Switchback Shale is correlative with the Park Formation and has a similar thickness and lithology but contains more arenaceous material than is found in the Park Formation of southwestern Montana.

Devonian System

Jefferson Formation

The Jefferson Limestone was first named and described by Peale (1893) for outcrops a few miles above the mouth of the Jefferson River near Three Forks, Montana. He described it as a brown and blackish microgranular limestone 640 feet thick occurring in alternating medium and thick beds lying between the Cambrian limestone below and the Three Forks Shale above.

Sloss and Laird (1947) proposed that the Devonian strata on the north side of the Gallatin River at Logan, Montana be considered the type section for the Jefferson and Three Forks Formations.

The Jefferson Formation in the thesis area is brown to gray brown, thin- to medium-bedded dolomite and limy dolomite about 340 feet thick. It crops out exclusively within the Paleozoic mountains located in the western part of the thesis area. It is resistant and forms high, steep ledges. These stand out well between the shales of the Cambrian Park Formation and the Three Forks Formation. The best outcrops are in the vicinity of the measured section located on the eastern edge of sec. 25, T. 9 S.,

R. 2 E. The basal contact of the formation is covered.

Lithology and Thickness

Where measured on the eastern edge of sec. 25, T. 9 S., R. 2 E., the base of the Jefferson Formation is thin-bedded (½ to 1½ inches), clayey, limy, light greenish-tan dolomite. The bedding is wavy, owing to a very irregular and coarsely pitted surface.

From the base to the top of the formation the thin-bedded limy dolomites are interbedded with thick-bedded brown dolomites. The former range from one to six inches thick and occur in units about 15 feet thick. The latter are thick-bedded near the top, to the extent that in the total section the thin- and thick-bedded dolomites become about equal in abundance.

The thick-bedded dolomites are brown, pitted, dense, and in part, vuggy. When the thicker dolomites are broken, they emit a fetid odor. Seen in thin section, these dolomites are fine- to medium-crystalline. The finely-crystalline part corresponds to the dense brown dolomite in outcrop. The medium-crystalline dolomite is porous and appears in outcrops as the softer and lighter-colored vuggy brown dolomite.

The thin-bedded dolomites are more limy than the thick-bedded, and they range in color from greenish-tan to gray brown. Sparse glauconite is present in one thin bed in the lower part of the Jefferson Formation.

The top 20 feet of the Jefferson Formation consists of massive brown dolomite, overlain by the Three Forks Shale in a conformable relationship. This sharp contact is well displayed in the northeast corner of sec. 25, T. 9 S., R. 2 E.

Fossils and Age

No fossils were found in the Jefferson Formation in the area mapped. Owing to the dolomitization, fossils are commonly sparse or absent, but certain areas in western Montana have a good Jefferson fauna. Coelenterates, brachiopods, gastropods, and pelecypods reported by Kindle (1908) indicate Early and Middle Devonian age. Sloss and Laird reported corals, brachiopods, and conodonts in northwest Montana and assigned a Late Devonian age to them. From a study of fossils found in the vicinity of Three Forks, Perry (1943) stated that the age of the Jefferson is late Middle and Late Devonian.

Regional Correlation

In western Montana there is a general southeastward thinning of the Jefferson Formation toward Yellowstone National Park, along with an increase in the amount of argillaceous and sandy beds. Where the Jefferson becomes noticeably argillaceous and sandy in western Wyoming, it is known as the Darby Formation (McMannis, 1962).

In northwestern, central, and north-central Montana, beds correlative with the Jefferson are known as the Duperow Formation, and they differ from the Jefferson Formation by the presence of anhydrite beds.

The Devils Gate Formation of southern Nevada is for the most part an age and lithologic equivalent of the Jefferson Formation. This correlation is based on a close similarity of faunal assemblages, as well as the fact that both are thick Late Devonian carbonate sequences (Cooper, 1942).

Three Forks Formation

The Three Forks Shale of Peale (1893) is equivalent to the Three Forks Formation in the thesis area. He first named and described the formation as 185 feet of reddish and brownish-yellow, calcareous and argillaceous shales at the base; overlain by a dense grayish-brown limestone; highly fossiliferous green, purple, and black calcareous shales; dark-colored argillaceous limestones; and yellow laminated sandstone. These rocks rest on the Jefferson limestone and underlie the Madison limestone.

A yellow sandstone 60 feet thick at the top of the Three Forks Formation near Sappington, Montana was named the Sappington Sandstone by Berry (1943) and assigned to the Mississippian. Sloss and Laird (1947) showed faunally and lithologically that the Sappington intertongues with the Three Forks Formation and must therefore be Devonian in age.

The Three Forks Formation in the area mapped consists of 180 feet of green to buff shales, red orange limestone breccia, brown to gray limestones, and pinkish-yellow, laminated, calcareous sandstones. It crops out only in the mountains in the western part of the area and forms covered slopes, steep-walled outcrops, or ledges, depending upon the resistance of the different lithologies of the formation. The limestone and dolomite breccia is the most distinctive unit in color and resistance to weathering. The formation creates a break in slope between the steep Jefferson and Lodgepole carbonate sequences. The most complete section of the Three Forks and Sappington Formations occurs on the eastern edge of sec. 25, T. 9 S., R. 2 E.

Lithology and Thickness

In the measured section a nine foot sequence of green, greenish-buff, and buff shales that become increasingly calcareous upward lies at the base of the formation and is overlain by a covered interval 31 feet thick. This covered interval occurs throughout the area.

Above the covered interval is a 39 foot sequence of yellow orange to red orange limestone breccia. It is composed of angular limestone and dolomite fragments ranging from two inches to one foot in diameter enclosed in a red mudstone matrix. Crude bedding appears near the top of the unit. This breccia is thought to have formed by solution and subsequent collapse of the original rock, which may have contained carbonate or evaporites that were easily removed by solution (Rau, 1962) (Figure 2).

Lying above the breccia are about 80 feet of limestone, limy dolomite, and shale. The limestone is gray brown, the limy dolomite is mottled yellow buff and red, and the shales are gray. The limestone is dense and mainly thin-bedded (3 to 5 inches) and is the dominant rock type. The limy dolomites are massive and coarsely-crystalline. Thin tan limestone beds occur locally. The shales are calcareous and occur at the top of the sequence where they are associated with dolomitic limestones.

The uppermost 20 feet of the Three Forks Formation is made up of yellow to pink calcareous sandstone, which has been named the Sappington Sandstone (Berry, 1943). The sandstone is thinly-laminated to thinly-bedded, with thin green to gray shale partings. It is very fine-grained, well-sorted, and highly calcareous. The quartz grains, comprising about 60 percent of the rock, were

Figure 2. A typical exposure of the middle breccia zone of the Three Forks Formation. Located in NE¼NW¼SE¼ sec. 24, T. 9 S., R. 2 E.

rounded at the time of deposition but now have angular quartz overgrowths that are but a small part of the quartz in the sandstone. Calcareous cement forms a mosaic texture as coarse as that of the quartz grains; the cement is stained yellow by iron oxide, which gives the sandstone its color. Dolomite crystals partly replace the cement.

Fossils and Age

No fossils were found in either the Three Forks or Sappington beds. The shales in the Three Forks Formation at the type locality near Logan, Montana (Peale, 1893), in Yellowstone National Park (Girty, 1899), and in the area of Three Forks are very fossiliferous and have yielded a fauna that includes brachiopods, pelecypods, bryozoans, and cephalopods. The Sappington beds contain corals, bryozoans, brachiopods, gastropods, foraminifers, ostracods, and sponges that indicate a Late Devonian and Early Mississippian age (Gutschick, 1962).

Regional Correlation

The Three Forks Formation or its lateral correlatives occur throughout the states of Montana, Idaho, and Wyoming and in the Canadian provinces of Alberta and Saskatchewan.

The name Three Forks is retained in central Montana, where the formation averages about 100 feet in thickness and is dolomitic. In northwestern Montana the Three

Forks Formation contains a prominent anhydrite sequence called the "Potlatch" anhydrite. This anhydrite grades into shale to the east and south (Hurley, 1962).

Mississippian System

Madison Group

In southwestern Montana the Madison Group consists of the Lodgepole and Mission Canyon Formations. The two formations are conformable and their mutual contact is gradational.

Hayden, Peale, and others of the Hayden survey in the 1870's first made mention of the "Carboniferous" limestone in the Three Forks vicinity. Peale (1893) named the "Carboniferous" limestone the Madison Formation and assigned to it a lower Carboniferous age. He divided the Madison, from bottom to top, into laminated limestones, massive limestones, and jaspery limestones. He stated that the Madison overlies "the yellow sandy beds of the Upper Devonian" and underlies the "Red limestones of the Quadrant Formation." Peale did not designate a type section. Sloss and Hamblin (1942) proposed a type section on the north side of the Gallatin River, across the river from Logan, Montana.

Collier and Cathcart (1922) considered the Madison as a group when they divided it into two parts; the lower part they called the Lodgepole Formation and the upper part they called the Mission Canyon Formation. The Lodgepole is essentially equivalent to Peale's laminated limestones and the Mission Canyon to his massive limestones.

Lodgepole Formation

In the thesis area the Lodgepole Formation is 615 feet thick and consists of dark gray-black to brown, thin- to medium-bedded, very fossiliferous limestone.

The lower contact of the Lodgepole with the Devonian Sappington Sandstone appears conformable in the field. The Sappington beds become more calcareous upward and grade upward into the black calcareous shale of the basal part of the Lodgepole (Figure 3).

The Lodgepole Formation is well exposed in the thesis area and forms vertical cliffs 200 to 300 feet high. The basal contact is exposed at numerous places in the Paleozoic mountains but generally is concealed by talus of Lodgepole and Mission Canyon limestone. The Lodgepole-Mission Canyon contact is gradational and could not be located exactly in the limestones. The break between the two formations was arbitrarily placed at the base of the lowest oolitic limestone where there is an upward thickening of the bedding and a decided decrease in the number of fossils. The description given of the Lodgepole Formation comes from the measured section in the NW¼SE¼ sec. 24,

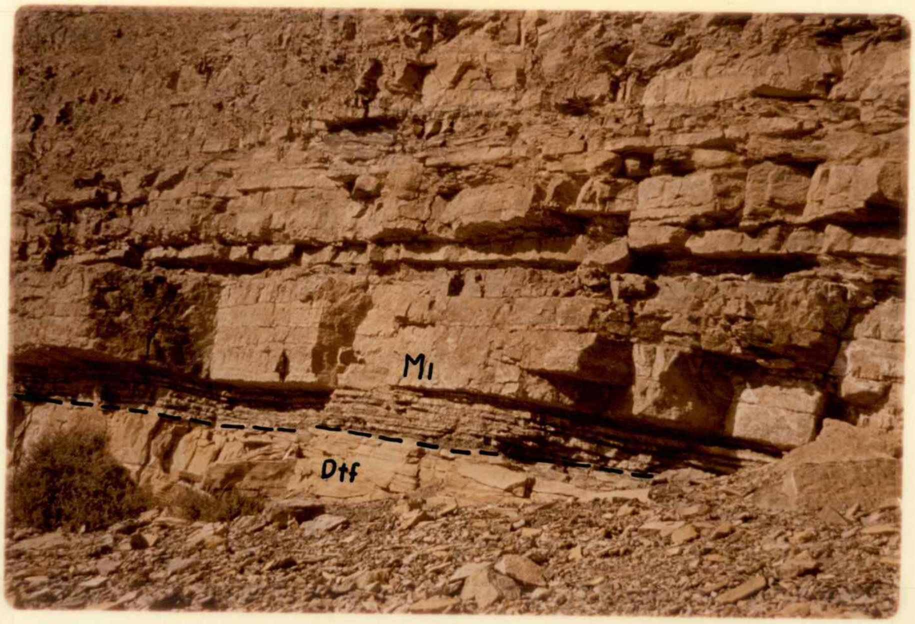

Figure 3. The contact between the Devonian Sappington (Dtf) sandstone and the Mississippian Lodgepole (Ml) Formation. The yellowish Sappington sandstones are overlain by thin- to medium-bedded limy shale and limestone. Center of sec. 24, T. 9 S., R. 2 E.

T. 9 S., R. 2 E. The resistance of the limestones of the Lodgepole and the Mission Canyon Formations is an important factor in the relief of the Paleozoic mountains in the western part of the mapped area.

Lithology and Thickness. The basal 56 feet of the Lodgepole Formation consists of highly fossiliferous, interbedded black calcareous shale and dark-gray limestone. Fossiliferous stringers and nodules of black chert are concentrated parallel to the bedding planes in the limestones but contain fewer fossils than do the shales or limestones. Siliceous shale occurs with the chert, and the siliceous material is formed by chert replacement of fossil fragments. In the dark shale the fossils are primarily a mat of fenestrate and other colonial bryozoans.

The overlying lithologic unit comprises 123 feet of brown to dark-gray, thin- to medium-bedded, fossiliferous limestones. Most of the limestones are medium- to coarsely-crystalline and have a fetid odor when broken. In the center of this sequence is a 10-foot section of dark-gray calcareous shales and shaly limestones containing black chert stringers and nodules. Here the fossil content is extremely high and includes large horn corals and abundant brachipods (Figure 4).

The next unit is 220 feet thick and is a sequence of interbedded dark-gray limestones and thin (1 to 2 inch)

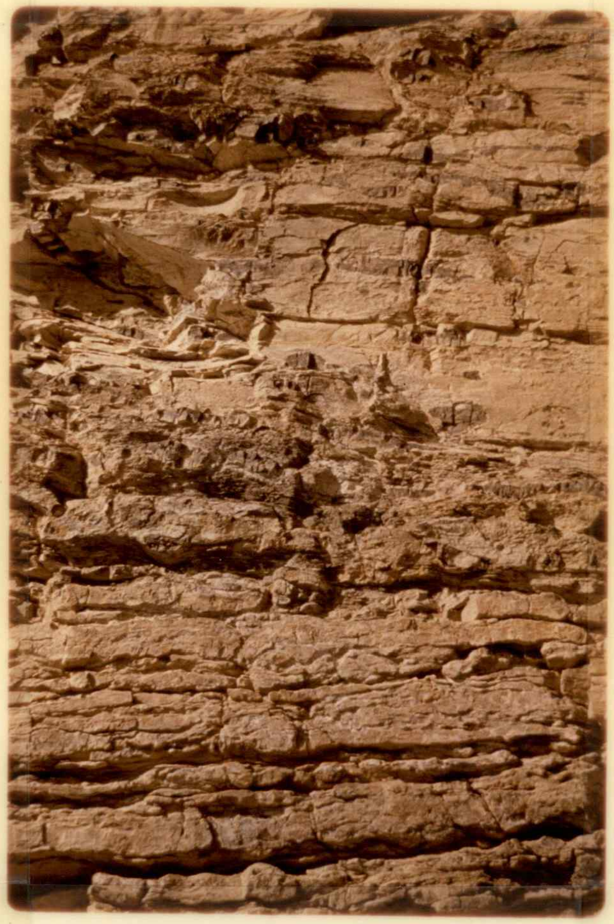

Figure 4. Close-up view of the lower Lodgepole Formation showing dark nodules of chert in light-colored weathered limestone. Center of section 24, T. 9 S., R. 2 E.

beds of yellow buff calcareous shale. This sequence is conspicuous in outcrop and can be easily distinguished from the other limestones. Oscillation ripple marks strike N. 10° W. The fossils in this part of the Lodgepole appear mainly on the surfaces of the bedding planes, but there are a few thin limestone beds near the top that are composed almost entirely of fossils, of which small horn corals, brachiopods, and crinoids are most common.

The remaining 215 feet of the formation is a sequence of thin- to medium-bedded, dark-gray to brown, and fine- to coarsely-crystalline limestone. Interbedded with these limestones near the middle of this sequence are thin yellowish-buff calcareous shales. The bedding ranges in thickness from two inches to four feet. All the limestones are fragmental (clastic) and carry well preserved fossils. Whole small corals, both solitary and colonial, and brachiopods are common; the corals are the more abundant.

Fossils and Age. The Lodgepole Formation is very fossiliferous throughout western Montana. The fossils found in the thesis area are as follows:

Orthotetes sp.	Composita sp.
Dictyoclostus sp.	Camarophoria
Dielasma sp.	Platyceras sp.
Eoptychia? sp.	Syringopora sp.

Loxonema sp.

Productus gleanus

Torynifer sp.

Spirifer albapinensis

Spirifer centronotus

Fenestrellina sp.

Aulopora sp.

Straparolus? sp.

Hexagonaria sp.

Worm trails

Crinoid plates and columnals

These fossils, and faunal assembleges collected by others, indicate a Kinderhookian age for the Lodgepole Formation (Andrichuk, 1955).

Regional Correlation. In western Montana, the Lodgepole is commonly differentiated into the Paine "Shale" and the overlying Woodhurst Limestone. The Paine "Shale" resembles the lower part of the Lodgepole Formation in the thesis area and comprises dark limestones and interbedded dark calcareous shale. Chert lenticules are common. Farther east the Paine loses its shaly character and becomes a rather massive limestone unit in south-central Montana. The Woodhurst is lithologically constant and forms thick limestone cliffs wherever the Lodgepole is encountered (Sloss and Hamblin, 1942).

Mission Canyon Formation

The Mission Canyon Formation in the thesis area consists of 852 feet of light-brown to brown, medium- to thick-bedded, saccharoidal limestones and intercalated limestone breccias.

The Mission Canyon Formation is well exposed in the mountains of the western part of the area, where it forms massive cliffs of limestone. The cliffs, very commonly 100 to 200 feet high and nearly vertical, weather to a light-tan color and produce large, steep talus slopes. The uppermost few feet are mottled red, purple, and tan owing to the staining affect of the overlying Amsden Formation. The contact with the Amsden was arbitrarily placed at the position where the red color becomes dominant. The best outcrops for study are in the eastern half of sec. 24, T. 9 S., R. 2 E.

Lithology and Thickness. The basal 95 feet of the Mission Canyon Formation are brown, massive, oolitic limestones. In this oolitic limestone sequence bedding is crudely developed, and only by weathering and fracturing do the nature of the original depositional surfaces appear. The top 20 feet of this sequence is made up of medium- to thick-bedded (1½ to 6 feet) limestones.

The oolites display well-developed concentric and radial internal structure. Near the base of the formation the oolites range from one-third to one millimeter in diameter and average one-half millimeter. The average size of the oolites decreases upward in the unit. Associated with the oolites are fossil fragments of the same size, many of which were coated by carbonate at the time of oolite formation. These coated fossil fragments are oblong, in contrast to the spherical to oblate oolites. Very minor amounts of chert replace parts of the oolites. Near the top of the unit the limestones are coarsely crystalline and contain small oolites.

Brown, fossiliferous, coarsely-crystalline, thin-bedded limestones 150 feet thick overlie the oolitic limestones. Bedding is thick (3 feet and greater) and commonly obscure. This unit includes the most fossiliferous beds in the Mission Canyon Formation and contains brachiopods, bryozoans, corals, crinoid columnals, ostracods, unidentifiable spicules, foraminifers, and much fossil hash. Along with the skeletal material are oblong calcareous pellets and coated fossil fragments that make up about 10 percent of the rock and reach two millimeters in length. Rounding of the larger fragments suggests current action during deposition of the limestone.

