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Signature Stanley Glenn Todd

Date Aug. 5, 1969



BEDROCK GEOLOGY OF THE SOUTHERN PART OF TOM MINER  
BASIN, PARK AND GALLATIN COUNTIES, MONTANA

by

STANLEY GLENN TODD

A thesis submitted to the Graduate Faculty in partial  
fulfillment of the requirements for the degree

of

MASTER OF SCIENCE IN APPLIED SCIENCE

Physical Science (Geology)

Approved:

Milton J. Edie  
Head, Major Department

Robert A. Chadwick  
Chairman, Examining Committee

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MONTANA STATE UNIVERSITY  
Bozeman, Montana

August 1969

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## VITA

Stanley Glenn Todd was born May 23, 1936, in Great Falls, Montana. His mother is Georgia Elise Miles and his father, Stanley Glenn Todd, is deceased.

After graduation in 1954, from Park County High School, Livingston, Montana, he attended Montana State University, Bozeman, Montana, and received a Bachelor of Science Degree in June 1959. Following graduation he taught in the secondary schools of Oregon and Montana. In September 1966, he returned to Montana State University to pursue a degree of Master of Science in Applied Science (Earth Sciences, geology option) while holding research and teaching assistantships.

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S.G.T.

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## ABSTRACT

In Tom Miner Basin south of Tom Miner Creek, an Eocene volcanic succession consists of well bedded to crudely stratified epiclastic volcanic beds with intercalated andesite flows of augite-hypersthene composition in the lower part of the succession and augite-hornblende-hypersthene flows in the upper part. The entire volcanic sequence is at least 2800 feet thick and rests unconformably on Precambrian metamorphic rock and in places on Cretaceous strata.

Vents in a north-northeast-trending horst in the Electric Peak-Sepulcher Mountain region of Yellowstone National Park may have supplied volcanic materials to the lower part and most of the upper part of the succession in the map area. Dikes east of Horse Creek may have fed some of the upper andesite flows. The volcanics high in the succession near Buffalo Horn Pass could have been supplied from sources in either the Northern Gallatin Range, the Electric Peak-Sepulcher Mountain region, or the dikes east of Horse Creek.

Dacite has intruded the volcanic succession in the form of a stock at Sheep Mountain, a sill southwest of Sheep Mountain and a plug east of Horse Creek. Seven andesite dikes also intrude the succession east of Horse Creek. These intrusions are located along the northwest-trending, potassium-poor Western Absaroka belt of volcanic centers which are in line with the Spanish Peaks Laramide reverse fault northwest of the map area.

Probable Plio-Pleistocene rhyolitic (?) welded tuff occurs as erosional remnants along Tom Miner Canyon between Sheep Creek and Horse Creek and also along the Yellowstone Valley east of Wigwam Creek. The Tom Miner deposits may represent welded ash flows which came from northwest of Tom Miner Basin.

The northeast-trending Deep Creek normal fault which forms the northwest border of the Beartooth structural block, cannot be positively traced into the map area. If it continues into the map area, it must trend along a strip about one-quarter mile wide, closely paralleling Tom Miner Creek. Any displacement along this projection of the fault must have been small because Precambrian metamorphic rock units and welded tuff remnants located on both sides of Tom Miner Creek are not appreciably offset.

## I. INTRODUCTION

### Location

The map area, consisting of approximately 40 square miles, is located in the Gallatin Range of Southwestern Montana approximately 35 miles southwest of Livingston and 20 miles northwest of Gardiner.

The Gallatin Range is a mountainous area extending from near Bozeman 50 miles southward into Yellowstone National Park and occupying the 20 to 30 mile wide area between the Gallatin and Yellowstone Rivers. It is part of the Northern Rocky Mountain physiographic province of Fenneman (1931).

The map area is bounded on the northeast by the Yellowstone River, on the southeast by the divide between Tom Miner and Cinnabar Basins, on the south by the northern boundary of Yellowstone National Park, on the west by the Gallatin-Yellowstone divide and on the north by Tom Miner Creek (Figure 1).

### Regional Setting

Tom Miner Basin is located in the northwest portion of what is termed the Absaroka-Gallatin volcanic province (R. A. Chadwick, in press). This early Tertiary volcanic province extends northwestward nearly 150 miles from near Thermopolis, Wyoming to the Gallatin River southwest of Bozeman, Montana (Figure 2).

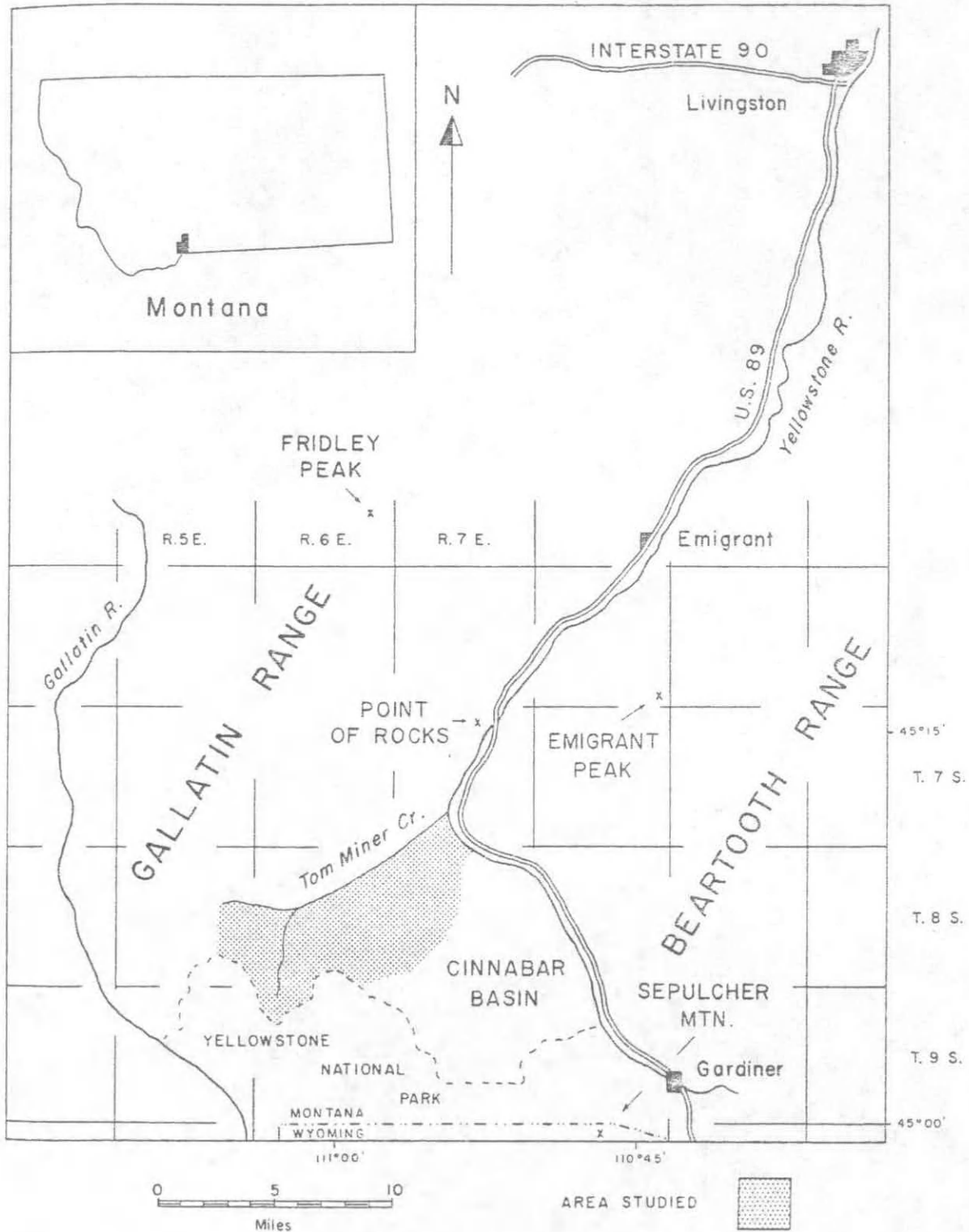


Figure 1 - Index Map

Many workers have noted that Absaroka-Gallatin volcanics were extruded from a number of volcanic centers that lie on a northwest-trending zone. The principal centers thus far recognized are shown in Figure 2 and lie along two subparallel belts: the Western Absaroka belt and the Eastern Absaroka belt (R. A. Chadwick, in press). The Western belt centers are: (1) Kirwin area (Hewett, 1914; Rouse, 1940; Wilson, 1964a, 1964b); (2) Ishawooa area (Rouse, 1933, 1937; Fisher, 1967); (3) Sylvan Pass area (Casella, 1967); (4) Mr. Washburn (Schultz, 1962, 1968); (5) Electric Peak-Sepulcher Mt. (Hague, Iddings and Weed, 1899; Smedes, 1968); (6) Porcupine Creek plugs (Hall, 1961). The Eastern Absaroka belt volcanic centers are: (7) Sunlight centers (Parsons, 1939, 1958, 1968); (8) Hurricane Mesa area (Rouse, 1947; Krushensky, 1960, 1962); (9) Cooke City area (Lovering, 1929); (10) Independence area (Emmons, 1908; Rubel, 1964, 1968); (11) Emigrant Peak area (A. L. Basler, 1965, 1966); (12) Point of Rocks area (Chadwick, 1965; Chadwick and McCaskey, 1968); (13) Northern Gallatin Range dike swarm (Chadwick, 1964).

Chadwick (1968) found that the Eastern Absaroka belt centers are generally richer in potash than those of the Western Absaroka belt and that the Eastern and Western belts, traced northwestward, seem to coincide with the Squaw Creek and Spanish Peak Laramide reverse faults, respectively (Figure 2).



