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Title: STRATIGRAPHY AND STRUCTURE OF THE CEDAR CREEK AREA OF THE MADISON RANGE, MADISON COUNTY, MONTANA

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Dr. David A. Bostwick

The Cedar Creek area, consisting of about 30 square miles, is located on the west flank of the central Madison Range in Madison County, Montana.

The rocks of the area include carbonates, sandstones, mudstones, cherts, phosphorite, metamorphic rocks, intrusive igneous rocks, and unconsolidated sediments and have been divided into 16 mapped units.

An undetermined thickness of Precambrian metamorphic basement rocks, approximately 7,000 feet of sedimentary rocks, and an undetermined thickness of Tertiary intrusive igneous rocks are exposed in the area. In addition, surficial deposits of unconsolidated alluvium and landslide debris are present in the area.

Sedimentary rocks in the area are correlated with the Devonian Jefferson and Three Forks Formations, the Mississippian Lodgepole

and Mission Canyon Formations, the Mississippian-Pennsylvanian Amsden Formation, the Pennsylvanian Quadrant Formation, the Permian Park City, Shedhorn, and Phosphoria Formations, the Triassic Dinwoody Formation, the Jurassic Sawtooth, Rierdon, and Morrison Formations, and the Cretaceous Kootenai Formation and Colorado Group.

The area has undergone two major episodes of deformation. The first occurred in latest Cretaceous to Early Tertiary time when compressive forces produced thrust-faulting and folding in the area. During the second episode, tensional forces, probably related to epeirrogenic uplift, initiated normal faulting in the area.

Stream erosion and several cycles of glaciation have modified the topography of the area to its present form.

No stratigraphic or structural conditions in the area are favorable for the accumulation of oil and gas. Beds of furnace-grade phosphorite are present in the area, but at this time the cost of mining the phosphorite beds is far greater than the value of the phosphorite.

Stratigraphy and Structure of the Cedar Creek Area of the Madison Range, Madison County, Montana

by

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INTRODUCTION

Location and Accessibility

The Cedar Creek area, lying about six miles southeast of Ennis, Montana, comprises about 30 square miles in the west-central part of Madison County. With the exception of about four square miles that are privately owned, the Cedar Creek area lies within the Ennis Ranger District of the Beaverhead National Forest. The Cedar Creek area consists of parts of Townships 6 and 7 South, and Ranges 1 and 2 East in the southeasternmost part of the Ennis quadrangle. The north-flowing Madison River lies west of the Cedar Creek area, and the crest of the north-south trending Madison Range lies east of the Cedar Creek area.

Access to the Cedar Creek area is somewhat limited. The nearest paved road is U.S. Highway 287, three miles to the west. Two gravel roads extend from the highway to the edge of the Cedar Creek area, one to the Double M Ranch in the SE1/4 sec. 10, T. 6 S., R. 1 E., the other to the Cedar Creek Ranch in the SW1/4 sec. 15, T. 6 S., R. 1 E. A good dirt road from the highway to the mouth of the Shell Creek canyon in sec. 33, T. 6 S., R. 1 E. provides access to the southern part of the area. A dirt road from the Cedar Creek

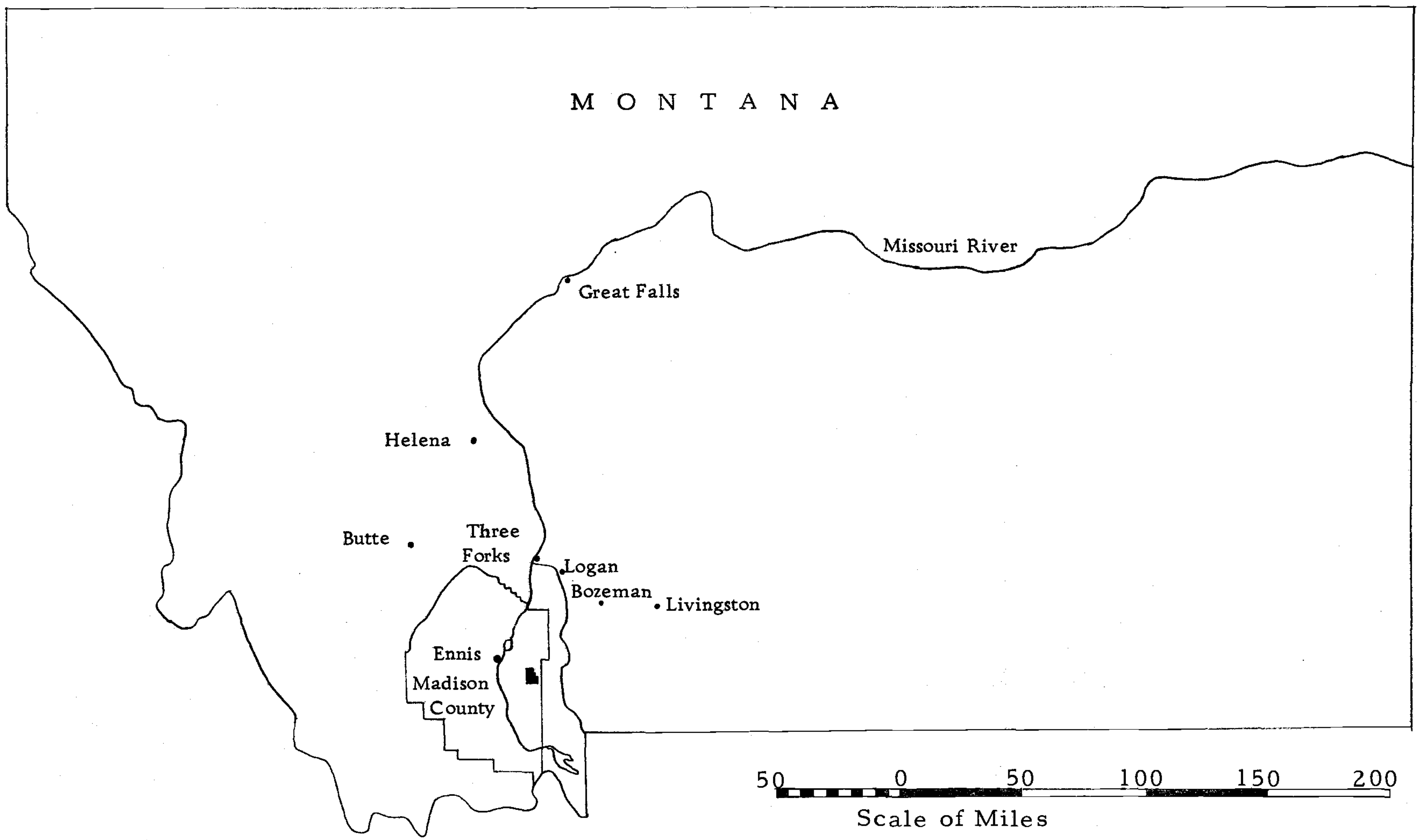

Figure 1. Index map showing location of the thesis area.

Ranch, passable only in good weather, penetrates the thesis area for a short distance. Trails along Aspen Creek and Cedar Creek are suitable for travel by foot or horse. Branch lines of the Union Pacific Railroad terminate at Alder, Montana, 24 miles west of the Cedar Creek area and at Norris, Montana, 17 miles north of the Cedar Creek area.

Purposes and Methods of Investigation

The primary purposes of this study were to produce a detailed geologic map of the Cedar Creek area, to describe and measure the major stratigraphic units, and to delineate the structures.

Field work began in late June 1972, and was completed ten weeks later in early September 1972. Low altitude (1:15,840) aerial photographs, purchased from the U.S. Forest Service at Missoula, Montana, were used to plot surface geology, sample locations, and the structural attitudes that were taken in the field with a Brunton compass. A pocket stereoscope was used in the field for aerial photo interpretation. Data from the aerial photographs were transferred to an enlarged copy of the U.S. Geological Survey 15-minute topographic map of Ennis quadrangle. Stratigraphic thicknesses were measured directly, using a Jacobs staff and Brunton compass. Field descriptions of the lithologies were made with the aid of a hand lens, dilute hydrochloric acid, and a Wentworth's grain chart.

Petrographic examination of 56 thin sections was made to supplement and confirm field observations. Slabs of 24 carbonate samples were stained to aid in the identification of calcite and dolomite. The Rock Color Chart (Goddard and others, 1963) was used for all rock colors. Terminology for stratification and cross-stratification is that proposed by McKee and Weir (1953).

Igneous rocks and sandstones were classified according to Williams, Turner, and Gilbert (1954). The classification of carbonates is that of Folk (1962). Metamorphic rocks were classified according to Turner (1968).

Previous Work

Some geologic studies have been conducted within and surrounding the Cedar Creek area. F. V. Hayden (1872) noted the overturned Carboniferous limestones along the west flank of the Madison Range. In 1896, A. C. Peale published a remarkable reconnaissance map of the old Three Forks one-degree quadrangle, which included the Cedar Creek area. In 1947 R. W. Swanson, J. A. Mann, and J. G. Evans measured several sections of Permian rocks, two of which are within the Cedar Creek area (in Cressman and Swanson, 1964). R. W. Swanson (1951) mapped an area including the Cedar Creek area, but this map was not published.

Several studies have been made of the geology of nearby areas. In 1954, John S. Mann mapped and published the geology of the Gravelly Range, 12 miles southwest of the Cedar Creek area. Frederick M. Beck (1960) mapped and published the geology of the Sphinx Mountain area. In 1963, G. D. Robinson remapped the Three Forks 15-minute quadrangle, 29 miles north of the Cedar Creek area. William J. McMannis and Robert A. Chadwick (1964) mapped and described the geology of the Garnet Mountain quadrangle, 13 miles east of the Cedar Creek area. Irving J. Witkind (1969) reported on the geology of the Tepee Creek quadrangle, 20 miles southeast of the Cedar Creek area. George E. Becraft and others (1970) published a paper, including a geologic map, evaluating the mineral resources of the Jack Creek Basin, adjoining the Cedar Creek area to the north. Jarvis B. Hadley (1969) mapped the Cameron quadrangle adjoining the Cedar Creek area to the south.

Unpublished geologic theses dealing with nearby areas include: John N. Bubb (1961), Harold H. Christie (1961), and Douglas C. Manske (1961) in the Gravelly Range; Frederick M. Beck (1959), William B. Hall (1961), Timothy C. Lauer (1967), Jimmie D. Ray (1967), and Robert R. Rose'(1967) in the Madison and Gallatin Ranges; and John L. Moran (1971) and Clyde L. Murray (1973) in the Centennial Range.

Relief and Drainage

The lowest elevation in the Cedar Creek area is about 5,650 feet in the northwesternmost corner of the map area. The highest elevation is 10,304 feet at the summit of Fan Mountain in the NE1/4 sec. 19, T. 6 S., R. 1 E. Thus, the maximum topographic relief is about 4,650 feet. Local relief is as much as 3,100 feet. The topography is characterized by a discontinuous, north-south trending, 7,000 to 8,400 foot ridge rising abruptly above the Madison River valley to the west, followed by successively higher peaks and ridges to the east.

The Cedar Creek area is drained by westward flowing creeks that empty into the Madison River. The largest stream in the thesis area is Cedar Creek, which, with its tributaries, drains about two thirds of the thesis area. Aspen Creek drains the northeastern corner of the thesis area, and McDeed and Shell Creeks drain the range front south of Cedar Creek. Part of the Tolman Creek drainage is included in the southern part of the mapped area. All named streams are perennial.

Climate and Vegetation

The nearest U.S. Weather Bureau stations are located at Hebgen Dam, about 35 miles south of the Cedar Creek area and at Ennis, six miles northwest of the Cedar Creek area. During the period 1951 through 1960, the Ennis station (elevation 4,953 feet) reported an annual average precipitation of about ten inches, nearly half of that amount falling in May, June and July. The driest months were November through February. Mean daily temperatures varied from a 14-degree minimum and a 33-degree maximum in January to a 48-degree minimum and a 82-degree maximum in July. During the ten-year period, temperatures reached as high as 96 degrees in July and dropped as low as -32 degrees in January.

Because the Cedar Creek area is 1,000 to 4,000 feet higher in elevation than the Ennis weather station, the weather data reported does not accurately reflect weather conditions in the thesis area. The weather data reported by the Hebgen Dam station (elevation 6,489 feet) is more typical of the Cedar Creek area.

During the same ten-year period, the Hebgen Dam station reported about 26 inches of precipitation with little seasonal variation. Temperature averages generally were five to ten degrees lower at Hebgen Dam than at Ennis. Average January temperatures varied from a high of 23 degrees to a low of 4 degrees. Average July temperatures varied from a high of 79 degrees to a low of 43 degrees. Maximum temperature range during the ten-year period was from 93 degrees to -42 degrees. Summer precipitation occurs as brief but frequent thundershowers. Winter precipitation is mostly snow.

Snowfalls are common from October to May.

Much of the Cedar Creek area is covered by moderate to heavy vegetation. The surface geology is commonly obscured by heavy vegetation, especially on shaded north slopes. Lodgepole pine, Engelmann spruce, and Douglas fir are common throughout the Cedar Creek area below timber line (about 9,500 feet). Aspen are locally abundant in creek bottoms. Open areas are covered by grasses, sagebrush, sedges, and wildflowers.

STRATIGRAPHY

The oldest rocks exposed in the Cedar Creek area are of Precambrian age. Exposed Paleozoic rocks, ranging in age from Devonian through Permian, consist of about 3,220 feet of marine carbonates and subordinate sandstones, mudstones, and cherts. Mesozoic rocks, estimated to be 4,000 feet thick, consist of both marine and non-marine mudstones, shales, carbonates, and sandstones. Cenozoic sediments of undetermined thickness include unconsolidated Quaternary landslide debris, alluvium, talus, and slope wash.

Cherry Creek Series

Peale (1896) named the Cherry Creek series for a section of metamorphic rocks consisting of quartz-feldspar gneiss, quartz-mica schist, crystalline limestone, quartzite, and hornblende-biotite schist. The type section is located on Cherry Creek, about ten miles north of the Cedar Creek area, in the Madison Range. Peale assigned an Alonkian (Proterozoic) age to the Cherry Creek series.

Most workers agree that Cherry Creek rocks were deposited and metamorphosed prior to deposition of the Belt series (Tansley and others, 1933; Reid, 1957; Heinrich and Rabbitt, 1960).

Precambrian metamorphic rocks of the Cedar Creek area are assigned to the Cherry Creek series on the basis of lithologic similarities to descriptions of the Cherry Creek series by Reid (1957), Henrich and Rabbitt (1960), and Witkind (1969).

Lithology

The two lithologies of the Cherry Creek series present in the Cedar Creek area are a dolomite marble and a biotite schist.

The dolomite marble is a resistant slope former with isolated, prominent outcrops. The best exposure of the dolomite marble are found near the top of hill 8407 in the SW1/4 SW1/4 sec. 3, T. 7 S., R. 1 E. The dolomite marble is light brownish gray (5YR 6/1) and weathers very light gray (N8) and breaks into large, angular blocks. The dolomite marble consists of interlocking xenoblastic, coarsely crystalline (0.5 mm) dolomite with scattered, accessory quartz (less than one percent).

The biotite schist forms low, grass-covered hills with abundant chips of biotite schist in the soil. The only exposure of the biotite schist found in the Cedar Creek area is in the NE1/4 NE1/4 sec. 15, T. 6 S., R. 1 E. The biotite schist is medium dark gray (N4) and weathers dark yellowish brown (10YR 4/2). Modal analysis of the biotite schist yields the following composition: 29 percent biotite, 38 percent andesine feldspar, 32 percent quartz, and 1 percent accessory minerals including clinozoicite, chlorite, tourmaline, and ilmenite. The grains are xenoblastic, ranging in size from 0.3 mm

Table 1. Summary of stratigraphic units.

Age	Formation	Lithology	Thickness (in feet)
Quaternary	Landslide	Unconsolidated rock and soil debris	?
Quaternary	Alluvium	Gravel, sand, silt, and clay	?
Unconformity			
Cretaceous	Colorado Group	Dark gray shales and mudstone; minor sandstones	3,000
Cretaceous	Kootenai Fm.	Gastropod limestone, siltstones, mudstones, sandstones	404
Disconformity			
Jurassic	Morrison Fm.	Reddish mudstones, shales, and sandstones	280
Jurassic	Rierdon Fm.	Oolitic limestone; limy siltstones, mudstones, and shales	104
Jurassic	Sawtooth Fm.	Sandy micrites, limy mudstones	95
Unconformity			
Triassic	Dinwoody Fm.	Dolomites and siltstones	0-176
Permian	Shedhorn Fm. (upper tongue)	Phosphatic quartz sandstone	65
Permian	Phosphoria Fm.	Bedded chert, mudstone, and phosphorite	42
Permian	Shedhorn Fm. (lower tongue)	Phosphatic quartz sandstone	12
Permian	Park City Fm.	Dolomite	80
Pennsylvanian	Quadrant Fm.	Quartz arenite and minor dolomite	410
Pennsylvanian-Mississippian	Amsden Fm.	Dolomites, limestones, mudstones, and siltstones	200
Disconformity			
Mississippian	Mission Canyon Fm.	Limestones	523
Mississippian	Lodgepole Fm.	Limestones and dolomites	1,390
Devonian	Three Forks Fm.	Shale and siltstone	220
Devonian	Jefferson Fm.	Dolomites	281
Thrust fault			
Precambrian	Cherry Creek Series	Dolomite marble and biotite schist	?

Table 2. Regional correlation chart (columns 1-3 modified after Balster and others, 1971).

