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GEOLOGY OF THE INDEPENDENCE AREA SWEET GRASS AND PARK COUNTIES, MONTANA

by
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of the requirements for the degree of
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INTRODUCTION

General Statement

The northern part of the Absaroka volcanic field of northwestern Wyoming and southwestern Montana consists of a thick series of Eocene volcanic ejecta that have been deeply incised during a long period of erosion. The source for most of the volcanic rocks has been attributed to many local vent areas which in turn have been deeply buried by subsequent volcanic activity. No large volcanic cones remain to emphasize the exact position of major intrusive centers. This report presents the description of a large cone complex more than 18 miles in diameter, now dissected by erosion, which was a major eruptive center for volcanic rocks that cover an extensive area just north of Yellowstone National Park. A major hiatus separates the Eocene volcanic rocks of the northern Absaroka volcanic field from the Pliocene volcanic rocks that occur in the northern part of Yellowstone Park.

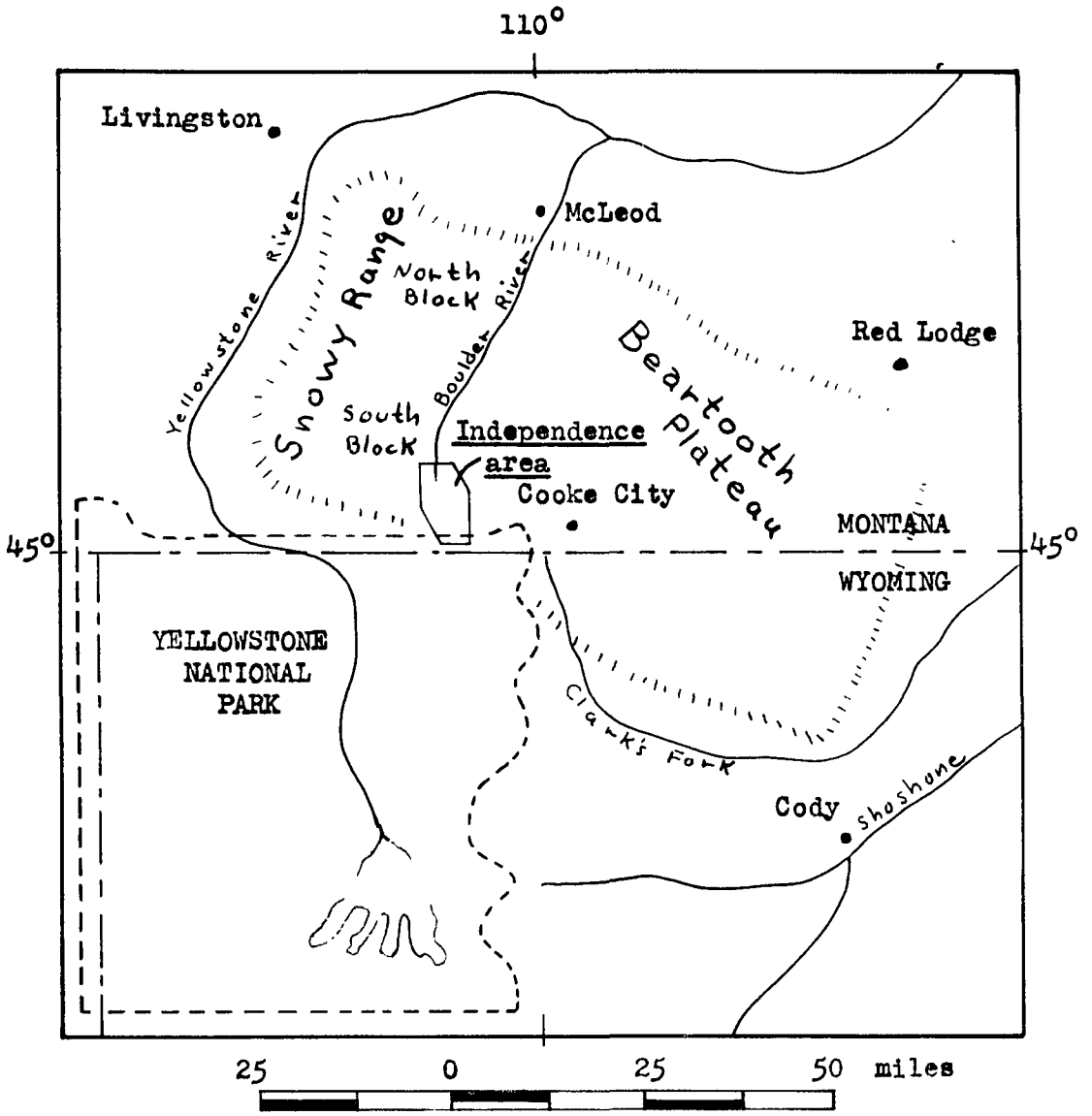


FIGURE 1.- Index map of southwestern Montana and northwestern Wyoming, showing location of the Independence area.

Location and Accessibility

The Independence area is just northwest of the northeast corner of Yellowstone National Park (Fig. 1). It lies in a region, which has not been land surveyed, bounded by parallels 45° 00' and 44° 20' north latitude and about six miles on each side of the meridian 110° 15' west longitude. The area covers approximately 185 square miles.

The northern half can be reached by a dirt road that leads up to the headwaters of the main Boulder River drainage 35 miles due south of McLeod post office. The southern half, which lies in the Absaroka Primitive Area, can only be reached effectively by horse or on foot up the Slough Creek drainage through Yellowstone Park.

Forest Service trails follow all major valleys. Well developed game trails supplement the Forest Service trails so that the heavily timbered portions of the low-lying areas can be covered readily on foot.

Previous Geological Work

The general geology of the area was mentioned briefly along with a geologic map of the Livingston one degree quadrangle in Folio No. 1 of the U. S. Geological Survey geologic atlas series (Iddings and Weed, 1894). A small part of the area covered by that report was studied in greater detail by Emmons (1908). Lobonoff (1960) attempted to re-evaluate part of Emmons' work. Brown (1957), Butler (1961) and Courtis (oral communication) have mapped areas immediately

to the south, southeast and the northeast, respectively, of the Independence area.

Present Work

The area was mapped during the summers of 1959, 1960, 1961 and a part of the summer of 1962. All of the geological data were plotted on U. S. Department of Agriculture vertical aerial photos of 1:15,850 scale and later transferred to a topographic base map with a scale of 1:31,680. A part of each of the following 15 minute quadrangle sheets (1: 62,250) was enlarged for use as a base: Cutoff Mountain, Mount Wallace, Mount Gowan and Mount Douglas, all which are located in Montana.

The laboratory phases consisted of detailed petrographic examination of 115 thin sections. The optical properties of the plagioclase were determined by means of a four-axis universal stage. Modal analyses were greatly facilitated by selective chemical staining of the orthoclase and plagioclase feldspars.

Acknowledgments

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Gratitude is also extended to the personnel of Yellowstone National Park and the Gallatin National Forest, who imported to the writer their knowledge of accessible routes into the Absaroka Primitive area.

The field work was greatly aided by Fred Fisher and Michael Paradis of Wayne State University who acted as field assistants during the summers of 1959 and 1960 respectively.

This study was made financially possible through support from a National Science Foundation Grant to Wayne State University under the direction of Dr. W. H. Parsons for the summers of 1959 and 1960. Additional financial aid was awarded by the Graduate School of the University of Michigan and the Montana Bureau of Mines and Geology at Butte, Montana. The summer field work of 1961 was made possible by a grant from The Society of the Sigma Xi and RESA Research Fund.

PHYSIOGRAPHY

The principal physiographic divisions of the region correspond to the major structural elements as shown in Figure 1. The perimeter of the Beartooth uplift, north and south blocks of the Snowy Range, and the Absaroka Mountains are well defined, but no previous map has adequately delineated the area where these three units merge.

The Beartooth and Snowy Range blocks are characterized by youthful dissection (Fig. 2) of the Precambrian summit peneplain (Bevan, 1925), with canyons more than 4,000 feet deep. The Absaroka Range is more spectacularly developed through the formation of an alpine topography with a relief in excess of 3,500 feet. The maximum relief in the Independence area is 4,200 feet. The lowest altitude is at 6,750 feet in the Slough Creek drainage near Silver Tip Ranch, and the highest point is Monument Peak at an altitude of 10,988 feet above sea level. Nearly all of the high ridges throughout the area average about 10,500 feet above sea level, and most of the valleys are near 7,750 feet above sea level.

A high, unbroken, southeast-northwest ridge that passes diagonally across the area forms the southwest border of the zone representing the onlap of volcanic rocks over the Precambrian surface. This ridge (Fig. 3) serves as a distinct divide for the drainage system. The headwaters of the Boulder River are on the north side of this ridge and the northward drainage empties into the Yellowstone River, sixty miles away, near Big Timber, Montana. Slough, Buffalo, and



FIGURE 2. View looking north across the north block of the Snowy Range. The Boulder River has cut deeply into the Precambrian metamorphic rocks. The northern edge of the Independence volcano appears as a high ridge in the right-hand portion of the photograph.



FIGURE 3. View of the major ridge that trends through the Independence area. This high ridge forms a major divide for the drainage system of the region. Photograph taken from the top of Monument Peak looking due south.

Hellroaring Creeks are on the southwest side of the divide. These creeks flow south and empty into the Yellowstone River just inside the northern boundary of Yellowstone Park. The headwaters for the Mill Creek drainage lie in the northwest part of the Independence area; these streams flow west and empty into the Yellowstone River in Yellowstone valley.

The evidence for rigorous alpine glaciation is remarkably preserved in the U-shaped valleys and the many cirques that appear on the north side of the major bisecting divide. Features of major valley floors are the broad flat meadows developed on thick alluvial fill. These wide grassy meadows contrast sharply with the heavily timbered slopes that merge into high, bare craggy ridges (Fig. 4).



FIGURE 4. View showing the alpine-type topography formed from the erosion of the volcanic rocks of the northern Absaroka volcanic field. View looking southeast. Pilot and Index Peaks near Cooke City, Montana appear in the left background.



FIGURE 5. View showing the summit peneplain of the Beartooth Plateau in the youthful state of erosion. Photograph taken from the top of Monument Peak looking due east.

PRECAMBRIAN AND PALEOZOIC ROCKS

INTRODUCTION

The Beartooth Mountains consist of a wedge-shaped crustal block of metamorphosed Precambrian sedimentary rocks. The Beartooth block is structurally highest on the northern and eastern edges where it is bounded by steep thrust faults. The surface of the block slopes gently southwestward where it passes beneath a veneer of Paleozoic strata and a thick volcanic cover. The zone in which the Paleozoic strata and volcanic rocks lap onto the Precambrian marks the northernmost edge of the Absaroka volcanic field. For the most part this zone of onlap is poorly exposed due to the dense overgrowth of vegetation.

Precambrian Rocks

General Statement.- Precambrian metamorphic rocks throughout the entire Beartooth Mountains consist only of pre-Beltian units, which include mainly granitic gneisses, migmatites with subordinate amounts of biotite-garnet schists, hornblende gneisses and minor amphibolites. Although the Precambrian rocks constitute the core of the Beartooth Mountains they appear only in the northeastern part of the Independence area where the Cenozoic volcanics lap onto the Precambrian rocks. The metamorphic rocks are poorly exposed in this zone. Immediately northeast of this zone the Precambrian surface is conspicuously exposed as a high plateau which has

been deeply dissected and is still in the youthful state of erosion (Fig. 5).

The Beartooth Mountains have been subdivided into three topographic elements by Iddings and Weed (1894): (1) Beartooth Plateau, (2) north block of the Snowy Range and, (3) south block of the Snowy Range. Wilson (1936) described the south Snowy Range block (Fig. 1) as dipping gently to the northeast and the north Snowy Range block dipping to the southwest. Brown (1961, Pl. I) corroborated the northeast dip of the south Snowy Range block in north-central Yellowstone Park. In the Independence area attitudes on erosional remnants of early Paleozoic strata reveal a gentle dip to the southwest. This disparity, on a part of the south Snowy Range block, can be accounted for by postulating either local warping or faulting (see Structural Geology).

During the field investigation for this report emphasis was placed on the distribution of erosional remnants of early Paleozoic strata and detailed mapping of Cenozoic volcanic rocks; only limited study i.e., field observations, were made on the Precambrian rocks in the Independence area. Butler (personal communication) studied the Precambrian rocks just northeast of the Independence area and has supplied the details on their petrology.

Rock Types.- Granitic gneiss is the major Precambrian rock type. Other important units include biotite-garnet schist, massive biotite amphibolite, hornblende gneiss, amphibolites and biotite and hornblende migmatites. Butler

(personal communication) states that there are several types of dikes: regionally metamorphosed ortho-amphibolites, late Precambrian diabase dikes that in most places trend about N 30° W, and Tertiary andesite and dacite dikes. Foliation in the granitic gneiss, in other gneisses, and in the schists indicates a series of open folds whose axial planes strike N 10° W and plunge about 15 degrees south. Hornblende and fold-axis lineations are parallel to the axes of major folds. Most of the fold axes plunge to the north. Locally pegmatite dikes are present and conform to the trend of the major folds. Butler emphasizes that the petrology and structure of the Precambrian rocks is similar to that described by Eckelman and Poldervaart (1957) and Harris (1959) in the Quad Creek area which is located in the eastern part of the Beartooth Mountains.

Petrology.- Granitic gneisses and biotite schists appear to be the two dominant metamorphic rocks in the vicinity of the Independence area. Six specimens of granitoid gneiss, as described by Butler (personal communication), have a compositional range of 30-40% quartz, 7-34% microcline, 2-18% biotite, 23-43% albite, and 0-10% muscovite. Compositional range for seven biotite schist specimens is 2-11% albite-oligoclase, 23-49% quartz, 30-48% biotite. Accessory minerals include garnet, apatite and rounded zircon. According to Heinrich (1956, p. 174) this composition of the schists reflects the lower range of the amphibolite facies. Quartz-feldspar rocks could represent the original sedimentary rocks.

Detailed work by Eckelman and Poldervaart (1957), Harris (1959) and Butler (1959) indicates a sedimentary origin for most of the Beartooth Precambrian rocks. The evidence includes: (1) mappable compositional units that are laterally persistent, (2) remnants of sedimentary quartzites and iron formation, (3) recognizable structures of sedimentary origin i.e., gradations and bedding planes, and (4) rounded zircons with length: breadth ratios similar to zircons in rocks of known sedimentary origin.

Correlation and Age.- Heinrich (oral communication) has divided the Precambrian of southwestern Montana into six major stratigraphic units:

(6) Sedimentary rocks of the Belt Series.
(5) Numerous widespread diabase dikes that cut all of the preceding units.
(4) Post-Stillwater Intrusives (e.g., the Beartooth Range granites).
(3) The Stillwater complex and associated unmetamorphosed ultrabasic intrusives.
(2) Post-Cherry Creek- Pre-Cherry group intrusives (e.g., Dillon granite gneiss and Pinto metadiorite of the Little Belt Mountains) that are variably metamorphosed.
(1) Cherry Creek - Pre-Cherry series which consist of a complex assemblage of interfingering metasedimentary and meta-igneous rocks.

The stratigraphic relationships and relative ages of the Cherry Creek and Pre-Cherry group are still an unsettled problem in southwestern Montana. The main distinction between the two series seems to be that the Cherry Creek series is mostly metasedimentary in origin and contains quartzite and marble beds, whereas the Pre-Cherry has a large percentage of presumed meta-igneous rocks and little or no quartzite

and marble. Heinrich and Rabbitt (1960, p. 11) estimated the minumum total thickness of the Cherry Creek in its type area to be 30,000 feet, with some marble layers as much as 7,900 feet.

According to Butler (oral communication), pre-Beltain rocks of the westernmost Beartooth uplift apparently are mostly metasedimentary in origin and include quartzite and some marble; therefore, they may be closer in composition to Cherry Creek series than Pre-Cherry group. However, Butler continues, it is not intended that the name Cherry Creek series be applied to the Beartooth rocks nor is an equivalence in age implied.

Rb-Sr and K-A ages of five samples from granitic gneisses from the Beartooth Mountains indicate an age of approximately 2,750 million years (Gast et al., 1958, p. 326). The stratigraphic position of the age-dated granitic gneisses with respect to the mafic dike swarms, regional granitization, folding, and mafic intrusion have led to a tentative geologic chronology in the Beartooth-Absaroka Mountains as presented in Table 1.

TABLE 1.- Geologic chronology in the Beartooth-Absaroka Mountains. Data modified after Poldervaart and Bentley, (1958, p. 8)

GEOLOGIC EVENT	DESCRIPTION	AGE
Glaciation	Extensive erosion followed by glacial activity	Pleistocene
Volcanism	Wide spread intrusive and extrusive activity, thick accumulation of volcanic flows and ejecta	Eocene to Pliocene
Laramide Revolution	Uplift, thrusting, emplacement of porphyry sills, stocks and dikes	Late Cretaceous
Subsidence and Deposition	Deposition of Flathead sandstone and younger sediments	Mid-Cambrian to late Cretaceous
UNKNOWN TIME INTERVAL * PENEPLANATION		
Proterozoic uplift	Emplacement of basic dikes Uplift, formation of joint systems Faulting, and cataclasis	Absolute Age Unknown
UNKNOWN TIME INTERVAL		
Metamorphism and Granitization	Emplacement of mafic dike swarms Regional granitization, emplacement of pegmatites, regional metamorphism to grade of high amphibolite facies	Stillwater(?) 2750 ± 150 MY
Folding	Open folds with NS fold-axes, plunge S	
Emplacement of mafic and ultramafic rocks	Abundant mafic intrusions which are locally concentrated, found as orthoamphibolites and serpentinites	
UNKNOWN TIME INTERVAL		
Deposition of Archean Sediments	Mainly argillites and siltites, minor arenites and banded ironstones Metamorphic equivalents preserved throughout the Beartooth range	

Paleozoic Sedimentary Rocks

General Statement.- Sedimentary rocks, ranging in age from middle Cambrian to Ordovician appear as isolated erosional remants in the north-central, central and southeastern part of the Independence area. The middle Cambrian rocks are locally exposed as windows under the volcanic cover and are best observed in the valley walls of most of the tributary streams in the headwaters of the Boulder River. The Ordovician rocks crop out only at the head of Bull Creek and on the west side of Slough Creek, disappearing under the volcanic cover to the southwest. Courtis (personal communication) reports excellent exposures of Devonian and Mississippian rocks just northeast of Cutoff Mountain (Pl. I). No complete sections of Cambrian and Ordovician rocks are exposed in the Independence area so that the total thickness can only be estimated at about 850 feet. Early Cambrian rocks are not present in the area and, according to Lochman (1949, p. 42), have not been recorded in the Wyoming-Montana shelf province.

The middle Cambrian sequence lies unconformably on the Precambrian metamorphic rocks and consists of a basal quartzite followed by a series of shales and limestones. These units have been divided into seven formations (Weed, 1899; Deiss, 1936; and, Dorf and Lochman, 1940). Due to the uneven distribution of the erosional remnants and also the poor exposures the seven formations are grouped into two units on the map of Plate I. The four middle Cambrian formations

comprise one unit and the three upper Cambrian formations make up the second (Table 2). Richard (1957), Fox (1960), Brown (1961) and Courtis (oral communication) have reported well exposed units with extensive horizontal distribution in the areas to the northwest, south and east of the Independence area.

The evolution of the Cambrian stratigraphic nomenclature in central and southern Montana and northwest Wyoming has been complex. Deiss (1936), Dorf and Lochman (1940), and Lochman (1950) have been the leading proponents in re-defining and clarifying the present status of the Cambrian system. Hansen (1953) has presented a complete review of Cambrian stratigraphy in southwestern Montana.

Cambrian System

Flathead Formation

The type locality of the Flathead Formation is along the northern side of Belt Creek valley in the Little Belt Mountains, Montana (Deiss, 1936, pp. 1271-1272). At the type locality, the Flathead consists of 10 feet of massive, cross-bedded quartzite with quartz pebbles ranging up to 3/4 inches in diameter in the upper 5 feet. This is overlain by 233 feet of brown to tan, limonite-stained quartz arenite with abundant quartz-pebble conglomerate lenses.

In the Independence area the Flathead Formation ranges from 0 to 133 feet thick. The formation is only partly exposed in the vicinity of the headwaters of the Boulder River

TABLE 2.- Summary of the lower and middle Paleozoic stratigraphy of the Independence area, Montana.

AGE	FORMATION	DESCRIPTION	THICKNESS
Mississippian	Madison	Massive to thin-bedded, light-gray to tan limestone, highly fossiliferous, some shales.	0-100'
Devonian	Jefferson (Incl. Threeforks)	Gray to brown limestone and dolomite, some fine-grained sandy beds.	225'
Ordovician	Bighorn	Massive cliff-forming buff dolomite, weathers to a rough, pitted surface. Thin bedded brecciated dolomite at top.	197'
Cambrian, Upper	Grove Creek-Snowy Range Formations	Interbedded gray limestone and dark gray shale with greenish limestone flat-pebble conglomerate.	93'
Cambrian, Upper	Pilgrim	Gray to tan partly, thin bedded mottled, oolitic limestone.	73'
Cambrian, Middle	Meagher	Thin bedded bluish-gray limestone with some shale.	86'
Cambrian, Middle	Wolsey	Soft, fissile, micaceous, olive green to blue-gray shale.	94'
Cambrian, Middle	Flathead	Light-tan and white to buff massive quartzite with local pebble conglomerates.	0-133'

and also in a thin lens on the west side of Horseshoe Mountain.

The Flathead Formation is a pale reddish brown to grayish orange quartzite. Subangular to subrounded quartz grains are common in the lower part of the unit. Higher in the section the quartzite is grayish orange with red mottling due to limonitic staining. On the west side of the Boulder River, on the ridge between Elk and Copper Creeks, the Flathead Formation pinches out on Precambrian "highs". This was previously noted by Emmons (1908, p. 198), and Richards (1957, p. 392) has reported this pinch-out in an area east of Livingston, Montana. This suggests a rather extensive area where knobs of Precambrian rocks protruded above the waters during transgression of middle Cambrian seas.

Directly east across the valley from the area of onlap the Flathead Formation has a thickness in excess of 100 feet. This relationship is rather unusual in that the thickest part of the Flathead lies about 880 feet higher, topographically, than the level at which the Flathead is absent due to pinch-out against Precambrian knobs. This discrepancy can be explained by the effects of Laramide faulting (see Structural Geology).

Wolsey Formation

The type locality of the Wolsey Formation is on South Hill adjacent to Keegan Butte in the Little Belt Mountains, Montana. At South Hill, the Wolsey consists of 174 feet of

brown to maroon to olive shale. The lower 166 feet has common, thin limestone-pebble conglomerate and crystalline limestone interbeds. The upper 8 feet contains thin green-gray, platey, micaceous limestone (Deiss, 1936, p. 1276).

In the Independence area the Wolsey Formation is poorly exposed in the Boulder River drainage on the ridge between Elk and Copper Creeks. On the west side of the Boulder River distribution of float on a soil covered slope indicates that about 94 feet of the Wolsey is present. Directly east, across the Boulder River, only 10-15 feet is present. The soft, fissile, micaceous, olive green to blue-gray shale is overlain conformably by the impure, thin-bedded limestones of the Meagher Formation west of the Boulder River.

Meagher Formation

The type locality of the Meagher Formation is the same as that of the Wolsey Formation. The type section consists of 86 feet of gray, thin-bedded, impure, argillaceous limestone with common shale partings. Additional diagnositic characteristics of the Meagher are irregularly disseminated clay nodules and the absence of intraformational conglomerates (Deiss, 1936, p. 1331).

The tan, thin-bedded, impure limestone of the Meagher Formation is poorly exposed above the Wolsey Formation of the west side of the Boulder River. Exposures in the headwaters of the North Fork of Bull Creek, central part of the area, are obscured by talus and soil.

Park Formation

The type locality of the Park Formation is along the North side of Dry Wolf Creek valley, two miles west of Lion Gulch, on the lower spur of Big Baldy Mountain in the Little Belt Mountains, Montana (Deiss, 1936, p. 1280). At the type locality, the Park Formation is 212 feet thick, and consists of olive to buff brown, fissile shale with thin interbeds of sandstones and impure limestone.

At the headwaters of the North Fork of Bull Creek, a vertical distance of 73 feet was measured from the base of the overlying Pilgrim mottled limestone to the lower Meagher Formation. Scattered float on the soil covered slope indicates the presence of the Park Formation.

Pilgrim Formation

The type locality for the Pilgrim Formation is on the north side of Dry Wolf Creek valley in the Little Belt Mountains, Montana. There the Pilgrim consists of 315 feet of thick- and thin-bedded light- and dark-gray, coarse-grained, intraformational conglomerates. The flat pebbles consist of gray, green, and tan argillaceous to lithographic limestone (Deiss, 1936, p. 1334).

Dorf and Lochman (1940, p. 555) suggested that lithologic changes in Late Cambrian rocks between central and southern Montana justified recognition and definition of new units in the southern Montana area. They defined three new formations; The Maurice for the Pilgrim Formation and

the Snowy Range and Grove Creek Formations for the Dry Creek Formation. Brown (1961) applied these formational names describing an area in north-central Yellowstone Park. Hansen (1953, p. 16) points out that the Maurice and Pilgrim Formations are easily correlated owing to their stratigraphic position, and therefore the Maurice is an unnecessary term. To maintain conformity to the Cambrian stratigraphic nomenclature in Montana the term Pilgrim Formation is retained.

In the Independence area the Pilgrim Formation is a gray and tan massive, locally thin bedded, mottled, and oölitic limestone. The formation is about 93 feet thick and crops out as a prominent cliff at the headwaters of the North Fork of Bull Creek. Brown (1957, p. 46) observed that the Maurice Formation attains a thickness of 140 feet on Buffalo Plateau which is 5 to 6 miles south of this area.

Grove Creek and Snowy Range Formations

At the type locality on the south slopes of Castle Rock near the mouth of the East Fork of Mill Creek (Dorf and Lochman, 1940, p. 545) the Snowy Range formation is 259 feet thick. The unit consists of intercalated gray-green shales and greenish, limestone-pebble conglomerates.

The Grove Creek Formation, which lies on top of the Snowy Range Formation, was defined by Dorf and Lochman (1940, pp. 543-544) from exposures along the south wall of the valley of the North Fork of Grove Creek, 5 miles southeast of Red Lodge, Montana. At the type locality the formation is 47

feet thick, and consists of an upper unit of yellow-green shales interbedded with gray, platy limestones and gray-green, limestone-pebble conglomerates.

In the Independence area a section about 120 feet at the head of the North Fork of Bull Creek consisting of intercalated gray-green shale and greenish flat-pebble conglomerate is partly exposed. One mile to the east at the head of Bull Creek about 80 feet of the same section is exposed beneath the overlying cliff of Bighorn dolomite. No attempt has been made to divide this section into two formations, and it has been lumped together as the Grove Creek-Snowy Range Formations, which appears to be common practice in southwestern Montana.

Ordovician System

Bighorn Formation

The Bighorn Formation was defined by Darton (1904, pp. 394-396) from prominent outcrops along the east side of the Bighorn Mountains, Wyoming. At the type locality the Bighorn formation is 250-300 feet thick and consists of three members: (1) a basal gray-buff, massive, siliceous, impure limestone and sandstone, (2) a middle massive, fine-grained, light colored limestone and (3) an upper thin-bedded, limestone.

In the Independence area the Bighorn Formation crops out as a conspicuous cliff on the west side of Slough Creek and extends as a prominent outcrop into Yellowstone Park. Erosional remnants are partly exposed in the valley walls under the volcanic rocks at the headwaters of Bull Creek and the North Fork of Bull Creek. The Bighorn is approximately 200 feet thick, and at the base is a thin, yellow-tan, nodular, impure dolomite about 10 feet thick. A cliff-forming member about 175 feet thick lies above the lower unit and consists of gray to tan, massive, crystalline dolomitic limestone which gives off a fetid odor upon fracturing. The prominent cliff member is capped by about 20 feet of white to buff, thin-bedded, partly brecciated dolomitic limestone.

The Bighorn Formation was originally mapped as the Devonian Three Forks shale and Jefferson limestone in the Livingston Folio No. 1 (Iddings and Weed, 1894). Subsequent

study of fossil assemblages has led to the re-definition of the age of this formation as Ordovician (Miller, 1930, p. 212).

Devonian System

Jefferson Formation

The type locality of the Jefferson Formation is along the sides of the Missouri River valley below Three Forks, Montana (Peale, 1893). The formation is 640 feet thick in the type area and consists of variably bedded, brown and black, crystalline limestone.

The Jefferson Formation crops out in a sequence of alternating thin to medium-bedded, impure limestones above the prominent Bighorn Formation cliff just northeast of Cutoff Mountain (Courtis, personal communication). The formation is about 250 feet thick and consists of brown to tan, finely crystalline to crypto-crystalline, impure, thin to medium-bedded limestone. The limestones of the Jefferson Formation are readily distinguished from the underlying white to chalky, crystalline dolomite and dolomitic limestone of the upper member of the Bighorn Formation.

Mississippian System

Madison Formation

Peale (1893) applied the name "Madison limestone" to the thick sequence of Mississippian limestones in the Three Forks, Montana quadrangle. The name "Madison" was taken from the nearby Madison River or the Madison Range. Peale recognized three lithologic subdivisions of the Madison Formation: (1) a basal, laminated limestone, (2) a middle variably bedded limestone and (3) an upper massive jaspery limestone.

The Madison Formation is exposed only in isolated sparsely fossiliferous outcrops just northeast of Cutoff Mountain.

CENOZIC ROCKS

General Statement

The volcanic rocks of the Yellowstone-Absaroka region were observed and recorded during the early reconnaissance surveys (Hayden, 1872; Jones, 1875). Hague et al., (1899) established a general six-fold classification for the volcanic rocks on the basis of apparently distinct petrographic characteristics.

Cenozoic rocks in the Independence area consist of a series of volcanics associated with a major eruptive center and include volcanic breccias and conglomerates, pyroclastic breccias, lava flows, tuffs and several small intrusive bodies. Glacial and post-glacial deposits include tills, lacustrine sediments, talus deposits, and valley alluvium.

