



General geology and geomorphology of the Middle Creek area, Gallatin County, Montana
by William Mark Weber

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE in Applied Science
Montana State University
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Abstract:

The stratigraphic section in the Middle Creek area, Gallatin County, Montana, is comprised of more than 4,400 feet of Paleozoic and Mesozoic sedimentary rocks. Rocks of known Ordovician, Silurian, and Triassic age are not present in the map area.

The sedimentary sequence is underlain by metamorphic gneiss and schist of Precambrian age, and is unconformably overlain by volcanic breccias and flows of middle Eocene age.

The existing structure of the area is thought to be the result of recurrent deformation along structural trends established in Precambrian time and subsequent Laramide compressional deformation and segmentation of the pre-Laramide structure.

The oldest and most extensive stage of glaciation has been tentatively correlated with the Marble Point stage which is late pre-Wisconsin in age. This glaciation was not restricted to the Middle Creek drainage but rather was a large ice sheet which capped most of the crest of the Gallatin Range.

Bedrock spurs within Hyalite Canyon suggests that there may have been a maximum of 600 feet of valley cutting between late pre-Wisconsin and early Wisconsin glaciation.

Comparative analysis of the morphology and areal extent of Wisconsin glacial features indicates that two stages of valley glaciation have occurred. Deposits of the earliest advance ' have been tentatively assigned to the Bull Lake stage and deposits of the succeeding advance have been tentatively assigned to the Pinedale stage.

Small terminal moraines indicate that ice of the Neoglacial, Temple Lake and Little Ice Age stages occupied cirques in the higher parts of the Gallatin Range.

GENERAL GEOLOGY AND GEOMORPHOLOGY OF THE MIDDLE
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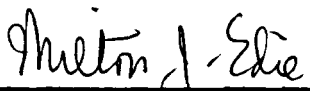
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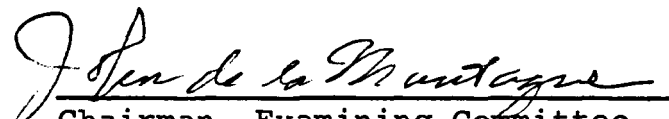
MASTER OF SCIENCE

in

Applied Science

Approved:


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MONTANA STATE COLLEGE
Bozeman, Montana

June, 1965

ACKNOWLEDGEMENTS

Sincere appreciation is extended to the National Science Foundation for the grant which made this study possible and to the Department of Earth Sciences for dispersing a portion of that grant and valuable field equipment to assist my research. I would like to thank Drs. John Montagne and William J. McMannis for their valuable suggestions and time as well as their editorial aid and Dr. Robert A. Chadwick for his critical advice on igneous problems. I would also like to thank my devoted wife, Gail, for typing and helping to prepare the preliminary manuscript and Carol Brooks for typing the final manuscript.

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ABSTRACT

The stratigraphic section in the Middle Creek area, Gallatin County, Montana, is comprised of more than 4,400 feet of Paleozoic and Mesozoic sedimentary rocks. Rocks of known Ordovician, Silurian, and Triassic age are not present in the map area.

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GENERAL GEOLOGY AND GEOMORPHOLOGY OF THE MIDDLE CREEK AREA, GALLATIN COUNTY, MONTANA

INTRODUCTION

Geographic Setting

The area of this field study is located along the Middle Creek drainage in the northern end of the Gallatin Range of south-central Montana. The Gallatin Range lies within the southeastern part of the Northern Rocky Mountain physiographic province. The map area (Figure 1) lies approximately 15 road miles south of Bozeman, Montana, and is bounded on the east, south, and west by the drainage divide of Middle Creek. The northern boundary lies along the Gallatin Range front.

The map area includes approximately 56 square miles of rugged, tree-covered topography ranging in elevation from 5440 feet at the range front to 10,300 feet along the crest of the Gallatin Range at Hyalite Peak. Relatively easy access is gained to the area by the Hyalite Canyon road. Numerous logging roads and Forest Service trails provide access to many of the more remote sections of the area.

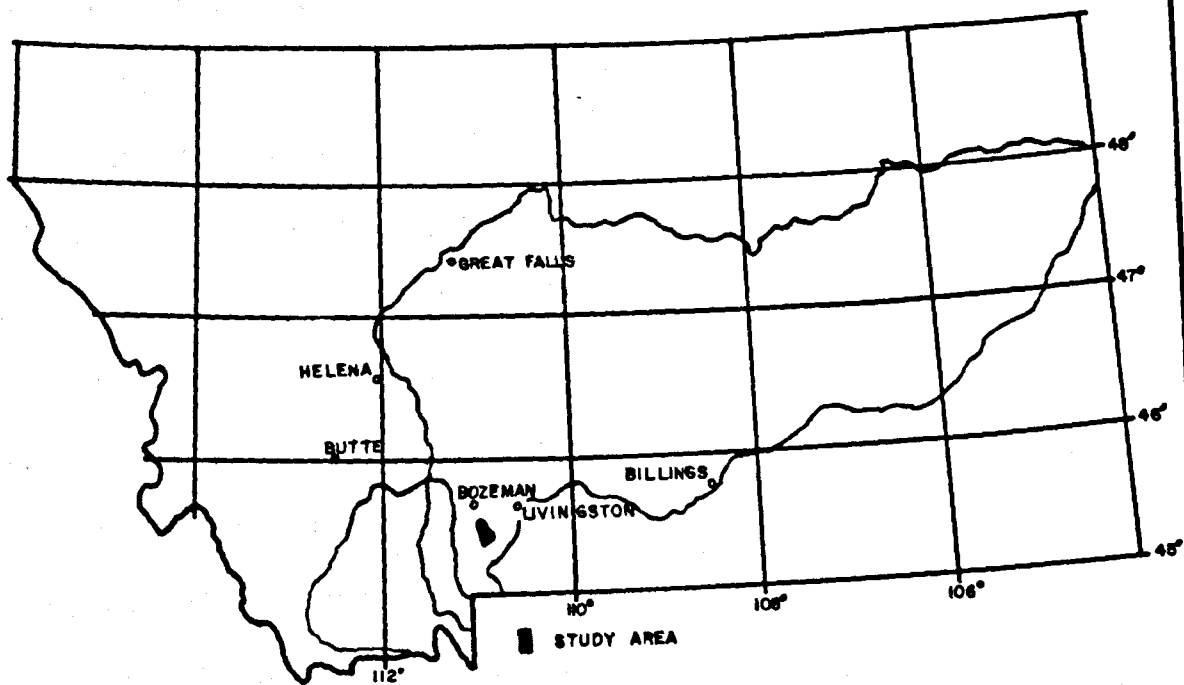


FIGURE 1 - INDEX MAP

Previous Investigations

The bedrock geology of this area has been previously mapped in part by Iddings and Weed (1894) in preparation of the Livingston Folio (No. 1), and in part by Peale (1896) in preparation of the Three Forks Folio (No. 24). These maps and their attendant descriptions are, at best, only generalizations regarding the gross structural trends and stratigraphy. A more detailed map of the area was begun in 1959 by S.A. Alsup as part of his M.S. requirements at Montana State College but this work was never completed. The most recent work in the area has been done by A.E. Roberts (1964) and McMannis and Chadwick (1964). Robert's research was concentrated on the Sourdough Creek drainage which lies directly to the east of the Middle Creek drainage. The southwesternmost part of Robert's map area does, however, fall within the Middle Creek drainage and, therefore, is very relevant to this study. The northeastern part of the Garnet Mountain Quadrangle (McMannis and Chadwick, 1964) also falls within the study area. This map and its related text has been very useful in this study.

No previous geomorphic studies have been done in the map area but the field notes of S.A. Alsup (Unpublished M.S. Thesis, 1960) do mention the general geomorphic characteristics. The work of M.D. Mifflin (Unpublished M.S. Thesis, 1962) and later unpublished data has many regional implications related to the Middle Creek map area which will be discussed at greater length in this paper.

Objectives

The objectives of this study were to construct a geologic map of the bedrock of a selected portion of the map area; to construct a second map of the glacial geomorphology of the map area; to describe rock units and structural and geomorphic relationships encountered in compiling the afore mentioned maps; and to propose a possible correlation of glacial substages within the map area with glacial substages previously described in adjacent regions.

STRATIGRAPHY

Lithologic units in the map area range in age from Precambrian (Archean ?) to Recent. These rocks crop out within the map area in a broad NE-SW trending belt (Figure 2). Although exposures are generally adequate for field mapping, heavy vegetal cover, glacial debris, and Tertiary volcanic cover precluded a detailed stratigraphic study of the formational units represented. The lithologic descriptions and formational thickness are, therefore, generalized. Thicknesses set forth herein were estimated by a detailed study of the literature of previous investigations in nearby areas.

Precambrian

Precambrian rocks are extensively exposed in the northern portion of the map area. The Precambrian is in probable fault contact on the north with Tertiary sediments and in depositional contact with Quaternary alluvial cover, and on the south it is bounded by the Precambrian -- Cambrian contact. One isolated exposure of Precambrian rock is exposed along a

