



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
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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.

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 thickness 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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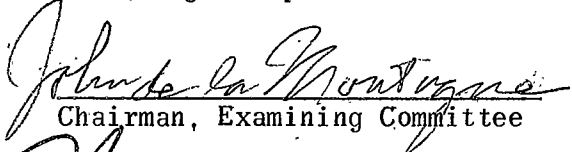
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Applied Science

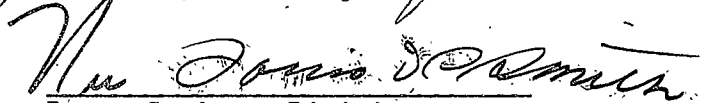
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Pre-Cenozoic bedrock geologic data around the basin rim was adapted from mapping done by Shelden (1960) in the Mt. Ellis-Bear Canyon area and Hackett and others (1960). Cenozoic map units in the basin proper are mainly taken from a map by Hackett and 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 horizontal 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.

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 thickness 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.

INTRODUCTION

Purpose and scope of investigation: 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).

Geography: 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 geologic 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

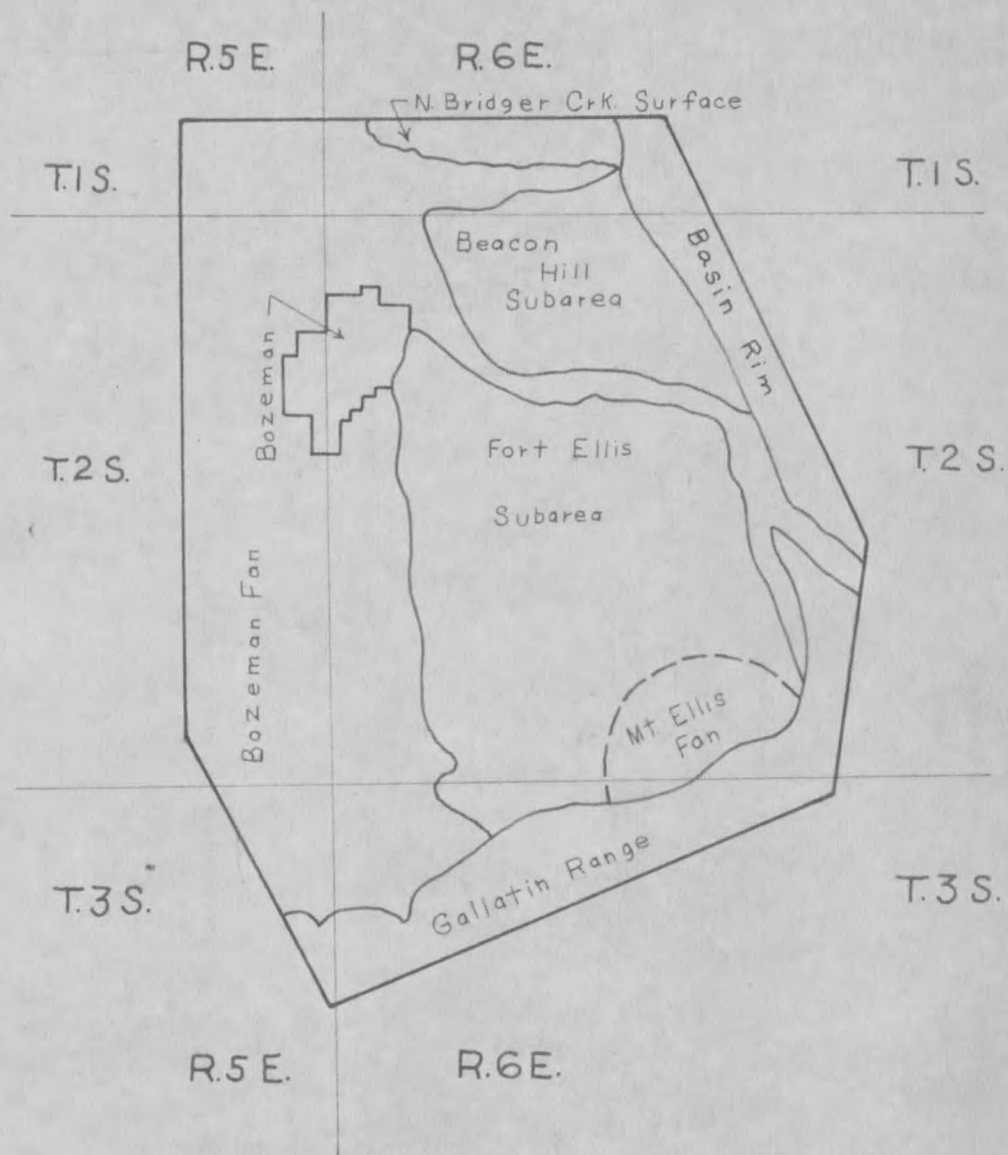


Fig. 1

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 Hackett'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.

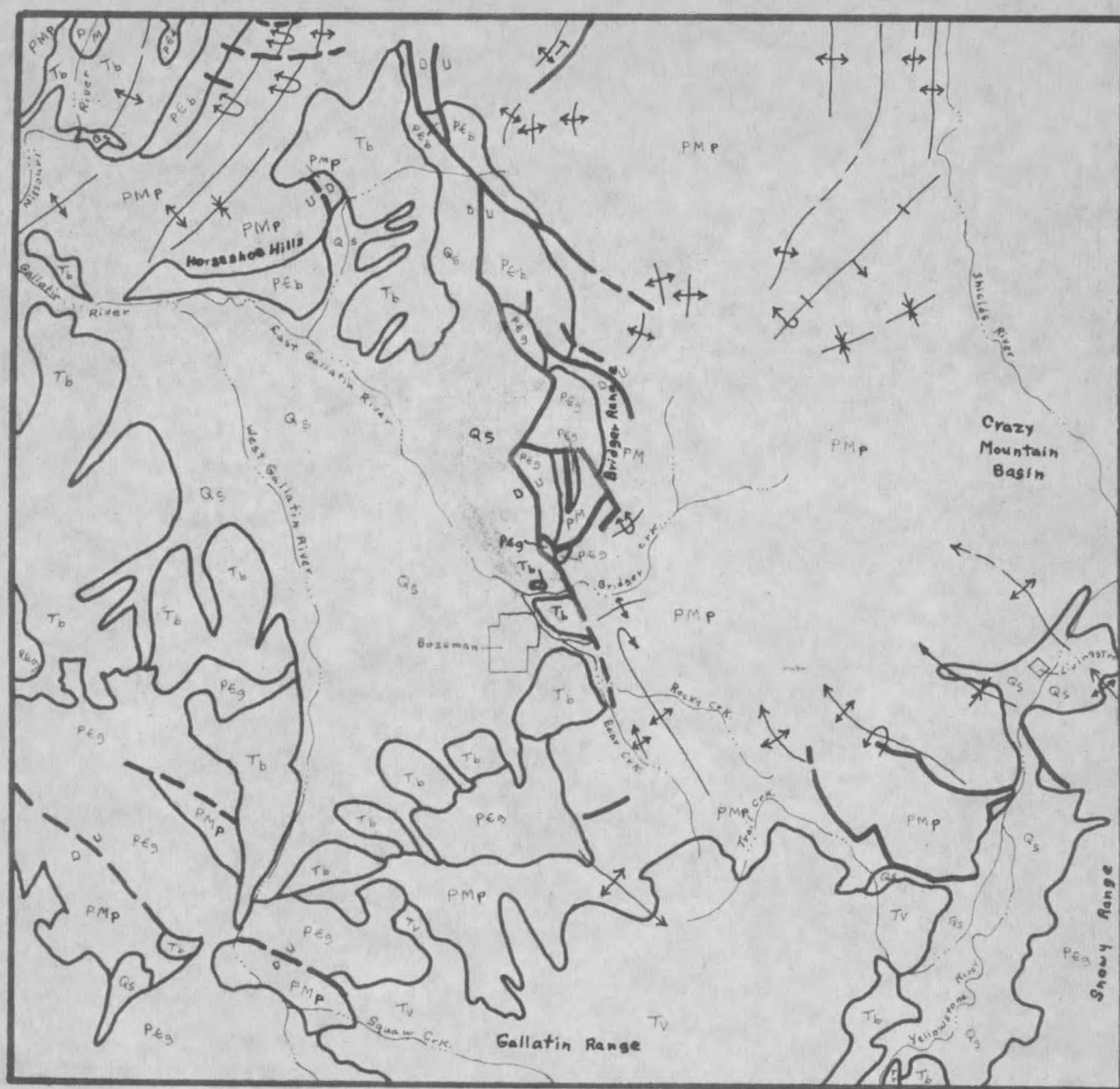
The writer uses terminology introduced by Hackett and others (1960) and Robinson (1961).

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
- Pcb Pre-Cambrian Belt
- Peg Pre-Cambrian Gneiss



Folds



High Angle Fault, Undifferentiated



Thrust Fault, T on H.W.

N

10 Miles
Scale

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

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 interrupted 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
TERTIARY	Oligocene	unconf.		
			Fluvial, igneous and quartzitic gravels and conglomerates; tuffaceous sandstones and siltstones; and pure ash deposits of fluvial and eolian origin.	0-1500 plus
		disconf.		
			White, tuffaceous, fossiliferous, thin-bedded siltstones and sandstone.	0-800 plus
	Eocene		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
CRETACEOUS	UPPER	Paleocene		
		Livingston fm.	Coarse conglomerate, some andesitic sand lenses Andesitic sandstone, sporadic conglomerate beds Coarse conglomerate, some andesitic sandstone Siltstone, shale, some andesitic sandstones and fresh-water limestones Andesitic sandstone, andesite conglomerates	up to 14,500

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
PERMIAN	disconf.			
	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	
		Amsden fm.	Upper light-gray dolomite with some thin quartz sandstone beds.	113- 185	
			Lower red siltstone unit with some variegated dolomite and impure fossiliferous limestone beds.	11- 189	
MISSISSIPPIAN	?	BIG SNOWY GROUP	disconf.		
				Cherty limestone. Black shaly limestone and black shale.	0- 171
			local disconf.		
				Locally red silty beds at top. Red and yellow sandstone or calcarenite.	0- 163
				Red siltstone, with a few purple and pale-yellow spotted dolomites. Basal dolomite and dolomite or limestone breccia	0- 100
UPPER		disconf.			
LOWER	MADISON GROUP	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, thick 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
		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
	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
C A M B R I A N	?			
	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 fissile shale, with thin-bedded limestone unit at top and, locally, intercalated conglomeratic, arkosic limestone and arkose beds in lower portion.	190-192

Generalized Stratigraphic Section, Bridger Range, Montana

Age		Stratigraphic Unit	General Lithology	Thickness Feet
C A M B R I A N	M I D D L E	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.		
P R E C A M B R I A N	A L G O N K I A N	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		
	A R C H E A N ?	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 preexisting 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 characteristic 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.

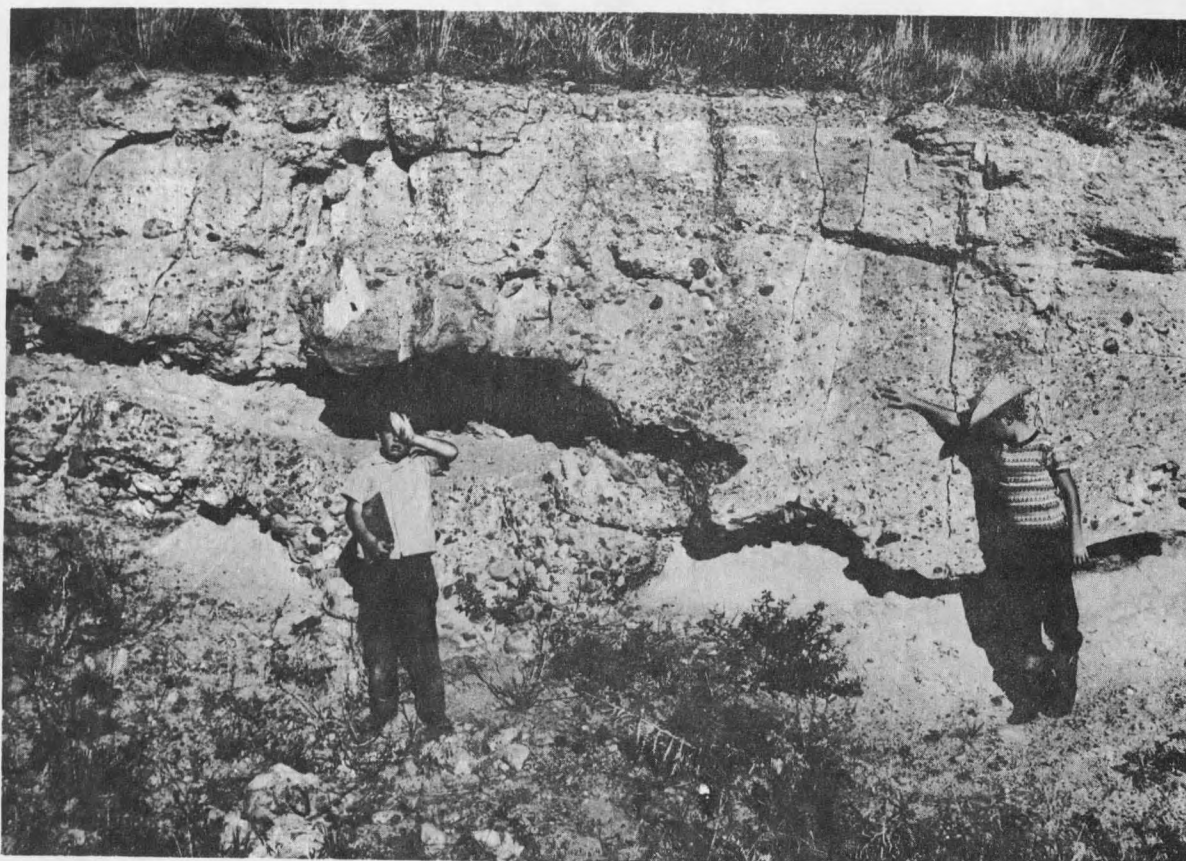


Figure 2. Typical Tertiary channel fill overlying tuffaceous sands--exposed on southwest face of Beacon Hill.