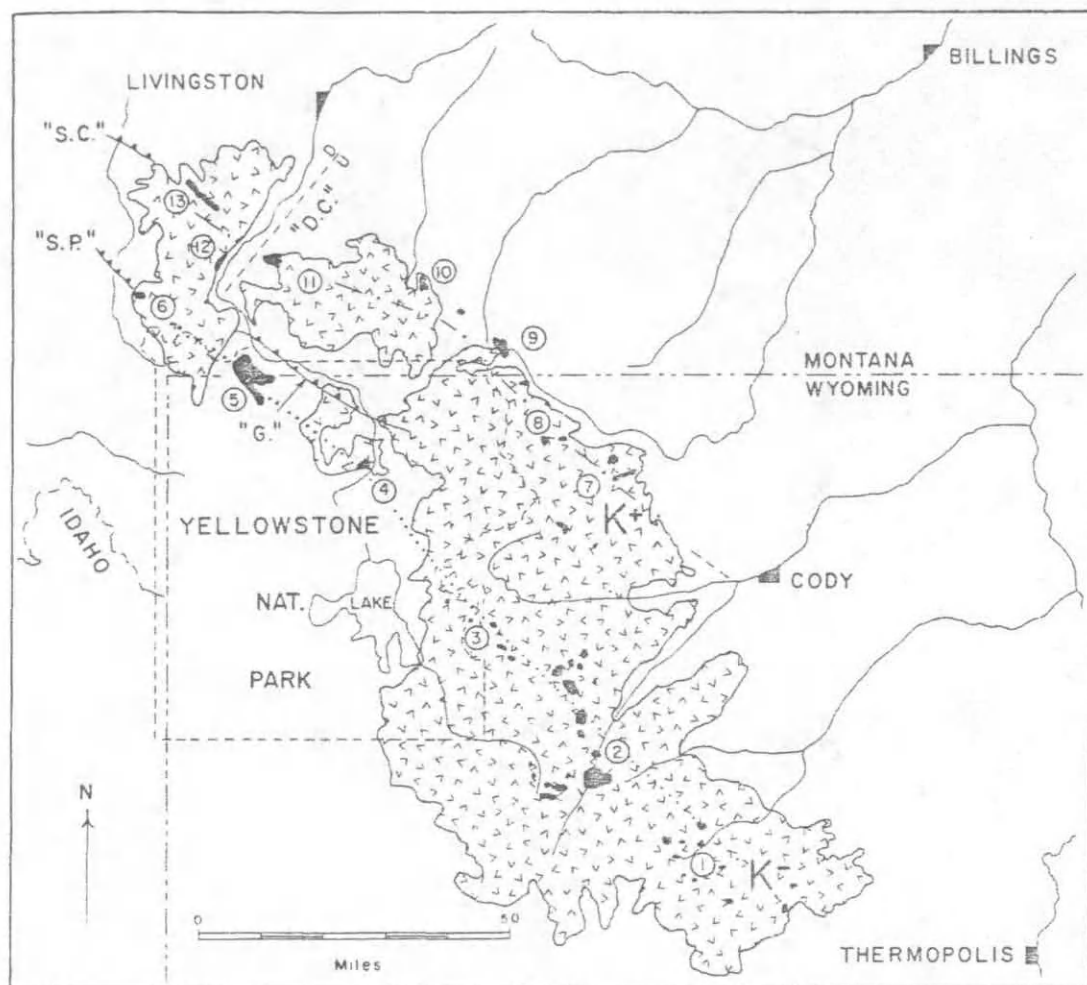


Figure 2. The Absaroka-Gallatin Volcanic Province Volcanic Centers

- |                                |                               |
|--------------------------------|-------------------------------|
| 1. Kirwin area                 | 8. Hurricane Mesa area        |
| 2. Ishawooa area               | 9. Cooke City area            |
| 3. Sylvan Pass area            | 10. Independence area         |
| 4. Mt. Washburn                | 11. Emigrant Peak area        |
| 5. Electric Peak-Sepulcher Mt. | 12. Point of Rocks area       |
| 6. Porcupine Creek stocks      | 13. Gallatin Range dike swarm |
| 7. Sunlight centers            |                               |
- K<sup>+</sup> -- Eastern potassium rich belt  
 -- K<sup>-</sup> -- Western potassium poor belt
- "D.C." Deep Creek fault      "S.P." Spanish Peaks fault  
 "S.C." Squaw Creek fault      "G." Gardiner fault

These fracture zones may be traced further northwestward across the Madison Range to the vicinity of the Tobacco Root batholith (Peale, 1896; Swanson, 1950; Reid, 1957; Andretta and Alsup, 1960; Kavanagh, 1965; Becraft and others, 1966).

Rock types recorded along the Eastern Absaroka belt include andesites, trachyandesites, latites, monzonites, orthoclase basalts, gabbros, diorites and syenites. The Western belt assemblage is predominantly normal calc-alkalic andesites, dacites, basalts and their phaneritic equivalents (Chadwick, 1968).

These rocks take the form of stocks, plugs, sheets, laccoliths, dikes, lava flows, volcanic breccias and other volcanoclastic rocks which have in large part come from the centers along the Eastern and Western Absaroka belts.

Chemical and mineralogical differences between the major igneous rock assemblages of the two belts may suggest that the Eastern and Western belts tapped a somewhat different magma series (R. A. Chadwick, oral communication, 1968).

#### Previous Geologic Investigations

Earliest detailed geologic work in the region was conducted by the United States Geological Survey, 1883-93 (Hague, Iddings and Weed, 1894, 1896; Peale, 1896).

The Livingston Folio (Hague, Iddings and Weed, 1894)

described the geology of Tom Miner Basin from the 111th meridian to the Yellowstone Valley. The igneous rocks were classified together as "basic andesitic breccias and flows". Precambrian granite, gneiss and schist were described separately but mapped as "Precambrian undifferentiated".

The Three Forks Folio (Peale, 1896) includes a general description of the geology of Tom Miner Basin west of the 111th meridian. The igneous rocks there were mapped as "basic andesitic breccias and flows". Hague, Iddings and Weed (1896, 1899) describe what appears to be the same unit as "early basic breccia", a sequence of volcanic breccias containing pyroxene-andesite, hornblende-pyroxene-andesite and basalt clasts intercalated with lava flows of similar lithology.

No detailed geologic investigations are known in Tom Miner Basin since 1893.

In the surrounding areas, Hall (1961) mapped a large portion of the upper Gallatin Valley west of Tom Miner Basin. Bryden (1950) studied the Precambrian east of Tom Miner Basin in Yankee Jim Canyon. The Rock Creek-Big Creek area north of Tom Miner Basin is currently being studied by Dr. R. A. Chadwick of Montana State University. Northwestern Yellowstone National Park is currently under investigation (Smedes, 1968) and Cinnabar Basin, directly south of Tom

Miner Basin, has been mapped by E. L. McCaskey (Pending M.S. Thesis, Montana State University).

#### Purpose of Study

The purpose of this study is to: (1) construct a geologic map of the southern part of Tom Miner Basin; (2) describe the rock units in field exposures and thin section; (3) record the structural and age relationships of these rock units; (4) determine, if possible, the origin of the various units encountered.

## II. GEOLOGIC UNITS

Evidence used for assigning ages to the various geologic units will be mentioned later in this paper.

### Precambrian Metamorphic Rocks

Precambrian metamorphic rocks crop out over approximately two square miles in the northwest corner of the map area. These Precambrian rocks, undifferentiated on Plate I, in pocket, include gneiss, schistose quartzite, schist, granulite, pegmatites and probable sills.

Gneiss occurs principally south of the Tom Miner road but extends across the entire mapped Precambrian area south of the intersection of Tepee and Wigwam Creeks. The gneiss is typically a massive, faintly banded, grey and white granitic-feldspathic rock. Muscovite and epidote are locally abundant.

Interbedded schistose quartzite and schist crop out north of the Tom Miner road and south of the road west of Tepee Creek below its intersection with Wigwam Creek. The schistose quartzite is light green and micaceous. The schist is predominantly a dark green hornblende-plagioclase-biotite-quartz schist (Plate II, Figure 1), but biotite and (or) plagioclase are locally absent. Plagioclase porphyroblasts are abundant locally.

A grey and white, faintly foliated, plagioclase-quartz-biotite-augite granulite is located on Wigwam Creek near the

PLATE II

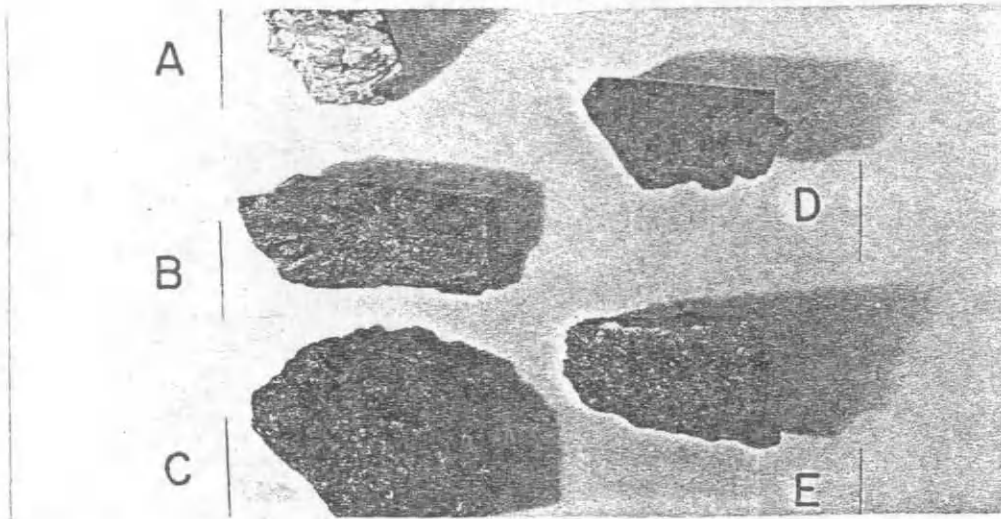


Figure 1. Common Precambrian rock types in the map area.

- A. Quartz-feldspar pegmatite.
- B. Light green schistose quartzite.
- C. Plagioclase-quartz-biotite-augite-granulite.
- D. Dark green schist.
- E. Grey and white gneiss.

