



Geology of a part of the north end of the Gallatin Range, Gallatin County, Montana  
by Russell Gene Tysdal

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of  
MASTER OF SCIENCE IN APPLIED SCIENCE With a Major in Geology  
Montana State University  
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Abstract:

In a 50-square mile area at the north end of the Gallatin Range, Gallatin County, Montana, about 4, 000 feet of sedimentary strata, ranging in age from Cambrian to Recent, is exposed. Rocks-of the Paleozoic and Mesozoic systems comprise a sedimentary sequence that does not exceed 3, 200 feet in thickness, which is uncommonly thin when compared to equivalent sequences in neighboring areas.

The map area was apparently one of slower subsidence, and deposition of sediments proceeded less continuously or at a slower rate. Ordovician, Silurian, Permian, Triassic, and Upper Cretaceous strata are absent. Trilobites of the genus *Glossopleura* were found in the Cambrian Flathead Quartzite and are the only known trilobites from the formation. Eocene volcanic rock overlies a major part of the sequence, whereas Precambrian metamorphic rock underlies the entire sequence.

Analysis of the structural features of the map area and the adjoining region indicates that deformation could have resulted from an east-northeast compressive stress applied during the Laramide orogeny. The major northwest-trending fault in the map area is the South Cottonwood Creek fault, a reverse fault with greater than 4,000 feet of throw. Sufficient evidence is presented to prove the existence of the Gallatin Range front fault, a post-Laramide normal fault truncating the range on the north.

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RANGE, GALLATIN COUNTY, MONTANA

by

RUSSELL GENE TYSDAL

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MASTER OF SCIENCE IN APPLIED SCIENCE

With a Major in Geology

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R. G. T.

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## ABSTRACT

In a 50-square mile area at the north end of the Gallatin Range, Gallatin County, Montana, about 4,000 feet of sedimentary strata, ranging in age from Cambrian to Recent, is exposed. Rocks of the Paleozoic and Mesozoic systems comprise a sedimentary sequence that does not exceed 3,200 feet in thickness, which is uncommonly thin when compared to equivalent sequences in neighboring areas. The map area was apparently one of slower subsidence, and deposition of sediments proceeded less continuously or at a slower rate. Ordovician, Silurian, Permian, Triassic, and Upper Cretaceous strata are absent. Trilobites of the genus Glossopleura were found in the Cambrian Flathead Quartzite and are the only known trilobites from the formation. Eocene volcanic rock overlies a major part of the sequence, whereas Precambrian metamorphic rock underlies the entire sequence.

Analysis of the structural features of the map area and the adjoining region indicates that deformation could have resulted from an east-northeast compressive stress applied during the Laramide orogeny. The major northwest-trending fault in the map area is the South Cottonwood Creek fault, a reverse fault with greater than 4,000 feet of throw. Sufficient evidence is presented to prove the existence of the Gallatin Range front fault, a post-Laramide normal fault truncating the range on the north.

# GEOLOGY OF A PART OF THE NORTH END OF THE GALLATIN RANGE, GALLATIN COUNTY, MONTANA

## INTRODUCTION

### Previous Investigations

The first geologic mapping in this and contiguous areas was by Peale in 1889, the results of which were published in 1896. His study of the Three Forks one-degree quadrangle was of a reconnaissance nature. Hackett and others (1960) mapped and briefly described the basin deposits of the adjacent Gallatin Valley. M. D. Mifflin (1963, Unpub. M. S. Thesis, Montana State Univ., Bozeman) and Robinson (1961) have also described some of the same basin deposits. Davis, Kinoshita, and Robinson (1965) published gravity and aeromagnetic data which contains pertinent structural data for the included part of the Gallatin Valley. W. M. Weber (1965, Unpub. M. S. Thesis, Montana State Univ., Bozeman) mapped the Middle Creek area just east of the margin of the present writer's map area. Unpublished data has been made available by W. J. McMannis which has aided materially in the interpretation of relationships, both within the map area and in nearby areas.

### Location

The Gallatin Range, of which the map area is a part, lies within the southeastern part of the Northern Rocky Mountain physiographic province of Fenneman (1931). The map area encompasses approximately

55 square miles in the northern part of the Gallatin Range and foothills at the front of the range, the Bozeman quadrangle between the  $111^{\circ}01'$  and  $111^{\circ}14'$  meridians and the  $45^{\circ}30'$  and  $45^{\circ}35'$  parallels. The small town of Gallatin Gateway lies approximately one mile north of the northwestern corner of the map area, and the town of Bozeman is approximately seven miles north of the northeast corner of the map area.

### Topography

Elevation of the land ranges from 5,000 feet at the northwest margin to greater than 8,600 feet atop Wheeler Mountain in the southeast. Three-fourths of the area consists of rugged, heavily forested terrain with local relief commonly varying between 1,500 feet and 2,200 feet. The best rock exposures are generally found elsewhere than on the northeast sides of mountains; this side is usually very heavily forested with small (2 inch diameter) evergreens and brush, and has a thick soil mantle. At the range front the area consists of gently inclined surfaces interrupted by stream incised valleys.

### Climate

As is typical of higher elevations in the Rocky Mountains, daily and seasonal fluctuations of temperature range widely. Midday temperatures during the summer months average between  $70^{\circ}$  F and  $80^{\circ}$  F, with occasional extremes in the nineties. Winter daytime temperatures are generally near or below freezing, and periods of below

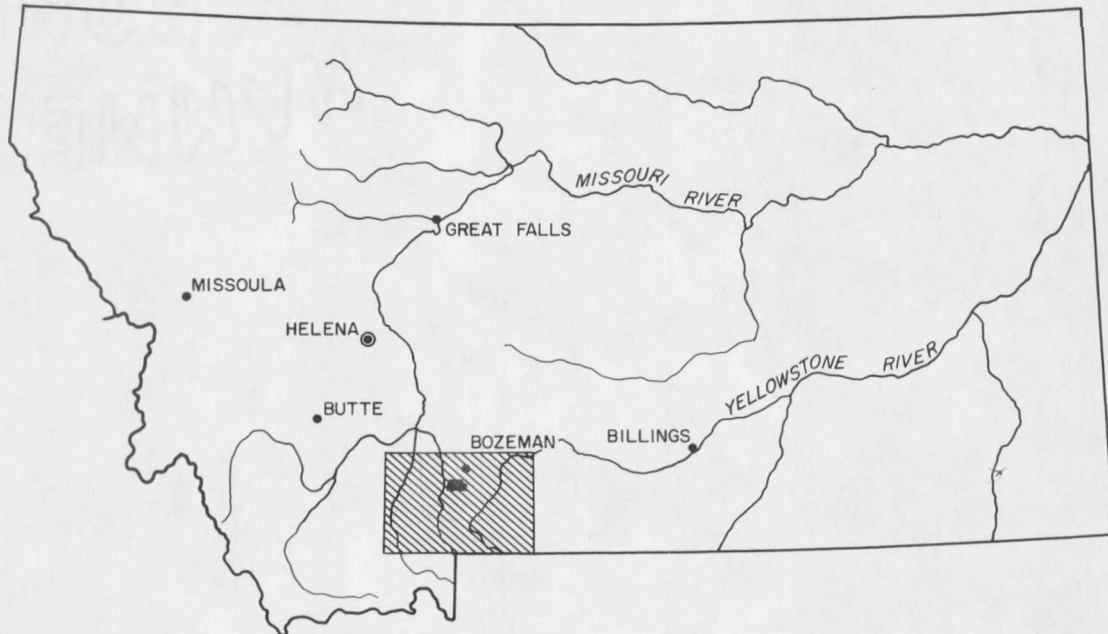
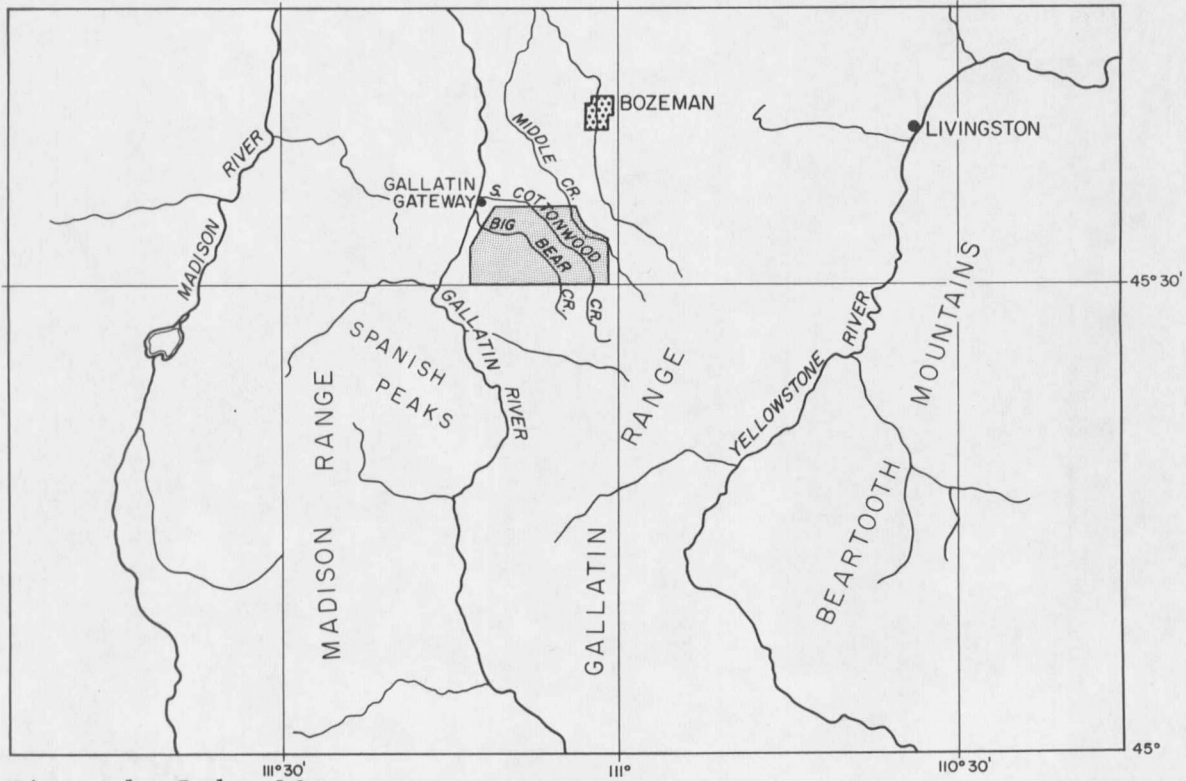


Figure 1 - Index Map

zero temperatures are common in January and February. Rare extreme wintertime temperatures may go as low as  $-50^{\circ}\text{F}$ . Snow depths in the higher portions of the map area may average as much as 50 inches during the middle winter and early part of spring. The average annual precipitation varies from 20 inches in the lower part of the map area to about 30 inches at the higher elevations. Geologic field work is feasible from May through October at lower elevations and June through September at the higher elevations.

The above climatological data is based on annual summaries contained in the U. S. Weather Bureau's publication, Climatological Data.

#### Land Economies

The mountainous regions of the map area is owned partly by the Northern Pacific Railroad and partly by the federal government. The region is heavily timbered, and the main enterprise is tree harvesting by independent logging concerns. During the summer and early fall, high open areas are used as grazing land for beef cattle. The lower reaches of the map area--the foothills--are privately owned and are dominantly used as pasture. The remainder of the land is used for dryland and/or irrigated grain production, alfalfa or other hay crops.

#### Access

Numerous roads permit year around access by car to the foothills at the front of the range. Two roads penetrate the mountainous area;

one leads up Middle Creek, the other up Big Bear Creek. Numerous logging roads branch from these two roads, permitting vehicular access to some of the higher elevations of the map area. A four-wheel drive vehicle provides the best conveyance on these roads, although a conventional pickup will suffice if the roads are dry. By far the greatest part of the area is accessible only on foot or on horseback.

### Objectives

The objectives of this study were to construct a geologic map of the bedrock within the mountainous part of the map area, and of the surficial deposits at the front of the range; to describe the rock units and structural relationships encountered in compiling the geologic map; and to describe the geologic events that have lead to the observed relationships.

## STRATIGRAPHY

### Precambrian

#### Metamorphic Rocks

Precambrian metamorphic rocks are extensively exposed in the southwestern and northeastern parts of the map area, and to a lesser extent in the south-central part of the map area. Gneiss, amphibolite, schist, and metaquartzite--in that order of abundance--make up the metamorphic complex. Layering is well developed and generally strikes N45-70E and dips 50-75S, with variation in dip occurring especially where the rocks are associated with faulting; foliation is parallel to layering. Resistant outcrops are generally scattered, with deeply weathered surface exposures occurring inbetween. Locally, deeply weathered metamorphic rocks are directly overlain by the Flathead Quartzite, suggesting that part of the weathering occurred prior to deposition of the overlying sedimentary sequence.

Most of the metamorphic rocks of the map area consist of alternating bands of medium-gray gneiss, pink gneiss, and amphibolite. The bands commonly grade into one another and range in thickness from a few feet to more than 100 feet. The medium-gray gneiss is the most common of the three types and is medium-grained; compositionally it consists of quartz (40-50%), microcline (15-30%), biotite (10-15%), and muscovite (5-10%). The biotite is dominantly brown and is present both as individual flakes and in minute books; much of the

feldspar is altered to sericite. The pink gneiss is medium- to coarse-grained and consists of quartz (20-35%), microcline (25-40%), oligoclase (25-35%); and biotite (5-10%). Much of the oligoclase is untwined; it and the microcline are easily mistaken for orthoclase megascopically. The amphibolite is dark, medium- to coarse-grained, gneissic, and rarely schistose. It consists of hornblende, plagioclase, quartz, biotite, and rarely garnet, in that order of abundance; hornblende is by far the most common mineral, but the percentages of all constituents vary so greatly that an average composition would be misleading. The hornblende is black and commonly occurs as stubby prisms. Feldspar grains are generally clear, but some are thoroughly saussuritized. The quartz is clear and forms only a minor percentage of the rock, as does the biotite which occurs as gold-brown flakes. Garnet amphibolite is not common in the map area, and where present the garnets are poorly developed. At one locality a nearly 100% black-green hornblende amphibolite may represent an intrusive body metamorphosed after emplacement.

Metamorphic rocks exposed along the Hyalite Canyon road differ from the above mentioned types in that they are apparently more intensely deformed--ptygmatic folding is very common. The predominant rock type is similar to the previously mentioned medium-gray gneiss except that oligoclase is present and garnets occur locally; sericitization of the feldspars is less common. The folia are generally steeply dipping; some folia dip steeply to the northwest as opposed to the

general southeast dip of the metamorphic rocks in the rest of the map area. The dip reversals may be due to faulting, some of which may have occurred in Precambrian time.

It is commonly believed that the rocks were originally a thick sedimentary sequence that was metamorphosed and intruded by igneous magmas, and subsequently underwent additional phases of metamorphism (e. g., see Reid, 1957, 1963; M. D. Mifflin, 1963, Unpub. M.S. Thesis, Mont. State Univ., Bozeman). In the Tobacco Root Mountains west of the map area, detailed study of the metamorphic complex by Reid (1963) indicates that the rocks have undergone three major metamorphic episodes and two stages of retrograde metamorphism. The metamorphic rocks present in the map area and adjacent areas support Reid's (1963) interpretation of several phases of metamorphism, as they include minerals and rock types characteristic of low to high grade metamorphism. An example of low grade metamorphic rock occurs immediately to the south of the map area in the NW 1/4 sec. 14, T. 4S., R. 4E., (Garnet Mountain quadrangle) where an actinolite schist is present. The gneiss of the map area (previously described) is of medium to high grade. Approximately 6 miles northwest of the map area high grade metamorphic rocks are represented by corundum bearing schists.

The metamorphic rocks of the map area are pre-Belt in age and are similar to those termed Pony metamorphics in nearby areas (as opposed to Cherry Creek metamorphics). Recent work by Reid (1957; 1963) indicates that the Pony (younger) and Cherry Creek (older)

metamorphics are part of the same depositional sequence and, therefore, the unconformity that has been said to lie between the two (see Peale, 1896; Tansley, Schafer, and Hart, 1933) apparently does not exist. Consequently, it is the recommendation of the Stratigraphic and Nomenclature Committee of the Billings Geological Society that the Precambrian metamorphic rocks be termed "pre-Belt" and thus discontinue use of the terms Pony and Cherry Creek, except in the type localities of those units (W. J. McMannis, personal communication, 1965).

Giletti (unpublished manuscript) has recently summarized preliminary work of radiogenic age dating in southwestern Montana. His data indicate that a major phase of regional metamorphism occurred about 1600 m. y. ago, and that the southeast margin of this metamorphism is located along a northeast-southwest trending "line" crossing the Gravelly Range and the Gallatin River Canyon. Southeast of this line the rocks may be 3200 m. y. old or older. He tentatively suggests that some of the rocks in the 1600 m. y. terrane are considerably older than 1600 m. y., but were remetamorphosed 1600 m. y. ago.