Criteria for Distinguishing Mappable Units.- Hague et al., (1899, pp. 4-5) originally mapped the northern Absaroka Mountains on a reconnaissance basis and introduced a classification of the Absaroka volcanic rocks that has been used consistently by other workers throughout the entire Absaroka Mountains up to the present time. This six-fold classification is:

(6) late basalt sheets.
(5) late basic breccias.
(4) late acid breccias.
(3) early basalt sheets.
(2) early basic breccias.
(1) early acid breccias.

Continued usage of this classification, in a stratigraphic sense, by later workers, has unfortunately led to the

connotation of formational rank for these generalized terms. A significant feature exists in that this general terminology has been applied in areas, away from known vent structures, to volcanic rocks that possess gross sedimentary features. Around a major eruptive center this classification becomes meaningless in that: (1) the basal volcanic rocks of one particular eruptive center can not be accurately correlated with the basal units associated with a nearby eruptive center, (2) all the rocks of the "early acid breccias" are not acid in composition, and (3) all of the rocks are not breccias. Thus, in the Independence area these time terms can not be applied with any degree of certainty or validity.

Hague based his division of the "early acid breccias" and the "early basic breccias" on the general over-all color of the outcrops, the general mineral composition, and the presence of unconformities. He noted that the "early acid breccia" series are lighter in color than the "early basic breccias" and contain an amphibole as the principal mafic mineral. The "early basic breccias" are darker and show a pyroxene-rich matrix.

During the course of his field work the writer found that the color of the outcrops was too unreliable for differentiating volcanic units. The degree of fragmentation, rate of weathering and auto-oxidation effects seemed to control the amount of apparent oxidation within a particular zone of the same volcanic unit. Many unconformities were found to exist within the cone-complex, so that the selection of

a particular erosional surface to designate the end or the beginning of a specific time period was not valid. The general mineral composition of a particular breccia is also unreliable. In many instances the mineralogy of a well-indurated, reworked volcanic unit was impossible to determine in the field. Some zones appeared to be rich in amphiboles (hence early acid breccia) whereas other portions of the same layer were richer in pyroxenes (hence early basic breccia).

The criteria used by the writer for defining mappable units were based partly on gross lithologic and textural features, but mainly on stratigraphic positions of various volcanic rocks with respect to a particular vent center.

The writer feels that the classification proposed by Hague in describing the volcanic rocks of the northern Absaroka volcanic field is no longer tenable. There are too many local variations associated with the major intrusive centers which have undergone separate and unique cycles of events. The remnants of an extensive cone-complex demonstrate clearly that volcanic activity, deposition, and erosion accompanied by re-deposition varies chaotically and is usually influenced by the nature of the topography. Not one mappable unit could be traced and correlated around the periphery of the vent structure of the Independence volcano. A general grouping of the volcanics has been developed and each unit mapped is interpreted as a significant event in the complex history of this intrusive center.

Cenozoic Stratigraphic Sequence.- The generalized stratigraphic sequence of the Cenozoic rocks in the Independence area is as follows:

(7) Group V Volcanics - trachybasalt flows, minor felsic tuffs.

(6) Group IV Volcanics - deposition of reworked, earlier formed volcanics in the form of conglomerates and sandstones.

(5) Group III Volcanics - accumulation of a series of dacites, latites, and some basalts. All volcanics from a single vent.

(4) Group II Volcanics - hornblende-quartz latite flows.

(3) Group I Volcanics - accumulation of a series of dacitic, latitic, and basaltic volcanic rocks from several small vents.

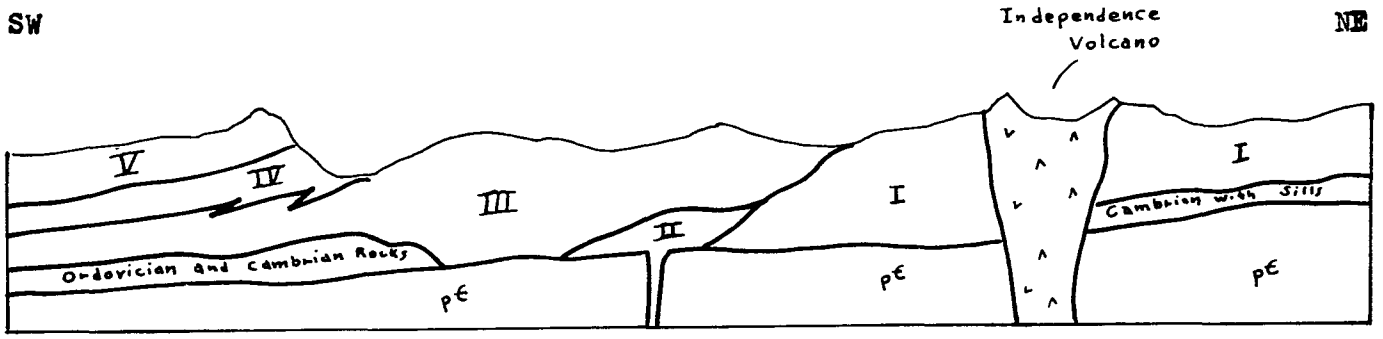
(2) Monument conglomerate.

(1) Quartz latite sills.

The generalized stratigraphic sequence of the Cenozoic rocks is diagrammatically shown in Figure 6.

General Features of the Volcanic Terrane.- To help understand the stratigraphic sequence of the volcanic rocks it is necessary to describe the general features of the volcanic terrane in the Independence area.

Vigorous erosion has dissected the volcanic rocks into a series of valleys and ridges having a relief in excess of 3,000 feet. Within the deeply incised valleys the nature of the topography prior to the extrusion and accumulation of the volcanic rocks can be observed. In the vicinity of the headwaters of the Boulder River the volcanic rocks lie on a surface of the Precambrian metamorphic rocks which contain



GENERAL VOLCANIC GROUPING

Oldest — youngest

I	II	III	IV	V
Leuco-latitic flow breccias, lava flows, tuff-breccias and tuffs.	Series of latitic porphyry flows.	Variety of melano-latitic breccias, tuffs, pyroclastic breccias and epiclastic.	Well developed volcanic conglomerates and sandstones.	Trachybasalt flows with minor felsic tuffs.

FIGURE 6.- Diagrammatic cross section of the Independence area showing the relative age grouping of the volcanic rocks.

erosional wedges of lower Paleozoic sedimentary rocks. To the northeast the volcanics lap onto the denuded Precambrian rocks of the Beartooth Plateau, which rises to an elevation of about 11,000 feet. The Precambrian surface has a regional dip to the southwest of about 12 degrees with a corresponding thickening of the volcanics in the same direction.

At the headwaters of the Buffalo Fork and Bull Creek the volcanics lie in part on Ordovician and Cambrian sediments and also on Precambrian metamorphic rocks. Farther south in the Slough Creek and Buffalo Creek drainage they lie on a persistent but thin veneer of Cambrian and Ordovician sedimentary rocks. To the west in the Hellroaring Creek area the base of the volcanic series is not exposed.

The total relief of the pre-volcanic surface is about 2,500 feet. Southeast of the Independence area, just east of Yellowstone National Park, the effects of widespread erosion prior to the main periods of volcanism were first recognized by Hague (1899, p. 3). Lovering (1929, p. 39), Rouse (1937, p. 1261), and Parsons (1958, p. 39) have reported exposures in valley walls with a relief in the pre-volcanic surface between 1,000 and 1,500 feet. Near Electric Peak, in northwestern Yellowstone Park, Iddings (1899, p. 89) reported a pre-volcanic surface of moderate relief that was further complicated by Laramide faulting and folding. Within the Independence area there is evidence of faulting prior to the main volcanic activity, as mentioned previously.

Because of the 2,500 feet of relief, the onlap of

volcanics on the Precambrian surface, and the various lithologies making up the pre-volcanic surface, the correlation of various volcanic rocks is, in part, arbitrary. The pyroclastic breccias vary lithologically and texturally from ridge to ridge near the dissected Independence volcano but become rather uniform and grade into epiclastic volcanic breccias to the south and southwest. The regional dip of the Precambrian surface seems to have influenced the general direction in which most of the volcanic debris was carried and deposited. In the Hellroaring Creek area the 3,000 feet deep valleys have failed to expose any rock types other than the crudely-bedded epiclastic volcanic breccias.

The volcanic pile south of the dissected Independence volcano increases in complexity up-section. The lower 2,000 feet consists of a series of flow breccias, tuffs, tuff breccias and lava flows that dip gently to the southwest. The upper 700 feet is made up of a variety of volcanic rocks that form local units dipping at high angles away from the general vicinity of the Independence volcano. The lower volcanic units are pierced by the Independence volcano (Figs. 7a, 7b). On the north side of the volcano the pyroclastics consist only of a thin unit of flow breccias and a thick section of lithic tuffs (Fig. 8).

Headward erosion by the Boulder River and the East Fork of the Boulder River has removed the upper units adjacent to the exposed volcanic vent. Two miles south of Monument Peak, at the head of the Boulder River, Sheepherder Peak (Fig. 9)



FIGURE 7a. View showing the intrusive breccias that cut across the Group I Volcanics. These intrusive breccias represent the southern part of the Independence volcano and form Monument Peak. Photograph taken from Boulder Pass looking northeast.

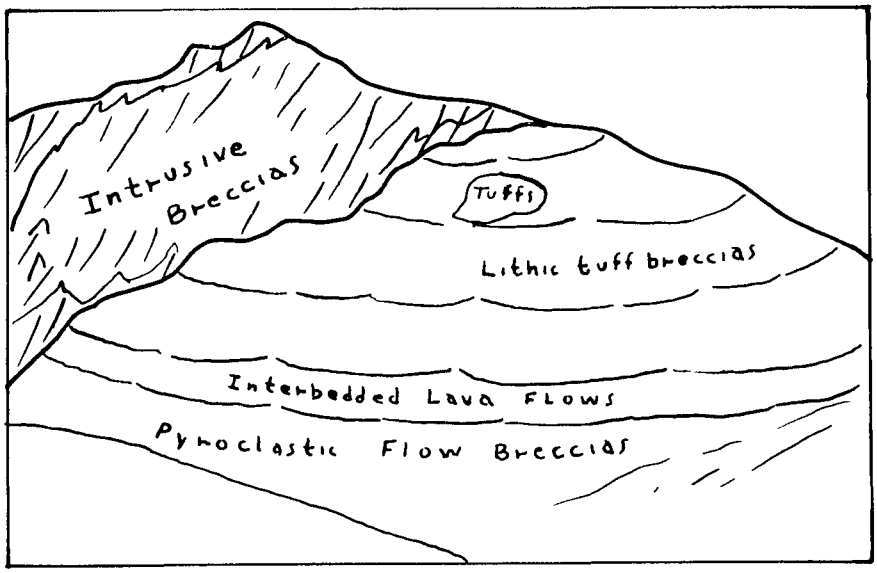


FIGURE 7b. Detailed sketch of figure 7a showing the various rock-types of the Group I Volcanics that have been cut by the intrusive breccias which belong to the Group III Volcanics.

stands as a bold erosional remnant of the upper flanks of the pre-existing cone-complex. There a series of agglomerates, lava flows, and tuff lenses are haphazardly interbedded with cut and fill channel deposits of tuff breccias. Similar complex structures and lithologies can be traced at higher elevations, in a semi-circle, from the headwaters of Slough Creek west and northwest to the vicinity of Bridge Lake in the northwest part of the Independence area. Volcanic ejecta were undoubtedly deposited to the north and northeast on the Precambrian surface but have been subsequently eroded away.

The preserved volcanic structures as observed in the higher parts of the ridges, from Monument Peak 8 miles due south to Lookout Mountain, indicate that a composite cone structure once existed with a radius of about 9 miles.



FIGURE 8. View showing the northern part of the Independence volcano that cuts across the Cambria sediments and the felsic lithic tuffs of the Group I Volcanics. View is due east looking across the Boulder River valley.



FIGURE 9. View showing the north face of Sheepherder Peak which is an erosional remnant of the upper flanks of the cone-complex that surrounds Independence volcano. Channel cut and fill structures consist of lithic tuff breccias, pyroclastic breccias and local basalt flows.

Quartz Latite Porphyry Sills

Near the headwaters of the Boulder River, from Bridge Creek to Sheep Creek (Pl. I), the middle Cambrian sediments have been intruded by a series of porphyritic sills which range from 9 to 287 feet in thickness. In most places the sills have been intruded between the Flathead Formation and the overlying Wolsey Formation. Where the Flathead Formation is missing; due to onlap, the sills have been intruded between the Precambrian rocks and the Wolsey Formation, as on the ridge between Copper and Sheep Creek. Directly across the valley, to the east, the sills appear only on the west and north side of Baboon Mountain. Limited exposures reveal that the Wolsey shales have been altered, slightly, by contact metamorphism.

Description:- Megascopically the sills are light gray and fine-grained with abundant phenocrysts of plagioclase feldspar crystals up to 1/4 inch in diameter. Some quartz and hornblende are present as phenocrysts also. At the contact, the sills are aphanitic and darker.

Microscopic study reveals the rock to be a quartz latite porphyry (Table 3). The groundmass is very fine-grained, but selective chemical staining (Bailey and Stevens, 1960) indicates that potash feldspar is present in amounts greater than 25 per cent. The dominant phenocrysts are andesine that show excellently developed normal zoning. Most of the plagioclase is fractured and sericiticized. Scattered quartz

TABLE 3.- Modal analyses of various volcanic rocks from the Independence area.

	BR-2	BR-34	BF-26	BF-14	IA-64	WM-4	WM-5	ML-1
Quartz	8.2	12.5	14.3	-	tr.	12.7	14.6	tr.
Plagioclase	36.6	33.5	41.6	56.3	55.4	43.3	36.2	29.1
Biotite	tr.	tr.	3.1	-	tr.	3.7	2.1	6.5
Hornblende	9.8	16.3	tr.	-	tr.	18.6	16.5	2.3
Pyroxene	-	-	-	18.3	26.3	-	-	7.2
Magnetite	1.2	1.7	1.1	2.6	1.8	1.2	2.3	1.7
Groundmass	43.6	33.7	39.3	22.7	16.8	21.1	38.4	53.7

BR-2
Quartz latite porphyry sills from the Bridge Creek area.

BR-34
Latite porphyry flow from Group I Volcanics.

BF-26
Buffalo Fork laccolith.

BF-14
Trachybasalt from Iron Mountain.

IA-64
Basalt flow from Group I Volcanics.

WM-4, WM-5
Group II hornblende quartz latite porphyries.

Ml-1
Labradorite latite porphyre from Mill Creek plug.

grains up to 1/8 inch in diameter are rounded and show embayments. The hornblende crystals are highly altered to aggregates of chlorite, calcite, limonite and traces of epidote. Magnetite and apatite occur as common accessories.

Age and Correlation.- Emmons (1908, p. 201) suggested, on the basis of reconnaissance work, that the porphyritic sills may represent the oldest Tertiary intrusives in the area. The following field evidence and petrographic data obtained in the course of this study support Emmons' original observation.

On the east side of the Boulder River, at the base of Monument Peak, a gneiss-schist boulder conglomeratic unit crops out. This conglomerate is a stream deposit, filling a channel cut into the Precambrian surface, and is overlain by 2,500 feet of the Group I Volcanics. This stream channel deposit undoubtedly represents the oldest Cenozoic sedimentary rock in the area. Fragments of porphyritic material similar to that of the described sills appear in the coarse matrix cementing the Precambrian boulders. In the upper 30 feet of the conglomerate, which is about 90 feet thick, fragments of metamorphosed Cambrian sediments were observed both in hand specimen and in thin section. This evidence indicates that the Cambrian sediments were altered prior to the accumulation of the pyroclastics of the Group I Volcanics.

A Paleocene (?) age for the sills may be indicated by the relative position of the Cambrian sediments, with respect to the intruded sills, on the east and west sides of the

Boulder River. A vertical fault with a displacement of about 880 feet, west wall down, is inferred (see Structural Geology).

Similar porphyry intrusions, in close proximity to the Beartooth Mountains, have been dated as late Cretaceous or early Tertiary. The Lodgepole intrusive (Rouse et al., 1937) is situated at the headwater of Deer Creek between the drainage systems of the Boulder and Stillwater rivers. The general form of the intrusive is that of a laccolith with marginal sills that have been intruded into lower Paleozoic strata. The northward dipping thrusts of the Beartooth uplift (Laramide time) were found to cut the dacite porphyry sills that had been intruded into the Cambrian shales. Similar dislocated sills were observed near Nye and Red Lodge, Montana.

Sedimentary Rocks

Monument Conglomerate.- The oldest Cenozoic sedimentary rock in the Independence area consists of a gneiss-schist boulder conglomerate that crops out on the east and west side of the Boulder River valley just below Monument Peak. The lower part of this stream channel deposit is obscured by valley alluvium. Partial exposures of the Precambrian surface, in nearby areas of the valley, indicate that this conglomerate is about 90 feet thick. The deposit appears to fill a channel cut into the Precambrian metamorphic rocks.

The lower part of the Monument conglomerate consists of well rounded boulders, up to six feet in diameter, and cobbles of schists and gneisses set in a graywacke-like matrix. The matrix is made up essentially of subangular lithic fragments and is poorly cemented with a friable, clay-like material. The lithic fragments range from Precambrian metamorphics to Cambrian sediments and minor amounts of quartz latite porphyry fragments from the sills of Paleocene (?) age.

The size of boulders decreases upward with a corresponding increase in the relative amount of volcanic and altered limestone pebbles. Twenty feet from the top of the conglomeratic unit the conglomerate grades into a series of arkosic sandstones and micaceous shale lenses. Although the contact is not observable, the conglomerate is overlain by a series of volcanic rocks more than 2,500 feet thick. These volcanic rocks are the oldest pyroclastic material in the area.

Similar coarse lower Cenozoic conglomerates have been reported in the middle Rocky Mountains region close to the margins of uplifted Laramide ranges. Hague et al., (1899) has described the Pinyon conglomerate near Jackson Hole, Wyoming and regarded it as Paleocene in age. In a more recent work, Love (1956a, p. 84) assigned an early Eocene age on the basis of the presence of a diagnostic species of terrestrial mollusks. Peale (1896, p. 3) considered the Sphinx conglomerate in the Madison Range to be early Tertiary. Lowell et al., (1953, p. 236) named the Beaverhead Formation which is a conglomerate that overlies with an angular unconformity the upper Cretaceous Aspen Formation. Structural and stratigraphic data indicates the latest Cretaceous or Paleocene age. On the east side of the Bighorn Mountains, Paleozoic and Cretaceous rocks are thrust over Paleocene-Eocene conglomerates (Sharp, 1948, p. 15). Wise (1958, p. 26) noted that a coarse conglomerate composed of granitic material overlies the Mesa Verde group on the eastern edge of the Beartooth Mountains. Brown (1961, p. 1177) suggested correlating the Hellroaring Formation of north-central Yellowstone Park with the Crandall conglomerate, named by Pierce (1957, p. 609), in the Clark Fork-Crandall Creek area on the basis of lithologic similarities. Both units are thought to be latest Paleocene or Eocene in age.

All of these coarse clastic deposits occur near the margins of uplifted areas and are considered early Cenozoic margins of uplifted areas and are considered early Cenozoic (Paleocene-early Eocene) in age. The Monument conglomerate

undoubtedly is related to the early Laramide uplift and represents a stream channel deposit of coarse material that was being transported away from the rejuvenated highlands. The writer suggests a Paleocene-early Eocene age for the Monument conglomerate on the basis of stratigraphic position and gross lithologic features.

Pierce (1957, p. 612) and Brown (1961, p. 1176) noted that the Crandall conglomerate and the Hellroaring Formation showed deformational features in the form of joints and crushed pebbles as the result of later stresses. Both of the writers emphasized the fact that no volcanic material was observed in the conglomerates. The Monument conglomerate contains abundant porphyritic material but no volcanic breccias. Jointing and crushed pebbles are absent. The quartz latite porphyry fragments seem to indicate an early phase of intrusive activity accompanied the Laramide uplift which is in agreement with other areas in the Beartooth Mountains (Rouse et al., 1937).

The Monument conglomerate probably represented a small stream channel deposit in the headwaters of a major drainage system. This unit is void of any distinct bedding features such as those noted by Pierce (1957, p. 612) in the Crandall conglomerate which has a width of at least 1,500 feet. The outcrop pattern of the Monument conglomerate and the known outcrops of Paleocene (?) altered limestones, in the Independence area, indicates that the stream probably flowed in a southeasterly direction. In the Bull Creek drainage large

Precambrian boulders are present in the stream bed which can only be accounted for by the erosion of the Monument conglomerate in the immediate vicinity. The lack of any rocks, younger than Cambrian, (volcanics excluded) within the conglomerate suggests that the source area was almost completely denuded of a sedimentary cover prior to or during the Laramide uplift.

Volcanic Terminology

General Statement.- More than 75 per cent of the Cenozoic rocks in the Independence area consist of volcanic fragmental material. These volcanics grade from pyroclastic breccias undisturbed since initial deposition to those that have been re-worked and re-deposited and possess sedimentary features. The remaining Cenozoic igneous rocks occur as intrusive bodies; these include: a laccolith, several dikes and sills, small plug-like bodies, and a major volcanic vent.

Classification of the Pyroclastic Rocks.- The terminology used in this discussion on the pyroclastic rocks is that outlined by Wentworth and Williams (1932, p. 45-51). The existence of a dissected cone-complex, with its corresponding vent, affords an excellent opportunity to define further the volcanic rocks on the basis of: (1) proximity to source area, (2) depositional environment, and (3) cause of brecciation. By prefixing the terminology presented by Wentworth and Williams (1932) with the appropriate adjective in respect to source, mode of origin etc., the classification is further extended in both a genetic and descriptive sense. Ambiguities in usage of certain terms have been avoided by following Fisher (1960, pp. 973-982); Wright and Bowes (1963, pp. 79-86) review of the classification of volcanic breccias.

Group I Volcanics

General Statement.- The Group I Volcanics are so grouped on the basis of stratigraphic position, succession, and gross lithologic features. Most of the volcanics consist of a variety of latities, dacites with minor amounts of basalts and all are apparently related to the earliest period of volcanism in the Independence area.

Distribution.- Volcanic rocks that can be designated as the oldest units make up the ridge directly south of Monument and Haystack Peaks (Pl. I). These rocks overlie the Monument conglomerate and form an apparent well-layered series about 2,500 feet thick. These volcanic rocks consist of a series of latitic tuffs, tuff breccias and pyroclastic flow breccias that are intercalated with basaltic and andesitic lava flows. Similar rocks occur directly across the valley to the west and form the low-lying ridges between the tributary valleys west of the Boulder River. Farther north, between Copper and Bridge Creeks, these volcanics are not well-layered and do not contain any lava flows, but still appear related in time due to their stratigraphic position.

In the eastern part of the Independence area the Precambrian surface is about 1,500 feet higher than the Precambrian surface near the head of the Boulder River. A thin capping of pyroclastic flow breccias is partly preserved as erosional remnants and may be related in time to the volcanics in the vicinity of the Boulder River. This same

pattern was observed on the higher elevations of Horseshoe Mountain, which is farther to the southeast in the Slough Creek Drainage.

Parts of the Group I volcanics were originally grouped and mapped as the "early acid breccia" by Iddings and Weed following the terminology used in Yellowstone Park by Hague (in, Iddings and Weed, 1894, p. 4). These light colored rocks, in part, extend under a series of darker pyroclastics of the Group III Volcanics (Fig. 10) to the south and to the west under the long divide that separates the drainage system of the region. The volcanic rocks at the bottom of the section at the head of the Boulder River are distinctly lighter in color, but northward, the lower Group I Volcanics possess the same brownish hue as the overlying Group III Volcanics. Field observations of fragmental rocks, supported by later petrographic data, indicate a rather striking relationship between the mode of origin of the rocks and their corresponding color. Volcanic rocks such as the flow breccias and pyroclastic flow breccias, which possess an igneous matrix, are lighter colored than those rocks that contain a fragmental groundmass i.e., tuff breccias and volcanic sandstones. Due to the induration of some of the tuff breccias it was practically impossible to determine the true nature of the groundmass in the field. Many tuff breccias of the Group I Volcanics appear identical to the tuff breccias of the Group III Volcanics in hand samples. It is probable that the greater permeability of



FIGURE 10. View showing the transitional zone between the apparently lighter-color Group I Volcanics and the overlying volcanic rocks of the Group III Volcanics. Photograph taken from the top of the northwestern edge of the Independence volcano looking southwest across the Boulder River valley.

the fragmental rocks has led to greater ground water activity and leaching of the mafic minerals.

Description.- The oldest unit of the Group I Volcanics is best observed on both sides of the Boulder River immediately above the Monument conglomerate (Pl. I). Although the contact is not exposed local talus debris indicates that a thin lens of light gray tuffaceous material separates the overlying pyroclastic flow breccia from the Monument conglomerate. Above the flow breccia, on the east side of the Boulder River only, distinct units of tuff breccias, felsic tuffs and latitic and basaltic flow are interlayered with pyroclastic flow breccias. This entire unit, about 2,500 feet thick, represents the best preserved section of the Group I Volcanics in the Independence area. Elsewhere in the area, west of the Boulder River, the Group I Volcanics do not exceed a thickness of 1,200 feet.

Pyroclastic Flow Breccias.- The basal unit of the Group I Volcanics consists of a pyroclastic flow breccia that crops out as a massive, dull gray to buff and uniform-appearing igneous rock. Where fractured the included fragments within the volcanic rock become readily apparent. Subangular to subrounded volcanic fragments from less than 1/4 of an inch up to 2 inches in diameter are common. Locally, conspicuous blocks of volcanic rocks are present. A few Precambrian and Cambrian rock fragments can be observed. All of these fragments are set in a light gray aphanitic groundmass.

Thin section study reveals that the matrix is holocrystalline and microporphyritic with slender laths of andesine (An_{31-36}) in a trachytoid texture. Some ghost relicts of hornblende phenocrysts are observable in the form of magnetite-lined outlines with the interiors filled with calcite. A few excellent basal section outlines attest to the former existence of an amphibole. The plagioclase shows only slight sericitization along fractures. The cryptocrystalline groundmass contains an essential amount of potash feldspar as indicated by selective chemical staining. This unit can therefore be considered as having a latitic composition.

The upper part of this breccia appears to grade into a fine tuff in places; in other places the breccia appears slightly decomposed which may be suggestive of proximity to an old erosional surface. The total thickness of about 300 feet is observable only in the vicinity of the Boulder River. The rest of the section above the lower breccia unit is a crudely layered pile of tuff-breccias, latitic and basaltic lava flows with variable amounts of well-bedded tuff lenses. The entire sequence is relatively light colored, and the thin lava flows are somewhat obscured by the massiveness of the tuff breccias.

Lava Flows.- The lava flows are intercalated with the tuff breccias, lithic tuffs and minor amounts of volcanic sandstones and appear as typical andesites and basalts. These flows average about eight feet thick and dip gently

to the southwest. The flows occur throughout a vertical section of 700 feet. Fourteen andesitic units were noted whereas only three basalt flows were recognized.

Two rocks that appeared to be typical andesites in the field, revealed distinctly different mineralogical features as the result of detailed petrographic work. Megascopically the oldest flow (sample BR-34) is a dark gray, fine-grained porphyry. Plagioclase phenocrysts, up to 4 mm in length occur with hornblende needles in a dark gray aphanitic groundmass. In thin section essential amounts of andesine (An_{35-40}) are present along with oxyhornblende crystals up to 2 mm in length. About 10-15 per cent of subhedral quartz is scattered throughout the section. Apatite, magnetite and biotite are present in accessory amounts. Some apatite occurs as distinct inclusions in a few of the clear crystals of plagioclase and hornblende. These minerals lie in a pilotaxitic groundmass of microlithic andesine (?) and interstitial microfelsite dusted with magnetite. The plagioclase exhibits strong normal zoning and shows slight sericitization along fractures. The oxyhornblende is commonly rimmed with magnetite. Staining of a rock slab indicates that potash feldspar is present in essential amounts in the groundmass. This rock is therefore a hornblende quartz latite porphyry.

Another flow (sample AI-34A) is an aphanitic dull gray "andesitic" rock that forms a distinct unit about 130 feet above the hornblende quartz latite porphyry. A lithic tuff-

breccia unit separates the two flows, but no contacts are observable. In thin section this rock is identified as an augite latite. It is holocrystalline and allotriomorphic. Andesine (An_{31-37}) makes up to 60-70 per cent of the rock and about 15 per cent of subhedral crystals of augite are scattered throughout the section. Some quartz is present. Tiny granules of magnetite are persistent throughout the groundmass. The feldspars are only slightly sericitized, whereas the clino-pyroxene shows varying degrees of alteration. Some augite crystals are perfectly clear whereas others are fractured and bordered with secondary magnetite and chlorite. In some places the crystals have been completely altered to a mass of chlorite, magnetite and calcite. The possibility of two different pyroxenes could not be demonstrated optically. Minor amounts of interstitial material are too scattered and minute to determine optically, but staining indicates the presence of essential potash feldspar.

The oldest basalts in the area occur in the Group I Volcanics in the form of three distinct flows from 3 to 8 feet thick. They are separated by a series of pyroclastic breccias and show some vesicular structures near the tops of the flows. The upper and lower contacts are obscured by talus and soil cover. A sample from the middle flow was selected for study. In hand specimen the rock is dense and black; small crystals of pyroxene are observable. In thin sections the rock is holocrystalline with a trachytic

texture. The feldspar laths range from submicroscopic size up to 2 mm in length and range in composition from medium to basic labradorite. Clino-pryoxene occurs as phenocrysts and also as intergrowths with magnetite in the groundmass. Traces of quartz and hypersthene were detected. The feldspar laths show little zoning or alteration. An estimate gives the following percentages: plagioclase, 60; augite, 25; magnetite, 12; with trace amounts of quartz and hypersthene. Minor amounts of potash feldspar are present as indicated by staining.

The remaining upper flows are similar to the described augite latite. The rocks vary in color, in shades of gray, and in texture; some are porphyritic whereas others appear very dense. Three specimens were sawed and stained. Their strong reaction to selective chemical staining indicates considerable potash feldspar is present and thus they are classified as a variety of latites and augite latite porphyries. No true andesites were found.