Period	Epoch	Beartooth Uplift	Sweet Grass Arch	Whitehall-Tobacco Root	Thesis Area
Cretaceous	U	Telegraph Creek Fm Colorado Gp: Cody Fm Frontier Fm	Telegraph Creek Fm Colorado Gp: Marias River Fm	Upper Colorado Gp	
	L	Colorado Gp: Mowry Fm Thermopolis Fm Cloverly Gp	Colorado Gp: Blackleaf Fm Kootenai Fm	Lower Colorado Sh. Basal Ss. Kootenai Fm	Colorado Gp Kootenai Fm
Jurassic	U	Morrison Fm Sundance Fm	Morrison Fm Swift Fm Rierdon Fm	Morrison Fm Swift Fm Rierdon Fm	Morrison Fm Rierdon Fm
	M	Gypsum Spring Fm	Sawtooth Fm	Sawtooth Fm	Sawtooth Fm
	L				
Triassic	U & M				
	L	Chugwater-Woodside Fm Dinwoody Fm			Dinwoody Fm
Permian		Phosphoria		Phosphoria	Shedhorn Fm Phosphoria Fm Shedhorn Fm Park City Fm
Pennsylvanian		Tensleep Fm Amden Gp		Quadrant Fm Amden Gp	Quadrant Fm Amsden Fm
Mississippian	U			Big Snowy Gp	
	L	Mission Canyon Fm Lodgepole Fm	Mission Canyon Fm Lodgepole Fm	Mission Canyon Fm Lodgepole Fm	Mission Canyon Fm Lodgepole Fm
Devonian	U	Three Forks Fm Jefferson Fm	Bakken Fm Three Forks Gp Jefferson Gp	Three Forks Fm Jefferson Fm	Three Forks Fm Jefferson Fm
	M		Souris River Fm	Maywood Fm	not exposed
	L	Beartooth Butte Fm.		Beartooth Butte Fm.	
Silurian					
Ordovician		Bighorn Fm.			
Cambrian		U & M Cambrian undivided	U & M Cambrian undivided	U & M Cambrian undivided	
Precambrian		Pre-Belt	Pre-Belt	Belt Series Pre-Belt	Cherry Creek

to 0.8 mm. The quartz grains are moderately strained. The biotite shows some alteration to chlorite, and the andesine plagioclase is slightly altered to sericite.

According to Tansley and others (1933) and Heinrich and Rabbitt (1960), the metamorphic rocks of the Cherry Creek series were undoubtedly formed from a sequence of sedimentary rocks.

Jefferson Formation

The Jefferson Formation was named by Peale (1893) for Devonian dolomites exposed in the Three Forks area of Montana. Peale described the Jefferson Formation as 640 feet of dark crystalline limestones, although his chemical analyses indicate the rock is dolomite. The north side of the Gallatin River at Logan, Montana, is generally accepted as the type section.

Sloss and Laird (1947) divided the Jefferson Formation at Logan, Montana, into a lower limestone unit and an upper dolomite unit. Sloss and Moritz (1951) have noted an upper dolomite member and a lower limestone member at several locations in southwestern Montana. However, this subdivision has not been recognized at several areas including the Bridger Range (McMannis, 1955), the Elkhorn Mountains (Klepper and others, 1957), and the Three Forks area (Robinson, 1963).

Sandberg and Hammond (1958) raised the Jefferson Formation east of the 111th meridian in Montana to group status and recognized that the Jefferson Group comprised equivalents of the Duperow and Birdbear Formations of the Williston Basin area. Since then McMannis (1962) and Sandberg (1963) have recognized the subdivision of the Jefferson Formation of southwestern Montana into a thick lower unit equivalent to the Duperow Formation and a thin upper unit equivalent to the Birdbear Formation.

Sandberg (1965) recommended continued use of the name "Jefferson Formation" in southwestern Montana and named the upper unit the Birdbear Member. Although the lower unit of the Jefferson Formation is equivalent to the Duperow Formation, Sandberg (1965) and Sandberg and Mapel (1967) intentionally avoided naming the lower unit.

In the Cedar Creek area, cliff-forming dolomites of the Jefferson Formation are conformable with the non-resistant shales of the overlying Three Forks Formation. In this report, the contact between the two formations is placed at the pronounced topographic break produced by the change in lithology.

Exposure and Topographic Expression

In the Cedar Creek area, the Jefferson Formation forms moderate cliffs and scree-covered slopes in the sequence of overturned beds in secs. 10, 11, 15, 21, and 22, T. 6 S., R. 1 E. along the western flank of the northeast trending ridge. The best exposures of the Jefferson Formation are found in the NE1/4 NE1/4 sec. 15, T. 6 S., R. 1 E., where the formation was measured and described. The Jefferson Formation is largely concealed south of Cedar Creek.

Thickness and Lithology

Because the base of the Jefferson Formation is not exposed in the Cedar Creek area, a complete section was not measured. A partial section of the Jefferson Formation, 281 feet thick, was measured along the south side of a small ridge in the NE1/4 NE1/4 sec. 15, T. 6 S., R. 1 E.

The Jefferson Formation in the Cedar Creek area is entirely dolomite and is commonly fetid. Typically, the dolomites contain thin (generally less than 2 mm) veins of sparry calcite and vugs (up to 1 cm in diameter), commonly filled with sparry calcite. The formation can be subdivided into three units that are discussed separtely below.

The lower unit consists of massive dolomite that weathers pinkish gray (5YR 8/1) to brownish gray (5YR 5/1). The fresh color is medium gray (N5). A representative sample of the lower unit is composed of very finely crystalline, hypidotopic dolomite (89 percent) and coarsely crystalline calcite (10 percent) present in thin veins and irregular patches. Porosity is low (1 percent) and consists of secondary pores (0.4 mm). Intergranular porosity has been reduced by recrystallization.

The middle unit consists of 115 feet of thin- to thick-bedded (four inches to three feet) dolomite that weathers pale yellowish brown (10YR 6/2). On a fresh surface of the rock, the color is medium light gray (N6). Vugs are filled or partially filled with sparry calcite. A representative sample of the unit is composed of medium crystalline (0.1 to 0.3 mm) hypidotopic dolomite (94 percent), thin, irregular veins (typically 0.3 mm thick) of gypsum (1 percent), and pore space (5 percent). Limonite is present in trace amounts. Porosity consists of intergranular pores and partially filled vugs.

The upper unit consists of 96 feet of very thin-bedded (1/2 inch to 2 inches) dolomite that weathers medium gray (N5). The fresh color is medium dark gray (N4). Irregular patches, typically 2 mm thick and 2 to 3 cm across, of grayish-orange (10YR 7/4), coarsely crystalline calcite, roughly parallel the bedding. Although the lower and middle units resemble the dolomites of other formations in the Cedar Creek area, the upper unit of the Jefferson Formation is easily distinguished from other dolomites in the area by the presence of the grayish-orange patches. A representative sample of the upper unit ranges from a dolomitic micrite (98 percent) with a few bioclasts (2 percent) to predominantly bioclasts (80 percent) and micrite intraclasts (2 percent) in a micrite matrix. Limonite colors the irregular patches of sparry calcite. Dolomite rhombohedrons are

Figure 2. Photomicrograph of limy dolomite from the upper unit of the Jefferson Formation in the Cedar Creek area showing crinoid columnals and fragments in a dolmicrite matrix.

locally abundant in vugs and veins.

Fossils and Age

Crinoid columnals and fragments of Amphipora? sp. were found in the upper unit of the Jefferson Formation in the Cedar Creek area. Jean M. Berdan and Helen Duncan have identified Amphipora sp. in the Jefferson Formation at a location in or near the Cedar Creek area (Helen Duncan, in Robinson, 1963).

According to Sandberg and Hammond (1958), the Jefferson Formation in southwestern Montana is considered to be Frasnian (early Late Devonian) in age based on its stratigraphic position between the underlying Maywood Formation of early Frasnian age (earliest Late Devonian) and the overlying Three Forks Formation of Famennian age (late Late Devonian).

Sandberg and Hammond (1958) further stated that the Duperow Formation of eastern Montana, equivalent to the lower member of the Jefferson Formation of western Montana, is Late Devonian in age.

Ethington and others (1961) collected Late Devonian conodonts from the Darby Formation in the Bighorn Mountains of Wyoming. The Darby Formation is equivalent to the lower member of the Jefferson Formation (Benson, 1966).

Denison (1968) assigned a Middle Devonian age to fossil fishes collected from the basal unit of the Jefferson Formation in the Lemhi

Range of Idaho.

In the Sun River Canyon area of northwestern Montana, the lower member of the Jefferson Formation contains corals of Frasnian age, and the Birdbear Member contains brachiopods of probable late Frasnian age (Dutro, in Mudge, 1972).

Regional Distribution and Correlation

The Jefferson Formation is recognized throughout western Montana, southern and east-central Idaho, western Wyoming, and northeastern Utah. In Montana, the Jefferson Formation ranges in thickness from 200 to 700 feet, but thickens abruptly west of the Beaverhead Range and becomes as much as 3,000 feet thick in east-central Idaho (Balster, 1971; McMannis, 1962). Devonian strata are absent in southeasternmost Montana (Perry, 1945).

Benson (1966) stated that the lower member of the Jefferson Formation of western Montana is equivalent to the Darby Formation of west-central Wyoming. According to Balster (1971) the Jefferson Formation is equivalent to the Duperow and Birdbear Formations, comprised of dolomites, limestones, and evaporites, of eastern Montana.

Origin and Depositional Environment

The presence of micrite intraclasts and sorted and abraded marine fossils in the upper unit of the Jefferson Formation in the Cedar Creek area and the presence of shallow-water marine fossils such as *Amphipora* in the Jefferson Formation at other locations indicate that the dolomites of the Jefferson Formation were deposited in shallow, marine waters. The lack of detrital material throughout the Jefferson Formation suggests that Jefferson seas were bordered to the southeast by a low lying, distant landmass.

Three Forks Formation

Peale (1893), working in the Three Forks area of Montana, named the Three Forks Shale for the ravine-forming unit above the resistant Jefferson Formation and below the cliffs of the Carboniferous limestones. Peale described the unit as a lower shale and an upper shale separated by 15 to 20 feet of grayish brown limestones, with 25 feet of yellow, laminated sandstones overlying the upper shale.

Haynes (1916) described the formation in greater detail and subdivided it into seven members at Logan, Montana. Haynes preferred the more general name, the Three Forks Formation, because the formation is a varied assemblage of clastic and carbonate rocks. The type section is considered to be the exposures on the north side of the Gallatin River at Logan, Montana.

Berry (1943) separated the 60 foot-thick, yellow sandstone unit at the top of the Three Forks Formation in Milligan Canyon, near Sappington, Montana, from the rest of the formation and named the unit the Sappington Formation.

Retaining the Sappington as a member is generally preferred by recent workers (Mann, 1954; Sandberg and Hammond, 1958; Robinson, 1963; Sandberg, 1965). In this report, the Sappington is considered as a member of the Three Forks Formation.

Robinson (1963) has recognized three distinct units of the Three Forks Formation in the Three Forks area. Sandberg (1965) applied Robinson's subdivisions at several locations in south-central Montana and proposed the following nomenclature: the Logan Gulch Member for the lower non-fossiliferous, evaporitic sequence; the Trident Member for the middle highly fossiliferous, calcareous clay shales; and the Sappington Member for the upper yellowish-orange and yellowish-gray siltstones, shales and limestones.

Although the Three Forks Formation is poorly exposed in the Cedar Creek area, the formation is easily recognized as a non-resistant shale unit between the resistant Jefferson and Lodgepole Formations. The upper and lower contacts appear to be conformable in the Cedar Creek area.

Exposure and Topographic Expression

In the Cedar Creek area, the Three Forks Formation typically forms minor gullies and saddles between the steep slopes of the Jefferson Formation and the cliffs of the Lodgepole Formation. The Three Forks Formation is present in the sequence of overturned beds in secs. 10, 11, 14, 15, and 22, T. 6 S., R. 1 E.

Because the shales of the Three Forks weather readily to form a deep soil that usually is covered by rock debris from the overlying Lodgepole Formation, exposures of the Three Forks Formation are very poor and limited in the Cedar Creek area. In the small saddle in the W1/2 NW1/4 sec. 14, T. 6 S., R. 1 E., a complete section of the Three Forks Formation could be unearthed by removing about one to two feet of overlying soil.

Thickness and Lithology

Because of limited time, a detailed study of the lithology of the Three Forks Formation was not attempted for this report. However, the thickness of the Three Forks Formation, measured at the small saddle in the W1/2 NW1/4 sec. 14, T. 6 S., R. 1 E., is 220 feet. Digging into the soil produced chips of light olive-gray (5Y 6/2) shale. Weathered chips of pale to dark yellowish-orange (10YR 8/6 to 10YR 6/6), calcareous siltstone were found in the soil of the upper fourth of the formation.

Fossils and Age

No fossils were found in the Three Forks Formation in the Cedar Creek area. However, at some locations in southwestern Montana, the formation is highly fossiliferous, containing brachiopods, bryozoans, corals, gastropods, ostracods, foraminifers, sponges, and conodonts (Berry, 1943; Holland, 1952; Robinson, 1963; Klapper, 1966).

Peale (1893, 1896), Raymond (1907, 1909), and Haynes (1916) considered the Three Forks Formation to represent a transition between Devonian and Mississippian time, the boundary occurring near the top of the formation. Berry (1943) raised the Sappington sandstone to formational status and assigned a Mississippian age. Many workers (Robinson, 1963; Sandberg, 1965; Sandberg and Mapel, 1967; Gutschick and Sanberg, 1970) have retained the Sappington as a member of the Three Forks Formation.

Klapper (1966) dated conodonts from the Three Forks Formation near Logan, Montana and assigned a Late Devonian age to the Trident Member and a Late Devonian and Early Mississippian age to the Sappington Member.

Sandberg and Klapper (1967) re-evaluated fossil evidence reported by Klapper (1966) and stated that, although the uppermost part of the Sappington Member is possibly Mississippian in age, fossil evidence does not support a Mississippian age. Sandberg and Klapper (1967) concluded the Three Forks Formation is Famennian (late Late Devonian) in age based on conodonts and spores collected from the Trident and Sappington Members of the Three Forks Formation near Logan, Montana.

Regional Distribution and Correlation

The Three Forks Formation and its correlatives are recognized throughout much of Montana, Idaho, Wyoming, and parts of Alberta and British Columbia. In southwestern Montana, the formation commonly ranges from about 100 to 250 feet (Peale, 1893; Wilson, 1934; Andrichuk, 1951; Mann, 1954; McMannis, 1955).

McMannis (1962) states "the general impression is that the formation becomes less shaly and dolomitic and more calcareous toward the west."

According to Balster (1971) and Sandberg (1965), the Three Forks Formation is equivalent to the Potlatch Formation, an anhydrite sequence of the Sweetgrass Arch area of northwestern Montana and to the Big Valley and Stettler Formations of the Wabamun Group of Alberta and Saskatchewan.

Origin and Depositional Environment

Robinson (1963) interpreted the lithology of the Three Forks Formation to indicate a shallow marine environment of deposition for most of the formation and stated that some of the shales were deposited in a restricted environment as indicated by the presence of pyrite. The siltstones and sandstones of the upper member were deposited "presumably close to shore in shallow, well-aerated waters in free communication with the ocean."

Robinson (1963) further suggested that the clastic components of the Three Forks Formation may have been derived from "a southern extension of the uplift postulated by Deiss (1933) in parts of the Swan, Flathead, and Lewis Ranges."

Southeastern Montana and adjacent parts of Wyoming appear to have been a low lying landmass during Devonian time and may have contributed detritus to the Three Forks Formation (Sloss, 1950).

Madison Group

Peale (1893) used the name Madison Formation for Carboniferous limestones exposed in the Three Forks area of Montana. He divided the Madison into three units, from bottom to top, Laminated Limestones, Massive Limestones, and Jaspery Limestones. Peale did not specify a type section.

In describing a section near Logan, Montana, Weed (1900) 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 (1922) raised the Madison to group status naming the lower thin-bedded limestones the Lodgepole Formation and the upper, massive limestones the Mission Canyon Formation.

Lodgepole Formation

Collier and Cathcart (1922) named the Lodgepole Formation for 550 feet of thin-bedded, fossiliferous limestones exposed in Lodgepole Canyon on the north flank of the Little Rocky Mountains, Montana.

Sloss and Hamblin (1942) recognized a subdivision of the Lodgepole Formation into two members. They applied Weed's nomenclature, calling the lower "Laminated Limestone" the Paine Member and the upper "Massive Limestone" the Woodhurst Member.

In the Cedar Creek area the Lodgepole Formation conformably overlies the Three Forks Formation and is conformably overlain by the Mission Canyon Formation. In this report, the contact between the Lodgepole Formation and the Mission Canyon Formation is placed at the base of the cliffs of gray weathering, massive limestones of the Mission Canyon Formation.

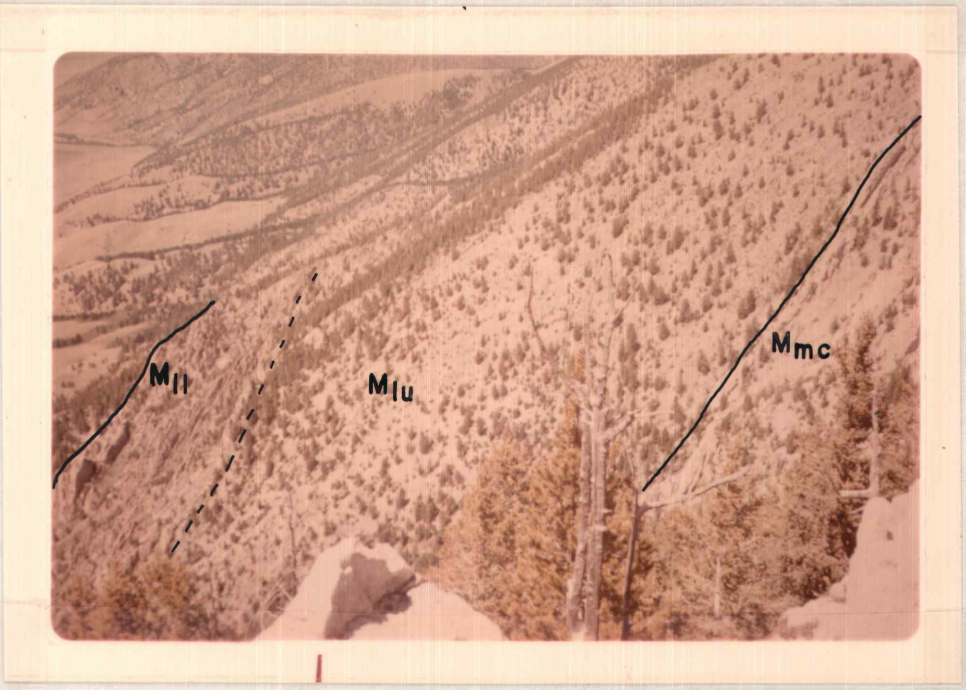

Figure 3. Overturned beds of the lower and upper units of the Lodgepole Formation (M_{ll} and M_{lu}) and the Mission Canyon Formation (M_{mc}) SW1/4 sec. 11, T. 6 S., R. 1 E.

