GEOLOGY OF THE SOUTHERN PART OF THE GRAVELLY RANGE, SOUTHWESTERN MONTANA

by

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INTRODUCTION

The purpose of this thesis is to describe the geology of the southern part of the Gravelly Range. Specifically, this paper includes the stratigraphy, general structure, geomorphology, geologic history, and a geologic map.

The thesis area includes approximately sixty square miles in southwestern Montana (plate 1) and is located between 111° 02.4' and 111° 44' West longitude and 44° 51' and 49° 56' North latitude. Beaverhead and Madison counties are almost equally represented in the area, and the Beaverhead National Forest includes the entire area mapped.

Reasonably good dirt roads provide easy accessibility in the western half of the area; however, only jeep trails traverse the eastern half. On the west and south good all-weather roads approach within four miles of the area.

Topographically, the area is one of early maturity in the progress of stream erosion. From a maximum elevation of 9560 feet on Lobo Mesa to a minimum elevation of 6880 feet at Landon Forest Camp, a relief of 2680 feet affords good exposures throughout most of the area. Most of the small streams in the area are intermittent, but the large

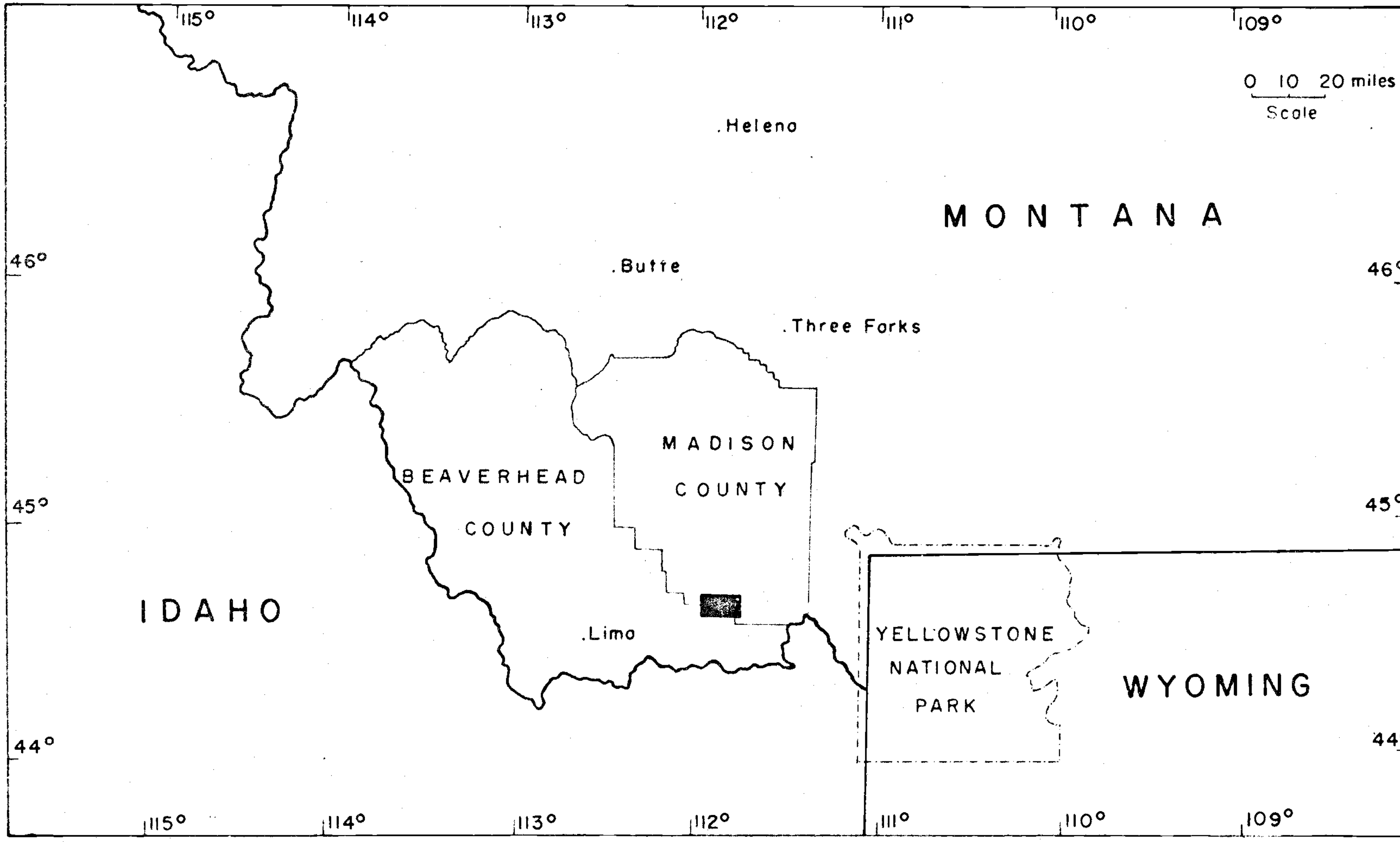

PLATE I. INDEX MAP SHOWING LOCATION OF THESIS AREA ones are generally spring-fed and permanent. The western half of the area consists of gently rolling grassy hills and dip slopes which descend to the Ruby Valley on the west and the Centennial Valley on the south.

The grassy uplands provide excellent grazing for sheep and cattle during the summer months. The numerous small springs found in the area increase the grazing facilities. Several ranches with excellent grazing conditions adjacent to them in the flat valley bottoms lie immediately to the south and east of the thesis area.

The climate of the Gravelly Range region consists of short hot summers and long cold winters. The closest meteorological station is located at Lima (90), about 30 miles southwest of the thesis area. Here the highest and lowest temperatures from 1931 to 1952 were 100° F. and minus 44° F., respectively. Precipitation is low and is mostly snow. Total annual precipitation in 1952 was 6.91 inches. Snow remains on higher parts of the Gravelly Range up to July 1, but most roads are usable by the middle of June. The first snowfall commonly comes in early September. Annual mean snowfall at Lima from 1931 to 1952 was 46.3 inches.

Some parts of the Gravelly Range are densely wooded; other parts support few or no trees. The east slope of the Gravelly Range is considerably steeper and more heavily wooded than the west and south parts. The common deciduous trees are aspen and cottonwood, and the evergreen trees are Douglas fir, spruce, white bark pine, alpine fir, and Rocky Mountain juniper. In the western and southern part of the thesis area, heavy growths of sagebrush and range grasses are common.

Ten weeks, from June 15 to September 1, were spent in the field during the summer of 1960. Geology was plotted on U. S. Department of Agriculture aerial photos with a scale of 1:15,000 and flown in 1957. From these photos the geology was plotted on Monument Ridge and Lower Red Rock Lake quadrangle maps, enlarged to 3 inches per mile. Stratigraphic sections were measured with a steel tape and brunton compass.

Previous geologic study of the southern Gravelly Range has been only of reconnaissance nature. In 1896 Peale (64) described the area to the north of the thesis area and south of Three Forks, Montana. Condit, Finch and Pardee (19) measured two sections in the Gravelly Range, and made a reconnaissance map of the general area, concentrating their study on the phosphate beds of the Phosphoria formation. In 1949 Honkala (39) completed reconnaissance geology in the western half of the Centennial Mountains to the south. Klepper (47) in 1951 published a reconnaissance map with a brief summary of the geology west of the Gravelly Range in part of Beaverhead and Madison counties. In 1954 Mann (54) mapped in detail the central part of the Gravelly Range directly north of the thesis area. Scholten and others (73) in 1955 mapped the geology of the Lima region, which included the Snowcrest Range immediately west of the thesis area. Bubb (9) and Manske (56) mapped the northern part of the Gravelly Range and Greenhorn Range during the summer of 1959.

STRATIGRAPHY

The thesis area includes about 10,000 feet of sedimentary rocks that represent all the Paleozoic and Mesozoic periods except the Ordovician and Silurian. An undetermined thickness of Precambrian metamorphic rocks and Cenozoic igneous rocks was also mapped in the thesis area (Table 1).

Detailed lithologies, fossil content, age, physiographic expression, and local and regional correlations (plate 2) are discussed in separate sections.

Cherry Creek Group

Peale (64, p. 2) in 1896 named the Cherry Creek group for marbles, mica-schists, quartzites and gneisses that are typically exposed near Cherry Creek located about 18 miles north of the thesis area. He mapped the Cherry Creek group as Algonkian (Proterozoic) in age.

Precambrian rocks in the thesis area are similar to those which Peale included in the Cherry Creek group, and on this basis the marbles and schists in the southern Gravelly Range are considered to belong to the group. Precambrian rocks in the thesis area occupy about $\frac{1}{2}$ square mile in sections 30 and 31, T. 12 S., R. 1 W. This outcrop is the westward extension of a much larger outcrop along the eastern part of the Gravelly Range. In the thesis area

Table I. Summary of Stratigraphic Units

Age	Formation	Lithology	Thickness
Quaternary		alluvial valley fill	0-75(?)
	Unconformity		
Quaternary		high-level gravels	0-50(?)
	Unconformity		
Tertiary		olivine basalt	0-800(?)
	Unconformity		
Tertiary		rhyolite	0-200(?)
	Unconformity		
Tertiary		tuffaceous sediments and agglomerates	0-50(?)
	Unconformity		
Cretaceous	Aspen formation	sandstones, shales and minor tuffaceous sediments	2500-3000'
Cretaceous	Colorado group	black shale and minor sandstone	appx. 300'
	Unconformity(?)		
Cretaceous	Kootenai formation	massive rusty-orange sandstone, limestone, calcareous shale and cherty conglomeratic sandstone	500'
	Unconformity		
Jurassic	Morrison formation	drab-colored siltstones, mudstones, limestones, and salt-and-pepper sandstones	300-500'
Jurassic	Ellis group	limestone and glauconitic sandstone	0-90'
	Unconformity		

Table I (Continued)

Age	Formation	Lithology	Thickness
Triassic	Thaynes formation	tan-colored siltstone and limestone with shale and mudstone	40'
Triassic	Woodside formation	red siltstone and shale	appx. 500'
Triassic	Dinwoody formation	chocolate-brown weathering siltstones and limestones	450-500'
Permian	Phosphoria formation	quartzitic sandstone and chert	400'
Pennsylvanian	Quadrant formation	sandstone and dolomitic sandstone	appx. 500'
Pennsylvanian	Amsden formation	calcareous siltstones and limestones	appx. 100'
Mississippian	Mission Canyon formation	thick-bedded limestone and minor chert	1100-1200'
Mississippian	Lodgepole formation	thin-bedded limestone	900-1000'
	Disconformity		
Devonian	Three Forks formation	mudstone breccia and limestone	150-170'
Devonian	Jefferson formation	varicolored shale and dolomite	500'
	Disconformity		
Cambrian	Meagher formation	thin- to thick-bedded limestone	500'
Cambrian	Wolsey formation	green shale and minor sandstone	200-240'
Cambrian	Flathead formation	quartzitic sandstone	120-140'
	Unconformity		
Precambrian	Cherry Creek group	marble and schist	not measured

Plate 2. TIME-ROCK CORRELATION CHART FOR SOUTHWESTERN MONTANA

A G E		Thesis Area	C. Gravelly Range (54) Mann '54	Snowcrest Mts. (73) Scholten et al '55	Three Forks Area (4) Berry '43
QUATERNARY	Quaternary	Alluvium	Alluvium	Alluvium	Alluvium
		High Level Gravels	Glacial Drift	Glacial Drift	
TERTIARY	Upper Tertiary				
	Lower Tertiary	Volcanics (Undiff.)	Volcanics & Sediments	Volcanics & Sediments	"Lake Beds"
CRETACEOUS	Upper Cretaceous	Aspen Fm.	Aspen? Fm.	Aspen Fm.	Livingston Fm.
		Colorado Fm	Colorado Fm		Colorado Fm
	Lower Cretaceous	Kootenai Fm.	Kootenai Fm.	Kootenai Fm.	Kootenai Fm.
JURASSIC	Upper Jurassic	Morrison Fm	Morrison Fm	Morrison Fm	Morrison Fm
		Swift Fm.	Swift Fm.	Swift Fm.	Swift Fm.
	Lower Jurassic				
TRIASSIC	Upper & Middle Triassic				
	Lower Triassic	Thaynes Fm	Thaynes Fm	Thaynes Fm	
		Woodside Fm	Woodside Fm	Woodside Fm	
		Dinwoody Fm	Dinwoody Fm	Dinwoody Fm	
PERMIAN	Upper Permian				
	Lower Permian	Phosphoria Fm.	Phosphoria Fm.	Phosphoria Fm.	Phosphoria Fm.

more than half of the outcrop consists of schists and the remainder of marbles. Generally, the Precambrian rocks crop out as rounded hills, but where the West Fork of the Madison River has eroded through the Cherry Creek group, steep rugged cliffs and talus slopes are formed (figure 1).

The marbles are white to shades of pink and gray and commonly weather to darker shades of these colors. Chert veins and stringers are common in the marbles; these chert veins are more resistant than the marble and characteristically impart rough and irregular surfaces to the weathered rock. The marble weathers to blocky fragments up to eight feet long that are very resistant. Microscopically the marble consists of interlocking calcite grains that make up most of the rock. Calcite twinning planes are commonly bent. Euhedral quartz grains that occur in veins make up about 15 per cent of the rock. The quartz is commonly strained and contains infrequent inclusions of calcite and dolomite crystals.

The schist is less resistant than the marble in the thesis area and forms low hills or low-angle talus slopes. Along Lobo Creek immediately east of the thesis area, the schist forms steep talus slopes. The schist is grayish green to bluish green and commonly is highly folded (figure 2). Microscopically, subhedral subparallel

Figure 1. Precambrian marble outcrop along the West Fork of the Madison River, section 31, T. 12 S., R. 1 W.

Figure 2. Typical folded Precambrian schist in section 30, T. 12 S., R. 1 W.

tremolite-actinolite crystals make up 40 per cent of the schist; chlorite, calcite, sphene, albite (?), epidote, and opaque ore mineral make up the remainder of the rock. Tremolite-actinolite, sphene, and calcite phenocrysts occur in a fine-grained granoblastic groundmass composed of the other mentioned minerals. Chlorite is an alteration product of tremolite-actinolite.

Evolution of Cambrian Stratigraphic Nomenclature of Southwestern Montana

In 1890 Peale (62, p. 131) applied the names Gallatin sandstones and Gallatin limestones to all Cambrian rocks in the Three Forks area. He later (63, p. 20-21) assigned the Gallatin sandstones to the Flathead formation, which included the Flathead quartzite and the Flathead shales. In the Gallatin formation he included five members, which are, in ascending order, Trilobite limestones, Obelella shales, Mottled limestones, Dry Creek shales, and Pebbly limestones. In 1899 Weed (93, p. 2) assigned all the Cambrian rocks in the Fort Benton quadrangle to the Baker formation, whose seven members, from the base upward, are Flathead sandstone, Wolsey shale, Meagher limestone, Park shale, Pilgrim limestone, Dry Creek shale, and Yogo limestone. Deiss (23), in a detailed study of the Cambrian formations in Montana, measured several comprehensive sections and redescribed the general characteristics of each formation. Where the type section of a particular formation was not typical of that formation, Deiss proposed a new type.

Flathead Formation

The Flathead formation in the southern Gravelly Range is equivalent to the Flathead quartzite of Peale (63). He designated the Flathead as consisting of quartzitic sandstone overlying the Belt formation and underlying the Flathead shales. He stated that a typical section was exposed at Belt Creek, 8 miles south of Monarch, Montana. Deiss (23, p. 1322-1323) described a section of the Flathead formation at Crowfoot Ridge, Gallatin Range, Yellowstone Park, which he stated was more typical of the Flathead than the type section at Belt Creek.

Lithology and Thickness

In the southern Gravelly Range the Flathead consists of buff, rust-red, and reddish-brown quartzitic sandstones which vary from thin- to thick-bedded. In the lower half of the formation, beds up to 3 or 4 feet thick are not uncommon. In the upper third the sandstone beds are interbedded with thin green micaceous beds which increase in number and thickness toward the top of the formation.

Where these green beds comprised more than 50 per cent of the section it was called Wolsey formation. The quartzitic sandstone of the Flathead weathers to shades of dark reddish brown, grayish red, and yellowish gray. Clear, glassy subrounded quartz pebbles ranging in size from $\frac{1}{4}$ inch to $\frac{1}{2}$ inch are found near the base of the formation. These pebbles decrease in number upward and completely disappear above the lowest 15 feet. Deiss (23, p. 1327) states that of all outcrops examined, "every exposure of these sandstones in Montana and Yellowstone Park exhibits these pebbles, regardless of the character of the rocks on which the Flathead rests." Microscopically the quartzitic sandstone consists of tightly packed subrounded quartz grains with sutured contacts. The cement is siliceous and contains limonite, which accounts for the yellow and brown colors in the rock. About 98 per cent of the rock consists of quartz grains, and the remainder is chert, calcite, opaque ore mineral, and feldspar fragments. Red, purple, and brown banding parallel to the bedding planes is a characteristic megascopic feature in the lower half of the formation. The Flathead is commonly cross-bedded throughout the thickness of the formation.

The Flathead formation was deposited by quartz sands and fine gravels which came from the south and entered western Montana. These sands and gravels on the surface of the old Archean granites to the east were weathered (24, p. 59).

The only outcrop of the Flathead in the thesis area is in sections 30 and 31, T. 12 S., R. 1 W., where it is about 130 feet thick. Mann (54, p. 6) states that immediately north of the thesis area at Elk River the Flathead is about 100 feet thick and beyond there it thins rapidly northward to Standard Creek, where the Wolsey shales are in contact with Precambrian rocks. Bubb (9) measured 137 feet of Flathead at Morgan Gulch, approximately 20 miles north of the thesis area.

Physiographic Expression

The Flathead is more resistant to erosion than the overlying Wolsey formation but less resistant than the underlying Precambrian. Generally the Flathead does not form steep cliffs but crops out at steep talus slopes. On these slopes slabs of quartzitic sandstone 1 to 4 inches thick and up to 3 feet long are common.

Fossils and Age

No fossils were found in the Flathead in the southern Gravelly Range; however, at Crowfoot Ridge in Yellowstone Park, Deiss (23, p. 1325) found "crinoid stems associated with trilobite fragments and calcareous brachiopods." The Flathead lies on the Precambrian with angular unconformity and is gradational into the overlying Wolsey shales in the thesis area. Hanson (37, p. 13) states that since the Flathead intergrades with the Wolsey shale which contains Middle Cambrian fossils, it is probably also Middle Cambrian and only slightly older than the Wolsey.

Regional Correlations

The Flathead of the southern Gravelly Range is very similar in lithology and thickness to the Crowfoot Ridge section in Yellowstone Park (23, p. 1322-1323). The only major differences are that the Crowfoot Ridge section contains fossils and is 37 feet thinner than the section measured in the thesis area.

