



Geology of the Emigrant Peak intrusive complex, Park County, Montana  
by Albert L Basler

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 Emigrant Peak area, located in Park County, Montana, 16 miles north of Yellowstone National Park, is an intrusive complex of andesitic to dacitic composition. It is located along the northwest-trending Cooke City structural zone and may represent an ancient volcanic conduit. The oldest rocks of the complex are andesitic intrusions, monolithologic autobreccias, and heterolithologic breccias which grade into one another in some places and are in sharp contact in others. The andesite varies from aphanitic to porphyritic with phenocrysts of zoned to unzoned plagioclase, An 45-60, up to 5 millimeters long. Green hornblende phenocrysts are present in lesser amount. The andesites are believed to have formed by subsurface crystallization because of the lack of vesicularity and ash layers in the breccias.

At the head of Emigrant Gulch, a dacite porphyry stock with two systems of associated dacite dikes intrudes the andesitic rocks. The older dikes contain little biotite and either strike parallel to the stock and dip into it in a discontinuous cone sheet pattern, or are arranged radially to the stock. The younger dikes are biotite-rich and are radial to the stock.

The andesitic rocks seem to represent vent breccias and solidified magma deep in the conduit of an old volcano. The dacites probably represent fracture fillings and larger masses crystallized in the vent during the last, more acidic phases of volcanism.

Similar datites in the nearby Mill Creek drainage have been dated as 49 million years, suggesting an Eocene age for the complex.

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194

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## ABSTRACT

The Emigrant Peak area, located in Park County, Montana, 16 miles north of Yellowstone National Park, is an intrusive complex of andesitic to dacitic composition. It is located along the northwest-trending Cooke City structural zone and may represent an ancient volcanic conduit. The oldest rocks of the complex are andesitic intrusions, monolithologic auto-breccias, and heterolithologic breccias which grade into one another in some places and are in sharp contact in others. The andesite varies from aphanitic to porphyritic with phenocrysts of zoned to unzoned plagioclase, An 45-60, up to 5 millimeters long. Green hornblende phenocrysts are present in lesser amount. The andesites are believed to have formed by sub-surface crystallization because of the lack of vesicularity and ash layers in the breccias.

At the head of Emigrant Gulch, a dacite porphyry stock with two systems of associated dacite dikes intrudes the andesitic rocks. The older dikes contain little biotite and either strike parallel to the stock and dip into it in a discontinuous cone sheet pattern, or are arranged radially to the stock. The younger dikes are biotite-rich and are radial to the stock.

The andesitic rocks seem to represent vent breccias and solidified magma deep in the conduit of an old volcano. The dacites probably represent fracture fillings and larger masses crystallized in the vent during the last, more acidic phases of volcanism.

Similar dacites in the nearby Mill Creek drainage have been dated as 49 million years, suggesting an Eocene age for the complex.

GEOLOGY OF THE EMIGRANT PEAK INTRUSIVE COMPLEX  
PARK COUNTY, MONTANA

INTRODUCTION

Location and Accessibility

Emigrant Peak is located in south-central Park county, Montana, approximately 25 miles south of Livingston on the east side of the Yellowstone River (Figure 1).

The area studied extends from Six Mile Creek on the southwest to Emigrant Gulch and the ridge north of Fridley Creek on the northeast. The northwestern boundary is the front of the Beartooth Mountains and the south and southeastern boundaries are the southern border of the Emigrant quadrangle and a hypothetical line somewhat southeast of the border of the Emigrant stock respectively (Plate 1). The area comprises approximately 18 square miles. Sec. ? T ? R ?

Purpose and Scope of the Study

Moderately altered volcanic breccia, intrusive andesites and dacites, and Precambrian schist comprise the bedrock in the area.

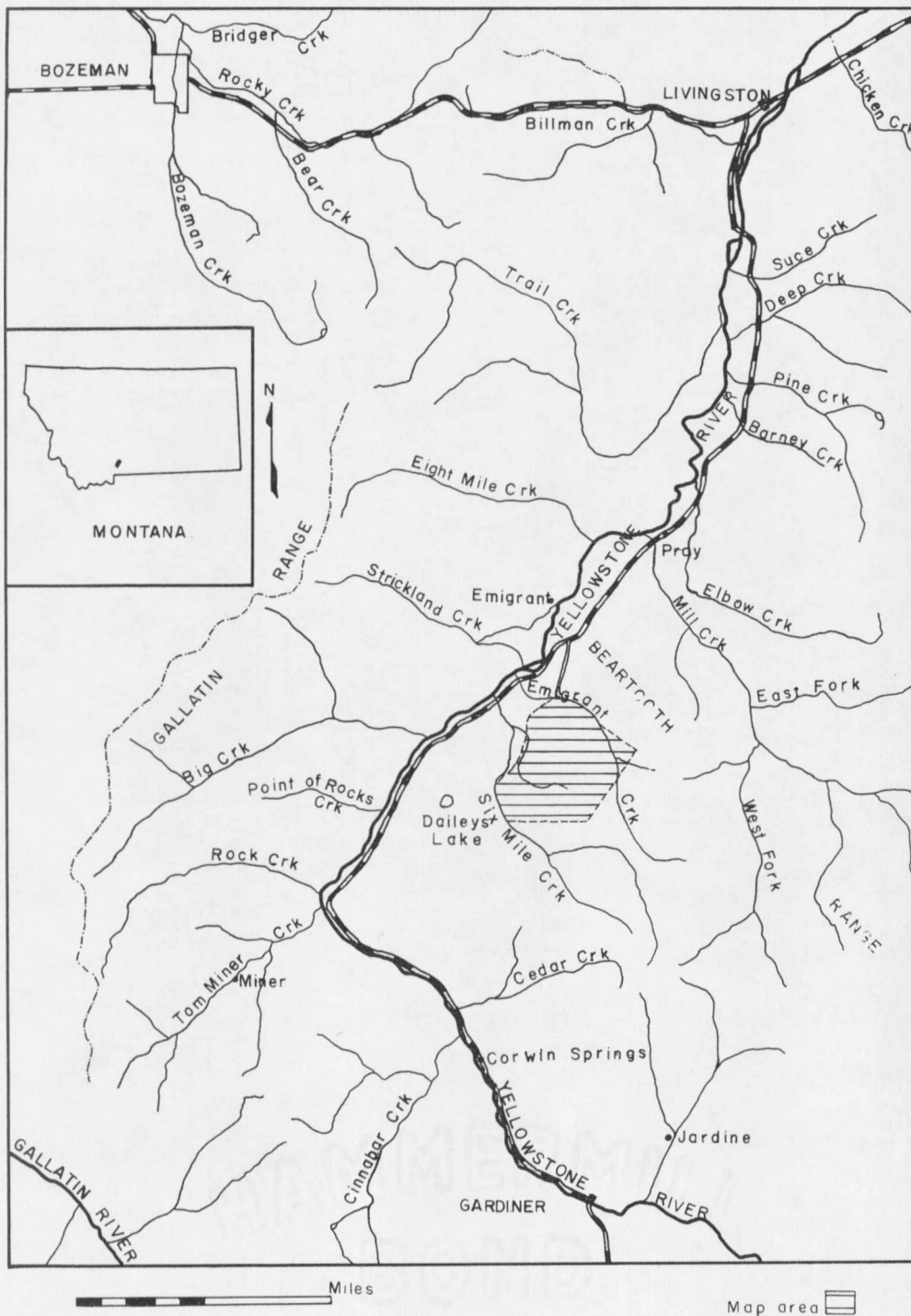


Figure 1. Index Map

The principal objectives of this investigation are:

(1) to determine the nature and mode of origin of the andesitic breccia and andesitic intrusive rocks; (2) to determine the relationships of the dacitic intrusive rocks to the andesitic rocks. A secondary objective is to gain some understanding of the associated sulfide mineralization.

#### Previous Work

Iddings and Weed (1894) studied the Emigrant Peak area as part of the Livingston 1° quadrangle. The geological work was very general. They considered the stock at the head of Emigrant Gulch to be a plug in an old volcanic conduit which had baked and altered the volcanic rock around it.

P. Purdy and R. Applegate, of American Metal Climax Company, studied an area along both sides of Emigrant Gulch during the summers of 1962 and 1963 prior to a drilling campaign. Purdy (oral communication, 1963) believes that the volcanic rocks are largely intrusive rather than extrusive and that Emigrant Peak may be an ancient dissected caldera.

Considerable work has been done in nearby areas and will be discussed in the succeeding section of this paper. The writers cited in connection with the Beartooth Mountains are: Emmons (1908), Foose, et al (1961), Lovering (1929), Rouse,