The cobbles and pebbles are generally subrounded to well rounded and exhibit extensive abrasion believed to be the result of a combination of long and rugged stream transport. The greywacke sandstones, derived from the Livingston Formation, constitute the major exception to this rule and commonly their shape is angular to sub-angular. Size of the coarse material varies widely in different channels, and boulders up to 2½ feet in diameter are present.

The conglomerates are cemented by calcite and the majority of the coarse materials, both consolidated and unconsolidated, are believed to be stream channel deposits. Their disconformable contacts with overlying and underlying strata as well as their lenticular shapes, lack of lateral continuity, and relatively poor particle size-sorting support this hypothesis of origin. These channel deposits, when reasonably well exposed, display characteristics that indicate varying directions of channel alignment at the time of deposition, depending on the particular bed observed. However, the majority of the channels display a general east-west alignment. The cobbles in these east-west channels are subtly imbricated with an orientation that indicates a stream transport direction from east to west.

The coarse-grained sandstones and sands are very similar in composition to the conglomerates and gravels; they consist of mineral fragments as well as rock fragments. The mineral grains appear to be derived from rocks resembling the gravels and conglomerates described above. The sand grains are angular, a fact which can be attributed to liberation from the larger rock fragments late in transport and also to frequent crushing by coarser bed load materials. The coarse-grained sandy material occurs in varying

degrees of consolidation depending on the amount of calcite cement. It is generally moderately to poorly size-sorted.

Fine-grained deposits: The fine-grained sandy and silty fluvial deposits of Tertiary age are composed mainly of volcanic ash fragments, mineral fragments, and fragments of very fine-grained igneous rock. They are characteristically very poorly size-sorted, very poorly bedded, and sporadically cemented by calcite. Results of microscopic thin section examination of these fine-grained sediments shows the mineral fragments to be mainly quartz, microcline, orthoclase, crypto-crystalline silica, amphibole, magnetite, and hematite. The rock fragment detritus consists of very fine-grained, basic igneous rock which exhibits varying degrees of chemical weathering. Feldspars generally are altered to clay minerals and the ferromagnesian minerals are replaced by magnetite and hematite.

Sedimentary rocks with calcite cement are virtually impermeable whereas the uncemented sediments are generally highly permeable and appear to be mainly consolidated by compaction. Volcanic ash in the uncemented sediments is generally only slightly chemically altered or devitrified. Borders of the glass shards appear to be slightly sericitized or may be coated by a very thin layer of detrital clay dust. However, under crossed nicols, borders around the shards are distinctively different in appearance from other clay size materials in the interstices probably indicating a slight devitrification of the glass, or chemical alteration, rather than a detrital dust coat. One very fine-grained specimen displayed relatively advanced devitrification or chemical alteration of the glass shards. Possibly the greater exposed surface area of the finer-grained particles permits more exposure

to atmospheric conditions resulting in subsequent faster alterations. However, in the majority of samples examined, the glass shards appear quite fresh and relatively unaltered.

Calcite cementation of Tertiary sediments occurs sporadically throughout the stratigraphic section. Lateral consistency of the cementation is difficult to determine because of a lack of continuity of exposures. Cementation of the sediments is believed to have occurred at or near the surface. The following evidence is cited to support this hypothesis. The calcite cemented fine-grained sediments display several interesting characteristics. The detrital fragments are spatially separated from each other whereas in the uncemented sediments they are in contact (Plate 1, Fig. 1&2). This detrital partical separation apparently results from secondary introduction of the calcite cement and subsequent force of crystallization of the calcite which separated the detrital particles. Although the detritus was apparently forced apart, no obvious calcite-filled fractures exist in the detrital particles. Under a heavy load of overlying sediment, the increase in volume accompanying the forceable separation of detrital particles during crystallization of the calcite cement would probably result in significant lateral and vertical stresses within the rock. It appears these stresses would cause at least some fracturing of the detrital particles and subsequently calcite filled the fractures. The absence of such fractures in the thin sections studied indicates the calcite may well have been introduced when little overburden material was present above the sediments being cemented.

As some of the cemented silts and sands are at present overlain by hundreds, and may at one time have been covered by thousands of feet of overburden, it is suggested that cementation took place shortly after deposition of these units and before deposition of the later sediments. This type of cementation could result from caliche deposition during intermittent flooding and ponding of streams in the area with subsequent evaporation of the floodwater and precipitation of the calcite. However, surface and underground water normally do not contain enough dissolved carbonate to effectively cement deposits in this manner except in more arid climates. The inferred climate at the time of deposition indicates a more humid environment not conducive to concentration of calcite deposition by evaporation.

The type of calcite deposition required might result from deposition in ephemeral lakes during periods of slight ash fall (McMannis, personal communication). However, no other indications of a lacustrine environment are present in the sediments. Therefore, because of conflicting evidence, the exact process of cementation is not known to the writer.

Other interesting characteristics of the fine-grained sediments include a striking absence of size-sorting among the detrital particles, the predominance of angular mineral grains, and only slightly altered, intricately shaped glass shards. It is not uncommon to observe pebbles or cobbles up to 2 inches in diameter included in very fine-grained sand or silt matrices. This evidence suggests a depositional environment in which the streams were clogged with detritus resulting in a slurry or virtual mud flow. Heavy ash falls in the drainage basins where the streams originated would overload the streams. The high viscosity of the resulting flow would cause large

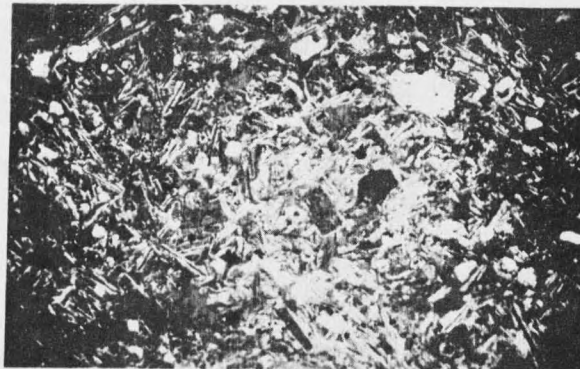


Figure 1. Photomicrograph in polarized light uncemented, fine-grained, Tertiary sediments, Beacon Hill Subarea. Neutral colored background is interstices between grains. Light colored borders around shards are caused by alteration of glass.

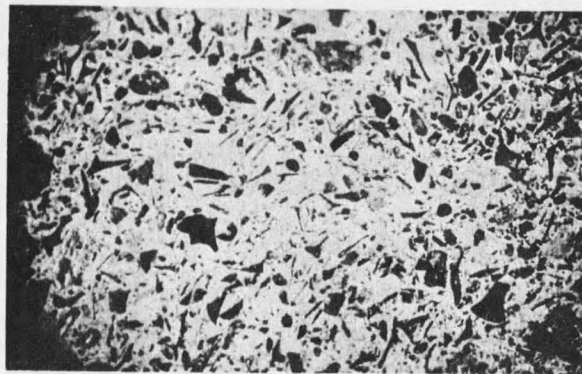


Figure 2. Photomicrograph in polarized light, cemented, fine-grained, Tertiary sediments, Beacon Hill Subarea. Light background is calcite cement.

and small particles to be transported and deposited with little rounding and exceptionally poor size-sorting. Rapid aggradation, or virtual dumping, of this material would take place in downstream basins or depressions nearest the source area. The strata thus deposited would resemble those in this part of the Three Forks Basin. Therefore, the writer attributes the origin ^{all?} of the fine-grained sediments to such processes.

Tuff and ash deposits: The Tertiary stratigraphic section contains a few beds of nearly pure volcanic ash. A four foot, gray ash bed was penetrated by a U.S.G.S. drill hole at a depth of 131 feet in the subsurface Tertiary beds about $1\frac{1}{2}$ miles west of the northwest corner of the map area in sec. 34, T.1S., R.5E. Sporadic pebbles in the ash indicates these beds are stream deposited. The exact origin of other ash beds is uncertain, possibly they represent exceptionally rapid ash falls from volcanic activity in the region. The ash beds (Ta on Plate I) in the SW $\frac{1}{4}$ sec. 10, T.2S., R.6E., are at least 25 feet thick and are deposited in coarse festoon type cross-beds. The coarse, long sweeping appearance of the cross beds and their orientation (steep on the west and approaching horizontal on the east) suggests deposition by westerly winds. Samples of the ash from various beds were analyzed. Devitrification was very slight in all samples attesting to the relative freshness of the deposits. The shape of shards from all deposits was very similar and is typified by the shapes in Plate 1, Figs. 1 & 2. Other results of these analyses are compiled in Table 1.

Table 1 - Volcanic Ash Analyses

<u>Sample Number</u>	<u>n</u>	<u>Color</u>	<u>Location</u>
7-26-3B	1.498	white	SW1/4 sec.9,T.2S.,R.6E.
7-26-7A	1.501	white	SE1/4 sec.9,T.2S.,R.6E.
7-26-7B	1.502	yellowish gray	SE1/4 sec.9,T.2S.,R.6E.
7-27-16B	1.510	yellowish brown	NW1/4 sec.10,T.2S.,R.6E.
7-27-16C	1.506	yellowish gray	NW1/4 sec.10,T.2S.,R.6E.
7-28-11C	1.510	medium light gray	SW1/4 sec.10,T.2S.,R.6E.
9-13-3C	1.502 & 1.506	light gray	NW1/4 sec.16,T.2S.,R.6E.

The samples 7-27-16 B & C have indices of refraction similar to 7-28-11C and they are situated approximately on strike with each other. A strong possibility exists that they are both part of the same stratigraphic unit and they are tentatively shown as the same unit (Ta) on the map (Plate I).

According to other writers (George, 1924 and Heinrich, 1956), indices of refraction of volcanic glasses generally range between 1.480 and 1.620. The low refractive indices and the restricted range of values obtained for ash deposits in this area suggests a gross similarity of composition of ash deposits observed. Although some disagreement exists regarding the relationship between index of refraction and the relative percentages of various oxides within the magma from which the glass originated, most authorities agree a low index of refraction indicates glass derived from a magma high in SiO_2 . (George, 1924). According to his tables the magmas from which the volcanic ash in this area was derived would vary between 68 and 73 percent SiO_2 . The parent magma, or magmas, would probably have been quite acidic, or more specifically rhyolitic in nature.

Source of Tertiary sediments: Determination of the source of Tertiary sediments is a difficult problem. Many varieties of the porphyries and basic igneous rocks are present in situ in a number of localities in the region. A southern and eastern source area seems most appropriate in view of available evidence. The wide variety and large volume of igneous rock required in the source area makes the Crazy Mountain, Upper Yellowstone, and Gallatin volcanic region the most likely choices.

Several rock varieties (discussed below) comprising the deposits are distinctive but a search of the Boulder River drainage, Stillwater area, Cooke City area, Yellowstone Valley, and the Gallatin, Madison, and Jefferson drainages failed to provide conclusive proof of the source of these rocks.

