Geology of a part of the southern margin of the Gallatin Valley, Southwest Montana
by Martin David Mifflin

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

Abstract:
A detailed study of an 88-square-mile area along the southern margin of the Gallatin Valley where late Miocene tuffaceous sediments rest with sinuous unconformable contact on Precambrian metamorphic rocks and Paleozoic strata indicates that structural features control the present configuration of the south margin of the valley. However, much of the evidence pertinent to the Cenozoic history of the area is either indirect or so sparse as to be only suggestive. The sinuous contact, which would suggest sediments partly filled the present valley rather than that structure controlled the valley margin, is the result of a partially exhumed pre-late Miocene paleotopography which displays 2,500 feet of relief and eastward paleodrainage subparallel to Laramide structural trends. Total exhumation of the pre-late Miocene paleo-topography apparently would yield mountainous topography with 3,500 or more feet of relief. Some of the old topographic high areas have broad summits which may be remnants of a pre-middle Eocene subvolcanic erosion surface stripped of Early Tertiary and/or late Miocene rock. Only locally has the erosion associated with the exhumation of the late Miocene strata modified the paleotopographic surface.

Bedrock geology is similar to that of the Gallatin, Madison, and Beartooth ranges and consists of northwesterly Laramide high angle faults which place Paleozoic rocks against Precambrian rocks. Early Tertiary basic volcanic rocks (Early Basic Breccia equivalents) occur as two isolated remnants with positions relative to equivalent rocks in the Gallatin Range suggestive of at least 2,400 feet of relative structural

GEOLOGY OF A PART OF THE SOUTHERN MARGIN OF THE GALLATIN VALLEY, SOUTHWEST MONTANA

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ABSTRACT

A detailed study of an 88-square-mile area along the southern margin of the Gallatin Valley where late Miocene tuffaceous sediments rest with sinuous unconformable contact on Precambrian metamorphic rocks and Paleozoic strata indicates that structural features control the present configuration of the south margin of the valley. However, much of the evidence pertinent to the Cenozoic history of the area is either indirect or so sparse as to be only suggestive. The sinuous contact, which would suggest sediments partly filled the present valley rather than that structure controlled the valley margin, is the result of a partially exhumed pre-late Miocene paleotopography which displays 2,500 feet of relief and eastward paleodrainage subparallel to Laramide structural trends. Total exhumation of the pre-late Miocene paleotopography apparently would yield mountainous topography with 3,500 or more feet of relief. Some of the old topographic high areas have broad summits which may be remnants of a pre-middle Eocene subvolcanic erosion surface stripped of Early Tertiary and/or late Miocene rock. Only locally has the erosion associated with the exhumation of the late Miocene strata modified the paleotopographic surface.

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depression of the margin of the Gallatin Valley since late early Eocene. Apparently the majority of this movement has occurred along the northeast-trending Gallatin Range Front Fault, heretofore unmentioned in geologic investigations. Late Miocene and/or later fault movements have occurred along some pre-existing north and northeast Precambrian structural trends and northwesterly Laramide structural trends. Post-early Eocene to pre-late Miocene movement along one Laramide fault may have also occurred.

Pardee describes a high, low-relief surface formed on bedrock in the map area as a remnant of a "Late Tertiary Peneplain". The distribution and composition of adjacent Pleistocene (?) pediment gravels indicate the surface is more likely a pre-late early Eocene erosion surface stripped of the last of its volcanic cover during the Pleistocene.

Lithologic distribution and structure near the mouth of the West Gallatin River canyon indicate that the position of the north flowing river is the result of superposition on late Miocene or younger strata over the presently incised bedrock areas. Valley margin structural relationships also suggest that antecedence may have played an important part in the formation of the West Gallatin River canyon.

Flanking the West Gallatin River are terraces and pediments developed on the semi-consolidated late Miocene strata. These features are believed to be Pleistocene in age, and are tentatively assigned to the Buffalo, Bull Lake, and Pinedale stages of glaciation. The increasingly higher gradients of the successively older terraces suggest the possibility of gradual valley margin warping throughout the Pleistocene and perhaps up to the present.