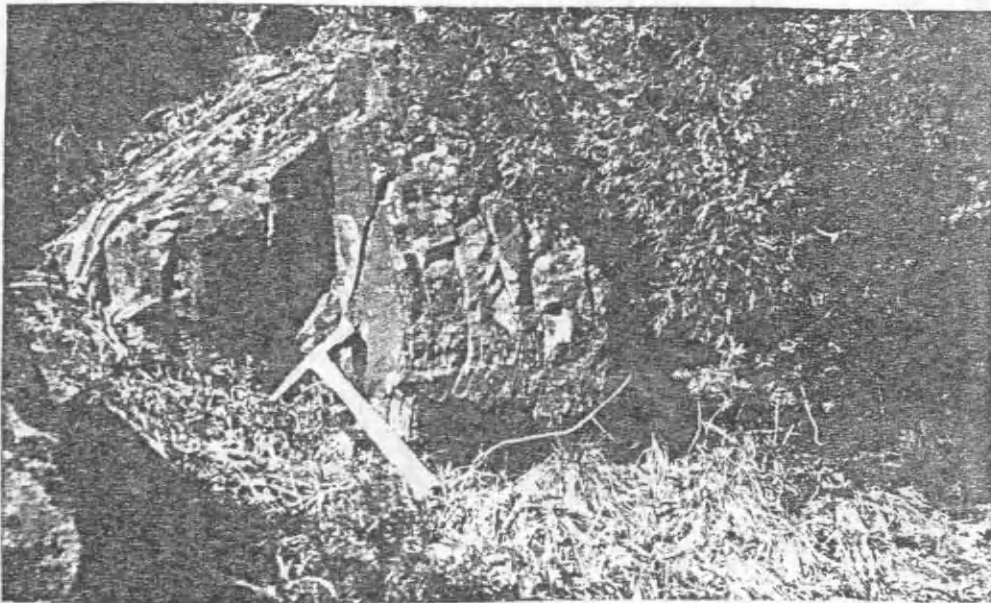


Figure 2. Sill in Precambrian granitic gneiss. The deformation of the sill is parallel to the foliation of the gneiss.

- A. Sill.

precambrian-Tertiary-volcanic contact.

Small quartz veins, pods, lenses and small quartz-feldspar pegmatite masses are common throughout the metamorphic terrain. Sills, 1 to 100 feet thick, located in the gneiss, are predominantly concordant but locally transect metamorphic foliation (Plate II, Figure 2).

### Major Eocene Lithologic Types

#### Lava Flows

Light grey to black andesite flow units, 80 to 1400 feet thick, are exposed in the map area. Flow banding, vesiculation and highly oxidized zones in brecciated parts and boundaries between flows are common to most flows.

#### Hypersthene-Augite Andesites

Andesite flows east of Horse Creek, with elevations less than 8400 feet, have exposures ranging from 0.125 to 2 square miles. They contain hypersthene and augite phenocrysts with hypersthene commonly more abundant than augite (Plate III, Figure 1).

#### Augite-Hornblende-Hypersthene Andesites

Andesite flows higher in the sequence occur principally in the southeastern and southern portions of the map area above 8400 feet. They are 80 to 480 feet thick and have

abundant phenocrysts of augite and hornblende and less abundant phenocrysts of hypersthene (Plate III, Figure 2).

### Epiclastic Volcanic Rocks

The term "epiclastic volcanic rocks" is used here to define sedimentary rocks consisting mainly of materials derived from older rocks of volcanic and (or) intrusive origin (Fisher, 1966).

Hall (1961) describes locally stratified coarse volcanic conglomerates, interlayered with volcanic ash and tuff on Fortress Mountain approximately two miles north of the northwest corner of the map area. He names these deposits the Fortress Mountain member of the Specimen Creek formation. However, in Tom Miner Basin these deposits are mainly breccias and finer grained lithologies which exhibit rapid lateral and vertical variations. Therefore Hall's terminology is not extended into the map area and epiclastic units in the map area are undifferentiated on Plate I.

The epiclastic deposits of Tom Miner Basin, exposed to a maximum-measured thickness of 2500 feet, contain all gradational types between volcanic breccia, conglomerate, sandstone and siltstone. For this reason, only two major lithologic types will be distinguished in the present discussion: (1) crudely stratified epiclastic volcanics; (2) well bedded



PLATE III

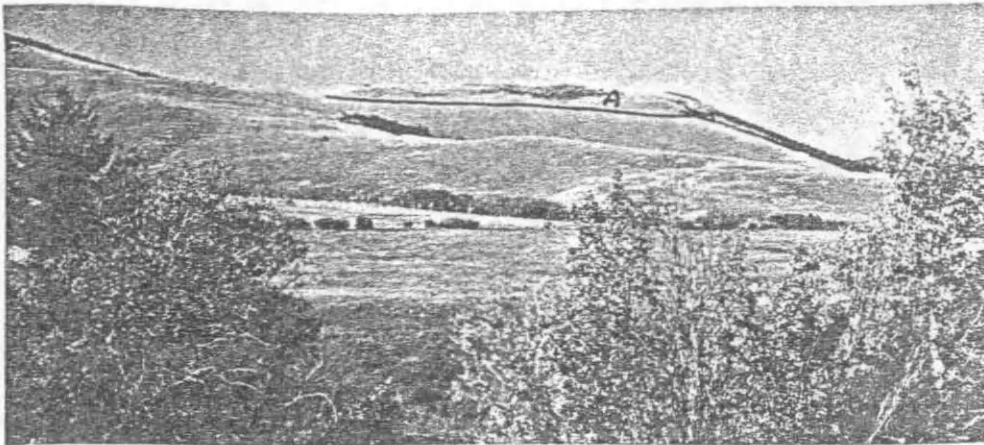


Figure 1. Typical exposure of lava flows below 8400 feet.  
A. Lava flows.

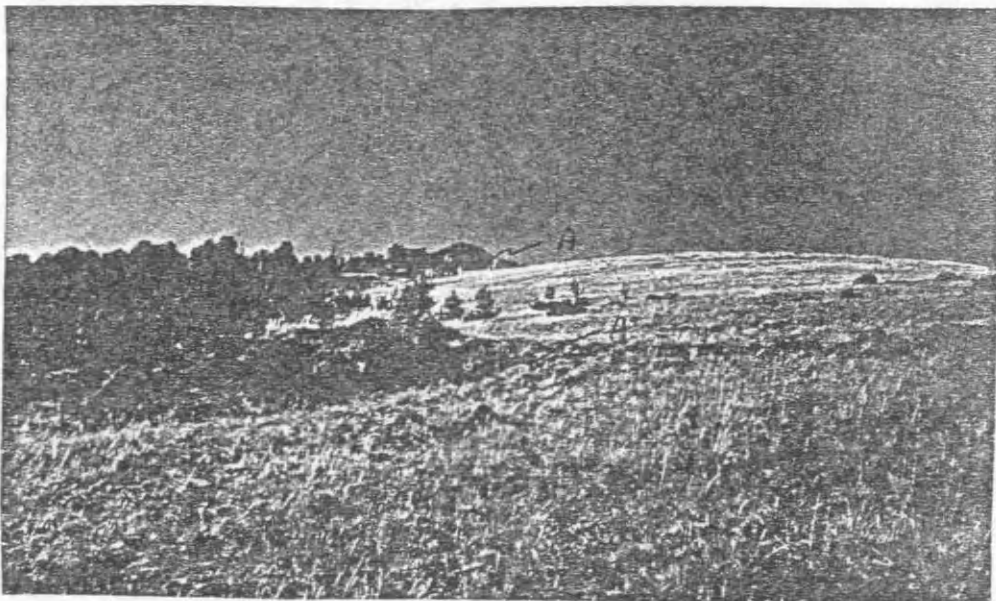


Figure 2. Typical exposure of lava flows above 8400 feet.  
A. Lava flows.

epiclastic volcanics (Plate IV, Figures 1 and 2). Both lithologic types contain secondary silica and calcite and are composed of grains and fragments similar in composition to the intercalated andesite flows and dacitic intrusions of the map and nearby areas. Both lithologic types are interbedded. Common colors, controlled by oxidation state and the ratio of dark to light fragments and mineral grains, are light grey, dark grey, reddish brown and locally green.

#### Crudely Stratified Epiclastic Volcanics

The crudely stratified epiclastic volcanic beds commonly consist of poorly sorted breccias containing mostly angular to subangular clasts, locally up to eight feet in diameter, in a finer grained matrix. Subordinate amounts of conglomerates and well bedded epiclastics are interbedded in the crudely stratified epiclastic beds.

Vesicularity, state of oxidation and angularity of the clasts is variable. Nonigneous clasts are rare except near the Gallatin-Yellowstone divide where Precambrian clasts are common (Plate V, Figure 1). Many levels of fossil forest are conspicuous in these epiclastic deposits (Plate V., Figure 2).

Crude stratification, angularity of clasts, large quantities of matrix between fragments, and clasts up to

PLATE IV

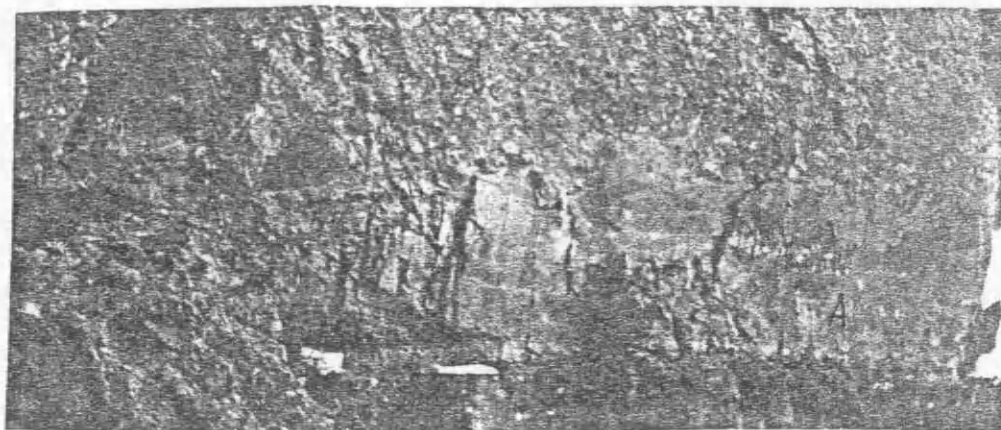


Figure 1. Lens of well bedded epiclastic volcanic in crudely stratified epiclastic volcanic beds.  
A. Well bedded epiclastic volcanic lens.  
B. Crudely stratified epiclastic volcanic bed.