GEOLOGIC MAP OF A PART OF THE MIDDLE CREEK AREA, GALLATIN COUNTY, MONTANA

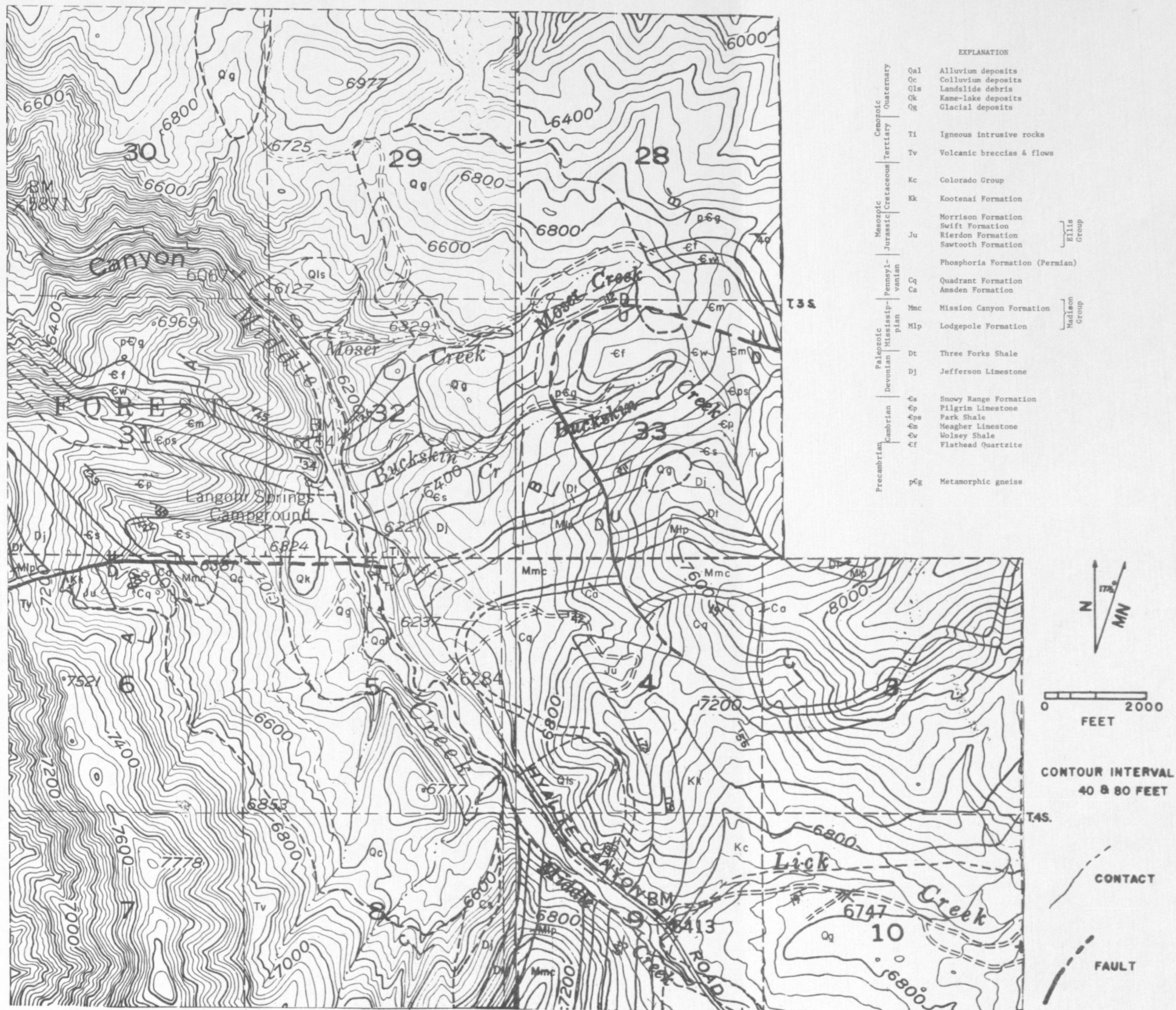


FIGURE 2

R.6.E.

fault at the head of Buckskin Creek in the northern half of sec. 33, T. 3 S., R. 6 E.

The Precambrian rocks consist mainly of gneiss with some schist, amphibolite and metaquartzite present in scattered zones. The gneisses observed are of three main types: feldspathic, garnetiferous, and granitic. For a more detailed description of the Precambrian lithology the readers is referred to Heinrich (1960), McMannis (1955), McMannis and Chadwick (1964), and Reid (1957).

The metamorphic rocks are generally well banded making determination of the attitude of the foliation quite easy. As a detailed analysis of the metamorphic rocks was not made in this study it is not known if the banding is a primary or secondary feature. Joints are well developed in most outcrops and were also measured and plotted. To the north of the map area in the Bridger Range there appears to be a general agreement between the attitude of the foliation and bedding in the overlying sediments in many folds indicating that the metamorphic rocks had been refolded during younger orogenic activity (McMannis, 1955). Little if any parallelism between the metamorphic foliation and the bedding of the

superjacent Cambrian sediments was observed, but the number of observations made and the length of this contact exposed within the map area is insufficient for any conclusions to be drawn on this point.

The metamorphic rocks in the southwestern part of the adjacent Garnet Mountain Quadrangle have yielded a radiogenic age of 2,070 million years or pre-Belt in age. The rocks of the Belt Series are not present in the map area and no subdivision of the Precambrian have been made or mapped in this paper; therefore, all Precambrian terrane is indicated as one unit on the map.

Cambrian

Six formations of Cambrian age were recognized and mapped within the map area. These formations are as follows: Flathead Quartzite; Wolsey Shale; Meagher Limestone; Park Shale; Pilgrim Limestone; and Snowy Range Formation. The total thickness of the Cambrian section is in excess of 1,000 feet. Each formation is discussed in detail below.

Flathead Quartzite

The oldest Cambrian formation recognized in the map area is the Flathead Quartzite which rests unconformably on pre-Belt metamorphic rocks. The formation consists of approximately 100 feet of buff to red medium- to coarse-grained, quartzitic sandstone. Thin to thick bedding with buff and red mottling, which is independent of bedding planes, is typical of the unit. Occasional thin lenses of subround quartz pebble conglomerate also characterize the unit. A basal arkosic zone is present on the east side of Middle Creek in the Langohr Springs Campground. Directly to the west of this arkosic zone the Flathead is absent either because of faulting or non-deposition. Faulting could not be proved in this locale but the arkosic nature of the adjacent Flathead strongly suggests that the unit was never deposited at this site. Many so-called "islands in the Middle Cambrian sea" and other such Precambrian surface irregularities have been described by Lochman-Balk (1956).

The thickness of the unit was interpolated from isopach maps taken mainly from Hanson (1952). The Flathead was assigned a Middle Cambrian age by Deiss (1936).

Wolsey Shale

Conformably and gradationally overlying the Flathead Quartzite is the Wolsey Shale. The formation is covered in most of the map area but where it is exposed it consists of gray-green to maroon, fissile, micaceous shale with a few thin beds of micaceous siltstone. Fucoid markings on bedding planes are a common feature of this unit. West of Langohr Springs Campground the Wolsey seems to lie unconformably upon the pre-Belt metamorphic rocks.

The thickness of the Wolsey was interpolated as 180 feet from an isopach after Hanson (1952). This thickness agrees with the 170 feet measured (McMannis and Chadwick, 1964) on Mount Blackmore just southwest of the map area. The Wolsey was assigned a Middle Cambrian Age by Deiss (1936).

Meagher Limestone

The Meagher Limestone is extensively exposed in the map area as a west-trending resistant ridge. This unit of Middle Cambrian age conformably overlies the Wolsey Shale. The thickness of the formation is approximately 350 feet (S.A. Alsup, personal communication, 1964) and consists of dark gray

thin-bedded limestone with yellow silty partings which give it a characteristic mottled appearance. The contact between the Meagher and the Wolsey is drawn at the base of the lowest ledge-forming limestone in a gradational zone (McMannis, 1955).

The thickness of the Meagher was measured (McMannis and Chadwick, 1964) on Mount Blackmore, adjacent to the study area, where a thickness of 471 feet was obtained. In the southern end of the Bridger Range the thickness of the formation is 368 feet (McMannis, 1955). The thickness of the unit varies considerably over short distances in the Garnet Mountain-Mount Blackmore area. McMannis attributed the variation to intensive shearing or faulting. The thinness of section measured by Alsup may well reflect similar shearing or faulting.

Park Shale

The Park Shale of Middle Cambrian age is poorly exposed in the map area but is easily mapped as it forms a topographic saddle between the more resistant underlying Meagher and overlying Pilgrim formations. Where exposed the formation consists of gray-green to maroon, micaceous, fissile shale with thin

interbedded siltstone and sandstone. The rarity of furoid markings in the Park Shale serves to distinguish it from the similar Wolsey Shale in this area.

In nearby areas the upper part of the formation is characterized by thin interbedded limestones and yellow calcareous shales and the lower part is characterized by a few thin beds of glauconitic limestone and limestone-pebble conglomerate (McMannis and Chadwick, 1964).

An approximate thickness of 200 feet, interpolated from an isopach map after Hanson (1952) agrees well with a thickness of 217 feet measured in the northeastern corner of the Garnet Mountain quadrangle (McMannis and Chadwick, 1964).

Pilgrim Limestone

The Pilgrim Limestone, poorly exposed in the map area, represents the lowest unit of the Upper Cambrian sequence and conformably overlies the Middle Cambrian Park Shale.

The lithology of the formation is generally quite uniform throughout the region (Dorf and Lochman, 1940). To the south and west of the map area, however, McMannis has noted several lithologic variations from the regional pattern

(McMannis and Chadwick, 1964). In the map area the formation is characterized by a lower unit composed of gray-green, coarse, edgewise and flat-pebble conglomerate with interbedded green shale. The upper unit consists of thick-bedded, light and dark gray, oolitic, mottled limestone.

In the map area the so-called upper unit of the Pilgrim Limestone is occasionally exposed and its oolitic and mottled nature makes it an excellent marker unit for field mapping.

The thickness of the Pilgrim Limestone ranges from 363 feet at Bridger Peak, in the Bridger Range (McMannis, 1955) to approximately 200 feet near Chico, Montana (Van Voast, 1964). In the northern part of the Garnet Mountain Quadrangle McMannis measured a thickness of 255 feet for this unit (McMannis and Chadwick, 1964). A thickness of 250 feet was measured in a section near Langohr Springs Campground by S.A. Alsup (personal communication, 1964). This figure agrees well with the work of McMannis and Van Voast but is less than the 300 foot thickness indicated on an isopach map by Hanson (1952).

Snowy Range Formation

The Snowy Range Formation is the uppermost formation of the Upper Cambrian sequence. The unit is poorly exposed in the map area and was mapped largely on the basis of float. The thickness of the Snowy Range Formation ranges from 235 feet near Mount Blackmore (McMannis and Chadwick, 1964) to approximately 300 feet in the Mystic Lake Quadrangle (Roberts, 1964).

The Snowy Range Formation has been subdivided into three members; the Dry Creek Shale, the Sage Pebble-Conglomerate, and the Grove Creek Limestone (Lochman-Balk, 1956). The lowest member is the Dry Creek Shale which conformably overlies the Pilgrim Limestone and consists of gray-green, fissile shale with tan to pink, fine-grained, calcareous, dolomitic, and pure sandstone and/or siltstone beds.

Conformably overlying the Dry Creek Shale is the Sage Pebble-Conglomerate member, which consists of a basal biostromal, columnar limestone of variable thickness and an overlying yellow-brown, medium-bedded limestone and limestone pebble conglomerate interbedded with gray-green fissile shales (Dorf and Lochman, 1940).

Conformably overlying the Sage Pebble-Conglomerate is the Grove Creek Member, originally described as a separate formation by Dorf and Lochman (1940). The unit was later included as the upper member of the Snowy Range Formation by Lockman-Balk (1956).

The best exposure of the formation in the map area is in the SE $\frac{1}{4}$ of sec. 31, T. 3 S., R. 6 E. At this exposure both the Dry Creek Shale and Sage Pebble-Conglomerate members of the Snowy Range Formation are present but no evidence was found to indicate the presence of the Grove Creek Member. In the Mystic Lake quadrangle (Roberts, 1964), directly east of the thesis area, the Grove Creek unit was mapped and reassigned a formational rank.