GEOLOGY OF A PART OF THE SOUTHERN MARGIN OF THE GALLATIN VALLEY, SOUTHWEST MONTANA

INTRODUCTION

This paper is the result of detailed geologic mapping of a portion of the southern margin of the Gallatin Valley. It was undertaken as a thesis project in partial fulfillment of the requirements for the Master of Science Degree in Applied Science, with a major in geology at Montana State College. Field work was done during the summer of 1961 and at intervals thereafter to the spring of 1963.

The objective of the study was to map in detail the geology of the area, with particular emphasis on geomorphic and structural features and distribution of Cenozoic deposits, in the hope that a more detailed knowledge of the Cenozoic history of the Gallatin Valley would become apparent. At the time the study was initiated, two general hypotheses for the origin of the intermontane valley had been proposed, but convincing proof for either hypothesis was not apparent from the literature on the subject. One hypothesis advances the idea of erosional valleys subsequently filled with basin sediments; the other advances the hypothesis that the valleys are the product of structural movements after the Tertiary sediments were deposited. Some geologists favor combinations of the two processes. None of the hypotheses have been proved to the complete satisfaction of all.

The area mapped in this study has been the subject of part of other geologic studies, sometimes specialized in their objectives, and has not been given the detailed coverage necessary to discover many of the relationships which might have a bearing on the Cenozoic history. Choice of the area was determined in part by the known exposures of bedrock geology, abundant features undescribed in previous works, accessibility, and the suggestion of the Department of Earth Sciences staff at Montana State College.

Previous Investigators

The earliest geologic observations in the general region were made by Hayden (1861, 1884). The first extensive geologic mapping was by Peale, (1893, 1896). His study of the Three Forks quadrangle was of a reconnaissance nature but was remarkably accurate in the gross features.

Interest in corundum-bearing rocks in the map area and adjacent areas has prompted a number of publications. Included are Heinrich (1950), Reed (1951), Clabaugh and Armstrong (1951), Clabaugh (1952), and Foster (1962). Detailed studies of Precambrian rocks in areas near the map area have been conducted by Reid (1957, 1963), McThenia (1960), and Kozak (1961). Douglass (1899, 1903, 1909) described vertebrate remains in Tertiary strata of western Montana, some of which were collected nearby. Later significant work in this field has been done by Wood (1933, 1938), Wood and others (1941), Schultz and Falkenbach (1940, 1941, 1949) and Dorr (1956).

Various regional studies which include the map area have been made by Fix (1940), Pardee (1950), Alden (1953), Hackett, and others (1960), Robinson (1961 b), and McMannis (1962).

Unpublished data collected by W. J. McMannis, John de la Montagne, and R. A. Chadwick has been made available to the writer and has aided considerably in many interpretations of relationships between features in the map area and those of surrounding areas.

Acknowledgments

The writer is indebted to many persons for timely aid, numerous suggestions, and constructive criticism. W. J. McMannis, as major thesis advisor, bore much of the burden in this respect. Also helpful were John de la Montagne, R. A. Chadwick, C. C. Bradley, and M. J. Edie. Thanks are due to Edward Lewis, R. L. Konizeski, and C. Lewis Gazin for identifications of vertebrate remains. Also, the writer is indebted to his wife for both patience and manuscript typing and to Sharon Torgerson for manuscript typing. Appreciation is extended to the numerous landholders of the map area who granted unlimited access.

GEOGRAPHY

Location

The map area, occupying approximately 88 square miles, lies on the southwestern margin of the Gallatin Valley, and includes part of the valley proper and some topographically higher and rougher terrain. The Gallatin Valley is in southwest Montana, with the map area lying between the 111° 10' and 111° 25' meridians and the 45° 30' and 45° 40' parallels. The southern part of the map area essentially comprises foothills of the Madison Range, or Gallatin-Madison Range, perhaps a preferable term due to the structural contiguity of the two ranges. The small town of Gallatin Gateway lies within the area, and the town of Bozeman is approximately eight miles east of the northeast corner of the map area.