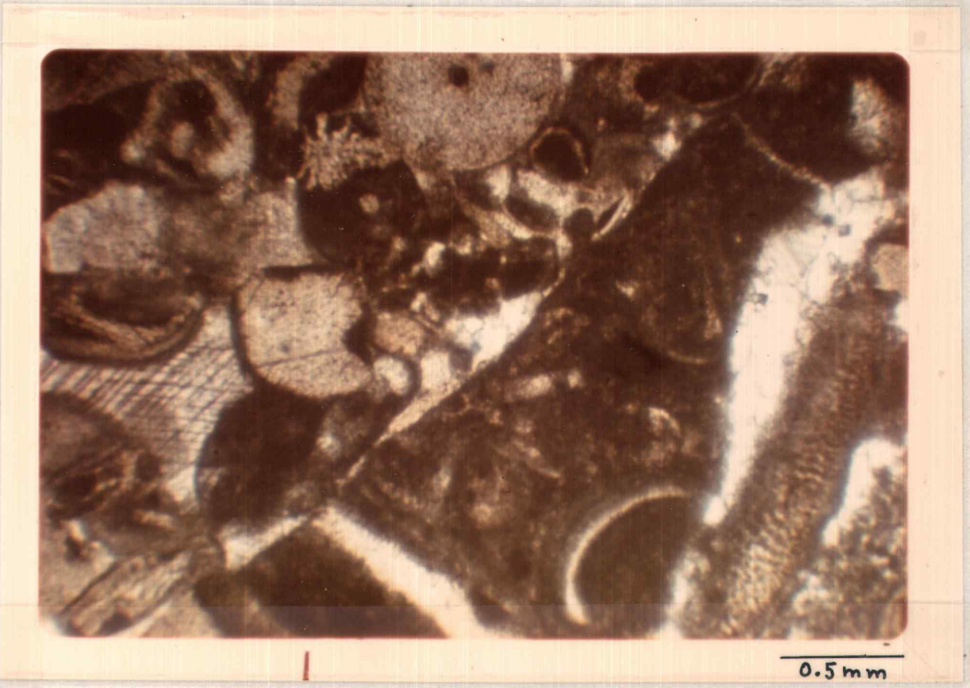

Figure 4. Photomicrograph of interlayered biosparite (upper left) and biomicrite (lower right) from the uppermost beds of the Lodgepole Formation.

Exposure and Topographic Expression. The Lodgepole Formation is well exposed in the Cedar Creek area. The lower unit tends to form high cliffs, and the upper unit forms very steep, scree-covered slopes with scattered outcrops. A cliff-forming unit marks the transition from the Lodgepole Formation to the Mission Canyon Formation.

The Lodgepole Formation crops out along the western side of the northeast trending ridge of secs. 11, 14, and 15, T. 6 S., R. 1 E.

Thickness and Lithology. The Lodgepole Formation, as measured and described along the small ridge in the S1/2 NW1/4 sec. 14, T. 6 S., R. 1 E., is 1,390 feet thick in the Cedar Creek area. The Lodgepole Formation in the Cedar Creek area can be divided into two units that are discussed separately below.

The lower unit consists of 652 feet of very thin- to thin-bedded (two inches to two feet) dolomites. The dolomites are light gray (N7) to light olive gray (5Y 6/1) that weather grayish orange (10YR 7/2), yellowish gray (5Y 7/2), or brownish gray (5YR 4/1) to pale yellowish brown (10YR 5/2). Weathered surfaces commonly show thin laminations (about 20 laminae per inch). Representative samples of the dolomites are composed of medium to finely crystalline (0.2 to 0.02 mm) subhedral to euhedral dolomite (97 to 97 percent), iron oxide (up to 1 percent), quartz silt (up to 1 percent), sparry calcite (up to 1 percent) in thin veins (0.2 mm thick), and porosity (1 to 7 percent). The more porous beds are commonly fetid.

The upper unit consists of 738 feet of thin- to very thin-bedded (one inch to one foot) limestones, brownish gray (5YR 4/1) to medium gray (N5) that weather light olive gray (5Y 6/1) or pale yellowish brown (10YR 6/2). Much of the limestone is flaggy to platy because of thin, interbedded shaley limestones. The limestones are typically very fossiliferous, ranging from beds with unbroken, disarticulated brachiopod shells to fossil "hash" beds composed of abraided fossil fragments and crinoid columnals, commonly 1 mm in diameter.

The thicker beds typically are biopelsparite, composed of very poorly sorted brachiopod shells and fossil fragments (30 percent), micrite pellets (50 percent) commonly 0.2 mm in diameter, sparry calcite (18 percent) cement and vug fillings, and solution porosity (2 percent). Some of the calcite has been replaced by dolomite in the vugs. Chert is uncommon although some irregular lens of chert were found in the lower part of the upper unit.

Fossils and Age. The upper part of the Lodgepole Formation in the Cedar Creek area contains abundant crinoid columnals, bryozoans, and brachiopod fragments. Specimens of *Schuchertella* sp., *Spirifer* sp., *Fenestrellina* sp., a poorly preserved gastropod, and an unidentified horn coral were found in the Lodgepole Formation in the Cedar Creek area.

Laudon and Sverson (1953) stated that the Lodgepole and Mission Canyon Formations probably represent continuous deposition through all of Kinderhookian and perhaps earliest Osagian time.

Sando and Dutro (1960) dated corals from the Madison Group of southwestern Montana, western Wyoming, and northeastern Utah and assigned an Early Mississippian age.

Klapper (1966) identified a conodont fauna of Kinderhookian age from the basal unit of the Lodgepole Formation in north-central Wyoming.

Sandberg and Klapper (1967) assigned a Kinderhookian age to the lower part of the Lodgepole Formation in western Montana based on conodont faunas.

Sando and others (1969) dated corals, brachiopods, and foraminifers from the Lodgepole Formation in southeastern Idaho, western Wyoming, and southwestern Montana and concluded the formation ranges in age from late Kinderhookian to middle Osagian.

Regional Distribution and Correlation. The Lodgepole Formation is recognized throughout Montana and in Idaho, Wyoming, the Dakotas, and southern Alberta. Typical thicknesses of the Lodgepole Formation in southwestern Montana are 731 feet near Three Forks, Montana (Sloss and Hamblin, 1942), 677 feet in the Gravelly Range (Mann, 1954), and 622 feet in the Centennial Range (Sloss and Moritz, 1951). In general, the Lodgepole Formation decreases in thickness from central Montana to the north and to the southeast (Sloss and Hamblin, 1942) and increases markedly in thickness in southwesternmost Montana in a short distance towards the Montana-Idaho border (McMannis, 1965). The Lodgepole Formation averages 200 feet in thickness in central and eastern Wyoming and averages 800 feet in thickness in western Wyoming (Strickland, 1960).

The Banff Formation of the Rocky Mountains in Alberta is correlative in part to the Lodgepole Formation (Stockwell, 1957).

Origin and Depositional Environment. The lithology of the lower unit and the total thickness of the Lodgepole Formation in the Cedar Creek area are anomalous for southwestern Montana, and the origin and depositional environment of the lower unit of the Lodgepole Formation in the Cedar Creek area are open to various interpretations. The most likely interpretation is that more rapid subsidence was localized in the vicinity of the Cedar Creek area producing a thicker section. Possibly, the presence of magnesium-rich waters in the local basin resulted in dolomitization prior to deposition of the typical Lodgepole strata of the upper unit. If fossils were present, they likely were destroyed by the dolomitization process.

The thin, even bedding, the lithology, and the abundant marine fauna of the upper unit of the Lodgepole Formation in the Cedar Creek area are typical of the Lodgepole Formation throughout southwestern Montana and suggest deposition in a normal marine environment in the sublittoral to shallow neritic zones. Borderlands to the southeast and to the west were probably low lying, contributing little detritus other than clay. Current energy varied from a low energy level producing shaly and argillaceous limestones to moderate energy level producing limestones with micrite intraclasts and abraided fossil fragments.

Mission Canyon Formation

Collier and Cathcart (1922) named the Mission Canyon Formation for exposures of massive limestones in the canyon of Saint Paul's Mission on the west flank of the Little Rocky Mountains, Montana. Sloss and Hamblin (1942) suggested that the name "Mission Canyon Formation" be applied to strata formerly known as the Jaspery Limestone of Peale (1893) and the Castle Limestone of Weed (1900).

In the Cedar Creek area, the Mission Canyon Formation conformably overlies the Lodgepole Formation and is disconformably overlain by the Amsden Formation. In this report, the upper contact of the Mission Canyon Formation is placed at the topographic break between the thick- and very thick-bedded, cliff-forming limestones of the Mission Canyon Formation and the non-resistant shales, siltstones, dolomites, and limestones of the Amsden Formation that commonly weather to a red soil.

Figure 5. Overturned beds of the Lodgepole Formation (M_l), Mission Canyon Formation (M_{mc}), and Amsden Formation ($\mathbb{P}_a$) SW1/4 SE1/4 sec. 11, T. 6 S., R. 1 E.

<u>Exposure and Topographic Expression.</u> In the Cedar Creek area, the Mission Canyon Formation forms high cliffs and steep, scree-covered slopes. The formation crops out in the sequence of overturned beds forming the mountain front on the western edge of the thesis area. Exposure of the formation is excellent at many locations in secs. 11 and 14, in the S1/2 sec. 28, and in the NW1/4 sec. 33, T. 6 S., R. 1 E. although the best exposures are commonly inaccessible.

<u>Thickness and Lithology.</u> A complete section of the Mission Canyon Formation is not exposed at any single location within the Cedar Creek area. A partial section of the Mission Canyon Formation, 523 feet thick, was measured and described by the writer in the NW1/4 SE1/4 sec. 11, T. 6 S., R 1 E.

The Mission Canyon Formation is typically a thick- to very thick-bedded limestone, with medium dark gray (N4) chert nodules and beds one to six inches thick commonly present. The limestone is light brownish gray (5YR 6/1) to pale yellowish brown (10YR 7/2) and weathers light gray (N7) to pale yellowish brown (10YR 7/2). Representative samples of the Mission Canyon Formation vary from micrite to very finely crystalline limestone. Porosity is low (up to 2 percent) and consists primarily of secondary solution pores. Fossil fragments (up to 2 percent) and iron oxide (up to 1 percent) are present in some samples. Thin (0.2 mm) sparry calcite veins (up to 2 percent) generally are present.

A limestone breccia, up to 30 feet thick with clasts of limestone up to ten inches in diameter, commonly is found in the upper part of the Mission Canyon Formation in the Cedar Creek area.

A representative sample of the cherts consists of chert (70 percent) replacing calcite (30 percent). Much of the calcite is present as fossil fragments. The chert commonly shows relict fossil "ghosts".

Fossils and Age. The Mission Canyon Formation in the Cedar Creek area is relatively unfossiliferous. Crinoid columnals and unidentifiable fossil fragments were found in abundance in a few beds of the lower part of the Mission Canyon Formation.

Sloss and Hamblin (1942) indicated the Mission Canyon Formation is Osagian (lower Middle Mississippian) in age. Gardner and others (1945) reported that the uppermost beds of the Mission Canyon are Middle Mississippian. Strickland (1956, 1960) has dated the Mission Canyon Formation as Osagian and possibly late Kinderhookian (Early Mississippian).

Sando and others (1969) collected corals, brachiopods, and foraminifers from the Mission Canyon Formation of southwestern Montana, southeastern Idaho, and western Wyoming and concluded the formation ranges in age from middle Osagian to early Meramecian.

Regional Distribution and Correlation. The Mission Canyon Formation is recognized throughout Montana, Idaho, Wyoming, the

Dakotas, and southern Alberta. Typical thicknesses of the Mission Canyon Formation in southwestern Montana are 865 feet in the Gravelly Range (Mann, 1954), 912 feet at Logan, Montana (Sloss and Hamblin, 1942), and about 500 feet in the Centennial Range (Sloss and Moritz, 1951). In general, the Mission Canyon Formation decreases in thickness from central Montana to the north and to the southeast (Sloss and Hamblin, 1942) and increases rapidly in thickness in southwesternmost Montana towards the Montana-Idaho border (McMannis, 1965).

The basal unit of the Rundle Group of the Canadian Rockies is correlative with the Mission Canyon Formation (Stockwell, 1957).

Origin and Depositional Environment. The very thick bedding and argillaceous nature of the micrites of the Mission Canyon Formation in the Cedar Creek area are typical of normal marine, deep neritic deposition. The low percentage of fossil fragments and the very finely crystalline nature of the limestones suggest chemical precipitation of calcite from sea water.

Robinson (1963) has stated that the limestone breccia, found in the upper part of the Mission Canyon Formation of western Montana is a solution or collapse breccia developed by cave-making processes above sea level.

Amsden Formation

Peale (1893) was the first to describe strata now considered to be beds of the Amsden Formation in the Three Forks area of Montana; however, he included the strata with the Quadrant Formation.

Darton (1904) named the Amsden Formation for red shales and limestones with cherty and sandy members exposed along the Amsden Branch of the Tongue River, west of Dayton, Wyoming. At the type locality, the Amsden Formation lies between the Madison Group and the overlying Tensleep Formation.

Maughan and Roberts (1967) proposed raising the Amsden Formation to group status in central and eastern Montana. They divided the Amsden Formation into three formations, from bottom to top: the Tyler Formation, dark-gray shales and sandstones that grade laterally and vertically into red beds; the Alaska Bench Limestone, limestone with interstratified red or gray mudstone; and the Devils Pocket Formation, dolomite with red mudstone in the lower part and sandstone in the upper part. However, Maughan and Roberts recommended continued use of the name "Amsden Formation" for equivalent strata in western Montana.

In the Cedar Creek area, the Amsden Formation disconformably overlies the Mission Canyon Formation. The contact with the overlying Quadrant Formation is gradational from dolomites to interbedded dolomites and quartz arenites to quartz arenites. In this report, the upper contact of the Amsden Formation is placed at the base of the lowest quartz arenite. Although arbitrary, Gardner and others (1946), Klepper and others (1957), and Robinson (1963) have used the same criteria in mapping the Amsden-Quadrant contact.

Exposure and Topographic Expression

In the Cedar Creek area, only the middle limestone unit of the Amsden Formation is well exposed, forming prominent outcrops that are commonly continuous for several hundred feet along strike. The lower unit, where not covered by scree from overlying formations, forms a characteristic red soil, typical of the Amsden Formation. The upper unit also is non-resistant and forms scree-covered slopes. The best exposures of the non-resistant lower and upper units of the Amsden Formation are found on the ridge top in the SW1/4 SE1/4 sec. 11, T. 6 S., R. 1 E.

Thickness and Lithology

Poor exposure of the Amsden Formation in the Cedar Creek area prohibited an accurate measurement of the section. The Amsden Formation is estimated to be about 200 feet thick in the Cedar Creek area. A description of the lithology of the formation was compiled from observations made at several locations in the Cedar Creek area along the ridge top in the SE1/4 sec. 11, T. 6 S., R. 1 E. and along Shell Creek in the SE1/4 sec. 33, T. 6 S., R. 1 E.

The Amsden Formation in the Cedar Creek area can be divided into three units that are discussed separately below.

The lower unit of the Amsden Formation, estimated to be 80 feet thick, is a non-resistant unit that forms a soil cover with few outcrops. Samples dug from the soil and from the outcrops indicate the lower unit of the Amsden Formation consists of moderate yellowish brown (10YR 5/4) and very pale orange (10YR 8/2) mudstones and dark yellowish orange (10YR 6/6), pale red (5R 6/2), light brownish gray (5YR 6/1), and pale reddish brown (10R 5/4) weathering siltstones with minor thin (typically one foot) interbeds of argillaceous dolomites and calcareous quartz sandstones. The argillaceous dolomites are light gray (N7) and weather very pale orange (10YR 8/2) and are very finely crystalline. The quartz sandstones are deeply weathered to dark yellowish orange (10YR 6/6). The quartz sandstones are composed of very fine-grained, subangular, well-sorted quartz (70 percent), fossil fragments including crinoid columnals, (3 percent), micrite intraclasts (1 percent), clay (1 percent), sparry calcite cement (20 percent), hematite cement (4 percent), and intergranular voids (1 percent).

The middle unit of the Amsden Formation, estimated to be 40 feet thick in the Cedar Creek area consists of a persistant, ridge forming biosparite, which can be traced throughout the Cedar Creek area, and a fossiliferous, shaly micrite. The thin- to thick-bedded (two inches to four feet) biosparite is light brownish gray (5YR 5/1) and weathers to very light gray (N8). A representative sample of the biosparite is composed of fossil fragments (30 percent), finely to very finely crystalline calcite (65 percent), and clay (5 percent). Finely distributed hematite (up to 5 percent) is present in pale yellowish brown weathering beds (10YR 6/2).

Thin (two to four inch) beds and irregular nodules of medium gray (N4) chert are generally present in the biosparite. Locally underlying and interbedded with the biosparite is a medium dark gray (N4), fossiliferous, shaly micrite unit (up to 30 feet thick) that weathers pale yellowish brown (10YR 6/2) and commonly contains abundant, disarticulated, unbroken brachiopod shells.

The upper unit of the Amsden Formation is estimated to be 80 feet thick in the Cedar Creek area. The upper unit consists of thin-bedded (eight inches to two feet), very finely to medium crystalline, argillaceous dolomite. The dolomite is yellowish gray (5Y 8/1) that weathers grayish yellow (5Y 8/4).

Fossils and Age

Fossils were collected from the Amsden Formation at several locations along Shell Creek in the thesis area. Abundant, well preserved Linoproductus sp. and Dictyoclostus sp. were found in the fossiliferous, shaly micrite of the middle unit. Rare and poorly preserved specimens of Spirifer sp., crinoid columnals, horn corals, and pelecypods were found in the biosparite overlying the shaly micrite.

Scott (1935) dated the Amsden Formation in central Montana as middle or late Chesteran (Late Mississippian). Berry (1943) reported the upper part of the Amsden is Early Pennsylvanian. Geologists of the U.S. Geological Survey and the Montana Bureau of Mines and Geology collected many brachiopods of Late Mississippian and Early Pennsylvanian age in the Amsden of western Montana (Gardner and others, 1946). Sloss and Moritz (1951) stated "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."

Regional Distribution and Correlation

The Amsden Formation is present in western North and South Dakota and in much of Wyoming and Montana. The Amsden Formation is not present in the southern part of Wyoming or north-central Montana (Perry, 1945).

The Amsden Formation is about 400 feet thick in the Powder River basin of northeastern Wyoming and southeastern Montana and progressively thins northward (Balster, 1971). Typical thicknesses of the Amsden Formation near the Cedar Creek area are 66 feet in Yellowstone National Park (Thompson and Scott, 1941), 159 feet in the southern Madison Range (Witkind, 1969), and up to 225 feet in the Gallatin Range (McMannis and Chadwick, 1964).