The name Flathead formation is used in most of Wyoming (58) for Middle Cambrian rocks similar to those found in the southern Gravelly Range. In northwestern Wyoming (58, p. 118) the basal beds usually contain thin layers of shale alternating with quartzitic sandstone layers; the remaining part of the formation is quartzitic sandstone. This lithology is closely related to that of the thesis area.

The Flathead in northwestern Montana (86, p. 66) is also similar to that of southwestern Montana. The formation there consists of cross-bedded, thin- to thick-bedded white quartz sand cemented in a matrix of siliceous and hematitic clay.

In the Clark Range of southeastern British Columbia (82, p. 325) Middle Cambrian strata are represented by a basal thin quartzite and an overlying green shale, totaling about 200 feet in thickness. This quartzite is correlative with the Flathead, and the green shale is correlative with the overlying Wolsey formation of southwestern Montana.

Wolsey Formation

The Wolsey formation is equivalent to the Flathead shales that Peale (63, p. 131) described. The name Wolsey was first used by Weed (93, p. 2) for the lowest shale unit of the Baker formation in the Fort Benton quadrangle, Montana. Weed (94, p. 285) stated that the "shales average 150 feet in thickness, and are well exposed at the old dam on Sheep Creek near Wolsey." Deiss (23) redescribed typical sections of the Wolsey in several places in Montana but not at the type locality since it was covered. He stated that the Crowfoot Ridge section was very typical of the Wolsey and consisted of 150 feet of green shale and white to buff sandstone lenses in the lower half, and brown and green shales and limestones in the upper half.

Lithology and Thickness

The Wolsey in the southern Gravelly Range consists of nonresistant green shales and a few thin beds of sandstone. The lower part of the Wolsey is gradational from the Flathead formation and contains sandstone very similar to that formation. This sandstone in the lower Wolsey occurs as thin beds which become fewer and thinner upward in the lower third of the section and which are not present higher than about 70 feet from the base. The sandstone differs slightly from the Flathead sandstone in that it is lighter colored and locally contains limonite nodules as much as ½ inch long. These nodules give the sandstone a light brown to yellow-brown color in some beds. Microscopically the Wolsey sandstone consists of highly compacted subrounded quartz grains in a yellowish-brown ferruginous and siliceous cement. Minor amounts of feldspars, chert, strained quartz, muscovite, and ore mineral are present. Worm trails are common on some of the bedding planes. The Wolsey sandstone is interbedded with green, micaceous soft shale. The middle and upper parts of the formation are generally covered by grayish-green soil which contains green and occasional brown shale fragments. The upper 50 feet of the formation in the southern Gravelly Range is covered by talus from the overlying Meagher formation.

During Wolsey time erosion of Beltian argillites and sandstones furnished the larger part of the clastic sediments in the western part of Montana (24, p. 60).

Along the West Fork of the Madison River in Section 31, T. 12 S., R. 1 W., the Wolsey is 130 feet thick. The thickness of the Wolsey appears to decrease northward and is missing on the east limb of the Gravelly Range, 22 miles north of the thesis area.

Physiographic Expression

The Wolsey is very nonresistant and consequently forms a shallow valley between the overlying Meagher limestone and the underlying Flathead sandstone. The lower third of the Wolsey is more resistant than the upper portion because of the interbedded sandstone, and as a result there is a break in the slope between the two portions.

Fossils and Age

Although no fossils were found in the Wolsey in the southern Gravelly Range, Hanson (37, p. 14) found trilobites in the Dillon area, approximately 45 miles northwest of the thesis area. These trilobite genera, *Glossopleura* and *Kootenia*, indicate a Middle Cambrian age for the Wolsey.

Regional Correlations

The thickness and lithology of the Wolsey appear to vary little throughout southwestern Montana (73, p. 363), (54, p. 7), (23, p. 1321-1322), (37, p. 25-41).

In northwestern Wyoming the Wolsey is equivalent to the lower shale member of the Gros Ventre formation (58, p. 119). The Wolsey in the Gravelly Range is very similar to this member which consists of greenish-gray, soft, micaceous shales and averages about 100 feet in thickness.

The Langston formation of northern Utah and southeastern Idaho (84, p. 14) is in part correlative with the Wolsey in the Gravelly Range. The upper part of the Langston is called the Spence member and consists of green shales, which are in the lower third of the Middle Cambrian series.

The Gordon shale in northwestern Montana (86, p. 66) is correlative with part of the Wolsey in the thesis area. The top of the Gordon is slightly lower than the Wolsey of southwestern Montana. The lower part of the Damnation limestone (86, p. 66) is equivalent to the upper part of the Wolsey.

Meagher Formation

The Trilobite limestone member of the Gallatin formation (63, p. 22) is equivalent to the Meagher formation. In the Three Forks area where Peale described this member it consists of thin-bedded, dark gray limestones which lie between the Flathead shales, below, and the overlying Obolella shales, now known as the Park formation. Deiss (23, p. 1330) stated that Keegan Butte section, which Weed (94, p. 285-286) described, is not composed of Meagher limestone, and so he proposed a new type section of the Meagher at Nixon Gulch in the Three Forks area.

Lithology and Thickness

The Meagher in the southern Gravelly Range consists of thin- to thick-bedded, brown, gray, or pink limestone. The upper half and lower third of the formation generally are thick-bedded (1 to 6 feet) and the central portion is relatively thin-bedded (1 to 5 inches). The Meagher limestone is light brown to dark gray, weathers dark brown to dark gray, and occasionally to black. In the lower half of the formation there are several beds which are pink, buff, and reddish gray; these weather reddish brown and gray. The weathered surfaces of the limestone in the lower half are smooth and conchoidal; whereas, in the upper half the surfaces are rough, pocked, and have sharp protruding points. Interbedded in the lowermost 10 or 15 feet of the formation are thin beds of soft green shale. Deiss (23, p. 1331) stated that the most diagnostic characteristics of the Meagher formation are the thick- and thin-bedded gray and tan colored limestone containing buff clay flakes and nodules in the lower beds, the green-gray fissile shales interbedded with the limestones, and the absence of intraformational conglomerates. In the southern Gravelly Range the Meagher has similar characteristics except for the absence of clay flakes and nodules. Microscopically the limestone from the lower part of the Meagher consists of large subhedral calcite crystals in a fine-grained calcareous matrix. About 1 per cent of the rock consists of chert and quartz grains which are randomly oriented, subrounded, and generally much smaller than the calcite crystals. Several beds in the upper half of the formation are dolomitic. Microscopically the dolomitic limestone consists mainly of anhedral calcite crystals in a calcareous and siliceous matrix. Dolomite crystals, which are usually smaller than the calcite crystals, commonly occur as inclusions in the calcite crystals. Subrounded quartz grains, with authigenic overgrowths, and chert are common accessories. The rock is well compacted, and the calcite grain contacts are sutured.

During middle Cambrian the Meagher limestone was deposited in the Cordilleran trough when little or no clastic material was supplied by Cascadia owing to its low relief (24, p. 60).

The thickness of the Meagher formation varies little in southwestern Montana (81, p. 2143) where it is approximately 500 feet. The section measured along the West Fork of the Madison River in Sections 36 and 25, T. 12 S., R. 2 W. is 517 feet thick.

Physiographic Expression

The Meagher in the southern Gravelly Range forms a series of steep, rugged cliffs and talus slopes (figure 3). The Wolsey below forms distinct draws, whereas the Jefferson formation, above, forms continuous steep slopes or cliffs. The upper half of the Meagher is commonly more resistant than the lower half and tends to form cliffs.

Fossils and Age

Hanson (37, p. 15) collected the trilobite genera *Glyphaspis* and *Brachiaspion* from the top of the formation and *Kootenia*, *Ehmania*, *Bathyuriscus* and *Acrotreta* from the basal part, and hence concluded that the Meagher is Middle Cambrian in age.

Figure 3. Typical steep cliffs and talus slopes of Meagher formation.

Regional Correlations

The Meagher is equivalent to the upper part of the Gros Ventre formation in northwestern Wyoming (58, p. 120-123). This upper part consists mainly of greenish-gray shales and subordinately of interbedded limestones that vary in thickness from an inch to several feet.

The Blacksmith formation of northern Utah and south-eastern Idaho (83, p. 14) is equivalent to the Meagher of southwestern Montana. The Blacksmith is similar to the Meagher in that it consists of thin- to thick-bedded ledge-forming limestones, and rarely contains intraformational conglomerates, but differs in that it is locally oolitic. The thickness of the Blacksmith is approximately 750 feet, which is considerably thicker than the Meagher of south-western Montana.

The Meagher is at least in part correlative with the upper part of the Damnation limestone, the Dearborn lime-stone, and the Pagoda limestone of northwestern Montana (86, p. 66). These limestone formations of northwestern Montana differ from the Meagher in the southern Gravelly Range in that they contain interbedded green, gray, and brown shales and claystones, and contain intraformational conglomerates.

Jefferson Formation

In 1893 Peale (63, p. 27-28) named the Jefferson formation for exposures along the Jefferson River near Three Forks, Montana. He described the formation as consisting of "black limestones" throughout the section, except for a brecciated limestone zone near the top. At the type section the Jefferson lies between the Pebbly limestones of the Gallatin formation below and the Three Forks shales above.

Sloss and Laird (80) subdivided the Jefferson into limestone and dolomite members, which they claim can be traced over most of Montana.

Lithology and Thickness

The Jefferson in the southern Gravelly Range can be divided into three parts which are lithologically and topographically different. The lowermost unit is a cliff-forming, consistently thin-bedded dolomite (figure 4) which is about 150 feet thick. A light-brown and grayish-brown weathered surface is characteristic of this unit. The dolomite is brown to grayish brown and medium to finely crystalline. Bedding planes commonly have worm trails on them (figure 5). Microscopically the dolomite consists of euhedral dolomite crystals tightly packed in a calcareous

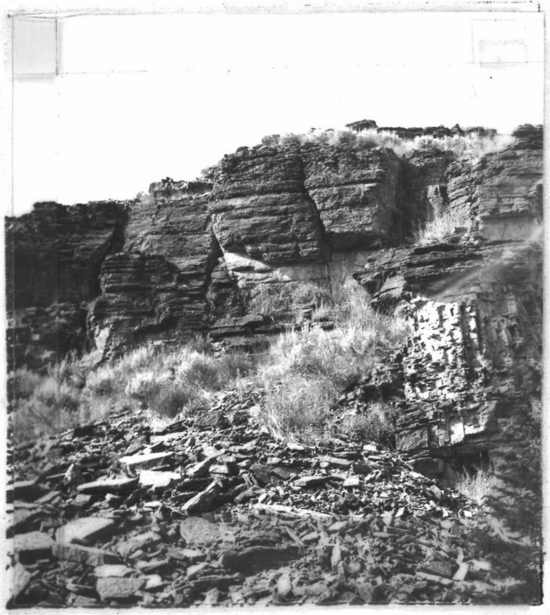

Figure 4. Thin-bedded Jefferson dolomite along West Fork of Madison River, section 25, T. 12 S., R. 2 W.

Figure 5. Worm trails commonly found on Jefferson dolomite bedding planes.

matrix. A few larger calcite grains occur in veins and in clusters.

The middle part of the formation is a covered zone which is about 180 feet thick and marked by brownish-yellow, green, and red shale fragments in a reddish-brown soil. A few grayish-red and reddish-brown limestone fragments were also present. Where the West Fork of the Madison has eroded through the Jefferson, a red calcareous mudstone unit about 40 feet thick is exposed at the top of the middle unit of the formation. This mudstone is made up of subrounded to well-rounded argillaceous and cryptocrystalline siliceous fragments embedded in a calcareous matrix, which is stained red from iron oxide. About 10 per cent of the rock is made up of quartz grains and opaque ore mineral.

The uppermost part of the Jefferson which is about 170 feet thick is a limestone unit which is more resistant than the underlying shale unit and less resistant than the dolomite at the base of the formation. This limestone is commonly thin- to thick-bedded, light to dark brown, finely crystalline, and weathers dark brown to almost black.

In the southern Gravelly Range the contact of the Jefferson and Meagher formations is covered by talus from the overlying Jefferson dolomite cliffs. To the north of the thesis area in the Gravelly Range, Mann (54, p. 7) states that an erosional unconformity separates the Cambrian and Devonian formations, and it seems probable that the same condition exists in the thesis area. The contact between the Jefferson and overlying Three Forks so far as could be determined is conformable in the thesis area. The total thickness of the Jefferson formation as measured along the West Fork of the Madison River in Section 25, T. 12 S., R. 2 W. is about 500 feet.

Physiographic Expression

The upper two-thirds of the Jefferson is commonly poorly exposed and forms a gentle grass- or tree-covered slope above the cliff-forming basal dolomite unit. The upper third of the formation can be differentiated from the middle unit by a slight steepening of the topography of the limestone unit. The contact between the limestone and shale units is drawn where the color changes from reddish brown of the shale to grayish brown of the limestone; this color change corresponds to the change in the slope angle.

Fossils and Age

No fossils were found in the Jefferson formation in the southern Gravelly Range, but Mann (54, p. 10) found three characteristic Jefferson brachiopods approximately six miles north of the thesis area. The exact age relationship of the Jefferson of the thesis area to the type Jefferson is not known.

Cooper (20, p. 1768) concluded from a study of the Jefferson fauna that the formation was early Senecan in age, but Sloss and Laird (80, p. 1427-1428) stated that the Jefferson ranges in age from mid-Senecan to early Chautauguan.

Regional Correlations

The Jefferson formation extends from southwestern Montana to the south and central parts of the state. It also occurs in Wyoming and southeastern Idaho. In southeastern Montana no rocks of Devonian age (65, p. 5) are known.

In central and northwestern Montana the Jefferson is divided into a lower limestone member, which consists of dark-brown, very dense limestone and dolomitic limestone, and an upper dolomite member which is massive, saccharoidal dolomite, commonly medium to dark brown in color (79).

The Jefferson of south-central Idaho differs from the section in the southern Gravelly Range in that it is composed mainly of dark bluish-gray, thick-bedded dolomite (72, p. 1107). In the southeastern part of Idaho

(55, p. 59) the Jefferson is primarily black magnesian limestone.

In the western Rocky Mountains of British Columbia and Alberta the Harogate formation of Middle Devonian age consists of unfossiliferous varicolored dolomite and shale overlain by limestone and quartzite (82, p. 328) and is approximately the same age as the Jefferson formation of the Three Forks area.

Three Forks Formation

The Three Forks formation was named by Peale (63, p. 29-30) in 1893 for exposures in the Three Forks area. He divided the formation into lower and upper shale members. The lower shales he described as containing reddish- and brownish-yellow, calcareous and argillaceous shales, and the upper shales as green argillaceous shales overlain by black or purplish calcareous and argillaceous limestones. The type section at Three Forks is overlain by the Madison limestones and underlain by the Jefferson formation.

Lithology and Thickness

The Three Forks in the thesis area consists of 150 feet of non-resistant calcareous siltstones, limestones, and siltstone breccia. Most of the formation in the southern Gravelly Range is poorly exposed. The siltstone breccia that comprises the upper half of the exposed section consists of grayish-yellow to red and orange calcareous siltstone containing rounded siltstone pebbles, which do not exceed 3/4 inch longest diameter and are frequently aligned with their long axis parallel to bedding. The resistance of the pebbles to weathering is less than the matrix, and so the matrix stands out in relief. Microscopically the matrix is composed of anhedral calcite crystals and iron oxide, the latter causing the characteristic red and yellow color. The limestone in the Three Forks occurs near the middle of the formation and is reddish brown, weathers dark brownish red, and is commonly thick-bedded. The only local exposure of this limestone occurs on the West Fork of the Madison River in section 25, T. 12 S., R. 2 W. Because of poor exposures elsewhere, the lithology of the extreme upper and lower part of the formation was undeterminable.

The contact between the Three Forks and the overlying Madison group is concealed in the southern Gravelly Range. However, several miles to the north of the thesis area, Mann (54, p. 11) states that "at the only site where this contact was observed, evidence of a slight disconformity was noted in the form of a thin nodular zone, about one foot thick, at the base of the limestones. This zone consisted of limestone nodules, usually flattened and irregularly shaped, enclosed in a matrix of reddish flaky argillaceous limestone."

In the middle part of the Gravelly Range the Three Forks and Jefferson formations are stated by Mann (54, p. 11) to be conformable. The contact between the two formations is covered in the thesis area.

The Three Forks is 152 feet thick where it was measured along the West Fork of the Madison River. The formation thickens westward, and so it is 600 feet thick in the Beaverhead Range (73, p. 263) and is approximately 200 feet thick in the Three Forks area (4, p. 14) and in the Centennial Range to the south (39, p. 1897).

Physiographic Expression

Talus from the overlying Lodgepole formation commonly covers the uppermost 30 to 40 feet of the formation (figure 6). The only part of the formation which crops out throughout the thesis area is the siltstone breccia (figure 7), which forms a steep slope.

Fossils and Age

Berry (4, p. 14) examined several sections near Three Forks and on the basis of several diagnostic fossils, he

Figure 6. Mississippian limestone talus covers the Three Forks-Lodgepole contact. West Fork of Madison River, section 26, T. 12 S., R. 2 W.

Figure 7. Limestone breccia (lower half of picture) outcrops as a conspicuous ledge below Lodgepole formation float.

concluded that the formation was Upper Devonian in age. Since no fossils were found in the thesis area, the Upper Devonian age assignment of the formation in the southern Gravelly Range is based on the similarity in lithology and stratigraphic position of the type section near Three Forks.

Regional Correlations

The Three Forks formation and its equivalents are widespread over Montana, Wyoming, Idaho, Alberta, and British Columbia (65, p. 5).

In central and northwestern Montana the Three Forks is represented by many lithologies (79). Unlike the formation in the Gravelly Range, the basal part is composed of dolomitic shale and shaly dolomite, the middle unit of green shale and black limestone, and the upper part of yellow-weathering calcareous sandstone.

The Three Forks in southeastern Idaho (55, p. 59) consists primarily of sandy limestones. In the central part of Idaho (72, p. 1109) the formation consists of argillaceous limestone with some calcareous shale, and locally a little quartzite. Here the Three Forks varies from 200 to 350 feet thick.

In the eastern Rocky Mountains of Canada (82, p. 329) the Fairholme group is approximately equivalent in age to the Three Forks of southwestern Montana. The Fairholme consists of organic and reef carbonates and bedded carbonates and shale in which large oil reservoirs have been found. In the Front Range and foothills of Alberta the Ghost River formation is in part correlative with the Three Forks. The Ghost River is composed of 150 to 200 feet of variegated dolomite and shale and shaly dolomite.

Madison Group

In 1893 Peale (63, p. 33-36) used the name Madison formation to include, from bottom to top, laminated limestones, massive limestones, and jaspery limestones. He indicated no type locality; however, he implied that the outcrops along the Gallatin River at Logan were typical of the formation.

Weed in 1900 (94, p. 289-294) in describing a section at Logan similar to Peale's, assigned the names Paine shale to the laminated limestones, Woodhurst limestone to the massive limestones, and Castle limestone to the jaspery limestones.