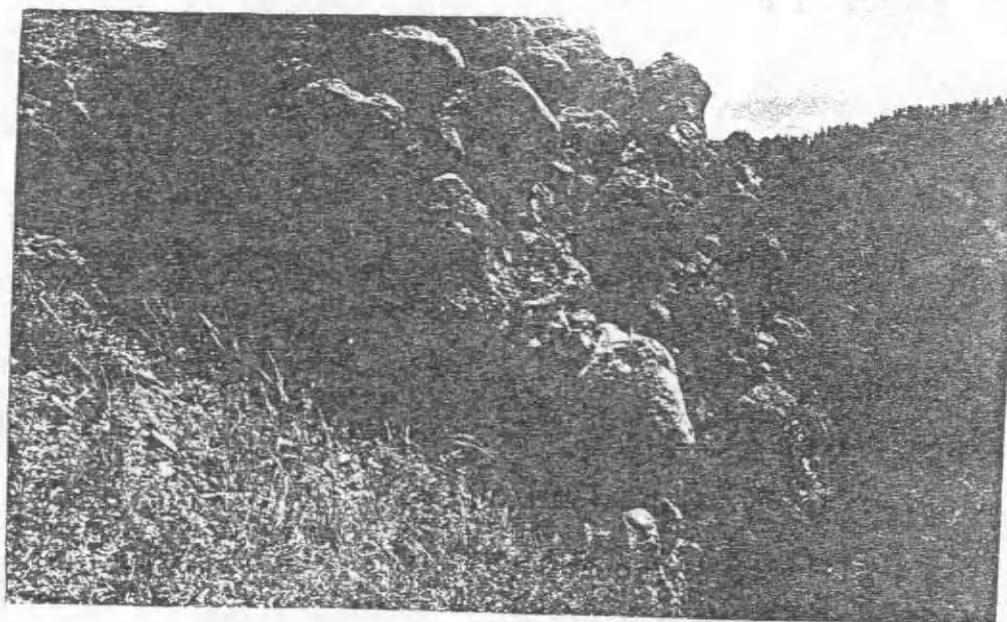


Figure 2. Typical exposure of crudely stratified epiclastic volcanic beds.

PLATE V



Figure 1. Banded Precambrian fragment in epiclastic volcanic beds.

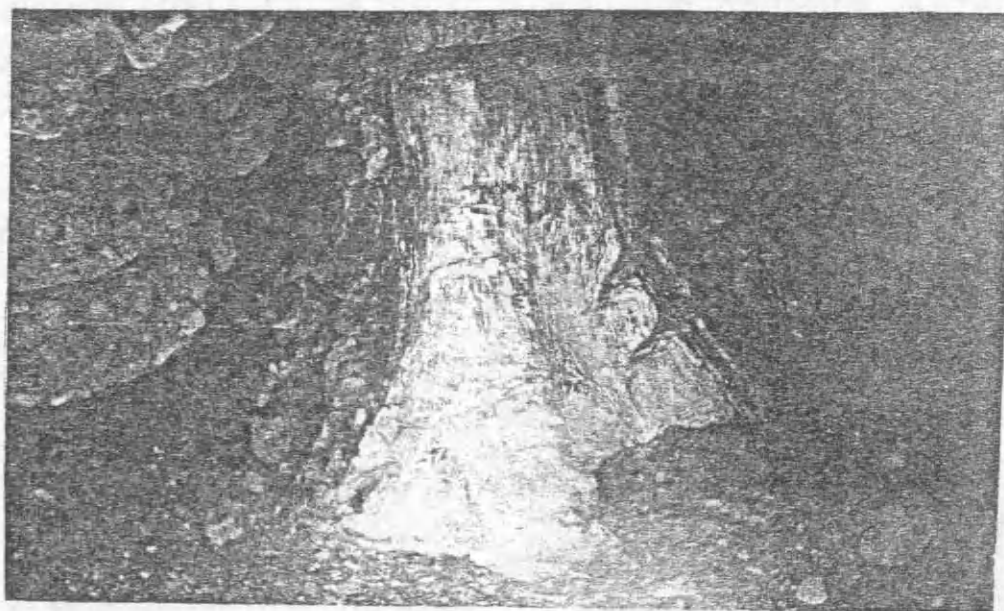


Figure 2. Upright opalized tree in coarse epiclastic volcanic bed.

eight feet in diameter suggest a mudflow origin for this epiclastic material.

Paleomagnetic measurements on andesitic clasts from an epiclastic volcanic breccia in sec. 16, T.8 S., R.6 E. show a random scatter of dipole orientations. This indicates that the thermo-remnant magnetization was disoriented by movement of fragments below their blocking temperatures, the temperature range in which magnetization is acquired during cooling. Emplacement by mudflow at temperatures below the blocking temperatures of the clasts is suggested, following the line of reasoning stated by Aramaki and Akimoto (1957) and Chadwick and McCaskey (1968). Further discussion of paleomagnetism will appear in this paper in a section on paleomagnetism.

#### Well Bedded Epiclastic Volcanics

The well bedded epiclastic beds are fairly well sorted, locally crossbedded, and include volcanic sandstone, siltstone and some breccia and conglomerate. These lithologic types occur as beds and discontinuous lenses, ranging from a few inches to hundreds of feet thick. The beds contain fossil leaves, plant fragments, and locally, an amberoid resin (Plate VI, Figure 1). These volcaniclastics are probably primarily water-laid because the beds: (1) are well stratified; (2) are locally crossbedded; (3) are fairly well sorted; (4)

PLATE VI

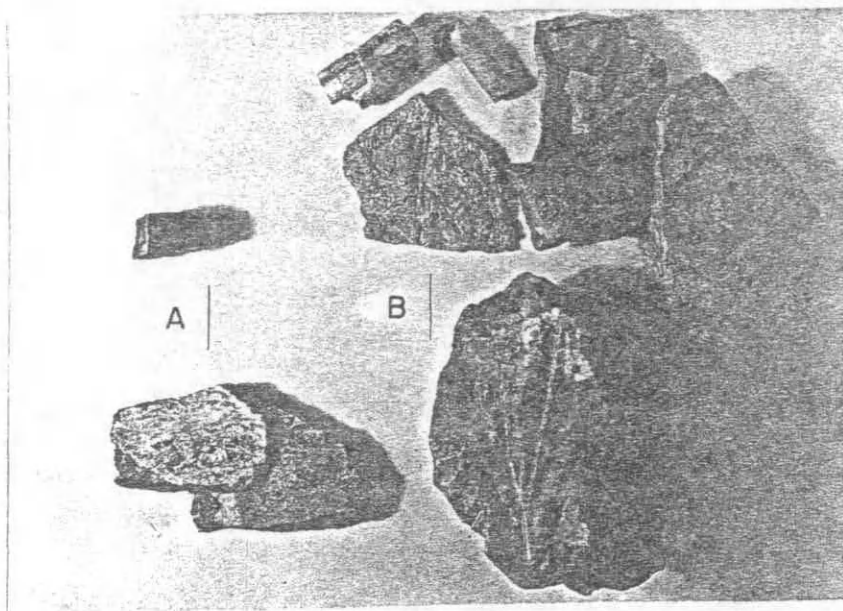


Figure 1. Fossil material from epiclastic volcanic beds.

- A. Amberoid resin, E $\frac{1}{2}$  NW $\frac{1}{4}$  sec. 25, T.8 S., R.5 E.
- B. Leaves and typical petrified wood fragment.

commonly occur as discontinuous lenses, interpreted to be channels; (5) locally contain stream-rounded petrified wood.

### Stratigraphic Succession

A representative section of the Eocene volcanics (secs. 6, 7 and 18, T.8 S., R.7 E.) (Plate I) along the ridge west of Wigwam Creek south to the boundary of the map area is illustrated below.

TABLE I. REPRESENTATIVE SECTION A

Feet	Description
280	Augite-hypersthene-hornblende andesite flows
880	Crudely stratified epiclastic volcanic beds
1360	Hypersthene-augite andesite flows
60	Intercalated well bedded and crudely stratified epiclastic volcanic beds
160	Hypersthene-augite andesite flows
	- - - - - unconformity
	Precambrian metamorphic rock

A representative section (secs. 14, 23 and 26, T.8 S., R.6 E.) (Plate I) along the ridge west of Grizzly Creek south

to the boundary of the map area is illustrated in Table II.

TABLE II. REPRESENTATIVE SECTION B

Feet	Description
Top Eroded	
120	Augite-hornblende-hypersthene andesite flows
160	Crudely stratified epiclastic volcanic beds
80	Augite-hornblende-hypersthene andesite flows
160	Crudely stratified epiclastic volcanic beds
160	Intercalated augite-hypersthene-hornblende andesite flows and epiclastic volcanic beds
320	Augite-hypersthene-hornblende andesite flows
720	Crudely stratified epiclastic volcanic beds, locally intercalated with well bedded epiclastic volcanic beds and lenses
40	Augite-hypersthene-hornblende sills
960	Crudely stratified epiclastic volcanic beds, locally intercalated with well bedded epiclastic volcanic beds and lenses
Covered	

A representative section (secs. 30 and 31, T.8 S., R.6 E., sec. 6, T.9 S., R.6 E., secs. 25 and 26, T.8 S., R.5 E., sec. 1, T.9 S., R.5 E.) (Plate I) along the boundary between Park and Gallatin Counties south from Tom Miner Creek to the



yellowstone National Park boundary is illustrated in Table III.

TABLE III. REPRESENTATIVE SECTION C

Feet	Description
Eroded top	
120	Augite-hornblende-hypersthene andesite flows
400	Intercalated crudely stratified and well bedded epiclastic volcanic beds, well bedded zones decrease in abundance upward
80	Augite-hypersthene andesite flows
80	Intercalated crudely stratified and well bedded epiclastic volcanic beds
80	Augite-hypersthene andesite flows
1840	Intercalated well bedded and crudely stratified epiclastic volcanic beds, well bedded zones decrease in abundance upward
Covered	

Examination of Tables I, II and III and Plate I suggest that in a westward direction, the uppermost andesite flows thicken (Plate I, sec. 26, T.8 S., R.6 E.) (Table II) becoming interbedded with epiclastic volcanic beds near Sheep Mountain and pinch out (Plate I, sec. 36, T.8 S., R.5 E.) west of Sheep Mountain near the Gallatin-Yellowstone divide.

