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The Rock Creek area consists of 53 square miles located in the eastern foothills of the Pioneer Mountains, Beaverhead County, Montana. Approximately 8,500 feet of late Paleozoic and early Mesozoic contact-metamorphosed sedimentary rocks and late Mesozoic sedimentary rocks are exposed in the area of study.

Most of the late Paleozoic and Mesozoic rocks were deposited along the eastern edge of the Cordilleran miogeosyncline. The oldest exposed rocks in the map area belong to the Amsden Formation of Late Mississippian to Early Pennsylvanian age. Other late Paleozoic rock units include the Quadrant Formation of Pennsylvanian age and the Phosphoria Formation of Permian age. Mesozoic formations include the Dinwoody Formation of Triassic age and the Kootenai Formation and Colorado Group of Cretaceous age.

The Tertiary is represented by basin deposits and basaltic andesite extrusives. Unconsolidated Quaternary glacial and fluvial deposits complete the stratigraphic succession.

Granodiorite intrusive rocks occupy the southwestern corner of the area mapped and compose part of the eastern margin of the Mount Torrey Batholith, which is probably genetically related to the Boulder Batholith. Along the margin of the intrusive, contact metamorphism has destroyed the original sedimentary characteristics of the late Paleozoic and early Mesozoic Formations.

During the Late Cretaceous Laramide orogeny the sedimentary rocks were tilted and faulted. The structures in the area are related to the main episode of Laramide deformation, emplacement of the Mount Torrey Batholith, and later phases of structural adjustment. The main structures are the Lost Creek tear fault and a northwest-trending high-angle reverse fault. Minor folds are present in the eastern half of the mapped area.

Stratigraphy and Structure of the Rock Creek Area, Beaverhead County, Montana

by

James Franklin Peters

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STRATIGRAPHY AND STRUCTURE OF THE ROCK CREEK AREA, BEAVERHEAD COUNTY, MONTANA

INTRODUCTION

Location and Accessibility

The Rock Creek area is located in the northeastern part of Beaverhead County, southwestern Montana (Figure 1). The map area is about 20 miles by road north of Dillon and 45 miles by road south of Butte, Montana. The 53 square mile area mapped includes parts of Townships 3 and 4 South, and Ranges 9 and 10 West and lies in the eastern foothills of the Pioneer Mountains. Approximately one-half of the area lies within the Beaverhead National Forest.

The thesis area is readily accessible. Automobile access is provided by U. S. Highway 91, which lies about two miles east of the eastern boundary of the thesis area. Principal access into the thesis area is provided by partially graveled and dirt improved roads that intersect U. S. Highway 91 and traverse the area from east to west along Cherry, Rock, and Lost Creeks. These roads intersect U. S. Highway 91 about 30, 24, and 20 miles respectively north of Dillon, Montana. Additional access is provided by an interconnecting network of unimproved dirt roads in the eastern lowlands, U. S. Forest Service roads, and mining roads in the western half of the Rock Creek area. These roads are not maintained and are impassable during periods

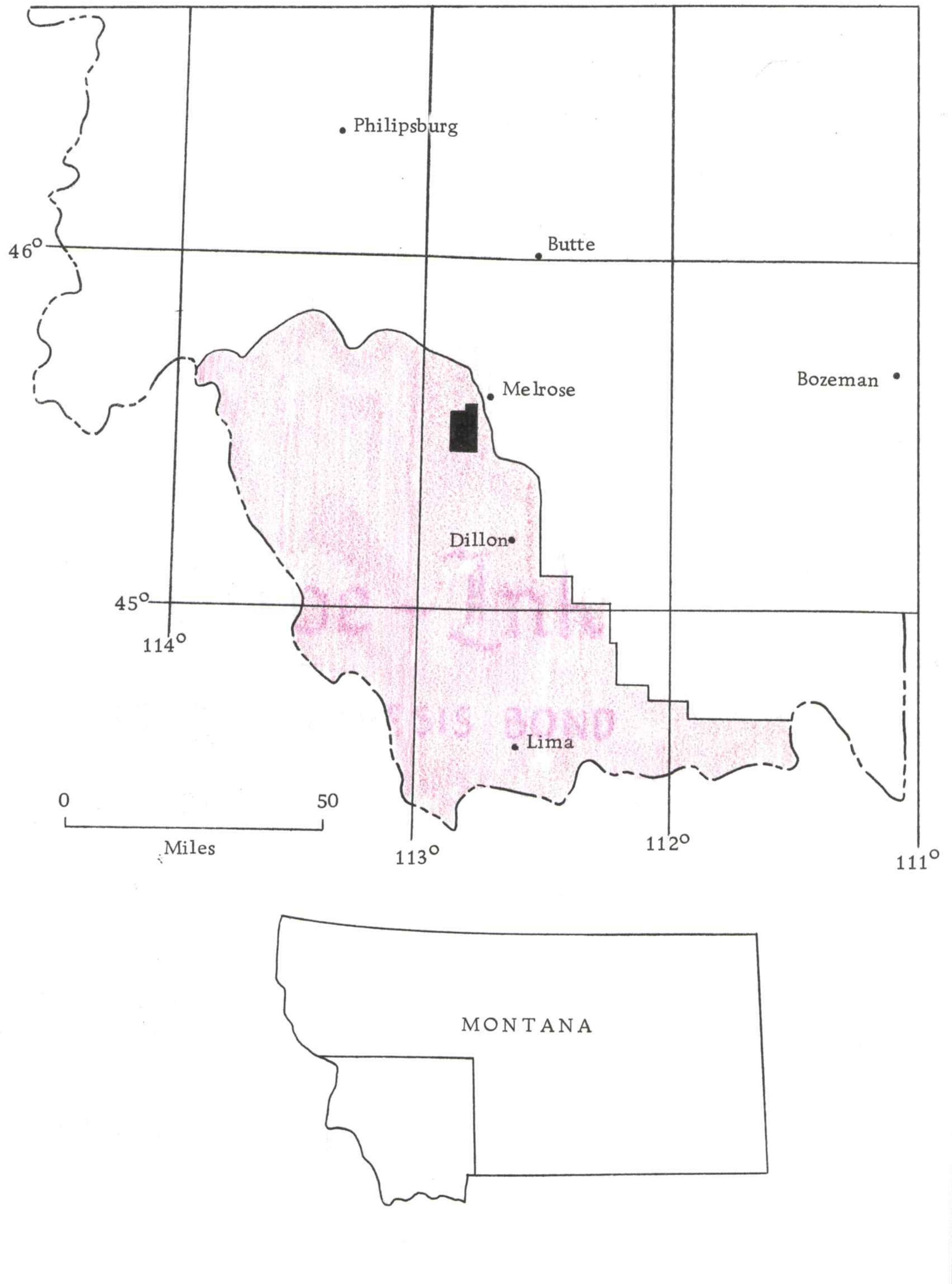

Figure 1. Index map of southwestern Montana showing location of the Rock Creek area (black) in Beaverhead County (red).

of heavy rain or snow. Several U. S. Forest Service pack trails provide foot access along the extreme western boundary.

Purpose and Methods of Investigation

The primary purpose of this study was to produce a detailed geologic map of the Rock Creek area and describe the major rock units within this area.

Field work began in late June 1969 and was completed in early September 1969. The surface geology was plotted in the field on low altitude (1:15,840) aerial photographs obtained from the U. S. Forest Service at Missoula, Montana. A pocket stereoscope was used in the field for aerial photo interpretation. Data was transferred from the aerial photographs to U. S. Geological Survey 7 1/2-minute topographic maps of Earls Gulch, Glen, and Twin Adams Mountain quadrangles and the southeastern corner of the 15-minute Vipond Park quadrangle, which was enlarged to 7 1/2-minutes. With the assistance of Mr. John Moran, stratigraphic sections were measured with tape, Jacobs staff, and Brunton compass. Wentworth's grain-size scale, Rock Color Chart (1963), dilute hydrochloric acid, and hand lens were field aids for rock descriptions.

Petrographic examination of 53 thin sections was made to confirm field observations. Gilbert's classification of sandstones (1954) and Folk's classification of carbonate rocks (1968) are used for the sedimentary rocks. Igneous rocks, both volcanic and plutonic, are classified according to Williams (1954). The classification of metamorphic rocks by F. J. Turner (1968) is used for this paper.

Previous Work

Pardee and Richards (1925) studied the Melrose Phosphate Field immediately north of the Rock Creek area. Hutchinson (1948) included the northern half of the Rock Creek area in an unpublished Master's thesis for the University of Michigan. Myers (1952) included part of the thesis area in an unpublished preliminary open-file report and geologic map of the northwestern quarter of the Willis 30-minute quadrangle. Theodosis (1956) described the geology of the Melrose area immediately north of the area of this report in an unpublished Doctoral thesis at Indiana University. Pattee (1960) included descriptions of presently inactive mines within the thesis area. Sharp (1969) mapped the geology of the Greenstone Mountain area, adjoining the Rock Creek area to the south, in an unpublished Master's thesis for Oregon State University.

Relief and Drainage

The lowest elevation in the area of investigation is 5,020 feet in the southeastern corner of the thesis area. The maximum elevation is 9,470 feet at the summit of Storm Peak in the N 1/2 sec. 21,

T. 3 S., R. 10 W. Thus, the maximum topographic relief is 4,450 feet. The relief is greatest in the western part of the area, locally exceeding 2,300 feet.

The Rock Creek area is drained by eastward flowing streams that empty into the Big Hole River immediately east of the mapped area. Cherry Creek drains the northern part of the mapped area. Browns Creek, Rock Creek, and its major tributary, Storm Park Creek, drain the central part of the thesis area. Lost Creek and its intermittent tributaries provide drainage for the southern part of the thesis area. All the named streams are perennial.

Climate and Vegetation

The nearest U. S. Weather Bureau station is located in Dillon, Montana. Climatological data for the year 1968 shows the annual precipitation was 9.87 inches. June was the wettest month with 1.72 inches. Frequent afternoon thunderstorms provide much of the summer precipitation, and winter precipitation is mostly in the form of snow. The average annual temperature recorded for 1968 was 42° F. During the summer months the days are quite warm with frequent afternoon thunderstorms, and the nights are cool.

Sparse grasses and sagebrush grow at the lower elevations of the eastern half of the thesis area. At the extreme eastern edge of the area, along the floodplain of the Big Hole River, irrigated lands produce crops of alfalfa, wild hay and grains. Hardwoods such as chokecherry and water birch are found around springs and along Cherry, Rock, Lost and Browns Creeks. Douglas fir and lodgepole pine grow densely in the higher elevations with isolated openings of grass. Several areas are so densely vegetated that the surface geology is obscured, making field work difficult.

STRATIGRAPHY

Rocks ranging in age from Precambrain to Quaternary are exposed in the Pioneer Mountains and surrounding Highland, Tobacco Root, Ruby and McCarty Mountains. A short summary of these rocks is presented in the following section.

Regional Stratigraphy

Precambrian metamorphosed sediments are the basement rocks of the region. The Precambrian crystalline rocks include the Pony and Cherry Creek Groups and associated rocks and the Dillon granite gneiss. Gneiss is the most abundant rock type, but schists, marble, quartzite, and amphibolite are also present in varying amounts. The Precambrian metamorphic rocks crop out extensively at the south end of the Ruby Mountains, in most of the central and southern parts of the Tobacco Root Mountains, and at the southern end of the Highland Mountains approximately five miles from the northeastern corner of the Rock Creek area.

Precambrain Beltain rocks unconformably overlie the rocks of the Pony and Cherry Creek Groups. Beltian rocks crop out in the central part of the Highland Mountains, in the north end of the Tobacco Root Mountains, and in the southeastern and western parts of the Pioneer Mountains. The Beltain rocks crop out in the central part of the Highland Mountains, on the north end of the Tobacco Root Mountains, and in the southeastern and western parts of the Pioneer Mountains. The Beltain rocks comprise red and green argillites and subordinate conglomeratic quartzites and sandstones.

All Paleozoic systems except Ordovician and Silurian are represented in the region surrounding the Rock Creek area. The Paleozoic rocks are predominantly marine sandstones, limestones, dolomites, and shales. Paleozoic rocks crop out in the northern and southern parts of the Pioneer Mountains, along the eastern side and the extreme southwestern corner of the Highland Mountains, and at the north end of the Ruby Mountains. The Cambrian system includes six well known formations which crop out four miles from the northeast corner of the Rock Creek area. The formations in ascending order are the Flathead Sandstone, Wolsey Shale, Meagher Formation, Park Shale, Pilgrim Limestone, and Red Lion Formation. Late Devonian rocks, represented by the Jefferson and Three Forks Formations, unconformably overlie the Cambrian rocks. The Mississippian system is represented by the Madison Group and the lower part of the Amsden Formation of Late Mississippian. The upper part of the Amsden Formation and the Quadrant Formation represents the Pennsylvanian, and the Phosphoria Formation the Permian system.

The Mesozoic rocks are clastics of both marine and terrestrial origin and subordinate carbonates. The lower part of the Mesozoic section consists mainly of marine sandstones, siltstones, shales, and limestones, and the upper part consists of continental sandstones, siltstones, and shales.

Large plutonic intrusives of Late Cretaceous to early Tertiary age occur in the north end of the Highland Mountains, the northeast end of the Pioneer Mountains (Boulder Batholith), and in the southern end of the Pioneer Mountains (Mount Torrey Batholith). The most abundant intrusive rock type is quartz monzonite. The Cenozoic Era is also represented by early Tertiary volcanic rocks and middle Tertiary basin deposits of tuffaceous mudstones, siltstones, and associated lenticular bodies of sandstone and conglomerate. The Quaternary is represented by glacial, landslide, and alluvial deposits. The intermontane basins, along which the major streams flow, are blanketed by alluvium.