Collier and Cathcart (17, p. 173) in 1922 were the first to designate the Madison as a group in which they included the Mission Canyon limestone and the Lodgepole limestone, both formations named for canyons on the north flank of the Little Rocky Mountains in north-central Montana. The Mission Canyon formation, according to Collier and Cathcart, consists of massive white marine limestone, and the Lodgepole formation of thin-bedded fossiliferous limestone and shale.

In 1942 Sloss and Hamblin (78, p. 315-318) stated that the Little Rocky Mountains should be the type section and proposed that the Lodgepole be divided into the Paine (the lower one-third) and the Woodhurst(the upper two-thirds). They stated that near the middle of the type section two highly massive beds with channeled bedding surfaces and an abundance of crinoid plates occur at the base of the Woodhurst member. The Paine member, in contrast to the Woodhurst, is exceedingly variable lithologically. The Paine is characterized by thin-bedded dense limestones in beds averaging 5 inches thick and separated by almost equal thicknesses of calcareous shale and shaly limestone. Chert lenticules are common, and there is a rich bryozoan fauna. To the east of the Little Rockies the amount of interbedded shale decreases, and the Paine becomes a cliff-forming, fine-grained limestone.

Lithology and Thickness

The Madison group can be divided into the Lodgepole and Mission Canyon formations in the thesis area.

Lodgepole Formation. In the Gravelly Range the Lodgepole is made up of thin-bedded, brown-weathering, gray, fossiliferous limestone (figure 8). The upper two-thirds of the formation is usually dark gray to black and has lighter colored weathered surfaces. The lower third of the formation is generally more thickly bedded than the upper part and is lighter gray in color. Beds 8 to 12 inches thick are relatively common in the lower third, but are rare in the upper two thirds of the Lodgepole except in the top 25 feet, where beds 1 to 2 feet thick are common. The Lodgepole disconformably overlies the Three Forks formation.

Mission Canyon Formation. In the Gravelly Range the Mission Canyon consists of thick-bedded to massive, light to dark gray limestone. Lenticules and bands of chert which parallel bedding planes are common in the upper part of the formation. The limestone is generally medium to coarsely crystalline, but the lowermost beds are finely crystalline. Beds up to 50 feet thick are not uncommon in the upper part of the formation. In the lower part of the formation a few thin beds are intercalated between the thick beds (figure 9). The uppermost beds of the Mission Canyon generally are conglomeratic and consist of rounded to subrounded, dark gray, dense limestone granules and

Figure 8. Typical outcrop of Lodgepole formation. Location: West Fork of the Madison River, Section 26, T. 12 S., R. 2 W.

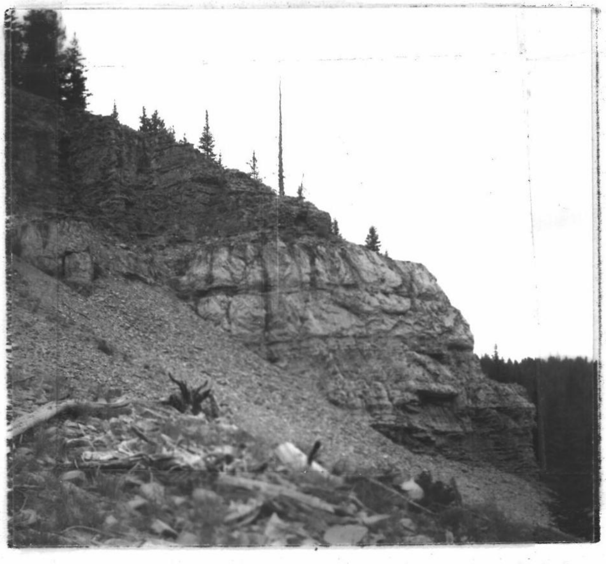

Figure 9. Lower part of Mission Canyon formation. Location: Cascade Creek, Section 14, T. 12 S., R. 2 W.

pebbles less than ½ inch in diameter in a light gray, calcareous, argillaceous matrix. Microscopically the matrix is composed of irregular calcite grains and interstitial argillaceous matter. Small pale green to dark brown, rounded argillaceous pebbles are also present; these are smaller on the average than the dense limestone pebbles. Commonly wash from the overlying Amsden formation causes upper Mission Canyon beds to be stained. The limestone conglomerate generally occurs in lenses, and bedding planes are poorly defined. The contact of the conglomerate with the overlying Amsden is commonly covered. In the lower half of the Mission Canyon a few very thin, dark gray mudstone beds are intercalated between the limestone beds.

The limestone breccias and conglomerates found at several localities near the top of the Mission Canyon formation indicate an intervening period of erosion before the Amsden formation was deposited. Sloss and Hamblin (78, p. 318) in the Little Rockies found large caverns filled with breccias and conglomerates, commonly colored red from the overlying Amsden. At one locality they found channels cut 200 feet into the Mission Canyon formation. Evidently the erosion extended over a wide area before the deposition of the Amsden.

The Madison group is the thickest Paleozoic rock unit in the area under study. Along the West Fork of the Madison River in the southeastern part of the area the Mission Canyon formation is 1160 feet thick, and the Lodgepole formation is 930 feet thick, a total of 2090 feet for the Madison group. These thicknesses are approximately the same throughout the southern Gravelly Range.

Physiographic Expression

The Mission Canyon formation generally forms talus slopes. The Lodgepole, however, is cliff-forming, especially the lower one-third; the upper two-thirds in some parts of the area forms cliffs, but more commonly high-angle talus slopes.

Fossils and Age

In the Madison group the Lodgepole is by far the more fossiliferous of the two formations, although several well-preserved fossils were found in the Mission Canyon. About 300 feet of beds near the middle of the Lodgepole are very fossiliferous; most of the Lodgepole fossils in my collection were obtained from these beds. The following fossils from the Lodgepole were identified:

Phylum Coelenterata
  Lithostrotionella sp.

Phylum Bryozoa

Ptylopora sp.
Fenestrellina sp.

Phylum Brachiopoda

Dictyoclostus galeanus Girty
Dictyoclostus parviformis Girty
Dictyoclostus sp.
Cleiothyridina sp.
Chonetes logani Girty
Chonetes cf. *C. loganensis* Girty
Chonetes sp.
Echinoconchus sp.
Seminula madisonensis Girty
Linoproductus altonensis Norwood and Pratten
Leptaena analonga Phillips
Schuchertella sp.
Camarotoechia sp.
Reticularia cooperensis Swallow
Spirifer striatus Martin
Spirifer striatus var. *madisonensis* Girty
Spirifer aff. *S. hyadenianus* Girty
Spirifer sp.
Orthotetes sp.
Martinia cf. *M. rostrata* Girty
Composita aff. *C. trinuclea* Hall
Schellwienella inequalis Hall
Schellwienella aff. *S. crenulicostata* Weller
Schellwienella sp.

Phylum Mollusca

Platyceras sp.
Straparolus ophirensis Hall
Straparolus sp.

Phylum Arthropoda

Phillipsia sp.

Phylum Echinoderma

Rhodocrinites sp.

The Mission Canyon formation contained fewer genera and numbers of fossils than the Lodgepole. Most of them, excluding the horn corals, occurred in the lower half of the formation; the horn corals, most of which are unidentifiable, occurred in increasing numbers toward the top of the formation. The following fossils were identified from the Mission Canyon formation:

Phylum Coelenterata
Clisiophyllum sp.

Phylum Brachiopoda
Dielasma cf. *D. utah* Hall and Whitfield
Schuchertella chemungensis Girty
Diaphragmus ? *elegans* Girty
Spirifer centronatus Winchell
Spirifer striatus. var. *madisonensis* Girty

Phylum Mollusca
Loxonema sp.

Phylum Echinoderma
Platycrinites sp.

No satisfactory detailed correlations with the section in the Mississippi Valley have been made. In the Madison group, I found *Spirifer centronatus* which is particularly abundant in the Lodgepole. Weller (95, p. 138) states that the Madison group is characterized by *Spirifer centronatus* and is believed to be of late Kinderhookian and Osagean age.

Laudon (49, p. 507) stated that the Lodgepole and Mission Canyon formations represent continuous uninterrupted marine deposition through all of Kinderhookian and perhaps earliest Osagean time in the upper part of the Mission Canyon formation.

Regional Correlations

The Mission Canyon and Lodgepole can be correlated with the lower two units of Peale's original definition (63, p. 33-36) of the Madison formation; the jaspery limestones at the top of his section are nowhere found in the Gravelly Range.

In the southern Gravelly Range lower and upper parts of the Lodgepole can be separated into the Paine and Woodhurst members, respectively, of Sloss and Hamblin (78) on the basis of lithology, fossils, and topographic expression. The division between the two members is below the middle of the formation, namely, at the base of the thin-bedded, very fossiliferous, medium gray limestone.

The Woodhurst member is approximately 600 feet thick in the southern part of the Gravelly Range and commonly forms a slope rather than a cliff, as does the Paine member. The dark gray to black limestone of the Woodhurst weathers light brown and contains brachiopods and crinoid fragments. The underlying Paine member is generally medium brown and contains nodules and stringers of chert along the bedding planes.

Berry (4, p. 16) stated that a limestone conglomerate is present near the top of the Madison group in the Three Forks area about 50 miles north of the Gravelly Range. He described it as poorly rounded, gray limestone pebbles and boulders embedded in a matrix of soft, argillaceous and arenaceous, red limestone. This conglomerate is very similar, lithologically and stratigraphically, to that found in the southern Gravelly Range.

In northeastern Montana and southeastern Saskatchewan (29, p. 52-58), and in central Montana (59, p. 63-67) the Madison group includes the Charles formation at the top, the Mission Canyon formation in the middle, and the Lodgepole formation at the bottom. The Mission Canyon consists of thick- to medium-bedded limestones, dolomites, and evaporites which grade into the Charles formation above and the Lodgepole beneath. No dolomites or evaporites were found in the thesis area. Unlike the Mississippian rock sequence of the Gravelly Range, the Charles formation and the Big Snowy group overlie the Mission Canyon formation in northeastern and central Montana.

The Madison group of northwestern Montana (3, p. 85-87), which is divided into the Mc, Mb, and Ma units, lithologically and stratigraphically is closely related to the section in the southern Gravelly Range. The Mc and Mb units are equivalent to the Lodgepole and Mission Canyon formations, respectively. The unit equivalent to the Ma is absent in the thesis area.

In the Rocky Mountains and foothills of Alberta (82, p. 331) the Banff formation (Kinderhookian age) is equivalent to the Lodgepole and consists mainly of basal, dark gray shale which grades upwards into dense, argillaceous limestone and cherty or crinoidal limestone. Although I found no argillaceous beds in the southern Gravelly Range, Berry (4, p. 17) found gray and buff argillaceous limestones near the bottom of the Lodgepole section in the Three Forks area. In Alberta (82, p. 331) the basal formation of the Rundle group is correlative with the Mission Canyon of southwestern Montana.

Amsden Formation

The Amsden formation as defined today includes the beds that Peale (63, p. 39) originally included in the Quadrant formation. Peale described rocks in the lower part of his Quadrant (now Amsden) as limestones which he divided into two members, the "Red limestones" and the "Cherty limestones."

Darton (22, p. 396) named the Amsden formation in 1904 for a tributary of the Tongue River in the Bighorn Mountains, Wyoming, where it is well exposed. At this locality the Amsden consists of a "somewhat variable succession of red shales and limestones, with cherty and sandy members" that lie above the Madison limestone and below the Tensleep formation. Darton stated that the thickness of the Amsden is about 150 feet near the Montana-Wyoming boundary line, but increases gradually to a maximum thickness of 350 feet in southern Wyoming.

Lithology and Thickness

Detailed study of the Amsden was impossible in the southern Gravelly Range because of poor outcrops. Generally the Amsden in the area consists of red, purplish-red, or pink, calcareous sandy siltstones, silty sandy limestones, and shale. In the field it is very difficult to distinguish between the two first-named rock types, since they commonly have very nearly the same color and average bedding thickness. Near the top of the formation poorly exposed outcrops of light gray, medium crystalline, unfossiliferous limestone was present at several localities. The thickness of this limestone was not determined, owing to inadequate exposures. A thin-bedded (1 to 5 inches) purplish-red, argillaceous sandy limestone occurs below this upper limestone in the northeast $\frac{1}{4}$ of section 27, T. 12 S., R. 2 W. Microscopically about 70 percent of this limestone is made up of subhedral to anhedral calcite crystals, and 25 percent consists of rounded quartz grains in a calcareous argillaceous matrix. The calcite grain boundaries are frequently indistinct. The rock has a red color from iron oxide stains on the calcite crystals and the matrix.

As previously stated, the contact between the Mission Canyon formation and the Amsden is disconformable and is marked by a conglomeratic zone at the top of the Mission Canyon. The absence of the Big Snowy group in Gravelly Range indicates a considerable interval of erosion or non-deposition.

The contact between the Amsden and the overlying Quadrant formation is gradational, and for this reason the Amsden and Quadrant are believed to represent continuous deposition. Scott (74, p. 1019) states that an erosional unconformity exists between the top of the Amsden and the base of the Quadrant; however, west and southwest of Three Forks, Montana, there is no sharp line of demarcation between the two formations.

Fossils and Age

Scott (74, p. 1023) states that the Amsden is of middle or upper Chester in age. Berry (4, p. 19) collected species of *Linoproductus*, *Spirifer opimus* Hall, and *Composita* cf. *C. subtilita* Hall which he states are generally considered Pennsylvanian in age. Other authors (81, p. 2159) say that, "in the higher parts of the Wyoming shelf area of southwestern Montana, where the Amsden is markedly thinner, it seems probable that only Pennsylvanian strata are represented." Since no fossils were found in the Amsden in the thesis area, it is on this latter statement concerning thickness that the Amsden is here assigned to a probable early Pennsylvanian age.

Regional Correlations

The Amsden is present in the northern half of Wyoming and in all of Montana except the north-central portion. The formation becomes progressively more shaly eastward in Montana until it is difficult to distinguish from the Minnelusa in easternmost Montana and western North Dakota (65, p. 6).

Sloss and Moritz (81, p. 2159) described the Amsden of southwestern Montana as characterized by a basal unit of shale, siltstone, and shaly dolomite, commonly bright red to purplish red in color. Overlying this unit are fossiliferous limestone and occasionally dolomites and sandy dolomites. No shale, dolomite, or fossiliferous limestone were found in the southern Gravelly Range.

In the Three Forks area (4, p. 21) 400 feet of limestones, arenaceous dolomites, and shaly sandstones which straddle the Mississippian-Pennsylvanian age boundary are assigned to the Amsden. To the west of the thesis area, in the Tendoy Range, Scholten (73, p. 366) reported a 200-foot section of Amsden consisting of a red limestone, sandy and calcareous shale, and a basal sandstone unit. This lithology is very similar to that in the thesis area.

In the Wind River Mountains of Wyoming the Amsden consists of a heterogenous mixture of limestone, sandstone, and shale (8, p. 310-311).

Quadrant Formation

In 1893 Peale (63, p. 39) described a prominent bed of quartzite overlying the Mississippian cherty limestones, which he considered to be near the base of the Mesozoic section in the Three Forks area. This quartzite bed is equivalent to the base of the Quadrant formation as it is known today.

Iddings and Weed (43, p. 33-34) in 1899 designated Quadrant Mountain, in the northwest part of Yellowstone

National Park, as the type section of the Quadrant formation. They defined the Quadrant as lying between the Madison limestone, below, and the "Teton formation" (equivalent to the Phosphoria formation), above. They measured the Quadrant to be 400 feet thick and described it as white quartzitic sandstone interbedded with a few light gray limestone beds throughout the entire section.

Scott (74, p. 1015-1019) in 1935 redescribed the Quadrant at the type locality in Yellowstone Park as those rocks which lie between the top of the Amsden formation and the bottom of the Phosphoria formation. Scott stated that the type section was 230 feet thick and consisted primarily of well-bedded, white to pink, medium-grained quartzite which is occasionally more sandy than quartzitic. The upper third of the type section consists of interbedded light gray dense limestone beds.

In 1941 Thompson and Scott (87, p. 349-350), on the basis of fusulinids, revised Scott's definition of the Quadrant. They concluded that the lower 66 feet of Scott's Quadrant Mountain section should be considered the Sacajawea formation of Mississippian age. By doing this, they eliminated the name Amsden formation, which Scott in 1935 considered as Pennsylvanian in age.

In the southern Gravelly Range the Quadrant includes pale yellow, pink, and gray medium-grained sandstones, underlain by the red beds of the Amsden formation and overlain by the Phosphoria formation.

Lithology, Thickness and Physiographic Expression

In the southern Gravelly Range the medium- to thick-bedded Quadrant sandstone is uniform in lithology. Throughout the formation the sandstone varies from slightly to very calcareous. About 130 feet of sandy dolomite occurs in the upper half of the formation. Microscopically this dolomite consists of small euhedral dolomite crystals which make up 70 per cent of the rock, and subrounded quartz grains, in clusters and veins, which make up 25 per cent of the rock. Accessory minerals are chert, plagioclase and opaque ore. The rock is tightly packed and cemented with calcite. The sandstones and dolomites of the Quadrant weather to shades of yellowish brown to pinkish gray to tan. Generally the Quadrant sandstone is very clean; about 90 per cent of the rock consists of well-compacted, subrounded to well-rounded quartz grains in a calcareous cement. Small opaque ore mineral grains are common inclusions in the quartz grains.

In the southeast part of the area, where the only fair exposure of the Quadrant is located, a limestone bed about

30 feet thick occurs near the base of the formation. This limestone contains unidentifiable brachiopod fragments. Distinctly yellow sandstone beds, 10 feet thick, which underlie the limestone mark the base of the Quadrant formation. Below the base lie the predominantly red siltstones and shales of the Amsden formation.

The Quadrant sandstone is considered to be of marine origin since it exhibits excellent bedding, marine cross-bedding, siliceous limestone, and contains marine fossils (74, p. 1018-1019).

The Quadrant is one of the most poorly exposed formations in the southern Gravelly Range, and no exposed section more than 40 feet thick was found. The Quadrant is similar to the Phosphoria in that it forms talus slopes (figure 10) which appear black when viewed from a considerable distance. In the case of the Quadrant, the dark color is mostly the result of lichen growth. Because of poor exposures, it was difficult to determine the thickness of the different lithologic units within the formation and, in some places, the formation thickness itself. The best exposure of this formation is along the West Fork of the Madison River, section 27, T. 12 S., R. 2 W. Here the Quadrant is about 527 feet thick and consists of partly covered slopes of sandstone and dolomite.

Figure 10. Typical outcrop of Quadrant formation. Section 22, T. 12 S., R. 2 W.

The thickness of the Quadrant in the southern Gravelly Range is more than twice the thickness of the type section in Yellowstone Park. Scholten (73, p. 366) measured about a 1000-foot section in the Snowcrest Range and a 2600-foot section farther east in the Tendoy Range. Bubb (9) reports a thickness of 311 feet of Quadrant along Wigwam Creek directly north in the Gravelly Range. The Quadrant appears to thicken rapidly to the west and south and to thin toward the north and east.