The basal clastic unit of the Amsden Formation in central Montana is known as the Cameron Creek Member (Gardner, 1959). According to Balster (1971), the lower part of the Amsden Formation is equivalent to the Sacajawea Formation of Branson (1936) in northern Wyoming.

Sando and others (1969) identified corals, brachiopods, and foraminifers from the Amsden Formation of southeastern Idaho and western Wyoming and concluded the formation ranges in age from Late Mississippian (Chesterian) to Pennsylvanian.

Origin and Depositional Environment

Robinson (1963) reported the Amsden Formation was deposited by a shallow transgressive sea. He proposed the source area was to the west in the vicinity of the Montana-Idaho border where Paleozoic and Precambrian rocks were exposed during Amsden time.

Balster (1971) suggested that the Amsden Formation was deposited in a shallow, oscillatory sea with local, intermittent restriction. Minor tectonic movements resulted in thin interbeds of different lithologies.

Quadrant Formation

Peale (1893) was the first to use the name "Quadrant Formation" in a published report. Peale described the Quadrant Formation in the Three Forks area of Montana as thin-bedded cherty limestone and quartzite layers underlain by a red, arenaceous limestone and vari-colored shales. Peale's Quadrant Formation included strata that are now considered Amsden Formation, Quadrant Formation, and Phosphoria Formation.

Iddings and Weed (1899) described the Quadrant Formation and designated the type section at Quadrant Mountain in Yellowstone National Park. At the type locality, the Quadrant Formation, as originally defined, consists of 400 feet of white quartzitic sandstone interbedded with a few light gray limestone beds.

Scott (1935) and Thompson and Scott (1941) redefined the Quadrant Formation at the type locality to include only strata of Pennsylvanian age and assigned the lower, red, arenaceous limestones and variegated shales to the Amsden Formation.

Scott (1935) proposed that the term "Quadrant" be replaced by the term "Tensleep" in south-central Montana. Current usage favors Scott's proposal and the term "Quadrant" is restricted to southwestern Montana and adjacent Wyoming where the term originated (Balster, 1971).

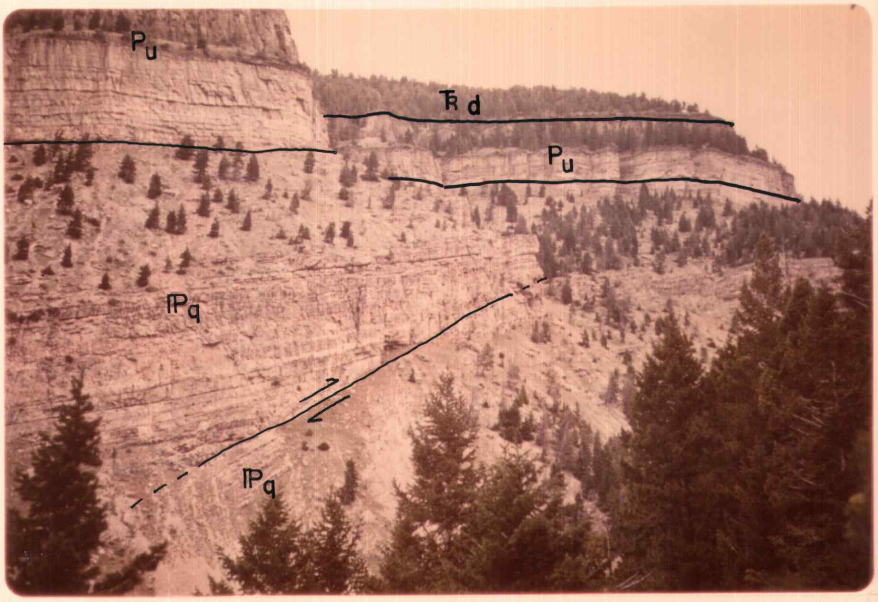

Figure 6. Small thrust fault and exposures of the Quadrant Formation (IP q), Permian beds (P_u), and the Dinwoody Formation (₸R d) along the north wall of the Shell Creek canyon NE1/4 SE1/4 sec. 33, T. 6 S., R. 1 E.

In the Cedar Creek area, the Quadrant Formation consists of quartz arenites with interbedded dolomites. The Quadrant Formation conformably overlies the Amsden Formation. The Quadrant Formation is conformable and transitional with the overlying Park City Formation of the Permian system. The upper contact was placed arbitrarily where dolomite beds begin to dominate the section.

Exposure and Topographic Expression

In the Cedar Creek area, the Quadrant Formation is present in the overturned belt along the western edge of the thesis area as ruble-covered slopes with isolated outcrops protruding a few feet above the slope. However, along Shell Creek, low dipping beds of the Quadrant Formation form nearly continuous cliffs, 30 to 40 feet high. On the north wall of Shell Creek canyon, a complete section of the Quadrant Formation is excellently exposed. Where the Quadrant Formation is well cemented by silica overgrowths, the rock is a resistant, cliff former. Where the formation is poorly cemented or cemented by calcite, the rock is less resistant and forms steep slopes.

Thickness and Lithology

A section of the Quadrant Formation, 410 feet thick, was measured on the north side of Shell Creek in the SE1/4 NE1/4 sec. 33, T. 6 S., R. 1 E.

The Quadrant Formation in the Cedar Creek area consists of a lower unit of thin, interbedded dolomites and quartz arenites, and an upper unit dominated by quartz arenites with subordinate interbeds of sandy and argillaceous dolomites that become more numerous upward and transitionally grade into the interbedded dolomites and quartz sandstones of the Park City Formation.

The quartz arenites are thin-bedded to very thick-bedded, although some beds cemented by calcite have been etched by weathering and show laminations and cross-laminations. The quartz arenites are yellowish gray (5Y 8/1) to dark yellowish orange (10YR 6/6) and weather yellowish gray (5Y 7/2), pale yellowish brown (10YR 6/2), and grayish orange (10YR 7/4). A typical sample is composed of very fine-grained, moderate- to well-sorted, subrounded quartz (83 percent), intergranular pores (6 percent), accessory minerals (1 percent), and cement (10 percent). Accessory minerals include leucoxene, zircon, altered pyrite cubes (0.02 to 0.05 mm), and hornblende. Cement is in the form of silica overgrowths with minor calcite. Locally, calcite is the principle cement.

Dolomite beds make up about 20 percent of the Quadrant Formation in the Cedar Creek area and are generally thin- to very thin-bedded. The dolomites weather grayish orange (10YR 7/4), pale yellowish brown (10YR 6/2), and very pale orange (10YR 8/2). The fresh colors are very light gray (N8) to medium light gray (N6) and yellowish gray (5Y 8/1). A typical sample consists of very finely crystalline dolomite (80 percent) with detrital, subrounded, very fine- to fine-grained quartz (20 percent). Detrital components in other samples range from 1 percent clay to 30 percent silt and sand sized quartz.

Fossils and Age

The Quadrant Formation typically is unfossiliferous, and no fossils were found in the Quadrant Formation in the Cedar Creek area.

Thompson and Scott (1941) found two fusulinid genera in the Quadrant Formation at the type section at Quadrant Mountain in Yellowstone National Park and dated the Quadrant Formation as Desmoinesian in age. Richards (1955) dated the Tensleep Formation, a lithologic correlative of the Quadrant Formation in Wyoming, as Desmoinesian in age. Scholten and others (1955), Klepper and others (1957), and Robinson (1963) have suggested the Quadrant Formation is gradational with Permian strata. Robinson (1963) further suggested "at least part of the Quadrant is late Pennsylvanian or even early Permian." Because of a lack of fossil evidence that supports a late Pennsylvanian or early Permian age, the Quadrant Formation is considered in this report to be mainly Desmoinesian in age.

Regional Distribution and Correlation

The Quadrant Formation is recognized in southwestern Montana, northwestern Wyoming, and southeastern Idaho. The Quadrant Formation is generally 200 to 300 feet thick in the Gallatin and Madison Ranges (Thompson and Scott, 1941; Hall, 1961; McMannis and Chadwick, 1964), but thickens to the west to 582 feet in the Gravelly Range (Mann, 1954) and 2,662 feet at Big Sheep Creek in southern Beaverhead County, Montana (Sloss and Moritz, 1951). Scott (1935) reported the Quadrant is absent in northern and central Montana because of non-deposition. Scott (1935) and Vine (1956) also reported the absence of the Quadrant Formation in northern and central Montana, but suggested the cause is pre-Jurassic erosion.

According to Balster (1971) the Quadrant Formation is considered correlative with and lithologically equivalent to the Tensleep Formation of Wyoming. The Quadrant Formation is in part correlative with the Wood River Formation (Bostwick, 1955; Shannon, 1961).

Origin and Depositional Environment

The well-sorted, mono-mineralic nature of the Quadrant sandstones, the wide areal distribution, laminations, and cross-laminations are typical of a shallow (littoral to shallow neritic), agitated, marine environment.

The interbedded dolomites are probably recrystallized and dolomitized clastic limestones that accumulated during intermittent periods when local shifts in current direction caused most of the detritus to bypass a particular part of the basin (Robinson, 1963).

The source area for the Quadrant Formation may have been a pre-existing quartz sandstone as indicated by the presence of well rounded zircon, although the presence of hornblende indicates a coarsely crystalline metamorphic or igneous source. Therefore, the source area probably contained both crystalline and sedimentary rocks. Robinson (1963) discusses the problems of locating an adequate source area for the Quadrant Formation and suggests "a northerly landmass of varied lithology."

Permian System

Peale (1893) was the first to describe the lithology of the Phosphoria Formation in the Three Forks area of Montana. However, he included these beds within his Quadrant Formation.

Richards and Mansfield (1912) named the Phosphoria Formation for exposures of Permian strata at Phosphoria Gulch near Meade Peak, Idaho. At the type section in southeastern Idaho, Richards and Mansfield described the Phosphoria Formation as consisting of 180 feet of phosphatic shales overlain by 240 feet of bedded cherts.

Stone and Bonine (1914) were the first to apply the name "Phosphoria Formation" to beds in Montana. They assigned all Permian strata in southwestern Montana to the Phosphoria Formation although the lithology varies laterally.

Economic interest in the phosphatic beds of the Phosphoria Formation has stimulated many investigations of the Phosphoria Formation. A few of these are Condit and others (1928), Cressman and others (1953), Cressman (1955), McKelvey and others (1956, 1959), and Swanson (1970).

McKelvey and others (1956) proposed a new nomenclature for the Phosphoria Formation. They extended the Park City Formation of Utah to include the carbonates with subordinate sandstone of Permian age formerly assigned to the Phosphoria Formation and limited the Phosphoria Formation to the phosphatic mudstones and the cherts. They introduced the term "Shedhorn Formation" for the dominantly sandstone unit and designated the type section of the Shedhorn Formation as exposures on the north side of Indian Creek in the Madison Range, Montana, about eight miles south of the Cedar Creek area.

In this report, the name "Phosphoria Formation" is restricted to the phosphatic mudstone and bedded chert unit following the usage of McKelvey and others (1956). Although the lithologies of the Park City, Phosphoria, and Shedhorn Formations are easily distinguished where encountered in the field, these formations are mapped as a single unit because the Permian section in the Cedar Creek area is thin. However, the lithologies are described separately.

In the Cedar Creek area, beds of Permian age conformably overlie the Quadrant Formation. The contact with the Quadrant Formation is gradational from quartz arenites with subordinate, interbedded dolomites to dolomites with subordinate interbedded quartz arenites. The upper tongue of the Shedhorn Formation is overlain by the Dinwoody Formation with apparent conformity in the southern half of the Cedar Creek area. In the northern part of the Cedar Creek area, pre-Jurassic erosion has removed the Dinwoody Formation; and the Ellis Group disconformably overlies the Permian rocks.

In this report, the lower contact is placed arbitrarily where dolomite beds begin to dominate the section. The upper contact of Permian beds is placed at the sharp lithologic change from the resistant sandstones of the Shedhorn Formation to the less resistant dolomites of the Dinwoody Formation in the southern half of the thesis area and the less resistant limestones of the Ellis group in the northern half of the thesis area. The break in slope that generally accompanies the change in lithology is useful in determining the contact where the formations are concealed.

Exposure and Topographic Expression

The Park City and Shedhorn Formations are resistant units that form bold outcrops or cliffs at many locations in the Cedar Creek area. The best exposures of the Shedhorn and Park City Formations are found along the north wall of the Shell Creek canyon. The Retort Phosphatic Shale Member of the Phosphoria Formation forms a covered slope throughout the Cedar Creek area. The Tosi Chert Member of the Phosphoria Formation is usually covered also, although the unit is exposed on the north wall of the Shell Creek canyon.

Thickness and Lithology

As measured and described along a small gully in the cliffs on the north wall of Shell Creek canyon in the SE1/4 NE1/4 sec. 33, T. 6 S., R. 1 E., the Permian beds are 200 feet thick in the Cedar Creek area. The basal Permian unit in the Cedar Creek area is assigned to the Park City Formation and consists of 80 feet of dolomites and silty dolomites with interbedded sandstones. The Park City Formation is conformably overlain by the sandstones of the Shedhorn Formation, consisting of a lower tongue 12 feet thick, and an upper tongue 65 feet thick. The Phosphoria Formation, a phosphorite, mudstone, and bedded chert unit, 42 feet thick, overlies the lower tongue of the Shedhorn Formation and is overlain by the upper tongue of the Shedhorn Formation.

Park City Formation. The Park City Formation in the thesis area consists of dolomites and silty to sandy dolomites with nodules, lens, and beds of chert and a thin, interbedded sandstone, present in the lower part of the formation. The sandstone bed is two feet thick and is similar in lithology to the sandstones of the Quadrant Formation.

The dolomites are thin-bedded (one foot) becoming thick-bedded (three to five feet) upward. The dolomites are light brownish gray (5YR 6/1) to light gray (N7) to very pale orange (10YR 8/2) and weather very light to light gray (N8 to N7) or light bluish gray (5B 6/1). Representative samples of the dolomite are composed of finely crystalline dolomite (80 to 90 percent), detrital quartz (1 to 15 percent), predominantly very fine-grained and silt-sized but also up to coarse-grained, and porosity (2 to 7 percent).. Porosity consists of intergranular pores with minor, larger solution pores. Iron oxides, clay, and organic matter are present in trace amounts.

Minor amounts of chert, present as nodules, lenses, and beds (two to six inches thick) are typical of the Park City Formation. Textural variations from dense dolomite to a gritty dolomite are associated with increased porosity, detrital quartz, and a tendency to form euhedral dolomite crystals.

Shedhorn Formation. The Shedhorn Formation in the Cedar Creek area is a sandstone with interbedded chert. The sandstone

Figure 7. Bedded chert member of the Phosphoria Formation on the north wall of the Shell Creek canyon SE1/4 NE1/4 sec. 33, T. 6 S., R. 1 E.

ranges from thin-bedded (two inches) to very thick-bedded (six feet). The sandstone is pale yellowish brown (10YR 6/2) and weathers to light brownish gray (5YR 5/1). A typical sample of the sandstone is composed of fine-grained, well-sorted, subrounded quartz (80 percent), collophane grains (10 percent), chert grains (2 percent), intergranular pores (1 percent), and cement (7 percent). The sandstone is very well cemented by silica overgrowths and minor calcite cement.

The upper tongue contains sparse, thin (two inches) interbeds of very light gray (N8) chert that weathers yellowish gray (5Y 8/1). The chert beds are predominantly chert, with varying amounts of detrital quartz. The chert has replaced fossil fragments leaving fossil "ghosts".

Phosphoria Formation. The Phosphoria Formation in the Cedar Creek area can be divided into a lower mudstone and phosphorite unit known as the Retort Phosphatic Shale Member, and an upper bedded chert unit known as the Tosi Chert Member (Cressman and Swanson, 1960).

The Retort Phosphatic Shale Member, ten feet thick, is covered throughout the Cedar Creek area. Angular pebbles and cobbles of medium dark gray (N4) phosphorite that weathers pale yellowish brown (10YR 6/2) and very pale blue (5B 8/2), are present in the soil overlying the Retort Phosphatic Shale Member. The phosphorite consists of poorly-sorted, well-rounded, elliptical, phosphatic nodules, 0.7 to 0.2 mm in diameter. Many of the nodules are intraclasts of aggregates of collophane pellets (0.05 mm in diameter) cemented together by chert. A representative sample consists of collophane (80 percent), chert cement (17 percent), detrital quartz (3 percent), and chalcedony veins and void fillings (3 percent).

The Tosi Chert Member, 32 feet thick, consists of dark gray (N3) interlaminated chert and silty dolomite. The dolomite laminae are typically 0.5 to 1 mm thick. The chert laminae are generally thicker, ranging up to 5 mm thick. Chert laminae consist of chert (65 percent), dolomite rhombohedrons (15 percent), phosphatic shell fragments (10 percent), and quartz silt (10 percent). Rare traces of radiolarians (?), replaced by chert, are present. Dolomite laminae consist of euhedral to subhedral, finely crystalline (0.05 mm) dolomite with quartz silt (2 percent) and finely dispersed organic matter. Dolomite layers exhibit varying amounts of replacement by chert, and proportions of chert to dolomite vary greatly from lamina to lamina.

Fossils and Age

Phosphatic shell fragments and radiolarians (?) were found in the Tosi Chert Member of the Phosphoria Formation in the Cedar Creek area.

Frenzel and Mundorf (1942) dated fusulinids found in the Park City Formation in the Three Forks of Montana as Wolfcampian (Early Permian) in age.

Miller and others (1957) found ammonites of Leonardian age above the Rex Chert Member of the Phosphoria Formation in Idaho and in the Wasatch Range.

McKelvey and others (1959) have assigned a Leonardian and early Guadalupian (Middle Permian) age to the Phosphoria Formation. Williams (McKelvey and others, 1959) suggested the Park City Formation in Montana is Leonardian in age.

Dunbar and others (1960) have reported that the Phosphoria and Shedhorn Formations in Montana are entirely Guadalupian (early Late Permian) in age.

Regional Distribution and Correlation

The Park City, Shedhorn, and Phosphoria Formations intertongue over a wide area in southwestern Montana, northwestern Wyoming, and eastern Idaho and represent three separate facies (Cressman and Swanson, 1964).

The Park City Formation, the carbonate facies, which is up to 600 feet thick in Montana, is recognized throughout southwestern and south-central Montana, central and western Wyoming, southeastern Idaho, and northeastern Utah (Balster, 1971).

The Shedhorn Formation, the sandstone facies, is limited in distribution to Yellowstone National Park and adjacent parts of southwestern Montana, eastern Idaho, and northwestern Wyoming (McKelvey and others, 1956). The Shedhorn Formation ranges up to 100 feet thick in Montana and generally consists of an upper and a lower tongue, although locally and southward into Wyoming and eastern Idaho the Shedhorn Formation consists of several thin tongues or lenses (Balster, 1971).

