Cenozoic geology of the southeastern part of the Gallatin Valley, Montana
by Patrick A Glancy

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

Abstract:
The southeastern part of the Gallatin valley is primarily a structural basin resulting from a combination of Laramide compressive forces and subsequent tensional stresses. The basin is partially filled by Tertiary and Quaternary deposits of fresh-water and eolian origin. Marked differences in lithology aid in differentiating Tertiary and Quaternary fill material.

Tertiary sediments consist of wind-and water-laid volcanic ash and tuffs interbedded with coarser fluvial channel deposits. The channel gravels are composed mainly of volcanic detritus, some fragments of Precambrian quartzite and gneiss, and a minor amount of debris from the Livingston Formation of Late Cretaceous and Early Tertiary age. These sediments are partially cemented by calcite. The exposed fluvial material is believed to have been deposited at least partly by westward flowing streams; a late Miocene age (of deposition) is reasonably well established by vertebrate fossil evidence. Total thicknes,s and oldest age of these deposits is undetermined because known drilled wells do not completely penetrate these sediments in the basin.

Fluvial Quaternary sediments consist of rock fragments derived from the bordering basin rim and of reworked Tertiary detritus. Topsoil may have . been deposited partially by wind.

Tertiary beds generally dip toward the basin rims and several minor normal faults displace these beds. No deformation of Quaternary deposits is apparent and faults that deform Tertiary strata are (often) overlapped by Quaternary sediments.

Geomorphic surfaces of several ages are developed on the basin fill. Present drainages appear to be near grade and are adjusted to master streams of the region.

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Pre-Cenozoic bedrock geologic data around the basin rim was adapted from mapping done by Shelden (1960) in the Mt. Ellis-Bear Canyon area and Hackett and others (1960). Cenozoic map units in the basin proper are mainly taken from a map by Hackett and others (1960) since this breakdown of the section into geologic map units and the mapped contacts appeared to be the most logical and consistent with the writer's observations. Subsurface well-log data was also adapted from Hackett and others (1960).

Topographic and base map data were taken from preliminary copies of the Bozeman Pass and Bozeman, Montana 15-minute quadrangle topographic maps prepared by the U.S. Geological Survey. These provided 20 foot contour interval vertical control at a horizonal map scale of 1 inch to 2,000 feet.

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ABSTRACT

The southeastern part of the Gallatin valley is primarily a structural basin resulting from a combination of Laramide compressive forces and subsequent tensional stresses. The basin is partially filled by Tertiary and Quaternary deposits of fresh-water and eolian origin. Marked differences in lithology aid in differentiating Tertiary and Quaternary fill material.

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Geomorphic surfaces of several ages are developed on the basin fill. Present drainages appear to be near grade and are adjusted to master streams of the region.

INTRODUCTION

<u>Purpose and scope of investigation</u>: The primary objective of this thesis is to present the results of a study and interpretation of the stratigraphy of Tertiary and Quaternary basin deposits in the southeast corner of the Gallatin Valley, Gallatin County, Montana. By means of fossil dating, I have attempted to accurately establish the relative geologic ages of the various Cenozoic stratigraphic units in this area. Secondary, but also critical and complementary objectives, were to investigate structural deformation of the basin deposits and the general geomorphic development of the present topography. The emphasis is directed toward phases of Cenozoic history and thus only surficial discussion of Archeozoic, Paleozoic, and Mesozoic geology is given where these data have a direct bearing on the Cenozoic history of the area.

The field investigation was conducted intermittently between the latter part of July and the middle of October, 1961. Laboratory work was conducted concurrently with the field work and completed late in November, 1961.

The area of study, approximately 50 square miles, is represented on the enclosed map (Plate I). A further division of the area into subareas of individual geologic and/or topographic characteristics is advantageous in facilitating discussion herein. These subareas, Bozeman fan, Mt. Ellis fan, Fort Ellis subarea, and Beacon Hill subarea, are plotted on the included index map (Fig. 1). The names Bozeman fan, Mt. Ellis fan, and Fort Ellis subarea were previously used by Hackett and others (1960).