Lithic Tuff Breccias.- Above the lava flows, the rest of the Group I Volcanics consist of a variety of light-colored pyroclastic breccias that have been lumped together as lithic tuff-breccias. This unit contains minor amounts of lapilli tuffs and flow breccias. The lithic tuff-breccias are overlain by a series of well-layered tuffs containing fossil wood and leaf fragments. This entire section, including the tuffs, is restricted to the high ridge immediately adjacent to the south side of Monument Peak.

Field observations indicate that all of the volcanic fragments range from ash dimension to blocks more than four feet across. The matrix of the lithic tuff breccias is largely indurated, and in some places it weathers out readily. Megascopically the fragments appear to range from rhyolites, andesites to basalts. Detailed observations revealed that most of the fragments are latitic. For the most part the fragments are porphyritic. Most fragments are hornblende or augite latites, but some are dacitic containing quartz phenocrysts. Microscopic studies of the fragments show a great variety of groundmass types i.e., glassy, microcrystalline and fine-grained. Many of the textures are pilotaxitic and trachytic.

The crudely-layered pile of lithic tuff breccias is considered to be the result of a relatively long explosive phase of volcanism that broke through and incorporated parts of the older rocks of the Group I Volcanics.

Felsic Tuffs.- Well-developed tuff layers crop out on the ridge about a half of a mile due south of Monument Peak just above the lithic tuff breccias. One well exposed unit is 36 feet thick. Fossil leaves and wood fragments are abundant. A thin unit of tuff-breccias above this tuff lens contains a great amount of fossil wood fragments and even logs up to 12 feet long and 2 feet in diameter. These wood fragments are completely silicified.

Only megascopic investigations were made of the tuffs. All of the tuffs appear similar in composition but vary

somewhat in texture. In outcrop the tuffs appear either as thin units of friable silty layers or as massive, well-indurated sand-size materials. All of the tuffs weather to a buff color, but on fresh surfaces they are light gray. In hand specimens 3-4 mm feldspar and quartz with some biotite can be observed. The tuffs are stained to various hues of yellow by the selective chemical staining techniques indicating that potash feldspar is present. They are considered to be a variety of latitic crystal-lithic tuffs.

A similar section of tuffs, but 286 feet thick, occurs on the northwest spur of Baboon Mountain. Most of the tuffs appear to represent ash fall deposits. In the middle part of the section the tuffs are finely laminated and reveal well-developed graded bedding. Bedding features and slump structures suggest that these tuffs were probably deposited in relatively quiet waters. Fossil logs and even stumps 3 feet in diameter occur throughout the water deposited tuffs. All of the fossil wood fragments have been completely replaced by fine-grained quartz. The fossil flora and reworked tuffs probably represents a stage of quiescence during the period of volcanism. Higher up in the section the tuffs appear similar to those described on the south side of Monument Peak.

Correlation.- The ridges from Copper Creek to Bridge Creek (Pl. I) consist of a series of darker lithic tuffs and tuff breccias. The lower part of the tuff breccias contains more Precambrian boulders than the pyroclastic flow

breccias above the Monument conglomerate. These breccias have a maximum thickness of about 1,200 feet and rest on an erosional surface consisting of Precambrian metamorphic and middle Cambrian sedimentary rocks. Up-section the fragments vary in size randomly, and there are local concentrations of scoriaceous materials. The average mineral composition of the breccia fragments is similar to that described at the head of the Boulder River. No lava flows were observed in any of the sections in the Group I Volcanics away and beyond the Boulder River area.

The tuff breccias that lie on the erosional surface of Precambrian rocks, east of the East Fork of the Boulder River and also on Horseshoe Mountain, at elevations greater than 9,500 feet, show similar lithologic and fragmental features to those west of the Boulder River in the vicinity of Copper, Elk, and Bridge Creeks. No true thickness can be estimated since they are erosional remnants. The patchy outcrops range in thickness from 0 to 150 feet. These tuff breccias are considered to be equivalents of those units in the vicinity of the Boulder River, because of their stratigraphic position and lithologic similarities. A significant feature of these breccias is the greater precentage of angular Precambrian and Cambrian rock fragments. This is probably due to the fact that erosion has exposed, over a relatively wide area, a unit representing the first products of volcanic accumulation on a pre-volcanic surface.

Sawed slabs of various Group I Volcanics reacted to

selective chemical staining which indicates the presence of potash feldspar in variable but essential amounts. These rocks are therefore latitic, unlike the andesites elsewhere in the Absaroka Mountains.

The Group I Volcanics may be similar in time to the "early acid breccias", noted elsewhere in the Absaroka Mountains and the Yellowstone Park area, in that they both represent the first products of volcanic activity.

Anderson Creek Lava Flows.- On the west side of Slough Creek, above Silver Tip Ranch, a group of basaltic lava flows, 65 feet thick, lies on top of the Bighorn Formation. These basalts are overlain by a succession of trachy-rhyolitic flows more than 600 feet thick. The uppermost part of the felsic flows appears to have been eroded prior to the accumulation of the transitional rocks of the Group III Volcanics. These flows are some of the oldest, in the map area, but are not continuous into the Independence area.

The source of the lava flows is completely masked by the younger volcanic rocks. A brief reconnaissance study of the area, on the west side of Slough Creek, just south of the Yellowstone Park boundary, revealed a chaotic assemblage of scoriaceous basalts and felsic tuff lenses cut by dikes. A probable vent area has been buried by the epiclastic volcanic breccias of the Group III Volcanics.

Origin.- The Group I Volcanics probably originated from a series of relatively small vents and fissures (Pl. I),

along a northwest trending line, that reflects a ruptured zone in the underlying Precambrian basement complex. Even though the Independence volcano cuts across the Group I Volcanics, it is probable that a much smaller vent existed during this time which contributed most of the volcanic ejecta. Two plug-like bodies, in the Sheep Creek and Buffalo Fork drainage, that are covered by the Group III Volcanics may have been of local importance. The oldest volcanics are thickest at the head of the Boulder River and form the only section that contains a series of lava flows. Northwest and southeast the volcanics are essentially all fragmental with a noticeable decrease in size of the clastics. The Group I Volcanics west of the Boulder River show crude bedding features that dip away from the general vicinity of the Independence area. A general summary of the Group I Volcanics is presented in Table 4.

TABLE 4 .- General summary of the Group I Volcanics

Rock Type	Composition	Thickness	Approx. %
Variety of tuffs and volcanic sandstones	Matrix of tuffs and lapilli tuffs consist primarily of about 50-60% lath-like plagioclase (medium andesine) with clay and accessory quartz, pyroxene, hornblende, biotite and opaques.	236'	10-12
Volcanic Sandstones	Brown, buff to gray medium to coarse-grained sandstone consisting of crystal and lithic volcanic fragments.	150'	5-10'
Lithic Tuff Breccias	Light-gray to buff tuffaceous matrix (crystal-lithic) enclosing angular to subrounded volcanic fragments consisting of light-gray dacites, dark gray-green latites and black basalts. Minor vitrophyres. Fragments make up 50-60% of rock. Size range from 1/4" to 3', average about 4-6".	1200'	55-65
Latite Flows	Eleven separate flows of augite latite porphyries, and dark, dense aphyric latites. One flow consists of a light-colored hornblende quartz latite porphyry.	90'	5
Basalt Flows	Three separate flows which consist of potash-bearing basalts.	24	1
Pyroclastic Flow Breccias	Light gray to green, dense latitic matrix enclosing innumerable fragments of various volcanic rocks, some sedimentary and a few Precambrian metamorphic rocks.	450	25-30

Group II Volcanics

Distribution.- A widespread latite porphyry flow covers much of the northeast part of the Independence area. This sheet flowed out onto an irregular surface consisting of Precambrian metamorphic rocks, isolated erosional remnants of Cambrian sediments and patches of pyroclastic flow breccias that belong to the Group I Volcanics. This flow is best observed on the high ridges extending from Horseshoe Mountain, northwestward for 7 1/2 miles, to the plateau that is due east of the Independence volcano (Pl. I). The flow also occurs on the heavily timbered ridge 3 1/2 miles due west of Horseshoe Mountain. Here the flow lies on the Cambrian Pilgrim Formation and is partly covered by the Group III Volcanics. This flow is preserved as erosional remnants over an area of more than 20 square miles.

The rocks making up the flow vary texturally throughout the area, and this is strongly suggestive of a series of flows. The thickness of this unit reaches a maximum of 700 feet in the vicinity of Horseshoe Mountain. Angular xenoliths, about 4 to 6 inches across, of Precambrian and Cambrian rocks are common in the basal part of the flow. Some of the limestone xenoliths show recrystallization and the formation of pockets of tabular hematite at the contact between the flow material and the carbonate fragments.

Description.- Megascopically these latites are porphyritic with large, white plagioclase crystals set in a gray

to gray-green aphanitic groundmass. Hornblende crystals and a few biotite flakes are common in some of the specimens. Samples collected near the base of the porphyry reveal well developed flow structures.

Microscopic studies of thin sections indicate that the rock is a hornblende-quartz latite porphyry (Table 3). Andesine (An_{31-42}) crystals, with an average of 3-4 mm across, make up most of the phenocrysts. One large labradorite lath (An_{52}), 6 mm long, was observed in a sample collected from the ridge just north of Wounded Man Creek. Some rocks contain abundant dark brown to green hornblende phenocrysts up to 3 mm long. In some rocks biotite flakes up to 1 mm are present. The groundmass consists of microlites of more sodic feldspar with some granophyre. Apatite is present in accessory amounts and magnetite occurs both as small anhedrons and tiny particles dusted throughout the matrix. The matrix is micro- to cryptocrystalline and for the most part is equigranular. Sawed slabs of the rocks show very prominent potash feldspar upon staining.

The latite porphyries from Horseshoe Mountain show the greatest amount of alteration. The plagioclase is mostly sericiticized, and the hornblende is almost completely replaced by an aggregate of chlorite, limonite, magnetite and calcite.

Origin.- The latite porphyry flows thicken toward Horseshoe Mountain and also show a greater degree of hydrothermal alteration. The Horseshoe Mountain area may represent a

relatively small eruptive center. The texture of the rocks varies considerably in the upper part of the ridge that forms the walls of Horseshoe Basin. Elsewhere, away from Horseshoe Mountain, the rocks do not vary in color or texture or show any hydrothermal effects.

Field evidence demonstrates that the flows are younger than the Group I Volcanics and older than the Group III Volcanics. The porphyritic flows are restricted to the east-central edge of the Independence area (Pl. I). The Group I Volcanics were formed and in the process of being eroded when the flows issued from a fissure-like zone near the vicinity of Horseshoe Mountain. Due to their stratigraphic position and occurrence, these latitic flows are considered an important extrusive phase in the volcanic history of the area.

Group III Volcanics

General Statement.- The Group III Volcanics are significant in that they reflect the gradual build-up of the major cone-complex that surrounded the Independence volcano. Crude bedding features within the volcanic rocks of this group show a gradual increase in dip up-section. The projection of lines, with these dips, indicates that the top of the cone-complex was about 4,000 to 5,000 feet higher, than the present topography, during Group III Volcanic time.

Distribution.- The Group III Volcanics constitute about 75 per cent of all the pyroclastic rocks in the Independence area. They are observable on the high ridges throughout the entire area with the exception of the eastern edge which is covered in part by Group II Volcanics.

The headwaters of Buffalo Fork and Bull Creek have cut the Group III Volcanics exposing the most confused arrangement of fragment rock in the area. In the West Fork of the Hellroaring Creek drainage, the Group III Volcanics consist of more than 3,000 feet of crudely-bedded epiclastics that have been transported more than eight miles from the source area. To the northwest well-bedded volcanics are present without any major cut and fill structures like those present at the head of the Boulder River. To the south, in the vicinity of Round Head Butte, the volcanics appear to grade from the typical pyroclastic materials into the more conspicuous water-deposited epiclastics. The high peaks from Round Head

Butte northwest to Iron Mountain, and farther north to Grow Mountain, are capped by basalt flows of the Group V Volcanics.

Description.- The rocks of the Group III Volcanics are laborious to describe due to the multiple origins of the many fragmental varieties and also the lens-like character of the units. The group has a minimum thickness of 3,000 feet and has been intruded by dikes, small plugs and sill-like bodies, having a restricted compositional range.

Latitic-Lithic Tuff-Breccia.- Light-colored latitic-lithic tuff-breccias crop out very conspicuously at the head of the North Fork of Bull Creek (Pl. I). This unit lies unconformably on the Bighorn Formation and partly on Group II Volcanics. This tuff-breccia is overlain by another breccia unit that is similar in character but is dark brown (Fig. 11). The tuff-breccia unit is about 350 feet thick and is restricted to the immediate area of the Bull Creek and Buffalo Creek drainages. This breccia contrasts so sharply with the overlying darker breccias, that when viewed from a distance, the Bull Creek basin stands out as a prominent light-colored band. From a distance this outcrop appears to typify the original concept of an "early acid breccia" unit overlain by an "early basic breccia" unit.

Closer observation of the outcrop reveals the diverse lithology of the breccia. Subangular to subrounded fragments from sand size to boulders and blocks three feet across are



FIGURE 11. View showing the pronounced unconformity between the lower latitic tuff-breccias and the overlying unit of volcanic mud flows. View looking northeast. Beds dip toward the viewer at about 16°.

present. The various sized fragments appear in about equal proportions. Most of the fragments appear to vary in composition from rhyolites to basalts, but minor amounts of limestone and granitic gneiss fragments are also present; all are set in a fine-grained, whitish-gray groundmass. In places large blocks of pyroclastic flow breccias similar to those of the Group I Volcanics in the Boulder River area can be observed. The tuff-breccia is firm and in most cases fractures through matrix and fragments alike.

When viewed from a distance the well-developed bedding can be easily observed. The nature of these layers could not be studied due to the cliff-like outcrop of the tuff-breccias. The breccia layers conform to the dip of the underlying Bighorn Formation which dips 9-16° SW.

Under the microscope, the matrix of the breccia appears remarkedly free from any alteration. Clear, sharp, angular fragments of plagioclase (andesine-labradorite), hornblende, augite, some hypersthene, quartz and glass are set in dust size material presumably of the same composition. Minor amounts of magnetite are scattered throughout the section. Fresh, fragmental amber-colored hornblende grains occur in about 3:2 ratio over fresh augite.

The small lithic fragments consist of dacites, quartz latites, latites, augite vitrophyres, basalts and possibly some andesites. The matrix and most of the fragments stain noticeably and on the basis of the potash feldspar present the unit is called a latitic-lithic tuff-breccia.

Due to the extreme fragmental nature of the diverse lithologic breccia, this rock probably represents the accumulation of explosive materials from a nearby vent. The restricted occurrence of the unit may be due to the filling of a topographic depression; or, the tuff-breccia may have covered a broader area and then was eroded prior to the accumulation of younger volcanics. The breccias possess an overall dip away from the Independence volcano which is considered to have been the source.

Volcanic Breccias.- Immediately above the latitic-lithic tuff-breccias lies a thick sequence of crudely-layered dark brown breccias. The size of the fragments varies considerably, with a higher proportion of basaltic and scoriaceous materials present than in the lower unit. This thick unit of volcanic breccias is considered to represent several separate lahars for the following reasons: (1) they are unstratified, (2) poorly sorted, (3) have a great percentage of subangular fragments, (4) appear to represent a valley fill, and (5) consist of material derived from Group I and III Volcanics. This laharic unit forms the high ridge between the North Fork of Bull Creek and the East Fork of the Buffalo Fork Creek (Fig. 12). When viewed from a distance the lahars seem to possess some bedding features, but upon close observation there is no apparent bedding present in the massive outcrops. These lahars porbably represent volcanic debris that has been partially reworked and mobilized over a relatively short distance. Sorting is poorly developed,

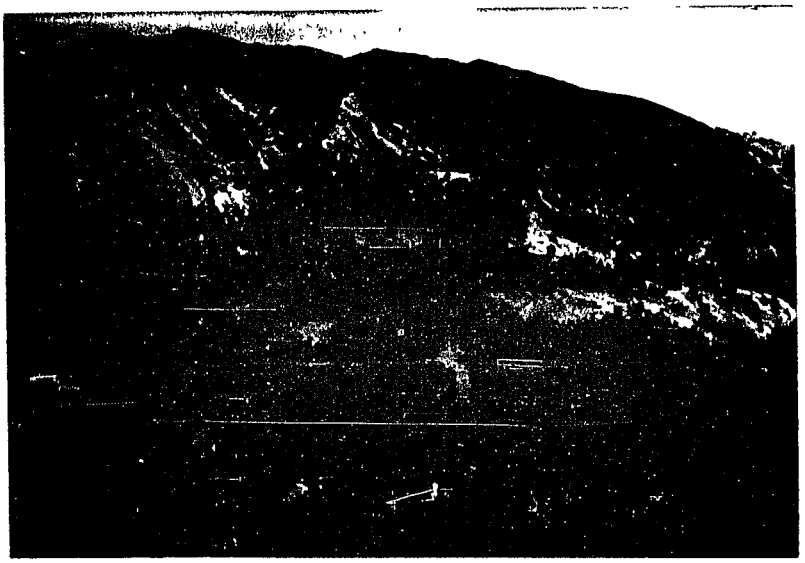


FIGURE 12. View showing the dark-colored ridge made up of a series of volcanic mud flows that are closely related in time. These flows dip away from the general vicinity of the Independence volcano at about 14°. View looking northeast across the East Fork of the Buffalo Fork Creek.

but portions of the unit show contortions indicative of plastic flow.

The laharic unit is about 1,100 feet thick and is interlayered with pyroclastic breccias and tuff lenses near the top of the section. Fossil wood fragments have weathered out of various parts of the unit. There are similar mud flows on the high ridge at the head of the tributary valleys of the Boulder River. Although these deposits are local, they constitute about 30-40 per cent of the total quantity of volcanic rocks in the Independence area.

In hand specimen the matrix of the mud flows consist of volcanic sandstone. The colors are various shades of brown that give the entire outcrop a rather dark appearance when viewed from a distance. All of the sand-sized fragments are of volcanic origin. The matrix fractures readily and breaks around the fragments revealing their subrounded- to subangular character.

In thin sections the crystal and lithic fragments of sand-size are highly angular (Fig. 13). The angular feldspar crystals are fresh whereas nearly all of the mafic minerals have been completely altered. A few remnants of pyroxene appear in the midst of some of the aggregates of magnetite, hematite, chlorite and carbonate. Most of the alteration apparently resulted from circulating ground waters; mechanical attrition is practically negligible.

Much of the pyroclastic material in the Independence area undoubtedly has been dispersed as mud flows. Rouse (1937,

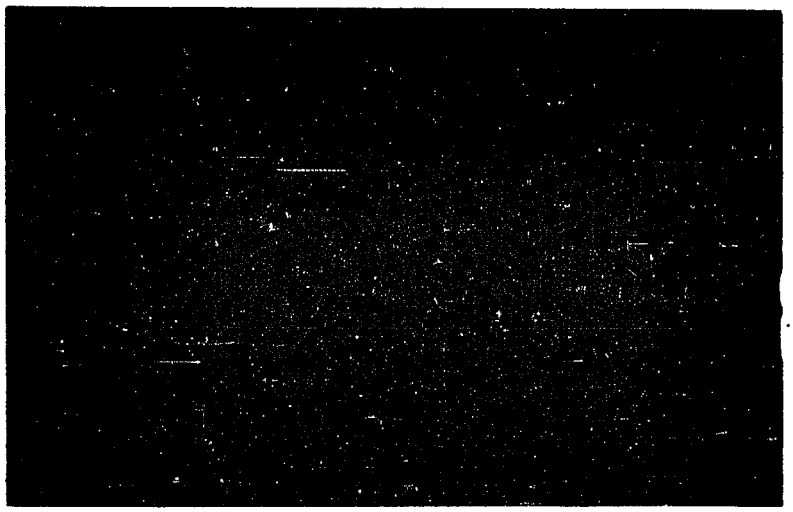


FIGURE 13. Photomicrograph of the matrix from the volcanic mud flows of the Group III Volcanics showing the angular character of the lithic and crystal fragments. The finer-grained matrix forms a flow pattern between the larger volcanic fragments. Plain light. 3X

p. 1281) pointed out the importance of mud flows as a mode of emplacement of volcanic breccias in the southern Absaroka Mountains. According to Dorf (1953, p. 1413) humid, subtropical conditions existed in the Yellowstone Park area during late Eocene time. The relief of the prevolcanic surface, coupled with periods of erosion during the volcanic cycle, maintained slopes on which flowage could take place. The conditions for the development of mud flows in this volcanic terrane were very favorable.

Agglomerates and Agglutinates.- Agglomerates occur in significant amounts in the area southwest of Monument Peak but are lacking in the areas to the west and northwest. They appear mostly on the high ridges and are excellently exposed on the north face of a cliff just west of Buffalo Pass. The agglomerates differ from the pyroclastic breccias in having a greater percentage of rounded fragments. The agglomerates differ from the volcanic conglomerates in the absence of well-developed bedding and in having distinctly subordinate tuffaceous matrix.

Collapse of vent walls and subsequent churning activity in the vent are considered to be the cause of the rounding of the various volcanic fragments. Many of the rounded fragments are up to 3 feet across and some are as much as 6 feet in diameter. The average size is about 8 to 12 inches in diameter. The six foot boulders indicate that they were deposited close to the source of origin. Just east of Sheepherder Peak (Fig. 14) the agglomerates are interlayered with

a series of lava flows and pyroclastic breccias possessing dips that range from 20 to 25 degrees to the south.

Agglutinates have been recognized in only three outcrops, but their distribution around the Independence volcano indicates that they may have been present in significant amounts prior to erosion. These volcanics are important in that they represent a distinct explosive phase i.e., lava fountaining, during the volcanic episode. They appear at different stratigraphic levels within the volcanic breccias. At the head of the North Fork of Bull Creek they lie on the volcanic mud flows and dip to the southeast at more than 30 degrees. Near Sheepherder Peak the agglutinates are interbedded with a series of tuff breccias and lava flows that are highly vesicular. This outcrop (Fig. 15) shows the complicated structures and varied rock-types that arise from the initial deposition of volcanic debris from a nearby vent.

The term agglutinate aptly describes the rounded, breadcrust structure of these pyroclastics that are held together like a mass of clinkers. They are brick-red, highly vesicular and range from cinders to boulders and blocks 2 feet across. Although no typical bombs were observed, most of the rounded debris reveals an outer vesicular crust and an interior that becomes progressively denser. Some of the former gas cavities are filled with secondary minerals such as calcite, quartz and in some places an unidentified zeolite. This unit varies in thickness. The agglutinate at the head of the North Fork of Bull Creek is about 275 feet thick, but elsewhere it does not exceed 30 feet.



FIGURE 14. View showing an interlayered series of basalt flows, pyroclastic breccias and distinct layers of agglomerates which dip away from the Independence volcano. Photograph taken just east of Sheepherder Peak. Beds dip to the southwest.

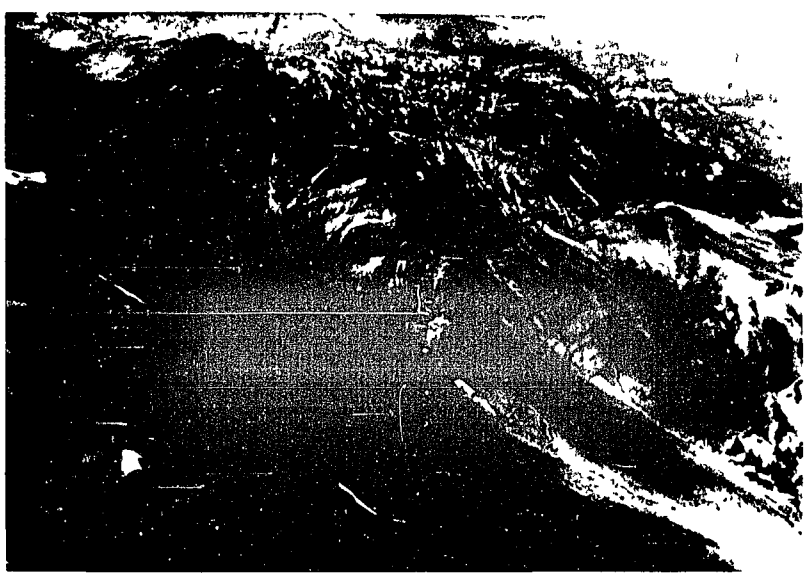


FIGURE 15. View showing a chaotic assemblage of lithic tuff-breccias, pyroclastic breccias, agglomerates and zones of agglutinates. Photograph taken at the head of South Fork of Sheep Creek looking northwest.

Compositionally, the agglutinates appear to range from andesites to basalts. Although most of the clinker-like fragments are brick-red on the surface, when fractured they reveal a dark gray to black aphanitic groundmass. The red coloring is probably due to auto-oxidation.

Latitic-Lapilli Tuffs.- Local units of lapilli tuffs crop out as conspicuous white lenses near the top of the ridges just north of Iron Mountain. These tuffs are no more than 30 feet thick and are patchy in their distribution. Six distinct units were recognized and correlated with each other on the basis of their stratigraphic position and megascopic character. The lapilli tuffs are well layered (Fig. 16) and contain abundant dark, angular volcanic fragments that average 1/2 to 1 inch diameter. Some fragments as much as 2 feet in diameter are present.

In a sample from a tuff lens at the head of the South Fork of Sheep Creek the dark gray to black fragments contrast sharply with the light-colored matrix. The rock is well indurated, but the weathered surface has a pebbly appearance. The layering dips about 25-30° SW, away from the Independence volcano.

Thin section studies show that the matrix is rich in crystal and vitric fragments. Elongate laths and angular fragments of andesine (An_{34-41}) make up about 40 to 50 per cent of the section. About 5 to 10 per cent of smaller anhedral hypersthene grains are present. Stringers and shards of clear, honey-brown partially devitrified glass are



FIGURE 16. View showing a section of latitic lapilli tuffs that is preserved on a ridge just north of Iron Mountain. These well-layered tuffs dip away from the Independence volcano at about 25-30 degrees to the southwest. View looking west.

disseminated throughout the section. The larger fragments of plagioclase and glass are set in a pumiceous groundmass that is sprinkled with magnetite dust and a few biotite flakes. The plagioclase is fresh and shows some normal zoning. Some of the hypersthene shows slight alteration in the form of marginal magnetite and chlorite. Selective staining of the matrix indicates that potash feldspar is present in amounts large enough for the rock to be called a latitic tuff.

In outcrop, the descent of large volcanic fragments has created impact structures which demonstrates that the tuffs were formed by the accumulation of airborne materials. In thin section, the flow-like structure formed by the stringers of glass suggest that the ejecta were hot when deposited. Continued deposition on an inclined slope aided by the weight of the overlying material probably induced flowage on a small scale. This unit may also represent, in part, an ash-flow deposit which could account for the flow-like character of the stringers and shards of glass.

Epiclastic Volcanic Breccia.- This term is used, as suggested by Fisher (1960, p. 978), to include all types of volcanic fragmental rocks (lahars, volcanic conglomerates, and volcanic sandstones) which have been transported by epigene geomorphic agents or by gravity transfer. The epiclastic volcanic breccias are best displayed in the Hell-roaring Creek area and also in the vicinity of the Cutoff Mountain (Fig. 17). These deposits appear as massive mudflows or water-laid volcanic breccias and are usually inter-



FIGURE 17. View showing Cutoff Mountain which is located in the southeast corner of the Independence area. This mountain consists of over 2,500 feet of epiclastic volcanic breccias of the Group III Volcanics. View looking due east.

bedded with volcanic sandstones. They are monotonous, extensive deposits that occur mostly on the outer flanks of the Independence volcano. For the most part they are crudely-bedded and form thick units. In the Hellroaring Creek area the streams have cut down through more than 3,000 feet of the epiclastics without exposing any other type of volcanic rocks.

Nearly all types of volcanic fragments occur in the epiclastic breccias. Some zones show well-rounded, various-sized fragments (Fig. 18) whereas others have pyroclastic characteristics. In some places distinct lenses of cross-bedded volcanic sandstones lie just a short distance above the very coarse conglomeratic units.

The epiclastics are considered to be flank-alluvial deposits that have filled in the low-lying areas to the west, south, and southeast of the Independence volcano. These epiclastics form thick volcanic breccia plateaus that are prevalent, in the Absaroka volcanic field, away from major source areas (Parsons, 1958, p. 40). The most prominent outcrop of the epiclastics occurs at Cutoff Mountain in the southeast corner of the Independence area (Pl. I). Similar deposits can be observed in the Buffalo Fork Creek drainage in the general vicinity of Iron Mountain (Fig. 19).

Similar epiclastic deposits occur in the northeast corner of Yellowstone National Park. The northeast entrance to Yellowstone Park lies in the deep, broad glaciated valley of Soda Butte Creek carved out of the epiclastics. The highway



FIGURE 18. View showing a section of well-indurated epiclastic volcanic breccias. Two separate flows are shown that are similar in composition but different in texture. Photograph taken just east of the Buffalo Fork laccolith below Round Head Butte.

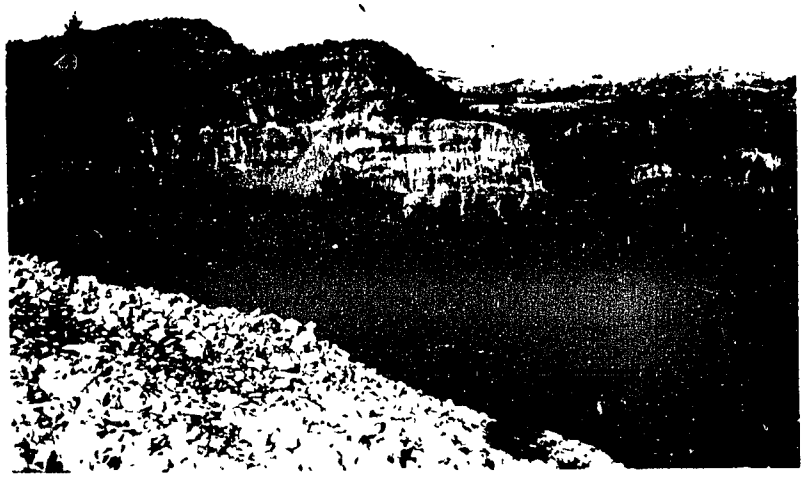


FIGURE 19. View showing a section of well-indurated lahars and volcanic conglomerates of the Group III Volcanics. View looking west across Buffalo Fork Creek.

that winds through these canyons affords an excellent view of the immense quantity of re-worked and re-deposited volcanic debris.