The Phosphoria Formation, comprising the phosphorite, bedded chert, and mudstone facies, includes the Retort Phosphatic Shale, Rex Chert, Tosi Chert, and Meade Peak Phosphatic Shale Members. Of these, only the Retort Phosphatic Shale and the Tosi Chert Members are present in the Cedar Creek area.

The Retort Phosphatic Shale Member ranges up to 80 feet thick in Montana and is persistent in southwestern Montana, western and central Wyoming, eastern Idaho, and possibly northern Utah (Balster, 1971).

The Tosi Chert Member is present in eastern Idaho, western and central Wyoming, and southwestern Montana, where it is as much as 150 feet thick (Balster, 1971).

Permian strata have been removed from most of central and northern Montana by pre-Jurassic erosion (McKelvey and others, 1956). Permian strata thicken southwestward to more than 1,000 feet in southeastern Idaho (Balster, 1971).

The Minnekahta Limestone and the Opeche Formation of eastern Wyoming and southeastern Montana are correlative with the Permian strata found in southwestern Montana (Perry, 1945).

Origin and Depositional Environment

Detrital quartz distributed throughout the Park City Formation suggests that the Park City Formation was originally a clastic limestone or dolomite, deposited by low to moderate energy current.

Cressman and Swanson (1964) have suggested that a sedimentary provenance emergent on the central Montana platform and the Sweetgrass Arch might have been the source areas for the Shedhorn Formation.

The phosphorites of the Phosphoria Formation accumulated in a north-northwest trending basin centered in southeastern Idaho and southwestern Montana east of the present Beaverhead Range. Upwelling of cold, marine waters led to the precipitation of phosphates between depths of 50 and 200 meters (McKelvey and others, 1953; Cressman and Swanson, 1964).

The bedded cherts of the Phosphoria Formation in the Cedar Creek area apparently originated at least in part from recrystallization of the siliceous tests of radiolarians.

Dinwoody Formation

Condit (1917) was the first to use the name "Dinwoody Formation" in a published report. However, Blackwelder (1918) defined the Dinwoody Formation and designated the type section at Dinwoody Canyon in the Wind River Mountains of Wyoming. Blackwelder described the formation as a unit, about 250 feet thick, of greenish-gray shale with interbedded thin platy carcareous sandstones lying between the Park City Formation below and the red strata of the Chugwater Formation above.

Newell and Kummel (1942) redefined the Dinwoody Formation at the type locality to exclude the upper shales. They placed the upper contact of the Dinwoody Formation below the upper shales since the upper shales vary from gray to red laterally and are best placed with red beds of the Chugwater Formation. As redefined at the type locality, the Dinwoody Formation includes only 90 feet of dominantly silty strata. In southeastern Idaho, Newell and Kummel subdivided the Dinwoody Formation into a basal siltstone, a Lingula zone, and a Claria zone.

Moritz (1951) noted that the three subdivisions of Newell and Kummel may be present in southwestern Montana. However, Moritz chose to divide the Dinwoody Formation of southwestern Montana into a lower unit of shales with thin-bedded limestones and an upper unit of brown-weathering limestones and siltstones with interbedded shales.

Kummel (1960) also recognized a twofold division of the Dinwoody Formation in southwestern Montana consisting of a lower shale unit and an upper unit of interbedded siltstone and limestones.

In the Cedar Creek area, the Dinwoody Formation conformably overlies the Shedhorn Formation. The Dinwoody is unconformably overlain by the Sawtooth Formation. The upper contact was placed at the slight topographic break accompanying the lithologic change from the dolomites and siltstones of the Dinwoody Formation to the Ostrea-bearing, sandy, dolomitic micrite of the lower part of the Sawtooth Formation.

Exposure and Topographic Expression

In the Cedar Creek area, the Dinwoody Formation forms a covered slope with scattered outcrops protruding a few feet above the ground surface.

The best exposures of the Dinwoody Formation in the Cedar Creek area are present on the hillside in the S1/2 NE1/4 sec. 33, T. 6 S., R. 1 E. and along the ridge top in the SE1/4 SW1/4 sec. 33, T. 6 S., R. 1 E.

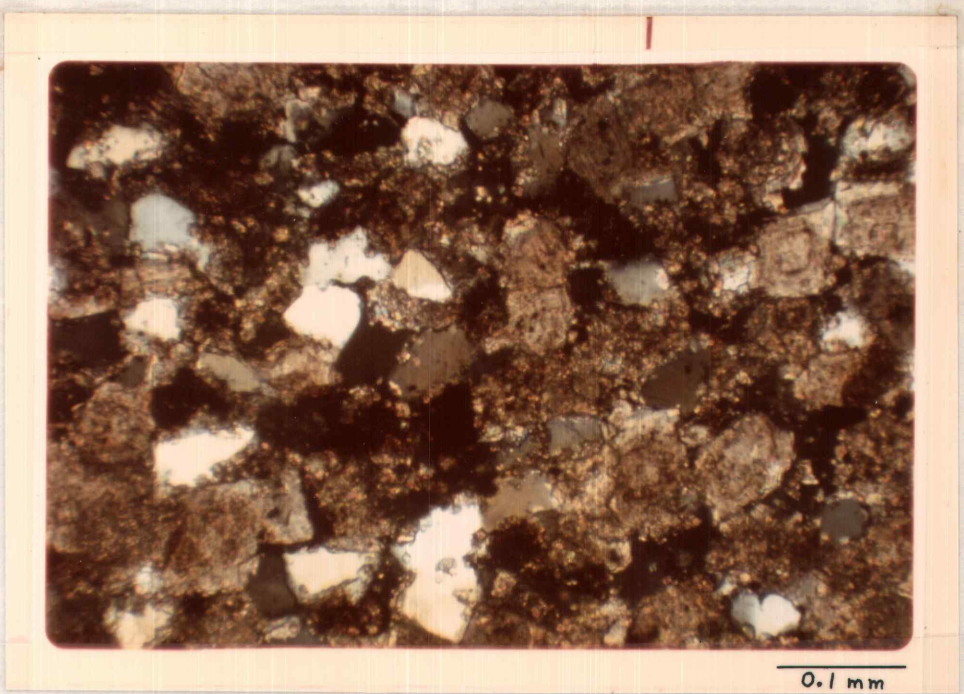

Figure 8. Photomicrograph of dolomitic siltstone from the Dinwoody Formation in the Cedar Creek area.

Thickness and Lithology

In the Cedar Creek area, the Dinwoody Formation is 176 feet thick as measured and described in the SE1/4 NE1/4 sec. 33, T. 6 S., R. 1 E. Pre-Jurassic erosion apparently has thinned the Dinwoody Formation and in the northern half of the Cedar Creek area has completely removed the formation.

The Dinwoody Formation in the Cedar Creek area consists of interbedded dolomites and siltstones. In general, dolomites dominate the lower part of the section and siltstones dominate the upper part of the section. Bedding generally is thin to very thin (1/2 inch to 1 foot), although a few beds are thick-bedded (three feet), and some beds are thinly laminated and cross-laminated (about 2 mm). Ripple marks are visible along bedding planes in a few siltstone beds.

The dolomites are medium light gray (N6) or grayish orange (10YR 7/4) that weather grayish orange (10YR 6/4), or pale yellowish brown (10YR 6/2). Representative samples of the dolomites consist of finely crystalline (0.02 to 0.03 mm) subhedral dolomite (93 percent), very fine-grained detrital quartz (1 percent), phosphatic shells of Lingula (3 percent), clay (2 percent), and prosity (1 percent). Iron oxide is present in trace amounts. Fossil ghosts are visible in the dolomite and are probably dolomitized calcareous fossils.

The siltstones of the Dinwoody Formation are brownish gray (5YR 4/1), medium gray (N5), or light brownish gray (5YR 7/1) that weather moderate yellowish brown (10YR 5/4), light olive gray (5Y 6/1), or grayish orange (10YR 7/4). The siltstones consist of angular to rounded, poorly sorted, silt-sized quartz (70 percent), chert (1 percent), subhedral dolomite (4 percent), dolmicrite cement (24 percent), and solution porosity (1 percent).

Fossils and Age

Abundant specimens of *Lingula* sp. were found in the Dinwoody Formation in the Cedar Creek area. Every section of the Dinwoody Formation measured by Moritz (1951) in southwestern Montana contained well-preserved specimens of *Lingula* sp.

Kummel (1954) studied two ammonite faunas found in the Dinwoody Formation in southwestern Montana and assigned an Early Triassic age to the formation.

Regional Distribution and Correlation

The Dinwoody Formation is recognized in southeastern Idaho, southwestern and south-central Montana, and in western and central Wyoming.

From the Cedar Creek area, the Dinwoody Formation thickens southward to over 2,440 feet in southeastern Idaho (Kummel, 1960). Typical thicknesses of the Dinwoody Formation in nearby areas are 700 to 800 feet in southern Beaverhead County (Moritz, 1951), 409 to about 600 feet in the Gravelly Range (Mann, 1954), and 265 feet in the Madison Range east of the Cedar Creek area (McMannis and Chadwick, 1964). Pre-Jurassic erosion has removed the Dinwoody Formation from northern Montana (Kummel, 1954).

According to Kummel (1960), the Dinwoody Formation intertongues with the red beds of the Woodside and Chugwater Formations in a zone along the Wyoming-Idaho border. The Dinwoody Formation is equivalent to the Spray River Formation of Alberta and British Columbia (Stockwell, 1957) and is correlative with the lower Moenkopi Formation of Utah, Arizona, and Nevada (Reeside and others, 1957).

The Woodside and Thaynes (?) Formations overlie the Dinwoody Formation in the southern Madison Range (Witkind, 1969), but pre-Jurassic erosion has removed the Woodside and Thaynes from the Cedar Creek area.

Origin and Depositional Environment

The abundance of clay and silt in the limestones of the Dinwoody Formation and the interfingering of the Dinwoody Formation with non-marine beds to the east led Moritz (1951) to conclude that the Dinwoody Formation was deposited "on a mildly unstable shelf or an intracratonic basin."

The presence in the Cedar Creek area of cross-laminations, ripple marks, and *Lingula*-bearing dolomites interbedded with siltstones strongly suggest shallow marine deposition and periodic fluctuations of sea level.

Well rounded quartz grains and detrital chert indicate the source for the detritus in the Dinwoody Formation was, at least in part, a sedimentary provenance with sandstones and limestones. Moritz (1951) proposed a distant, eastern source area as the most likely.

Ellis Group

Peale (1893) used the name "Ellis Formation" for rocks lying between the Quadrant Formation and Cretaceous strata in the area between Three Forks and Livingston, Montana. Peale did not designate a type section.

Cobban and others (1945) designated the type section for the Ellis Formation as exposures in Rocky Creek Canyon, Gallatin County, Montana.

Later, Cobban (1945) raised the Ellis Formation to group status and divided the Ellis into three formations, the Sawtooth Formation, the Rierdon Formation, and the Swift Formation.

The Sawtooth and Rierdon Formations crop out in the Cedar Creek area; but the Swift Formation is absent. The Sawtooth and Rierdon Formations are mapped together as a single unit, the Ellis Group, because both formations are thin and poorly exposed.

Sawtooth Formation

Cobban (1945) named the Sawtooth Formation for exposures in the Sawtooth Mountains of Montana. The type locality is in Rierdon Gulch where the Sawtooth Formation is defined as a basal unit of fine-grained sandstone, a middle unit of dark gray shales with interbedded limestones, and an upper unit of calcareous siltstones. At the type locality, the Sawtooth Formation is 137 feet thick.

Moritz (1951) extended the usage of the name "Sawtooth Formation" from the type locality into southwestern Montana where the Sawtooth Formation is characterized by calcareous shales or argillaceous limestones.

In the southern half of the Cedar Creek area, the Sawtooth Formation unconformably overlies the Dinwoody Formation. In the northern half of the area, the Sawtooth unconformably overlies Permian strata. The Rierdon Formation overlies the Sawtooth Formation with apparent conformity in the Cedar Creek area.

Exposure and Topographic Expression. In the Cedar Creek area, the Sawtooth Formation is poorly exposed and forms covered slopes with isolated ledges protruding a few feet above the ground surface. The Sawtooth Formation forms slightly steeper slopes than the underlying Dinwoody Formation aiding the placement of the Dinwoody-Ellis contact wherever the bedrock geology is concealed.

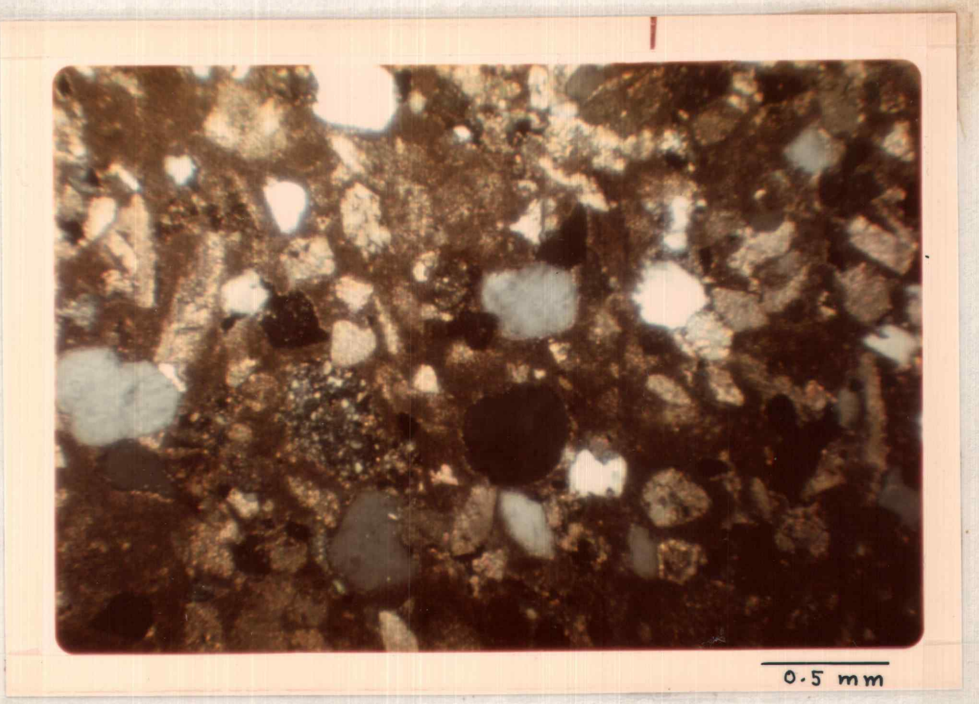

Figure 9. Photomicrograph of sandy, dolomitic micrite from the basal unit (unit A) of the Sawtooth Formation in the Cedar Creek area showing medium-grained quartz and chert, subhedral to euhedral dolomite crystals, and micrite matrix.

The best exposures of the Sawtooth Formation in the thesis area are found in the NE1/4 NE 1/4 sec. 33, T. 6 S., R. 1 E. although parts of the formation are usually exposed where the formation crosses a ridge.

Thickness and Lithology. In the Cedar Creek area, the Sawtooth Formation is 95 feet thick and can be divided into four units that are discussed in ascending order below. The Sawtooth Formation was measured and described in the NE1/4 NE1/4 sec. 33, T. 6 S., R. 1 E.

The basal unit of the Sawtooth Formation, unit A, is 42 feet thick and consists of *Ostrea*-bearing, sandy, dolomitic micrites that are medium gray (N5) to grayish orange (10YR 6/4). Weathered surfaces are pale yellowish brown (10YR 6/2) to very pale orange (10YR 8/2). Unit A is generally thick-bedded (two to three feet). Representative samples of unit A consist of Micrite (45 percent), 0.2 mm dolomite rhombohedrons (35 percent), well rounded, medium-grained and silt-sized quartz (15 percent), fossil fragments (4 percent), and chert replacing carbonates (1 percent).

Unit B of the Sawtooth Formation is 35 feet thick and is a light brownish-gray (5YR 5/1) micrite that weathers grayish orange (10YR 7/4) to yellowish gray (5Y 8/1). The micrite includes very minor quartz silt (1 percent), and authegenic iron oxide (1 percent).

Unit C of the Sawtooth Formation is nine feet thick and consists of very thin-bedded (one to two inches), medium gray (N5), sandy pelmicrite that weathers pale yellowish brown (10YR 7/2). A representative sample of unit C comprises well sorted 0.05 mm pellets (60 percent), quartz (10 percent), subhedral dolomite (10 percent), oolites (5 percent), and fossil fragments (5 percent) cemented by micrite (10 percent). Iron oxide and chert are presented in trace amounts.

Unit D is nine feet thick and is comprised of flaggy (two inch) thinly laminated, grayish orange (10YR 7/4), calcareous sandstones that weather medium light gray (N6). Thin (0.1 mm), clay-rich laminae that weather pale yellowish orange (10YR 8/4) are interlaminated with thicker, sand-rich laminae (1 to 2 mm thick). A representative sample consists of subangular, very fine-grained quartz (60 percent), 0.1 mm micrite pellets (30 percent), oolites (3 percent), fossil fragments (1 percent), detrital chert (1 percent), and micrite cement (5 percent). Unit D has a limited areal extent and was recognized only at a few outcrops north of Shell Creek.

Fossils and Age. The Sawtooth Formation typically is highly fossiliferous in southwestern Montana, but in the Cedar Creek area, the Sawtooth Formation lacks an abundant fauna. However, several specimens of *Ostrea* sp., an unidentified pelecypod, columnals of

Pentacrinus sp., and abundant fossil fragments were found in a few beds of the Sawtooth Formation in the thesis area.

Mann (1954) identified *Pentacrinus* sp. and *Ostrea* sp. in the Sawtooth Formation in the Gravelly Range.

Witkind (1969) identified echinoderms, ammonoids, and numerous pelecypods from the Sawtooth Formation in the Madison Range southeast of the Cedar Creek area and considered the Sawtooth Formation to be Middle Jurassic (Bathonian) in age.

Regional Distribution and Correlation. The Sawtooth Formation is present in western Montana, ranging up to 230 feet thick (Balster, 1971). Typical thicknesses of the Sawtooth Formation in nearby areas are 120 feet in the Madison Range east of the Cedar Creek area (McMannis and Chadwick, 1964), about 200 feet in the Madison range, southeast of the Cedar Creek area (Witkind, 1969), and 131 feet in the Centennial Range (Moran, 1971).