Roberts also mapped a very thin bed of Bighorn Dolomite of Ordovician age overlying the Grove Creek Member but no exposure or float of this formation could be found in the Middle Creek area. Exposures in the eastern portion of the map area are obscured by glacial debris and colluvium but adequate evidence was found to map other formations in this interval. It was concluded, therefore, that neither the Grove Creek Member of the Cambrian Snowy Range Formation or

the Ordovician Bighorn Dolomite are present in the map area. Detailed stratigraphic studies of this interval in this portion of the Gallatin Range are needed to give the final answer to this problem.

Devonian

Ordovician, Silurian, and lower to Middle Devonian rocks are not present in the map area. This hiatus is represented by an unconformity of slight relief and no measured angularity. The upper Devonian stratigraphic units present in the map area are the Jefferson Limestone and the overlying Three Forks Shale. These formations are discussed in detail below.

Jefferson Limestone

The Jefferson Limestone disconformably overlies the Snowy Range Formation in the map area. The unit is poorly exposed, the best exposures occurring in logging road cuts, and therefore mapping was done largely on the basis of float.

The formation consists of approximately 500 feet of tan to brown, thin to thick-bedded dolomite, dolomitic limestone, and limestone. Interbedded throughout the formation are thin beds of yellow-brown shale and dolomitic siltstone. The

carbonate horizons weather to a distinctive pitted texture which facilitates field recognition. According to McMannis (1962), solution breccias are found at several horizons in the formation. A thick solution breccia and/or shaley dolomite zone generally subdivides the formation into a more massive dolomitic upper member (Birdbear Member) and a lower unit consisting of medium-bedded limestone, dolostone, shale, and lesser solution breccias (McMannis, 1962). Although field exposures are poor in the study area, it was noted that float from the upper part of the Jefferson tends to be more dolomitic than float from lower horizons of the unit.

The Jefferson is considered to be late Devonian by most writers, a small collection of brachiopods made in the map area seems to indicate a somewhat younger late Devonian age (Che Mung) than previously thought (McMannis, 1962, p. 8).

Three Forks Shale

The Three Forks Shale is very poorly exposed in the map area and is usually expressed in the form of a topographic low between the top of the underlying Jefferson and the base of the overlying Lodgepole Formation of Mississippian age.

A section measured in the nearby Mystic Lake area and a partial section measured in the map area indicate that the unit is approximately 105 feet thick in the Middle Creek drainage (McMannis, 1962). McMannis also suggests that the Sappington Formation, a widespread sandy unit, is present between the Three Forks Shale and the Mississippian Lodgepole Formation. This unit was projected into the map area by correlation of units between Mystic Lake on the east and Garnet Mountain on the West.

Although float of the Sappington Formation was found by McMannis (personal communication, 1965) near the drainage divide west of Langohr Springs Campground, no outcrops or float of this formation were found in the map area and, therefore, the Sappington, if present, has been included in the Three Forks map unit. If the inferred thickness of the Sappington Formation is added to the thickness of the Three Forks Shale the total thickness is approximately 150 feet. This agrees well with the thickness for the Three Forks interval measured from geologic cross-sections.

The Three Forks Shale is subdivided into two members in this portion of the Gallatin Range, neither of which contain

much shale (McMannis and Chadwick, 1964). The lower member is called the Logan Gulch Member (Sandburg, 1965) and consists of red, yellow, and greenish-orange silty carbonate breccia. Commonly a dolomitic shale is found at the base and a massive ledge-forming dolomite or limestone at the top.

The upper member is called the Trident Member (Sandburg, 1965) and consists of medium-gray, dense, thin-bedded dolomite or dolomitic limestone with minor gray-green shale partings (McMannis and Chadwick, 1964).

Mississippian

The Mississippian strata in the map area consists of the Lodgepole and Mission Canyon formations of the Madison Group. Together, these formations constitute approximately 1,300 feet of thin- and massive-bedded limestone.

Lodgepole Formation

The Lodgepole Formation, disconformably overlying Devonian strata, (Sandberg, 1965), is the most conspicuous ridge and ledge forming unit within the map area.

The formation, of Early Mississippian age, consists of thin to medium bedded, medium grained limestone. Interbedded

are minor amounts of silty limestone and calcareous shale. An outstanding characteristic of this formation is the abundance of fossil material. Most abundant are crinoids, bryozoans, brachiopods and the coral *Syringopora*.

A section measured in the nearby Garnet Mountain quadrangle (McMannis and Chadwick, 1964) includes four units: a basal 3 to 5 foot black silty shale and carbonaceous siltstone; a lower 225 to 235 feet of dense, thin-bedded, moderately fossiliferous limestone with abundant chert nodules; a middle horizon of 200 to 225 feet of alternating thin-bedded fossil-fragmental limestone and argillaceous limestone or calcareous shale; and an upper 140 to 160 feet of thicker-bedded fossil-fragmental limestone with less argillaceous material and capped by a fine grained dolomitic limestone and yellow-brown, fine-grained, argillaceous, platy limestone.

The total thickness of the Lodgepole in the northeastern part of the Garnet Mountain quadrangle, immediately adjacent to the map area, is approximately 610 feet (McMannis and Chadwick, 1964). Similar sections measured by McMannis

(1955) to the north in the Bridger Range show a total of 750 to 800 feet.

Mission Canyon Formation

The Mission Canyon Formation is late Early and early Late Mississippian in age and conformably overlies the Lodgepole Formation. The formation is well exposed in most of the map area.

The formation consists of pale-gray-brown, medium to massive-bedded, dense, medium grained dolomite, dolomitic limestone, and limestone. Massive chert zones are common in the formation, especially near the base of the overlying Tertiary lava flows lying north of Blackmore Lake and north of Lick Creek. The lithology of the formation is quite uniform throughout the map area with the exception of a few scattered and discontinuous beds of solution or collapse breccia. McMannis (1955) found that similar breccias were widespread and seemed to occupy a nearly identical stratigraphic position from place to place.

A section measured in the nearby Garnet Mountain quadrangle indicated that the Mission Canyon is approximately 675

feet in thickness (McMannis and Chadwick, 1964). To the north, in the Bridger Range, the thickness of the Mission Canyon Formation ranges from 950 feet at Sacajawea Peak to only 430 feet at Flathead Pass (McMannis, 1955).

Mississippian, Pennsylvanian and Permian

The Amsden Formation of latest Mississippian and Early Pennsylvanian age, the Quadrant Formation of Pennsylvanian age, and the Phosphoria Formation of Permian age are discussed in this section. The Phosphoria Formation is mapped together with the Quadrant Formation, and the Amsden Formation is mapped as a separate unit.

Amsden Formation

The Amsden Formation disconformably overlies the Mission Canyon Formation and was probably deposited upon a karst topography. The absence of the Big Snowy Group in the interval between the Mission Canyon and Amsden Formations may be indicative of nondeposition or pre-Amsden erosion.

The formation is poorly exposed in the map area but the characteristic red color and nonresistant nature make field recognition relatively easy. The thickness of the formation

is quite variable and ranges from approximately 100 feet on the eastern side of the map area (Roberts, 1964) to nearly 200 feet in the west-central part of the map area. To the southwest in the Garnet Mountain Quadrangle, the Amsden varies from 0 to about 225 feet in thickness (McMannis and Chadwick, 1964). A similar variation in the thickness of this unit is reported in the Bridger Range (McMannis, 1955).

The Amsden consists of variable amounts of red to yellow dolomitic sandstone, gray to white dense dolomite, dark red siltstone, and red and green shale.

Quadrant Formation

The Quadrant Formation conformably overlies the Amsden Formation and was assigned an Early Pennsylvanian age by Thompson and Scott (1941). The formation is generally well exposed in the map area and is commonly expressed as a resistant ledge or ridge.

The formation consists of buff to brown, thick-bedded, fine to medium grained quartz sandstone. Locally the formation is quartzitic and has very little carbonate cement. Cross-bedding and intense shearing are very prominent charac-

teristics of most of the outcrops. North of Lick Creek the formation is highly silicified as are many of the units in this area. Near the lower part of the formation medium bedded, medium grained sandy dolomite and thin to medium bedded dolomite are interbedded with the quartz sandstone.

A section measured in the northeastern part of the Garnet Mountain quadrangle (McMannis and Chadwick, 1964) indicated that the Quadrant is approximately 250 feet thick. A section measured in the map area by S.A. Alsup (personal communication, 1964) indicates that the Quadrant is only 125 feet thick. A similar wide variation in the thickness of the Quadrant Formation was found in the Bridger Range by McMannis (1955). He attributed this variation in thickness to erosion during Permian, Triassic, and Early Jurassic Time, when the area was apparently above sea level. In the map area, however, the Quadrant is overlain by the Permian Phosphoria Formation, which is absent in the Bridger Range section. The presence of the Phosphoria suggests that the variation in thickness observed in the Quadrant of the map area is due to differential movement during deposition or irregularities on the sea floor

upon which the Quadrant was deposited. The possibility of pre-Phosphoria erosion cannot be eliminated in this problem.

Phosphoria Formation

The Phosphoria Formation of Permian age is very poorly exposed in the map area. The only good exposures of the unit occur along Lick Creek in sec. 3, T. 4 S., R. 6 E. and along the Hyalite Canyon Road in sec. 9, T. 4 S., R. 6 E. (McMannis, personal communication, 1965). The thickness of the Phosphoria at this exposure is about 75 to 100 feet. In the adjacent Garnet Mountain quadrangle the Phosphoria ranges in thickness from 105 to 119 feet (McMannis and Chadwick, 1964).

The exposures of the Phosphoria in the Garnet Mountain quadrangle consist of a lower unit composed predominantly of nodular chert, medium-grained quartzite, and silicified siltstone interbedded with chert, and an upper unit of fine to medium-grained quartzite with interbedded nodular chert in the uppermost part. McMannis and Chadwick (1964) correlate this entire assemblage with Unit E of the Phosphoria as described by Cressman (1955).

Jurassic

Rocks of Triassic and Early Jurassic age are absent in the map area either by non-deposition, erosion, or a combination of both. The Triassic Dinwoody Formation apparently pinches out to the south and west of the map area (McMannis and Chadwick, 1964). The Jurassic beds present in the map area are the Sawtooth, Rierdon, and Swift Formations, comprising the Ellis Group, and the Morrison Formation. These rocks are shown as a single undifferentiated map unit (Ju) totaling approximately 700 feet in thickness.

Sawtooth Formation

The Sawtooth Formation of Middle Jurassic age is best exposed along Lick Creek in sec. 3, T. 4 S., R. 6 E. The formation rests disconformably upon the Phosphoria Formation of Permian age.

The formation consists of light gray, thin-bedded, fine grained limestone and interbedded shale. The lower part of the formation is characterized by interbedded brown to gray-green siltstone and yellow-gray, fine to very coarse-grained sandstone. The upper 50 feet of the unit consists predomi-

nantly of red to red-brown siltstone (S.A. Alsup, personal communication, 1964).