Topography

Elevation of the land varies from 4,600 feet on the northeast margin near the West Gallatin River, to greater than 7,200 feet on the south margin at the Salesville triangulation marker. The general landform of the area is one of low, rolling plains in the north and gradually increasing elevations southward toward the foothills of the Spanish Breaks, where the terrain becomes mountainous. Along the eastern margin of the area, floodplain terraces produce more or less continuous smooth surfaces. Locally throughout much of the map area, broken terrain occurs where small streams are incised.

Climate

The average precipitation in the area is not known exactly, but according to measurements made in 1952 (Hackett, and others, 1960, p. 18) the precipitation varies from less than 15 inches per year in the northern part of the map area, to greater than 20 inches in the Spanish Breaks on the south margin. Up to 3 inches per month fall in the spring months, and the rest of the year averages slightly less than 1 inch per month. The daily and seasonal fluctuations in temperature range widely, which is typical of most of the higher areas of the Rocky Mountains. The average temperature in the area is probably slightly less than 40° F., based on comparison with the town of Bozeman, which has an average of 42° F. and extreme temperatures range from above 110° F. to below -50° F. Snow depth in most of the map area during the winter months rarely exceeds more than two feet for prolonged periods of time. The best means of access for geologic field work are by four-wheel-drive vehicle or by horse during the summer months.

Land Economics

Most of the map area at present is in agricultural use, either as farm land or pasture. Areas of low relief and good soil cover are utilized in dryland grain production or, with the aid of irrigation, in alfalfa or other hay crops. Most of the high areas and areas of broken terrain are used as grazing land for beef cattle. Except for minor amounts of federal land, most of the northern part of the area is owned by farmers and ranchers, and the southern part by two large livestock companies.

At the present time there is no economic development of mineral deposits. In the past, corundum of industrial quality was mined, but synthetic abrasives have made these deposits uneconomical. Possible economic materials include Flathead sandstone for building stone, some local areas of Precambrian gneiss in which freshness of the rock would permit usage for building stone, extensive deposits of alluvial gravels for road beds and concrete aggregates, and Paleozoic carbonates for Portland cement manufacture.

Vegetation

Vegetation of the map area where undisturbed by man consists of evergreen timbered areas on the higher northern exposures, sagebrush and grass on other high exposures, and various deciduous shrubs and trees along drainages and on well-watered soil. Grasses and occasional juniper shrubs occupy the lower and drier, uncultivated areas. For a more comprehensive description of plant types and distribution, the reader is referred by DeYoung and Smith (1936).

STRATIGRAPHY

Precambrian

About one-half of the map area is occupied by high grade metamorphic rocks very similar to those termed Pony gneiss in adjacent areas. This metamorphic complex consists generally of the following rock types: gneiss, schist, amphibolite, and metaquartzite, listed in order of abundance. Detailed studies in adjacent areas have indicated that the rocks are a product of a number of stages of high grade and at least one stage of retrograde metamorphism. In adjacent areas determinations on radiogenic minerals indicate ages which range from 3.1 billion years to less than 2 billion years (R. R. Reid, personal communication, 1963). Most authorities believe that the rocks were originally a thick sedimentary sequence that was metamorphosed and intruded by igneous magmas, and subsequently underwent additional phases of metamorphism.

In the map area most of the surface exposures of the metamorphic rock are deeply weathered, generally displaying scattered outcrops of more resistant folia and intervening areas covered by varying thicknesses of gruss and soil. Typically, metaquartzites, amphibolites, and massive gneisses form most of the resistant outcrops. Only in sharp and relatively recent stream incisions are exposures continuous.

Compositional layering is generally well developed, with schistosity commonly parallel to compositional layering over wide areas. Locally the foliation reverses itself, forming large isoclinal folds with amplitudes ranging up to miles in length. In the crestal part of these folds schistosity generally crosses the compositional layering. Attitude of compositional layering was mapped in this study, but upon analysis of structures it became apparent that the schistosity may be critical in recognizing faults which displace only metamorphic rocks. The crestal parts of isoclinal folds, unless well enough exposed to be recognized as such, can create the illusion of post-metamorphic deformation if the relationships of schistosity are not known.