TABLE 5.- General summary of the Group III Volcanics.

ROCK TYPE	COMPOSITION	MAXIMUM THICKNESS
Epiclastics	Undifferentiated series of volcanic conglomerates, sandstone, mudflows and pyroclastic breccias.	3,000'
Lapilli Tuffs	Thin lenses of well bedded tuffs containing pebble size volcanic fragments. Fragments about equal proportion to matrix, which consists of crystal vitric fragments.	40-60'
Agglomerates, Agglutinates	Rounded fragmental rocks, tuffaceous matrix subordinate, some "welded spatter", clinkery, with prominent bread crust structures.	0-200'
Volcanic Breccias	Mud flows representing partial reworking of volcanic debris near source area. All types and sizes of volcanic fragments present. Poor sorting.	1,100'
Pyroclastic Breccias	Angular fragmental rocks, tuffaceous matrix subordinate. Forms lens-like deposits. All fragments of volcanic origin. Size range from less than an inch to blocks more than 6' across.	350'
Lithic tuff-breccias	Local units of fragmental rocks in which the matrix predominates. Matrix consists of angular crystal lithic fragments and appears fresh. Rich in pyroxene with some amphiboles. Plagioclase consists of medium andesine .	250'

Group IV Volcanics

General Statement.- The Group IV Volcanics are so grouped in that they consist of mappable units of volcanic conglomerates and sandstones. They are unlike the poorly developed volcanic conglomerates and sandstones of the Group III Volcanics that were lumped together under the general term of epiclastics. The Group IV Volcanics reflect a period of extensive aggradation around the flanks of the Independence volcano. They represent a transitional zone from most of the Group III Volcanics to the basalt flows of the Group V Volcanics.

The volcanic conglomerates and sandstones of the Group IV Volcanics differ from the epiclastics of the Group III Volcanics in that they have: (1) better developed sorting, (2) well-developed vertical grading, and (3) possess a greater percentage of rounded fragments. They occur primarily as aggradational fills in the Group III Volcanics.

Distribution.- The volcanic conglomerates occur principally in the Buffalo Fork drainage; whereas the volcanic sandstones crop out at the head of Sheep, Copper and Elk Creeks and on the ridge north of Bridge Creek. At the head of Sheep and Copper Creeks the volcanic sandstones form the high, sharp ridges. Here the sandstones lie on lithic tuff-breccias of Group III Volcanics. In the Bridge Creek area the volcanic sandstones appear as channel fills in the epiclastic breccias of the Group III Volcanics and are

covered by the basalt flows of Group V Volcanics.

Volcanic Conglomerates.- The volcanic conglomerates are best exposed in the Buffalo Fork area where they form a prominent ridge more than 900 feet high (Fig. 20). From a distance these layered volcanic conglomerates stand out in sharp contrast with the pyroclastic breccias nearby. The conglomerates dip about 9 degrees to the southwest away from the Independence volcano. This unit contains thin lenses of volcanic sandstone, some which show well developed cross-bedding. The conglomerate does not have wide lateral extent and appears to represent a valley fill.

The volcanic conglomerate consists of sub-rounded to rounded pebbles, cobbles and boulders of all of volcanic origin. Most of all the rock types that were previously described can be observed in this conglomeratic unit. Rounded pebbles of granitic gneisses are rarely present. The fine-grained matrix is a mixture of subangular to subrounded crystal and lithic fragments.

Volcanic Sandstones.- Lenticular volcanic sandstones crop out at the head of Sheep and Copper Creeks in the form of nearly vertical cliffs. Nearly all of these sandstones appear the same texturally, but vary in color and mineral composition. Some of the sandstones carry greater quantities of rounded pebble-size fragments than others. Locally, cobbles and boulders are scattered throughout the sandstone lenses. Some lenses are light gray in color, whereas others are shades



FIGURE 20. View showing a ridge that is made up of a thick section of volcanic conglomerates of the Group IV Volcanics. The crude bedding is caused by the presence of thin layers of volcanic sandstones. View looking west across Buffalo Fork Creek.

of darker brown. In thin sections the darker sandstones show greater amounts of mafic minerals and limonite staining. Color variations within some sandstone lenses probably reflect the conditions of deposition or the compositional differences of the original volcanic rocks that were being eroded, reworked and finally re-deposited.

In the Bridge Creek area, the volcanic sandstones do not possess the distinct channel-fill pattern as do those at the heads of Sheep and Copper Creeks. Textures and compositional features are similar. One lens about 200 feet thick, just north of Bridge Creek, has a wide distribution and may be a cross section of a broad alluvial fan-type deposit.

The volcanic conglomerates occur topographically lower than the lenses of volcanic sandstones. The conglomerates may represent rapid filling of a pre-existing valley. Erosion and deposition probably reduced the overall gradient around the flanks of the volcano prior to the deposition of the sandstone lenses. The leveling of the flanks by erosion and deposition, as characterized by the Group IV Volcanics, could then account for the nearly flat surface that existed prior to the outpouring of the basalts of the Group V Volcanics.

Group V Volcanics

General Statement.- The Group V Volcanics reflect a new period of volcanism in which great quantities of relatively non-explosive extrusive materials poured out on the surface. This unit consists of lava flows with some basaltic pyroclastics and felsic tuffs. They are preserved only in the southern, western and northwestern parts of the area and occur as cappings on many of the high ridges. Their distribution indicates that they were widespread and formed a relatively thick cover over the older volcanic rock. Local felsic tuff lenses occur within the basalt flows.

Distribution.- The basalt flows and pyroclastics of the Group V Volcanics are best exposed at Iron Mountain in the west central part of the Independence area. The basaltic rocks weather to a very dark brown which gives this mountain its rusty appearance. The ridge farther south, that encircles Hummingbird Basin, also consists of these flows. They also cap Round Head Butte to the east and a sharp ridge near Lookout Mountain to the southeast. To the northwest Elk and Bridge Lakes are bottomed by the basal units of these basalt flows. The Group V Volcanics appear to the thickest to the northwest in the vicinity of Pyramid Mountain which is just outside the map area, and here the unit has a minimum thickness of about 1,200 feet. The Group V Volcanics are considered to be time equivalents of the "early basalt sheets" that occur in the vicinity of Yellowstone Park (Hague et al., 1894, p. 4).

Description.- The outcrop at Iron Mountain is typical of basalt flows elsewhere in the area and will be used for a general description.

A sharp unconformity marks the division between the older volcanics and the basal units of the Group V Volcanics (Fig. 21). The basal unit consists of a series of basaltic pyroclastics, with abundant scoriaceous fragments, and in interlayered with thin, highly vesicular basalt flows. Parts of the pyroclastics are crudely bedded whereas other parts possess a definite agglutinatic appearance. Higher in the section basalt flows are more prevalent, with only subordinate thin layers of basaltic pyroclastics. The total thickness of the unit, as preserved on Iron Mountain, is about 850 feet, with the more distinct basalt flows occuring in the upper 200 feet. Abundant quartz amgydules, 2 inches across, are commonly exposed on the weathered surfaces.

Trachybasalts.- The trachybasalts of the Group V Volcanics are more porphyritic than the basalts of the Group I Volcanics in possessing larger phenocrysts of plagioclase and pyroxene. In one specimen from the peak of Iron Mountain phenocrysts of labrodorite (An_{51-55}), up to 3 mm in length, are present in amounts of 50-60 per cent. Anhedral phenocrysts of augite attain a length of 2 mm and make up about 15-20 per cent of the rock. Some smaller phenocrysts of hypersthene are present in minor amounts. These phenocrysts are set in a hyalopilitic matrix of the same minerals with some magnetite and brown glass (Fig. 22). The rock is unaltered. The rock



FIGURE 21.- View showing the unconformity between the basalt flows and pyroclastics of the Group V Volcanics and the lower Group III Volcanics. View looking southwest from a point just west of Buffalo Pass.

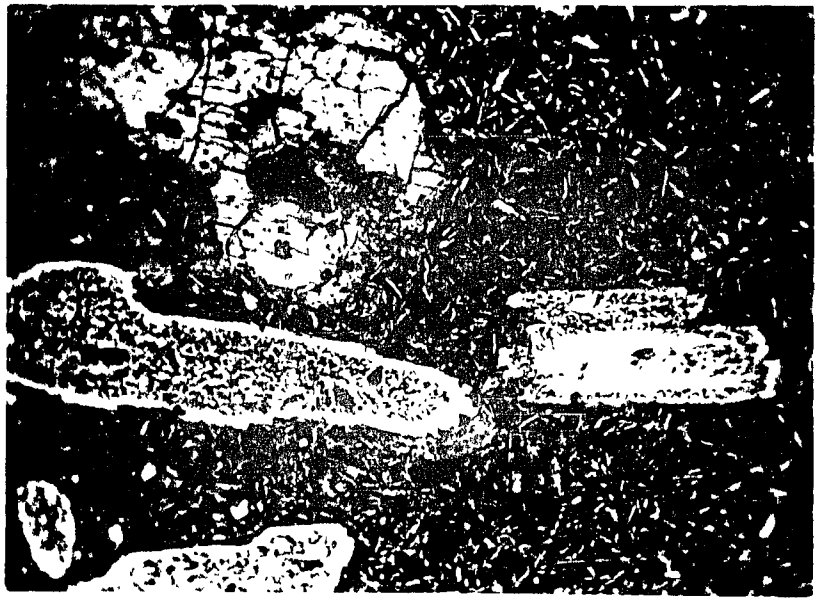


FIGURE 22.- Photomicrograph of a trachybasalt from Iron Mountain showing hyalopilitic texture. Labradorite crystals in lower half of picture are heavily charged with glass and microlites. The clear rims of the labradorite are slightly less calcic than the interiors of the crystals. Polars not crossed. 25X

reacts to staining which indicates the presence of potash feldspar; hence, the term trachybasalt seems to be justified.

For the most part the pyroclastic debris contains more glass than do the flows. One scoriaceous sample contains as much as 30 per cent of black, magnetite-charged glass. Plagioclase makes up 50 per cent and much of this is glass-charged, zoned labradorite up to 3 mm in length; and the rest occurs as clear microlites. The remaining minerals are subhedral augite crystals, less than 0.5 mm long, and a few grains of hypersthene and magnetite. Compared with the Group I basalts, the Group V basalts are richer in glass and carry a greater percentage of pyroxene and plagioclase phenocrysts. A few basaltic tuff lenses occur within the pyroclastics.

Felsic Vitric Tuffs.- An unusual tuff lens within the trachybasalt flows is best exposed on a ridge just southeast of Iron Mountain. This lens averages about 16 feet in thickness. The tuff is light gray to white and weathers to a light pink color. The tuff is well bedded, with considerable particle variation from layer to layer. Parts of the tuff are very fine-grained and friable. Some zones are coarser grained, more indurated, and appear very gritty with black grains of volcanic glass.

In thin section the minerals consist of about 33 per cent of fragmented andesine (An_{42-48}) and more than 60 per cent of glass shards. Some small crystals of apatite is also present. Tiny clusters of magnetite and a white opaque substance make

up the rest of the thin section. The plagioclase crystals are clear, weakly zoned and fresh. Practically all of the glass occurs as subrounded shards. Some of the shards are collapsed and possess features suggestive of welding, but these are not common. Most of the glasses are brown, yellow and orange; whereas, some of the glasses are colorless but are crowded with tiny particles that act as pigments. Some glass fragments show well developed flow structures (Fig. 23). Nearly all the glass is devitrified and shows weak birefringence. The index of refraction of the clear glass falls within the range 1.51-1.53 which is representative of volcanic glass of intermediate composition. The rock is considered to be a felsic vitric tuff.

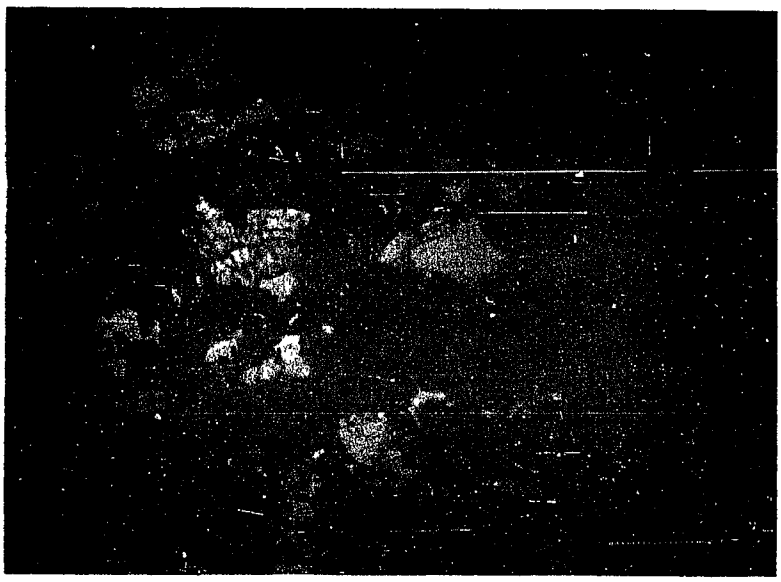


FIGURE 23. Photomicrograph of felsic vitric tuff that occurs interlayered with the basalts of the Group V Volcanics. The tuff consists of angular fragments of andesine (A), glass (S) with some showing flow structures, and minor amounts of pyroxene (P). Plain light. 25X

Intrusive Rocks

Buffalo Fork Laccolith.- The Buffalo Fork Laccolith occurs in the Buffalo Fork drainage 3 miles south of Boulder Pass and forms three low lying ridges that are partly covered by younger volcanics. This once continuous body was 2 1/2 miles long and 3/4 mile wide, but has been split by the Buffalo Fork Creek and its eastern tributary into three separate units. A remnant of altered Cambrian limestone rests on the mass on the east side of Buffalo Fork Creek. This block of altered limestone has a higher topographic position than an equivalent Cambrian limestone about 2 miles to the southeast and strongly suggests a laccolithic structure for this intrusive mass. The height from the stream bed to the base of the altered limestone indicates a minimum thickness of 830 feet. The intrusive mass is not observable in the lower parts of adjacent valleys to the east and west.

Group III Volcanics cover the laccolith in part (Fig. 24). The absence of any deformational features in the pyroclastics and the lack of xenoliths in the borders of the laccolith points to a pre-Group III Volcanics age for this intrusive mass. The laccolith is probably related in time to the Group I Volcanics in the Boulder River area.

The flanks of the laccolith are covered with thin angular slabs which show few effects of weathering. In hand specimen the rock is a dense, white to gray porphyry with a subconchoidal fracture. A few white anhedral plagioclase feldspar crystals up to 2 mm long are present. A few specks of



FIGURE 24. View showing the light-colored rocks of the Buffalo Fork laccolith that are covered, in part, by the dark epiclastic volcanic breccias of the Group III Volcanics. Photograph taken from the vicinity of Iron Mountain looking southeast.

biotite are scattered throughout the rock.

Thin section study shows the rock to be a quartz latite porphyry. It is holocrystalline and porphyritic with distinct anhedral andesine (An_{32-36}) crystals in a microcrystalline matrix. Minor amounts of biotite in flakes up to 0.5 mm are present. The goundmass is equigranular. Quartz and orthoclase are present in essential amounts. Small needles of apatite and hornblende are accessories and very small specks of magnetite are sprinkled throughout the section. The andesine phenocrysts show strong, normal zoning and are fragmental in part. Some feldspars are clear and glassy and only a few show slight sericitization. A few of the biotite flakes are altered to chlorite, and some of the hornblende is rimmed with magnetite. Parts of the rock stains to a brilliant yellow, and in section, interstitial patches of material that reacted to the staining process proved, optically, to be orthoclase. The modal analyses of the rock is presented in Table 3 (sample BF-26).

Farther south in the Bull Creek drainage, similar light-colored rocks are poorly exposed in the heavily timbered valleys and on the ridges (Pl. I). These outcrops form a linear pattern and may be an extension of the laccolith in the Buffalo Fork Creek drainage.

Sheep Creek and Buffalo Pass Plugs.- Two cylindrical bodies, partly exposed in the Group I Volcanics, crop out northwest of the Buffalo Fork Laccolith. The rocks of these plugs are so badly weathered and shattered that a fresh sample

could not be obtained. Megascopically they appear to represent a latitic or andesitic porphyry.

These plug-like bodies fall along a northwest line or zone punctuated with intrusive bodies (Pl. I). The plugs are considered to belong to the Group I Volcanics, and may have been a feeder for some of the younger volcanic rocks. The only definite evidence of intrusion was observed near the plug just north of the Buffalo Fork laccolith. A small irregular dike, originating from the plug, cuts the Group I Volcanics. Elsewhere contact relationships are obscured.

Mill Creek Plug.- The Mill Creek plug crops out in a circular pattern at the headwaters of Mill Creek, in the extreme northwest part of the Independence area (Pl. I). The more resistant rocks of the plug have caused the stream to split into two tributaries which encircle the plug. The contact between the plug and the Group I Volcanics is obscured by soil and bushes. Several dikes radiate from the plug. The dikes cut the lower Group I Volcanics and also the Group III Volcanics on the high ridges that surround the plug, but they do not cut the basalt flows of the Group V Volcanics.

In hand specimen the rocks of the plug appear as a dark andesitic porphyry. Large anhedral feldspar phenocrysts stand out against the dark aphanitic groundmass. The dikes radiating from the plug appear as finer grained equivalents of the plug rock.

In thin section the rock is identified as a labradorite latite porphyry. Large, partially resorbed, labradorite

(An_{59-61}) crystals, up to 7 mm in length, are the dominant phenocrysts. Smaller crystals of subhedral pyroxene, mostly augite with some hypesthene, occur in essential amounts in the matrix. The matrix consists of about equal amounts of orthoclase and a more sodic plagioclase (An_{36-44}). Ten to fifteen per cent magnetite is present. Quartz and apatite are present in accessory amounts. The texture of the matrix is hypidiomorphic-granular and is holocrystalline.

The large labradorite crystals show marked resorbed edges (Fig. 25) and are partly rimmed with a less calcic plagioclase. The interior of the labradorite is very clear whereas the matrix feldspars are clouded with alteration material. The pyroxenes show varying degrees of alteration. The larger crystals possess reaction rims that are crowded with magnetite. The entire thin section is highly altered with secondary material consisting of biotite, chlorite, magnetite, limonite, calcite, and minor amounts of kaolinite and sericite.

The seemingly anomalous occurrence of very calcic plagioclase phenocrysts, within a relatively acid matrix, may be due to a mingling of magmas at depth prior to intrusion. Larsen et al., (1938, p. 429) have reported unusual feldspar phenocryst and matrix associations from some of the volcanic rocks of the San Juan region in Colorado and suggested the mingling of magmas.

The Mill Creek plug probably arose in the form of a parasitic one on the flank of the major Independence volcano.

Dikes.- Nearly all of the dikes in the area crop along a



FIGURE 25. Photomicrograph of the labradorite latite porphyry from the Mill Creek plug. Large crystals of labradorite (An_{59-61}) lie in a fine-grained matrix consisting of a more sodic plagioclase (An_{36-41}) and essential potash feldspar. Polars not crossed. 3X

zone that trends northwest from the central part of the area to its northwestern corner (Pl. I). This line conforms to the same trend formed by the larger intrusive bodies. The alignment of the intrusive bodies probably reflects a major fault zone in the buried Precambrian rocks (see Structural Geology). With the exception of the Mill Creek plug and its conspicuous radial dike pattern, no radial pattern was found near the Independence volcano.

The attitude of the dikes varies, but for the most part they are nearly vertical. These dikes cut across all of the rocks in the Independence area, but most of them have been intruded into volcanic rocks. The longest dike crops out on the high ridge east of Sheepherder Peak and is more than 3,500 feet long. Most dikes crop out for short distances only and are not conspicuous. The width of the dikes ranges from 2 feet to 16 feet and averages 3 to 5 feet.

The dikes appear to be a variety of andesites and basalts. Most of the dikes contain phenocrysts of pyroxene with some dikes being more porphyritic than others. Only basaltic dikes cut the Group V Volcanics. This feature coupled with the predominant occurrence of andesitic dikes exposed on the lower ridges strongly suggests two distinct periods of intrusion. The andesitic dikes cut the Group I and Group III Volcanics whereas the basaltic dikes seem to cut all of the volcanic rocks in the area.

The dikes appear to have been intruded from below. In the Sunlight area of Wyoming, Parsons (1939, p. 23) found that

radial dikes around a volcanic vent were injected horizontally from the volcanic neck, into the volcanic rocks, without cutting the underlying Paleozoic strata. In the Independence area, the northwest zone of intrusive bodies, seem to support the theory of vertical intrusion for all of the dikes.

The Independence Volcano Intrusive Complex

General Statement.- The Independence volcano, named after a prominent peak just south of Basin Creek, is believed to have been the source for most of the volcanic ejecta in the map area. The dissected volcanic vent, roughly 3 square miles in extent, consists of coarse-grained rocks that grade from an older syenogabbro into a younger monzonite and granodiorite. The coarse-grained rocks of the core weather more rapidly than the fine-grained border zone which remains as a high ridge surrounding all but the eastern edge of the vent (Fig. 26).

The small body of intrusive rocks was originally mapped by Iddings in 1890. He suggested it as a problem for further study to W. H. Emmons. In 1908 Emmons presented a short paper on the petrography of the "Haystack Stock" in which he recognized 7 rock types and supported his petrographic observations with 6 chemical analyses. Emmons interpreted this zoned igneous body as originating by differentiation of a parent magma at depth and subsequent intrusion into the "early acid breccias" as a composite stock.

On the basis of detailed petrographic data and cross-cutting relationships, the writer considers this igneous body as a former volcanic vent, occupied in the late stage by the compound stock-like body.

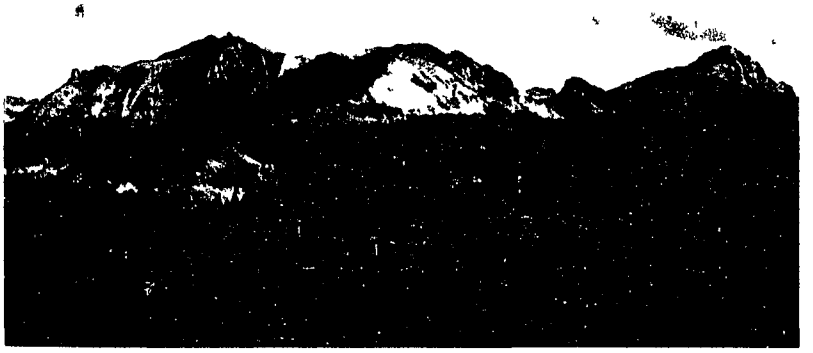


FIGURE 26. View showing the outer rim of intrusive breccia which forms a circular wall around the coarser-grained rocks of the Independence volcano. View looking southeast.

The field evidence for this hypothesis follows:

1. The central location of the coarse-grained rocks with respect to the layered volcanics that dip away from the structure.

2. Proximity of undisturbed deposits of agglomerates, agglutinates and ash-flow tuffs.

3. The distribution and semi-radial pattern of the epiclastic volcanic breccias away from the vent area.

4. The diverse lithologies noted in the intrusive breccias that surround the core.

5. The absence of any other major intrusive body in the area that may have been a vent.

6. The over-all mineralogical similarity of the potash-rich volcanic rocks that surround the volcano with the potash-rich coarse-grained rocks of the core.

Rock Types and Intrusive Sequence.- Detailed investigations on the western 3,000 foot slope of Monument Peak, and also on the cliff north of Basin Creek, revealed cross-cutting relationships indicating the following sequence of intrusive events:

5. Granitic dikes.
4. Granodiorite.
3. Monzonite.
2. Syenogabbro.
1. Latitic intrusive breccia.

The oldest intrusive rocks of the volcano consist of latitic intrusive breccias which constitute Monument and Haystack Peaks (Fig. 27). For the most part the intrusive breccias appear to grade into the syenogabbro. Just below Monument Peak, and to the west, stringers of the syenogabbro cut across the intrusive breccia for short distances. Northward, toward the central part of the core, the syenogabbro



FIGURE 27. View showing the north face of Monument Peak which is made up of intrusive breccias. This vertical cliff rises more than 1,400 feet above the general level of the immediate area and forms part of the ridge that encircles most of the coarse-grained rocks of core.

grades into the monzonite. On the west side of the core the monzonites cut the intrusive breccia. North of Basin Creek the granodiorites interfinger with the monzonites forming subtle gradation zones. Practically all the rocks of the core are cut by thin granite dikes. A small zone within the granodiorites reflects the final phase of igneous activity in the form hydrothermal alteration and sulfide mineralization.

The rocks north of Basin Creek appear to be separate from and later than the rocks in the southern part of the core. Although the rocks belong to the same general time period, this may reflect the migration of the conduit in the formation of the volcanic vent. The asymmetrical shape of the coarse-grained body seems to substantiate this observation. The reverse L-shape of the vent structure (Pl. I) could be the result of the intersection of two rift zones that were widened by volcanic activity. The intrusions probably followed two zones; one with a general east-west trend and the second with a northwest-southeast trend.

Petrography.- Twenty-eight modal analyses made from various rocks of the coarse-grained core are presented in Table 6. Modal analyses were supplemented by selective chemical staining of the potash feldspar in each thin section (Bailey and Stevens, 1960). The writer followed Chayes (1956) method for making the modal analyses. About 850 counts per thin section were made. The anorthite content of the plagioclase feldspars was determined by following Slemmons's (1962)

TABLE 6.- Modal analyses in volume per cent of the rocks from the core of the Independence volcano.

sample #	plagioclase	orthoclase	quartz	pyroxene	biotite	magnetite	amphibole	alteration products[1]	rock name
IA-20	48.1	12.4	4.5	16.2	8.5	tr.	--	8.2	syenogabbro
HS-51	51.5	17.3	2.5	18.4	4.7	1.9	--	2.1	syenogabbro
IA-09	51.5	23.7	---	20.5	---	2.2	--	2.3	syenogabbro
IA-11	58.7	15.9	---	24.9	2.1	3.6	--	1.6	syenogabbro
HS-54	52.3	22.3	tr.	22.7	tr.	1.1	--	1.7	syenogabbro
IMC-B	52.5	14.3	6.2	20.8	4.3	1.4	--	tr.	monzonite
HS-59	49.5	23.1	tr.	17.6	tr.	2.7	--	4.9	monzonite
AI-88	51.8	18.7	1.7	10.8	tr.	4.1	4.3	7.9	monzonite
HS-89	60.6	17.8	2.6	1.6	12.4	1.3	tr.	1.9	monzonite
HS-90	46.9	32.1	7.5	9.2	tr.	1.7	---	1.9	monzonite
IA-22	45.2	26.3	2.6	11.4	tr.	6.5	--	5.6	monzonite
HS-61	39.2	34.6	11.6	8.9	1.6	0.9	--	3.2	monzonite
HS-88	57.5	14.6	tr.	11.6	8.3	1.9	tr.	tr.	monzonite
SH-14	48.2	24.8	tr.	19.4	tr.	3.1	--	3.6	monzonite
AI-19	35.5	21.6	4.2	3.9	9.3	2.5	22.1	1.6	monzonite
HS-84	48.3	33.1	10.3	--	0.6	0.7	tr.	tr.	monzonite
HS-80	58.2	17.6	2.9	3.2	6.5	2.9	tr.	9.7	monzonite
HS-98	59.2	16.1	2.3	13.4	4.6	tr.	--	2.3	monzonite
HS-67	61.6	11.7	11.8	tr.	6.9	1.1	tr.	2.2	monzonite
HS-10	58.5	17.9	1.1	14.3	2.4	2.8	--	2.8	monzonite
HS-35	58.7	19.9	tr.	15.3	2.5	2.2	--	tr.	monzonite
HS-36	52.5	24.5	2.8	14.1	3.6	tr.	--	tr.	monzonite
HS-25	34.4	39.5	17.7	4.1	3.5	tr.	tr.	tr.	granodiorite
HS-29	42.1	25.2	22.1	6.2	4.4	tr.	tr.	tr.	granodiorite
HS-30	44.7	32.6	12.3	tr.	1.3	tr.	--	7.1	granodiorite
HS-04	45.5	24.6	17.5	tr.	6.3	tr.	--	3.9	granodiorite
HS-02	44.5	30.1	15.5	2.1	2.3	1.9	tr.	2.9	granodiorite
HS-55	59.8	11.7	10.7	16.1	tr.	1.3	--	tr.	latite

[1] Alteration products include: sericite, chlorite, carbonate, and in places an unidentifiable turbid aggregate.

procedure for measuring the optical and crystallographic directions in twinned plagioclase with a four-axis universal stage. The optically determined anorthite content of 6 plagioclase feldspars, from 6 different porphyries, was cross-checked by fusion methods (Gradwell, 1958). The glass beads were matched with mixed oils. The index of refraction of the oils was then measured on the Abbé refractometer. The results are shown in Table 7. According to Slemmons (1962, p. 18) the normal accuracy for percentage of anorthite is ± 3 per cent anorthite for a single twin measurement. It was found that simple fusion methods fell within 2 per cent of the optical methods. Measurements on various fragments of the same glass bead were duplicated within ± 0.001.

Rock names were determined by utilizing the modal classification suggest by Johannsen (1939, p. 141-161). The rocks were divided, and so grouped, by the ratio of plagioclase to the potash feldspar and by the anorthite content of the plagioclase. The plot of the modes and the resultant fields of similar rock-types are shown in Figure 28.