The overlying unit comprises 182 feet of nonfossiliferous, fine- to medium-textured limestones. At the base the limestones are thin- to medium-bedded (6 inches to 2 feet), micritic, and have a splintery fracture. They become thicker upward in the sequence. The beds are finely-crystalline throughout except near the top where they become saccharoidal and dolomitic. The dolomite occurs in coarsely-crystalline discrete blebs that are lined with the dolomite but have centers of calcite. These blebs are abundant and scattered throughout the limestone. Small dolomite rhombs also occur in the micritic part of the limestones. Dolomite makes up about 25 percent of the rock.

The uppermost unit of the Mission Canyon Formation consists of 424 feet of light-brown to tan saccharoidal beds of limestone and limestone breccias. The breccias at the base of the unit contain dark, angular clasts set in a sparse matrix of micrite and up to four percent detrital quartz grains. Most of the clasts are angular, micritic, dark-brown limestone. One bed of breccia is stained by red argillaceous material and is noticeable at considerable distances. Clasts of the breccias at the base of the unit are of a more uniform size than those in the breccias higher in the section.

Above these basal breccias are limestones and breccias of a different character. The thick-bedded limestones are intermixed micritic and micritic-dolomitic, light-brown to tan, and form prominent cliffs. The micritic-dolomitic limestones contain about 30 percent dolomite that is concentrated in interconnected blebs throughout the rock. The clasts of the breccia are lighter colored, have a larger range of size, are considerably fewer in number, have no orientation, and are held together by more micritic limestone matrix than the clasts in the breccias of the basal unit.

The uppermost few feet of the Mission Canyon Formation are mottled red, purple, and tan dolomitic limestones. The red coloration increases in intensity upward towards the Amsden, from which the coloration apparently has been derived.

Fossils and Age. In the thesis area many genera of fossils were found in the lower one-third of the Mission Canyon Formation. The fossils identified are as follows:

Linoproductus sp.

Proetus loganensis

Seminula humilis

Dictyoclostus sp.

Plectogyra sp. or Endothyra sp.

Three genera of spiriferoids

A zaphrentoid coral

These fossils, together with faunas collected by other workers (Sloss and Hamblin, 1942) indicate an Osagian age for the Mission Canyon. More recently, workers have dated the Mission Canyon as Osagian and possibly upper Kinderhookian (Strickland, 1956).

Regional Correlation. In southwestern Montana and northwestern Wyoming the name Mission Canyon is used for carbonate rocks of Osagian age whose lithology is that described above. Towards the Montana-Idaho border the Mission Canyon, as well as the Madison Group, increases rapidly in thickness (McMannis, 1965).

In Wyoming the Mission Canyon is considered to be the middle to upper part of the Madison Group. The Madison Group decreases in thickness in a southeasterly direction and is absent in southeast Wyoming, probably owing to erosion (Sloss and Hamblin, 1942).

In central Montana the Mission Canyon is a sequence of variable thickness composed of marine limestone, dolomitic limestones, and subordinate amounts of dolomite. Evaporite sediments occur in the upper parts of the formation. From central Montana the Mission Canyon Formation decreases in thickness to the north and southeast (Sloss and Hamblin, 1942). Sloss and Laird (1945) divided beds of the Madison Group in the Sweetgrass Arch into units Ma, Mb, and Mc in descending order. The Mission Canyon Formation is correlative with the Mb unit and includes the thick-bedded, partly fragmental limestones between units Ma and Mc.

Amsden Formation

The Amsden Formation in the area is correlative with the Red Limestones of the Quadrant as originally defined and mapped by Peale (1893) in the Three Forks area. He considered these beds to be Upper Carboniferous in age.

Darton (1904), assigned the name Amsden to beds of red shale, white limestone, and cherty and sandy limestone that range in thickness from 150 to 350 feet and crop out along a branch of the Tongue River west of Dayton, Wyoming, in the Big Horn Mountains.

The Amsden Formation in the thesis area consists of

43 feet of red siltstones and shales. It is steeply dipping and well-exposed in the high mountains in the western part of the thesis area and is a good stratigraphic marker because of its red color and position between two resistant formations. In the mountains it commonly forms gullies. Good exposures of the Amsden Formation occur in the northeast corner of sec. 24, T. 9 S., R. 2 E.

Lithology and Thickness

The basal six feet of the formation consist of limy dolomite beds mottled purple and yellow buff. The dolomite is micritic and contains about 20 percent calcite centered in small randomly scattered calcite-filled vugs. Limestone breccias similar to but less abundant than those in the upper Mission Canyon Formation occur in this basal unit.

The remainder of the formation consists of interbedded calcareous red shales, siltstones, and breccias. The shales are very thin-bedded, red, and calcareous, and they decrease in abundance upwards. The siltstones and shaly mudstones are the dominant rock types in the formation. The siltstones are composed of silt-sized quartz and calcite grains in a matrix of red clay. Interbedded with the mudstones are many thin beds of breccia made up of red and white limestone and mudstone clasts. The breccias appear to be intraformational and probably are due to the action of swift currents of water that tore material from a slightly hardened depositional surface. One thin micritic white limestone bed occurs in the upper one-third of the Amsden Formation.

The overlying contact with the Quadrant Formation appears to be conformable and gradational in the thesis area. Both red and white colored sandstones are interbedded in a seven foot interval grading into the Quadrant sandstones at the top. The contact was selected at the top of the dominantly red strata. Lauer (personal communication) has found that the Amsden is absent at Pulpit Rock 11 miles to the northwest but is present within one mile of Pulpit Rock. This evidence of erosion suggests that the contact is in reality disconformable, not conformable.

Fossils and Age

Many brachiopods of Late Mississippian and Early Pennsylvanian age in the Amsden have been collected throughout western Montana by geologists of the United States Geological Survey and the Montana Bureau of Mines and Geology (Gardner *et al.*, 1946). Because no fossils were found in the Amsden in the thesis area, the exact age is not known. It is possible that owing to erosion of part of the upper Amsden only beds of Late

Mississippian age remain.

Regional Correlation

The Amsden Formation is present in the northern half of Wyoming, in central, southern, and eastern Montana, and in the western one-third of North and South Dakota (Perry, 1962).

In the Big Horn Mountains in south-central Montana, the Amsden Formation is a 250 foot sequence of red siltstone and shale overlain by gray limestone, dolomite, chert, and sandstone.

In the Big Snowy Range of central Montana the Amsden Formation consists of red siltstone, claystone, and fossiliferous limestone overlain by discontinuous patches of red shales and siltstones and ranges in thickness from 0 to 150 feet (Gardner *et al.*, 1946).

The Amsden has been mapped as far west as the Tendoy Mountains of southwestern Montana, where it is 200 feet thick and consists of gray to buff limestones and red calcareous sandy shales and sandstones (Scholten, 1955).

Pennsylvanian System

Quadrant Formation

The name Quadrant Formation first appeared in print in a publication of the Three Forks geology by Peale

(1893) and was applied to a sequence consisting of an upper 150 feet of cherty limestone and a basal 200 feet of red limestone that overlies the Madison Limestone. Iddings and Weed (1899) first described the Quadrant Formation at Quadrant Mountain, and designated it as the type section. It consists of white, yellowish, and occasional pink beds of quartzite and intercalated beds of drab saccharoidal limestone that lie between the Amsden below and the Phosphoria above. They considered the formation to be "Upper Carboniferous" in age.

Later, Scott (1935) restricted the Quadrant Formation to beds of Pennsylvanian age and assigned the lower red beds of Weed's original description to the Mississippian Amsden Formation. He stated that the type section of the Quadrant was 230 feet thick and consisted primarily of well-bedded, white to pink, medium-grained quartzite, and a few sandy beds.

The Quadrant Formation in the thesis area is about 220 feet thick and consists of aqueous cross-bedded, white, calcareous and noncalcareous sandstones. Because the Quadrant in the thesis area is not exposed in a complete section, it was measured outside the area at Pulpit Rock, in the center of the NE¼ sec. 3, T. 9 S., R. 1 E. along U.S. Highway 191. The lithologies of the sections in the two areas are very similar except for a 30 feet bed of pink, calcareous sandstone that appears near the middle of the formation in sec. 13, T. 9 S., R. 2 E. but is absent from the Pulpit Rock section (Figure 5).

In the thesis area and at Pulpit Rock the Quadrant Formation is resistant and well-exposed, commonly cropping out in cliffs up to 60 feet high. In the thesis area the best outcrops occur in the northwest corner of sec. 13, T. 9 S., R. 2 E. The lower contact at Pulpit Rock is gradational with the Mission Canyon Formation and was selected at the base of a thick cavernous bed where quartz grains become dominant over carbonate.

Lithology and Thickness

The bedding in the Quadrant Formation ranges from thin to thick, the thinnest beds at the base (1 to 6 inches) becoming thicker toward the middle (2 to 5 feet) and thinner again toward the top (6 inches to 1½ feet). Cross-bedding is common throughout the sequence but is concentrated near the middle and shows an aqueous current flow from north to south. Upward through the formation the sandstone becomes more dense and less calcareous owing to an increase in silica cement in the form of quartz overgrowths and to a tighter packing of the grains. The quartzite level of induration is never reached, however.

The sandstones of the Quadrant Formation consist mainly of well-sorted, fine-grained, and subrounded quartz

Figure 5. Typical Quadrant Formation exposures south of Shedhorn Mountain. Note pink sandstone zone near the middle of the Quadrant Formation. These northeast-dipping rocks occur in the NW¼NW¼ sec. 13, T. 9 S., R. 2 E.

grains. Before the silica cement was deposited, the quartz grains were rounded. Associated with the quartz grains are minor amounts of chert, tourmaline, zircon, monazite and hypersthene. The carbonate cement in these sandstones occurs as sparry calcite and ranges from about 35 percent at the base to less than one percent at the top.

Fossils and Age

No fossils were found in the Quadrant Formation at Pulpit Rock or in the thesis area. Thompson and Scott (1941) have reported two fusulinid genera from Quadrant Mountain that indicate a Middle Desmoinesian age for the Quadrant. In Jefferson Canyon, west of Three Forks, Scott (1935) reported a number of sponge spicules that were similar to those found in the Pennsylvanian of Illinois and Indiana. These fossils and others have led to a general acceptance of a Middle Pennsylvanian age for the Quadrant.

Regional Correlation

The Quadrant Formation and its correlatives are found throughout Wyoming, southern Montana, and eastern Idaho (Perry, 1960). The term Quadrant Formation is used for Middle Pennsylvanian sandstones in southwest Montana and northwest Wyoming that range in thickness from 230 feet at Quadrant Mountain (Thompson and Scott, 1941) to 2,662 feet at Big Sheep Creek, Montana (Sloss and Moritz, 1951). The Quadrant becomes more calcareous towards the west (Idaho-Montana border) and more siliceous towards the east (Big Horn Mountains), reflecting an eolian character in the Big Horn Mountains that gives way to marine sediments westward (Scott, 1935).

The Quadrant of southwestern Montana is the lithologic equivalent of the Tensleep Sandstone of north-central Wyoming. The Tensleep also occurs in south-central Montana and central and south-central Wyoming. The sandstones of the Tensleep are relatively loose and friable in these areas (Sloss and Moritz, 1951).

The correlative of the Quadrant in eastern Idaho is the Wells Formation, a sequence of sandy limestones, calcareous sandstones, and somewhat variable quartzites which, in Wells Canyon, Idaho, is 2,400 feet thick (Richards and Mansfield, 1912).

Permian System

Phosphoria Formation

The Phosphoria Formation was named by Richards and Mansfield (1912) for beds of Permian age at Phosphoria Gulch, Bear Lake County, Idaho, where two members of the formation were recognized: the lower Phosphatic Shale

Member and the upper Rex Chert Member. These members lie between the Pennsylvanian Wells Formation below and the Triassic Dinwoody Formation above. At the type locality the phosphatic shale is 180 feet thick and the Rex Chert is 240 feet thick (McKelvey, 1944).

The phosphatic rocks of Permian age in Montana were first recognized and mapped by Condit, Finch, and Pardee (1916). They traced these rocks through the Madison, Gravelly, and Centennial Ranges.

Cressman (1955) subdivided the Phosphoria into five members on a lithologic basis. They are in ascending order: Unit A, a basal sandstone and dolomite member; Unit B, a thin lower phosphatic shale member; Unit C, a middle sandstone and dolomite and chert member; Unit D, an upper phosphatic shale member; Unit E, a chert and quartz sandstone member. Unit A has not been recognized in southwestern Montana.

The Park City and Shedhorn Formations, also of Permian age, occur in southwestern Montana, Wyoming, Utah, and westernmost Idaho. Because these two formations intertongue with the Phosphoria, problems of formational terminology and correlation exist. Solution of these problems has been offered by McKelvey and others (1956) who proposed that the intertonguing lithic units be designated as follows: Park City Formation - carbonate rocks and subordinate sandstones; Phosphoria Formation - phosphatic, calcareous and cherty sandstones, mudstones, and shales; Shedhorn Formation - dominantly sandstone.

The name Shedhorn Formation was introduced by McKelvey and others (1956) for Permian outcrops in cliffs on the north side of Indian Creek in the SW¼ sec. 20, T. 8 S., R. 2 E., Madison County, Montana, about one-quarter mile west of the mouth of Shedhorn Creek. This area of outcrop was designated the type locality, where it consists of a lower 17-foot member of sandstone, cherty sandstone, and minor interbedded dolomite, and an upper 75-foot member of medium gray, fine-grained, well-sorted quartzose sandstone containing small amounts of dark chert and collophane grains.

The Shedhorn sandstones are well developed in the thesis area but the author prefers to use the designation Phosphoria Formation for the Permian rocks.

The Phosphoria Formation in the thesis area is mostly sandstone and chert and subordinate sandy limestone. Where measured in sec. 13, T. 9 S., R. 2 E., the formation is 230 feet thick. The contact with the Quadrant Formation is seemingly conformable and gradational and is placed between the nearly white sandstone of the Quadrant Formation below and a silty limestone of the Phosphoria above. The contact is disconformable however, because of missing Late Pennsylvanian and Early Permian rocks.

The Phosphoria Formation forms good outcrops wherever encountered, owing to the resistance of its calcareous sandstones and chert. The sandstones weather to hoodos 20 to 30 feet high and to ledges of lesser height, and the cherts weather to rubbly cliffs and low ledges. The best outcrops of this formation occur in the eastern half of sec. 13, T. 9 S., R. 2 E., where the stratigraphic section was measured (Figure 6).

Lithology and Thickness

The basal 16½ feet of the formation consists of silty fossiliferous limestone and randomly interbedded calcareous sandstone beds. The sandstones are buff to light-brown, thin-bedded (¼ to 3 inches), and contain scattered glauconite grains. Isolated chert nodules occur near the top of this sequence.

The overlying lithologic unit consists of 92½ feet of calcareous sandstones; chert nodules, stringers, and beds; thin conglomerates; and argillaceous limestones. The sandstones are the dominant rock type and are light-brown to tan, medium- to thick-bedded (2 to 6 feet), fine- to very fine-grained, and calcareous. Quartz grains are the dominant clasts (55 to 65 percent); chert (5 to 10 percent) and collophane (8 to 12 percent) grains are subordinate. Zircon and brown tourmaline occur locally in small quantity. The cement is sparry and microcrystalline calcite, and ranges from 20 to 30 percent of the rock.

Figure 6. Typical Phosphoria Formation outcrop occurring in the N½ sec. 13, T. 9 S., R. 2 E. The covered slope above these outcrops is in the Dinwoody Formation. View is to the north.

A six foot thick unit of argillaceous limestone underlies two thin conglomerates. The limestone is buff to tan, thin-bedded (6 inches), sandy near the top, and weathers to talus-covered slopes. The thin conglomerates are near the middle of the Phosphoria and grade vertically into conglomeratic sandstones. The lower conglomerate is thinner and contains pebbles smaller in size (2 to 20 millimeters) than those of the upper conglomerate. The pebbles include limestone, sandy limestone, and minor chert and quartzite. Pelecypod and gastropod shells are sparse. The upper conglomerate is thicker and is associated with several feet of pebbly sandstone. The conglomerate pebbles range from 4 to 45 millimeters in diameter and consist of limestone, chert, fossils, calcareous siltstones, quartzites, and other conglomerates. The many coarse grains of black chert in the associated pebbly sandstones possibly are derived from the lower Madison Group.

The chert in this unit occurs as beds, as well as in nodules and stringers nearly parallel to the bedding. The chert is scattered randomly through the sandstones, is light-colored, and is sandy near the top of the unit.

An overlying covered interval eight feet thick forms a gentle slope partly covered by chert float in the measured section. This covered interval probably represents, at least in part, the upper phosphatic member of the

Phosphoria described and measured at Indian Creek (McKelvey *et al.*, 1956).

The overlying lithologic unit comprises 37 feet of bedded chert, referred to as the Tosi Chert Member of the Phosphoria. At the type locality, Tosi Creek, Sublette County Wyoming, the chert is 33 feet thick and ranges in color from brownish-gray to brownish-black through the lower 25 feet and is light-gray through the upper eight feet of the unit (McKelvey *et al.*, 1959) (Figure 7).

At the measured section (see measured sections) in the thesis area the cherts range from dark-gray near the base to light-gray near the top. The dark pigment in the chert is argillaceous and carbonaceous matter, with a few apatite grains. Alternating dark and light bands and dark and light mottling are characteristic in this interval. These cherts are thin-bedded (1 to 3 inches) and have undulatory bedding planes. Thin laminae of yellow brown silt separate the beds. The cherts consist of 75 percent featureless chert and 25 percent sponge spicules, phosphatic spicule-canal fillings, and subrounded grains of iron oxide, glauconite, apatite, and quartz. The sponge spicules are chert and many have their canals filled with apatite and carbonaceous material. Round columns of sandstone oriented normal to the bedding occur in the lighter-colored upper cherts of this unit. The columns are several inches in diameter, reach

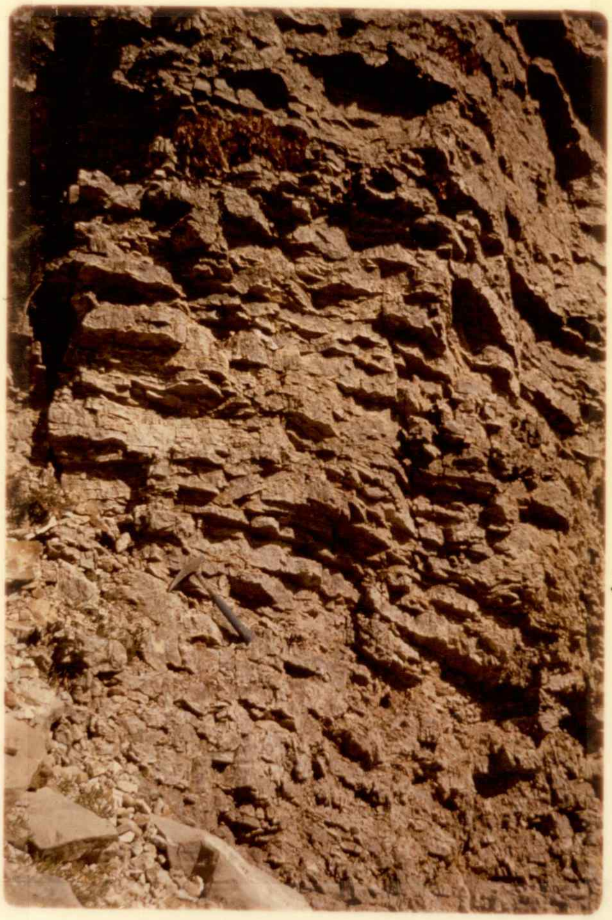

Figure 7. Close-up view of the Tosi Chert Member of the Phosphoria Formation. Note evenly bedded character. For location see Figure 6.

two feet in height, and are spaced up to six feet apart. These structures have been found in the Phosphoria in other areas of southwestern Montana. Cressman and Swanson (1960) have suggested that these columns are filled-in burrows of an unknown animal.