Thesis Area Stratigraphy

Sedimentary, volcanic, plutonic and contact metamorphosed sedimentary rocks ranging in age from Late Mississippian to Quaternary are exposed in the Rock Creek area. Late Paleozoic and early Mesozoic formations have been thermally metamorphosed by the intrusion of the Mount Torrey Batholith. Approximately 8,500 feet of Paleozoic and Mesozoic sedimentary rocks and contact metamorphosed sedimentary rocks are exposed within the area mapped. Table 1 gives

Table 1. Summary of Rock Units, Rock Creek Area, Montana

Age	Rock Units	Lithology	Thickness in feet
Quaternary		Recent alluvium Landslide deposits and talus.	
Unconformity			
Quaternary		Glacial moraine.	
Unconformity			
Quaternary		Terrace gravels.	
Unconformity			
Tertiary	Volcanic rocks	Basaltic andesites.	200-300?
Tertiary	Basin beds	Light-colored tuffaceous sandy siltstones; vitric tuffs, and volcanic pebble conglomerate.	
Unconformity			
Early Tertiary and Late Cretaceous		Granodiorite batholith	
Unconformity			
Early and Late Cretaceous	Colorado Group	Shales, argillites, subordinate sandstones; siltstones, shales and argillites and lithic sandstones; conglomerate, and interbedded siltstones, shales, and sandstones.	6000-6500
Early Cretaceous	Kootenai Formation	Conglomerate and sandstone, varicolored argillites, siltstones, and shales; fresh-water gastropod limestone at top.	800-900
Disconformity			
Early Triassic	Dinwoody Formation	Siltstones, shales, and limestones metamorphosed to hornfelses and brown to gray weathering marbles.	600-650
Early and Middle Permian	Phosphoria Formation	Cherty quartzites, marbles, phosphatic rocks, and quartzites.	150-200?
Possible unconformity			
Middle Pennsylvanian	Quadrant Formation	Varicolored, well-sorted vitreous quartzite.	600
Early Pennsylvanian and Late Mississippian	Amsden Formation	Sandy carbonates and fine-grained clastics metamorphosed to marbles, calc-silicates and pelitic hornfelses.	250-350

a summary of the units, approximate thicknesses, rock types, and ages. A correlation chart (Table 2) is provided for a comparison with regions surrounding the Rock Creek area.

Paleozoic Rocks

Amsden Formation

The oldest rocks mapped in the Rock Creek Area belong to the Amsden Formation, which includes rocks of both the Late Mississippian and Early Pennsylvanian age. Darton (1904) first described the Amsden Formation along the Amsden Branch of the Tongue River in the Bighorn Mountains west of Dayton, Wyoming, where it forms a sequence of red shales and white limestones with cherty and sandy members. Sloss and Moritz (1951) reported that the greater part of the Amsden beds in southwestern Montana are probably of Mississippian age.

In the Rock Creek area, the Amsden Formation has been thermally metamorphosed by the Mount Torrey Batholith and now consists of marbles, hornfelses, and tactites.

Distribution and Topographic Expression

The outcrops of the Amsden Formation are discontinuous along the eastern border of the Mount Torrey Batholith in the southwest corner of the thesis area. Four small exposures of the Amsden

Table 2. Regional correlation chart (columns 1-3 modified after Groff, 1963).

Period		1 Drummond-Philipsburg Montana	2 S.W. Montana Generalized	3 Three Forks Quadrangle	Thesis Area
Tertiary		Tertiary undiff.	Rhyolite tuff Basalt Andesite volcanics Beaverhead Cgs.	Bozeman Group undiff.	Basaltic Andesites Tertiary Basin Beds
Late Cretaceous	Montanan	Montana ? ? Elkhorn Mtn. Volcs.	Aspen Fm.	Elkhorn Mtn. Volcanics	? Colorado undifferentiated
Late Cretaceous	Coloradan	Carter Creek Jens Coberly	Frontier Fm?	Colorado Group	
Early Cretaceous	Coloradan	Blackleaf	Thermopolis Shale		
Early Cretaceous		Kootenai	Kootenai	Kootenai	Kootenai
Jurassic	L	Morrison Swift Rierdon	Morrison Swift Rierdon	Morrison Ellis	
Jurassic	M	Sawtooth	Sawtooth		
Triassic			Thaynes Woodside Dinwoody		Dinwoody
Permian		Phosphoria	Phosphoria	Phosphoria ?	Phosphoria ?
Pennsylvanian		Quadrant	Quadrant	Quadrant	Quadrant
Mississippian	L	Amsden	Amsden Big Snowy Group	Amsden Big Snowy Group	Amsden
Mississippian	E	Madison	Mission Canyon Lodgepole	Mission Canyon Lodgepole	Not Exposed
Devonian	L	Three Forks Jefferson Maywood	Three Forks Jefferson Maywood	Three Forks Jefferson Maywood	
Devonian	M				
Devonian	E				
Silurian					
Ordovician			Bighorn		
Cambrian	L	Red Lion Pilgrim Hasmark	Red Lion Hasmark: Pilgrim, Park, Meagher	Pilgrim Park Meagher	
Cambrian	M	Silver Hill Flathead	Wolsey Flathead	Wolsey Flathead	
Cambrian	E				

Formation were mapped. Two exposures, one on the north side and one on the south side of Lost Creek Canyon, are in secs. 11 and 13, T. 4 S., R. 10 W. The Amsden has limited exposures in bulldozer cuts on grass-covered slopes. The two best exposures of the Amsden Formation are on the north and south walls of Rock Creek Canyon, near Browns Lake. On the south wall of the steep sided, glaciated canyon the Amsden Formation is exposed in the Browns Lake open-pit mine at an elevation of about 7,000 feet. The outcrop on the north wall forms a near vertical cliff. The Amsden overlies the plutonic rocks of the thesis area, and the contact is nearly concordant.

Thickness and Stratigraphic Relationships

A conservative estimate of thickness for the formation in the thesis area, on the north wall of Rock Creek Canyon, is between 250 and 350 feet. Owing to poor exposures, near vertical cliffs, and metamorphic effects, the Amsden Formation was not measured. The section of the Amsden beds near Lost Creek appear to be thinner, but estimates were not made because of limited outcrop and the effects of metamorphism. Darton (1904) measured 150 feet of Amsden beds near the Montana-Wyoming border in the Big Horn Mountains. Theodosis (1956) described 383 feet of Amsden beds in the Melrose area north of thesis area mapped. Sharp (1969) measured 375 feet of Amsden beds in the Greenstone Mountain area, which lies immediately south of the Rock Creek area.

The exposed Amsden is in contact with the Mount Torrey Batholith to the west and conformably underlies the quartzites of the Quadrant Formation of Pennsylvanian age, on the east. Glacial moraine overlies the exposure of the Amsden Formation on the south wall of Rock Creek Canyon above Browns Lake mine. Sloss and Moritz (1951) stated that the Amsden Formation in other areas of southwestern Montana disconformably overlies the Madison Group and is commonly involved with a solution-channelled surface developed on the underlying beds. The Amsden-Quadrant contact appears to be transitional and was placed immediately below the lowermost massive quartzite of the Quadrant Formation.

Lithology and Petrography

The Amsden Formation, where not affected by contact metamorphism, has been described by Theodosis (1956) as consisting dominantly of two members. The lower member consists of calcareous sandstones and siltstones. The upper member consists of siltstone beds interbedded with carbonate beds that become increasingly sandy toward the top.

The Amsden Formation, metamorphosed by the Mount Torrey Batholith, consists of tactites, hornfelses, and marbles. The rocks appear as intercalated beds that range in thickness from approximately one foot up to 60 feet in some tactites. Marble is the most abundant rock type. An aplite sill is exposed between the beds in the Browns Lake mine (Figure 2).

Tactite. This coarsely crystalline rock was formed by the contact metamorphism and metasomatism of carbonate rock. The best exposures of the tactite are at the Browns Lake mine where two units are exposed: a lower unit, approximately 50 to 60 feet thick, and an upper unit, six feet thick which is separated from the lower unit by marbles and hornfelses about ten feet in thickness.

The tactite is composed dominantly of garnets and lesser amounts of quartz and calcite. The color is grayish brown (5YR 3/2), dusky brown (10YR 2/2), blackish red (5R 2/2), and very dusky red (10R 2/2). The garnets average about one-eighth inch in diameter, but a few larger crystals of one-half to three-quarter inches in diameter were observed. Copper minerals, epidote, specular hematite, and limonite are scattered through the tactite, and scheelite and powellite have been reported by Patee (1960).

Hornfelses. The nonfoliated, very finely crystalline rocks are contact metamorphosed aspects of the Amsden Formation. Two major types are recognized from petrographic study: a pelitic hornfels and a calc-silicate hornfels. The pelitic type is represented by quartz-orthoclase hornfels and the calc-silicate type by diopside-quartz and diopside-wollasonite hornfels.

Figure 2. Aplite sill with near-vertical jointing between intercalated beds of hornfelses and marbles of the metamorphosed Amsden Formation at Browns Lake mine. Glacial moraine exposed at the top of the mine cut.

The quartz-orthoclase hornfels is medium dark gray (N4) to dark gray (N3), and has a hornfelsic texture. Petrographic study reveals about 37 percent quartz and about 35 percent orthoclase with grain sizes ranging from 0.05 to 0.15 mm. Orthoclase is typically interstitial with the quartz, and both can be readily recognized by differences in relief. Muscovite (7%) is colorless and tabular and commonly surrounds grains of quartz. Greenish-brown biotite (11%) occurs as shreds up to 0.3 mm long and shows alteration to chlorite. Magnetite makes up about eight percent of the rock and tourmaline two percent. Tourmaline, in short prismatic crystals about 0.1 mm in length, typically shows neutral gray to blue pleochroism. Zircon grains are rounded and constitute less than one percent of the rock.

The diopside-quartz hornfels has fresh colors of dark greenish gray (5G 4/1) and weathered colors of greenish gray (5GY 6/1). The rock has a granoblastic texture and is dominantly composed of diopside (40%), quartz (45%), plagioclase (12%) and calcite (3%). Minor accessories include biotite, pyrite, and magnetite. The plagioclase present is too small in size to permit any optical determinations of Ab-An content.

The diopside-wollastonite hornfels has colors of light greenish gray (5G 8/1) and very pale green (10G 8/2) for both fresh and weathered surfaces. The major minerals are quartz, diopside, and wollastonite and the texture is hornfelsic. Quartz constitutes approximately 53 percent of the rock, and grains range in size from 0.05 to 0.3 mm. The diopside (23%) is non-pleochroic, pale green, and shows two good directions of cleavage at nearly right angles on a few crystals. Larger diopside crystals show twinning. The wollastonite (20%) is columnar to fibrous and exhibits parallel to nearly parallel extinction. Sphene, zircon, and calcite are present in minor amounts.

Marble. Marbles occur interbedded with the hornfelsic rocks. The marbles are medium to coarsely crystalline, and where free of impurities, are very light gray (N8) to white (N9). Marbles that contain more impurities are medium gray (N5) and medium light gray (N6). The degree of effervescence with dilute hydrochloric acid seems to vary from one hand specimen to another.

Petrographically, the marbles typically have a granoblastic texture. Calcite constitutes at least 95 percent of the marble. Calcite crystals range from 0.5 to 3 mm in size. Forsterite and diopside constitute as much as three percent of the marble and occur as isolated, colorless, round grains, which are conspicuous in thin section because of their high refractive indexes and bright polarization colors. The diopside crystals show twinning and two directions of cleavage. Minor accessories include spinel, magnetite, pyrite, and some questionable graphite.

Age and Correlation

No fossils were found in the Amsden Formation of the Rock Creek area, presumably as a result of thermal metamorphism.

Scott (1935) originally considered the Amsden Formation in central Montana to be middle or late Chesterian in age. Berry (1943) stated that in the vicinity of Three Forks, Montana, the lower part of the Amsden Formation contains a Late Mississippian fauna not only comparable to that of the Brazer limestone of southeastern Idaho but probably equivalent to the Sacajawea Formation of Wyoming and Montana. In the upper 100 feet of the Amsden Formation, Berry found fossils generally considered Pennsylvanian in age. Scott (1945) reported fusulinids of Morrowan age from the upper Amsden beds. Mundt (1956) agreed with earlier geologists working in southwestern Montana that the Amsden Formation straddles the Mississippian-Pennsylvanian boundary, and he assigned a Chesterian to Atokan age for the formation in Montana and northern Wyoming.

Origin and Conclusion

The Amsden in southwestern Montana comprises marine shale, siltstone, commonly of bright red to purplish red in color, and thin-bedded to massive fossiliferous limestones.

The hornfels of the metamorphosed Amsden that contains dominantly quartz, feldspar, and micas indicates original siliceous pelitic rocks or the finer grained clastics of the original Amsden Formation. The calc-silicate hornfels probably represents an original sandy carbonate rock. The marbles are derived from limestones and, in part, magnesian or dolomitic limestones, as indicated by the presence of forsterite and diopside. Thus, the rocks of the metamorphosed Amsden mimic the original siltstone and limestone beds in the upper part of the Amsden Formation, as described by Theodosis (1956). The author believes that the only parts of the stratigraphic section exposed in the Rock Creek area are those that represent the upper carbonate member of the Amsden Formation.

The rocks belong to a high grade contact metamorphic facies. Owing to the limited number of slides prepared and mineral assemblages present, no attempt is made here to assign the rocks to a more detailed facies category.

Quadrant Formation

The Quadrant Formation was first named in print by Peale (1893) for a lower unit of red and arenaceous limestone, a middle unit of cherty limestone and quartzite, and an upper unit of quartzite, in the Three Forks area, Montana. The term, as applied by Peale, included what is now the Amsden Formation. Iddings and Weed (1899) first described the Quadrant Formation in the southeast corner of Quadrant Mountain in the northwest part of Yellowstone National Park as white and pink beds of quartzite and interbedded drab saccharoidal limestone. However, rocks of Amsden age were included in the lower part of the formation, and Scott (1935) redescribed the Quadrant, restricting the formation to beds of Pennsylvanian age and assigning the lower red beds to the Amsden Formation.

In the thesis area, the Quadrant Formation has been thermally metamorphosed by the intrusion of the Mount Torrey Batholith. In the thesis area, the Quadrant partly conformably overlies the Amsden Formation, and partly is intruded by the Mount Torrey Batholith. The contact with the overlying Phosphoria Formation is not exposed, and contact relationships could not be observed. The contact with the overlying Phosphoria Formation is placed at the top of the vitreous quartzites of the Quadrant Formation. North of Browns Lake, in the N 1/2 sec. 34, T. 3 S., R. 10 W., there is a distinct lithologic and color change from vitreous quartzites to marbles and cherty to quartzitic appearing rocks. Other workers in southwestern Montana (Sloss and Moritz, 1951; Robinson, 1963) reported a conformable Quadrant-Phosphoria contact. On the other hand, Theodosis (1956) reported a limonitic sandstone at the top of the Quadrant which he interpreted as a product of pre-Phosphoria erosion.

Distribution and Topographic Expression

The Quadrant Formation, locally interrupted by the Mount Torrey Batholith, forms a nearly continuous outcrop in the southwestern corner of the mapped area (Plate 1).

The very resistant quartzites form prominent cliffs and ridge crests. Talus slopes of blocky quartzite, as well as stands of conifers, are characteristic of Quadrant outcrops. Large talus slopes of quartzite have formed on the walls of Rock Creek Canyon near

Browns Lake, entirely covering the underlying Amsden beds in places. In the NW 1/4 sec. 13, T. 4 S., R. 10 W., Quadrant talus forms a rounded knob without bedrock exposure.