Throughout the thesis area, the Quadrant-Phosphoria contact is covered by talus from the Phosphoria cliffs above. However, in the central and northern Gravelly Range, Mann (54, p. 18) found the Phosphoria and Quadrant to be disconformable. He states that "usually a thin bed of chert nodules and stringers in a matrix of fine-grained, yellowish-gray sandstone is present at the contact, which is taken to indicate a transitional period during which some reworking of Quadrant sediments may have occurred."

As stated previously, the contact between the Amsden and Quadrant is gradational, and so it is believed that these formations represent continuous deposition.

Fossils and Age

In the thesis area no fossils were found; however, at the type section in Yellowstone Park (74, p. 350) approximately 35 miles east of the area of this study, fusulinids have been found and identified. Thompson and Scott (74, p. 350-353), on the basis of the fusulinid genera *Wedekindellina* and *Fusulina* in the upper limey part of the formation, dated the Quadrant as Desmoinesian (Pennsylvanian) in age.

Regional Correlations

The Tensleep formation of northern Wyoming and southern Montana is considered to be in part correlative with the Quadrant of southwestern Montana. Agatston (1, p. 44) described the Tensleep as composed of white, tan, and pink fine- to medium-grained, cross-bedded, massive sandstone interbedded with dolomite, limestone, and some shale and anhydrite. Lithologically the formation is very similar to the section in the Gravelly Range. The Tensleep gradually thins to the east and becomes more argillaceous. In the Big Horn Basin in Wyoming the Tensleep is 75 to 125 feet thick and similar in lithology to the section measured in the thesis area.

In southeastern Idaho (55, p. 71-72) the Wells formation is equivalent, at least in part, to the Quadrant in the Gravelly Range. The Wells is about 2500 feet thick; the lower third is made up of sandy and cherty limestones and interbedded sandstones. The upper two-thirds of the

Wells is more siliceous and comprises sandy limestones, fine-grained sandstone, and a few beds of quartzite.

In central and northern Montana the name Quadrant is used for beds of Pennsylvanian age of approximately the same lithology as found in the Gravelly Range.

In the foothills and Rocky Mountains of Alberta and British Columbia (82, p. 331) the Rundle group of Mississippian age is conformably overlain by the Rocky Mountain formation. This formation is about 300 to 500 feet thick and consists of quartzite and sandy dolomite of possible Pennsylvanian age. The Rocky Mountain formation thins rapidly to the southeast, east and north, in part because of pre-Triassic and pre-Jurassic erosion.

Phosphoria Formation

In 1912 Richards and Mansfield (70, p. 684) named the Phosphoria formation for Phosphoria Gulch, near Meade Peak, Idaho, where it is typically exposed between the Wells formation of Pensylvanian age and the Dinwoody formation of Triassic age. There the type section can be divided into a lower phosphatic shale member, approximately 180 feet thick, and an upper member, the Rex chert, which is about 240 feet thick.

Condit, Finch and Pardee (19), in 1928, mapped the Phosphoria formation in the Three Forks-Yellowstone Park region (including the Gravelly Range). They concentrated their study on the phosphate beds in the Phosphoria formation.

A detailed separation of the Phosphoria formation into members in southwestern Montana was made in 1955 by Cressman (21). Cressman divided the Phosphoria into five members, which are, in ascending order, a basal quartz sandstone dolomite member (unit A), a thin lower phosphatic shale member (unit B), a middle sandstone-dolomite-chert member (unit C), an upper phosphatic shale member (unit D), and a chert-quartz sandstone member (unit E).

Lithology and Thickness

In the southern Gravelly Range the Phosphoria is equivalent to unit E, as used by Cressman (21). Other very thin units may be present at the base of the formation, but poor exposures in the lower third of the formation obscure the nature of the lowermost beds.

The Phosphoria can be divided into three parts in the southern Gravelly Range. The lower part, about 180 feet thick, consists of alternating sandstone and chert beds. The sandstone varies from light to brownish gray to darker shades of these colors, is medium- to thick-bedded, and commonly has light brown chert stringers and veins perpendicular to bedding planes. The sandstone is usually quartzitic and is resistant to erosion. The alternating chert beds are about 4 to 10 feet thick, colored shades of brown, gray, and yellow and are frequently nodular.

The middle part, about 100 feet thick, of the Phosphoria consists mostly of chert and minor beds of quartzitic sandstone. The chert is 1 to 5 feet thick, ranges in color from brown, tan, white, yellow to red, and contains lenses of gray quartzitic sandstone. The middle chert and sandstone unit is possibly correlative with the Rex chert of Cressman (21).

The upper part of the Phosphoria consists of sandstone, about 80 feet thick, which is less resistant than the lower sandstone unit. The upper sandstone is gray to brown, weathers reddish to yellowish gray, and is medium-bedded. Locally the sandstone is very fossiliferous and is cross-bedded. In the lower half of the sandstone unit cylindrical columns of lighter-colored sandstone, 2 to 4 inches in diameter are locally abundant. They usually stand perpendicular to the bedding planes. Where exposed, most of these columns exhibited concentric rings colored gray and red, even on freshly broken surfaces. Condit (18, p. 113) described similar columns in the Phosphoria in the Yellowstone Park region. Microscopically the sandstone in the upper third of the formation has subrounded to well rounded quartz grains loosely cemented by microcrystalline quartz and chalcedony. Limonite is present in small amounts, primarily as a cement. A few well-rounded grains of glauconite are also present.

In a study of the Phosphoria in southwestern Montana, Cressman (21, p. 22-23) states that the source for the sandstone in the lower and upper parts of unit E came from the north and east respectively. He suggested (21, p. 25) that the chert originated in large part from "the accumulation and partial diagenetic reorganization of sponge spicules and other siliceous organisms."

As stated previously, the Phosphoria disconformably overlies the Quadrant formation in the Gravelly Range. The Dinwoody formation (Triassic) appears to overlie the Phosphoria conformably in the thesis area.

In the north-central part of the thesis area where a section was measured, the Phosphoria is 400 feet thick. To the south along the West Fork of the Madison, the Phosphoria thickness was estimated to be 200 feet. Cressman (21, p. 16) states that in southwestern Montana there is a gradual thinning of the Phosphoria formation to the southeast.

Physiographic Expression

In the southern Gravelly Range the Phosphoria forms a prominent ridge between the relatively nonresistant Dinwoody and Quadrant formations. The sandstone units at the extreme upper and lower parts of the formation generally form talus slopes above and below the persistant cliff-forming chert unit (figure 11).

Fossils and Age

The only identifiable fossils found in the Phosphoria in the thesis area were the brachiopod *Nuculana*, and the bryozoan *Rhombopora*, both from the extreme uppermost unit in sections 10 and 30, T. 12 S., R. 2 W., respectively. Frenzel and Mundorff (31, p. 679-684) described fusulinids from the basal part of the Phosphoria near Three Forks, Montana; they stated that "these fossils indicate a Lower Permian (Wolfcampian) age."

Regional Correlations

The Phosphoria gradually becomes thinner to the north in the Gravelly Range. Mann (54, p. 82-83) measured two sections which were approximately 200 feet thick, and Bubb (9) measured a 50-foot section of the Phosphoria at Wigwam Creek, about 24 miles north of the thesis area. The Phosphoria thickens to the southeast in southwestern

Figure 11. Cliff-forming chert unit of Phosphoria formation; section 10, T. 12 S., R. 2 W.

Montana and reaches a maximum thickness of 500 feet in the Lima area (21, p. 5).

Northeast of the thesis area in the Three Forks area the Phosphoria is 70 feet thick and rapidly thins to the north and east (4, p. 20). The Phosphoria extends into the southern Rocky Mountains of Alberta, where it is 200 to 250 feet thick and consists of sandy dolomite, chert, and phosphatic beds (82, p. 331).

In southeastern Idaho and western Wyoming (57, p. 43-46) the Phosphoria differs considerably in lithology from that of the thesis area. The lower half of the formation consists of calcareous shales and mudstones, limestones, and phosphatic rocks. The upper half consists of the Rex chert member overlain in some localities by a shale member. In the Wind River Mountains of central Wyoming, the E unit is primarily nodular chert layers separated by films of carbonate; the upper part of the E unit consists of limestone and dolomite. No carbonate or dolomite rocks were found in it in the southern Gravelly Range area.

The Minnekahta and Opeche formations of eastern Wyoming and southeastern Montana have been correlated with the Phosphoria of southwestern Montana (65, p. 8). In southern Montana the Phosphoria grades into the Embar formation which consists of yellowish-brown sandstone, siltstone, dolomite, and limestone with a maximum thickness of 80 feet (32).

Dinwoody Formation

Blackwelder (6, p. 425-426) named and defined the Dinwoody formation from outcrops in Dinwoody Canyon on the northeastern slope of the Wind River Mountains, Wyoming. He defined the formation as 200 feet of gray and olive shaly siltstones and shales with thin brown limestones near the base. At the type section, the formation was bounded by the Phosphoria below and by the red shales and siltstones of the Chugwater formation above.

Newell and Kummel (61, p. 940-941) stated that the boundary between the Chugwater formation and the Dinwoody was neither a "useful nor natural boundary." They proposed that the Dinwoody should include the dominantly silty strata between the Phosphoria and the top of the resistant siltstones located about half way toward the top of the original Dinwoody type section. Newell and Kummel (61, p. 941-942) suggested that the Dinwoody be divided into three units, a basal siltstone, a *Lingula* zone, and at the top, a *Claria* zone. The last two units were so named for the abundance of the characteristic fossils in these zones.

Lithology and Thickness

The Dinwoody in the southern Gravelly Range consists of calcareous siltstones and sandstones, limestones, and silty limestones. No systematic progression of these three lithologies was apparent, but the limestones are more common in the lower half of the formation.

The Dinwoody formation in the thesis area consists mostly of calcareous siltstones. These siltstones are commonly tan, grayish brown, and occasionally grayish green, and they weather to a characteristic chocolate-brown color. Bedding varies in thickness from less than an inch to 1½ feet in some places. These calcareous siltstones grade into silty limestones, and in the field it is difficult to distinguish the two. Microscopically the siltstones consist of subangular to subrounded quartz grains in a calcareous matrix. Quartz grains constitute about 50 per cent of the rock; the remainder is fine-grained matrix and accessory minerals. Oolites and rounded grains of argillaceous rocks are common in some parts of these rocks along with a few grains of muscovite and chert. Iron stains are frequent on fresh fractures of these siltstones, especially in the thinner beds.

The siltstones are interbedded with silty limestones of very similar bedding and color. The silty limestones are, however, slightly darker brown to brownish gray on fresh fracture, but they commonly have the same chocolate-brown weathered surfaces. These rocks are generally medium-bedded and rarely thick-bedded, are more dense and harder than the siltstones, and are more resistant. Approximately 100 feet above the base of the formation is a bed 4 to 8 feet thick of medium- to thick-bedded limestone of dark- to medium-gray color. In the lower part of this gray limestone unit pyrite and calcite crystals are visible through a hand lens. The limestone weathers dark gray to bluish gray. A few white calcite veins about one-eighth of an inch wide irregularly transect the beds.

Very thin, soft, green shale beds are occasionally intercalated in the lower third of the formation. These shale beds do not exceed 2 inches in thickness and gradually decrease in number and thickness upward in the section.

Worm trails and borings are particularly common on the siltstone and silty limestone beds of the upper half of the formation. Ripple marks suggesting a shallow water environment were found on most bedding planes in the formation except on the dense, gray limestone beds and the shale beds.

The Dinwoody, according to Moritz (60, p. 1800) indicates mildly unstable shelf conditions and repeated shifts from lagoonal or littoral environmental conditions to normal neritic conditions. The presence of the mud-inhabiting brachiopod Lingula attests the shallow water conditions.

The contact of Dinwoody and overlying Woodside is gradational, and was arbitrarily established where the section grades into predominantly red shales. This transitional zone does not exceed 4 to 5 feet at every section examined. As stated previously, the contact between the Dinwoody and the underlying Phosphoria appears to be conformable in the southern Gravelly Range.

The only well-exposed outcrop of the Dinwoody is along Fossil Creek, where the thickness is about 470 feet. The Dinwoody gradually thins to the north. Manske (56) reports that the Dinwoody is absent in the northern Gravelly Range. To the southeast of the Gravelly Range in Idaho the Dinwoody attains thicknesses of 700 to 2400 feet (48, p. 167).

Physiographic Expression

The Dinwoody is a relatively nonresistant formation, compared to the cliff-forming Phosphoria formation; but the Dinwoody is more resistant than the slope-forming Woodside formation. The only good outcrops of the Dinwoody in the area occur in stream beds and on hill tops, but most outcrops are moderately weathered (figure 12). In

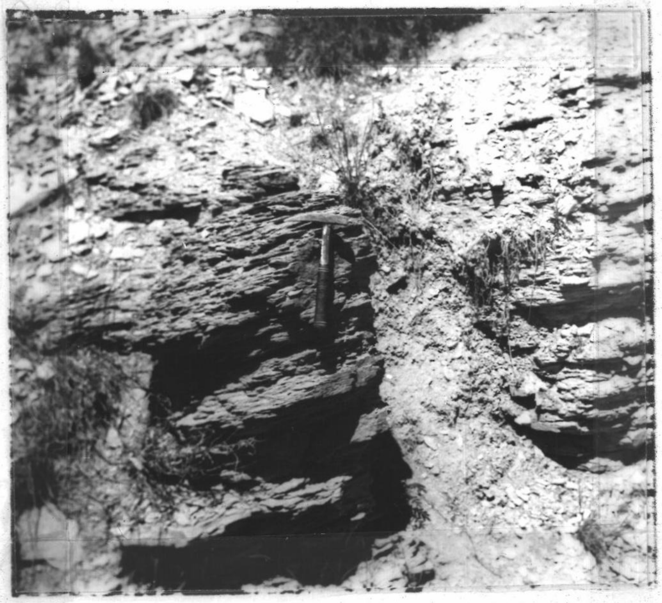

Figure 12. Typical, partly weathered outcrop of Dinwoody formation along Fossil Creek.

the southern part of the thesis area the Dinwoody commonly forms a wide valley along with the Woodside formation.

Fossils and Age

On the basis of the characteristic fossils *Claria strachei* Bittner and *Lingula borealis* Bittner, the Dinwoody in the southern Gravelly Range can be correlated with the same zones designated by Newell and Kummel (61) in southeastern Idaho. *Lingula* was found throughout the formation, but the lowermost 110 feet contain an abundant number of well-preserved specimens. *Claria* was rare compared to *Lingula*; however, several fair specimens were collected from the middle of the upper half of the formation.

Kummel (48) in a comprehensive study of the Triassic stratigraphy of southeastern Idaho concluded that the Dinwoody contained the ammonite zones of the Otoceratan, Gyronitan, and Fleminton divisions. On this basis he dated the Dinwoody formation as very early Triassic (early Scythian).

Regional Correlations

The local Dinwoody formation can be correlated with the two upper zones of the same formation in Idaho, as outlined by Newell and Kummel (61), but the lowermost basal siltstone member is absent in the southern Gravelly Range.

In western Wyoming (48, p. 168) the Dinwoody ranges from about 40 to 700 feet thick and generally comprises the three lithologic and faunal zones of Newell and Kummel (61). The Dinwoody becomes arenaceous in central Wyoming (51) and grades into red siltstones and silty sandstones in the upper part. This redbed facies is possibly equivalent to the Woodside formation in the southern Gravelly Range.

The Dinwoody can be traced from the thesis area into southeastern Idaho (48, p. 169) where it ranges in thickness from 700 to 2200 feet. There it differs from the Gravelly Range section in that the lowermost part is a shale sequence. The remaining portion of the section is lithologically very similar to the Dinwoody of the thesis area.

The Dinwoody or its equivalents are unknown in northern Montana, owing to pre-Jurassic erosion. The lower Chugwater formation of south-central Montana and some parts of northern Wyoming is probably equivalent in age to the Dinwoody of the thesis area. The Chugwater commonly consists of red sandstones and shales (65, p. 8).

The Dinwoody can be traced into Alberta and British Columbia where it is called the Spray River formation (82, p. 332). The lower part of this formation consists of dark gray calcareous shale, siltstone, and argillaceous limestone of Early Triassic age and is at least approximately equivalent in age to the Dinwoody of the southern Gravelly Range.

Woodside Formation

The Woodside formation was named by Boutwell (7, p. 446) in 1907 for an homogeneous lithologic unit at Woodside Canyon in the Park City mining district, northeastern Utah. The type section at Woodside Canyon consists of approximately 1000 feet of maroon and red shaly siltstones, bounded by the Phosphoria formation below and the Thaynes formation above.

Lithology and Thickness

The Woodside lithologically varies less than any other unit in the thesis area. It consists of thin- to medium-bedded siltstones, mudstones, and occasionally a few thin-bedded shales. The siltstones and mudstones are calcareous and maroon to dark red, and commonly have very thin white veins of calcite perpendicular to the bedding planes. The shale beds are red and thin-bedded, and seem to be absent at some places in the thesis area. Some of the mudstone and siltstone beds are arenaceous. Microscopically the siltstone consists of small subrounded quartz and calcite grains and minor amounts of glauconite and biotite, cemented by red ferruginous, argillaceous material. On the surfaces of many beds ripple marks and mud cracks are common. Cross-bedding occurs in some of the thin beds in the upper half of the formation. The Woodside siltstones and shales are generally thought to have been deposited under mildly unstable shelf conditions (60, p. 1800).

The Dinwoody-Woodside contact is gradational through a thickness of about 5 feet, as stated previously. The contact with the Thaynes formation above is also gradational but through a thickness of about 10 feet.

The Woodside varies little in thickness throughout the southern Gravelly Range from the measured section along Fossil Creek, section 9, T. 12 S., R. 2 W., where it is about 522 feet thick. Regionally the Woodside thickens toward the west, where it is reported to be 610 feet thick in the Snowcrest Range (73, p. 171) and toward the south in the Centennial Range (39). At Ruby Canyon in the central part of the Gravelly Range, Mann (54, p. 21) reports that the Woodside is missing and only represented by red-stained upper Dinwoody rocks.

Physiographic Expression

The Woodside is a very nonresistant formation and so only a few outcrops were found in the thesis area; however, its distinctive red color makes the formation easy to follow in the field. Generally the Woodside forms gentle slopes; an exception to this occurs along Fossil Creek where the slope angle ranges from 20 to 80 degrees (figure 13). This steep slope is due partly to the resistant overlying Thaynes formation and partly to recent undercutting by Fossil Creek.

Fossils and Age

To my knowledge, no fossils have been found in the Woodside formation in the Gravelly Range. On the basis of stratigraphic position, lithologic correlation with the Woodside type section, and interfingering of the Chugwater formation from the east, the Woodside is considered Lower Triassic in age.