The uppermost 75 feet of the Phosphoria Formation consist of sandstones and cherts. The sandstones are dark-brown to light-brown, fine-grained, generally well-sorted, and calcareous. Thin sandstone interbeds (4 to 6 inches) in the thicker-bedded cherts have columns penetrating the chert above at right angles to the sandstone beds. The sandstones of the uppermost 75 feet consist of quartz, collophane, chert, and glauconite grains cemented by calcite. The quartz grains make up 60 to 80 percent of the clasts; collophane and glauconite (15 percent) and chert (10 to 15 percent) make up the remaining clasts. The calcite cement comprises 2 to 15 percent of the rock.

Light-gray chert nodules up to six inches in diameter occur only in the basal two feet of the uppermost unit. Light-colored bedded cherts occur near the middle of the unit and range in thickness from 2½ to 6½ feet. These have nearly the same composition as the Tosi Cherts.

Fossils and Age

The only fossils found in the formation were sponge spicules (monaxons), pelecypod shell fragments, shells of the gastropod genus *Bellerophon*, and crinoid columnals. Well-preserved specimens of *Bellerophon* have been found by Ray (personal communication) in an adjacent area to the northeast. The fossil fauna of the Phosphoria in other areas is varied and includes brachiopods, pelecypods, cephalopods, gastropods, conodonts, and fusulinids (McKelvey *et al.*, 1959; Frenzel and Mundorf, 1942).

Studies of fossils and stratigraphic relationships indicate that the Phosphoria Formation is Leonardian and Early Guadalupian (Middle Permian) in age (McKelvey *et al.*, 1959). Dunbar and others (1960) have indicated that the Phosphoria and the Shedhorn Sandstone in Montana is entirely Guadalupian (early Late Permian) in age.

Regional Correlation

To the northwest, north, and east of the thesis area the Permian becomes almost entirely sandstone and is known as the Shedhorn Sandstone.

In eastern Idaho and western Wyoming, all Permian beds are included in the Phosphoria Formation. In southeastern Idaho the Phosphoria Formation has its greatest thickness, more than 1,300 feet, but decreases in thickness rapidly to the east. Eastward into Wyoming it loses its phosphatic rock, carbonaceous matter, and bedded chert but gains carbonate rock, nodular chert, and sandstone and is referred to as the Park City Formation (McKelvey, 1953). The Park City is correlative with the nonmarine red beds of the Goose Egg Formation of central and eastern Wyoming. These red beds are correlative with the Maroon Formation of Colorado (Dunbar, 1960).

Triassic System

Dinwoody Formation

The Dinwoody Formation was named by Blackwelder (1918) for outcrops in Dinwoody Canyon near Dubois, Wyoming. He restricted the name to strata above the Phosphoria Formation and below the red shales and siltstones of the Chugwater Formation (Kummel, 1954).

Newell and Kummel (1942) redefined the formation to include only the dominantly silty strata between the Phosphoria and the top of the resistant siltstones about halfway toward the top of the originally defined Dinwoody Formation.

The Dinwoody Formation in the thesis area consists of 242 feet of brown, calcareous sandstones and siltstones, and brown limestones. It is relatively nonresistant and forms low weathered ledges several feet high on hilltops and cliffs along steep-banked streams. The best outcrops occur in the NW¼SW¼NE¼ sec. 13, T. 9 S., R. 2 E. (Figure 8).

Figure 8. Outcrop of Dinwoody siltstones and sandstones. Located in NW¼SW¼NE¼ sec. 13, T. 9 S., R. 2 E.

Lithology and Thickness

The lower 36 feet of the Dinwoody Formation consist of light-buff to gray and brown, fossiliferous limestone. The lower four feet of buff to gray limestone contain abundant quartz sand grains. These grains are subrounded to subangular and average one-fifth millimeter in diameter. Vugs containing calcite and an asphalt-like substance occur throughout the limestone. The remaining 32 feet of brown limestone are micritic and glauconitic. The color is due to the presence of phosphatic Lingula shells and collophane in the micrite. The glauconite is sparse (about 1 percent) and in rounded grains.

The upper 206 feet of the Dinwoody Formation comprise an interbedded sequence of calcareous sandstone, siltstone, and limestone. Sandstone is most abundant and is thin- to medium-bedded (2 inches to 2 feet) and very fine-grained. It varies in color from buff to dark-brown dependent on the amount of collophane present. Quartz makes up the bulk of the framework (50 to 60 percent), the remainder consisting of collophane (8 to 12 percent). Calcite (35 to 40 percent) cements the framework tightly in most places. Glauconite is present only in trace amounts.

Near the top of the sequence the sandstones grade into thin-bedded (2 to 3 inches), ripple-marked siltstones. The siltstones commonly contain intraformational breccias and other evidences of penecontemporaneous deformation. The interbedded siltstones are the same color and composition as the sandstones.

The limestones in the upper unit are brown, phosphatic, and micritic. They occur as thin interbeds in the sandstones and contain abundant fossils of Lingula.

Fossils and Age

The only fossils found in the Dinwoody Formation in the mapped area were sponge spicules, a few gastropods, and abundant Lingula, all of which are useless as index fossils.

Kummel (1960) found a well preserved ammonite fauna at Frying Pan Gulch, Montana, in the lower and middle Dinwoody, which indicates a Gyronitan and Flemingitan age (Early Triassic) for the formation.

Regional Correlation

The Dinwoody and its correlatives occur throughout Wyoming, Utah, southwestern Montana, southeastern Idaho, northern Arizona, and southern Nevada (Newell and Kummel, 1942).

In southwestern Montana the Dinwoody Formation consists of thin silty and argillaceous limestones, siltstones, and fine-grained sandstones that usually weather chocolate brown. The thickness increases rapidly to the west (Moritz, 1951). In southwestern Montana, westernmost Wyoming, and eastern Idaho three zones are recognized in the Dinwoody; the basal siltstone, the *Lingula* zone, and the *Claraia* zone. These zones are very helpful in stratigraphic correlation throughout these states (Newell and Kummel, 1942).

In southeastern Idaho the Dinwoody Formation contains large amounts of brown and drab shale and calcareous siltstone and gray limestone. The formation is thickest in this area and reaches 2,443 feet near Henry, Idaho (Kummel, 1954).

In Wyoming the Dinwoody Formation undergoes a drastic change. In western Wyoming it has essentially the same lithology as in southeastern Idaho but thins greatly eastward, and all but the basal siltstones and silty limestones are replaced by "red beds". In central Wyoming the Dinwoody Formation is only 90 feet thick and disappears farther east as it is replaced by its nonmarine correlative, the Chugwater Formation (Kummel, 1954).

The Dinwoody Formation is considered to be correlative with the lower part of the Moenkopi Formation in Utah, Arizona and Nevada (Reeside *et al.*, 1957).

Woodside Formation

The Woodside Formation was named and defined by Boutwell (1907) for exposures in Woodside Gulch in the Park

City mining district of Utah. He considered the formation to be Permian in age. At the type locality the formation consists of nearly 1,200 feet of fine-grained, dark red shales that bear ripple marks, mud cracks, and raindrop imprints.

The term Woodside was then extended to southeastern Idaho and included all the beds between the Rex Chert Member of the Phosphoria Formation and the lowest beds of the Meekoceras zone of the Thaynes Formation (Moritz, 1951). Newell and Kummel (1942) redefined and restricted use of the name only to those beds that bear a lithologic similarity to the beds at the type section.

The Woodside Formation tongues out westward in southeastern Idaho and southwestern Montana into the Dinwoody Formation (Kummel, 1954).

Where measured in the thesis area (see Measured Sections) the Woodside Formation is 105 feet thick and consists of ripple-marked, red and buff siltstones and very fine-grained sandstones, red mudstones and breccias, and gypsum. The Woodside and Amsden Formations are very similar in color and lithology in the area of investigation, but may be distinguished by their stratigraphic position and thickness.

The basal contact of the Woodside Formation is conformable and gradational and is arbitrarily placed at the base of the dominantly red-colored siltstones and sandstones. The upper limit of the Woodside Formation is arbitrarily placed at the top of the uppermost siltstone bed present. This contact with the overlying Rierdon Formation appears gradational, and it is possible that the uppermost siltstones considered here as part of the Woodside were reworked by the invading Jurassic sea. Because of the large hiatus between the Woodside and Rierdon Formations and their paraconformable relationship, the contact is considered disconformable.

Beds of the Woodside Formation in the area are nonresistant and deep gullies indicate the occurrence of the formation even where overlain by a thick soil layer. The best exposure of the formation occurs in the bank of a small stream in the northeast corner of sec. 13, T. 9 S., R. 2 E.

Lithology and Thickness

The lower 20 feet of the Woodside Formation include sandstones, siltstones, shales, and breccias. The breccias are most abundant near the base of the formation and occur interbedded with the other rock types. The breccias consist of subangular limestone clasts (15 to 20 percent) and pink to red calcareous mudstone clasts (10 to 15 percent) in a red argillaceous, calcareous matrix (65 to 75 percent). The sandstones, siltstones, and shales are thin-bedded (2 to 4 inches), ripple-marked, and highly calcareous. The asymmetrical ripple marks have wave lengths ranging from one-half inch to one foot and show a N. 10° E. current flow direction. The sandstones are very fine-grained quartz and have a ferruginous, calcareous cement. The ferruginous material is a mixture of iron oxide and clay.

The remaining 85 feet consist mainly of interbedded red and buff siltstones, but include minor shale and gypsum. In this sequence the color changes from red near the base to predominantly buff and greenish-buff near the top. The beds become increasingly calcareous toward the top of the formation. The shale interbeds are red and greenish-buff and thin (about 1 inch). The gypsum occurs mainly as thin (2 to 5 inch) beds of white gypsum associated with laminated red and green shaly gypsiferous rocks. These gypsum-rich beds are well-exposed only at a locality south of the measured section and east of Tumbledown Creek. These beds could not be correlated exactly with the measured section (see measured sections) of the Triassic because of poorer exposures in the measured section. The beds are placed near the top of the Woodside Formation because of their lithology and relationship to overlying beds.

Fossils and Age

No fossils were found in the Woodside Formation in the thesis area nor have any been found in adjacent areas. In southeastern Idaho fossils in beds considered to be equivalent to those of the Woodside Formation of Utah have been dated as Early Triassic in age (Newell and Kummel, 1942).

Regional Correlation

In southeastern Idaho the Woodside includes both red and non-red strata. At Montpelier Canyon the Woodside appears as relatively thin tongues (50 to 150 feet thick) in the Dinwoody Formation. Farther to the south in Utah the Woodside becomes all red and reaches a thickness of 1,000 feet.

In western Wyoming the Woodside consists of several hundred feet of red shales and siltstone overlying and intertonguing with the Dinwoody Formation. These beds are thought to represent only the upper half of the typical Woodside as defined in the type section in the Park City area (Newell and Kummel, 1942).

Jurassic System

Ellis Group

The rocks of the Ellis Group were first described as the Ellis Formation by Peale (1893) who included all the Late Jurassic rocks lying between what was then called the Quadrant Formation below and the Dakota Formation above. These rocks were described in the general area between Livingston and Three Forks, Montana, and were named for Fort Ellis near Boseman, Montana.

Cobban (1945) recognized three lithologic divisions or formations of the Ellis and raised it to group status. The three formations he named are, from oldest to youngest, the Sawtooth, Rierdon, and Swift. He defined the Rierdon Formation as a sequence of calcareous shales and limestones that lie above the Sawtooth Formation and disconformably underlie the Swift Formation. The Swift Formation was defined as a sequence of dark-gray, noncalcareous shales, overlain by fine-grained, glauconitic, flaggy sandstone. The Sawtooth Formation consists, from bottom to top, of fine-grained sandstone, dark-gray shale containing a few dark limestones, and light-gray calcareous siltstone, and fine-grained sandstone or sandy oolitic limestone.

The Rierdon and Swift Formations crop out in the area mapped, but the Sawtooth is absent. From the thesis area the Ellis Group increases in thickness to the north, east, and south and reaches its maximum thickness in Idaho (Mortiz, 1951) (Figure 9).

Rierdon Formation

The Rierdon Formation consists of 195 feet of highly

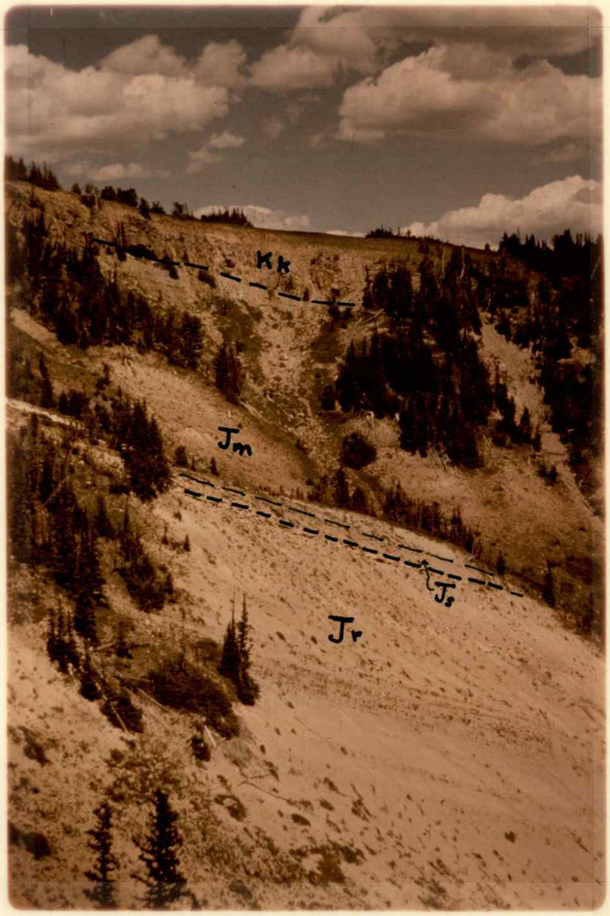

Figure 9. The Rierdon (Jr), Swift (Js), Morrison (Jm), and basal Kootenai (Kk) Formations cropping out in the northwest corner NE¼ sec. 13, T. 9 S., R. 2 E. View is to the east.

fossiliferous gray to tan, limy mudstones, clayey limestones, and oolitic limestones. Most of the Rierdon Formation forms outcrops that are slightly visible above the general slope of the ground, but the more resistant limestones occasionally form low ridges. The rocks weather to a rubbly or splintery talus. From a distance the formation may be located by its stratigraphic position above the generally conspicuous deep red strata of the Woodside Formation. The best exposures of the Rierdon Formation occur in the northeast corner of sec. 13, T. 9 S., R. 2 E.

The contact was arbitrarily placed between the lowest calcareous shale and argillaceous limestone of the Rierdon and the top siltstone of the Woodside.

Lithology and Thickness. The lower 140 feet consist of thin-bedded, gray to tan, limy mudstones and clayey limestones. Calcareous shales interbedded with clayey limestones occur near the base, but these diminish upward and are replaced by limy mudstones. Most rocks are transitional between clayey limestones and limy mudstones. Some of the limestone beds have a high percentage of silt-sized quartz grains (up to 25 percent) and fragmental fossil material. These beds also contain authigenic pyrite. The beds range from less than one inch to one and one-half feet thick and have an average thickness of two to three inches.

Above this sequence is a 34-foot covered interval overlain by nine feet of tan, very thin- to medium-bedded pellet-oolitic limestones. The limestones contain about 80 percent oolites and pellets, both averaging one-quarter millimeter in diameter. Argillaceous micrite and sparry calcite cement the clasts. The sparry calcite fills the primary voids. Hematite pseudomorphs of pyrite are abundant through the limestone and cause a yellow buff stain on the weathered surface.

The uppermost 11 feet of the formation consist of medium-bedded (1 to 2 feet), dense, brown, oolitic limestone. The oolites, as well as included pellets, decrease in size upward from one-half millimeter at the bottom to one-third millimeter near the top but increase in numbers. Most of the fossil material is fragmented, although crinoid columnals are abundant in the top beds and include those of Pentacrinus. Many of the fossil fragments have been partly or entirely replaced by authigenic chert.

The limestone is cemented by sparry calcite or pseudospar. The cement is relatively clear and does not obscure the oolitic texture. Hematite pseudomorphs after pyrite are present in minor amounts, staining the rock dark-brown on a weathered surface and imparting a reddish-brown color to the unweathered rock (Figure 10).

Fossils and Age. The Rierdon Formation is extremely fossiliferous, and pelecypods are especially abundant. The following is a list of the fossils found in the area:

Figure 10. Northeast-dipping resistant oolitic limestones of the upper Rierdon (Jr) Formation. Immediately above these limestones is the Swift (Js) Formation. The Morrison (Jm) Formation is seen at the top of the hill.

Volsella subimbricata	Cypricardi? sp.
Pleuromya subcompressa?	Camptonectes sp.
Pleuromya sp.	Gervillia montanensis
Anatina punctata	Gervillia sp.
Trigonia montanensis	Pholadomya sp.
Trigonia americana	Pholadomya kingii
Cidaris? sp.	Modiola sp.
Arctica sp.	Lima sp.
Astarte sp.	Pinna sp.
Pentremites sp.	Homomya gallatinensis
Gowericeras? sp.	Ostrea sp.
Astarte meeki	

Pelecypods, foraminifers, and ammonites are the most numerous fossils in the Rierdon Formation. The ammonites indicate an age of early Late Jurassic (lower Callovian) for the Rierdon (Imlay, 1948).

Regional Correlation. The Rierdon Formation and its correlatives are found throughout Montana and Wyoming, central and eastern Utah, and northeastern Arizona (Imlay, 1957).

In general, the Rierdon Formation in central and western Montana, western Wyoming, eastern Idaho, and central Utah consists of shale and limestone, and in eastern Montana, North Dakota, western South Dakota, and the remainder of Wyoming it is shale and sandstone. In eastern Utah and northeastern Arizona the Rierdon Formation consists of red beds.

Throughout most of Wyoming the Rierdon is correlative with the upper "lower Sundance". These rocks thin towards the southeast corner of Wyoming and thicken to the north and west (Imlay, 1957).

The Hulett Sandstone, Stockade Beaver Shale, and the Canyon Springs Sandstone Members of the Sundance are all correlatives of part of the Rierdon. These members occur in North and South Dakota and northeastern Wyoming (Imlay, 1957).