Latitic Intrusive Breccia.- The oldest rock of the Independence volcano consists of intrusive breccias that cut across the Group I Volcanics. This type of breccia is best observed on the south side of Monument Peak and has a semi-arcuate trend for more than 400 yards on the high ridge (Fig. 29). From a distance the intrusive breccias offer a sharp color contrast with the light-colored intruded volcanics. A traverse from the valley floor to the top of the

TABLE 7.- Comparison of the anorthite percentage determined by means of the index of refraction of fused plagioclase feldspar fragments with that estimated from optical data determined by means of a four-axis universal stage.

Specimen No.	An % U-stage	index of fused fragment	An % by fusion	An % curves by Foster (1955)	An % curves by Schairer (1956)
EB-2	35-38	1.519	36	37	39
WM-4	34	1.518	35	36	37
TS-1	33-40	1.519	36	37	39
BR-34	40	1.523	41	42	44
BL-7	34-38	1.520	37	38	40
HSB-15	31	1.517	33	34	37

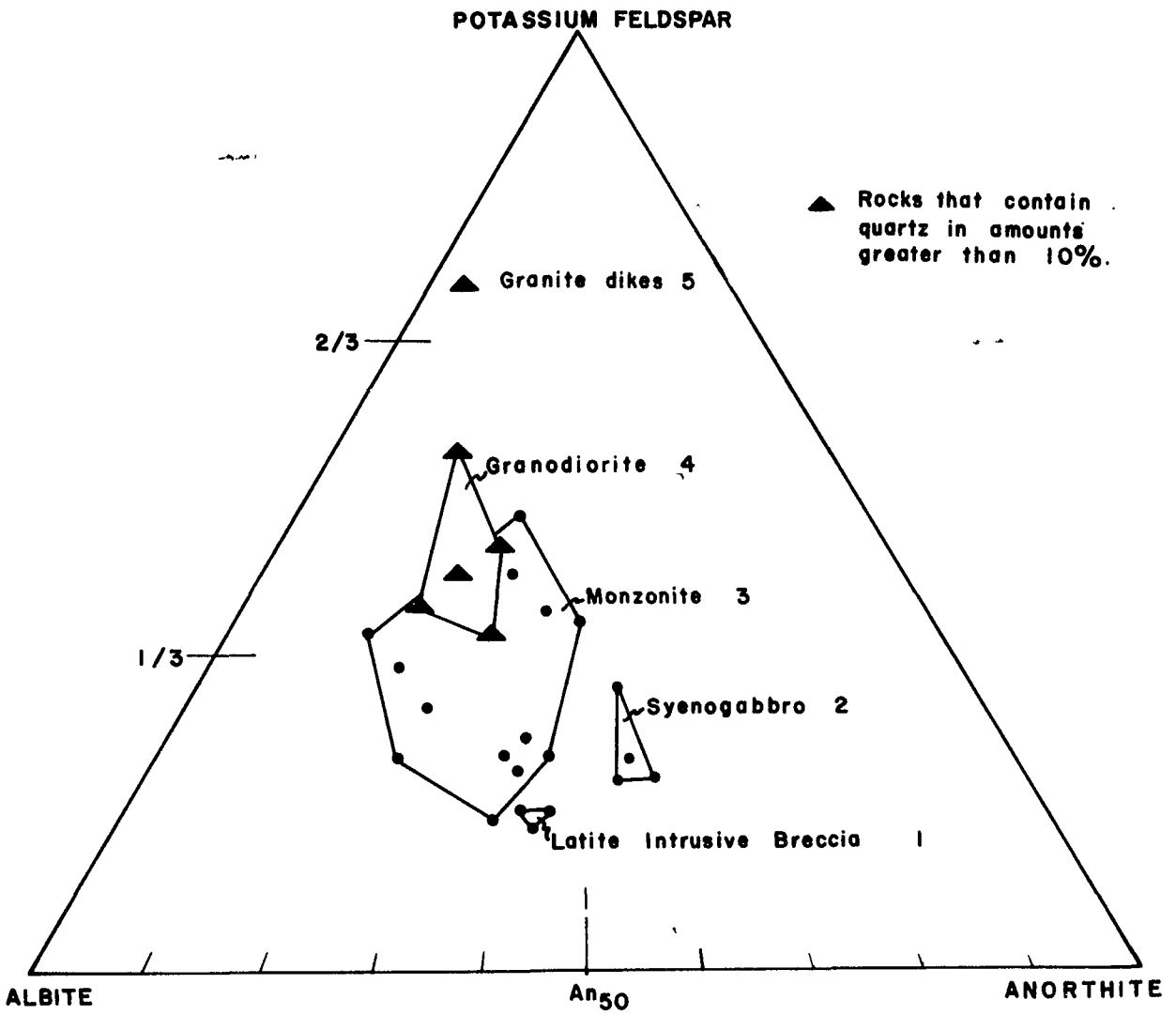


FIGURE 28.- Modal plot, and resulting fields, of the various rocks from the core of the Independence volcano. Arabic numbers refer to intrusive sequence.

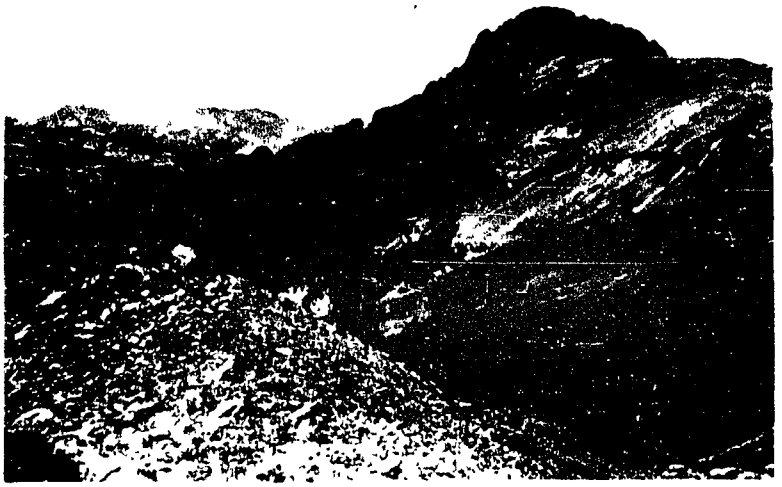


FIGURE 29. View showing the south side of Monument Peak which represents the southern part of the Independence volcano. This peak rises to an elevation of 10,988 feet above sea level and is made up of a latitic intrusive breccia that cuts across the Group I Volcanics.

ridge did not reveal a sharp contact between the intrusive breccias and the Group I Volcanics. Similar breccias occur elsewhere around the periphery of the volcano. On the east side of the volcano the intrusive rocks have been removed by glaciation, and soil cover obscures the contact relationships with the Precambrian metamorphic rocks.

The intrusive breccia is notably heterolithologic, with angular fragments ranging in size from less than one-fourth inch to more than 2 feet across. The average size is 2 to 3 inches. The fragments which are incorporated in a dark gray latitic groundmass make up as much as 60-70 per cent of some specimens. The weathered surface reveals the fragmental character of the rock more readily than a freshly fractured surface. Fragments from the entire Group I Volcanics plus Precambrian and Cambrian rocks can be recognized within a small area of a single outcrop. Many of the larger fragments are tabular in outline and are oriented, for the most part, in nearly vertical positions. This feature indicates that the intrusive breccias possess flow structures. The large percentage of accidental fragments, plus the flow structures, demonstrates that the fragmental material was completely incorporated, mobilized and carried upward more than 3,000 feet. In all probability some of the intrusive breccias poured out on the surface as part of the extrusive cycle of the volcano.

The ratio of fragments to igneous matrix diminishes in the intrusive breccias toward the core of the volcano so that

the breccias appear to grade into fine-grained igneous rocks. Thin section studies indicate that the rock is a latite. The mode of the rock is shown in Table 6 (sample HS-55). The holocrystalline rock is hypidiomorphic-granular. Most of the plagioclase (An_{39-48}), up to 0.5 mm long, shows resorbed edges and is set in a finer-grained matrix of a more sodic plagioclase and small subhedral crystals of augite. Late formed potash feldspar and quartz are interstitial. Magnetite is scattered throughout the thin section. The rock is almost fresh with just a trace of alteration products present. These include minor amounts of biotite, chlorite and some sericite.

Syenogabbro.- The syenogabbro is restricted to the southern part of the core of the volcano in the vicinity of Mud and Blue Lakes (Fig. 30), except that stringers of the syenogabbro intrude the intrusive breccias on the western slope of Monument Mountain. The syenogabbro makes up less than one-fifth, by volume, of the rocks within the interior of the core. The dark, medium-grained rocks weather quite readily into an arkozic residue. The rock varies somewhat in color dependent on the percentage of mafic minerals present. Plagioclase, pyroxene and traces of biotite can easily be seen in the hand specimen.

Thin section studies of the syenogabbro are similar to those described by Emmons (1908, p. 213) except for the olivine he mentioned. Examination of five thin sections failed to reveal the presence of olivine or any aggregates

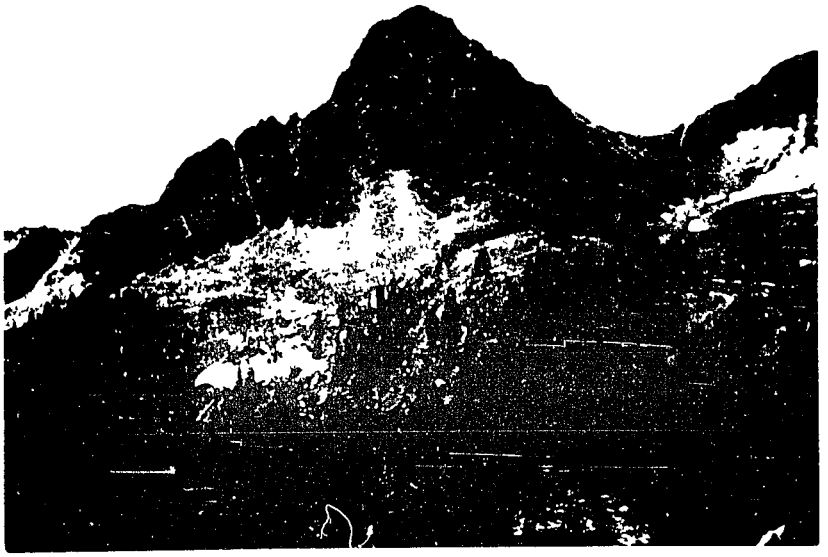


FIGURE 30. View showing the effects of differential erosion between the resistant intrusive breccias that make up Haystack Peak and the easily eroded syenogabbro that constitutes the low hill in the middle foreground. Blue Lake lies between these two local landforms. View looking south.



FIGURE 31. Photomicrograph of a syenogabbro from the low hill noted in Fig. 30. Dark areas between labradorite represent stained orthoclase. Augite shows excellent herringbone structure consisting of exsolved magnetite. Polars not crossed. 25X

of altered materials suggestive of its former presence. This discrepancy appears to be due to the gradational character of the syenogabbro and the nature of the sampling.

The rocks are allotriomorphic-granular. Pyroxene, magnetite and orthoclase occur interstitially to larger crystals of labradorite (An_{52-61}). The modal analyses of 5 samples appear in Table 6. Two pyroxenes are present, with titaniferous augite occurring at about 5:2 ratio over hypersthene. The unusual essential amounts of untwinned orthoclase are interstitial to both the plagioclase and pyroxene. In some thin sections accessory quartz appears as either micrographic intergrowths with orthoclase or as isolated blebs filling tiny angular interstices. Common accessories include biotite, magnetite and small needles of apatite. Biotite and magnetite occur either as primary minerals or as secondary minerals after pyroxene. The pyroxenes show various degrees of alteration. Some augite occurs as clear crystals containing exsolved magnetite which has formed well-defined herringbone structures (Fig. 31); in some places hypersthene contains sub-microscopic materials which in turn form excellent schiller structures.

Monzonite.- The monzonites are the most abundant rocks and are well-exposed in the central, western and northwestern part of the core. Exposures indicate they constitute about three-fourths of the core by volume.

The texture and color of the monzonites vary depending on location and the amount of mafic minerals present. These

rocks grade into the intrusive breccias and syenogabbros, within the core, but cut across these rocks on the western slope of the volcano. The monzonites are difficult to recognize in the field because they resemble the granodiorites in places and also look like typical syenogabbros elsewhere.

Microscopically the monzonites are allotriomorphic-granular. Most of the rocks are medium-grained. Andesine (An_{33-49}) and orthoclase are the only essential minerals present in all rocks (Table 6). Pyroxene and quartz vary from accessory to essential amounts. Common accessories include magnetite, apatite, biotite and rare epidote and sphene. As noted in the syenogabbros, all the minerals in the monzonites occur interstitially to the plagioclase feldspars.

Pyroxene is a common accessory with both augite and hypersthene present. Augite is the most common and occurs as stubby, prismatic crystals or as anhedra in aggregates with biotite and magnetite. Some of the pyroxene is uralitized to a greenish-brown amphibole. The plagioclase commonly occurs as elongate laths. Normal zoning predominates. As a rule the larger plagioclase is marked by resorbed edges. The smaller plagioclase laths are more sodic than the larger laths. Optical measurements revealed that the plagioclase varied as much as 15 per cent in An-content.

Fine-grained magnetite along cleavages in augite, slight sericitization of the plagioclase and chlorite in biotite suggest that the minerals were probably hydrothermally altered.

Granodiorite.- The granodiorite crops out north of Basin Creek as a dome-like mass (Fig. 32). This rock makes up less than one-third of the total volume of the rocks within the core. Just north of Basin Creek, where the road crosses the stream, stringers of granodiorite cut monzonite. No chilled margins were observed, even though the lighter-color granodiorite penetrates the darker and finer-grained monzonites. Elsewhere, in the north-central part of the core, the granodiorite interfingers with light-colored monzonites to form a zone of gradation. An extensive talus slope obscures the contact relationships of the granodiorite with the monzonites to the north.

In hand specimen the coarse granodiorite has a granitic appearance. Plagioclase, biotite and pyroxene are easily detected. The finer-grained variety appears darker and possesses a speckled appearance due to tiny flakes of biotite. Emmons (1908, p. 206) reported hornblende in essential amounts in the sample he collected, but the writer could not locate an outcrop in the granodiorite body in which it appeared to be present.

Under the microscope the coarse granodiorite exhibits an allotriomorphic-granular texture. The finer-grained varieties are essentially hypidiomorphic-granular. Plagioclase (An_{24-39}), quartz and orthoclase are the essential minerals. Accessories include augite, biotite, magnetite, zircon, pyrite, apatite and some rare sphene. The orthoclase occurs either as interstitial material or as a poikilitic host to plagioclase.



FIGURE 32. View showing the northeast part of the Independence volcano. The high, circular ridge consists of latitic intrusive breccias that grade into an inner zone of monzonite. The granodiorite crops out in the central part of the circular structure.

The granodiorite shows varying degrees of hydrothermal alteration. Most of the plagioclase is slightly sericitized. Some pyroxenes are present as small fragments surrounded by a turbid aggregate of chlorite, carbonate, limonite and possibly an amphibole. Most biotite is rimmed with chlorite. Hypersthene is present in trace amounts and has altered similarly to augite. Some areas are so crowded with alteration products that it is impossible to determine what the original mafic mineral may have been.

Granitic Dikes.- Small granitic dikes represent the youngest rock-type within the volcano. They range in width from small stringers of 1/4 inch to those that are 6 inches across. They do not conform to any well-defined trend and are not persistent in length. These dikes can be observed throughout the entire core of the volcano. In some places the dikes make sharp contacts with the host rock; whereas, in other places they appear gradational. Although numerous, the granitic dikes make up less than 1 per cent of the total volume of rocks within the core.

The granitic dikes vary in texture from place to place. They grade from aplitic varieties to those that appear as small pegmatites. For the most part they are granitic. The dikes are mineralogically simple. Thin section study of one sample showed that potash feldspar and quartz make up more than 96 per cent of the rock. Trace amounts of hornblende, biotite and magnetite make up the rest of the section. No plagioclase was detected in the section investigated by

the writer. Emmons (1908, p. 225) reported about 5 per cent of andesine in the granite dike he described.

Mode of Emplacement.- The composite body consists of five intruded rock types that are closely related in time and composition. There is a striking relationship between the asymmetrical shape of the structure and the intrusive sequence. The oldest rocks of the volcano are restricted to the southern part of the core and form a linear body with an east-west trend. The modal compositional difference between the intrusive breccias and the syenogabbro is in the amount of quartz present and the anorthite content of the plagioclase. As the intrusive cycle continued the magma slowly changed in composition by differentiation from a syenogabbro to a monzonite. The conduit for the monzonitic magma migrated to the north and formed a linear body with a northwest-southeast trend. The granodiorite body was intruded soon after the monzonites and conforms to the same general northwest-southwest orientation. Tension cracks, formed by cooling, afforded channelways for the later granitic dikes that appear throughout the core.

The forceful intrusion, and boring action of the magma, undoubtedly followed inherited fault zones in the Precambrian metamorphic rocks. It is also probable that the older and partially congealed magma offered some resistance to the younger and more fluid magma thereby causing the northward migration of the conduit.

The coarse-grained rocks appear to represent the differentiation products of a secondary magma that was intruded in three closely related pulses (see Origin of the Independence volcano).

QUATERNARY SEDIMENTS

General Statement.- If the general volcanic stratigraphy in the middle and southern Absaroka Mountains (Hague, 1899; Rouse, 1937; Parsons, 1958; Boyd, 1961; and Brown, 1961) can be applied to the entire range then a thick sequence of pyroclastics has been eroded in the northern part of the Absaroka Mountains as compared to the southern part. However, no volcanic rocks younger than the basalt flows of the Group V Volcanics have been recognized in the Independence area. The Quaternary deposits consist of glacial till, landslide debris, fluvial and lacustrine sediments and valley alluvium.

Glacial Till.- Glacial Till is restricted to the southern part of the Independence area in the Buffalo, Hellroaring and Slough Creek areas. The tills occur principally as medial moraines at the confluence of the larger tributary valleys with the main streams. Within some of these moraines small ponds have formed, thus indicating that they are not river gravels. Most of the till consists of pebbles, cobbles and boulders of volcanic materials with a clay-like matrix. In the Slough Creek drainage a considerable amount of granitic gneiss and schist fragments derived from the head waters of Slough Creek is present.

Landslide Debris.- Landslide debris is restricted to a few of the tributary valleys and can be recognized readily on aerial photographs. The slide or slump areas are free

from erratics as compared with the morainal material on the surrounding valley floor.

Lacustrine Sediments.- Lacustrine sediments occur only in the Slough Creek valley just below Silver Tip Ranch. Howard (1937, p. 92-124) has described ~~in~~ detail the glacial history of the Lamar and Yellowstone River Valleys. Two distinct terraces are preserved, just below Silver Tip Ranch, which may reflect the damming of Slough Creek by the Lamar Valley glacier and the subsequent formation of a marginal lake.

Valley Alluvium.- Each major valley contains (Fig. 33) alluvium which is the result of natural barriers, acting as dams in the streams, in the form of Precambrian ridges or spurs. The glacially over-deepened part of the valleys was the site of temporary lakes until the barriers were subsequently eroded. The valley fills are quite extensive in the southern part of the Independence area. Frenchy's Meadows, in Slough Creek is more than a half mile wide and 3 miles long.



FIGURE 33. View showing a typical alluvium-filled valley caused by local base leveling. View looking south and down stream across Buffalo Fork Creek. Mount Washburn Range of Yellowstone Park is in background.

ORIGIN OF THE INDEPENDENCE VOLCANO

Summary of the Volcanic Cycle

The Laramide revolution was followed by a relatively long period of erosion as demonstrated by the formation of the Monument conglomerate. Middle Eocene volcanism was ushered in by an explosive phase as indicated by the tuffs overlying the Monument conglomerate. Dacitic and latitic pyroclastic flow breccias then accumulated, followed by a series of basalts and dense, aphyric flows of augite latites. Activity continued with the build up of more than 2,300 feet of fairly acid volcanic rocks. The materials for the Group I Volcanics appear to have originated from many small vents that paralleled a major fault zone in the underlying Precambrian rocks. The exposed intrusive bodies of the Group I Volcanics consist essentially of dacitic and latitic porphyries.

A distinct break in the volcanic activity took place and was followed by a shift in the eruptive centers which led to the extrusion of a series of porphyritic flows that covered much of the area to the northeast. Sporadic volcanic activity was separated by relatively long periods of erosion. Thick sections of water-deposited tuffs and sandstones were formed that contain many fossil wood and leaf fragments of probable late-middle Eocene age.

A renewed and more vigorous period of volcanism occurred which was centered around a single vent structure. The Independence volcano is considered to have been the major

source of the Group III, IV, and V Volcanics. Continued activity led to the formation of a major cone-complex consisting of a chaotic assemblage of fragmental volcanic rocks. Violent explosions took place which led to the accumulation of thick sections of lithic tuff-breccias composed of older volcanic breccias, of the Group I Volcanics, along with scoriaceous, porphyritic potash-bearing basalts and large amounts of latites. Most of the Group III Volcanics are rich in augite and hypersthene and a considerable amount of potash feldspar is present. About the same time, a minor parasitic outburst took place on the flank of the major volcano in the form of the Mill Creek plug. Large labradorite phenocrysts incorporated within a latitic groundmass strongly suggest a mingling of magmas prior to the extrusion of lavas and pyroclastics from the Mill Creek plug.

Erosion and deposition took place almost simultaneously during the build-up of the cone-complex. Thick deposits of volcanic conglomerates and sandstones reflect aggradation with subsequent filling of valleys and channels on the flanks of the volcano.

A quiet phase of volcanism then took place with the extrusion of a thick series of basalt flows. The basalts flowed out on relatively even surfaces with no extensive channels being present. The basalts are characterized by the great paucity of olivine and the relatively high percentage of augite and hypersthene along with accessory amounts of potash feldspar. Short periods of explosive activity took

place forming lenses of hypersthene-rich felsic vitric tuffs between the basalt flows.

Reconstruction of the probable size of the volcano suggests that a great quantity of material was probably removed thereby obliterating any later events of volcanism that may have occurred.

Differentiation of the Intrusive Rocks

The feldspathic rocks, from the core of the Independence volcano, possess petrographic similarities and are closely related in time and space. These relations suggest a common source. The distribution and intrusive sequence indicate that the magma was differentiated at a lower level prior to intrusion. Most of the rocks are monzonitic; the rest consist of syenogabbros and granodiorites.

Petrographic studies show that there is not a sharp mineralogic break between the various types. Plagioclase and potash feldspar are present in all rocks and the plagioclase-potash feldspar ratio decreases from the mafic to felsic rocks. The anorthite content of the plagioclase decreases gradually from a high of An_{61} in the syenogabbro to a low of An_{22} in the granodiorite. Quartz is an accessory mineral in some of the basic rocks and becomes essential in the granodiorites. Pyroxenes persist throughout the series. Augite and hypersthene are essential in the syenogabbros, accessory in the monzonites. In the granodiorites pyroxenes are either accessory or present in trace amounts.

Essential primary amphibole is conspicuously absent, even through some biotite is present in all the rocks. This may reflect an original relatively dry magma at depth. The formation of primary biotite as a late forming mineral may have been due to the concentration of microscopic amounts of water during the course of crystallization.

Emmons (1908, p. 219) presented 6 chemical analyses and

norms from the rocks of the "Haystack Stock". Even though the exact location of the samples collected by Emmons can not be accurately determined on his small-scaled geologic map, a comparison of the modal analyses (Tables 6 , 8) indicates similar percentages for similar rock-types. An exception occurs in the percentage of potash feldspar between the two modes. The potash feldspar content is consistently higher in the modes of this report and can be attributed to selective chemical staining techniques which aided rapid visual identification. The writer, therefore, considers that Emmons' chemical data can be utilized for a tentative discussion on the differentiation of the coarse-grained rocks from the core of the Independence volcano, but that his mineralogical data requires some revision.

Thorton and Tuttle (1960) have presented a discussion on the system SiO_2-$NaAlSiO_4$-$KAlSiO_4$, petrogeny's residua system, with respect to more recent results of studies on related systems. These writers have demonstrated that Bowen's theory (1937) pertaining to petrogeny's residua system is the goal toward which all magmatic liquids move as the result of fractional crystallization. In most instances, the rock forming minerals, quartz, orthoclase, albite, nephelene, leucite and kalsilite are the final products of fractional crystallization. Thorton and Tuttle have proposed a method by which the proportion of constituents in petrogeny's residua system can be used as a measure of the "basicity" of the rock. The sum of the normative sialic minerals (quartz, albite, orthoclase, etc.,) reflects how far the system has

TABLE 8.- Rock types and modal analyses of the "Haystack Stock" as presented by Emmons (1908).

	A	B	C	D	E	F	G
Quartz	22.9	21.8	12.2	6.8	3.7	-	24.5
Orthoclase	17.8	11.7	9.7	15.4	13.2	4.9	47.2
Albite	30.7	30.1	31.2	27.5	26.5	19.2	17.8
Anorthite	10.3	15.1	20.8	19.7	18.9	26.7	2.6
Hornblende	9.7	-	-	-	-	-	-
Pyroxene	-	11.2	13.5	19.5	28.8	30.9	3.3
Biotite	4.2	4.8	6.7	4.6	3.1	4.5	-
Olivine & Serpentine	-	-	-	0.5	0.3	6.8	-
Magnetite & ilmenite	4.1	4.9	4.9	5.2	4.8	5.8	3.9
Apatite	0.3	0.4	1.1	0.8	0.7	1.2	-

Rock names as applied by Emmons (1908)

A. Granodiorite
B. Granodiorite porphyry
C. Quartz-bearing diorite
D. Quartz-bearing orthoclase-gabbro
E. Orthoclase gabbro
F. Olivine gabbro
G. Granite dikes

differentiated toward its goal. The resulting sum of the normative minerals is termed the differentiation index (D.I.). Thorton and Tuttle have presented the D.I. for 5000 superior analyses of igneous rocks from Washington's Tables. These data, as shown on a histogram and various oxide-D.I. diagrams, have been contoured and show significant trends toward petrogeny's residua system. The writers point out that when the oxide-D.I. diagrams are used it is possible to tell at a glance whether a rock series is normal, abnormal, undersaturated, oversaturated, etc., and in what respect it differs from the average for 5000 analyses in Washington's Tables.

The writer re-evaluated Emmon's chemical and normative data (Table 9) in terms of the differentiation index and plotted the results as shown in Figures 34, 35. The oxide-D.I. diagrams reflect the trend of normative minerals and support the trend shown by the modal plot (Fig. 29) in which the mafic constituents can not be shown. A strong argument for a classical example of fractional crystallization is indicated.

The silica-D.I. diagram (Fig. 34) indicates that the rock sequence began with an undersaturated syenogabbro and differentiated into a saturated monzonite and finally into an oversaturated granodiorite. This sequence appears normal in that the silica content was progressively enriched during fractional crystallization by the corresponding decrease of all other major oxides. The silica content of the final product (granite dikes) falls near the maximum field for the 5000 analyses in Washington's Tables. The alumina distribution

TABLE 9.- Normative minerals as presented by Emmons (1908), along with the differentiation index.

	A	B	C	D	E	F	G
Quartz	19.50	19.20	10.83	4.68	1.56	0.0	24.50
Orthoclase	20.57	15.01	11.68	16.68	16.12	5.56	47.26
Albite	32.49	33.01	34.02	28.30	28.82	20.44	17.82
Anorthite	12.51	19.18	23.07	21.41	20.29	30.86	2.78
Hypersthene	4.80	5.82	4.71	11.87	13.88	12.00	2.65
Diopside	3.02	2.08	8.64	7.32	11.22	14.34	0.68
Magnetite	3.02	3.71	4.87	5.34	4.18	5.34	3.94
Ilmenite	1.22	0.91	1.67	1.98	1.98	1.98	-
Hematite	0.80	-	-	-	-	-	-
Apatite	0.34	0.34	1.01	1.01	1.01	1.01	-
Water	1.41	0.66	0.63	1.27	0.97	1.53	-
Olivine	-	-	-	-	-	6.72	-

Differentiation index determined by summing the sialic normative minerals quartz, orthoclase and albite.

Varieties	D.I.	Rock Name
G	89.55	Granite dikes
A	72.56	Granodiorite
B	67.22	Granodiorite
C	55.07	Monzonite
D	49.66	Monzonite
E	46.50	Syenogabbro
F	26.00	Syenogabbro

The differentiation index for the major igneous rocks of Daly's (1914) averages. (After Thorton and Tuttle 1960)

	D.I.
Alkali granite	93
Granite	80
Granodiorite	67
Diorite	48
Gabbro	30
Olivine gabbro	27
Peridotite	6

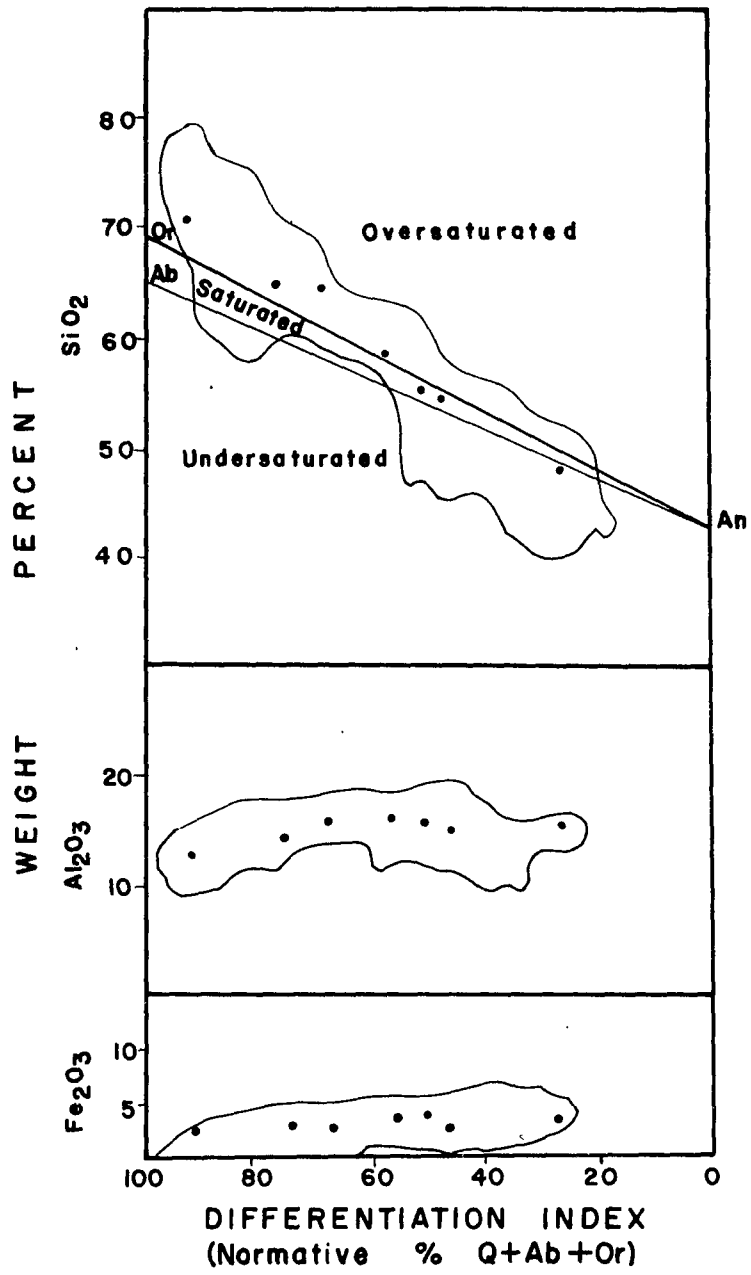


FIGURE 34.- Oxide vs. differentiation index of the rocks from the core of the Independence volcano for the oxides: silica, alumina and ferric oxide. Contoured area represents fields of concentration based on 5000 analyses from Washington's Tables (Thorton and Tuttle, 1960).