Two of the most distinctive rock types in the Tertiary gravels of the southeast part of the Gallatin Valley are described below: one is a basic porphyry consisting of large cream colored phenocrysts of plagioclase, commonly about $\frac{1}{2}$ inch long, enclosed in a very fine-grained, black matrix consisting of minerals too fine to identify easily with a microscope (Plate 2, Fig. 1 & 2). Also randomly scattered through the matrix are particles identified as rock fragments, probably xenoliths, consisting of very fine-grained quartz, orthoclase, and plagioclase. The matrix, which appears to consist of microlites and crystallites, also contains many minute grains of an opaque material, apparently mostly magnetite, which appears to be a secondary mineral replacing the matrix. The writer has tentatively named the rock a basalt porphyry because of the overall dark color of the rock and identity of the coarser mineral constituents. Fragments of this rock are

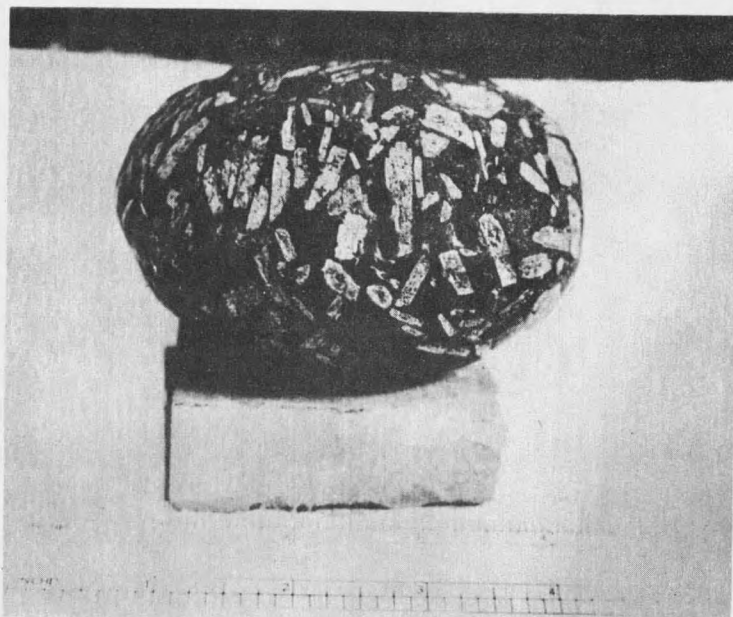


Figure 1. Basic porphyry cobble from Tertiary gravel, Fort Ellis subarea. Large, light-colored grains are plagioclase phenocrysts.



Figure 2. Photomicrograph in polarized light basic porphyry, Fort Ellis subarea. Large grains are plagioclase phenocrysts.



Figure 1. Granodiorite cobble from Tertiary gravel, Beacon Hill subarea.

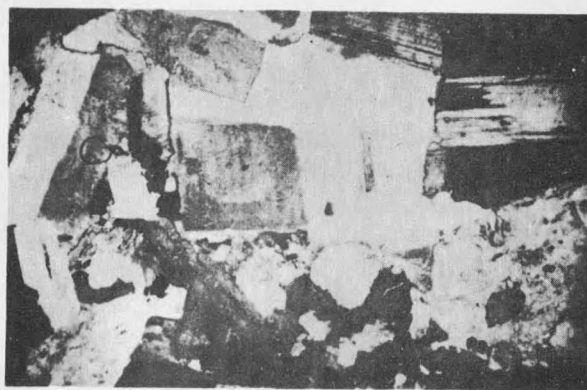


Figure 2. Photomicrograph of granodiorite, Beacon Hill subarea.

common in the Tertiary gravels and conglomerates in both the Beacon Hill and Fort Ellis subareas.

The other unusual rock type is also present in the same Tertiary sediments and apparently comprises one to two percent of the coarse deposits. In hand specimen it is coarse-grained, pink and black speckled and gives the impression of being a pink granite (Plate 3, Figs. 1 & 2). However, a Rosiwal analysis of a thin section of this rock showed it to be a pink and black granodiorite according to the classification of Travis (1955). Percentages of minerals present are as follows: quartz, 14.72%; orthoclase, 23.90%; plagioclase, 49.37%; ferromagnesian, 9.50%; and opaques, 2.51%.

McMannis (personal communication, 1962) recently observed igneous intrusive outcrop in the Crazy Mountains that strongly resembles granodiorite cobbles in the Tertiary section. John Blaemle (1962) conducted a microscopic comparison of this intrusive and the granodiorite cobbles and concluded they were certainly closely related and very possibly the same. If no other intrusives can be located that are composed of the same rock type, the Crazy Mountain intrusives must be considered a source material for some of the Tertiary gravel constituents. The geographic location of the Crazy Mountains, as a source area, further substantiates an east-to-west transport direction for some of the Tertiary material. This is in agreement with other field evidence.

A comparison was made of the deposits of the thesis area with gravels of the "White Cliff" Tertiary deposits (Horberg, 1940) directly north of Yankee Jim Canyon in the Yellowstone Valley. Although these deposits are considered similar in age and other characteristics (dominant igneous

lithology and wide variety of volcanic constituents) the distinctive rock types mentioned above are not present in the "White Cliff" deposits.

The writer also made brief comparison of Tertiary gravels of the thesis area with surface gravels just west of the West Gallatin River and with conglomerate lenses in the Madison bluffs (Bozeman Group) south of Logan, Montana. The results indicated a gross similarity of lithologic constituents of the gravels. However, in this comparison, as in the comparison made with the "White Cliffs" (discussed earlier in this paper), distinctive differences in lithology of the gravels were observed.

These general similarities and specific differences of deposits believed to be of similar age, suggest to the writer that drainage into the basin during Tertiary deposition may have been multidirectional as it is today but including a major^v west-flowing stream in the map area.

Measured Tertiary stratigraphic section: Tertiary deposits of the Beacon Hill subarea were measured (indicated on Plate I). The 2,016-foot section is comprised of a monotonous repetition of channel deposits consisting of gravels and conglomerates interbedded with highly tuffaceous, fine-grained sandstones and siltstones. Several relatively pure volcanic ash layers are also interbedded. Calcite cementation of the beds is sporadic and permeability of the sediments appears to be largely controlled by the amount of calcite cement present. Description of units and comments pertaining to the method of measurement are included in Appendix B.

Fossils and age of deposits: Establishing accurate ages for the various basin deposits was one of the primary objectives of the investigation. Several significant vertebrate fossils were collected in the area and studied by Edward Lewis, vertebrate paleontologist for the U.S. Geological Survey in Denver, Colorado. Results of this study are included in Table 2 (Appendix B). Fossil evidence indicates Tertiary deposits in the area are of late Miocene to early Pliocene age.

This age is further suggested by the following reasoning: Older Tertiary rocks (Eocene and Oligocene) of the basin are exposed in the extreme western part of the region (Hackett and others, 1960 and Robinson, 1961). According to the same authorities, the surface exposures of the basin become progressively younger in an easterly direction. The youngest beds definitely dated are the Miocene deposits of the Anceney area about 10 miles west of Bozeman (Dorr, 1956). If the Tertiary deposits are still younger farther east, and no evidence was found to indicate they are not, then deposits of the Beacon Hill and Fort Ellis subareas would most likely be at least as young as the age stated, or possibly younger.

Quaternary Deposits: These deposits were mapped by Hackett and others (1960) as three distinct units: QToa (old stream-laid and fan deposits), Qf (younger predominantly alluvial fan deposits), and Qa (younger predominantly stream-laid deposits). All are unconsolidated at the surface in the map area. The most distinctive characteristic of these deposits, as in the case of the Tertiary deposits, is their lithologic composition. Many of the gravels contain rock fragments that appear to be materials reworked from the Tertiary deposits by downcutting streams. However, all contain abundant

Precambrian gneiss and Tertiary basalt fragments, and/or distinctive, relatively soft rocks representative of Paleozoic and Mesozoic strata present around the rim of the basin. Many of these relatively "soft" rocks have persisted through distances of more than five miles of stream transport. This fact is significant because the softer constituents are absent in the Tertiary gravels and conglomerates. Most of these Quaternary surface deposits can be traced up present drainages to their source.

The age of two gravel deposits in the map area is uncertain, and they may be either Tertiary or Quaternary. A stream terrace about 40 feet above and north of the present East Gallatin River drainage is composed of gravels that overlap the steep Tertiary bedrock slopes in the southern extension of the Beacon Hill subarea. These gravels, although Quaternary in gross appearance, closely resemble those present in the Tertiary deposits, but contain fragments of pre-existing Tertiary conglomerates and sandstones. They are unlike gravels of the East Gallatin River floodplain adjacent to this terrace. The East Gallatin, along this portion of its course adjacent to the Tertiary sediments, also contains some reworked Tertiary material, and Paleozoic and Mesozoic constituents derived from the Rocky Creek and Bear Creek drainage. This evidence suggests the terrace may be considerably older than present floodplains; at least the differences in lithologies indicate a difference in source materials available during the time the terrace gravels were deposited.

A related gravel was examined in a gravel pit in NW 1/4 sec. 16, T.2S., R.6E. It occurs directly south of the East Gallatin floodplain at a slightly higher elevation than the previously discussed terrace and contains similar

reworked Tertiary gravels. It was originally believed to represent a terrace matching the one previously discussed, just north of the East Gallatin River. However, it is overlain by a thin layer of pure volcanic ash (sample 9-13-3C, Table I) and the ash deposit is overlain by definite Quaternary gravels (Fig. 3). The volcanic ash overlying the gravel of questionable age appears very similar to ash deposits of the Beacon Hills subarea, dated as Tertiary. Therefore, the age of the underlying gravels may be Tertiary even though they strongly resemble gravels of possible early Quaternary age (previously mentioned) that overlap the Tertiary escarpment directly north of the East Gallatin River floodplain.

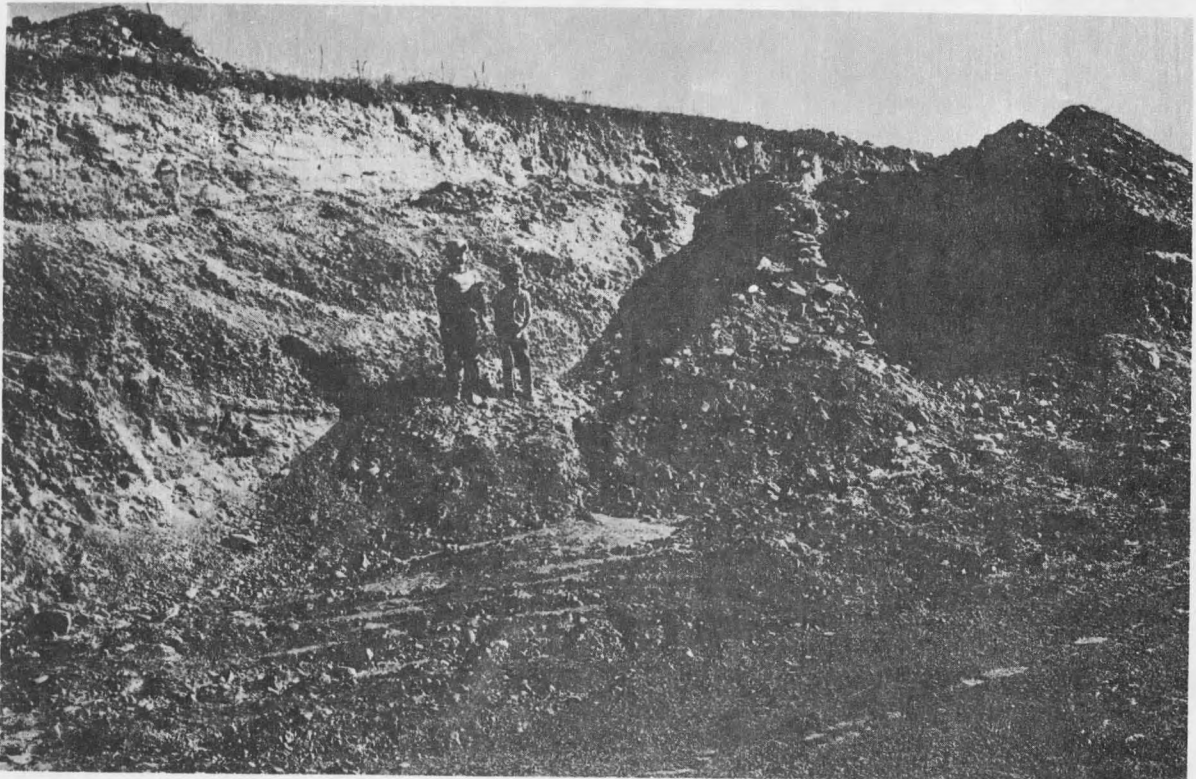


Figure 3. Gravel exposure south of East Gallatin River showing stratigraphic sequence of gravel and ash beds.

- "A" - Reworked Tertiary gravel.
- "B" - Ash layer.
- "C" - Quaternary gravel.

Loose gravels mantling the surface of the Beacon Hill subarea are considered to be reworked Tertiary sediments because of their lithology; they are therefore classed as Quaternary lag gravels. They are not shown on the map because they are relatively thin.