The middle epiclastic volcanic beds thin (Plate I, sec.

13, T.8 S., R.6 E.) (Table II) westward toward Sheep Mountain and become increasingly intercalated with thickening andesite flows. These epiclastic beds thicken again west of Sheep Mountain (Plate I, sec. 6, T.9 S., R.5 E.) (Table III) and become increasingly well bedded toward the Gallatin-Yellowstone divide.

The lower andesite flows, westward toward Horse Creek, grade from a sequence of massive flows (Plate I, sec. 12, T.8 S., R.6 E.) (Table I) to a sequence of interbedded flows and epiclastic volcanic beds (Plate I, sec. 14, T.8 S., R.6 E.) (Table II). The flows pinch out west of Horse Creek (Plate I, sec. 15, T.8 S., R.6 E.) (Table III).

### Eocene Intrusions

#### Andesites

Seven andesite dikes, with recorded thicknesses of two to twelve feet and six andesite sills, ranging from 40 to 80 feet in thickness, occur east of Horse Creek and southwest of Wigwam Creek. Four additional sills, 20 to 40 feet thick, are mapped between Sunlight and Horse Creeks.

The dikes and sills are dark grey and contain phenocrysts of plagioclase, augite, hornblende and hypersthene.

#### Dacites

A north-south elongated dacitic stock, approximately two

square miles in area, comprises Sheep Mountain and the northwest end of Sawtooth Mountain (secs. 16, 21, 28, 29, 32 and 33, T.8 S., R.6 E.) (Plate VII, Figure I). A small northwest-elongated dacitic plug, approximately 0.125 square mile in exposure, is located about one mile east of Horse Creek (secs. 11, 12, 13 and 14, T.8 S., R.6 E.) and a dacite sill at least 80 feet thick caps a ridge approximately 0.75 miles southwest of Sheep Mountain (secs. 5, 31 and 32, T.8 S., R.6 E.).

The dacites are light to dark grey or reddish grey and contain phenocrysts of plagioclase, biotite and hornblende.

PLATE VII

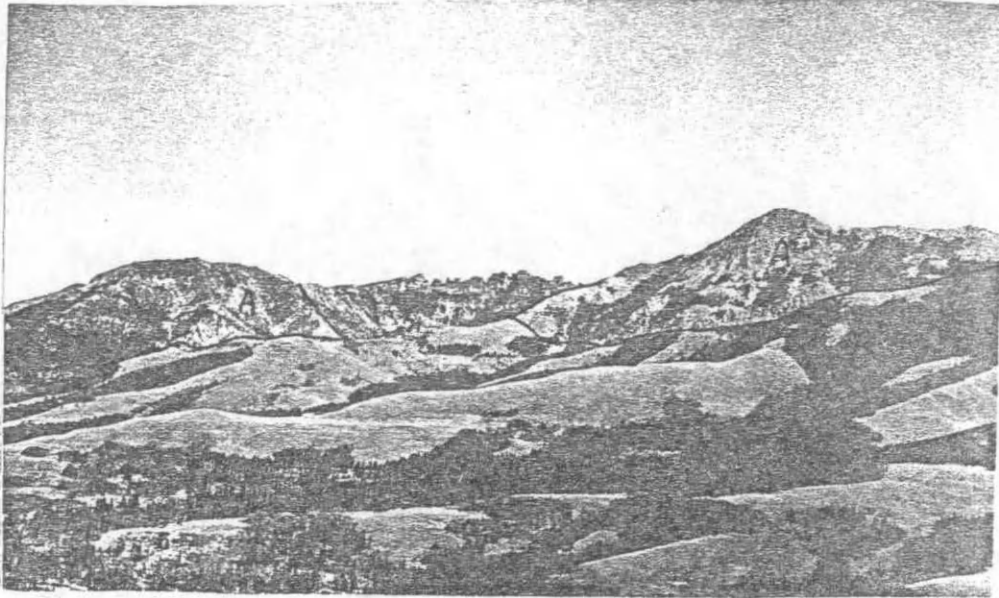


Figure 1. View looking south toward Sheep Mountain, a  
dacite intrusion.

A. Sheep Mountain stock, a dacite intrusion.

Plio-Pleistocene

Welded Tuff

Welded tuff erosional remnants occur: (1) east of Sheep Mountain (sec. 17, T.8 S., R.7 E.) at an altitude of about 7200 feet; (2) west of Horse Creek (sec. 3, T.8 S., R.6 E.) at about 6300 feet; (3) east of Wigwam Creek (secs. 6, 7, T.8 S., R.7 E.) at about 7600 feet (Plate I).

The deposit east of Sheep Creek consists of about 60 feet of welded tuff, resting on a "paleo-soil" (Plate VIII, Figure 1). The lithologic sequence is as follows (Refer to Plate VIII, Figure 2):

TABLE IV. WELDED TUFF SEQUENCE

Feet	Description
	Eroded top
26'0"	Pink friable partially welded tuff
23'6"	Black densely welded tuff with lithophysal cavities and spherulites.
6'11"	Black glassy densely welded tuff
2'0"	Brown partially welded tuff
0'3"	Volcanic ash
	- - - - - unconformity (?)
covered	"paleo soil"
	- - - - - unconformity
	epiclastic volcanic bed

PLATE VIII



Figure 1. View of Tom Miner Basin looking east. Crudely stratified epiclastic volcanic bed in left foreground.

- A. Exposure of welded tuff remnant south of Tom Miner Creek and east of Sheep Creek.
- B. Exposure of welded tuff north of Tom Miner Creek.

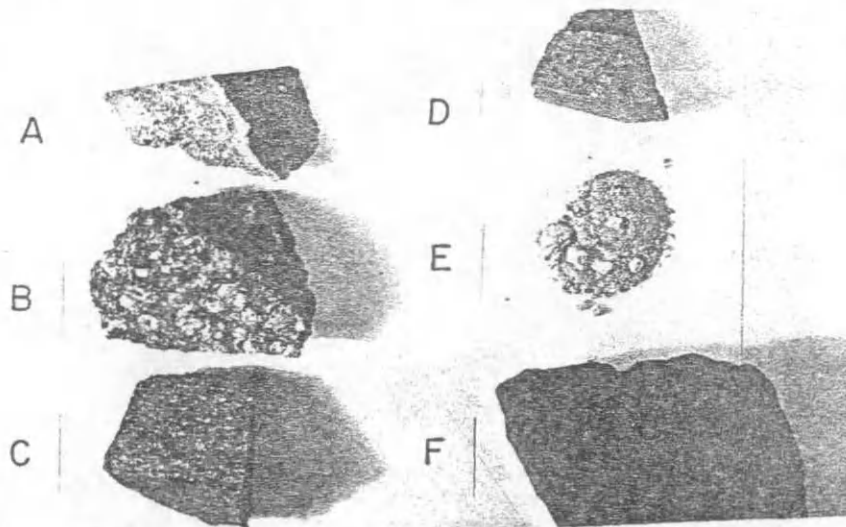


Figure 2. Lithologic sequence of welded tuff remnant (sec. 17, R.6 E., T.8 S.) located east of Sheep Creek.

- A. Pink partially welded tuff.
- B. Black densely welded tuff with lithophysal cavities and spherulites.
- C. Black glassy densely welded tuff.
- D. Brown partially welded tuff.
- E. Ash.
- F. "Paleo soil".

The remnant located west of Horse Creek, at least four to five feet thick, is a pink or grey, friable, partially welded tuff.

The welded tuff remnant east of Wigwam Creek, about 80 feet thick in exposure, occurs as a highly altered, dark brown crystalline rock, with thin wavy stringers that resemble flow banding.

## Quaternary

### Surficial Deposits

Alluvial, glacial and landslide material cover older rocks of the map area.

The surficial deposits of Tom Miner Basin are mainly glacial drift with minor amounts of alluvium.

Quaternary deposits along the Yellowstone River consist of glacial debris, recent landslide material (Good, 1964) and alluvium.



### III. PETROGRAPHIC DESCRIPTIONS

#### Precambrian Metamorphic Rocks

##### Gneiss

The gneisses contain quartz (35-50%), plagioclase (20-55%), biotite (5-30%), epidote (0-1%), muscovite, including sericite, (0-1%), and traces of garnet, microcline, chlorite and opaques.

Quartz, biotite and plagioclase are abundant in all the gneisses examined. Southward toward the Precambrian-volcanic contact the percentage of plagioclase increases, and the percentage of biotite decreases. Thin sections indicate no consistent change in quartz and the minor minerals through the area.

Quartz occurs as (1) anhedral masses and (2) anhedral to subhedral masses of interlocking grains up to 4.0 mm. in maximum dimension. The quartz masses are elongated parallel to the foliation. Grains are fresh, exhibit wavy extinction and some have recrystallized margins.

Plagioclase occurs as subhedral lath shaped crystals, up to 4 mm. long, having irregular boundaries and inclusions of quartz and biotite. Composition determined by the "Michel-Levy Method" is  $An_{69}$ , labradorite. Most crystals are fresh but some are pitted. Albite, carlsbad and

pericline twinning are common.

Subhedral biotite, up to 2 mm. long, is commonly bent, and elongated parallel to the foliation. Most crystals have fresh interior but are commonly rimmed by anhedral magnetite and locally altered to chlorite and muscovite.

Anhedral epidote crystals are fresh, slightly pleochroic in shades of pink, up to 6 mm. in maximum dimension and occur in aggregates. Extinction is parallel in elongated sections.

Garnets are anhedral, up to 1.75 mm. in maximum dimension, pale pink in thin section and commonly altered to sericite on their margins.

Microcline occurs as subhedral crystals exhibiting "gridiron structure" and wavy extinction.

### Schist

The schists are composed of quartz (33-50%), hornblende (27-55%), plagioclase (0-32%), biotite (0-7%), magnetite (1%) and epidote (0-1%).

In the slides examined, biotite and plagioclase are locally absent and plagioclase may be present as porphyroblasts. All mineral grains in the schist are parallel to the foliation.