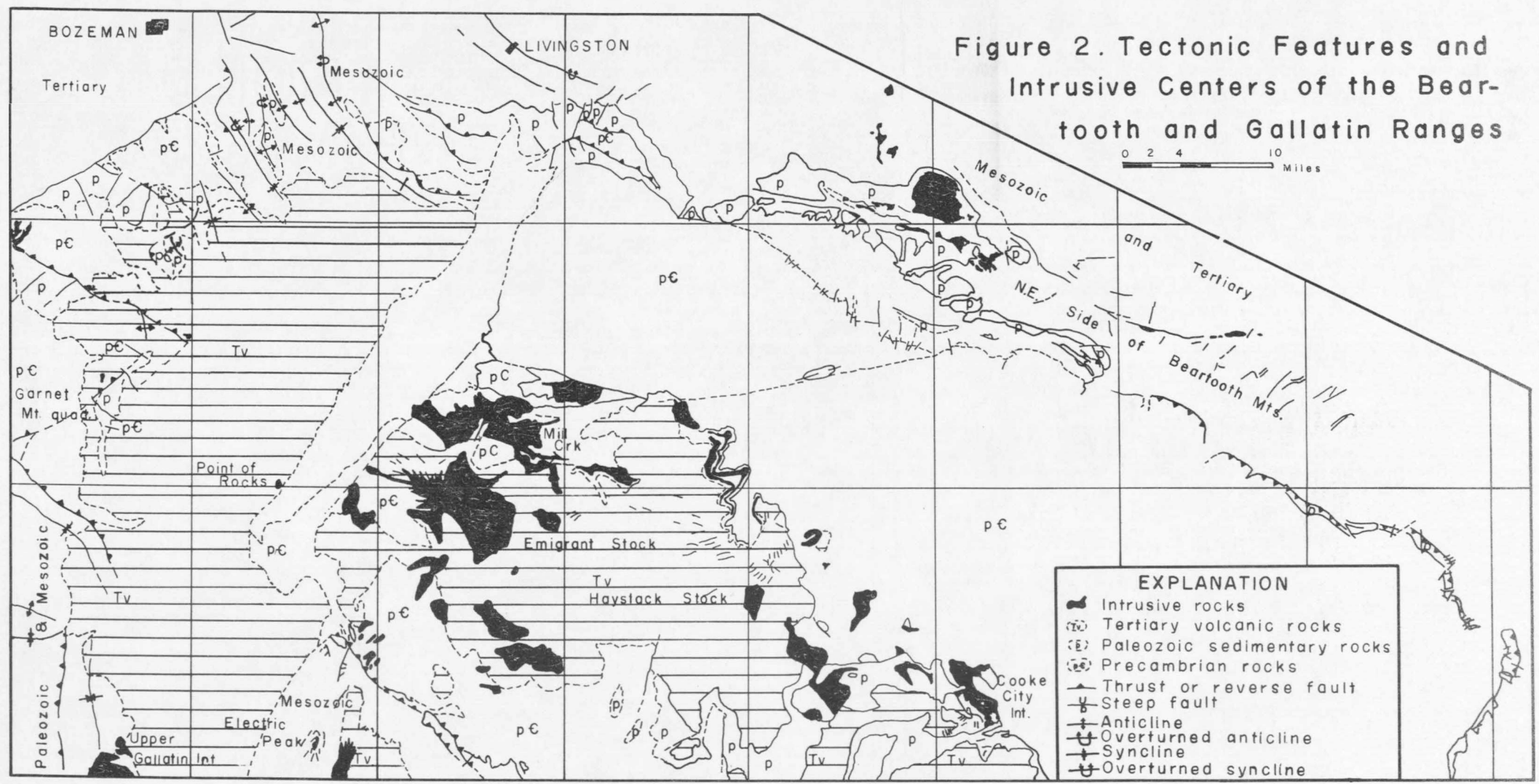


Figure 2. Tectonic Features and Intrusive Centers of the Beartooth and Gallatin Ranges

( Compiled from Iddings and Weed, 1894, Peale, 1896, Spencer, 1958, and McMannis and Chadwick, 1964 )

et al (1937), Parsons (1942), and Wilson (1936). Those cited in connection with the Gallatin Range are: Iddings (1899), McMannis and Chadwick (1964), McMannis (1964), and Peale (1896).

## REGIONAL GEOLOGIC SETTING

### General Geology, Structure, and Geomorphology

The Beartooth Mountains rise abruptly along the east side of the Yellowstone Valley in southwestern Montana.

Emigrant Peak is part of the uplifted block from which the Beartooth Mountains are carved and is situated about 12 miles north of the southwestern corner of the block (Figure 2). The Beartooth block is a northwest trending 80 by 40 mile structural unit in the middle Rocky Mountains. Most of the Beartooth block consists of Precambrian crystalline rocks; Paleozoic and Mesozoic sedimentary rocks are draped along the east, northeast and southwest flanks of the block and are preserved in downdropped blocks along the Mill Creek fault zone.

The southern part of the Beartooth block is covered in places by a thick sequence of volcanic rocks which are believed to correlate with the early acid breccia and the early basic breccia in Yellowstone National Park (Lovering, 1929).

At Cooke City the early acid breccia consists of light colored angular hornblende andesite, latite, and dacite fragments of variable size. They are rudely stratified and are interbedded with andesitic flows. The early basic breccia includes a sequence of andesite and basalt flows, basic tuff layers, and basic andesitic breccia (Lovering, 1929).

Near Cowles, Montana, in the vicinity of the Haystack stock, the early acid breccia and the early basic breccia have been differentiated and attain a total thickness of 4500 feet (Emmons, 1908). The published descriptions of these rocks are very similar to those of the Cooke City volcanic rocks.

Just north of the Emigrant Peak area, in the Mill Creek drainage, a sequence of volcanic breccias, tuff layers, flows, and conglomerate has been tentatively divided into early acid and early basic breccias (Wilson, 1936). A tuff layer between the two units has been dated as early Oligocene or possibly late Eocene (Wilson, 1936).

The Gallatin Range which lies west of the Yellowstone Valley is largely composed of a thick sequence of Eocene volcanic extrusive rocks which largely cover older sedimentary and metamorphic rocks (Figure 2).

In the Garnet Mountain quadrangle the crudely bedded sequence consists of basic andesite flows, flow breccias, and stratified volcanic breccias, which dip 5-10 degrees east and southeast and attain a calculated thickness of 4000 feet in places (McMannis and Chadwick, 1964). The volcanic rocks were evidently poured out on an irregular erosion surface with relief of at least 3000 feet in places (McMannis, 1964). The heterolithic breccias were deposited from laharic flows which developed between or during episodes of lava flow (McMannis and Chadwick, 1964).

Near the intrusive-extrusive complex at Electric Peak and Sepulchre Mountain, in the southern part of the Gallatin Range, the volcanic rocks have also been divided into early acid and early basic breccia. They total 3500 feet in thickness and consist of bedded breccias, containing Precambrian fragments near the base, grading locally into tuffs (Iddings, 1899). A period of erosion between the deposition of the two units was postulated.

The structures in the Beartooth and Gallatin Ranges are predominantly northwest-trending although some trend northeast (Figure 2). The Beartooth block is bounded on the northwest by the Deep Creek fault which dips steeply to the northwest and

displaces Cambrian strata at least 6000 feet, relative to the Precambrian basement rocks, near Deep Creek (McMannis, oral communication, 1965). Recent movement along the fault is indicated by scarps which cut the fans of Barney and Deep Creeks and the alluvium near the mouth of Yankee Jim Canyon. At the northwest end of Yankee Jim Canyon the upper surface of the basement rocks of the Beartooth and Gallatin Ranges are at approximately the same altitude (Foose, et al, 1961) indicating that displacement on the Deep Creek fault is much less. Along its east and northeast flanks the Beartooth block is bounded principally by thrust or reverse faults which separate it from the Crazy Mountain Basin. These faults dip steeply northward near Livingston whereas they dip southwestward near Red Lodge. The northward-dipping Gardiner thrust fault forms the southwestern boundary near Gardiner although most of the structural relations in this portion of the block are obscured by volcanic rocks.

Two major structural zones transect the Beartooth block: the Mill Creek and Cooke City zones. The Mill Creek fault zone trends almost east-west from the west Stillwater River drainage to Mill Creek and separates the upthrown North Snowy block from the downthrown South Snowy block (Wilson, 1936). The Cooke City

zone, which is characterized by northwest trending fractures, extends from Cooke City to Mill Creek and evidently was a locus of intrusive activity and sulfide mineralization (Foose, et al, 1961).

The most prominent geomorphic features of the upper Yellowstone Valley, between the mouth of Yankee Jim Canyon just south of Point Rocks and the canyon south of Livingston, are those produced by Quaternary glaciation. In Wisconsin time a piedmont glacier, originating in Yellowstone National Park, <sup>AREA</sup> flowed down the Yellowstone Valley as far north as Mill Creek (Weed, 1893). It was fed by ice fields in Yellowstone Park and was augmented by numerous valley glaciers descending from the adjacent mountains. In the vicinity of Emigrant Peak, valley glaciers descending from Six Mile Creek, Emigrant Gulch, and Mill Creek forced the piedmont glacier against the foothills of the Gallatin Range (Weed, 1893). In Yankee Jim Canyon the ice could not have been less than 3000 feet thick (Horberg, 1940) but thinned rapidly northward when it entered the broad upper valley of the Yellowstone River.

In Emigrant Gulch, about 1/4 mile southeast of its mouth, there is a deposit of coarse sand and gravel (Plate 1) preserved on the west side of the gulch which Van Voast (1964) tentatively

described as a lake deposit formed by glacial damming (Van Voast, 1964). Van Voast thinks that these deposits were formed during the piedmont glacial maximum. He projected the surface of this deposit to an altitude of 5800 feet near the mouth of Emigrant Gulch, suggesting that the glacier was approximately 600 feet thick at this point. To the south in the Six Mile Creek valley there is a varved glacial lake deposit which is 400 feet thick (John Montagne, oral communication, 1965). Montagne thinks that during the time of piedmont glacial maximum the valleys of Emigrant and Six Mile Creeks contained glacial lakes, and little or no ice was present in the lower part of these valleys. Horberg (1940) postulated that a late Wisconsin glacial substage extended down the Yellowstone Valley two miles north of the town of Emigrant but Van Voast (1964) suggested that the late Wisconsin substage terminated near Gardiner and never reached the upper Yellowstone Valley. Van Voast postulated two minor advances of the early Wisconsin piedmont glacier. North of Mill Creek, in the North Snowy block, younger moraine confined within the higher lateral moraines of early Wisconsin valley glaciers seem to indicate that valley glaciers were active in late Wisconsin times (Horberg, 1940).

Some evidence for pre-Wisconsin glaciation in the Yellowstone Valley has been found by Horberg (1940) and John Montagne (oral communication, 1963).

