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IGNEOUS GEOLOGY OF THE FRIDLEY PEAK QUADRANGLE, MONTANA

by

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Palisade Falls plunge over columnar andesite of Hyalite Peak Volcanics.
Andesitic breccias are exposed from falls to top of Palisade Mountain.

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Preface

Field work on the quadrangle was begun in 1962, emphasizing an examination of the igneous rocks that dominate the bedrock geology. This report is a summary of the geology, emphasizing igneous geology, as reported by Chadwick (1969), and as modified by additional information (Smedes and Prostka, 1972; Chadwick, 1972, 1981; Shaver, 1978). A preliminary geologic map of the quadrangle was published (Chadwick, 1969), but the map accompanying the present report shows geology in more detail and with relation to topography. Mapping was done using 1:24,000 scale topographic maps and altimeter in more rugged, timbered country and air photos in the more open areas. Field assistants included A. L. Basler, W. W. Boberg, J. Elliott, W. Hotchkiss, D. A. Howard, T. D. Irwin, W. Lustgraaf, and W. A. Van Voast. Much of the mapping was supported by National Science Foundation grants G-24326 and GP-2912.

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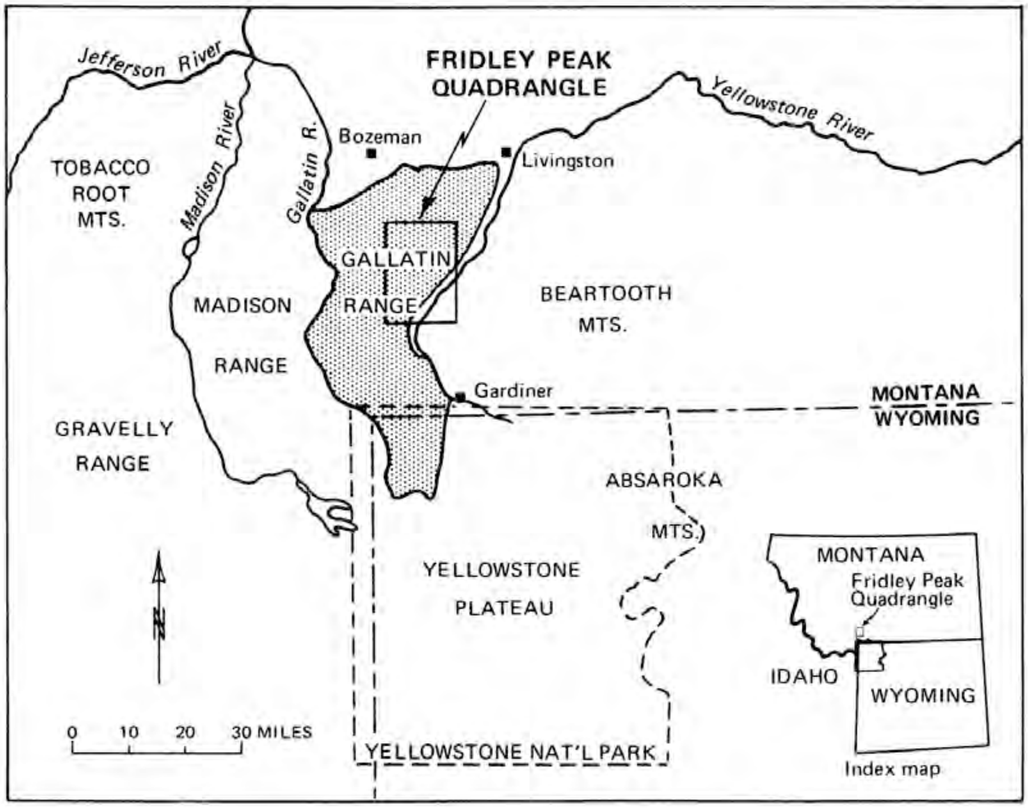

Figure 1—Index map of Fridley Peak quadrangle, Montana.