Gravel exposures were carefully examined in an attempt to differentiate Tertiary and Quaternary deposits on the basis of lithology. A statistical analysis, for which 50 cobbles and pebbles were randomly selected, was made in 21 critically situated gravel deposits. Percentages of the rock types present were then calculated. These percentages are not volume percentages since size of the pebbles and cobbles varied widely; and results are only intended to give a rough approximation of the types and quantities of various constituents present in the gravels. Results of this sampling are compiled in Table 3, Plate III. These results indicate marked differences in the lithology of various gravel units and these differences are the basis for differentiating Tertiary and Quaternary deposits.

A significant igneous rock fragment was observed in the Quaternary exposure GR-5 (Plate I & Table 3). It is a granite porphyry containing many very coarse-grained orthoclase phenocrysts. Its striking appearance would render it easily recognizable in outcrop or in stream gravels. If found elsewhere in the future it could provide valuable information on the source of some of the gravel deposits.

Summary of Cenozoic Stratigraphy: Coarse Tertiary sediments in the area consist mainly of porphyritic and other volcanic igneous rocks, quartzites, and graywacke sandstones. Most of the detrital particles are very hard, resistant, and rounded indicating a combination of long and rigorous

transport, and many of the fragments are unusually coarse. Streams that transported such sediments must have been very competent. The aggradation of these sediments is believed to represent a normal tendency of the streams to build a steeper gradient in the basin thereby providing higher stream velocities and adjusting stream competence to sufficiently move the available sediment load.

Imbrication indicates that at least the local direction of transport was from the east or southeast. A possible and likely source area that could furnish material of the type described is the volcanic region of Yellowstone Park, the Crazy Mountains, and the Gallatin Range. The gray-wacke sandstones apparently were locally derived from the east.

Fine-grained Tertiary sediments are lithologically similar to the coarse Tertiary material in the Bozeman Group; they contain vast quantities of slightly altered volcanic ash and are poorly size-sorted. They indicate deposition by ash choked, aggrading streams. The fresh condition of the shards suggests relatively rapid burial and protection from atmospheric and percolating water, and other weathering processes. Calcite cementation probably occurred near the surface as sediments were being deposited but the exact process of cementation is not understood.

The presence of nearly pure ash deposits interbedded with other Tertiary sediments suggests periodic ash falls over the region; the ash was then reworked by stream and wind action. Analysis of the indices of refraction of glass shards suggests the ash was derived from rhyolitic magmas.

Quaternary sediments, characteristically different in lithology from Tertiary sediments, were derived from both reworked Tertiary deposits and

erosional products of basin rim bedrock. The general increase in particle angularity approaching the mountain fronts that is apparent in these deposits supports this hypothesis.

No loess deposits are present in the map area, but farmland in the northern part of the Fort Ellis subarea may be partially covered by this type of material.

Recent lag gravel deposits are developing at present on the Beacon Hill subarea surface.

STRUCTURE

Thrust faulting and tear faulting in the southeast corner of the basin (Plate I), adjacent to Bear Canyon, suggest multiphase release from compressional forces. East-west compression would account for the north-south imbricate thrust pattern developed in Paleozoic and Mesozoic formations. These thrusts are further cut by a northwest-southeast aligned tear fault that probably indicates relief from a force couple initiated by continued compressive forces. The overturned Paleozoic and Mesozoic strata involved in these thrust plates suggests that they may mark the margin of an overturned anticlinal uplift. The west flank of the uplift either has been subsequently removed by erosion or down faulted by normal faults now obscured by basin fill. If the latter is true, this anticlinal flank, or parts of it may now form part of the basin floor.

The Bridger Creek-Bear Canyon Fault: A major northwest trending fault is indicated along the west flank of the Bridger Range. It was referred to

by McMannis (1955) and Hackett and others (1960) as the Bridger Creek-Bear Canyon fault. Several springs mark the general trace of the postulated fault.

The Tertiary strata in the Beacon Hill subarea strike approximately north and dip 2-7 degrees east toward the mountain front where they appear to terminate against the postulated Bridger Creek-Bear Canyon fault. However, directly adjacent to the fault, the strata are covered by Recent lag gravels. This general eastward dip is also indicated in the eastern three-fourths of the Fort Ellis subarea, although suitable outcrops to determine structural attitude are very scarce. Several cobbles in the gravel, lithologically similar to those contained in the Tertiary conglomerates, were found in topographic depressions northeast of the fault. This suggests that if the fault is a normal tensional fault with the west block downthrown, as is postulated by McMannis (1955) and Hackett and others (1960), later Tertiary or reworked Tertiary deposits may have overlapped the upthrown east block. The exact trace of the fault plane at the surface is now obscured by lag gravels mentioned under "Quaternary deposits". Faulting may also have isolated previously overlapping Tertiary sediments on the upthrown block. However, vegetative growth patterns (aligned parallel to exposed dipping strata to the west) near the top of south facing slopes of the Beacon Hill subarea are visible about a hundred yards west of the fault line. Their alignment suggests a persistence of the gradual east dip of the Tertiary strata into the fault. This evidence suggests to the writer that the Tertiary strata now preserved west of the fault were actually deposited prior to the final significant vertical displacement of the fault and any

Tertiary sediments deposited later as a stratigraphic overlap of the fault have since been eroded and no definite evidence of them remains.

The combination of dip of the strata and the imbrication of the gravels also supports the hypothesis of deposition prior to faulting rather than, simply a stratigraphic onlap relationship. Age of the Tertiary gravels and direction of sediment transport suggests most recent movement on the fault to be of post-late Miocene age.

Structural relationships between Tertiary strata and the front of the Gallatin Range: Structural attitudes in the Tertiary strata of the extreme northwest part of the Fort Ellis subarea differ from those of the Beacon Hill subarea. The strike here is approximately east with a general 12 degree south dip. This attitude is generally persistent to about the middle of the east border of sec. 19, T.2S., R.6E., as indicated on the map (Plate I). Attitudes of the Tertiary beds are obscured to the south along the west facing Sourdough Creek escarpment.

The gentle southward dip of Tertiary strata along Sourdough Creek toward the Gallatin Range is analogous to the gentle eastward dip of Tertiary strata toward the postulated Bridger Creek-Bear Canyon fault (bordering the front of the Bridger Range) of the Beacon Hill subarea. The writer accepts this analogy as evidence suggesting presence of a buried fault between mountain front and basin along the north front of the Gallatin Range. Hackett and other (1960) did not map a fault contact between basin deposits and older rocks comprising the front of the Gallatin Range. He mapped a stratigraphic contact where the Recent gravels are in contact with the very old rocks that form the mountain front. The writer

was also unable to discover evidence that would accurately indicate or locate a fault along this front so the dotted stratigraphic map contact of Hackett was retained because of lack of evidence as to the exact location of a fault. However, McMannis (personal communication, 1961) has observed Tertiary strata dipping gently into the mountain front directly adjacent to the Gallatin Range a short distance west of the map area. This evidence also strongly suggests a major fault separating basin and range along the north front of the Gallatin Range.

Significance of deformed Tertiary strata: The geometric relationships of the Tertiary strata discussed above are suggestive of late Tertiary (or early Quaternary) relative subsidence of this part of the basin causing the Tertiary strata to dip toward observed or postulated normal faults that border the mountain fronts. Restoration of the Tertiary strata to a horizontal attitude is impractical since even approximate location of the hinge line is unknown. The extent to which basin deposits covered the basin rim before faulting is equally difficult to imagine since ^{the} net displacement of the fault and the extent to which erosion had planed down Mesozoic and Paleozoic rock formations around the rim at this time is unknown. The thickness and dip of the measured stratigraphic section indicates stratigraphic displacement on the fault is greater than 1,500 feet. Seismic information on the nature of the basin floor adjacent to the mountain fronts might provide more precise data on the stratigraphic displacement along the faults and thereby remove some of the complications of restoring paleo-topography. Possibly the Tertiary deposits extended as far east

as the Yellowstone Valley, or maybe they never reached the top of the basin rim--one can only speculate in the light of present knowledge.

The change in attitude between the Tertiary beds along Sourdough Creek, the Beacon Hill subarea, and those exposed in the first major north-south incised gully east of Sourdough Creek is obscured by Quaternary alluvium. The change may be related to faulting but there is no evidence to support such a conclusion.

Faulted Tertiary deposits: Two definite fault zones were observed within the Tertiary sediments. The observed faults are shown on the map by dotted lines since they are visible only in eroded faces and the direction and extent of their traces is speculative. Displacements are small.

One of the fault zones is in the SW 1/4 sec. 7, T.2S., R.6E. At least three east-trending faults are visible on which apparent displacements vary from less than a foot to a maximum of five feet. The southerly two are relatively upthrown on the south. The fault farthest to the north shows the opposite displacement (Fig. 4).

The other fault zone observed displaces beds in the ash deposit located in SW 1/4 sec. 10, T.2S., R.6E. Two faults are exposed in an excavation and both appear to strike in a northeast direction. Both have their southeast blocks upthrown relative to the northwest blocks. The eolian ash and disconformably overlying fluvial sand and gravel deposits are all cut by the faults (Plate 4, Figs. 1 & 2).

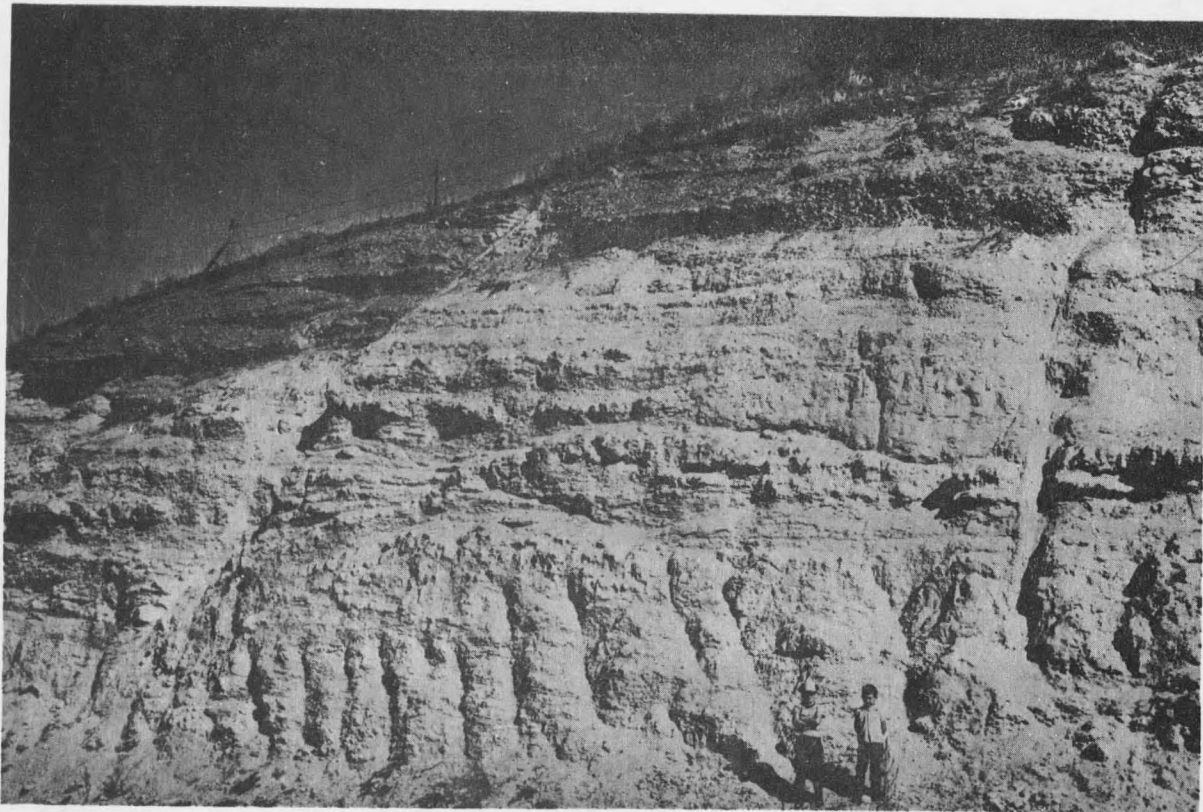


Figure 4. Faulted Tertiary deposits along Sourdough Creek. Coarse gravel deposits at top of exposure are underlain by highly tuffaceous sands and silts. Note that present erosion is exploiting the less resistant sediment exposed along fault planes.

Although the faults of both zones appear impossible to trace, examination of trends on the map suggests they may both belong to the same system and may be interconnected. The amount of relative displacement on the ash bed faults appears to be slightly greater than on those along Sourdough Creek.

Albert E. Roberts of the U.S. Geological Survey (personal communication to McMannis, 1961) reported finding a west trending fault with considerable displacement that cuts across the northern end of the Chestnut Mountain anticline east of the map area. He suspects this fault intersects the Bridger

Creek-Bear Canyon fault near the north central boundary of sec. 14, T.2S., R.6E. At that point a small, light colored, very fine-grained igneous intrusive is exposed. Further projection of that postulated fault trend in a westerly direction nearly coincides with the observed fault zone exposed along Sourdough Creek. Therefore, the Sourdough fault zone may mark the extremities of the above mentioned fault on Chestnut Mountain anticline. In the light of present knowledge and because of the lack of more concrete evidence, the writer has no definite conclusions on the interrelationships of the fault zones discussed.

