Dacites of the northern Gallatin and western Beartooth Ranges, Montana
by Kenneth Charles Shaver

A thesis submitted, to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Earth Science (Geology)
Montana State University

Abstract:
The dacitic rocks of the northern Gallatin and western Beartooth Ranges are shallow intrusives of early to middle Eocene age. They have intruded folded Paleozoic and Mesozoic sedimentary sequences and members of the Absaroka-Gallatin volcanics with which they are contemporary.

The locations of the bodies evidently have been governed primarily by two major northwest-striking fault trends which seem to continue through the entire length of the Absaroka-Gallatin volcanic province. Northeast-trending high angle faults which are postulated to lie on both sides of the Yellowstone Valley probably provided some control over the locations of the intrusives in these areas, but this control was secondary to that of the northwest zones. Although faulting evidently preceded igneous activity in most of the province, the block faulting which produced the Gallatin Horst in the southern Gallatin Range probably followed intrusion of dacitic rocks into the sedimentary sequences in that area.

Several episodes of intrusive activity have been recognized in the northern Gallatins and western Beartooths. During the first of two long magnetically normal periods which prevailed during deposition of the volcanics in this area, several intrusive bodies were emplaced. The oldest recognized intrusive cuts Golmeyer Creek volcanic rocks and is overlain by Hyalite Peak volcanics at upper Dry Creek.

The Point of Rocks and north and south Moose' Creek dacites were evidently emplaced during middle or late Hyalite Peak time. These were followed by the Big Creek, Cinnabar-Mol Heron, and Little Trail Creek bodies which intruded during the magnetically reversed interval at the upper Washburn-lower Sunlight group interface. Still later, the normally magnetized Tom Miner and Mill Creek rocks invaded lower Sunlight group volcanics. It is not known whether the normally magnetized Emigrant Peak dacites pre or post-date the reversed magnetic interval.

The Intrusives of the northern Gallatin and western Beartooth Ranges are petrologically very similar; most of the differences between them are textural differences which seem to reflect slightly different rates' of magma ascent rather than radically different initial source material. Comparison of observed compositional and textural features of these rocks with published experimental studies of crystallization trends in similar rocks suggests that these magmas originated in the lower crust or upper mantle.

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Signature Kenneth Charles Shaver

Date June 3, 1974

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by

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

of

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Earth Science (Geology)

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August, 1974

ACKNOWLEDGEMENTS

Dr. Robert Chadwick first introduced me to the volcanic and intrusive rocks of the northern Gallatin Range, and discussed various aspects of the problem during the course of the investigation. The National Park Service kindly granted permission to collect samples in Yellowstone National Park, and many private landowners allowed access to their lands. Michael Kaczmarek assisted with field work in the back country of the Park. Dr. Chadwick critically reviewed the manuscript. Montana State University provided funds which helped to defray field and laboratory expenses.

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ABSTRACT

The dacitic rocks of the northern Gallatin and western Beartooth Ranges are shallow intrusives of early to middle Eocene age. They have intruded folded Paleozoic and Mesozoic sedimentary sequences and members of the Absaroka-Gallatin volcanics with which they are contemporary.

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INTRODUCTION

The 150 mile long Absaroka-Gallatin volcanic province covers approximately 9,000 square miles between Bozeman, Montana and the Owl Creek Range in Wyoming. The province includes most of the Gallatin Range, the southwestern half of the Beartooth Uplift, the Absaroka Range, and the northern portions of the Washakie and Owl Creek Ranges (fig. 1). The main study areas cover approximately 150 square miles in the northern Gallatin and western Beartooth Ranges in the northeastern portion of the province.

Previous mapping largely by faculty members and students at Montana State University in portions of the study area north of Yellowstone National Park, and by the U.S. Geological Survey inside the Park have outlined numerous small intrusive igneous bodies which appear to be associated with the volcanics. Generally these rocks have received less attention than the extrusive rocks of the province. This investigation was designed to take a closer look at the intrusive bodies in the northwestern portion of the province in order to compare them petrogenetically. While some bodies in northern Yellowstone National Park were visited during the investigation, the major emphasis was directed towards the area north of the Park. This was

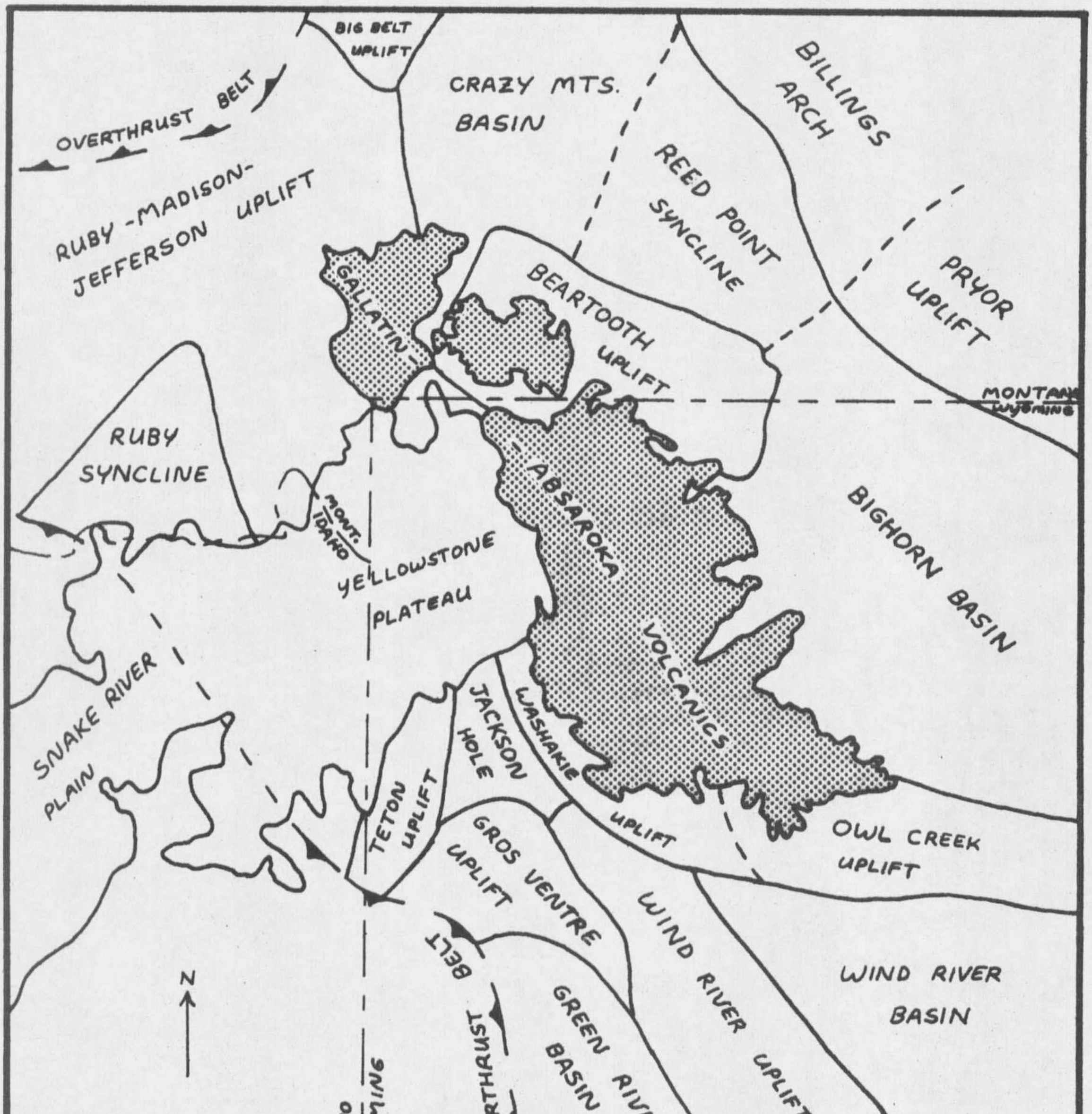


Figure 1. The Absaroka-Gallatin volcanic province and surrounding tectonic features. (after Grose, 1972; and A.A.P.G., 1944)

done because most bodies inside the Park boundaries have been previously described (Iddings, 1891; Hague and others, 1899; Witkind, 1969; and Ruppel, 1972). During the course of this investigation it was learned that L.L. Love (1972) recently made a similar study of three intrusives in the southern and north central portions of the province.

The present study was conducted during the 1973 field season and through the following academic year. The work involved observing the field characteristics of the bodies and sampling for subsequent petrographic and paleomagnetic work. It was hoped that new chemical analyses of the specimens could be obtained for this report, but numerous complications with the analytical proceedures has delayed those results.

Until fairly recently the Cenozoic volcanics of the Gallatin and western Beartooth Ranges had been the subject of very few geologic studies, and even now most of this area is not as well studied as much of the rest of the Absaroka-Gallatin volcanic province. Yellowstone National Park has been more thoroughly studied than the rest of the area as the result of work by Iddings (1891), Hague and others (1899), Brown (1961), the U.S.G.S. (1972), Ruppel (1972), Smedes and Prostka (1972), and L.L. Love (1972).

The general geology north of the Park was summarized by Iddings and Weed (1894). The Gardiner area was described in more detail by C.W. Wilson (1934) and by Fraser and others (1969), Emigrant Peak was studied by Basler (1965), J.T. Wilson (1936) mapped the Mill Creek area, and McMannis (unpublished preliminary data, 1969) mapped the Emigrant Quadrangle. Todd (1969, 1972) examined the southern part of Tom Miner Basin, Chadwick mapped the Fridley Peak Quadrangle (1969) and described the Point of Rocks vent complex (1965), and the Garnet Mountain Quadrangle was studied by McMannis and Chadwick (1964). The geomorphology of the area has been the subject of several investigations by faculty and students at Montana State University and by others including Horberg (1940).

GEOLOGIC SETTING

The volcanic field is characterized by Eocene calc-alkaline rocks which are the products of numerous eruptive centers that are apparently aligned along two subparallel belts (Chadwick, 1968, 1970). The volcanic rocks rest unconformably on Precambrian, Paleozoic, and Mesozoic rocks. The Precambrian rocks are highly deformed and evidently have been affected by three or possibly four major Precambrian orogenic events (McMannis and others, 1971). The Paleozoic and Mesozoic sediments unconformably overlie the Precambrian rocks, and evidently were not folded significantly until the Laramide orogeny. The Absaroka-Gallatin volcanics are only slightly tilted.

The rocks are mostly andesitic to dacitic in composition, but some belong to the absarokite-shoshonite-banakite series (Hague and others, 1899). Since the excellent early work of Hague and others (1899), the Absaroka volcanics have traditionally been divided, stratigraphically upward, as: early acid breccia, early basic breccia, early basalt flows, late acid breccia, late basic breccia, and late basalt flows. Until recent detailed work by many members of the U.S. Geological Survey, specific formation names were in use only in a few well-explored areas. However, Smedes and Prostka (1972) recently published the results of the new U.S.G.S. work in Yellowstone National Park, and it now seems desirable to replace the terminology of Hague and others with that of Smedes and Prostka (fig. 2). They have divided the Absaroka-Gallatin volcanics into three main groups: the Washburn, Sunlight, and Thoroughfare Creek groups. The Washburn group is early to middle Eocene in age and is found throughout the northern two thirds of the Gallatin Range and in the extreme western portion of the Beartooth Range. The Sunlight group is middle Eocene in age and occurs in the central portion of the province. The Thoroughfare Creek group has tentatively been assigned middle to late Eocene age; it covers the southern portion of the field (Plate I, and fig. 3,8 in Smedes and Prostka, 1972). These ages were assigned on the basis of both paleontologic and radiometric data from the extrusive rocks and eruptive centers; L.L. Love (1972, 1974) has obtained an early Oligocene radiometric date for the Washakie Needles intrusive in the southern portion of the province.

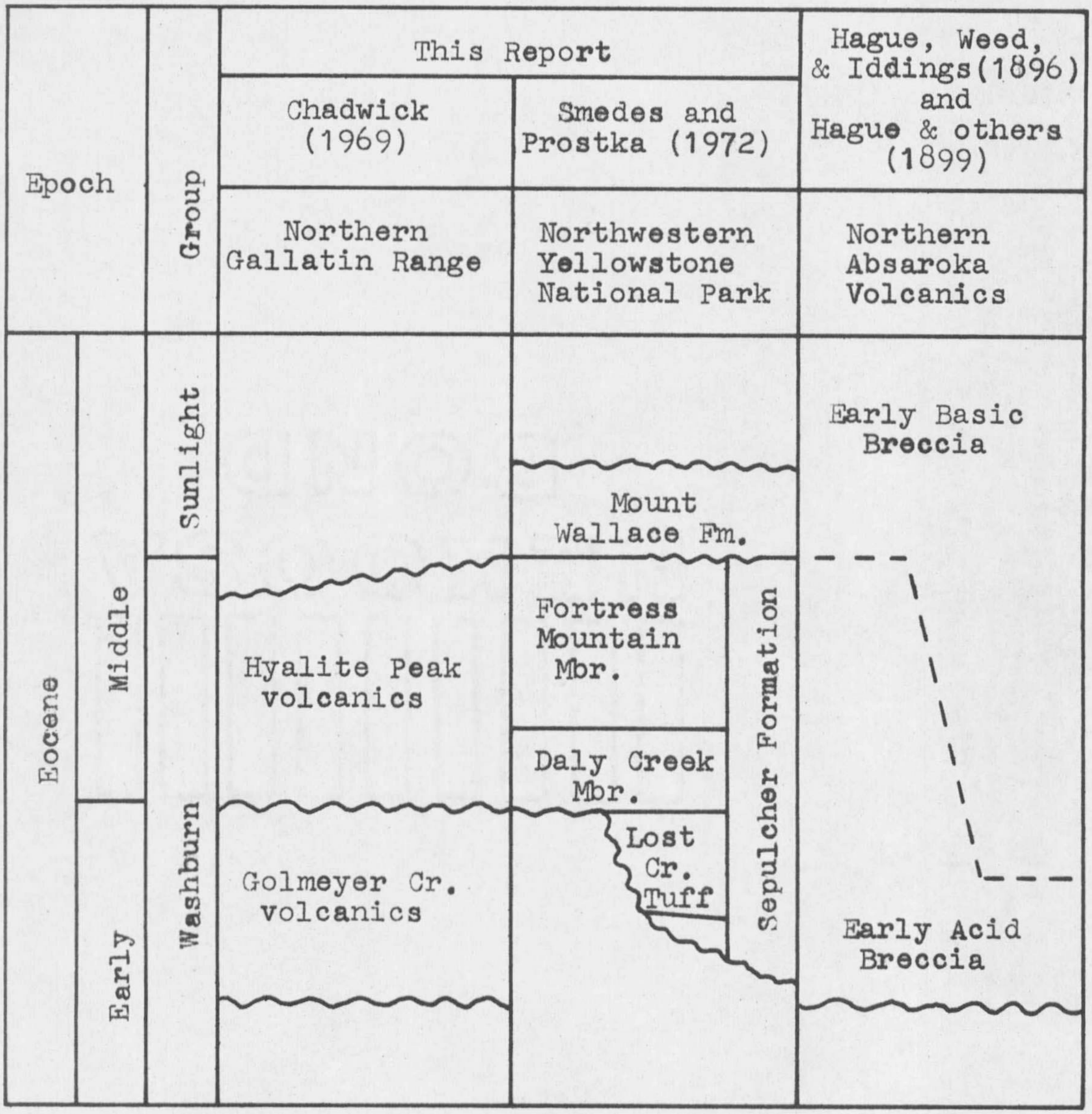


Figure 2. Stratigraphic relations and terminology in the Gallatin and western Beartooth Ranges. Vertical scale is not proportional to thickness or time. (after Smedes and Prostka, 1972)

CENOZOIC STRUCTURAL ELEMENTS

Most major Cenozoic structural elements in the area are faults which are oriented principally northwest, north-south, and northeast (Plate I). The northwest-trending faults include the Cherry Creek, Squaw Creek, Spanish Peaks, and Gardiner faults. The Cooke City lineament described by Foose and others (1961) also appears to be related to a northwest-trending fault. All of these appear to be high angle reverse or thrust faults with the northeastern sides as the upthrown blocks (McMannis and Chadwick, 1964; Hall, 1961; C.W. Wilson, 1934; Fraser and others, 1969; Foose and others, 1961). The major north-south faults (Plate I) are the Mol Heron, Reese Creek (or East Gallatin), and Mammoth faults (Ruppel, 1972). These are all normal faults; the Mol Heron and Reese Creek faults define the Gallatin Horst, and the Reese Creek and Mammoth faults bound the Sepulcher Graben. The northeast-trending Gallatin Range Front fault (McMannis and Chadwick, 1964) and the Deep Creek (Emigrant) fault (Horberg, 1940) are normal faults with the south-eastern sides upthrown. The northeast-trending Moose Creek fault is a steeply dipping thrust or reverse fault with the northwestern side upthrown (McMannis and Chadwick, 1964). In addition to these three major fault trends, the Mill

Creek fault (J.T. Wilson, 1936) at the northeastern edge of the study area strikes eastward. The Mill Creek fault plane dips steeply northward in some places and southward in other, but the northern side is always the upthrown side (J.T. Wilson, 1936). Most of the movement on all of these major faults seems to have been Laramide or slightly later.

The northwest-trending faults evidently moved first. Displacement along the Squaw Creek fault took place sometime between the late Cretaceous and the early Eocene (McMannis and Chadwick, 1964). Major movement on the Spanish Peaks fault is post late Cretaceous and may in part be as young as very early Eocene (McMannis and Chadwick, 1964). Hall (1961) estimated 10,000 feet of displacement along this fault, and McMannis and Chadwick (1964) think Hall's data may suggest as much as 13,500 feet of predominantly dip-slip movement. The Gardiner fault also shows at least 10,000 feet of throw, most of which probably happened after late Cretaceous and before early or middle Eocene time (Fraser and others, 1969).

Displacement is probably 2500 to 300 feet on the Mammoth fault and 4000 to 6000 feet on the Reese Creek and Mol Heron faults (Fraser and others, 1969; Ruppel, 1972). Fraser and others believe that most of the faulting took place before early Eocene time because only 250 to 500 feet of displacement can be measured in even the earliest volcanic rocks (early Eocene) near these faults. Fraser and others think that the earliest movement along these faults was post Cretaceous. Ruppel (1972) disagrees with this; he believes that most movement was post-Eocene because of seemingly significant displacement of the Eocene volcanics on either side of the Gallatin Horst. However, Fraser and others noted that part of the Gardiner fault evidently was reactivated during Quaternary time and produced displacements of up to a few hundred feet in the northwest. This happens to be the area in which the Gardiner fault is intersected by the Reese Creek and Mol Heron faults. Prior to initial activation of these faults, a gentle anticlinal fold evidently developed in the area of the present Gallatin Horst (Ruppel, 1972).

The Gallatin Range Front fault and the Deep Creek Fault (Plate I) may be related; they seem to outline a block in the northern Gallatin Range which has been tilted towards the southeast. The Gallatin Front fault offsets the Cherry Creek-Squaw Creek fault and then seems to die out to the southwest. The Deep Creek fault may similarly offset a possible connection between the Squaw Creek fault and the

Cooke City lineament and also a possible connection between the Spanish Peaks fault and the Gardiner fault. However, these offsets associated with the Deep Creek fault are somewhat conjectural because key areas are under thick accumulations of volcanic rocks or post-volcanic sediments. It is also possible that the Deep Creek fault dies out before it reaches the Spanish Peaks fault (Horberg, 1940; Foose and others, 1961; Todd, 1969). Displacement of Quaternary alluvium material indicates that the Deep Creek fault has been active recently, but this latest activity is not nearly enough to account for the total displacement which has been variously estimated at 8000 to 10,000 feet (Horberg, 1940) to as much as 18,000 to 20,000 feet (Bonini and others, 1972). Chadwick (1969) believes that at least some of the tilting of the northern Gallatin block was a result of movement along these two northeast-trending faults happened during Eocene (Washburn) time because lower volcanic flows and laharic units in the Fridley Peak Quadrangle dip approximately ten degrees towards the Yellowstone valley while the upper units are nearly horizontal. This seems to be in agreement with Foose and others (1961) who think that the major uplift of the Beartooth block took place during middle to late Fort Union

(Paleocene) time, with its culmination in the early Eocene. No direct evidence exists that another large scale northeast-trending fault is present on the west side of the Yellowstone Valley parallel to the Deep Creek fault, but the possibility probably should be considered. Gravity data (Bonini and others, 1972) seem to suggest that either a flexure or a fault lies under the volcanic rocks and post-volcanic sedimentary cover on the west side of the valley (fig. 3). After descending gradually southeastward over the gently dipping Gallatin block, the Bouguer gravity contours fall abruptly at the west side of the Yellowstone Valley until they reach a low point near the eastern side of the valley. Then they begin to climb steeply where the Beartooth block has been uplifted along the Deep Creek fault.

The Mill Creek fault, which strikes approximately east-west in this area, is not well-dated. Evidently it is mainly pre-volcanic, but it is difficult to date closely its first movement (J.T. Wilson, 1936). Wilson reported a minimum of 4000 feet of throw along this fault.