The Rierdon Formation throughout southwestern Montana is very similar in lithology to the beds in the thesis area. The thickness of the formation increases eastward from the area, as does the clastic ratio (Moritz, 1951; Imlay, 1952).

Swift Formation

In the mapped area the Swift Formation is represented by 35 feet of dark-gray, glauconitic sandstones and pebbly sandstones. It forms low outcrops and occasionally low ridges of conglomeratic sandstone. The sandstones of the Swift Formation weather a dirty orange color and are recognizable by the presence of black chert grains and pebbles. The lower sandstones overlie the resistant oolitic limestones of the Rierdon Formation. The best exposure of the Swift Formation occurs on the western edge of the area in the NW¼NE¼ of sec. 19, T. 9 S., R. 3 E. The lower contact is conformable and is placed at the top of the oolitic limestone of the Rierdon Formation.

Lithology and Thickness. The lower one-third of the formation consists of sandstones containing oolites, pellets, quartz and glauconite grains, fossils, and carbonate cement. The grain size increases upward from fine to coarse and reaches gravel size in the upper one foot. The amount of chert increases upward owing mostly to authigenic replacement of fossils. The carbonate cement is micrite-microspar and increases in abundance upward. Minor glauconite and pyrite occur in the sandstones.

The top one foot of the lower unit is a conglomeratic sandstone consisting of grains of quartz, chert, oolites, and pellets and pebbles of black chert. The pebbles are rounded to subrounded and range in size from two to seven millimeters. Brachiopod fossils are abundant and partly replaced by chert.

The remaining two-thirds of the formation consists of thin interbedded, oolitic, fossiliferous limestone and conglomeratic calcareous sandstones. The limestones decrease upward and are absent near the top. The sandstones change from medium- to coarse-grained below, to fine-grained at the top. All the sandstones of this sequence exhibit aqueous cross-bedding. They consist of pellets (25 percent), quartz grains (16 percent), fossils (15 percent), chert grains (10 percent) and oolites (7 percent) in order of decreasing abundance. The pellets are structureless and micritic grains, and the oolites are concentrically ringed carbonate grains. The cement is argillaceous micrite and microspar making up about 25 percent of the rock.

Fossils and Age. The Swift Formation is very fossiliferous; belemnoid shells and brachiopods are the most abundant. Unfortunately, because of distortion, the brachiopods are not identifiable.

Imlay (1948) has studied ammonites of the Swift Formation and its correlatives in Montana, Wyoming, and the Black Hills and has dated the formation as middle Late Jurassic (Oxfordian) in age.

Regional Correlation. The Swift Formation and its correlatives extend throughout Montana and Wyoming, western North and South Dakota, and into northeastern Utah. In Montana the Swift Formation usually has shale at the base and glauconitic sandstones above. This basal shale increases in thickness eastward, from the base upward, resulting in more shale toward the east (Imlay, 1957).

In eastern Idaho and western Wyoming the Swift Formation is known as the Stump Sandstone. Both the Stump and Swift Formations contain abundant glauconite, the raw material for which came from a western igneous or metamorphic source (Imlay, 1957).

Eastward into central and eastern Wyoming and western North and South Dakota the Swift is correlative with the upper Sundance Formation. In all these areas the beds are dominantly dark-colored glauconitic shales. In the Black Hills these shales are called the Redwater Shale Member of the Sundance Formation. In Utah beds correlative to the Swift are called the Curtis Formation (Imlay, 1952).

Morrison Formation

The Morrison Formation was named and defined by Eldridge (1896) for exposures near Morrison, Colorado. He described the formation as a series of green, drab, or gray marls some 200 feet thick overlain by the Dakota Sandstone and underlain by the pink sandstone of the Trias. Eldridge considered the Morrison Formation to be Early Cretaceous in age (Emmons, 1896).

Waldschmidt and Leroy (1944) studied the Morrison Formation in Colorado and proposed a type locality two miles north of Morrison, Colorado, where it is 277 feet thick and consists of red, gray, and buff shales, sandstones, limestones, and claystones.

The Morrison Formation is 296 feet thick in the stratigraphic section (see measured section) of the thesis area and consists of olive, greenish-gray, reddish-gray to red, shaly mudstones with thin limestone and sandstone interbeds. The sandstone increases in abundance upward and is the dominant rock type at the top of the formation.

The Morrison Formation is nonresistant and usually forms outcrops that lie close to the slope surface. The upper sandstones form low ridges where the slope is steep. The interbedded red and gray colors show up through a thin soil cover, a circumstance which is helpful in recognizing the formation in the field. The measured section occurs in the SW¼NW¼NE¼ sec. 19, T. 9 S., R. 3 E. A section of the upper Morrison that includes a good exposure of the Kootenai-Morrison Formation contact is found in a cirque at the eastern edge of sec. 34, T. 9 S., R. 3 E. (Figure 11).

The lower contact is conformable and gradational and is placed below the lowest calcareous shales.

Lithology and Thickness

The lower 156 feet of the Morrison Formation are mostly olive, green, red, and gray calcareous mudstones. Red mudstones, dominant in the lower three-fourths of this unit are absent in the upper one-fourth which consists of olive green, green, and gray calcareous mudstones. Mudstones of the entire unit weather to thin shaly chips.

Limestone beds, 8 to 30 inches thick, occur at random through the mudstones. These limestones

Figure 11. Contact of the Morrison (Jm) and Kootenai (Kk) Formations well-displayed in a cirque wall. Note lensing character of the Morrison sandstones. Located in the NE¼SE¼ sec. 34, T. 9 S., R. 3 E.

are brown, pink and green, and tan and have a very dense massive appearance. They are made primarily of highly argillaceous micrite. Two thin sandstone units are present near the center of this 156 foot interval. These sandstones are 32 inches thick and are thin-bedded. They are very fine-grained and highly calcareous owing to the sparry calcite cement. Authigenic pyrite occurs throughout the sandstones and its limonite weathering product imparts a yellow color to the weathered rock.

The remaining 160 feet of the Morrison Formation consist of limonitic sandstone and mudstones. The mudstones make up the lower half of this sequence and are gray to olive green and calcareous. Most of these rocks weather to a shaly appearance. The sandstones are by far the most abundant and are fine-grained, laminated to thick-bedded, and cross-bedded. The cross-bedding in the upper sandstones shows a current flow direction from south to north. The sandstones increase in abundance and thickness upward through this sequence. The thicker sandstones are fairly persistent laterally, but the thin-bedded to laminated sandstones tongue and lens within short distances laterally. All the sandstones consist predominantly of quartz grains; chert and carbonate constitute the remainder of the detrital fraction. Limonite and calcite act as a cement with the limonite also acting as a coloring agent. The calcite cement is pseudospar and decreases in abundance upward. Wood fragments appear occasionally on the bedding planes.

Fossils and Age

The only fossils found were several pieces of reptilian bone from the middle Morrison.

At the proposed type locality near Morrison, Colorado, numerous Atlantasaurus remains, charaphytes, and sponge spicules have been found (Waldschmidt and Leroy, 1944). Simpson (1926), making use of all reptile and fish fossils from the Morrison known up to that time, concluded that the Morrison is upper Jurassic (Kimmeridgian and Portlandian) in age. This is the view held today.

Regional Correlation

The Morrison Formation and its correlatives is very widespread and occurs in Montana, Wyoming, western North and South Dakota, Colorado, Utah, Idaho, Arizona, New Mexico, and western Kansas. Throughout these states the overall lithology of the Morrison remains fairly constant, although local rapid changes in lithology are common.

In southwestern Montana the Morrison lithology is the same as that in the thesis area. Along the Montana-Idaho border the Morrison Formation is nearly 400 feet thick but thins to the north and northwest (Moritz, 1951).

In Wyoming the Morrison Formation is a sequence of silty claystones and sandstones, the latter thickening locally to make up the entire section. The Morrison is generally less than 200 feet thick and is thinnest in central Wyoming (Love, 1945).

Cretaceous System

Kootenai Formation

Dawson (1885) described beds cropping out along several rivers in the Rocky Mountains of Canada and named them the Kootanie Group. The following year he described the Kootanie Group as 5,000 to 7,000 feet of coal-bearing shales and sandstones, some conglomerates, and many coals which contain an earliest Cretaceous flora (Dawson, 1886). Fisher (1909) referred to 450 to 475 feet of coal-bearing sandstones and shales in the Great Falls region of Montana as the Kootenai Formation. Beds of similar age and stratigraphic position, but of a lithology dissimilar to the strata at Great Falls, are referred to the Kootenai Formation in the thesis area.

In the thesis area the Kootenai Formation consists of three units: a Lower Unit of fine to coarse sandstones, conglomerates, and conglomeratic sandstones; a Middle Unit of claystones, limestones, sandstones, and conglomerates; and an Upper Unit of limonitic quartz arenites. The basal conglomerates and sandstones of the Lower Unit are prominent cliff-formers in nearly all types of terrain. The sandstones of the Upper Unit commonly form cliffs 20 to 25 feet high but do not crop out as persistently as the rocks of the Lower Unit. The claystones and limestones of the Middle Unit form slopes that are usually grass- or tree-covered. The upper contact with the Thermopolis Formation was observed only in the center of sec. 20, T. 9 S., R. 3 E. (Figure 12) where the formations appear to have a conformable relationship. The best exposures of the Kootenai Formation occur in the NE¼ sec. 13, T. 9 S., R. 2 E., where the section (see measured section) was measured for this report.

Lithology and Thickness

Lower Unit. The Lower Unit consists of 38 feet of current cross-bedded sandstones, pebbly sandstones, conglomerates, and sandy conglomerates. The cross-bedding in the sandstones is omni-directional and no persistent current flow direction could be determined. The entire unit forms rounded outcrops that weather dark-brown. The contacts between conglomerates and sandstones range from gradational to sharp, but the contact is usually sharp where conglomerates lie upon sandstones.

The ratio of dark chert pebbles to light-colored chert pebbles in the conglomerates decreases upward through the unit as does the size of the pebbles, which

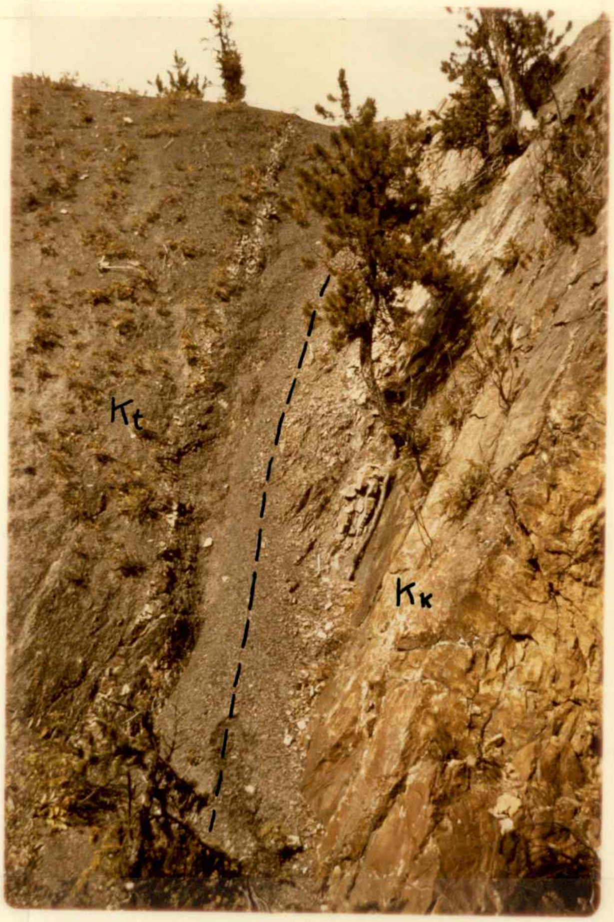

Figure 12. Contact between the upper Kootenai (Kk) quartz arenites and the Thermopolis (Kt) Shale. Location is in the center of sec. 20, T. 9 S., R. 3 E. LIGHTNING CREEK

range in diameter from 2 to 76 millimeters. The conglomerates and sandy conglomerates contain an average of 60 percent chert in the form of sand-sized or larger particles. Quartz grains make up about 25 percent of the rock, a figure that includes the quartz overgrowths that bind the rock together. Most of the conglomerates and sandy conglomerates have calcareous cement.

The sandstones in this unit range from fine- to very coarse-grained; most are medium-grained. These sandstones are termed salt-and-pepper because of the abundance of dark and light grains. The dark fragments are black chert and volcanic rock fragments which are rounded and range in size from one-tenth to two millimeters. The light-colored grains are mostly quartz but include a few light-colored grains of chert. Quartz overgrowths on the rounded quartz grains makes up part of the cement. Most of the cement is calcite, which occurs in grains as large or larger than the quartz and chert grains.

Middle Unit. This unit of the Kootenai Formation is 311 feet thick at the measured section. The lower half consists of sandstones, mudstones, limestones, conglomerates, and siltstones. The upper half is mostly covered, but from float and a few outcrops it apparently consists of claystones and limestones.

The sandstones are phosphatic and limonitic arenites and calcareous quartz arenites. Quartz grains are the most abundant clasts with basic volcanic fragments, phosphate, and chert subordinate. All the sandstones have a carbonate cement which varies in amount with the type of sandstone; the purer quartz-rich rocks contain the most cement, up to 30 percent of the rock. Limonite is also present in varying amounts in all rocks as a cementing and coloring agent.

Interbeds of sandy limestone, limestone conglomerates, limestones, and sandy siltstones occur between the sandstones. The limestone is micritic and argillaceous and where conglomeratic, the clasts are micritic limestone. The conglomeratic limestone also contains sand-sized quartz grains and basic volcanic rock fragments. All of these rock types appear to be conformable although outcrops are poor.

The claystones are generally covered and are grouped into 10- to 15-foot thick sequences. They are calcareous and range in color from brown to yellow brown.

The upper half of the unit, mainly a slope-forming covered interval, consists mostly of claystones and siltstones. These rocks are calcareous and contain limestone nodules. Fifty feet from the top is the base of a 30-foot interval of clayey limestones, calcareous mudstones, breccias, and gastropod limestones. This sequence is referred to as the "gastropod limestone" (Cobban and Reeside, 1952). All the rocks are milk-white to buff except for thin black shale partings associated with the gastropod limestones. The calcareous rocks range from thin- to medium-bedded (½ inch to 1½ feet). The gastropod limestones are composed of oolites, pellets, and gastropods cemented by coarse sparry calcite. The uppermost 20 feet are covered.

Upper Unit. This unit consists of 58 feet of limonitic, noncalcareous, quartzose sandstones and siltstones at the measured section (see measured sections). All the sandstones exhibit symmetrical ripple-marks locally associated with probable mud cracks. The sandstones weather yellow to brown because of limonite staining. The sandstones are thin- to medium-bedded, ranging from one-quarter inch to three-foot beds. The thin-bedded sandstones are concentrated at the bottom, middle, and top of this unit in eight-foot sequences with thick-bedded sandstones between. All sandstones have conformable relationships however. Wood fragments are locally present on bedding plane surfaces and increase in abundance upward. The very fine-grained sandstone is composed of angular to subangular, poorly-sorted quartz grains averaging one-tenth millimeter in diameter. Quartz cement occurs as overgrowths. A few sandstone beds approach the quartzite level of induration. The top of the Upper Unit is not exposed because of tree cover.

Fossils and Age

Abundant fossil gastropods occur in the "gastropod limestone" of the Middle Unit of the Kootenai Formation. The gastropods *Reesidella montanaensis* and *Viviparus*? sp. were identified from the thesis area and according to Yen (1951) they are both of Cretaceous age.

At Great Falls and in the surrounding area an abundant fossil fauna from the Kootenai Formation was determined to be Early Cretaceous in age (Fisher, 1909).

Regional Correlation

The Kootenai Formation and its lateral correlatives are found throughout Montana, Wyoming, Idaho, and Colorado (Cobban and Reeside, 1952). The name Kootenai is recognized throughout Montana except in south-central Montana, where correlative beds are called the Cloverly Formation.

Throughout Wyoming the Kootenai is known as the Cloverly Formation. The Fall River and Greybull sandstones of the upper Cloverly, according to Cobban and Reeside (1952), are age correlatives of the Upper Unit in the thesis area.

In eastern Idaho and western Wyoming, the upper Gannett Group is the correlative of the Kootenai Formation and consists of limestones, shales, and conglomerates.

The shale increases eastward from Idaho into western Wyoming, the conglomerate disappears to the east in eastern Idaho (Cobban and Reeside, 1952).

Thermopolis Formation

The Thermopolis Shale was first named and described by Lupton (1916) for exposures near Thermopolis, Wyoming, where it consists of 700 feet of dark-colored shale with one or more lenticular sandstones. The most persistent of these sandstones is known as the Muddy Sand which ranges in thickness from 15 to 55 feet. The Thermopolis Shale rests conformably upon the Greybull Sandstone and is overlain conformably by the Mowry Shale (Lupton, 1916).

In the thesis area, the Thermopolis Formation and Muddy Member were mapped as separate lithologic units, although the Muddy is referred to on the geologic map as a member of the Thermopolis Formation. They will be discussed in the text as separate units.

The Thermopolis Formation comprises 180 feet of dark-colored shales, claystones, and siltstones. The shale is very nonresistant and has been formed into small valleys and covered slopes. It is visible only where recently exposed by running water, snow, or ice. The shale weathers to a black soil and forms smooth slopes that support scant vegetation. The best exposure of the Thermopolis shale occurs on the eastern edge of the NW¼ sec. 34,

T. 9 S., R. 3 E.

The upper contact is not exposed; however, its approximate position can be determined from a change in soil color and a definite break in slope.

Lithology and Thickness

Nearly the entire section of the Thermopolis Formation consists of dark-gray, slightly calcareous shale. The shales in the upper half contain clay and ironstone concretions that average two inches in diameter. In the lower part of the sequence resistant calcareous siltstones and claystones form low-lying ledges.

Fossils and Age

No fossils were found in the Thermopolis Formation in the thesis area. Arenaceous foraminifers, poorly preserved pelecypods and gastropods, fossil leaves, and scattered reptile bones have been collected from the Thermopolis Formation in the Big Horn Basin. These fossils and correlation with the dated Skull Creek Shale have led to an assignment of the Thermopolis to a late Early Cretaceous (middle Albian) age (Eicher, 1962).

Regional Correlation

The Thermopolis Shale occurs throughout Montana, Wyoming, and western South Dakota. In Wyoming the

Thermopolis thins from the north to the south and from the west to the east. In easternmost Wyoming and western South Dakota the Thermopolis is known as the Skull Creek Shale (Eicher, 1962). The Skull Creek Shale also continues into eastern and central Montana (Wulf, 1962).

Muddy Member

The Muddy Member is the middle member of the Thermopolis Shale. Lupton (1916) states that it lies 210 to 330 feet above the Greybull Sandstone and ranges in thickness from 15 to 55 feet in exposures near Thermopolis, Wyoming.

In 1944, Reeside used the term "Muddy Sandstone Member" of the Thermopolis Shale on a correlation chart. Love (1948) referred to the Muddy as a formation and his notation has increased in popularity and today is accepted by most workers in Wyoming Cretaceous areas (Eicher, 1962).