Most of the pre-Wisconsin debris has been eradicated by later glaciation and periglacial activity such as solifluction. Some erratics have been found in high level saddles along the mountain front which are thought to be pre-Wisconsin. In the Emigrant Peak area the only debris which may be of pre-Wisconsin age is in the northwest-facing cirque just below the highest prominence of Emigrant Peak (SW $\frac{1}{4}$ , Sec. 35, T. 6 S., R. 8 E.) at an altitude of 9600 feet. The debris consists of angular blocks of Precambrian quartzite and schist several feet across. It is scattered among angular fragments of volcanic rocks on the bottom of the cirque. There is no distinct morainal form. The debris could have two origins: (1) it could be the remnant of a moraine produced by a very large piedmont glacier in the Yellowstone Valley or (2) it could have been rafted up from below by the andesitic or dacitic intrusives. Small fragments of schist have been observed in the dacites near the contact with the Precambrian rocks but only one large block has been observed in the dacites. No Precambrian rocks have been observed in the andesites. A few miles south in Stands

Basin erratics which are probably pre-Wisconsin have been found at an elevation of 7300 feet (John Montagne, oral communication, 1965). These erratics are much lower than the Precambrian blocks on Emigrant Peak and it is doubtful if the pre-Wisconsin glacier was large enough to deposit the debris on Emigrant Peak. They were probably rafted up in the dacitic or andesitic magma.

Most of the cirques on Emigrant Peak, especially those on the east flank, contain very active rock glaciers. The cirque in the E $\frac{1}{2}$ , Sec. 1, T. 6 S., R. 8 E., is a very good example. The aerial photographs of the area show the festoon-shaped ridges perpendicular to the direction of flow. These rock glaciers were probably initiated by oversteepening of the slopes during periods of glaciation.

Along the northwest flank of Emigrant Peak, facing the Yellowstone Valley, there is a prominent break in slope at an altitude of about 7600 feet. North of Mill Creek, in the North Snowy block, Horberg (1940) suggested that a fault may separate the foothills region from the main mountain mass because of the abrupt termination of the foothills along a linear eastern margin. Faulting may have been the cause of the break in slope in the Emigrant Peak area, too, but there is little direct evidence to prove it. One feature which may suggest faulting

is the alignment of the lower portion of Balm of Gilead Creek and the gulch on the west side of Emigrant Creek. Both are very linear where they are incised into Precambrian rocks; however, the foliation of the Precambrian rocks strikes parallel to this lineation and could also be the cause of it. Some slickensided andesite was found in the center of Sec. 34, T. 6 S., R. 8 E., which may also indicate faulting. Other possible explanations for the break in slope are glacial abrasion and cyclic erosion. The postulated pre-Wisconsin glacier may have been large enough to scour out the valley to form the break in slope. More work is needed to define the extent of pre-Wisconsin glaciation in the Yellowstone Valley.

The topography in the region is maturely dissected. The streams in the Emigrant Peak area flow in V shaped valleys, occasionally on bedrock. Besides fluvial action the area is being modified by the action of various types of mass wasting processes, especially the rock glaciers previously mentioned. Emigrant Peak was probably formed because of the greater resistance to erosion shown by the andesitic intrusives and breccias compared to the dacitic and Precambrian rocks.

Intrusive Centers of the Beartooth and Gallatin Ranges

Table 1 summarizes the characteristics of the intrusive centers of the Beartooth and Gallatin Ranges.

Intrusive activity in the Beartooth Range is localized principally in two areas: along the northeastern boundary of the Beartooth block and along the Cooke City zone (Figure 2). The intrusive bodies along the former zone are cut by faulting related to the uplift of the range and were thus emplaced prior to the uplift of the range (Rouse, et al, 1937). Many of these intrusives, especially those in the southeastern portion of this zone, wedged their way into incompetent Cambrian shales or along the Cambrian-Precambrian contact and are now exposed most extensively along the range front. In the Deer Creek area, near the northwestern end of this zone, the intrusives cut both Paleozoic and Mesozoic rocks. Several vent areas have been described in the Deer Creek area (Parsons, 1942).

Faulting evidently controlled emplacement of the intrusives along the Cooke City zone. At Cooke City the gabbro stocks are postulated as possible vents because of the similarity between the chemical composition of the stocks and that of the breccias (Lovering, 1929). The Haystack stock cuts the early

Intrusive center	Form	Country rocks	Rock types	Minerology and texture	Volcanic vent ?	Mineralized ?	Age	Miscellaneous
Northeast side of the Beartooth Mts.	Plugs, sills, dikes, and laccoliths.	Paleozoic and Mesozoic sedimentary rocks and volcanic breccia.	Quartz keratophyre, diorite, and monzonite; andesite, and dacite.	The plagioclase ranges approximately from An <sub>60</sub> -An <sub>30</sub> . Quartz and orthoclase occur in lesser amounts. Mafic minerals occur sparsely. Augite hornblende in the andesite.	Yes	Yes	Late Cretaceous	These intrusives were emplaced prior to the uplift of the Beartooth block.
Cooke City	Stocks, pipes, sills, and dikes.	Precambrian and Paleozoic rocks and other intrusives.	Monzonite, syenite, basalt, and gabbro.	The plagioclase ranges from albite to labradorite. The other minerals are; orthoclase, quartz, hornblende and biotite. Augite occurs in the gabbro.	One gabbro stock may be.	Yes	One gabbro stock may be contemporaneous with part of the early basic breccia	Commonly altered.
Haystack stock	Stock	Volcanic breccia.	Quartz monzonite to gabbro and andesite.	The minerals in order of abundance are; plagioclase, orthoclase, augite, hyperthene, biotite, quartz, hornblende, magnetite, and olivene.	Possibly	Yes	The stock cuts most of the early basic breccia ( Eocene ? ).	The rock types grade into one another in places and are in sharp contact in other places.
Hill Creek	Laccolith, byssalith, dikes, and sills.	Precambrian and Paleozoic rocks.	Dacite	Phenocrysts of plagioclase ( albite to andesine ), quartz, biotite, and some hornblende are embedded in a glassy to holocrystalline groundmass.	No	Yes ?	Eocene 49 m.y. by K-A method	Little variation or alteration.
Emigrant Peak	Stock, dikes, and irregular intrusives.	Precambrian metamorphic rocks and volcanic breccia.	Dacite and andesite.	See petrography section of this paper.	Yes	Yes	Eocene ?	Very altered.
Point of Rocks	Plugs and dikes.	Volcanic breccia.	Dacite and andesite.	Phenocrysts of andesine, quartz, and biotite occur in a glassy to microcrystalline groundmass.	Yes	No	Eocene ?	May be associated with the Cooke City zone.
Electric Peak	Stock, dikes, sills.	Mesozoic sedimentary rocks.	Diorite and related rocks.	The chief minerals are; plagioclase ( oligoclase to labradorite ), orthoclase, quartz, hyperthene, augite, hornblende, and biotite. The rock is medium grained.	Yes	No ?	Eocene ?	
Upper Gallatin	Laccolith	Paleozoic and Mesozoic sedimentary rocks.	Dacite	Phenocrysts of plagioclase ( andesine to labradorite ), hornblende, and quartz are embedded in a fine grained granular matrix which contains much magnetite.	No	No ?	Eocene ?	
Garnet Mt. quadrangle	Stocks, dikes, sills, and irregular domed intrusives.	Precambrian, Paleozoic, and Mesozoic sedimentary rocks and volcanic breccia.	Dacite, andesite, diorite, and rhyolite.	Dacite- The main phenocrysts are plagioclase ( andesine to oligoclase ), biotite, and hornblende. The groundmass is glassy to microcrystalline. The andesite contains hornblende and plag.	No	No	The andesite is Cretaceous	Apparently related to faulting.

**Table I. Characteristics of the intrusive centers of the Beartooth and Gallatin Ranges.**

(Compiled from Idings, 1899, Emmons, 1908, Wilson, 1936, Rouse et al, 1937, Parsons, 1942, Peale, 1896, and McMannis and Chadwick, 1964)

acid breccia but may be older than the upper part of the early basic breccia (Emmons, 1908). Although there is no conclusive evidence that it reached the surface, Emmons suggested that the stock may have been a source for some of the breccias because of compositional similarity. The Emigrant-Mill Creek intrusive center is the largest along the Cooke City zone (Figure 2), probably because of the convergence of the Cooke City structural zone, the Mill Creek fault zone, and the Deep Creek fault. The major relations of the Emigrant Peak area have been summarized in Table 1 and will be discussed in detail later. The Mill Creek intrusives show little variation from one to another and appear to have been localized because of:

- (1) the presence of the adjacent Emigrant Peak center, and
- (2) the existence of high angle faults that controlled magmatic emplacement, and incompetent Cambrian shales that allowed the magma to spread out (Wilson, 1936).

The exposed intrusive centers of the Gallatin Range are smaller and less numerous than those of the Beartooth Range, although others may be buried under the lavas. Two of them, the Electric Peak intrusive (Iddings, 1849) and the plugs of the Point of Rocks area (Chadwick, 1965) are thought to be volcanic vents. At Electric Peak a dioritic stock with

associated dikes and sills intrude the Mesozoic sedimentary rocks (Iddings, 1849). These intrusives have been divided into three groups: (1) most of the dike rocks and some of the contact zones of the stock, which are oldest, (2) the main body of the stock and some of its apophyses, and (3) the quartz-mica diorite porphyry which intrudes the stock and produces some dikes (Iddings, 1899). The stock is thought to represent an old volcanic conduit which supplied much of the material for the volcanic sequence of Sepulchre Mountain. It has been exposed by erosion because of uplift along a north trending fault which has raised Electric Peak with respect to Sepulchre Mountain.

At Point of Rocks, plug-like dacitic intrusives cut volcanic breccias and flows. The extrusive volcanic breccias contain fragments of both the dacitic intrusives, and the andesitic flows (Chadwick, 1965). The glassy nature of the dacitic plugs indicates that the exposed portions of this complex represent a near-surface phenomenon.

The upper Gallatin intrusives are dacite porphyry laccoliths which intrude Paleozoic and Mesozoic sedimentary rocks (Peale 1864). The upper Gallatin apparently is not a vent area.