This interval was mapped by Roberts (1964) and was designated the Piper Formation. This formation is described as follows: "Olive-gray shale in upper part; flaggy very fossiliferous argillaceous limestone beds in middle part; multicolored siltstone in lower part". The general similarity between the Piper Formation and the Sawtooth Formation is obvious but the described lithology observed within the map area does not correspond to Roberts' description.

To the southwest, in the Garnet Mountain quadrangle, (McMannis and Chadwick, 1964) this interval was mapped as the Sawtooth Formation. The lithology described is very similar to that observed in the map area. According to McMannis (1955, p. 1405), "the thin red to maroon shale at the top of the Sawtooth Formation is a westward-extending tongue of the upper part of the Piper Formation of central Montana." He concludes (McMannis, 1955, p. 1405) that "only the red unit is typical of the Piper lithology and, therefore, because of the abundance of Sawtooth lithology in the section

. . . the writer prefers to call the beds below the Rierdon the Sawtooth Formation."

Rierdon Formation

The Rierdon Formation is of Middle and Late Jurassic age and rests conformably upon the Sawtooth Formation.

The formation consists of a lower gray to brown, massive, oolitic limestone and an upper brown calcareous shale. This upper shale was found to be 40 feet thick in the northeast corner of the Garnet Mountain quadrangle and approximately 30 feet thick near Rocky Canyon (McMannis and Chadwick, 1964; McMannis, 1955). The thickness of the upper shale beds were not measured but variations in thickness should be expected since regional relationships and fossils demonstrate an unconformity between the Rierdon and the overlying Swift (Imlay, 1956).

Swift Formation

The Swift Formation, of Late Jurassic age, rests disconformably upon the Rierdon Formation (Imlay, 1956). The formation is the uppermost unit in the Ellis Group.

The formation consists of tan, thin bedded, medium grained, cross-bedded, calcareous and glauconitic sandstone. The unit has scattered conglomeratic horizons or lenses composed of black to green chert pebbles. To the southwest, in the Garnet Mountain quadrangle, the Swift Formation ranges from 25 to 115 feet in thickness (McMannis and Chadwick, 1964).

Morrison Formation

The Morrison Formation, of Late Jurassic age, conformably overlies the Swift Formation and is the uppermost Jurassic formation in southwestern Montana. The Morrison is poorly exposed in the map area due to its nonresistant nature and the nonresistant nature of most of the overlying rocks.

The formation consists of approximately 275 feet of varicolored shale, siltstone, and limestone and interbedded quartz sandstone. The upper part is predominately black shale.

In the nearby Garnet Mountain quadrangle the thickness of the Morrison ranges from 275 feet in the northeastern part of the map area to 450 feet in the northwest corner of the area.

Cretaceous

The Cretaceous rocks of the map area consist of the Kootenai Formation and basal part of the Colorado Group. The formations range in age from Early Cretaceous to early Late Cretaceous. The exposures of the basal part of the Kootenai are good and make a good marker for mapping. The Colorado Group is generally poorly exposed due to its non-resistant nature and overlying glacial debris and is, therefore, mapped as Kc (Colorado Group, undifferentiated).

Kootenai Formation

The Kootenai Formation, of Early Cretaceous age, lies unconformably upon the Jurassic Morrison Formation, and ranges in thickness from 350 feet in the center of sec. 2, T. 4 S., R. 6 E. to 400 feet in the center of sec. 9, T. 4 S., R. 6 E. (Roberts, 1964; S.A. Alsup, personal communication, 1964). A similar variation in thickness of the Kootenai is found in the Garnet Mountain quadrangle (McMannis and Chadwick, 1964) and in the Bridger Range (McMannis, 1955).

The formation consists of a basal conglomeratic, coarse grained, medium bedded, cross-bedded, gray sandstone; an

overlying varicolored shale, siltstone, and interbedded yellow sandstone; and an upper fresh water limestone overlain by red-brown siltstone. The upper limestone unit is commonly fossiliferous, containing gastropods and ostracods.

Colorado Group

The Colorado Group is generally mapped as an undifferentiated unit in southwestern Montana. As demonstrated by Cobban (1951), it is possible to subdivide the group into lithologic units that can be correlated with the standard sequence in the Black Hills. In the adjacent Mystic Lake quadrangle Roberts (1964) mapped the Colorado Group in four subdivisions. The units mapped were the Mowry and Thermopolis shales (Lower Cretaceous); the Frontier Formation and the lower shale member of the Cody Shale (Upper Cretaceous); the Eldridge Creek Member of the Cody Shale (Upper Cretaceous); and the Upper Shale Member of the Cody Shale (Upper Cretaceous).

The exposures in the map area are too poor to make such subdivisions, and, therefore, this interval was mapped as the Colorado Group, undifferentiated. This follows the convention

of McMannis (1955) in the Bridger Range and McMannis and Chadwick (1964) in the Garnet Mountain quadrangle.

In general, the Colorado Group of the map area consists of dark gray to black, fissile shale and thin-bedded siltstone interbedded with yellow-brown, medium-bedded quartz sandstone in the lower part. Exposures higher in the sequence include abundant soft salt and pepper sandstone beds.

Tertiary

Very few outcrops of Tertiary sedimentary rock were found in the map area. The exposures are in the valley bottom of Middle Creek in a steep-sided road cut, approximately three quarters of a mile south of Langohr Springs Campground on the Hyalite Canyon Road and a similar distance south of the campground in an under-cut stream bank along Middle Creek (north central part sec. 5, T. 4 S., R. 6 E.). The contact between these deposits and the underlying Paleozoic rocks is not exposed but the presence of an angular unconformity between these units is attested to by the structural attitudes of the units; the Tertiary deposits strike N 10° W and dip 0 to 20° W, and the nearby Paleozoic rocks strike N 70° and dip 35° S.

At these outcrops the Tertiary consists of white to light tan, thin to thick-bedded silt and/or claystone. The deposit is sandy in places, micaceous, and some horizons are moderately carbonaceous. The limits of outcrop of these beds are unknown because of heavy glacial and colluvial cover.

These deposits are very similar to a tuffaceous siltstone of probably Middle Eocene age which occurs in the lower part of the volcanic breccia sequence slightly south of the map area (sec. 8, T. 45, R. 6 E.) (McMannis, personal communication, 1965). Several similar outcrops of gray to brown, thin-bedded, micaceous carbonaceous siltstone were mapped in the Garnet Mountain Quadrangle (McMannis and Chadwick, 1964). These siltstones were tentatively assigned a late early Eocene age on the basis of spore and pollen analyses.

Overlying the exposure of silt and/or claystone in the bank of Middle Creek is a thin bed of partially cemented conglomerate. The conglomerate is composed of rounded cobbles of intermediate to basic volcanic rock and Precambrian gneiss and is cemented by a white sparry calcite cement. The cement may be partially leached out of the exposed outcrops and may occupy a considerably greater percentage of the pore space in

a fresher outcrop. The conglomerate appears to be a channel fill in the underlying siltstone. The degree of rounding and sorting of the cobbles is suggestive of a stream deposit but no imbrication was noted.

Similar conglomerates consisting of cobbles of Tertiary volcanic, Precambrian metamorphic, and Paleozoic sedimentary rocks occur throughout the Gallatin Range at the base of the volcanic breccia and flow sequence. These deposits have been tentatively dated as middle Eocene (McMannis and Chadwick, 1964).

The upper exposure of Tertiary silt and/or claystone along the Hyalite Canyon Road is cut by a basaltic dike striking N15°W and dipping 72°W. No definite chill zone is present in the dike but the siltstone is slightly baked along the contacts. Similar dikes cut the volcanic sequence south of the map area and are considered to be in part synchronous with or feeders for the upper part of the volcanic sequence.

On the basis of these varying lines of guidance the deposits south of Langohr Springs Campground are tentatively dated as late early to middle Eocene.

Volcanic Breccias and Flows

Extrusive volcanic rocks unconformably overlies rocks ranging in age from Precambrian to Tertiary and form the crest of the Gallatin Range. The volcanic sequence consists of 2,000 to 4,000 feet of crudely layered breccias and flows which generally dip eastward and southward 5 to 10 degrees throughout the region. Both the flows and the breccia are of a basic andesite composition and have been tentatively dated as middle Eocene (McMannis and Chadwick, 1964).

Quaternary

Quaternary deposits are extensively developed throughout the map area. These deposits can be subdivided into five general categories: glacial deposits, kame-lake sediments, landslide debris, slope wash and colluvium and stream alluvium. These deposits have been mapped and differentiated in the map area wherever possible. The age and origin of these deposits will be discussed later in this paper under the heading of geomorphic history.

Glacial Deposits

Glacial deposits in the map area consist mainly of terminal, lateral, and ground moraines varying from a few feet to more than 100 feet in thickness. The deposits are characterized by their unconsolidated, unsorted, and unstratified nature and in the case of the terminal and lateral morainal deposits by their distinctive morphology. The coarse fraction of these tills is commonly composed of cobbles averaging less than one foot in diameter. Several large erratics more than 10 feet in diameter were observed near the valley walls. Invariably these large erratics are composed of volcanic breccia (Figure 3).

The lithologies found in the tills include abundant intermediate to basic volcanic rock, a small percentage of Precambrian gneiss and amphibolite and a still smaller percentage of Paleozoic and Mesozoic sedimentary rock.

It should be noted that the andesitic volcanic breccias and flows which form the crest of the Gallatin Range include a few zones that contain fragments of Precambrian gneiss and lower Paleozoic sedimentary rocks, but no fragments of Precambrian amphibolite or Mesozoic sedimentary rocks have been



Figure 3. Large erratic composed of Tertiary volcanic breccia.

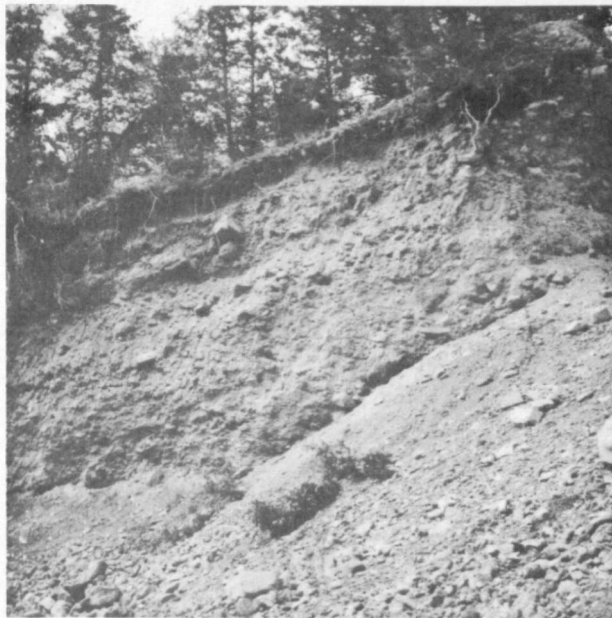


Figure 4. Glacial outwash north of Middle Creek Dam.

found to date (Chadwick, personal communication, 1964). None of the tills examined contained a high percentage of local bedrock material.