The Muddy Member in the thesis area is 100 feet of cross-laminated, calcareous sandstone that crops out as rounded ledges and cliffs. Outcrops occur only where the topography is steep. The sandstones usually make crumbly and flaky outcrops that have weathered to sand in many places. The basal contact of the Muddy Sandstone in the thesis area is covered. The best exposure of the Muddy is at the measured section just to the east of the thesis area in the center of sec. 7, T. 9 S., R. 4 E.

Lithology and Thickness. The sandstones of the Muddy Member are mostly very fine-grained but become coarse-grained and locally conglomeratic near the top. The cross-laminations in the Muddy are omni-directional owing to fluvial currents. The sandstones are brown-weathering and have a gray, salt-and-pepper fresh appearance derived from the presence of quartz, chert, and other lithic fragments. Small clay galls are scattered through the sandstones.

Rock fragments, in the form of chert-quartzite and basic volcanics, constitute about 25 percent of the sandstones. The chert-quartzite grains are angular to subangular, and the basic volcanic grains are round to subrounded; both average one-sixth millimeter in diameter.

The quartz grains constitute about 50 percent of the rock, are well-sorted, and average one-tenth millimeter in diameter. They were round when deposited but overgrowths of quartz have given them an angular shape. Many of these overgrowths approach one-half the volume of the original grains.

About 20 percent calcite cement binds the grains firmly together in the unweathered rock. The calcite is in coarse grains that are in the process of replacing the quartz grains. Minor constituents are authigenic pyrite, limonite, and glauconite.

Fossils and Age. Only wood fragments and leaves were found in the Muddy Member in the thesis area, and these could not be identified. In the Big Horn Basin of Wyoming, foraminifers, pelecypods, turtles, and crocodile teeth have been reported from the Muddy Member but they have not been satisfactory age indicators. The best means of dating the Muddy Member lies in the abundant fossils in the black shales above and below the member. These fossils place the Muddy Member in late Early Cretaceous (middle Albian) time (Eicher, 1962).

Regional Correlation. The Muddy Member and its lateral correlatives occur throughout Montana, Wyoming, western South Dakota, and northern Colorado (Cobban and Reeside, 1952).

In western and central Montana and Wyoming the Muddy Member is referred to as the Muddy Sandstone. In northwestern Wyoming (Jackson Hole) it is 55 feet thick and increases to over 100 feet in southwestern Montana (Love, 1956). Eastward through Wyoming the Muddy Member varies in thickness and lithology and in the Black Hills area is known as the Newcastle Sandstone. Both the Newcastle and the Muddy sandstones thin to the north (Wulf, 1962).

In south-central Montana the Muddy Sandstone is known as the Birdhead Sandstone. It averages about 13 feet in thickness and consists of a very fine- to fine-grained, cross-bedded, calcareous sandstone. It commonly contains clay galls, scour-and-fill structures, and thin conglomerate lenses (George, personal communication). The term Birdhead Sandstone is used in central and north-central Montana, where the lithology varies only slightly from the lithology in south-central Montana (Wulf, 1962).

In northwestern Montana lower Cretaceous rocks are included in the Blackleaf Sandstone for which no named subdivisions have been formally recognized (Wulf, 1962).

Albino Formation

The Albino Formation was named by Hall (1961) for outcrops of dark-brown, yellow, pink, and green siliceous shales, tuffs, claystones, and bentonites at Lincoln Mountain, immediately east of the thesis area.

In the thesis area the Albino Formation consists of 255 feet of siliceous sandstones, tuffs, and siliceous mudstones. Good outcrops are exposed in the E½SW¼ sec. 21, T. 9 S., R. 3 E., along a small creek. All other Albino exposures are weathered to a light-colored thick bentonitic clay. The Albino Formation is nonresistant, usually covered, and erodes easily.

Lithology and Thickness

The lower 90 feet consist of sandy tuffs and sandstones, which are the only well-exposed Albino rocks in the area. The sandy tuffs contain mostly a clay matrix and minor detrital grains. The matrix has been formed mainly by the devitrification of volcanic glass and is made of the authigenic minerals nontronite, clinoptilolite, glauconite, and unidentified clays. The detrital grains are quartz, plagioclase, and rock fragments; they range from angular to rounded. Most of the rock fragments are rounded, fine-grained, basic volcanic rocks. All the sandy tuffs are silicified, the silica having formed in the matrix and as small overgrowths on the quartz grains.

Sandstones are not as common as the sandy tuffs. The sandstones contain clastic grains of quartz, rock fragments, and plagioclase comprising up to 75 percent of the rock. All rock fragments and many of the quartz grains are rounded. The rounded quartz grains have quartz overgrowths. The plagioclase ranges in composition from albite to andesine. Near the top of this 90-foot unit the sandstones contain the orange red (hematite-stained) mineral, clinoptilolite, that replaces the glass and ferromagnesium minerals and imparts a red to pink color to the rocks.

The upper unit of the formation consists of 165 feet of light-colored tuffs and sandy tuffs. The beds weather very readily to a light-colored, highly bentonitic product, and outcrops of the unit are scarce.

Fossils and Age

The only fossils found in the Albino were fern and reed imprints and tree limbs which are unsatisfactory for age determination. Because the Albino Formation overlies the Muddy Sandstone and is similar in lithology to the Mowry Shale (Rubey, 1929), it is considered by the author to be late Early Cretaceous (Late Albian) in age.

Regional Correlation

The lithology and the stratigraphic position of the lower member of the Mowry Shale on the Sweetgrass Arch in northwestern Montana (Cobban, 1951) is similar to that of the Albino Formation in the thesis area. Cobban and others (1959) have showed that part of the Vaughn Member of the Blackleaf Formation around the Boulder batholith is correlative with the Mowry Shale. The lithology of the Vaughn is similar to that of the Albino Formation and probably is correlative, at least in part.

Upper Cretaceous Rocks

The name Colorado Group was suggested by Hayden for marine deposits conformably overlying the Dakota Formation and conformably underlying the Fox Hills Group (Hayden, 1874). The Colorado included only the Benton and Niobrara Formations and their equivalents, as they were originally defined, but today the Colorado Group in Montana includes the Niobrara and Benton Formations and the Dakota Sandstone (Cobban and Reeside, 1952).

Where the Upper Cretaceous sequence in Montana is divided into smaller units, it is known as the Colorado Group. The terms Colorado Shale and Colorado Formation have commonly been used by workers where the Colorado Group has not been subdivided. The designation Upper Cretaceous rocks is used in the thesis area because the age of these beds is not precisely known.

The Upper Cretaceous rocks in the mapped area consist of 1,900+ feet of tuffaceous sandstones, shales, and siliceous tuffs that are nonresistant and form rolling hills and few outcrops. These rocks are divided into three units on the basis of lithology: Unit One, black shale and sandstone; Unit Two, tuffs and siltstones; Unit Three, tuffaceous sandstones and black shale. It is possible that these units may be used as stratigraphic markers over a wider area. This can only be demonstrated by further detailed work on the Upper Cretaceous in the southern Madison Range (Figure 13).

Unit One

This basal unit of the Upper Cretaceous is composed of about 100 feet of black shale and thin sandstone beds. At the measured section of the Albino Formation the contact appears to be conformable and gradational. The outcrop is too small, however, to indicate with certainty the true relationship. This unit forms steep, smooth shale slopes with limited exposures and is best exposed in the center of the NW¼ sec. 7, T. 9 S., R. 4 E.

The shale of this unit is noncalcareous, black, and weathers gray. About 20 feet of fine-grained, dense to friable, dark-colored sandstones occur near the top of the unit. The bottom six feet of sandstone is cross-laminated and indicates a current direction from east to west. The sandstones are composed mainly of quartz (50 to 55 percent) and rock fragments (15 to 20 percent); minor plagioclase feldspar and biotite, about 10 percent, complete the framework. Some sandstone layers contain significant amounts of glauconite, chert, carbonate, and clay matrix. The carbonate is present as the cement and makes up from 2 to 15 percent of the sandstones.

Unit Two

Unit Two consists of about 80 feet of light-colored siliceous tuffs and siltstones. The base of the unit is arbitrarily placed at the lowest occurrence of siliceous rocks. This unit crops out as light-colored, rubbly, low ledges or weathers to slope debris of greenish, siliceous tuff. The best exposure is in the center of the NW¼ sec. 7, T. 9 S., R. 4 E.

The basal 10 feet of the unit is a siliceous, very fine-grained sandy tuff containing wood fragments on the bedding planes. The tuff consists mainly of clay, devitrified glass, and many quartz and plagioclase grains. The remainder of the unit is a silicified vitric tuff consisting mostly of glass shards and minor quartz and plagioclase crystals in a clay matrix. The glass and crystals are fresh-looking and show little evidence of weathering.

This tuff is believed to have been emplaced by the settling of volcanic ejecta into a standing body of water on a land mass of low relief.

Unit Three

This unit is comprised of about 1,700 feet of interbedded tuffaceous sandstones and shales. The basal contact occurs in the center of the NW¼ sec. 7, T. 9 S., R. 4 E., and was placed at the lowest occurrence of tuffaceous sandstone above the silicified tuffs of Unit Two. Unit Three is best exposed in the stream cut of Cache Creek, in the SE¼ sec. 4, T. 9 S., R. 3 E., and on the top of the valley wall in the NW¼SE¼ sec. 3, T. 9 S., R. 3 E.

The basal 20 feet of the unit is exposed at the top of Lincoln Mountain and consist of interbedded very fine- to fine-grained, calcareous, thin-bedded (1 to 2 inches) to laminated sandstone. The sandstones are tuffaceous in appearance and weather to a light brownish-gray color. The main clastic constituent is quartz (40 percent), followed in order of abundance by rock fragments, chert, glauconite, and biotite. The calcite cement ranges from less than five percent to 25 percent, and in thin section it appears to be replacing the quartz grains (Figure 14).

A very fine-grained, fossiliferous, brown to gray sandstone two feet thick occurs 18 feet above the base of the unit. Its dark color and mixture of invertebrate and plant fossils suggests a brackish water environment.

The remainder of Unit Three consists mainly of interbedded calcareous sandstones and black shales. The sandstones crop out better than the shales and were therefore examined more intensively. Most of the sandstones are cross-bedded (current from east to west), loosely cemented, calcareous, salt-and-pepper, and fine-grained. They weather to rounded and sculptured outcrops but are generally laminated to thinly bedded. Many beds contain clay galls randomly spaced through the beds. Dense, dark sandstones occur at intervals throughout this thick sequence.

Figure 13. View to the northeast of the topography developed on the Upper Cretaceous Colorado Group in the Cache Creek drainage area.

Figure 14. Good outcrop of Upper Cretaceous Unit Three showing typical bedding characteristics. Note lensing in the sandstone bed at the center of the picture. Location is the NE¼SE¼ sec. 12, T. 9 S., R. 3 E.

They are thick-bedded (3 to 4 feet), calcareous, and contain abundant grains of hematite and/or chert. A few of these thick beds contain oscillation ripple marks.

A thin coal seam and associated peat occur approximately 200 feet from the top of the unit. This coal seam crops out at the middle of the western edge of sec. 3, T. 9 S., R. 3 E. and was traced to the center of the western edge of sec. 2, T. 9 S., R. 3 E. It is possible this coal may be used as a stratigraphic marker over a wider area. This is the only coal observed in the unit. The sandstones above the coal are the dense, dark type and the sandstones below are the gray, friable type.

The shales of Unit Three are generally covered but were observed in two places, where they are black to dark-gray and contain marine fossils.

Fossils and Age. The fossils found in the Upper Cretaceous beds all came from Unit Three and consist of peat, coalitized tree limbs, *Inoceramus*? prisms, pelecypod shell fragments, a fish tooth, *Turritella* sp., *Coricula* sp., *Unio* sp., *Inoceramus*? sp., and *Leptosolen* sp. These fossils are not good age indicators, but the assemblage suggests a near-shore, shallow marine, or brackish water environment.

Regional Correlation. The regional correlation of the Colorado Shale is difficult, owing both to lateral changes in lithology that reflect different depositional environments and source areas and to the numerous name changes from one area to another.

Correlatives of the Colorado Shale include the Frontier Formation of western and central Wyoming, and the Graneros Shale, the Greenhorn Limestone, and the Carlile Shale in eastern Wyoming. The Colorado Shale is correlative with the lower half of the Mancos Shale in western Colorado, and the Benton and Niobrara Shales in the eastern and central parts of Colorado. The Colorado Shale in north-central and southeastern Montana is known as the Colorado Group (Cobban and Reeside, 1952).

Tertiary System

Acid Volcanic Rocks

The acid volcanic rocks in the thesis area occur mainly in sec. 22, T. 9 S., R. 3 E. They vary in composition, color, and density, and in most places they are welded tuffs. Nearly all of the welded tuff contains gravel-sized sandstone, gneiss, and pumice fragments.

The difference in the tuffs from locality to locality is due to the variation in the original material as it was deposited. Where the material was hot and subsequently compacted, it became welded, as shown by flowage and collapsed pumice fragments. The flowage is characterized by alignment of the phenocrysts, collapsed pumice fragments, and the glass shards. Where the heat and compaction were less, the tuff contains uncollapsed pumice, is porous, and does not show flowage.

The basal contact of the welded tuff is covered, but the thickness is estimated to be 80 feet at its thickest part. The surfaces of the outcrops are pitted where pumice fragments have been weathered out. The talus is composed of granular and thin, platy rock debris.

Lithology

The welded tuffs vary in the amount of phenocrysts from 5 to 25 percent. The phenocrysts are euhedral sanidine, subhedral plagioclase (andesine) and clinopyroxene (augite?), and anhedral quartz. The sanidine phenocrysts make up 10 to 25 percent of the rock; each of the other types of phenocrysts are less than one percent. The groundmass of the welded tuff consists of devitrified glass, feldspar, and magnetite.

Age

Because of the proximity to the extensive rhyolitic extrusions of the Yellowstone Park area, the welded tuff in the thesis area is thought to be related to the same period of extrusion. Hamilton (1960) states that welded tuff in the southern Madison Range and in the westernmost part of Yellowstone Park is of Pliocene age.

His description of the outcrops and lithology closely match those found in the thesis area. For these reasons the welded tuff in the map area is considered to be Pliocene in age.

Quaternary System

Unconsolidated Deposits

Alluvium

Deposits of alluvium occur mainly in the valley of Taylor Fork, with lesser amounts in Cache Creek and Lightning Creek. The alluvial fill in Taylor Fork consists of gravel to clay-sized material, a great deal coming from the deposits of till, including moraine, that partly fill the valley and cap the hill tops. The remaining alluvium originates from the mountains in the western part of the area mapped.

In Cache Creek the alluvium is mainly recent "wash" from the surrounding hills and consists of sand and clay from the breakdown of Upper Cretaceous rocks. Gravel-sized material comes mainly from glacial deposits in the bottom of the valley.

Two areas of alluvium on Lightning Creek and one to the east in the SE¼ sec. 20, T. 9 S., R. 3 E. are all of similar origin. These deposits have been created by damming of water sources and the subsequent slowing down of the streams. This has led to deposition of material, mostly sand, clay, and minor gravel derived from till laid down during the first episode of glaciation.

The alluvial deposit that stretches from the breached anticline in sec. 21 appears to be fairly stable. No stream flows along the deposits at the present time, and it must be considered a deposit of an earlier age. The eastern one-third of the alluvium consists almost entirely of reworked tuffaceous clay from the Albino Formation.

Mass Gravity Deposits

The region of the southern Madison Range is characterized by abundant mass-gravity movements. In the thesis area about 11 square miles have undergone mass movements.

All the mass-gravity movements mapped in the area can be classed as landslides, according to Sharpe (Thornbury, 1954). Earthflows, slump, rock fall, rock slide, and creep occur in the thesis area. The causes for mass-gravity movements are as follows: over-steepened slopes; nonresistant, poorly cemented, loosely consolidated rocks; large amounts of water in the ground; force of gravity alone; and large amount of tuffaceous material in the rocks.

Earthflows are the most widespread type of movement. They are characterized by a steep head wall, usually cresent-shaped, a lobate toe, and rough hummocky topography. They occur in areas where glaciation has over-steepened slopes and where bentonitic beds contribute to the potential instability of slopes. The head wall ranges in height from five feet to over 100 feet and is nearly vertical. The toe or terminal point of the flows has a steep front, is lobate, and is convex in the direction of movement. The earthflows that have the best developed toe usually have a hummocky and rolling surface rather than a rough, choppy surface. Earthflows that have a longer path of flow or a low angle of slope have a smoother surface, such as those in secs. 28, 29, 32, and 33; in secs. 12, 13, 24, and 26; and in sec. 1. Earthflows that have traveled short distances over steep terrain do not develop a good lobate toe and have a very rough surface. Examples of these flows are seen in secs. 5, 6, 10, and 16.

On an aerial photograph the earthflows exhibit an irregular surface and many undrained depressions. Moreover, photographs show ridges and gullies parallel to the direction of flow and a well-developed lobate toe at the end of the earthflow. Where the ground is heavily forested, tree masses are separated by white ground scars.

Slumping is wide-spread and commonly associated with the earthflows. Slump is usually the movement that initiates the earthflow and produces a steep headwall from which the material moves. It also occurs on steep slopes by backward rotation of poorly consolidated rock to form terraces that have a local reversal of slope.

Almost all of these movements occur in the tuffaceous rocks of the Upper Cretaceous. The two small projections of earthflow into the Lower Cretaceous and Upper Jurassic in the northwest corner of the thesis area occur in shales and claystones that are nonresistant and susceptible to sliding. Most of the mass movements occur in the Upper Cretaceous tuffaceous rocks because of the great water retention property of the sediments. The greater the amount of water the sediments trap and hold, the larger and faster the mass movements become.

Rock fall and rock creep are well displayed in the western mountains, where nearly vertical cliffs of the Madison Group and large, steep talus piles associated with the Madison beds are conspicuously developed. This talus is slowly creeping into the valley of Taylor Fork and its small tributaries.

The small area of mass-gravity movement in secs. 34 and 35 is the result of two different processes. This area consists of large blocks of Kootenai and Morrison sandstone, many of which were apparently placed on the small cirque floor by plucking of a glacier that occupied the position during the Pleistocene. Today, rock fall and rock slide are adding more rocks to the cirque floor.

The other small slide in sec. 31, T. 9 S., R. 3 E., appears to be the result of two different processes. The main part of the slide material initially was scooped from the mountain by a small glacier; later the material moved down the mountain as an earthflow to its present position.

Glacial Deposits

The glacial sediments deposited in the area are shown on Plate 2 as till and moraine. The glacial till south of Taylor Fork is the oldest. The next younger deposits are those till deposits north of Taylor Fork. The youngest are those designated as moraine and located in the valley of Taylor Fork. All of these deposits contain gravel made of gneiss, limestone, sandstone, and schist in a matrix of clay and silt. All of these rock types are present in the mountains in the western one-third of the area. These glacial deposits locally reach 100 feet in thickness.

STRUCTURAL GEOLOGY

Regional Structure

The Rocky Mountains of Montana are characterized by asymmetrical folds and thrust faults. These structures trend northwest and were produced by compressional forces of the Laramide orogeny acting from the west and southwest. Stream erosion reduced the Laramide mountains thus formed to a surface of low relief by middle Tertiary time.