Radiogenic age determinations have not been made on any of the rocks of the map area, but Giletti (unpublished manuscript) has dated some samples from nearby areas. Approximately 10 miles northwest of the map area, in the Anceney quadrangle (sec. 23, T. 2S., R. 2 E.), a biotite schist was dated as 1550 m. y. old. South of the map area, in the Garnet Mountain quadrangle, the following dates were obtained:

1690 m. y. (Granitic gneiss; sec. 15, T. 5S., R. 4E.), 1790 m. y. (psammitic gneiss; sec. 36, T. 5 S., R. 4 E.), and 3220 m. y. and 3270 m. y. (granitic gneiss; sec. 13, T. 6 S., R. 4 E.). The localities occur approximately 7, 10, and 13 miles, respectively, south of the map area. The southeast margin of the 1600 m. y. ago metamorphism apparently lies between 10 and 13 miles south of the map area.

### Belt Supergroup

Rocks of the Belt Supergroup are not present in the map area; the nearest occurrence of Belt strata is immediately north of an east-west trending line which transects the central part of the Bridger Range on the east and the Highland Mountains on the west. The line is believed to be a fault zone that was active in Precambrian Belt time, permitting a thick sequence of very coarse arkosic Belt sediments to accumulate on the north side (McMannis, 1963).

## Cambrian

### Flathead Quartzite

The Flathead Quartzite of the map area is fairly consistent in thickness (40-75 feet) and unconformably overlies Precambrian metamorphic rock with marked angular discordance. The formation consists of maroon, tan, brown, pink, and white medium- to thick-bedded and massive cross-bedded quartz sandstone. Locally present is a cream and dull brick red mottled quartz sandstone, the mottling being

independent of bedding planes. The sand grains vary in size from medium to coarse and are subangular to angular. Locally present at the Flathead-Precambrian contact is (1) a conglomerate consisting of well rounded white vitreous quartz cobbles in a matrix of coarse-grained quartz sandstone, and (2) arkosic material that is in places difficult to differentiate from the underlying deeply weathered Precambrian metamorphic rock. Near the top of the formation the sandstone commonly contains glauconite and greenish-gray micaceous shale. The Flathead is gradational with the overlying Wolsey Shale and the contact is therefore arbitrary; the author chose the base of the first prominent shale zone as the contact. This boundary is in agreement with that of Deiss (1936) who emended the definition and type section of the formation. The Flathead is generally poorly indurated, but seems to be better indurated where the formation is thicker; the term sandstone is more appropriate than quartzite for the formation in the map area.

The Flathead is a basal, slightly transgressive sandstone of the Cambrian sequence, being older in the west than in the east. Because of the almost total absence of fossils in the Flathead, the age of the formation has been inferred from the (conformable) superjacent Wolsey Shale. This procedure suggests that the Flathead was deposited during the early Middle Cambrian--Albertella zone time--(Lochman, Balk, 1956, p. 616; Lochman, 1957, p. 132). However, in a surficial deposit in the SW 1/4 SE 1/4 sec. 26, T. 3 S., R. 4 E., the writer found trilobites of the genus Glossopleura which are definitely from the Flathead (the fossils were identified by

A. R. Palmer, U. S. Geological Survey, Washington, D. C.), indicating that the formation in the map area is slightly younger than previously believed. It is definitely younger than the Flathead in the western part of the state where the Albertella faunal elements occur in shale beds well up in the overlying Wolsey equivalent (Silver Hill Formation), and the Glossopleura zone there is in the upper part of the same formation (see fig. 2). Approximately 35 miles northwest of the map area the Glossopleura fauna occurs in the lower part of the Wolsey (A. R. Palmer, 1965, written communication to W. J. McMannis).

#### Wolsey Shale

The Wolsey Shale rests conformably on the Flathead Quartzite and is clearly transitional between the latter and the overlying Meagher Limestone. The Wolsey ranges from 40 feet to 195 feet in thickness, increasing toward the south. The 195 foot thickness is high when compared to the common range of 40 feet to 80 feet in the map area and may represent deposition on a irregular Middle Cambrian sea floor; the Wolsey is thicker where the Flathead is thicker. Commonly, the formation is poorly exposed and forms grass covered slopes.

The basal part of the Wolsey consists of gray-green soft fissile micaceous shale interstratified with reddish-brown fine- to medium-grained thin-bedded and cross-bedded glauconitic quartz sandstone. Locally the sandstone of the basal part is medium- and thick-bedded and of the type found in the Flathead. The upper part (3/4) of the formation contains chocolate brown to green fissile micaceous shale,

W.

E.

Philipsburg  
Area

Logan  
Area

Map  
Area

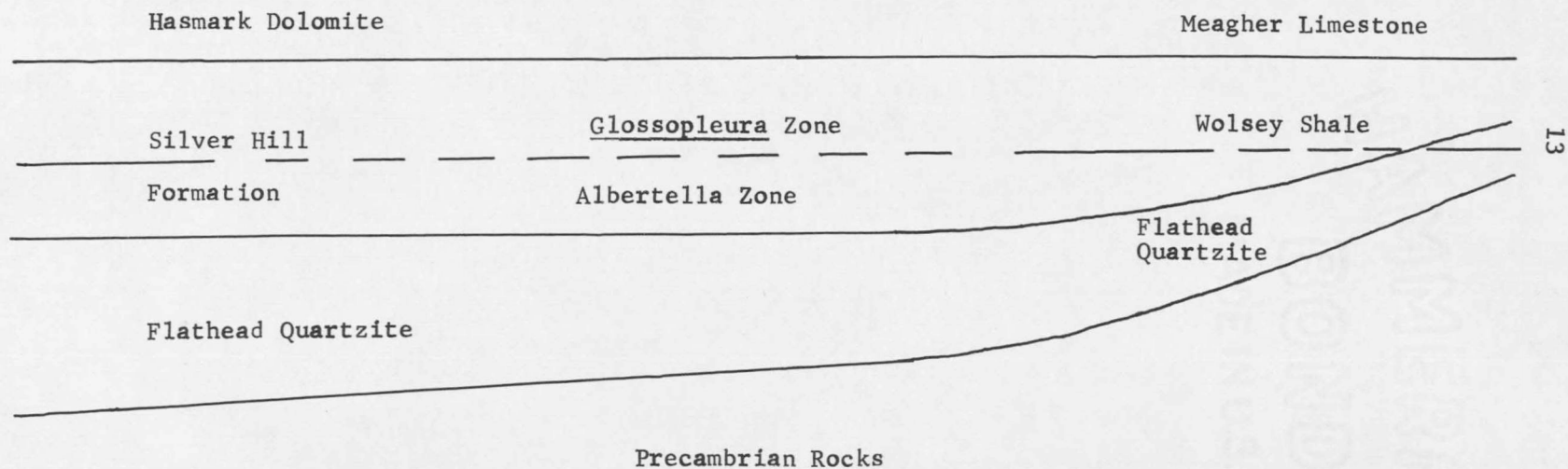


Figure 2. Cross-section showing position of Albertella zone--Glossopleura zone boundary in the Cambrian strata of western Montana.

with sparingly interstratified brown fine-grained quartz sandstone. Worm trails and casts are common on the shale and sandstone. In the uppermost part of this unit the sandstone becomes more common. Gray-green thin-bedded and nodular limestone also occurs in the uppermost part, some of which contains fossil fragments. According to Lebauer (1964) much of the green color of the Wolsey is due to the presence of illite and not chlorite as many workers had thought.

The age of the Wolsey is early Middle Cambrian, containing the Zacanthoides-Glossopleura-Kootenia zones. The formation is transgressive eastward, with the oldest deposits being in westernmost Montana (Hanson, 1960, p. 208-209).

#### Meagher Limestone

The Meagher Limestone is the most prominent formation in the map area, exhibiting a persistent ledge forming unit between two non-resistant shaly limestone units. The formation ranges from about 300 feet to 340 feet in thickness, and is gradational with the subjacent Wolsey Shale and the superjacent Park Shale.

The lower unit (75-100 feet) consists of a basal gray to yellow rubbly limestone interbedded with olive green fissile micaceous shale; locally present is a glauconitic limestone pebble conglomerate. Comprising the remainder of the lower unit is light-gray to tan thin and irregularly bedded dense limestone and interbedded yellow-gray calcareous shale. The lower unit is poorly exposed and commonly covered.

The middle unit (150 feet) consists of medium-gray to brown thin and irregularly bedded dense limestone (locally fetid), with thin irregular yellow or orange shaly or silty calcareous partings that produce a characteristic gray or brown and orange mottling (Hanson, 1952, p. 14). The yellow and orange color of the mottles is due to the presence of limonite (Lebauer, 1965, p. 430). An analysis of the light (yellow and orange mottles) and dark colored portions for samples of the Meagher from the Limestone Hills (north of the map area) was reported by Ruppel (1950, p. 18); the analysis was made by Hartzell (then at the Montana College of Mineral Science and Technology, Butte). The results are as follows:

Segregate of light-colored portion

|                                  |              |
|----------------------------------|--------------|
| Insoluble (S: O <sub>2</sub> ?)  | 14.00        |
| Iron and alumina                 | 3.30         |
| CaO (31.00) as CaCO <sub>3</sub> | 55.34        |
| MgO (12.20) as MgCO <sub>3</sub> | <u>25.50</u> |
|                                  | 98.14 %      |

Segregate of dark-colored portion

|                                 |             |
|---------------------------------|-------------|
| S:O <sub>2</sub>                | 4.75        |
| Iron and alumina                | 2.18        |
| CaO (50.5) as CaCO <sub>3</sub> | 90.14       |
| MgO (1.25) as MgCO <sub>3</sub> | <u>2.60</u> |
|                                 | 99.67 %     |

Locally the middle unit is massively bedded and consists of blue gray weathering dense limestone. Very thin discontinuous brown chert stringers sporadically occur at what are obviously former bedding planes. The unit forms prominent ledges throughout the map area.

The upper 75-90 feet consists of non-resistant yellow to gray thin-bedded and locally nodular fine-grained limestone, with abundant yellow silty partings. The unit is very poorly exposed in the map area and occurs as a grass covered slope.

The Meagher Limestone is of middle Middle Cambrian age--containing the Bathyuriscus-Elrathina zone (Lochman-Balk, 1956; p. 617).

#### Park Shale

The Park Shale ranges from 40 feet to 70 feet thick in the map area, generally thickening southward. The formation is poorly exposed and forms gently inclined grassy slopes. The Park consists of green-gray and purple-brown finely micaceous fissile shale interbedded with tan to brown thin beds of calcareous quartz sandstone. Locally, worm casts are present on the sandstone. The formation conformably overlies the Meagher and conformably underlies the Pilgrim. It is distinguished from the Wolsey Shale by the size of the mica flakes--coarse-grained in the Wolsey, fine-grained in the Park.

The Park is of late Middle Cambrian age (Lochman-Balk, 1956, p. 617). The Park-Pilgrim contact is generally considered to coincide with the Middle Cambrian-Late Cambrian time boundary in this part of Montana.

### Pilgrim Limestone

The Pilgrim Limestone conformably overlies the Park Shale and ranges from 245 feet to 286 feet thick. The formation is divisible into two major units: a lower slope-forming unit that is generally poorly exposed, and an upper massive ledge-forming unit.

The lower unit consists of light-gray to buff and pink medium- to thick-bedded locally oolitic and/or glauconitic fossil fragmental limestone and limestone pebble (flat and edgewise) conglomerate, with interbedded green calcareous shale. The limestone pebbles are of the flat type, are well rounded and fine-grained, whereas the limestone matrix is medium- to coarse-grained and locally saccharoidal. This unit is dolomitic in the upper part.

The upper unit is dark brown and tan-gray mottled thick- and massive-bedded ledge forming medium-grained oolitic dolomitic limestone. The tan-gray mottles are roughly oriented parallel to the bedding and are dolomitic whereas the dark brown areas are limestone or slightly dolomitic limestone. McMannis (1955, p. 1395) and Brown (1959, p. 260) state that the mottling is a product of partial dolomitization of a pre-existing oolitic limestone; McMannis and Chadwick (1964, p. 8) note evidence for a second phase of dolomitization of the unit in parts of the Garnet Mountain quadrangle (adjoining the map area to the south). The upper few feet of the unit contains a light-gray and yellow mottled thin-bedded brittle limestone identical to the Meagher type.

The Pilgrim is of late Cambrian age (Dresbachian) and contains the Cedaria, Crepicephalus, and Aphelaspis faunal zones (Lochman-Balk, 1956, p. 617).

#### Red Lion Formation

The Red Lion Formation conformably overlies the Pilgrim Limestone and is the youngest formation of the Upper Cambrian sequence present in the map area. The Red Lion is a bipartite formation, consisting of a lower shaly member--the Dry Creek Shale--and an upper unnamed limestone member. The Dry Creek Shale Member is the lithic and age equivalent of the Dry Creek Shale Member of the Snowy Range Formation; the limestone member is the age--but not the lithic--equivalent of the Sage Pebble Conglomerate Member of the Snowy Range. The name Red Lion is used here because the limestone member described herein more closely resembles the lithology of the Red Lion than that of the Snowy Range.

The Dry Creek thickens from 6 feet near Langohr Nob<sup>1</sup> to 20 feet on Wheeler Mountain, whereas for the same two locations the limestone member increases from 70 feet to 95 feet, respectively.

The Dry Creek Shale Member is a poorly exposed unit; it consists of olive green very finely micaceous fissile shale, interstratified with

---

<sup>1</sup>Named herein for the prominent topographic high in the SE 1/4 sec. 36, T. 3 S., R. 5 E.

orange and yellow stained brown dense siltstone. Some of the siltstone is shaly and contains abundant fine grained mica flakes. A thin limestone pebble conglomerate bed is generally present at the base of the Dry Creek and several beds also occur at the top of the member. The latter conglomeratic unit is 10 feet thick where measured on Wheeler Mountain and is of the edgewise or flat-pebble type. The limestone pebbles are dense subrounded to rounded pea green, tan, white, and yellow and occur in beds exhibiting wavy surfaces.

At the base of the unnamed upper limestone member is a dark gray weathering massive biostromal columnar limestone, composed of the calcareous algae Collenia magna Fenton and Fenton. Overlying this basal unit is 2 to 25 feet of gray and tan fine to coarse-grained thin- and medium-bedded limestone and fossil hash beds and limestone pebble conglomerate of the type that occurs at the top of the Dry Creek. Sparingly present is intercalated olive green fissile shale. The remainder of the member consists of medium- and thick-bedded and massive green-brown limestone which becomes thin-bedded and dolomitic in the upper part. The limestone beds are separated by yellow and orange silty and/or calcareous shaly laminae that commonly contain fossil debris. In the massive beds these laminae occur as thin dolomitic stringers and stand out on weathered surfaces. Chert lenses and stringers are also common in the upper part of the massive beds and locally irregular chert masses are present. The dolomite of this member is light brown and medium-grained or saccharoidal. McMannis and Chadwick (1964, p. 8)

state that the silicification and dolomitization of the Red Lion, as well as the second phase of dolomitization of the Pilgrim, are believed to be the result of alteration during exposure prior to Devonian deposition.

According to Dorf and Lochman (1940, p. 547) the Snowy Range Formation--the Red Lion equivalent--appears to be the exact time equivalent of the Franconia Formation of Wisconsin. Lochman (1950, p. 2213) states that the basal columnar limestone of the Snowy Range (Red Lion) contains the Elvinia zone of the standard Cambrian section.

#### Grove Creek Limestone

In 1940 Dorf and Lochman first described the Grove Creek limestone and gave it formational status. Lochman-Balk (1956) reduced the unit to member status, considering it the youngest member of the Snowy Range Formation. It apparently has no equivalent in the Red Lion. The Grove Creek Limestone is not present in the map area but a thin tongue of it was mapped by Roberts (1964) in the Mystic Lake quadrangle 1 1/2 miles to the east. W. M. Weber (1965, Unpublished M.S. Thesis, Mont. State Univ., Bozeman) could find no trace of it in the intervening area, but the outcrops in this area are so poor that no definite conclusion was reached concerning its distribution. The thickest known outcrop of Grove Creek is only 50 feet and according to Lochman-Balk (1956, p. 612) remnants of the formation are found only "east of a line running from the Gallatin Range southeast... to Wind River Canyon in the Bridger Mountains of Wyoming." That imaginary line apparently trends up Hyalite Canyon;

the Grove Creek was most likely removed from the map area by post-Cambrian, pre-Late Ordovician erosion.

### Ordovician

#### Big Horn Dolomite

The Big Horn Dolomite (Late Ordovician) is not present in the map area but was mapped by Roberts (1964) in the Mystic Lake quadrangle  $2\frac{1}{2}$  miles to the east. According to his map the formation is only about 20 feet thick, no strata of which were found by W. M. Weber (1965, Unpub. M.S. Thesis, Mont. State Univ., Bozeman) in the intervening area. A feather edge of the formation has also been reported in the Madison Range to the southwest (Sloss and Moritz, 1951). At the above two areas where the formation crops out, it is described as "massive dolomite". These same two areas mark the westernmost appearance of the formation as depicted on the isopach maps of Sloss (1950) and Richards and Neischmidt (1957). The presence of the formation in nearby areas, the lack of clastics that might suggest shoreline conditions for rocks at the present edge of the formation, and the extensive length of time the formation was exposed to erosion (at least the Silurian Period), suggest that the Big Horn was removed from the map area by erosion.