The matrix fraction of the glacial deposits is generally the smaller part of the deposit. Where matrix is predominant the deposit is generally stratified. Such deposits are thought to be of glaciofluvial origin but were not differentiated from other glacial deposits (Figure 4).

Kame-Lake Sediments

Several kame-lake deposits were found in the map area. The most notable of these occurs to the south and slightly west of Langohr Springs Campground on the boundary between sec. 32, T. 3 S., R. 6 E. and sec. 5, T. 4 S., R. 6 E. These lake basins have been only partially filled with debris and still form topographic lows which are commonly quite marshy.

The sedimentary material filling the kame-lake basin near Langohr Springs Campground was sampled using a portable subsurface soil sampling device and was found to consist of a highly saturated, gray, slightly varved clay. Due to

limitations imposed by the sampling device, the thickness of this deposit could not be determined.

Landslide Debris

Landslide debris is present in many parts of the map area. These landslides range from simple slump types to large debris avalanches and the associated deposits vary accordingly.

In general, landslide debris was recognized and mapped using a combination of the following criteria: hummocky topography, angular debris of local derivation, landslide scarps and tension cracks, "drunken forests", and distinctive lobate morphology.

A small landslide adjacent to the Hyalite Canyon road and slightly north of the Precambrian-Cambrian (SW $\frac{1}{4}$ sec. 29, and NW $\frac{1}{4}$ sec. 32, T. 3 S., R. 6 E.) contact is of considerable interest because of its unusual nature. The slide occurs on Precambrian terrane and is actively moving. The lobate morphology of the landslide seems to suggest that it is moving as a flow rather than as a block slide which might be expected in a metamorphic terrane. Rock fragments in the landslide are schistose and highly micaceous. The foliation of

the bedrock seems to strike in a northeasterly direction and dips nearly vertically. The landslide is moderately vegetated with willows and moderate sized pine trees. These pines are being tilted in a random fashion suggesting that movement is by turbulent, irregular flowage rather than by massive block translation or rotation.

Slope Wash and Colluvium Deposits

A thin to moderate thickness of slope wash and colluvial deposits is developed throughout the map area but these deposits are especially well developed on or adjacent to the Tertiary volcanic breccias and flows.

These deposits were mapped where they were found to be especially well developed or of geomorphic significance.

Stream Alluvium

Stream alluvium is found in the bottoms of most valleys in the Middle Creek drainage. The alluvial fill is invariably thin amounting to only a few feet in most cases, and is in a state of quasi-equilibrium with the stream.

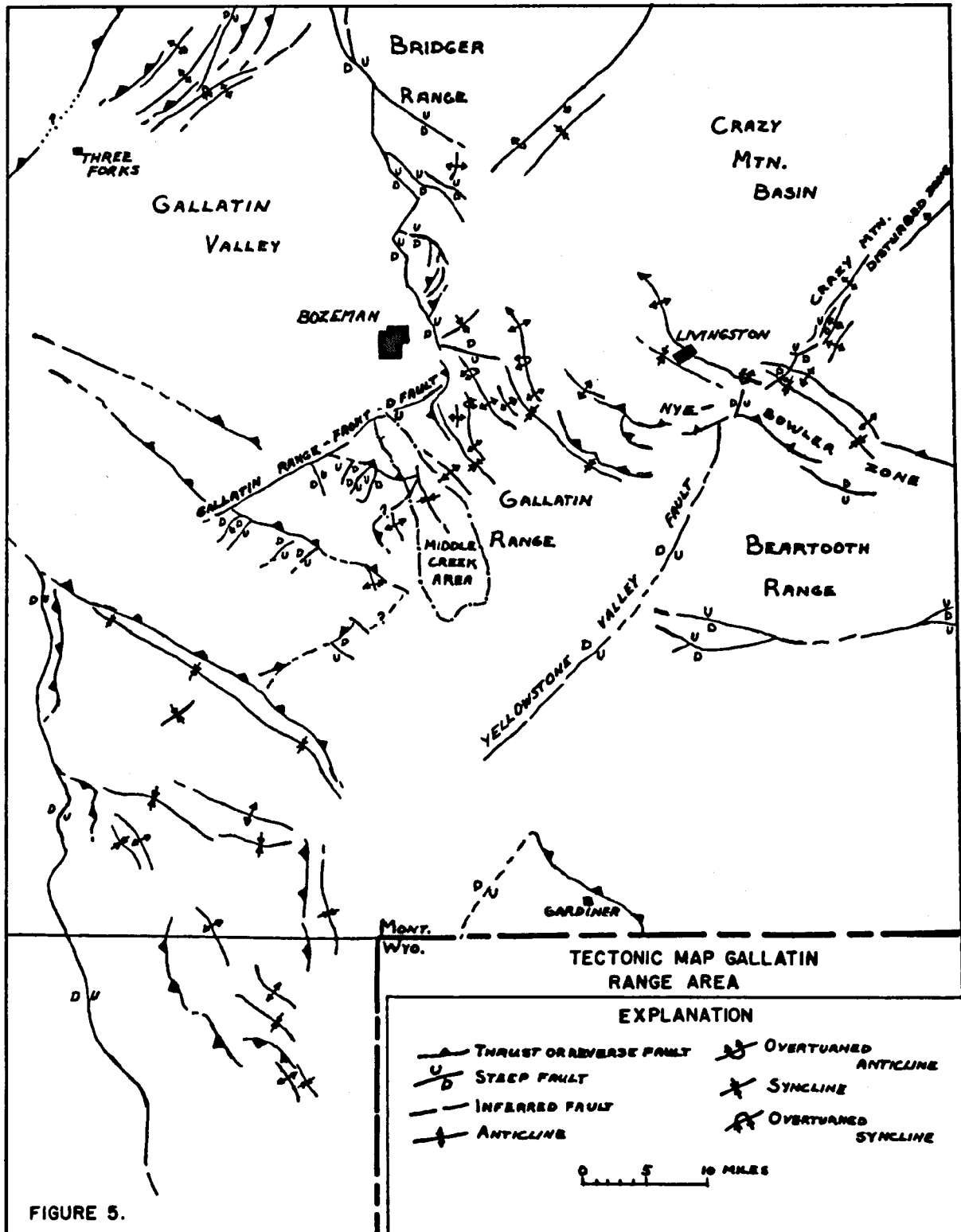
Fragments in the deposits are characteristically poorly sorted, highly rounded, slightly stratified, and lithologically

heterogenous. These deposits were mapped where they are conspicuously developed along major drainage courses.

TECTONIC SETTING

Figure 5 shows the main tectonic features of the Gallatin Range area. The major structural units in the region are the Bridger Range, Beartooth Range, and Gallatin Range blocks, and the Crazy Mountains Basin. Each of these structural units is a product of recurrent deformation along structural trends established in Precambrian time and subsequent Laramide compressional deformation and segmentation of the pre-Laramide structure. The dominant northwest-trending structure of the region is a product of reactivation of old Precambrian trends by a gross eastnortheast compressive stress during the Laramide orogeny.

The Bridger, Beartooth, and Gallatin range blocks or segments thereof are characterized by extensive outcrops of pre-Belt metamorphic rock; by the conspicuous absence of Belt strata; and by the general thinness of the overlying Paleozoic and Mesozoic sedimentary sequence. The dominant structural features of these blocks are northwest- and northeast-trending high-angle faults (McMannis, in press, 1965; Thom, 1957). However, on the basis of the gross trend of the ranges, the



Bridger and Gallatin range blocks are usually grouped with the Northern Rockies and the Beartooth Range is grouped with the Middle Rockies.

The Bridger Range block was once much more extensive than the present topographic limits of the range, the axis of the uplift lying somewhere to the west in the Gallatin Valley (Skeels, 1939; McMannis, 1955). The Bridger Range block is characterized by steeply dipping north-trending beds which have been cut by a series of high angle faults. The range 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 (McMannis, 1955).

The Beartooth block is characterized by an internal east-trending structure and is considered to be the northernmost unit of the Middle Rockies. The northeast side of the block is bounded on the north by the northwest-trending, north dipping, and southward thrust Nye-Bowler zone. On the west the uplift is bounded by a northeast-trending high angle normal fault. This fault has been named the Yellowstone Valley fault and serves as the structural boundary between the Gallatin

Range (including the Yellowstone Valley) block and the Beartooth Range block. The geometry of the Nye-Bowler zone changes markedly from the east to the west side of the Yellowstone Valley fault; i.e., high angle reverse faults on the northwest margin of the Beartooth block as compared to low angle thrusts to the west of the Yellowstone Valley fault on the Gallatin Range block. Richards(1957) observed that the Yellowstone Valley fault has been offset by the Nye-Bowler zone and, therefore, pre-dates some of the movement on the Nye-Bowler zone. The presence of high angle thrusts along the northwest corner of the Beartooth block as opposed to the low angle thrusts to the west of the Yellowstone Valley fault suggest that the Beartooth block was topographically higher at the time folding and thrusting took place (McMannis, 1964).

The Gallatin Range block is characterized by a series of northwest-trending folds and faults which are probably a product of reactivation of old Precambrian trends by the east-northeast Laramide compressive stress. The deformation of the Gallatin Range block is intimately interrelated with the Laramide history of the Crazy Mountains Basin and will be described in conjunction with the description of the basin.

The Crazy Mountains Basin is a northwest-trending complex structural basin which is cut by the northeast-trending Crazy Mountains disturbed zone. To the west of this zone, structural contours suggest that Upper Cretaceous and Paleocene strata thicken abruptly (Dobbin and Erdmann, 1955). This implies that the western part of the basin acted as a strongly negative basin during late Cretaceous and Paleocene time. Regional evidence suggests that the culmination of the compressional phase of the Laramide orogeny occurred in late Paleocene time (McMannis, 1955). Thus, when the culmination of the major east-northeast Laramide compressive stress was felt in the Gallatin Range block a strongly negative basin existed to the northeast. Compression of the basin resulted in down warping and deformation of the sedimentary rocks in the basin. The deformation pattern developed within the basin is a series "of asymmetric anticlines...which have been produced within a frame--of deformation provided by the rims surrounding that particular basin" (Thom, 1957, p. 16). Along the southwest margin of the basin, however, compressional deformation formed a series of asymmetric folds and low angle northeastward dipping thrusts which rode southwestward into the topographically low Gallatin Range block.