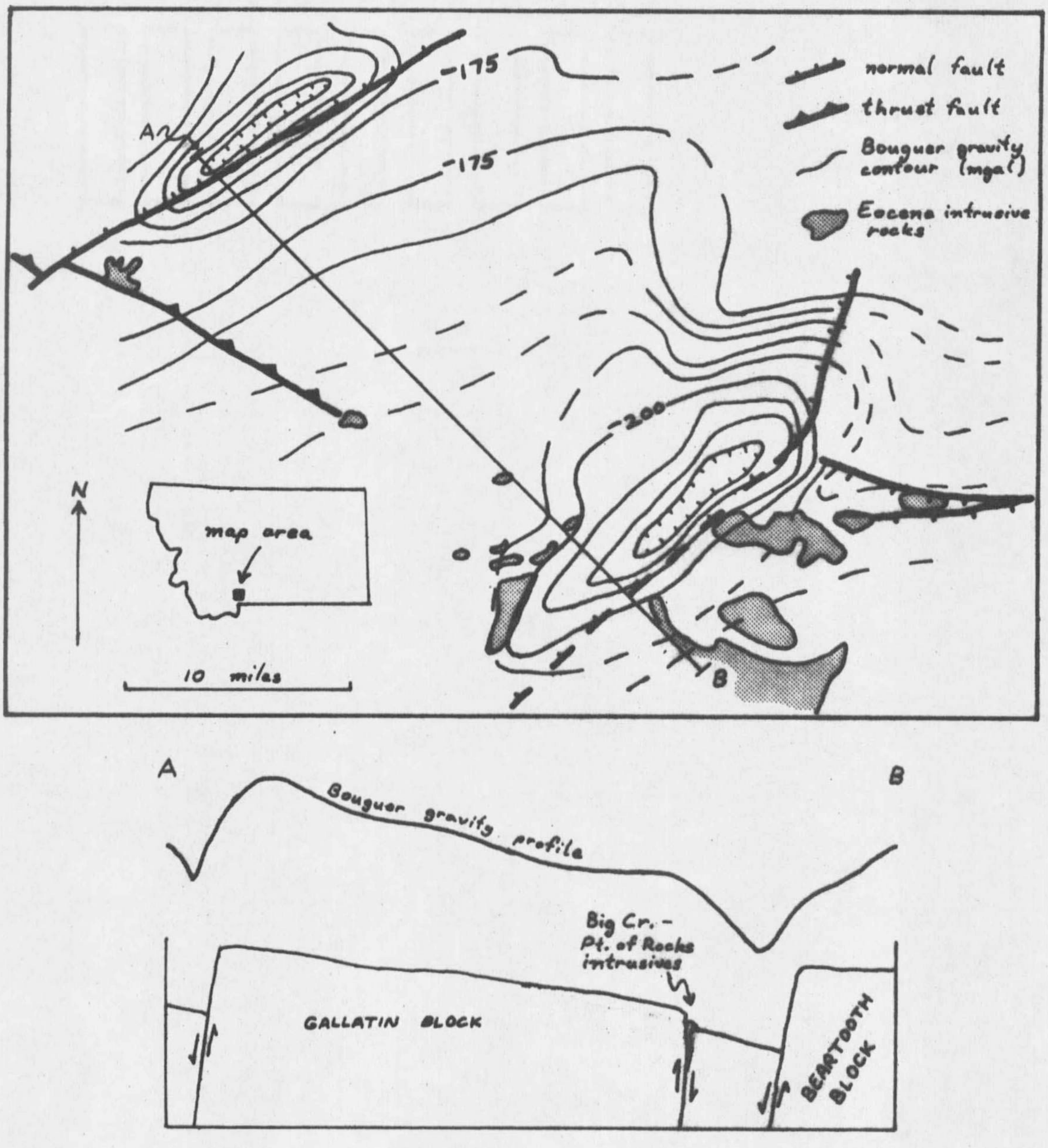


Figure 3. Simplified tectonic and Bouguer gravity map of the northern Gallatin Range (modified from Bonini and others, 1972), and hypothetical cross section.

PALEOMAGNETISM

The study of remanent magnetism has proved to be a very useful tool for working out stratigraphic relations in some portions of the Absaroka-Gallatin volcanic province (Chadwick, 1969; Smedes and Prostka, 1972). Paleomagnetic investigations which have been conducted so far seem to indicate that the remanent magnetism in the Washburn group maintains a normal orientation (that is, the north-seeking direction of natural remanent magnetism (NRM) in the rock points down towards the Earth's present north magnetic pole) throughout the Golmeyer Creek and Hyalite Peak volcanics (Chadwick, 1969) and on up through the middle of the upper Washburn group Fortress Mountain member of the Sepulcher formation (Smedes and Prostka, 1972). The upper portions of the Fortress Mountain member and the lower portions of the Mount Wallace formation of the Sunlight group have a reversed magnetic orientation (north-seeking direction in the rock points upward and to the south), and the remainder of the Sunlight group seems to be normally magnetized (Smedes and Prostka, 1972). J.D. Obradovich of the U.S.Geological Survey has obtained a K-Ar biotite date of 49.5 ± 1.5 m.y. for the Big Creek stock which has a reversed remanent magnetic orientation (Chadwick, 1969).

The magnetic studies for the present investigation were conducted with both a portable fluxgate magnetometer and a laboratory astatic magnetometer. The portable unit was used for most measurements, but dacite specimens which gave uncertain readings with the field unit were sawed into one-inch cubes and measured carefully with the astatic unit. After the initial measurements with the astatic equipment, the cubes were treated with alternating current to remove any secondary magnetism which might have been superimposed on the thermoremanent magnetism of the dacites. The demagnetizing equipment, which was constructed for the M.S.U. Earth Sciences Department Paleomagnetics Laboratory by the M.S.U. Electronic Research Laboratory, includes an AC demagnetizing coil, a random tumbler for the sample, and a Helmholtz coil which reduces the effects of the Earth's magnetic field to a negligible value in the vicinity of the sample. The treatment with this equipment was repeated in increasing increments of field strength and the remanent magnetism was remeasured after each treatment until further treatment failed to produce much change in the NRM orientations. It was then assumed that the final readings were the correct orientations. For most samples, this treatment caused only a small migration of the NRM directions, and helped to more closely cluster the measured NRM orientations for samples collected from the same bodies. However, in some specimens the NRM directions reversed themselves form the directions measured in the untreated rock (fig. 4). Generally those which reversed themselves during AC treatment are those which show secondary hematization. Specimens free of such alteration did not reverse; this type of specimen was collected wherever possible.

The results of the paleomagnetic work are summarized in Table 1, and equal area plots for the individual bodies are presented in the appendix.

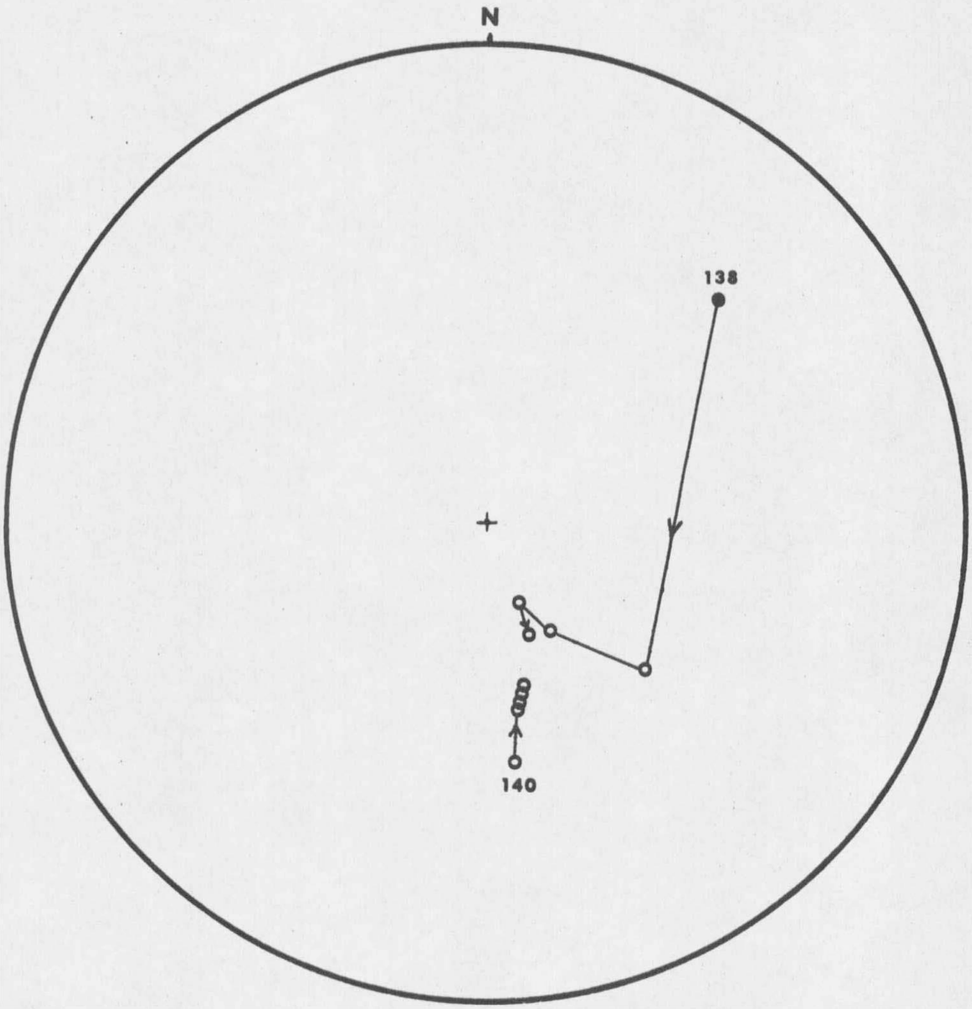


Figure 4. Changes in the magnetic dipole orientations of two specimens from the Little Trail Creek vent area as the result of treatment of the specimens with increasing doses of AC current. Specimen #140 is fairly fresh, and specimen # 138 has been hematized. The equal area plot shows the north pole position; solid dots = lower hemisphere, and open circles = upper hemisphere. The plots show the pole orientations at 0, 100, 200, 300, and 400 oe.

Table 1. Paleomagnetic NRM orientations of Eocene dacite intrusives in the Gallatin and western Beartooth Ranges.

body	orientation	method of measurement*
Northern Moose Cr.	normal	F
Southern Moose Cr.	normal	F
Upper Dry Cr.	normal	F
Lower Dry Cr.	reversed	F
Big Creek stock	reversed	FL
Point of Rocks	normal	F
Mill Cr.	normal	FL
Emigrant stock	normal	F
Tom Miner	normal	FL
Cinnabar Basin	reversed	F
Mol Heron Cr.	reversed	FL
Little Trail Cr.	reversed	FL
Black Butte	normal	F
Meldrum Mtn.	normal	FL
Rainbow Lake	normal	F
Bunsen Peak	normal	F

* F = measured with portable field unit only.
FL = measured with field unit and with laboratory astatic equipment, and treated to remove any secondary magnetism.

FIELD DESCRIPTIONS AND AGE RELATIONS

Northern Moose Creek Body

The northern Moose Creek body is located in the Garnet Mountain Quadrangle in sec. 32 and 33, T.5 S., R.5 E., and sec.5, T.6 S., R.5 E. The outcrop is roughly oval in shape and is approximately 3/4 mile long and 1/3 mile wide at its widest part (fig. 5). In hand specimen the rock is dark grey and very fine grained with well-developed flow banding. Near the contacts the flow banding is parallel to the contacts. The banding generally dips 30° to 40° away from the center of the intrusion, and it is nearly horizontal at the top of the outcrop. At the contacts, the dacite has bent and brecciated the surrounding Hyalite Peak andesite flows and breccias. All these features suggest that the dacite forms a shallow dome-like intrusion which has not been deeply eroded. The body is located in the upper plate of the pre-volcanic Moose Creek thrust fault, and it seems likely that the fault has controlled the location of the intrusion (McMannis and Chadwick, 1964); probably the magma rose along the fault plane until it was shallow enough to dome and fracture the rocks of the upper plate. Along portions of the western margin of the dome, a zone of breccia extends at least 50 feet outward from the edge of

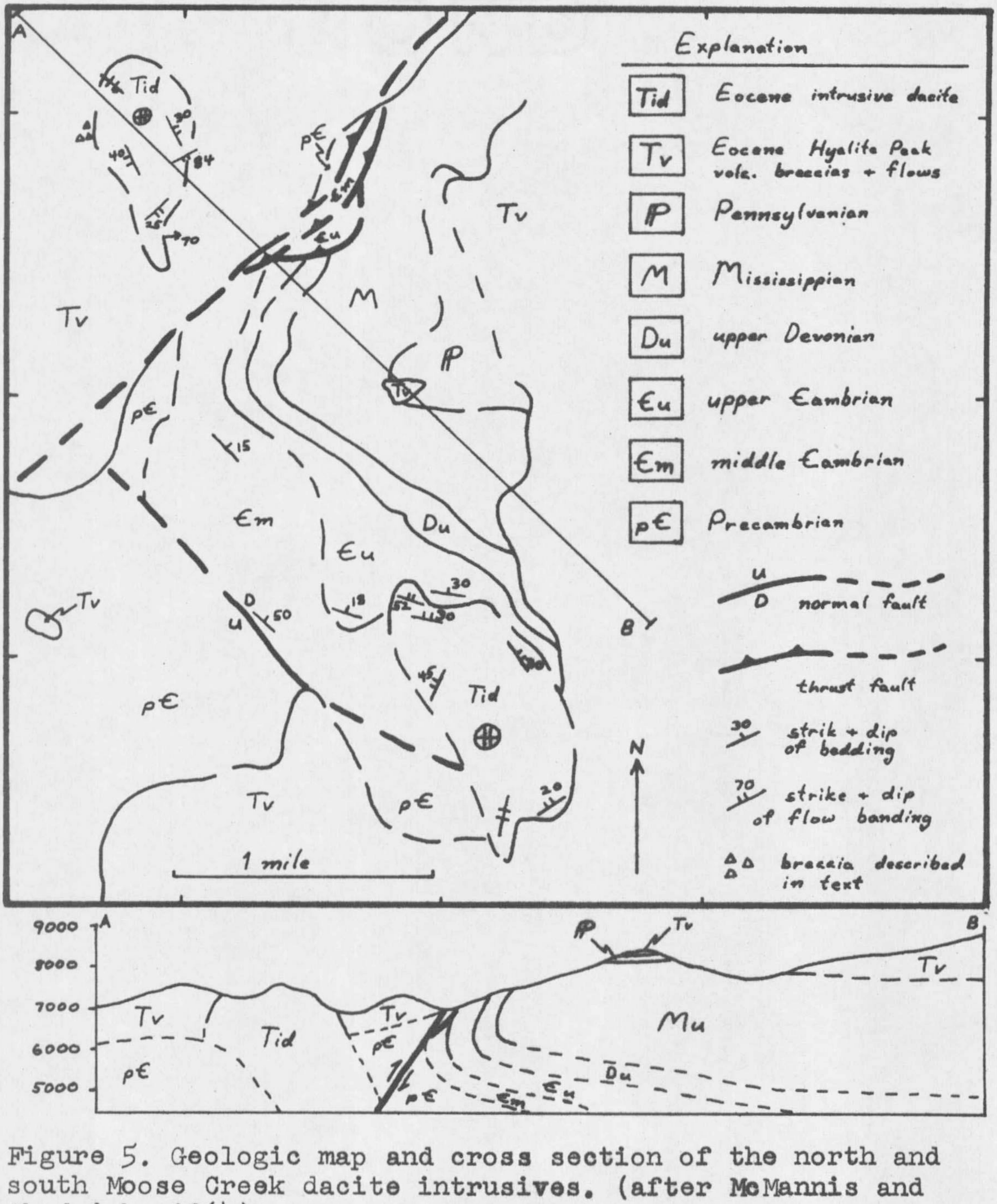


Figure 5. Geologic map and cross section of the north and south Moose Creek dacite intrusives. (after McMannis and Chadwick, 1964)

the body. This breccia consists of angular blocks of the intrusive in a rubbly matrix of andesitic volcanic debris. The breccia has the same overall appearance as the present day talus slopes which surround much of the body today except that it is cemented in a matrix of volcanic fragments. This suggests that the dome may have been exposed to erosion before volcanic activity had entirely ceased in the area. Paleomagnetic studies indicate that the dacite has a normal NRM orientation. Since intrusion of the dacite evidently took place between two episodes of Hyalite Peak volcanic activity, and its remanent magnetism is the same as that reported for most of the Washburn group (Smedes and Prostka, 1972), it is probable that the northern Moose Creek dome was intruded during Hyalite Peak time.

Southern Moose Creek Body

The southern Moose Creek body lies approximately 2½ miles southeast of the northern body in sec. 9, 10, 15, and 16, T.6 S, R.5 E. It too is an oval shaped body, but it is about twice as large in outcrop area as the northern Moose Creek intrusive (fig. 5). In hand specimen the rock contains small (1-2mm) phenocrysts of hornblende, andesine, quartz, and a little biotite in a fine grained light grey groundmass. In various places it is in contact with Precambrian metamorphics, Cambrian sedimentary rocks, and Hyalite Peak volcanics. The contacts dip outward very steeply except on the northern end of the body where the dip is gentler evidently because the intrusion has wedged itself between the Park shale and the Pilgrim limestone. The flow banding near the top of the body is nearly horizontal (McMannis and Chadwick, 1964), and suggests that the intrusive has not been deeply eroded. The outcrop typically displays columnar jointing oriented perpendicular to the contacts. Another prominent set of joints is oriented parallel to the contacts and seems to be associated with multiple chill zones and multiple zones of columnar jointing (fig. 6). Together these features suggest emplacement by multiple intrusive surges. The intrusion is located about two miles south of the Moose Creek thrust along a normal fault which intersects the thrust (fig. 5); the magma may possibly have risen along the thrust and then migrated southeastward along the normal fault before it finally was emplaced. Paleomagnetic measurements indicate that the remanent magnetism of this body has a normal orientation. Contact relations, paleomagnetism, and petrologic data which will be discussed in a later section

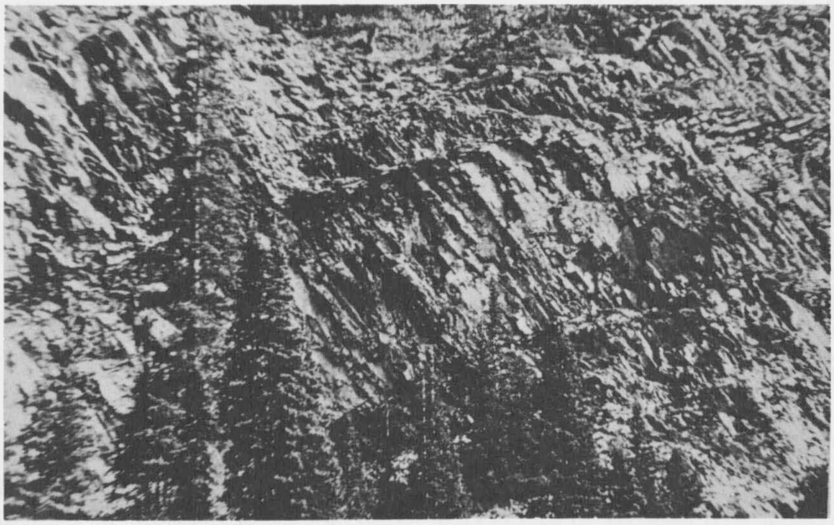


Figure 6. Multiple chill zones and columnar jointing at the upper contact of the southern Moose Creek dacite intrusion with the overlying Pilgrim limestone.

suggest that this intrusive was emplaced during Hyalite Peak time.