Regional Correlations

The Woodside formation and correlative formations can be traced over a wide area in northern Utah, western Wyoming, and southwestern Montana. It interfingers westward in southeastern Idaho and southwestern Montana into the upper part of the Dinwoody formation (48).

The Red Peak member of the Chugwater formation (69) in most of Wyoming is correlative with the Woodside in the southern Gravelly Range. The Red Peak member in central

Figure 13. The Woodside formation forms steep slopes along Fossil Creek, section 4, T. 12 S., R. 2 W.

Wyoming (51) consists of 800 to 1000 feet of red siltstones, shales and silty sandstones. In south-central Montana the Chugwater formation consists of red and brown sandstone, siltstone, and some shale. The Chugwater pinches out 50 miles north of Montana-Wyoming state line, because of pre-Ellis erosion (32).

From west to east, Triassic sedimentary rocks in Montana grade from marine to continental types. The Woodside is tentatively correlated with the Spearfish formation of eastern Montana, which is made up of limy and shaly redbeds that include salt and anhydrite (65, p. 8).

The Woodside is equivalent to the Whitehorse member of the Spray River formation of southwestern Alberta and southeastern British Columbia (82, p. 332). This member consists of gray limestone with shaly and sandy beds.

Thaynes Formation

Boutwell (7, p. 448) named the Thaynes formation for Thaynes Canyon in the Park City mining district, Utah. He described the type section at this canyon as over 110 feet of limestone, calcareous sandstone, sandstone and shale. The Thaynes is overlain by the Ankareh formation and underlain by the Woodside formation at the type locality.

In 1954 a comprehensive study of the stratigraphy of the Thaynes formation was made by Kummel (48). He described the lithology and fauna of the Thaynes in southeastern Idaho and the adjacent regions.

Lithology and Thickness

In the southern Gravelly Range the Thaynes is a relatively thin formation which consists of calcareous sandstones, siltstones, and subordinate shales and mudstones. The sandstones are very light brownish gray to yellowish brown, fine-grained, frequently calcareous, and thin- to medium-bedded. The sandstones are commonly very silty and grade into sandy siltstones, making it very difficult to distinguish the two. At most outcrops a dolomitic sandstone is present in the middle of the formation. Northeast of Fault Lake in section 4, T. 12 S., R. 2 W., the dolomitic sandstone contains small unidentifiable brachiopods. Microscopically about 40 per cent of the dolomitic sandstone consists of subrounded quartz grains; a dolomitic and calcareous matrix makes up 55 per cent of the rock. The quartz commonly has authigenic overgrowths. Accessory minerals include acidic plagioclase, chert, and opaque ore. The siltstones have the same color and bedding thickness as the sandstones. The siltstones commonly grade into sandy siltstones and sandstones. A few sandy siltstone beds contain mudstone pebbles, less than $\frac{1}{2}$-inch in longest diameter, scattered irregularly throughout the beds. These mudstone pebbles are well-rounded, very light yellowish brown, and locally comprise about 50 to 60 per cent of the rock. These pebbly siltstone beds occur in the upper half of the section and are about 6 inches to $1\frac{1}{2}$ feet thick and make up about 10 per cent of the Thaynes formation in the southern Gravelly Range. Interbedded with the sandstones and siltstones are thin beds of olive-green, micaceous shale that weathers chalky green. This shale was found only in the lower third of the formation in the thesis area. Mudstones in the Thaynes are hard, medium-bedded, grayish brown, and calcareous. They commonly weather light brown. No fossils were found in the mudstones.

The Thaynes is thought to have been deposited under stable shelf conditions. The presence of limestone suggests the Thaynes was deposited in relatively clearer seas than the Woodside (60, p. 1800).

The Thaynes and underlying Woodside formation have a gradational contact. Since the upper Thaynes contacts are commonly covered, a disconformity is inferred at the Thaynes-Morrison contact in the north-central part of the area and with the Thaynes-Ellis contact in the southwestern part. The disconformity is based on the fact that the Thaynes is lower Triassic and the Ellis group is upper Jurassic and upon the approximate equivalence in dip and strike of each formation in the southern Gravelly Range.

The thickness of the Thaynes is relatively constant, varying from 35 to 40 feet throughout the area; along Fossil Creek, section 4, T. 12 S., R. 2 W., the Thaynes is 38 feet thick. The Thaynes thickens northward from Fossil Creek as far as Monument Hill north of the thesis area, where it is 100 feet thick. However, Thaynes beds seem to be absent in the vicinity of Black Butte, about 6 miles north of the thesis area (54, p. 22). Scholten (73, p. 367) reports that the Thaynes is 636 feet thick in the Snowcrest Range. To the south in the Centennial Range the Thaynes is 130 feet thick (39, p. 1897). This variability of the Thaynes and its absence immediately north of the thesis area are probably the result of pre-Jurassic erosion.

Physiographic Expression

The Thaynes forms a prominent ridge between the nonresistant Morrison, above, and the nonresistant Woodside, below, throughout most of the thesis area. On the west bank of Fossil Creek in sections 4 and 9, T. 12 S., R. 2 W., the Thaynes forms an almost vertical cliff above steep slopes of the Woodside. In section 24, T. 12 S., R. 3 W., the Thaynes forms a conspicuous ridge at the nose of an anticline, but forms only a slight break in the slope on the west limb of the fold farther south.

Fossils and Age

On the basis of lithologic correlation and stratigraphic position, the Thaynes in the southern Gravelly Range is considered to be of early Triassic age. Kummel (48, p. 171) states that the Thaynes formation is early Triassic on the basis of the characteristic *Meekoceras* fauna that has been found in most sections where the formation outcrops, including southwestern Montana. No fossils were found in the thesis area to confirm this correlation.

Regional Correlations

Throughout most of Montana, excluding the southwestern part, pre-Jurassic erosion has removed most, if not all, of the Thaynes formation (65, p. 9). Berry (4) reports no Triassic rocks in the Three Forks area, directly north of the Gravelly Range.

The Thaynes of the thesis area possibly is correlative with the lower limestone member of the Thaynes formation in southeastern Idaho (48, p. 173), and the lower portion of the Thaynes formation in northeastern Utah and western Wyoming (48, p. 166). The lower Thaynes in western Wyoming, consisting of limestone, mostly silty and sandy, and interbedded with fine-grained sandstone (48, p. 176), is especially close in lithology to that of the thesis area.

The lower Triassic strata are represented in the Rocky Mountains of Alberta and eastern British Columbia (82, p. 333) by the upper Whitehorse member of the Spray River formation. This member consists of gray limestone with shaly and sandy beds, and is possibly correlative with the Thaynes of southwestern Montana.

Ellis Group

Peale (63, p. 40) in 1893 named the Ellis formation for rocks between the Quadrant formation, below, and the Dakota formation, above, in the Livingston-Three Forks area. The formation was named after Fort Ellis, about 3 miles east of Bozeman, but no type section was designated. Iddings and Weed (42, p. 2) and Peale (63, p. 4) later described the Ellis in the Livingston and Three Forks areas, respectively. Cobban, Imlay and Reeside (14, p.451-453) designated the type section as that along Rocky Creek Canyon about 3.7 miles southeast of the site of Fort Ellis, Montana. Cobban (10, p. 1263) proposed raising the Ellis to a group and restricting that name to marine Jurassic beds. He divided the Ellis group into three formations which are, in ascending order, the Sawtooth, Rierdon, and Swift. The Sawtooth is made up of calcareous siltstones, arenaceous oolitic limestones, sandstones, and dark shales; the Rierdon consists of calcareous shales and limestones; and the Swift is composed of non-calcareous shale overlain by glauconitic sandstone. In the southern Gravelly Range the Swift is the only formation of the Ellis group present.

Lithology and Thickness

The Swift formation of the Ellis group is poorly exposed in the southern Gravelly Range. Where the Swift is exposed, it consists of thin- to medium-bedded glauconitic sandstone and light gray limestone in the upper third of the formation. The sandstone is greenish gray, medium-grained, and has brown iron stains irregularly dispersed throughout. Subangular clear quartz grains, angular to subrounded chert grains, and subangular glauconite grains make up 85 per cent of the rock. This sandstone is loosely packed in a calcareous and ferruginous cement. Accessory rock constituents are rounded argillaceous rock grains and biotite grains.

The limestone is not known to outcrop in the thesis area. However, blocky limestone fragments found above the glauconitic sandstone are believed to belong to the Swift. Because of the blocky nature of the fragments, bedding is thought to be massive or thick. The limestone of the blocks is generally finely crystalline, light gray to greenish gray, and locally porous and friable. Bluish-green clay flakes and nodules, no larger than ½-inch in diameter, occur in increasing numbers toward the top of the Swift. Throughout the limestone unit are light brown stringers and veins of translucent chert that have no definite orientation.

Poor exposures prevented a positive determination of the relationships of the Swift with the overlying Morrison and underlying Thaynes formations. However, on the basis of the known ages of the Thaynes and Swift and the parallel position of both formations, a disconformable relationship probably exists. Where the Swift is thin or absent in the north-central part of the thesis area, the disconformity between the Thaynes and Morrison is of greater magnitude, owing to the absence of all the formations of the Ellis group.

In the Gravelly Range the Ellis group ranges from a thickness of 350 feet north of the thesis area (9) to nil near Fault Lake in the area of the thesis. South of Fault Lake the Swift crops out as small exposures of sandstone, but these are not continuous. In an anticline in section 24, T. 12 S., R. 3 W., the Swift is about 86 feet thick and maintains approximately the same thickness southeastward to the limit of outcrops in the thesis area.

Physiographic Expression

Commonly the Swift is covered, but in section 13, T. 12 S., R. 3 W., it forms a resistant sandstone ridge (figure 14) at the nose of an anticline.

Fossils and Age

A few pelecypod fragments were found at the base of the section of the Swift formation in section 24, T. 12 S., R. 3 W., and were tentatively identified as the genus *Ostrea*. The Swift formation is assigned to the Oxfordian European stage of the Upper Jurassic series on the basis of ammonites (44, p. 968). Because the Swift in the southern Gravelly Range is relatively thin and contains no lower shale member similar to that of the type locality, probably only the upper part of the type Swift section is represented in the southwestern part of the thesis area.

Regional Correlations

In northern Montana (10, p. 1281) the Swift formation consists of dark gray, non-calcareous shale overlain by

Figure 14. Ellis group sandstone ridge at nose of anticline in section 13, T. 12 S., R. 3 W.

Figure 15. Sandstone in middle unit of Morrison formation northeast of Fault Lake.

fine-grained, glauconitic, flaggy sandstone. This sandstone unit is probably equivalent in part to the sandstone of the Swift in the southern Gravelly Range.

The Swift in the thesis area is possibly correlative with the glauconitic shale and sandstone of the Sundance formation of central and northern Wyoming and equivalent to the Stump sandstone of southeastern Idaho and northern Utah (44). The upper member of the Sundance passes southeastward into the Curtis formation of parts of Wyoming and Colorado. The Stump sandstone is similar to the Swift in that it consists mainly of thin-bedded, gray to greenish gray, fine-grained sandstones (55, p. 99-100). In central Wyoming the upper Sundance is a glauconitic sequence of gray and grayish-green shale, sandstone and sandy limestone (66, p. 53). The Curtis formation of southern Wyoming and parts of Utah, like the Swift, is characterized by glauconitic flat-bedded sandstones and olive-gray shales (98, p. 177).

The Swift formation can be traced over most of Montana, except in the northeastern and extreme northwestern parts, where post-Jurassic erosion removed it. The lithology of the formation in the rest of Montana is about the same as that of the thesis area. The Swift can be traced into Alberta and British Columbia (82, p. 335), where some

50 feet of glauconitic sandstone is included in the upper part of the Fernie group.

In north-central Wyoming the Swift formation consists of greenish-gray to yellowish-gray glauconitic sandstone (45, p. 60).

Morrison Formation

Eldridge (28, p. 60-62) in 1896 named the Morrison formation for beds near the town of Morrison, Colorado, that lie between the Cretaceous Dakota sandstone and a brown and pink sandstone of Triassic age. The lower two-thirds of the Morrison in the type section consists of green, drab or gray marls and numerous lenticular bodies of limestone of a characteristic drab color. He found numerous reptilian remains in this lower part, associated with a persistent band of sandstone and limestone in thin alternating layers. The upper third of the formation is a succession of sandstone and marls.

Because of the vagueness of Eldridge's descriptions of the type section, Waldschmidt (92, p. 1097-1114) in 1944 described in detail the type section at Morrison, Colorado. He subdivided the formation into six lithologic units which, in descending order, are as follows: Sandstone and Shale unit, Red Shale unit, Gray Shale and

Sandstone unit, Gray Clay and Limestone unit, Gray and Red Shale unit, and Basal Sandstone unit.

Lithology and Thickness

In the southern Gravelly Range the Morrison can be divided into three lithologic units. The top unit consists of about 200 feet of nonresistant red sandy shale; the middle unit consists of about 150 feet of sandstone with brown shales near the top; and the bottom unit consists of about 150 feet of thin-bedded shales, mudstones, limestones, siltstones, and a few sandstones. This lowest unit is colored green, gray, yellow and red. Because of its nonresistance, the upper shale unit is poorly exposed throughout the area and consequently a detailed study of it was impossible. The shale fragments in this poorly exposed area contained fine- to medium-sized sand grains. The shale ranged from bright red to maroon.

The middle unit is made up of three different sandstones, each varying in composition. The uppermost sandstone of this middle unit is a salt-and-pepper type that contains mostly white quartz and dark brown to black chert grains; yellow and red chert grains are also present. Quartz and iron oxide are the predominant cementing materials. This sandstone is poorly bedded and in some places is massive (figure 15). The second or middle sandstone is generally yellow, owing to an abundance of iron oxide. The main constituent is well-sorted quartz grains that are commonly medium-grained and subangular. This sandstone is well indurated and occurs in beds 1 to 4 feet thick. The third sandstone at the base of the unit is a graywacke containing angular and well-compacted quartz and feldspar grains.

The lowest third of the Morrison is the most varied. The shales are very thin-bedded, commonly green but in places reddish gray, calcareous, and nonresistant. The mudstones are generally medium-bedded, show shades of gray, red, and green, and are more resistant to weathering than the shales. The siltstones are medium-bedded and include shades of yellow, gray, green and rarely brown. These three types of lithology commonly grade into each other, and so it is difficult to determine exactly where one begins and the other ends.

The Morrison conformably overlies the Swift formation in the southwestern part of the thesis area. In the south-central part of the area there is a disconformity between the Thaynes and Morrison, as stated previously. At the only exposure where the contact between the Morrison and Kootenai was seen, there is a difference of about 7 degrees in the dip of the two formations. The strike and exact dip of the Morrison were not positively clear; however, an angular unconformity is suggested by the difference in dips. Mann (54, p. 30) reports that at Cottonwood Creek, 8 miles north of the thesis area, "the Morrison is overlain by the basal conglomeratic sandstone of the Kootenai with a 10 degree angular unconformity." Cobban (10, p. 1270) also states the unconformable relationship of the Kootenai and Morrison in the Sweetgrass Arch area.

The greatest exposed thickness (450 feet) of the Morrison formation in the southern Gravelly Range is along the west bank of Fossil Creek in sections 4 and 9, T. 12 S., R. 2 W. A gradual thinning is evident to the south and west; the formation is approximately 250 feet thick in the extreme southwest corner of the area. Thinning of the middle unit is responsible for most of the reduction in thickness. Because of low relief and sagebrush cover, precise measurement of the thickness was impossible.

Physiographic Expression

Except for the relatively good exposure near Fossil Creek, the Morrison forms gentle slopes of greenish-gray and sometimes reddish-gray soil and poorly exposed sandstone beds. The sandstone beds are the only part of the formation that can be traced throughout the area; since they were not found in the southwestern part of the thesis area and because of a smaller formation thickness, the sandstone presumably is missing there.

Fossils and Age

The only fossils found in the thesis area were unidentifiable dinosaur bone fragments. These were not found in place, but it is believed that they came from the lower third of the formation. Farther north in the Gravelly Range (54, p. 30) bone fragments have been collected and identified as *Stegosaurus*. Eldridge (28, p. 61) found that the clays of the lower two-thirds of the Morrison at the type section were so replete of dinosaur remains that he coined the term "*Atlantosaurus* clays."

Regional Correlations

The argillaceous rocks comprising the lower unit in the area can possibly be correlated with the drab-colored marls and lenticular limestones of the type section (28, p. 60-62). The middle unit of sandstone is very similar to Eldridge's description of the sandstone from the upper third of his section.

The red sandy-shale unit in the southern Gravelly Range is similar to Waldschmidt's Sandstone and Shale unit and his Red Shale unit (92, p. 1097-1114). Since the total thickness of the sandstone unit of the thesis area is much smaller and the lithology is variable, it is impossible to correlate it with certainty with the Gray Shale and Sandstone unit.

The Morrison is present in much of Wyoming, part of Colorado, central and southern Montana, and forms a thin interrupted unit in northern Montana (65, p. 9).

The Morrison throughout Montana does not differ much in lithology from the section in the southern Gravelly Range. In south-central Montana the formation consists of 100 to 400 feet of nonresistant siltstones, claystones, and sandstones that erode to badland topography (32).

The Morrison in the southern Gravelly Range can be correlated with the Morrison formation of central Wyoming (50), where it consists of a variable sequence of variegated silty claystones and lenticular earthy fine soft sandstone.

In the Black Hills (26, p. 46) the Morrison is represented by greenish-gray and green mudstones and shales, some minor amounts of purplish, red or pink shale, thin lenses of shaly limestone, and black or carbonaceous shale.

The Passage beds in the upper part of the Fernie group in Alberta, consisting of 150 to 190 feet of interbedded shales and sandstones, have been dated as Oxfordian to early Portlandian in age (82, p. 335) and probably are correlative with the Morrison in Montana.

Kootenai Formation

Dr. G. M. Dawson proposed the name Kootenai group (97, p. 1119) for sandstones, shales and conglomerates of Jurasso-Cretaceous age in southern Alberta. He later described the Kootenai series as consisting of 5000 to 7000 feet of "shales and sandstones of very varied texture and appearance, some conglomerates, and many coals, containing a flora of lowest Cretaceous age."

Lithology and Thickness

The Kootenai formation in the thesis area can be divided into four different lithologic parts which are, in ascending order, cherty conglomeratic sandstone, alternating bedded shales and limestones, gastropod limestone, and massive sandstone. The best exposure of the Kootenai is northeast of Fault Lake in section 4, T. 12 S., R. 2 W., where the formation is about 512 feet thick.

The base of the Kootenai is easily recognized by the relatively resistant cherty sandstone member which is 95 feet thick near Fault Lake. This member contains white and clear quartz and quartzite pebbles and dark red, black, and yellow chert pebbles near the base of the formation (figure 16); these pebbles are well-rounded, do not exceed 1 inch in diameter, and gradually decrease in number from the base

Figure 16. Basal conglomeratic sandstone unit in Kootenai formation, northeast of Fault Lake.

to half way up the section, above which they are absent. The sandstone of this member is coarse-grained and contains varicolored chert and quartz grains cemented in a yellowish-brown siliceous and ferruginous cement. This sandstone is poorly sorted and is commonly cross-bedded. Bedding is poorly defined, and beds range from ½ to 3 feet in thickness.