Subsequent to the compressional phase of the Laramide orogeny the entire region was subjected to tectonic readjustment generally expressed as normal faulting along new and pre-existing trends and the intrusion and/or extrusion of many igneous bodies. Late Miocene movement on several northwest- and northeast-trending normal faults along and near the northern boundary of the Gallatin Range Block suggests that the Gallatin Range block may have been tilted southeastward a few degrees during this phase (McMannis and Chadwick, 1964). This period of readjustment probably continued until late Pliocene time when a cycle of regional uparching was initiated (Love, 1954 and 1956, and Thom, 1957). The tensional stress induced by this regional upwarping resulted in relative subsidence of many blocks along the pre-existing fault trends. The recent movement along the Yellowstone Valley fault bounding the east side of the Gallatin Range block is probably an expression of continued readjustment to this last tectonic phase.

STRUCTURE

The general structural pattern of the map area is that of south-dipping Paleozoic and Mesozoic sedimentary rocks deformed by northwest- and northeast-trending faults and folds and capped by southward- to eastward-dipping Tertiary volcanic flows and breccias.

Two major faults cut the sedimentary sequence in the map area. The paucity of good exposures in the map area has precluded a detailed examination and classification of these faults. The relative movement along the faults has been determined from the outcrop pattern and the inclination of the fault planes has been inferred from the outcrop pattern and the regional tectonic pattern (Figure 2).

On the western side of the map area (sec. 5 and 6, T. 4 S.; R. 6 E.) a high angle fault cuts rocks ranging in age from Precambrian to Early Cretaceous (cross-section A-A', Figure 6). The fault is shown as a vertical fault on the cross-section but evidence is insufficient to verify its exact inclination. This fault has been traced into the South Cottonwood drainage to the northwest of the map area by W.J. McMannis (personal communication, 1965). Along this extension the

CROSS — SECTIONS

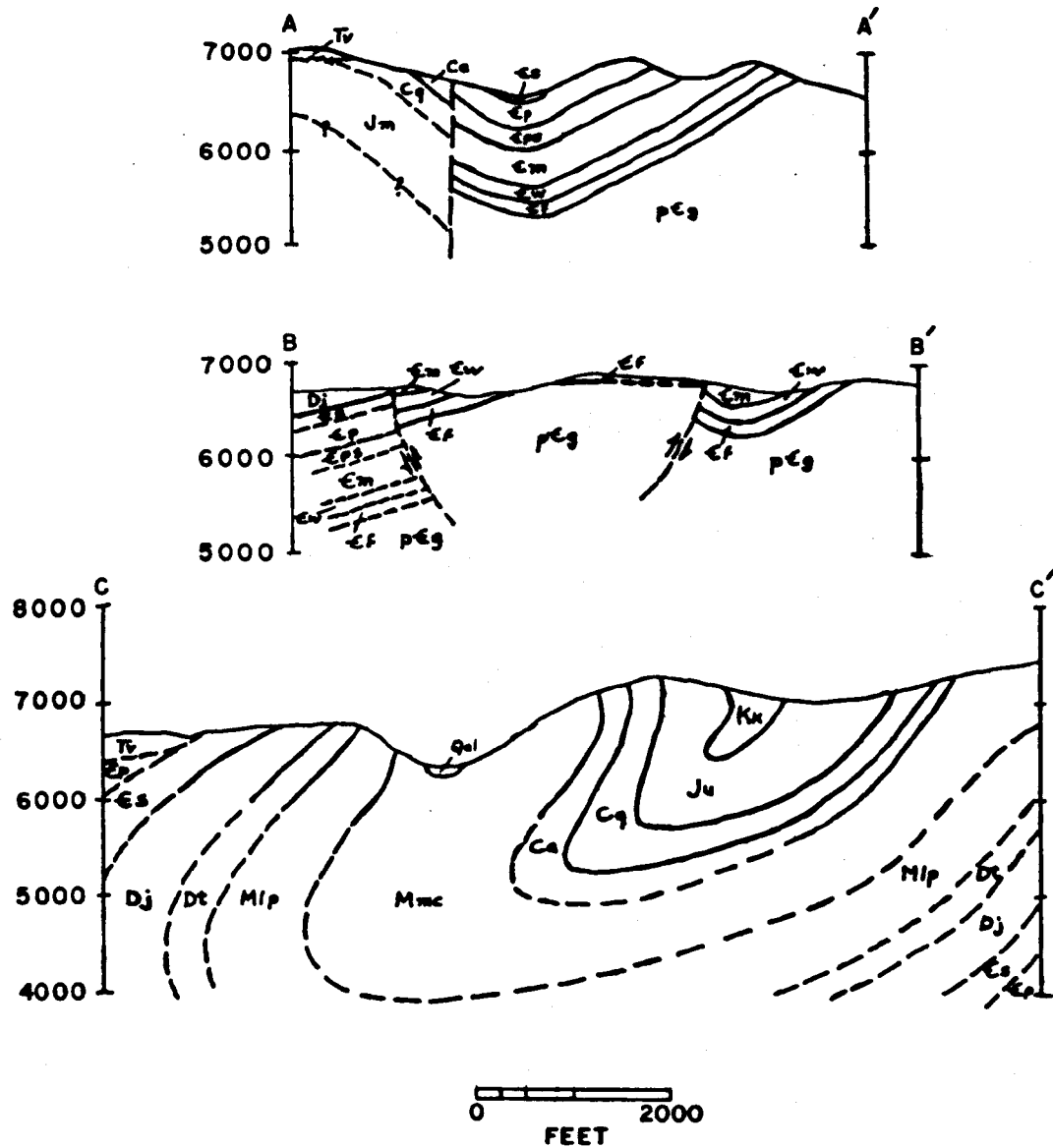


FIGURE 6.

fault has a reverse nature; i.e., the fault plane dips towards the northeast and the hanging wall has moved to the southwest relative to the footwall (Figure 5). Thrust movement along this fault in South Cottonwood Canyon suggests that there may be a component of strike-slip movement along the fault farther east in the writer's map area.

Just north of the fault in sec. 31, T. 4 S., R. 6 E. (Figure 2) the Upper Cambrian Pilgrim and Snowy Range formations are deformed into a small eastsoutheast plunging syncline. If this syncline relates to, and is contemporaneous with the faulting then strike-slip motion is likely along this part of the fault.

The sedimentary sequence on the south side of the fault is strongly overturned to the northeast, whereas the sedimentary sequence on the north side of the fault is upright and dips to the south and southwest except for the previously mentioned syncline. This suggests that considerable folding preceded the faulting and/or that the fault had a large component of strike-slip displacement. However the fault could be traced no further than the north central part of

sec. 5, T. 4 S., R. 6 E., and, therefore, a major gross displacement along this fault is not likely in the map area. The amount and nature of movement along this fault, therefore, remains in doubt.

The fault is overlain by undisrupted Tertiary volcanic rocks near the Middle Creek-South Cottonwood Creek drainage divide. These rocks have been assigned a tentative middle Eocene age by McMannis and Chadwick (1964). Therefore, movement along this fault probably ceased sometime previous to middle Eocene time.

In the eastern part of the map area (sec. 33, T. 3 S., R. 6 E. and sec. 4, T. 4 S., R. 6 E.) and a high to low angle fault cuts rocks ranging in age from Precambrian to Pennsylvanian (cross-section B-B', Figure 6). The magnitude and direction of displacement varies markedly along the trace of this fault. Along the west part of the fault there is approximately 850 feet of stratigraphic displacement with the east side of the fault up relative to the west side. As the fault trace swings around to the north and east the displacement becomes progressively smaller to the point at which the stratigraphic displacement is zero. Beyond this point the

displacement increases to approximately 650 feet with the north side of the fault up relative to the south side (Roberts, 1964). Thus, there has been a reversal of displacement along this fault; i.e., the fault block lying to the east and south of the fault has moved up on the west and down on the northern and eastern part.

Field evidence was insufficient to accurately determine the attitude of the fault plane but the drag fold developed just north of the fault (cross-section B-B', Figure 6) and the general map pattern along the western portion of fault suggests that the fault is a reverse fault everywhere west of the point of zero stratigraphic displacement.

Slightly to the south and west of the previously described reverse fault a large asymmetrical syncline plunges toward the southeast (cross-section C-C', Figure 6). This fold is comprised of rocks ranging in age from Cambrian to Late Cretaceous. The southern part of the west limb of the syncline is slightly to strongly overturned towards the east. To the southeast in the Garnet Mountain quadrangle there is a strong suggestion that a northeast-trending fault is responsible for similar overturning of beds along the continuation

of the west flank of this syncline (McMannis and Chadwick, 1964). The presence of a high angle bedding fault may, therefore, explain the nature of this structure.

The eastern flank of the syncline is cut by the previously described reverse fault and, therefore, the faulting apparently post dates or is penecontemporaneous with the folding.

IGNEOUS GEOLOGY

The basaltic dike discussed under the previous heading is exposed three quarters of a mile south of Langohr Springs Campground. The dike intrudes late early to middle Eocene siltstone and may intrude rocks of middle and late Paleozoic age but glacial debris covers this interval at this location. The dike strikes N 15° W and dips 72° to the west. No definite chill zone is present in the dike but the siltstone is slightly baked along the contact. A thin-section was made from a specimen collected from this dike and a petrographic analysis performed. As a detailed petrologic study was not a major object of this study, only a general description is submitted here.

Microscopic Description

Mineral or Constituent	Approximate Percentage	Description
Labradorite	65%	Albite twinning, max. extinction angle 29°-A _n 52. Phenocrysts show sericitic alteration. Microcrystals euhedral and show flow structure.

Augite	7%	Moderate biref. and relief, and characteristic inclined extinction. Some grains show poikilitic texture and subhedral crystal form.
Hypersthene	3%	Low biref., moderate relief, and characteristic parallel extinction. Euhedral to subhedral crystal form.
Sericite	2%	Moderate biref., low relief and parallel extinction. Occurs as an alteration product of the Labradorite.
Opakes	3%	Consisting of Magnetite, Hematite, and Pyrite showing dull gray, reddish, and brassy lusters respectively in reflected light.
Glass	20%	Amorphous glass includes and is interstitial to the crystals of Labradorite and Augite. Brown in color.

The rock is here called a basalt on the basis of texture and composition (Travis, 1956). However, because the phenocrysts of plagioclase are likely to be slightly more calcic than the microcrystals the term andesite or basic andesite would probably be more appropriate.

The correlation of this dike is unknown but it may relate to many two pyroxene basic andesite dikes which are present to the south of the map area in the Tertiary volcanic breccias and flows (R.A. Chadwick, personal communication, (1965)).

GEOMORPHOLOGY

The geomorphic history of the Middle Creek area records the activities of wind, water and glacial ice during Tertiary and Quaternary time. The geomorphic features developed in Tertiary time, however, have been intensely modified by the effects of Pleistocene and Neoglacial glaciation. Therefore, the following discussion of the geomorphology will be confined largely to a description of the glacial features of the area (Figure 7). The growing tendency is to correlate all Wisconsin glacial features in the Rocky Mountain area with the Bull Lake and Pinedale stages of Blackwelder (1915). The possible correlation of the glacial features of the Middle Creek area to Blackwelder's stages will be discussed in the following sections. For an excellent summary of the Cenozoic geomorphology of the Gallatin Range the reader is referred to McMannis (1964), McMannis and Chadwick (1964, p. 23) and Horberg (1940).