### Silurian

Silurian strata have not been found in western Montana; the region was apparently a land surface undergoing erosion. Indeed, the only known

Silurian strata in Montana occur in the northeastern part of the state in the subsurface of the Williston Basin. Sloss and Moritz (1951) note that the Silurian is well represented in the Lemhi Range, west of the Idaho-Montana border, but these beds thin and are truncated southwest of the border.

### Devonian

#### Beartooth Butte and Maywood Formations

Neither the Beartooth Butte Formation (Early Devonian) nor the Maywood Formation (early Late Devonian) was found in the map area. The Beartooth Butte consists of "discontinuous estuarine and fluvial channel-fill deposits, sinkhole fillings, and regoliths" (Sandberg, 1961, p. 1301). The formation occurs at scattered localities in the Beartooth Range and possibly at localities farther northwest, but is apparently absent from the Gallatin Range (McMannis, 1962). It is possible that the Beartooth Butte was deposited in the map area and subsequently removed by erosion; however, considering the channel-fill nature of the formation and its apparent absence from the entire Gallatin Range, it is more likely that the formation was never deposited in the map area. The Maywood consists of limestone, dolomite, and mudstone, and conformably underlies the Jefferson Limestone. The nearest outcrop of the formation is  $2\frac{1}{2}$  miles south of the southwest corner of the map area, where it was "deposited in marginal-marine brackish or fresh waters, whereas at most known

locations deposition was in shallow, open, or slightly restricted marine waters" (Sandberg and McMannis, 1964, p. C 50). The map area was apparently near a shoreline when the Maywood was deposited at the above location, and the absence of the formation suggests that the map area was still above sea level at that time.

### Jefferson Limestone

The Jefferson Limestone disconformably overlies the Red Lion with an irregular contact. The formation is 254 feet thick along Big Bear Creek, thinning slightly eastward to the Langohr Nob area where it is approximately 225 feet thick. Strata of the formation are divisible into two units: (1) a lower slope-forming unit, correlated with the Duperow Formation of the Williston Basin by Sandberg and Hammond (1958) and designated the "lower member" by Sandberg (1965, p. N5), and (2) an upper ledge-forming unit, correlated with the Birdbear Formation of the Williston Basin by Sandberg and Hammond (1958) and designated the "Birdbear Member" by Sandberg (1965, p. N7).

The lower member consists of dark brown to dark gray weathering medium brown to tan medium-bedded to massive fine- to medium-grained saccharoidal dolomite and dolomitic limestone. In the upper part of the lower member these strata are commonly coarse-grained, locally contain quartz sand, and are only moderately indurated. Interstratified are thin beds of light brown to pink and yellow dense and commonly shaly dolomite and dolomitic limestone; these beds are most prevalent in the upper one-half of the lower member. Solution breccia zones are common in the

upper part of the lower member, and orange weathering brown and gray chert lenses, nodules, and stringers are present at various horizons in the member. Most of the beds have a strong petroliferous odor on fresh fracture.

The Birdbear Member is approximately 60 feet thick in the map area, and consists of brown to buff thick-bedded to massive fine- to medium-grained commonly pseudobrecciated saccharoidal petroliferous dolomite. The member is generally a ledge-forming unit in this part of southwestern Montana (McMannis, 1964; Sandberg, 1965); in the map area, however, the Birdbear is only locally ledge-forming.

Few fossils were found in the Jefferson of the map area, mainly due to the dominance of dolomite comprising the formation. Fossils found by the writer include Amphipora and Stromatopora. The Jefferson is considered to be of Late Devonian age by most modern workers. Cooper and others (1942) believed the formation to be of the middle and upper Finger Lakes stage; McMannis (1962, p. 8) tentatively identified fossils from the upper beds of the lower member which suggest that part of the Jefferson may be equivalent to upper Chemung. If so, the upper age limit of the formation in the Gallatin Range is younger than that given by Cooper and others (1942). The fossils collected by McMannis (1962) are from an outcrop  $1\frac{1}{2}$  miles east of the southeast corner of the map area.

### Three Forks Formation

The Three Forks Formation consists of three members: the Logan Gulch Member, the Trident Member, and the Sappington Member (Sandberg, 1965, p. N10). These names replace the evaporitic member, shale member, and Sappington Sandstone Member, respectively, of Sandberg (1962); they also replace the Potlatch Member, green shale member, and Sappington Formation, respectively, as used by McMannis (1962), and McMannis and Chadwick (1964).

The formation is comprised of very incompetent material in the map area, forming grass covered saddles and slopes. As a result the strata are very poorly exposed and subdivision of the formation into members is generally impossible. Thickness of the formation ranges from 40 feet to 60 feet, except at one locality where it is about 85 feet thick.

Locally present at the base of the Three Forks is a thin unit of orange to brown iron stone nodules (limonite) interbedded with pale yellow-green thin-bedded shaly and sandy dolomite and limestone. Strata higher in the formation consist of pale yellow and tan thin-bedded sandy limestone and calcareous sandstone. The incompetent nature of the formation suggests that shale may constitute a major part of it. At the mouth of South Cottonwood Canyon (NW 1/4 NW 1/4 sec. 35, T. 35, R. 5 E.) 85 feet of strata of the Logan Gulch Member and possibly the basal part of the Trident Member is exposed. These strata consist of light-yellow-green thin-bedded and fissile finely micaceous calcareous

and dolomitic shale and gray-green rubbly limestone, interstratified with pink to tan thin- to medium-bedded dolomite, that appears to be extensively weathered near the contact with the underlying Jefferson Formation. The shale decreases upward in the formation, whereas the dolomite is less common in the basal part. Elsewhere in the map area strata typical of the Sappington are present and consist of yellow-brown thin-bedded fine grained calcareous quartz sandstone. A black shale unit commonly present at the base of the Sappington is not present in the map area, nor is it present to the south in the Garnet Mountain quadrangle (McMannis and Chadwick, 1964). The black shale (where present) overlies the Trident Member with regional disconformity (Sandberg, 1963). Where the black shale is absent the Sappington and in places the Lodgepole Limestone overlies the Trident.

At the above locality (mouth of South Cottonwood Canyon) the anomalously thick (85 feet) Logan Gulch Member poses a problem. Why should the Trident and Sappington members be absent in the one place where the thickness of the Three Forks (total) is greatest? The answer may be related to the normally brecciated nature of the Logan Gulch and locally of the Trident. It is possible that these two members represent solution collapse breccias, the collapse probably occurring due to the introduction of ground water during the post-Trident, pre-Sappington erosion interval. Such a phenomenon could have reduced the thickness of the two members to 40-50 feet, except for the 85 foot thick dolomite unit which would have resisted solution. It is noteworthy that this is

the only locality (in the map area) where the member(s) is nearly all dolomite.

The dolomite would have been a higher positive area during any post-Trident, pre-Lodgepole Limestone erosion time; thus the Trident and Sappington members could have been stripped off the high, but remained elsewhere.

The Three Forks ranges from Late Devonian to earliest Mississippian in age. McMannis and Chadwick (1964, p. 10) state that the Birdbear Member of the Jefferson Formation apparently contains upper Chemung equivalents; therefore, the base of the Three Forks may be latest Senecan or early Chautauquan (if the Jefferson and Three Forks are conformable). According to Sandberg (1965, p. N8) the uppermost part of the Three Forks is earliest Mississippian (earliest Kinderhookian). Cooper and others (1942) considered the Three Forks to have a very limited age range within mid-Cassadagan. However, their definition of the Three Forks did not include the Sappington.

### Mississippian

#### Dark Shale Unit

A dark shale unit, present in nearby areas, is not present within the map area. Where present, the unit overlies the Sappington Member of the Three Forks Formation and underlies the Lodgepole Limestone. McMannis (1955) recommended that the black shale be included as part of the Sappington, which some subsequent workers have done. With

further field work, however, McMannis (1962) noted that the unit is unconformable on the Sappington and appears locally to grade upward into and be conformable with the overlying Lodgepole; he therefore considered it as the basal unit of the Lodgepole, as have some other workers (e. g. , Cooper and Sloss, 1943; Gutschick and Perry, 1959). According to Sandberg (1965), however, correlation of the unit in Montana and Wyoming indicates that it not only unconformably overlies the Sappington, but is unconformably overlain by the Lodgepole, and should be considered as a separate unit.

The unit is present in northern Wyoming and south-central and much of western Montana; it thickens eastward and southeastward from the local region, where it varies from 0 to 4 feet thick (Sandberg, 1963). The absence of the shale unit in the map area is not surprising in view of the persistent positive tendency of the map area, and the fact that the unit pinches out in this part of Montana. It is quite possible that the black shale may never have been deposited in the map area. Sandberg (1963) states that the black shale unit in southwestern Montana is entirely of Early Mississippian age--Kinderhook. The overlying Lodgepole ranges in age from about middle Kinderhookian to early Osagian in the local region (Sando and Dutro, 1960). Since the shale unit is of early Kinderhookian age, any unconformity that may be present must represent a very short length of time, and only a very short time would be available for erosion of the shale. However, the unit is very thin and a short period of time may have been sufficient for removal of the unit.

Conversely, the widespread thin nature of the shale suggests that the topography of the depositional area had very little relief and erosion should have been very slow.

### Lodgepole Limestone

The Lodgepole Limestone is about 440 feet thick in the map area and rests disconformably on the Three Forks. Commonly the Lodgepole overlies the Sappington Member of the Three Forks, but near the mouth of South Cottonwood Canyon (NW 1/4 NW 1/4 sec. 35, T. 35., R. 5 E.) the Sappington is absent and the Lodgepole rests on the basal part of the Trident Member. Probably due to compensation for the increased thickness of the Three Forks at this location (as previously noted) the Lodgepole is thinner than elsewhere in the map area.

The lower one-third of the Lodgepole consists of medium-gray locally orange stained medium- to thick-bedded moderately fossiliferous limestone. Present in this part of the formation are zones of gray and brown chert nodules, stringers, and lenses, which tend to be massive but in which former bedding planes can commonly be delineated. The unit commonly forms ledges. Strata of the middle one-third of the formation consist of yellow, orange, and gray thin-bedded locally cross-bedded commonly shaly argillaceous limestone, with interstratified gray-brown medium-bedded microcrystalline to coarsely crystalline limestone. The argillaceous limestone typically contains well preserved fossils as well as fossil fragments, whereas the interstratified limestone contains mainly fossil fragments. The upper one-third of

the formation consists of orange-brown medium- and thick-bedded locally cross-bedded limestone, containing thin-beds of intercalated buff colored non-calcareous shale in the lower part. Present in the middle part of this unit are thick beds of coarsely crystalline fossil-hash-limestone. The contact of Lodgepole with the overlying Mission Canyon Limestone is sharp and conformable.

The Lodgepole is of Early Mississippian age, ranging from middle Kinderhookian to early Osagian (Sando and Dutro, 1960).

#### Mission Canyon Limestone

The Mission Canyon Limestone conformably overlies the Lodgepole and is about 375 feet thick. The base of the Mission Canyon is considered to be at the first occurrence of a massive limestone unit immediately overlying thin- to medium-bedded strata of the Lodgepole.

The lower part of the Mission Canyon consists of tan light-gray weathering thick-bedded and massive, locally cross-bedded, fine- to coarse-grained limestone, with interstratified light-gray to yellow-brown thin- and medium-bedded limestone and dolomitic limestone. The lower part commonly contains oolitic zones, fossil hash, and locally well preserved fossils.

The upper part of the formation is characterized by limestone similar to that of the lower part, but the interstratified beds are mainly dolomite. The dolomite is principally of three types, listed in order of decreasing abundance: (1) gray-brown thin-bedded to massive fine- to medium-grained dolomite, (2) light-tan white weathering thin- to medium-bedded

dense dolomite, and (3) brown thick-bedded fine-grained saccharoidal petroliferous dolomite, identical to that of the Jefferson. Roberts (1961, p. B294) believes the dolomite to have been deposited directly from sea water; his reasoning is based on (1) the intimate interlayering of dolomite and limestone, (2) the finer crystallinity of the dolomites as opposed to that of the limestones, and (3) a larger content of insoluble residues in the dolomites. However, dolomitized fossil fragments suggest that dolomitization is a secondary feature.

Gray and brown chert lenses, nodules, and stringers are abundant in the upper part of the formation, but are less common in the lower part. Some of the chert nodules and stringers contain silicified fossils, notably solitary corals.

Solution or collapse breccias are common in the upper part of the formation and are of two types: (1) irregular masses, and (2) laterally continuous zones. The irregular masses of breccia occur higher in the formation than the laterally continuous breccia zones and may have served as conduits to the laterally continuous breccia. The laterally continuous breccia commonly weathers bluish-gray and consists of fragmented dense brown dolomite, with a few irregular chert zones. It is locally cemented with yellow or red calcareous mudstone, typical of that of the Amsden Formation. Klepper and others (1957, p. 20) believe the breccia formed "during a post-Mission Canyon pre-Amsden erosion interval by penecontemporaneous formation and collapse of solution caverns." Middleton (1961) also believes the breccia is a solution and collapse feature, but did

not form penecontemporaneously (or by metasomatic replacement or by recrystallization).

The Mission Canyon is of late Early to early Late Mississippian age (late Osage and early Meramec) (Roberts, 1961, p. B294; Sando and Dutro, 1960, p. 117-123).

#### Big Snowy Group

The Big Snowy Group is not present in the map area, and the nearest known occurrence of the group is to the north in the Bridger Range. In this range definite Big Snowy strata are present as far south as Bridger Peak, and apparently are absent in the southern portion of the range (McMannis, 1955, p. 1403). The strata appear to pinch out at or near Bridger Peak, but the rocks do not suggest shoreline conditions (personal communication, W. J. McMannis, 1965). This suggests that the Big Snowy was once more widespread, quite possibly including the map area, and was removed by post-Big Snowy, pre-Amsden erosion.

#### Mississippian and Pennsylvanian

##### Amsden Formation

Strata of the Amsden Formation range from 49 feet to 78 feet thick in the map area. The formation disconformably overlies the Mission Canyon and is generally believed to have been deposited on karst topography. The Amsden forms steep slopes but outcrops are poor.

The Amsden consists of purplish thin- to medium-bedded dolomitic limestone, yellow to white thin- to medium-bedded calcareous mudstone, buff colored thin-bedded medium- to coarse-grained porous limestone, and a red, gray, and black cherty dolomite zone. The uppermost Amsden consists of tan and purple mottled thin-bedded siltstone which is overlain by yellow-gray thin- to medium-bedded medium- to coarse-grained and generally poorly indurated sandy dolomite, that grades upward into typical Quadrant Quartzite. The Amsden-Quadrant contact was chosen at the top of the highest red stratum between the Mission Canyon carbonates and typical Quadrant sandstone.

Red strata are present wherever the Amsden is present, with the exception of one locality. At this location (on South Cottonwood Creek) the formation is very faintly pink to white, the usual red color possibly having been leached by ground water. If so, the movement of the water was not downward as the solution breccias of the underlying Mission Canyon are not stained their characteristic red color.

Recent paleontologic studies in the general region of the map area indicate that the Amsden is of Late Mississippian and Early Pennsylvanian age (Robinson, 1963, p. 48-49).

#### Quadrant Quartzite

The Quadrant Quartzite conformably overlies the Amsden and disconformably underlies the Sawtooth Formation (Jurassic). Complete sections of the Quadrant are present only in South Cottonwood Canyon, where the formation crops out on the northeast side of the creek. In

terms of thickness, the Quadrant is the most variable formation in the map area; it ranges from 198 feet thick in the NW 1/4 SE 1/4 sec. 1, T. 4S., R. 5E., to approximately 300 feet thick in the NE 1/4 SE 1/4 sec. 35, T. 35., R. 5E. --a distance of only one mile. The variation is attributed to post-Quadrant-pre-Sawtooth erosion.

The lower part of the Quadrant contains tan and yellow-gray medium- and thick-bedded fine- to medium-grained dolomite interbedded with yellow and white medium-grained quartz sandstone. The dolomite beds are progressively fewer and thinner upsection. The major part of the formation is tan to white medium and thick-bedded fine- to medium-grained locally cross-bedded quartz sandstone. The sandstone is generally moderately indurated but is locally quartzitic. Locally interbedded in the upper 25 feet of the formation are thick beds of yellow-white fine- to medium-grained calcareous quartz sandstone containing gray chert nodules and stringers; less commonly present is medium-bedded dolomite. The Quadrant commonly forms talus comprised of rectangular blocks.

The Quadrant has yielded very few fossils in the region, but the formation is generally considered to be of Pennsylvanian age.

## Permian

### Phosphoria Formation

Strata of the Phosphoria Formation are not present in the map area. To the south in the adjacent Garnet Mountain quadrangle the formation

thins from 119 feet in the southwestern corner of the quadrangle to 105 feet on Squaw Creek in the northeastern part (McMannis and Chadwick, 1964, p. 14), and is between 75 feet and 100 feet thick  $1\frac{1}{2}$  miles east of the southeast corner of the map area ( W. M. Weber, Unpub. Master of Science Thesis, Montana State Univ., Bozeman, 1965, p. 25). At Rocky Canyon about 12 miles to the north-northeast, the Phosphoria is only .36 feet thick (Cressman and Swanson, 1964, p. 305) and is absent 6 miles farther north in the southern end of the Bridger Range (McMannis, 1955, p. 1404).