Moritz (1951) reported the thickness of the Sawtooth Formation to range between 0 and 140 feet and described the lithology of the formation as calcareous shales and argillaceous limestones in southwestern Montana. However, the lithology of the Sawtooth Formation in the Cedar Creek area more closely resembles that of the Sawtooth Formation of the Sweetgrass Arch area of Montana where Cobban (1945) reported the formation consists of a basal sandstone, a medial dark-gray shale, and an upper sandy, oolitic limestone.

The Sawtooth Formation grades eastward into the sequence of red beds, limestones, and evaporites known as the Piper Formation (Balster, 1971). The Sawtooth Formation is considered correlative with the Gypsum Spring Formation of eastern Montana and northern and central Wyoming (Moritz, 1960; Balster, 1971) and with the lower part of the Twin Creek Limestone of southeastern Idaho, northern Utah, and western Wyoming (Imlay, 1952).

Origin and Depositional Environment. Typical Sawtooth sediments in southwestern Montana contain abundant clay and silt and only minor amounts of coarser detritus, indicating a distant, low-lying source area. However, the abundance of sand-sized quartz in parts of the Sawtooth Formation in the Cedar Creek area suggests the formation was derived, in part, from a local source area.

The depositional environment of the Sawtooth Formation in the Cedar Creek area varied from sublittoral to deeper shallow water. Current energy of the sublittoral environment was sufficiently high to form oolites, to fragment fossils, and to transport quartz sand. The lower current energy of the deeper water environment produced the accumulation of micrites.

Rierdon Formation

Cobban (1945) named the Rierdon Formation for exposures of "alternating gray limy shale and limestones" at the type locality in

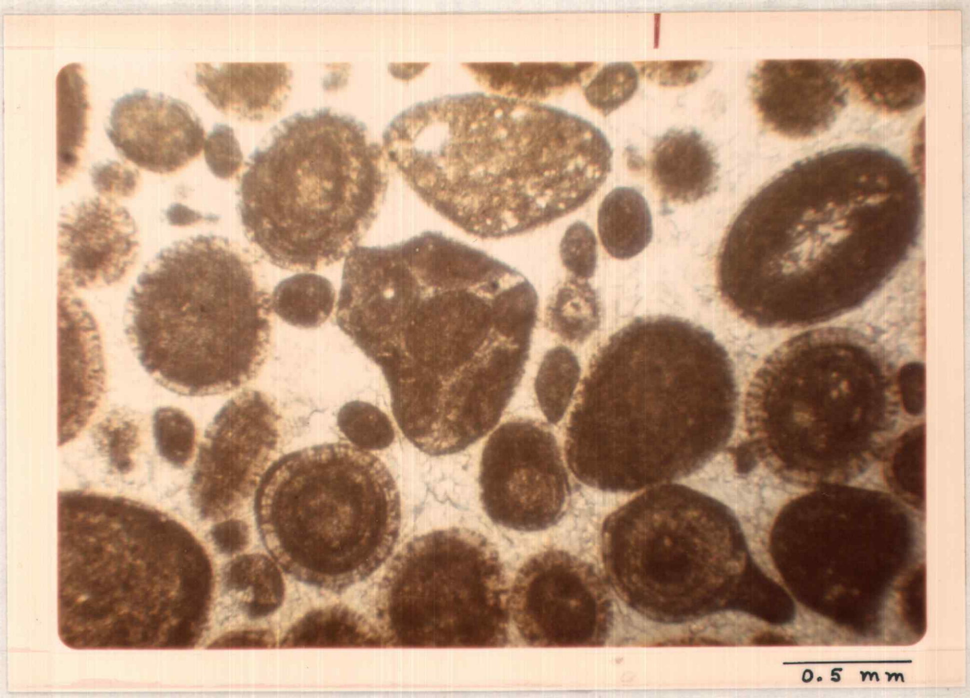

Figure 10. Photomicrograph of oosparite from the Rierdon Formation in the Cedar Creek area.

Rierdon Gulch in the Sawtooth Range of Montana where the Rierdon Formation is 137 feet thick.

Moritz (1951) extended usage of the name "Rierdon Formation" from the type locality into southwestern Montana where the formation is characterized by oolitic limestone and argillaceous and sandy limestones.

In the Cedar Creek area the Rierdon Formation conformably overlies the Sawtooth Formation, and is disconformably overlain by the Morrison Formation.

Exposure and Topographic Expression. In the Cedar Creek area, the Rierdon Formation forms covered slopes and low ledges of oolitic limestone that crop out only a few feet above the slope. The best exposures of the Rierdon Formation are found in the NE1/4 NE1/4 sec. 33, T. 6 S., R. 1 E. and in the SW1/4 NE1/4 sec. 4, T. 7 S., R. 1 E. where the formation is well exposed. Parts of the formation are usually exposed where the formation crosses a ridge.

Thickness and Lithology. In the thesis area, the Rierdon Formation is 104 feet thick as measured and described in the NE1/4 NE1/4 sec. 33, T. 6 S., R. 1 E.

The Rierdon Formation in the Cedar Creek area is a sequence of three or four thin- to thick-bedded (six inches to three feet) oolitic limestones, 5 to 15 feet thick, separated by covered intervals, typically 35 to 50 feet thick, of limy siltstones, mudstones, and shales that weather light brown (5YR 5/6), moderate yellowish brown (10YR 5/4), or grayish orange (10YR 7/4).

The oolitic limestones are medium dark gray (N4) to light brownish gray (5YR 5/1) that weather moderate yellowish brown (10YR 5/4) to very light gray (N8). Representative samples of the oolitic limestones are oosparite composed of oolites (75 to 80 percent), quartz (1 to 2 percent), sparry calcite cement (12 to 15 percent), and intergranular pores (1 to 3 percent). The oolites average 0.2 mm to 0.5 mm in diameter and are concentric deposits of micrite around nuclei of silty micrite intraclasts, fossil fragments, and detrital quartz up to 0.2 mm in diameter. Silica overgrowths, some replacing calcite, are common on the detrital quartz grains.

Another section of the Rierdon Formation was measured and described on the north side of the canyon in the SW1/4 NE1/4 sec. 4, T. 7 S., R. 1 E. where the Rierdon Formation is 60 feet thick. At this location the Rierdon Formation is composed entirely of oosparite.

Fossils and Age. Like the Sawtooth Formation, the Rierdon Formation typically is highly fossiliferous in southwestern Montana. However, no identifiable fossils were found in the Rierdon in the Cedar Creek area, although gastropods and crinoid columnals and spines were found in thin section.

Cobban (1945) has dated the Rierdon Formation as late Bathonian and early Callovian (late Middle and Late Jurassic). He also has noted the formation varies in age from place to place.

Imlay (1952) has identified a faunal assemblage from the Rierdon Formation in southwestern Montana, where he considers the Rierdon to be early Callovian (earliest Late Jurassic).

Regional Distribution and Correlation. Moritz (1951) and Imlay (1952) reported an eastward increase in the thickness and the clastic ratio of the Rierdon Formation in southwestern Montana.

Balster (1971) stated that reported thicknesses of the Rierdon Formation range up to 240 feet. The Rierdon Formation is present throughout much of Montana and in eastern North Dakota.

The Hulett Sandstone, Beaver Shale, and Canyon Springs Sandstone Members of the Sundance Formation of North and South Dakota and northeastern Wyoming are considered correlative with the Rierdon Formation (Schmitt, 1953).

Origin and Depositional Environment. The presence of oosparite and shallow-water marine fossils such as pelecypods, reported in the Rierdon Formation in the southern Madison Range (Witkind, 1969), indicate the Rierdon Formation was deposited in shallow, agitated, marginal parts of the Jurassic sea. The interbedded micrites, of varying thickness, suggest local deeper water conditions.

An eastward increase in the clastic ratio and the thickness of the Rierdon Formation indicates an eastern source area.

Moritz (1951) has reported evidence from a study of heavy mineral assemblages in the Rierdon Formation that indicates a sedimentary and igneous provenance. He suggested the sedimentary provenance consisted of Permian strata which were being eroded during Jurassic time.

Morrison Formation

The Morrison Formation was named by Cross (1894) for exposures near Morrison, Colorado. Later, Eldridge (Emmons and others, 1896) described the formation as about 200 feet of green, drab, or gray marls lying between a brown and pink sandstone of Triassic age and the Dakota Sandstone of Cretaceous age. Cross and Eldridge did not designate a type section.

Waldschmidt and Leroy (1944) proposed a type section two miles north of Morrison, Colorado and subdivided the Morrison Formation into six units that are, in ascending order: a basal sandstone, a gray and red shale, a gray clay and lithographic limestone, a gray shale and sandstone, a red shale, and upper sandstone and variegated shale. At the type section, the Morrison Formation is 277 feet thick.

In the Cedar Creek area, the Morrison Formation disconformably overlies the Rierdon Formation. The Kootenai Formation disconformably overlies the Morrison Formation. The lower contact, between the Rierdon and the Morrison Formations, was placed at the top of the highest oolitic-limestone ledge of the Rierdon Formation. The upper contact of the Morrison Formation was placed at the base of the resistant sandstone of the Kootenai Formation.

Exposure and Topographic Expression

In the thesis area, the Morrison Formation forms moderate slopes covered by slope wash and vegetation. However, a partial section of the Morrison Formation is well exposed in the SW1/4 NE1/4 sec. 4, T. 7 S., R. 1 E. and a complete section is poorly exposed in the NW1/4 NW1/4 sec. 34, T. 6 S., R. 1 E. Locally, sandstone beds crop out as small, discontinuous ledges. At a few locations, gully erosion has exposed some of the beds of the Morrison Formation.

Thickness and Lithology

In the Cedar Creek area, the Morrison Formation is 280 feet thick as measured and described in the NW1/4 NW1/4 sec. 34, T. 6 S., R. 1 E. The poor exposure of the Morrison Formation in the Cedar Creek area prohibited a detailed study of the lithology.

Ninety percent of the formation consists of mudstones and shales usually concealed by a thin soil, typically grayish red (10R 4/2) to light gray (N7).

Thin- to very thin-bedded (one foot to one inch) sandstone units, commonly three to five feet, compose 10 percent of the formation.

The sandstones weather to pale reddish brown (10R 5/4), moderate yellowish brown (10YR 5/4) or grayish orange (10YR 7/4). The sandstones are generally weathered throughout. Where found, fresh surfaces are light brownish gray (5YR 6/1) to medium light gray (N6). A representative sample of the sandstones, taken near the base of the formation, is composed of quartz (40 percent), chert grains (30 percent), clay (15 percent), iron oxide (5 percent), and calcite cement (10 percent). Well rounded zircon grains were found in trace amounts. Porosity is low. Grains are generally subangular, moderately sorted, and very fine- to fine-grained (0.1 to 0.2 mm).

Fossils and Age

No fossils were found in the Morrison Formation in the Cedar Creek area.

Waldschmidt and Leroy (1944) found numerous *Atlantasaurus* remains, charaphytes, and sponge spicules in the Morrison Formation near Morrison, Colorado. Mann (1954) and Christie (1961) found dinosaur bones in the Morrison Formation in the Gravelly Range southwest of the Cedar Creek area.

The Morrison Formation has been dated as Late Jurassic in age at the type locality in Colorado by Simpson (1926). In Montana, Yen (1952) has identified fresh-water forms of Late Jurassic age. Imlay (1952) and Peck (1957) consider the Morrison of Montana as

Late Jurassic in age.

Robinson (1963) pointed out that although the Morrison Formation is entirely Late Jurassic in age in Colorado, the Morrison of Montana may be, in part, Cretaceous.

Regional Distribution and Correlation

The Morrison Formation is very widespread and is present in Montana, western North and South Dakota, western Nebraska, Wyoming, Colorado, western Kansas, Idaho, Utah, New Mexico, and Arizona (McKee and others, 1956).

Moritz (1951) reported the Morrison Formation is about 400 feet thick along the Montana-Idaho border and thins to the north and northwest. In south-central Montana, the Morrison Formation is 100 to 400 feet thick (Gardner and others, 1945). Love (1945, 1956) described the Morrison Formation in Wyoming as variegated silty claystones and argillaceous sandstones, generally less than 200 feet thick. In the Black Hills region, the Morrison Formation is predominantly greenish-gray and green mudstones and shales (Downs, 1949).

The Passage Beds in the upper part of the Fernie Group of Alberta consist of interbedded shales and sandstones, 150 to 200 feet thick, that are probably correlative with the Morrison Formation (Stockwell, 1957).

Origin and Depositional Environment

Many authors have reported that the depositional environment of the Morrison Formation is non-marine including fluvial, paludal, and lacustrine environments (Moritz, 1951; Robinson, 1963; McKee and others, 1956; Balster, 1971). However, no evidence to support this conclusion was found in the Cedar Creek area.

The presence of well rounded zircon and abundant chert in the sandstones in the Cedar Creek area strongly suggests a sedimentary provenance for the Morrison Formation of southwestern Montana. The source areas for a continental basin of the size proposed for the Morrison Formation, extending from Arizona and New Mexico to Montana and from Kansas and Nebraska to Utah and Idaho (McKee and others, 1956) probably were numerous and varied in lithology.

Suttner (1969) proposed westernmost Montana and adjacent Idaho, where Morrison strata are absent, as the source area for the Morrison Formation in west-central Montana.

Kootenai Formation

Dawson (1885) applied the name "Kootenie Group" to a sequence of shales, sandstone, conglomerate, and thin coal beds exposed along Old Man River, Martin Creek, and Coal Creek of the Bow Valley region of Alberta.

Fisher (1908) changed the spelling from Kootenie to Kootenai and applied the name "Kootenai Formation" to alternating pebbly sandstones, red sandy shales and mudstones, occasional coal beds, and concretionary limestones exposed in the Great Falls region of Montana.

Berry (1943) assigned to the Kootenai Formation 1,500 feet of sandstones, shales, and fresh-water limestones exposed in the Three Forks area of Montana.

In the Cedar Creek area, the Kootenai Formation disconformably overlies the Morrison Formation, and is conformably overlain by the Colorado Group. In this report, the lower contact of the Kootenai Formation was placed at the base of the resistant sandstones and conglomerates. The upper contact was placed at the sharp break in slope produced by the change in lithology from gastropod limestones of the Kootenai to the mudstones and shales of the Colorado Group.

Exposure and Topographic Expression

In the Cedar Creek area, the basal sandstone unit forms prominent ridges and discontinuous ledges and cliffs 3 to 25 feet high. Although the middle and upper units of the Kootenai Formation form covered slopes throughout most of the Cedar Creek area, the Kootenai Formation is more resistant than the overlying Colorado Group sediments, and the Kootenai commonly caps dip slopes. The best exposures of the Kootenai Formation in the Cedar Creek area are present in the NW1/4 sec. 34, T. 6 S., R. 1 E.

Thickness and Lithology

The Kootenai Formation is 404 feet thick in the Cedar Creek area as measured and described in the NW1/4 sec. 34 and the SW1/4 SW1/4 sec. 27, T. 6 S., R. 1 E. The Kootenai Formation can be divided into three units that are discussed separately below.

The lower unit, 39 feet thick, consists of subfeldspathic arenite with lens of very coarse-grained, pebbly sandstone. The subfeldspathic arenite is very thick-bedded and locally cross-bedded. At some outcrops faint laminations are visible. Representative samples of the lower unit are fine-grained (0.4 mm average) and poorly sorted, and consist of subangular with some well rounded quartz (60 percent), chert grains (20 percent), volcanic rock fragments (14 percent), clay (3 percent), magnetite (1 percent), zeolites (trace), and intergranular pores (2 percent). The subfeldspathic arenites are light gray (N7) that weather medium light gray (N6). The rock has a salt and pepper appearance caused by the admixture of light quartz grains and dark chert and volcanic rock fragments. Locally, the subfeldspathic arenite grades laterally and vertically into thin lenses of very coarse-grained sandstone with chert, quartz, quartzite, and volcanic rock pebbles (6 mm average).

The middle unit, 347 feet thick, is comprised of siltstones and mudstones with thin, interbedded limestones and sandstones. The mudstones and siltstones typically weather yellowish to reddish brown and consists of silt-sized quartz and chert (30 to 60 percent), volcanic rock fragments (up to 1 percent) and clay with calcite cement (40 to 70 percent).

The limestones of the middle unit are medium light gray (N6) that weather pale yellowish brown (10YR 6/2) and are very thin-bedded (one to two inches). A representative sample of the limestones is intramicrite consisting of poorly sorted intraclasts (60 percent) and very fine-grained quartz (1 percent) cemented by micrite (20 percent) and medium crystalline calcite (17 percent). Intraclasts range from 0.5 mm to 10 mm in diameter and are composed of mudstone, micrite, and pseudosparite. Chert (1 percent) has replaced some of carbonate. Porosity (1 percent) consists of vugs. Iron oxide is present in trace amounts.

The upper unit of the Kootenai Formation, 18 feet thick, is a thin-bedded (two to eight inches), medium gray (N5) limestone that weathers pale yellowish brown (10YR 6/2). Many of the beds are gastropod biosparite consisting of a framework of gastropod shells (25 percent), pelecypod shell fragments (5 percent), and oolites (2 percent), cemented by medium crystalline (0.1 to 0.2 mm) calcite. Shell material has been replaced by chert. The interiors of the fossils are filled by micrite (3 percent), sparry calcite (2 percent), and chalcedony (2 percent).

Fossils and Age

The upper parts of the Kootenai Formation in the Cedar Creek area contain beds of gastropod biosparite. These gastropod limestones are excellent marker beds and are distinctive of the Kootenai Formation in southwestern Montana. A fresh-water molluscan assemblage, including Reesidella sp., is common in the Kootenai Formation throughout southwestern Montana (Yen, 1951).

Stanton (1903), Fisher (1908), Yen (1951), Kauffman (1963), and Gwinn (1965) have dated the Kootenai Formation of Montana as Early Cretaceous.

Regional Distribution and Correlation

The Kootenai Formation is recognized in Montana, North Dakota, southern Alberta, and southern Saskatchewan (Balster, 1971).

Perry (1945) reports the lithology of the Kootenai Formation is fairly uniform over most of Montana and Wyoming, consisting of a basal conglomerate or sandstone overlain by interbedded mudstones and fresh water limestones.

In Montana, the Kootenai Formation unconformably overlies the Morrison Formation and, locally, older Mesozoic formations. The

Kootenai Formation is generally 300 to 600 feet thick (Balster, 1971) although the formation thickens in westernmost Montana (McMannis, 1965). Scholten and others (1955) reported a thickness of about 1,500 feet in the Lima area of southwesternmost Montana.