Summary of structural features: Early Laramide compressional forces were instrumental in influencing development of the southeast corner of the basin. Two phases of relief of compressional stress are suggested by fault patterns in this area. Normal tensional faulting, erosion, or a combination of both apparently contributed to development of a depression, including the map area, that subsequently served as a depositional site for Tertiary sediments. However, structure is favored by the writer as the primary influence on basin development.

Structural attitudes of Tertiary strata and their relation to the mountain fronts bordering the basin suggest a phase of normal faulting that further relatively dropped the floor of the basin in this area. Some of this late Cenozoic faulting may be the result of recurrent movement along previously established fault planes as postulated by McMannis (1955, p. 1426-1427).

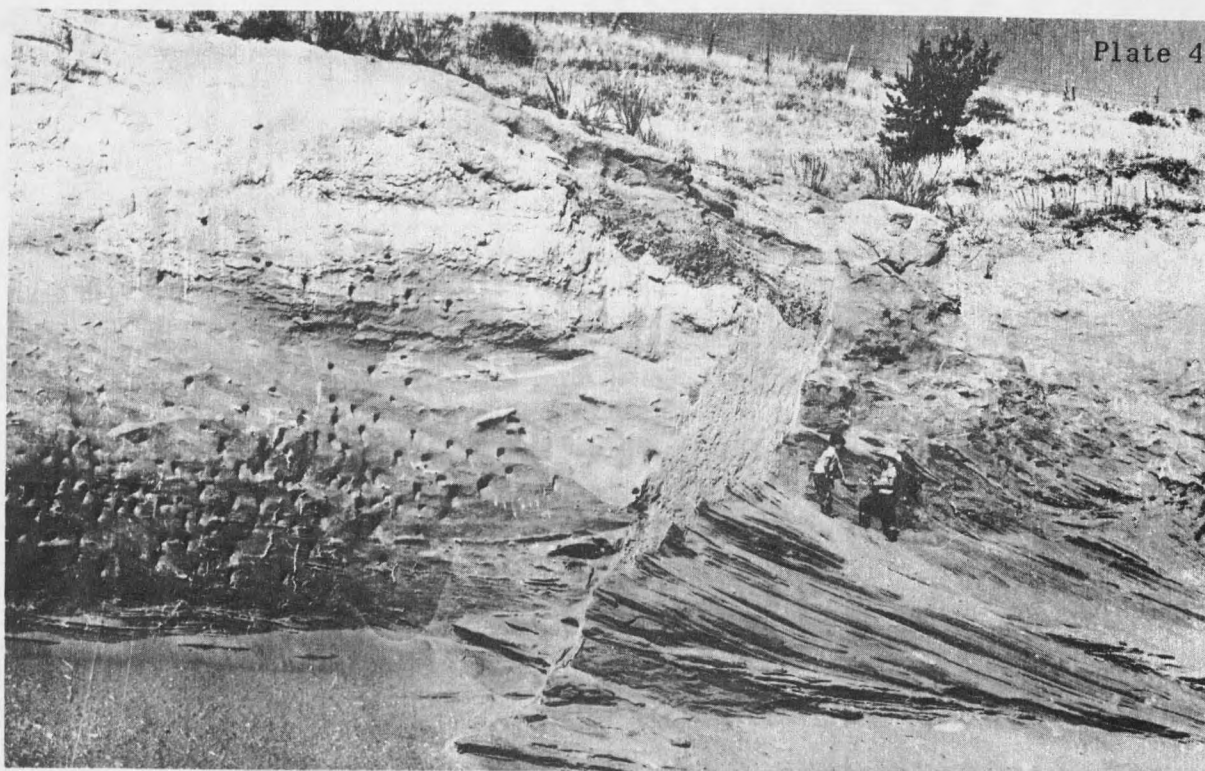


Figure 1. Normal faults in crossbedded Tertiary ash deposits, Beacon Hill subarea.

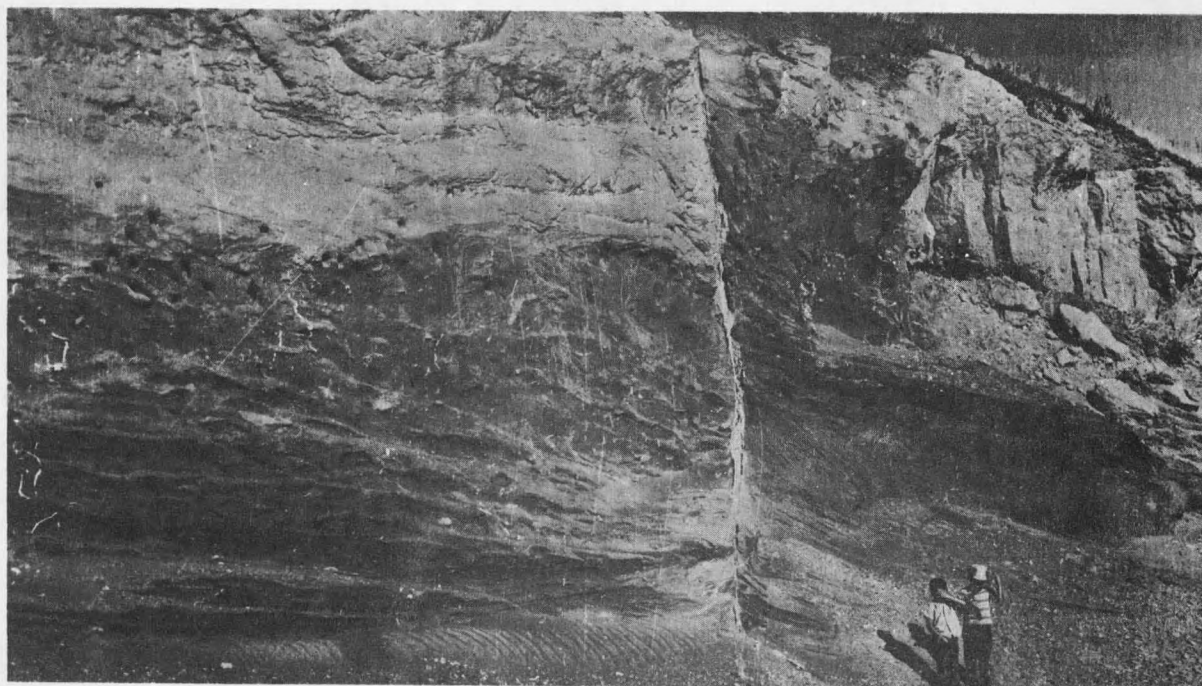


Figure 2. Normal faults in crossbedded Tertiary ash deposits, Beacon Hill subarea

No faults are observed cutting Quaternary deposits in the southeast corner of the valley, which is in agreement with the findings of McMannis (personal communication) and this apparently restricts the latest significant structural movement in the southeast corner of the basin to pre-Recent time.

GEOMORPHOLOGY

The characteristic geomorphic features in the map area are the planar topographic surfaces, alluvial fans, and present stream drainages. No glacial features are visible in the valley but strong evidence of glaciation is present directly south of the map area in the Gallatin Range. Loess deposits, which may be the result of a periglacial environment, are present in several locations in the valley, however, the writer saw no clearcut loess deposits in the map area.

Surfaces: Surfaces in the area can be grouped into five major categories; 1) the westward sloping surface north of Bridger Creek; 2) the northwest sloping surfaces of the Beacon Hill subarea, hereafter known as the Beacon Hill surfaces; 3) the gently northward sloping surface in the Fort Ellis subarea, hereafter known as the Fort Ellis surface; 4) the gently northward sloping Bozeman fan; and 5) the gently sloping floodplains of the present major drainages.

Surface north of Bridger Creek: The surface north of Bridger Creek appears to be underlain by Tertiary sediments (GR-12, Plate I and Table 3) capped by Quaternary gravels probably derived from the Bridger Range to the east. Only one exposure of the underlying Tertiary sediments is present along the north side of Bridger Creek Valley and the structural attitude

of Tertiary strata is obscure. The presently developed surface slopes west and is everywhere lower than the adjacent Beacon Hill surfaces south of Bridger Creek. It may represent a west sloping alluviated surface cut during late Tertiary time that connected the Gallatin Valley and the Bridger Range at some stage in their development. It is at present overlapped by a Quaternary alluvial fan derived from the Bridger Range and graded to a base level determined by a previous drainage system in the valley. The fan terminates about 50 feet above the present East Gallatin River floodplain. McMannis (1955) suggests the pedimented Tertiary surface may be a continuation of the north sloping Beacon Hill surface immediately south of Bridger Creek. However, only one very restricted outcrop of Tertiary material is exposed and the extensive Quaternary cover prevents more precise analysis.

Beacon Hill surfaces: ^{Stage 4 1/2} The well developed surfaces located in the western part of the Beacon Hill subarea are believed to be cut exclusively on Tertiary strata. Two of these surfaces, with similar slopes but different elevations, are separated along an intermittent drainage (Fig. 5). The marked difference in elevation, sharply defined at the western margin of the subarea, decreases eastward along the valley separating them where the planar appearance of the surfaces becomes obscured by the rough topography. Possibly a fault along the intermittent stream valley offsets the surfaces. However, no definitive evidence was found in the area of the suspected fault trace. Lag gravel caps on both surfaces resemble gravels of underlying Tertiary strata. If the surfaces are offset by erosion, the cutting was probably not stratigraphically controlled since bedding is sharply transected. No definite conclusions can be drawn on the



Figure 5. View eastward toward the Beacon Hill subarea from Highway 10. Note smooth planar erosion surfaces.

basis of available evidence. However, the Quaternary lag-gravel caps lithologically are unlike other Quaternary gravels in the area. This leads the writer to conclude that these surfaces represent the oldest remaining erosional surfaces in the map area. They appear to have been isolated (by means discussed later) from the remainder of the area and were consequently reasonably well protected from the extensive erosion that cut and developed more recent lower surfaces.

Fort Ellis surface and Bozeman fan: Tertiary strata underlying the northern part of the Fort Ellis surface, with the exception of rocks exposed along the east bank of Sourdough Creek, have the same general structural attitude as those of the Beacon Hill subarea. However, the roughly planar surface developed on these strata, although transecting bedding as in the case of the Beacon Hill surfaces, slopes gently northward and terminates about 50 feet above the south edge of the floodplain of the East Gallatin

River. The southern part of this surface is overlapped by Quaternary deposits apparently laid down by streams originating in the Gallatin Range to the south. As a result the surface is concave upward in its southern extremities and abuts sharply against the mountain front along the north slopes of Mt. Ellis and is capped by Quaternary gravels which become more angular toward the mountain front. The overall appearance suggests a pedimented surface cut on Tertiary strata that is now partially overlapped in its southern part by Quaternary sediments comprising the Mt. Ellis fan (sections A^a-A and B-A, Plate IV).

The surface is now moderately gullied by intermittent seasonal streams. Although the northern part of the surface is apparently cut on Tertiary bedrock, the gravels in the gully bottoms include Paleozoic and Mesozoic materials similar to the type that could have been derived from bedrock rimming the basin to the south, as well as intermixed reworked Tertiary materials. These may have been derived from Tertiary deposits along the gully banks and from bedload material of the Mt. Ellis fan area during seasonal flood runoff.

One important deposit of Quaternary type gravels is perched on the surface at the top of the east bank of a major northward draining gully in the SW 1/4 sec. 15, T.2S., R.6E. The deposit comprises a topographically high point on this part of the surface and at present is being quarried for aggregate. Lithologically it consists of rock ranging in age from Precambrian thru Mesozoic; most of the constituents are presently represented by bedrock outcrops directly to the south along the basin rim. Sample GR-5 (Plate I) from this locality was analyzed and the results are compiled in

Table 3 (Plate III). Its high isolated position and distinctive lithologic character aroused speculation that it may be an erosional outlier of an older Quaternary alluvial fan that formerly completely mantled the Tertiary surface.

The Fort Ellis surface appears to be an eastward extension of the Gooch's Ridge surface (west of and outside the map area). The latter is a topographically high surface cut on Tertiary bedrock. This surface slopes northwestward away from the mountain front between Middle Creek and South Cottonwood Creek. Lines drawn generally coincident with the 5,000 foot contour lines on both surfaces are smoothly arcuate and concave toward the mountain front. An eastward extension of the arc drawn on the Gooch's Ridge surface and a westward extension of the arc on the Fort Ellis surface intersect as a phantom above the present Bozeman fan. The single resultant arc may define the 5,000 foot contour on a restored surface cut on Tertiary strata. A repetition of the above operation performed on the 5,200 foot contour yields similar results. This reconstructed surface, of which only the end portions remain partially intact, appears to have had its central part cut away by degrading northward flowing streams in the southern part of the Bozeman fan. Composition of surface gravels indicates the Bozeman fan is Quaternary while those of the Fort Ellis and Gooch's Ridge surfaces more nearly resemble Tertiary. Both the older restored surface and the Quaternary fan appear to be the result of grading of surfaces extending from the Gallatin Range front northward into the valley that were controlled by master drainage patterns of the basin or the drainage exit from the basin.