Introduction

The Fridley Peak quadrangle is located in the northeastern Gallatin Range of southwestern Montana (**Figure 1**), from 45°15′ to 45°30′N. latitude and from 110°45′ to 111°W. longitude. The Gallatin Range, together with the Madison Range to the west, forms a continuous structural block in which Precambrian metamorphic basement rocks are overlain in places by infolded Paleozoic and Mesozoic sedimentary rocks. Eocene volcanic rocks unconformably overlie these older rocks in the Gallatin Range portion of the block and dip gently eastward toward the Yellowstone Valley. This valley bounds the Gallatin Range on the east. The eastern edge of the Yellowstone Valley in and north of the Fridley Peak quadrangle consists of a major range-front fault, the Deep Creek fault, along which the Beartooth Mountains block has been uplifted on the east. The southeastern corner of the Fridley Peak quadrangle includes a portion of the Deep Creek fault and adjacent Beartooth Mountains block.

To the north, the Gallatin Range is bounded by a range-front fault from the Gallatin Valley and it is adjacent to the Bridger Range and Crazy Mountains basin northeast of Bozeman. To the south, the Gallatin Range is in contact with rhyolites of the Yellowstone Plateau.

Relief in the Fridley Peak quadrangle ranges from high peaks such as Hyalite Peak, 10,299 feet (3,160 m); Fridley Peak, 10,150 feet (3,116 m); and Overlook Mountain, 10,276 feet (3,155 m), to the floor of the Yellowstone Valley at about 4,900 feet (1,500 m). The principal streams such as Eightmile, Fridley, Dry and Big creeks, drain eastward and southeastward via canyons to the Yellowstone River, but in the northwestern part of the quadrangle, drainage is to the north and west into Hyalite Creek (formerly called Middle Creek).

Regional igneous geology

In Eocene time, extensive volcanism erupted throughout the Montana-Wyoming region and resulted in the deposition of lavas, breccias and tuffs of the Absaroka-Gallatin volcanic field. Volcanism was dominantly andesitic in composition; associated intrusives and plugs include a range of rock compositional types but consist largely of dacite in the Gallatin Range, which is in the northwestern part of the volcanic field. Much of the igneous material was emplaced along two subparallel, NW-trending chains of volcanic-intrusive centers. The northeastern of the two chains, which has been termed the Eastern Absaroka belt, trends through the Fridley Peak quadrangle (Chadwick, 1970).

From the southeastern end, this belt includes the Sunlight and Crandall centers in Wyoming; Cooke City, Independence and Emigrant Peak-Chico Peak centers in Montana southeast of the Fridley Peak quadrangle; Point of Rocks in the southeastern part of Fridley Peak quadrangle; and a swarm of NW-trending dikes in the northwestern part of the quadrangle. Further northwest, the belt of eruptive centers is in line with the Squaw Creek Laramide reverse fault, which is termed the Cherry Creek fault further northwest (McMannis and Chadwick, 1964). The Red Mountain Eocene rhyolitic volcanic center near Norris, Montana, is located along the Cherry Creek fault. The fault zone appears to represent a major zone of weakness in the crust, which has served as a locus of movement and as a conduit for magmatic activity during the period 80 to 40 million years ago, and particularly during the Eocene (Chadwick, 1981). Thus, the Gallatin Range volcanics and related intrusives are part of a zone of Eocene igneous activity that can be traced from the southern Absaroka Mountains of Wyoming to the vicinity of Norris, Montana, a distance of over 150 miles (250 km).

Pre-Tertiary rocks

Precambrian metamorphic rocks are exposed in the southeastern corner of the quadrangle on the upfaulted Beartooth Mountains block southeast of the Deep Creek fault. Lithologies include hornblende-quartz schist, mica-quartz schist and micaceous quartzite. The hornblende-quartz schist ranges from fine to medium grained and contains crystals of green hornblende in elongated bands and subradial aggregates. Small recrystallized quartz grains form lenses and stringers between the hornblende grains. The rocks are foliated in a N 45-50°E direction, approximately parallel to the Deep Creek fault. Perhaps the fault was in part controlled by the bedrock foliation. The foliation dips generally northwest at various angles. Lineation is locally present and plunges northwest to northeast at gentle to moderate angles. The rocks of the Beartooth Mountains underwent major metamorphism about 2.6 billion years ago (Reid and others, 1975).