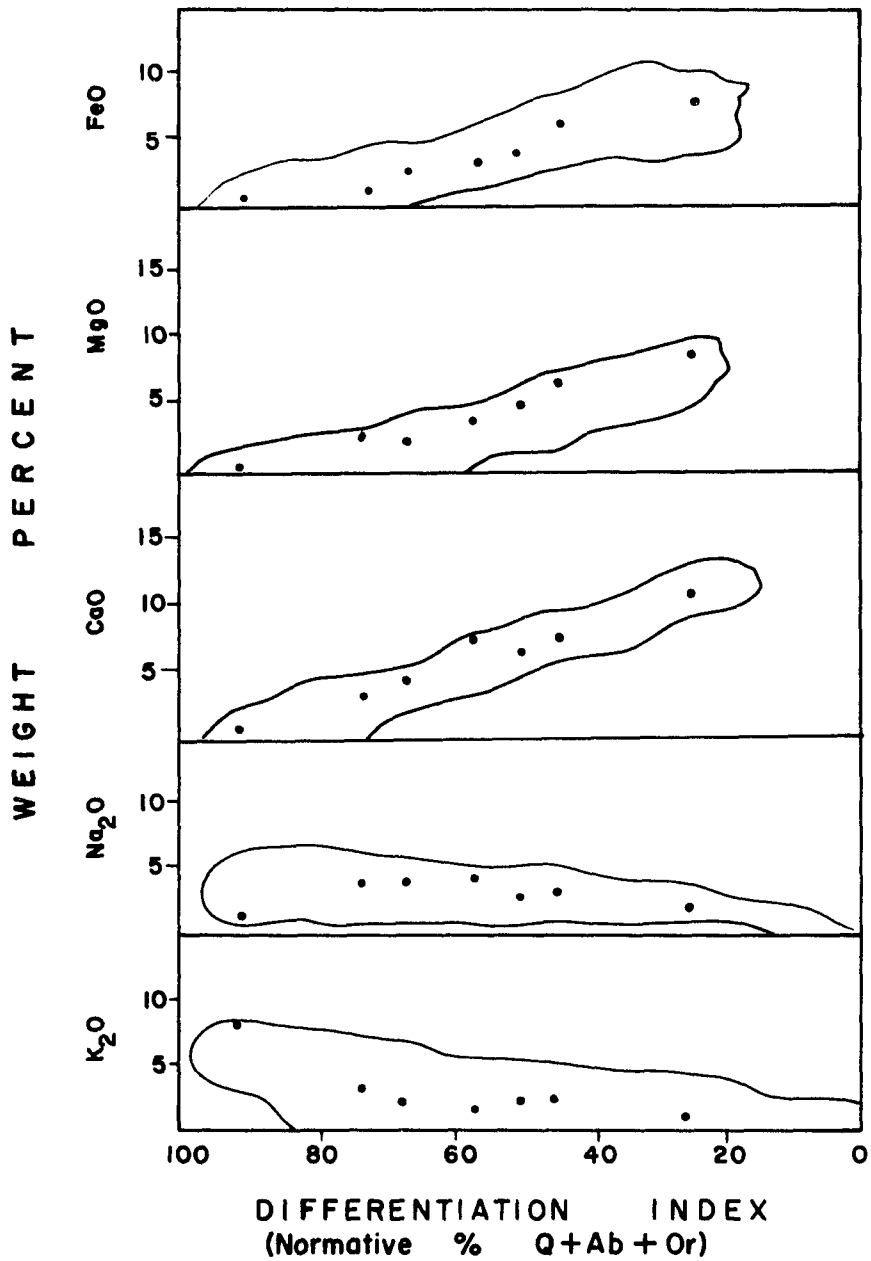


FIGURE 35.- Oxide vs. differentiation index of the rocks from the core of the Independence volcano for the oxides: lime, magnesia, ferrous oxide, potash and soda. Contoured area represents fields of concentration based on 5000 analyses from Washington's Tables (Thorton and Tuttle, 1960).

is normal and varies antithetically with the silica distribution where the rock becomes oversaturated. Ferric oxide concentration is normal and reflects a straight-line trend, parallel to the abcissa, which indicates the Fe_2O_3 was removed at a constant rate from the magma during fractional crystallization.

The basic oxides, lime, magnesia and ferrous oxide, show a normal trend from higher concentrations (Fig. 35) in the syenogabbro to diminishing amounts in the granodiorite and granite dikes. The alkali distribution follows a normal trend with soda and potash varying antithetically as the end product is reached. This is to be expected with an increase of potash feldspar, which may contain some soda, and a decrease of the sodic plagioclase. The final potash concentration of the granite dikes falls above the maximum field whereas the soda content falls slightly below the maximum field which may indicate the degree of differentiation.

Chemical evidence strongly supports the view that the rock sequence was derived by fractional crystallization of a single magma. Table 10 (columns 1f, 2e, 3d, etc.) lists the composition of 7 materials, which when subtracted from a hypothetical syenogabbroic magma in appropriate amounts, produce norms similar to the norms of the rocks chemically analyzed. The compositions of the materials, to be removed, were determined graphically by using the addition and subtraction diagram (Bowen, 1928, p. 76). This method does not offer empirical evidence to solve this type of problem, but noteworthy trends support petrographic data.

TABLE 10.- Composition of materials, which, when removed from an assumed syenogabbroic magma, produce rocks later in the series.

Weight per cent	Syenogabbro 1f	Syenogabbro 2e	Monzonite 3d	Monzonite 4c	Granodiorite 5b	Granodiorite 6a	7[1]
SiO_2	44.3	47.8	54.1	58.0	61.0	64.0	70.3
Al_2O_3	16.5	13.2	16.1	17.4	17.0	15.1	13.7
Fe_2O_3	3.6	-	3.3	3.7	2.4	0.4	2.7
FeO	8.4	13.3	4.7	3.8	2.6	3.8	1.8
MgO	9.2	8.5	5.1	4.7	2.7	2.7	0.7
CaO	11.8	12.6	6.5	8.7	5.7	3.9	0.7
Na_2O	2.1	3.6	3.2	4.0	4.7	4.0	2.1
K_2O	-	-	3.1	1.7	-	2.3	7.9

Norms

	f	F	e	E	d	D	c	C	b	B	a	A	7
Q	-	-	-	1.5	1.7	4.6	6.7	10.3	22.8	19.2	18.4	19.5	24.5
Or	-	5.5	-	16.2	18.9	16.8	10.1	11.6	-	15.1	13.5	20.5	47.2
Ab	18.3	20.4	30.1	28.2	26.8	28.3	33.4	33.1	36.4	33.1	33.4	32.5	17.8
An	35.3	30.8	17.2	20.2	20.1	21.4	24.6	23.1	23.4	19.2	16.4	12.5	2.7
Mt	4.9	5.3	-	4.2	4.9	5.3	5.1	4.8	3.1	3.7	3.7	3.1	3.9
Di	20.6	14.4	14.2	11.2	9.6	7.3	14.2	8.6	2.8	2.1	2.1	3.1	0.7
Hy	-	12.0	-	13.8	13.9	11.8	8.5	4.7	7.5	5.8	9.8	4.8	2.6
Ol	16.5	6.7	16.7	-	-		-	-	-	-	-	-	-

Capital letters (A, B, C, D, E, F,) refer to norms presented by Emmons (1908).
Lower case letters (a, b, c, d, e, f,) refer to norms calculated for this report.
[1]Chemical composition of granite dike as presented by Emmons (1908)

The proportion of mafic normative minerals to the salic normative minerals decreases correspondingly from the syenogabbro to the granodiorite. Olivine appears only in the norms of the syenogabbro, whereas normative hypersthene is present in the silica saturated monzonites and granodiorites. The molecular compositions of the feldspars vary accordingly and parallel the trend shown by the differentiation index (Table 9), and also the decrease in the anorthite content of the plagioclase (Fig. 29).

In general, it was found that by subtracting the materials of a granodiorite (Table 10, 6a) from the syenogabbro (2e) the final product was a monzonite (3d). Similarly, when the materials of the granite dikes (7) were subtracted from the monzonites (4c) the final product was a granodiorite (6a), The norm of the calculated granodiorite (Norm a) is very similar to the norm of the granodiorite that Emmons presented from a chemical analysis (Norm A). A hypothetical magma was determined graphically from which the monzonitic material (Table 10, 3d) was removed; the resulting material (1f) produced norm values (f) almost identical to the norm (F) that Emmons presented from a chemical analysis of a syenogabbro from the core of the Independence volcano.

Petrographic and chemical data indicate that fractional crystallization was brought about, within the core of the Independence volcano, by the removal of the basic oxide-rich minerals. Therefore, by removing the early formed pyroxene and calcic plagioclase in corresponding amounts, the

composition of the magma could change successively from a syenogabbro to a granodiorite. The granitic dikes would then represent the final products of differentiation which indicates that fractionation migrated toward petrogeny's residua system.

A graphical comparison between the hypothetical norms calculated for this report and the norms presented by Emmons from chemical analyses is shown in Figure 36.

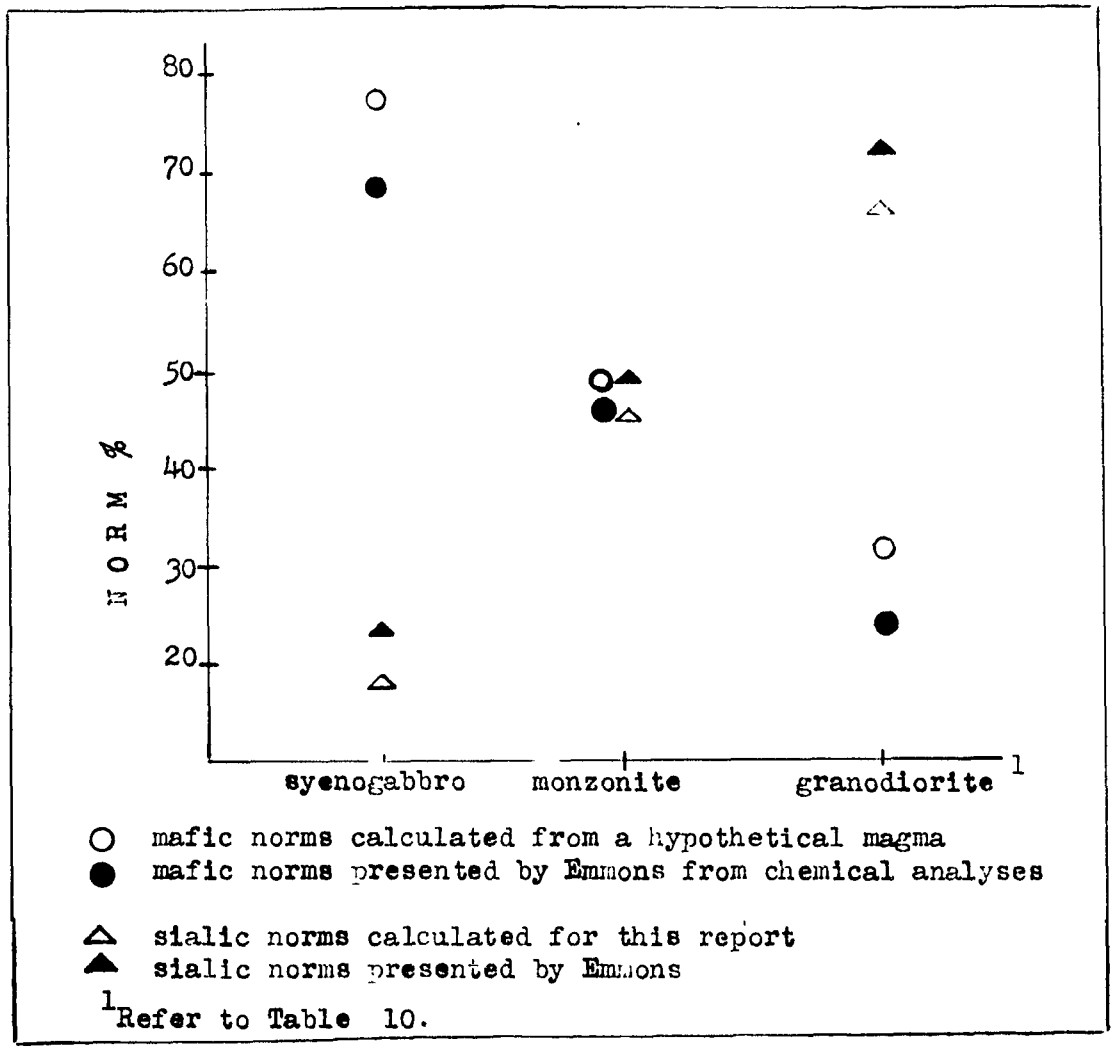


FIGURE 36.- Comparison of theoretical norms with the norms determined by Emmons from chemical analyses.

Thermal State Comparison of the Plagioclase

General Statement.- Investigations on the plagioclase feldspars, over the past several years, have clearly demonstrated that plagioclase formed at high temperatures differs optically from that formed at lower temperatures. A transitional series also exist between the optically different feldspars. Muir (1955, p. 545) points out that nearly all published data on natural high-temperature plagioclase are confined to volcanic rocks and all published information on plutonic or metamorphic rocks indicates a low-temperature state for the plagioclase. A review of the literature indicates that no systematic investigation on the areal distribution of plagioclase from a small plutonic intrusion appears to have been undertaken.

The distinction between high-and low-temperature plagioclase is brought about by an order disorder transformation (Reynolds, 1952; Bradley, 1953; Muir, 1955; and Megaw, 1959). This order-disorder relationship is based upon the Al-Si positions within the plagioclase. In the low-temperature structure ordering exists with Al-Si occupying geometrically different lattice positions. The high-temperature structures are characterized by Al-Si being statistically arranged over one set of lattice positions. Deer et al., (1963, p. 94-165) suggest that the exact cause for order-disorder relationships, other than in laboratory experiment, is an open question. Some of the variables involved include temperature, rate of cooling, composition, P_{H_2O}, and even the presence of

water. The manner in which these variables influence the plagioclase is not fully known.

The terminology used in describing high-low, volcanic-plutonic, and ordered-disordered transformation has become confused in that the temperature and degree of disordering of synthetic or heat-treated natural plagioclase may be greater than those of natural plagioclase.

The writer follows Slemmons' (1962, p. 3) suggestion in the usage of the following terms:

> Plutonic plagioclase for those that possess well-ordered structures and referred to in the literature as "low-temperature" plagioclase.
>
> Volcanic plagioclase for the typical plagioclase of extrusive and shallow intrusive igneous rocks showing disordered structures.
>
> Transitional plagioclase includes plagioclase that has properties approximately midway between those of plutonic and volcanic plagioclases.

Occurrence and Distribution.- The distribution and age relations of the coarse-grained rocks from the core of the Independence volcano become exceedingly significant when the structural state of the plagioclase feldspars is considered. Optical determinations on the plagioclase show that the feldspars reflect 3 different structural states (Table 11). The intrusive breccias near the borders of the core all contain volcanic plagioclase. This is to be expected in that the border zone represents true hypabyssal features. Most of the plagioclase toward the center of the core reveals plutonic features. Notable exceptions occur in the gradational zones between the syenogabbro and the monzonites and

TABLE 11.- Optical data of the plagioclase from the coarse-grained rocks from the core of the Independence volcano.

Sample No.	Composition[1] Mol. % An	$2V_z$	Twin[2] Law	Angles X-Y-Z to Twin Axis			Thermal[3] State	An%[4] Range
				X	Y	Z		
IA-20	61	78	2	59.5	35.5	75.0	P	57/61
HS-51	55	79	1	59.5	41.5	64.0	P	55/59
IA-09	53	81	1	41.0	58.5	63.0	P	52/56
IA-11	52	76	7	80.0	62.5	29.0	P	52/57
HS-54	51	82	1	44.5	57.0	62.0	P	48/55
IMC-B	38	86	4	87.5	20.0	70.0	T	33/42
HS-59	38	91	2	34.0	57.5	78.0	P	36/47
AI-88	42	86	1	42.0	53.0	70.5	P	39/48
HS-89	41	80	3	86.0	68.0	22.0	P	39/46
HS-90	39	102	1	55.5	42.5	68.5	V	34/41
IA-22	48	88	2	47.0	46.5	77.0	V	46/52
HS-61	38	84	6	82.0	22.0	70.5	P	33/41
HS-88	41	86	1	55.0	47.5	63.0	T	32/43
SH-41	47	90	1	42.0	59.5	67.5	V	44/49
AI-19	39	81	6	81.0	22.0	62.5	P	39/41
HS-84	46	82	2	43.0	49.5	80.0	P	38/48
HS-80	39	104	7	86.0	66.0	24.5	V	37/41
HS-98	41	80	2	36.5	57.0	80.0	T	35/44
HS-67	38	84	2	32.5	58.0	81.5	P	34/46
HS-35	27	91	4	75.0	23.5	71.0	T	22/31
HS-25	26	105	3	87.0	74.0	16.0	V	21/33
HS-29	22	108	1	69.0	24.0	78.5	V	21/29
HS-30	37	92	6	80.0	25.0	72.0	V	32/39
HS-04	37	78	1	55.5	38.0	78.5	P	31/39
HS-02	24	91	2	25.0	67.0	79.0	P	22/31
HS-55	45	82	5	38.0	55.5	76.0	T	39/48

[1] Fragments in which arcs of the X-Y-Z directions close with the smallest area on the arc of the composition plane.

[2] Twin Laws: 1-Carlsbad; 2-albite-Carlsbad; 3-albite; 4-Manebach-Ala; 5-Baveno; 6-pericline; 7-acline.

[3] Thermal States: P-plutonic; V-volcanic; T-transitional.

[4] An% Range as determined by the measurement of the optical properties on a minimum of 4 plagioclase fragments.

also between the monzonites and the granodiorites. The rocks from these zones contain transitional and volcanic plagioclases with the latter predominating.

The rock-types and structural states of the plagioclase are plotted on a map view of the dissected core of the Independence volcano (Fig. 37). Inferred boundaries of the various rock-types are drawn on the basis of petrographic data and field relations. The distribution of the volcanic plagioclase within the transitional zones is noteworthy in that these zones may represent "contacts" during multiple intrusion. The host rock was probably still hot and mobile when a new pulse of magma came in. Poor exposures prevented any observations of possible orientation effects in these gradation zones.

The fact that the plagioclase reveals various structural states seems to indicate changes in the physical system of the magma i.e., temperature, pressure, as it was being intruded. The volcanic plagioclase occurring in the border zone of the core may be due to rapid cooling of the intruding magma. The occurrence of the plutonic plagioclase undoubtedly reflects local static conditions (slow cooling) which led to complete ordering in the feldspars. The volcanic and transitional plagioclase are found where there is a compositional change in the rock-types. A later and more acid magma indicates a corresponding decrease in temperature of the system. The paucity of primary and secondary hydrous minerals suggests that the initial magma was relatively dry when intruded.

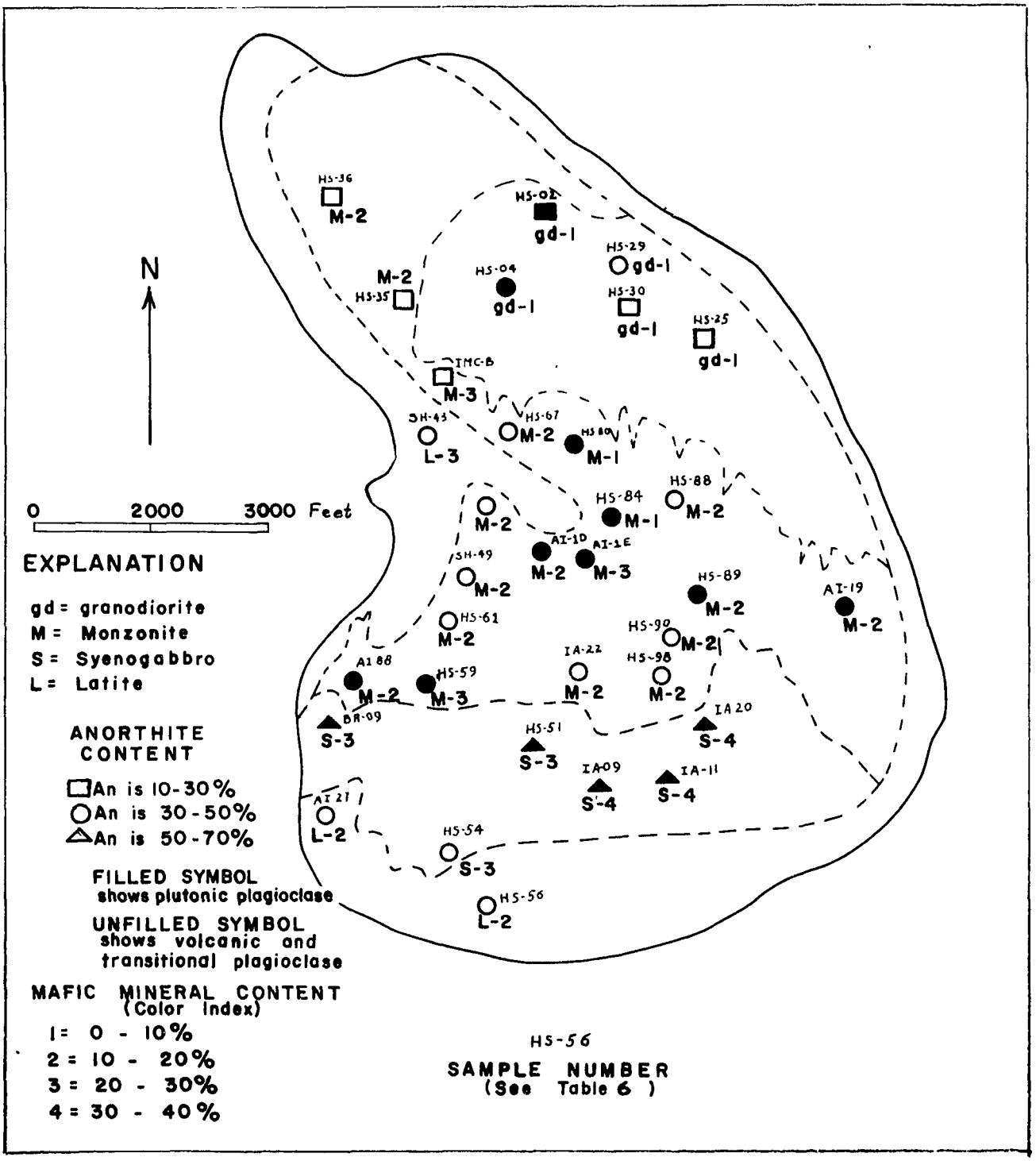


FIGURE 37.- Sketch map of the dissected core of the Independence volcano showing the distribution of rock types, the structural state of the plagioclase, anorthite content of the plagioclase, and the color index of the rocks.

Due to the limited study of this problem, no empirical cause can be given for the structural anomalies in the plagioclase that occur in the gradational zones between the various rock-types.

The writer compared the volcanic and plutonic plagioclase from the core of the volcano with the volcanic plagioclase from various hypabyssal rocks throughout the Independence area. These data are presented in Table 12. This information, along with the optical data from Table 11 was plotted against composition on the thermal state diagram (Fig. 38) of J. R. Smith (1958, Fig. 2). Visual inspection of the various plots shows a significant grouping of the volcanic plagioclase, from the hypabyssal rocks and the core of the volcano, around the high-temperature curve. A similar distribution of the plutonic plagioclase, from the core of the volcano, is shown around the low-temperature curve. Phair et al., (1962, p. 489) concluded, on the basis of detailed X-ray and chemical data, that this type of diagram, using optical data, is valid in indicating the thermal-state of plagioclase. They also suggest, from their regional study on the distribution of plagioclase, that the rate of cooling might be the principal factor affecting the structural state of the plagioclase. The plagioclase from the Independence volcano appears to have been affected by more than the rate of cooling. This problem in the Independence area warrants further investigation.

TABLE 12.- Optical data of the volcanic plagioclase from various hypabyssal rocks throughout the Independence area.

Sample No.	Composition Mol. % An	$2V_z$	Twin Law	Angles X-Y-Z to Twin Axis		
				X	Y	Z
HSR-5	31	105	1	62.5	33.0	78.0
BR-34	41	84	2	25.5	59.0	78.5
	33	94	1	81.0	35.0	66.0
ER-2	41	106	4	81.0	32.0	59.0
	31	102	5	89.0	24.0	67.0
	43	-	3	86.0	62.5	23.0
	40	104	2	34.0	60.0	79.0
BF-13	51	81	1	44.0	63.0	62.0
	55	86	3	74.0	59.0	34.0
LS-2	33	94	6	88.0	22.5	67.5
	37	-	3	86.5	68.0	22.5
Bul-7	34	96	1	60.0	38.0	70.0
	39	108	3	88.0	63.0	26.0
	46	103	1	49.0	53.0	65.0
SH-45	45	96	2	41.0	52.0	76.0
ML-1	61	78	1	37.5	67.5	65.5
WM-4	34	96	1	57.0	37.5	74.0
WM-5	33	102	5	83.0	19.0	76.0
BF-14	44	86	1	51.0	52.0	63.0
TS-1	41	106	3	85.0	68.0	22.5
BF-7A	38	102	6	83.0	19.0	76.0
IA-64	44	86	3	85.0	61.0	29.0
LD-1	33	-	6	88.5	23.0	67.5

Twin Laws: 1-Carlsbad; 2-albite-Carlsbad; 3-albite; 4-Manebach-Ala; 5-Baveno; 6-pericline

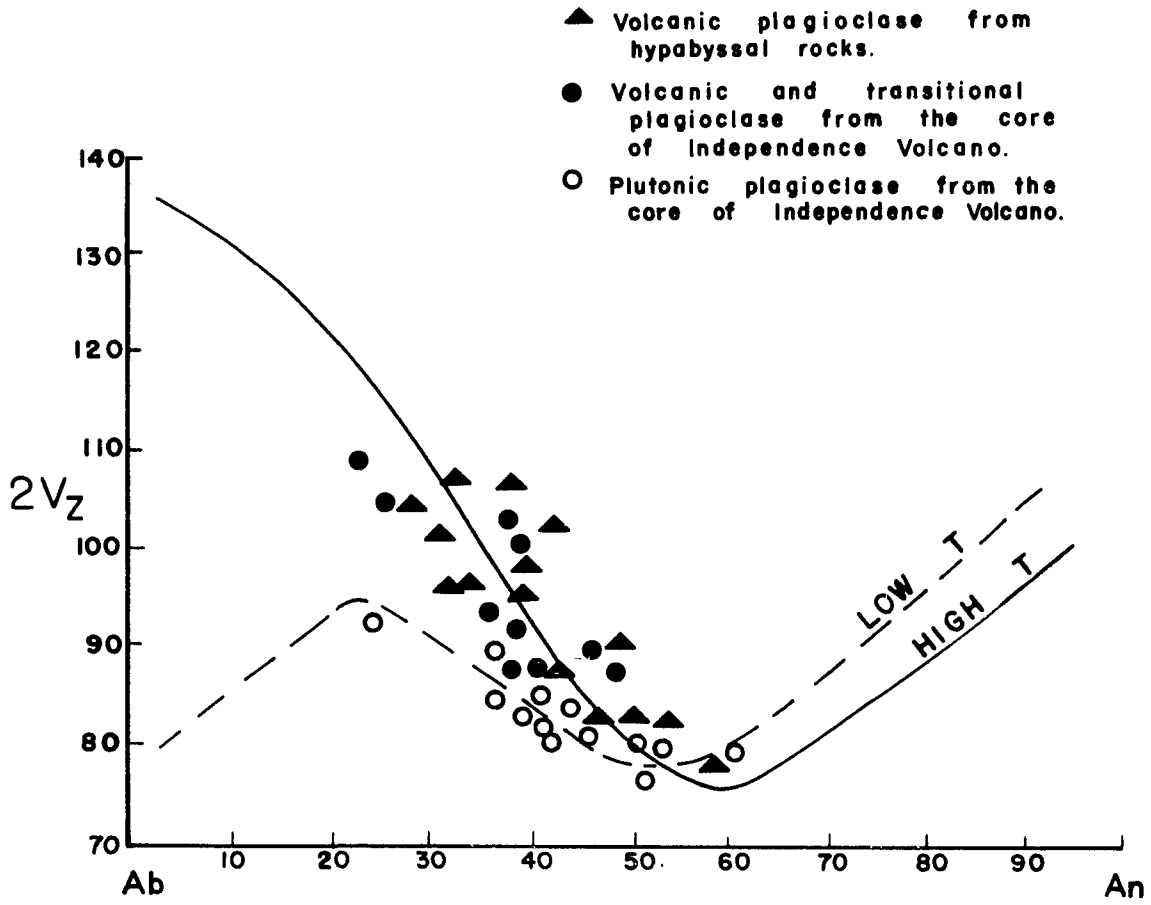


FIGURE 38.- Comparison of the thermal-state of the plagioclase with anorthite content. Temperature curves from Smith (1958, Fig. 2).