Quartz is locally cataclastic, recrystallized and contains many unidentifiable crystallites. Individual grains are

anhedral to subhedral, and up to 0.5 mm. in maximum dimension. Wavy extinction and graphic intergrowths are evident.

Pale green subhedral to anhedral contorted laths of hornblende up to 1.0 mm. long are present. Some grains are seam-twinned and others rim biotite. Anhedral magnetite rims some grains and is included in others.

Plagioclase appears as subhedral laths up to 0.5 mm. long and is commonly albite, carlsbad and pericline twinned. Some grains are zoned.

Biotite is present as deformed subhedral flakes up to 0.75 mm. long.

Epidote occurs as anhedral grains up to 0.1 mm. in maximum dimension.

#### Schistose Quartzite

The green schistose quartzite contains quartz (97-98%) and muscovite, including sericite (2-3%). Both muscovite and quartz are elongated parallel to the foliation.

Most quartz grains are 1.5 mm. long, have wavy extinction and an interlocking texture. Individual grains form sub-parallel bands.

#### Granulite

Based on one thin section, the granulite is composed of

plagioclase (45%), augite (45%), graphic intergrowths (5%), magnetite and hematite (2%), hornblende (1%), biotite (1%) and traces of microcline.

Plagioclase, commonly zoned, bent, corroded and fractured, occurs as subhedral laths up to 3.0 mm. long.

Anhedral to subhedral augite, up to 2 mm. in maximum dimension and subhedral books of biotite, up to 1.25 mm. long, are altered to hornblende along their margins.

Microcline and graphic intergrowth are random in intensity and magnetite and hematite occur as alteration products of augite.

### Sills

The sills exhibit diabasic texture and consist of plagioclase (40-50%), augite (40-50%) interstitial graphic intergrowths (0-1%), hypersthene (0-1%) and hornblende (less than 1%).

Anhedral augite, up to 1.25 mm. in diameter, is seam-twinned and locally uralized to hornblende.

Subhedral laths of plagioclase, up to 1.5 mm. long, have a composition of  $An_{59}$ , labradorite (Michel-Levy Method).

Magnetite rims and is included in hypersthene and augite.

Metamorphism of the sills is suggested by: (1) plagio-

clase grains with recrystallized edges; (2) fractured crystals; (3) local cataclastic structures; (4) alteration of augite to green amphibole.

Hand-specimens of pegmatite consist of coarse grained quartz, feldspar and some muscovite and biotite.

### Eocene Lava Flows

#### Hypersthene-Augite Andesites

These andesites contain plagioclase (15-55%), augite (1-6%), hypersthene (1-2%), basaltic hornblende (0-2%), secondary silica and calcite (0-1%) and ground mass (35-83%).

Phenocrysts of hypersthene are commonly more abundant than augite.

The plagioclase occurs as unoriented anhedral to euhedral laths up to 2 mm. long. Larger crystals are generally zoned, pitted and have corroded margins. Smaller crystals are commonly fresh and albite, carlsbad and pericline twinned. Composition of the phenocrysts determined by the "Michel-Levy Method" is  $An_{54}$ , labradorite.

Anhedral to subhedral augite, up to 1.5 mm. in maximum dimension, is locally seam-twinned and rarely altered.

Hypersthene is pleochroic, in shades of light green to pink, euhedral to anhedral and up to 0.5 mm. in maximum dimension.

Basaltic hornblende occurs as subhedral elongated crystals up to 1.25 mm. long and is rimmed by magnetite and hematite.

The ground mass consists of microlites of hypersthene, augite, plagioclase, anhedral magnetite and crystallites.

#### Augite-Hornblende-Hypersthene Andesites

Augite and hornblende are the most abundant phenocrysts in these andesites. In the uppermost andesite flows of the map area, hornblende phenocrysts are nearly as abundant as augite.

These andesites contain plagioclase (15-55%), augite (1-6%), hypersthene (1-3%), basaltic hornblende (0-2%), hornblende (1-2%), and ground mass (35-85%).

Plagioclase laths, up to 4 mm. long are commonly albite, carlsbad and pericline twinned. Larger crystals are commonly zoned, pitted and have corroded boundaries. Smaller crystals are generally fresh. Composition of phenocrysts determined by the "Michel-Levy Method" is  $An_{51}$ - $An_{53}$ , labradorite.

Augite phenocrysts are commonly fresh, anhedral to subhedral and up to 1.25 mm. in maximum dimension. Seam-twinned phenocrysts are common.

Hornblende phenocrysts are fresh to highly altered, elongate, subhedral to euhedral and up to 1.25 mm. long. Most crystals are pleochroic in shades of green, some are

seam-twinning.

Hypersthene appears as subhedral to anhedral crystals of prismatic habit, up to 1.25 mm. long.

The ground mass consists of microlites of plagioclase, augite, hornblende, anhedral magnetite and crystallites.

#### Eocene Crudely Stratified Epiclastic Volcanic Beds

Most clasts in the crudely stratified epiclastic volcanic beds have petrographic descriptions similar to the andesite flows and dacite intrusions of the map area. Dacite clasts are rare. Precambrian clasts are very rare. None were observed in thin section.

The matrix contains crystals of augite, hypersthene, plagioclase, basaltic hornblende, magnetite, sparse hornblende and small andesite and dacite particles. Locally, the matrix is cemented by silica and calcite.

#### Eocene Well Bedded Epiclastic Volcanic Beds

The well bedded epiclastic volcanic beds are composed of crystals of augite, hypersthene, plagioclase, basaltic hornblende, magnetite, sparse hornblende and andesite and dacite fragments. The plagioclase is commonly saussuritized. Cementation by silica and calcite is common.

## Eocene Intrusions

### Andesite Dikes

In the slides examined, the dikes had petrographic characteristics similar to the augite-hornblende-hypersthene andesite flows of the map area.

### Andesite Sills

Sills associated with augite-hypersthene or augite-hornblende-hypersthene andesite flows have similar petrographic descriptions.

### Dacite Intrusions

The similarity in composition among the dacite bodies in the map area suggests they are connected at depth.

The dacite contains plagioclase (5-6%), hornblende (less than 1-4%), biotite (less than 1-2%) and ground mass (89-95%).

The plagioclase occurs as subhedral to anhedral unoriented crystals up to 3.25 mm. long. The larger phenocrysts are commonly anhedral, zoned, pitted, and corroded around the margins. Smaller crystals are fresh; some are albite and carlsbad twinned. The composition, determined by the "Michel-Levy Method", is  $An_{41}$  to  $An_{42}$ , andesine.

Hornblende appears as poorly terminated elongate crystals



up to 3.0 mm. long. The hornblende is commonly seam-twinned and rimmed by anhedral magnetite.

Biotite occurs as tabular and prismatic crystals up to 2.0 mm. in maximum dimension. Crystals are commonly fresh; some contain inclusions of magnetite.

### Plio-Pleistocene Welded Tuff

#### Characteristics Common to the Welded Tuff Remnants

Phenocrysts of quartz, plagioclase, orthoclase and augite comprise 1 to 2 percent of the welded tuffs. Biotite phenocrysts are sparse.

Fragments of andesitic and dacitic composition are locally abundant.

Vapor-phase minerals occur in pore spaces. Devitrification minerals occur in glass.

Vapor-phase minerals are coarser than devitrification minerals but both are too small to be identified by microscope. Smith (1960) finds devitrification minerals are chiefly cristobolite and feldspar and vapor-phase minerals, in rhyolite ash flows, are predominantly alkalic feldspar, tridymite and cristobolite.

Welded Tuff Remnant East of Sheep Creek  
Zones Described from Bottom to Top

Brown Partially Welded Zone

Shards bent around crystals and barely collapsed pumice fragments suggest compression. Welding is not intense but undeformed shards are rare.

Hematitic staining, resulting in a dull brown color, suggests oxidation.

No devitrification or vapor-phase minerals are exhibited.

Black Glassy Densely Welded Zone

Dense welding is illustrated by flattened severely deformed shards and flattened pumice fragments that have nearly lost all structure.

Thin sections did not display devitrification or vapor-phase minerals.

Black Densely Welded Zone with Lithophysal Cavities and Spherulites

Dense welding is illustrated by severely flattened and deformed shards and pumice fragments. Shard structure is destroyed near lithophysal cavities and locally by devitrification minerals which cut across shard structure. Devitrification minerals, too small to be identified, are coarser in pumice fragments than shards. Devitrification forms radial aggregates of minerals in spherulites and locally axiolitic

structure in shards.

#### Pink Partially Welded Zone

Shard structure is almost completely destroyed by devitrification and vapor-phase minerals. Devitrification minerals, too small to be indentified, are coarse in pumice fragments and spherulites and finer in shards. Vapor-phase minerals, although unidentifiable, are coarser than devitrification minerals.

Welding is not as intense as in densely welded zones but more intense than in the brown partially welded zone.

#### Welded Tuff Remnant West of Horse Creek

The rock exposed petrographically resembles the pink partially welded zone of the remnant east of Sheep Creek.

#### Welded Tuff Remnant East of Wigwam Creek

Shard structure is almost completely destroyed by devitrification. Where observable, shards are deformed and flattened. Welding is present but not intense.

Inclusions of andesitic (plagioclase, augite, hypersthene phenocrysts) and dacitic (plagioclase, hornblende phenocrysts) clasts up to six inches in diameter, are present.

#### Refractive Index of Glasses

The refractive index of the ash at the base of the welded

tuff remnant east of Sheep Creek was found to be 1.501. The refractive index of glass shards obtained from the other welded tuff remnants is 1.500 to 1.502. A comparison with George's (1924) graph (percent  $\text{SiO}_2$  vs. index of refraction) suggests the percent silica of the rock is about 72.5. This amount of silica suggests classification of the original magma as rhyolitic (Bowen, 1928).

#### IV. STRUCTURE

##### Precambrian

Precambrian foliation strikes N30-60W and dips 43-55NE on the eastern and northern margins of the Precambrian outcrop area and strikes N50-70E and dips 28-90NW on the western margin. The resulting configuration is a northward plunging antiform.

The dikes in the Precambrian metamorphic rock strike N70E and dip 25NW.