The Kootenai Formation is correlative with the Cloverly Formation of Wyoming and south-central Montana and the upper Gannett Group, conglomerates, sandstones, shales, and limestones, of eastern Idaho and western Wyoming. The clastic units of the upper Gannett Group become finer grained eastward (Cobban and Reeside, 1952).

The Kootenai Formation is equivalent to the Kootenay Formation of Alberta where the formation consists of 550 feet of sandstones and shales with several coal seams (Stockwell, 1957).

Origin and Depositional Environment

The presence of conglomeritic sandstone lenses and cross-bedding in the basal unit of the Kootenai Formation strongly suggests fluvial deposition. The highly calcareous, finer grained clastics of the middle unit were probably deposited in a lacustrine environment. The limestones of the middle and upper units are widespread over southwestern Montana and are generally considered to represent deposition in large, shallow lakes subjected to wave action and associated currents producing oolites and intraclasts.

Yen (1951) has identified an abundant fauna of fresh water pelecypods and gastropods, present in the Kootenai Formation.

The abundant chert grains in the basal unit of the Kootenai Formation was derived from a sedimentary source and the volcanic rock fragments indicate nearby volcanic activity. Regional analysis of cross-bedding data suggests a western source area for Kootenai sediments (McMannis, 1965).

Colorado Group

Hayden (1876) named the Colorado Formation for gray-black shales with a few sandstones exposed along the eastern flank of the Front Range of Colorado.

In the Sweetgrass Arch region in northwestern Montana, the Colorado Group is divided into two formations, the Blackleaf Formation and the Marias River Shale. The lower Blackleaf Formation is composed of the Flood, Taft Hill, Vaughn, and Bootlegger Members. The upper formation, the Marias River Shale, is composed of the Floweree, Cone, Ferdig, and Kevin Members (Cobban and others, 1959).

In the Clark Fork Valley area of west-central Montana, the Colorado Group is divided into four formations that are, in ascending order, the Blackleaf Formation, the Coberly Formation, the Jens Formation, and the Carter Creek Formation. The Blackleaf

Figure 11. Topography typically developed on Colorado beds and andesite porphyry sills. View is southeastward along Cedar Creek in sec. 23, T. 6 S., R. 1 E. Highest peak in background is peak 9801 in the SE1/4 SE1/4 sec. 35, T. 6 S., R. 1 E.

Formation in the Clark Valley area is divided into the Flood, Taft Hill, and Dunkleberg Members (Gwinn, 1965).

Roberts (1965) subdivided the Colorado Group in the Livingston area of Montana, about 60 miles east of the Cedar Creek area, into four units which he correlates with the Thermopolis Shale, the Mowry Shale, the Frontier Formation, and the Cody Shale.

Because outcrops of the Colorado Group in the Cedar Creek area are rare, the Colorado Group is not subdivided into units for this report. All beds lying above the gastropod limestones of the Kootenai Formation in the Cedar Creek area were mapped as the Colorado Group. Consequently, some of the uppermost beds mapped as Colorado Group are possibly younger than the Colorado Group.

Exposure and Topographic Expression

In the Cedar Creek area, the Colorado Group forms ridges with broad, grass-covered tops and steep, forested sides supported by the numerous sills of the Fan Mountain laccolith.

The beds of the Colorado Group are covered by thick soil and vegetation throughout most of the area. However, the contact with the underlying Kootenai Formation and the basal few hundred feet of the Colorado Group are moderately exposed along the saddle and ridge top in the N1/2 NE1/4 sec. 34, T. 6 S., R. 1 E. Strata of the upper part of the Colorado Group are well exposed in the headwalls of cirques developed in the SE1/4 sec. 35, T. 6 S., R. 1 E. and the SE1/4 sec. 1, T. 7 S., R. 1 E., but these exposures are inaccessible.

Thickness and Lithology

Strata assigned to the Colorado Group are poorly exposed in the Cedar Creek area and no attempt was made to measure and describe a section of the Colorado Group. The thickness of the Colorado Group in the thesis area is estimated to be greater than 3,000 feet.

Observations made at scattered outcrops indicate the Colorado Group is predominantly shales and mudstone with subordinate sandstones and siltstones.

The shales and mudstones typically are weathered yellowish gray (5Y 7/2) to dark gray (N3). The sandstones are very thin- to thin-bedded and are commonly cross-bedded or cross-laminated although no persistent current direction could be determined. The sandstones consist predominantly of quartz (about 60 to 70 percent) with volcanic rock fragments (about 10 to 15 percent) and feldspar (about 10 to 15 percent). The cement is generally silica, although in some of the sandstones calcite is the main cementing agent. The sandstones are well-sorted, medium-grained to very fine-grained and are generally very light gray (N8) weathering light brownish gray (5YR 6/1) although some of the sandstones are medium gray (N5) and weather brownish gray (5YR 4/1).

An exposure of yellowish gray (5Y 8/1) vitric tuff (five feet thick) that weathers moderate brown (5YR 4/4) to grayish orange (10YR 7/6) and a thin (one foot) coal bed were found along the west side of the small ridge in the SE1/4 NE1/4 sec. 3, T. 7 S., R. 1 E.

Hadley (1969) correlated equivalent strata present in the Cameron quadrangle, immediately south of the Cedar Creek area, with the Thermopolis and Frontier Formations. In this report the beds of the Colorado Group of the Cedar Creek area are tentatively correlated with the Thermopolis and Frontier Formations.

Fossils and Age

No identifiable fossils were found in the Colorado Group in the Cedar Creek area. Carbonized plant fragments are present in much of the strata.

Klepper (1950) reported plant remains of Late Cretaceous age in the Colorado Group of Beaverhead and Madison Counties, Montana. Cobban and others (1959) reported an Early and Late Cretaceous age for the Colorado Group. According to Balster (1971) most workers accept an Early and Late Cretaceous age for the Colorado Group in Montana.

Regional Distribution and Correlation

The Colorado Group consists of widespread, dark gray to gray-black shales with some siltstone and sandstone beds. The Colorado Group is recognized in Montana, the Dakotas, Wyoming, Colorado, Nebraska, Kansas, Iowa, and New Mexico. Locally, the Colorado Group has been subdivided into as many as ten formations and members (Balster, 1971).

For numerous reasons subdivision of the Colorado Group in southwestern Montana and correlation with formations of neighboring regions is very difficult. The Colorado Group is sparsely fossiliferous, and the fossils that are found generally are poor indicators of age. Poor exposure and lateral variations in lithology prohibit the use of marker beds or lithologic sequences to establish correlations from one region to another. Subsurface control is lacking because of little petroleum interest in southwestern Montana. For these reasons workers are reluctant to make regional correlations of the Colorado Group in southwestern Montana.

Origin and Depositional Environment

The sandstones of the Colorado Group in the Cedar Creek area probably were deposited in a paralic environment, as indicated by cross-bedded, uniformly stratified sandstones, carbonized plant fragments, a scarcity of fossils, and rapid lateral variations in lithology. The shales probably were deposited in quiet, deeper waters. McMannis (1965) stated the Colorado Group represents predominantly non-marine deposition in southwestern Montana and predominantly marine deposition to the east. McMannis suggested a general, westward transgression during Colorado Group deposition.

Strong (1972) interpreted depositional environments from foraminifers found in the Colorado Group in west-central Montana and concluded that most of the beds were deposited in shallow marine and laggonal environments although conditions varying from non-marine to deep marine were represented.

A significant increase in volcanic rock fragments in the Colorado Group, especially to the west, indicates increased volcanic activity that McMannis (1965) suggested "may be related to the beginning of emplacement of the Idaho batholith."

Unconsolidated Quaternary Sediments

Unconsolidated Quaternary sediments in the Cedar Creek area include landslide debris, alluvium, talus, and slope wash. Talus and slope wash deposits are not areally extensive and were not mapped in this report.

Alluvium

Alluvial deposits are present as coalescing fan deposits along the western edge of the Cedar Creek area and as terraced stream gravels along Cedar Creek. Very minor deposits of alluvium are present along the other streams of the area.

Alluvial fans have formed where westward-flowing streams of the Cedar Creek area emerge from the Madison Range. By far the largest of these fans has formed at the mouth of Cedar Creek. The Cedar Creek Alluvial Fan covers about 20 square miles of which only a small part is in the thesis area.

Stream gravels along the upper parts of Cedar Creek are noticeably terraced to as much as 15 feet above the present stream level. These deposits of sand and gravel with little clay were derived locally from Pleistocene valley glaciers, were reworked and deposited as outwash, and are now being cut by stream erosion. In the lower part of Cedar Creek, the terraces are not as noticeable, because erosion has dissected the deposits to a greater extent.

Landslide Debris

Landslides have occurred in secs. 1, 2, and 3, T. 7 S., R. 1 E. These landslides have developed in the nonresistant strata of the Colorado Group. The soft mudstones and shales of the Colorado Group appear to be able to absorb and hold large amounts of water, which acts as a lubricant along glide planes. Trapped water also increases instability by adding to the weight of the regolith. Landslides have not formed where numerous andesite porphyry sills have intruded the Colorado Group along Cedar Creek. The sills act as natural restraining walls and the Colorado Group rocks are able to form steep slopes and cliffs.

Talus and Slope Wash

The largest talus deposits in the Cedar Creek area have formed as accumulations of angular boulders and cobbles below the cliffs of andesite porphyry along Cedar Creek. Talus has also accumulated below the cliffs of the Quadrant and Phosphoria Formations along Shell Creek and below other cliffs elsewhere in the Cedar Creek area.

Slope wash forms a pebbly and cobbly veneer on most moderate and gentle slopes in the thesis area. In a few places, slope wash obscures the bedrock geology.

INTRUSIVE IGNEOUS ROCKS

Fan Mountain appears to be the center of a large, complex laccolithic intrusion composed of numerous sills intruding the Cretaceous Colorado Group strata along several horizons. The sills, thicker and more numerous toward Fan Mountain, form a dome in the country rock. Lone Mountain, 3 1/2 miles east and 1 1/2 miles south of Fan Mountain, is reportedly the center of a similar multiple-horizon intrusion (Hall, 1961). Neither intrusion has been studied in detail. However, the general similarities in lithology and emplacement, and the closeness of the two intrusions, indicate they probably are related.

The base of the Fan Mountain laccolith is not exposed, and the top has been removed by erosion. Swanson (1951) estimated the total thickness of the intrusion to be 1,500 to 2,000 feet thick. Only the thickest or most persistent sills were mapped in this report.

The intrusion generally follows bedding surfaces in the Colorado Group, although in many places the intrusion cuts bedding at low angles. Thicknesses of the sills range from a few feet to over 100 feet. The thicker sills commonly form vertical cliffs with talus at their base. Where the contact between the intrusion and the country rock was observed, the shales and mudstones show no visible alteration. Quartz veins and other evidence of mineralization are absent.

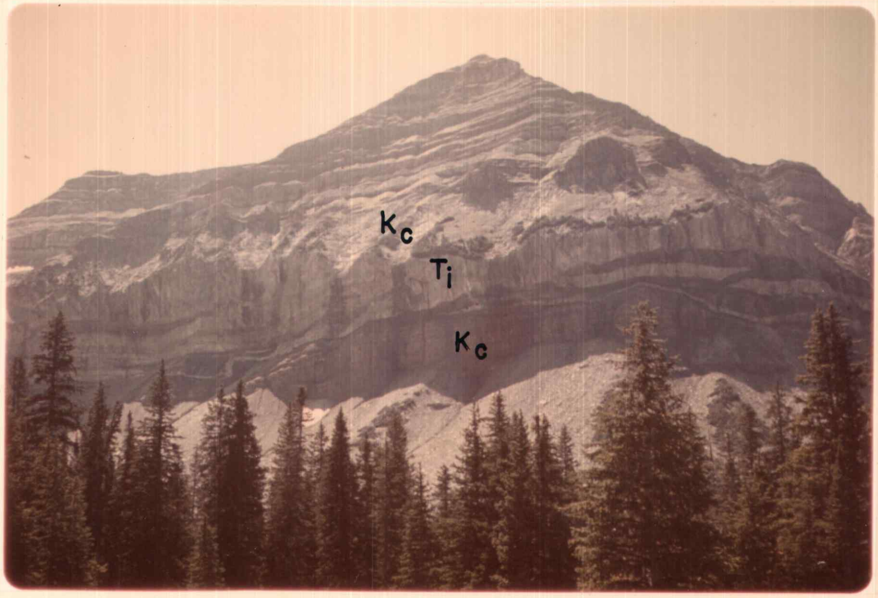

Figure 12. Dark gray Colorado beds (K_c) intruded by light gray andesite porphyry sills (T_i), SE1/4 SE1/4 sec. 1, T. 7 S., R. 1 E.

Lithology

The intrusive rock is an andesite porphyry with phenocrysts of plagioclase up to 4 millimeters across. The fresh and weathered color is generally light to medium gray (N7 to N5). Composition appears to be fairly uniform throughout the Cedar Creek area; however, slight variations in crystal size were noted.

Modal analysis of the andesite porphyry indicates the following composition: andesine (29 percent), hornblende (5 percent), magnetite (2 percent), quartz (1 percent), accessory minerals includingl biotite and apatite (1 percent), and microcrystalline and cryptocrystalline groundmass (62 percent). The andesine is present as euhedral phenocrysts, typically 1.5 mm by 1.0 mm but up to 4 mm by 3 mm. The andesine is unzoned and has altered slightly to sericite. Phenocrysts of hornblende are euhedral, typically 0.5 to 0.7 mm in size. The hornblende generally is completely altered to calcite, magnetite, and chlorite. Magnetite is present as subhedral crystals averaging 0.05 mm in size. Quartz is present as anhedral crystals averaging 0.1 mm in size. Tabular crystals of biotite are commonly 0.3 mm across, but phenocrysts of biotite up to 2 mm across are present. The biotite shows alteration to magnetite and chlorite. Euhedral apatite crystals are typically 0.1 mm by 0.3 mm. The groundmass consists of subparallel microlaths of feldspar, microcrystalline quartz and magnetite, and altered mafic glass. Rare irregular blebs of mafic glass, averaging 0.2 mm in size, are present in the groundmass. The glass has completely altered to saponite or nontronite.

Age

The youngest beds cut by the Fan Mountain laccolith in the Cedar Creek area are those of the Cretaceous Colorado Group. However, Beck (1959) reported that sills associated with the Lone Mountain laccolith have intruded the Upper Cretaceous Livingston Formation south of the Cedar Creek area. Emplacement of the Fan Mountain laccolith may be related to the emplacement of the Gallatin River laccolith which Witkind (1969) believes is "most probably of late early Eocene age." Structural relations in the thesis area indicate the Fan Mountain laccolith was emplaced prior to the main phase in the Cedar Creek area of folding and thrust-faulting, probably related to the latest Cretaceous-early Tertiary Laramide orogeny.

STRUCTURAL GEOLOGY

Regional Structure

To the west of the Madison Range are the intensely folded and thrust-faulted miogeosynclinal sedimentary rocks of the Disturbed Belt that are typical of the tectonic province of the Northern Rocky Mountains as defined by King (1959). According to King, "The ranges of the Northern Rocky Mountains are formed from long, narrow, closely spaced folds and thrust blocks made up of geosynclinal sedimentary rocks alone, not of basement rocks."

However, the Madison, Gravelly, Gallatin, and Centennial Ranges are formed of uplifted blocks of Precambrian basement rocks overlain by thin shelf sedimentary rocks. The blocks are separated by intermontane basins. Precambrian rocks are exposed in many places in the cores of the ranges by modifying thrust and normal faults and erosion (Spencer, 1958). The tectonic framework of the Madison Range and neighboring ranges is more typical of the Central Rocky Mountain Tectonic Province than of the Northern Rocky Mountains. According to Eardley (1951) the Central Rocky Mountain Tectonic Province is characterized by broadly uplifted asymmetric anticlinal units bounded on at least one side by prominent faults.

The latest Cretaceous-Early Tertiary Laramide orogeny, acting on older, northeast-trending structures in the basement, has produced the dominant structural features in the region (McMannis and Chadwick, 1964). Laramide structural features typically trend northwest and were produced by compressional forces of the Laramide orogeny acting from the west and southwest. Later, compressional forces relaxed and were replaced by tensional forces producing normal, block faulting.

Local Structure

Precambrian, Paleozoic, Mesozoic, and Cenozoic rocks of the Cedar Creek area are folded and faulted. The thesis area is characterized by gentle folding and doming in the eastern part of the area. The western edge of the thesis area is highly deformed by thrusting, intense folding, and subsequent normal faulting.

Folds

The major fold in the Cedar Creek area is the asymmetrical north- to northeast-trending syncline in the western part of the thesis area. The east limb generally has low dips, but the west limb is nearly vertical or commonly overturned. The youngest rocks folded in this syncline are the Cretaceous Colorado Group. This fold is the result of the compressive forces related to the Laramide orogeny. The anomalous north to northeast trend suggests that the structural pattern has been modified by the northeast-trending structural fabric

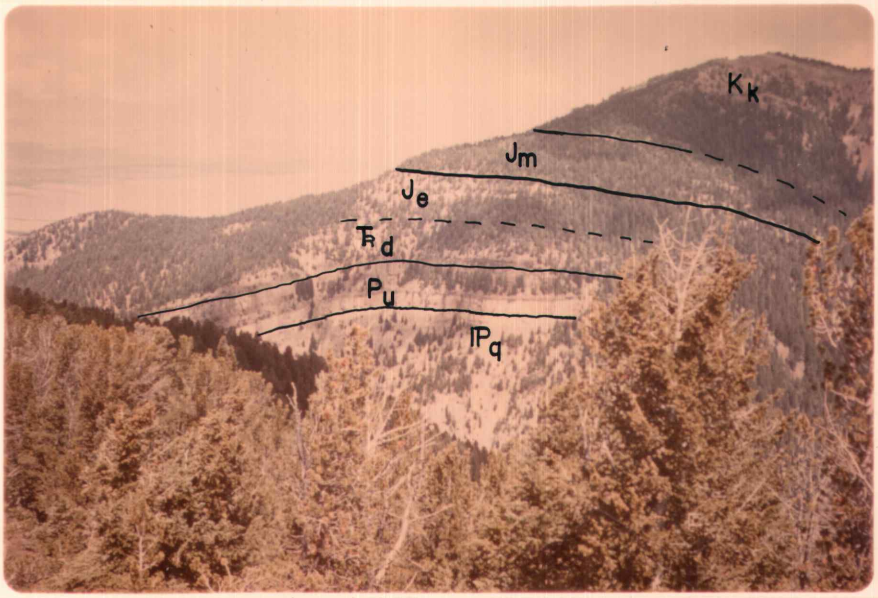

Figure 13. North wall of the Shell Creek canyon, NE1/4 sec. 33 and the NW 1/4 sec. 34, T. 6 S., R. 1 E. Dome formed in the Quadrant Formation ($\mathbb{P}_q$), Permian beds (P_u), the Dinwoody Formation ($\overline{R}_d$), Ellis Group (J_e), Morrison Formation (J_m), and the Kootenai Formation (K_k).

typical of the Precambrian basement (Thom, 1955, 1957).