The intrusive bodies in the Garnet Mountain quadrangle are stocks, irregular domed intrusives, dikes, and sills. Most of the sills and some of the dikes are andesitic in composition and are apparently much older than the dacitic material. A K-A date puts them in the Cretaceous Period (McMannis and Chadwick, 1964). Except for one diorite stock and a rhyolite dike, the rest of the intrusives are dacitic and seem to be controlled by faulting (McMannis and Chadwick, 1964).

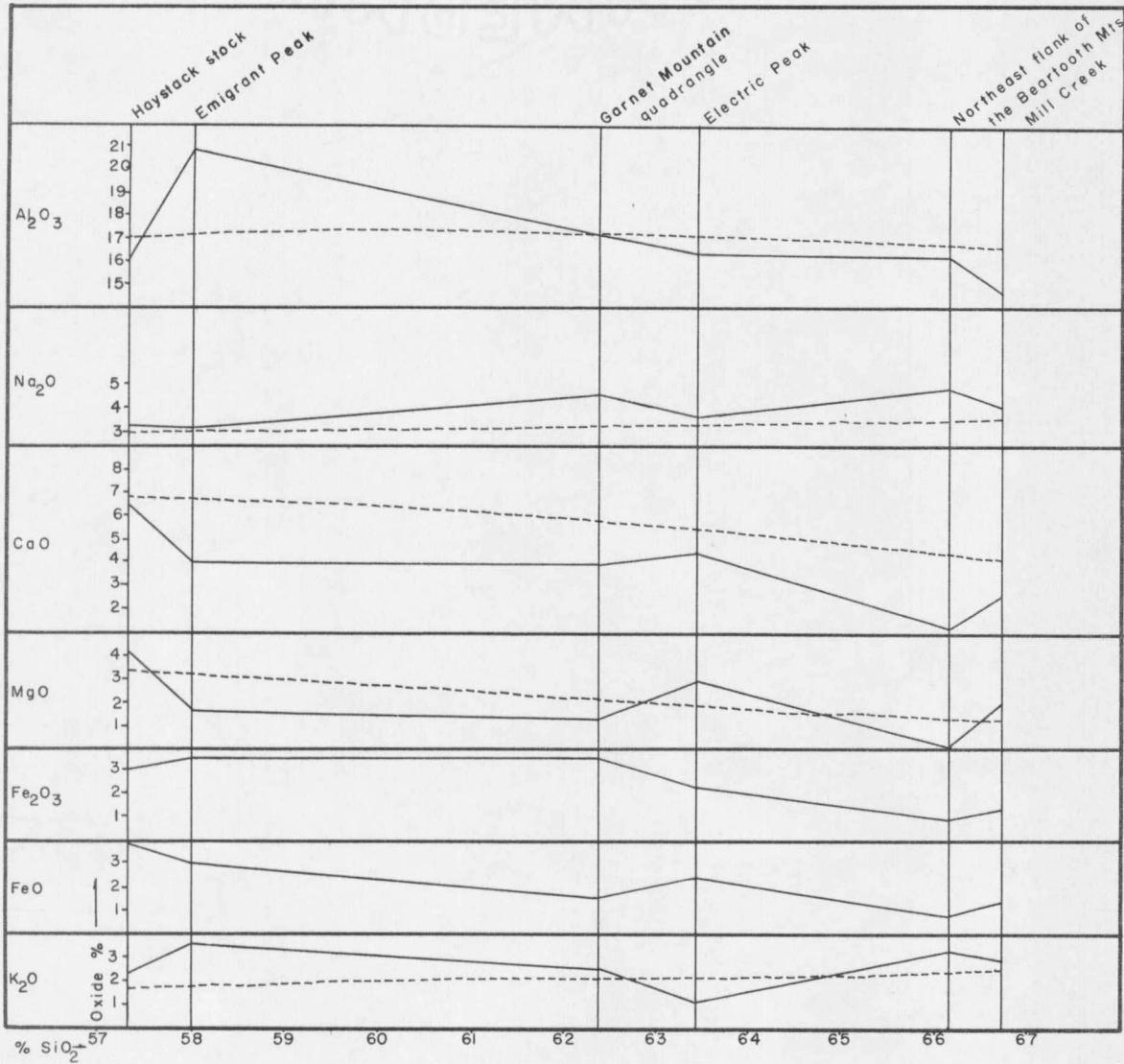
#### Regional Relationships of Chemical Composition

Table 2 lists chemical analyses available for the intrusive centers described. Those for the northeast side of the Beartooth Mountains, Electric Peak, Haystack Stock, and the Garnet Mountain quadrangle are averages of several samples. The writer believes that, for regional comparison, averages of several samples from each of the various areas are more significant because they help avoid misinterpretations due to minor variations in composition between the various rock types. The number of samples from each area is given in the last row of the table.

A variation diagram (Figure 3) has been constructed to show the relationships of the oxide percentages of the rock

	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	FeO	CaO	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	?
Northeast side of the Bear-tooth Mountains	66.18	16.27	0.98	0.71	2.38	0.59	3.37	4.86	5
Mill Creek	66.79	14.77	1.50	2.49	2.74	2.23	2.98	4.12	1
Electric Peak	63.45	16.44	2.50	2.67	4.64	2.99	1.08	3.94	12
Haystack stock	57.32	16.11	3.15	4.05	6.61	4.16	2.40	3.46	6
Garnet Mountain quadrangle	62.42	17.18	3.54	1.66	4.15	1.47	2.68	4.87	6
Emigrant Peak	58.00	20.92	3.62	3.19	4.20	1.67	3.65	3.29	1

Table 2. Average chemical analyses of the intrusive centers in the Beartooth and Gallatin Ranges, Montana.



**Figure 3. Diagram showing the relationships of the oxide percentages given in table 2 to Daly's average basalt-andesite-dacite-rhyolite series.**

--- Daly's average. Compiled from Iddings, 1899, Emmons, 1908, Wilson, 1936, Rouse et al, 1937, and McMannis and Chadwick, 1964.

types of the various areas. The  $\text{SiO}_2$  percent increases along the abscissa. The other oxides are separated to avoid confusion and their percent is given along the ordinate. The average chemical composition of the various areas are plotted along the labeled vertical lines corresponding to the appropriate  $\text{SiO}_2$  percent. The percent of each oxide is connected by an unbroken line for the sake of continuity. The dashed curves represent the chemical variation of Daly's basalt-andesite-dacite-rhyolite series (Barth, 1942) which are given for comparison.

Of special interest is the comparison of the Mill Creek and adjacent Emigrant Peak areas. The  $\text{Al}_2\text{O}_3$  content is somewhat lower in Mill Creek and much higher in the sample from Emigrant Peak compared to what would be expected on the basis of silica content. In both samples the  $\text{K}_2\text{O}$  is higher and the  $\text{CaO}$  is lower than normal. The  $\text{MgO}$  percentage for Emigrant Peak is lower than normal and that of Mill Creek is higher than normal. These relationships suggest that the Mill Creek intrusives and those of the Emigrant Peak area possibly were not differentiated from the same magma and may have been separated in time. However, since only one sample was analyzed from each of these areas the above comparisons must be considered with some caution.

## SUMMARY

Intrusive activity in the Beartooth and Gallatin Ranges can be divided into two major episodes. The first episode was the intrusive activity along the northeast side of the Beartooth block which took place in Late Cretaceous time (Rouse, et al, 1937). The second episode includes the intrusives along the Cooke City zone of the Beartooth Range, and those of the Gallatin Range. The intrusives along the Cooke City zone seem to be controlled by faulting and probably took place during or after the major uplift of the Beartooth Range.

One of the Mill Creek intrusives has been dated as Eocene, 49 million years, by the K-A method (McMannis and Chadwick, 1964).

The Cooke City zone may extend further than is shown in Figure 2. To the southeast, in Wyoming, the dissected volcano at Hurricane Mesa and the Sunlight-Windy intrusive center line up with the Cooke City zone. To the northwest the intrusives at Point of Rocks and those of the Garnet Mountain quadrangle, which are also controlled by faulting, may be a continuation of the Cooke City trend.

PETROGRAPHY AND FIELD RELATIONS  
OF THE ROCK TYPES

Precambrian Metamorphic Rocks

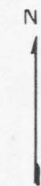
Rocks of Precambrian age are exposed on the western side of the area along both sides of Gold Prize Creek, and on the northern border of the area along Emigrant Gulch and on the ridge between Balm of Gilead and Fridley Creeks (Plate 1). The rocks are predominantly dark greenish-gray schist with layers of white to grey quartzite intercalated parallel to the foliation. The quartzite layers are generally thin ranging from fractions of inches to several inches in thickness. On the ridge south of Gold Prize Creek, in Sec. 4, T. 6 S., R. 8 E., an exceptional quartzite layer attains a thickness of seven to ten feet. Light colored, yellow to tan, phyllitic schist crops out principally in two localities: near the contact of the Precambrian rocks and the dacite porphyry on the north side of Gold Prize Creek, Sec. 33, T. 6 S., R. 8 E., and south of the Art Conlin Ranch, Sec. 22, T. 6 S., R. 8 E. Amphibolite, containing large porphyroblasts of plagioclase, crops out on the ridge between Balm of Gilead and Fridley Creeks, Sec. 19, 20, 29, T. 6 S., R. 9 E. On the foliation planes it bears a striking resemblance to andesite