The outcrops of two unusual lithologies plus the similarity of lithologic sequences throughout most of the map area suggest that the very thick metamorphic complex may be repeated by displacements along northwesterly trending faults. The two lithologic types, a corundum rich zone and a siliceous magnetite layer, each occur in two localities on opposite sides of northwest-trending faults. The magnetite layer is exposed in sec. 26, T. 2 S., R. 3 E. and sec. 3, T. 3 S., R. 3 E., on opposite sides of Camp Creek and Salesville Faults. If the unusual lithologies are unique, similar thick sequences are exposed in the northern and southern parts of the map area.

The mineral assemblages of the metamorphic rocks support Reid's (1963) interpretation of a number of phases of metamorphism. Minerals characteristic of high to low grade metamorphism are present. In two parts of the map area, the northeastern and southeastern exposures of metamorphic rocks, the rock types differ from those of the rest of the map area in that there is more massive gneiss present and in having a higher percentage of migmatite veins and less constant attitudes. Elsewhere in the map area layering is fairly constant and includes alternating zones of the following rock types: gneiss-schist-amphibolite, gneiss-metaquartzite, and gneiss-metaquartzite-amphibolite. In these sequences the compositional layers range from a few inches to more than 10 feet in thickness, commonly being about 2 to 4 feet thick.

For more detailed lithologic and petrographic descriptions of similar rocks, the reader is referred to the works mentioned under previous investigations.

Paleozoic

Paleozoic sedimentary strata are preserved primarily in down-faulted and small synclines in the southern half of the map area. Formations as young as Mississippian are exposed, but the majority of the exposures consist of Cambrian and Devonian rocks. Although some of the formations are fairly well exposed, no detailed stratigraphic studies were made. A brief description of the rock units follows:

Middle Cambrian: The Flathead Quartzite, resting unconformably on the Precambrian metamorphic complex, consists of three general zones of differing lithologies. The basal unit consists of alternating maroon and white medium- to coarse-grained quartz sandstone and orthoquartzite, in places containing thin granule to pebble conglomeratic lenses and cross-bedding. The middle unit consists of red to maroon beds of medium- to coarse-grained, cross-bedded orthoquartzite. The upper unit is glauconitic and somewhat shaly, and grades into the overlying Wolsey shale. Total thickness, as determined by map distribution, appears to vary from area to area, but probably does not exceed 200 feet. In most of the map area the depositional contact with the underlying metamorphic rocks is subparallel to foliation. Locally, due to pre-Middle Cambrian and post-metamorphism structural movements, the contact is quite angular.

The Wolsey Shale is poorly exposed in the map area, with one exception near the mouth of the West Gallatin River Canyon in sec. 32, T. 4 S., R. 4 E. There greenish micaceous shale and siltstone are exposed and contain numerous worm trails. The estimated thickness is as much as 250 feet in places, but accurate formational boundaries are usually impossible to obtain due to dip slope exposures and extensive cover.

Lying directly above and in gradational contact with the Wolsey shale is the Meagher Limestone which typically forms hogbacks and ledges. In the Bridger Range the Meagher has been divided into three units: a lower thin-bedded dense gray limestone with intercalated greenish shale, a middle unit of resistant thin-bedded dark gray fine-grained limestone, and an upper unit of interbedded shale and fine-grained limestone (McMannis, 1955, p. 1393). In the map area only the lower two units are extensively exposed. The upper unit, if developed in the map area, is on dip slope exposures and is commonly covered by rubble from the underlying unit. On Ruby Mountain the ledge-forming unit is approximately 150 feet thick and is abruptly overlain by what is assumed to be the Park Shale interval (almost entirely covered throughout the map area). Therefore, it is possible that upper less resistant unit has been mapped as part of the Park Shale, or is not present in the map area. Total thickness of the Meagher seems to be from 200 to 400 feet, but no complete exposures were seen.

Directly overlying the Meagher, probably gradationally, is the Park Shale. Only a few feet of poor exposure of this formation were observed in a shallow road cut on the southern boundary of sec. 13, T. 3 S., R. 3 E. Here red soil and a minor amount of micaceous red and green shale are present. The total thickness is unknown, but map relationships of a typically covered saddle on the unit suggest a thickness of approximately 200 feet.