<u>Geography</u>: The southeast corner of the Gallatin Valley is bordered on the east by the southern extremity of the Bridger Range and adjacent highlands and on the south by the Gallatin Range.

Major streams included within the area are Bridger Creek, Sourdough or Bozeman Creek, Bear Creek and Rocky Creek which combine within the area to form the East Gallatin River. The West Gallatin River and Middle Creek are important streams, located beyond the west boundary of the map area, that are geographically and geologically related to problems associated with the thesis area. The regional master stream is the Missouri River which leaves the valley at Trident.

The southeastern part of the Gallatin Valley includes the city of Bozeman, cultural and commercial center of the region, and home of Montana State College. It is also a transportation hub, being served by two railroads, and is a junction point of north-south and east-west highway systems. Agriculture is the major industry and the region is famous as an outdoor recreational area.

The climate of the area is characterized by long cold winters and short mild summers. Average annual precipitation at Bozeman is approximately 18 inches (Hackett and others, 1960).

PREVIOUS GEOLOGIC INVESTIGATIONS

Iddings and Weed (1894) and Peale (1896) provided the first geolgic mapping and description of the area. Peale (1896) was first to describe the Tertiary basin deposits in the Gallatin Valley and named them the "Bozeman Lake Beds". He believed the Three Forks Basin, in which the Gallatin Valley is situated, was the site of a huge fresh water lake, Gallatin Lake, possibly covering an area as great as 1,400 square miles during middle and late Tertiary time. He attributed basin deposits of this age to stream transport of locally derived sediments into the lake, settling of volcanic