The present edge of the Phosphoria is most likely not the depositional edge, but the latter may not have been very far from the present edge of the formation. A very important factor in this regard is the length of time that the formation was exposed to erosion. The strong possibility exists that Lower Triassic strata were once present in the map area (see Triassic). The duration of the Phosphoria erosion, then, is dependent on (1) the thickness and extent of the postulated Lower Triassic strata, and (2) the amount of time necessary to cut through the Triassic strata (rate of erosion).

McMannis and Chadwick (1964) note that the lower unit of the Phosphoria in the Garnet Mountain quadrangle contains progressively more quartzite from south to north (toward the map area); the upper unit of the formation is nearly all quartzite and contains abundant burrow structures. The burrow structures are confined to platform sediments and indicate that the burrowing animals were of shallow-water habitat (Cressman and

Swanson, 1964, p. 351-354). This suggests that the depositional sea was shallow and possibly near a shoreline. The increase in quartzite toward the map area suggests that the map area may have been positive during at least part of Phosphoria time and supplied the material for the quartzite (probably derived from the Quadrant Quartzite). In view of the fact that all of the formations in the map area are thinner than those of the Garnet Mountain quadrangle, it is possible that the Phosphoria was never deposited in the map area. As previously mentioned, there exists the equally probable alternative that Phosphoria strata were deposited in and subsequently removed from the map area. A more positive answer awaits a detailed study of the Phosphoria in the north end of the Gallatin Range.

### Triassic

Triassic strata are absent in the map area but are present nearby. The Triassic of southwestern Montana is represented by the following sequence of Lower Triassic formations: the marine Dinwoody Formation which intertongues with, and is overlain by, the red bed Woodside or Chugwater Formation, which in turn is overlain by the marine Thaynes Formation where the latter is present (Kummel, 1960; Moritz, 1951). The nearest occurrence of Dinwoody is 15 miles south of the map area where McMannis and Chadwick (1964) measured 265 feet of strata. Dinwoody strata are also reported in the Madison Range, west of the map area (Moritz, 1951). The Woodside is present approximately 40 miles

south of the map area where it overlies the Dinwoody and has a minimum thickness of 350 feet (Witkind, 1964). Witkind also mapped what may possibly be a 9-foot thick section of the Thaynes. No other Thaynes strata have been reported in the vicinity of the map area and, in Montana, are apparently restricted to the southwesternmost part of the state. Moritz (1951, p. 1798) states that Middle and Upper Triassic strata are not present in southwestern Montana and that there is "no evidence to indicate that they were ever deposited."

Moritz (1951) states that the siltstones of the Dinwoody are of the subgraywacke type and are therefore suggestive of mildly unstable conditions; this may reflect increasing subsidence of the shelf and consequently inundation of a larger area. The Dinwoody of the Garnet Mountain quadrangle is not typical of a shoreline deposit; it is possible, therefore, that the formation was once more widespread (possibly covering the map area) and was subsequently removed by erosion. The long post-Early Triassic, pre-Middle Jurassic hiatus (approximately 50 m. y.) would have been sufficient time to remove Triassic strata from the map area.

#### Jurassic

Jurassic strata are confined to the east-central part of the map area where they crop out on the east wall of South Cottonwood Canyon. The marine Ellis Group, including the Sawtooth, Rierdon, and Swift formations, and the non-marine Morrison Formation together comprise the 403-foot Jurassic sequence.

### Sawtooth Formation

The Sawtooth Formation is 82 feet thick in the map area and disconformably overlies the Quadrant Formation. At the base of the Sawtooth occurs a gray to dark brown conglomeratic sandstone, comprised of maroon, gray, and black subangular to subrounded chert pebbles and light gray limestone pebbles in a matrix of quartz and chert sand. The unit is irregularly thin. Upward, approximately 25 feet of thin-bedded fossiliferous carbonaceous siltstone and dolomite are present. The major overlying portion of the formation is comprised of 52 feet of light gray thin-bedded blocky, hackly, or shaly abundantly fossiliferous limestone. The uppermost few feet of the formation consists of yellow-brown fossiliferous mudstone.

East of the map area Roberts (1964) mapped equivalent strata and termed the sequence the Piper Formation, the central and eastern Montana age equivalent of the Sawtooth. However, his lithologic description is very similar to that of the writer, and differs very significantly from that of the Piper at the type section as defined by Imlay and others (1948) and expanded by Nordquist (1955) to include member status for certain units. The formation in the two map areas are closely similar to that of the Sawtooth in the type Ellis sections as described by Cobban (1945, p. 1272-1273).

The Sawtooth is of Middle Jurassic age, and includes the Bajocian and Bathonian stages (McKee and others, 1956, p. 5).

### Rierdon Formation

The Rierdon Formation, middle unit of the Ellis Group, is 51 feet thick in the map area and rests conformably on the Sawtooth. The formation consists of a basal light gray weathering tan medium-bedded densely oolitic limestone. Upward, the Rierdon becomes thick-bedded and massive and consists of a ledge forming gray-brown weathering fossil-fragmented oolitic limestone. The latter unit weathers to a pitted surface and locally contains brown chert fragments and thin stringers at what are obviously former bedding planes. Stylolites are locally present on non-cherty bedding planes. The surface of the top most bed of the Rierdon is very uneven, and limonite and hematite deposits are characteristic of it. The Swift-Rierdon contact is markedly irregular (disconformable); consequently, typical upper Rierdon strata consisting of gray-green thinly laminated fossiliferous limestone and less commonly nodular limestone are only locally present. These strata do not exceed three feet in thickness.

The Rierdon is of late Middle Jurassic age (early to middle Callovian) (McKee and others, 1956, p. 5).

### Swift Formation

The Swift Formation is 58 feet thick in the map area and overlies the Rierdon with a marked disconformity. The basal part of the formation consists of gray thick-bedded medium grained limonitic calcareous quartz sandstone that is only locally present. It is overlain by 10 feet of dark brown to black medium- and thick-bedded, cross-bedded medium grained

sparingly glauconitic non-calcareous quartz sandstone. Ripple marks are present on some beds and differential weathering has caused some of the cross-beds to stand out in relief. Gray, green, and black subangular chert pebbles are sporadically present in the unit. The remainder of the Swift consists of 45 feet of tan locally maroon stained medium- and thick-bedded sparingly cross-bedded limonitic moderately indurated calcareous sandstone; near the top of the unit are a few interstratified beds of light blue-gray sandy and shaly limestone.

The erosional unconformity at the Rierdon-Swift contact (Imlay and others, 1948; Imlay, 1956) is attested to by the markedly irregular contact and the sporadic presence of the upper Rierdon shale in the map area, and the persistent presence of the latter to the east and its absence to the south.

The Swift is of early to middle Late Jurassic age (Oxfordian) and the hiatus represents the upper one-half of the Callovian (McKee and others, 1956, p. 5).

#### Morrison Formation

Strata of the non-marine Morrison Formation overlie and are markedly different from those of the Swift; the ledge-forming sandy limestone or sandstone of the marine Swift changes upward to deep red claystone of the non-marine Morrison. Imlay (1956, p. 565) states that no evidence has been found for a disconformity at this contact. The Morrison is 212 feet thick in the map area and is poorly exposed.

The lower one-half of the formation consists of reddish-brown mudstone and shale with interstratified red-gray thin-bedded fine-grained hard calcareous quartz sandstone and siltstone, fine-grained non-calcareous limonitic and hematitic quartz sandstone, and thin discontinuous beds of light green and gray nodular limestone. The upper one-half of the Morrison contains light green thin-bedded sandy limestone in the lower part, but the unit is dominated by tan to gray thin- and medium-bedded limonitic calcareous fine-grained quartz sandstone and siltstone. The sandstone and siltstone are locally cross-bedded and are poorly to well indurated. Plant fragments were found in the upper beds of this unit.

Imlay and others (1948) consider the Morrison to be of Late Jurassic age, ranging from early Kimmeridgian through early Portlandian.

### Cretaceous

Cretaceous strata are present only in the east-central part of the map area, high on the east side of South Cottonwood Creek. They are represented by 250 feet of sedimentary rocks of the Kootenai and Thermopolis formations. A thicker sequence of these strata (about 700 feet) is reported by McMannis and Chadwick (1964) 10 miles southwest of the above location, and thicker sequences of these and younger Cretaceous strata are present near Hyalite Reservoir about two miles southeast of the map area (4000 feet) (Roberts, 1964), the Bridger Range (10,000 feet) (McMannis, 1955), and near Livingston, Montana (12,000 feet) (Roberts,

1965). The absence of the younger Cretaceous rocks in the map area is due to (1) recent erosion, (2) faulting and erosion prior to deposition of Tertiary volcanic rocks, and (3) probably in part non-deposition.

Roberts (1965) has correlated the Cretaceous (and Lower Tertiary) rocks of this region with those of other areas of Montana and Wyoming. In so doing he elevated the Livingston and Colorado formations to group rank, the latter formation having long had this status in various areas. He then applied formation names to the correlated units and designated member status for certain lithologic subdivisions of the formations.

#### Kootenai Formation

The Kootenai Formation is a tripartite sequence of non-marine strata disconformably overlying the Morrison. The formation is 205 feet thick where measured in South Cottonwood Canyon.

The basal unit of the Kootenai, the so called Pryor Conglomerate Member of Roberts (1965), is 45 feet thick. It consists of light gray, tan, and pink thick-bedded to massive cross-bedded medium- and coarse-grained to conglomeratic sandstone. The sandstone is of the salt and pepper type, being comprised of subangular to subrounded grains of tan and white quartz and black chert. Subrounded and rounded white, tan, gray, purple, and black chert pebbles and rarely quartzite pebbles comprise the conglomeratic part of the sandstone. Locally the sandstone is poorly indurated and does not form prominent outcrops.

The middle unit of the Kootenai is 130 feet thick, and its unity lies in the fact that it is comprised of many different lithologies. It consists of white, pink, and red blocky mudstone; white, gray, and light green hackly, shaly, or nodular limestone; red and maroon thin- and medium-bedded calcareous siltstone and fine grained-sandstone, the latter locally containing small red and black chert pebbles. The red mudstone commonly forms benches in the map area.

The 30-foot thick upper unit consists of light gray thin- and medium-bedded gastropod- and ostracod-bearing fresh-water limestone overlain by yellow-brown and gray shaly mudstone. The "gastropod limestone" is a widely recognized marker bed near or at the top of the Kootenai in southwestern Montana.

According to Roberts (1965, p. B57) the Kootenai is of Early Cretaceous age (late Aptian).

#### Thermopolis Shale

The Thermopolis Shale is represented in the map area by approximately 50 feet of the lower sandstone member of the formation. The strata are poorly exposed and consist of a basal yellow-brown (limonitic) thin-bedded fine- and very fine-grained quartz sandstone interbedded with light and dark gray very fine-grained sandstone and siltstone. Roberts (1965) states that the formation lies unconformably on the Kootenai, his evidence being that in many places the Thermopolis fills depressions in the latter. W. A. Cobban (oral communication, 1963, in Roberts, 1965, p. B55) believes the hiatus to be small, citing evidence that the

index fossil Protelliptio douglassi occurs immediately above and below the widespread disconformity separating the two formations.

The lower sandstone member is of Early Cretaceous age, ranging from latest Aptian to early Albian (Roberts, 1965, p. B57).

#### Implications of Marine Sedimentary Sequence

The most outstanding characteristic of the Paleozoic and Mesozoic sedimentary sequence is its lesser thickness as compared to sedimentary strata of the same age in nearby areas. In the map area the thickness ranges from 2700 feet to 3300 feet, whereas to the south in the adjacent Garnet Mountain quadrangle, for example, the sequence is in excess of 4500 feet thick. East of the map area an estimate of the comparable stratigraphic units yields a value in excess of 5500 feet. From these data it is apparent that the strata of the map area underwent a somewhat different history than strata of the bordering areas.

The map area was apparently one of slow subsidence as compared to the bordering areas and (marine) deposition may logically be considered to have proceeded less continuously or at a slower rate. Individual formations are commonly thinner in the map area than in the bounding areas; formations that are thin in the bordering areas may be absent in the map area (for example, the black shale unit at the base of the Lodgepole and the Permian Phosphoria Formation). This thinning or absence is in part due to the persistent positive nature of the map area and the resultant erosion of formations subsequent to their

deposition. It is also due in part to nondeposition of sediment or deposition at a reduced rate. This fact is well illustrated even within the map area by the Cambrian Red Lion Formation. It is a bipartite formation that is thickest in the Big Bear Creek drainage and considerably thinner atop Langohr Nob. At the latter location both the lower (Dry Creek Shale) member and the upper member are thinner than along Big Bear Creek and there is no hiatus between the members. Slower but continuous deposition is thus indicated for the Langohr Nob section for at least the lower member; the upper member may have been thinned by subsequent erosion. Other examples are given in the text of this section (Stratigraphy) and figure 3 gives the comparison of formation thicknesses.

| AGE           |               | FORMATION                | THICKNESS<br>(FEET) |                                  |
|---------------|---------------|--------------------------|---------------------|----------------------------------|
|               |               |                          | MAP<br>AREA         | GARNET<br>MOUNTAIN<br>QUADRANGLE |
| CRETACEOUS    | EARLY         | THERMOPOLIS SHALE        | >50                 | >400                             |
|               |               | KOOTENAI FM              | 205                 | 360-412                          |
| JURASSIC      | MIDDLE & LATE | MORRISON FM              | 212                 | 275-450                          |
|               |               | SWIFT FM                 | 58                  | 25-115                           |
|               |               | RIERDON FM               | 51                  | 28-63                            |
|               |               | SAWTOOTH FM              | 82                  | 120-185                          |
| TRIASSIC      |               | DINWOODY FM              | 0                   | 0-265                            |
| PERMIAN       |               | PHOSPHORIA FM            | 0                   | 105-119                          |
| PENNSYLVANIAN |               | QUADRANT QUARTZITE       | 198-300             | 135-250                          |
| MISSISSIPPIAN |               | AMSDEN FM                | 49-78               | 0-225                            |
|               |               | MISSION CANYON LIMESTONE | 375                 | 675                              |
|               |               | LODGEPOLE LIMESTONE      | 440                 | 575-610                          |
|               |               | BLACK SHALE UNIT         | 0                   | 3-5                              |
| DEVONIAN      | LATE          | THREE FORKS FM           | 40-85               | 138-225                          |
|               |               | JEFFERSON LIMESTONE      | 254                 | 315-450                          |
|               |               | MAYWOOD FM               | 0                   | 0-34                             |
| CAMBRIAN      | LATE          | RED LION FM              | 76-115              | 130-225                          |
|               |               | PILGRIM LIMESTONE        | 245-286             | 170-255                          |
|               | MIDDLE        | PARK SHALE               | 40-70               | 175-241                          |
|               |               | MEAGHER LIMESTONE        | 300-340             | 449-471                          |
|               |               | WOLSEY SHALE             | 40-195              | 140-170                          |
|               |               | FLATHEAD QUARTZITE       | 40-75               | 50-125                           |
| PRECAMBRIAN   |               | METAMORPHIC COMPLEX      | ?                   | ?                                |

Figure 3. Chart comparing thicknesses of sedimentary units in the map area with those of the Garnet Mountain quadrangle.

## Tertiary

Early Tertiary Conglomerate

A conglomerate similar to the Sphinx Conglomerate (Peale, 1896, p. 3) crops out east of the mouth of Little Bear Creek (SE 1/4 NE 1/4 sec. 31, T. 3S., R. 5 E.), and is the only known occurrence of the unit in the map area. It is exposed in a road cut, forming an outcrop that measures approximately 6 feet high and 150 feet long. The conglomerate consists of poorly sorted pebbles and cobbles of Paleozoic carbonate rocks in a red-orange to white calcareous matrix. The pebbles and cobbles are subangular to subrounded and have a white hard calcareous coating; the matrix is earthy, generally silty, and is cemented by powdery calcite. Robinson (1963) in interpreting a similar conglomerate in the Three Forks quadrangle discussed two possible origins for the red-orange color in the matrix: (1) it may represent a "lateritic soil developed on local uplands of low relief during warm and wet episodes" in early Tertiary time; or (2) the red-orange color may have been developed by ground water, in part by oxidation of ferrous iron from the carbonate rocks, and in part by redistribution of ferric iron "washed from hematitic pebbles derived from a variety of iron-rich pre-Quaternary rocks". He opposed this latter view stating that if the color is postdepositional, the pebble surfaces should be colored red-orange as well as the matrix. The same reasoning can be used for the conglomerate of the map area.

The fact that the conglomerate is comprised of poorly sorted and not too-well rounded Paleozoic limestone debris suggests a source that was not far distant. At least four formations (Pilgrim, Jefferson, Lodgepole, Mission Canyon) are represented in the clasts; this fact coupled with the size and sorting of the component rocks suggests that the source area had appreciable relief. The deposit, therefore, may be part of an alluvial fan. Similar conglomerates comprised of carbonate cobbles has been interpreted as possibly being indicative of early uplift during the Laramide orogeny (Lowell and Klepper, 1953; Robinson, 1963).