# GEOLOGIC MAP OF THE EMIGRANT PEAK INTRUSIVE COMPLEX, PARK COUNTY, MONTANA

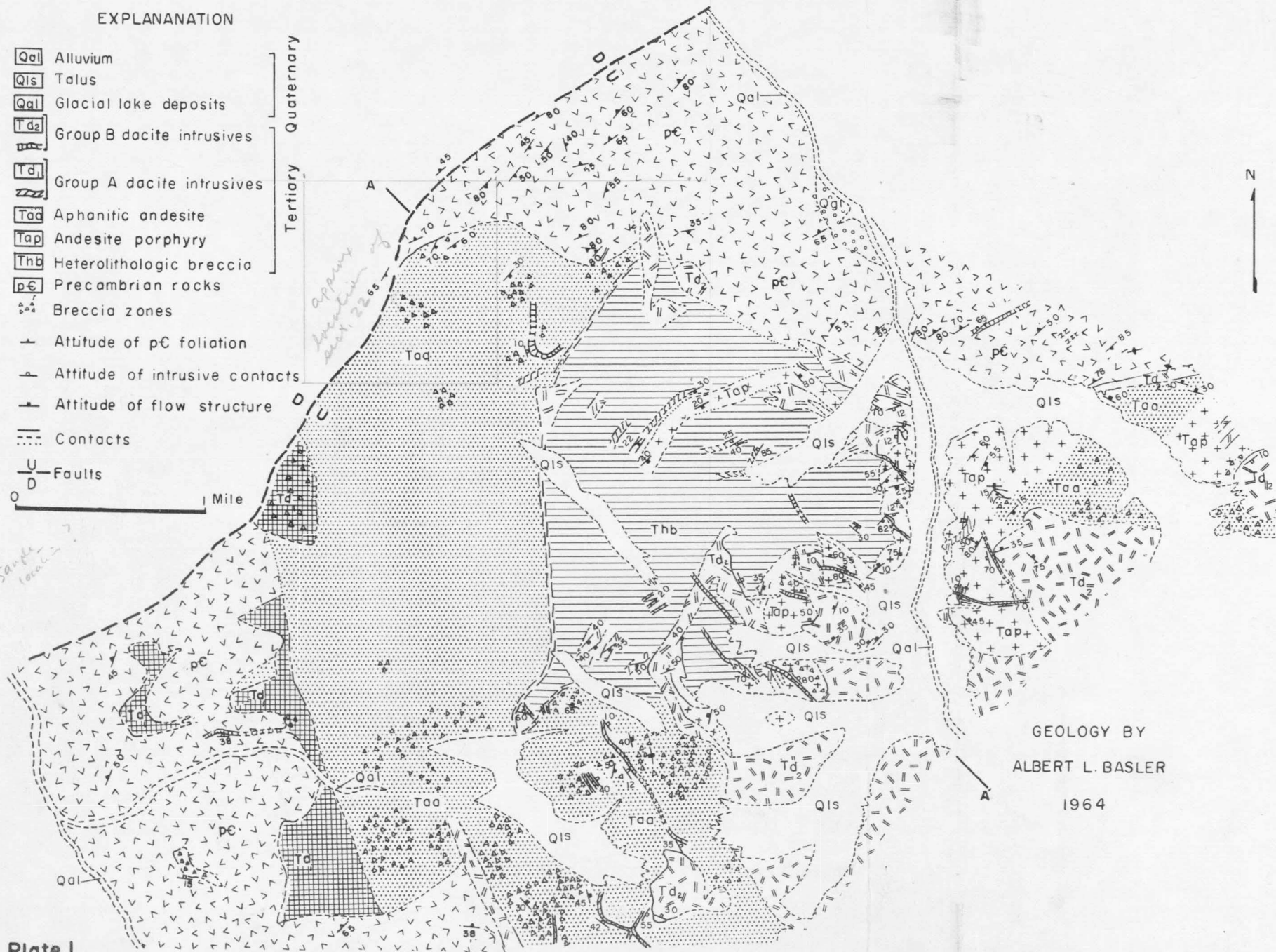
EXPLANANATION

- |  |                                |            |
|--|--------------------------------|------------|
|  | Alluvium                       | Quaternary |
|  | Talus                          |            |
|  | Glacial lake deposits          |            |
|  | Group B dacite intrusives      | Tertiary   |
|  | Group A dacite intrusives      |            |
|  | Aphanitic andesite             |            |
|  | Andesite porphyry              |            |
|  | Heterolithic breccia           |            |
|  | Precambrian rocks              |            |
|  | Breccia zones                  |            |
|  | Attitude of pC foliation       |            |
|  | Attitude of intrusive contacts |            |
|  | Attitude of flow structure     |            |
|  | Contacts                       |            |
|  | Faults                         |            |

0 1 Mile



GEOLOGY BY  
ALBERT L. BASLER  
1964



# CROSS SECTION

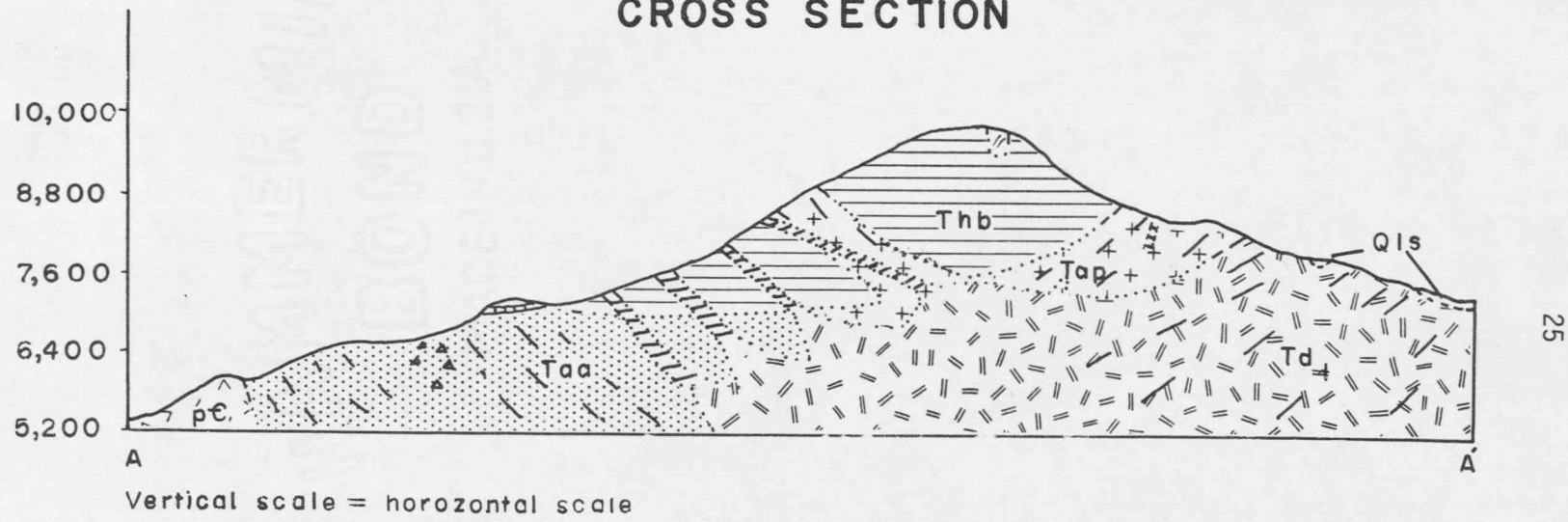


Plate I.

porphyry and may be a metamorphosed basic intrusion. Below the amphibolite unit, in the Fridley Creek drainage, Sec. 30, T. 6 S., R. 9 E., a quartzite pebble breccia occurs in the float and probably crops out directly below the amphibolite.

The foliation of the Precambrian rocks generally strikes N50-60 E and dips 45- 90° either NW or SE.

No microscopic work has been done on the Precambrian rocks, but the rock types suggest that they are a metamorphosed series of argillaceous rocks with minor amounts of silty or sandy rocks and sedimentary breccia. The interlayering of quartzite and schist suggests an original sandstone-argillaceous sequence. The quartzite pebble breccia is also of sedimentary origin. The amphibolite is probably a metamorphosed basic intrusion which has retained its original porphyritic texture.

#### Heterolithologic Volcanic Breccia

Volcanic breccia composed of angular fragments of varying rock types is extensively exposed in Sec. 23, 25, 26, and 35, T. 6 S., R. 8 E. The fragments are small, averaging an inch or less in diameter, and few exceed 18 inches. The fragments are predominantly aphanitic volcanic types but some are porphyritic and a few are pure epidote. The volcanic types are predominantly andesite. The color is dark greenish to bluish

grey. Vesicles are sparse and ash layers and bedding are absent. Locally, as in parts of Sec. 25, T. 6 S., R. 8 E., the breccia contains fragments of andesite porphyry which have very irregular shapes. The fragments have long slender projections, and the phenocrysts in these fragments are aligned parallel to the borders of the fragments (Plate 2, Figure 2). Xenoliths of breccia enclosed within the fragments also attest to the fact that the fragments were plastic at the time they were incorporated into the breccia. Greenish alteration rims are common, and specularite forms coatings in fractures. The breccias are very hard and fracture evenly across fragments and matrix alike. They generally form blocky vertical cliffs (Plate 3, Figure 1).

The matrix of the breccias is predominantly fragmental. Commonly it has a granular appearance much like the groundmass of some crystalline rocks. The granular texture may be due to silicification which is very common in the area, or to recrystallization due to baking. The matrix shows no flow structure. Plagioclase, An<sub>54-60</sub>, is the predominant phenocryst in the fragments and matrix. It may be zoned or unzoned and is extensively altered in places to a mixture of calcite, chlorite and epidote. Augite and hypersthene are abundant in one sample from Sec. 35, T. 6 S., R. 8 E., (Plate 3, Figure 2)

but are altogether lacking elsewhere. The augite grains are subhedral to anhedral, twinned, and slightly to strongly zoned. They are pale green and not pleochroic. Hypersthene is less abundant than augite and is pleochroic from pale green to tan. It is generally untwinned. Secondary quartz, sericite, calcite, chlorite, and epidote are common alteration products of the breccia. Many fragments contain very large amounts of fine grained primary magnetite, and secondary magnetite forms reaction rims around others. Epidote fragments contain small amounts of fine grained quartz among the epidote grains. The epidote grains are elongate and are locally arranged in a crude radial pattern (Plate 4, Figure 1).