Thickness

The Quadrant Formation is about 600 feet thick in the southwestern corner of the area mapped. Thompson and Scott (1941) reported a thickness of 279 feet for the type section on Quadrant Mountain, Wyoming. Condit (1918) reported 1,000 feet in the eastern part of the Snowcrest Range. Scholten et al. (1955) reported 2,600 feet in Big Sheep Creek Canyon west of Lima. Thus, the Quadrant in southwestern Montana thickens markedly to the southwest. In the Three Forks Quadrangle, Montana, Robinson (1963) reported a range in thickness from 250 to 500 feet. Ten miles to the north of the thesis area, Theodosis (1956) reported thicknesses up to 450 feet.

Lithology and Petrography

Within the thesis area, the Quadrant Formation is a very thick-bedded to massive, vitreous quartzite. Cross-stratification occurs but is not common.

The color of the quartzite is variable and appears to be determined by the content of hematite and limonite. The colors of the varicolored quartzite are dark yellowish orange (10YR 6/6), grayish orange (10YR 7/4), grayish pink (5R 8/2), moderate pink (5R 7/4), and white (N7). Light brown (5YR 5/6) prevails in the lower part of the formation.

Petrographically, the quartzites show a finely-crystalline granoblastic texture. A typical quartzite sample is composed of 98 percent quartz. Individual grains of quartz range from about 0.06 to 0.25 mm. Quartz grains have irregular, regular, and acicular inclusions (Keller and Littlefield, 1950). The irregular inclusions are the most abundant. Minerals present as inclusions are zircon and apatite. Recrystallization of quartz is indicated by crenulated grain boundaries and fractures across individual grains. Some quartz grains show undulatory extinction and a slight tendency toward an anisotropic fabric. Accessory minerals include zircon, tourmaline, muscovite, magnetite, hematite, and limonite. Rounded zircon grains make up as much as one-half of a percent of the rock and have an average grain size of about 0.08 mm. Tourmaline grains show rounding and have an average size of about 0.12 mm. The magnetite shows alteration to hematite.

Age and Correlation

The quartzite in the thesis area is unfossiliferous. Identification of the formation is based on its stratigraphic position above the Amsden Formation and its distinctive lithology. Quadrant beds were observed and traced from adjoining areas.

In the type section of the Quadrant Formation at Quadrant Mountain, Wyoming, Thompson and Scott (1941) found Wedekindellina and Fusulina in the upper part of the formation. These fusulinids indicate a middle Desmoinesian age. If the Quadrant of southwestern Montana is truly gradational with the Phosphoria as suggested by Klepper et al. (1957), Scholten et al. (1955), and Robinson (1963), then at least part of the Quadrant Formation is probably Late Pennsylvanian. A Pennsylvanian age is assigned to the Quadrant Formation in the Rock Creek area.

Origin and Conclusions

The original unmetamorphosed Quadrant Formation of the thesis area was a quartz arenite with a high degree of textural and mineralogical maturity. The rocks, almost monomineralic and locally cross-bedded, suggest a shallow neritic or beach condition on a stable shelf. The very high content of quartz, rounded zircon, and tourmaline suggests that the sand has gone through several cycles of sedimentation.

The homogeneous quartz arenite in the Rock Creek area was then metamorphosed during the intrusion of the Mount Torrey Batholith to form a quartzite.

Phosphoria Formation

Richards and Mansfield (1912) named the Phosphoria Formation for exposures of Permian rocks in Phosphoria Gulch northwest of Meade Peak, Idaho. The Phosphoria at the type locality was divided into two members: the lower 180 feet consisted of phosphatic mudstone, mudstone, and phosphate rock; the upper 240 feet consisted of the Rex Chert.

Klepper (1950) divided the Phosphoria Formation in the Snowcrest Range into five members, which, in ascending order, are: (A) sandstones and dolomites; (B) interbedded phosphatic mudstone and phosphate rock; (C) carbonate rock, chert, and sandstone; (D) interbedded bituminous mudstone, phosphatic mudstone, and phosphate rock; and (E) quartzite, sandstone, and chert. The stratigraphic nomenclature for the Permian strata in the western phosphate field was later revised by McKelvey et al. (1956). Rocks previously ascribed to the Phosphoria Formation were separated into three lithofacies units, to each of which formational rank was assigned. McKelvey and his associates restricted the phosphorite, dark mudstone, and chert facies to the Phosphoria Formation, the limestone and dolomite facies to the Park City Formation, and the sandstone facies to the Shedhorn Sandstone.

In the Rock Creek area, the Permian rocks were mapped as one unit, the Phosphoria Formation, because of poor exposures, thinness of the formation, and effects of thermal metamorphism. The author was unable to differentiate either the individual members named by Klepper (1950) or the lithofacies units named by McKelvey et al. (1956).

The Phosphoria-Quadrant contact is not exposed in the thesis area, and the nature of the contact relationship cannot be observed. The contact with the overlying Triassic Dinwoody Formation is conformable. A conformable Phosphoria-Dinwoody relationship has been recognized throughout part of southwestern Montana by Cressman (1955) and by Sloss and Moritz (1951).

Distribution and Topographic Expression

The Phosphoria Formation has very limited and discontinuous outcrops in the southwestern corner of the mapped area. The formation is locally interrupted by the Mount Torrey Batholith and by faulting. Phosphoria beds have been intruded by the Mount Torrey Batholith about one mile south of Browns Lake.

The Phosphoria beds are generally covered on grassy slopes, with little or no observable exposure above the Quadrant quartzites. In places the quartzites of the Phosphoria Formation form low resistant ledges. The best exposure of the Phosphoria beds is in the N 1/2 sec. 34, T. 3 S., R. 10 W. Several small trenches have been cut into Phosphoria beds, probably during exploration for phosphate.

Thickness

The Phosphoria Formation was not measured in the mapped area because of poor exposures. Approximately 150 feet of Phosphoria beds are exposed above the Quadrant quartzites north of Browns Lake. Richards and Mansfield (1912) measured 415 feet of Phosphoria beds at the type section in southeastern Idaho. Sloss and Moritz (1951) reported that the Phosphoria Formation thins markedly northward and eastward in southwestern Montana. Cressman (1955) has indicated that the formation is 155 feet thick about 30 miles north of Dillon, Montana, and 270 feet thick about 15 miles northwest of Dillon. Cressman and Swanson (1964) have reported a measured section of Phosphoria strata 209 feet thick along Canyon Creek approximately five miles north of the Rock Creek area.

Lithology and Petrography

Theodosis (1956), using the divisions of the Phosphoria Formation proposed by Klepper (1950), reported members C, D, and E to be present immediately north of the Rock Creek area. Member C consists of a lower cherty-siliceous, dolomitic limestone, a siliceous limestone, and a cherty sandstone. The D member consists of shale, phosphate rock, and phosphatic mudstone. The uppermost

E member consists of chert and quartzite.

In the Rock Creek area the intrusion of the Mount Torrey Batholith has caused the carbonate rocks to be changed to marble, locally with silicate minerals, and the sandstones to be changed to quartzites. The writer could not differentiate the individual members described by Theodosis (1956) or Klepper (1950). However, a threefold division could be determined in the exposed section in the N 1/2 sec. 34, T. 3 S., R. 10 W.

The lower part of the exposed Phosphoria Formation in the N 1/2 sec. 34, T. 3 S., R. 10 W., comprises thick-bedded cherty quartzites and fine- to medium-crystalline marble. The cherty quartzites have a fresh color of medium gray (N5) and weathered surfaces of pale yellowish brown (10YR 6/2) and medium gray (N5). Petrographic examination of the cherty quartzite reveals relic detrital grains of quartz suspended in a dense groundmass of microcyrstalline quartz. The quartz grains within the microcrystalline quartz groundmass range in size from 1/8 to 1/4 mm, and have peripheries corroded by the encroachment or suturing of the microcrystalline quartz. A few authigenic quartz overgrowths are still visible around quartz grains. The sand-sized quartz grains constitute from 30 percent to nearly 80 percent of the quartz. Several grains of detrital quartzite and chert are still visible in thin section and have sizes up to 1.25 mm. The quartz grains contain acicular and regular inclusions

(Keller and Littlefield, 1950). The only mineral recognized in the quartz grains was zircon. Minor constituents include rounded zircon, magnetite, tourmaline, hematite, and limonite. The magnetite shows alteration to hematite. Trace amounts of calcite are scattered throughout some of the cherty quartzites.

The marbles in the lower and middle part of the formation are fine- to medium-crystalline, and fresh surfaces are pale yellowish green (10GY 7/2) and medium gray (N5). Weathered colors are medium light gray (N6), dark gray (N3), and yellowish gray (5G 8/1). The marbles have the appearance of limestones because of their fine crystalline size but are referred to as marbles because of the presence of silicate minerals formed during thermal metamorphism and their granoblastic texture. The dominant constituent, calcite (93%), has a grain size from about 0.15 to 0.6 mm. Many crystals of calcite appear dark from impurities. Quartz constitutes up to five percent of the rock in thin section and appears to have been replaced by calcite around the boundaries. Minor accessories include tremolite, magnetite, hematite, chlorite, and diopside.

A dark-colored unit approximately 25 feet thick that has fresh and weathered colors of dark gray (N3) and grayish black (N2) is exposed below the uppermost quartzite of the Phosphoria beds. The author believes this may represent what was originally the phosphorite, shale, and phosphatic mudstone. These rocks commonly have dark color, and Lowell (1955), in a study of igneous intrusions in phosphatic rocks, reported a similar dark color of the phosphate rock. Cressman and Swanson (1964), while working in a sequence of phosphorite and shale next to an intrusive, reported that the beds were grayish black and that equipment during sampling became unusually dirty, as if working in graphitic schists. They also stated that the dark color of these rocks, which appears in thin section to be a black matrix of quartz and collophane, suggested a high content of carbonaceous material, but their chemical analysis showed little. They stated, "It seems probable that much of the carbonaceous material occurs in the form of graphite, which would not be detected in the chemical analysis." A petrographic examination of one rock, from the lower part of this unit, revealed quartz and chert grains with sizes of 1/8 to 1/4 mm randomly oriented in a microcrystalline quartz cement and an unidentifiable dark to black matrix. Also noted were infrequent rounded to elliptical, dark pellet-shaped bodies. These may represent phosphatic (?) pellets. Phosphatic pellets have often been reported to be clouded by carbonaceous matter and to appear dark (Cressman and Swanson, 1964).

The uppermost part of the Phosphoria Formation in the N 1/2 sec. 34, T. 3 S., R. 10 W. is chert or quartzitic chert. Fresh and weathered colors range from light gray (N6) to medium dark gray (N4). Petrographically, the rock is composed of 98 percent microcrystalline quartz. Accessory minerals listed in order of abundance are calcite, hematite, and zircon.

Age and Correlation

No fossils were found in the Permian beds of the Rock Creek area. Fusulinids of Wolfcampian age have been described from the basal beds of the Phosphoria by Frenzel and Mundorff (1942), near Three Forks, Montana. Miller et al. (1957) have reported Leonardian ammonites in rocks above the Rex Chert Member of the Phosphoria Formation in Idaho and in the Wasatch Mountains. Diagnostic fossil evidence is lacking in the upper part of the Phosphoria Formation, and McKelvey et al. (1956) state "its [Phosphoria] age can only be said now to be older than Early Triassic."

Correlation of the Phosphoria rocks in the thesis area with the Phosphoria Formation, as defined in other areas, is based on: (1) stratigraphic position overlying the Quadrant quartzites, (2) similarity to metamorphosed Phosphoria beds described by Lowell (1955) immediately north and northeast of the mapped area, and (3) unmetamorphosed rocks described by Cressman and Swanson (1964) five miles north of the mapped area along Trapper Creek.

Origin and Conclusion

According to Cressman and Swanson (1964), the Phosphoria

Formation in southwestern Montana is of marine origin and represents both transgressive and regressive deposits. The quartzites of the Phosphoria strata probably represent depositional environments similar to those of the Quadrant Formation. The rounded zircon and abundant quartz indicates a previously existing sedimentary source and possibly several cycles of sedimentation.

The depositional environment for the shales and mudstones of the Phosphoria Formation was thought by Cressman and Swanson (1964) to be below wave base in water containing little or no oxygen.

Cressman and Swanson (1964) hypothesized that the phosphatic pellets originated through direct precipitation of phosphate from sea water, infiltration of fecal pellets, and inorganic accretion of phosphatic material disseminated through sediments.

The origin of the massive chert members of the Phosphoria Formation is a controversial subject. Suggestions of the origin of the chert include recrystallization of siliceous organisms during diagenesis and precipitation of silica from marine waters as a primary gel. Krauskopf (1959) has demonstrated that in present day seas the concentration of dissolved silica is too low for direct precipitation. Cressman and Swanson (1964) pointed out "the immediate source of most of the silica in the chert was siliceous sponge spicules."

Rocks of the Phosphoria Formation in the Rock Creek area, before thermal metamorphism, were probably similar to those of the measured section described by Cressman and Swanson (1964, p. 367) along Trapper Creek approximately five miles to the north. There, using the nomenclature of McKelvey et al. (1956), they reported the following members in ascending order: Franson and Grandeur Members of the Park City Formation, Retort Phosphatic Shale Member, Tosi Chert Member, and a tongue of the Shedhorn Sandstone.

Mesozoic Rocks

Dinwoody Formation

Blackwelder (1918) named and described the Dinwoody Formation as greenish-gray shales interbedded with thin, calcareous sandstones or argillaceous shales, which weather tawny brown or black in color. The name is derived from the Canyon of Dinwoody Lakes on the northeast slope of the Wind River Mountains, Wyoming. Moritz (1951) and Kummel (1954) recognized a twofold division of the Dinwoody Formation in southwestern Montana: a lower shale unit, and an upper unit of interbedded calcareous siltstone, silty limestone, gray crystalline limestone, and gray to buff shale. Moritz (1951) referred to the two members as the lower "shale member" and the upper "limestone member" of the Dinwoody Formation.

In the thesis area, the carbonates of the Dinwoody Formation have been changed in marble, and the mudstones, siltstones, and shales to hornfelsic and argillitic appearing rocks. The formation apparently conformably overlies the Permian Phosphoria Formation and is disconformably overlain by the Early Cretaceous Kootenai Formation. Newell and Kummel (1942) reported a disconformable Dinwoody-Kootenai contact along Trapper Creek, immediately north of the area mapped. In parts of southwestern Montana, such as Greenstone Gulch approximately ten miles south of the thesis area, the Triassic Woodside Formation overlies the Triassic Dinwoody Formation (Newell and Kummel, 1942).

Distribution and Topographic Expression

The Dinwoody Formation crops out in the western half of the thesis area. It forms a nearly continuous outcrop from the southwestern corner to the northwest corner, where it leaves the mapped area. The Dinwoody outcrop is interrupted by the Lost Creek tear fault immediately north of Lost Creek, where the beds are offset about half a mile in a northeasterly direction.