Upper Cambrian: Overlying the Park Shale, apparently in conformable contact, is the Pilgrim Limestone. In the map area this formation is dominantly thick-bedded, medium to light gray, medium- to coarsely crystalline limestone, in places glauconitic and slightly sandy. No limestone pebble conglomerates, common in the lower Pilgrim of adjacent areas, were noted. Where fairly well exposed on Ruby Mountain, the formation displays massive ledge-forming outcrops, whereas to the southeast it forms low hogbacks. The thickness is about 200 feet, with the basal part unexposed.

Above the Pilgrim on Ruby Mountain, in apparent parallel contact, is a saddle-forming, nonresistant thin interbedded yellow to buff sandy and dolomitic limestone and red shale interval 60 to 80 feet thick. This is believed to represent the Upper Cambrian Dry Creek Shale Member of the Red Lion Formation.

In gradational contact with the Dry Creek on Ruby Mountain is a thin-bedded, light gray, medium- to coarsely-crystalline limestone. This contains abundant irregular tan chert stringers and nodules. This ledge-forming limestone is about 42 feet thick, and on the basis of lithologic similarity, it is called Red Lion Limestone (Hanson, 1952).

However, near Goose Creek in sec. 20, T. 4 S., R. 4 E., poor exposures of the same interval (between Dry Creek Shale and Jefferson Limestone) indicate that the limestone present at this locality is similar to the Sage Pebble Conglomerate Member of the Snowy Range Formation. Here, sparse exposures of limestone pebble conglomerate are present. These exposures are adjacent to the Salesville Fault and could possibly be fault slivers of the Pilgrim Formation, which also is known to have similar lithologies. However, it is possible that somewhere between the Ruby Mountain and Goose Creek exposures there may be a facies change in the Red Lion - Snowy Range interval.

Devonian: On Ruby Mountain the Jefferson Limestone directly overlies the Upper Cambrian with an abrupt change in lithology. There is little physical evidence of this major hiatus that represents all of Ordovician and Silurian, as well as part of Devonian time. At Goose Creek the contact between the Sage Pebble Conglomerate Member(?) and the Jefferson Limestone is not exposed. The Jefferson is composed of alternating limestone and dolomite with thin to thick beds of gray to grayish brown fine- to coarsely crystalline textures. It weathers with a characteristic medium to dark brown color. The total thickness of the Jefferson at Goose Creek is approximately 420 feet. On Ruby Mountain the Jefferson may be thicker, but the uppermost beds are either stripped away by erosion or are unexposed because of vegetative cover on dip slopes.

At Goose Creek the Three Forks Shale gradationally overlies the Jefferson Limestone. The Sappington Sandstone is also present. The poorly exposed interval between the Jefferson and Lodgepole formations appears to consist of green and red shales, yellow calcareous siltstones, and yellow calcareous sandstones. The paced interval indicates approximately 140 feet of combined thickness for the Three Forks-Sappington unit.

Mississippian: Exposed above and apparently conformable with the Sappington Sandstone are 175 feet of the Lodgepole Formation. The rock exposed is thin-bedded, dark gray; finely crystalline limestone with intercalated shaly partings. Younger Paleozoic rocks, if present, are covered by Miocene and/or Quaternary deposits.

Tertiary: Erosion prior to middle Eocene time removed a large amount of Paleozoic, Mesozoic, and possibly Paleocene strata before the widespread Gallatin Range Volcanic rocks were formed. Erosion after this phase of volcanism and prior to late Miocene deposition removed most of the volcanic cover and additional unknown amounts of older rock.

Eocene: Volcanic rocks of probably middle Eocene age occur in the map area as two erosional remnants of slightly more than one-fourth square mile each. One is poorly exposed one-half mile southeast of the mouth of the Gallatin canyon. There the rock is mainly oxidized and vesicular basic andesite. The dip is probably southeast at a gentle angle on the basis of vesicule orientation and areal distribution, and thickness is probably less than a few hundred feet.