Pre-Wisconsin Geomorphology and Glacial Geology

Evidence of pre-Wisconsin glaciation in the Gallatin Range has been presented by several writers (Hall, 1960;

GEOMORPHIC MAP OF THE MIDDLE CREEK AREA, GALLATIN COUNTY, MONTANA

CONTOUR INTERVAL
40 & 80 FEET

SCALE 0 1 MILE

N
17°
W

EXPLANATION

NEOGLACIAL	PRE-WISCONSIN	WISCONSIN
Qli		
Qtl		
Qp		
Qbl		
Qmp		

LIMITS OF DEPOSITS
RECESSIONAL MORaine
PROTalus RAMPART

FIGURE 7

The map illustrates the distribution of glacial deposits across the Middle Creek area. The legend identifies five types of deposits: Little Ice Age Deposits (Qli), Temple Lake Deposits (Qtl), Pinedale Deposits (Qp), Bull Lake Deposits (Qbl), and Marble Point Deposits (Qmp). These are categorized under two main periods: NEOGLACIAL and PRE-WISCONSIN/WISCONSIN. The map also shows the locations of various landmarks, including Hyalite Station, Junior Hyalite Camp, Chisholm Cabin, and several peaks like Mount Brackmore and Mount Mumby. The contour interval is specified as 40 and 80 feet, providing a clear view of the topography.

58

Holmes, 1883, p. 55; Richmond, 1957). Deposits which are thought to be pre-Wisconsin in age are generally found high in the range on interfluvies or on large poorly drained plateau-like areas. Many of these deposits are poorly defined whereas others still retain the characteristic glacial morphology. All deposits are similar, however, in that they are composed in part of erratics which have been derived from what are now different drainage basins. The most common rocks represented in these pre-Wisconsin tills are Precambrian gneiss, schist and amphibolite. Many of these erratics are found at elevations topographically higher than any potential source rock. The pre-Wisconsin tills have one other unifying characteristic in the Gallatin Range in that they are not extensively weathered nor do they have well developed soil profiles. It is possible, however, that periglacial activity has continually stripped off any soil that formed. These deposits are in contrast to the deeply weathered pre-Wisconsin deposits of Jackson Hole, Wyoming (de la Montagne, 1956) or of Glacier National Park (Richmond, 1957). The freshness of the tills in the Gallatin Range may, in fact, suggest that they are younger than much of the pre-Wisconsin of surrounding

areas or that they are very early Wisconsin age. Therefore, Hall (1960) has proposed that these Gallatin Range tills be assigned to the Marble Point stage (named after a deposit on Marble Point, sec. 4 and 9, T. 9 S., R. 4 E., Gallatin County, Montana).

In the Middle Creek area several large patches of till are found on the rolling topography to the north and east of Langohr Springs Campground (sec. 19, 28, 29, 30, 32 and 33, T. 3 S., R. 6 E.) at an average elevation of 6800 feet and 600 feet above the main drainage. These deposits are composed of angular to subrounded cobbles of Tertiary volcanic rock, and Precambrian amphibolite and gneiss. One deposit examined (sec. 30, T. 3 S., R. 6 E.) contains a few sandstone cobbles from the Cretaceous Colorado Group. The deposits are characteristically formless, slightly weathered, poorly sorted, unstratified, and unconsolidated. No striated or faceted cobbles were found in the deposits examined.

It should be noted, as discussed in a previous section, that fragments of Precambrian amphibolite are not found in the Tertiary volcanic breccias which form the crest of the Gallatin Range (R.A. Chadwick, personal communication, 1964). In

addition, the amphibolite lithology is not common in the Precambrian terrane of the Middle Creek drainage. In fact, the closest outcrops of Precambrian amphibolite are in the bottom of the Cottonwood Creek valley and in the Spanish Peaks region (W.J. McMannis, personal communication, 1965).

Precambrian gneiss is common in the Middle Creek drainage, both in outcrop in the northern part of the area and in the Tertiary volcanic breccias in the southern part of the area. A notable exposure of Precambrian gneiss in the Tertiary volcanic breccias is at the base of Palisade Falls (sec. 24, T. 4 S., R. 6 E.). Here the gneiss occurs as rounded cobbles generally less than one foot in diameter. Approximately 1/2 mile to the north of this site angular slabs of Precambrian gneiss, some more than 4 feet in diameter, cover the hillside. The size and shape of these slabs as compared to the cobbles at Palisade Falls strongly suggests a source other than the Tertiary volcanic breccias. Therefore, the possibility exists that some of the Precambrian gneiss found in the tills above Langohr Springs Campground may have been derived from a source outside the present Middle Creek drainage. Glaciation is the only feasible process to account for the presence of the erratics.

Tertiary volcanic rock and Cretaceous Colorado Group sandstone crop out in the Middle Creek drainage basin. The presence of these lithologies in the tills above Langohr Springs Campground is, therefore, not unusual.

The abundance of erratics such as the amphibolite and gneiss which have probably been derived from distant sources in different drainage basins strongly suggests that the tills which contain the erratics were deposited by a large, north-east flowing ice sheet.

Thus, the tills above Langohr Springs Campground are very similar to tills of the Marble Point stage described by Hall (1960), and therefore, are tentatively assigned to the Marble Point stage.

Wisconsin Geomorphology and Glacial Geology

Early Wisconsin Glaciation

Evidence for early Wisconsin glaciation in the Gallatin Range has been presented by Hall (1960) and Horberg (1940). Deposits of early Wisconsin age invariably occupy the bottom and sides of U-shaped valleys. The deposits show the characteristic morphology of moraines associated with mountain

valley glaciation and are much fresher in appearance than the Marble Point tills. Many if not all of the major valleys in the Gallatin Range were occupied during this stage by valley glaciers which issued from large cirques developed along the flanks of the higher peaks of the range.

Much of the valley of Middle Creek is covered with a veneer of glacial drift. A large and fairly well defined set of terminal and lateral moraines approximately $3/4$ mile south of Langohr Springs Campground (sec. 32, T. 3 S., R. 6 E.) marks the terminal zone of a large valley glacier. These moraines are composed almost entirely of cobbles of Tertiary volcanic breccias and flows with minor amounts of Paleozoic and Mesozoic sedimentary rocks and Precambrian gneiss and amphibolite. As discussed in the previous section, much of the Precambrian gneiss and amphibolite seems to have been transported into the Middle Creek drainage by pre-Wisconsin glaciation. The presence of these lithologies in younger deposits is probably due, in part, to re-working of the pre-Wisconsin deposits. Boulders as large as 4 feet in diameter can be found in these moraines but the average size is about 1 foot in diameter. The gneiss and amphibolite

cobbles are angular to subangular and quite fresh but the cobbles of Tertiary volcanic rocks and the Paleozoic and Mesozoic sedimentary rocks are round to subround in form and slightly weathered.

The moraines are rounded on the top and stand 20 to 80 feet above the valley floor. Cobbles are moderately abundant on the surface of the moraines.

In the vicinity of Lick Creek (sec. 7, 10, and 11, T. 4 S., R. 6 E.) a moderately well defined morainal ridge some 20 to 30 feet in height has a similar appearance to the moraines of Langohr Springs Campground except that perched on the crest of the moraine are several large boulders composed of volcanic breccia (Figure 3). The bulk composition of the moraine is similar to the moraines near Langohr Springs Campground as is the sorting and average size of cobbles. The moraine has not achieved the degree of stability, exhibited by those in the terminal zone and, therefore, a slightly younger age is suggested. Just south of the moraine a thin skim of drift overlies Cretaceous shales and an examination of many exposures in this area did not indicate the presence of loess or soil horizons in the till. Therefore,

it seems likely that only one stage of valley glaciation has extended this far north in Middle Creek. On the basis of this evidence the Lick Creek moraine has been interpreted to be a recessional moraine which represents a minor resurgence of the waning early Wisconsin ice.

Glacial till of the same general character can be traced to the south along the sides of the valley as far as East and West Forks where oversteepened valley walls have precluded the preservation of glacial till but show obvious glacial modification.

The troughs of both East and West Fork are cut in Tertiary volcanic breccias and flows which weather and erode to form a series of cliffs and benches. As such, it is very difficult to ascertain the presence of a trim line along the valley walls. Near Palisade Falls (sec. 24, T. 4 S., R. 6 E.) early Wisconsin till can be found as high as 1000 feet above the valley and, therefore, glacial ice which deposited this till was of a similar thickness at this point. Further to the south, however, the thickness of the ice cannot be accurately estimated.

The cirque amphitheater at the head of East Fork has a present threshold elevation of 8800 feet, whereas the average elevation of the top of the ridge is approximately 10,000 feet. The difference between these elevations, 1200 feet, is of the same order of magnitude as the thickness of ice at Palisade Falls. The cirque threshold of West Fork also lies at an elevation of 8800 feet and the average height of the rest of the ridge above the cirque threshold is approximately 1200 feet. As valley glacier ice generally thickens headward it is possible that the ice in the cirques of East and West Fork was thicker than 1200 feet. Early Wisconsin valley glaciation in the Middle Creek drainage may, therefore, have originated from a small local ice cap. However, both these cirques hang above the main valley trough and it is not known if there need be any relationship between the thickness of the ice in the trough and the thickness of ice in these hanging cirques.

Most of the tributaries to the main troughs of East and West fork were probably occupied by early Wisconsin glacial ice but the evidence for this has been largely eradicated by more recent glaciation.

A short distance north of the terminal zone of the early Wisconsin glacial advance the valley of Middle Creek assumes a V-shaped configuration just as it enters Precambrian terrane. Within the V-shaped valley there are several benches or spurs (sec. 30, T. 3 S., R. 6 E., and sec. 25, T. 3 S., R. 5 E.) which lie at an elevation of 600 to 800 feet above the present stream elevation. The terminal zone of the early Wisconsin glaciation lies approximately 600 feet lower than till of the Marble Point stage. But it is not known, however, if the older till was deposited at lower elevations and has been subsequently stripped back by solifluction. It is possible, therefore, that there has been a maximum of 600 feet of canyon cutting between the deposition of the Marble Point till and the emplacement of the early Wisconsin terminal moraine.

The problem of proper age assignment must be considered in any discussion of valley glaciation phenomena. The only means of correlation when two sets of features are not found together is a relative or absolute age determination. It is possible that an age can be determined for the early Wisconsin glaciation in Middle Creek by spore or pollen analysis of the

kame lake sediments adjacent to the terminal moraine (Figure 7). Lacking such dating, correlation of this glacial stage must be made on the basis of regional relationships. Hall (1960) has described early Wisconsin glaciation in the southern Gallatin Range and suggested that it may correlate with the Bull Lake stage of Blackwelder (1915) in northwestern Wyoming. Earlier Horberg (1940) applied Blackwelder's terminology to glacial features observed in Yellowstone Valley and its tributaries. Therefore, until a more accurate means of correlation is available, the early Wisconsin glacial features of Middle Creek are tentively assigned to the Bull Lake stage.