Paleozoic and Mesozoic sedimentary rocks are infolded into the metamorphic rocks in the northern part of the quadrangle. They crop out in the northwestern corner and in a small area in the northeastern corner of the quadrangle. Units recognized in the northwestern area include the Madison Group (Mississippian), Amsden Formation (Mississippian-Pennsylvanian), Quadrant Formation (Pennsylvanian), Phosphoria Formation (Permian), Ellis Group and Morrison Formation (Jurassic), and Kootenai Formation and Colorado Group (Cretaceous). Beds dip generally northeastward and eastward. In the northeast corner of the quadrangle, Cretaceous shales are exposed.

Eocene igneous rocks

Golmeyer Creek Volcanics

The oldest Eocene sequence of volcanic rocks, the Golmeyer Creek Volcanics, is exposed along Golmeyer and Dry creeks in the southeastern part of the quadrangle (Chadwick, 1969). These rocks consist of pyroxene and hornblende-pyroxene andesite flows and breccias intruded by a sill of andesite porphyry. The base of the sequence is not exposed, and at the top is an erosional unconformity overlain by the next youngest unit, the Hyalite Peak Volcanics. The Golmeyer Creek sequence appears to be at least 2,000 feet (615 m) thick.

Especially in the lower part of the sequence, the rocks are broken by numerous faults and are argillized, hematized, propylitized and locally pyritized. Breccia clasts include various andesitic and dacitic lithologies, commonly strongly altered. Some breccia units are well stratified and contain sandy lenses; others are crudely stratified. Most breccias appear epiclastic in origin.

Units within the sequence, including the sill, have been delineated along the ridge between Dry and Golmeyer creeks but are difficult to follow away from this ridge. These units are labeled A to H from oldest to youngest (Chadwick, 1969), and are delineated on cross section A-A' and in **Table 1**.

The Golmeyer Creek Volcanics are slightly less mafic than the Hyalite Peak Volcanics, having a higher hornblende/pyroxene ratio and slightly more sodic plagioclase (An_{35-49}) where measured. Paleomagnetic measurements show them to have normal natural remanent magnetization (NRM). Smedes and Prostka (1972) considered them to be Late Wasatchian in age and probably older than the Sepulcher Formation (Early Bridgerian Washburn Group) of Yellowstone National Park.

Table 1—Units of the Golmeyer Creek Volcanics.

Unit	Thickness (ft.)	(m)	Lithologic type	Description
H	70	21	Breccia	Clasts of white, pink and gray argillized, hematized biotite dacite and andesite in fragmental matrix; grades downward into unit G.
G	650 ±	200 ±	Flow	Dark-gray to greenish-gray augite-hypersthene-hornblende andesite; contains red hematite specks.
	up to 600	up to 185	Sill	Hornblende-augite andesite porphyry; pilotaxitic to swirly pattern of microlites; irregularly intrudes units F and G.
F	400 ±	120 ±	Flow	Blue-black to gray hornblende-augite andesite, considerably propylitized and hematized. Along Dry Creek, locally coarsens near intrusive masses and veinlets of granodiorite and dacite, where it may contain sparse biotite.
E	250 +	77 +	Breccia	Gray to greenish-gray; probably epiclastic; contains clasts of altered pyroxene and hornblende andesite, some dacite; crudely stratified with one well-stratified sandy unit.
D	130 +	40 +	Breccia	Similar to unit E but green to tan; strongly chloritized.
C	140	43	Flow	Black, microcrystalline andesite with augite, subordinate hypersthene, minor chloritized hornblende (?).
B	130	40	Breccia, tuff breccia	Brown, tan, gray-green; altered clasts of pyroxene and hornblende andesite and some dacite.
A	270 +	83 +	Flow	Black augite andesite, sparse hypersthene; base not exposed.