#### Intrusive Andesite and Monolithologic Andesitic Breccia

Massive crystalline andesite, which locally grades into autobreccia, is the predominant rock type in the area. The crystalline andesites can be divided into two more or less distinct types: (1) andesite porphyry characterized by a uniform dark grey groundmass and large phenocrysts of plagioclase and (2) aphanitic andesite which locally contains very small phenocrysts. Both types contain local zones of autobreccia and grade into one another.

### Andesite Porphyry:

Excellent exposures of andesite porphyry occur along both sides of Emigrant Gulch in Sec. 25, 30, 31, and 36, T. 6 S., R. 8 and 9 E. Phenocrysts of plagioclase, An 45-60, attain 1/2 inch in length. Both progressive and oscillatory zoning are common and some are unzoned. Phenocrysts of mafic minerals are exceedingly rare (Plate 4, Figure 2). Hornblende phenocrysts rarely exceed 1-2 percent. They are pleochroic from blue green to light yellowish green. (100) twins are common, often manifest as twin seams. Magnetite is the most common accessory mineral comprising from 1-3 percent, as fine cubic grains in the groundmass. Calcite and chlorite are the most common alteration products, attaining 8 percent each locally. Flaky to radiating feathery aggregates of chlorite, intimately associated in many places, with magnetite, replacing mineral grains, permeating the groundmass and filling small cavities. Granular aggregates of epidote and quartz are subordinate to calcite and chlorite. The matrix varies from granular to microlitic and may contain some primary quartz.

Andesite porphyry crops out in massive blocky exposures similar to exposures of heterolithologic breccia, and the two cannot be distinguished at a distance. Phenocryst alignment

generally forms a swirly pattern but where it is consistently parallel it dips steeply, generally about  $50^{\circ}$  or more. Gradations between massive crystalline andesite porphyry and auto-breccia are well displayed in Sec. 25, T. 6 S., R. 8 E. The matrix is fragmental, containing much ground up plagioclase. The andesite porphyry intrudes the heterolithic breccia in places, but generally the two are intergradational showing that the andesite is contemporaneous with the breccia to somewhat younger than the breccia.

#### Aphanitic Andesite:

Aphanitic andesite is more abundant than andesite porphyry and crops out most extensively in Sec. 2, 3, 22, 27, and 34, T. 6 S., R. 8 E. It is dark grey to brown and contains a few small phenocrysts of plagioclase, hornblende, and augite. The plagioclase ranges from An 39-55 and generally shows progressive or oscillatory zoning. Phenocrysts of augite are common (Plate 5, Figure 1) but rarely exceed 2-3 percent of the rock. The augite is pale blue green, non-pleochroic, and exhibits (100) twins often as twin seams. The grains are somewhat more elongate than normal for augite. Some of them are altered to a fibrous, pleochroic mineral (Plate 5, Figure 1), possibly a type of amphibole. Green hornblende is common and is locally

rimmed by or completely replaced by magnetite. This rimming is especially well developed in rocks from Sec. 34, T. 6 S., R. 8 E., where the ferromagnesian minerals are completely replaced by magnetite (Plate 5, Figure 2). Calcite, chlorite, and to a lesser extent epidote are common alteration products especially in the autobreccia zones. Calcitization is so extreme on the northwest ridge of the main peak (Sec. 35, T. 6 S., R. 8 E.) that calcite comprises as much as 40 percent of the andesite. The calcite is probably derived from the alteration of plagioclase and from hydrothermal solutions.

Flow structure in the aphanitic andesite is less well developed than in the andesite porphyry. Where present it dips between 30 and 90 degrees. The aphanitic andesite is gradational with the andesite porphyry and also with the heterolithologic breccia. Near the top of Emigrant Peak, in the southern half of Sec. 35, T. 6 S., R. 8 E., gradations between andesite and autobreccia are well exposed. Some vertically dipping, markedly flow banded aphanitic andesite is similar to some of the fragments in the heterolithologic breccia. The writer believes that the material for the heterolithologic breccia is locally derived because of the similarity of the fragments in it to the intrusive andesites.

Dacite Porphyry:

The Emigrant stock with associated dikes and other irregular dacitic bodies intrudes the andesitic rocks. The dacitic rocks are divided into two types: (1) group A; plagioclase-orthoclase-quartz dacite porphyry which comprises the stock and associated dikes and (2) group B; plagioclase-biotite-quartz dacite porphyry dikes and associated irregular intrusives which cut group A. Only a small portion of the Emigrant stock is included in the study area so the following petrographic descriptions are not representative of the whole stock.

Group A; <sup>ard</sup> Plagioclase-orthoclase-quartz dacite porphyry:

The rocks of group A consist of phenocrysts of plagioclase, orthoclase, and quartz in a glassy to microcrystalline groundmass. Plagioclase occurs as single grains and interlocking rosette-like aggregates. It is slightly zoned and ranges from An 32 - 40. Sericitization and calcitization generally obscure the optical properties. Orthoclase phenocrysts are much less altered than plagioclase. They are euhedral to subhedral, generally showing Carlsbad twinning. Some crystals appear zoned (Plate 6, Figure 1) but there is no detectable difference in the refractive indices from the inside of the grain to the

border. The apparent zoning may be due to irregular crystallization. Rounded, resorbed phenocrysts of quartz comprise less than 4 - 5 percent of the rock. Pyrite and magnetite are accessory minerals. Silicification is common, locally permeating the matrix and filling fractures. On the northwest ridge of the main peak, in a zone of intense calcitization of the andesites, several dacitic dikes have been completely silicified. They are apple green and exhibit extreme flow banding. The flow banding consists of layers of varying sizes of microcrystalline quartz (Plate 6, Figure 2). Only vague remnants of the feldspar phenocrysts remain. The dikes grade laterally into relatively little altered dacite which does not show the extreme flow banding. The dike rocks were probably mobilized by silica-rich hydrothermal solutions derived from the stock. Calcite and chlorite are common in all the rocks, locally forming large aggregates. The large dike near the northern boundary of Sec. 25, T. 6 S., R. 8 E., contains irregular, dark green aggregates of calcite and chlorite up to 2 inches in length (Plate 7, Figure 1). The groundmass of the group A dacites varies from glassy to microcrystalline. <sup>(microcryptocrystalline?)</sup> The dacites in Sec. 36, T. 6 S., R. 8 E., are the best examples of the glassy variety. The glass is dark brown

and exhibits very distinct flow banding (Plate 7, Figure 2) which strikes generally N. 45 E. and dips 30° to 40° N.W. The microcrystalline groundmass is granular and appears very siliceous.

The dikes of group A are arranged primarily in a crude, discontinuous cone sheet pattern dipping from 10 to 60 degrees toward the stock (Plates 1 and 1'). A few dikes and irregular fingers are arranged radially (Plate 1).

Group B; Plagioclase-biotite-quartz dacite porphyry:

The rocks of group B contain little or no orthoclase and consist essentially of plagioclase, quartz, and biotite phenocrysts in a microcrystalline, granular groundmass (Plate 8, Figure 1). Both zoned and unzoned plagioclase phenocrysts, An 38-40, predominate over biotite and quartz. Quartz averages 5-6 percent but attains 10 percent locally. It is clear and remarkably unstrained. The quartz grains are usually resorbed, but straight-sided crystals may be present. Brown, pleochroic biotite is the most abundant ferromagnesian mineral, comprising up to 6 percent of some samples. It locally has iron staining around the grain borders. <sup>Add</sup> Green hornblende occurs sparingly. Maxwell!

The groundmass is generally granular but locally has a very

patchy, diffuse texture (Plate 8, Figure 2). Calcite, sericite, hematite, and chlorite are common although alteration is not as extensive as it is in the group A rocks.

The white, biotite-rich fresh-appearing group B dikes in Sec. 25, 31, and 36, T. 6 S., R. 8 and 9 E., cut group A dikes. The irregular group B intrusives along the west side of the area are intruded along the Precambrian-andesite contact. They are more weathered than the dikes and locally contain zones of autobreccia.

The Precambrian-andesite contact along the northern boundary is intruded by a dike of group A. This contact is nearly vertical throughout the area (Plate 1).

#### Chemical Composition of the Rock Types:

One complete chemical analysis of a sample of andesite porphyry from Sec. 25, T. 6 S., R. 8 E., is listed in Table 2. Five  $\text{SiO}_2$  analyses have been made on the following samples: (1) group B dacite (Sec. 36, T. 6 S., R. 8 E.) - 69.00 percent  $\text{SiO}_2$ , (2) group A dacite (Sec. 25, T. 6 S., R. 8 E.) - 70.32 percent  $\text{SiO}_2$ , (3) group A dacite (Sec. 30, T. 6 S., R. 9 E.) - 68.50 percent  $\text{SiO}_2$ , (4) aphanitic andesite (Sec. 29, T. 6 S., R. 9 E.) - 57.82 percent  $\text{SiO}_2$ , and (5) aphanitic andesite (Sec. 35, T. 6 S., R. 8 E.) - 62.30 percent  $\text{SiO}_2$ . There is

very little variation of  $\text{SiO}_2$  between the three samples of dacite. The greater amount of mafic minerals in the group B dacite is probably due to variation in water content. The mafic minerals in the group B dacites are all hydrous and a higher water content would favor their formation. The andesite porphyry, Sec. 25, T. 6 S., R. 8 E., Table 2, and the aphanitic andesite, sample 4, above, also have very similar  $\text{SiO}_2$  content. Sample 5 is very altered. It is in the same area as the completely silicified dacite dikes and may have an anomalously high  $\text{SiO}_2$  content.



Figure 1. Emigrant Peak, shows prominent break in slope and scarps due to faulting.