Upper Dry Creek Body

The upper Dry Creek dacite body is exposed in the canyons near the head of Dry Creek in the Fridley Peak Quadrangle in sec. 29, 30, 31, and 32, T.5 S., R.7 E. (fig. 7). Hand specimens contain a few biotite flakes and locally minor amounts of andesine phenocrysts in a very fine grained dark grey matrix. The dacite intrudes the underlying volcanics which were termed Golmeyer Creek by Chadwick (1969). It is overlain by Hyalite Peak (Chadwick, 1969) epiclastic beds which contain fragments of the dacite body. This places the time of intrusion at late Golmeyer Creek or early Hyalite Peak time. Based on Chadwick's interpretation of the ages of the Hyalite Peak and Golmeyer Creek volcanics, the intrusion must be late early or early middle Eocene in age. The NRM orientation in this body is normal. The upper Dry Creek dacite is located in line with the strike of the Squaw Creek reverse fault which is exposed as close as six miles northwest of the body. However, the volcanics cover the fault, which is of pre-volcanic age (McMannis and Chadwick, 1964), and they obscure any relationships which might exist between the

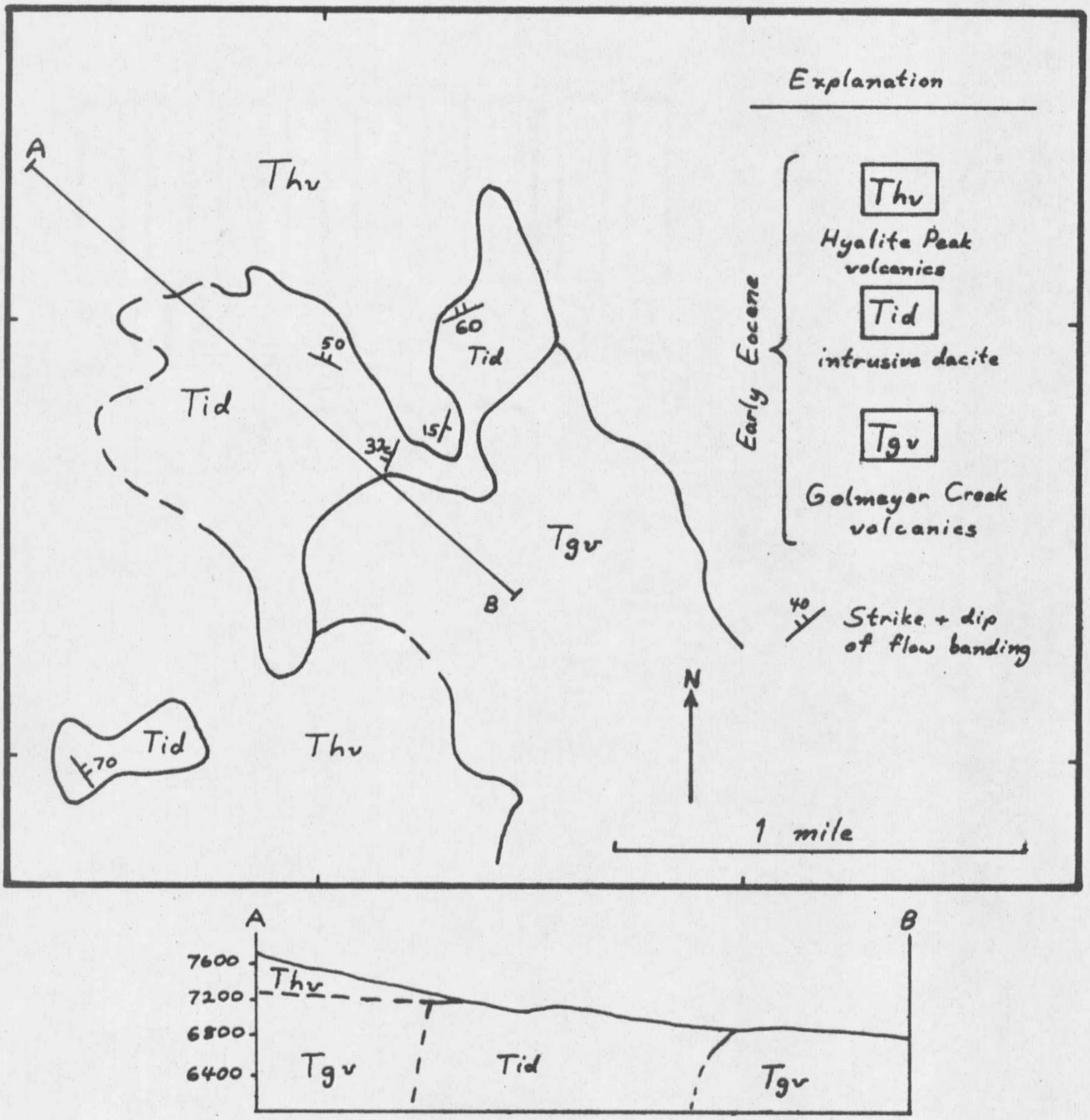


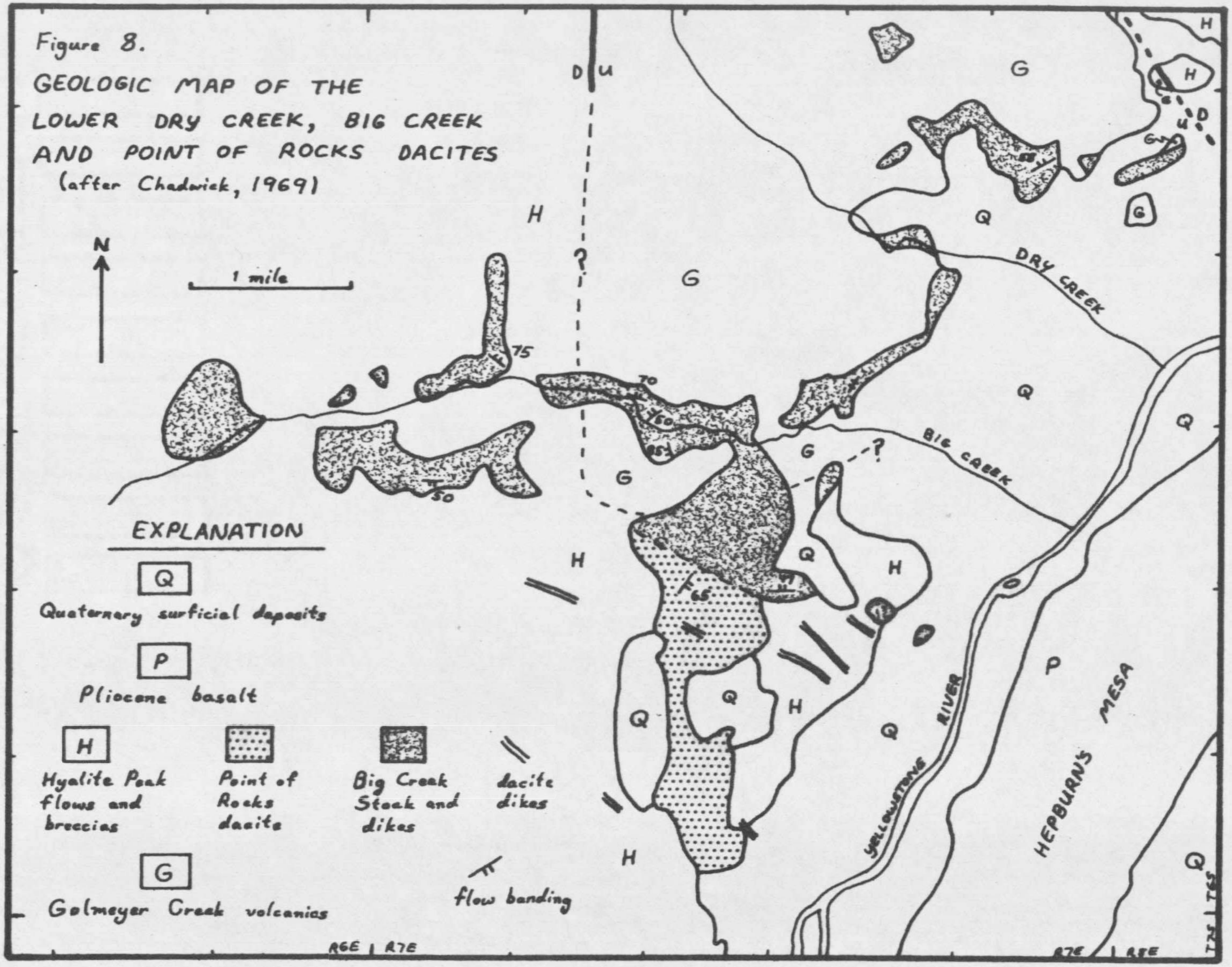
Figure 7. Geologic map and cross section of the upper Dry Creek intrusive. (after Chadwick, 1969)

upper Dry Creek dacite and the fault. Because the Squaw Creek fault has evidently controlled the locations of two other dacitic intrusions in the Garnet Mountain area (Plate I, this paper; McMannis and Chadwick, 1964), it seems possible that it may also have controlled the location of the upper Dry Creek body.

Lower Dry Creek Dacites

Dacite crops out in the low hills and cliffs north of the lower portion of Dry Creek in sec. 5, 10, 11, and 12, T.6 S., R.7 E. (fig. 8). Glacial boulders and landforms suggest that these exposures were produced by the ice sheet and ice-marginal streams which occupied this portion of the Yellowstone Valley during Bull Lake time (Horberg, 1940; J. Montagne, oral communication, 1973). In hand specimen the dacites are characterized by phenocrysts of biotite, andesine, partially resorbed quartz, and some hornblende in a dark grey or black matrix which is commonly very fine grained or glassy. The rock weathers to a chalky texture and a pink or white color. The surrounding rocks are part of the Golmeyer Creek volcanics (fig. 8, this paper; Chadwick, 1969). Flow banding and observable contacts suggest that the dacite in this area was intruded primarily along a conjugate dike system. Most of the dikes either

Figure 8.
GEOLOGIC MAP OF THE
LOWER DRY CREEK, BIG CREEK
AND POINT OF ROCKS DACITES
(after Chadwick, 1969)



strike northwest and dip steeply northeast or strike northeast and dip steeply northwest. The northwest trend is approximately in line with the Squaw Creek fault, and the northeast trend is approximately parallel to the Deep Creek fault. Also, a northeast trending cataclastic zone runs through the easternmost outcrops of dacite in this area.

In the southwest ¼ of sec.11, T.6 S., R.7 E., the dacite intrusive body is overlain by water-laid sediments. These sedimentary rocks vary abruptly from poorly-sorted conglomerate to well-sorted cross-bedded siltstone. The units contain rounded clasts of the underlying dacite and rounded clasts of volcanics of the Golmeyer Creek type. Small slump structures are present in places. It is not obvious whether this unit is a local fluvial feature of the Golmeyer Creek volcanics or is a much later development. If the sediments are part of the Golmeyer Creek volcanics, then the dacite is definitely of Golmeyer Creek age. On the other hand, if the sediments are younger, then the dacite could be younger also. Remanent magnetic polarity of the dacite has a reversed orientation. Chadwick (1969) found no members of recognized Golmeyer Creek volcanics which have a reversed NRM orientation, and the earliest known reversed interval in the entire Washburn group is in the upper portions of the Fortress Mountain member of the Sepulcher formation (upper Washburn group) (Smedes and Prostka, 1972). Southwest of the lower Dry Creek area is the Big Creek stock (fig. 8). The Big Creek stock also has a reversed remanent magnetic orientation, and portions of its easternmost outcrops and contacts seem to follow the same northeast trend as that of the eastern portion of the lower Dry Creek dacites, Although the lower Dry Creek have been chilled much more than most of the Big Creek stock, the phenocryst assemblages are similar. Thus it seems possible that the lower Dry Creek dacites may be dikes or irregular lenses which are associated with the Big Creek stock.

Big Creek Stock

The Big Creek stock is exposed discontinuously along Big Creek and the west side of the Yellowstone Valley, and forms a total of approximately 3½ square miles of outcrop in the west-central portion of T.6 S., R.7 E., and adjacent parts of T.6 S., R.6 E. (fig. 8). Hand specimens contain phenocrysts of andesine, hornblende, biotite, and partially resorbed quartz in a fine or very fine grained grey or reddish grey groundmass. Portions of the body are deeply weathered; this is especially true along cataclastic zones which seem to trend parallel to Big Creek. The outcrops seem to be truncated by an erosion surface (elevation approximately 5600 feet) which begins at the mountain front above the Ox Yoke Ranch and extends to the Yellowstone glacial valley with a gentle eastward slope of about 2°. The surface is covered with a thin veneer of gravel which resembles Hyalite Peak volcanics. Big Creek canyon is incised approximately 400 feet into this surface. The dacite body is in intrusive contact with volcanics of the Washburn group; according to Chadwick (1969) it cuts both the Golmeyer Creek and the Hyalite Peak volcanics. It in turn is cut by andesite dikes which seem to radiate from under the Hepburn's Mesa basalt flows in the Yellowstone Valley (Chadwick, 1969). Paleomagnetic studies indicate that the stock has a reversed NRM direction. Based on paleomagnetic studies by Chadwick (1969) and by Smedes and Prostka (1972) mentioned earlier in this paper, this would date the Big Creek stock as very late Washburn or very early Sunlight age. A K-Ar biotite date of 49.5 ± 1.5 m.y. has been obtained for this stock by J.D. Obradovich of the U.S.G.S. (Chadwick, 1969); this is in agreement with the paleomagnetic date for the stock. Flow banding in much of the eastern portion of the body is nearly vertical and strikes northeast roughly parallel to the Deep Creek fault which is across the Yellowstone Valley. This is the flow banding orientation which would be expected if the location of this dacite had been at least partially controlled by the fault which was inferred from the gravity data of Bonini and others (1972) in an earlier section (fig. 3).

Point of Rocks Complex

The Point of Rocks dacite lies to the south of the Big Creek stock in sec. 20, 28, 29, 32, and 33, T.6 S., R.7 E. (fig. 8). It is highly variable megascopically. Near its borders the rock is pink or grey with phenocrysts of biotite and sparse grains of quartz and feldspar in a glassy matrix. The sides of the body are generally steeply dipping and are autobrecciated (fig. 9) Several zones of chilling and autobrecciation suggest multiple intrusions. A vent complex has been described at the southern end of these dacite outcrops (Chadwick, 1965) (fig. 10) Here stratified flows and andesite breccias dip away from the central vent area. Over a distance of a few hundred feet, portions of the dacite plug grade laterally from an autobrecciated plug wall or spine to a poorly-sorted avalanche or talus breccia and finally to a zone of mixed dacitic and andesitic breccia which seems to have been transported and redeposited by erosional agents. In places

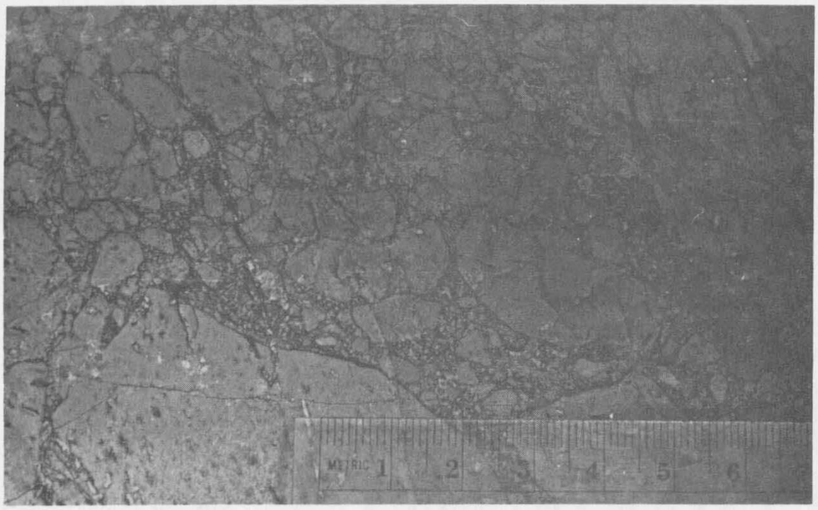


Figure 9. Autobrecciated border of the Point of Rocks plug.

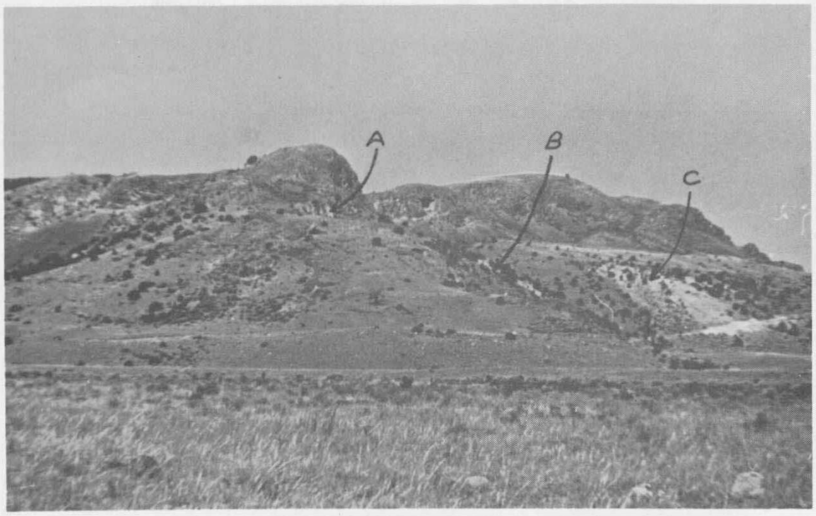


Figure 10. The Point of Rocks plug. Portions of the dacite plug grade laterally from an autobrecciated plug wall (A) to a poorly sorted avalanche or talus breccia (B) and finally to a mixed dacitic and andesitic breccia which was transported and redeposited by erosional agents.

where the dacite was evidently at sufficient depth to avoid very rapid chilling, its texture is finely crystalline instead of glassy to within a few feet of the contacts. Columnar jointing is well-developed near these contacts. The dacite transects earlier Hyalite Peak volcanics, and is in turn cut by later dacite dikes. Remanent magnetism of both the main portion of the Point of Rocks dacite and the later crosscutting dacite dikes is normal. Flow banding suggests that the north end of the Point of Rocks dacite is truncated by the Big Creek stock (fig. 8). Thus, flow banding, contact relations, and paleomagnetism suggest that the Point of Rocks dacite was emplaced during Hyalite Peak time.

Mill Creek Intrusives

Dacite forms several square miles of irregularly shaped outcrops in the vicinity of Mill Creek at the western edge of the Beartooth uplift (Plate I; fig. 11); it forms major portions of Chico Peak, Green Mountain, Arrow Peak, Knowles Peak (formerly Mill Peak), and the divide between Elbow Creek and the East Fork of Mill Creek. Hand specimens contain phenocrysts of biotite, andesine, partially resorbed quartz, and a little hornblende in a finely crystalline grey groundmass. In most places the dacite has

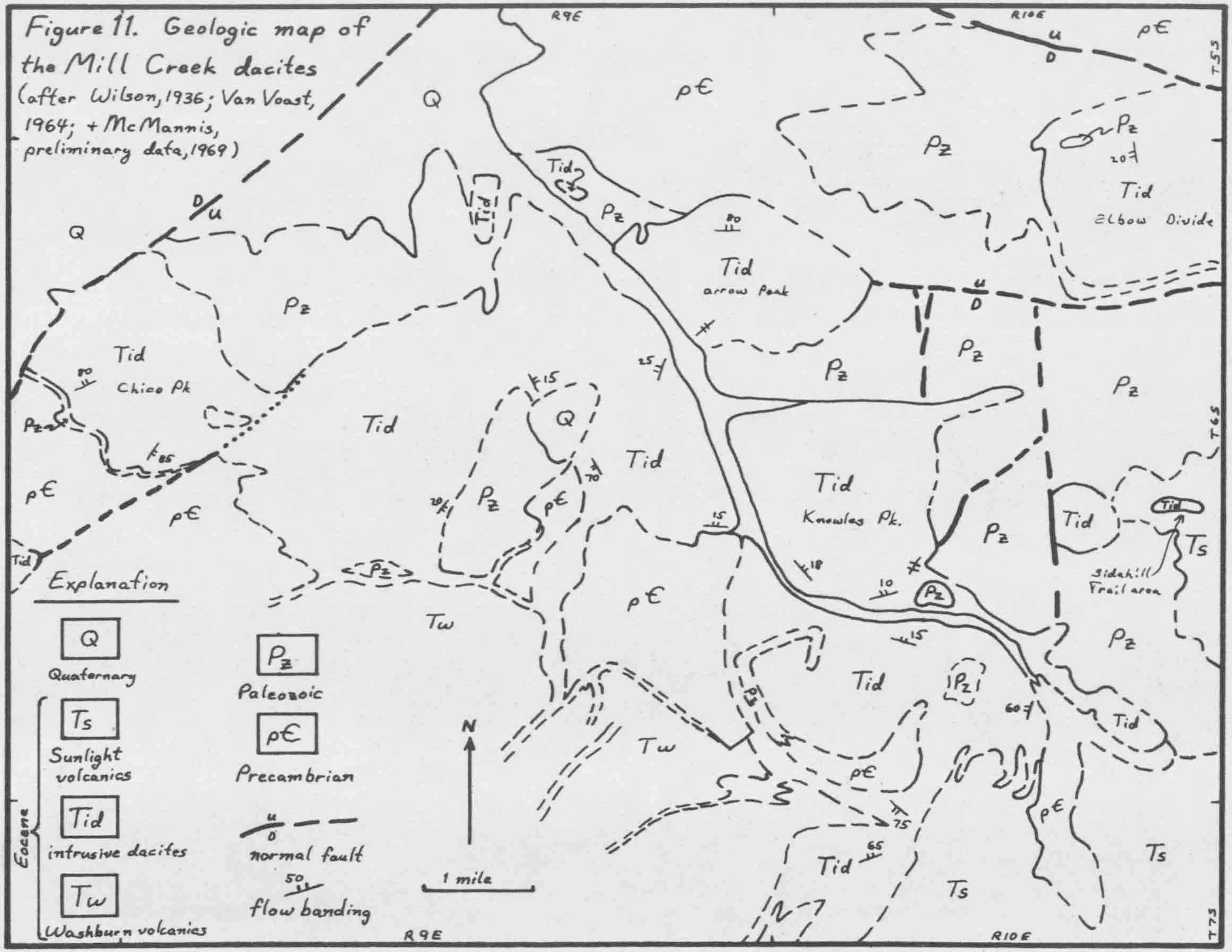


Figure 11. Geologic map of the Mill Creek dacites (after Wilson, 1936; Van Voast, 1964; + McMannis, preliminary data, 1969)

contact metamorphosed Cambrian sedimentary sequences as it evidently intruded along the shaly members of those sequences and formed laccoliths and sills. Portions of these bodies are located along branches of the Mill Creek and Deep Creek faults (Plate I; fig. 11); the dacite is interpreted as post-faulting because it shows no extensive fracturing near the faults. The geologic evidence in the area suggests that the magmas rose through the Precambrian basement along the Mill Creek, and to a lesser extent, the Deep Creek faults and then spread out mainly in the shaly layers of the Cambrian sedimentary rocks as was postulated by J.T. Wilson (1936) and Van Voast (1964). At the head of East Dam Creek along the Sidehill Trail, Mill Creek-type dacite cuts through the early Sunlight volcanics and seems to form a small vent complex similar to the one at Point of Rocks. A K-Ar biotite date from the dacite at the southwest side of Arrow Peak yielded an age of 49.0 ± 1.7 m.y. (Chadwick, 1969). This is in agreement with the contact relations at East Dam Creek which suggest that the Mill Creek dacites are early Sunlight in age. The Mill Creek dacites were evidently emplaced during a period of normal magnetic dipole orientation.