INDEX MAP OF AREA

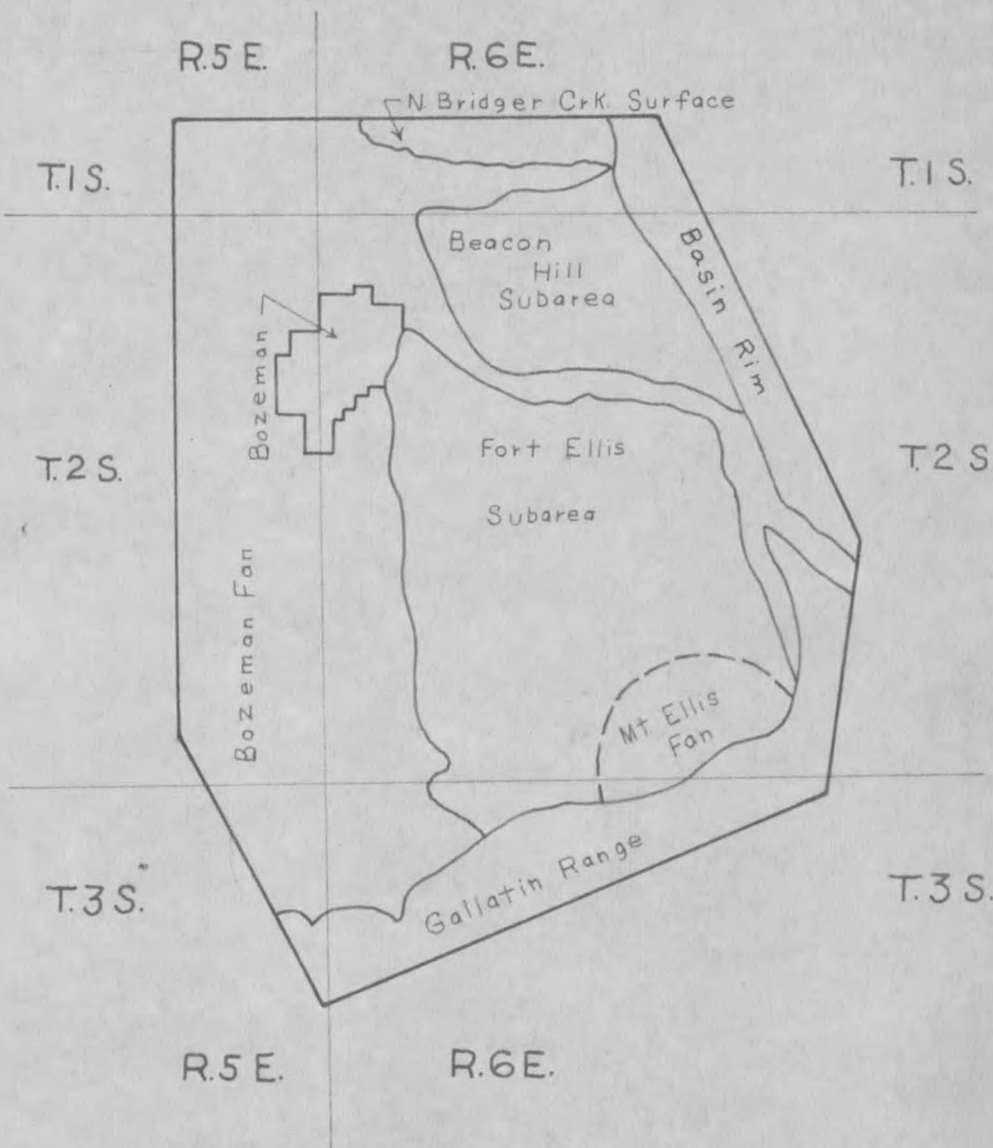


Fig. 1

ash in the lake during volcanic eruptions in the adjoining region, and transport of ash into the lake by streams.

In 1903, Douglas described Miocene and Pliocene faunas that were collected in basin deposits along the Madison River bluffs ten miles west of Bozeman. These sediments are lithologically and stratigraphically similar to the deposits in the southeast part of the valley discussed in this present paper.

Wood (1933, 1938), Schultz and Falkenbach (1940), and Dorr (1956) described faunas extracted from Tertiary strata near Anceney between the West Gallatin and Madison rivers west of the map area. Maps of Skeels (1939) and McMannis (1955) in part overlapped the thesis area and these authors described structural, tectonic, and stratigraphic features that have a direct relationship to the geology of the southeast corner of the valley. Geologic structure of the Gallatin Valley was also described by Fix (1940).

The name "Bozeman Lake Beds" remained in vogue for many years. The most recent, but certainly not the first, disagreement with Peale's lacustrine interpretations is contained in work by Hackett and others (1960), who studied the geology of the area with reference to its relation to underground water resources. Robinson (1961) published a synthesis of geologic development of the basin that included results of his investigations in the Toston-Three Forks area and also incorporated results of most of the previously mentioned investigations as well as other investigations in adjacent areas.

Although the name "Bozeman Lake Beds" remained in use for many years, Hackett and others (1960) found evidence (fresh water lake fossils) of true lacustrine deposits in the western portion of the basin but concluded that the majority of the deposits exposed in the bluffs east of the Madison River, in the Anceney area and eastward, are the result of fluvial and eolian deposition on a land surface rather than in a lake.

Robinson (1961) generally concurs with Hacketts's conclusions on the fluvial and eolian origin of many of the deposits and suggests that various stratigraphic units are deserving of formational status and that Peale's "Bozeman Lake Beds" should be renamed the Bozeman Group. However, he did not formally introduce specific formational names at that time.