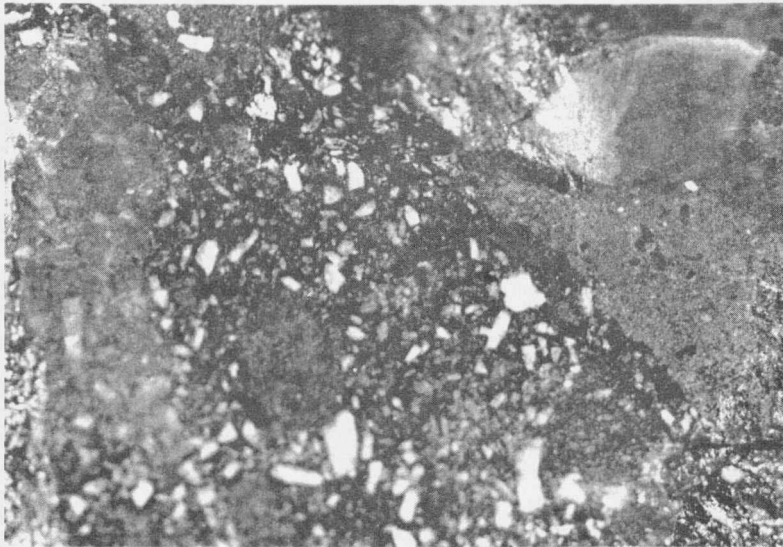


Figure 2. Irregular fragment in the heterolithologic breccia, note the slender projection.



Figure 1. Blocky outcrop of volcanic breccia and andesite porphyry.



Figure 2. Heterolithic volcanic breccia. A-hypersthene. Note the hourglass shape of the fragment near the center. Plain light.

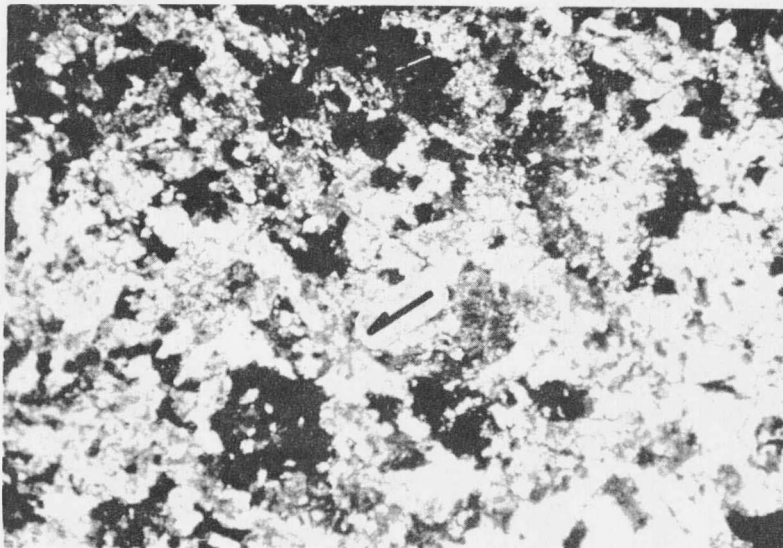


Figure 1. Epidote fragment from the heterolithologic breccia. Note the crude radiating grain pattern. Polarized light.



Figure 2. Andesite porphyry showing flow structure and lack of mafic minerals. Polarized light.



Figure 1. Aphanitic andesite. A-augite, B-fibrous amphibole. Polarized light.

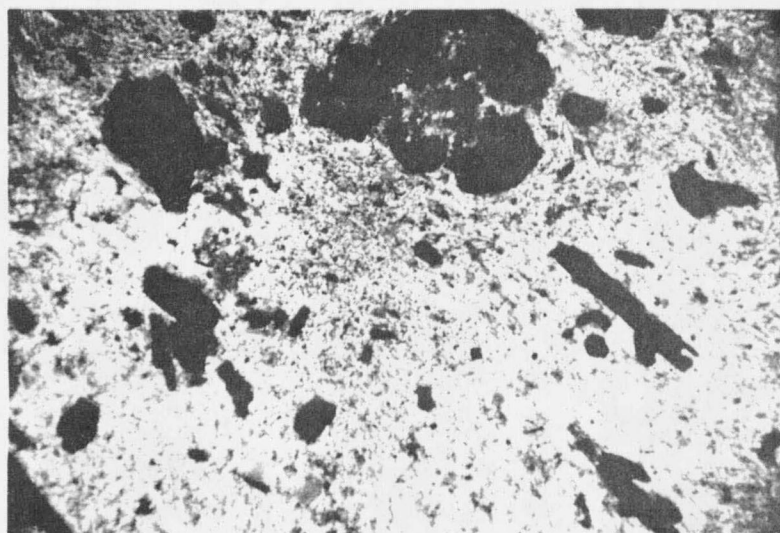


Figure 2. Aphanitic andesite. All mafic minerals are replaced by magnetite. Plain light.

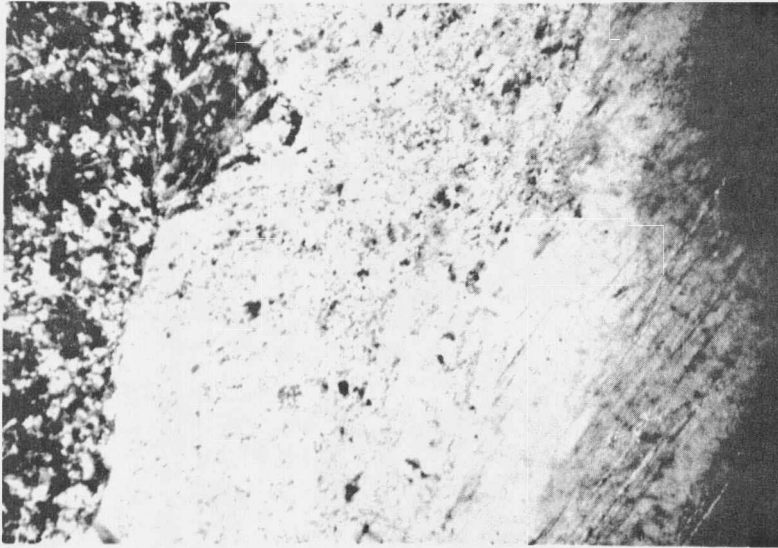


Figure 1. Group A dacite. Note apparent zoning in the large orthoclase grain and the granular matrix. Polarized light.

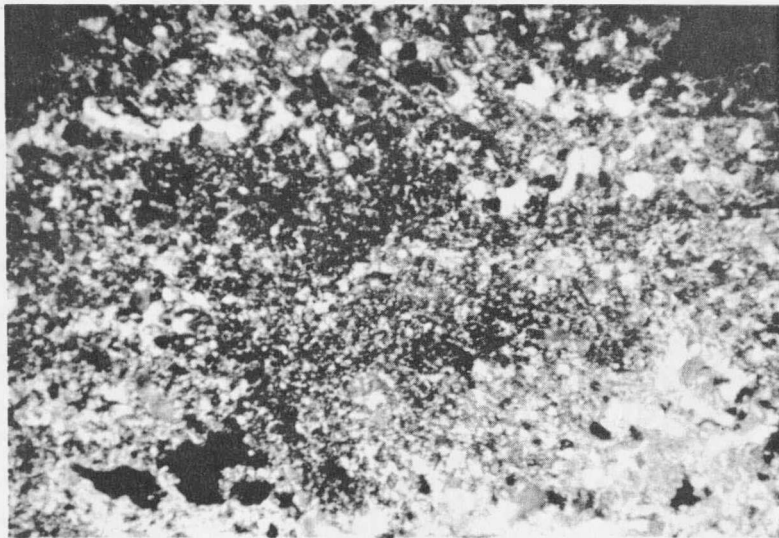


Figure 2. Silicified group A dacite showing layers of different sized quartz grains. Polarized light.

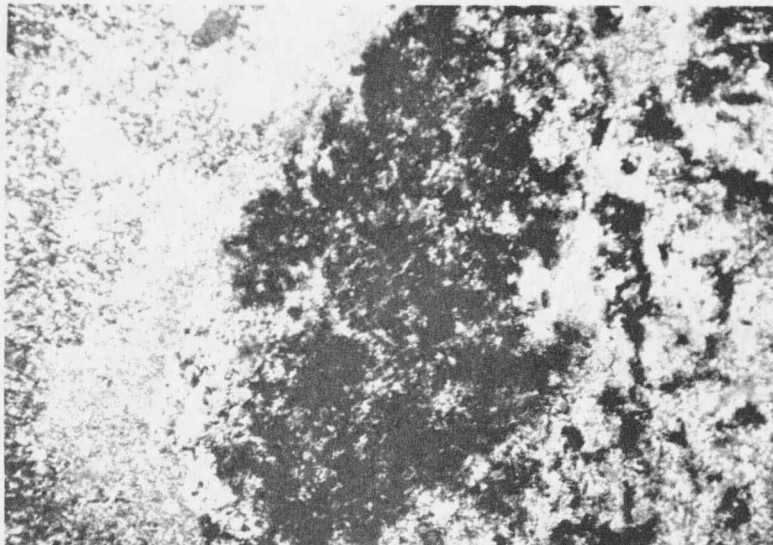


Figure 1. Group A dacite which is extremely calcitized and chloritized. The dark patch in the center is a pod of chlorite and calcite.

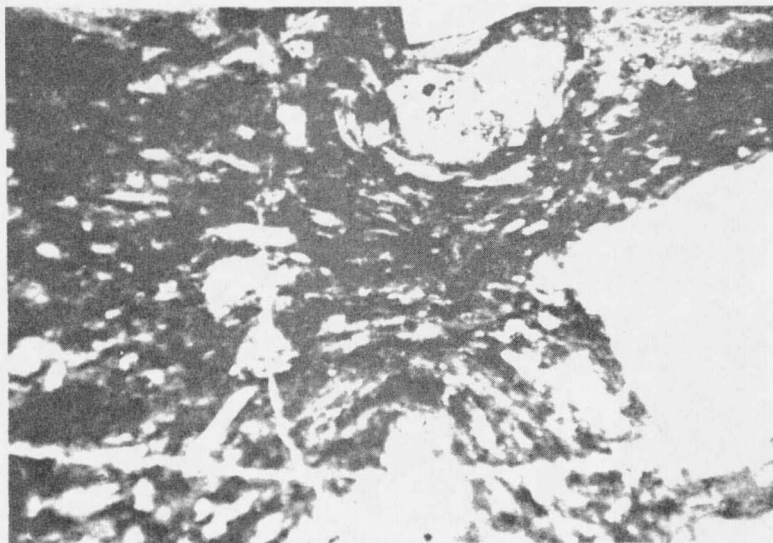


Figure 2. Group A dacite with a glassy matrix. Note flow structure.