Emigrant Peak Dacites

The Emigrant stock is exposed along Emigrant Gulch on the east side of Emigrant Peak and the west side of the unnamed peak across the gulch (fig. 12). Basler (1965) divided the dacite in this area into two groups which he called groups A and B. The group A dacite forms the main portion of the Emigrant stock and an associated sheet cone complex. This group is found in two distinct varieties which, according to Basler (1965), grade into one another. Near the walls of the stock and in the dikes it is a black glassy rock with light colored phenocrysts of plagioclase, some orthoclase, and partially resorbed quartz (fig. 13). Farther in towards the center of the stock the group A rocks are characterized by large (1-2cm) zoned albite crystals which are sometimes Carlsbad twinned, and by smaller (1-2mm) phenocrysts of hornblende, plagioclase, K-feldspar, and partially resorbed quartz, in a fine grained tan colored groundmass (fig. 14). Some of the unusual features of this coarser grained portion of the group A rocks may be due to metamorphism during later hydrothermal mineralization of the stock and will be discussed in more detail in the petrology section of this paper.

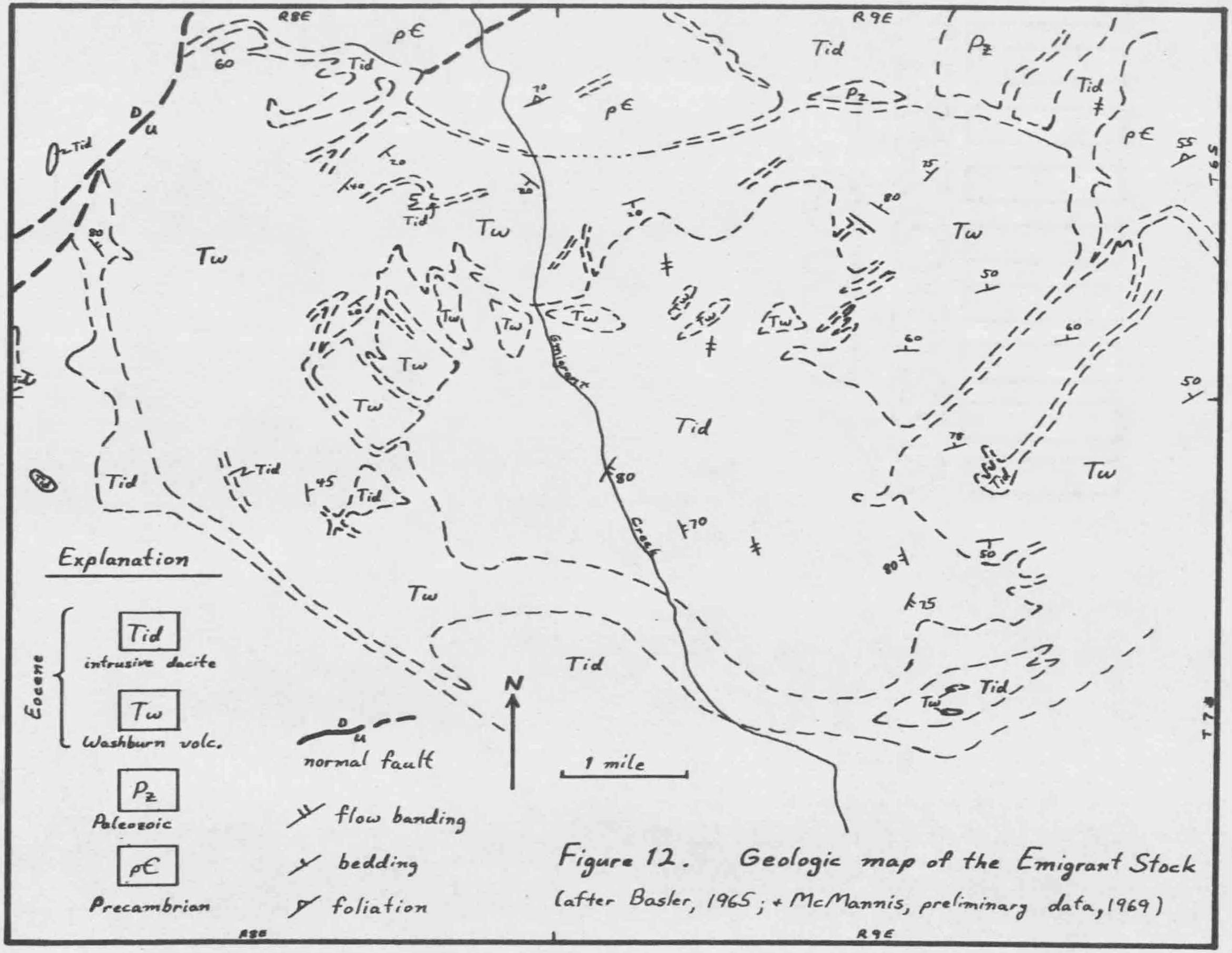


Figure 12. Geologic map of the Emigrant Stock (after Basler, 1965; + McMannis, preliminary data, 1969)

Figure 13. Strongly flow banded group A dacite from the margin of the Emigrant Peak stock.

Figure 14. Large zoned albite crystal in the coarser grained group A dacite from the main portion of the Emigrant Peak stock.

The group B dacite forms dikes and sills which cut the group A dacites (Basler, 1965). The group B rocks contain small (1mm) phenocrysts of plagioclase, biotite, and partially resorbed quartz in a very fine grained light grey matrix. The main portion of the Emigrant stock has intruded older intrusive and extrusive andesites which were designated as Washburn group by Smedes and Prostka (1972). The andesites are petrographically very similar to the Golmeyer Creek volcanics at Big Creek and lower Dry Creek (Chadwick, 1969). A K-Ar biotite age date (Geochron Labs) of 53.5 ± 2.3 m.y. has been obtained for similar andesites which lie approximately three miles east of the Emigrant stock on the West Fork of Mill Creek (Chadwick, 1969). Dikes of the dacites seem to have forced their way between the Precambrian-Washburn andesite contacts almost all the way around the Emigrant area. NRM orientations of the glassy portions of the group A dacite are normal; remanent magnetism in the other Emigrant dacites was too weak to detect. Basler (1965) pointed out that the group B dacites are very similar to some of the finer grained portions of the Mill Creek dacites; possibly they are related. If the group B rocks are related to the Mill Creek intrusions, then group B is probably early Sunlight or late Washburn in age. This would make the group A rocks middle to late Washburn age since they cut andesites which are probably early Washburn in age.

Tom Miner Body

The Tom Miner dacite body forms most of Sheep Mountain and the northwestern end of Sawtooth Mountain just north of Yellowstone National Park in sec. 21, 28, 29, 32, and 33, T.8 S., R.6 E. (fig. 15). In hand specimen the rock has a fine grained medium grey groundmass containing phenocrysts of andesine, hornblende, and a little biotite. The body is evidently intrusive. It lacks extensive chilled and autobrecciated zones such as those at the Point of Rocks complex, the contacts dip steeply outward, and the borders of the body contain xenoliths of material similar to that found in the surrounding lahars. The intrusion is located near the point where the Spanish Peaks and Deep Creek faults would intersect if they were extrapolated from their last known exposures (Plate I). However, if these faults do extend under the volcanic cover they have been completely obscured by it, and there is no clearly visible relation between this intrusive body and pre-emplacement tectonic activity. The body intrudes laharic beds, volcanic breccias, and andesite flows which are probably the upper

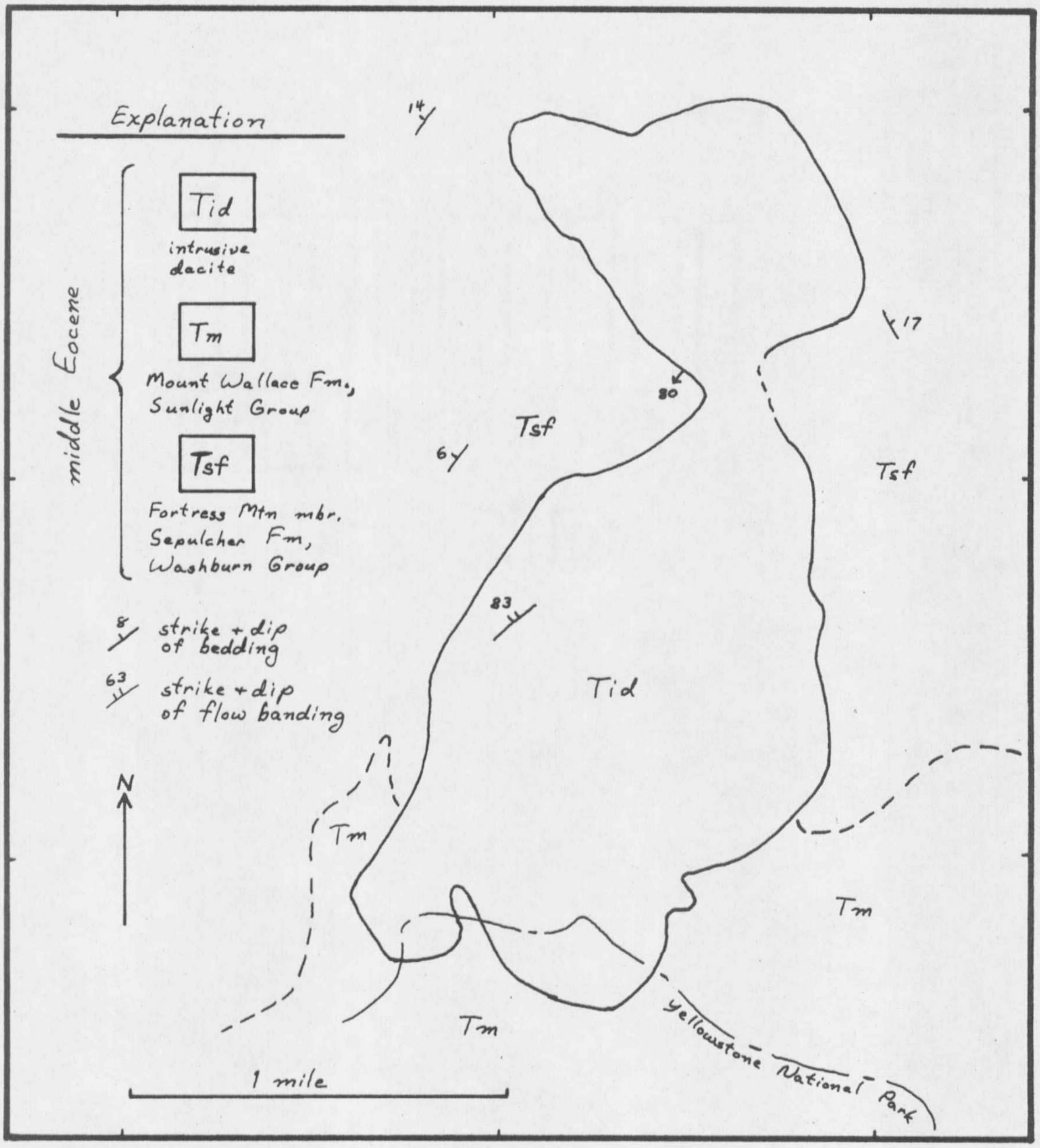


Figure 15. Geologic map of the Tom Miner dacite intrusive. (after Todd, 1969; and U.S.G.S., 1972)

portions of the Fortress Mountain member of the Sepulcher formation and the lower portion of the Mount Wallace formation as these were described by Smedes and Prostka (1972) and the U.S.G.S. (1972). Todd (1969) reported two paleomagnetic readings with gently dipping reversed dipole orientations for the dacite; however, this study obtained only normal readings with both field and laboratory equipment. Because these normal readings did not change with treatment with AC current in a field strength of up to 250 oe, it is believed that the body was emplaced during a period of normal magnetic pole orientation. One or two miles east of the intrusive, Sepulcher formation members which probably correlate with those intruded by the Tom Miner body have reversed magnetic polarity (E.L. McCaskey, preliminary data reported <u>in</u> Smedes and Prostka, 1972). Because the only known reversed magnetic interval in the Washburn or Sunlight groups occurs at the boundary of these two groups, and because the dacite intrusion seems to cut rocks of this interval, the Tom Miner dacite is probably Sunlight in age and is younger than the 49.5 m.y. old Big Creek stock which has a reversed NRM direction.

Cinnabar and Mol Heron Intrusives

Two very similar dacite bodies are located approximately six miles north of Electric Peak in Cinnabar Basin and on the divide between Cinnabar and Mol Heron Creeks (fig. 16). The Cinnabar Basin body, in sec. 20, 21, and 29, T.8 S., R.7 E., has an inverted L-shaped outcrop pattern of about 1¼ square miles. The dacite in the Mol Heron area forms a roughly triangular outcrop pattern which extends across sec. 26, 27, 28, 34, and 35, T.8 S., R.7 E. Their close proximity and remarkable similarity suggest that these two bodies are connected at depth. Poor exposures show megascopic phenocrysts of andesine, hornblende, biotite, and minor amounts of partially resorbed quartz in a fine grained grey groundmass. The contacts are hidden, but the relatively coarse texture of these rocks suggests that they are intrusive. These bodies are located along and near the Mol Heron fault and are also close to the probable extension of the Gardiner fault (Plate I). Because much of the displacement on these faults evidently was accomplished prior to volcanism in this area, it seems possible that the magma may have risen along these faults. The NRM directions in both of these intrusives are reversed. The surrounding Mount Wallace or Sepulcher volcanics which the dacites seem

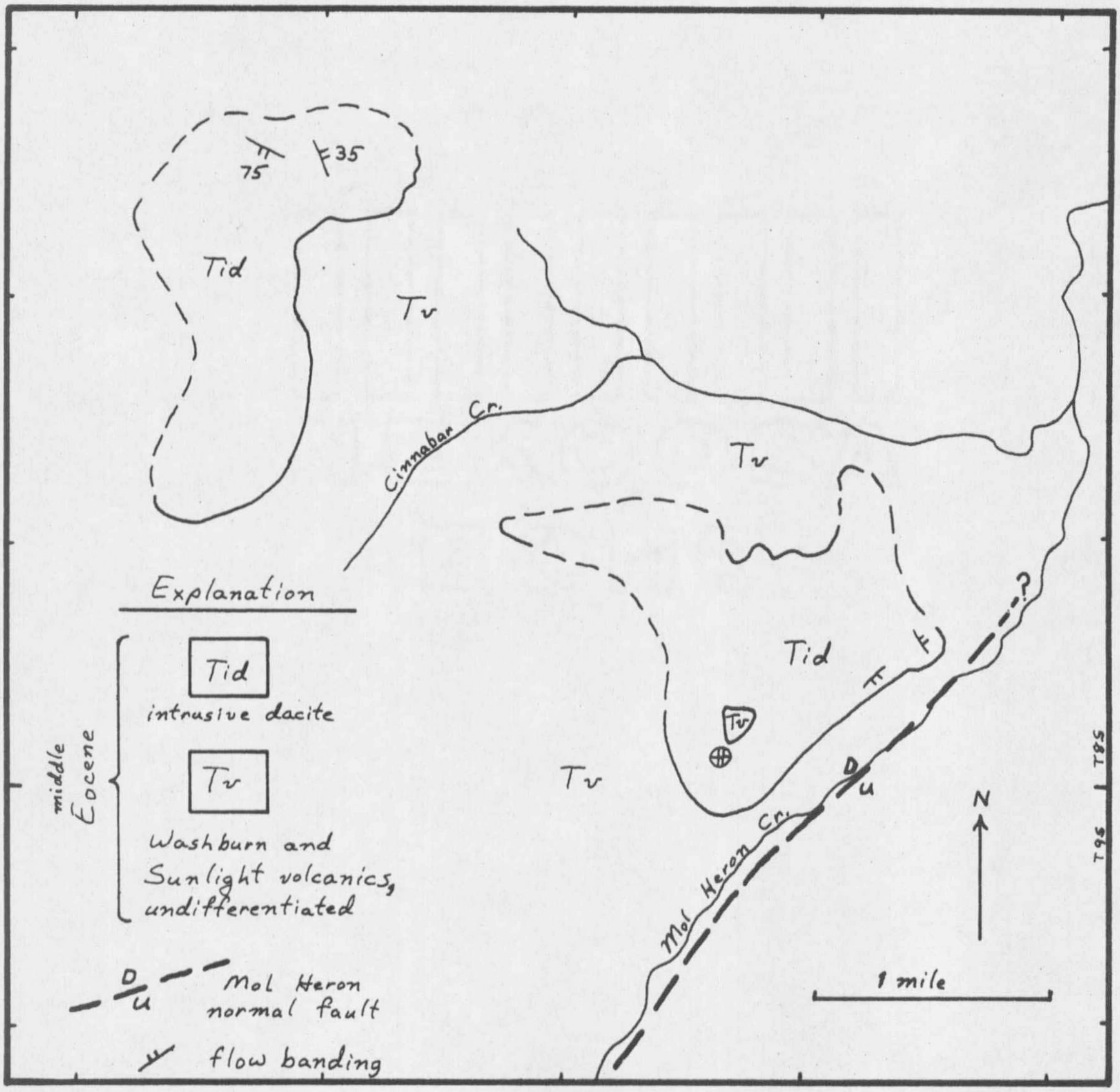


Figure 16. Geologic map of the Cinnabar and Mol Heron dacites. (after E.L. McCaskey, preliminary data, 1969)

to intrude were found to be normal in some places and reversed in other places (E.L.McCaskey, preliminary data reported <u>in</u> Smedes and Prostka, 1972). Based on our present knowledge of the paleomagnetic time scale and the stratigraphy of the Absaroka-Gallatin volcanics, the dacites in the Cinnabar-Mol Heron area are probably roughly contemporaneous with the upper Sepulcher and lower Mount Wallace formations and with the 49.5 m.y.old Big Creek Stock.

Little Trail Creek Complex

Along the north fork of Little Trail Creek, which is on the northeast side of the Yellowstone River across from Sepulcher Mountain, are several irregularly shaped exposures of dacite which are evidently remnants of flows and the vent that probably fed them. These are found in sec. 28, 33, and 34, T.8 S, R.8 E., and sec. 4 and 9, T.9 S., R.8 E. (fig. 17). In hand specimen the dacite contains phenocrysts of andesine, biotite, replaced hornblende, and sparse partially resorbed quartz in a very fine grained matrix which is grey, reddish grey, or tan depending on whether it is fresh, stained with hematite, or bleached. The flows and portions of the vent are autobrecciated (fig. 18; Fraser and others, 1969). The breccias contain fragments of dacite and a few clasts of the

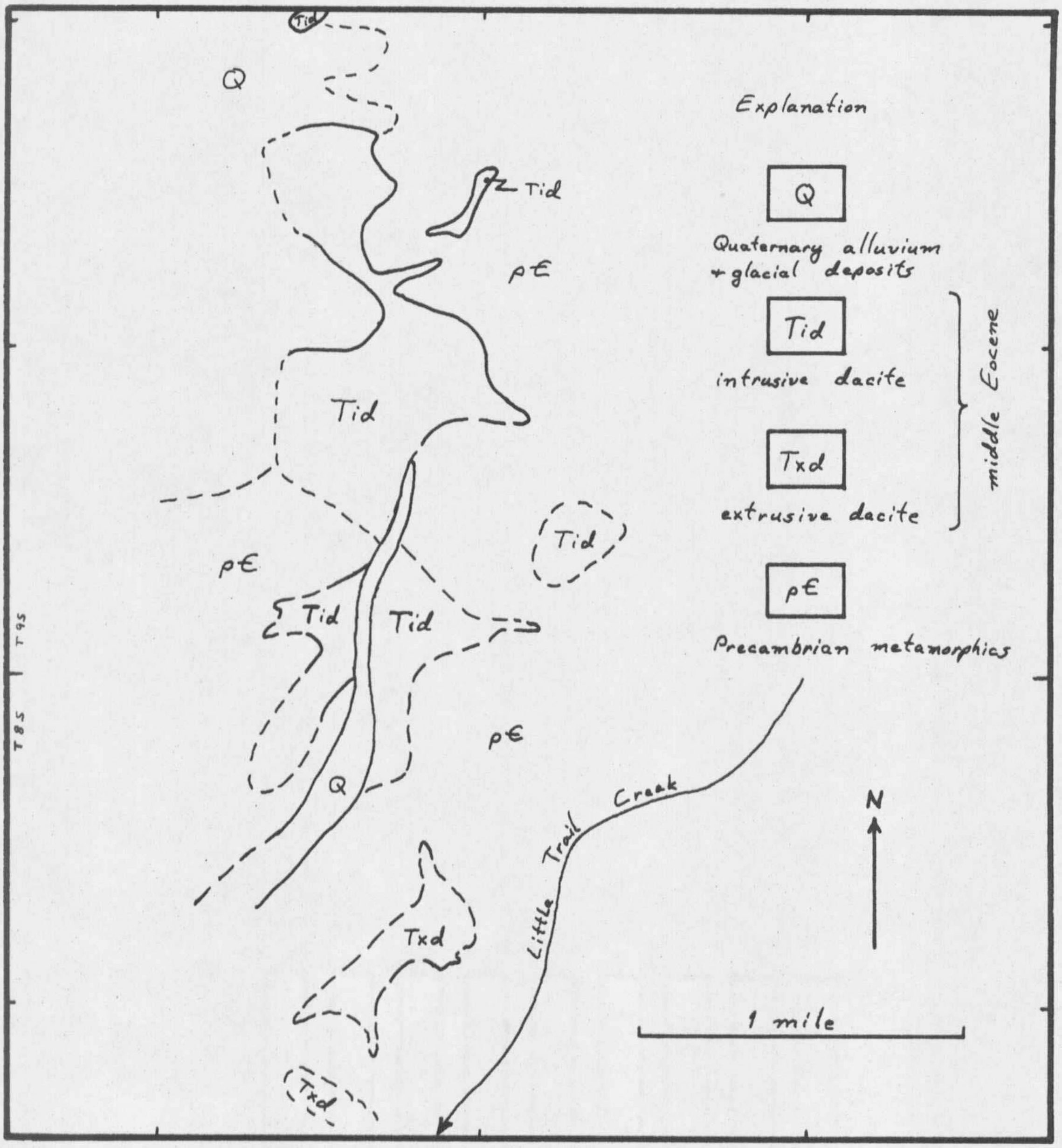


Figure 17. Geologic map of the Little Trail Creek complex. (after Fraser and others, 1969)

Figure 18. Dacite flow breccia at Little Trail Creek.