The lower part of the Dinwoody Formation is covered by grass or slope debris. The upper marbles form thin ledges and low cliffs. The best exposure of the upper Dinwoody beds is on the small peak immediately south of Sugarloaf Mountain in the NE 1/4 NE 1/4 sec. 3,

T. 4 S., R. 10 W. (Figure 3).

Thickness and Lithology

The Dinwoody Formation is about 650 feet thick in the southwestern corner of the thesis area. Pre-Early Cretaceous erosion has removed an undetermined amount of Triassic rock, accounting for the erosional surface at the top of the formation, where it is disconformably overlain by a Kootenai conglomerate of Early Cretaceous age.

Blackwelder (1918) measured 250 feet of Dinwoody beds at the type locality. However, Newell and Kummel (1942, p. 941), redefined Blackwelder's original measured section to include only the "dominantly silty strata between the top of the Phosphoria and the top of the resistant siltstone about halfway toward the summit of the original Dinwoody." They measured 639 feet of Dinwoody beds along Trapper Creek in sec. 22, T. 2 S., R. 10 W.

Moritz (1951) reported that the most characteristic feature of the formation in southwestern Montana is the chocolate brown color on weathered surfaces of the limestones and siltstones. In southwestern Montana, the Dinwoody Formation, according to Kummel (1954), has a twofold division, a lower shale unit, and an upper unit of interbedded calcareous siltstone, silty limestone, gray crystalline limestone and gray to buff shale. Even after the effects of thermal

Figure 3. Upper gray medium to coarsely crystalline marbles of the Dinwoody Formation exposed on the small peak immediately south of Sugarloaf Mountain in the NE 1/4 NE 1/4 sec. 3, T. 4 S., R. 10 W.

metamorphism, a twofold division can still be recognized in the Dinwoody Formation of the thesis area.

The lower unit of very thin- to thin-bedded siltstones and shales now consists of hornfelses and argillites. The weathered rock colors are moderate yellowish brown (10YR 5/4), grayish brown (5YR 5/2), and light olive gray (5Y 4/1). Fresh surfaces are medium light gray (N6) and dark greenish gray (5GY 4/1).

The upper unit of the Dinwoody Formation in the thesis area now consists of medium- to coarsely crystalline marbles with inter-bedded hornfelses. Fresh surface colors of the marble are very light gray (N8) and light brownish gray (5YR 6/1). Weathered surface colors are light brownish gray (5YR 6/1, grayish brown (5YR 3/2), and light gray (N7). The limestones have maintained their chocolate brown weathering color after recrystallization to marble. The marbles are thin- to thick-bedded and include beds up to three feet thick. The size of the calcite crystals varies within the marble; some crystals are as large as 3 mm. The marbles consist of about 99 percent calcite crystals with an average grain size of about 0.75 mm. Dark impurities surround calcite crystals. Minor accessories include magnetite and quartz. The magnetite shows alteration to hematite.

The very thin- to thin-beds, that were siltstones and shales before thermal metamorphism, are interbedded with the marbles in the upper part of the formation and are up to about one foot thick. Colors and lithologies of the metamorphosed fine-crystalline rocks are similar to those of the basal beds of the formation.

Age and Correlation

No fossils were found in the Dinwoody Formation within the thesis area, their absence a result of thermal metamorphism. Well preserved specimens of Lingula sp. have been reported in adjoining areas (Theodosis, 1956; Sharp, 1969; Steur, 1956) and were observed by the writer.

Newell and Kummel (1942) reported a fauna of Early Triassic age in the Dinwoody beds of southwestern Montana. Kummel (1954, p. 236) reported two ammonite faunas in beds overlying the lower shale unit of the Dinwoody Formation in southwestern Montana, one in Frying Pan Gulch, Beaverhead County, and the other at Dalys Spur, 13 miles south of Dillon. He dated these as early Scythian (very Early Triassic) in age.

Correlation of the beds in the thesis area with the Dinwoody beds of other areas was based on the formation's stratigraphic position overlying the Permian Phosphoria Formation as well as on interpretations of pre-metamorphosed lithologies in adjoining areas.

Origin and Depositional Environments

Moritz (1951) reported that Early Triassic seas apparently advanced from the south into southwestern Montana and deposited the siltstones, shales, and limestones of the Dinwoody Formation. Moritz also concluded that the "sediments of the Dinwoody exhibit characteristics that suggest deposition on a mildly unstable shelf." He points out that "repeated shifts from lagoonal or littoral environmental conditions to normal neritic conditions are suggested by the repetition of the Lingula and Claraia faunas in some of the stratigraphic sections." The instability of the shelf is also indicated by the cyclic presence of siltstones and shales and interbedded limestones.

Abundant fossils of Lingula, reported in Dinwoody beds of areas adjoining the Rock Creek area, indicate a shallow-water environment (Shrock and Twenhofel, 1953). Environmental conditions during deposition of Dinwoody beds, as indicated by Moritz, were probably similar to those in the Rock Creek area. The Dinwoody beds were recrystallized during the intrusion of the Mount Torrey Batholith of Late Cretaceous to early Tertiary age.

Kootenai Formation

Dawson (1885) first used the name Kootenie for a sequence of sandstone, shale, conglomerate, and coal beds in southern British Columbia (Willmarth, 1938). The name Kootenie comes from an Indian tribe that hunted in the Southern Canadian Rockies in the vicinity of the type locality, near Kootenie Pass. The present spelling of Kootenai was introduced by Fisher (1908), who applied the name Kootenai Formation to beds of pebbly sandstone, red sandy shale and clay, local coal beds; and concretionary limestone exposed near Great Falls, Montana. He correlated these beds with the Kootenie beds of Dawson in British Columbia.

Klepper et al. (1957) divided the Kootenai Formation into three units in the southern Elkhorn Mountains of western Montana. The basal unit is salt-and-pepper sandstone; the medial unit is characterized by red and green shale and siltstone; and the uppermost unit is gray limestone.

Kauffman (1963) and Gwinn (1965) have noted that the Kootenai Formation of the Clark Fork Valley in western Montana contains four mappable units, which they informally referred to as the "lower clastic member," "lower calcareous member," "upper clastic member," and the "upper calcareous member" (gastropod limestone).

In the area of this report the formation is informally divided into three members, which were collectively mapped as a single unit. The basal beds of the Kootenai, Member 1, consist of salt-and-pepper sandstone and conglomerate. Member 2 consists of varicolored argillite, siltstone, shale, and beds of sandstone. Member 3, the uppermost member, is a sequence of biomicrosparite calcirudite and interbeds of fine-grained sandstone and shale. The uppermost gastropod limestone marks the top of the Kootenai Formation and is recognized over much of western and central Montana (Gwinn, 1965; Kauffman, 1963; Suttner, 1969).

In the thesis area, the Kootenai Formation disconformably overlies the Triassic Dinwoody Formation and is conformably overlain by the Cretaceous Colorado Group.

Distribution and Topographic Expression

The Kootenai Formation forms a nearly continuous belt that trends from slightly southeast to northwest in the western-half of the thesis area. Kootenai rocks also crop out in the extreme northeastern corner of the thesis area in secs. 4 and 5, T. 3 S., R 9 W. The Kootenai beds are offset in a northeasterly direction by the Lost Creek tear fault in secs. 12 and 13, T. 4 S., R. 10 W.

Exposures of the Kootenai Formation are fair to poor, and at no one place within the thesis area is a complete section of the Kootenai exposed. The lower sandstones and conglomerates commonly form low subdued ledges, and beds of shale, siltstone, and argillite are grassy slope formers. The uppermost unit of calcirudite forms persistent ledges in the extreme northeastern corner of the map area and is generally subdued to covered in other parts. Best exposures of the Kootenai Formation are in secs. 4 and 5, T. 3.S, R. 9 W., in the northeast corner of the area mapped.

Thickness and Lithology

Because a complete section of Kootenai beds could not be found at any one locality, the author was unable to measure a section of the formation with any degree of reliability. An estimated thickness of 900 feet of Kootenai beds crops out on the west side of Storm Peak. Klepper (1950), reported a thickness of about 1,000 feet of Kootenai beds along the east flank of the Snowcrest Range. Scholten et al. (1955) measured 1,500 feet of Kootenai beds in the area of Saw Mill Creek, southeast of Lima. Gwinn (1965) noted a thickness of 860 to 1,100 feet for the formation in the Clark Fork Valley.

Member 1. The lowermost member consists of conglomerate and coarse-grained sandstone. The conglomerate contains pebbles and cobbles of chert and quartz arenite. The pebbles and cobbles are dominantly of chert and are up to eight inches in diameter. The black chert and white to yellowish white quartz arenite sand-sized grains, pebbles, and cobbles are rounded to subrounded. The conglomerate has weathered and fresh rock colors of pale yellowish brown (10YR 6/2) to dark yellowish brown (10YR 5/2). Microscopic inspection of the basal conglomerate reveals pebbles of microcrystalline to chalcedonic chert (65%) set in a matrix of poorly sorted fine- to coarse-grained detrital quartz (16%), and chert (4%). The sand-sized grains are angular to subrounded. Minor detrital accessory minerals include plagioclase, muscovite, tourmaline, biotite, and zircon. Interstitial argillaceous matrix surrounds the sand-sized grains and constitutes up to five percent of the rock. Authigenic quartz overgrowths (2%) and microcrystalline quartz (8%) are the cementing agents for the conglomerate. Limonite rims many of the grains, adding to the brown color of the rock. The conglomerate ranges from approximately nine feet thick on the west side of Storm Peak to 20 feet thick in the northeastern corner of the thesis area.

Textural changes from conglomerate to thick-bedded or massive sandstone occur over short distances. The sandstones of the lower member are predominantly medium- to very coarse-grained and locally show cross-bedding. Colors on weathered surfaces are pale yellowish brown (10YR 6/2) and pale red (10R 6/2), and fresh surfaces are light gray (N7). The sandstones closely resemble the matrix of the conglomerates.

Member 2. The middle member of the Kootenai Formation consists of varicolored argillite, fissile shales, siltstones, and interbeds of sandstone. The argillites, siltstones, and shales have colors of greenish gray (5GY 6/1), grayish green (5G 5/2), very dusky red (10R 2/2), very dusky red purple (5RP 2/2), and dusky red (5R 3/2) on fresh and weathered surfaces. The very thin- to thin-bedded strata are commonly slightly calcareous. Silt-sized angular to subangular quartz grains constitute up to 20 percent of the rock. An argillaceous matrix, partly containing sericitic and chloritic material, makes up about 80 percent of the argillite.

The interbedded thin- to thick-bedded sandstones from the middle member have fresh colors of light gray (N7) and medium light gray (N6). Weathered colors are pale red (10R 6/2), pale yellowish brown (10YR 6/2), and medium gray (N5). The sandstones show cross-laminations and locally contain subrounded pebbles of chert up to 6 mm in size. The framework of the sandstone consists of subrounded, medium- to coarse-grained quartz (70%) and chert (10%). Minor accessories include zircon and limonite. The sandstone is cemented by microcrystalline quartz (12%) and authigenic quartz overgrowths (7%), which are well-defined by an iron oxide ring around the original detrital grain. Authigenic quartz overgrowths developed first as a cement, and microcrystalline quartz developed later around the siliceous overgrowths.

Member 3. The upper member of the Kootenai Formation consists of biomicrosparite calcirudite and interbeds of mudstone, shale, and fine- to medium-grained sandstone.

The thin- to thick-bedded biomicrosparite has fresh rock colors of medium gray (N5) to medium dark gray (N4) and weathered rock colors of medium gray (N5). Gastropods are ubiquitous in the biomicrosparite and have lengths up to 1.5 cm. Gastropods constitute up to 75 percent of the biomicrosparite. Microsparite and sparry calcite compose and fill the fossil allochems. The matrix is microsparite (20%). Ostracod shells, chert, and quartz are minor constituents. The very fine- to fine-grained subangular quartz grains are scattered throughout the rock and in the whorls of some of the gastropod shells. The microsparite has probably recrystallized from micrite. Sparry calcite was precipitated in the gastropod shells and along the small veins. The quartz grains show replacement by calcite.

Nonresistant interbeds of mudstone and thinly laminated shales have fresh and weathered colors of medium gray (N5) to dark gray (N3). The mudstones and shales are commonly calcareous and have undulating bedding surfaces.

The thin- to thick-bedded, fine- to medium grained, interbedded sandstones have weathered surfaces of yellowish brown (10YR 4/2) and fresh surfaces of medium dark gray (N4). The sandstones are calcareous, probably indicating calcite cement.

Age and Correlation

In the thesis area, fossils in the Kootenai Formation include gastropods (Reesidella?) and ostracods. Stanton (1903) first described a Kootenai invertebrate fauna collected near Harlowtown, Montana and dated it as Early Cretaceous. Yen (1951) later collected fossils from Stanton's locality, identified the fresh-water molluscan assemblage, including Reesidella, and concluded that the Kootenai is Early Cretaceous in age. Young (1960) reported that pelecypods are reliable Aptian indicators in the upper Kootenai beds of Montana. Cobban et al. (1959) reported that the lower shales of the overlying Blackleaf Formation contain Inoceramus comancheanus, an index fossil of middle late Albian age. On the basis of this evidence, the Kootenai is now generally accepted as being of Aptian age (Suttner, 1969). It is important to note that the fauna collected for dating was collected from the upper gastropod limestones of the Kootenai Formation.

Correlation of the Kootenai beds within the Rock Creek area is based on fossil evidence, stratigraphic position, and lithologic similarities to Kootenai beds described by Kauffman (1963), Klepper et al. (1957), Gwinn (1965) and Suttner (1969).

The three members identified in the map area may be correlative with the three members described by Klepper et al. (1957) in the Elkhorn Mountain region of southwestern Montana. Suttner (1969) has recognized four members analogous to those described by Kauffman (1963) and Gwinn (1965) immediately south and north of the Rock Creek area exposed along Birch Creek and Trapper Creek, respectively. The author believes these four members are present within the Rock Creek area. However, because of limited exposures of the middle Kootenai strata, the author has included Suttner's "lower calcareous member" and "upper clastic member" in Member 2 of this report.

Yen (1951) correlated the Kootenai with part of the Cloverly Formation of Montana and Wyoming and with part of the Peterson Limestone of the Gannett Group in Wyoming and Idaho on the basis of non-marine molluscs.

Origin and Environment of Deposition

The presence of fresh-water gastropods, red-colored strata, and a basal conglomerate suggests that the Kootenai Formation is non-marine. Detrital chert and quart arenite grains in the conglomerates and sandstones indicate that material of the Kootenai strata was derived from pre-existing sedimentary rocks. The rounded to subrounded character of the cobbles, pebbles, and sand grains of the Kootenai beds suggests a somewhat distant provenance for the sandstone and conglomerate. The coarse- to fine-grained clastic sediments were perhaps deposited on large alluvial floodplains, as pointed out by Glaister (1959) and Suttner (1969). Suttner (1969) and McMannis (1965) believe the basal conglomerate of the Kootenai Formation is a reflection of Early Cretaceous uplift in Idaho.