Investigation of shoulders developed on the mountain front rimming the southern and southeastern part of the valley failed to disclose evidence that basin fill had ever extended up to the elevation of the shoulders. Rock fragments present on the shoulders were angular fragments of bedrock derived in situ from strata rimming the basin.

The Mt. Ellis fan is a striking feature of the present topography and its relationship to the Fort Ellis surface is significant in the Cenozoic history of the area. It consists of Quaternary debris that apparently overlaps buried Tertiary strata and appears to spill out over the gently north sloping Fort Ellis surface below. Whether it was built by continuously flowing major streams, or is mainly the result of surface creep aided by gravity on the steep slopes is uncertain. The writer favors deposition by major flowing streams to account for the great volume of debris, but no drainages of significance are now present on the fan. Limestone Creek may have been one of the important drainages that once contributed to the aggradation of the fan, however, it apparently was diverted to a course paralleling the mountain front at some stage of fan development, as is the case with many streams contributing to fan aggradation (Johnson, 1932). After its westward diversion, parallel to the mountain front, it became entrenched and is now a tributary to Sourdough Creek on the Bozeman fan.

The origin of the Mt. Ellis fan remains an unsolved problem in the mind of the writer and a lack of good exposures that would disclose its true relationship to the Fort Ellis surface restricts hope of any solution in the near future.

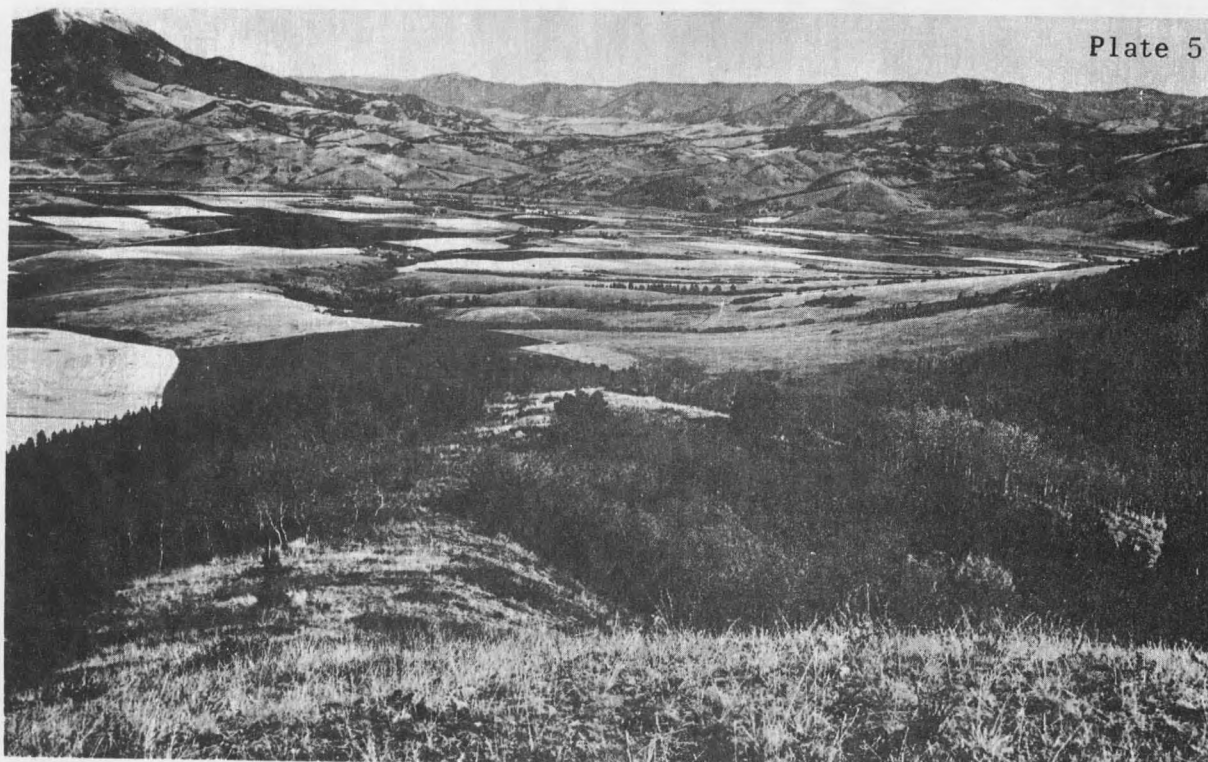


Figure 1. A northward view of Thesis area from the Gallatin Range. Part of the Mt. Ellis fan is visible at right center.

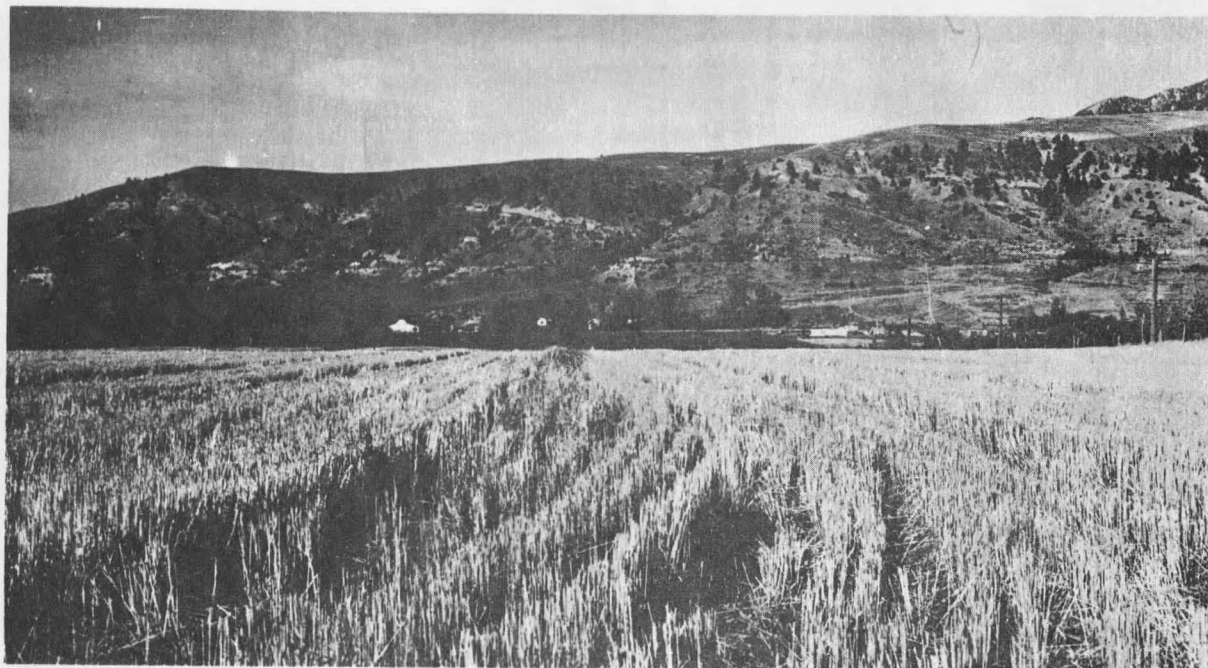


Figure 2. Tertiary beds of Beacon Hill subarea--showing their gentle eastward dip.

Present major drainages of the area: Sourdough Creek is now entrenched along the east margin of the Bozeman fan. In conjunction with Middle Creek, it appears to be the major drainage responsible for the cut and fill relationships resulting in development of the fan. Changes in sediment -to-runoff-water ratios during Pleistocene and Recent time were probably the factors that governed the cut or fill conditions of the stream. Fluctuating climatic conditions strongly influenced these factors.

The role of Rocky Creek, Bear Creek, and Bridger Creek in influencing present basin topography presents interesting possibilities. The Beacon Hill subarea, as mentioned earlier, appears to be isolated by erosion from the Fort Ellis surface and the surface north of Bridger Creek. At the time of development of the Beacon Hill surfaces which slope northward and northwestward, Rocky Creek may have been developing into one of the major drainages of the area. Bear Creek, or an ancient related drainage was probably also active at the time. Rocky Creek, by superposition or extensive headward erosion, cut Rocky Canyon through the Chestnut Mountain anticline. During this more active downcutting stage it entrenched itself along the present course just west of the mouth of Rocky Canyon and isolated the Beacon Hill subarea from the Fort Ellis subarea.

Bridger Creek to the north may also have been concurrently isolating the Beacon Hill subarea from the surfaces north of the creek. This resulted in preservation of its previously developed surfaces and shielded them from deposition of abundant fragments of Precambrian, Paleozoic, and Mesozoic rock that comprise the younger Quaternary gravels in the remainder of the map area.

Summary of geomorphic conclusions: Major planar surfaces in the southern part of the Gallatin Valley appear to have been graded from the neighboring mountain fronts to some level in the basin. The ultimate limiting factor in location of previous base levels was the status of development of a drainage outlet from the basin. The rock barrier through which the Gallatin River flows at Logan, at the north side of Gallatin Valley, was probably influential during the latter part of the basin's history and may have been the controlling factor of surface development in the southeast corner of the valley.

Surfaces believed to be the oldest pediment remnants have relatively steep north-northwest slopes and appear graded from a high basin rim to a base level in the valley that was probably much higher at the time the surfaces were developed than is the present base level.

Later pedimented surfaces along the south margin of the area are more gently northward sloping and may have been essentially graded to the basin master streams and ultimately to the basin exit.

Evidence of several stages of aggradation and degradation is present on the Bozeman fan. Well data on the map indicates Quaternary fill gradually thins northward away from the mountain front. This is suggestive of a structural trap caused by tilting of the basin toward the mountain front.

Evidence suggests the Fort Ellis pediment may once have been totally covered by Quaternary gravels and later exhumed.

Major drainages appear to be essentially at grade but the possibility exists they may not be since agricultural development of the valley resulted in much interference with the normal drainage systems, and their true state of development is thus further obscured.

GENERAL SUMMARY OF CONCLUSIONS AND GEOLOGIC SEQUENCE OF EVENTS

1. Preliminary structural conditions developed and set the stage for initiation of the evolution of the basin. These developments were primarily produced by Laramide compressive forces that began during Late Cretaceous time and continued into the early Tertiary. Apparently several directions of relief resulted in complexly folded and faulted Archean, Paleozoic, and Mesozoic rocks. Vulcanism became prominent early in the Laramide and continued sporadically into the Cenozoic Era practically to Recent time. Many of the rocks that make up the basin deposits were derived from these igneous products.
2. Tensional stresses were activated that may have marked relaxation of the compressive forces. These stresses accentuated the relative uplift and collapse of various parts of the region and probably marked the major structural development of the basin. Erosion and deposition were active processes during both the compressional and tensional stress stages further aiding in the evolution of the basin.
3. The topographic depression created as the basin sank served as a trap for material being carried into the basin; these sediments consisted of pyroclastic debris that was being erupted in the region and rock fragments that were eroded from neighboring highlands. The erosional products deposited in the southeastern part of the basin consist mainly of igneous material, resistant sedimentary and metamorphic rocks, and locally, less resistant graywackes of the Livingston Formation. The size of the coarse detritus indicates deposition by competent streams and the generally resistant nature and rounding of the detritus indicates a long transport

distance. The softer, more angular Livingston fragments were apparently being derived from areas much nearer the basin proper than the more resistant constituents. Periodic clogging of the streams with debris, mostly volcanic ash, is believed to account for the tremendous quantities of fine-grained sediments deposited in the basin. The erratic cementation of parts of the deposits are believed to have occurred shortly after, or possibly concurrently with deposition. Deposits of nearly pure volcanic ash are also interbedded with the Tertiary strata. These deposits probably originated by gravity settling from the atmosphere, stream aggradation, and eolian processes. The age of these Tertiary deposits as indicated by stratigraphic and paleontologic evidence is late Miocene and possibly early Pliocene.

4. Recurrent movement along faults bordering the southeast part of the basin apparently caused the Tertiary strata to be tilted toward the mountains that form the basin rim. This later faulting probably occurred very late in Tertiary time (post late-Miocene) or early in the Pleistocene since the Tertiary strata are affected but the late Quaternary deposits are not.
5. Following was a period of pedimentation of Tertiary during which the surfaces were graded from the adjacent mountain fronts to a base level controlled by basin drainage exits and/or master stream drainage in the basin. Concurrent with this degradational period, or shortly after, more minor faulting occurred that may have resulted from differential settling of the basin deposits; possibly it was controlled by deep seated faulting in the basin floor.