Precambrian schists and gneisses which surround the vent and underlie the flows. Much of the brecciation probably took place in the vent, but some may have also resulted from autobrecciation of the flows. The location of this vent less than two miles north of the northeast-dipping Gardiner fault suggests that the fault may have served as a conduit for the magma until it was near the surface. The NRM orientation in these rocks is reversed. This suggests that they were formed at about the same time as the Cinnabar-Mol Heron bodies and possibly the 49.5 m.y. old Big Creek stock.

STRUCTURAL CONTROL OF ERUPTIVE CENTERS AND INTRUSIVE ROCKS

Because the volcanic rocks so thoroughly cover the pre-volcanic rocks in much of the Absaroka-Gallatin volcanic province, structural data has been slow to accumulate and is still very incomplete in many areas. At the southern end of the province J.D. Love (1939) reported that he was unable to find any causal relation between observable structure and centers of igneous activity, and I am unaware of any subsequent studies which have found such structural features. In the older areas to the north and west, however, such relations have been found at least locally. C.W.Wilson (1934) suggested that the Gardiner fault controlled the locations of the porphry bodies nearby, and J.T. Wilson (1936) believed that the dacite bodies in the Mill Creek area were controlled by the Mill Creek fault. Foose and others (1961) point out that the only igneous activity along the Mill Creek fault took place near its intersection with the Cooke City lineament. They suggest that this lineament, which seems to have controlled the locations of many other centers of igneous activity, probably exerted primary control over the Mill Creek bodies also. McMannis and Chadwick (1964) described similar relations between faults and intrusions in the Garnet Mountain Quadrangle.

Chadwick (1968; 1970) pointed out that the eruptive centers as a whole generally lie along two sub-parallel belts which he presumed were controlled by pre-existing zones of crustal weakness. He noted that these two trends appear to coincide with the trends of the Cherry Creek-Squaw Creek fault and the Spanish Peaks fault at the northwest end of the province (Plate II). Prior to Chadwick's papers, Peale (1896), Iddings (1904), C.W.Wilson (1934), and Horberg (1940) suggested that the Spanish Peaks fault and the Gardiner fault are continuous under the Gallatin volcanics, and C.W. Wilson (1934) even speculated that this fault then continued southeastward towards Cody where it re-emerged as the Rattlesnake Mountain fault. However, if Chadwick is correct, and the two apparent belts of igneous centers are controlled by zones of crustal weakness, then the Rattlesnake fault is more likely the southeastern end of the Cherry Creek-Squaw Creek fault trend. The Cooke City lineament described by Foose and others (1961) is probably the central portion of this fault trend since it is in line with and has the same sense of motion as the end members. According to Foose and others, tectonic activity along the Cooke City lineament preceded the igneous activity along it.

In the southwestern belt relations are more speculative. While several authors, as mentioned above, have agreed that the Spanish Peaks fault and the Gardiner fault are probably connected, it has so far been impossible to find persuasive evidence that the fault continues to the southeast in the area of the youngest members of the Absaroka volcanic supergroup. However, based on the observed structural control of the northeastern belt, and on the southeastward trend in the locations of the igneous centers of the southwestern belt in line with the Spanish Peaks and Gardiner faults, it seems likely that the zone of crustal weakness does continue to the southeast under the relatively young volcanic cover.

The northeast-trending normal faults have played a perhaps relatively minor role in controlling the locations of igneous activity. Van Voast (1964) suggested that the dacite intrusive of Chico Peak (fig. 11) had been in part controlled by the Deep Creek fault, but he believed that the effects of the Deep Creek fault were secondary to the effects of the Cooke City lineament which seems to intersect both the Deep Creek and Mill Creek faults in this area. At least some of the dacites in the lower Dry Creek, Big Creek, and Point of Rocks areas may have been controlled similarly; flow banding, contacts, and outcrop patterns all seem to follow a steeply dipping northeast trend (fig. 8). These bodies are aligned along and were perhaps controlled by the fault which seems to be suggested by the gravity data of Bonini and others (1972) (fig. 3). However, these bodies, like those in the Mill Creek area, are also located near the Squaw Creek-Cooke City trend, and this zone may have been the primary controlling factor here as well as at Mill Creek.

As noted earlier in this paper and by McMannis and Chadwick (1964), the northeast-trending Moose Creek thrust fault evidently controlled the locations of the two Moose Creek intrusives. It is probably responsible for their unusual locations midway between the two major belts of igneous centers.

In the northwest portion of Yellowstone National Park are several igneous centers which are located as much as several miles south of the Spanish Peaks-Gardiner trend (Plates I, II); these are the intrusive bodies of the southern Gallatin Range and include the Mount Holmes stock, Indian Creek laccolith, Gray Peak-Snowshoe laccolithic complex, and the Electric Peak eruptive and intrusive center (Ruppel, 1972). These bodies seem to be mostly restricted to the area of the Gallatin Horst (Plate I). Ruppel (1972) thinks that they were emplaced before the Gardiner, Mammoth, Reese Creek, and Mol Heron faults were activated because the bodies have been cut and deformed by the faults. He postulates emplacement during the gentle anticlinal folding which preceded faulting on the horst. Concentration of these bodies along the center of the horst rather than along its faulted boundaries tends to support this view. Fraser and others (1969) believe that most of the movement along these faults took place before volcanism began in the area because the earliest volcanic rocks they could find (in the Gardiner area) have only been displaced about 250 to 500 feet while total displacement along these faults is approximately twenty times that. It is interesting to note that Fraser and others drew most of their evidence from the Mammoth Fault, while Ruppel cited the Mol Heron and Reese Creek faults to support most of his argument. Perhaps these differences in opinions are related to the greater amount of reactivation of the Gardiner fault in the Mol Heron and Reese Creek vicinity which would probably also have affected the Mol Heron and Reece Creek faults. Also, Ruppel bases much of his argument on offsets and deformation of the intrusive rocks which evidently predate volcanic activity in this area because the youngest of these intrusives are cut by the conduits of the Electric Peak eruptive center. Fraser and others use the extrusive rocks for their dating. Perhaps the major movement along these faults was post-intrusive and pre-volcanic.

From all this, a picture of the development of the northern part of the Park begins to emerge. First, magmas intruded along a north-south line extending from Mount Holmes at least to Electric Peak . Shortly thereafter, the Gardiner fault became active and began to produce a broad northwest-trending syncline as the result of drag folding on the downthrown side of the fault. However, the pre-Gardiner laccoliths and sills had effectively reinforced the sedimentary rocks they had intruded so that this area behaved rigidly. Instead of being flexed downward with the rest of the syncline, normal faults developed at the borders of this rigid section as it remained structurally high thus forming the Gallatin Horst. By the time this feature was well-developed, volcanic activity had begun along the northwest-trending reverse faults. The eruptive center at Electric Peak may be the result of some of this later magma which came part way up the Gardiner fault and then exploited the Reese Creek fault.

PETROGRAPHIC DESCRIPTIONS AND CHEMICAL COMPOSITION

Many thin sections of the dacites in the Gallatins and western Beartooths were examined for this study; approximately half of these sections were made specifically for this investigation, and half came from Montana State University's collection of thin sections from previous work. Modal analyses of representative sections are given in Table 2. The modes are based on counts of 1000 counts per thin section. When the use of partially altered specimens was unavoidable, the altered grains were counted as the original minerals. A review of published chemical analyses for the dacites in the study area is presented in Table 3. Originally it was hoped that many additional silicate analyses could be obtained with an emission spectrograph in the M.S.U. Chemistry Department; however, numerous problems have been encountered in developing methods which produce satisfactory results with the equipment available, and additional analyses could not be made.

Northern Moose Creek Body

The northern Moose Creek body contains a phenocryst assemblage primarily of hornblende and very calcic andesine. The andesine is present as 1mm pieces of broken

Table 2. Representative thin section modes of Gallatin-Beartooth dacites.

Location	southern Moose Cr.		northern Moose Cr.		Big Creek	
Spec. #	255a*	255c	254A	254b*	204	399*
quartz				0.5	0.4	
orthoclase						
plagioclase	3.3	3.1	9.4	9.8	16.8	26.3
hornblende	4.5	4.4	6.7	7.1	4.5	2.2
biotite					1.9	3.5
magnetite		0.1	0.7	0.8	0.2	0.8
groundmass	92.2	92.4	83.2	81.8	86.2	67.2

*chemically analysed specimen listed in Table 3.

Table 2. Continued

Location	Point of Rocks		Mill Creek		Emigrant Group B#
Spec #	324d*	345a	17	Wilson* (1936)	6441
quartz		tr	3.2	0.1	14.7
orthoclase				0.1	
plagioclase	19.7	17.6	13.6	13.1	19.2
hornblende	3.9	4.1	0.4	1.9	
biotite	3.2	1.2	4.2	1.1	4.1
magnetite	1.1	0.7	0.3	0.3	
groundmass	72.1	76.4	78.3	83.4	62.0

#Emigrant group A was too altered to provide a meaningful mode for the purposes of this paper.

Table 2. Continued

Location	Tom Miner		Cinnabar-Mol Heron		Little Trail Creek	
Spec. #	28-1	88	156-3	159	139	141
quartz	2.0		0.1	tr		1.1
orthoclase						
plagioclase	16.9	17.7	24.2	15.0	18.0	17.9
hornblende	8.6	6.6	8.8	6.3	7.7	5.4
biotite	1.6	1.5	2.8	4.4	5.2	4.8
magnetite	1.4	1.9	0.8	0.9	0.3	0.3
groundmass	69.5	72.3	63.3	73.4	68.8	70.5

Table 3. Chemical analyses and CIPW normative minerals for northern Gallatin and western Beartooth dacites.

Chemical analyses weight percent	1	2	3	4	5
SiO_2	66.82	65.32	65.12	66.00	66.74
Al_2O_3	16.15	15.66	13.15	18.79	14.77
Fe_2O_3	3.37	3.06	2.67	2.86	1.50
FeO	.38	.98	1.87	1.20	2.49
MgO	.61	1.48	1.56	.99	2.23
CaO	2.88	2.88	3.70	2.16	2.74
Na_2O	4.96	5.80	3.41	2.77	4.12
K_2O	2.80	2.62	4.88	2.94	2.98
total	97.97	97.80	96.36	97.71	97.57

1 = Northern Moose Creek (McMannis and Chadwick, 1964)
2 = Southern Moose Creek (McMannis and Chadwick, 1964)
3 = Big Creek stock (Chadwick, 1969)
4 = Point of Rocks (Chadwick, 1969)
5 = Mill Creek (J.T. Wilson, 1936)

Table 3. (continued)

CIPW normative minerals	1	2	3	4	5
Q	18.8	13.2	17.0	30.9	19.4
Or	16.5	15.5	29.0	17.5	17.5
Ab	44.5	51.5	31.0	25.0	37.0
An	13.5	8.7	6.0	10.5	13.0
C				8.0	
Wo	.4	2.2	5.0		.2
En	1.6	4.0	4.4	2.8	6.2
Fs			1.2		2.8
Mt	.9	2.4	2.7	3.0	1.6
Hm	1.7	.5			
total	97.9	98.0	96.3	97.7	97.7

euhedral crystals with oscillatory zoning. The hornblende forms euhedral crystals which are mostly about 0.8mm long and are in places cracked or broken. It is pleochroic in yellow greens to browns. Some of the hornblende contains small anhedral grains of feldspar and a few subhedral grains of magnetite. The hornblende crystals are rimmed by an extremely fine grained opaque mineral. The groundmass contains microlites of plagioclase and minute grains of a spinel which is probably magnetite. The remainder of the groundmass is extremely fine grained and glassy, and the resulting texture is trachytic near the contacts to hyalopilitic in towards the center of the body. Modal analyses are summarized in Table 2, and a chimical analysis (McMannis and Chadwick, 1964) and CIPW norm are presented in Table 2.

Southern Moose Creek Body

The characteristic phenocryst assemblage of the southern Moose Creek intrusive consists of hornblende and very calcic andesine. The andesine forms 1 to 2mm broken euhedral grains with oscillatory zoning. The hornblende forms 1mm-long euhedral grains which are pleochroic in yellowish greens to browns. Some of these contain subhedral to euhedral grains of magnetite and anhedral feldspar.

Minute grains of a black opaque mineral rim the hornblende. Much of the hornblende seems to have been broken just before the rock completely solidified because the broken pieces of individual grains have not been widely separated. The black rims around the grains evidently formed prior to the fracturing of the grains since the rims are found only on the crystal faces and not on the broken grain boundaries (fig. 19). Away from the chill zones the rock contains 0.5 to 1.0mm aggregates of .05mm anhedral quartz grains (fig. 20). The individual grains have uniform extinction which suggests that they are primary features rather than microxenoliths. The groundmass contains fewer plagioclase microlites than that of the northern Moose Creek body, but there are more plagioclase phenocrysts in these rocks than in those of the northern body. The groundmass also contains some hornblende microlites and some extremely small opaque grains which may be magnetite. Away from the chilled margins, the groundmass also contains some very small anhedral grains of quartz and/or K-feldspar. Most of the rest of the matrix is extremely fine grained or glassy; the groundmass is trachytic near the contacts and chill zones and hyalopilitic in the center of the intrusive. Modal analyses are listed in Table 2, and a chemical

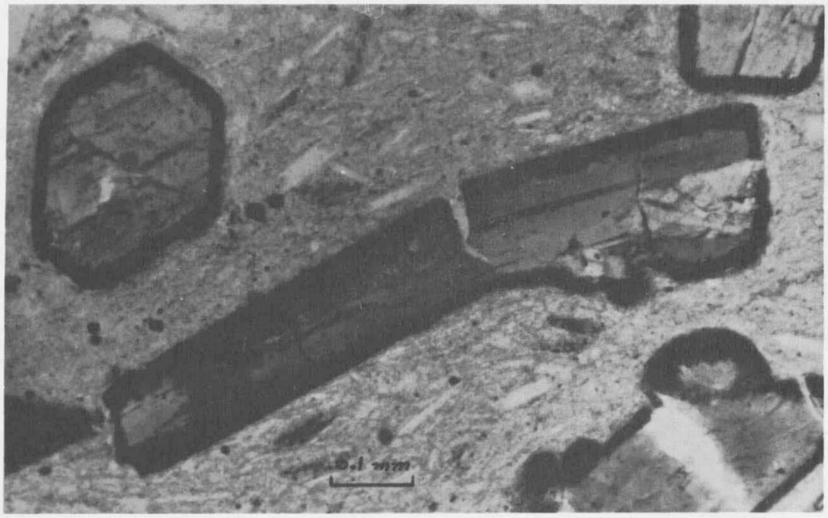


Figure 19. Photomicrograph of a hornblende phenocryst broken during emplacement of the southern Moose Creek intrusive. Note the pre-emplacement reaction rim of a very fine grained opaque mineral. Plane light.

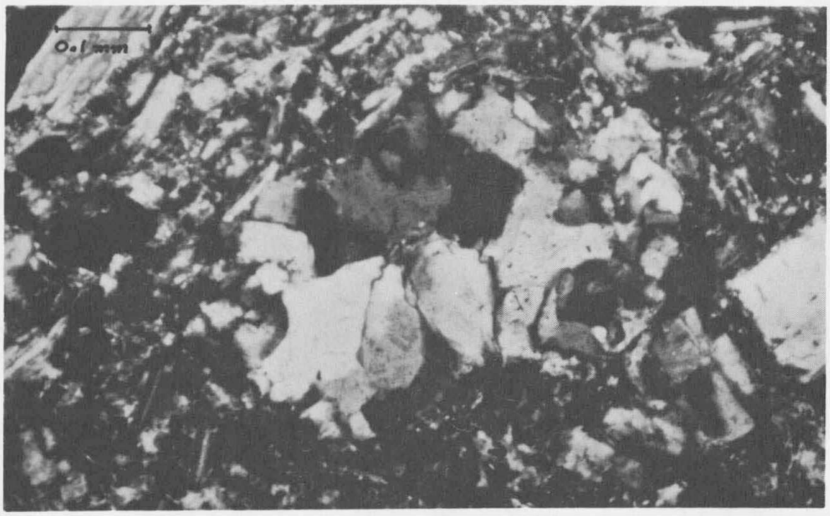


Figure 20. Photomicrograph of quartz aggregates in the groundmass of the southern Moose Creek intrusive. X-nichols.

analysis (McMannis and Chadwick, 1964) and CIPW norm are given in Table 3.

Upper Dry Creek Body

The upper Dry Creek dacite contains very few phenocrysts. Those that are present are of calcic andesine, biotite, magnetite, and hornblende. The andesine forms 1 to 2mm euhedral grains with oscillatory zoning. The biotite is present as 2 to 3mm flakes; in some specimens it has been replaced by hematite. Magnetite grains are subhedral and most are approximately 1mm across. Where it is present, hornblende forms 1mm-long grains which appear to be slightly rounded suggesting incipient resorption. Pleochroism of the hornblende is brown, and the grains have rims of a black opaque mineral. Small inclusions of plagioclase and magnetite are contained in the hornblende grains. In the trachytic groundmass, minute specks of opaque minerals, microlites of plagioclase, and some biotite flakes are surrounded by a brown or dark red glass. The biotite in the groundmass, like that of the phenocrysts, is commonly altered to hematite. By visual estimate the rock typically is 99 percent groundmass, and approximately 2/3 to 3/4 of all the phenocrysts are feldspar.

Lower Dry Creek Dacites

The dacites at lower Dry Creek are very glassy and strongly flow banded. Phenocrysts, which seem to account for only about one percent of the rock, are 1 to 3mm euhedral flakes of biotite, 1 to 3,, broken fragments of euhedral plagioclase, and sparse .5 to 1mm grains of partially resorbed quartz. The plagioclase displays oscillatory zoning, The trachytic groundmass consists of a few very small plagioclase microlites surrounded by glass and devitrified glass.

Big Creek Stock

The Big Creek stock typically contains a phenocryst assemblage of intermediate to slightly calcic andesine, biotite, altered hornblende, a little magnetite, and some partially resorbed quartz grains. The andesine grains are generally 1 to 5mm broken or cracked euhedral crystals. They display patchy and oscillatory zoning, and some of the larger grains seem to contain outlines of previously rounded plagioclase grains around which the euhedral crystals have formed. Extinction angles indicate that these rims are slightly more calcic than the cores. In altered specimens, plagioclase grains commonly have been selectively calcitized along certain zones while other zones remain unaltered. A few grains of andesine were observed which seem to be intergrown with biotite. Except in these relatively rare instances in which biotite is in anhedral intergrowth with plagioclase, the biotite in the Big Creek stock forms euhedral flakes which are approximately 1 to 3mm across. The outer portions of the biotite flakes commonly contain a fine scattering of an extremely fine grained opaque mineral, and the central portions of some of the flakes contain subhedral magnetite and anhedral feldspar. In most specimens the hornblende has been replaced by limonite or hematite, calcite, and in places epidote or chlorite. The outlines suggest that the hornblende had formed euhedral crystals which were 1 to 3mm long. Magnetite typically forms .1 to .5mm subhedral to euhedral grains in the groundmass. The groundmass is hypocrystalline allotriomorphic with very few plagioclase microlites. Some specimens collected near the contacts contain broken phenocrysts of augite which may have come from the andesite which the dacite intrudes. Thin section modes are listed in Table 2, and a chemical analysis (Chadwick, 1969) and CIPW norm are given in Table 3.