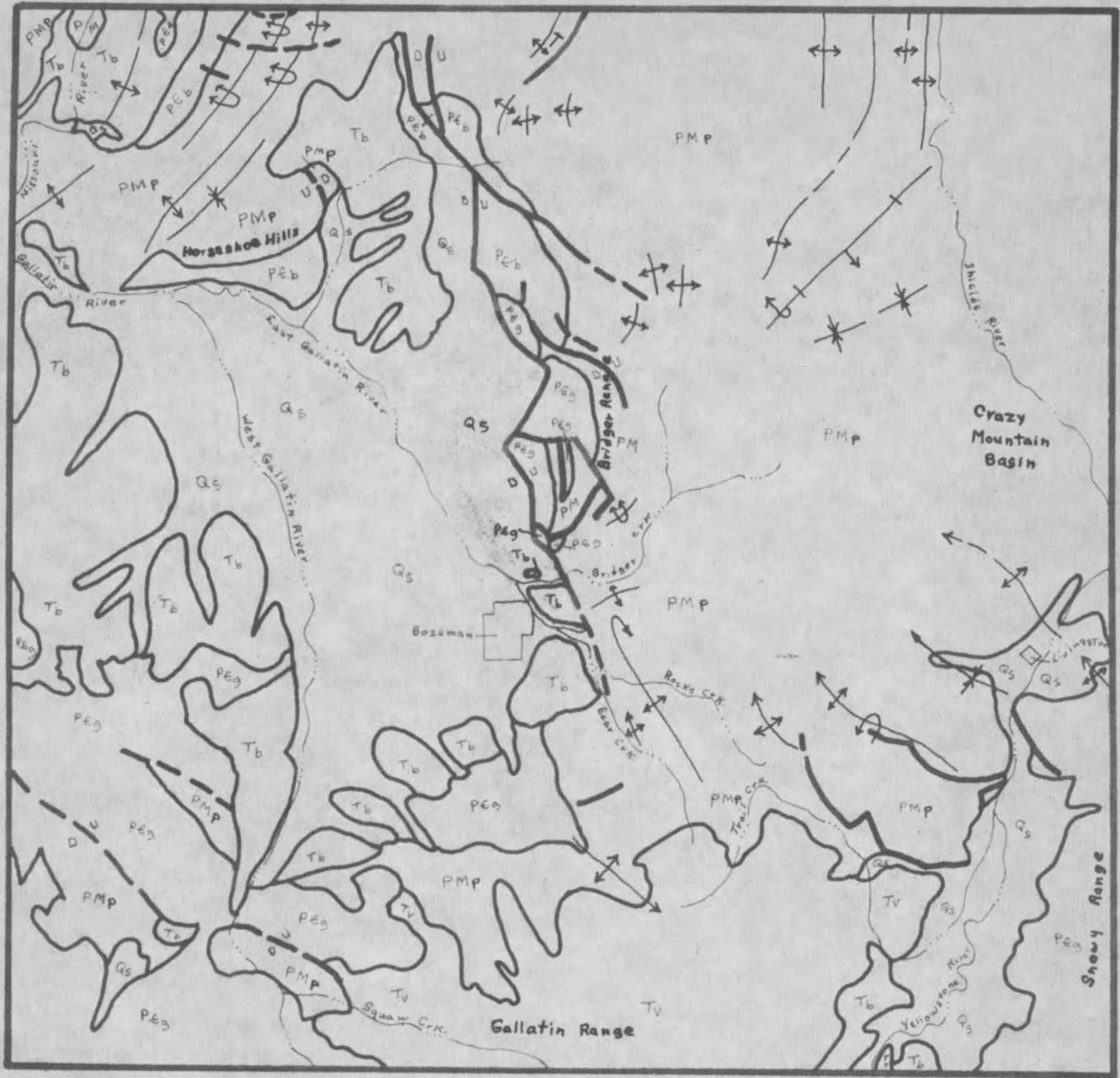
The writer uses terminology introduced by Hackett and others (1960) and Robinson (1961).