The other remnant, three miles west of Gallatin Gateway, dips approximately 30 degrees to the north on the basis of the physiographic expression and orientation of flow structures (Fig. 1). The exposures are poor, but the following generalized section was obtained on a traverse of the remnant.

Top: Unconformably overlain by late Miocene tuffaceous sedimentary strata.

300' Dominantly vesicular medium gray to oxidized finely crystalline andesite and scoria. Vesicule pipes suggest northward flow. Some vesicules filled with calcite and opal.

350' Mostly covered. Appears to be interlayered gray, slightly porphyritic finely-crystalline andesite and oxidized scoria.

100' Oxidized scoria, dark gray scoria, and vesicular basalt.

30' Finely crystalline medium gray andesite, mafic phenocrysts appear to be altered to golden brown biotite, also the plagioclase phenocrysts are altered.

50' Flow breccia with vesicular basalt fragments up to 6" in diameter.

50' Oxidized vesicular basalt.

100' Black to dark gray glassy and porous basalt, some faint flow bands visible. In some zones plagioclase laths appear altered.

Base: Precambrian metamorphic rock in angular contact.

Total Thickness: About 1,000 feet exposed.

The age of the volcanic sequence is uncertain but is assumed to be Middle Eocene on the basis of the following evidence. Six miles to the south of the map area near Garnet Mountain W. J. McMannis (personal communication, 1962) has found a thin carbonaceous siltstone directly underlying similar volcanic strata. These deposits rest on the subvolcanic erosion surface. Spore identifications from the siltstone indicate a late early Eocene age; therefore, the volcanics must be no older than that. To the south in Yellowstone Park similar and probably correlative volcanics accumulated until "well into Middle Eocene" Dorf (1960). Therefore, it is probable that the bulk of the sequence is middle Eocene in age.

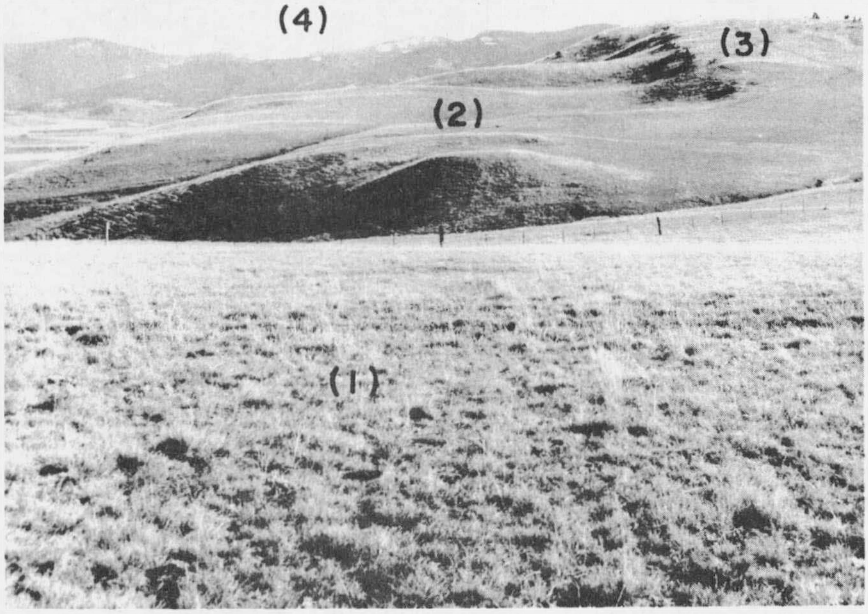

Fig. 1 View to the southeast from sec. 7, T. 3 S., R. 4 E., of: (1) Qpg[2] gravel surface overlying late Miocene strata, (2) remnant of basic volcanic rocks dipping 30° toward the foreground, (3) Precambrian metamorphic rock topographic high, (4) high peaks of the Gallatin range in the background.

Near High Flat in the northern part of the map area in sec. 28, T. 2 S., R. 4 E., a poorly exposed possible remnant of volcanic rock occurs. Angular blocks of andesite are concentrated in one small area and are generally covered by soil or loess. Adjacent to them are rounded lag pediment gravels of the same lithology. However, due to the size and