##### Eocene Extrusive Rocks

The strike of the intercalated epiclastic volcanic beds and andesite flows is generally northwest. Locally, dips are as much as 40 degrees but most are near horizontal.

##### Eocene Andesite Dikes

Locally, andesite dikes are irregular in attitude. Recorded strikes vary from N60-85W. Dips vary from vertical to 65N.

##### Eocene Dacite Intrusions

The Sheep Mountain stock lacks flow structure. The plug east of Horse Creek has near vertical flow banding near its margins. Where exposed, the sill southeast of Sheep Mountain has a brecciated base.

A northwest trending near vertical fault, estimated to have four to six feet of displacement, is located west of the head of Horse Creek (sec. 34, T.8 S., R.6 E.). Doming of beds by the Sheep Mountain dacite, the exposed contact of which is located 0.50 miles north, could have produced the faulting.

A vertical northeast trending fault with 780 to 820 feet of stratigraphic displacement is located at the head of Tom Miner Creek on the west flank of Big Horn Peak (sec. 12, T.9 S., R.5 E.). H. W. Smedes (oral communication, 1968) feels that doming of the beds on Big Horn Peak is probably related to a dacite intrusion. This suggests the fault could have been produced by the doming.

Doming of beds, flow banding and a brecciated base suggest the dacites were forcibly emplaced.

#### Deep Creek Normal Fault

The trace of the northwest trending Deep Creek normal fault, a fault bounding the northwest side of the Beartooth block, is exposed about one mile northeast of the map area and trends toward the map area. Displacement of fans suggests recent movement along this fault northwest of the map area. No surface expression of this fault is recognized in the map area. Precambrian granitic gneiss and hornblende-biotite schists can be traced with no apparent offset from Dome

Mountain, one mile northeast of the map area, southwestward to near the mouth of Tepee Creek (R. Kern, R. Mackin and R. McNeil, oral communication, 1969). Hornblende-biotite schists, striking N40W and dipping 48-50NE are located on both sides of Tom Miner Creek near its mouth. These factors suggest southwestward extension of the Deep Creek fault if any, is limited to a southwest trending strip about one-quarter mile wide paralleling Tom Miner Creek in secs. 25, 30 and 36, T.7 S., R.6 E. If the fault is located in this strip, little displacement is suggested because Precambrian hornblende-biotite schists with similar attitudes and orientations would be located on both sides of the fault. Welded tuff remnants located on both sides of Tom Miner Creek, sec. 3, T.8 S., R.6 E., altitude of 6300 feet and in sec. 35, T.7 S., R.6 E., just off the map area at an altitude of 6080 feet, suggest little if any displacement along Tom Miner Creek since emplacement of the welded tuff. If the fault swings southwestward up Wigwam, Grizzly, Horse, Sheep, Walsh or Tom Miner Creeks, no appreciable offset is recognized in well-bedded epiclastic volcanic beds and andesite flows.

#### Spanish Peaks and Gardiner Faults

The trace of the northwest-trending Spanish Peaks reverse fault is exposed about five miles northwest of the map area. The trace of the northwest-trending Gardiner reverse fault is

exposed approximately six miles southeast of the map area (Figure 2). General alignment of these faults suggest they may represent the same fault trend (Wilson, 1934; McMannis and Chadwick, 1964). However, the age relationship between these faults has not been established (Ruppel, 1968), and no surface expression of these faults is recognized in the map area. Alignment of the Spanish Peaks reverse fault with part of the Western Absaroka belt volcanic centers suggests it is not an extension of the Gardiner fault.

The dacite intrusions and northwest striking andesite dikes (secs. 13, 16, 21, 22, 23, 24, 28, 29, 31 and 32, T.8 S., R.6 E.) of the map area are all located along the potassium poor Western Absaroka belt, labeled K<sup>-</sup> on Figure 2, as established by Chadwick (1968). Alignment of the andesite dikes and dacite intrusions with the Western Absaroka belt and Spanish Peaks fault suggests that shearing, fracturing and pre-Eocene faulting created a zone of weakness along which the andesite dikes and dacite intrusions were emplaced.



## V. PALEOMAGNETICS

When a lava cools, magnetic minerals take on a magnetic moment which is aligned parallel to the earth's magnetic field at the time of crystallization. This alignment of magnetic moments causes the rock to become slightly magnetized. Each rock fragment will have a north seeking and south seeking pole, a dipole. The orientation of this magnetic dipole is usually altered only by reheating or lightning strike. Orientation of a rock fragment's magnetic dipole may be recorded using a Brunton compass and a portable fluxgate magnetometer. The magnetometer is used to locate the position of the north (N) and south (S) seeking poles. The north (N) and south (S) seeking poles are marked on each fragment. Then the fragment is placed in its original orientation and the orientation of a line (the dipole) passing through the north (N) and south (S) seeking poles is measured. Orientations parallel or nearly parallel to the earth's present magnetic dipole, north seeking pole pointing northward and dipping downward, are called normal. Orientations with the south seeking pole pointing northward and dipping downward are called reversed. These orientations, normal and reversed, are "fixed" in the lava upon cooling. Differences in the attitude of the dipole are thought to be reflect a reversal of the earth's magnetic field.

Magnetic dipole orientations of andesite flows, dacite intrusions, welded tuff remnants and a sill in the Precambrian metamorphic rock are listed in Table V.

Examination of Table V shows andesite flows with, azimuths of 10-40 degrees and dips of 37-51 degrees, north seeking pole down, normal orientations. E. L. McCaskey (oral communication, 1969) found andesite flows south of the map area at an altitude of about 5900 to 6780 and 9360 to 9680 feet, with reversed dipole orientations. This suggests andesite flows of the map area between 5900 to 6780 and 9460 to 9680 feet may have reversed dipole orientations.

The dipole orientation of the third dacite sample in Table V is questionable because: (1) the dacite forms a ridge that has been struck by lightning and (2) the dacite is weakly magnetized making the dipole orientations reading very uncertain. If the dipole orientations are correct, a reversal of the earth's magnetic field is suggested between the emplacement of the Sheep Mountain dacite and the dacite sill southwest of Sheep Mountain.

A reversal of the earth's magnetic field is also suggested between the emplacement of the andesite flows with altitudes from 7600 to 9360 feet and the Sheep Mountain dacite.

A reversal in the earth's magnetic field took place in early Pleistocene or very late Pliocene (Nagata, 1961). If

TABLE V. WELDED TUFF DIPOLE ORIENTATIONS

Location	Altitude	Rock type	Inclination Declination
SW $\frac{1}{4}$ sec. 30, T. 8 S., R. 6 E.	7600	Andesite flow	20° 43°(N) down
NW $\frac{1}{4}$ sec. 30, T. 8 S., R. 6 E.	7600	Andesite flow	10° 37°(N) down
SW $\frac{1}{4}$ sec. 24, T. 8 S., R. 6 E.	8800	Andesite flow	20° 37°(N) down
NE $\frac{1}{4}$ sec. 31, T. 8 S., R. 6 E.	9000	Andesite flow	40° 51°(N) down
NE $\frac{1}{4}$ sec. 24, T. 8 S., R. 6 E.	9040	Andesite flow	30° 47°(N) down
NW $\frac{1}{4}$ sec. 5, T. 9 S., R. 6 E.	9360	Andesite flow	20° 40°(N) down
NW $\frac{1}{4}$ sec. 28, T. 8 S., R. 6 E.	8400	Sheep Mt. Dacite	155° 25°(S) down
NE $\frac{1}{4}$ sec. 21, T. 8 S., R. 6 E.	8640	Sheep Mt. Dacite	58°15°(S) down
SW $\frac{1}{4}$ sec. 31, T. 8 S., R. 6 E.	9360	Dacite sill SW. of Sheep Mt.	35° 57°(N) down
NW $\frac{1}{4}$ sec. 31, T. 7 S., R. 7 E.	6000	Andesite sill in Precambrian metamorphic rock	330° 70°(N) down
S $\frac{1}{2}$ sec. 17, T. 8 S., R. 6 E.	7200	Upper pink partially welded zone, remnant east of Sheep Creek	235° 11°(N) down
S $\frac{1}{2}$ sec. 17, T. 8 S., R. 6 E.	7200	Upper pink partially welded zone, remnant east of Sheep Creek	220° 63°(N) down
S $\frac{1}{2}$ sec. 17, T. 8 S., R. 6 E.	7200	Middle black glassy densely welded zone, remnant east of Sheep Creek	185° 3°(N) down
S $\frac{1}{2}$ sec. 17, T. 8 S., R. 6 E.	7200	Middle black glassy densely welded zone, remnant east of Sheep Creek	220° 5°(N) down
S $\frac{1}{2}$ sec. 17, T. 8 S., R. 6 E.	7200	Lower brown partially welded zone, remnant east of Sheep Creek	231° 11°(N) down

the welded tuffs are Plio-Pleistocene in age, anomalous but consistent dipole orientations, north-seeking pole pointing southward and dipping downward, obtained for the welded tuff zones may suggest they were deposited during the Pliocene-Pleistocene reversal.

As previously mentioned, random scatter of dipole orientations of andesitic clasts from an epiclastic volcanic breccia located in sec. 16, T.8 S., R.6 E. suggests emplacement by mudflows at temperatures below the blocking temperatures of the clasts. Table VI lists the orientations obtained.

The emplacement temperature for this epiclastic volcanic breccia was estimated using heating curves ( $J/J_0$  vs.  $T^{\circ}\text{C.}$ ) where the magnetic intensity of a cube sawed from each block before heating ( $J_0$ ) is compared to the magnetic intensity of the cube at various temperatures during heating, ( $J$ ). The theory upon which this method is based is discussed in Aramaki and Akimoto (1957). Table VII lists the emplacement temperature data.

Examination of Table VII shows an emplacement temperature of  $117^{\circ}\text{C}$  or less is suggested if it is assumed that during cooling, at least 75 percent of the ultimate magnetization is acquired at temperatures above that of the final emplacement of the breccia. The magnetic dipoles "frozen into" the rock above this temperature were then rotated by continued movement of the breccia to disorient the dipoles.