The age of the conglomerate cannot be directly ascertained, but indirect evidence suggests that it may be of early Tertiary age (Paleocene or Eocene). The conglomerate is bounded on three sides and partially overlain by landslide material consisting entirely of Eocene volcanic rock, yet the conglomerate contains no volcanic rock. Therefore, the conglomerate must be older than the landslide deposit. Two possibilities now exist: (1) the conglomerate is younger than the volcanic rock (not the landslide), or (2) the conglomerate is older than the volcanic rock. The latter possibility seems to be the more reasonable due to the absence of volcanic rock in the conglomerate. If possibility (1) were true the conglomerate should contain some volcanic rock, as volcanic deposits must have capped the nearby source area of the landslide debris. The evidence suggests, therefore, that the conglomerate is of early Eocene age at the youngest and may possibly be Paleocene or even Cretaceous in age.

All known Upper Cretaceous and Paleocene deposits in any direction from this locality, however, are conglomeratic volcanic (andesitic) sandstones. The data regarding conglomerates in the Livingston of the Bridger Range suggests a source somewhere to the south and southwest (McMannis, 1964). Conglomerates in the "Livingston" of the Upper Gallatin Valley (Hall, 1960, Unpub. Ph.D. Thesis, Univ. of Wyo.) are significant regionally, too, as they lack Precambrian metamorphic and Paleozoic cobbles. The source for conglomerates east of the Bridger Range, then, was apparently the Gallatin Range-Spanish Peaks-Gallatin "Valley" area.

#### "Basal" Tertiary Conglomerate

Not found in the map area is a "basal" Tertiary conglomerate reported by McMannis and Chadwick (1964) as overlying Paleozoic and Precambrian rocks in parts of the Garnet Mountain quadrangle and as also being present in the upper Middle Creek drainage. The unit is thin, very poorly exposed, and consists of cobbles and boulders of Precambrian gneiss, amphibolite, quartz, and some Paleozoic carbonate and Tertiary volcanic rock. The conglomerate may be present in the map area but was not found due to the poor exposure; in the Garnet Mountain quadrangle it is exposed only in road cuts.

### Eocene Siltstone

In the southeastern part of the map area in the South Cottonwood Canyon drainage area a carbonaceous siltstone locally overlies Jurassic sedimentary rocks and underlies post-latest early Eocene volcanic rocks. The claystone is gray-green, thin-bedded to fissile, locally silty, calcareous, and contains abundant carbonaceous matter. Similar deposits occur in the Middle Creek drainage area (W. M. Weber, Unpub. Master of Science Thesis, Montana State Univ., Bozeman, 1965) and in the Squaw Creek drainage area (McMannis and Chadwick, 1964); the latter authors identified the carbonaceous material as being plant fragments. Spore and pollen analysis tentatively indicate a Wasatchian (late early Eocene) age for the deposits in the Squaw Creek area (A. E. Roberts, written communication, 1962, in McMannis and Chadwick, 1964, p. 18).

### Late Miocene? Strata

Tertiary strata underlying the erosion surfaces along the Gallatin Range front are poorly exposed because of their low degree of induration and because of extensive surficial deposits of soil and gravel. Exposures are limited to draws cut through the strata by streams; even here the exposures are poor. No fossils were found in these strata in the map area. However, Hackett (1960, p. 38) states that these beds are equivalent to similar strata in the Camp Creek Hills (northwest of the map area), which have yielded vertebrate fossil remains dated as late Miocene (M. D. Mifflin, 1963, Unpub. M. S. Thesis, Mont. State

Univ., Bozeman, p. 15).

Strata tentatively correlated with late Miocene strata are described for three representative locations in the map area. Late Miocene? strata crop out in the W 1/4 sec. 22 and E 1/3 sec. 21, T. 3 S., R. 5 E., at the mouth of South Cottonwood Canyon. The lowest exposed beds consist of white to light gray calcareous tuffaceous fine- to medium-grained quartz sandstone. The middle part of the sequence is covered. Toward the top of the exposure the strata consist of thin- to medium-bedded calcareous tuffaceous fine-grained sandstone, the sand grains also being multicolored. Recrystallization and fracture fillings occur sparingly. The topmost strata exposed are buff to white dense calcareous ash, containing a few silt grains. Calcite fracture fillings in some of this rock gives it a "graphic" appearance.

A 50 foot thick section of basin strata crops out in the SE 1/4 sec. 29, T. 3 S., R. 5 E., on Big Bear Creek. The strata consist of buff to brown medium- to thick-bedded and massive gray weathering dense limestone that commonly exhibits a pitted surface. White calcite fracture fillings occur in strata near the base of the exposure. The top 6 feet of the unit differs only in that it contains an abundance of algal pisolites.

Another outcrop of late Miocene? strata occurs in the NW 1/4 sec. 31, T. 3 S., R. 5 E. It is best termed a fanglomerate and consists of subangular to subrounded cobbles of gneiss, andesite, and Flathead quartzite. The individual cobbles are coated with a well cemented chalk,

but as a unit the fanglomerate is very poorly indurated.

### Quaternary

#### Alluvial Fan Deposits

Alluvial fans, probably of late Pleistocene age, are described for four localities in the map area. An extremely small part of a fifth fan--the Bozeman fan--occurs in the NW  $\frac{1}{4}$  sec. 14 and N $\frac{1}{2}$  sec. 15, T. 3 S., R. 5 E., but is not described here. In the W $\frac{1}{2}$  sec. 3, E $\frac{1}{2}$  sec 4, T. 4 S., R. 4 E., and the SW  $\frac{1}{4}$  sec. 34, T. 3 S., R 4 E, a fan exists that is not actively forming at present. The surface of the fan is covered with about 95% gneissic materials and 5% andesitic lava materials. Another fan not presently forming occurs in the E $\frac{1}{2}$  sec. 35 and the W $\frac{1}{2}$  sec. 36, T. 3 S., R. 4 E. The lower part of this fan has about 90% gneissic materials and 10% lava materials exposed at the surface; the upper part contains a smaller percentage of gneiss, a higher percentage of andesite, but contains a predominance of Cambrian rocks, thus reflecting its source area which it abutts. ✓ Two more fans not actively forming radiate from South Cottonwood Creek and Big Bear Creek. Cobble types at the surfaces of these fans were not studied in detail.

✓In general the rocks at the upper reaches of the fans are larger than those nearer the base. Rounding of rocks was not notably different between the head and foot for either of the smaller fans. Limestone decreased percentagewise toward the foot of all fans and the rocks present on the

fans mapped reflected the lithologies of strata near the head of the fan.

#### Stream Channel Deposit

A good exposure of a stream channel deposit occurs in a road cut in the SW 1/4 sec. 18, T. 3S., R. 5 E. The deposit consists of subangular to subrounded pebbles and cobbles, dominated by andesite (about 90%) gneiss (about 5%) and other rocks (about 5%). Sand, silt, and clay commonly fill the voids between the larger fragments or clasts. The gneiss is deeply weathered, suggesting that the deposit may be of middle? Pleistocene age.

## IGNEOUS ROCKS

### Tertiary Volcanic Rocks

Volcanic rocks in the map area unconformably overlie Precambrian metamorphic rocks, Paleozoic, Mesozoic, and some early Tertiary sedimentary rocks. The maximum thickness of the volcanic sequence in the map area is about 1400 feet; McMannis and Chadwick (1964, p. 19) note that in the adjacent Garnet Mountain quadrangle a total thickness in excess of 4000 feet apparently existed at one time. The sequence dips gentle to the north in the map area.

Two volcanic types are dominant in the map area, as in the Garnet Mountain quadrangle. (1) The first type consists of lava flows of basic andesite interstratified with flow breccias. The dominant rock type is a tan weathering dark gray to black dense basic andesite that is commonly slightly porphyritic. The lava sequence occurs as a series of individual flows superimposed upon one another. The material can be divided into two main types: (a) massive crystalline columnar-jointed rock, and (b) flow breccia comprised of andesite rocks set in a varicolored matrix consisting of (according to McMannis and Chadwick, 1964) "finely ground lithic fragments and labradorite and pyroxene crystals."

(2) The second dominant volcanic type is less common than the first and consists of crudely stratified breccia containing several volcanic lithologies, but mainly basic andesite. The component rocks range from fragmental to boulder size and vary from subrounded to

angular. The matrix of the breccia contains small lithic fragments. Both volcanic types (1 and 2) are described in greater detail by McMannis and Chadwick (1964, p. 19-23), including chemical analyses.

The age of the volcanic sequence is based in part on the dating of spores in the underlying late early Eocene siltstone (McMannis and Chadwick, 1964). A recent potassium-argon date obtained from a sample taken 700 to 800 feet above the base of the volcanic sequence on the East Fork of Middle Creek (southeast of the map area) yielded an age of 42.7 ( $\pm$  2.4) m. y. -- late Eocene (W. J. McMannis, personal communication, 1966). Hall (1960, Unpub. Ph.D. Thesis, Univ. of Wyo.) has suggested that some of the Gallatin Range volcanics may be as young as Oligocene.

### Intrusive Rocks

Igneous intrusive bodies occur in the southwest corner of the map area (in sec. 2, 10, and 11, T. 4 S., R. 4 E.) where they cut Precambrian metamorphic rock. The intrusives are identical to the Shenango Creek intrusive mass of McMannis and Chadwick (1964, p. 28), being a light gray dacite porphyry with phenocrysts of oligoclase, biotite, and some hornblende. The closeness of the two intrusive areas (about one mile apart) and the identical lithology of the intrusive bodies suggest that all are part of the same mass.

The age of the Shenango intrusive mass is not directly known; however, according to the following lines of evidence, it is believed to be Tertiary. Four lithologically similar intrusive bodies (including

the Shenango intrusive) occur in the Garnet Mountain quadrangle, three of which transect the Tertiary volcanic sequence and are thus younger than the volcanic rocks. The fourth--the Shenango Creek intrusive mass--does not transect volcanic rocks, but, like the other three intrusive bodies, is located along a major fault which apparently acted as a conduit for the intrusive material. The age of movement on the Squaw Creek fault, along which the Shenango intrusive is located, could be any time between Late Cretaceous and early Eocene. Therefore, at the oldest the Shenango intrusive is Late Cretaceous, but similarity to other intrusives suggests a Tertiary age (McMannis and Chadwick, 1964). A potassium-argon analysis of a similar dacitic intrusive near Mill Creek (approximately 35 miles east-southeast of the Shenango Creek intrusive area) yielded an age of  $49.0 \pm 1.7$  m. y. -- middle Eocene (personal communication, W. J. McMannis, 1966). Although the Mill Creek intrusive is quite far distant, it is possibly developed along the same structural weakness as the Shenango Creek intrusive.

## STRUCTURE

### General

The Gallatin Range lies within the southeastern extremity of the Northern Rocky Mountain Province of Fenneman (1931). Structurally, however, it is unlike the mountains of this province and should be considered a part of the Central Rocky Mountain Province, because "the ranges of the Northern Rocky Mountains are formed from long, narrow, closely spaced folds and thrust blocks made up of geosynclinal sedimentary rocks alone, not of basement rocks" (King, 1959, p. 137). The Central Rocky Mountains are broad-backed uplifts, commonly with wide areas of basement rock exposed in their cores; also, they are of diverse trend and widely spaced, with broader basin areas in between (King, 1959, p. 112). The structure of the Gallatin and adjacent areas better fits the latter description.

The map area lies within the northern part of the Gallatin Range and constitutes a part of what Sloss (1950) calls the Wyoming Shelf. The sedimentary cover of the shelf is generally thin (less than 3300 feet thick in the map area)--too thin to have exerted much control over the structures formed by the general east-northeast Laramide compressive stress. The shelf deposits are of relatively uniform thinness whereas deposits of a geosyncline are thick centrally and thin shelfward. During compression strata of the thick part of the geosyncline move shelfward and are broken along a series of thrust faults; the reason is that the basement rock underlying the geosyncline is nearer the surface shelfward and the strata are

forced to rise over the buttress, rupturing in the process. It is commonly believed that the resulting structures of the shelf region are expressions of ancient trends in the Precambrian basement, re-activated during the Laramide orogeny. The history of some of the faults as recorded in the sedimentary sequence (thickness and facies distribution) is the basis for implying that some have definitely had a long history of movements dating from Precambrian time. Other faults of similar trend are, by analogy, believed to be of similar vintage. The dominant structures generally trend west-northwest, whereas less obvious structures trend northeast (see figure 4).

#### Regional Tectonic Pattern

Interpretation of structures in the map area requires a knowledge of regionally salient structures and of the gross causal mechanism. In south-central and southwest Montana is a group of prominent structures, the members of which are oriented west-northwest. Two of them deserving of discussion here are the Lake Basin fault zone and the Nye-Bowler linement.

The Lake Basin fault zone is in excess of 100 miles long and consists of a series of en echelon northeast striking normal faults that form a major west-northwest trending zone. Stratigraphic evidence across the fault indicates periodic movement that influenced sedimentation, particularly during post-Madison, pre-Jurassic time. The Big Snowy Group is present north of the fault and is absent on the south; the Quadrant and Chugwater are present mainly to the south of the fault zone but are absent

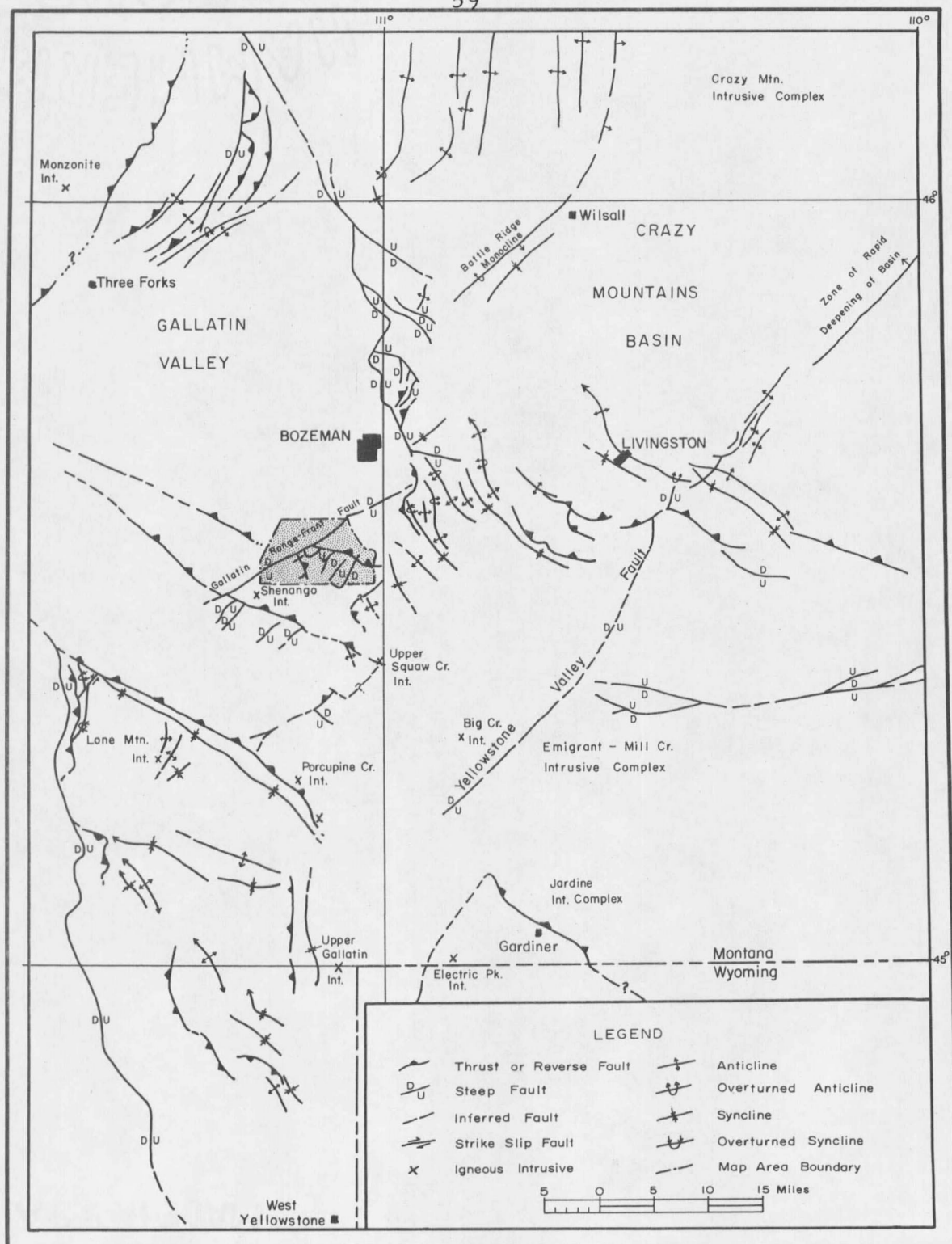


Figure 4. Map showing major structural features of the region near the map area.

to the north (Alpha and Fanshawe, 1954). During the Laramide orogeny, the east-northeast compressive stress was resolved into a left-lateral strike-slip movement along this pre-existing zone of weakness (Badgley, 1965, p. 109). The Lake Basin fault zone is believed by some workers to be a continuation of the Osborn fault zone (Montana lineament), a west-northwest oriented feature transecting western Montana. For critical observations on the subject the reader is referred to Blackstone (1956), Wallace and others (1960), Gwinn (1961), Kauffman (1963), and Smith (1965).