Middle and late Tertiary black faults parallel and cut across the Laramide structures. These faults produced thousands of feet of relief and are partly responsible for the relief seen today in the Montana Rockies.

Local Structure

The thesis area lies between the intense Laramide deformation to the west and the less intense deformation to the east. In the area the northwest-trending Laramide folds are generally bounded on the east by high-angle reverse faults of the same age. Late Cenozoic faulting displaces strata previously folded and tilted by the Laramide orogeny.

Folds

In the northwestern corner of the map area the asymmetrical Shedhorn anticline trends approximately N. 10° W.

and plunges to the south. It is expressed topographically by whale-backed Shedhorn Mountain (Figure 15). A partly exposed syncline to the southwest trends in the same direction as the anticline and plunges to the north.

The northeast-dipping Paleozoic and Mesozoic strata in the westernmost part of the map area constitute the east limb of a large northwest-trending anticline with Precambrian rocks exposed in the core.

The northwest-trending, asymmetrical Carrot Basin anticline extends approximately three and one-half miles into the southern part of the thesis area, where it plunges to the northwest.

A broad, north- and northwest-trending syncline is located in the center of the map area. Because the surface beds are nonresistant, field exposures are poor, and adequate control for this structure is lacking. Further study to the north of the area probably would show that this fold continues to the northwest.

Faults

High-Angle Reverse Faults

The fault located in secs. 30 and 31, T. 9 S., R. 3 E. is a moderate- to high-angle reverse fault and is the northern extension of the Beaver Creek fault (Witkind, 1960). This fault has a large throw, as shown by the

Figure 15. View to the northwest. The earthflow in the center occurred in 1946 in Upper Cretaceous rocks. The nose of the whale-backed Shedhorn Mountain occurs in the northwestern corner of the thesis area.

juxtaposition of Mississippian and Upper Cretaceous strata. It is believed to die out in the "covered" area on the map near the confluence of Taylor Fork and Lightning Creek, because there is no evidence of its existence north of that area. Because of stratigraphic conditions a small isolated block of west-dipping Lower Cretaceous strata in the center of sec. 20, T. 9 S., R. 3 E. is believed to have been emplaced there by faulting. The inferred fault shown on the map east of the block and closely paralleling Lightning Creek may be a low-angle thrust and related to the Beaver Creek fault. Almost certainly this block was emplaced by faulting, stratigraphic conditions making it most unlikely that the block moved here by mass gravity movement. Landsliding could not explain the 90 degree reversal in dip of the strata this exposure has undergone.

Normal Faults

Two faults in secs. 1 and 12 and secs. 3 and 4, T. 9 S., R. 3 E., trend northwest and visibly displace Upper Cretaceous strata. The fault in secs. 1 and 12, has displaced the topography developed on Upper Cretaceous strata about 40 feet. Because the topography is displaced and the scarp is not dissected, a recent origin for this fault is indicated. This non-tectonic fault was probably caused by glacial steepening and undercutting and subsequent failure of the strata. The other fault, best seen on aerial photographs, is older and apparently has a smaller amount of displacement.

A fault in secs. 10, 15, 16, and 21, T. 9 S., R. 3 E. visibly displaces Upper Cretaceous strata. The apparent displacement is down on the northeast side, with a small stratigraphic throw. The headwalls of two landslides occur along this fault, probably owing to the weakening of the strata along the fault.

The presence of disturbed Upper Cretaceous strata in sec. 32 and a lineation on the aerial photographs indicates the presence of the fault in secs. 29 and 32, T. 9 S., R. 3 E. (Plate 2). The fault is not exposed in the field, so the stratigraphic displacement could not be determined.

Small faults displacing middle Paleozoic strata are visible in the field but most of them are too small to be shown on the map (Plate 2). They are normal faults, have no orientation to the Laramide fold axes, and range in displacement from 20 to 100 feet. These faults cannot be accurately dated, but it is possible they were the result of stress during the Laramide folding of the competent Paleozoic strata.

GEOMORPHOLOGY

The topography in the thesis area varies from low foothills in the east-central and northern part of the map area to rugged mountains in the west. The landforms of the area were produced by stream erosion, glaciation, and mass-gravity movements.

Stream Erosion

Stream erosion following the Laramide orogeny slowly reduced the area of the southern Madison Range to a plain of low relief. Late Tertiary uplift rejuvenated the streams, such as Taylor Fork, and superposed them on the underlying structure. Glaciation interrupted stream erosion several times in the Pleistocene and late in the epoch Taylor Fork Valley, as seen today, was carved by glaciers. Today the topography is one of middle to late youth, defined by narrow valleys, wide interfluves, and rapids in the streams. Meanders and ox-bow lakes do occur on the streams, however, where earthflows, moraines, and resistant strata have caused local base leveling and a slowing of the running water.

Stream terraces are common along Taylor Fork below Taylor Falls. At the junction of Taylor Fork and Tumbledown Creek, three levels of terraces are developed. These may be due, in part, to damming by landslides and ice of the Sawmill Glacier. Tumbledown Creek is the only creek in the map area that flows nearly its entire course on bedrock.

During the Pleistocene, when the Sawmill Glacier occupied Taylor Fork valley (Hall, 1960), two small meltwater channels in secs. 1 and 2, T. 9 S., R. 3 E. were cut in the Upper Cretaceous rocks and channeled the meltwater of these glaciers into Albino Lake.

Glaciation

Evidence indicating glaciation includes valley moraine, till, U-shaped valleys, and cirques. Four substages of glaciation were noted within the area (Figure 16).

The oldest glacial substage is the Marble Point substage (Hall, 1960), named for debris lying on Marble Point, in secs. 4 and 9, T. 9 S., R. 4 E. Glacial debris occurring as three isolated deposits in the southern part of the map area is correlated with the Marble Point debris (Hall, 1960). The two deposits in secs. 27 and 34, T. 9 S., R. 3 E. rest on Upper Cretaceous strata, and the deposit in sec. 21, T. 9 S., R. 3 E. rests on Pliocene welded tuff. These three deposits consist of rounded gravel of gneiss, igneous rock, limestone, and sandstone. A boulder of Sphinx Conglomerate found in the gravels is of particular interest because the Sphinx Conglomerate at present occurs only at Sphinx Mountain, about 12 miles to

Figure 16. Westward view showing the glacial valley of Taylor Fork in the mountains in the western part of the mapped area. The light-colored rocks are Paleozoic in age; the darker rocks are Precambrian.

the north-northwest of the till deposit. All the remaining rock types represented by the gravels occur in the mountains three miles to the west. These till deposits are locally 100 feet thick. The deposits in secs. 34 and 27 are the thickest and contain the coarsest debris, including boulders several feet in diameter. A mature soil profile has not formed on any of the three deposits and the gravel-sized clasts are not weathered.

Besides the above-mentioned till deposits, the hill tops along Wapiti and Eldridge Creeks are covered by glacial gravels of all degrees of coarseness. These gravels apparently were deposited as a blanket over this area when the topography was less rugged than it is today and at the same time as the Marble Point deposits.

The next younger substage is termed the Intermediate substage (Hall, 1960) and is characterized by till (see Plate 2) appearing mainly north of Taylor Fork in secs. 1, 5, and 17, T. 9 S., R. 3 E. These deposits are not readily visible on the aerial photographs and show no hummocky topography. They are composed of gravels containing fragments of varying shape up to two feet in diameter, and are made of gneiss, limestone, and sandstone from the mountains to the west. Hall (1960) has correlated, with question, the Intermediate substage of this area with morainal deposits of the early Wisconsin Bull Lake stage of Blackwelder in northwestern Wyoming.

The next youngest substage is referred to by Hall (1960) as the Sawmill substage, named for the terminal moraine that occurs in secs. 1 and 2, T. 9 S., R. 3 E. This moraine is 80 to 100 feet high, has a crescent-shaped outline, and a hummocky surface. An immature soil is developed on the moraine but the glacial gravels remain fresh. Lateral moraines lie near the mouths of Cache and Eldridge Creeks, in secs. 3, 9, and 11, T. 9 S., R. 3 E. and secs. 2, 3, 10, and 11, T. 9 S., R. 3 E. respectively. They have the same hummocky topography, undrained depressions, soil profile, and fresh look as the terminal moraine. Both the lateral and terminal moraines are composed of debris derived from the Precambrian gneisses, Paleozoic limestones and sandstones, and igneous rocks, cemented by clay- and silt-sized matrix. The gravel in the debris ranges from several inches to several feet in diameter and is subrounded to rounded. Clasts of limestone and sandstone are the most abundant constituents; the gneiss clasts are next in abundance. The nearest source for the gravels is the mountainous terrain in the western one-third of the thesis area some six miles from the terminal moraine. The Sawmill substage has been tentatively correlated by Hall (1960) as Pinedale, after Blackwelder, who applied the name to glacial material in northwestern Wyoming (Figures 17, 18, 19 and 20).

Figure 17. View west up Taylor Fork. Notice the terminal moraine at the bottom, the glaciated valley wall on the right, and Shedhorn Mountain at upper right.

Figure 18. View east down Taylor Fork showing the terminal moraine in the center. Note the meandering and meander scars of Taylor Fork and the hummocky topography of the moraine.

Figure 19. Lateral moraine deposit located at the southern edge of the SW$\frac{1}{4}$ sec. 2, T. 9 S., R. 3 E.

Figure 20. Lateral moraine deposit located close to Figure 15. Note the poor sorting and size of the cobbles.

The youngest glacial substage occurs in the higher elevations only and consists of nivation cirques and limited glacial debris. The ice that occupied these cirques was probably limited to the cirques. The debris from these cirques is made of unweathered blocks of the local rock ranging in diameter from six inches to six feet. Good examples of such material occur in secs. 22 and 36, T. 9 S., R. 3 E. Hall (1960) tentatively assigns these glacial features to what he terms the Little Ice Age.

Mass Gravity Movements

Deposits produced by mass-gravity movements are widespread and cover approximately 11 square miles of the thesis area. These movements are presently active and are a significant agent in bringing the oversteepened glaciated valley walls into equilibrium and in bringing the topography to maturity. Mass-gravity movements in the area may be divided into slump, rock creep, rock fall, and earthflows. Earthflows are the most abundant and most important mass movements that modify the Upper Cretaceous strata. The earthflows create locally steepened areas at the headwalls and hummocky topography on the materials involved in the flows. The ends of the flows are usually lobate and convex into stream valleys, causing a narrowing of the valleys and frequently a damming or diversion of the stream.

Slumping is frequently associated with the earth-flows and acts as the initial movement at the headwall. Slumping also causes terrace-like steps on the valley walls and local reversals of slopes.

Rock fall and rock creep produce large talus piles in the mountains at the base of steep cliffs.

GEOLOGIC HISTORY

During the Precambrian, clays and muds were deposited in a geosyncline, later destroyed by an orogeny that caused the sediments to be metamorphosed and uplifted. Erosion of these rocks led to development of a low-lying surface before inundation by the Middle Cambrian seas.

All the Paleozoic and most of the Mesozoic sediments occurring in the thesis area were deposited on the Wyoming stable shelf close to the misogeosyncline that lay to the west of the area.

The transgressing Middle Cambrian sea reworked the Precambrian metamorphic rocks, depositing the sediments of the Flathead Formation. As the sea transgressed eastward, the water became deeper in the area. Muds, clays, and lime muds were deposited to form the Wolsey and Meagher Formations. The sea receded slightly, and the Park Shale was deposited. Marine sedimentation continued until the end of the Cambrian, when the sea withdrew from the area. During Early Ordovician time the Cambrian sediments were exposed to erosion. A sea covered the area briefly during Middle Ordovician and the Big Horn Dolomite was deposited. Uplift and withdrawal of the sea again exposed the area to erosion until Middle Devonian time. This erosion removed Middle Ordovician and Upper Cambrian rocks from the thesis area (Sloss and Moritz, 1950) and (Perry, 1962).

By Middle Devonian the sea had returned and deposition of carbonates took place. These sediments were later dolomitized and are called the Jefferson Dolomites. Carbonate sedimentation was terminated by a lowering sea level or slight rising of the land or both, initiating Three Forks deposition of clays, muds, and lime-muds. A brief uplift caused solution and subsequent collapse of some of the limestones, forming a limestone breccia that appears in the middle of the Three Forks Formation. Marine sedimentation resumed with the deposition of lime muds, clay and sand until the end of Three Forks time.

A slight deepening and restriction of the waters of the Early Mississippian led to the deposition of black clays and limy muds. These notably fossiliferous sediments form the lower part of the Lodgepole Formation. Later in the Early Mississippian circulation of the waters improved, as indicated by lighter colored limestones and an increase in the number of fossil genera. Oolites formed as the sea became shallow and clear, initiating Mission Canyon carbonate deposition. Deeper water followed and thick sequences of limestone and limestone breccia were deposited. Uplift and erosion during late Middle and early Late Mississippian time removed thick carbonate sequences that overlay the Mission Canyon. Doubtless a small amount of the Mission Canyon was also eroded. In Late Mississippian time the Amsden sequence of red sediments was deposited in a shallow marine, perhaps mudflat, environment. Erosion followed, and the upper part of the Amsden Formation was removed.

The marine depositional environment returned by Middle Pennsylvanian time, and the Quadrant sands were deposited. The water was clear, shallow and in constant agitation as shown by the nearly pure white, well-sorted, and current cross-bedded sandstones made of rounded quartz grains. Slight emergence of the area brought on an interval of little or no deposition, or possibly minor erosion, until Phosphoria deposition began in the middle Permian (Dunbar, 1960). Sediments from the north and east were deposited in the area, forming mostly sandstones, but high concentrations of siliceous organisms led also to the deposition of cherts. In restricted areas of a reducing environment, phosphates were deposited (McKelvey, 1959).

During the Paleozoic Era this area of deposition was relatively stable, and had only minor fluctuations in sea level. The thickness of the deposits indicates conditions of shelf environment. The relatively stable shelf conditions continued into the Triassic, accompanied by deposition of silt, sand, clay, and minor limy mud in shallow marine water to form the Dinwoody Formation. Minor fluctuations in sea level and continuing deposition resulted in the continental red siltstones and shales of the Woodside Formation and the marine sandstones, siltstones, and limestones of the Thaynes Formation. An emergent condition throughout Middle and Late Triassic and Early Jurassic time led to erosion of the Thaynes and upper Woodside beds and reduced the area to a surface of low relief.

During Middle Jurassic time the seas advance across the area and deposited limy muds and clays in an environment that teemed with many species of marine invertebrates. Late in Rierdon deposition the sea became shallow, and oolites and pellets formed in clear, warm waters. Slight uplift of the adjacent land in Swift time led to an influx of clastic material and the formation of glauconite grains and calcareous pellets and oolites. Abundant black rounded chert pebbles either came from an eroding area of rocks of the lower Madison Group or were a reworked product from an unknown sedimentary source. The sea withdrew from the area but sedimentation continued as clays, silts, and sands accumulated on low-lying plains to form the beds of the Morrison Formation. Dense limestones were deposited in fresh water lakes. As Morrison deposition came to a close, rapid uplift of the area caused a widespread but short episode of erosion, followed by deposition of Early Cretaceous Kootenai conglomerates. This is the first evidence of the Laramide orogeny.

As the uplands were slowly reduced to low-lying hills and plains, sand, lime-muds, clays, and silts were deposited in a rapidly changing continental environment. Near the middle of Kootenai deposition, the area became stable, and a large shallow fresh water lake formed. Gastropods were abundant and their shells accumulated to form gastropod limestones. Associated rocks deposited in the lake were calcareous clays, breccias, and argillaceous lime-muds. Tuffaceous material included in these rocks indicates that volcanism was present to the west in the area undergoing deformation.

Erosion followed for a brief time but was halted by marine invasion from the north and deposition of quartzose sand. These sands were deposited in a marginal marine environment. Continued transgression of the sea led to deposition of clays and muds of the Thermopolis shale. Uplift and withdrawal of the sea and subsequent influx of sand initiated deposition of the Muddy sands. These sands came from the west, southeast, and south and were deposited by streams spreading over low-lying plains. Volcanism continued and contributed volcanic rock fragments to the sandstone. This volcanism accompanied Laramide orogeny that was progressing from Idaho into Montana. As the Laramide deformation proceeded eastward, lacustrine deposits of pyroclastic origin were laid down upon the Muddy sandstones and formed tuffs, sandy tuffs, and volcanic sandstones of the Albino Formation.

The large fresh water lake disappeared at the end of Albino deposition as a slight lowering of the area caused an invasion of the sea. The basal black shales of the Upper Cretaceous Colorado Group were deposited in shallow, nearshore, restricted marine waters, perhaps in a back-bar environment. Volcanic activity increased, and tuffs were laid down in still water. A thick sequence of interbedded sands and muds accumulated in depositional areas ranging from shallow marine to low coastal environments during Late Cretaceous time. Subsequent uplift during the Laramide orogeny subjected the thesis area to erosion. Compressional forces from the southwest caused northwest-trending structures to develop in Late Cretaceous to early Tertiary time. A long period of erosion took place, and a mature topography developed before Pliocene time. Volcanism became important during the Pliocene and produced extensive flows of welded tuff in the southern Madison Range and in the thesis area, only a remnant of which is present today.

Glaciation during late Pleistocene was the last great modifier of the land in the area, carving valleys and mountains and depositing till. During the Late Cenozoic block faulting occurred in the area and is still occurring today as shown by the faulting that occurred at Hebgen late in 1959.

At the present time stream erosion and landsliding are very active in transporting sediments into the valleys and from there out of the area.

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APPENDIX

Measured Stratigraphic Sections

Albino Formation Late Early Cretaceous

Measured in the SE¼NW¼ sec. 7, T. 9 S., R. 4 E. west of the junction of Wapiti Creek and Taylor Fork. Traverse begins in dry creek bed and trends south down the south side of Lincoln Mountain. The Albino formation is overlain by the black shale of the Upper Cretaceous.

	Thickness in Feet
1. Shale: black, may be the base of Upper Cretaceous Unit One	10
2. Siltstone: pink when fresh, weathers flesh pink	0.5
3. Claystone: black, shaly, contains coaly wood fragments	7.0
4. Tuffaceous clay weathering product: cream-buff, green, red, brown, and greenish-buff; poorly exposed outcrop of carbonaceous siliceous siltstone	27.5
5. Tuffaceous clay weathering product: greenish-buff, popcorn-like texture	4.0
6. Covered	5.0
7. Siltstone: laminated red and black, sandy, siliceous	3.0
8. Siltstone: green when fresh, weathers white; sandy, glass shards visible	3.4
9. Covered	8.1
10. Claystone: black-brown, crumbly, contains coaly wood fragments	11.0
11. Siltstone: pinkish-cream, many orange blebs, thinly bedded, glass shards visible	18.2

12.	Siltstone: white and red, siliceous, tuffaceous, clayey, very finely laminated..	4.6
13.	Covered: pinkish-cream mud covers the ground....................................	33.0
14.	Covered: pinkish-cream mud and siliceous siltstone float..........................	29.0
15.	Claystone: purple to black, sparse orange blebs; mud at the time of traverse.......	4.5
16.	Siltstone: weathers greenish-buff.......	2.5
17.	Claystone: dark gray with orange blebs..	3.8
18.	Siltstone: gray, muddy..................	11.9
19.	Claystone: greenish, muddy..............	7.8
20.	Covered.................................	15.5
21.	Siltstone: dark gray with orange blebs, siliceous, hard, contains biotite grains.	2.0
22.	Tuffaceous clay weathering product: buff, purple-gray, cream with greenish tinge, and dark gray; siliceous siltstone near the base contains biotite flakes and bright orange blebs, weathers white......	27.5
23.	Covered: light buff to cream mud, tuffaceous.................................	9.5
24.	Claystone: siliceous, hard, vuggy.......	1.0
25.	Covered.................................	4.2

The contact is disconformable. The sandstones of the Muddy are overlain by the siliceous silty and sandy rocks of the lower Albino. The exact contact could not be found.