The uppermost limestones represent deposition in areally extensive lakes that received little or no clastic debris (Yen, 1951). Suttner (1969) pointed out the difficulty in explaining regionally extensive lake basins and their preservation for long periods of time. He compares the Kootenai limestone with the Eocene lacustrine beds of the Green River Formation and points out that conditions may have been similar during Kootenai deposition.

Colorado Group

The Colorado Group was named by Hayden, in 1876, for exposures along the eastern base of the Front Range in Colorado, where it consists of dark to black shale and a few laminated sandstones (Wilmarth, 1938).

The correlative rocks on the Sweetgrass Arch of northwestern Montana are dominantly dark gray shales, and until lithologic subdivisions were recognized, it was customary to treat the Colorado strata as a single formation, the Colorado Shale (Cobban, 1951). Cobban _et al._ (1959) later divided these rocks into a lower unit, the Blackleaf Formation, composed of the Flood, Taft Hill, Vaughn, and Bootlegger members of Early Cretaceous age, and an upper unit, the Marias River Shale, composed of the Floweree, Cone, Ferdig, and Kevin members of Late Cretaceous age. The Colorado Shale was defined by Cobban _et al._ (1959) as those Cretaceous rocks overlying the Kootenai Formation and underlying the Telegraph Creek

Formation of the Montana Group.

Gwinn (1965) divided the rocks of the Colorado Group in the Clark Fork Valley of west-central Montana into the Blackleaf, Coberly, Jens, and Carter Creek Formations, the first one of Early Cretaceous age and the last three of Late Cretaceous age. Gwinn also subdivided the Blackleaf Formation in the Clark Fork Valley into three members; the Flood Member, the Taft Hill Member, and the Dunkleberg Member, in ascending order.

In northeastern Wyoming and parts of Montana the lower part of the Colorado Group is known as the Thermopolis and Mowry Shales.

In the thesis area, the Cretaceous rocks overlying the Kootenai Formation are informally divided into three members that are mapped as two separate lithologic units. The strata may be in part equivalent to the Early Cretaceous Colorado Group and in part equivalent to the Late Cretaceous Montana Group of central and northwestern Montana. However, because diagnostic fossils were not found and correlative lithologic subdivisions of the Montana Groups were not recognized, the three members are arbitrarily included in the Colorado Group without definite age assignment.

The Colorado Group conformably overlies the Kootenai Formation and dependent upon the locality, is unconformably overlain by Tertiary volcanic rocks, Tertiary basin beds, or Quaternary terrace gravels.

Distribution and Topographic Expression

The Colorado Group, the most widespread outcropping unit, covers an area of approximately 20 square miles in the eastern half of the mapped area. Quaternary terrace gravels cover the Cretaceous sediments along the eastern lowlands. Volcanic rocks cover part of the Colorado beds in the north-central and northeastern parts of the mapped area. Numerous faults have locally offset the Cretaceous beds throughout the thesis area.

The shales, siltstones, and mudstones are nonresistant and commonly form strike valleys and grass-covered slopes. Sandstones and conglomerates of Members 2 and 3 form slopes, ledges, and small cliffs. The rocks of the uppermost part of Member 3 are dominantly nonresistant and form slopes and small ledges.

Member 1 is poorly exposed throughout the thesis area. Best exposures of Members 2 and 3 are in sec. 31, T. 3 S., R. 9 W.; sec. 36, T. 3 S., R. 10 W.; sec. 13, T. 4 S., R. 10 W.; and sec. 18, T. 4 S., R. 9 W.

Thickness and Lithology

Colorado strata overlying the Kootenai beds in the eastern half of the map area have a thickness of approximately 6,000 to 6,500 feet. Theodosis (1956) reported a thickness between 4,000 to 5,000 feet for Colorado strata in the Melrose area. In an area adjoining the Rock Creek area to the south, Meyers (1952) and Sharp (1969) reported an approximate thickness of 6, 000 feet for post-Kootenai Cretaceous sedimentary rocks. Gwinn (1965) reported about 19, 000 feet of Cretaceous rocks in the Clark Fork Valley between Garrison and Drummond, Montana, approximately 11, 000 feet of which are Colorado rocks.

Member 1. The lower member, about 1, 350 feet thick, consists dominantly of dull-hued shale and argillite and subordinate amounts of sandstone and porcellanite.

Well-indurated fissile shales occur in the lower part of the member. The colors of fresh and weathered surfaces are medium gray (N5) and grayish black (N2).

The very thin- to thick-bedded argillites of the lower member have fresh surfaces of medium dark gray (N4), light olive gray (5Y 6/1), and grayish green (10GY 5/2). Weathered surfaces have colors of dark gray (N3), light bluish gray (5B 7/1), and moderate yellowish brown (10YR 5/4). The very dense, well indurated, slightly recrystallized strata are composed of clay- and silt-sized particles.

The upper 700 feet of the member includes very thin to thick beds of porcellanite. The porcellainites have fresh and weathered colors of grayish green (10GY 5/2), pale greenish yellow (10Y 8/2), yellowish gray (5Y 7/2), grayish yellow (5Y 8/4), and white (N9).

The porcellanites are well-bedded and contacts between bedding planes are planar. The porcellanites consist of about 95 percent cryptocrystalline silica with minor amounts of silt-sized to fine-grained quartz, plagioclase, relic glass shards, biotite and hornblende. Diagenetic alteration of volcanic detritus has probably produced the striking silicification of the porcellanites. Rubey (1929) stated "that the silica in the Mowry Shale was in some way derived from the alteration of volcanic ash." In one porcellanite specimen collected, the author noted small spherical to ellipsoidal bodies up to 6 mm in diameter. In thin section, the centers of the spherical objects are seen to contain crystals of quartz, feldspar, and volcanic glass and are concentrically surrounded by cryptocrystalline silica.

Subfeldspathic lithic arenites are present in the middle and upper parts of Member 1. The sandstones are greenish gray (5GY 6/1), and very light gray (N8) on fresh surfaces, and weathered surfaces are medium light gray (N6) and light brown (5YR 6/4). The thin- to thick-bedded sandstones are medium- to coarse-grained. Subangular to subrounded quartz (70%) and chert (13%) are the dominant framework constituents. Fine-grained argillaceous fragments and tuffaceous (?) fragments together form up to 15 percent of the framework. Detrital plagioclase and zircon are minor accessories. Authigenic quartz overgrowths and microcrystalline quartz cement the sandstone.

Member 2. The middle member, about 1,300 feet thick, is composed of a basal pebbly sandstone that grades upward into interbedded gray, green, and rare dull maroon siltstones, shales, and argillites accompanied by minor amounts of sandstone and porcellanite.

A cross-bedded sandstone forms a prominent ridge at the base of the member and is about 50 feet thick. The sandstone is very similar to the upper sandstones of Member 1 but contains lenses of pebbles up to three feet thick. The thick-bedded sandstone is light brown (5YR 6/4) on fresh and weathered surfaces.

Thin- to thick-bedded argillites overlie the prominent ridge formed by the lowermost sandstone. Argillites are light olive gray (5Y 5/2) on fresh surfaces and moderate yellowish brown (10YR 5/4) on weathered surfaces. The unit is approximately 155 feet thick.

Overlying the lower prominent sandstone and argillites are 1,050 feet of interbedded calcareous and siliceous silty shales, shales, sandstones, siltstones, and minor amounts of porcellanite.

Fresh surfaces of the siltstones and shales are dusky yellow green (5GY 5/2), grayish green (10GY 5/2), greenish gray (5G 6/1), moderate dusky red (5R 4/4), pale yellowish brown (10YR 6/2), and medium dark gray (N4). Weathered surfaces are moderate yellowish brown (10YR 5/4), pale grayish red (10R 5/2), and light greenish gray (5GY 8/1). The shales are thinly laminated to laminated. Shaly siltstones and siltstones are laminated- to thin-bedded. Worm borings up to 7 mm in diameter are found locally in the fine-grained clastics. Silt-sized to very fine-grained angular to subangular detrital quartz, chert, plagioclase, muscovite, and argillaceous lithic fragments constitute up to 20 percent of the calcareous silty shale. Quartz constitutes about 80 percent of the detrital grains. The detrital grains are surrounded by calcite cement and argillaceous matrix. The silty shale contains about 25 percent calcite. Hematite is abundant in the matrix of the red silty shales examined.

The sandstones of Member 2 are fine- to medium-grained and are characterized by a salt-and-pepper appearance. The thin- to thick-bedded sandstones have beds up to four feet thick. The sandstones are both calcareous and siliceous. Fresh surfaces are light olive gray (5Y 6/1) and light to medium bluish gray (5B 6/1), and weathered surfaces are light gray (N7) and yellowish gray (5Y 7/2).

Beds of porcellanite, similar to those of Member 1, are minor in Member 2.

<u>Member 3</u>. The lower part of Member 3 consists predominantly of interbedded siltstone, shale, and sandstone. A conglomerate at the base of the member marks the contact between Member 2 and Member 3. The upper part of the member is characterized by

nonresistant mudstones, shales, siltstones, sandstones, and pebbly sandstones. A partly exposed section of Member 3 about 2,200 feet thick was measured in sec. 31, T. 3 S., R. 9 W. The author estimates that the total thickness of the member is about 3,500 feet.

The conglomerate that lies at the base of Member 3 is about 2,700 feet above the base of the formation. The conglomerate thins markedly from north to south in the thesis area. At the southern end of the thesis area, south of Lost Creek, the conglomerate is five to six feet thick. It is 30 to 40 feet thick at the northern extremity of the thesis area. Theodosis (1956) reported a similar conglomerate in the Melrose area, immediately north of the Rock Creek area, to be 2,000 to 2,500 feet stratigraphically above the base of the formation. Gwinn (1965) has reported similar conglomerates in the Blackleaf Formation of the Colorado Group in the Drummond-Garrison area of west-central Montana. The conglomerate contains rounded to subrounded cobbles and pebbles of chert and quartz arenite up to 170 mm in diameter. The pebbles and infrequent cobbles are enclosed in a poorly sorted, medium- to fine-grained sand-sized matrix. The conglomerates have fresh and weathered surfaces of moderate yellowish brown (10R 6/2). Locally, more than one conglomerate bed occurs near the base of the member, and these beds are separated by finer-grained clastics that show normal grading upward. The conglomerate is best exposed at the base of Member 3 along Rock Creek Road in sec. 25, T. 3 S., R. 10 W.

Overlying the basal conglomerate, are 2,170 feet of monotonously interbedded sandstones, siltstones, shales and argillites.

The sandstones are very fine- to very coarse-grained and both calcareous and siliceous. The siliceous sandstones are more resistant to weathering than the calcareous sandstones. Fresh surfaces of the sandstones are yellowish gray (5Y 7/2), light bluish gray (5B 6/1), and medium light gray (N6). Weathered surfaces are moderate yellowish brown (10YR 5/4), light gray (N7), and pale yellowish brown (10YR 6/2). The sandstones commonly have a salt-and-pepper appearance from the light-colored detrital grains and dark-colored chert grains. The sandstones are very thin- to very thick-bedded and commonly have irregular to nearly planar bedding planes. Cross-bedding is common. Pebbles up to 15 mm in diameter were noted in lenses in the siliceous sandstones. A microscopic study of one representative sample from the lower part of Member 3 shows the sandstone to be a lithic arenite. The framework is dominantly composed of subangular to rounded lithics (28%), quartz (27%), and chert (25%). Most of the lithics have been derived from fine-grained siliceous sedimentary rocks. Minor lithics include quartzite fragments. Minor detrital constituents include feldspar and biotite. Authigenic quartz overgrowths and microcrystalline quartz cement the sandstone. An argillaceous matrix makes up about five percent of the rock and voids about three percent.

Both calcareous and siliceous siltstones and shales are represented. Fresh surfaces are medium bluish gray (5B 6/1), grayish olive (10Y 4/2), greenish gray (5GY 6/1), and medium gray (N5). Weathered surfaces are dark greenish gray (5GY 5/1), moderate yellowish brown (10YR 5/4), pale red (10R 6/2), and dark yellowish brown (10YR 5/2). The siltstones are generally thin-bedded and weather into flaggy and slabby fragments. Siliceous silty shales contain silt-sized to fine-grained subangular to subrounded quartz, up to 2 mm in diameter. Minor detrital components include plagioclase, biotite, zircon, and limestone clasts. Several zoned grains of plagioclase were noted. The detrital components compose about 30 percent of the rock. The voids are filled with microcrystalline to cryptocrystalline quartz and argillaceous material. The high amount of silica present in the matrix may be an indication of diagenetic alteration of volcanic material and consequent silicification.

The uppermost part of Member 3 consists of interbedded mudstones, siltstones, shales, sandstones, and pebbly sandstones.

Fresh surfaces of the sandstones are medium light gray (N6) to light gray (N7), and weathered surfaces are pale red (5R 6/2), grayish red (10R 4/2), and pale yellowish brown (10YR 6/2). The sandstones are thin- to thick-bedded, medium- to coarse-grained, and commonly show cross stratification (Figure 4). Sandstone beds are generally separated by mudstones and shales. Bedding surfaces are commonly undulating and show gradational contacts with the finer-grained beds. The sandstones locally contain subrounded chert pebbles up to 45 mm in diameter. Petrographic analysis of a thin section shows the sandstone to be a lithic arenite. The framework consists of subangular to subrounded lithics, chert, and quartz grains. The lithics are dominantly fine-grained clastic sediments and minor amounts of carbonates and tuffaceous (?) fragments. Lithics compose about 25 percent of the sandstone. Argillaceous matrix makes up about five percent of the rock, and microcrystalline quartz, along with quartz overgrowths and calcite, constitute the cement.

The interbedded mudstones and shales have darker colors than the lower beds of the member. Fresh surfaces are medium dark gray (N4), and brownish gray (5YR 4/1); weathered surfaces are light olive gray (5Y 6/1) and gray black (N2). Many of the fine-grained clastics are calcareous.

Age and Correlation

The only fossils found in beds of the Colorado Group were fossil tree segments and algae (?). Myers (1952) reported a few poorly preserved marine pelecypods in post-Kootenai Cretaceous sediments, immediately south of the Rock Creek area. In several localities he

Figure 4. Cross-stratification in quartzose sandstone of the upper part of Member 3 of the Cretaceous Colorado Group.

collected leaf impressions considered to be of Late Cretaceous age, probably "somewhere near Judith River or later." Myers also reported specimens of Platanus sp. and Winchellia sp. that were collected from near the top of the post-Kootenai strata in the SE 1/4 sec. 18, T. 4 S., R. 9 W., in the Rock Creek area. Klepper (1950) in his reconnaissance of parts of Beaverhead and Madison Counties, Montana, reported remains of plants to be as young as Judith River or Mesa Verde age (Late Cretaceous, Montana Group) in the Ruby Valley, east of the Lima region. An Early and Late Cretaceous age for rocks of the Colorado Group is reported by Cobban et al. (1959) on the Sweetgrass Arch, Montana. Cobban and Reeside (1952) indicate on their correlation chart of Cretaceous rocks that the Colorado Shale straddles the Albain (late Early Cretaceous) and Cenomanian (early Late Cretaceous) boundary in the Dillon region.