The Nye-Bowler lineament is approximately 115 miles long and consists of a series of anticlines, faults, domes, volcanic features, and laccoliths. It trends parallel to the Lake Basin fault zone and, like the latter, exhibits evidence of left-lateral strike-slip movement (Alpha and Fanshawe, 1954). In relation to the Beartooth Mountains the lineament may (1) terminate against the northwest trending frontal edge of the mountains, (2) extend northwest parallel to and merge with the margin of the Beartooth massif, or (3) trend westward along the Mill Creek--Stillwater structural zone, thus dividing the northwest part of the Beartooth Mountains into separate structural blocks (Foote and others, 1961).

#### Tectonic Patterns of Adjacent Areas

The topographic expression of the Laramide orogeny in the immediate region consists of fault block mountains and intermontane basins. Major

geographic<sup>2</sup> units in the immediate vicinity of the Gallatin Range include the Spanish Peaks, the Beartooth Mountains, the Madison and Bridger ranges, and the Three Forks and Crazy Mountains basins. The Gallatin, Madison, Spanish Peaks, and Beartooth areas, and the southern part of the Bridger Range are typified by the following characteristics: (1) high-angle reverse and normal faults, (2) absence of Belt strata, (3) extensive exposures of pre-Belt metamorphic rock, and (4) thinness of the Paleozoic and Mesozoic strata (McMannis, 1965).

The Spanish Peaks border part of the Gallatin Range on the west and are geographically separated from the latter by the Gallatin River; structurally, however, the Spanish Peaks are equivalent to the central part of the Gallatin Range. On the northeast the Spanish Peaks are delimited by the northwest trending Squaw Creek--Cherry Creek fault--a northeast dipping reverse fault along most of its length. On the southwest side the Spanish Peaks are bounded by another northwest trending, northeast dipping reverse fault, believed by Swanson (1950) to be a continuation of the Gardiner reverse fault.

Farther south the Gallatin River serves to separate the southern part of the Gallatin Range on the east from the northern block of the

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<sup>2</sup>Geographic units are used here because the features (mountains and basins) of the area have been delineated on a topographic basis only, and thus are not necessarily structural units.

Madison Range on the west.

The dominant structure in this block of the Madison Range is that of a "broad, flat syncline trending west of north and having a sharply folded and faulted western flank" (Swanson, 1950, p. 7). The latter folding and related faulting caused Swanson to propose two stress directions with compression occurring first from the west, later from the northeast, and subsequently from the west again. An east-northeast compressive stress is all that need be required if it is remembered that (1) the basement rocks are not homogeneous, and deviation of structural trends expected to result from the northeast compressive stress are to be anticipated, and that (2) yield to stress should not be simultaneous everywhere.

The northwest trending Beartooth Mountains lie southeast of the Gallatin Range and are separated from the latter by a high-angle, northeast trending fault (the Yellowstone Valley fault). Dip-slip movement on this fault probably developed as a complement to reverse faulting along the northeast side of the Beartooth Mountains. McMannis (1964, p. 4) has found evidence to suggest that the Yellowstone Valley fault had already been active previous to Laramide deformation. The evidence is: (1) low-angle folded thrusts and linear folds typify the area west of the Yellowstone, whereas east of the valley, faults are steep and folds are not as common; and (2) there is a large increase in thickness of Late Cretaceous (and apparently Paleocene) strata from east to west across a northward projection of the Yellowstone Valley

fault trend, and corresponding deepening is evident in the Crazy Mountains basin.

The Bridger Range is a north-south oriented uplift lying north of the Gallatin Range. It appears to be the large east limb of a structurally complex, northeast plunging anticline which has been severed from the western limb by post-late Paleocene normal faulting. The range is divided into northern and southern parts by the Ross Pass fault zone. South of the fault zone no Belt strata are present whereas to the north a thick Belt sequence is present; this fault zone was active in Precambrian time (McMannis, 1955; 1963).

The Three Forks basin bounds the northwest side of the Gallatin Range and is separated from the latter by a high-angle normal fault. (Further interpretation of the southern part of the basin will be made later.) Trending east-west across the northern end of the basin is a monoclinial fold believed by Hackett and others (1960) to reflect a subsurface fault--termed the Central Park fault. It coincides approximately with the westward extension of the Ross Pass fault zone, and like the latter, apparently coincided approximately with the shoreline of the Belt sea (Late Precambrian).

The Crazy Mountain's basin lies northeast of the map area and is a structurally complex downwarped area whose deformation is intimately related to that of the Gallatin Range. The eastern margin of the basin is cut by the northeast trending Crazy Mountain's disturbed zone (a northeastward extension of the Yellowstone Valley fault zone),

(as previously described) to the west of which structural contours suggest an abrupt increase in thickness of Upper Cretaceous and Paleocene strata; rapid thickening of the same strata is indicated to the east of the Battle Ridge monocline, a structural feature of the west-central part of the basin which exhibits dips that are vertical to overturned along its length (Dobbin and Erdmann, 1955). Seismic data indicate the monocline is developed along a subsurface fault, and that a thick pre-Flathead sedimentary sequence lies on the northwest side (personal communication, W. J. McMannis, 1966). During the Laramide orogeny the Crazy Mountain's Basin disturbed zone--Yellowstone Valley fault trend served as an eastern boundary, and the Battle Ridge subsurface fault--southern "end" of the Bridger Range trend served as the western boundary of a structural low. Increasing compression "channeled" the sedimentary sequence of the Crazy Mountain's Basin southwestward onto the structurally low-lying north end of the Gallatin Range. The structures produced consist of arcuate, en echelon anticlines and northeast dipping reverse faults that are convex to the southwest (Skeels, 1939). At the same time these structures were developing, the Bridger uplift was being forced eastward and the Beartooth uplift northeastward (Roberts, 1965). The Three Forks Basin did not exist during the time of deformation, but was a mountainous area which acted as a resistant structure.

From the foregoing discussion two major conclusions are warranted:

(1) all major structures (or Laramide reactivation thereof) can be

explained by an east-northeast compressive stress; and (2) there is ample evidence to indicate that major structural weaknesses existed prior to the Laramide orogeny and were reactivated during the orogeny. Similar structures and trends should exist within the map area.

#### South Cottonwood Creek Fault

The gross east-northeast compressive stress caused reverse faulting along a fault located in the South Cottonwood Creek drainage, here named the South Cottonwood Creek fault. Simultaneously, and/or possibly starting somewhat later, faults developed approximately perpendicular to the South Cottonwood Creek fault and most likely owe their existence to differential movement of the blocks which they border.

The South Cottonwood Creek fault is the major northwest trending fault in the map area. As was originally suggested by Peale (1896, p. 3), it appears to be a continuation of the Salesville fault (see figure 4) present to the northwest of the map area, but intervening valley deposits mask any connection of the two. Also, possible horizontal displacement on the Gallatin Range front fault has offset any such connection.

The South Cottonwood Creek fault dips steeply to the northeast along most of its length and exhibits a reverse relationship. In sec. 36, T. 3 S., R. 5 E., this reverse fault is transected by a cross fault (the Wheeler Gulch fault, described later). Northwest of the cross fault,

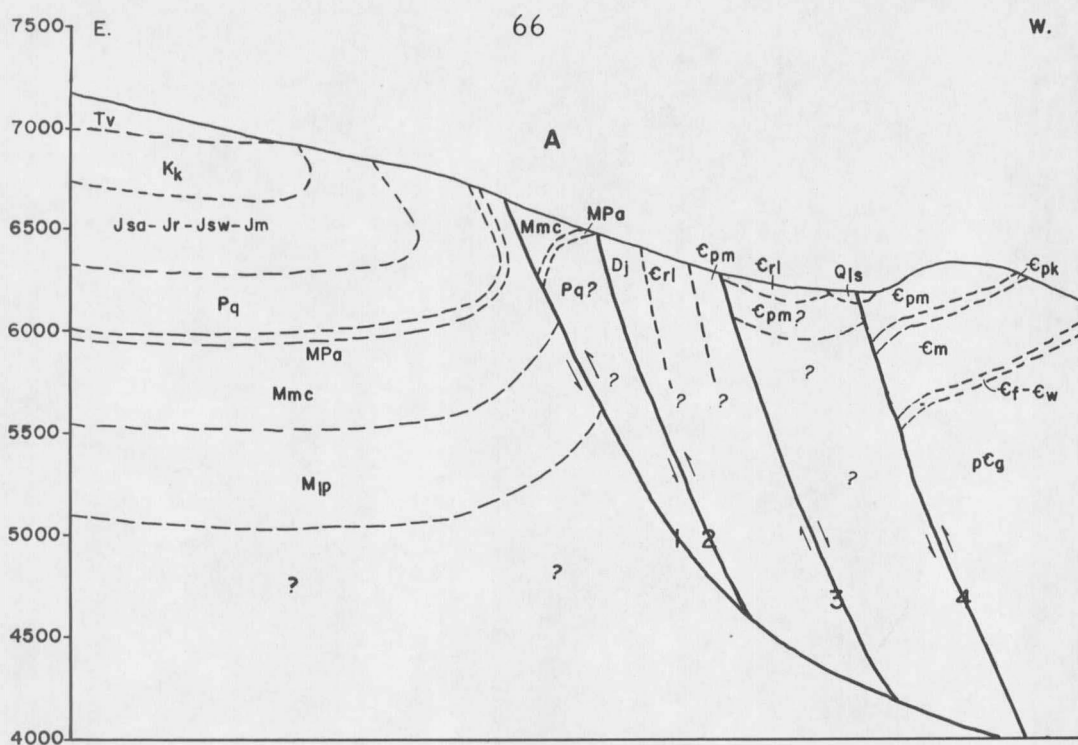
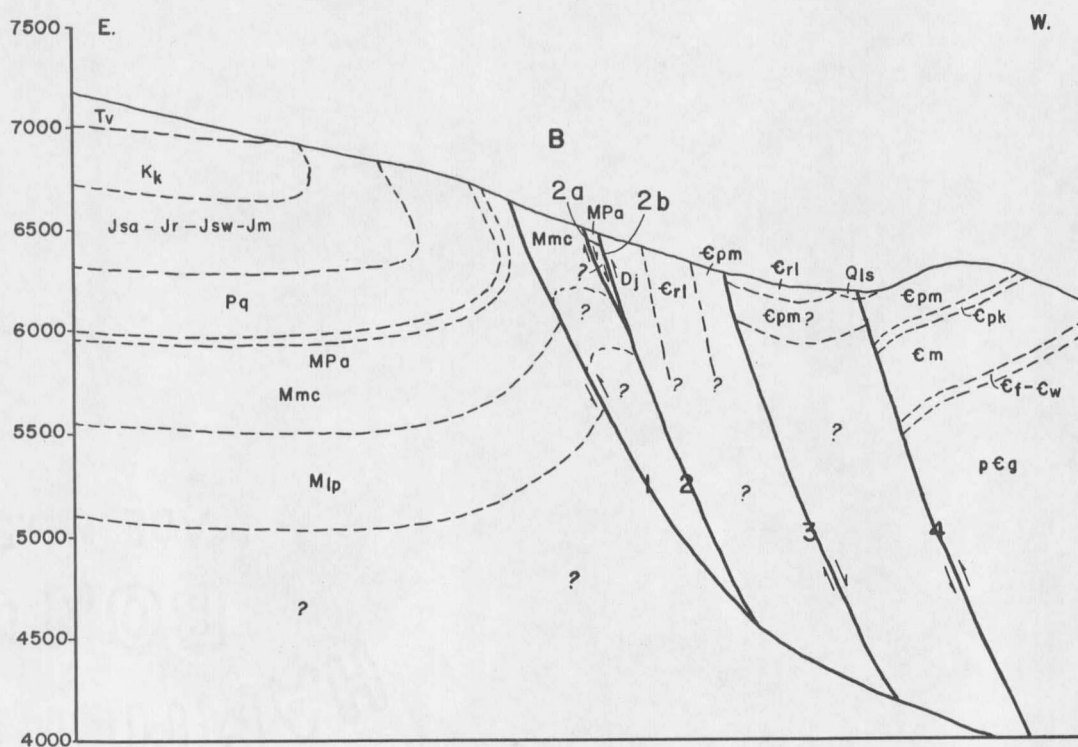


Figure 5. Enlarged speculative cross-sections of structures along east-trending extension of the South Cottonwood Creek fault ( $N\frac{1}{4}$  sec. 6, NW  $\frac{1}{8}$  sec. 5, T. 4 S., R. 6 E., and SE  $\frac{1}{8}$  sec. 32, T. 3 S., R. 6 E.)

minimum stratigraphic displacement on the reverse fault is in excess of 4000 feet; Precambrian metamorphic rock on the upthrown (northeast) side lies against all stratigraphic units from Cambrian to Pennsylvanian of the downdropped side. Southeast of the cross fault, minimum stratigraphic displacement on the reverse fault is approximately 1600 feet; Cambrian to Mississippian strata of the upthrown side lie against Cretaceous strata of the downdropped side.

In the NE 1/4 sec. 1, T. 4 S., R. 5 E., the South Cottonwood Creek fault is concealed by volcanic rock. Two other faults meet at approximately the same location, one of which trends east from the junction and the other of which trends southwest. The actual junction of the faults is concealed by the volcanic cover; consequently, the question arises as to what happens to the South Cottonwood Creek fault? The possibility exists that it may extend beneath the volcanic cover and retain its northwest strike. On the south side of the east-striking fault, however, Jurassic strata are present and occur approximately at the horizon expected if they are to be continuous with equivalent Jurassic strata on the opposite side of the ridge (i. e., in the South Cottonwood Creek drainage). This suggests that the South Cottonwood Creek fault does not retain its northwest strike beneath the volcanic rock as there is apparently little or no stratigraphic displacement across such a trend.

The southwest trending fault radiating from the junction is a reverse fault (up on the southeast, down on the northwest) that exhibits a small component of left-lateral strike-slip movement. It dips steeply to the

southeast, has a stratigraphic displacement of approximately 150 feet, and a southwest termination near South Cottonwood Creek. The minimal displacement and the rather abrupt termination of this fault indicate that it is not the continuation of the South Cottonwood Creek fault. The stratigraphic displacement on the east trending fault, however, is far in excess of that of the southwest trending fault and compares favorably with that of the South Cottonwood Creek fault. The east trending fault, therefore, is most likely a continuation of the South Cottonwood Creek fault. It is shown as a vertical fault because evidence is insufficient to verify its inclination. The fault could be traced no farther east than the SE 1/4 sec. 32, T. 3 S., R. 6 E.

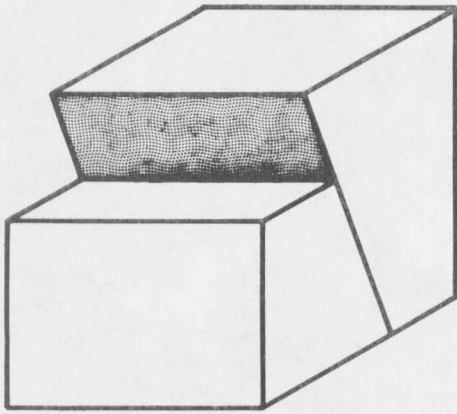
Sedimentary strata located in sec. 31 and E 1/2 sec. 35, T. 3 S., R. 5 E., occur on the upthrown side of the South Cottonwood Creek fault and commonly dip to the south and southwest. An exception to the common direction of dip occurs in sec. 31, T. 4 S., R. 6 E., where the Upper Cambrian Pilgrim and Red Lion formations are deformed into a southeast plunging syncline; the syncline is truncated on the south by the east trending part of the South Cottonwood Creek fault. A cross-section of the syncline is shown by W. M. Weber (1965, Unpub. M.S. Thesis, Mont. State Univ., Bozeman, p. 49). Also, a few beds of the Lodgepole Limestone are overturned adjacent to the South Cottonwood Creek fault in the E 1/2 SW 1/4 sec. 36, T. 3 S., R. 5 E. These data suggest that the strata in the above mentioned sections have been moved southwestward (as a unit), as well as having been thrust upward. The

throw of the South Cottonwood Creek fault is sec. 35, T. 3 S., R. 5 E., is approximately 1600 feet and the inclination is believed to be steep, indicating that southwestward translocation of the strata is not great.

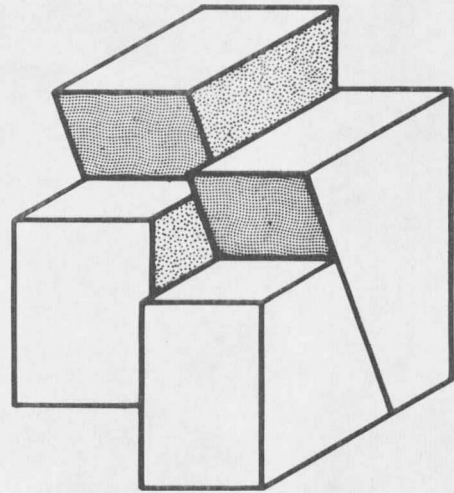
Sedimentary strata south of the east trending extension of the South Cottonwood Creek fault are strongly faulted, folded, brecciated, silicified, and partially covered by volcanic strata. Interpretations of the structural and stratigraphic relationships are, for the most part, based on a minimum (if not an insufficient) amount of data and are therefore highly conjectural. The series of faults existing in this area may be splay faults which represent the southeast termination of the South Cottonwood Creek fault.