REGIONAL GEOLOGY

Basin evolution: The southeast corner of the Gallatin Valley is part of an intermontane basin known as the Three Forks Basin (Robinson, 1961). Peale (1896) attributed formation of the basin to folding and faulting which depressed the basin area with respect to the mountain fronts and dammed through-flowing drainages at the basin mouth. Damming of the streams resulted in formation of lakes in the basin which were the depositional site of the so called "Bozeman Lake Beds".

Atwood (1916) believed the intermontane basins of southwestern Montana, presumably including the Three Forks Basin, originated by warping and some normal faulting of an Eocene peneplain. He postulated that this structural deformation "defined great intermontane troughs, and determined the location of the main drainage lines" (Atwood, 1916, p. 708). Enlargement of the troughs and further development of the basins were the result of stream erosion during a subsequent degradational period. Lava flows and warping in

GENERAL GEOLOGIC MAP OF REGION



EXPLANATION

Qs — Quaternary Sediments

Tb — Tertiary Basin Deposits

Tv — Tertiary Volcanics

PMp — Paleozoic-Mesozoic and Paleocene Rocks Undifferentiated

P€b — Pre-Cambrian Belt

P€g — Pre-Cambrian Gneiss

Folds

U/D — High Angle Fault, Undifferentiated

Thrust Fault, T on H. W.

10 Miles
Scale

N

Geology after McMannis, W.J. (1955) and Geologic Map of Montana (1955)

Plate II

the mountain areas were believed to have blocked drainage exits from the valleys and basins forming lakes.

Pardee (1950) attributed the intermontane troughs and valleys to depression caused by crustal movement that also caused Oligocene and Miocene drainage to become sluggish in the depressions with resultant aggradation of the "lake beds". He also attributed later cessation of deposition and deformation of the "lake beds" to accelerated local crustal movements that relatively elevated the present mountains. These movements took place during Pliocene or early Pleistocene.

Robinson (1961) attributes initial formation of the basin to the last phase of Laramide compressive forces that interruped an eastward drainage system during middle or late Eocene time. This interruption later resulted in a brief period of interior drainage during which a lake formed in the southwest part of the area and began to collect sediments. Fluvial and lacustrine aggradation continued throughout Eocene and into Oligocene time and sediments consisting of mountain waste and volcanic ash were deposited. Resumption of exterior drainage during later Oligocene caused degradation to be dominant in the basin until late Miocene. During this erosional phase, many Eocene and Oligocene deposits were removed.

A partially closed basin may have begun to develop in late Miocene, probably caused by a new uplift of the Bridger Range, and fluvial aggradation of ash and coarse waste became dominant in the eastern part of the basin. During this period of aggradation in the east, erosion dominated the western part. Ash deposition ceased and coarse sediment deposition became dominant at the end of Miocene time. Rejuvenation of eastward flowing streams also occurred. The entire basin was deeply filled with sediment by late Pliocene time forming a gravel plain on the surface; the drainage remained easterly but became sluggish. Late Pliocene or early Pleistocene were marked by a regional uplift with greatest relative uplift along the southern rim of the basin. "The late Tertiary plain developed a northwesterly slope, and a consequent stream system formed" (Robinson, 1961). A recurrent rise of the Bridger Range impeded eastward drainage and the present Missouri River drainage system evolved.

Robinson postulates recurrent eastward tilting of the basin and a progressive eastward shift of the depositional center to account for Eocene and Oligocene sediment dominating the exposure in the western half of the basin and Miocene and Pliocene sediments dominating the eastern half.

The writer also favors a general structural origin for the southeast corner of the basin, rather than an erosional origin, for reasons discussed later in this paper.

Stratigraphy: McMannis (1955) described in detail the stratigraphy of the Bridger Range, located directly north of the thesis area. The following is an adaptation of McMannis' and Robinson's versions of the stratigraphic units in the area; they are believed to be generally characteristic of rocks of the regions in and surrounding the Gallatin Valley.