Correlation of the Colorado Group in the thesis area with the Colorado Group, as defined in other areas, is based on stratigraphic position above the Early Cretaceous Kootenai Formation and lithologic similarities to sections in Montana described by Gwinn (1965), Cobban et al. (1959), and Swartz (1969, oral communication). Swartz (1969, oral communication), states that the Cretaceous rocks directly overlying the Kootenai Formation in the area mapped and immediate adjoining areas are equivalent to the Blackleaf Formation of Early Cretaceous age. The informally named Members 1, 2, and parts of 3 may be in part correlative with the Flood, Taft Hill, and Dunkleberg Members of the Blackleaf Formation described by Gwinn (1965) in the Drummond-Garrison regions of west-central Montana. The members are described by Gwinn (1965) as follows: (1) the Flood Member comprises 550 to 700 feet of dominantly clastic sediments; (2) the Taft Hill Member comprises about 1,000 feet of well-sorted sandstone, and interbedded argillaceous sandstone, siltstone, and mudstone. The finer clastics are gray, green, and rarely dull maroon and contain lithic and devitrified volcanic glass fragments; (3) the Dunkleberg Member comprises 1,700 feet of sandstone, siltstone, and mudstone with several zones of conglomerate. Beds of the member are often rich in lithic, crystal, and devitrified volcanic detritus. Members 1, 2, and 3 of the Rock Creek area do not correspond respectively to the Flood, Taft Hill, and Dunkleberg Members, but there are lithologic similarities in the section. Theodosis (1956) stated that the conglomerate in the Colorado strata of the Melrose area is similar to a conglomerate he has observed in the Blackleaf Member of the Colorado Shale in the Sun River area in northwest Montana. The upper part of Member 3 may be correlative with the Late Cretaceous Montana Group of central and northwest Montana, as pointed out by Theodosis (1956) and indicated by fossil evidence obtained by Myers (1952) and Klepper (1950).

The stratigraphy and paleontology of Cretaceous rocks younger than the Kootenai Formation would have to be studied in detail before these rocks could be subdivided into formations and correlated more precisely with Cretaceous rocks elsewhere.

Origin and Depositional Environments

The fine- to coarse-grained clastic sediments of the Colorado Group represent deposition in fluvial and paralic environments. The fine-grained clastics of Member 1 represent deposits in shallow marine or lagoonal waters. The cross-stratified arenites of Member 2 indicate barrier-bar, shallow sublittoral deposits. The finer clastics of Member 2 may have accumulated in lagoonal or paralic mud-flat conditions. The pebble and cobble conglomerate at the base of Member 3 indicates stream channels on an alluvial plain. The marked increase in grain size above Member 2 may indicate increased tectonism in the source area. Cross-stratified sandstones of Member 3 indicate shallow sublittoral, barrier-bar deposits.

The primary provenance for the Colorado Group was sedimentary, as indicated by the presence of argillaceous fragments, limestone clasts, quartz arenite, and chert grains. The presence of volcanic debris in porcellanites and some of the sandstones indicates a volcanic source area. McMannis (1965) states that the "debris may be related to the beginning of emplacement of the Idaho batholith and associated volcanic activity."

Cenozoic Rocks

Tertiary Basin Beds

In southwestern Montana intermontane basins were depositional sites during the Tertiary Period. The light-colored Tertiary deposits, frequently referred to in the older literature as "lake beds," have been discussed by Atwood (1916) and Richards and Pardee (1925). All Tertiary deposits in these basins are terrestrial and have been collectively referred to as the Bozeman Formation by Alexander (1955) and as the Bozeman Group by Robinson (1963).

Within the Rock Creek area, tuffaceous beds lie unconformably on the Late Cretaceous sedimentary rocks and are in turn overlain unconformably by Quaternary terrace gravels.

Distribution and Topographic Expression

The tuffaceous beds crop out over an area of nearly one square mile in the northeastern corner of the thesis area in secs. 16 and 21, T. 3 S., R. 9 W. Another small outcrop is present in secs. 4 and 5, T. 4 S., R. 9 W., west of Kambich Springs. The tuffaceous beds are easily recognized on aerial photographs by their light color. Road cuts have recently been made in the tuffaceous beds by Montana Power Company during installation of a power line, making exposures relatively good.

The topography normally developed on the tuffaceous beds is that of gently rounded, grass- and sagebrush-covered hills. Where recent erosion has stripped the soil and vegetation from the tuffaceous rocks, the exposure of the beds varies, locally showing gentle slopes (Figure 5) to low vertical cliffs (Figure 6).

Thickness and Lithology

Because of limited exposures and cover by terrace gravels, no accurate estimates of thicknesses could be made. Richards and Pardee (1925) reported "basin beds" possibly as much as 500 feet thick near Melrose, Montana. Riel (1963) measured 1,200 feet of sedimentary tuff near McCarty Mountain, which is approximately three miles east of the area mapped.

Within the thesis area, the tuffaceous beds consist predominantly of thick beds of light-colored tuffaceous sandy siltstones, with a few thin beds of air-laid vitric tuffs and very thin to thin beds of fine pebbly volcanic conglomerates. Colors on fresh and weathered surfaces are very pale orange (10YR 8/2), grayish orange (10YR 7/4), and pinkish gray (5YR 8/1). The thin interbeds of vitric tuff have colors of light gray (N7) to very light gray (N9). The color of the tuffaceous basin beds is largely due to the clay.

Bedding is generally difficult to see because the lithology of the

Figure 5. Gentle slope-forming light-colored Tertiary tuffaceous basin deposits in the northeastern corner of the mapped area. Tertiary basaltic andesites cap crest of the sagebrush covered ridge.

Figure 6. Exposure of tuffaceous sandy siltstones in N 1/2 sec. 21, T. 3 S., R. 9 W. Thin bed of vitric tuff just below the point of the rock hammer.

rock is nearly uniform. The tuffaceous sandy siltstones occur as poorly defined beds up to 1.5 feet thick. Bedding is not pronounced at all localities and may be so thick as not to be detected. The beds have been tilted and show low dip angles of about 5° to 15° to the east and northeast.

In the N 1/2 sec. 21, T. 3 S., R. 9 W., two vitric tuff beds, one five inches thick and another 2.5 inches thick, are present in the tuffaceous sandy siltstones. Also noted at this locality is a thin bed of pebbly volcanic conglomerate two to three inches thick. The fine pebbles are dominantly volcanic lithics of andesitic or basaltic composition.

A petrographic study of a sample from the vitric tuff bed shows nearly all volcanic glass, mostly in the form of glass shards. Many of the shards are broken and show a random arrangement. Small crystals of feldspar and fragments of pumice up to 6 mm in size were noted.

A sample of the tuffaceous sandy siltstones collected for petrographic analysis from this locality is composed primarily of silt-sized to medium-grained shards of volcanic glass, pumice, quartz, plagioclase, hornblende, and sanidine(?) in a clay matrix. The crystals are subangular to angular, indicating very little transport. Most of the vitroclastic material has undergone considerable alteration to clay. The clay mineral, as determined by X-ray analysis by Mr. Clyde

Murray, is montmorillonite.

Calcite veins up to 1.5 feet in thickness occur along minor fault and fracture surfaces. Weathering commonly produces a cracked surface on the tuffaceous beds, which is probably due to alternation of swelling and shrinkage of the clay.

Age and Correlation

Invertebrate fossils gathered from tuffaceous strata in areas adjacent to the map area indicate an early Oligocene age. Douglass (1905) described vertebrates of Oligocene age from beds on McCarty Mountain, approximately three miles east of the area mapped. Later, Riel (1963) colleced an early Oligocene fauna from the sedimentary tuff beds on the south side of McCarty Mountain. On the basis of fossil evidence from nearby beds, the writer considers it probable that the light-colored tuffaceous beds are also Oligocene in age, although diagnostic fossils were not found in the thesis area itself.

Correlation of the tuffaceous beds within the thesis area is based on the writer's observations of these strata in adjoining areas and their similarities to strata of Oligocene age as described by Alexander (1955), Riel (1963), Robinson (1963), and Field and Petkewich (1967).

Origin and Depositional Environment

There has been a question as to whether these tuffaceous beds and other Tertiary sedimentary rocks in the region were deposited in a lake or by streams meandering on a floodplain. The early workers, Richards and Pardee (1925) and Atwood (1916), concluded that these strata were deposited in fresh water lakes. Riel (1963) reported that the sedimentary tuffs and stream gravels present at McCarty Mountain "were deposited on a floodplain at the margin of a basin." Evidence for Oligocene lakes is supported by fossils of fish and fresh water gastropods found in the Douglass Creek Basin by Konizeski (Riel, 1963).

From a brief study of the tuffaceous beds in the Rock Creek area no new information can be added to the understanding of the origin of these beds. The fine-grained tuffaceous beds indicate a quiet water environment of deposition. The vitric tuff beds are relatively thin and well-sorted, indicating that the source was probably at a considerable distance. The vitric tuffs were probably deposited in subaerial conditions. The tuffaceous sandy siltstones indicate times when pyroclastic ejecta was falling into basins where normal sedimentation was going on, and the pyroclastic and epiclastic material were being mixed. The angularity of the crystals in the tuffaceous rocks indicates very little reworking. Evidence of a major fluvial system is lacking within the thesis area. It is suggested here that the tuffaceous beds represent deposition in a quiet body of water or shallow lake while areas surrounding the lake were being modified by fluvial processes.

Quaternary Deposits

Unconsolidated deposits of Pleistocene and younger age are localized along canyon walls, terraces, and valley floors and are classified as terrace gravels, glacial deposits, alluvium, and landslide deposits, including talus.

Terrace Gravels

An undetermined thickness of unconsolidated gravels cap low hills and terraces along the eastern border of the area mapped. The gravels unconformably overlie the tuffaceous siltstones, Colorado Group strata, and extrusive volcanic rocks of the mapped area. The terrace gravels occur at elevations up to 6, 300 feet.

The terrace gravels were deposited on surfaces eroded across Tertiary and Cretaceous rocks by streams from adjacent mountains. The sands, pebbles, cobbles, and rare boulders that form the gravel consist dominantly of volcanic rocks, chert, quartzite, and small amounts of argillaceous, carbonate, and plutonic rocks. Most pebbles and cobbles and boulders are rounded, but many are angular and evidently were not transported a great distance. Pardee and Richards (1925) described unconsolidated terrace gravels similar to those of the thesis area covering Tertiary "lake beds," immediately north of the thesis area. They concluded that the gravel "appears to be chiefly of Pleistocene age."

Glacial Moraine

The glacial moraine deposited along Rock Creek closely marks the extent that valley glaciers descended into the mapped area. The valley glacier that deposited this debris terminates at an elevation of approximately 6,000 feet near the eastern boundary of Beaverhead National Forest. About one mile west of the national forest boundary, the boulders are piled in a low moraine and cover the slopes up to an elevation of approximately 250 feet above Rock Creek. The valley morainal material consists predominantly of quartz monzonite boulders, as large as ten feet in diameter, and a heterogeneous mixture of metamorphosed sedimentary rocks and sedimentary rocks of various sizes and composition.

Lateral moraine is present along the walls of Rock Creek Canyon in secs. 33 and 34, T. 3 S., R. 10 W., and secs. 3 and 4, T. 4 S., R. 10 W. The deposits extend westward along the slopes of Rock Creek Canyon and block the mouth of a tributary gulch on the south wall of the canyon, so that it impounds Lake Agnes. The present level of this lake is maintained by an artificial dam. Here morainal deposits are as high as 800 to 1,000 feet above the bottom of Rock Creek Canyon. Granitic boulders up to about 15 feet are present in the lateral moraine.

Alden (1953), in a report on the glacial geology of western Montana, stated that the youngest morainal debris in Rock Creek Canyon was deposited by a valley glacier of Wisconsin Stage. The geomorphic features of glaciation are described in the section on geomorphology.

Landslides and Talus

Apron-like accumulations of fresh angular blocks below steep cliffs and unconsolidated rockslide and rockfall deposits were mapped as one unit. In many places along Rock Creek Canyon, blocks of rock up to about 20 feet wide have become detached from the outcrops and moved downhill. The slumped blocks have rotated considerably from their original positions. Individual blocks and broken rock debris are so numerous that, in places, they obscure the underlying geology. The largest deposit of talus and landslide debris in the area mapped surrounds Sugarloaf Mountain and covers the south wall of Rock Creek Canyon in secs. 2 and 3, T. 4 S., R. 10 W. and secs. 34, 35, and 36 in T. 3 S., R. 10 W.

Recent Alluvium

An undetermined thickness of unconsolidated silt, sand, and gravel is spread along the streams and cultivated lowlands in the eastern half of the thesis area. The most extensive deposits occur along Rock Creek in secs. 32 and 33, T. 3 S., R. 9 W. Alluvium is now being deposited along Browns, Rock, Cherry, and Lost Creeks, as well as their major tributaries.

IGNEOUS ROCKS

Igneous rocks, both intrusive and extrusive, occupy approximately 11 square miles of the Rock Creek area and are divided into two main map units. All intrusive rocks are phaneritic and were mapped as one unit, granodiorite. The extrusive unit is basaltic andesite.

Intrusive Rocks

Granodiorite is exposed over an area of about six square miles in sec. 33, T. 3 S., R. 10 W., and secs. 3, 4, 9, 10, 14-16, T. 4 S., R. 10 W. These intrusive rocks extend outside the thesis area to the west for undetermined distances and compose part of the Mount Torrey Batholith (Pattee, 1960).

Although the intrusive rocks are mapped as one unit, granodiorite, the author noted textural changes in the granitic rock along Rock Creek Canyon, and a modal analysis shows one sample to be a quartz monzonite. No attempt was made to determine if more than one intrusion was present along Rock Creek. Further study of the intrusive rocks and detailed mapping might reveal separate intrusions in the Rock Creek area.

Within the thesis area, fresh surfaces of the granodiorite are medium light gray (N6) to light gray (N7); weathered surfaces are pale yellowish brown (10YR 6/2), grayish orange (10YR 7/4), and medium gray (N6). The rock is nonresistant to weathering, and disintegration has produced grus, large accumulations of which occur along Lost Creek Road in sec. 14, T. 4 S., R. 10 W. The granitic rocks characteristically support a growth of conifers. Two prominent steeply dipping to nearly vertical joint sets are well developed in the granodiorite. One set strikes north to northwest and the other east to northeast (Figure 7). The spacing between joints ranges from about five inches to about four feet (Figure 7). Medium gray (N5) granitic zenoliths ranging in size about two inches to two feet in diameter were observed.