The member above the conglomeratic sandstone is poorly exposed in the southern Gravelly Range, but about 180 feet of shales, limestones and sandstones were measured northeast of Fault Lake. At this section a sandy limestone unit lies above the basal conglomeratic sandstone unit. This limestone is about 20 feet thick, yellow to brownish yellow, thin- to medium-bedded, and weathers pale yellow to tan. The sand-sized quartz grains in this limestone are clear, infrequently white, and angular. Overlying the limestone is a 40-foot concealed zone with dark brown shale fragments as float. Above this covered zone is approximately 20 feet of partly covered sandy limestone, which is crudely medium-bedded, yellow on fresh surface, and weathers yellow and orange. Overlying the sandy limestone is a 10- to 15-foot covered interval with reddish-brown mudstone fragments as float. About 60 feet of limestone overlie this covered unit. The lower part of the limestone is finely crystalline, light grayish-brown, weathers light brown, and is thin-bedded. The upper part of the limestone is similar except that chert veins and nodules are common, and lenses of limestone breccia are present. Above the limestone a 10- to 13-foot covered interval is followed by a 25-foot section of dense, medium-bedded, light gray limestone. This limestone, considered the top of this member in the thesis area, is overlain by the gastropod limestone member which can be traced over most of southwestern Montana where the Kootenai formation outcrops.

The gastropod limestone, which is 138 feet thick in the measured section near Fault Lake, is medium-bedded, light gray to brownish-gray, weathers very light gray, is fine- to medium-crystalline, and contains an abundance of fresh-water gastropods and in some outcrops pelecypods. The presence of fresh-water fossils in this limestone suggests that the Kootenai formation had a lacustrine depositional environment. Locally this limestone member is oolitic. Microscopically this oolitic limestone consists of oval or round calcareous oolites, which make up as much as 65 per cent of the rock, set in a calcareous matrix, which comprises about 30 per cent of the rock. Most of the oolites have distinct concentric bands around a shell fragment or a calcite or quartz grain. The calcite matrix is commonly dolomitized. Subrounded quartz grains make up the remaining 5 per cent of the rock.

The uppermost member of the Kootenai formation is a homogeneous medium-grained massive sandstone unit 97 feet thick near Fault Lake. This sandstone is distinctive in that it is a bright orange brown on both fresh and weathered surfaces. The weathered surfaces, however, are commonly stained dark reddish brown by iron oxide. Microscopically, about 90 per cent of the sandstone consists of tightly packed subangular to subrounded quartz grains in an argillaceous and ferruginous cement. Accessory minerals include chert, muscovite, and minor amounts of opaque ore mineral.

The Kootenai unconformably overlies the Morrison, as stated previously, and underlies the Colorado shale with apparent conformity in the southern Gravelly Range. Poor exposures prevented an exact determination of the character of the Kootenai-Colorado contact in the thesis area.

Physiographic Expression

The lowermost sandstone member of the Kootenai formation is fairly resistant and commonly forms a line of steep slopes or small cliffs that can be traced throughout most of the southern Gravelly Range. The overlying shale and limestone member is poorly exposed and forms gentle slopes of brown, reddish-brown, and gray soil. The gastropod limestone is distinctive owing to its relative resistance as compared with that of the underlying unit and because of the presence of the gastropods. The top of the formation forms gentle slopes covered by occasional large blocks of sandstone. An exception to this is at Fault Lake, where the massive sandstone forms steep talus slopes consisting of large angular sandstone blocks up to 8 feet long.

Fossils and Age

The only fossils found in the Kootenai were the gastropod *Circamelania ortmanni* Stanton and a pelecypod, *Unio*? Both of these fresh-water forms were found only in the gastropod limestone member.

On the basis of similarity in lithology and stratigraphic position to other sections in Montana, the Kootenai in the Gravelly Range is considered late Lower Cretaceous in age.

Regional Correlations

The Kootenai or its equivalents can be traced with little variation in lithology over most of Montana and Wyoming (65, p. 10).

To the east of the Gravelly Range in the Snowcrest and Tendoy Ranges, the Kootenai is very similar to that of the thesis area. However, in the Tendoy Range Scholten

(73, p. 356) measured a thicker section with coquina at the top.

The upper half of the Gannett group found in most of the southern part of Idaho is correlative with the Kootenai of southwestern Montana. The group consists of the following formations, in ascending order: Ephraim conglomerate, Peterson limestone, Bechler conglomerate, Draney limestone, and Tygee sandstone. The Kootenai of the Gravelly Range does not have any unit equivalent to the Ephraim conglomerate.

The Kootenai in northwestern Montana (12, p. 108-109) consists of a lower and an upper member. The lower member consists of cross-bedded quartz and chert sandstone, mudstone, siltstone, and sandstone overlain by bright red mudstone. The upper member is chiefly mudstone, siltstone, and greenish-gray sandstone.

The Dakota sandstone and Cloverly formation (15) found in parts of Wyoming consist of a shale member and a conglomeratic sandstone member; these two members are age equivalents of the Kootenai in southwestern Montana.

The Kootenai in southwestern Montana is equivalent to the Kootenay in Alberta (82, p. 336), where it consists of about 550 feet of sandstone and shale with several coal seams, two of which are mined.

Colorado Shale

The Colorado group was named by Hayden (38, p. 45) in 1876 for rocks of middle Cretaceous age typically exposed along the eastern base of the Front or Colorado Range. Hayden described the Colorado group as consisting of "indurated clayey material, more or less distinctly laminated, which geologists generally, but somewhat loosely, designate shales." A few soft sandstone layers were also present at the type locality. In the Colorado group he included the Fort Benton and Niobrara formations.

In 1929 Collier (16, p. 70-73) used the term Colorado shale to include about 3000 feet of shale and sandstone in the Sweetgrass Arch of Montana and Alberta. He divided the Colorado shale into two members, but did not use the two names Fort Benton and Niobrara.

In the thesis area the Colorado is considered a formation because of the uniformity of its lithology. Most authors in recent decades have considered the Colorado of this region to be a formation of early Upper Cretaceous age.

Lithology, Thickness, and Physiographic Expression

The Colorado in the southern part of the Gravelly Range consists of dark gray fissile shale and medium-grained, medium-bedded sandstone. In the lower third of the formation the shale has a greenish-gray hue, weathers to light grayish-brown soil, and contains disc-shaped clay ironstone concretions which are as much as six inches long. These concretions are reddish-black on the outside and light gray on fresh fracture. In the middle third of the formation these concretions are larger, up to nine inches long, but have the same general shape and color. The concretions are absent in the upper part of the formation. Generally the shale is nonresistant and forms a gentle slope. Thirty feet above the base of the only fair exposure known in the southern Gravelly Range, that is located in section 12, T. 12 S., R. 2 W., the Colorado contains a 10-foot bed of rusty-orange, medium-bedded quartz sandstone in which a few thin shale beds are intercalated. The weathered surfaces of this sandstone are commonly colored dark brownish-red by iron oxide, and the bedding planes have flowcasts and ripple marks. Poor exposures of the Colorado prevented detailed lithologic and paleontologic study.

The Colorado generally forms a gentle slope, but where erosion is actively taking place its slopes are steeper, as along the West Fork of the Madison, in sections 11, 12 and 14, T. 12 S., R. 3 W. Here the formation is approximately 270 feet thick and comprised mostly of black fissile shale.

Although the predominantly black shale unit that overlies the Kootenai formation and underlies the Aspen formation with apparent conformity was mapped as the Colorado in the southern Gravelly Range, some authors (47, 55) include several sandstone units in the Colorado. Because no diagnostic fossils were found to define the limits of the Colorado, its uppermost contact was arbitrarily drawn at the base of the medium-bedded, ridge-forming, brownish-yellow sandstone considered here to be lower Aspen beds. Most authors working with Montana stratigraphy regard the base of the Colorado as immediately above the massive rusty-orange sandstone unit that overlies the gastropod limestone of the Kootenai formation.

Fossils and Age

On the basis of similarity of lithology and stratigraphic position, the Colorado formation of the southern Gravelly Range is tentatively correlated with the Colorado shale of early Upper Cretaceous age as designated by Klepper (47), and Cobban and Reeside (15), although no fossils were found in the Colorado shale in the thesis area.

Cobban (11) found marine fossils throughout the Colorado group in central, northwestern, and northeastern Montana. On this basis, the Colorado in the thesis area is considered marine in origin.

Klepper (47) reported finding molluscs in the Ruby River Valley, northeast of the thesis area, certain species of which he states are characteristic of the Colorado group of early Upper Cretaceous age. Cobban and Reeside (15) also stated the Colorado is early Upper Cretaceous in age, basing this age determination upon a study of ammonites and pelecypods. No fossils were found in the Colorado shale in the thesis area.

Regional Correlations

The Colorado is a widespread body of sediments present over most of Montana and generally much thicker than in the Gravelly Range.

Because of inexact dating and incompleteness of the stratigraphic section in the thesis area, the Colorado shale cannot be closely correlated with Colorado sections elsewhere. However, beds in the thesis area are seemingly correlative with part of the Warm Creek formation in the Little Rocky Mountains (36, p. 102), the Blackleaf member of the Colorado in northwestern Montana (13, p. 108), and the Skull Creek shale of the basal Colorado in central Montana (11, p. 2175). It probably is correlative also with part of the Graneros shale of North and South Dakota

(12, p. 86), the lower Frontier formation of Wyoming and Idaho (15), and the Blackstone formation in the northern Rocky Mountains and foothills in Alberta (82, p. 339).

Aspen Formation

Veatch (91, p. 64) in 1907 defined the Aspen shale for exposures near Aspen Station, Uinta County, Wyoming. He described the Aspen as "dark colored, splintery, somewhat arenaceous shale beds, bounded below by the Bear River formation and above by the coal-bearing Frontier formation." Veatch (91, p. 65) stated that the Aspen ranged in thickness from 1600 to 2200 feet but averaged 1800 feet.

Lithology, Thickness and Physiographic Expression

In the southern Gravelly Range the Aspen has undergone considerable erosion, particularly from its upper portion, which has resulted in poor exposures and an incomplete section. The local Aspen consists of alternating sandstones, shales, and a few tuffaceous clays.

The lowermost unit of the Aspen is a resistant thin- to medium-bedded sandstone, which is fine- to medium-grained, yellowish-gray to yellowish-brown on fresh fracture and weathers light brown or light yellowish-gray. Fossil wood fragments and pelecypods are abundant at some outcrops. Microscopically the sandstone consists of grains of quartz, chert, and argillaceous matter. The quartz and chert grains are angular to subrounded, the argillaceous grains rounded. The cement is quartz and argillaceous material. Accessory minerals are muscovite, biotite, and glauconite. This sandstone member is 120 feet thick in section 12, T. 12 S., R. 3 W., and approximately the same thickness throughout the thesis area. Because of its generally superior resistance, this sandstone unit is the most conspicuous ridge-maker in the Cretaceous section.

Overlying the sandstone is a nonresistant shale unit that does not crop out in the southern Gravelly Range. The position of the unit is marked by dark brown soil and small brownish-gray shale flakes on a grassy slope. This brown shale unit is about 150 feet thick in section 12, T. 12 S., R. 3 W.

The next higher stratigraphic unit consists of about 250 feet of nonresistant tuffaceous clays and varicolored sandy shales. The clays and shales are commonly pink or green and occasionally white or gray. These clays and shales are poorly exposed, but they appear to be lenticular in the thesis area. The shales appear to become progressively more sandy upward in the section and to grade into the overlying sandstone unit. The clays and shales of this unit form a hummocky miniature badland topography.

Above the clay and shale unit is a fairly resistant salt-and-pepper sandstone unit, which is medium- to thick-bedded and commonly is conspicuously mottled. These color irregularities are sometimes round, oval, or lens-shaped of the order of $\frac{1}{2}$ to 3 inches in diameter and are caused by local concentrations of white quartz and black chert grains. Microscopically the sandstone is coarse-grained, with over 85 per cent of the rock made up of subrounded quartz and chert grains and subhedral to euhedral acidic plagioclase crystals. This sandstone is dense and has a siliceous and ferruginous cement. Opaque ore mineral, fine-grained sandstone fragments, and biotite make up about 10 per cent of the rock. In section 12, T. 12 S., R. 3 W., this sandstone member is 27 feet thick and forms a conspicuous ridge between two shale members.

A covered interval distinguished by about 110 feet of brown soil and fragments of dark brown shale and mudstone overlies the second sandstone member.

The next stratigraphic unit consists of 30 feet of dark gray to brownish-black sandstone. This member is covered at many places, but where exposed it is thick-bedded and highly fractured. Microscopically about 80 per cent of this sandstone is well compacted and consists of subrounded quartz, subangular chert, and angular cryptocrystalline quartz grains. The cement is ferruginous and argillaceous. Its relatively high percentage of opaque ore mineral may explain the dark color of the rock. Accessory minerals include feldspar, argillaceous rock fragments, and biotite.

Above this sandstone unit in the thesis area are approximately 2000 feet of partly exposed alternating sandstone and shale units. These form rolling, soil-covered low hills and shallow valleys. Northwest of the thesis area several thin beds of coal crop out along Coal Creek. An abandoned coal mine is located on one of these coal beds.

The presence of marine fossils and glauconite in the lowermost sandstone unit of the Aspen indicates a definitely marine environment. The Aspen formation is generally regarded to be entirely marine (83, p. 82). However, because of the presence of 20 species of nonmarine molluscs, Yen (100) suggested the possibility of the Aspen being partly nonmarine in western Wyoming.

In the thesis area the Aspen is about 2700 feet thick, although the top of the formation is believed to be lacking on account of extensive erosion. Scholten (73, p. 368) states that in the Tendoy Range, west of the Gravelly Range, more than 3500 feet of Aspen is present and that the upper portion had been removed by pre-Tertiary erosion.

Fossils and Age

The age of the Aspen is considered late Lower Cretaceous by some authors and early Upper Cretaceous by others. The Bear River formation which underlies the Aspen in Wyoming is considered early Upper Cretaceous by Yen (100). Cobban and Reeside (15, p. 1015) consider the Aspen late Lower Cretaceous on the basis of the two ammonites, *Gastroplites* and *Neogastroplites*.

In the southern Gravelly Range the pelecypods *Inoceramus* and *Anomia* occur in the lower sandstone member of the Aspen. These are known to range from Jurassic to Recent and Silurian to Recent, respectively (76). I found no evidence to indicate the exact age of the Aspen in the southern Gravelly Range.

Regional Correlations

The Aspen formation can be traced over most of central, eastern, southern, and southwestern Montana and all of Wyoming. In the southern part of Wyoming lava flows form part of the sequence. The greatest thickness is in northern Utah and southwestern Wyoming (68).

To the west of the Gravelly Range, Scholten (73, p. 356) reports up to 3500 feet of Aspen which is lithologically and stratigraphically very similar to the formation in the thesis area. Mann (54, p. 34) mapped undifferentiated late Cretaceous beds in the central Gravelly Range and suggests their possible correlations with the Mowry and Aspen formations.

In the Camp Davis area of Wyoming, Dobrovolny (25, p. 438) reports the Aspen to contain gray sandstone, a number of green, gray, and white volcanic tuff beds, and some siltstone. He correlates the gray sandstone, volcanic tuff, and siltstone with the splintery and arenaceous shale of the type section in southwestern Wyoming.

In southeastern Idaho the Aspen is mostly nonmarine, and passes westward into the Wayan formation and eastward into the Mowry shale (83, p. 18).

The Aspen of the thesis area is possibly correlative with the upper part of the Wayan formation, which consists chiefly of red and gray sandstones and subordinately of shales and calcareous beds (55, p. 105-106).

The Blairmore group and Crowsnest formation of upper Cretaceous age in Alberta (82, p. 336) are possibly correlative with the Aspen of southwestern Montana. The Blairmore group consists of shale, sandstone, and limestone beds overlain by tuff and agglomerate beds of the Crowsnest formation.

High-level Gravels

Along the crest of the Gravelly Range is a conspicuous deposit of well-rounded to subrounded gravels ranging in thickness from 0 to 50(?) feet (figure 17). In the southern Gravelly Range these gravels lie on Cretaceous rocks. The size range of the gravels is from pebbles to boulders up to 10 feet in diameter; the composition ranges through gneiss, schist, quartzite, quartz, limestone, and chert. In general the lithology of the gravels closely resembles Precambrian and Paleozoic rocks to the east of the gravels. These gravels outcrop at most high elevations on the Cretaceous rocks, but only in sections 5 and 8, T. 12 S., R. 2 W., were these deposits large enough to map. A thickness of up to 50 to 60 feet is thought to be present at these outcrops.

Several authors (75) (2) (54) have studied these gravels and postulated a source. Scott (75) in 1938 stated that the gravel deposits on the Gravelly Range were an Eocene glacial deposit which he named the Black Butte till. He found the gravels to be typically exposed near Black Butte, which is about 5 miles north of the thesis area. In 1945 Atwood and Atwood (2) concluded that the Gravelly Range gravels were a glacial moraine deposit of Eocene age. They stated that during Eocene time the Gravelly Range was

Figure 17. High-level gravels along the crest of the Gravelly Range.

Figure 18. Basalt (Tvb) flows overlying Mission Canyon formation (Mmc) on Lobo Mesa.

a topographic low, and a glacier moved along what is now the crest of the Range.

Mann (54) studied the gravel deposit in detail and stated the gravels are not the result of a glacier but are a mudflow deposit. He concluded (54, p. 41) that the gravels could not be ascribed to a glacial origin owing to the warm climate in Eocene time and the low relief of the Gravelly Range during this epoch. Mann considered the mudflow to be middle to late Eocene or early Oligocene in age.

Poor exposures and absence of fossils prevented any further determination of the origin and age of the high-level gravels in the southern Gravelly Range.

Quaternary Alluvium

Unconsolidated soil and rock fragments from all rock units in the thesis area cover the floors of wide valleys, especially in the southern part of the area where the relief is low. In the southwest part of section 34, T. 12 S., R. 2 W., rocky soil was derived from the Mission Canyon, Amsden, Quadrant, Phosphoria, and Dinwoody formations and the Tertiary basalt flow of Landon Ridge. The soil and mantle rock in the wide valleys is gray to shades of brown and ranges from 0 to 50-75 feet thick above the bedrock.

Igneous Rocks

Most of the higher elevations in the southern Gravelly Range are the direct result of the resistance of basalt and rhyolite that cap portions of the Paleozoic and Mesozoic sedimentary rocks in the thesis area. Approximately 14 square miles of the thesis area consists of deeply eroded outcrops of rhyolite and basalt and minor outcrops of tuff and agglomerate.