Point of Rocks Complex

Away from chilled margins the Point of Rocks dacite contains phenocrysts of andesine, hornblende, biotite, and magnetite. Quartz is very rare, but in places a few very small remnants of resorbed grains are present. The andesine forms euhedral crystals which are generally broken and are about 1 to 3mm in size. They typically show oscillatory and some patchy zoning. Many of the larger grains and fragments appear to contain partially resorbed andesine grains around which the outer portion of the final crystal has grown (fig. 21). Extinction angles suggest that the outer zones of these grains are more calcic (An_{46}) than the central portions of the grains (An_{39}). Smaller (.5 to 1mm) euhedral andesine grains without any apparent partially resorbed cores are also present in the phenocryst assemblage; these are An_{46}. In some grains the later portions of the andesine crystals have partially enveloped hornblende grains. The hornblende, whether or not it is in contact with plagioclase, is typically slightly frayed and rounded as if it had been partially resorbed. The grains are 1 to 2mm long and are rimmed by a slight amount of an opaque mineral. In some specimens the hornblende has been extensively replaced by calcite and hematite. Where it is fresh, it is

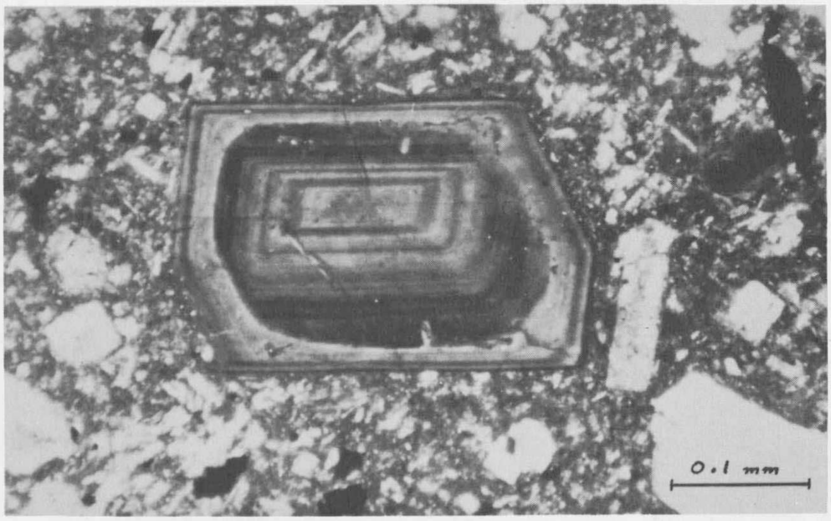


Figure 21. Photomicrograph of a plagioclase phenocryst from the Point of Rocks dacite. A euhedral rim of An_{46} surrounds a rounded and embayed core of An_{39}. X-nichols

pleochroic in dark greens to browns. Biotite is present in lesser amounts than hornblende. It generally forms 1 to 2mm flakes with very slightly frayed or ragged edges. Sparse inclusions of feldspar and magnetite can be observed in most of the flakes. The biotite is not as extensively rimmed by opaques as is the hornblende. Magnetite is most evident as .1 to .5mm subhedral grains in the groundmass. The groundmass itself is typically trachytic to hyalo-pilitic. Near the contacts the groundmass is trachytic, and the rock contains noticeably fewer phenocrysts. Representative modes are given in Table 2, and a chemical analysis (Chadwick, 1969) and CIPW norm are presented in Table 3.

Mill Creek Intrusives

The dacites in the Mill Creek area contain phenocrysts of quartz, plagioclase, biotite, hornblende, and magnetite. The quartz grains range from .5 to 5mm in size, and are rounded and embayed as if they had been partially resorbed (fig. 22). Some quartz grains are partially encircled by biotite flakes. The feldspar forms .5 to 5mm grains of intermediate to calcic andesine. They are euhedral and many grains are broken. Typically they display patchy and oscillatory zoning. Some grains appear to be intergrown with biotite. Most of the biotite in the Mill Creek dacites

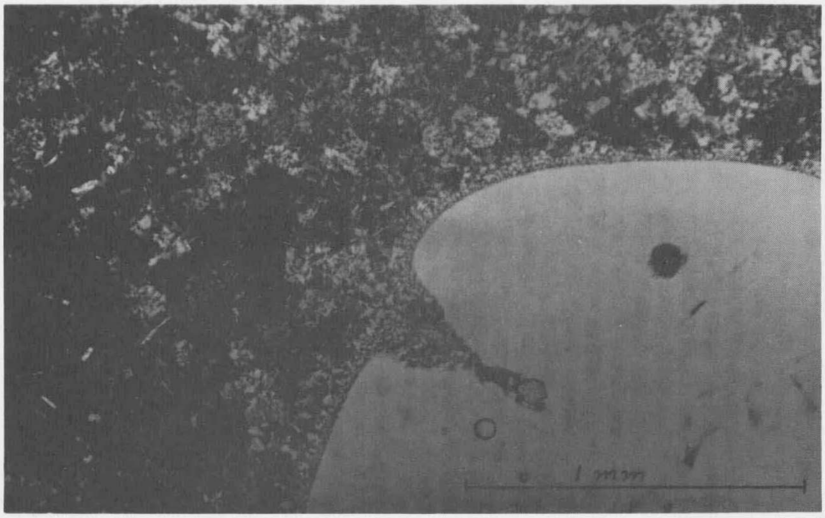


Figure 22. Rounded and embayed quartz phenocryst from the Mill Creek dacites. X-nichols

is not intergrown with other minerals, but instead forms euhedral to slightly corroded .5 to 3mm flakes which are surrounded by the groundmass. The biotite generally contains a little magnetite and feldspar, and it is rimmed by a very fine grained opaque mineral. Magnetite commonly forms very small subhedral grains in the groundmass. Most hornblende has been altered to calcite, magnetite, and chlorite, but where fresh it forms 2mm-long crystals which are slightly corroded and broken. The groundmass generally appears to be a micrographic intergrowth of quartz and sanidine mixed with plagioclase microlites. However, near the contacts the groundmass is partly grassy. Secondary replacement patches of calcite are present throughout some specimens. Representative modal analyses are listed in Table 2, and a chemical analysis from the Elbow Creek divide (J.T. Wilson, 1936) and CIPW norm are given in Table 3.

Emigrant Peak Dacites

The Emigrant Peak dacites of Basler's (1965) group B contain phenocrysts of intermediate andesine, biotite, and quartz. The andesine forms 1mm euhedral grains which are cracked and broken. They exhibit both patchy and oscillatory zoning, and in most samples they are extensively calcitized. The biotite forms fresh euhedral flakes which show no rimming by opaque minerals. Some of the flakes contain minor amounts of feldspar. Quartz is unusually common in these rocks; it generally forms 1mm grains which are partially resorbed. The groundmass is hypocrystalline allotriomorphic and contains principally quartz, feldspar, and glass with a few opaque grains scattered through it.

Basler's group A dacite was the most unusual dacite studied. The glassy border variety contains phenocrysts of sodic to intermediate andesine, orthoclase, and hornblende. The 1 to 2mm andesine grains display patchy and oscillatory zoning and are very slightly rounded. Much of the andesine has been partially replaced by calcite. Some of the grains are in anhedral contact with hornblende. Most of the hornblende in the specimens is entirely surrounded by matrix, however, and it shows nearly euhedral outlines. Pleochroism is bluish green. The hornblende generally has a slight rim of opaque minerals, and some is partially altered to chlorite. The orthoclase forms 1 to 2mm grains which are only slightly rounded and are much less altered than the andesine grains. The groundmass is hyalopilitic to trachytic and is seemingly composed of quartz, feldspar, and glass with minor opaques.

The coarser grained variety of the group A dacite contains phenocrysts of sodic to intermediate andesine, albite, partially resorbed quartz, and a little muscovite. In addition, some chlorite is present which is evidently pseudomorphic after hornblende. The andesine grains are 1 to 2mm broken euhedral crystals which show evidence of patchy zoning and are mostly replaced by calcite. The albite develops unusually large (10 to 25mm) crystals. these display oscillatory zoning which is more evident in hand specimen (fig. 14) than in thin section perhaps because compositional changes across the zones are slight. The borders of the albite crystals are ragged, and much matrix material and other phenocrysts are included in the albite crystals. Chlorite is present entirely as replacements of hornblende crystals; a few fragments of the hornblende still remain, and these display bluish-green pleochroism. The muscovite in these rocks form small (.1 to .5mm) euhedral flakes which commonly contain tiny needles of cummingtonite. The groundmass is a granular mixture of quartz, K-feldspar, and a few plagioclase microlites. The rock is generally extensively altered. Modes are listed in Table 2; no complete major element silicate analyses are available for these rocks.

Tom Miner Body

The Tom Miner body contains a phenocryst assemblage of plagioclase, hornblende, biotite, magnetite, and quartz. The plagioclase is very calcic andesine. It typically is present as 1 to 3mm clusters of elongate crystals with slightly rounded outlines. The grains show oscillatory and a slight amount of patchy zoning. The hornblende crystals are .5 to 3mm long and are slightly corroded and rimmed by a black opaque mineral. Most of the hornblende grains contain a little feldspar and magnetite. A few of the hornblende crystals are at least partially surrounded by plagioclase. Biotite appears as .5 to 2mm euhedral flakes which are only weakly rimmed by the opaque mineral. Some of the biotite seems to be an alteration product of the hornblende. The biotite generally contains a little feldspar and magnetite, and some of the flakes are intergrown with plagioclase phenocrysts. Magnetite typically crystallized as very small subhedral grains scattered throughout the groundmass. Quartz, where present, tends to form small 1mm aggregates of .2mm anhedral grains. They show no signs of resorption. The groundmass contains quartz, K-feldspar, plagioclase microlites, magnetite, and glass; the texture is trachytic near the contacts of the stock and hyalopilitic towards the center. Representative modes are given in Table 2; no chemical analyses are available for this body.

Cinnabar and Mol Heron Intrusives

The Cinnabar Basin and Mol Heron Creek dacites contain phenocrysts of calcic andesine, hornblende, biotite, a little magnetite, and a few quartz grains. The andesine is present as 1 to 5mm euhedral and broken crystals which which display well developed oscillatory zoning and minor patchy zoning. Some feldspar grains are intergrown with hornblende or biotite. The hornblende is typically corroded and broken; much has been either calcitized or hematized. The fresh hornblende displays brown pleochroism and has a reaction rim of a very fine grained opaque mineral. Some of the grains contain inclusions of feldspar. Where hornblende is intergrown with plagioclase, the grain boundaries are anhedral. The hornblende crystals are from .5 to 3mm long. The biotite in these rocks generally forms 1mm euhedral flakes, but in places it appears to have replaced hornblende. Some of the biotite flakes are partially encircled by plagioclase. The biotite commonly contains feldspar and magnetite, but the flakes are not rimmed by opaques. Small subhedral grains of magnetite are scattered through the groundmass. Quartz can be found in only a few specimens; in these it is in the form of small (.1 to 1.0mm) grains which have been partially resorbed. The groundmass is trachytic to hyalopilitic and evidently contains quartz, K-feldspar, plagioclase microlites, and glass. Representative modes are listed in Table 2; no chemical analyses are available for these rocks.

Little Trail Creek Complex

The dacite from Little Trail Creek contains phenocrysts of calcic andesine, hornblende, biotite, magnetite, and quartz. The andesine forms 1 to 4mm euhedral and broken grains with oscillatory and some patchy zoning. Portions of many grains are selectively calcitized. The hornblende has been replaced by calcite and limonite, but outlines of opaque rims suggest that the Little Trail Creek dacites contained .1 to 2mm grains of broken and slightly corroded hornblende. Biotite is generally fresh and forms euhedral flakes which are 1 to 3mm across. These flakes typically contain slight amounts of feldspar and magnetite, and lack opaque rims. Some of the biotite is intergrown with andesine, but most of it is entirely surrounded by the matrix. Small subhedral magnetite grains are disseminated throughout the matrix. A few small quartz grains are partially resorbed, but more commonly the quartz grains in these dacites are small 1mm aggregates of .2mm anhedral grains. The groundmass is generally a trachytic mixture of quartz, K-feldspar, plagioclase microlites, and glass. Limonite is present in some specimens as staining. Modes are listed in Table 2; no chemical analyses are available for rocks of this area.

PETROLOGY

The chemical and modal data in the preceding section indicate that most of the intrusives in the northern Gallatin and western Beartooth Ranges are rather similar to each other. The major differences which exist are related principally to the reaction textures of the phenocrysts.

Experimental studies of the crystallization trends in andesitic, dacitic, and rhyolitic magmas under various P_{total} and P_{H_2O} conditions (T.H.Green and Ringwood, 1968; Green, 1972; Stern and Wyllie, 1973; Lambert and Wyllie, 1974; and others) seem to help explain many of the modal and textural relations which were observed in the dacites of the present investigation. Under dry conditions at high pressure (30kb), quartz is the liquidus phase in liquids with compositions ranging from rhyolite almost to andesite (fig. 23). If anhydrous conditions are maintained while pressure is lowered, the quartz stability field leaves the liquidus and migrates towards the solidus; at 18kb quartz is still the liquidus phase in dacites but it is post-liquidus in andesites. At 9kb quartz is only a liquidus phase in rhyodacite where it coprecipitates with plagioclase (fig. 24, 25, 26) (Green and Ringwood, 1968). The addition of water has a profound effect on the stability

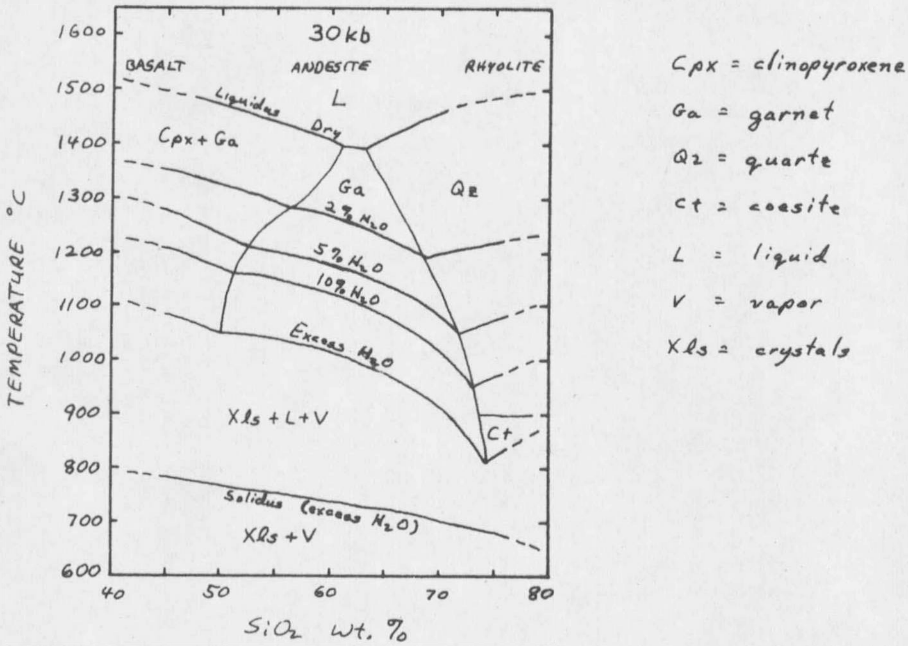


Figure 23. Effects of water on the liquidus temperatures and primary phases of calc-alkaline rocks at 30kb. Excess water varies from 20 to 25 wt.% with increasing silica content. (after Stern and Wyllie, 1973)

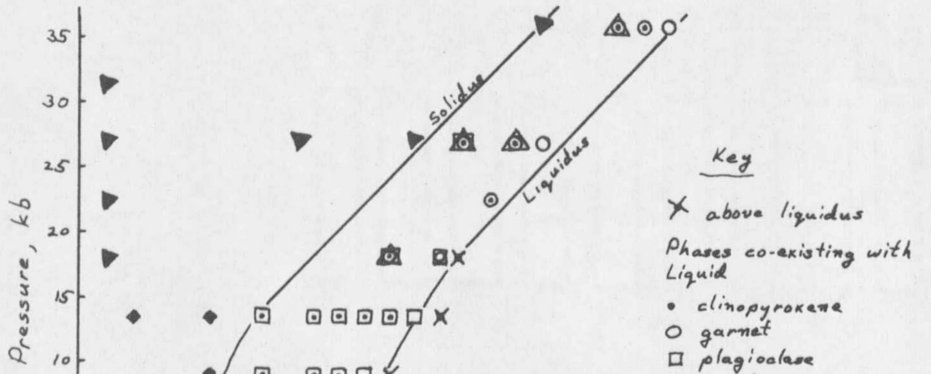


Figure 24. Results of dry experimental crystallization runs on andesite. (after Green and Ringwood, 1968)

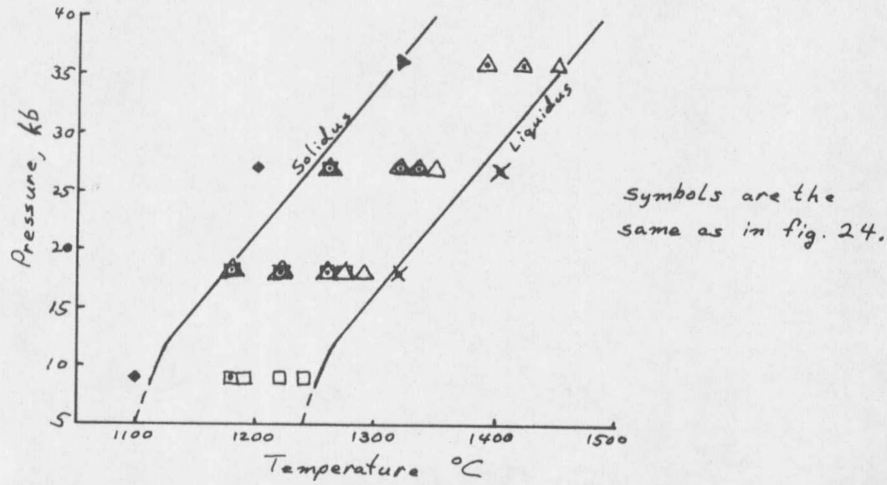


Figure 25. Results of dry experimental crystallization runs on dacite. (after Green and Ringwood, 1968)

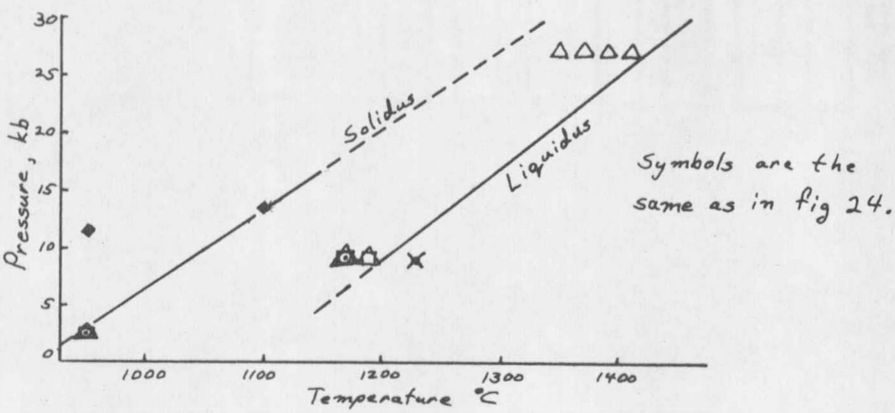


Figure 26. Results of experimental crystallization runs on rhyodacite. (after Green and Ringwood, 1968)

fields in these systems. At 30kb, just two or three percent of water drastically lowers the liquidus and solidus boundaries (Green, 1972; Stern and Wyllie, 1973) and restricts liquidus quartz to very silicic compositions (fig. 23) (Stern and Wyllie, 1973). Green's (1972) work with andesites at various pressures and water concentrations indicates that the first appearance of quartz is greatly delayed in the presence of even only a few percent water (fig. 27). He reports that water also has similar effects on the appearance of plagioclase; while it is a liquidus or near liquidus phase in andesite at pressures up to 18kb in anhydrous conditions, 5 percent water completely removes plagioclase from the liquidus so that it is retained in the melt even at very low pressures. While water in andesitic magmas delays the crystallization of quartz and plagioclase and tends to restrict these minerals to low pressures, it has been found to promote early appearance of amphibole at pressures up to almost 25kb (fig. 27) (Green, 1972; Lambert and Wyllie, 1974). With slightly less than 5 percent water at intermediate pressures, amphibole forms before plagioclase and well before quartz which is almost restricted to the solidus under these conditions. Green's data indicate that in the

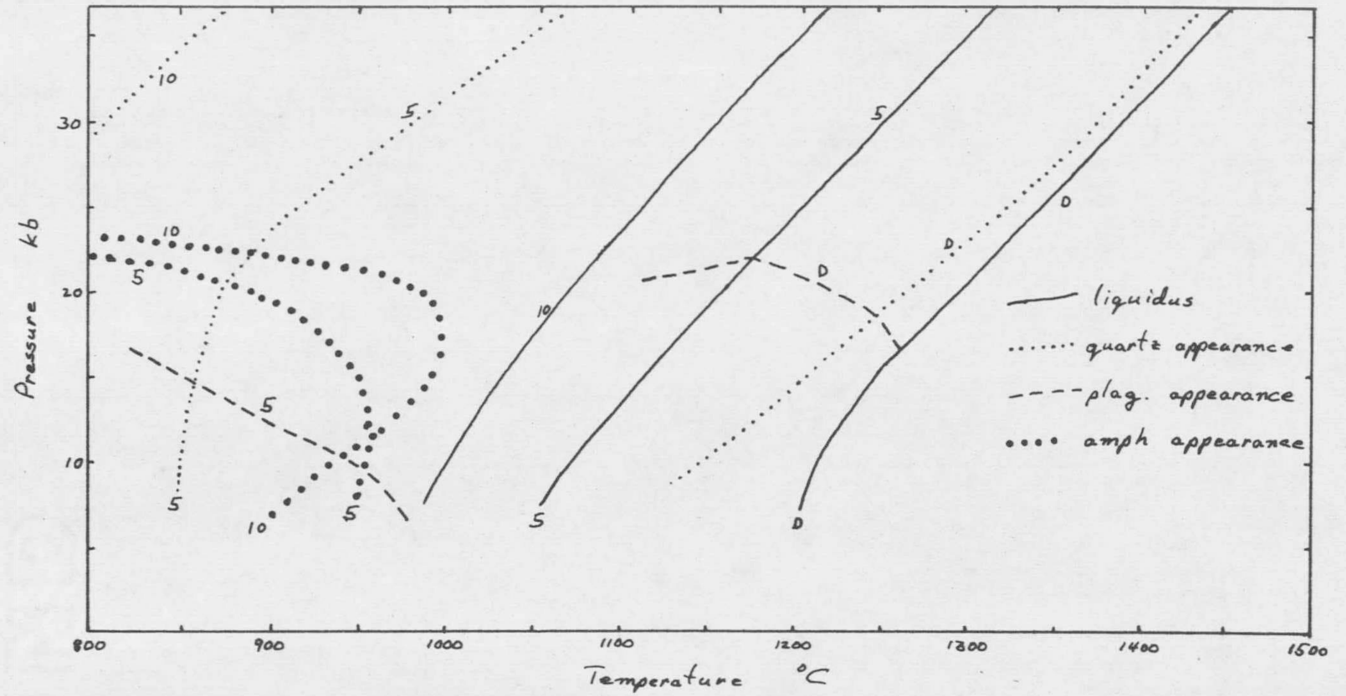


Figure 27. Combined P,T plot for anhydrous and hydrous experimental crystallization runs on andesite showing the effects of water on the liquidus and the first appearance of quartz, plagioclase, and amphibole. D dry; 5, 10 wt.% water content. (modified from Green, 1972)

presence of water, plagioclase forms before amphibole only at near surface pressures; at shallow to intermediate depths amphibole should precede plagioclase in the presence of water. He also noted that at low (but evidently not extremely low) pressures there is a fractionation trend which tends to increase Na/K.