Generalized Stratigraphic Section

Age		Stratigraphic Unit	General Lithology	Thickness Feet
QUATERNARY			Valley Fill, alluvium, gravel fans, outwash and morainal material	0-300 plus
		unconf.		
TERTIARY	Late Miocene and Pliocene	BOZEMAN GROUP	Fluvial, igneous and quartzitic gravels and conglomerates; tuffaceous sandstones and siltstones; and pure ash deposits of fluvial and eolian origin.	0-1500 plus
		disconf.		
TERTIARY	Early Eocene (Oligocene)	BOZEMAN GROUP	White, tuffaceous, fossiliferous, thin-bedded siltstones and sandstone.	0-800 plus
TERTIARY	Eocene	BOZEMAN GROUP	Basal localized limestone conglomerate; grades upward into lacustrine, white tuffaceous limestone, sandstone and conglomerate, which grades upward into lacustrine and fluvial, bentonitic clay and sand grades upward into Oligocene units.	0-1300 plus
		unconf.		
TERTIARY	Paleocene	BOZEMAN GROUP	Coarse conglomerate, some andesitic sand lenses Andesitic sandstone, sporadic conglomerate beds	
		unconf.?		
TERTIARY	Paleocene	Livingston fm.	Coarse conglomerate, some andesitic sandstone Siltstone, shale, some andesitic sandstones and fresh-water limestones	up to 14,500
?				
CRETACEOUS	UPPER	Livingston fm.	Andesitic sandstone, andesite conglomerates	

Generalized Stratigraphic Section

Age		Stratigraphic Unit		General Lithology	Thickness Feet
CRETACEOUS	UPPER	Eagle Sandstone		Salt and pepper sandstone, partly marine.	100-600
		Colorado fm.		Black shale, rusty gray-green sandstone and siltstone, minor gray, salt and peper sandstone. Marine.	1200-2400
	? LOWER	Kootenai fm.		Basal conglomeratic sandstone and upper sandstone medial red-purple claystone and shale.	386-447
		disconf.			
JURASSIC		Morrison fm.		Variegated shale and mudstone, with interbedded rusty calcareous sandstones	110-444
		Ellis Group	Swift sandstone	Yellow calcareous sandstone, basal conglomerate or pebbly zone.	50-100
			disconf.		
			Rierdon fm.	Massive grey, oolitic limestone, with overlying shaly beds.	0-114
			Sawtooth fm.	Fine-grained dark-gray limestone, interbedded shale. Fragmental limestone with chert pebbles in lower part. Locally at top a red-yellow siltstone.	20-145
		disconf.			
PERMIAN		Phosphoria fm.		At many places a chert breccia phosphorite nodular chert, and conglomerate zone occurs at this horizon	0-26
		disconf.			

Generalized Stratigraphic Section

Age		Stratigraphic Unit		General Lithology	Thickness Feet
PENNSYLVANIAN			Quadrant fm.	Pale-yellow to white, pure quartz sandstone or quartzite, locally calcareous. A few thin, light-gray dolomite beds.	40-165
PENNSYLVANIAN			Amsden fm.	Upper light-gray dolomite with some thin quartz sandstone beds.	113-185
?			Amsden fm.	Lower red siltstone unit with some variegated dolomite and impure fossiliferous limestone beds.	11-189
MISSISSIPPIAN	UPPER	BIG SNOWY GROUP	disconf.	Cherty limestone. Black shaly limestone and black shale.	0-171
MISSISSIPPIAN	UPPER	BIG SNOWY GROUP	local disconf.	Locally red silty beds at top. Red and yellow sandstone or calcarenite.	0-163
MISSISSIPPIAN	UPPER	BIG SNOWY GROUP		Red siltstone, with a few purple and pale-yellow splotched dolomites. Basal dolomite and dolomite or limestone breccia	0-100
MISSISSIPPIAN	LOWER	MADISON GROUP	disconf. Mission Canyon fm.	Solution channels, caves at top. Massive, light-gray limestones, solution breccias at several horizons	430-950