Hyalite Peak Volcanics

The Hyalite Peak Volcanics (Chadwick, 1969) extend across most of the Fridley Peak quadrangle; have normal NRM; and have been correlated with the lower part of the Sepulcher Formation of Yellowstone National Park (Smedes and Prostka, 1972). These volcanics are considerably less altered and faulted than are the Golmeyer Creek Volcanics; contain augite and hypersthene with little hornblende; and have plagioclase crystals, where measured, of An_{45-58}. The sequence is 2,830 feet (869 m) thick where exposed on Flanders Mountain north of Hyalite Peak and probably exceeds 4,000 feet (1,230 m) near Hyalite Peak when the basal buried portion is considered. The sequence unconformably overlies the Golmeyer Creek Volcanics and a late or post-Golmeyer Creek dacitic stock (Td_1).

The rocks consist of intercalated lava flows and breccias. The flows range in thickness from about 10 to 200 feet (3 to 60 m). Some individual flows exhibit a flow banded and/or glassy base; a columnar to blocky-jointed middle portion; and an oxidized, partly brecciated upper zone (**Front Cover**). Some flows are autobrecciated throughout, and others are massive but grade laterally into autobreccia (**Figure 2**). Autobrecciated zones are not distinguished from flows on the map because of the intimate interpenetration of these units.

The rocks are finely crystalline, black to dark gray, and may contain plagioclase phenocrysts. Augite and hypersthene are present in roughly equal amounts; hornblende is relatively sparse and commonly rimmed with magnetite, suggesting crystallization at deeper levels and subsequent reaction with late-stage fluids in the mag-

Figure 2—Autobrecciated andesite of Hyalite Peak Volcanics exposed north of Fridley Creek.

ma. Exposures of flow units are excellent on the upper slopes of Hyalite Peak, Overlook Mountain, Flanders Mountain and Fridley Peak. The top of the sequence is eroded away.

Epiclastic breccia units are intercalated with sequences of flows and flow breccias. In places, autobreccia grades laterally into crudely stratified epiclastic breccia, suggesting that the epiclastic material was largely derived from the breakup of lava flows as they moved along and became mixed with water.

Distinct epiclastic units are distinguished on the map. Overall in the quadrangle, they are less abundant than the lava-autobreccia lithology in the Hyalite Peak Volcanics. A reference section on Flanders Mountain measures 27 percent epiclastic breccia and 73 percent flows containing pockets and lenses of flow breccia (Chadwick, 1969).

The epiclastic units may be poorly to well stratified. Subangular to subrounded clasts of pyroxene andesite and subordinate hornblende andesite and dacite of various textures and colors commonly range up to 3 feet (1 m) in diameter. In the poorly stratified units, clasts tend to be matrix supported; the matrix consists of finely comminuted andesite and clay. Glass shards have not been observed. These breccias appear to be of mudflow origin. Crude stratification may be visible on a scale of several meters. More finely stratified silty, sandy and conglomeratic units are intercalated and may represent thin, soupy mudflows or muddy stream and sheetwash deposits. Locally, the breccias contain petrified wood fragments and leaf imprints.

A major mudflow unit extends east-west across the quadrangle from the West Fork of Hyalite Creek drainage along Eightmile Creek canyon to Antelope Butte east of the quadrangle, for a distance of over 12 miles (19 km). On Antelope Butte, it is 1,000 feet (310 m) thick. Other mudflows piled up to a thickness of 1,700 feet (520 m) along Pine Creek in the northeastern corner of the quadrangle. This area evidently consisted of one or more steep canyons that were filled by the mudflows in Eocene time. Undoubtedly mudflow-deposit configurations were strongly influenced by modification of drainage by the near-contemporaneous lava flows. The mudflows probably came from the west and southwest and originated by autobrecciation of lava flows.

Isolated, small, channel-like deposits of conglomerate and breccia-conglomerate occur locally at the base of the Hyalite Peak sequence, i.e., above Palace Butte, at Grotto Falls, Palisade Falls (**Front Cover**), and along Hyalite Creek. In some places, these deposits appear to be distinctly older units representing pre-lava-flow deposits in stream channels—clasts of Precambrian metamorphic rocks and Paleozoic carbonates are present. In other places, similar deposits grade upward into Hyalite Peak epiclastic breccia units and appear to represent an early phase of Hyalite Peak volcanism. Neither of these types of conglomeratic deposits is shown separately on the map.