Late Wisconsin Glaciation

The evidence for a second and later major stage of Wisconsin valley glaciation is more easily recognized than most of the evidence for the earlier (even though more extensive) ice advances. Glacial phenomena belonging to this stage of glaciation have been described in the Gallatin Range by Hall (1960) and Horberg (1940).

In general the moraines and till of this stage of glaciation are fresh in appearance, contain many nonresistant boulders of Tertiary volcanic breccia, have abundant cobbles on the surface, and lie within well shaped glacial troughs.

The terminal zone of this stage lies approximately $3/4$ to 1 mile north of Middle Creek Dam (sec. 9, 10, 15, 16, T. 4 S., R. 6 E.) and consists of a series of closely spaced terminal moraines having a well developed crescentric form. The terminal zone lies approximately 700 feet below the upper limits of Bull Lake stage moraine at this point and 3 miles south of the Bull Lake terminus.

The moraines of this stage are composed almost entirely of cobbles of Tertiary volcanic breccia and flow rock with minor amounts of Paleozoic and Mesozoic sedimentary rocks. The Precambrian gneiss and amphibolite, so characteristic of the older tills, is almost totally absent in these late Wisconsin tills. This fact is significant in that if most of the gneiss and amphibolite erratics were derived from the Tertiary volcanic breccias then these lithologies would be present in comparable amounts in all the tills. The glacial

trough of East Fork cuts a bed of Tertiary volcanic breccia containing abundant gneiss yet no gneissic erratics are found in the late Wisconsin tills of this area. Therefore, it is probable that most of the gneiss and amphibolite found in the older tills was deposited by pre-Wisconsin glaciation and re-worked and incorporated in the tills of the initial advance of ice of the Bull Lake stage. Thus, with the onset of late Wisconsin glaciation the supply of the Precambrian erratics had been concentrated in the moraines of the Bull Lake stage and was generally unavailable for incorporation in the smaller late Wisconsin glacial advance.

On the hillside to the east of Middle Creek Dam a series of well defined lateral moraines mark the initial slow recession of late Wisconsin ice (Figure 8). Similar lateral moraines are present south of Middle Creek Dam on West Fork. Here the moraines are paired forming a breached crescentric terminal moraine at the mouth of West Fork. The valley of East Fork is conspicuously devoid of recessional moraines which suggests that late Wisconsin ice retreated more rapidly or more steadily in this fork.



Figure 8. Lateral moraines on hillside above Middle Creek Dam.



Figure 9. Glacial trough of West Fork.

Although of differing size, the troughs of East and West Fork join at the same elevation. South of this juncture both troughs lack constructional features but glacial modification or sculpture of the valleys is obvious (Figure 9). The trough of West Fork lies approximately 1200 to 1400 feet below the threshold elevation of the tributaries draining into West Fork. These seem to be true hanging valleys and not controlled by resistant beds in the Tertiary volcanic sequence; i.e., the volcanic sequence dips towards the south and east but the difference in elevation between thresholds and valley bottoms increases in a southerly direction from 1200 feet at Twin Falls to 1400 feet at Maid of the Mist Falls. If the tributaries are true hanging valleys then the threshold elevation is the minimum elevation of the surface of the main valley ice mass at that point (greater if tributaries are inset). Thus, plotting the elevations of the terminal zone north of Middle Creek Dam and the threshold at Maid of the Mist Falls and comparing this difference in elevation with the distance between the points, an overall ice surface gradient of 190 feet per mile is obtained.

On the east flank of Mount Blackmore, Blackmore Creek heads in a large glacial cirque which fed a small valley glacier of late Wisconsin age (Figure 10). No evidence of a terminal moraine could be found in the valley but approximately $1\frac{1}{4}$ miles from the cirque the morphology of the valley changes from U-shaped to V-shaped. It seems, therefore, that late Wisconsin valley glaciation in Blackmore Creek never reached the trunk glacier in Middle Creek.

Hall (1960) described similar glacial features in the southern Gallatin Range and applied the name Sawmill stage to them. He suggested that the Sawmill stage may correlate with the Pinedale stage of Blackwelder (1915). Horberg (1940) described late Wisconsin glacial features in the Yellowstone Valley and adjacent portions of the Gallatin Range and correlated them with the Pinedale stage. Therefore, the glacial features of this younger stage of valley glaciation in Middle Creek are tentatively assigned to the Pinedale stage of Late Wisconsin glaciation.



Figure 10. Glacial cirque on northeast flank of Mount Blackmore.



Figure 11. Temple Lake terminal moraine in the cirque amphitheater of West Fork.

Neoglacial Geomorphology and Glacial Geology

High on the north slopes of mountain ridges in the cirque amphitheaters which head East and West Fork of Middle Creek small terminal moraines and miniature cirques indicate that small pocket glaciers existed subsequent to the retreat of Pinedale stage glaciation. Similar glacial features in nearby areas have been reported and discussed by de la Montagne (1956), Hall (1961), Dort (1962), and Birman (1964).

Subsequent to the maximum advance of Pinedale stage glaciation the climate of the western United States gradually changed from one favorable to the existence of vigorous mountain glaciers to an unfavorable combination of higher temperatures and lower precipitation known as the Anathermal period (Dort, 1962). During this period (8,000 to 11,000 ybp.) the last remaining remnants of Pinedale glaciers probably disappeared. Following the Anathermal period was a long interval of higher temperatures and less precipitation known variously as the Altithermal or Hypsithermal period. Estimates of the age and duration of this interval range from 8,000 to 9,000 years ago for the beginning to 4,000 years ago for the conclusion (Dort, 1962). Birman (1964) has suggested

that the Hypsithermal period be used to designate the end of Wisconsin glacial epoch and that post-Hypsithermal glaciation (Medithermal period) be called Neoglacial.

Thus, the small glacial features in the cirque amphitheaters of East and West Fork have been assigned to the Neoglacial epoch.

Evidence suggests that there are two stages of Neoglacial glaciation represented by the glacial debris within the cirques. The largest and oldest stage is represented by low crescentric mounds of drift above 8400 feet in elevation and lying 0.2 to 0.3 mile from their miniature cirques (Figure 11). Most of the cobbles on the surface of the moraines are stable and are encrusted with lichen. The moraines are composed of a fine grained matrix containing cobbles of Tertiary volcanic breccia and flow rock. Moraines of this type occur in the main cirques of East and West Fork and in the cirques of Maid of the Mist Creek and Palace Creek. They have been tentatively assigned to the Temple Lake stage (2,800 ybp.) of Holmes and Moss (1955).

Very small knife-edged, horseshoe-shaped moraines are found within the confines of the Temple Lake moraines (Figure

12). Similar moraines are found in protected locations in the cirques of Maid of the Mist Creek and Palace Creek but Temple Lake moraines are not associated with them at these sites. The moraines are very unstable and are composed of very angular blocks of Tertiary volcanic breccia and flow rock. No vegetation has developed on these moraines which have been tentatively assigned to the Little Ice Age stage (1000 to 100 ybp.) of Matthes (1930) and Dort (1962).

Periglacial and Post-Glacial Geomorphology

The periglacial environment which has probably prevailed throughout most of the last 4000 years in the cirque amphitheaters in the heart of the Gallatin Range has developed several characteristic geomorphic features.

Most of the cirque amphitheaters examined have small protalus ramparts developed near the north wall of the cirque. These protalus ramparts consist of low mounds of unsorted rock debris which has been formed by rock fragments dropping onto and sliding down upon the surface of small firn patches. Characteristically these deposits have a higher percentage of fine grained material than the moraines of the Temple Lake



Figure 12. Little Ice Age terminal moraine in the cirque of Shower Creek.



Figure 13. Stone stripe on Temple Lake terminal moraine.

or Little Ice Age stages. This is probably due to the fact that the protalus rampart is formed by previously weathered rock fragments whereas the moraines are formed by freshly plucked rock fragments.

The development of stone stripes is conspicuous on the face of the Temple Lake terminal moraine in West Fork (Figure 13). Such patterned ground features are characteristic of a periglacial environment. Several significant post-glacial geomorphic features were noted in the troughs of East and West Fork.

The first such feature is the extensive development of coalescent talus deposits at the base of the valley walls. These deposits have a surface inclination of approximately 18° and are currently building up and modifying the configuration of the glacial valley floors. Such deposits have probably been forming since the retreat of Pinedale ice from these valleys. At the mouth of several of the small tributaries of East and West Forks recent mud flows are found on top of the talus deposits. These mudflows probably occur at times of maximum runoff in the spring and after heavy rains.

Also of special significance in the post-glacial geomorphic development of Middle Creek drainage is the relatively slight amount of post-Pinedale downcutting. A careful examination of Pinedale cirques and cirque thresholds indicates that there has been approximately 5 feet of canyon cutting since the end of Pinedale glaciation.

The glacial morphology of the Middle Creek drainage is presently being modified by the effect of running water but pronounced down-cutting of Middle Creek is not evident. The present average stream gradient of Middle Creek is only 140 feet per mile. On East and West Fork, however, the average stream gradient is approximately 300 feet per mile which probably reflects the effects of the recency of glaciation in these troughs.

Conclusions

Evidence is fairly conclusive that 5 separate stages of glaciation have occurred in the Middle Creek area. The oldest and most extensive stage of glaciation has been tentatively correlated with the Marble Point stage which is thought to be slightly younger than Blackwelder's pre-Wisconsin Buffalo stage. Marble Point glaciation was not restricted to the Middle Creek drainage but rather was a large scale ice cap or piedmont ice sheet that probably capped most of the crest of the Gallatin Range. Following the Marble Point stage, 600 to 800 feet of valley cutting occurred in the Middle Creek area.

Glaciers of two stages of Wisconsin glaciation have occupied and extensively modified the morphology of the Middle Creek drainage. The oldest and most extensive valley glaciation has been tentatively correlated with Blackwelder's Bull Lake stage. The youngest stage of valley glaciation has been tentatively correlated with Blackwelder's Pinedale stage.

Following the Hypsithermal period two stages of Neoglaciation have occurred in the cirque amphitheaters of the area. The first stage is confined to the cirques and

has been tentatively correlated with the Temple Lake stage of Holmes and Moss. The second stage is within the area of the Temple Lake deposits or occurs in protected locations on the north face of ridges. These deposits are tentatively correlated with the Little Ice Age stage of Matthes and Dort.

Only a minor amount of valley cutting has ensued since the conclusion of the Wisconsin glacial epoch.

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