Yoder (1969) and Green (1969) have studied the effects of pressure and water content on the albite-anorthite system, and have concluded that a decrease in the total pressure or an increase in the water pressure while temperature remains constant will cause a more calcic plagioclase to crystallize (fig. 28). Therefore one might expect plagioclase which formed at shallower depths or under more hydrous conditions to be more calcic than plagioclase which crystallized in similar rocks but at greater depths and/or under anhydrous conditions.

These experimental studies give us a framework to use in evaluating the observed characteristics of the dacites of the northern Gallatin and western Beartooth Ranges. Because the lower Dry Creek, Big Creek, Point of Rocks, Mill Creek, Emigrant Peak, Cinnabar-Mol Heron, and Little Trail Creek dacites all contain partially resorbed quartz phenocrysts, their magmas all probably started to crystallize under

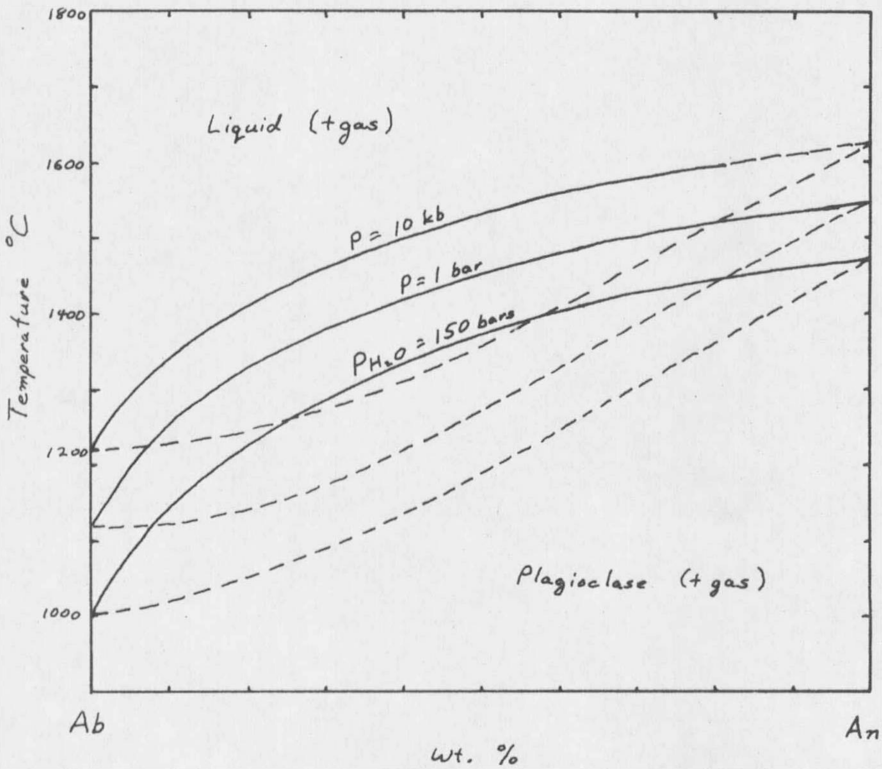


Figure 28. The albite-anorthite system at 1 bar and 10kb and the albite-anorthite-water system at 150 bars. (after Yoder, 1969)

anhydrous conditions of at least 18kb pressure (60km). The presence of partially resorbed quartz phenocrysts further implies that the rates of ascent and cooling of these magmas were rapid enough so that the resorption reactions were halted by solidification of the rocks or by re-entry into the quartz stability field before complete resorption was accomplished.

The two shallow intrusions on Moose Creek evidently had a slightly different crystallization history. The similar chemical, modal, and textural characteristics of these probably nearly contemporaneous bodies suggest that they may have originated from a mutual source. Both of these dacites lack any evidence of early quartz which would have indicated early crystallization at deep anhydrous conditions. The high groundmass percent in the modes (Table 2) of both of these bodies suggests that they were quenched fairly rapidly upon emplacement; the northern intrusive evidently cooled even more quickly than the southern one. Both of these dacites contain a normal amount of amphibole in comparison with the other bodies studied, but they are low in plagioclase phenocrysts. The more rapidly chilled northern intrusive contains fewer feldspar phenocrysts than the southern one. This suggests that amphibole crystallization was nearly completed by the time of emplacement, but plagioclase had only begun to grow by that time. The chemical compositions of these rocks also differ slightly from those of the other analyzed bodies in this study; the Moose Creek intrusives both have a higher than usual sodium content (Table 3). In view of the experimental results of Green and Ringwood (1968), Green (1972), and Lambert and Wyllie (1974) presented earlier, the observed features seem to suggest that crystallization of the Moose Creek magmas began at moderately shallow or intermediate depths under hydrous conditions. This interpretation seems to be supported by the feldspars also; they are consistently small, euhedral, and essentially uniform in composition, and they are three to five percent higher in anorthite content than the feldspars of most of the other bodies.

The Tom Miner intrusive, which also lacks evidence of early quartz, contains feldspars which are similarly high in anorthite content; perhaps this dacite has a crystallization history similar to those of the Moose Creek bodies. The modal differences between the Tom Miner and the Moose Creek dacites may mainly reflect a deeper emplacement depth which allowed the Tom Miner rocks to grow more late feldspar phenocrysts.

In contrast to the Moose Creek intrusives, the dacites which contain partially resorbed quartz grains (fig. 22) were evidently drier and deeper when they first began to crystallize. The amphibole and biotite in them indicates that their magmas must have acquired water as they rose to the surface. The resorbed cores and relatively more calcic rims of the larger plagioclase grains in the Big Creek and Point of Rocks dacites (fig. 21) suggest that some of the plagioclase had started to crystallize prior to the ascent of and introduction of water to these magmas.

The presence of high pressure anhydrous assemblages in some bodies and the absence of such remnants in others does not rule out the possibility that these magmas may still have had similar origins. In fact, the remarkable similarities of their chemistry and most petrographic characteristics suggests that they did have similar origins. The minor differences which can be observed probably developed as the result of differences in their emplacement histories; magmas which rose and solidified quickly probably retained some remnants of early quartz and more sodic feldspar, while magmas which rose more slowly or paused longer at intermediate depths where water was acquired probably completely resorbed any crystals which had formed earlier in deeper and drier conditions.

The high pressures and anhydrous conditions indicated by the early phenocrysts in some of these dacites suggest that the magmas originated in the upper mantle or lower crust. The presence of later hydrous phases such as hornblende indicate that the magmas acquired water during their ascents; a logical source for this water would seem to be the Precambrian basement rocks in the crust.

The unusual large zoned albite crystals in the coarser-grained portions of the Emigrant Peak group A dacite are thought to be porphyroblasts. The cummingtonite needles observed in the muscovite in these dacites indicates that these rocks have been subjected to amphibolite facies metamorphism which could have produced the albite porphyroblasts. This metamorphism probably happened during hydrothermal mineralization of the stock as was suggested by Basler (1965).

RELATION TO REGIONAL VOLCANISM

Recently, Lipman and others (1972) proposed that the Absaroka-Gallatin volcanic province may have formed over an eastward-dipping subduction zone which they pictured as extending all along the Rocky Mountain front. They noted a general eastward increase in potash content across the front and suggested that this trend is comparable to the trends in potash contents in the volcanic rocks of island arcs which have been described by Kuno (1959), Hatherton and Dickenson (1968, 1969), Dickensen (1972), and others. In support of this hypothesis they cited a paper by Chadwick (1970) which had noted that the eastern eruptive belt of the Absaroka-Gallatin volcanic province tends to be more potassic than the western belt. Actually, this trend is poorly defined in the Gallatin and western Beartooth Ranges (fig. 29), and Chadwick (1970) and L.L. Love (1972) have pointed out that the potash content of rocks of the eastern belt is highest in the southeastern portion of that belt. These rocks comprise most of and are mainly restricted to the Sunlight group of Smedes and Prostka (1972), and Love (1972) has suggested that these shoshonitic rocks should be considered as a distinct subprovince of the Absaroka-Gallatin volcanic province.. Love feels

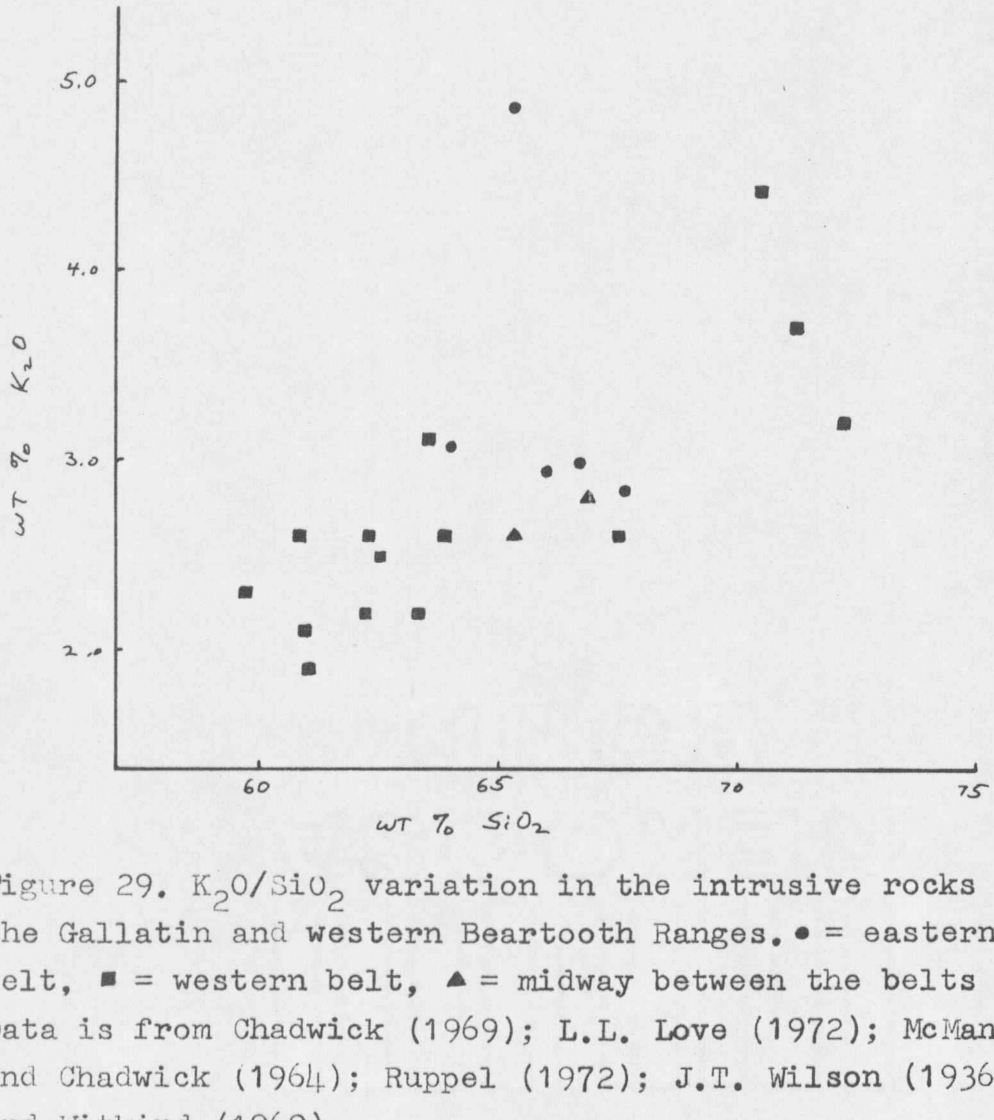


Figure 29. K_2O/SiO_2 variation in the intrusive rocks of the Gallatin and western Beartooth Ranges. ● = eastern belt, ■ = western belt, ▲ = midway between the belts Data is from Chadwick (1969); L.L. Love (1972); McMannis and Chadwick (1964); Ruppel (1972); J.T. Wilson (1936); and Witkind (1969).

that the island arc analogy is strained because the Sunlight rocks are the intermediate age group in the province, while the potassic rocks in a typical island arc system generally appear late in the volcanic history of the arc. Recent syntheses of radiometric dates of Cenozoic rocks in the northwestern United States (Armstrong and Higgins, 1973; Armstrong, 1974) also tend to cast doubt upon Lipman and others' subduction zone hypothesis. On a map drawn by Armstrong and Higgins (1973), isochrones which represent the beginning of andesitic volcanism in the northwestern U.S. generally trend east-west and decrease in age from north to south. Age dates from various localities in the Absaroka-Gallatin province (Chadwick, 1970; Smedes and Prostka, 1972; and L.L. Love, 1972, 1974) seem to fit well with this pattern. Armstrong (1974) reports that similar rocks which are time-correlative with the Absaroka-Gallatin volcanics probably extend at least as far west as the eastern edge of the Columbia River basalts at Council, Idaho. Instead of the north-south trend implied by Lipman and others' subduction zone theory, radiometric dates of volcanic and plutonic rocks suggest that during the early Cenozoic an east-west trending wave of igneous activity swept across much of the northwestern part of the country.

SUMMARY AND CONCLUSIONS

The dacites of the Gallatin and western Beartooth Ranges are shallow intrusives of early to middle Eocene age which typically form small domes, stocks, and plugs where they have intruded Absaroka-Gallatin volcanic rocks, and generally form sills and laccoliths where they have intruded Paleozoic and Mesozoic sedimentary sequences. With the exception of the sills and laccoliths of the Gallatin Horst, the intrusions post-date extensive displacement along major faults in the area, and the locations of the intrusives are probably governed by the faults. Two sub-parallel lines of northwest-trending, northeast-dipping reverse faults, the Cherry Creek-Squaw Creek- Cooke City-Rattlesnake Mountain trend and the Spanish Peaks-Gardiner trend, seem to have been the most important controlling influences on the locations of the intrusive and eruptive centers of the province. Where the two northwest trends approach each other in the northern Gallatin Range, the northeast-trending Moose Creek thrust fault evidently was also an important controlling factor. However, the north-east trending Deep Creek normal fault and the postulated Big Creek-Point of Rocks fault probably were subordinate to the Squaw Creek-Cooke City trend in controlling the locations of igneous activity in these areas.

The Gallatin Horst seems to be unique because most of the intrusives within it seem to pre-date the major faults in the area. Rather than being controlled by the faults, the Gallatin Horst intrusives seem to have controlled the formation of the horst. It is thought that as the Gardiner fault plastically deformed the sedimentary rocks on its south side into a syncline, normal faults developed along the margins of the intrusive-filled Gallatin anticline which was too rigid to be flexed.

The dacitic intrusives of the northern Gallatin and western Beartooth Ranges are very similar petrologically. Most of the differences between them are textural differences which seem to reflect slightly different rates of magma ascent rather than radically different initial source material. The presence of remnants of high pressure anhydrous crystalline phases in most of these dacites suggests that their magmas originated in the upper mantle or lower crust. The presence of intermediate to relatively low pressure hydrous phases indicates that the magmas acquired water as they rose through the crust. This may have been derived from the Precambrian basement rocks. Most of the magmas seem to have risen through the crust fairly quickly because most of these rocks contain remnants of high pressure-low water content liquidus phases which would have been unstable phases during the ascent of the magmas. However, the two Moose Creek bodies and the Tom Miner intrusive which do not contain any relects of these deep anhydrous phases probably rose more slowly and any early quartz or plagioclase which had crystallized was completely resorbed by these magmas at hydrous intermediate depths.

The spatial, temporal, and magnetic characteristics of the dacite intrusives in the northern Gallatin and western Beartooth Ranges are summarized in figure 30. From this, it can be seen that at least four intrusive episodes have taken place in this area; one was during late Golmeyer Creek or early Hyalite Peak time (upper Dry Creek), another was during mid-Hyalite Peak time (north and south Moose Creek, followed (?) by Point of Rocks and possibly Emigrant Peak), another group was emplaced during magnetically reversed late Fortress Mountain-early Mount Washburn time (Big Creek, lower Dry Creek, Cinnabar-Mol Heron, and Little Trail Creek), and at least one later episode during post-reversed Sunlight time (Mill Creek, Tom Miner, and possibly Emigrant Peak). At least one other earlier episode can be inferred from dacite clasts which are contained in early

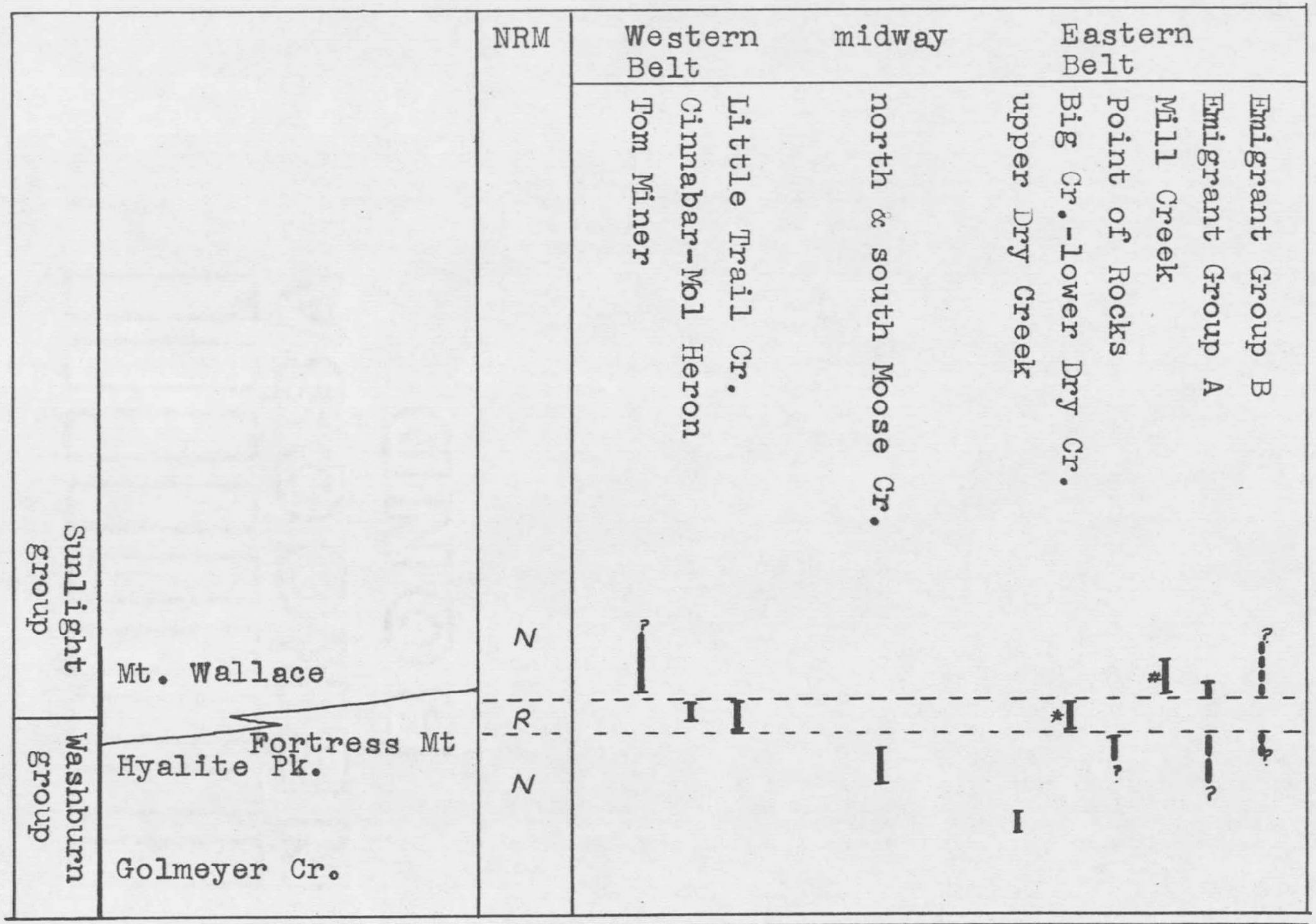


Figure 30. Spatial, temporal, and magnetic characteristics of the Gallatin-Beartooth dacites. * age date = 49.5 ± 1.5m.y.
age date = 49.0 ± 1.7 m.y.