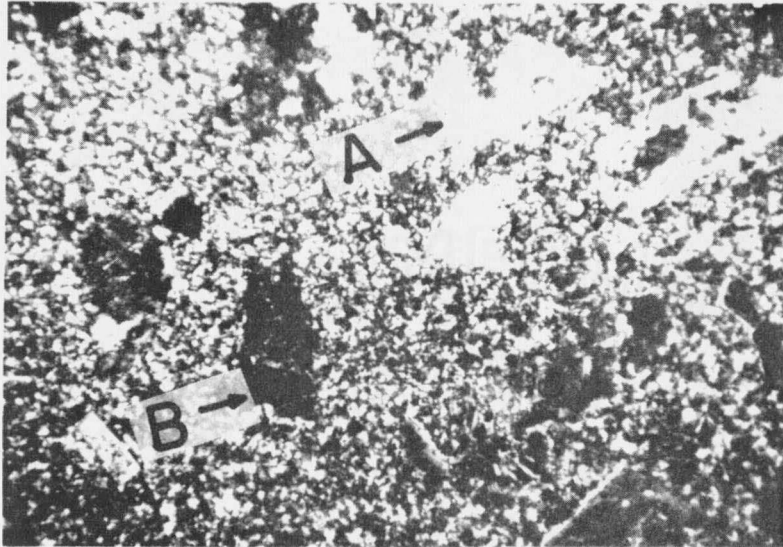


Figure 1. Group B dacite -- A-quartz, B-biotite.

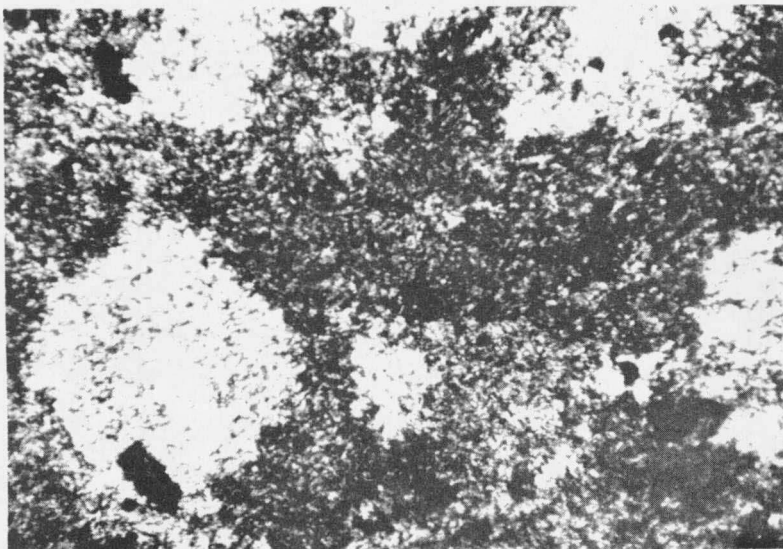


Figure 2. Group B dacite showing a patchy matrix.

## PETROGENESIS OF THE ROCK TYPES

The andesitic intrusive rocks and breccias apparently represent a portion of a deeply eroded volcanic vent. The dacitic rocks probably are fracture fillings and larger masses crystallized in the vent during the last, more acidic phases of volcanism.

The main problem in the area is the origin of the heterolithologic breccia. The lack of bedding and ash layers rules out mudflows or water-laid deposits, and the lack of vesicularity argues against near-surface phenomena, although it is conceivable that some ejecta could be nonvesicular.

The following hypotheses are postulated to explain the origin of the heterolithologic breccia; (1) formation by mixing of various types of andesite in a volcanic conduit and (2) formation on the slopes of a vent from talus debris and molten pyroclastic fragments.

In the first hypothesis the breccia is assumed to have formed by mixing various types of andesite in a conduit, possibly by the inward collapse of the vent walls. Collapse could be initiated by cauldron subsidence following rapid withdrawal of magma. Mixing of the various types of fragmental debris and magma could produce a heterolithologic breccia

containing fragments with slender projections. Attrition in the vent could easily produce the fragmental matrix, but this process would destroy the slender projections observed on many of the fragments.

In the second hypothesis the breccia is assumed to have originated from a talus pile on the flanks of a pre-existing volcano. Renewed activity deposited ash and molten ejecta which was mixed with the older debris, possibly by repeated small scale sliding due to oversteepening of the slope. A large volcanic sequence was built by up continuous activity and intruded by andesite magma. The breccias were hardened and altered by prolonged, intense heat and the action of volcanic gases and solutions which recrystallized the ash and altered it beyond recognition. The last phase of volcanism was the filling of the vent and fractures by dacitic magma and deposition of sulfides locally. The group B dacite intrusives are somewhat younger than the Emigrant stock and may be related to the Mill Creek intrusives which they closely resemble.

The second hypothesis explains the varied nature of the fragments, the formation of the irregular fragments, which were plastic when incorporated in the breccia, the unstratified nature of the breccia, and the fragmental matrix. The

lack of large ash zones could be explained if the magma were not as gas rich as usual and did not produce the tremendous quantities of ash often associated with volcanism. If most of the fragments were formed from talus fragments which had spalled off from massive intrusive rocks or autobreccia of varying types they would probably not be very vesicular. The area from which the fragments were derived was probably an intrusive complex of varying types of andesite similar to the rocks presently exposed. The epidote fragments were derived from previously altered rocks and were not altered in place. The strongest argument in favor of the talus origin for the breccia is the presence of the fragments with slender projections. They were squeezed into openings in the breccia and have not suffered much attrition since they were incorporated into the breccia. It is difficult to see how this texture could have been preserved in a vent during the attrition process necessary to produce the fragmental matrix.

The andesitic rocks intrude the breccia and apparently grade into it. Thus they are penecontemporaneous with to slightly younger than the heterolithologic breccias. The steeply dipping flow structure (Plate 1) and lack of vesicularity suggests that the magma crystallized relatively deep

within the vent. The zones of monolithologic breccia within the massive andesites were probably formed by autobrecciation. The magma may have been almost completely crystallized and gas pressure from below forced it upward causing zones of intimate fracturing and the formation of zones of monolithologic breccia. The matrix is fragmental indicating that there was no engulfment by the liquid portion of the intrusive.

The dacitic rocks probably represent the last phases of volcanism. The crude cone sheet pattern of the group A dikes dips irregularly toward the stock and does not show a progressive change in dip with altitude. In addition to the dikes shown on the map (Plate 1) there are innumerable small irregular pods and veinlets of dacite. The cone sheet pattern and the intimate injection of the andesitic rocks by the dacitic rocks suggests that the dacites were emplaced very forcefully, perhaps explosively. Later hydrothermal alteration produced the mineral deposits and altered the andesitic and dacitic rocks. The fact that the group B intrusives show very little effect of hydrothermal alteration supports the hypothesis that they were emplaced after the crystallization of the stock.

## ECONOMIC GEOLOGY

The first mining in the Emigrant Gulch district began in 1863 and was primarily for placer gold in the stream gravels. Placer gold was also taken with a dredge operating for a short time after 1945 in the thick gravel deposits at the mouth of Emigrant Gulch near Chico. Several attempts have been made to mine bedrock deposits but there are no producing mines in the area today. American Metal Climax conducted a drilling campaign in the area (Sec. 1, T. 6 S., R. 8 E.) in 1963 but more than 2000 feet of core apparently did not show enough ore for profitable mining.

Most of the bedrock deposits are fracture fillings in the brecciated outer portions of the Emigrant Stock. The following description of the ore from the Great Eastern lead-silver mine and the Allison molybdenite mine are probably representative of the ore bodies in the vicinity.

The Great Eastern mine is located along the Emigrant Gulch trail in the SE $\frac{1}{4}$ , Sec. 36, T. 6 S., R. 8 E., (Plate 1). The country rock is silicified brecciated dacite. Mineralized veinlets are spaced fractions of an inch to several inches apart and rarely exceed an inch in width. The veinlets are vuggy and contain well formed crystals of quartz and a few

crystals of chalcopyrite. This texture indicates that cavity filling was the dominant process of ore deposition. Minerals comprising the vein matter are; galena, chalcopyrite, pyrite, siderite, calcite and quartz. The paragenetic sequence from older to younger is: (1) quartz (2) pyrite, (3) siderite, (4) chalcopyrite, (5) galena, (6) quartz (well developed crystals), and (7) calcite and siderite (including a colloform variety).

The Allison molybdenite mine is located about one mile southeast of the Great Eastern mine and although it is not in the map area a description of its ore is pertinent. The tunnel is about 600 feet long and is still open. The ore is similar to that of the Great Eastern mine except that the dacite country rocks are more intimately brecciated and the veinlets are not so vuggy. The vein minerals are molybdenite and pyrite. Some apatite occurs in fracture fillings with molybdenite in prospect pits slightly south of the tunnel. Other prospect pits about 1/4 mile north of the tunnel reveal a vuggy ore similar to that of the Great Eastern but not so extensively mineralized.

The source of the mineralizing solutions is probably the Emigrant stock. The solutions were driven off during the

crystallization of the core of the stock through the outer brecciated portions of the stock. Because of the dense nature of the surrounding rocks the solutions deposited the minerals in solution in the outer portions of the stock.

The molybdenite mine is situated nearer to the center of the stock than the lead-silver mine and it is possible that there may be a zonal arrangement of deposits. A more thorough study of the stock would be required to prove or disprove this hypothesis.

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