Basalt

Lobo Mesa, Landon Ridge, Cascade Mountain, and the prominent hill south of Fossil Peak are all composed of flow basalt. Fossil Peak is interpreted as a volcanic neck. The flow basalt outcrops as massive, well-jointed and fractured layers that seldom show any tendency toward columnar structure. In section 13, T. 12 S., R. 2 W., flow basalt is about 800 feet thick (figure 18), and a few of the flows exhibit crude columnar structure. This unusually thick deposit of basalt on Lobo Mesa is believed to be the result of a flow into a valley eroded in the Mission Canyon limestone. Excluding Lobo Mesa, the thickness of the basalt elsewhere in the area ranges from almost 0 to 400 feet. By reason of columnar structure and its prominence compared to the surrounding basalt flows, Fossil Peak is thought to be a volcanic neck. Landon Ridge and the basalt hill immediately south of Fossil Peak are both believed to have their origin from the Fossil Peak neck. The basalt at Lobo Mesa and Cascade Mountain is thought to have originated from one of the two volcanic necks, Black Butte and Lion Mountain, described by Mann (54, p. 46), north of the thesis area.

The basalt in the southern Gravelly Range outcrops as black to dark gray rock that is dense or scoriaceous and erodes to angular blocky fragments. On fresh surface the basalt shows distinctive phenocrysts of olivine. Microscopically most of the basalt consists of a fine-grained groundmass of euhedral subparallel labradorite crystals, opaque ore and augite crystals. Olivine phenocrysts, which are commonly altered to antigorite, comprise about 15 per cent of the rock. Opaque phenocrysts of ore mineral of amphibole form make up about 7 per cent of the rock.

Rhyolite

Rhyolite is found on Patchtop Mountain, the northeast part of section 19, T. 12 S., R. 2 W., the southeast part of section 18, T. 12 S., R. 2 W., and as a small patch on Lobo Mesa in section 1, T. 12 S., R. 2 W. A source for this rhyolite is not known.

Like the basalt in the southern Gravelly Range, the rhyolite is poorly exposed and outcrops as blocky fragments. The rhyolite is reddish-gray to purplish-gray on fresh fracture and weathers lighter shades of these colors. Hand specimens reveal white phenocrysts which are probably oligoclase. Microscopically the rhyolite consists of phenocrysts up to 2 mm. in diameter of sanidine and oligoclase in a holocrystalline groundmass consisting of sanidine and quartz crystals with accessory diopside and opaque ore. The centers of the oligoclase phenocrysts are commonly altered to sericite.

Tuffs and Agglomerates

The only tuff in the thesis area is in the southern half of section 32, T. 12 S., R. 2 W. Here the tuff occurs as white, gray, yellowish-gray, and pinkish-gray fragments on a slope. No good exposures were found. The tuff is occasionally slightly calcareous and is associated with rhyolite; the direct relationship of the two rocks is uncertain owing to poor exposures. Microscopically about 20 per cent of the tuff consists of sanidine phenocrysts, and 50 per cent of glass shards. The shards are commonly bent and irregularly shaped. The sanidine phenocrysts are cracked and anhedral. Fragments of basalt, rhyolite, and pumice as well as volcanic glass comprise the remaining part of the rock.

The only agglomerate outcrop was found in the center of section 20, T. 12 S., R. 2 W., associated with a basalt flow. Megascopically, the agglomerate consists of subangular to angular fragments of white pumice(?), pink rhyolite(?), black basalt, and yellow-brown tuff in a yellow tuffaceous(?) matrix which makes up about 40 per cent of the rock. Most of the fragments are from 2 to 5 inches in diameter and are not stratified. The agglomerate is poorly indurated and readily weathers to a yellowish-brown soil. This rock is considered an agglomerate on the size and angularity of its fragments as well as its close association to the volcanic neck, Fossil Peak.

Age and Correlation of Igneous Rocks

Because of the absence of fossils and lack of interstratified sedimentary formations, the extrusive igneous rocks in the southern Gravelly Range are not dated with certainty. The basalt in the thesis area is lithologically similar to the Medicine Lodge volcanics of late Oligocene to early Miocene (73, p. 375). The rhyolite in the southern Gravelly Range can be tentatively correlated with the Muddy Creek volcanics that Scholten (73, p. 377) states are Oligocene in age. However, the rhyolite outcrop on Lobo Mesa is probably post-Miocene, since it overlies Miocene?

basalt flows. On the basis of vertebrate fossils, Mann (54, p. 43) suggests that the tuffs in the Gravelly Range were deposited during Oligocene time.

GEOMORPHOLOGY

The geomorphology of the southern Gravelly Range is directly related to the structure, which was formed during the Laramide orogeny.

Stream erosion has developed valleys along the strike of the nonresistant formations. Because of the greater resistance of some formations, a series of ridges have formed with the beds dipping to the west. On the east limb of the plunging anticline in the west half of the area the beds dip toward the east.

In section 24 and part of 19 and 30, T. 12 S., R. 2 W., an anticlinal valley was formed in part by the erosive action of the West Fork of the Madison River. In section 18, part of 7, T. 12 S., R. 2 W., and part of section 12, T. 12 S., R. 3 W., a synclinal valley is rapidly being deepened by Fox Creek.

Most of the streams in the southern Gravelly Range are subsequent, paralleling the strike of the strata. However, the West Fork of the Madison River transects the anticline in the western half of the area and flows perpendicular to the strike of the strata in the southeastern part of the thesis area. Hence, this river probably is a superposed stream. Mann (54, p. 62) suggests that the Ruby River, to the west of the thesis area, originated on

Oligocene lava flows and was superposed on the underlying structure. The West Fork of the Madison River in the thesis area could have a similar origin.

Where basalt and rhyolite flows have not been completely eroded from sedimentary rocks, small mesas have formed in the thesis area. Landon Ridge in the southeast part of the area, and Lobo Mesa and Divide Mountain in the northeast part are examples of mesas resulting from erosion of basalt-capped sedimentary rocks. Patchtop Mountain in section 32, T. 12 S., R. 2 W., is a small mesa consisting of horizontal rhyolite overlying tilted Permian and Triassic strata.

Downgrading of the southern Gravelly Range is the direct result of fluvial erosion and slumping. The effects of glaciers in the thesis area are minor.

In section 26, T. 12 S., R. 3 W., a portion of an Aspen sandstone unit has slumped along the dip slope into Fish Creek. Slumping of parts of the Aspen formation is not uncommon, owing to the nonresistant shale units overlain by sandstone.

The thesis area is characterized by a drainage system adjusted to the structure, and in the extreme southern part streams are beginning to meander. The relief of the area is approaching its maximum, and the area consists mostly of slopes of hillsides and valley sides. The southern Gravelly Range is thought to be in the early part of the mature stage of the fluvial cycle.

STRUCTURAL GEOLOGY

The Gravelly Range is located in the Northern Rocky Mountain physiographic province of the Rocky Mountain System. The Gravelly Range forms the east limb of a large south-plunging syncline; the Greenhorn and Snowcrest Ranges make up the west limb. To the south of the Gravelly Range the Centennial Valley represents a graben structure, and to the east the Madison Valley is an anticlinal valley.

The Laramide orogeny is responsible for the formation of the folds, and post-Laramide deformation caused the gravity faults in the southern Gravelly Range. No evidence was found in the thesis area for thrust faulting which is common in adjacent areas (73, p. 382-384) (54, p. 52).

Folds

Two major folds comprise the major structure in the thesis area, a northwest-trending plunging anticline and corresponding plunging syncline located to the east. The folding was caused by compression in a northeast-southwest direction.

The anticline, whose axis trends approximately N. 30° W., is over 7 miles long. The anticline plunges about 20 degrees northwestward and is asymmetrical, its west limb dipping 15 to 20 degrees and the east limb dipping 45 to 50 degrees. The West Fork of the Madison River exposes rocks as old as Pennsylvanian in the southern part of the anticline, and to the northwest the anticline includes the upper part of the Aspen formation (figure 19) of Cretaceous age.

The syncline adjacent on the east plunges about 20 degrees in a N. 20° W. direction. The syncline is asymmetrical, the west limb dipping about 45 to 50 degrees, and the east limb dipping about 20 degrees. Rocks as young as the Aspen formation are exposed in the northern part of the syncline, and Permian rocks are exposed in the southern part. Most of the formations in the syncline, unlike those in the anticline, are obscure or covered by Tertiary rhyolite and basalt. The east limb of the syncline forms the Gravelly Range and can be followed 40 miles northward.

In the southern Gravelly Range the Aspen formation is the youngest formation that is folded. Relatively horizontal Oligocene? basalt and rhyolite flows cap part of the folds so as to suggest that the folding is post-upper-Cretaceous and pre-Oligocene?.

Faults

A high-angle gravity fault about 2 miles long occurs in the north half of sections 21 and 22, T. 12 S., R. 2 W.

Figure 19. Nose of anticline, illustrating approximate position of axis along West Fork of the Madison River. Ka (Aspen formation), Kc (Colorado formation), Kk (Kootenai formation).

The strike of the fault is approximately N. 85° W., and the downthrown side is to the south, with strata displaced down and toward the east. The strike-slip is about ½ mile, and the dip-slip about 500 feet.

In section 16, T. 12 S., R. 2 W., a gravity fault about 3/4 mile long has an approximate east-west strike and a downthrown side to the south. A displacement of about 200 feet along the dip of the fault exposes the Quadrant formation on the north and the Phosphoria on the south of the fault.

A fault perpendicular to the strike of the strata that diagonally transects sections 24 and part of 14, T. 12 S., R. 3 W., parallels the West Fork of the Madison River. The displacement is about 200 feet, and the fault strikes approximately N. 40° W. All formations from Woodside to Aspen are displaced along this fault.

A fault similar to the one at the West Fork of the Madison but showing an approximate east-west strike is located in the extreme south part of section 8 and extreme north part of section 9, T. 12 S., R. 2 W. The Colorado and Aspen formations are offset about 450 feet along this fault, which is approximately 3/4 of a mile long.

Fault Lake in sections 5 and 8, T. 12 S., R. 2 W., represents a small graben. The faults forming the graben are each about 1 mile long, and the graben is about 500 feet wide. The graben has vertical sides of about 400 feet in the Aspen and Colorado formations.

In section 10, T. 12 S., R. 2 W., Woodside rocks are stratigraphically displaced so as to lie adjacent to the Dinwoody rocks on the ridge north of Cascade Mountain, a circumstance most simply explained by a gravity fault with the downthrown side to the south. Dip-slip displacement along this fault seemingly is about 500 to 800 feet. Although the fault cannot be traced any distance, its easterly trend is in a direction that would coincide with a small displacement in Mission Canyon rocks in section 12, T. 12 S., R. 2 W., about three miles distant.

No Tertiary sediments are present in the southern Gravelly Range by which the faults can be dated. However, Scholten (54, p. 387) states that most of the block faulting west of the thesis area is post-Laramide, Miocene or possibly also Oligocene. Honkala (40, p. 112) states that in Pleistocene time block faulting along previously established lines accentuated the topography in the Centennial region.

GEOLOGIC HISTORY

During Precambrian time the Cherry Creek group was formed when clastic and nonclastic sediments previously deposited in a miogeosyncline were metamorphosed. These Precambrian metamorphic rocks were uplifted and eroded to a relatively flat surface before the inundation by Middle Cambrian seas.

The Paleozoic and most of the Mesozoic sediments in the southern Gravelly Range were deposited on a relatively stable shelf environment which lay between the miogeosyncline to the west, the shelf area of Wyoming to the southeast, and the craton to the east. The Flathead formation of Middle Cambrian age seemingly derived its quartz sands and conglomerates from Precambrian rocks located to the east of the area. Advancing shorelines during the Cambrian accompanied by deposition of the Wolsey shales was followed by the limestones of the Meagher formation. In the mountain ranges surrounding the thesis area the Park shale and Pilgrim limestone overlie the Meagher. Since these two formations are absent in the southern Gravelly Range, either this area was a positive element during this time or the Park and Pilgrim were deposited and then were eroded.

Most of southwestern Montana, including the thesis area, probably was emergent from Late Cambrian to Middle

Devonian time. If any sediments were deposited during this time, they were removed prior to deposition of late Devonian formations.

Clear seas marked the deposition of the Upper Devonian Jefferson dolomite, but these were followed by muddy seas from which was deposited the overlying shale unit. Three Forks seas alternated from muddy to clear as attested by the presence of the shales, mudstones, and limestones that are characteristic of the formation in the thesis area.

The slight disconformity that probably exists between the Three Forks and Lodgepole formations represents a slight period of erosion following the deposition of the Three Forks mudstones. Owing to the presence of limestones, Mississippian time probably was represented by clearer seas than those of latest Devonian time in this area. After the deposition of the Lodgepole formation, the seas became clearer and deposition of massive Mission Canyon limestone and chert took place.

The Big Snowy group, which represents upper and middle Mississippian rocks over much of southwestern Montana, was probably deposited in the area of the Gravelly Range also. However, a distinctive erosion surface associated with a limestone conglomerate and breccia in the Mission Canyon formation and lack of Big Snowy equivalents suggest a period of erosion during late and possibly middle Mississippian time.

Earliest Pennsylvanian time is represented by an influx of clastic material that gradually became coarser. The deposition of argillaceous limestones of the Amsden was followed by deposition of arenaceous material of the Quadrant formation, which is commonly calcareous and associated with clastic dolomite. Uplift and erosion during late Pennsylvanian time is suggested by the disconformity separating the Quadrant and Phosphoria formations.

Permian sediments were deposited in relatively shallow seas with abundant siliceous organisms which provided a possible source for the massive chert beds. Cressman (21, p. 15) indicated the presence of a thin layer of phosphate rock at the base of the Phosphoria section in the southern Gravelly Range. This lithology suggests a reducing environment prior to the influx of upper Phosphoria quartz sands that overlie it.

During early Triassic time the water became muddy, and calcareous shales and muddy limestones were deposited. The presence of the characteristic brachiopod Lingula indicates muddy shallow-water environmental conditions during Dinwoody time. The predominance of redbeds in the Woodside formation immediately above the Dinwoody formation suggests that the area was uplifted to flood-plain conditions. Ripple marks, which are common in both the Dinwoody and Woodside formations, indicate that during part of the time these formations were deposited in very shallow water. Calcareous and argillaceous rocks of the Thaynes formation, overlying the Woodside, represent environmental conditions similar to those of the Dinwoody.

Middle and Late Jurassic deposits are believed to have been deposited over the thesis area and later partly eroded away. A very thin section of the Ellis group is present in the southeastern part of the thesis area but is absent over the rest of the area. Relatively shallow, unstable marine environmental conditions existed during the deposition of the glauconitic sandstone of the Ellis, followed by clear waters in which limestone was deposited. Late Jurassic is represented by the Morrison formation, whose lithology suggests flood-plain conditions. The occasional beds of limestone in the Morrison possibly were deposited in fresh-water lakes.

Early Cretaceous time witnessed conditions similar to those of the late Jurassic. Conglomeratic sandstones, fresh-water limestones, and argillaceous rocks were deposited on floodplains or lowlands associated with lakes and rivers.

The Colorado and lower part of the Aspen formation of middle and late Cretaceous age are considered to be marine on the basis of their fossils. During middle and late Cretaceous time, marine seas transgressed over the area and deposited the shales and marine sandstones of the Colorado and Aspen formations. The upper part of the Aspen formation represents terrestrial conditions as indicated by the presence of land plants (73, p. 396).

The Laramide orogeny in the late Cretaceous and early Tertiary caused most of the major folding in the southern Gravelly Range. Faulting is believed to have taken place in mid-Tertiary (Miocene?) time. Northwest-trending folds in the thesis area were caused by compression from the west and southwest. Four gravity faults trending east-west and having the downthrown side to the south are present in the thesis area.

Tertiary time witnessed erosion of the entire thesis area, followed by deposition of rhyolite, and basalt flows associated with tuff and agglomerate deposits. Exact dating of these deposits is uncertain. However, Scholten (73, p. 397-398) states that Eocene, part of Oligocene, and all of Miocene time was dominated by periods of erosion followed by deposition of lavas and pyroclastics.

High-level gravels occur over parts of the thesis area and were deposited possibly by glaciers during Eocene time. At lower levels in the extreme southern part of the thesis area, alluvial fill derived from the rounded hill tops is being deposited.

ECONOMIC GEOLOGY

Mineral resources in the southern Gravelly Range probably are of small value but are known to include placer gold. Coal and oil possibly are present in rocks in the area. Water is a natural resource, as well as large stands of timber.

In sections 14, 23, 24, and 30, T. 12 S., R. 2 W., placer gold has been recovered in the valley of the West Fork of the Madison River. The Minerals Yearbook (88, p. 420) lists the production in 1936 as 4.63 fine ounces of gold valued at $162 and in 1941 (89, p. 370), 28 fine ounces valued at $980. Gold may have been recovered during other years, but production was probably small or unreported since no other listings were made. Atwood and Atwood (2, p. 198) stated that gold has been recovered from the gravels along the crest of the Gravelly Range and several claims have been staked. Because of the presence of the gold in the high-level gravels, the gold found along the West Fork of the Madison may have come from these deposits.

An abandoned coal mine is located in Aspen rocks about 2 miles north of the thesis area in section 28, T. 11 S., R. 3 W. Carbonaceous films are interstratified with the beds in the uppermost part of the Aspen formation in the thesis area, but no coal deposits are known.

An irrigation canal diverts the water of the West Fork of the Madison River to the ranches directly south of the thesis area. In section 24, T. 12 S., R. 2 W., the irrigation canal drains the West Fork of the Madison and empties it into Metzel Creek two miles south.

The faulted anticline located in the western half of the thesis area possibly contains oil, especially in the Mississippian and Devonian limestones. Oil from formations of these ages has been produced in other parts of Montana and Wyoming. However, lack of closure of the plunging structure, as well as lack of any known oil-producing beds in the vicinity, make it unlikely that the area offers any favorable chance for oil production.

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APPENDIX

MEASURED STRATIGRAPHIC SECTIONS

Aspen Formation

Section along the west bank of the West Fork of the Madison River, West ½, Sec. 12, T. 12 S., R. 3 W.

		Thickness in feet
1.	Sandstone, salt-and-pepper, with vari-colored shales and pastel-colored clays; few light gray limestone beds; the sand-stones form ridges between the shales and clays.	2000 (est.)
2.	Sandstone, dark gray; bedding massive; highly fractured; weathers medium brown to black; uppermost part of unit covered by dark brown soil.	30
3.	Covered; marked by medium brown soil.	32
4.	Covered; marked by dark brown soil and mudstone fragments.	78
5.	Sandstone, intermixed light gray and very dark gray lenses associated with varying shades of brown sandstone; prominent ridge former.	27
6.	Tuffaceous clay lenses, light green and pink forming hummocky slopes; poorly exposed.	250
7.	Covered; light brown soil and light gray salt-and-pepper sandstone fragments on slope.	152
8.	Covered; includes brown soil and yellow-brown sandstone.	72
9.	Graywacke sandstone, yellowish brown, non-calcareous, weathering dark brown, fine- to medium-grained; bedding 2 to 7 inches; fossil wood fragments and pelecypods common in some outcrops.	48
	Total thickness of Aspen formation	2689

Colorado Formation

Section on north bank of the West Fork of the Madison River, SW$\frac{1}{4}$, Sec. 12, T. 12 S., R. 3 W.