Albino Formation = 255 feet

Muddy Member   Late Early Cretaceous

Section position is the continuation of that of the Albino Formation. The traverse trend is S. 35° W.

	Thickness in Feet
1. Sandstone: salt-and-pepper, fine-grained quartz, chert, and rock fragments, loosely consolidated, laminated...............	10
2. Sandstone: salt-and-pepper, calcareous, fine-grained, well-sorted, laminated and cross-laminated..........................	10
3. Conglomerate: dark colored, pebbles of dark chert and quartz are subangular to subrounded; wood fragments on bedding planes....................................	1
4. Sandstone: salt-and-pepper, coarse-grained, contains claystone nodules (to one inch), pebbles of black chert and wood fragments.....................................	4
5. Covered..................................	8
6. Sandstone: salt-and-pepper, calcareous, fine-grained.............................	2
Offset to the east 30 feet to measure better exposed outcrops of Muddy.	
7. Sandstone: gray, highly calcareous, fine-grained, laminated, cross-laminated (current flow to N. 17° W.), platy...........	1.5
8. Covered..................................	12.5
9. Sandstone: salt-and-pepper, calcareous, fine-grained, well-sorted, laminated, with angular grains of quartz, chert and rock fragments.......................	1
10. Sandstone: salt-and-pepper, calcareous, very fine-grained, thinly bedded.........	2
11. Covered..................................	3

12.	Sandstone: salt-and-pepper, noncalcareous	4
13.	Sandstone: salt-and-pepper, noncalcareous, fine-grained..............................	1
14.	Sandstone: salt-and-pepper, noncalcareous, fine-grained, laminated............	5
15.	Sandstone: salt-and-pepper, calcareous, fine-grained, laminated, cross-laminated with current flow N. 35° W. and N. 85° E., determined by fore-set beds. Noticeable slump or infill structure................	5
16.	Sandstone: dark-gray when fresh, weathers light gray; salt-and-pepper, calcareous, fine-grained, laminated..................	2.5
17.	Sandstone: gray when fresh, weathers tan to orange, salt-and-pepper, calcareous, fine-grained, loosely cemented, fractured	5
18.	Sandstone: gray, calcareous, very fine-grained, cross-laminated, laminated, grains are yellow, black,and white. Cross lamination shows flow to N. 4° W...	9.5
19.	Sandstone: gray when fresh, weathers buff to tan, calcareous, quartzose, cross-bedded..............................	6
20.	Covered..................................	4.5
21.	Sandstone: salt-and-pepper, calcareous, very fine-grained, laminated, iron concretions ranging from 1/16" to 1" in diameter near the top....................	4
22.	Sandstone: salt-and-pepper, calcareous, very fine-grained, highly cross-bedded...	2

Basal contact not seen because of soil cover.

Muddy Member = 110 feet

<u>Thermopolis</u> <u>Formation</u> Late Cretaceous

Measured in sec. 21, T. 7 S., R. 4 E. on the east side of the Gallatin River. (Contact with the Muddy Member is not visible.)

	Thickness in Feet
1. Shale: dark-gray when fresh, weathers olive gray; slightly calcareous; laminated, iron and clay concretions averaging 2" in diameter........................	100
2. Siltstone to claystone: dark-gray when fresh, weathers olive gray; laminated, platy (plates ¼" to ½" thick), calcareous. Forms small low ledges.........	40
3. Shale: dark-gray when fresh, weathers olive gray; slightly calcareous; laminated. Many organic (?) impressions on bedding surface; impressions are 1/8" wide, some reaching 1½" in length, and branching.................................	40

The contact is not observed.

Thermopolis Formation = 180 feet

Kootenai Formation Early Cretaceous

Section measured in the NE¼NE¼ sec. 13, T. 9 S., R. 2 E. northeast of Tumbledown Creek. The traverse proceeded S. 40° W.

	Thickness in Feet
1. Sandstone: pinkish-brown when fresh, weathers yellow buff to gray; very fine-grained; (laminated) oscillatory ripple marks, (bedding 1/8" to 2"). Siltstone is present as thin interbeds in small amounts.........................	12.6
2. Sandstone: weathers yellow; very fine-grained quartz arenite; bedding ranges from 1' to 3' and 1/16" to 2" beds, (thick beds are found at the top.) Oscillatory ripple marks and questionable mud	

cracks. Wood fragments are locally found on bedding planes........................ 45

3. Covered.................................. 25.3

4. Limestone: gray to cream when fresh, weathers buff to orangish-cream, tufface-ous, fossiliferous, conglomeratic, beds ¼" to 1" thick, interbedded with thin black shale partings and limy tufface-ous mudstone. Mud cracks associated with intraformational breccia................. 28.3

5. Covered: calcareous siltstone and gray brown limestone found as float........... 103.5

6. Covered: limy claystone and limestone occur as float........................... 38

7. Limestone, sandstone, siltstone, lime-stone conglomerate: all interbedded, all calcareous, all gray to light brown, beds 4" to 1½' thick, sandstone very fine-grained.................................. 23.4

8. Mostly covered: red and yellow calcareous mudstones occur as float, some interbedded limestone............................... 44

9. Sandstone: weathering yellow buff, very fine-grained, conglomeratic in places, calcareous, cross-laminated. Conglomer-atic portions contain light colored chert and quartzite pebbles with minor black chert. A brown (phosphatic) sandstone is present near the middle............... 33.7

10. Sandstone: weathers yellowish-tan, medium-grained, calcareous, quartzose, scattered black chert pebbles present, fractured, forms slopes............................ 5.2

11. Covered.................................. 9.8

12. Sandstone and conglomerate: the conglomer-ates are gray and white, contain black and gray chert pebbles and some quartzite peb-bles, decrease in pebble size upwards, black chert diminishes upward, all but the top conglomerate are calcareous, lens later-ally into sandstones, pebbles attain a 3"

diameter occasionally. All conglomerates have a sandstone "matrix". The sandstones are salt-and-pepper colored, calcareous, fine- to coarse-grained, cross-bedded, contain quartz and black and light colored chert.................................... 38

The contact with the underlying Morrison Formation is disconformable. The conglomeratic sequence of the Kootenai lies on the mildly undulating sandstone surface of the Morrison.

Kootenai Formation = 407 feet

Morrison Formation Late Jurassic

Section measured on the eastern edge NE¼NW¼ sec. 19, T. 9 S., R. 3 E. Traverse proceeded S. 40° W. down the steep slope of Morrison.

Thickness in Feet

1. Sandstone: weathering light brown, quartzose, thick-bedded, cross-laminated, cliff-forming, found at the base of this 120' and two-thirds of the way up from the base. Between these sandstones and near the upper contact are lensing, thin-bedded, very fine-grained sandstones, siltstones, and shales, all buff colored, calcareous, laminated, cross-laminated (current flow from south to north taken on fore-set beds), sandstones are quartzose...... 120

2. Mudstone and sandstone: the mudstone is gray and olive, calcareous; the sandstone is limonitic, calcareous, fine-grained, finely laminated. Bone fragments appear as float..................... 24

3. Sandstone: tan when fresh, weathers yellow buff, very calcareous, limonitic, quartzose, beds ¼" to 1" thick........... 7

4.	Covered: olive and green calcareous mudstone float..............................	16
5.	Limestone: light brown when fresh, weathers tan, beds 2' to 2½' thick; interbedded with shaly limestone with 1" beds........	10.3
6.	Mudstone: red, green, gray, and olive, calcareous, poorly exposed. Red color predominates.............................	21
7.	Siltstone: red, very calcareous.........	2.7
8.	Covered.....................................	4.7
9.	Sandstone: blue gray when fresh, weathers yellow-buff, very fine-grained, very calcareous, occasional iron concretions at the top averaging ½" in diameter.........	2.7
10.	Mudstone: red, gray, green, and olive, calcareous, shaly weathering. Red color predominates..................................	29.5
11.	Limestone: brown when fresh, weathers tan, contains green ovals, micritic...........	.7
12.	Mudstone: red, olive, and gray, calcareous, shaly weathering.........................	.9
13.	Limestone: brown when fresh, weathers tan, contains green ovals, micritic...........	2.5
14.	Covered: red soil.......................	21
15.	Limestone: mottled pink and light green, scattered black chert grains.............	1
16.	Mudstone: olive, greenish-gray and reddish-gray, shaly, calcareous..................	33.7

Visible contact is conformable and gradational. The sandstones of the Swift Formation become finer grained and grade up into the Morrison mudstones.

Morrison Formation = 306 feet

Swift Formation Middle Jurassic

The measured section is a continuation of the Morrison section located downhill and to the west. Traverse proceeded S. 55° W.

	Thickness in Feet
1. Limestone and sandstone, interbedded: limestone weathers yellowish; oolitic, beds 1" to 4" thick. Sandstone greenish-gray, conglomeratic, calcareous, cross-bedded, finer grained toward the top; bed thickness similar to limestones. Wood fragments on bedding planes.........	22.6
2. Sandstone: yellowish, calcareous, fine-grained, conglomeratic; grains angular to subrounded, pebbles of black chert; 1' bed of very fine-grained calcareous salt-and-pepper sandstone at base. Fossiliferous............................	2.3
3. Sandstone: dark-gray when fresh, weathers orange buff, calcareous, glauconitic, fine-grained; grains composed of subrounded to rounded chert, quartz, and glauconite...............................	11

The contact is abrupt but conformable. The sandstones of the Swift lie on the gently undulating surface of the oolitic limestone unit of the Rierdon Formation.

Swift Formation = 36 feet

Rierdon Formation Middle Jurassic

Measured section in NE¼NW¼ sec. 13, T. 9 S., R. 2 E. starting at the base of the Swift sandstones at the top of slope made of Rierdon strata. Traverse proceeds downhill S. 30° W.

1. Limestone: pinkish-brown when fresh, weathers brown, oolitic, dense; beds 1' to 2' thick, fractured, oolite percentage increases toward the top, fossiliferous throughout.................................. 11

2. Limestone: tan when fresh, weathers grayish-white with yellow stain, oolitic, beds ¼" to 2" and 8" to 12". Occasional pyrite cubes visible............................. 9.2

3. Covered: contains the change from limy mudstones to oolitic limestones.......... 36

4. Mudstone: gray when fresh, weathers light-tan to light-gray, limy, shaly, occasional thin beds (6" to 8") of shaly limestone.. 38

5. Limestone: gray when fresh, weathers light-gray, shaly; beds less than 1' thick fractured, forms low cliff outcrop, fossiliferous.................................. 21

6. Limestone and mudstone: gray to tan, weathers buff, very fossiliferous. Beds in the limestone are 6" to 1½' thick and less than 1' thick in the mudstone. The mudstone is limy and predominates in the top of the sequence...................... 46.3

7. Shale and mudstone: weather buff and grayish-tan, fossils abound. The shale is limy as is the mudstone. Limy mudstone forms resistant beds............... 33.2

The contact is visible and disconformable. Separation of the two formations is arbitrarily taken at the lowest siltstone above the disappearance of red-colored strata.

Rierdon Formation = 195 feet

<u>Woodside Formation</u> Early Triassic

Measured section is at the same location as the Rierdon Formation with best outcrops occurring in a stream cut at the base of the Rierdon.

Thickness in Feet

1. Siltstone: red and buff, calcareous; interbedded with greenish-buff and red, calcareous shale. Carbonate content increases toward the top......... 83

2. Siltstones: red, gray, buff, calcareous, asymmetrical ripple-marks, intraformational breccia found near the base; interbedded gray, green, and buff shales at random intervals near the top and the bottom. Ripple marks show current flow to N. 10° E. and vary in width from ½" to 12"......... 21.7

The contact is conformable and gradational. It was arbitrarily selected at the first appearance of red siltstones and shales of the Woodside Formation.

Woodside Formation = 105 feet

Dinwoody Formation Early Triassic

Section measured at the same location as the Rierdon Formation, but down section and downhill from the Rierdon. Traverse trend is S. 50° W.

Thickness in Feet

1. Siltstone: brownish-gray and greenish, calcareous, oscillation ripple-marks. Poorly exposed, becomes red at the top... 10

2. Siltstone to sandstone: dark-brown to brown, calcareous. The sandstone is very fine-grained, emits fetid odor when crushed, beds 2' to 3' thick. Penecontemporaneous deformation and intraformational breccia present............. 5

Off set 300' to the west through a forested area to the top of a hill to well-exposed outcrops.

3.	Sandstones and siltstones: dark-brown to brown when fresh, weathers tan, calcareous, beds 1" to 3" thick, sandstones very fine-grained....................................	26
4.	Covered: sandstone and siltstone float..	13
5.	Siltstone and sandstone: brown when fresh, weathers light-brown, beds 1" to 6" thick, sandstone is very fine-grained. One 4" bed of brown *Lingula* limestone occurs in the center of the sequence...............	8.7
6.	Covered....................................	8.7
7.	Sandstone and siltstone: various shades of brown when fresh, weathers yellow buff, calcareous, beds 1" to 4" and 1' to 2' thick, sandstone is very fine-grained, fossiliferous....................	21.7
8.	Partly covered: thin, buff, very fine-grain sandstone..........................	26
9.	Sandstone: buff, calcareous, very fine-grained, beds 1' to 3' thick, contains *Lingula* beds............................	17.3
10.	Covered....................................	69.3
11.	Limestone: brown, beds ¼" to 12" thick, contains *Lingula*, fetid odor when crushed; interbedded randomly with a brown, limy mudstone...................................	26
12.	Covered: limestone float.................	6.3
13.	Limestone: light-buff and gray when fresh, weathers tan, sandy, contains asphalt pods, beds 8" to 12" thick.....................	4.3

The contact is disconformable and visible. It is arbitrarily selected by the appearance of the first limestone unit above the chert and sandstone beds of the Phosphoria Formation.

Dinwoody Formation = 242± feet

<u>Phosphoria Formation</u> Middle Permian

The measured section is at the SE¼NW¼ sec. 13, T. 9 S., R. 2 E. southwest of Tumbledown Creek and just downhill from the Dinwoody measured section. Traverse direction is S. 50° W.

	Thickness in Feet
1. Sandstone: brown to light gray brown, calcareous, 1½' white chert layer near the top. Chert, quartz, and collophane grains make up the sandstone.............	25.3
2. Chert: yellow to buff, bedding 1" to 6"; interbedded with brown sandstone, 1" to 6" thick.................................	2.5
3. Sandstone: brown, calcareous, sparkling, many red collophane and black chert grains	4
4. Chert: white to light-gray when fresh, weathers white, contains two thin brown sandstone beds...........................	5
5. Sandstone: brown, fine- to very fine-grained, calcareous, very irregular bumpy bedding surfaces, many chert and quartz grains. Collophane present.......	2.5
6. Chert: weathers white, bedded, contains vertical sandstone tubes; two thin brown sandstone layers within the chert........	5.5
7. Sandstone: brown, sparkling, very fine-grained. Bottom 2' contain chert nodules, bottom one-third is highly calcareous, middle one-third not calcareous, top one-third calcareous and fine-grained. Contains quartz, collophane, and chert grains.................................	32.5
8. Chert: dark-and light-gray, dense and fractured, beds 1" to 3" thick, bedding planes undulatory, bedding surface yellow brown in color. The upper lighter cherts contain vertical tubes of sandstone.............	37

9. Covered.................................. 8.8

10. Sandstone: brown, calcareous, contains white weathering chert nodules................. 1

11. Sandstone: light-brown when fresh, weathers brown, very fine-grained, calcareous, sparkling, quartzose.......................... 3.7

12. Chert: gray-white, bedded, contains sand grains of all sizes...................... 5.9

13. Sandstone: brown, very coarse-grained, calcareous, contains many chert grains... 3.5

14. Limestone: weathers tan, sandy and silty, massive, occasional pebbles.............. 1.3

15. Sandstone: brown, calcareous, coarse- to fine-grained, thin 2" beds of pebbles consisting of chert about 1" in diameter. 1.7

16. Sandstone: brown, calcareous, very fine-grained, conglomerate lenses. Pebbles range from 4 to 45 mm. and are made of limestone, fossils, chert, calcareous siltstone, quartzite, and conglomerate............................... 2

17. Sandstone: light-brown when fresh, weathers brown, very fine-grained, quartz, chert and collophane grains, calcareous, sparkling, bedding 4' to 6'.................... 20

18. Sandstone: tan, very fine-grained, calcareous, conglomeratic at the base, pebbles range from 2 to 20 mm. in diameter. Pebbles made of light-brown to buff chert, gray chert, and quartzite................ 1

19. Mudstone: buff to tan when fresh, weathers white to light-tan, limy , beds 6" thick, fractured at right angles to bedding, nonresistant, contains brown phosphatic stringers............................... 9.3

20. Sandstone: milk-white when fresh, weathers buff to brown, very fine-grained, quartz and chert grains, slightly calcareous, cross-bedded, beds 2½' to 3' and 6' to 7' thick, contains a few chert beds 2" to

3" thick.................................. 35

21. Sandstone: light-brown to buff, calcareous, poorly cemented, contains buff colored chert nodules, beds, and stringers. The nodules are concentrically layered; chert beds range from less than 1" to 4" thick. 6.3

22. Limestone, siltstone, and sandstone: light-brown when fresh, weathers tan, glauconitic, beds ¼"-3" to 12" thick; small crinoid columnals in limestone near the base; chert nodules at the top...................... 16.4

The contact with the underlying Quadrant Formation is disconformable, and is arbitrarily selected as the first brown colored sandstone above the white sandstones of the Quadrant Formation.

Phosphoria Formation = 230 feet

Quadrant Formation Pennsylvanian

Section measured at the NE corner of sec. 3, T. 9 S., R. 4 E. west of U.S. Highway 191 at Pulpit Rock. Traverse direction was S. 33° W. down the outcrops starting at the top of the well-exposed sandstones.