6. Pleistocene time was characterized by cycles of stream aggradation and degradation undoubtedly influenced by the fluctuations of climatic conditions of the time. Many of the pedimented surfaces present in the valley today may have been formed or modified during this time.
7. Continuing influence of stream action during late Pleistocene and Recent time is evident in the development of present floodplains and the dissection of previously pedimented surfaces. No evidence of major structural deformation during this period is apparent in the southeast part of the basin, although present structural activity, including normal faulting in the Hebgen Lake area, continues elsewhere in the region.

SUGGESTIONS FOR FUTURE INVESTIGATIONS

The paucity of good exposures in this part of the basin seriously limits the amount of specific conclusions that can be derived by standard surface geologic methods. However, many clues to basin history may possibly be revealed by extensive investigation of the bordering mountains to the east and south. Many geomorphic, stratigraphic, structural, and general geologic problems may be solved by critical investigation of these adjacent mountain ranges and the remainder of the valley.

Subsurface information from this portion of the valley is deficient. Well logs compiled by the U.S. Geological Survey (Hackett and others, 1960) are useful but in no instance were wells drilled deep enough to penetrate bedrock below the level of basin deposits. Several test holes drilled through basin sediments along the mountain front and a few drilled in the central part of the basin would provide invaluable information on the

mechanics of basin evolution and true depth of the fill. Seismic studies may also yield information on the shape of the basin floor and structure of the underlying bedrock.

Several of the igneous constituents comprising the Tertiary gravels and conglomerates are very distinctive rock types and careful observation of igneous bedrock in the surrounding region, especially to the east, southeast, south, and southwest, might more accurately disclose source areas of the materials making up the Tertiary sediments. Many of the igneous constituents of the gravels are typical rocks of the region. Many could have originated in several localities around the basin. However, several particular types are very distinctive therefore easy to recognize. Familiarity with the gravels described and careful observation of bedrock in the region might disclose the source areas for some of the rocks comprising the basin gravels and greatly aid in further reconstruction of ancient drainage patterns into the basin thus providing critical information on the basin's depositional history.

APPENDIX

Appendix A

Measured stratigraphic section in the Beacon Hill subarea

The described measured section consists of a composite section resulting from a stratigraphic strip-log and visual field matching of six partial measured sections (Plate I).

Measurement of the partial sections was accomplished using a home made Jacob's staff. A general north-south strike and an average five degree east dip were assumed. The resulting total measured thickness (2,016 ft.), obtained after matching the six partial sections, is considerably greater than a calculated thickness (1,460 ft.) using dip of strata, map distance, and difference in elevation. The disagreement in thickness is probably largely the result of attempting to trace beds of laterally varying thickness, and perhaps in part to mismatching of the composite sections.

Note: Top of section removed by erosion. Uppermost measured beds apparently abut against the Bridger Creek-Bear Canyon Fault. For location of section see map (Plate I).

<u>Unit</u>	<u>Description</u>	<u>Thickness</u>
1. Cover.....		315'
2.	Gravel, unconsolidated; composed mainly of sub-rounded to rounded pebbles and cobbles of volcanic and porphyritic igneous rock, quartzite, and graywacke sandstone. Vertebrate jaw bone fragments (sample number 9-5-1) were extracted from gravels similar to this, and believed to be the same unit, to the south (see Plate I)...	20'
3. Cover.....		250'
4.	Ash, non-calcareous, gray, fine-to medium-grained, very friable; well developed festoon cross-bedding. Ash deposit is disconformably overlain by fluvial gravel deposits and fine-to medium-grained, poorly size-sorted sandstones. Fossil bone fragments (sample number 7-28-11e) found loose on surface of the fluvial deposits overlying the ash. A vertebrate tooth (sample number 10-1-1) was found in place in beds mapped as a northward exposure of this unit (see Plate I).....	25'

5. Cover..... 30'
6. Limestone, sandy, tuffaceous, very light gray, very fine-to coarse-grained, poorly size-sorted, poorly bedded, impermeable. Glass shards appear unaltered in thin section and constitute approximately 30% of the rock; very fine-grained calcite cement constitutes approximately 65%; and the remaining 5% is composed of mineral fragments (quartz, feldspar, amphibole, biotite, magnetite, and hematite) and very fine-grained igneous rock fragments. The detrital fragments are slightly corroded by the calcite cement..... 30'
7. Cover..... 50'
8. Cover-appears to consist at least in part of sandstone, very tuffaceous, non-calcareous, tan, fine-to medium-grained, poorly size-sorted, friable, permeable. Glass shards constitute approximately 80% of the rock, dust and very fine-grained matrix approximately 10%, and the remaining 10% is composed of mineral fragments (quartz, feldspar, amphibole, magnetite, and hematite) and very fine-grained igneous rock fragments..... 68'
9. Sandstone, very tuffaceous, non-calcareous, tan, fine-to medium-grained, poorly size-sorted, poorly bedded, permeable..... 2'
10. Cover..... 30'
11. Conglomerate, calcareous, gray; composed mainly of pebbles and cobbles of aphanitic volcanic rock and porphyritic igneous rock, quartzite, and graywacke sandstone. Conglomerate is lenslike in form and disconformably overlies a coarse-grained conglomeratic sandstone..... 5'
12. Cover..... 87'
13. Sandstone, calcareous, gray, coarse-grained to conglomeratic, poorly size-sorted, poorly bedded; contains fragments of quartz, feldspar, amphibole, magnetite, fine-grained basic igneous rock and quartzite..... 5'
14. Cover..... 23'
15. Sandstone, highly tuffaceous, non-calcareous, tan, fine-to medium-grained, poorly size-sorted, poorly bedded, permeable. Sand also contains a minor amount of mineral fragments (quartz, feldspar, amphibole, magnetite, and hematite) and fine-grained basic igneous rock fragments..... 20'
16. Cover..... 10'

17. Conglomerate, calcareous, gray. Sub-rounded to rounded pebbles and cobbles are composed mainly of basic volcanic and porphyritic igneous rock, quartzite, and graywacke sandstone..... 10'
18. Conglomerate overlain by a sandstone sequence grading upward through the unit from non-calcareous to highly calcareous. Conglomerate is calcareous, gray, and composed of sub-rounded to rounded pebbles and cobbles of basic volcanic and porphyritic igneous rock, quartzite, and graywacke sandstone. The sandstones are tuffaceous and also contain mineral fragments (quartz, feldspar, amphibole, magnetite, and hematite), tan, vary from fine-to coarse-grained, poorly size-sorted, poorly bedded. Glass shards and other detritus are only slightly altered in non-calcareous zones but are highly corroded around particle borders by calcite cement where it is present..... 85'
19. Conglomerate, calcareous, gray. Sub-rounded to rounded pebbles and cobbles of the conglomerate are mainly composed of basic volcanic and porphyritic igneous rock, quartzite, and graywacke sandstone..... 5'
20. Cover-probably same material as unit 21 below..... 20'
21. Tuff, contains concretionary calcareous zones, tan, medium-grained, poorly size-sorted containing some pebbles, poorly bedded. Pebbles are volcanic igneous rock fragments. Tuff also includes sand grains of various minerals (quartz, feldspar, amphibole, and iron oxide)..... 37'
22. Tuff, non-calcareous, gray, medium-grained, poorly size-sorted, containing some pebbles, poorly bedded. The pebbles are volcanic igneous rock fragments..... 3'
23. Sandstone, tuffaceous, fine-to medium-grained, contains calcareous concretions intermittently interbedded with conglomerate lenses. Conglomerate is calcareous and composed of sub-rounded to rounded pebbles and cobbles of basic volcanic and porphyritic igneous rock, quartzite, and graywacke sandstone..... 20'
24. Cover--probably silty, tuffaceous sandstone..... 20'
25. Conglomerate, calcareous, gray, poorly exposed. Sub-rounded to rounded pebbles and cobbles are mainly composed of basic volcanic and porphyritic igneous rock, quartzite, and graywacke sandstone..... 45'
26. Cover..... 24½'

27. Sandstone, contains mineral fragments (quartz, feldspar, amphibole, and magnetite) and fragments of fine-grained, basic igneous rock; tuffaceous, non-calcareous, tan, fine-to medium-grained, poorly size-sorted, poorly bedded, permeable..... 15'
28. Conglomerate, calcareous, gray. Contains sub-rounded to rounded pebbles and cobbles that are mainly composed of basic volcanic and porphyritic igneous rock, quartzite, and graywacke sandstone. Interbedded with sandstone, calcareous, gray, composed of quartz, feldspar, magnetite, amphibole, and fragments of basic, fine-grained igneous rock, coarse-grained..... 72'
29. Ash, pure, white (one foot thick) underlain by fine-grained sandstone (about two feet exposed and bottom contact not visible). Ash is overlain by a similar sandstone (about five feet thick) that is disconformably overlain by unit 28..... 8'
30. Cover..... 22½'
31. Conglomerate, calcareous, gray; composed of sub-rounded to rounded cobbles that are mainly composed of volcanic and porphyritic igneous rock, quartzite, and many fragments of graywacke sandstone of angular shape that are noticeably larger in size than the igneous and quartzitic rock fragments. Interbedded with sandstone, tuffaceous, slightly calcareous in isolated zones, very fine-to fine-grained, poorly size-sorted, poorly bedded, impermeable. Contains many fragments of minerals (quartz, feldspar, amphibole, magnetite, and hematite), and fragments of very fine-grained, basic igneous rock..... 55'
32. Cover..... 94'
33. Sandstone, identical to that described in Unit 35 except that this unit is cemented with calcite in places..... 15'
34. Conglomerate, calcareous, gray; rest disconformably on sandstone of unit 35; interfingers laterally with lenses of sand and silt. Sub-rounded to rounded pebbles and cobbles are mainly composed of basic volcanic and porphyritic igneous rock, quartzite, and graywacke sandstone..... 15'
35. Sandstone, tuffaceous, non-calcareous, tan, very fine-to fine-grained, poorly size-sorted, poorly bedded, permeable. Devitrification and alteration of the glass shards appears to be more extensive in this unit than in other comparable units. Glass shards compose the majority of the detrital particles (65%) but mineral fragments are also present (quartz, feldspar, amphibole, magnetite, and hematite) and fine-grained igneous rock fragments as well as extremely fine-grained clay and dust matrix (20%)... 4'

36. Cover..... 21'
37. Conglomerate, calcareous, gray. Sub-rounded to rounded pebbles and cobbles are mainly composed of basic volcanic and porphyritic igneous rock, quartzite, and graywacke sandstone..... 7'
38. Cover--probably very fine-grained sandstone or siltstone..... 18'
39. Conglomerate, calcareous, gray. Sub-rounded to rounded pebbles and cobbles are mainly composed of basic volcanic and porphyritic igneous rock, quartzite, and graywacke sandstone..... 12'
40. Siltstone, tuffaceous, highly calcareous, very light gray, poorly size-sorted and containing fragments ranging down to very fine-grained sand size with a few coarse-grained fragments, poorly bedded, impermeable. Glass shards and other detritus (quartz, feldspar, amphibole, magnetite, hematite, and fine-grained igneous rock fragments) are corroded around their borders by the calcite cement. The detrital fragments are separated by the calcite cement..... 25'
41. Cover..... 29'
42. Sandstone, tuffaceous, non-calcareous, grayish tan, very fine-to fine-grained but also contains some medium-grained particles, poorly bedded, exhibits good permeability. The glass shards have slightly altered borders, probably slight sericitization, and display a wide variety of shapes in thin section varying from straight needles to intricately cusped forms..... 12'
43. Siltstone, non-calcareous, tuffaceous, yellowish tan, exhibits subtle, local bedding in microscope thin section as localized swirls that may be the result of depositional eddy currents. Very slight alteration of the glass shards borders is interpreted as slight sericitization. Other detrital constituents are quartz, feldspars, amphibole, magnetite, and iron oxides. Approximate composition of the siltstone: glass shards, 70%; other detrital particles, 10%; and clay size matrix, 20%..... 15'
44. Cover..... 18'
45. Conglomerate, calcareous, sandy, gray; sub-rounded to rounded cobbles and pebbles are mainly composed of basic volcanic and porphyritic igneous rock, quartzite, and graywacke sandstone.. 5'
46. Cover--may consist of sandstone described in unit below..... 75'
47. Sandstone, intermittently calcareous, light brown, very fine-to fine-grained, poorly size-sorted, poorly bedded; upper and lower contacts not visible..... 10'

48.	Conglomerate, calcareous, gray; contains sub-rounded to rounded pebbles of basic volcanic and porphyritic igneous rock, quartzite and graywacke sandstone. Interbedded with unconsolidated sand and gravel that consist of quartz, microcline, plagioclase, amphibole, magnetite, and fine-grained, basic igneous rock fragments.....	15'
49.	Cover.....	94'
50.	Sandstone, calcareous, light brown, coarse-grained, sub angular grains, poorly bedded; detrital particles are composed of quartz, microcline, plagioclase, amphibole, magnetite, and very fine-grained, basic igneous rock fragments.....	5'
51.	Conglomerate, calcareous, gray, particle size varies from fine-grained sand to four inch cobbles; unit contains interbedded sand lenses. Sub-rounded to rounded cobbles and pebbles are mainly composed of basic volcanic and porphyritic igneous rock, quartzite, and graywacke sandstone.....	62'
52.	Sandstone, tuffaceous, very calcareous, light gray, very fine- to fine-grained but contains some coarse-grained mineral and rock fragments, poorly bedded; contains zones of calcareous concretions that weather in positive relief. Approximate composition; calcite, 60%; glass shards, 20%; mineral and igneous rock fragments, 15%; matrix consisting of dust and clay-size fragments, 5%.....	53'
TOTAL.....		2,016'

Note; Bottom of section obscured by Quaternary deposits of the East Gallatin River and the Bozeman fan.