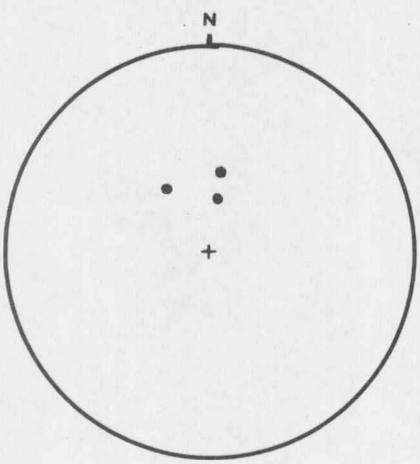
Golmeyer Creek volcanics which were described by Chadwick (1969).

Review of spatial-temporal-compositional variations in the Absaroka-Gallatin volcanic province does not lend much support to Lipman and others' hypothesis that the province formed over an eastward or northeastward dipping paleo-subduction zone analogous to contemporary circum-Pacific destructive plate boundaries. In fact, recent syntheses of radiometric data for the northwestern United States (Armstrong and Higgins, 1973; Armstrong, 1974) suggest that the province formed at the eastern end of an east-west trending wave of igneous activity which swept southward during early to mid-Cenozoic time. The geochronology of the Absaroka-Gallatin volcanic province (Chadwick, 1969; Smedes and Prostka, 1972; L.L. Love, 1972, 1974) seems to be in agreement with this interpretation.

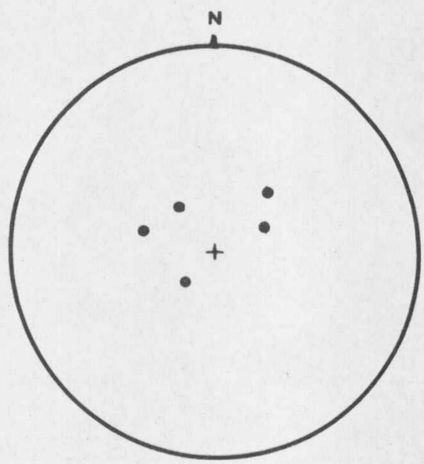
APPENDIX

APPENDIX

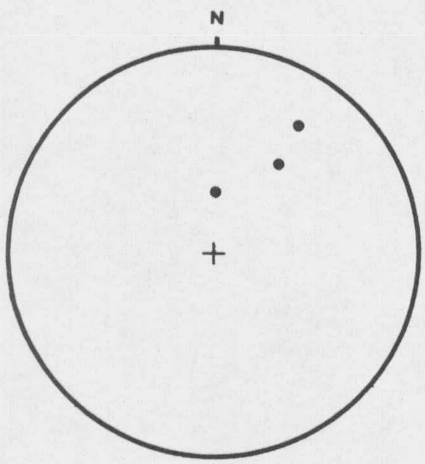
NRM orientations for intrusive bodies of the Gallatin and western Beartooth Ranges. Equal area plots show the position of the north-seeking pole. Solid symbols = lower hemisphere; open symbols = upper hemisphere. Circles = measurements made with a portable fluxgate magnetometer; squares = final orientations in specimens treated with AC current with a field strength of at least 250 oe, and measurements made with a laboratory astatic magnetometer.



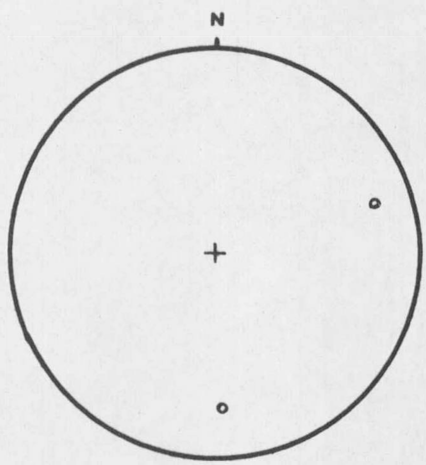
Southern Moose Creek



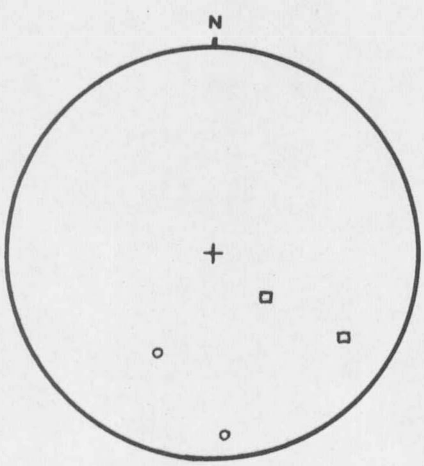
Northern Moose Creek



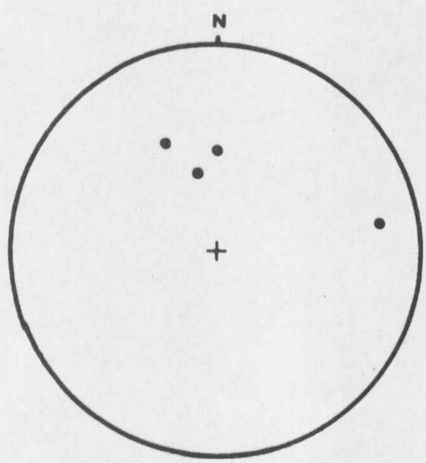
Upper Dry Creek



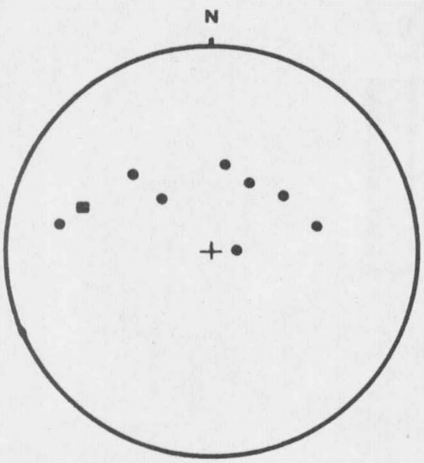
Lower Dry Creek



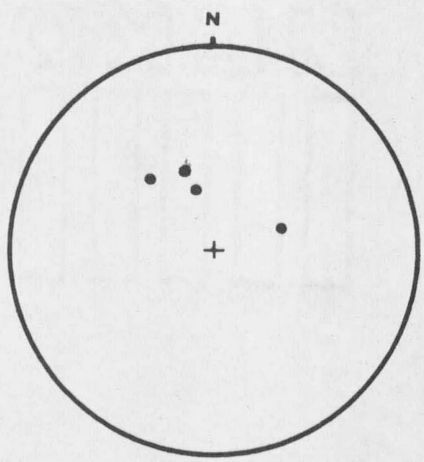
Big Creek



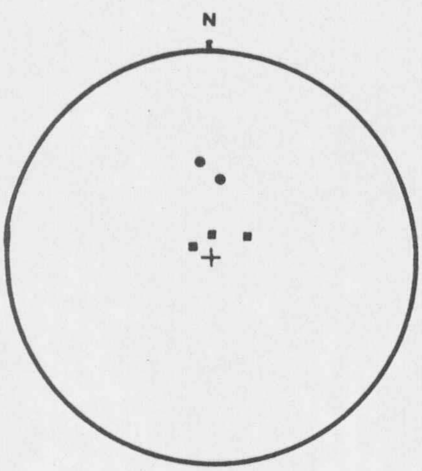
Point of Rocks



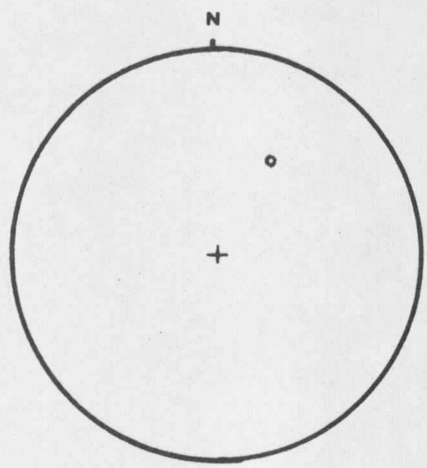
Mill Creek



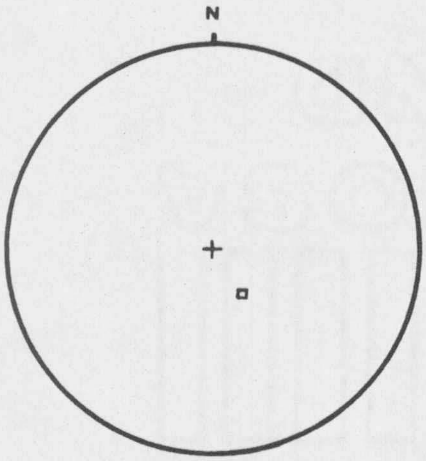
Emigrant Peak



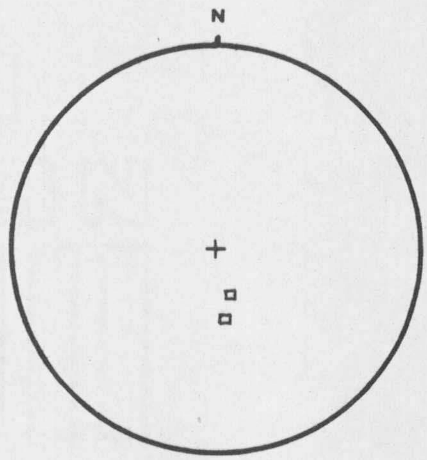
Tom Miner



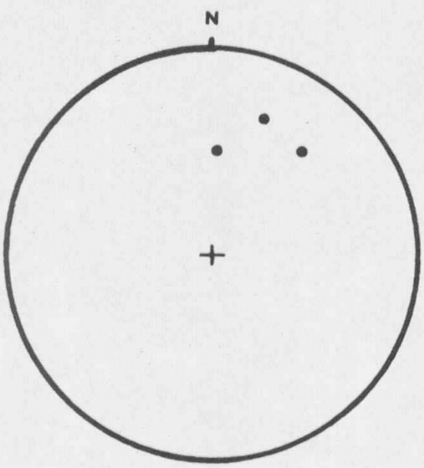
Cinnabar Basin



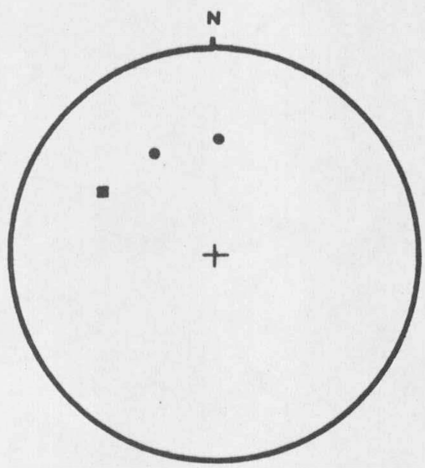
Mol Heron Creek



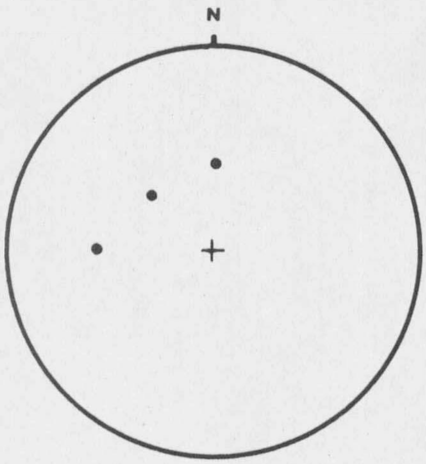
Little Trail Creek



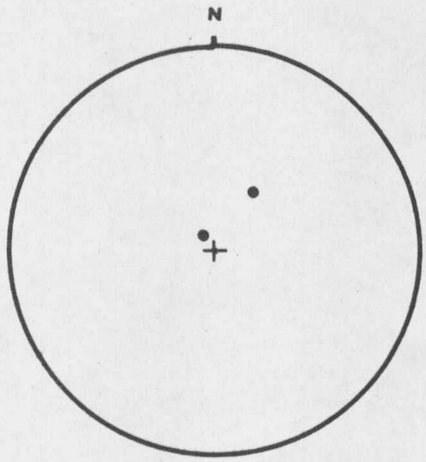
Black Butte



Meldrum Mountain



Rainbow Lake



Bunsen Peak

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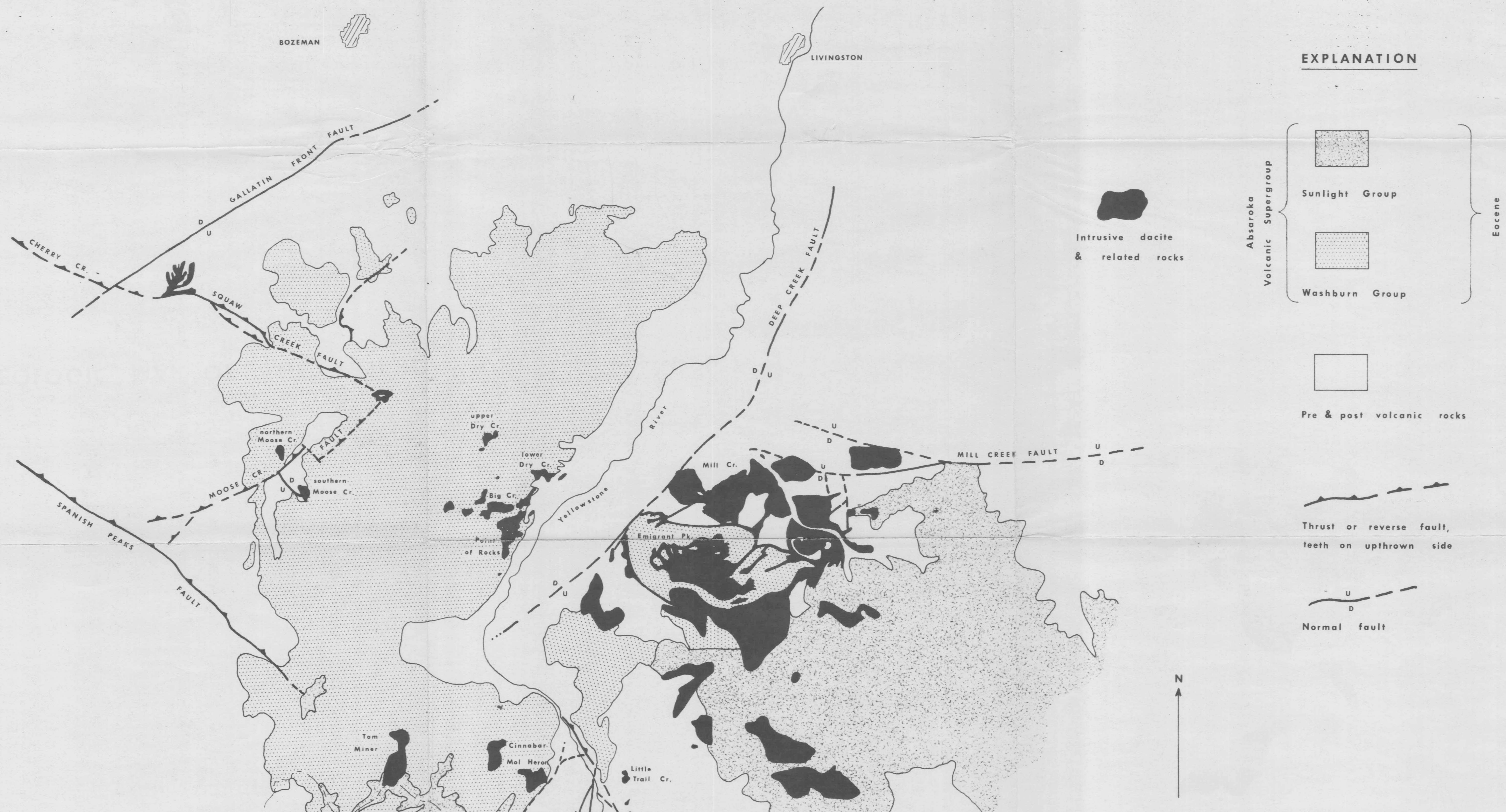
GEOLOGIC MAP OF THE ABSAROKA VOLCANIC ROCKS OF THE GALLATIN AND WESTERN BEARTOOTH RANGES, MONTANA AND WYOMING



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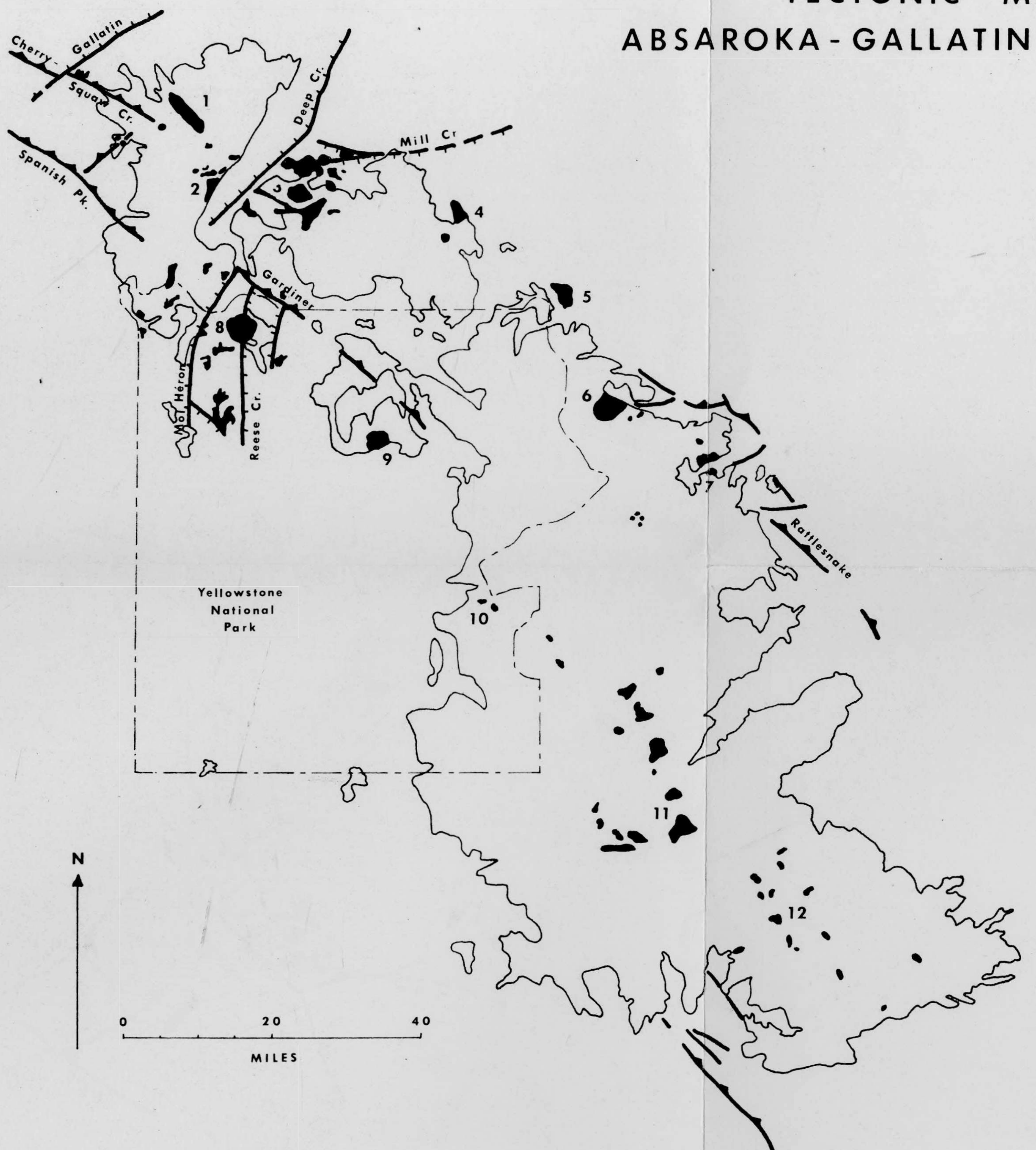
TECTONIC MAP OF THE ABSAROKA-GALLATIN VOLCANIC PROVINCE



EXPLANATION

Absaroka Volcanic Supergroup — Eocene and Oligocene

Eruptive centers and intrusive rocks

Outline of volcanic and volcaniclastic rocks

Reverse or thrust fault teeth on upthrown side

Normal fault hachures on downthrown side

PRINCIPAL ERUPTIVE CENTERS

1 Northern Gallatin dike swarm
2 Point of Rocks
3 Emigrant Peak
4 Independence
5 Cooke City
6 Crandall
7 Sunlight
8 Electric Peak
9 Mt. Washburn
10 Sylvan Pass
11 Ishawooa
12 Kirwin

SOURCES

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McMannis and Chadwick, 1964
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