The Hyalite Peak Volcanics predate a crosscutting dacite stock on Big Creek, which has been dated radiometrically by the K-Ar method at 49.5 ± 1.5 million years (m.y.). Andesites on the West Fork of Mill Creek east of the quadrangle yield a date of 53.5 ± 2.3 m.y. (Chadwick, 1970), and may be contemporaneous with either Golmeyer Creek or Hyalite Peak extrusions.

The Hyalite Peak Volcanics exposed in the Fridley Peak quadrangle evidently erupted from the Point of Rocks volcanic center in the southeastern part of the quadrangle and in part from fractures represented by NW-trending dikes in the central and northwestern part of the quadrangle. Andesite dikes plotted on the map are of more than one age. Some cut post-Hyalite Peak dacites; however, many dikes appear to be feeders for the Hyalite Peak flows. Traced upward, a dike near Twin Falls on the West Fork of Hyalite Creek (sec. 3, T. 5 S., R. 6 E.) appears to merge into an overlying lava flow.

At the Point of Rocks volcanic center, epiclastic breccias and vesicular vent breccias and agglomerates are intercalated with autobrecciated lava lenses and sheets. Major breccia sheets dip outward quaquaversally from the Point of Rocks area and become more stratified. The Point of Rocks breccias, which are treated as one unit on the map, are intruded by numerous andesite and dacite dikes and by dacite plugs (**Figure 3**). To the west, the breccias are overlain by a thick sequence of flows of younger Hyalite Peak age.

Dacite

Dacites occur in the quadrangle as stocks, plugs, dikes, veinlets and clasts in breccias. Evidently several episodes of dacitic intrusion took place in Eocene time as indicated by various relative age relationships. Most dacites are light gray, pink or white and contain andesine and biotite crystals, plus or minus hornblende and quartz. Textures range from aphanitic to glassy; structures include massive, flow banded or autobrecciated.

Dacitic emplacement must have preceded the deposition of the lower portion of the Golmeyer Creek Volcanics because dacitic clasts are present in breccia units B, D and E (**Table 1**). However, the oldest exposed dacite body (labeled Td_1 on the map) is located on upper Dry Creek. The dacite body is argillized and hematized and intrudes through unit G of the Gol-

Figure 3—Dacite plugs intruding andesitic breccias of Hyalite Peak age at Point of Rocks volcanic center.

meyer Creek Volcanics. If the dacite clasts in unit H are from this stock, the stock is late Golmeyer Creek in age. Alternatively, the stock may be post-Golmeyer Creek. It is pre-Hyalite Peak, because it is overlain unconformably by Hyalite Peak flows. The upper part of the stock is highly weathered and fragmented. The stock has normal NRM.

Veinlets and irregular masses of dacite to granodiorite of uncertain age intrude unit F of the Golmeyer Creek Volcanics in sec. 9, T. 6 S., R. 7 E., south of Dry Creek. Pyritization of the andesites north of Dry Creek, in NW¼ sec. 10, may be related to a dacitic intrusion beneath the surface.

Dacitic plugs intrude Point of Rocks andesitic breccias of Hyalite Peak age and in places have shed talus blocks that have become incorporated into other units of Hyalite Peak breccia. These plugs, along with related dikes, have normal NRM and are interpreted to be of Hyalite Peak age. They are labeled Td_2 on the map.

Stocks along Big Creek (Td_3) cut Hyalite Peak andesites and are the youngest exposed group. As indicated earlier, the major stock on Big Creek (sec. 16, 17, 20, 21, T. 6 S., R. 7 E.) yields an age of 49.5 m.y. These dacites have reversed NRM and intrude dacite of Td_2 age along the boundary of sec. 21 and 28, T. 6 S., R. 7 E. Shaver (1978) placed the Td_3 dacites approximately on the boundary between the Washburn and Sunlight groups of Smedes and Prostka (1972).