Relationship of the Extrusive and Intrusive Rocks

Each of the major volcanic rock types of the Independence volcano area is represented by a coarser plutonic equivalent in the core complex: dacites-granodiorites, latites-monzonites, and trachybasalts-syenogabbros.

Owing to the fragmental character of the volcanic breccias and the erosive cycle that accompanied volcanism, a mineralogical correlation can not be made of specific layers of volcanic breccias with a particular coarse-grained intrusive body with respect to time. The volcanic breccias do reflect a general change in composition from a hornblende latite (pyroclastic flow breccias of Group I Volcanics) through a series of augite latites (Group III Volcanics) to the potash-bearing basalts (Group V Volcanics). The compositional change noted in the rocks of the Independence volcano, with respect to the intrusive cycle, is the reverse for that noted in the pyroclastic breccias. This seeming contradiction can be resolved by assuming that the former volcanic vent was occupied, in the final stages of volcanism, by a composite stock-like body; therefore, any evidence of former intrusive events could have been obliterated. In general, the average composition of the various pyroclastic rocks is similar to that of the latitic intrusive breccias that surround the core of the Independence volcano.

Reconstruction of the Independence Volcano and its Age

The Independence volcano is signficant in that it represents a cone-complex in which the sequence of volcanic activity can be reliably established. This volcano supplied great quantities of volcanic debris that filled the low-lying areas to the south and southwest. Most of the ejecta that make up the cone-complex consist of pyroclastic breccias whereas the materials away from the volcano have been reworked and deposited by geomorphic agencies.

The assumed initial dips of the pyroclastics on the high ridges adjacent to the volcano afford a means by which the original size of the structure can be estimated. Some of the pyroclastic units still lie near their angle of repose, which may imply that the point of origin was undoubtedly characterized by steeper slopes. A reconstruction through the critical horizons indicates that the volcano was at least 4,000 feet higher than the present remnants of the coarse-grained interior. This would indicate that a volcano attained an estimated maximum elevation of about 16,000 feet above sea level with respect to the present topography (Fig. 39; Pl. II).

The high elevation and steep slopes would be more than sufficient to account for the wide distribution of the epiclastic material that dip away from the source area. The many ravines on the flanks of this projected volcano would then account for the restricted character of several deposits. A conservative estimate, from the projected section, indicates that more than 50 per cent of the original structure has been removed.



FIGURE 39.- View showing the probable topographic expression of the Independence volcano during late Eocene time. View looking northwest from Daisy Pass, near Cooke City, Montana.

Age of the Volcanic Rocks.- The lower part of the Group I Volcanics is probably of the same age as the "early acid breccias" that occur in other parts of the Absaroka-Yellowstone Park region.

In the Bighorn Basin (Van Houten, 1952) the "early acid breccia" is equivalent to part of the Tatman Formation, the uppermost Willwood Formation and the lower part of the Pitchfork Formation. In the Wind River Basin, dactic pyroclastic material of late early Eocene age is in the Wind River Formation (Hay, 1956, p. 1886) and the lower part of the Aycross Formation. Brown (1961, p. 1176) suggests that the Aycross Formation appears to be equivalent to the "early acid breccias" of Yellowstone Park.

Although the volcanics of the Independence area can not be specifically correlated with other areas, in the Absaroka-Yellowstone Park region, the suggested age relation of the volcanic rocks in the Independence area is presented in Figure 40.

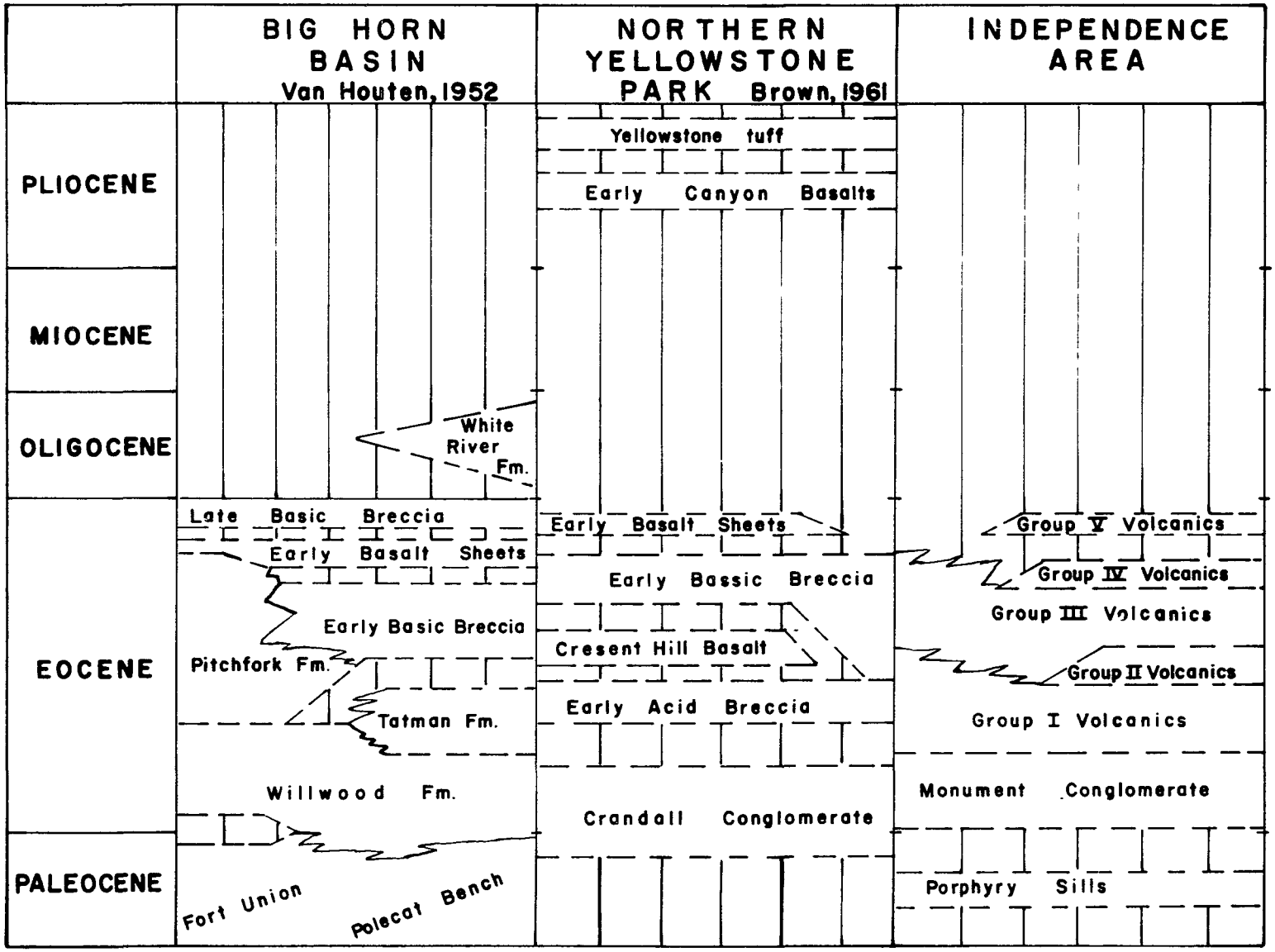


FIGURE 40.- Cenozoic correlation chart, Yellowstone National Park region. (Modified in part from Brown, 1961)

Relationship of the Independence Volcano to Regional Igneous Activity

Petrogenesis and Consanguinity.- The northern Absaroka Mountains have been designated by Larsen (1940) as the Absaroka sub-province of potash-rich, soda-rich, lime-poor rocks. Nearly all of the rocks from the Independence area contain significant amounts of potash feldspar but are not soda-rich or lime-poor and the series is best designated as subalkalic. Therefore, this may indicate that the Independence area represents a local sub-province within the larger Absaroka sub-province.

The origin of the potash-rich rocks of central Montana is still an open question. Larsen (1940) attributes the origin of the potassic rocks, of the whole central Montana region, to magmatic differentiation of a parental olivine basalt and modified by partial assimilation of granitic rocks at depth. Turner et al., (1960, p. 148) point out, with minor exception, that Larsen's interpretation is well founded based on known chemical and petrographic data. All the provinces in central Montana are considered to be related to similar primary magmas. Differentiation at depth had led to the removal of calcic plagioclase and hypersthene with a corresponding increase in the alkalinity of the magma. Periodic tapping of the magma reservoir, at various stages of development, is then considered to have formed the respective secondary magmas in the various central Montana provinces. The bulk composition of the magma that produced

the rocks in the Independence area was probably monzonitic. The overall trend in the composition change, as noted in the various rocks, indicates a normal line of descent from trachybasalts to latites and finally dacites with the bulk of the rocks falling in the latitic range. The process of differentiation by fractional crystallization and crystal separation of a monzonitic magma could produce the rocks observed in the area. The dacites and trachybasalts would then be normal acid and basic differentiates.

The writer suggests the following hypothesis to explain the occurrence of various igneous rocks in the Independence area:

(1) The magma that produced the volcanic rocks was derived from a differentiating magma having a monzonitic composition.

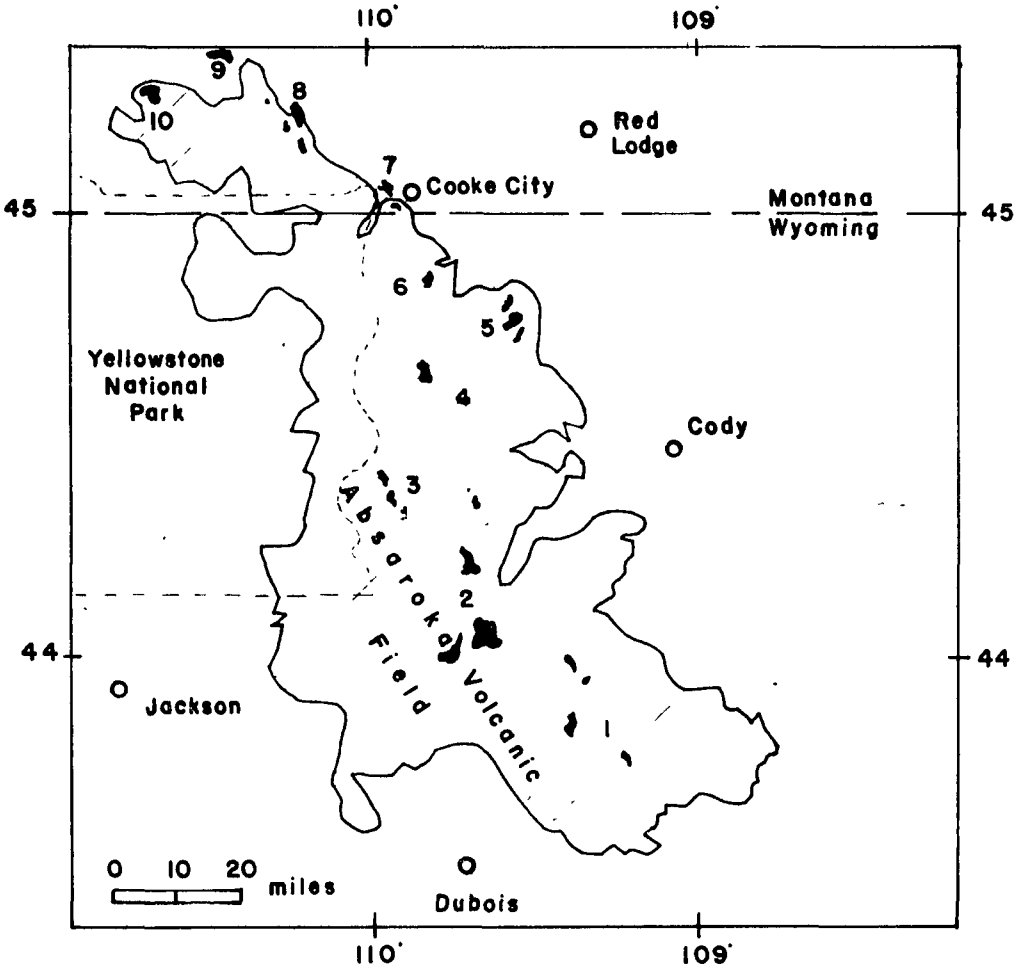
(2) The early intrusions of leuco-quartz latites (Buffalo Fork laccolith) represent the felsic magma that accumulated at the top of the magma chamber. As volcanism continued fractions of increasing mafic-mineral content appeared in which the plagioclase also became more calcic. The felsic magma slowly changed to a melanolatite. This suggests that with time successively lower levels in the chamber were being tapped.

(3) Extrusion of the latites of the Group III Volcanics suggests the tapping of an undifferentiated portion of the monzonitic magma.

(4) The trachybasalts, under this hypothesis, then reflect the eruption of the basic differentiates of the monzonitic magma after the bulk of the monzonitic material had been removed.

Other Vents in the Absaroka Mountains

The distribution of known intrusive centers in the Absaroka Mountains is shown in Figure 41. These intrusive



1. Kirwin-Caldwell area (Rouse, 1940)
2. Ishawooa-Deer Creek (Rouse, 1937)
3. Sylvan dikes (Hague, 1898)
4. Sunlight center (Parsons, 1939)
5. White Mountain (Parsons, 1939)
6. Hurricane-Crandall center (Rouse, 1937; Krushensky, 1960)
7. Cooke-City area (Lovering, 1929)
8. Independence area (This report)
9. Mill Creek area (Tuzo Wilson, 1936)
10. Immigrant Peak area (Iddings, 1894)
11. Electric Peak (Iddings, 1899)

FIGURE 41.- Sketch map of the Absaroka Mountains showing known areas of Tertiary intrusive rocks.

centers line up in a broad northwest trend which parallels the general trend of the middle Rocky Mountains. The Independence volcano appears to be the only large well-exposed cone-complex with a centrally located coarse-grained core. The other intrusive centers consist essentially of small stocks, volcanic plugs, laccoliths, sills and dikes. Initial dips in the volcanic rocks around these centers are very local and relatively gentle. According to Rouse (1937, p. 1273) volcanic necks and cones do not stand out as conspicuous topographic features throughout the Absaroka Mountains. Most of the intrusive centers have been covered by later ejecta so that only detailed field work established the exact locations (Parsons, oral communication).

Even though the intrusive centers line up in a northwest trend, this broad zone may actually represent two major rift patterns in the basement complex. The locations of the intrusive centers may represent the continuation of two regional Laramide structural elements that have been subsequently buried by middle Eocene volcanic rocks. The northernmost trend parallels the Cooke City zone, within the interior of the Beartooth uplift, and may line up with the pre-Laramide Bighorn synclinal axis. The northwest trend that passes through the southern Absarokas lies farther to the southwest. The trend is coincidental with the anticlinal axis of the Owl Creek Mountains (Wilson, oral communication).

STRUCTURAL GEOLOGY

General Statement.- The structural geology of the Beartooth-Absaroka Mountain area is related to the setting of the middle Rocky Mountain province. Most of the general information for the summary of the regional geology is taken from the Tectonic Map of the United States (1962) and Eardley (1962).

Regional Structure.- The Beartooth-Absaroka area is located in the middle Rocky Mountain province (Fenneman, 1930) of southwestern Montana and northwestern Wyoming. Several major northwest trending ranges (Beartooth, Bighorn, Absaroka, Wind River) (Fig. 42) are separated by broad oval topographic and structural depressions (Bighorn, Wind River, Green River and Powder River basins). These northwest-trending ranges are transected, to the south, by east-west elements such as the Owl Creek and Sweetwater uplifts.

The Absaroka Mountains were formed by the dissection of a volcanic plateau whereas the rest of the middle Rockies consist of flexures bordered in part by normal and reverse faults. The middle Rocky Mountains are divided into two broad types: (1) the ranges to the east are characterized by flexures and wedge uplifts under a Paleozoic and Mesozoic sedimentary cover from 5,000 to 15,000 feet thick and, (2) the western part consists of a zone of strongly folded low-angle thrusts in a sedimentary sequence that is 20,000 to 40,000 feet thick. The Precambrian basement rocks, in the

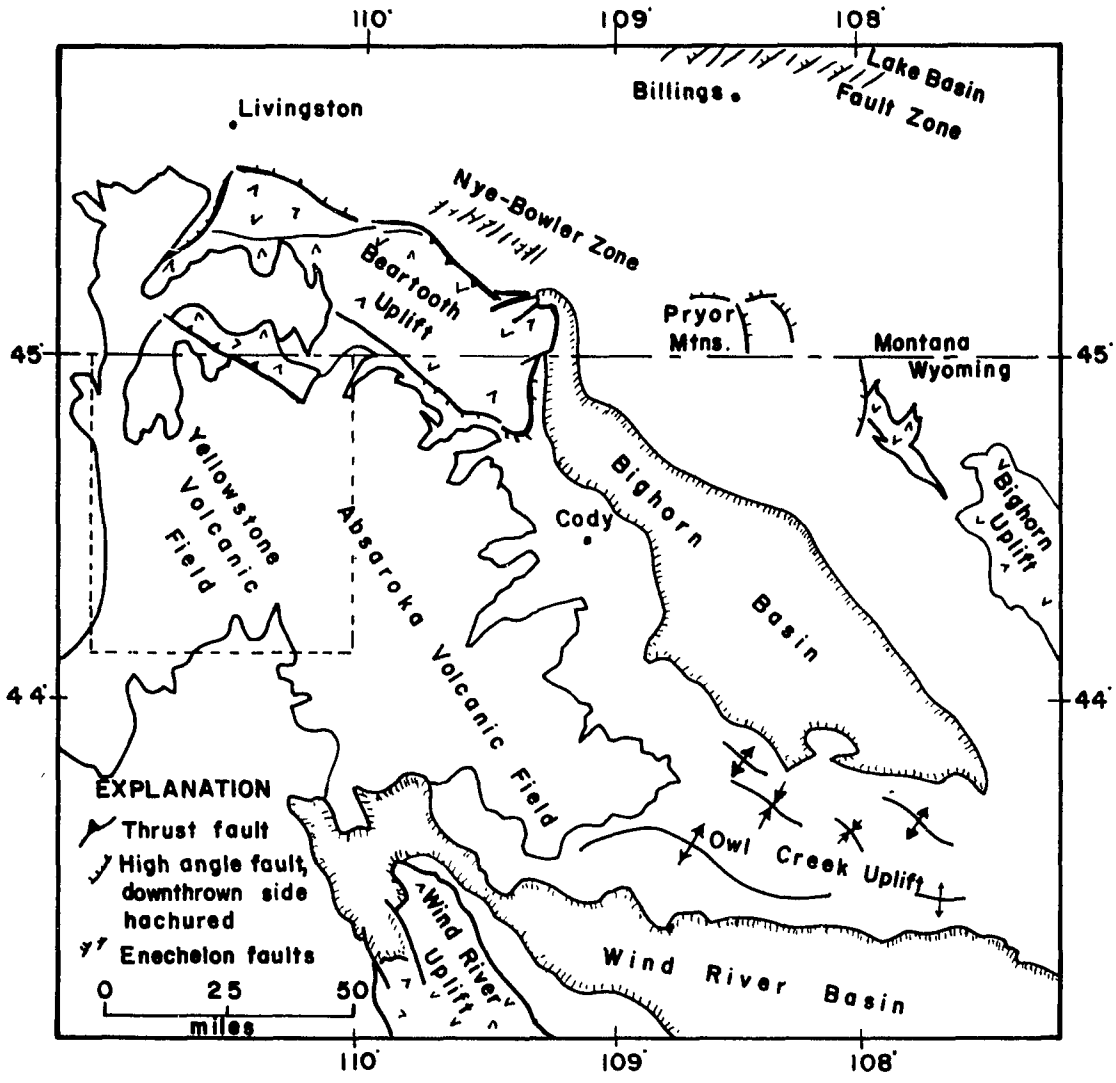


FIGURE 42.- Tectonic sketch map of northwestern Wyoming and southwestern Montana. (Data modified after the Tectonic Map of the United States, 1962)

western part, are rarely exposed (King, 1959; Eardley, 1962; Blackstone, 1956).

The northwestern part of the middle Rockies has been transected along the Montana lineament in southern Montana and northern Wyoming. The lineaments consist of the Nye-Bowler zone, Lake Basin fault zone and the more northern Cat Creek zone. These zones trend west-northwest. The Lake Basin fault zone terminates near Billings, Montana.

The main period of deformation in the middle Rockies took place during late Cretaceous and Paleocene time. In northern Yellowstone Park (Brown, 1961, p. 1187) folding and faulting terminated prior to the first outpouring of the volcanic rocks that subsequently led to the formation of the Absaroka volcanic field. During Eocene, Oligocene and Miocene time (Van Houten, 1952) epeirogenic uplift of the Beartooth region took place. According to Love (1961) normal faulting of the Yellowstone tuffs, within the park, is suggestive of gentle arching which continued through Pliocene time. The recent Hebgen Lake earthquake seems to imply further regional uplift of the area and Basin-Range type faulting (Fischer, oral communication).

Structure of the Beartooth Mountains.- The local structure within the Independence area is intimately related to the broader aspects of the Beartooth Mountain uplift. Foose et al., (1961, p. 1143-1172) have presented a detailed summary of the geologic structures surrounding the Beartooth uplift. The vertically-uplifted Beartooth block is bounded

by a series of high angle thrust planes and vertical faults (Fig. 43). Northeast-southwest horizontal compressive forces are considered to have initiated the uplifting and the resultant thrusting. The thrust planes and vertical faults are well developed and preserved in the Paleozoic and Mesozoic sedimentary rocks exposed around the perimeter of the Beartooth Mountains.

The Precambrian surface is higher topographically and structurally along the northeast and northwest parts of the Beartooth block and dips toward the southwest as the result of thrusting to the northeast. Near Gardiner, Montana (Wilson, 1936) the Precambrian surface dips toward the northeast as the result of thrusting toward the southwest. The southeast part of the Beartooth block is buried beneath a thick cover of volcanic rocks.

In general, the Precambrian surface around the edge of the Beartooth block dips toward the central part of the block. This feature has been designated the Cooke City zone (Foose et al., 1961, p. 1149). The Cooke City zone originates as a high angle normal fault on the southeast edge of the exposed block with a displacement of more than 3,000 feet. This fault disappears to the northwest, in the vicinity of Cooke City, and passes into a broad fault-zone within the interior of the uplifted block. Some workers have suggested that the Cooke City zone may have been a continuation of the Bighorn syncline prior to the Laramide revolution.

Previous workers (Rouse, 1937; Parsons, 1958) have

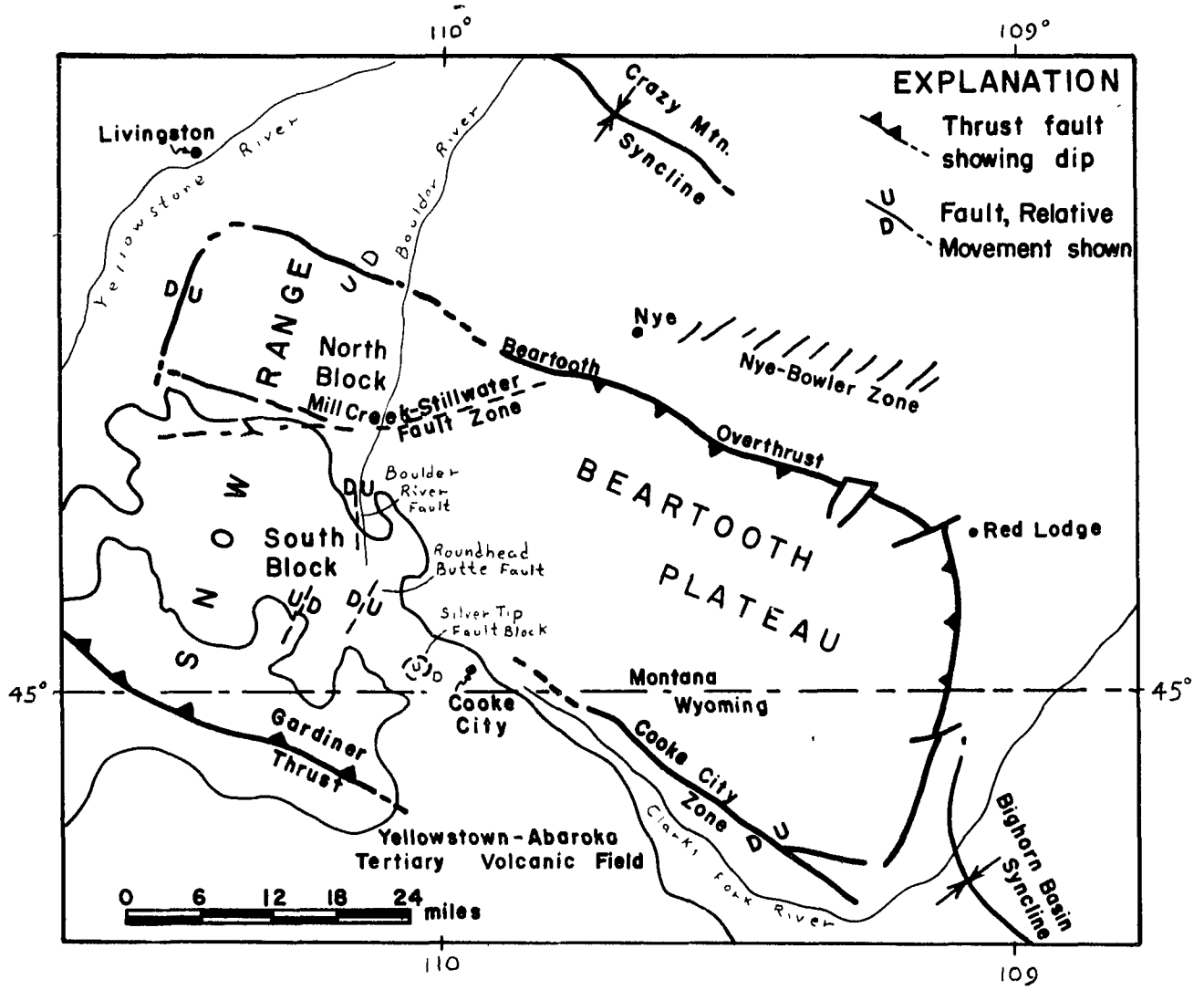


FIGURE 43.- Tectonic sketch map of the Beartooth-Absaroka Mountains area. (data modified after Fanshawe and Alpha, 1954)

emphasized the northwest-trending zone of intrusives in the middle and southern Absaroka Mountains. This northwest trend merges into the so-called Cooke City zone. Several small intrusive bodies have been mapped, by the writer, that fall in a line along this zone. This undoubtedly reflects a weakened, and possibly faulted, zone which controlled the emplacement of subsequent plugs, volcanic vents and dikes of Eocene age.

Local Structure

Practically all the evidence of tectonic events, in the Independence area, is masked by the cover of volcanic rocks. However, two and possibly three distinct episodes of tectonic activity can be recognized.

Granitic gneisses and schists, exposed on the northeast side of the area, reflect Precambrian metamorphism. Laramide events are indicated by the Monument conglomerate which marks a period of vigorous uplift and subsequent erosion. A fault in the present site of the main Boulder River, in the north central part of the area, is related to this period. Another fault occurs in the central part of the Independence area in the vicinity of Round Head Butte and Lookout Mountain.

Middle Eocene (?) deformation is indicated by the Silver Tip fault block which is located in the southeast part of the area near Cutoff Mountain. Except for slumping, no disruption or dislocation of any volcanic rocks has been recognized in the Independence area.

Boulder River Fault.- A strike line across the Boulder River valley from Treasure bench to the ridge between Elk and Bridge Creeks (Pl. I) reveals a stratigraphic discrepancy within the Cambrian sediments, that can only be resolved by postulating a fault. On the east side of the valley the Flathead Formation is 133 feet thick; whereas, on the west side of the valley the Flathead Formation has a maximum thickness of 12 feet and pinches out on a Precambrian high. The area where the Flathead Formation pinches out is 880 feet lower, topographically, than where the Flathead Formation is 133 feet thick. It appears logical to assume that, under the original conditions of deposition, the area of pinch out must have been higher, topographically, than where the thicker part of the Flathead Formation was formed.

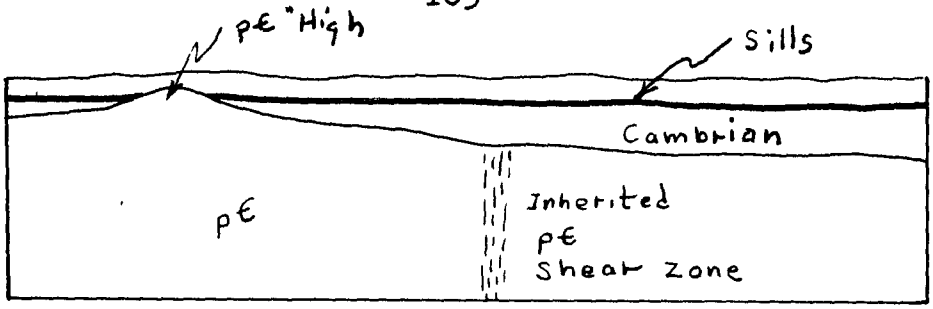
This fault is probably local in extent and by no means implies that the entire Boulder River is fault controlled. Detailed evidence of faulting in the valley floor is lacking due to the effects of glaciation and also the heavy growth of vegetation. Just below War Eagle Mountain there are several shear zones in the weathered Precambrian metamorphic rocks that are parallel to the valley. Near the confluence of Sheep Creek with the Boulder River a shear zone in the Precambrian rocks has been mineralized to a limited degree. The shear zone near War Eagle Mountain and the shear zone that has been mineralized form a trend that parallels the Boulder River valley for a distance of about 4 miles.