Generalized Stratigraphic Section

Age	Stratigraphic Unit	General Lithology	Thickness Feet
LOWER	MADISON GROUP: Lodgepole fm.	Thin-bedded, yellow to red-stained, fossiliferous limestone. Lower dark-gray, think bedded, less fossiliferous limestone	750-810
?			
DEVONIAN(?)	Sappington fm.	2-3 feet black silty shale. Yellow sandstone grading downward into silty and sandstone limestone. Basal black shale.	46-99
?	disconf.		
DEVONIAN: UPPER	Three Forks fm.	Gray limestone at top-Yellow siltstone and green shale. Middle ledge-forming, brecciated limestone. Basal evaporite solution breccias, and red and orange nodular limonitic shale.	155-156
DEVONIAN: UPPER	Jefferson fm.	Light- and dark-brown, thick-bedded dolomite, dolomitic limestone, and limestone. A few intercalated yellow and pale pink dolomitic siltstone beds.	497-620
DEVONIAN: MIDDLE & LOWER	Maywood (?) fm.	Yellow mudstones and siltstone, thin dolomite beds. Grades upward into Jefferson. Red, blocky siltstone, with red-stained brecciated limestone beds in lower part. Basal red, fissile shale.	39-92

Generalized Stratigraphic Section, Bridger Range, Montana

Age		Stratigraphic Unit		General Lithology	Thickness Feet
?					
CAMBRIAN	UPPER	SNOWY RANGE FORMATION	Sage pebble conglomerate member	Fine-grained, thin-bedded dense limestone and limestone pebble conglomerate, with interbedded green shale. Basal columnar limestone.	121-204
			Dry Creek shale member	Gray-green fissile shale, with interbedded yellow calcareous siltstone and sandstone.	42-76
		Pilgrim fm.		Massive light- and dark-gray mottled, oolitic limestone. Local reefoid development at base. Thin to thick-bedded, gray edgewise and flat-pebble limestone conglomerate with interbedded green shale. Basal ledge-forming, massive, oolitic, mottled limestone.	363-433
	MIDDLE	Park fm.		Green and maroon fissle shale, with thin-bedded limestone unit at top and, locally, intercalated conglomeratic, arkosic limeston and arkose beds in lower portion.	190-192

Generalized Stratigraphic Section, Bridger Range, Montana

Age		Stratigraphic Unit	General Lithology	Thickness Feet
CAMBRIAN	MIDDLE	Meagher fm.	Thin-bedded, dark-gray dense limestone with interbedded green shale. Middle massive dark-gray dense limestone with interbedded green and yellow silty shale.	368-370
		Wolsey fm.	Green and maroon, micaceous shale with interbedded micaceous sandstone and siltstone. Locally contains conglomeratic arkosic limestone and arkose.	152-210
		Flathead fm.	Red, pale orange, and white sandstone, locally quartzitic. Locally contains much feldspar, becoming arkosic. Conglomeratic in places.	119-142
		unconf.		
PRECAMBRIAN	ALGONKIAN	Belt series (LaHood fm.)	Coarse, massive, poorly bedded arkoses and conglomeratic arkoses, very coarse gneiss boulder conglomerate in southwest part of area. Interbedded dark-gray argillite and a few siliceous limestone beds in northern part of area.	10,000 plus
		fault		
	ARCHEAN?	Metamorphics	Gneiss, schist, metaquartzite, marble, injection gneiss, numerous pegmatite dikes, and veins.	?
			Approximate total thickness of section.	27,000 plus

Laramide tectonics: The most obvious structural features of the region were formed during the Laramide orogeny. The beginning of compressional folding took place in late Cretaceous time and progressed, apparently sporadically (McMannis, 1955), until late Paleocene or early Eocene (Klepper and others, 1957). Vulcanism and igneous activity occurred contemporaneously with the folding and faulting and was responsible for supplying vast quantities of sediment that was deposited locally as the Livingston Formation. Many writers believe the compressional and tensional forces developed during the Laramide revolution exploited ancient structural weakness zones in crystalline basement rocks and many of the structural trends and features of the region are a result of control by this ancient structural pattern.