The Td_3 dacitic eruptions did not end Eocene igneous activity; yet another andesitic episode is indicated by andesitic dikes with normal NRM, which intrude Td_3 dacite in sec. 14, T. 6 S., R. 6 E., and sec. 11, T. 6 S., R. 7 E. **Table 2** summarizes the alternation of dacitic and andesitic episodes as illustrated in the Fridley Peak quadrangle.

Table 2—Summary of igneous episodes in Eocene, Fridley Peak quadrangle.

Event no.	Dacite sym.	NRM	Lithology and relationship
8		N	Andesite dikes cutting Big Creek stocks.
7	Td_3	R	Dacite stocks on Big Creek.
6		N	Hyalite Peak andesites overlying Point of Rocks breccias.
5	Td_2	N	Dacite plugs and dikes intruding Point of Rocks breccias; contemporaneous with some breccias.
4		N	Hyalite Peak breccias and massive units of Point of Rocks complex; associated flows north of Point of Rocks.
3	Td_1	N	Dacite stock on Dry Creek.
2		N	Golmeyer Creek andesites.
1		?	Dacite represented by clasts in lower units of Golmeyer Creek breccias.

Post-Eocene rocks

Miocene sediments

Miocene white, tuffaceous, poorly consolidated siltstones and claystones overlie the Eocene volcanic sequence in the Yellowstone Valley. They are exposed in bluffs along the west side of Hepburn Mesa, a flat bench between the Yellowstone River and Dailey Lake. The exposed siltstone is 175 feet (54 m) thick, contains vertebrate remains, and has been radiometrically dated at 17.1 m.y. (Hughes, 1980). A Pliocene(?) stream gravel 80 feet (25 m) thick overlies the siltstone and is in turn overlain by the basalt flows described below.

Pliocene basalt

Eroded remnants of Pliocene olivine basalt form a capping on Hepburn Mesa and are also exposed in and near a railroad ballast quarry in sec. 5, T. 6 S., R. 8 E. The basalt is medium gray to black and contains olivine, augite and labradorite crystals. Columnar jointing is prominent. Some zones within the basalt are autobrecciated. The basalt has reversed NRM and the lower unit, Tb_1, yields a whole-rock K-Ar date of 5.4 m.y. (Chadwick, 1969, p. 153).

Two flows can be delineated (Bush, 1967). The lower flow (Tb_1) has prominent ophitic texture, especially near the top and bottom. The upper flow is black to dark gray, non-ophitic and has a magnetite-bearing, glassy matrix. Each flow is about 60 feet (18 m) thick where fully exposed. Slumping of basalt down the west side of Hepburn Mesa creates the illusion of several additional flows.

A sequence of two older basalt flows occurs south of Hepburn Mesa adjacent to the quadrangle on the south. This basalt sequence is black and contains olivine crystals. Cobbles of this basalt are present in the Pliocene gravel beneath the younger basalt sequence at the railroad ballast quarry. This older basalt has normal NRM and is dated at 8.4 m.y. (Bush, 1967, p. 23).

No vent or conduit sources for the Hepburn Mesa basalts have been identified. Basalt may have risen along the Deep Creek fault since it is the nearest major structure penetrating to depth. The basalts did not come from the Gardiner area upriver, because the basalts at Gardiner are much younger, probably 0.6 m.y. (Chadwick, 1981).

Quaternary

Quaternary deposits in the quadrangle are unconsolidated sediments and consist of alluvial deposits of the upper Yellowstone River Valley and other streams, glacial deposits, colluvium and landslide and slump deposits. These types are undifferentiated on the map. Glaciation in the higher peaks has produced cirques, horns, rock basins and other erosional features. Glaciation in the upper Yellowstone River Valley in and near the quadrangle has produced terminal and lateral moraines, outwash deposits, ice marginal channels, polished and grooved outcrops and erratic boulder fields (Montagne and Chadwick, 1982).

During Pinedale time, the Yellowstone ice sheet advanced twice down the valley from the Yellowstone Plateau. Erratic boulders up to 1,500 feet (460 m) above the valley floor at Big Creek attest to the thickness of the ice. Prominent ice marginal channels extend along the west side of the upper Yellowstone River Valley from Big Creek northward to Eightmile Creek.

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