TABLE VI. DIPOLE ORIENTATIONS OF CLASTS FROM AN  
EPICLASTIC VOLCANIC BED

Sample Number	Declination	Inclination
1	352°	2°(S) down
2	26°	4°(N) down
3	328°	9°(S) down
4	48°	10°(N) down
5	10°	85°(S) down
6	318°	27°(N) down
7	42°	42°(N) down
8	330°	59°(N) down
9	352°	9°(S) down
10	28°	36°(S) down
11	290°	52°(S) down
12	305°	3°(S) down
13	28°	56°(S) down
14	89°	48°(S) down
15	312°	79°(N) down
16	35°	28°(N) down

TABLE VII. EMPLACEMENT TEMPERATURE DATA

J/Jo	Temperature °C	
	First run	Second run
1.00	25	25
.90	80	45
.80	105	80
.75	117	100
.70	130	115

## VI. SOURCE OF VOLCANICS

### Pre-Volcanic Topography

Prior to deposition of the Eocene volcanic sequence, the map area was part of a topographic basin bounded on the west by a ridge of Precambrian to Cretaceous strata, on the north by intermittent topographic highs of Precambrian metamorphic rock and on the east by a ridge of Precambrian metamorphic rock that extended southward at least to Mol Heron Creek (Peale, 1896; Hague, Iddings and Weed, 1894; Hall, 1961; McMannis and Chadwick, 1964; E. L. McCaskey, oral communication, 1968; Plate I, this study).

### A Southeastern Source

A source southeast of the map area is suggested for the greater part of the Eocene volcanic sequence because: (1) andesite flows thin and pinch-out in a northwesterly direction; (2) toward the west and northwest, epiclastic volcanic beds, particularly at altitudes below 8800 feet, become better stratified with more rounded clasts and contain more fine grained beds; (3) fossil forests become more abundant westward and northwestward; (4) ridges in the pre-volcanic topography, as indicated above, would have probably blocked any materials coming from the east, north or west at least in the earlier stages of deposition before topographic lows filled up.

Smedes (1968) suggests the Eocene volcanic sequence, south of the map area, was derived from vents in a large north-northeast trending horst in the Electric Peak-Sepulcher Mountain region, southeast of the map area in Yellowstone National Park (Figure 2). The same origin is suggested for the greater part of the Eocene volcanic sequence of the map area because the two Eocene sequences are in part coextensive and probably contemporaneous.

#### A Northern Source

A northern source for some of the upper part of the volcanic sequence in the northwestern part of the map area is suggested by: (1) numerous Precambrian fragments in crudely stratified epiclastic volcanic beds at altitudes above 8720 feet; (2) beds striking northeastward and dipping as much as 30 degrees southeastward, which is greater than what could reasonably be due to regional tilting; (3) an augite rich andesite flow occurs at an altitude of about 9280 feet (sec. 35, T.8 S., R.5 E.) that closely resembles the augite-rich northern Gallatin Range andesites; (4) some andesite flows with altitudes of about 8400 to 9200 feet located in the northern Gallatin Range grade southward into epiclastic volcanic beds which seem continuous from the northern Gallatin Range to the Ramshorn Peak area, about one mile north of the northwest corner of the map area (R. A. Chadwick, oral

communication, 1969).

### Andesite Dikes

Compositional similarity between the seven augite-hornblende-hypersthene andesite dikes, east of Horse Creek, and the upper augite-hornblende-hypersthene andesite flows may suggest the dikes fed upper flows.

Thus the upper andesite flows and epiclastic volcanic beds, in contrast to the lower andesite flows and epiclastic volcanic beds, could have come in part from: (1) the southeast, as a continuation of volcanism from Electric Peak-Sepulcher Mountain region; (2) the andesite dikes west of Horse Creek. However, much if not all of the material probably came from the north, as indicated by the evidence stated above.

### Plio-Pleistocene Welded Tuff Remnants

The source of the welded tuff remnants east of Sheep Creek and west of Horse Creek is thought to be northwest of the map area because: (1) a welded tuff remnant on the north side of Tom Miner Creek just off the map area (sec. 18, T.8 S., R.6 E.) has the same welding zones; (2) welded tuff remnants are restricted to the valley of Tom Miner Creek and occur at lower altitudes eastward; (3) in thin section, the welded tuff exposure west of Horse Creek is petrographically similar to



the pink partially welded zone of the outcrop east of Sheep Creek, suggesting both welded tuffs are remnants of the same welded ash flow.

## VII. GEOLOGIC HISTORY

### Precambrian

Intercalated quartzites and hornblende-biotite schists suggest deposition of a quartzo-feldspathic sedimentary sequence as the earliest recorded event in the map area. These schists flank a quartz-biotite-plagioclase gneiss that may represent: (1) a granitic intrusion into the quartzo-feldspathic sediments; (2) a granitic topographic high that was on-lapped by the quartzo-feldspathic sediments; (3) a block of arkosic or granitic composition brought to the surface by faulting; (4) a granitized area.

Intrusion of basic sills into the quartz-biotite-plagioclase gneiss before metamorphism and folding is suggested by the following features in the sills: (1) plagioclase grains with recrystallized edges; (2) fractured crystals; (3) local cataclastic structures; (4) alteration of augite to green amphibole; (5) parallelism of sills to foliation.

These sills are probably of Precambrian age because of suggested metamorphism and orientation parallel to the foliation. However, a Precambrian age is not positive because mafic Tertiary dikes are located in the Lonesome Mountain area of the Precambrian Beartooth block and similar mafic dikes intrude Cambrian beds near the map area (Larsen, Poldervaart

and Kirchmayer, 1966; W. J. McMannis, oral communication, 1969).

Diagnostic relationships were not observed to determine whether folding was before, during or after metamorphism.

Pegmatites occur both parallel to and crosscutting foliation. Diagnostic features were not observed to establish whether the pegmatites formed during or after metamorphism.

From Tom Miner Creek southward along the west side of Tepee Creek, the metamorphic sequence consists of interbedded hornblende-plagioclase-biotite schists and schistose quartzites; quartz-biotite-plagioclase gneiss and granulite. An increase in metamorphic intensity southward is suggested by: (1) appearance of biotite, hornblende, plagioclase and epidote in the schists; (2) garnet, graphic intergrowths of feldspar and quartz and recrystallized quartz in the gneiss; (3) augite, abundant graphic intergrowths of quartz and feldspars, recrystallized grains of quartz and fractured plagioclase laths in the granulite. The mineral assemblage epidote, biotite-hornblende, garnet and augite suggests medium to high grade regional metamorphism of the almandine-amphibolite to granulite facies.

A pre-Belt age is suggested for the metamorphic rocks of the map area by age dates of 1.6 to 3.2 billion years determined on metamorphic rocks, north, northeast, northwest and southeast of the map area (D. G. Brookins, 1965, written

communication to W. J. McMannis; McMannis and Chadwick, 1964; Giletti, 1966).

### Paleozoic-Mesozoic

Following folding and metamorphism a sedimentary sequence at least 10,000 feet thick was deposited with angular unconformity on the Precambrian metamorphic rock (Iddings, 1904; Wilson, 1934a, 1934b). At a later date, this sedimentary sequence was partly removed by erosion since volcanics in many places, including the map area, rest directly on Precambrian metamorphic rock.

### Cenozoic

Movements along the Spanish Peaks fault probably took place in several phases from late Cretaceous up to pre-middle Eocene time (McMannis and Chadwick, 1964).

The intercalated epiclastic volcanic beds and andesite flows were emplaced during Eocene time. Dacite intrusions and andesite dikes were emplaced along the northwest-trending Western Absaroka belt also during Eocene time.

The epiclastic volcanic beds and andesite flows of the map area are interpreted as Eocene because they are continuously traceable southward from Big Horn Peak into beds mapped as Eocene by Smedes (1968).

The dacite intrusions of the map area are Eocene or

younger in age because they intrude the Eocene volcanic sequence. The dacite intrusions are interpreted as Eocene because similar dacite intrusions located along the potassium-rich Eastern Absaroka belt on Mill and Big Creeks, northwest of the map area, yielded K/Ar dates of 49.0 and  $49.5 \pm 1.5$  million years respectively (R. A. Chadwick, in press).

Since Eocene up to Plio-Pleistocene time, erosion was the only recognized geologic event in the map area. However, many geologic events took place during this period according to evidence from nearby areas. In the Yellowstone Valley, northeast of the map area, olivine basalt flows, capping Hepburn's Mesa, have been dated as Pliocene by Bush (1967). These basalt flows overlie a late Miocene-early Pliocene siltstone (Horberg, 1940) and gravel.

One or more welded tuff deposits rest unconformably on Eocene epiclastic volcanic beds and augite-hypersthene andesite flows. This relationship indicates that the welded tuffs are Eocene or younger. Welded tuffs in nearby regions are Eocene (Sepulcher Mountain and northern Yellowstone National Park. Prostka, oral communication 1968; 1968) and Plio-Pleistocene (Yellowstone Plateau: Christiansen and others, 1968). The welded tuffs of the map area are interpreted to be Plio-Pleistocene because: (1) post-cooling alteration of glass and oxidation of iron are lacking; (2) tridymite and

cristobalite have not been converted to opal, chalcedony or quartz. Absence of these types of alteration is characteristic of Pliocene and younger welded tuffs according to Smith (1960).

The welded tuff remnants located along Tom Miner Creek lie about 50 to 480 feet above the present valley floor. This suggests the valley floor was about 50 to 480 feet higher before the welded tuffs were deposited in Plio-Pleistocene (?) time. Relative altitudes of the welded tuff remnants suggest the valley floor had a steeper gradient to the east at that time than it does at present.

The area was glaciated at least once during this period. Cirques in Tom Miner Basin have floors at altitudes of 8800 feet and above and glacial drift, moraines and erratics occur at altitudes up to at least 7600 feet. Roches moutonnees and striated ice marginal channels, which parallel the present Yellowstone River, have been cut in Precambrian metamorphic rocks in Yankee Jim Canyon. Yankee Jim Canyon is interpreted as having been carved, at least in part, by glacial action because striated Precambrian metamorphic rocks occur at altitudes about even with the present Yellowstone River channel.

The formation and destruction of a landslide dam blocking the Yellowstone River in Yankee Jim Canyon is suggested by

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remnants of material that formed the dam and outwash material of similar composition deposited downstream when the dam broke. This event is well documented by Good (1964).

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