Light colored aplitic dikes and sills are exposed along the margin of the pluton. The sills have thicknesses up to about 15 feet. The dikes are generally two to three feet thick. An aplitic sill is shown in Figure 2 at the Browns Lake mine.

The Mount Torrey Batholith is in both concordant and discordant contact with the metamorphosed sedimentary rocks in the southwestern corner of the area where two contacts with the country rocks are exposed. One, on the north side of Rock Creek Canyon is nearly concordant. The other contact, exposed in Browns Lake mine on the south wall of Rock Creek Canyon, is sharp and discordant. Sharp (1969) reported that the contacts of the Mount Torrey Batholith with country rocks are generally sharp in the Greenstone Mountain area.

Figure 7. Two near-vertical joint sets in the granodiorite of the Mount Torrey Batholith along the ridge crest south of Lake Agnes in the NW 1/4 sec. 10, T. 4 S., R. 10 W.

Petrography

The granodiorite is medium-grained and has a holocrystalline hypidiomorphic-granular texture. Crystals range in size from 0.2 mm to 3 mm and are subhedral to anhedral in form. Examination of three thin sections of granodiorite shows the essential minerals are plagioclase, quartz, orthoclase, biotite, and hornblende. Percentages of the major minerals were determined by 700 point counts on two of the three thin sections examined. Subhedral plagioclase feldspar makes up 44 percent of the rock. The plagioclase is composed of andesine (An_{38}-An_{44}) and commonly shows normal zoning. A few reaction rims of myrmekite occur where plagioclase and orthoclase are in contact. Orthoclase is subordinate to plagioclase and constitutes 17 percent of the rock. The orthoclase occurs as interstitial material between subhedra of plagioclase and mafic minerals and as anhedral crystals that poikilitically enclose subhedral plagioclase, apatite, hornblende, and biotite. Anhedral quartz forms 28 percent of the rock and occurs interstitially or as large anhedra. Biotite constitutes six percent and hornblende three percent of the rock. Accessory minerals are magnetite, apatite, sphene, and zircon. Sphene and apatite are euhedral to subhedral. Chlorite is a common alteration product of biotite and hornblende. Alteration products of plagioclase are sericite and calcite. Orthoclase is partly replaced by kaolinite.

Petrographic examination of a porphyritic rock collected from the north wall of Rock Creek Canyon shows the rock to be a quartz monzonite. The quartz monzonite is porphyritic, holocrystalline, and has a hypidiomorphic-granular texture. Phenocrysts of orthoclase are up to 7 mm long. The mineral assemblage of the quartz monzonite is the same as the granodiorite, but differs in proportions of minerals present. The quartz monzonite is composed of plagioclase (42%), orthoclase (30%), quartz (22%), biotite (5%), and hornblende (1%). Accessory minerals are sphene, apatite, and magnetite.

Age

Rocks of the Triassic Dinwoody Formation are the youngest rocks intruded by the Mount Torrey Batholith in the area of investigation. Rocks mapped as part of the Colorado Group, of Early Cretaceous age, have been moderately thermally metamorphosed by the pluton, and are therefore older than the pluton.

The batholith in the Rock Creek area is probably related to the Boulder Batholith, the southern part of which is exposed about 12 miles north of the map area (Theodosis, 1956). Age determinations from rocks of the Boulder Batholith by Chapman et al. (1955), Knoff (1964), Tilling et al. (1968) indicate the pluton was emplaced at or near the end of the Cretaceous period. Tilling et al. (1968)

states that the composite Boulder Batholith and satellitic intrusive masses range in age from 78 to 68 m.y. Steur (1956) described unmetamorphosed strata of Oligocene age that unconformably overlie metamorphosed sedimentary rocks of Late Cretaceous age at McCarty Mountain. It seems reasonable to assume that the Mount Torrey Batholith was emplaced during Late Cretaceous or early Tertiary time.

Contact Metamorphic Effects

Within the thesis area, the Mount Torrey Batholith is in contact with the Amsden, Quadrant, Phosphoria, and Dinwoody Formations. The aureole of contact metamorphism extends outward approximately 1 1/2 miles from the eastern margin of the batholith south of Lost Creek and 2-2 1/2 miles from the contact along Rock Creek Canyon. The width of the contact aureole and the increase in dip of strata toward the east suggests that the subsurface contact of the intrusive dips gently. The contact of the plutonic rocks with the country rocks dips about 20° to the east along the north wall of Rock Creek Canyon. Although the effects of thermal metamorphism diminished outward from the contact, no attempt was made in the field to recognize metamorphic facies.

The chief results of contact metamorphism were recrystallization and metasomatism. The effects of thermal metamorphism on the individual formations have been discussed elsewhere under each formation.

Extrusive Rocks

Basaltic Andesites

Basaltic andesites are restricted to the northeastern corner of the thesis area in secs. 4, 5, 8, 9, 17, 20, and 21, T. 3 S., R. 9 W. The flows unconformably overlie beds of the Colorado Group and are in turn unconformably overlain by Quaternary terrace gravels. The relationship between the Oligocene tuffaceous siltstones and the volcanic rocks is uncertain. Presumably the volcanic rocks overlie the tuffaceous siltstones, but no exposure of the contact of the volcanic rocks with the tuffaceous siltstones was found.

The base of the basaltic andesites is not exposed, but outcrops indicate that the unit must be at least several hundred feet thick. On fresh surfaces the basaltic andesites are medium dark gray (N4), medium light gray (N6), and very dusky red (10R 2/2); weathered surfaces are grayish red (10R 4/2) and pale brown (5YR 5/2). The following percentages were estimated for constituents in thin sections of the basaltic andesites: plagioclase feldspar (65%), olivine (10%), augite (15%), and hypersthene (5%), with minor accessories of magnetite, hornblende, and biotite. Microscopically the texture is porphyritic and intergranular. The groundmass makes up about 80 percent of the rock, and phenocrysts of olivine, hypersthene, and augite make up the remainder of the rock. The plagioclase occurs in small laths of 1/16 to 1/8 mm and in composition is between andesine and laboradorite (An_{50} by the Michel-Levy method). Relatively few crystals exhibit zoning. Olivine occurs as anhedral to subhedral phenocrysts up to a maximum dimension of 1.25 mm and is altered to iddingsite. Subhedral augite crystals occur as phenocrysts and in the groundmass. Slightly pleochroic hypersthene, noted in two of the four thin sections analyzed, occurs as subhedral phenocrysts up to 0.75 mm in length.

Magnetite grains have been altered in part to hematite. Several crystals of clinopyroxene were observed to have altered to hornblende as a late magmatic effect. Small amounts of brown volcanic glass, partially devitrified, were noted in one thin section. Data from X-ray emission spectroscopy of thesis area basaltic andesites is shown in Table 3.

The abundance and shape of vesicles varies throughout the basaltic andesite. Near the tops of the flows, the volcanic rocks are commonly very scoriaceous, with vesicles constituting as much as 50 percent of the rock. The vesicles range in size from 1/2 mm up to nearly 25 mm. Many vesicles are flattened and drawn out in a horizontal plane with pointed terminations. Amygdaloidal fillings of calcite are common. Crude columnar joints were developed in the flow rocks.

Table 3. Data from X-ray emission spectroscopy of thesis area basaltic andesites. Analyzed by Dr. Edward Taylor, Oregon State University.

Oxide		Weight percent
SiO_2		55.9
Al_2O_3		16.4
FeO		8.5
CaO		6.6
MgO		6.7
K_2O		1.9
TiO_2		0.87
	total	96.87

In the NW 1/4 sec. 9, T. 3 S., R. 9 W., a lithic pebbly sandstone bed, interposed between the volcanic flows, appears to have been baked by the overlying flow. The sandstone was not mapped as a separate unit because of its very limited areal distribution. The bed is about three or four feet thick and can be traced laterally between flows for several hundred feet. It appears to have experienced erosion before the overlying basaltic flow covered it, as indicated by the undulating contact with the overlying flow. The fine pebbly sandstone contains sandstone, argillaceous, and volcanic lithics.

Volcanic lithics are basaltic or andesitic in composition, rounded, and up to 3 mm in size. Pyroxene crystals, feldspar laths, and altered volcanic glass are visible in the lithics. Sandstone and argillaceous lithics, not as abundant as the volcanic lithics, are up to 2 mm in size and show rounding. The cementing material that fills the voids is calcite. The vesicles of the scoriaceous lithics are also filled with calcite.

What appears to be a small, highly dissected cinder cone, mapped with the extrusive volcanic rocks, occurs in the SW 1/4 sec. 17, T. 3 S., R. 9 W. The cone stands about 120 feet above the small intermittent stream on the south side of the cone. The rock is scoriaceous and is distinctive from a distance because of its moderate reddish brown (10R 4/6) and dark reddish brown (10R 3/4) colors. The scoriaceous lava occurs only on the south side of the cone. The very dense basaltic rock that makes up the rest of the cone may represent what was originally the vent. On the west side of the dissected cone is a small outcrop of agglomerate (Figure 8) that contains pumice and scoriaceous fragments up to about ten inches in diameter. The matrix appears to be highly altered pyroclastic material. The agglomerate apparently represents a deposit of pyroclastic material contemporaneous with the extrusive flows.

The volcanic rocks of the thesis area are probably middle Tertiary in age. Theodosis (1956) reported that extrusive volcanic rocks

Figure 8. View looking north at the west side of an apparent small cinder cone in the SW 1/4 sec. 17, T. 3 S., R. 9 W. Small outcrop of agglomerate exposed near the base and to the left of the cone. Colorado (Kc) strata exposed along the stream bed and covered in the near foreground. Tertiary volcanic rocks exposed in the background.

are interbedded with middle Tertiary tuffaceous beds, probably of Oligocene and Miocene age, in the Melrose area. Riel (1963) reported that volcanic rocks rest unconformably upon tuffaceous beds of Oligocene age on McCarty Mountain. The major source for the volcanic flows was undoubtedly the dikes exposed just north of the thesis area. Another likely source may have been small vents, such as the one exposed within the thesis area.

STRUCTURAL GEOLOGY

Regional Structure

The thesis area is located in the Disturbed Belt of western Montana, south of the Lewis and Clark Line, in a complex region of thrust faults, large reverse and normal faults, and folds that generally trend northwest to north. The area is situated approximately between the eastern edge of the intensely deformed miogeosyncline belt and the western edge of a relatively stable craton whose exposed core consists of a pre-Beltian metamorphic complex. The Rock Creek area lies about ten miles west of the exposed Precambrian crystalline basement rocks (Ross et al., 1955).

The Laramide Orogeny, which began in Late Cretaceous and continued to Eocene (McMannis, 1965), produced the complex structures by great compressional forces directed from the west and southwest. Eardley (1951) stated that two systems of compressional structures developed at nearly right angles. The first, and main, phase of orogeny is characterized by northeast-trending structures, and a second phase is characterized by north-northwest trending folds and thrusts.

After the compressive deformation of western Montana was about completed, vertical forces acted during middle Tertiary time and continued throughout much or all of the remainder of the Tertiary

Period to dome and block fault the rocks in western Montana (Perry, 1962).

Rock Creek Area Structure

The pre-Tertiary beds of the Rock Creek area have been tilted so as to strike northwest and dip gently to steeply toward the east. The east-dipping Colorado beds have been cut by a high-angle reverse fault that nearly parallels the strike of the beds in the thesis area as well as the northwest-trending regional structures. A large tear fault has offset the east-dipping beds in a northeasterly direction (Plate 1). There are several minor north-trending folds. Several reverse faults and numerous normal faults trend either nearly parallel, perpendicular, or diagonal to the strike of the northwest-trending beds.

The faults and minor folds are related to the main episode of Laramide deformation, emplacement of the Mount Torrey Batholith, and later phases of structural adjustment. Minor folding in middle to late Tertiary time is indicated by gently folded tuffaceous siltstones and basaltic andesites.

Folds

No major folds are known to occur in the Rock Creek area. However, the low angle east-dipping Colorado rocks in the eastern half of the thesis area may represent the west limb of a large syncline whose axis lies east of the thesis area, probably near the Big Hole River. The author has noted west-dipping beds across the Big Hole River Valley from the Rock Creek area, which may represent an east limb.

Minor folds are present in the low-dipping beds of the Colorado Group in the eastern half of the mapped area. The largest fold, a syncline, which enters the area mapped in the SW 1 4 sec. 18, T. 4 S., R. 9 W., extends for nearly two miles in a northerly direction and terminates in sec. 5, T. 4 S., R. 9 W. Dips on the limbs toward the axial plane range from about 5° to 20°.

Faults

Two major faults are present in the thesis area, the Lost Creek tear fault and a northwest-trending high-angle reverse fault. Numerous longitudinal and transverse normal faults are also present in the map area.

Lost Creek Tear Fault. The Lost Creek tear fault, named for the first time in this report, has offset the Mount Torrey Batholith and Late Mississippian to Late Cretaceous beds about one-half mile in a northeasterly direction. The Lost Creek tear fault originates an undetermined distance south of the thesis area but enters it in the SW 1/4, sec. 14, T. 4 S., R. 10 W. and terminates in the W 1/2, sec. 5, T. 4 S., R. 9 W. The fault strikes about N. 50° E. and continues for a distance of nearly four miles. The strike-slip displacement is right-lateral. The fault branches into two nearly parallel faults in the E 1/2, sec. 14, T. 4 S., R. 10 W., and continues for about 2 1/4 miles along the strike to a point near the Spritzer Ranch in the N 1/2 sec. 7, T. 4 S., R. 9 W., where the faults again join. The greatest distance separating the two parallel faults is about 900 feet in secs. 12 and 13, T. 4 S., R. 10. Small outcrops of Quadrant, Phosphoria, Dinwoody, and Kootenai beds are situated between the two parallel faults. Beds of the formations between the two faults are chaotically oriented. The strike of the bedding south of the tear fault in sec. 13, T. 4 S., R. 10 W., is about N. 8° E. and the strike on the north side of the tear fault in sec. 12, T. 4 S., R. 10 W., is about N. 25° W. The Lost Creek tear fault was recognized in the field by the large horizontal displacement of the Mount Torrey Batholith and late Paleozoic to Cretaceous strata. The approximate location of the Lost Creek tear fault is shown in Figure 9. The fault formed after the main episode of deformation and after the intrusions of the Mount Torrey Batholith.