APPENDIX B

Table 2

Fossil Samples

<u>Sample Number</u>	<u>Description</u>	<u>Location</u>
7-28-11e	Vertebrate jawbone (?) unidentified	SW 1/4 sec. 10,T.2S.,R.6E.
9-5-1	Vertebrate jaws (rodent)--probably of Recent age.	NW 1/4 sec. 15,T.2S.,R.6E.
9-14-1	Vertebrate tooth--Merychippus sp. probably of Late Miocene age	NW 1/4 sec. 8,T.2S.,R.6E.
10-3-1	Vertebrate tooth--tentatively identified as Camelid of inter- mediate genns and species, very possibly of same age as "9-14-1"	NW 1/4 sec. 10,T.2S.,R.6E..

Identifications made by Edward Lewis, U. S. Geological Survey.

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Rock Types Represented

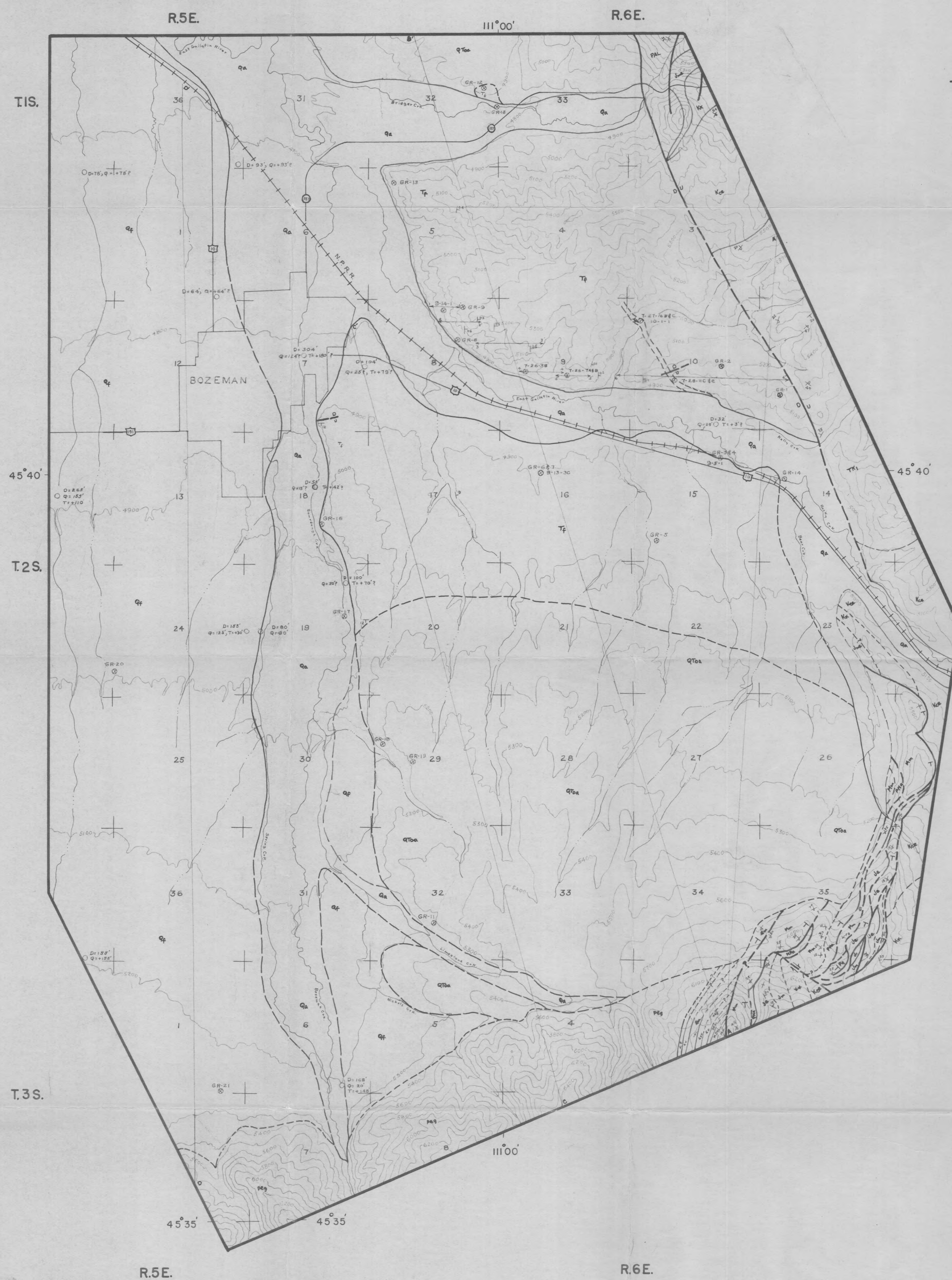
Gravel Samples	GR-1	2	4	3	10		8	12	6	26		16		4	6						100					
			6		10	14	6	2		20	6		12			18			2		4	100				
	GR-3	6	2			28				28			16	2		16			2			100				
	GR-4						2		2	2			2	12	8	4	30			4	2	10	2	2	18	10
	GR-5	2			2	2				6		2	2		4	36		18		2		10	8	4	2	100
	GR-6		4		6			4		14		12	2		2	26	2	2								100
	GR-7									8	2			12	22	4	6	24			2		4	16		100
	GR-8		6		2	2		4	4	48	16	6		8						2	2					100
	GR-9	6	2		2	10		4		22	24	8		18			2	2								100
	GR-10	46		4	14		2			20	6			4						2	2					100
	GR-11	12												2								24	62			100
	GR-12	4	2		6				2	34	8	12		12		16			4							100
	GR-13	4	4		6			4	2	44	18	12		6												100
	GR-14				2					4				6	2	18	10	6			2		44	6		100
	GR-15	4			4				2	8	2		2		2	9	9		12		8	4		32	2	100
	GR-16	2			8		4	4	4	22	4	6		20				14	8						4	100
	GR-17	38			28					10													24			100
	GR-18	16			16				2	32					8								26			100
	GR-19	14			12					32	12			14		8	8									100
	GR-20	8			14	76								2												100
	GR-21	100																								100

Table 3

PERCENTAGE
DISTRIBUTION OF ROCK
TYPES IN ALLUVIAL GRAVELS

GEOLOGIC MAP OF THE SOUTHEAST PART OF GALLATIN VALLEY, MONTANA

Cenozoic Geology Modified By P. A. Glancy

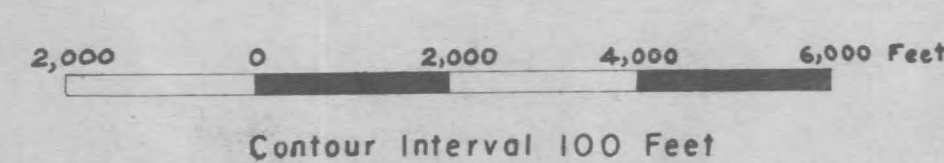


EXPLANATION

Submitted by Patrick A. Glancy to the Graduate Faculty in Partial Fulfillment of the Requirements

For the Degree of Master of Science in Applied Science at Montana State College Bozeman, Montana

Scale 1:24,000



1962

Geology after W. J. McMannis, 1955; O. M. Hackett and others, 1960; and A. W. Shelden, 1960

Topographic contours and base map data after U.S.G.S. preliminary maps, 1947 & 1948

Plate I

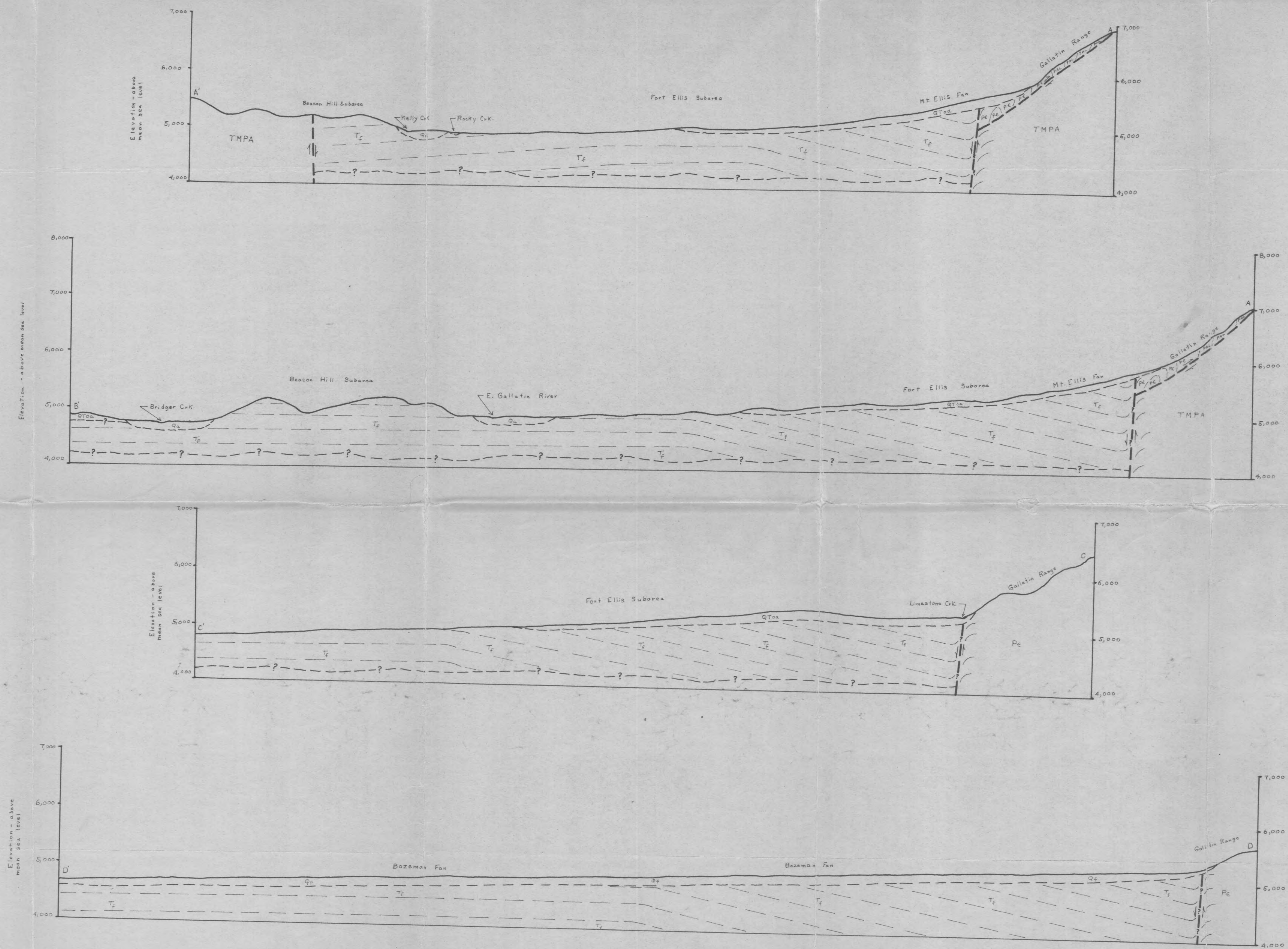
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Cap. 2

Geologic Cross Sections



Legend

- Scale: Horizontal-1 in = 2,000 ft.
Vertical-1 in = 4,000 ft.
- Land surface
 - Probable formation contacts
 - Possible formation contacts
 - Probable faults
 - Possible faults
 - General bedding plane trends
 - Q₁ - Recent stream deposits
 - Q₂ - Quaternary fan deposits
 - Q₃ - Old alluvium, stream-laid and fan deposits
 - T₁ - Non-marine basin deposits of Tertiary age
 - TMPA - Early Tertiary, Mesozoic, Paleozoic, and Precambrian rocks undifferentiated
 - PAL - Paleozoic rocks undifferentiated
 - Pe - Precambrian gneiss and schist

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