Strata exposed west of fault 1 (figure 5, both cross-sections) are known to be overturned to the west. That the fault dips steeply to the east is not certain, but the dip and relative movement indicated are consistent with other structural data of the map area. In both interpretations (figure 5, a, b), as a unit all strata east of fault 1 exhibit a reverse relationship to the footwall block. The relative amount of movement along individual faults varies.

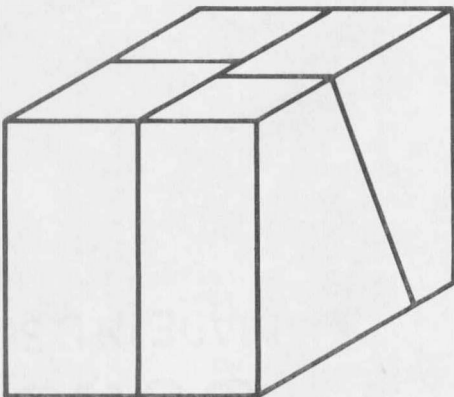
Field evidence suggests that the Mission Canyon and Amsden strata in the NE 1/4 sec. 6, T. 4 S., R. 6 E., may be overturned to the south. Proof of the overturning is lacking because of extensive deformation of the strata, but figure 5a shows a possible relationship if this is the case. The difficulty with the interpretation arises along fault 2; the upward movement of strata east of the fault is not consistent with the



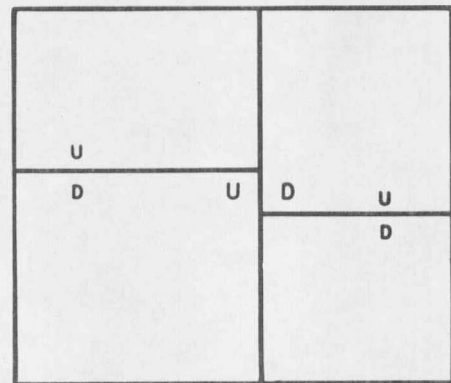
A-Reverse faulting



B-Vertical faulting



C-Erosion



Plan view

Figure 6. Diagrammatic illustration of development of the South Cottonwood Creek fault at its intersection with the Wheeler Gulch fault.

drag exhibited by strata on the west side of the fault. Figure 5b shows another interpretation, which assumes that the Mission Canyon and Amsden strata are not overturned. In this interpretation the drag exhibited along fault 2a is not inconsistent with the direction of movement indicates. Both interpretations are consistent with local and regional structural data. Figure 5b is the more acceptable in that it is the least spectacular in terms of "structural gymnastics." By contrast, the deformation north of the east trending extension of the South Cottonwood Creek fault is much less than that south of it; the interpretation required for figure 5a, therefore, is also reasonable.

Undisrupted Tertiary volcanic rocks in part overlies the southwest trending fault (in South Cottonwood Creek drainage), the South Cottonwood Creek fault and the east trending extension of it (including the splay faults). The volcanic rocks are post-late early Eocene in age, and movement on the faults must have ceased prior to their deposition.

Structures associated with the South Cottonwood fault: Along the South Cottonwood Creek fault a series of minor thrust faults is developed each of which dips toward the main fault. Cross-section C-C<sup>1</sup> (plate I) shows a group of imbricated thrust faults occurring in sec. 35, T. 3 S., R. 5 E; the dip of each upward succeeding fault is steeper than that of any fault below it. The thrust slices were apparently brought up as drag phenomena along the South Cottonwood Creek fault.

In the west-central part of sec. 32, T. 3 S., R. 6 E., a small lead deposit is present in Precambrian metamorphic rock. A small fault occurs south of the deposit in sedimentary strata and may extend into the metamorphic rock, thus affording a weakness zone along which the lead deposit formed.

### Cross Faults

Developing simultaneously or possibly (in part) somewhat earlier than the South Cottonwood Creek fault was the Wheeler Mountain monocline, so named (herein) for its prominent exposure on the southeast side of that mountain (sec. 2 and 11, T. 4 S., R. 5 E.). On the southwest side of the mountain the beds dip gently to the northeast, begin to increase in dip (northeast) near its crest, and then lessen to a gentle northeast dip again on the flanks of the mountain near South Cottonwood Creek. Associated with the monocline is a series of transverse faults that are oriented approximately perpendicular to the axis of the fold and in part owe their development to different degrees of folding of the monocline.

Adjacent to Wheeler Gulch (sec. 2 and 11, T. 4 S., R. 5 E.) is a fault that trends south-southwest and is here named the Wheeler Gulch fault. In sec. 36, T. 3 S., R. 5 E., this fault transects the South Cottonwood Creek fault and, as noted earlier, the minimum stratigraphic displacement on that fault is different on opposite sides of the Wheeler Gulch fault. The Wheeler Gulch fault plane (in sec. 36) is apparently vertical and exhibits a stratigraphic displacement of

approximately 400 feet. Quadrant Quartzite of the upthrown (northern) block is equal in elevation to Jurassic strata of the downdropped block. A plan view of the structure in section 36 suggests that there may be a small component of right-lateral strike-slip movement developed along the Wheeler Gulch fault. However, this apparent movement can also be explained by vertical displacement on the same fault, as is illustrated in figure 6. Actually both types of movement may exist, but the dip-slip is believed by the writer to be by far the more significant.

The thickness of the Quadrant northwest of the fault is 300 feet, whereas it is only 200 feet thick on the southeast side; the Amsden Formation exhibits a similar relationship. This suggests that the Wheeler Gulch fault was active in Pennsylvanian time and that subsequently Laramide faulting developed along a pre-existing structural trend. McMannis (1955) has noted similar occurrences for Pennsylvanian as well as other strata in the Bridger Range, and Alpha and Fanshawe (1954) and Sonneberg (1956) have also found evidence to indicate minor Paleozoic (and Mesozoic) movement on present day structural trends in central and south-central Montana.

Farther to the northeast (i. e., northeast of the South Cottonwood Creek fault) the Wheeler Gulch fault enters Precambrian metamorphic rock, but could not be traced farther because of the heavy overgrowth and lack of outcrops.

Adjacent to Wheeler Gulch and near the southern margin of the map area, the fault is vertical and again exhibits a stratigraphic displacement

of approximately 400 feet; lower Lodgepole Limestone on the upthrown (northern) block lies against upper Lodgepole Limestone of the down-dropped block. Southwest of the map area (in the Garnet Mountain quadrangle) McMannis and Chadwick (1964) mapped the southwest extension of the Wheeler Gulch fault. There (sec. 10, 11, 14, 15, T. 4 S., R. 5 E.) it changes from a vertical fault to a northwest striking-northeast dipping thrust fault, which implies a minor left-lateral component of strike-slip movement on the main north-northeast part of the fault.

Folding along the monocline seems to be more intense on the southeast side of the Wheeler Gulch fault than on the northwest side. Thus greater thrust displacement on the northwest side of the fault could be compensated by the tighter folding (greater shortening) present on the southeast side.

Northwest of the Wheeler Gulch fault is a normal fault that dips to the northwest and trends southwest, transecting sec. 9, 3, 2, T. 4 S., R. 5 E., and sec. 35, T. 3 S., R. 5 E. In section 9 Precambrian metamorphic rock (upthrown block) is emplaced against Meagher Limestone, whereas in section 3 (at the head of Dry Gulch) upper Mission Canyon Limestone of the downdropped (northwestern) block lies against upper Lodgepole Limestone of the upthrown block. The stratigraphic displacement at each location is approximately 350 feet. The fault apparently dies out in the SW 1/4 sec. 35, T. 3 S., R. 5 E., as it does not exist northeast of South Cottonwood Creek. Undisturbed

Eocene volcanic rock conceals the fault to the southwest (S  $\frac{1}{2}$  sec. 9, T. 4 S., R. 5 E.), indicating that movement on the fault ceased previous to that time. Reverse drag occurs on both sides of the fault (in the NE  $\frac{1}{4}$  SW  $\frac{1}{4}$  sec. 3, T. 4 S., R. 5 E.) and its origin will be discussed with that of the next fault to the northwest.

Transecting the monocline one mile farther to the northwest is a reverse fault that trends southwest in sec. 33, 34, T. 3 S., R. 5 E., changing trend to nearly due south in sec. 4, T. 4 S., R. 5 E. The fault dips steeply to the northwest and has a stratigraphic displacement of approximately 550 feet in the NE  $\frac{1}{4}$  sec. 33. At this location upper Jefferson Limestone of the upthrown (northwestern) block lies against lower Mission Canyon Limestone of the downthrown block. Farther to the northeast the fault probably connects with the South Cottonwood Creek fault, but valley alluvium and colluvium (in SW  $\frac{1}{4}$  sec. 27, T. 3 S., R. 5 E.) conceal any such connection. The south end of the fault is concealed by undisturbed Eocene volcanic rock, indicating a minimum age for movement on the fault.

Reverse drag is exhibited on the downdropped (southwest) side of the fault in sec. 33, and occurs on the opposite end of the same block for which reverse drag was noted along the normal fault previously described. Figure 7 is a sketch of the relationship of reverse drag to the stratigraphic displacement along the two faults. The block bordered by the two faults may have moved upward adjusting itself after the main phase of faulting occurred. Motion of the block would not have been entirely vertical but slightly to the southeast, too, as guided by

the already existing faults.

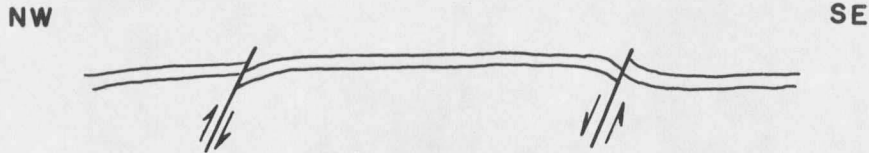


Figure 7. Sketch of reverse drag relationships along two cross faults.

The northwesternmost of the faults transecting the monocline occurs in sec. 28, 32, 33, T. 3 S., R. 5 E. In sections 28 and 33 it trends southwest and is a normal fault dipping steeply to the northwest. In the SW  $\frac{1}{4}$  NW  $\frac{1}{4}$  sec. 33, the stratigraphic displacement is approximately 500 feet; basal strata of the Lodgepole Limestone of the downdropped (northwest) block are adjacent to the lower part of the Pilgrim Limestone of the upthrown block. In section 32 the fault changes to a more westerly strike, maintaining its normal fault attitude with the fault plane dipping steeply to the north.

#### Little Bear Creek Fault and Related Structures

The little Bear Creek fault, here named for its proximity to that stream, trends northwest and is apparently of high angle reverse nature, as suggested by overturned strata on the downdropped side of the fault. The minimum stratigraphic displacement is approximately 800 feet with Meagher Limestone of the downdropped (southwest) block in contact with Precambrian metamorphic rock of the upthrown block. The southern part of the fault is buried by volcanic rock. The fault apparently continues southeastward beneath the volcanic cover as suggested by the similarity of relationships of the Paleozoic and Precambrian rocks in secs. 7 and 8,

T. 4 S., R. 5 E. The volcanic rock is undisturbed and is of Eocene age, indicating that movement on the fault ceased prior to that time.

Two southwest trending faults are associated with the Little Bear Creek fault. The southernmost, in sec. 7, T. 4 S., R. 5 E., is considered a vertical fault as field evidence is insufficient to determine its inclination. Stratigraphic displacement on the fault is approximately 200 feet, with Precambrian metamorphic rock of the upthrown (northwest) side adjacent to lower Meagher Limestone of the downdropped block.

The other more westerly trending fault in sec. 6, T. 4 S., R. 5 E., and sec. 1, T. 4 S., R. 4 E., exhibits a normal relationship, with the fault plane dipping steeply to the north. Near Willson Creek the stratigraphic displacement is approximately 400 feet, with Precambrian metamorphic rock of the upthrown (southern) block against Meagher Limestone of the downdropped block. Near Little Bear Creek the relationship is not clear, but the displacement appears to be less and may not exceed 100 feet.

The fault could not be traced into the metamorphic rock south of Willson Creek, but two lines of evidence suggest that it may exist there: (1) a draw is present in the metamorphic rock along the projection of the fault; and (2) a reversal in dip of the folia occurs across the projection of the fault in the SE  $\frac{1}{4}$  sec. 2, T. 4 S., R. 4 E. The northeast terminus of the fault seems to be at the junction with the Little Bear Creek fault. Connection of this fault with the northeast trending fault in the NE  $\frac{1}{4}$  sec. 6, T. 4 S., R. 5 E., does not appear to be valid because: (1) the two faults are not continuous, but intersect the Little Bear Creek fault at different

places; and (2) the northeast striking fault (NE  $\frac{1}{4}$  sec. 6, T. 4 S., R. 5 E.) and that part of the Little Bear Creek fault north of its junction with the latter fault were apparently active in the Quaternary. This is suggested by the preservation of landslide material in the NE  $\frac{1}{4}$  sec. 6, T. 4 S., R. 5 E., and in E  $\frac{1}{2}$  sec. 31 and W  $\frac{1}{2}$  sec. 32, T. 3 S., R. 5 E. The landslide debris is apparently preserved on the downdropped sides of these two faults. (This indicates a reversal in movement for that part of the Little Bear Creek fault being discussed.)

Associated with the Little Bear Creek fault is a syncline, the axis of which trends nearly parallel to the fault. The sedimentary strata of the southwestern limb of the syncline have been tilted in unity with underlying basement blocks, except where influenced by the aforementioned southwest and west trending faults. Strata of the northeastern limb have been turned up sharply and slightly overturned along the Little Bear Creek fault.

The Little Bear Creek fault, the syncline, and the two transverse faults have a closely related history of development. As stress was applied from the east-northeast, the northeast block of the Little Bear Creek fault was thrust upward and strata of the downdropped block were simultaneously being deformed to produce a synclinal structure. The southwest trending faults probably developed concurrently, due to differential stress developed during the compression and movement on the Little Bear Creek fault.

### Gallatin Range Front Fault

One of the most significant structures in the map area is the Gallatin Range front fault or fault zone. Hackett and others (1960, p. 50) and Robinson (1961, p. 1009) state that the necessary data to prove the existence of this fault is lacking, but the present writer does not concur. The following lines of evidence suggest that the fault does exist: (1) the trend of the mountain front is linear; (2) landslide debris is concentrated along the mountain front; (3) much of the landslide material preserved along the mountain front is comprised of volcanic rock, yet such rock is commonly absent in the immediately adjacent mountain range, thus suggesting preservation on the downdropped block; (4) pre-Tertiary outcrops are virtually absent in the basin proper, indicating that the older rock must lie at considerable depth below the Tertiary and younger materials of the basin; (5) Tertiary strata locally abut against the mountain front with a steep plane of contact (SE  $\frac{1}{4}$  sec. 29, T. 3 S., R. 5 E.); (6) pre-Tertiary strata of the mountain range generally dip gently to the northeast, but near the range front (sec. 32, 35, and 36, T. 3 S., R. 4 E.) the dip increases and changes direction so that it is toward the proposed fault; (7) M. D. Mifflin (1963, Unpub. M. S. Thesis, Mont. State Univ., Bozeman) has shown that considerable vertical displacement of rocks has occurred along the suggested fault trend west of the map area; (8) McMannis and Chadwick (1964) show horizontal offset of the Squaw Creek-Cherry Creek fault, the displacement occurring along the same range front trend; (9) in the SW  $\frac{1}{4}$  sec. 14, SE  $\frac{1}{4}$  sec. 15, and the NE  $\frac{1}{4}$

sec. 22, T. 3 S., R. 5 E., evidence indicates that Precambrian metamorphic rock has been disrupted by the fault or a branch of it. Metamorphic rock in the disrupted zone is highly sheared, fractured, and contorted. Folia of the southeast block dip  $70^{\circ}$  to the southeast whereas folia on the opposite side dip approximately  $10^{\circ}$  northeast, strongly suggesting faulting. Also, a remnant of volcanic rock (not landslide debris) is preserved on the downdropped (northwest) block; (10) striking parallel to the trend of the suggested fault and northwest of it, a subsurface fault has been detected through the use of gravity and magnetic data (Davis and others, 1965).

The northeast trending Gallatin Range front fault extends from the southern margin of Spanish Creek Valley (southwest of the map area) to the mouth of Bear Canyon northeast of the map area. The fault is at least 23 miles long, forming the mutual boundary of the Gallatin Range, the Gallatin Valley, and the Tertiary deposits of the latter. The fault has a normal relationship and dips steeply to the northwest. Strata of the upthrown block range from Precambrian to Eocene (volcanic rock of the Tom Lay Prairie area), and those of the downthrown block range from Miocene to Recent except: (1) on the southwest end of the fault where Tertiary volcanic rock and Precambrian metamorphic rock are also on the downdropped side, and (2) at the mouth of Middle Creek (SW  $\frac{1}{4}$  sec. 14, and SE  $\frac{1}{4}$  sec. 15, T. 3 S., R. 5 E.) where a sliver of Precambrian metamorphic rock is downdropped relative to the main mountain mass (but is still upthrown relative to the basin).

Martin D. Mifflin (1963, Unpub. M. S. Thesis, Mont. State Univ., Bozeman) estimated stratigraphic displacement on the fault to be between 1500 feet and 2500 feet near the mouth of Gallatin Canyon, west of the map area. His estimate is based on the similarity of two vertically offset surfaces bearing basic volcanic remnants. Displacement may be greater on the northeast end of the fault. Peale (1896) postulated eastward tilting of the basin to explain the eastward dip of the Tertiary strata therein. Robinson (1961, p. 1009) noted that older Tertiary rocks dominate the western half of the basin whereas the eastern half is dominated by younger Tertiary strata. He attributed this to recurrent tilting of the basin, which suggests greater displacement on the northeast end of the Gallatin Range front fault.