High-Angle Reverse Fault. The line of rapid change in dip along the northwest-trending Colorado beds, immediately east of the Beaverhead National Forest boundary south of Rock Creek, and immediately west of the Forest Service boundary north of Rock Creek, was mapped by the author as a probable high-angle reverse fault, dipping steeply to the west. The fault enters the mapped area from the south in

Figure 9. View northwest into the Rock Creek area from U. S. Highway 91 at Glen, Montana. Approximate location of the Lost Creek tear fault is shown in the southern end of the thesis area. Sugarloaf Mountain, the largest peak in center background, and Storm Peak in right background.

sec. 18, T. 4 S., R. 9 W., trends north to northwest for a distance of nearly 5 1/2 miles, and terminates in the NW 1/4, sec. 24, T. 3 S., R. 10 W., near Browns Creek. At the southern end of the thesis area in sec. 18, T. 4 S., R. 9 W., the reverse fault is bordered immediately to the east by a small syncline. Directly north of the termination point of the fault, a steeply dipping normal fault cuts the Colorado beds. The trend of the fault nearly parallels the strike of bedding. However, the strike of the fault shows a slight cross-cutting effect on the bedding north of Rock Creek to the point where the fault terminates. Bedding planes immediately west of the fault dip from about 60° to 70° east. Beds on the east side of the fault dip gently both to the east and west. On the east side of the fault dips are generally about 10° to 20°. The strike of the beds on both the west and east sides of the fault remains nearly the same throughout the area. The general strike is about N. 15° W. The only anomalous strikes on the east side of the fault are just north of Rock Creek in sec. 24, T. 3 S., R. 10 W. and secs. 30 and 19, T. 3 S., R. 9 W. At this location the change in strike from the west side of the fault to the east side cannot be accounted for by pure rotation, assuming the beds had the same initial strike and dip before faulting occurred. The beds on either side of the fault must have had different attitudes before faulting to explain the strike change by pure rotation. However, the strike change may be explained by folding before faulting, or folding after faulting, or a combination of the two. The pre- or post-folding or combination of the two may have taken place with some rotation. Mild folding has taken place since the Laramide Orogeny, as indicated by the folding of the tuffaceous siltstones.

Besides the proposed high-angle reverse fault there are other possible explanations for the rapid changes in dip mentioned: (1) pronounced angular unconformity, (2) folding.

In reviewing the literature on Cretaceous rocks of surrounding areas, the author has failed to find any mention of pronounced angular unconformities in Early and Late Cretaceous rocks of southwestern Montana. Scholten et al. (1955) reported Early and Late Cretaceous rocks in the Lima region of southwestern Montana, but found no angular unconformities within the Cretaceous rocks of that area. Immediately north of the mapped area, Theodosis (1956) reported that beds of the late Early and early Late Cretaceous Colorado and Montana Groups are conformable, and he mapped them as one unit, the Colorado Group. Robinson (1963) reported that the Cretaceous Kootenai Formation is succeeded with probable, but not pronounced, angular unconformity by the Late Cretaceous Elkhorn Mountain Volcanics in the Threeforks area, Montana. After reviewing the literature concerning the surrounding areas, the author concludes that there seems to be no way of explaining a pronounced angular unconformity in post-Kootenai Cretaceous sedimentary rocks.

Careful examination of the beds reveals no evidence of folding. The conglomerate bed at the base of Member 3 of the Colorado Group provides a distinct lithologic marker bed that can be traced throughout the thesis area. Beds on the east side of the line of pronounced change in dip could not be traced into the steeply dipping beds on the west side.

Minor Faults. Many small faults in the mapped area were produced during the main episode of deformation and emplacement of the batholith. The faults strike either nearly parallel, diagonal, or perpendicular to the bedding. The diagonal faults have relatively small stratigraphic separations, commonly on the order of about 50 feet. Most of the minor faults are steeply dipping normal faults. Several small faults are nearly perpendicular to the margin of the Mount Torrey Batholith and are probably a result of the forcible intrusion of the pluton. The faults have small displacements, similar to those on the north side of Rock Creek Canyon.

GEOMORPHOLOGY

The landforms in the map area have developed subsequent to the Laramide Orogeny and the emplacement of the Mount Torrey Batholith. Running water and glaciers are the dominant geomorphic agents that have produced the present topography of the Rock Creek area. Degradational processes clearly operating here are weathering, mass-wasting, and stream erosion. Aggradational processes include deposition by glaciers, running water, and the extrusion of lavas.

Stratigraphic and Structural Control of Topography

The landforms in the map area are related to the nature of the stratigraphic units. Structure also influences the topography.

The western half of the thesis area is characterized by tree-covered mountains, three of which are peaks 9, 000 feet or more in elevation, which are underlain by plutonic intrusive rocks and late Paleozoic and early Mesozoic metamorphosed sedimentary rocks. The eastern half is characterized by grass- and sagebrush-covered hills, underlain mostly by late Mesozoic sedimentary rocks.

In the western and central parts of the area is a northeast-dipping, northwest-trending, homoclinal sequence of Paleozoic and Mesozoic strata. In this thick sequence, sandstones and conglomerates form resistant hogbacks, and siltstones and shales form strike valleys and gentle slopes.

In the western half of the thesis area, resistant rocks, dominantly Quadrant quartzites, have formed cliffs along steep canyon walls. Weathering aided by mass-wasting has produced great accumulations of talus that cover the underlying bedrock along the canyon walls. In the northwestern corner of the area, resistant sandstones form the crest of Storm Peak, and shales and fine-grained clastics form the antidip slope on the west side of the peak.

In the eastern half of the area, Cretaceous sedimentary rocks have low dip angles, and low east-dipping cuestas and a gentle rolling topography are formed. The low-dipping beds do not stand out in relief as do the steeply dipping beds of Cretaceous rocks in the central part of the area.

Stream Erosion

A radial drainage is well-developed around the core of the Pioneer Mountains. Major streams in the Rock Creek area drain the east side of these mountains and are part of this radial drainage pattern.

The canyons along which the major streams flow are bounded by steep cliffs. The valley floors are narrow, except the upper part of Rock Creek Canyon, which has been widened by glaciation. Small waterfalls, rapids and narrow valley floors indicate that the streams in the thesis area are still in a relatively youthful stage of the fluvial cycle.

Following the accumulation of the basin deposits in early Tertiary time, the region was gently uplifted in the late Miocene or early Pliocene (Fields and Petkewich, 1967; Perry, 1962). The major streams developed as east-flowing consequent streams. The streams probably continued down-cutting as the regional uplift was occurring in mid to late Tertiary time and were soon superposed across the tilted strata. The streams maintained their superposed positions and now flow at nearly right angles to the strike of the beds.

A floodplain, along the extreme eastern edge of the thesis area, has been developed by the Big Hole River, which lies approximately one mile east of the mapped area. The Big Hole River Valley, with meanders and meander scars, shows characteristics of an early mature stage of the erosion cycle.

Glacial Features

Glacial features are common in the core of the Pioneer Mountains west of the mapped area. In the thesis area features related to processes of glaciation are limited to Rock Creek Canyon. Rock Creek occupies a U-shaped valley formed by the scouring of valley glaciers that advanced into the area from the west (Figure 10). Rock

Figure 10. View to the west along Rock Creek Canyon. Note U-shaped, glaciated canyon. Granite Mountain is in central and right background, and Lake Agnes in the foreground. Cliff-forming contact metamorphosed Amsden rocks exposed along the north canyon wall.

Creek Canyon loses its characteristic U-shape about one mile west of the Beaverhead National Forest Boundary.

Lateral moraine and terminal moraine deposits are preserved along Rock Creek Canyon. Lateral moraine on the walls of the canyon in secs. 3 and 4, T. 4 S., R. 10 W. and sec. 33, T. 3 S., R. 10 W. reaches elevations up to about 7,600 feet. The morainal deposits at the end of Browns Lake in secs. 34 and 35, T. 3 S., R. 10 W. may represent a terminal deposit of the last stage of glacial advance. Another low terminal deposit left by a valley glacier occurs about one mile west of the Beaverhead National Forest Boundary in secs. 35 and 36, T. 3 S., R. 10 W. Alden (1953) has suggested two glacial advances in Rock Creek Canyon: the first glacial advance pre-Wisconsin, and the second advance of the Wisconsin Stage. According to Alden, the terminal deposit near Browns Lake represents the Wisconsin Stage. Later workers in southwestern Montana, Hall (1960) and Witkind (1969), have recognized more than two stages of glaciation. Four stages of glaciation have been recognized in the Madison and Gallatin Ranges by Hall. Witkind recognized three separate episodes of glaciation in the Tepee Creek Quadrangle in the southern end of the Madison and Gallatin Ranges. The oldest glacial deposit recognized by Witkind was assigned to pre-Bull Lake age, of probable pre-Wisconsin, or possibly Illinoian age. The second glacial deposit Witkind assigned to Blackwelder's (1915) Bull Lake Stage, or to

Richmond's (1960) Bull Lake Glaciation of early Wisconsin age, or a time prior to the Wisconsin Stage. The last episode of glaciation he dated as late Wisconsin and assigned to Blackwelder's (1915) Pinedale Stage or to Richmond's (1960) Pinedale Glaciation. Because of a limited time in the field the author did not recognize any correlation between Witkind's three episodes of glaciation and the glacial deposits in the Rock Creek area but thinks the last glacial deposit is probably Wisconsin in age.

GEOLOGIC HISTORY

Although Precambrian and early Paleozoic rocks do not crop out in the thesis area, a short summary of their history may be inferred from work done in southwestern Montana by Sloss (1950), Sloss and Moritz (1951), and Alpha (1958).

The tectonic framework that provided the setting for Paleozoic and Mesozoic deposition was inherited from the pre-Paleozoic (Sloss, 1950). Evidence from the early Precambrian metasediments indicates that there were deep basins containing thousands of feet of sediments, orogenic compression and folding, and igneous activity followed by epeirogenic movement that exposed the area to truncation (Alpha, 1958). In late Precambrain time, there were shallow water deposits of clastics derived from the craton to the east; these accumulated in a shallow water trough of continued subsidence in western Montana (Belt Series). Epeirogenic uplift and truncation in late Precambrian and Early Cambrian time developed two tectonic provinces and a connecting hinge area, which persisted throughout the Paleozoic and most of the Mesozoic. In western Montana and Idaho a geosyncline persisted, which varied through time in size, shape and depth.

During Middle and Late Cambrian time, sediments were deposited unconformably on the Beltain rocks in the miogeosyncline.

Ordovician and Silurian strata have not been recognized in the vicinity of the mapped area, a result of pre-Middle Devonian uplift and erosion. During the Middle Devonian, southwestern Montana was submerged, and Devonian sediments were deposited. Seas withdrew near the close of Devonian time and readvanced in Early Mississippian time to deposit thick sequences of carbonate rock.

The discussion of the geologic history from Late Mississippian time to the present will be restricted to the rocks within the Rock Creek area.

Many of the clues to the geologic history of the late Paleozoic to early Mesozoic rocks in the area of investigation were destroyed during contact metamorphism. However, from late Paleozoic to early Mesozoic time, the area is assumed to have had a geologic history similar to that reported for southwestern Montana.

The known geologic record of the thesis area begins in Late Mississippian to Early Pennsylvanian time with the deposition of shales, siltstones, and limestones of the Amsden Formation. The lower clastic member of the Amsden Formation was deposited under shallow marine or beach conditions, and the upper carbonate member was probably deposited in the deeper parts of the neritic zone. A notable change in sedimentation followed during the Pennsylvanian Period, with the deposition of well-sorted, texturally and mineralogically mature quartz arenites of the Quadrant Formation, deposited in a shallow neritic or littoral environment. After the deposition of the Quadrant Formation, similar environmental conditions persisted into Permian time. During the time of a dominantly regressive shallow marine environment (Robinson, 1963), cherty and phosphatic sandstones, siltstones, and dolomitic limestones of the Phosphoria Formation were deposited. The phosphatic mudstones of the Phosphoria Formation probably were deposited below wave base in tranquil, oxygen-deficient waters.

The relatively stable shelf and miogeosynclinal conditions during the Paleozoic continued into Mesozoic time. According to Moritz (1951), the Early Triassic seas advanced from the south into southwestern Montana and deposited the siltstones, shales, and limestones of the Dinwoody Formation. The sediments were deposited under mildly unstable conditions, probably in littoral and neritic environments. Following the deposition of the Dinwoody Formation, seas withdrew from the map area. Rocks representing post-Dinwoody Triassic and all Jurassic time are missing in the area, indicating a long period of erosion and uplift during post-Dinwoody and pre-Kootenai time. During the Early Cretaceous, the area was above sea level, and continental clastic sediments and lacustrine limestones of the Kootenai Formation were deposited disconformably on Dinwoody beds. The basal conglomerate of the Kootenai Formation according to McMannis (1965) indicates a strong uplift in areas west of Montana. The conglomerate was probably deposited on large alluvial floodplains. Shales, sandstones, and conglomerates of the Colorado Group reflect dominantly fluvial and paralic environmental conditions. There were probably several advances and retreats of the sea during Late Cretaceous time. The volcanic debris in the rocks of the Colorado Group indicates a contemporaneous volcanic source area, possibly related to the emplacement of the Idaho Batholith and associated volcanic activity.

The deformation that drove the shallow Cretaceous sea from the area for the last time probably marked the beginning of the Laramide Orogeny, which produced the steeply tilted strata and many of the faults in the area. After deformation of the sedimentary rocks, the Mount Torrey Batholith was emplaced. The late Paleozoic and early Mesozoic rocks were contact metamorphosed to marbles, quartzites, and hornfelses by the intrusion.

In Oligocene and possibly Miocene time tuffaceous sediments and pyroclastic debris from distant volcanic sources, accompanied by lava flows, collected in the valleys. The flows may have succeeded in damming the valleys. In late Miocene time and continuing through the middle Pliocene, the region was gently uplifted (Fields and Petkewich, 1967). Alpine glaciers were active during late Pleistocene in the western part of the thesis area. Today, streams are actively eroding the area, and minor local alluvial deposits are forming along the creeks and valley floors.

ECONOMIC GEOLOGY

In the Rock Creek area several mines are situated along the eastern margin of the pluton between Lost Creek and Rock Creek. The mining district is known as the Lost Creek or Browns Lake mining district (Pattee, 1960). There are four inactive tungsten mines in the district.

Tungsten was discovered in 1907 on Lost Creek and in 1942 on Rock Creek near Browns Lake. The Minerals Engineering Company constructed a mill in 1953 in secs. 4 and 5, T. 4 S., R. 9 W. to process ore from both the Lost Creek and Browns Lake areas. By 1957, when mining was discontinued, the district had produced about 646,300 tons of ore averaging 0.35 percent WO_3 (Pattee, 1960).

In the district, scheelite and powellite occur in tactite that was formed by the metamorphism of carbonate rock of the Amsden Formation. The largest tactite body is at the Browns Lake mine along the south wall of Rock Creek Canyon. A smaller deposit is on the north side of Twin Adams Mountain, where numerous cuts and adits have been placed in the metamorphosed Amsden sedimentary rocks.

Ore minerals, observed near the mines in the thesis area include malachite, azurite, chalcopyrite, specular hematite, magnetite, and chrysocolla. Gangue minerals are dominantly garnets, and smaller amounts of quartz, epidote, and calcite.

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