		Thickness in feet
1.	Covered; light brown soil and light brownish-gray sandy shale fragments.	127
2.	Covered; soil ranging from bluish gray to black; iron concretions (less than 9" long) common.	78
3.	Covered; black soil.	10
4.	Shale, greenish gray, weathers light gray; mudstone concretions (smaller than 6" long) pancake shaped and parallel to bedding planes.	14
5.	Sandstone, rusty orange on both fresh and weathered surfaces; fine grained; flow casts and ripple marks on bedding surfaces; weathered surfaces iron stained; minor faulting common; thin beds of shale in lower half.	10
6.	Covered; marked by black soil and dark brown shale fragments.	33
	Total thickness of Colorado formation	272

Kootenai Formation

Section on the west bank of Fossil Creek, SW $\frac{1}{4}$, Sec. 4, T. 12 S., R. 2 W.

1.	Sandstone, brownish orange, fine- to medium-grained, massive-bedded; ripple marks, flow casts, and cross-bedding very common; bedding surfaces commonly iron stained.	97
2.	Limestone, light gray, coarse- to medium-crystalline, with numerous gastropods; lenses of oolitic limestone common.	88

		Thickness in feet
3.	Covered; dark brown soil and gastropod limestone fragments.	50
4.	Covered; reddish-brown soil and reddish-black shale fragments.	21
5.	Limestone, light gray, dense, medium-bedded (3" to 8"); some limestone conglomerate locally.	25
6.	Covered; dark red to black soil.	8
7.	Limestone; medium gray, medium-bedded; chert veins irregularly throughout; limestone conglomerate lenses common.	34
8.	Limestone, light grayish-brown, weathers light brown, finely crystalline, thin-bedded (2" to 7").	26
9.	Covered; marked by red soil and yellow mudstone fragments.	10
10.	Sandy limestone, yellow, weathers to pale shades of yellow and orange, medium grained, thick-bedded (1' to 4').	17
11.	Covered; dark brown soil.	41
12.	Sandstone, light gray, weathers darker gray and stained to rust yellow or red from iron, coarse-grained with black, yellow and red chert pebbles, crudely thick-bedded.	20
13.	Covered; includes black soil and cherty sandstone fragments, yellowish to grayish brown; chert pebbles up to $1\frac{1}{4}$" long common.	75
	Total thickness of Kootenai formation	512

Morrison Formation

Section northeast of Fault Lake, North ½, Sec. 4, T. 12 S., R. 2 W.

		Thickness in feet
1.	Covered; red soil and sandy red shale fragments.	169
2.	Covered; black soil; few dark brown shale fragments.	43
3.	Covered; black soil and salt-and-pepper sandstone fragments.	12
4.	Covered; dark brown soil and shale fragments.	38
5.	Shale, grayish blue to grayish tan, fissile, very nonresistant.	5
6.	Sandstone, yellow, weathers grayish yellow, well sorted, beds are 2" to 4" thick; beds grade into the graywacke sandstone below.	44
7.	Graywacke sandstone, yellowish gray, weathers yellowish brown, bedding crude but varies up to 3' thick; hand lens shows quartz grains in a calcareous ferruginous cement; this sandstone erodes to large angular blocks.	38
8.	Shales and mudstones, green and red, medium-bedded (7" to 10"), calcareous, interbedded with thick (1-1½') limestone beds.	14
9.	Shales, green and red, calcareous, fissile, nonresistant.	7
10.	Limestone, gray, finely crystalline, massive.	4
11.	Mudstone beds, green, thin-bedded (up to 6"), calcareous, intercalated with less resistant green and red shale beds. At base of unit is a limestone bed, gray, finely crystalline, one foot thick.	35

		Thickness in feet
12.	Shale, red, weathers pale red, fissile, nonresistant, calcareous.	3
13.	Limestone, red and green, massive and highly jointed.	9
14.	Siltstone, brownish gray to greenish gray, medium-bedded (6" to 11").	4
15.	Limestone, light gray, with gray, red and brown mudstone fragments; quartz veins and fillings irregularly throughout limestone beds.	2
16.	Siltstone, gray, nonresistant, poorly exposed.	3
17.	Siltstone, grayish red, weathers to pale red slopes.	11
18.	Siltstone, greenish gray, very nonresistant, weathers light green.	10
19.	Covered; greenish-gray soil.	13
20.	Mudstone, red, single bed.	1
21.	Mudstone, greenish gray, medium-bedded (7" to 1').	3
22.	Siltstone, green to buff, thick-bedded (1' to 2').	6
23.	Mudstone, red, weathers pale red, very nonresistant.	2
24.	Siltstone, reddish yellow to buff, weathers pale yellow, nonresistant.	1
	Total thickness of Morrison formation	477

Ellis Group

Section on the north bank of Anderson Creek, NW$\frac{1}{4}$, Sec. 24, T. 12 S., R. 3 W.

		Thickness in feet
1.	Limestone, light gray, float; limestone has chert nodules and stringers; green mudstone veins and nodules in upper part.	29
2.	Sandstone, greenish gray and iron stained, massive.	12
3.	Covered with grayish-green soil; greenish-gray sandstone as float.	45
	Total thickness of Ellis group	86

Thaynes Formation

Section northeast of Fault Lake, North $\frac{1}{2}$, Sec. 4., T. 12 S., R. 2 W.

1.	Mudstone pebbles in calcareous sandstone matrix; bedding 8" to 10" thick and intercalated with tan colored sandstone, siltstone, and mudstone beds 2" to 8".	11
2.	Siltstone and sandstone, tan colored, beds 2" to 1'.	5
3.	Sandstone and mudstone beds, tan colored, medium-bedded (5" to 7"); few small unidentifiable brachiopods? At Base of unit is 1' thick bed of sandstone with mudstone pebbles averaging 3/4" diameter.	4
4.	Sandstone, dolomitic, reddish brown, thin-bedded (2" to 5"); sandstone beds intercalated with thin, light brown mudstone beds; fossil fragments (brachiopods?).	7
5.	Shale, light green, micaceous, weathers pale grayish green, fissile.	4

		Thickness in feet
6.	Siltstone and mudstone beds, intercalated, red and light brown, thin-bedded ($\frac{1}{4}$" to 2").	7
	Total thickness of Thaynes formation	38

Woodside Formation

Section on west bank of Fossil Creek, NW $\frac{1}{4}$, Sec. 9, T. 12 S., R. 2 W.

1.	Siltstone and shale, red, thin-bedded (1" to 4"); interbedded with tan, calcareous siltstone (2" to 5") in upper 10 feet.	114
2.	Siltstones and mudstones, interbedded, red, thin- to medium-bedded ($\frac{1}{2}$" to 11").	293
3.	Covered; marked by red soil.	115
	Total thickness of Woodside formation	522

Dinwoody Formation

Section along Fossil Creek, Sec. 9, T. 12 S., R. 2 W.

1.	Covered; marked by red soil from Woodside formation.	48
2.	Limestone, silty, light brown to gray, weathers red from overlying Woodside formation; medium-bedded (5" to 9").	17
3.	Sandstone, calcareous, light brown, interbedded with light brown siltstone beds; beds vary from 4" to 13" and weather light brown; ripple marks and worm trails common.	40
4.	Siltstone, calcareous, light brown, weathers rust brown to dark brown, medium-bedded (3" to 7"); ripple marks and worm trails common.	28

		Thickness in feet
5.	Covered; reddish-brown soil.	36
6.	Sandstone, calcareous, light brown, weathers dark brown and gray, medium-bedded (3" to 9").	4
7.	Covered; marked by light brown to reddish brown soil.	38
8.	Mudstone, calcareous, light brown, thick-bedded (1' to 1½'); thin layers of black carbonaceous matter between the beds.	11
9.	Limestone, light brown, weathers darker brown, medium-bedded (4" to 8"); unidentifiable brachiopods.	43
10.	Limestone, gray, sandy, thin-bedded (2" to 3½").	31
11.	Covered; brown soil.	22
12.	Limestone, silty, light brownish gray to light gray, weathers dark brown, thin- to medium-bedded (4" to 16").	8
13.	Covered; light brown soil.	30
14.	Mudstone, slightly calcareous, light brownish gray, medium-bedded (3" to 11"), numerous brachiopods.	5
15.	Limestone, dense, blue gray; weathers light brown to blackish brown, medium-bedded (2" to 10").	4
16.	Limestone, silty, light brown; brachiopods fairly common.	4
17.	Covered; brown soil.	11
18.	Siltstone, calcareous, medium-bedded (8" to 12") alternating with beds somewhat thinner (2" to 3").	7

		Thickness in feet
19.	Limestone, shaly, grayish green, weathers light green, thin-bedded (½" to 2"); fossil fragments (brachiopods?) common.	32
20.	Covered; includes light brown calcareous sandstone weathering dark brown; slabs approximately 4" thick common.	49
	Total thickness of Dinwoody formation	468

Phosphoria Formation

Section in SW¼, Sec. 2, T. 12 S., R. 2 W.

1.	Sandstone, light shades of reddish brown and yellowish brown, weathers darker shades; unidentifiable pelecypods present.	17
2.	Covered; includes sandstone, gray that weathers brown to dark gray and dark brown; pelecypods (unidentifiable) abundant.	11
3.	Sandstone, gray, quartzitic; poorly exposed.	50
4.	Chert, brown, tan, white, yellow and red, massive.	29
5.	Covered; chert and gray quartzitic sandstone rubble.	54
6.	Chert, white, yellow, gray, red and brown, weathers to black and green from lichen growth, medium-bedded (2" to 7").	10
7.	Sandstone, quartzitic, and contains chert nodules and stringers; sandstone light gray and light brown, weathers dark gray; chert is white to grayish yellow.	4

		Thickness in feet
8.	Covered; oolitic sandstone and chert.	27
9.	Covered; varicolored chert.	50
10.	Covered; chert and quartzitic sandstone boulders and few chert boulders; sandstone weathers brownish gray.	49
11.	Covered; light gray, quartzitic sandstone; chert is yellow to shades of red; sandstone is light gray.	53
12.	Sandstone, quartzitic, light brown to buff with chert stringers and veins crossing the bedding at right angles; sandstone medium-bedded (3" to 7"); chert weathers reddish brown and sandstone weathers light gray.	22
13.	Covered; quartzitic, gray sandstone.	17
14.	Sandstone, quartzitic, light gray to light brown, weathers dark gray and reddish brown, massive, conchoidal fracture.	6
	Total thickness of Phosphoria formation	399

Quadrant Formation

Section along the West Fork of the Madison River, Sec. 27, T. 12 S., R. 2 W.

1.	Sandstone, yellowish brown, weathers light gray, medium-bedded; poorly exposed.	46
2.	Covered; grayish brown soil.	57
3.	Sandstone similar to unit 1.	82
4.	Sandy dolomite, shades of pinkish gray to yellow, slightly calcareous, medium-grained and well indurated; no definite bedding; poorly exposed.	130

		Thickness in feet
5.	Covered; includes light shades of pink and yellow, medium-grained sandstone.	175
6.	Limestone, coarsely crystalline, massive; fossil fragments (unidentifiable).	30
7.	Sandstone, light yellow to light gray to tan, medium-grained, calcareous, crudely medium-bedded.	7
	Total thickness of Quadrant formation	527

Amsden Formation

Section along the West Fork of the Madison River, Sec. 27, T. 12 S., R. 2 W.

1.	Covered; red soil and Quadrant sandstone fragments.	21
2.	Covered; red soil and sandy argillaceous limestone fragments; soil is partly sandy.	97
	Total thickness of Amsden formation	118

Madison Group

Mission Canyon Formation

Section along the West Fork of the Madison River, Sec. 26, T. 12 S., R. 2 W.

1.	Covered; limestone, light gray, containing chert nodules and stringers.	195
2.	Limestone, mouse gray, weathers orange and grayish red shades from overlying formation, massive; chert nodules and bands (1" to 2") parallel bedding planes.	75
3.	Covered; marked by light gray, finely crystalline limestone fragments.	253

		Thickness in feet
4.	Limestone, light gray, weathers slightly darker gray to shades of brown, finely crystalline; horn corals abundant; beds highly fractured.	75
5.	Limestone, mouse gray, weathers darker gray, medium- to coarse-crystalline, medium-bedded (3" to 15"); beds highly fractured perpendicular to bedding planes; horn corals common.	100
6.	Limestone, gray, weathers to light brown to bluish gray, medium-crystalline, very thick-bedded (8' to 50').	288
7.	Limestone, light gray to shades of light brownish gray, thin-bedded (1" to 5"); some beds have thin layers of mudstone between them; brachiopods fairly common.	48
8.	Limestone, brownish gray, weathers shades of dark brown, medium-crystalline, thin- to thick-bedded (1" to 31"); few thin (less than ½") beds of light brown mudstone between the thick limestone beds.	42
9.	Limestone, bluish gray, weathers brownish gray, finely crystalline, medium-bedded (4" to 7"); few to no fossils.	84
	Total thickness of Mission Canyon formation	1160

Lodgepole Formation

Section along the West Fork of the Madison River, Sec. 26, T. 12 S., R. 2 W.

Woodhurst member

1.	Limestone, medium gray, weathers bluish to brownish gray, medium- to thick-bedded (7" to 18"), few fossils.	24

		Thickness in feet
2.	Limestone, dark gray to black, weathers light brown, dense, very thin-bedded (1" to 2").	21
3.	Limestone, light gray, weathers light brown, thin-bedded (3" to 6"), few fossils.	39
4.	Limestone, bluish gray, finely crystalline, thin-bedded (1" to 6"), relatively fossiliferous (brachiopods and some crinoids).	63
5.	Covered; marked by light gray to bluish-gray limestone.	102
6.	Limestone, light gray, finely crystalline, thin bedded (1" to 5"); white veins of calcite irregularly transgress beds.	70
7.	Limestone, dark gray to black, weathers light gray to light brown, very dense, thin- to medium-bedded (2" to 8"); some of the thinner beds very fossiliferous.	88
8.	Limestone, medium gray, weathers light gray, thin-bedded (2" to 3"), very fossiliferous (brachiopods).	210
	Total thickness of Woodhurst member	617
Paine member		
1.	Limestone, medium gray, weathers dark brown, dense, medium-bedded (4" to 8").	117
2.	Limestone, gray, weathers shades of reddish brown, thin-bedded (1" to 4").	37
3.	Limestone, medium gray, weathers reddish brown, medium-bedded (4" to 13"); chert nodules up to 8" long parallel to bedding planes.	43
4.	Covered; brown soil.	9

		Thickness in feet
5.	Limestone, dark gray, medium- to thick-bedded (4" to 19"), finely crystalline, few fossils.	34
6.	Limestone, light to medium gray, dense, thin-bedded (1" to 6"), some chert nodules; fossils (crinoid stems and brachiopods) common in some beds.	14
7.	Covered; includes brown soil and light gray limestone.	59
	Total thickness of Paine member	313
	Total thickness of Lodgepole formation	930
	Total thickness of Madison group	2090

Three Forks Formation

Section along the West Fork of the Madison River, Sec. 25, T. 12 S., R. 2 W.

1.	Covered; includes limestone from Madison group.	33
2.	Mudstone breccia, shades of gray and yellow mudstone in a red argillaceous matrix, very calcareous.	73
3.	Mudstone breccia, red matrix with pink and white mudstone fragments; very calcareous; no fossils.	14
4.	Limestone, light brown to reddish brown, weathers reddish brown, finely crystalline, thin- to medium-bedded (2" to 18").	16
5.	Covered; reddish brown soil.	16
	Total thickness of Three Forks formation	152

Jefferson Formation

Section along the West Fork of the Madison River, Sec. 25, T. 12 S., R. 2 W.

		Thickness in feet
1.	Covered; light brown soil and brown limestone fragments.	77
2.	Limestone, light brown, weathers light brown to dark brown, finely crystalline, thin-bedded (2" to 5").	20
3.	Limestone, dark brown, weathers very dark brown to black, medium-bedded.	40
4.	Limestone, dark brown, weathers dark brown to black, finely crystalline, crudely thin-bedded.	32
5.	Covered; marked by dark red soil and small, shaly-mudstone fragments; non-resistant unit forming gentle slopes.	55
6.	Covered; marked by red soil and red, green, and brownish-yellow shale fragments and medium-crystalline, reddish-brown limestone.	132
7.	Dolomite, dark brown, mottled dark and light brown on weathered surface, fine- to medium-crystalline, thin-bedded (1" to 3").	149
	Total thickness of Jefferson formation	505

Meagher Formation

Section along the West Fork of the Madison River, NE $\frac{1}{4}$, Sec. 36, and SE $\frac{1}{4}$, Sec. 25, T. 12 S., R. 2 W.

1.	Limestone, slightly dolomitic, dark gray, weathers bluish gray, dense, thin- (1" to 4") to thick-bedded (12" to 19").	218

		Thickness in feet
2.	Covered; marked by finely crystalline gray limestone that weathers to a brown rough surface.	59
3.	Limestone, gray to light brown, medium-crystalline, thin- to thick-bedded (2" to 1½'), conchoidal fracture.	12
4.	Limestone, dolomitic, brown, weathers to a grayish-brown smooth surface, thin-bedded (1" to 4").	19
5.	Limestone, light grayish brown, weathers dark brown, dense, thin-bedded (2" to 3").	21
6.	Limestone, grayish brown to shades of pink, weathers dark brown to dark gray rough surface, dense to medium-crystalline, massively bedded.	65
7.	Limestone, pink to reddish gray, finely crystalline, thin-bedded up to 6' but few beds 1'; limestone iron stained, causing rust-colored veins and fractures.	123
	Total thickness of Meagher formation	517

Wolsey Formation

Section along the West Fork of the Madison River, NW¼, Sec. 31, T. 12 S., R. 1 W.

1.	Covered; includes limestone from Meagher formation.	65
2.	Covered; marked by green-gray soil; tan colored glauconitic sandstone fragments and green shale fragments.	163
	Total thickness of Wolsey formation	228

Flathead Formation

Section along the West Fork of the Madison River, NW$\frac{1}{4}$, Sec. 31, T. 12 S., R. 1 W.

		Thickness in feet
1.	Sandstone, tan colored, thin-bedded (1" to 5"), alternating with thin beds of green glauconitic sandstone and green shales.	19
2.	Sandstone, quartzitic, buff, medium-bedded (2" to 7"), cross-bedded; intercalated with few thin green shale beds.	35
3.	Sandstone, quartzitic, rusty yellow brown to dark red and dark gray, weathers darker shades of these colors, thin- (1" to 4") to thick-bedded (2' to 5'); clear quartz pebbles common at base of unit.	76
	Total thickness of Flathead formation	130