The range front fault apparently exhibits a left-lateral component of strike-slip movement as it seems to offset the Salesville fault from its projected continuation--the South Cottonwood Creek fault. Such movement indicates that the range front fault is younger and essentially uninfluenced by the west-northwest trends.

✓Some control for dating movement on the range front fault exists in the SE  $\frac{1}{4}$  sec. 21, T. 3 S., R. 5 E. The alluvial fan deposit (Qf) is undisturbed along the fault trace. Late Miocene--early Pliocene fluvial deposits (T.), however, are disturbed as they abut against Precambrian metamorphic rock. Thus movement had ceased prior to formation of the alluvial fan.

### Subsurface Faults of Basin

Gravity and magnetic data of Davis and others (1965) suggest that a "bedrock trough" exists beneath the southeastern margin of the Three Forks basin. The northern boundary of this trough is formed by a buried fault located southeast of Gallatin Gateway; the southern boundary is formed by a buried fault trending roughly parallel to the Gallatin Range front fault in the map area, but is in part coincident with the latter fault to the northeast (see plate I). The southern boundary fault extends from the mouth of Gallatin Canyon to the mouth of Bear Canyon (northeast of the map area), a distance of about 17 miles. Displacement on this fault is in excess of 4000 feet beneath South Cottonwood Creek, with the floor of the trough (bottom of basin fill) computed to be 6000 feet below the surface (Davis and others, 1965, p. 3). A step fault relationship must therefore exist between the trough and the Gallatin Range front. The fault on the northwest side of the trough extends northeast from the mouth of Gallatin Canyon for more than 8 miles, has at least 2000 feet of vertical displacement, and may intersect the southern boundary fault near the mouth of Gallatin Canyon. Northwest of the northern boundary fault the bedrock surface rises gradually to bedrock outcrops in the Camp Creek Hills (Davis and others, 1965, p. 3).

## GEOMORPHOLOGY

Discussion of the geomorphic history of the map area is confined to two topics: interpretation of the glacial features and interpretation of the erosion surfaces at the front of the Gallatin Range. For a summary of the Cenozoic history of the Gallatin Range, the reader is referred to McMannis (1964), McMannis and Chadwick (1964), and Horberg (1940).

### Glacial Geology

Blackwelder (1915) named glacial deposits in the Wind River Mountains of Wyoming the Bull Lake and Pinedale glaciations (early and late Wisconsin respectively). There has been a growing tendency to attempt correlation of Wisconsin glacial features of the Rocky Mountains with these two stages.

### Early Wisconsin Glaciation

Glacial deposits tentatively assigned a Bull Lake age occur at the front of the range high on an interstream divide between Little Bear Creek and Big Bear Creek (sec. 5, 6, and 8, T. 4 S., R. 5 E., and sec. 31, and 32, T. 3 S., R. 5 E.). The deposits predominantly consist of subangular cobbles and boulders of Meagher Limestone, Precambrian gneiss, and Pilgrim Limestone, with samples of other formations making up a small percentage of the deposits.

The cobbles and boulders exposed at the surface are not deeply weathered. Limestone types at depth in the deposit are only slightly weathered, but the metamorphic rocks at depth are typically deeply weathered. No striated or faceted rocks were found. A pit dug in the

glacial deposit of Tom Lay Prarie revealed a not-too-well developed soil profile. The upper part of the B-horizon is dominantly sand, but a sample kneaded with a slight amount of water tended to maintain a ball, thus indicating the presence of a significant amount of clay. The lower part of the B-horizon contains peds  $\frac{1}{4}$  to  $\frac{1}{2}$  inches in diameter, indicating a greater amount of clay than in the upper part. The soil is "weak" but is still better developed than that of a Pinedale deposit (personal communication, J. Montagne, 1966). The advanced state of weathering of the metamorphic rocks also suggests an age older than Pinedale. Also the abundance of cobble size limestone rocks is not suggestive of a pre-Bull Lake age as such deposits are typically characterized by boulder size limestone types, if any limestone remains at all. A Bull Lake age for the deposit seems to be the most reasonable.

An interesting and significant problem exists with respect to the Paleozoic limestone present in the drift. It has no potential source area within the drainage system as the system presently exists, without crossing interstream divides or incised valleys. A major drainage change since Pinedale glaciation is unlikely, a conclusion suggested by the fact that Pinedale deposits of the Middle Creek drainage (and regionally) are confined to the existing valleys. However, it is not impossible that considerable downcutting has occurred since Bull Lake time, and that the presently deeply incised canyons were not yet cut. Thus, a source for the limestone could possibly have existed in Bull Lake time that would not require crossing an incised stream canyon. A possible source area for the glacial deposits being considered could then have

been in the northeast corner of the Garnet Mountain quadrangle.

### Other Glacial Deposits

Small glacial deposits occur at two locations in the South Cottonwood Creek drainage. They have not been assigned an age because this would require a knowledge of the glacial features much farther up the canyon, an objective not within the scope of this Thesis. However, the physical characteristics of the deposits will be noted here for future reference.

In the W  $\frac{1}{2}$  sec. 7, T. 4 S., R. 6 E., cobbles and boulders of Precambrian gneiss occur on a steep slope at about 400 feet above the present stream level and at an average elevation of about 6600 feet. The rocks are subrounded, are not striated, faceted, or deeply weathered, and are set in a poorly developed soil profile.

In the SW  $\frac{1}{4}$  sec. 1, T. 4 S., R. 5 E., subrounded Paleozoic limestone cobbles are present on a steeply sloping hillside. The deposits occur approximately 600 feet above the present stream level and at an average elevation of about 6800 feet. The cobbles are subrounded, and are neither striated nor faceted, but they are deeply weathered. The weathering may be due in part to their position on the northeast slope of the ridge. Moisture remains longer on such slopes and the vegetation is dense, two factors which promote weathering.

### Erosion Surfaces

The geologic map (Plate I) shows approximately what are believed to be the dissected remnants of three major erosion surfaces: Q<sub>S1</sub>, Q<sub>S2</sub>, and Q<sub>S3</sub>. The remnants as outlined suggest a gentle northeast

slope of the originally continuous surfaces. Origin of the erosion surfaces is in doubt except that they were probably cut by streams issuing from the Gallatin Range, as suggested by the close correlation of surficial deposits ( $Q_{0a}$ ) and the probable source areas. Northwest of the map area, immediately west of the Gallatin River, M. D. Mifflin (1963, Unpub. M. S. Thesis, Mont. State Univ., Bozeman) found a steepening of the (northeast-sloping) erosion surfaces toward the Gallatin River Canyon, with the older (higher) erosion surfaces inclined more than the lower surfaces. He was not able to ascertain for certain the cause (or causes) of the differing degrees of slope. Mifflin believed, however, that the erosion surfaces represented periods of increased discharge and detrital increment of the Gallatin River, directly related to periglacial climatic conditions in the drainage basin. Thus he correlated erosion surfaces (terraces) with stades of glaciation, his terrace No. 1 was designated as a Pinedale feature. The basis for this decision was that "outwash deposits from the youngest alpine glaciation in the Spanish Peaks graded to a terrace which appears to be equivalent to terrace No. 1" because of its position relative to present river level. "

The erosion surfaces of the map area may have resulted from the same phenomena. Proof of this by correlation of erosion surfaces in the map area with those of Mifflin's area is not feasible, however, because: (1) the rock types of the surficial deposits are different. In the map area, the surficial rocks are greater than 90% volcanic rocks, and any other lithologic types present reflect only the immediate sources

near canyon mouths (at the range front). (2) Correlation of erosion surfaces in the two map areas on the basis of elevation is ruled out. The erosion surfaces of the writers' map area are higher than those of Mifflins' area, and are separated from these by the broad Gallatin River valley bottom. Faulting along the Gallatin Range front fault (and probably the buried trough faults as well) is quite likely responsible for some of the elevation differences. Therefore, no glacial stade--erosion surface correlation is possible.

Northward tilting of the Gallatin Valley is suggested by (1) the gentle northward inclination of the surfaces in the map area, and steep southwest slopes; and (2) headward erosion proceeding toward the southwest (migrating up the gentle slope). Thus the erosion surface inclinations do not represent the gradient (or gradients) of the stream which cut them; the inclinations are steeper now, and are certainly steeper than the inclination of the present Gallatin River flood plain. These data suggest that the tilting of the erosion surfaces may be related to recurrent or continuing northerly tilt of the Gallatin Valley.

## CONCLUSIONS

The following is a list of the major conclusions derived from work in the map area.

(1) The sedimentary sequence is considerably thinner than equivalent sequences in adjacent areas.

(2) Trilobites of the genus Glossopleura were found in the Flathead Quartzite and are the only known occurrence of trilobites in the formation. They indicate that the Flathead <sup>in</sup> the map area is younger than previously believed.

(3) A conglomerate similar to the Sphinx Conglomerate is present near the front of the range.

(4) The main deformation occurred during Laramide time, starting probably in the Late Cretaceous and effectively ceasing by the time of Eocene volcanism.

(5) The structural movements are not inconsistent with an east-northeast compressive stress even though the trends of structures are not those expectable <sup>if</sup> ~~is~~ they were formed entirely by such a stress orientation.

(6) Some structural trends of the map area existed prior to Laramide deformation.

(7) Ample evidence exists to prove that the Gallatin Range front fault does exist.

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# GEOLOGY OF A PART OF THE NORTH END OF THE GALLATIN RANGE, GALLATIN COUNTY, MONTANA

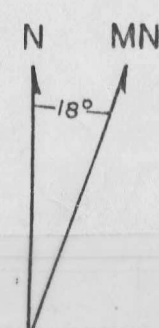
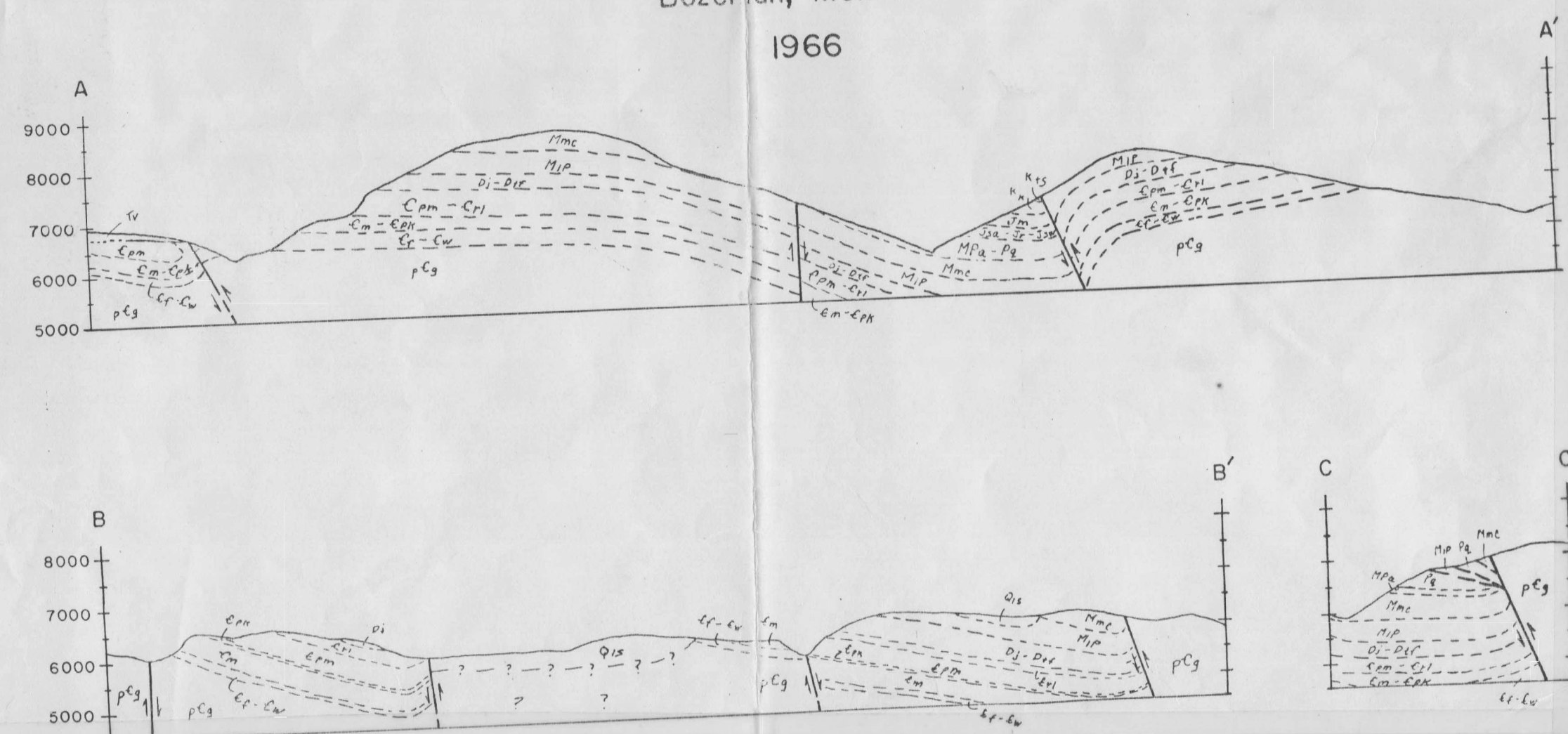
by  
Russell G. Tysdal

presented to the faculty of the Department of Earth Sciences  
in partial fulfillment of the requirements for the degree of  
Master of Science  
at  
Montana State University  
Bozeman, Montana  
1966

- |           |                      |               |                |            |          |           |                             |
|-----------|----------------------|---------------|----------------|------------|----------|-----------|-----------------------------|
| PALEOZOIC | CAMBRIAN             | DEV. JURASSIC | CRET. TERTIARY | QUATERNARY | CENOZOIC | Qal       | RECENT ALLUVIUM             |
|           |                      |               |                |            |          | Qa        | ALLUVIAL FAN DEPOSIT        |
|           |                      |               |                |            |          | Qoa       | OLDER ALLUVIUM              |
|           |                      |               |                |            |          | Qs        | EROSION SURFACE             |
|           |                      |               |                |            |          | Qg        | GLACIAL DEPOSIT             |
|           |                      |               |                |            |          | Qls       | LANDSLIDE DEPOSIT           |
|           |                      |               |                |            |          | Ti        | FLUVIATILE DEPOSIT          |
|           |                      |               |                |            |          | Li        | IGNEOUS INTRUSIVE ROCKS     |
|           |                      |               |                |            |          | Lv        | VOLCANIC BRUCCIAS and FLOWS |
|           |                      |               |                |            |          | Lcgl      | Eocene? CONGLOMERATE        |
| MESOZOIC  | JURASSIC             | CRETACEOUS    | TERTIARY       | QUATERNARY | CENOZOIC | Kts       | THERMOPOLIS SHALE           |
|           |                      |               |                |            |          | Kk        | KOOTENAI FORMATION          |
|           |                      |               |                |            |          | Jm        | MORRISON FORMATION          |
|           |                      |               |                |            |          | Jsw       | SWIFT FORMATION             |
|           |                      |               |                |            |          | Jr        | RIERDON FORMATION           |
|           |                      |               |                |            |          | Jso       | SAWTOOTH FORMATION          |
|           |                      |               |                |            |          | Pq        | QUADRANT FORMATION          |
|           |                      |               |                |            |          | MPa       | AMSDEN FORMATION            |
|           |                      |               |                |            |          | Mmc       | MISSION CANYON LIMESTONE    |
|           |                      |               |                |            |          | PALEOZOIC | CAMBRIAN                    |
| Dtf       | THREE FORK FORMATION |               |                |            |          |           |                             |
| Dj        | JEFFERSON LIMESTONE  |               |                |            |          |           |                             |
| El        | RED LION FORMATION   |               |                |            |          |           |                             |
| Epm       | PILGRIM LIMESTONE    |               |                |            |          |           |                             |
| Epk       | PARK SHALE           |               |                |            |          |           |                             |
| Em        | MEAGHER LIMESTONE    |               |                |            |          |           |                             |
| Ew        | WOLSEY SHALE         |               |                |            |          |           |                             |
| Ef        | FLATHEAD QUARTZITE   |               |                |            |          |           |                             |
| Eg        | METAMORPHIC GNEISS   |               |                |            |          |           |                             |

- |                                                           |                        |
|-----------------------------------------------------------|------------------------|
| 40°                                                       | Strike and dip of beds |
| 60°                                                       | Overturned beds        |
| Vertical                                                  | Vertical beds          |
| 30°                                                       | Foliation              |
| 50°                                                       | Vertical foliation     |
| Strike and dip of flow banding (igneous intrusive rocks)  |                        |
| Synclinal axis                                            |                        |
| Monoclinical axis                                         |                        |
| Contact                                                   |                        |
| Fault                                                     |                        |
| Reverse fault, showing dip                                |                        |
| Subsurface fault, inferred from gravity and magnetic data |                        |
| Boundary of map area                                      |                        |

Contour Interval 40 Feet



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