Two domal structures are present in the Cedar Creek area. The top of the dome exposed along Shell Creek has been cut by a small thrust fault. Beds dip gently in the upper plate, but in the lower plate beds on the east side of the dome are steeply dipping to overturned. The other dome is associated with the Fan Mountain laccolith. Cretaceous strata of the Colorado Group dip at low angles away from the center of the intrusion as a result of the forceful emplacement of the andesite porphyry.

Colorado Group beds in the southern part of the Cedar Creek area have been folded into a minor, symmetrical syncline. The axis of this northwest-trending syncline is located in secs. 1 and 2, T. 7 S., R. 1 E. and sec. 35, T. 6 S., R. 1 E. The youngest rocks folded are sills of the Fan Mountain laccolith.

Faults

Low-Angle Thrust Faults. A low-angle thrust fault in secs. 3 and 4, T. 7 S., R. 1 E. has juxtaposed Precambrian metamorphic rocks on Permian, Jurassic, and Cretaceous sedimentary rocks. Minimum displacement is estimated at 5,000 feet. This fault appears to be the northward continuation of the thrusting known as the Madison Fault that has pushed a mass of Precambrian crystalline rocks northeastward over Mesozoic and Paleozoic strata. This thick thrust

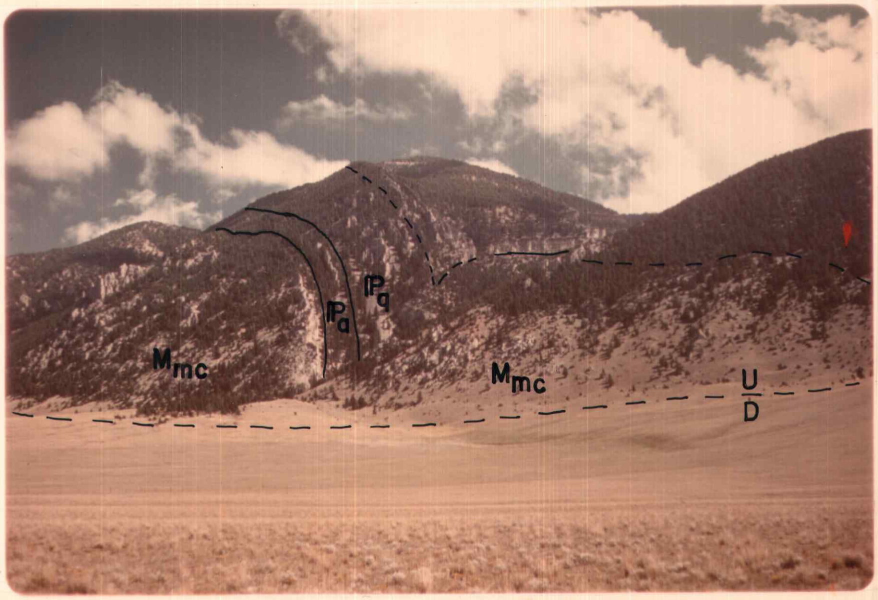

Figure 14. Overturned beds of the Mission Canyon Formation (M_{mc}), Amsden Formation ($\mathbb{P}_a$), and Quadrant Formation ($\mathbb{P}_q$) and a normal fault of the Madison Range Fault System at the mouth of the Shell Creek canyon W1/2 sec. 33, T. 6 S., R. 1 E.

plate of Precambrian rocks forms the backbone of the southern Madison Range.

The other low-angle thrust fault is present in secs. 33 and 34, T. 6 S., R. 1 E. This minor thrust has sheared the top off the Shell Creek domal structure and the thrust has subsequently been folded. Minimum displacement on this fault is estimated at 400 feet.

High-angle Thrust Faults. Two high-angle thrust faults that juxtapose older, nearly vertical to overturned strata with younger beds are present in the Cedar Creek area. Both faults roughly parallel bedding planes of strata in the upper plates. The larger of the two high-angle thrust faults extends more than 3 1/2 miles through secs. 11, 14, 15, 21, and 22, T. 6 S., R. 1 E. before passing out of the area to the north. Estimated minimum displacement is 4,000 feet. This estimate does not include displacement parallel to bedding and therefore, the actual displacement may be considerably greater.

The high-angle thrust fault located in sec. 3, T. 7 S., R. 1 E. is probably associated with the overlying low-angle thrust fault. The estimated minimum displacement on this fault is 1,000 feet.

Normal Faults. The normal faults paralleling the range front along the western edge of the thesis area are part of the Madison Range Fault System (not to be confused with the Madison Fault). This fault zone is a system of normal faults that extends some 50 miles along the western edge of the Madison Range and accounts for the abrupt rise of the Madison Range above the Madison River valley. Movement along this fault system probably was initiated in Miocene time (Hamilton, 1960) and has continued intermittently into Recent time (Swanson, 1938). Displacement along the Madison Range Fault System may exceed 10,000 feet (Swanson, 1970).

Numerous minor faults were mapped in the Cedar Creek area. Eight of the minor normal faults trend northwest and four minor normal faults trend northeast to east. Displacements along these faults probably are less than a few hundred feet at most. None of these faults can be traced for more than one mile.

Figure 15. Cedar Creek area of the Madison Range. View is eastward across the Madison River Valley. The Cedar Creek Alluvial Fan spreads out across the valley floor at the base of the mountains in the left half of the photograph.

GEOMORPHOLOGY

Following the Laramide orogeny, stream erosion slowly developed a surface of low relief in southwestern Montana. A general concordance of ridge and peak summits in southwestern Montana, remnants of this erosional surface, has been reported by Atwood and Atwood (1945). Block faulting and uplift of the Madison Range along the Madison Range Fault System, beginning in probable Miocene time, initiated the present cycle of erosion. Rejuvenation of existing streams, development of consequent drainage, and several cycles of glaciation have shaped the Madison Range fault block into the present landforms.

Fault-related Features

Many of the topographic features in and near the Cedar Creek area are related to block faulting along the Madison Range Fault System. Movement along this fault system has directly resulted in the abrupt and imposing range front along the west edge of the Madison Range. Triangular facets on spurs truncated by faulting are common along the range front. Several alluvial fans extend from the range into the Madison River valley. The Cedar Creek Alluvial Fan covers about 20 square miles, part of which lies within the thesis area. A piedmont scarp, that is traceable for about 50 miles along the western edge of the Madison Range, has formed in alluvium and is evidence of recent movement along the Madison Range Fault System (Swanson, 1938).

Stream Erosion Features

The Cedar Creek area is in the late youth stage of the erosional cycle and has a well developed drainage system. Streams have formed steep-walled valleys separated by narrow, rounded interfluves. Because stream gradients are high, stream erosion is dominated by down-cutting.

The barbed drainage pattern of Cedar Creek in the eastern half of the thesis area is evidence that the upper part of Cedar Creek flowed slightly east of north into the Jack Creek drainage system. A low divide, about 120 feet high, separates Cedar Creek and the South Fork of Jack Creek in secs. 28 and 29, T. 6 S., R. 2 E. This divide appears to be underlain by glacial morraine. The direction of flow of Cedar Creek in sec. 25, T. 6 S., R. 1 E. and secs. 29 and 30, T. 6 S., R. 2 E. appears to have been reversed by blocking of the original channel with glacial morraine and by stream piracy.

Glacial Features

Hall (1960) has identified four episodes of Pleistocene glaciation in the Madison Range that have resulted in the development of cirques, U-shaped valleys, hanging valleys, and terraces of glacial outwash in the Cedar Creek area. Valley glaciers have formed U-shaped valleys and associated cirques in the southeastern part of the thesis area. Terraces of glacial outwash are present along Cedar Creek in secs. 29, 30, and 32, T. 6 S., R. 1 E. and are discussed in the section of Quaternary deposits.

GEOLOGIC HISTORY

The first geologic event recorded in the rocks of the Cedar Creek area was deposition of sandstones, limestones, and mudstones during Precambrian time. With time, the depositional basin in which these sediments accumulated was destroyed by orogeny. The sediments were strongly folded, faulted, and uplifted. These metamorphosed rocks are now quartzites, schists, and marbles of the Cherry Creek series that form the basement complex in the Cedar Creek area. The orogeny imparted northeast structural trends that have influenced tectonic movement in the basement rocks to the present. Following uplift, the metamorphic rocks were eroded to form a low-lying surface.

Later in Precambrian time, the structural framework that was to control sedimentation throughout Paleozoic and part of Mesozoic time began to develop. To the west, the Cordilleran geosyncline, trending north-northwest and centered through central Idaho, began to form. To the east of the Cordilleran geosyncline and underlying the Cedar Creek area the Wyoming shelf developed as a broad, westward-sloping, slowly-subsiding platform.

During Early Cambrian time, the Cedar Creek area was exposed to a long period of subaerial erosion. All Precambrian sediments that may have accumulated on the Cherry Creek metamorphic rocks were removed during this period of erosion.

Cambrian sedimentary rocks are not exposed in the thesis area which is assumed to have had a geologic history similar to surrounding areas. From a study of rocks in the southern Madison Range, Witkind (1969) has suggested the following history of Cambrian and Ordovician deposition. In Middle Cambrian time, submergence of the Wyoming shelf initiated sedimentation of the quartz arenites of the transgressive Flathead Formation. As the Wyoming shelf subsided, the Cambrian sea became deeper, and muds accumulated in areas of the Wyoming shelf below wave base. As the shoreline transgressed farther eastward, thick carbonates were deposited. Mild oscillations of the shelf caused repetitions of the mud-carbonate sequence producing the shales and carbonates of the Cambrian System.

Emergence of the Wyoming shelf halted Cambrian deposition and initiated a long episode of erosion. This emergence lasted until Middle Ordovician time, when submergence resulted in the deposition of the Bighorn Dolomite. Following deposition, uplift and erosion removed the Bighorn Dolomite from many areas of original deposition and again exposed Cambrian sedimentary rocks to erosion until Middle Devonian time, when marine waters returned to the Wyoming shelf.

According to Sandberg (1961), the Beartooth Butte Formation of Early Devonian age was deposited in an estuarine environment as an Early Devonian sea transgressed eastward. Because the Beartooth

Butte Formation is present in the Beartooth Range to the east and may be present to the north at Logan, Montana, and the Beaver Creek area in west-central Montana (Sandberg, 1961), the Beartooth Butte Formation may have been deposited in the Cedar Creek area.

According to Johnson (1971), the Antler orogeny, the major orogenic event in the Paleozoic of the western United States, was active along the western margin of the North American continent from late Early Devonian to Late Mississippian time.

Continued transgression of Devonian seas during Late Devonian time (Johnson, 1971) resulted in deposition of the Jefferson Formation in the Cedar Creek area. Sources of quartz sand were very distant and low lying, and these sediments were not carried onto the shelf where Jefferson deposition was taking place. Increased subsidence of the Wyoming shelf eliminated wave-induced currents typical of the deposition of the upper unit of the Jefferson Formation in the Cedar Creek area.

According to Gilluly (1967), uplift along the Antler orogenic belt in west-central Nevada and central Idaho in Late Devonian time significantly increased the supply of detritus to the Wyoming shelf, resulting in the shales of the Three Forks Formation and later the siltstones of the Sappington Member of the Three Forks Formation.

For much of the Mississippian time, shallow seas covered the Cedar Creek area, where mild oscillations of sea level produced the thin-bedded, highly fossiliferous limestones of the Lodgepole Formation. As subsidence of the shelf increased, Lodgepole deposition was gradually replaced by the deeper water deposition of the very thick-bedded, unfossiliferous Mission Canyon Formation. Post-Mission Canyon uplift and subaerial exposure in a humid climate led to the widespread development of caverns in the limestones of the Mission Canyon Formation in western Montana (Robinson, 1963). Collapse of the caverns produced the solution breccias that occur in the upper parts of the formation.

In Late Mississippian or Early Pennsylvanian time, shallow-water marine conditions returned with subsidence of the Cedar Creek area resulting in deposition of the Amsden Formation. Transgression of Amsden seas eroded much of the red regolith that had developed on the Mission Canyon surface and deposited the detritus as the red mudstone that commonly makes up the basal unit of the Amsden Formation. At maximum transgression, little detritus was deposited in the Cedar Creek area, and deposition of mudstones was replaced by carbonate deposition. A period of regression with minor interruptions followed that lasted until Middle Pennsylvanian time when subsidence of the area brought transgression of Quadrant seas. Uplift and increased erosion of a source area and continuous reworking of pre-existing sedimentary rocks brought clean quartz sand to the Cedar Creek area, forming the Quadrant Formation.

With increasing subsidence of the Cedar Creek area in Early or Middle Permian time and base leveling in the source area, carbonate deposition began to dominate sandstone deposition, and beds of the Park City Formation were formed. The sands of the Shedhorn Formation accumulated on the eastern margins of a shoaling sea floor that sloped westward into the miogeosyncline. Upwelling of the deep waters of the geosyncline supplied silica-and phosphate-rich waters to the area resulting in deposition of the Retort Phosphatic Shale and the Tosi Chert Members of the Phosphoria Formation. Fluctuations of sea level produced intertonguing of the Shedhorn and Phosphoria Formations.

The shallow, marine conditions that characterized Paleozoic deposition continued into the Early Triassic. Deposition of silt and carbonate muds in the Cedar Creek area led to the development of the Dinwoody Formation. Younger Triassic rocks are present in nearby areas of the Madison Range southeast of the Cedar Creek area (Rose', 1967; Ray, 1967; Lauer, 1967; Witkind, 1969) and probably were deposited in the Cedar Creek area, but pre-Jurassic erosion removed them.

By Early Jurassic time, regional southward tilting had occurred and pre-Jurassic erosion had reduced western Montana to a low plain, truncating older strata northward.

In Middle Jurassic time, shallow seas returned to the area depositing carbonate muds of the Ellis Group. The Wyoming shelf was no longer a broad, extensive platform sloping toward the miogeosyncline. Low islands protruded above sea level and these islands were the source of local concentrations of sand in Sawtooth sediments. As Jurassic seas retreated, oolites of the Rierdon Formation formed in the carbonate muds agitated along the margins of the sea.

Following withdrawal of Jurassic seas, a broad plain emerged with swamps, ephemeral fresh-water lakes, and large, slow-moving rivers. Mud and sand from surrounding highlands accumulated on the low plain, resulting in the Morrison Formation.

Uplift of Paleozoic and Mesozoic strata and volcanic activity to the west supplied sediments to the Cedar Creek area resulting in the basal sandstones and conglomerates of the Kootenai Formation. As this western source area was reduced, the derived clastics became finer grained, producing the mudstones of the middle unit of the Kootenai Formation. Extensive fresh-water lakes formed in which the limestones of the middle and upper units were deposited.

A new period of transgression began as an extensive, shallow inland sea invaded the low-lying plain of Kootenai sedimentation. The shallow sea underwent numerous advances and retreats as the area subsided. Sedimentation resulted in the marine, paralic, and non-marine deposits of the Colorado Group. Volcanic activity to the west supplied ash and volcanic rock fragments.

Prior to the main phase of folding and thrust-faulting in the Cedar Creek area, rising andesitic magmas encountered the impervious mudstones of the Colorado Group. Following natural zones of weakness along bedding planes, the magma horizontally intruded the Colorado Group beds. Shallow burial of the Colorado Group beds allowed the intrusion of andesite porphyry to forcefully separate and dome the strata, forming the Fan Mountain laccolith. The addition of the andesite porphyry intrusion to the rocks in the eastern part of the Cedar Creek area increased the competance of these strata; in addition, the andesite may have mended any pre-existing weaknesses in the basement complex. As a result, the eastern part of the thesis area remained relatively undisturbed during the main phase of folding and thrust-faulting in the Cedar Creek area. As movement occurred along pre-existing weaknesses in the basement rocks in the western part of the thesis area, the thin veneer of Paleozoic and Mesozoic strata became strongly folded and thrust-faulted.

Tertiary volcanics and sediments, if they ever were present in the thesis area, have been eroded from the Cedar Creek area.

At some time in middle Tertiary time, possibly Miocene, tensional forces, probably related to epeirogenic uplift, initiated basin range faulting (Gilluly, 1967). Regional block faulting, parallel to Laramide thrusts, resulted in the relative uplift of the Madison Range along the Madison Range Fault System. Consequent drainage developed. Streams eroded the uplifted block and deposited the detritus as alluvial fans along the base of the scarp. Several cycles of Pleistocene valley glaciation and later stream erosion have modified the topography to its present form.

ECONOMIC GEOLOGY

Oil and Gas Possibilities

No oil or gas has been produced from nearby parts of southwestern Montana. Although some test holes have been drilled, Paleozoic formations, some of which produce oil and gas in other regions, are largely untested.

Although some rocks of the Cedar Creek area are fetid, the area is unattractive for oil and gas exploration. The Tensleep (Quadrant equivalent) Formation and the Madison Group are noted producers of oil elsewhere, but samples of the Quadrant Formation and the Madison Group taken from surface exposures in the Cedar Creek area have a low porosity and would be unsuitable as reservoirs for petroleum accumulation. Two structural features in the Cedar Creek area have closure. One of the structures, formed by the intrusion of the Fan Mountain laccolith can immediately be eliminated as a suitable structural trap. The other structure, the Shell Creek dome, is also unfeasible as a site of petroleum accumulation. The dome not only is small but has been breached down to the Amsden Formation by erosion. In addition, the dome may be too close to the general area of andesite porphyry to be favorable for accumulation of oil.

Mineral Possibilities

The Phosphoria Formation is mined for its phosphates in several areas of southwestern Montana. Although the Cedar Creek area contains a four-foot thick unit of furnace-grade phosphorite, containing 24 to 31 percent P_2O_5 (Swanson, 1970), mining of the unit is economically unfeasible at this time. The unit is too thin, the area is unaccessible to rail transportation, and overburden is too thick or dips are too steep for strip mining. Because there are large reserves of phosphate that occur in thicker beds, are more accessible, and are easier to mine, mining of the phosphates in the Cedar Creek area will not take place in the foreseeable future.

Other mineral deposits were not found in the Cedar Creek area, and it seems unlikely that any are present.

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