Thickness in Feet

1. Sandstone: white, calcareous, quartz arenite, very fine-grained, beds 3' to 4' thick, top 1' not calcareous.......... 11.7

2. Sandstone: dirty white, noncalcareous, very fine-grained, porous, cross-laminated with current movement from north to south taken on fore-set beds, beds 3' to 4' thick in the middle of the sequence, fractured at right angles to the bedding.............................. 39

3. Sandstone: white, slightly calcareous,

beds dominantly ½" to 3" thick, but 4' at the base.................................. 32.2

4. Sandstone: white, calcareous, beds 3' to 4' thick, well cross-bedded, calcareous cement sparse at the top, iron concretions 1 mm. to 4 mm. in diameter............... 40

5. Sandstone: yellowish-white, very fine-grained, well-sorted, calcareous, highly cross-laminated, 4' layers between cross-laminated beds........................... 22.5

6. Sandstone: white, calcareous, cross-lamination shows current flow from N. 10° E. taken on fore-set beds 5' thick, bedding lines seen due to weathering and solution 41.8

7. Sandstone: grayish-white when fresh, weathers yellow buff, very fine-grained, calcareous, beds 1" to 6" thick, cross-laminated, scattered chert nodules. At the base is a 4', cavernous, calcareous sandstone with calcite-filled voids...... 34

The contact is disconformable, as shown by the absence of the Amsden Formation. The beds of the Mission Canyon Formation below are parallel to the bedding of the Phosphoria Formation.

Quadrant Formation = 221 feet

<u>Amsden Formation</u> Late Mississippian

Section measured at the western edge NW¼ sec. 19, T. 9 S., R. 3 E. north of Taylor Fork in a narrow gully formed by the Amsden.

<u>Thickness in Feet</u>

1. Covered.................................. 5

2. Sandstone: milk-white fresh color, weathers pinkish-white, quartzose............. 1

3.	Mudstone: buff and red; buff limestone; red, calcareous mudstone.................	5
4.	Mudstone: red, shaly, calcareous........	3.3
5.	Siltstone: red with buff blotches, calcareous, massive.........................	1.3
6.	Mudstone: red, shaly, calcareous........	1.5
7.	Limestone: white.........................	1
8.	Mudstone: red, shaly, calcareous, contains mottled buff and red intraformational breccias...........................	14
9.	Mudstone: red, silty, calcareous, massive	2
10.	Mudstone: red, shaly, calcareous........	2
11.	Mudstone: red, silty, calcareous, massive	2
12.	Mudstone: red, shaly, calcareous........	1.5
13.	Limestone: purple red to buff, mottled, shaly, bedding 1" and less...............	1.7
14.	Limestone: mottled purple and yellow and buff, dolomitic, vuggy, intraformational breccia in places, fractured at right angles to the bedding.....................	6

The contact is disconformable and arbitrarily taken as the point where the red color is dominant.

Amsden Formation = 43 feet

<u>Mission Canyon Formation</u> Late Early Mississippian (Osagian)

The section is a continuation of the Amsden Formation section and proceeds into the eastern one-half sec. 24, T. 9 S., R. 2 E. The traverse trend S. 37° W.

		Thickness in Feet
1.	Limestone: tan, weathers light-gray.....	15

2. Limestone: tan, saccharoidal, massive... 89.6

3. Limestone: tan, fine-textured........... 58.5

4. Limestone breccia: yellowish-white when fresh, clasts 1" to 2" in size and bounded by saccharoidal carbonate................ 30.3

5. Interbedded limestone and limestone breccia: brown, sugar textured, dolomitic, breccia has small and large fragments, no bedding, breccia more extensive near the top.................................. 72.7

6. Limestone: light-tan to brown when fresh, weathers light-brown, saccharoidal. A three foot limestone breccia is in the center of this sequence.................. 31.6

7. Limestone: light-brown, massive, saccharoidal, rubbly weathering, fractured.. 101

8. Breccias: weather yellow brown to red, all sizes of fragments. Fragments are angular to subangular, largest ones at the base and stained red and are all limestone.................................... 25.3

9. Limestone: light-brown when fresh, weathers tan, medium crystallinity, massive, fractured, becomes saccharoidal near the top and weathers grayish-brown. Calcite-lined voids and veins are scattered...... 135.2

10. Limestone: light-brown when fresh, weathers grayish-tan, very fine-textured, splintery, no fossils visible, beds 6" to 2' thick with surfaces finely pitted........ 48.3

11. Limestone: brown when fresh, weathers light-brown, coarsely saccharoidal, made of fossil fragments, bedding is thick to obscure, fossils collected in this sequence, limestone fractured at right angles to the bedding (jointed)................. 149

12. Limestone: brown, oolitic (small oolites), coarsely-crystalline, beds 1½' to 6' thick 23.2

13. Limestone: brown when fresh, weathers light-brown, oolitic (small oolites),

bedding crudely developed................ 25

14. Limestone: brown, oolitic, contains fossil fragments, massive, rough and pitted bedding planes are visible............... 34.8

15. Limestone: brown, oolitic, poorly developed bedding, occasional corals seen..... 12.2

The contact with the Lodgepole Formation is conformable and gradational and is selected at the lowest appearance of oolitic limestones and the disappearance of well-defined bedding.

Mission Canyon Formation = 852 feet

<u>Lodgepole Formation</u> Early Mississippian

Section measured westward from the Mission Canyon-Lodgepole contact and is found in the northern one-half SE¼ T. 9 S., R. 2 E. Traverse direction S. 42° W.

Thickness in Feet

1. Limestone: dark-brown, beds 4" or less in thickness, weathers rubbly but has sub-concoidal fracture, fossils not readily visible.......................... 35.2

2. Limestone: brown, coarsely crystalline, beds 2" to 7" thick, highly fossiliferous 44.2

3. Limestone and shale interbeds: limestone is brown when fresh, weathers dark-brown, finely-crystalline, small abundant fossils; shale is buff when fresh, weathers yellowish-buff, limy.......................... 50.6

4. Limestone: brown, coarsely textured, beds 3' to 4' thick, small solitary horn corals abundant, colonial corals seen. Interbeds of thin (1" to 4"), brown, coarsely-crystalline limestone.......................... 18

5. Limestone: dark-gray when fresh, weathers gray to brown, very finely-crystalline, beds 3" to 4" thick, scattered limy shale. Thicker beds of limestone (1' to 3') are brown, coarsely-crystalline and highly fossiliferous, and are scattered through the thinner bedded limestones.... 62.2

6. Limestone and shale: limestone weathers purplish-gray, fossils on bedding planes, beds 4" to 6" thick, shales weather reddish to yellow buff, calcareous beds 1" to 2" thick. Several limestone beds are fossiliferous throughout. Fossils are small horn corals, small crinoid columnals, and brachiopods.......................... 99

7. Limestone and shale: as above. Fossils only on bedding planes, beds have oscillatory ripple marks trending N. 10° W. Brachiopods dominate, some crinoid columnals.................................... 127.4

8. Limestone: light-brown when fresh, weathers brown, coarsely-crystalline, beds 3½' thick, fossiliferous, fetid odor when crushed. Thin interbeds of limestone are brown on fresh surface, weathering yellowish-buff, beds 1" to 2" thick. More brachiopods than bryozoan and crinoid parts... 27

9. Limestone: weathers gray brown to brown, coarsely-crystalline, beds 2' thick, fossiliferous. Towards the top beds 2" to 3", and the limestone becomes finely-crystalline................................ 50.6

10. Limestone: gray, beds 2' thick, fossiliferous.................................. 8.3

11. Limestone and shale: limestone is black, shaly; shale is black, limy, both are fossiliferous. Chert stringers and nodules are present. Fossils are crinoids, brachiopods, and bryozoans..................... 10.3

12. Limestone: dark-gray when fresh, weathers reddish-brown, beds 6" thick, beds folded, highly fossiliferous. Large horn corals appear.................................. 21.3

13. Limestone: very light-brown when fresh, weathers brown, saccharoidal, beds 6" to 2' thick. Some interbeds of shale 1" to 2" thick.............................. 5

14. Limestone and shale: limestone is dark-brown, shaly; shale is dark-brown, limy. Both are fossiliferous. Black chert stringers and nodules are present in the limestone................................ 14.5

15. Limestone: dark-gray, beds 2" to 6" thick, fossiliferous; interbedded with dark-gray, limy, fossiliferous shale. Fossils mainly fenestrate bryozoans, crinoid columnals, and brachiopods. Black chert stringers appear in the limestones................. 32

16. Shale: dark-gray, beds 2" to 10" thick, extremely fossiliferous, glauconitic, contains flattened limestone ovals, interbedded with dark-gray limestone.......... 5

17. Limestone: brownish-gray when fresh, weathers brown, beds 1" to 1½" thick, fossiliferous............................ 3.7

18. Shale and sandstone interbeds: shale is black, calcareous; sandstone is tan when fresh, weathers yellowish-buff, very fine-grained. This is the gradation between the Lodgepole Formation and the Devonian Three Forks Formation.......................... 1.5

The contact is conformable and gradational. The base of the Lodgepole is taken as the first dark limy shale above the Devonian yellow sandstone.

Lodgepole Formation = 615 feet

<u>Three Forks Formation</u> Late Devonian

Section measured south of Taylor Fork at the eastern edge and corner NE¼NE¼NE¼ sec. 25, T. 9 S., R. 2 E. Section started at the base of Lodgepole cliff and proceeded to the southwest downhill.

		Thickness in Feet
1.	Sandstone: pinkish when fresh, weathers yellow brown, very fine-grained, highly calcareous. Contains greenish to gray shale partings..............................	20.4
2.	Limestone: gray brown, dolomitic, interbedded with calcareous, gray shale..........	18.4
3.	Limestone: gray brown, weathers light-brown, dense, beds 1" to 5" thick........	36.8
4.	Limestone: yellow with red splotches when fresh, weathers yellow brown, dolomitic, coarsely-crystalline, massive with crude bedding. Tan limestone beds included..................................	19.4
5.	Limestone: gray brown, dolomitic, dense, massive..................................	7.4
6.	Limestone breccia: orange red, made of limestone and dolomite clasts cemented by red shale. Very crude bedding at the top	39
7.	Covered..................................	31.4
8.	Shale: green, greenish-buff, and buff, calcareous, oval iron concretions in top shale are ¼" to ½" in diameter...........	9

Contact is conformable and abrupt. The shale of the Three Forks lies on the slightly irregular dolomite surface of the Devonian Jefferson Formation.

Three Forks Formation = 182 feet

Jefferson Formation   Late Middle and Late Devonian

Section is a continuation of the Three Forks Formation section and is slightly to the west and down slope ending in a talus covered slope above a stream that flows into

Taylor Fork. Traverse direction S. 35° W.

		Thickness in Feet
1.	Dolomite: brown, massive, bedding surface is pitted and irregular..................	19.6
2.	Dolomite: grayish-brown when fresh, weathers tan, beds ¼" to 3½" thick and becoming very thin-bedded at the top..............	4.5
3.	Dolomite: brown, vuggy, pitted surface where weathered............................	67
4.	Dolomite: brown when fresh, weathers tan to buff, dense and hard, beds 4" to 5" thick, grades into limestone in places...	3.5
5.	Dolomite: brown, massive, vuggy.........	16.4
6.	Dolomite: brown when fresh, weathers light-tan, beds 8" to 10" thick, smooth surface and hard..........................	4
7.	Dolomite: brown to grayish-brown when fresh, weathers yellow buff, vuggy, beds 1" to 3" thick. Beds 1' to 3' thick are found at random intervals................	16.7
8.	Dolomite: light-brown when fresh, weathers tan to buff, contains yellow iron-stained blebs, beds 1' thick......................	4
9.	Shale: weathers yellowish-buff, limy....	3
10.	Dolomite: brown when fresh, weathers tan, thin- and medium-bedded (3" to 1½').......	25.8
11.	Dolomite: brown, vuggy, dense, massive, fetid odor when crushed, saccharoidal texture, near the top it becomes thin- (1" to 6") and thick-(3') bedded at random......................................	92
12.	Dolomite: gray when fresh, weathers tan, slightly calcareous, beds 1" to 3" thick.	1.3
13.	Siltstone: greenish-tan when fresh, weathers greenish-buff, calcareous, shaly, beds 1" or less thick.........................	2.7

14.	Dolomite: grayish-brown when fresh, weathers brown, massive, but with crude bedding; weathers rubbly and rough................	7.3
15.	Dolomite: light grayish-brown when fresh, weathers brown, hard, beds 6" thick......	1.7
16.	Dolomite: light-brown, saccharoidal texture, vuggy, no bedding..................	8.7
17.	Limestone: grayish-brown, shaly, beds 1/8" to ½" thick..............................	1.3
18.	Limestone: grayish-brown, beds 4" thick, dense.....................................	9
19.	Limestone: light-gray when fresh, weathers tan to buff, massive, glauconite seen in one 1½' bed............................	39.8
20.	Limestone: light greenish-tan when fresh, weathers yellow-buff, shaly, beds ½" to 1½" thick with wavy bedding planes.......	10.4

Contact is covered.

Jefferson Formation = 338 feet

Park Formation Late Middle Cambrian

Not measured because outcrop covered by talus from Devonian Formation. Estimated to be 100' thick.

		Thickness in Feet
1.	Shale: red, green, buff, olive, micaceous, calcareous..........................	100

Basal contact covered.

Park Formation = 100 feet

Meagher Formation Middle Cambrian

Section measured at the SW¼SE¼ sec. 24, T. 9 S., R. 2 E.

north of Taylor Fork. Traverse proceeds S. 20° W. from the top of a mildly forested hill to the base of the visible outcrops.

	Thickness in Feet
Top of the Meagher Formation is covered.	
1. Limestone: gray and brown when fresh, oolitic, glauconitic, mostly covered.....	23
2. Limestone: gray and brown when fresh, glauconitic, oolitic, weathered surface is smooth where gray, but pitted where brown. Beds 1½" to 4" thick, bedding planes are wavy, glauconite parallels the bedding..............................	9.2
3. Limestone: weathers light-gray, beds 1" to 2" thick, mottled..................	27.7
4. Limestone: oolitic, glauconitic.........	11.5
5. Limestone: weathers yellow buff, grayish-brown fresh color, beds 1" to 4" thick, bedding planes rough and pitted, coarser texture toward the top. Thin beds are oolitic and glauconitic toward the top...	32.3
6. Limestone: mottled gray and buff, weathers grayish-brown, beds 1" to 12" thick, weathers to rubbly outcrops..............	41.5
7. Limestone: brown when fresh, very fine-textured, thick-bedded, fetid odor when broken. Calcite veins cut through the limestone................................	64.5
Offset to the southeast 500' downhill to better outcrop.	
8. Limestone: brown, massive, very fine-textured, bedding planes show mottled buff and brown color.....................	75
9. Limestone: brown, thin-bedded...........	15.5
10. Limestone: dark grayish-brown when fresh, weathers light-gray, beds 1½" thick......	3.4

11. Covered....................................	11.7
12. Limestone: mottled brown and light grayish-brown, weathers grayish-brown, beds ½" to 1½" and 1' to 2½' thick. Thin and thick units are interbedded. The limestone contains small round calcite blebs 2 mm. in diameter........................	30.2
13. Limestone: mottled light-brown and light grayish-brown, weathers yellowish-buff, beds ½" to 1½" thick, bedding planes wavy, bedding surface pock-marked........	65.4

Base is not exposed at this section.

Meagher Formation = 413+ feet

Wolsey Formation   Middle Cambrian

Section measured south of Taylor Fork at the center of NE¼, sec. 25, T. 9 S., R. 2 E. at the base of a vertical Meagher cliff and trending initially N. 70° W. downhill. Contact between the overlying Meagher Formation and the Wolsey Formation is conformable and gradational. The top of the Wolsey is selected at the last shale unit below a thick limestone sequence.

	Thickness in Feet
1. Limestone: mottled gray and brown, gray dominant; beds 1½' to 3' thick, wavy bedding planes with white calcite stringers at right angles to the bedding. Thin (1" to 2") interbeds of gray shale.......	7
2. Limestone: as above, undulatory bedding surface, beds 1½' to 2' thick, with interbeds of gray shale 4" thick..............	5
3. Interbedded limestone and shale: limestone is mottled gray and brown, beds 3" to 4" thick, becomes thicker at the top; shale	

is green in 3" to 4" beds................	15
4. Shale: green, slightly calcareous with thin 1" beds of limestone................	2
5. Limestone: mottled brown and gray.......	1
6. Interbedded shale and limestone: shale is more abundant and green, 2" to 3" beds; limestone mottled brown and gray, 1" to 2" beds..................................	2
7. Limestone: mottled gray with brown, 2" to 4" beds, thin (1" or less) interbeds of green shale...........................	5
8. Limestone: gray, medium crystalline, 2" beds, wavy bedding surface. Tiny pits on the weathered surface..................	1.7
9. Interbedded limestone and shale: limestone is mottled gray with brown, 1" to 1½" beds; shale is green, micaceous, calcareous................................	8.3
10. Limestone: mottled dark-brown and gray, beds 1" to 2-3" thick, wavy bedding surfaces, calcite stringers at right angles to the bedding, tiny pits developed on weathered surface. Near the top 1" to 2" green micaceous shale beds appear.....	22

Base is not exposed due to talus and soil cover.

Wolsey Formation = 68+ feet

Flathead Formation   Early Middle Cambrian

Measured section south of Taylor Fork in the center of NE¼ sec. 25, T. 9 S., R. 2 E. terminating in small creek bottom. The top is not exposed due to cover by talus and soil. Traverse trend is N. 70° W.

Thickness in Feet

1. Shale: green, micaceous, slightly

	calcareous, worm tube casts on bedding planes; interbedded with pinkish, glauconitic, calcareous sandstone beds 1" to 2" thick..................................	1.3
2.	Sandstone: pinkish, glauconitic, calcareous, fine-grained, quartzitic...........	1.2
3.	Shale: green, micaceous.................	.5
4.	Sandstone: limonitic, glauconitic, calcareous, fine- to medium-grained. Glauconite forms laminations.................	1.3
5.	Shale: green, micaceous, lenses laterally into sandstone...........................	.8
6.	Sandstone: limonitic, glauconitic, calcareous, fine-grained, a quartz arenite, cross-bedded. Grains are subangular to rounded with coarser ones found in thin lenses...	3
7.	Shale: green, micaceous, slightly calcareous, wavy bedding surface...............	2
8.	Sandstone: orange-buff, calcareous, very fine-grained, a quartz arenite, beds 2" to 4" thick. Lode casts on bottom surface of sandstone. Green micaceous shale interbeds, 1" thick...........................	2
9.	Claystone: green........................	0.5
10.	Sandstone and claystone: deep red, very fine-grained, upper 6" is green claystone	3.5
11.	Sandstone: deep red, calcareous, very fine-grained, containing small lenses of buff-green sandstone.................	2.3
12.	Sandstone: buff, calcareous, grades above and below into deep red sandstone..	1
13.	Sandstone: deep red, calcareous, very fine-grained; grades laterally into green and buff sandstones......................	.3
14.	Sandstone: orange buff, calcareous, very fine-grained, quartz arenite, scattered amber quartzite pebbles at the base. Green clay is scattered through the sandstone.	

Possible ripple marks.................... .5

The contact between the Flathead and the Precambrian beds lies between the basal pebbly sandstone of the Flathead and a deeply weathered zone interpreted as a regolith on the Precambrian.

Flathead Formation = 20+ feet

Regolith on the Precambrian gneiss consists of 1.2' of clay: red to purple, micaceous, containing many quartz grains, becoming more clayey toward the top.

The gneiss below the regolith is yellow to red and weathered deeply to quartz, clay, and chlorite.

p.173 attached as a seperate file.