According to McMannis (personal communication), structural features in the region indicate at least two major directions of relief from apparently continually active compressive stresses that resulted in intermittent failure as variable rock units adjusted to relieve the compression.

Late Tertiary faulting is indicated by field evidence and is reported by many (McMannis, 1955). Indications of recent faulting are disclosed by field evidence in the basin west of the West Gallatin River (Martin Mifflin, personal communication).

Quaternary events: Glacial activity, during Pleistocene time, occurred in the Bridger Range to the north and was apparently very extensive in the Gallatin Range to the south (McMannis, personal communication). Effects of associated climatic extremes are believed to be very important in the Quaternary development of landforms throughout the basin and in the southeast corner particularly.

Although no late Quaternary faulting or folding of the southeastern basin deposits is evident in the map area, structural deformation in the region appears to be presently active and this activity suggests that the relaxational phase of the Laramide orogeny, believed by most writers to be in its waning stages, is still in progress.

STRATIGRAPHY

Basin deposits of the Bozeman Group exposed in the southeast corner of the Gallatin Valley consist of fluvial gravels, conglomerates, sandstones, and siltstones. Some beds of nearly pure volcanic ash are also present, part of which appear to be of fluvial origin and part of which show eolian characteristics.

Quaternary deposits consist of fluvial gravels, sands, and silts eroded from pre-Eocene rocks, comprising the rim of the basin, and/or those reworked from prexisting Tertiary basin deposits. Possibly some finer-grained deposits are loess although evidence in this part of the basin does not clearly indicate an eolian origin.

Tertiary deposits: Tertiary sediments, other than Livingston (Late Cretaceous-Paleocene) beds, in this area are considered to be a part of the Bozeman Group after Robinson (1961). Robinson's statement that exposed Tertiary rocks of the basin are oldest in the west and youngest in the eastern extremities suggests that strata in the southeast are among the uppermost units of the Bozeman Group, as yet not formally named. The writer does not propose a formation name for these beds since it is assumed Robinson will soon publish names of the formations comprising the Bozeman Group.

The Beacon Hill and Fort Ellis subareas (Fig. 1) are underlain mainly by Tertiary sediments. Well logs (Hackett and others, 1960) indicate the Bozeman fan and present stream flood plains, mantled by Quaternary gravels, are also underlain by similar Tertiary sediments. A well just west of the map area in sec. 22, T.2S.,R.5E., penetrated to a total depth of 1,000 feet without passing through the base of Tertiary sediments. Well depths in this area do not exceed the depth of Tertiary fill in any instance. Quaternary deposits apparently have a maximum thickness of approximately 175 feet and are underlain by Tertiary strata in every well which passes through Quaternary sediments.

Coarse deposits: A striking charcteristic of the coarse sediments is their lithologic composition. Conglomerate consists mainly of fine-grained and porphyritic igneous rocks, quartzite, and graywacke sandstone cobbles. Aphanitic volcanic constituents include basalt and andesite; porphyritic constituents are mainly andesite, diorite, and gabbro porphyries although porphyritic granodiorites and granodiorite porphyries are abundant. More acidic varieties are also encountered. Some coarse-grained igneous material, including diorite, granodiorite, monzonite and granite, are present. The most common igneous cobbles appear to be andesite porphyry amphibole as dominant phenocrysts and the other with plagioclase as dominant phenocrysts (Table 3).

Precambrian gneiss fragments are sporadically present and very rarely sandstone, limestone, or other relatively non-resistant rock fragments representative of Paleozoic or Mesozoic rocks. The only non-resistant fragments present with any consistency are graywacke or sub-graywacke materials derived locally from the Livingston Formation.