The absence of any evidence of faults in the pyroclastic

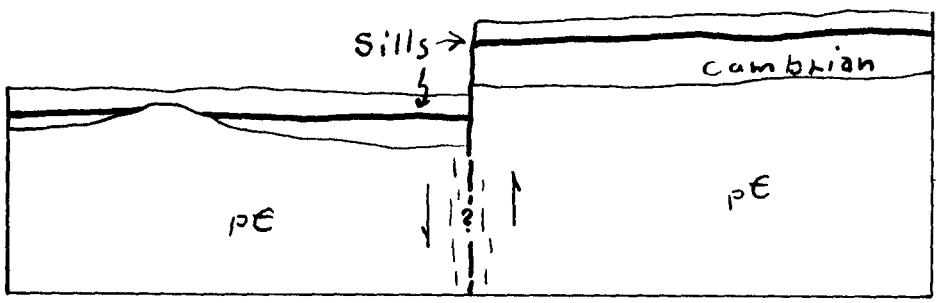
debris indicates that the faulting must have taken place prior to the accumulation of the Group I Volcanics. The fault is undoubtedly related to the Laramide deformation and is of probable Paleocene (?) age. Due to the volcanic cover the exact length of the fault can not be determined, but the inferred fault has a minimum length of 4 miles. The Boulder River fault appears to be a north-south, nearly vertical fault with a displacement, west wall down, of at least 880 feet. The dislocation of the Precambrian surface along inherited shear zones during Paleocene (?) time is diagrammatically shown in Figure 44.

A significant feature of this fault is that if the Beartooth uplift is considered to be a tripartite structure consisting of the Beartooth Plateau, and the north and south blocks of the Snowy Range, then the Boulder River fault could represent a known part of the southwestern border of the Beartooth Plateau.

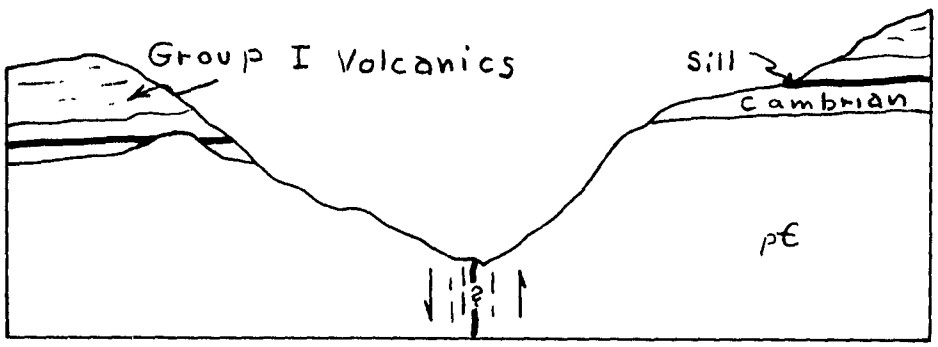
Round Head Butte Faults.- Just north and south of Round Head Butte, in the lower reaches of the valleys, two faults, that may be related, are partially exposed under the volcanic cover. In the East Fork of Buffalo Creek drainage the Bighorn and upper Cambrian Formations are disrupted by a high angle normal fault that dips to the west. The Bighorn dolomite is downthrown on the west side against the upper Cambrian Grove Creek-Snowy Range Formations. The displacement is about 90 feet. The volcanics that cover this fault have not been displaced.



(a) Paleocene (?) time after intrusion of porphyritic sills. Area of pinch-out highest point on Precambrian surface.



(b) Late Paleocene - Eocene. Laramide faulting along Inherited (?) Precambrian shear zones.



(c) Present topography showing the Precambrian "high" now lower than area of thickest Cambrian deposition.

FIGURE 44.- Diagrammatic cross section across the Boulder River showing the inferred fault that may have dislocated the Precambrian surface during Paleocene (?) time prior to the main period of volcanism.

South of Round Head Butte, on the low divide that separates the two tributaries of Slough and Buffalo Creeks, a patch of middle Cambrian sediments crops out on a small exposure of the Precambrian surface. The elevation of this divide is 9,250 feet. Directly east, the entire section down to 7,730 feet consists of undisturbed volcanic rocks. This indicates a relief in the Precambrian surface of more than 1,500 feet. The short horizontal distance, less than 3,000 feet, when compared with the horizontal distance is highly suggestive of a fault scarp.

The two faults line up on the same trend, about N 20° E, with a horizontal distance of about 3 1/2 miles. The northern part of the fault, when projected under the volcanics, is coincidental with a small irregular intrusive body.

Brown (1961, Pl. I) shows dips in the Cambrian sediments, on Buffalo Plateau, of 6° NE. The dips of the Cambrian sediments in the Independence area average about 11° SW. These opposing dips point to a significant trough, with a northwest-southeast trend, in the vicinity of the Hellroaring and Buffalo Creek area. This trough may be the northwest extension of the Cooke City zone that was mentioned earlier. If the southern part of the Round Head Butte fault represents a fault scarp, with the west block dropped down in excess of 1,000 feet, then the Cooke City zone in the Independence area may consist of a graben-like structure. Six miles to the west, near Hellroaring Creek, a fault with the same trend as the Round Head Butte fault is shown on the Livingston Folio

(Fig. 43). Here the east block is dropped down at least 600 feet.

A significant feature is that both the Round Head Butte fault and the unnamed fault shown in the Livingston Folio are transverse to the northwest trend of the Cooke City zone. These faults may represent a part of a major fault zone, and the intersection of the Cooke City zone with this fault zone could be the actual structural boundary between the Beartooth Plateau and the south block of the Snowy Range.

Silver Tip Fault Block.- The most conspicuous faults, and the only ones that are well exposed, form a circular pattern around a Precambrian fault block, in the southeast part of the area in the immediate vicinity of the Silver Tip Ranch (Pls. I, II). This circular-shaped Precambrian block, about 2 miles in diameter, has been uplifted in excess of 2,700 feet with a corresponding thrusting (or sliding) of the sediments to the northwest and upturning of the sediments on the southeast side. The sediments on the northeast side are apparently nearly horizontal (Courtis, oral communication). Slough Creek flows through a narrow canyon cut deeply into this Precambrian block. Upstream from this natural barrier, the narrow canyon suddenly opens up into a broad alluvial-filled valley known locally as Frenchy's Meadows.

The upper Cambrian and Ordovician sediments have been thrust, or perhaps displaced by gravity sliding, to the northwest over a section of undisturbed Ordovician Bighorn Formation (Fig. 45). These thrust sediments are exposed as a long crescent-shaped outcrop in which the bedding dips 79° to the northwest and west. The sediments appear to drape over the edge of the Precambrian fault block. The entire thrust block is strongly fractured, which may indicate rapid movement and settling of the sediments. The edge of this thrust block can be traced where exposed under the volcanic cover for more than a mile and a half.

In the deep ravine of Cutoff Creek, on the southern side of the Precambrian fault block, the Flathead Formation strikes east and dips vertically. About 100 yards, directly south



FIGURE 45a.- View showing a part of the Bighorn Formathat has been displaced to the northwest away from Silver Tip fault block. View looking west across Slough Creek.

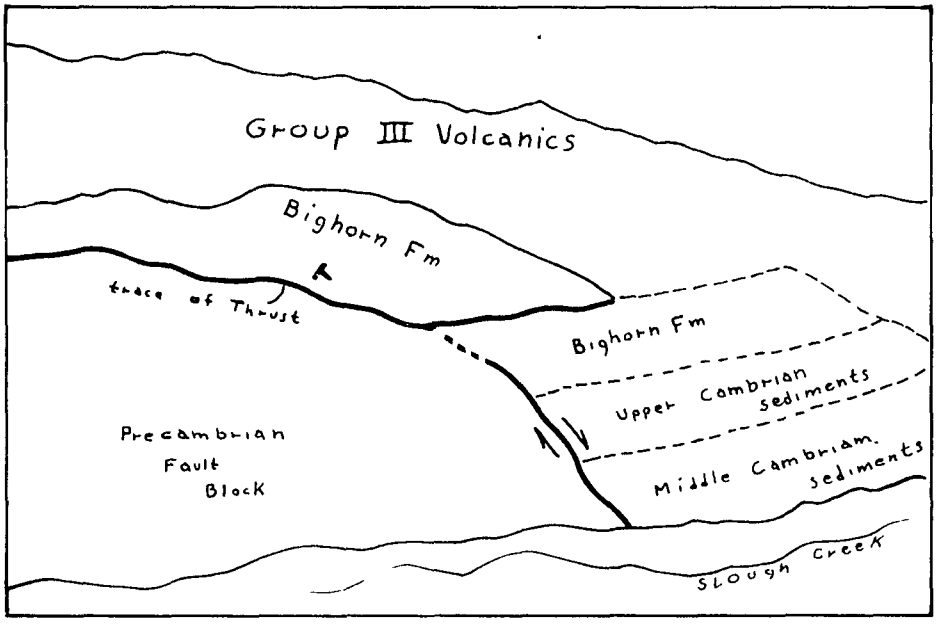


FIGURE. 45b.- Detail of Fig. 45a explaining the lithologies.

across the ravine, upper Cambrian and Ordovician sediments are nearly flat. Lost Creek bounds the north side of the fault block. On the east side, the block is covered with a thick series of Group III Volcanics that are exposed on Cutoff Mountain.

On the east side of Slough Creek, 2 miles north of the Precambrian fault block, the upper Cambrian sediments are partly exposed at an elevation of about 6,750 feet and dip 9° SW. The top of the fault block attains an elevation of 9,500 feet; therefore, the block has a vertical displacement of at least 2,700 feet. No Paleozoic sediments were observed at any place on the Precambrian block.

Origin.- The Silver Tip fault block is unique in that the circular fault pattern is suggestive of a ring dike complex; but, no ring dikes were observed in the area bounding the fault block and the cylindrical-like mass of Precambrian rocks has been displaced vertically for at least 2700 feet and probably more. This block was probably forcefully uplifted by magmatic intrusion. The proximity of two sill-like bodies, plus the fact that the fault block lies in a northwest-trending zone that contains several intrusive bodies seems to support this view.

The same type of mechanism that forms the shear fractures of ring dike complexes is suggested, with slight modifications, to account for the origin of the Silver Tip fault

block. The suggested sequence of events is as follows:

1. Formation of concentric fractures as the result of magmatic doming.

2. Release of magmatic pressure and the partial solidification of igneous material in the probable faulted or brecciated zone.

3. A resurgence of magmatic doming with the plug-like Precambrian block being forced upward along the previously formed shear fractures.

4. The termination of vertical movement as the magma was intruded laterally in the form of sills.

TECTONIC HISTORY AND INTERPRETATION

The tectonic history of the area is intimately related to the tectonic events that formed the Beartooth Mountains. The following discussion is, in part, condensed and modified from the detailed geologic chronology presented by Foose et al., (1961, p. 1163-1168). The tectonic events of the region are divisible into two parts: (1) the Precambrian events which led to the formation of the core of the Beartooth uplift, and (2) post-Precambrian events which led to the direct formation of the present mountain range. The Beartooth Mountains have a similar history to many other mountain ranges, with exposed Precambrian cores, in the Wyoming shelf area.

In early Precambrian time a thick sequence of sedimentary rocks was deposited in the form of quartzites, ironstones with some argillites, marls and subgraywackes. A period of deformation followed that resulted in moderate folding with fold axes plunging gently toward the south and southwest. A period of ultramafic injections occurred on a regional basis which Hess (1955, p. 392) considered to be a part of a northwest-trending alpine belt. An intensive period of granitization followed, dated at about 2.7 billion years ago (Gast et al., 1958, p. 326), which formed a metamorphic assemblage of amphibolites, biotite gneisses, migmatites, and leucogranitic gneiss. The latter constitutes the bulk of the Beartooth area. Almost simultaneously with the granitization widespread mafic igneous activity took place. The

Stillwater complex, located about 35 miles north of the Independence area, may have been intruded with the later phases of mafic activity. Apparently no sediments of later Precambrian time were deposited in the region.

During middle Cambrian time deposition began in the shallow waters of the broad Wyoming shelf and continued through most of Paleozoic time, except during a marked epeirogenic uplift in Silurian and early Devonian time. Deposition continued during Triassic, Jurassic and early Cretaceous. In late Cretaceous time, a thickening of the sediments reflected a general and more rapid subsidence of the shelf area which was the first evidence of Laramide crustal instability.

The downwarping of the region was accompanied by volcanic activity on the northern side of the present Beartooth uplift in the vicinity of the Nye-Bowler lineament (Rouse, 1937, p. 738) Parsons (1942, p. 1178) pointed out that the Livingston volcanics are interbedded with rocks as old as the upper Cretaceous Judith River Formation. During this time also differential movement on opposite sides of the Nye-Bowler zone resulted in a thickening of the sediments to the south (Chamberlin, 1940, p. 680).

Prior to the main uplift of the Beartooth block, a series of monzonite porphyry sills and stocks were intruded along favorable zones on the perimeter of the block. Faulting of these igneous bodies, and subsequent covering by early Tertiary sediments, indicates their relative age to the main period

of deformation. The sills intruded into the Cambrian sediments in the Independence area are considered to be of this same period.

Major uplift of the Beartooth block occurred during middle and late Fort Union (Paleocene) time and ended during early Wasatch (Eocene) time. The early upward movement of the block was along bounding faults that were probably vertical or nearly vertical. The north edge of the block moved to the highest structural position with respect to the depressed Bighorn basin during Wasatch time. The covering sediments on top of the block were stripped off during Fort Union time (Stow, 1946, p. 680). The Monument conglomerate in the Independence area was probably formed during this time.

Deformation of part of the Wasatch sediments, in the form of local upturning and faulting on the east side of the block, indicated that uplifting continued after the main upheaval (Wilson, 1936, p. 1180).

Volcanism began during early Eocene at the culmination of the Beartooth uplift. The so-called "early acid breccias", with which the basal unit of the Group I Volcanics have been tentatively correlated, were extruded. About this same time a series of intrusive bodies were emplaced parallel to the Cooke City zone which trends through the Independence area. The thick cover of pyroclastic breccias has covered most of the southwestern portion of the Beartooth block, but enough evidence is present to delineate partially the character of the Laramide structures. These are essentially tilted fault

blocks with volcanics filling in the inferred depressed areas.

Pierce (1957, p. 591) described the horizontally displaced masses of Paleozoic rocks that constitute the Heart Mountain overthrust. These rocks have moved a minimum distance of 18 miles during the period of volcanism in middle Eocene time. The Silver Tip fault block was probably displaced during this same period.

The normal faulting of Mio-Pliocene time in much of the Cordilleran region is absent in the Beartooth region. Only minor faults have been reported in the volcanic rocks of the Yellowstone Plateau area; these faults are unrelated to prior structures and are relatively insignificant in terms of the Beartooth block uplift. In the Independence area no faulting or displacement of the volcanic rocks has been observed.

The Beartooth block attained its present structural relief during middle Eocene time; however, it did not have its present topographic relief until Miocene-Pliocene time. Faunal and floral evidence (Van Houten, 1952) from the Eocene rocks of the Bighorn Basin indicates the entire area was at considerably lower elevations. During Miocene-Pliocene time, regional uplift occurred in the order of 4,000 to 6,000 feet. Subsequent erosional modification created the present topographic relief.

MINERAL RESOURCES

General Statement

The Independence area contains several small deposits of metallic minerals that have been worked to a limited degree, but none seems to have justified further development. The entire area has been prospected, but no activity is in progress at present. Attempts have been made in the past (1890's and the 1930's) to mine for gold and lead, but the deposits were either too low grade or too small to warrant further exploitation. Recently, in 1961, some interest was expressed in an apparently low-grade molybdenum deposit. Inaccessibility and short summers have thwarted any serious attempts to evaluate fully the grade and extent of the molybdenum deposits.

The mineral deposits of the area may be classified as follows:

1. Gold
   - (a) Pyritic quartz veins within the coarse-grained rocks of the Independence volcano and the latite prophyries of Horseshoe Mountain.
   - (b) Pyritic disseminations in the hydrothermally altered granodiorite within the Independence volcano.
   - (c) Placers.
2. Lead
   - (a) Replacement in sedimentary rocks.
   - (b) Replacement in fault or shear zones.
3. Molybdenum

Gold Deposits

Veins and Disseminations.- Quartz-pyrite veins occur in the core rocks of the Independence volcano and also in the porphyries of Horseshoe Mountain. Most of the veins in the Independence volcano occupy joints and small fractures in syenogabbros and monzonites.

For the most part the small veins are mineralogically simple and never exceed 6 inches in width. They have a general northwest trend and are nearly vertical. Quartz makes up the bulk of the veins. Locally, concentrations of oxidized pyrite have led to a high degree of iron staining of the wall rock. In some places transported iron has stained nearby joint planes for a distance of several feet. Many of these stained joint planes have been prospected, some for a length of fifty feet. All of the patented claims within the core of the volcano are on thin quartz veins that contain small amounts of pyrite.

The old Independence mine, located 300 yards east of Independence Peak, reportly is the oldest mine in the area and the only one that produced any gold. This mine is on the spur of a steep cliff which afforded convenient disposal of dump material. A rotted and collapsed wooden chute indicates that some effort was made to move high-grade ore down to the Basin Creek trail.

A caved shaft reveals that the mining activity was restricted to a zone of closely spaced, vertical fracture planes that were partly mineralized. The country rock is

a fine-grained monzonite. The mineralized zone is about 30 feet wide with no veins thicker than one-half inch. The veins contain about equal amounts of quartz and pyrite with trace amounts of chalcopyrite. The wall rocks are not altered.

About 100 yards southeast of the Independence mine, material from a dump with a nearby caved shaft indicates that the veins contain only quartz and pyrite. The Omega claim represents the only other workings, of local importance, within the core of the volcano. A caved shaft, probably 50 feet deep, with a nearby dump, suggests that this operation may have been partly successful. The country rock is a medium-grained monzonite, and dump material shows that part of the wall rock was highly altered to a bleached aggregate rich in quartz, kaolinite, sericite and limonite. Pyrite is the chief metallic mineral observed in dump specimens, but rare specks of molybdenite occur in some of the thin quartz stringers.

The area of disseminated sulfide mineralization is restricted to a hydrothermally altered zone in granodiorites just north of Basin Creek, within the core of the volcano. This mineralized zone, in plan view, is about 900 feet long and 400 feet wide and parallels Basin Creek. The poorly defined contact between the granodiorite and the monzonite may have controlled the upward migration of the hydrothermal solutions. Two patented claims cover this mineralized zone; the Hidden Treasure to the east and the Hidden Treasure No. 4 to the west.

The disseminated zone was first worked in the 1890's. Four adits were driven in a northerly direction, but they

are now caved so that the actual distance can not be determined. The workings were reactivated during the 1930's in hopes of finding the source of the free gold that occurs in some of the Basin Creek gravels. A ball-mill with 2 shaker tables was constructed to process the ore from two new adits driven along disseminated zone. All indications suggest that the operation was a failure. No free gold was ever recovered from the shaker tables (John Murphy, oral communication), but some concentrates that were sent to the East Helena smelter reportly had gold values of $16.50/ton.

The sulfide mineralization was accompanied by extensive wall rock alteration. The secondary minerals in the granodiorite consist mainly of pyrite, quartz, sericite with some chlorite, limonite and calcite. The altered rock as seen on the mine dumps, is a whitish-gray to yellow siliceous rock containing abundant disseminated pyrite. The entire disseminated zone carries pyrite as the only major metallic mineral along with trace amounts of chalcopyrite.

The mineralization in the Horseshoe Mountain area consists of a combination of veins and scattered, small disseminations. The entire vicinity of Horseshoe Mountain is covered with small prospect pits. The only metallic mineral detected in the various dumps was pyrite. Most of the mineralization is restricted to the latite porphyry flows that encircle Horseshoe Basin. A small mineralized zone occurs in the Precambrian metamorphic rocks on the northside of Horseshoe Mountain.

Placer.- Placer mining has not been important in the

Independence area. Some hydraulic work was done in the Basin Creek drainage just west of the old Cowles Post-Office. This placer site lies downstream from the vein deposits of the Independence mine and the disseminated zone in the granodiorite of the Hidden Treasure claim.

The amount of gold recovered from this placer operation has never been recorded. Mr. J. Clemmons of Big Timber, Montana (oral communication) stated that he worked the sluice ways in the 1930's and averaged about $12 of gold per day. A few colors per pan can still be recovered from the Basin Creek gravels.

Lead Deposits

The Ski Line claim is on the northern slope of Baboon Mountain. This claim represents the only lead-sulfide replacement deposit in sedimentary rocks that has been recognized in the Independence area. The workings consist of one adit that is now partly collapsed.

The mineralized zone is restricted to the Flathead and Wolsey Formations which have a combined thickness of 93 feet and dip 11° SW toward the Independence volcano. The mine opening indicates that a mineralized zone about 25 feet wide, 40 feet long and 6 feet high was worked. Elsewhere in the immediate vicinity the Cambrian Formations do not reveal any effects of replacement.

A study of dump material from the workings indicates that this mineralized zone was probably of a low-temperature type.

Some bedding features are preserved in the altered sedimentary rock. A few samples contain large euhedral crystals of galena, up to 1 1/2 inches across, imbedded in a drusy matrix of quartz and possibly some anglesite. For the most part the content of quartz gangue far exceeds that of the lead minerals. There is no record of any ore shipped from this working.

The outer edge of the Independence volcano lies about 1000 feet south of the mineralized area. The contact between the Flathead and Wolsey Formations may have acted as a channelway for the mineralized solutions during the late stages of volcanism.

The "Four Sevens" claim lies about one mile west of the confluence of Sheep Creek and the main Boulder River. This prospect reveals the only observed mineralized fault or shear zone in the Precambrian metamorphic rocks near the Independence volcano. The workings are caved and most of the former dump material lies in the stream bed. Limited exposures suggest the presence of a highly silicified shear zone in the Precambrian metamorphic rocks. No Cambrian sediments are present in the immediate vicinity, and the overlying volcanic rocks have not been altered or mineralized.

Two adits were driven in a northwesterly direction. Samples from the mine dump indicate that the mineralized zone consists of a light to dark gray, fine-grained silicified sheared gneiss with small crystals of pyrite disseminated throughout the rock. There are a few very small veinlets of sphalerite and galena in some samples. Mr. Jess Clemmens,

of Big Timber, Montana (oral communication) stated that the prospect was worked in 1948 and 1949, without any ore being shipped.

Molybdenum Deposit

Mr. Charles Rasnik, of McLeod, Montana, directed the writer to a molybdenum prospect on the south side of Bridge Creek 4 1/2 miles west of the Main Boulder River. Heavy vegetation and slumping permitted observations of exposures in only a few old prospect pits.

The mineralized zone, about 1,200 feet long, parallels the south side of Bridge Creek. Due to soil cover and vegetation the country rock can not be accurately identified. To the east, on War Eagle Mountain, the Cambrian sediments have been intruded by a series of quartz latite porphyry sills. The sills and sediments can not be traced west through the timber; but the topographic expression suggests that the sediments and sills end abruptly above the mineralized zone. This may indicate faulting. The volcanic rocks, where exposed above the mineralized zone, have not been altered and reveal no effects of mineralization.

Samples from the various dumps show pyrite and magnetite as the only metallic minerals along with some quartz. These minerals occur in highly fractured and altered rock. The writer did not observe any molybdenite in any samples from the dumps. Mr. Rasnik did show the writer samples containing small flakes of molybdenite in combination with quartz.

CONCLUSIONS

A major eruptive center existed in the northern Absaroka volcanic field during middle and late Eocene time. Continued volcanic activity, from a single vent, the Independence volcano, led to the formation of a huge cone-complex and the accumulation of thick volcanic deposits in the surrounding low-lying areas.

A large volume of potash-rich volcanic rocks was extruded and distributed over the Independence area during five phases of volcanic activity. These are represented by five groups of volcanic deposits: (1) Group I Volcanics which consist of a variety of dacitic to latitic volcanic breccia and minor amounts of flows; (2) Group II Volcanics, consisting of a series of latite porphyry flows that originated from a separate, but local, eruptive center; (3) Group III Volcanics which led to the formation of the cone-complex that surrounded the Independence volcano. These volcanic rocks consist of a variety of latitic pyroclastic breccias, tuffs, and agglomerates that are chaotically intermixed with volcanic mudflows, conglomerates and sandstones; (4) Group IV Volcanics which reflect a period of aggradation and leveling of the flanks of the Independence volcano. This unit is represented by a series of well-bedded volcanic conglomerates and sandstones, predominately water-laid deposits; and (5) Group V Volcanics which consist of a thick series of potash-rich basalts that flowed out on relatively flat surfaces.

The overall composition of the various volcanic rocks

shows a normal line of descent from trachybasalts to latites and finally to dacites. Coarse-grained equivalents of the fine-grained rocks are preserved in the core of the Independence volcano in the form of syenogabbros, monzonites, and granodiorites.

The magma that produced the various volcanic rocks was probably derived from a differentiating magma having a bulk composition of a monzonite. The general sequence of extrusion from dacitic materials to latites and finally trachybasalts strongly suggests the tapping of a differentiating magma body in the following way; (1) the early dacites could be equivalents of the felsic magma concentrated in the upper parts of magma chamber by crystal fractionation and crystal settling, (2) the bulk of the latites that were extruded may represent a relatively undifferentiated zone in the middle part of the chamber, and (3) the extrusion of the trachybasalts may be the normal basic differentiates of a monzonitic magma.

Several small intrusive bodies were emplaced during the main period of volcanism along a northwest-trending line. This trend parallels a major structural element within the interior of the Beartooth Mountains which probably reflects a major fault zone. This element has been termed by previous workers, the Cooke City zone.

Most of the Laramide structures are covered by volcanic debris, but two inferred faults (Boulder River and Round Head Butte faults) indicate a possible structural boundary between the southwest corner of the Beartooth Plateau and the east edge of the south block of the Snowy Range.

Local deformation during Eocene time is indicated by the Silver Tip fault block, which is unique in that it is surrounded by a circular fault pattern and the central core of Precambrian metamorphic rocks has been vertically uplifted, by magmatic activity, for more than 2,700 feet. Apparently the upward thrust of a stock-like intrusive body was responsible for the displacement of the circular fault block.

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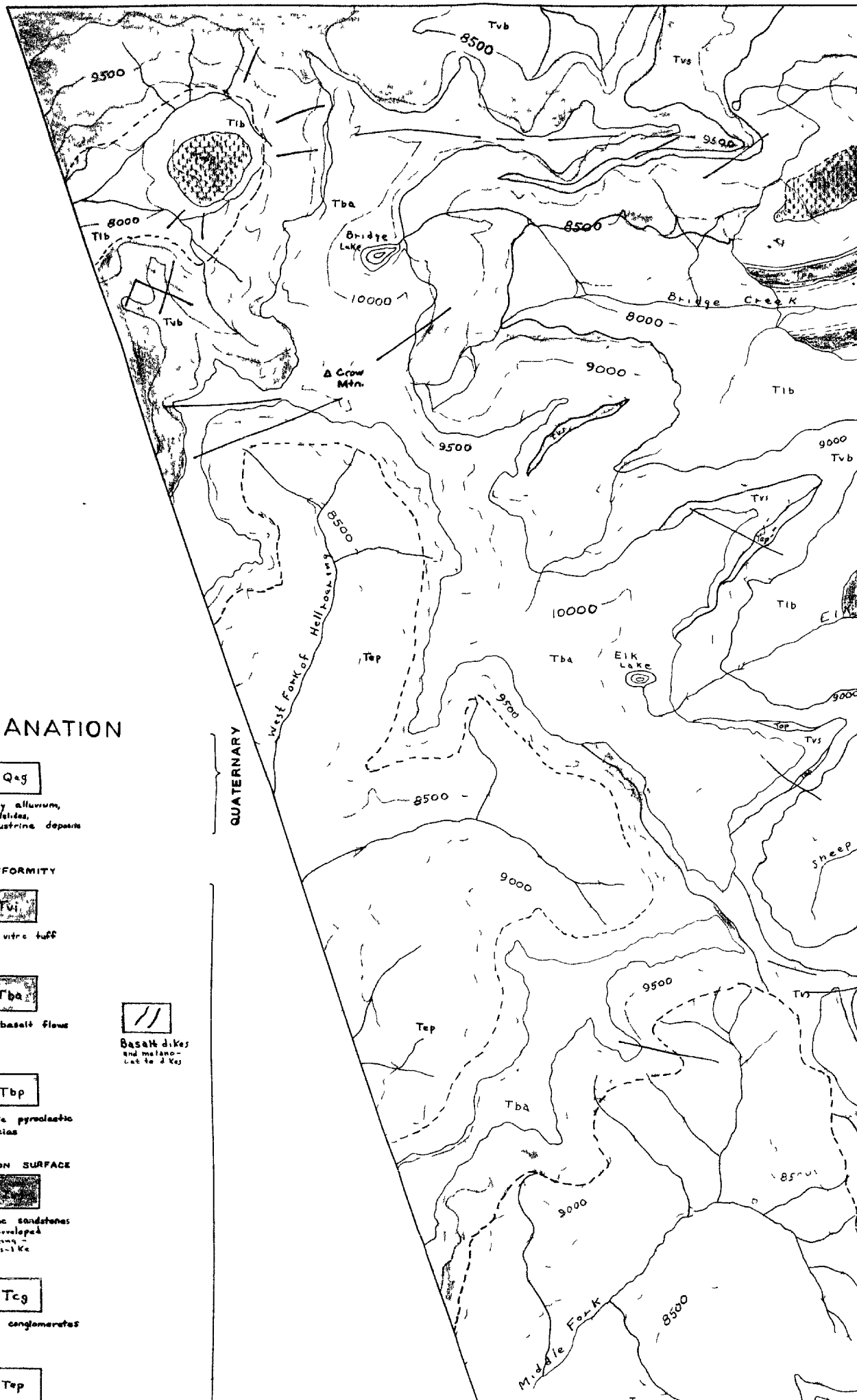
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EXPLANATION

QUATERNARY

Qag — Valley alluvium, landslides, lacustrine deposits

UNCONFORMITY

GROUP V VOLCANICS

Tvl — Felsic vitric tuff

Tba — Trachy basalt flows

Tbp — Basaltic pyroclastic breccias

Basalt dikes and melano-latite dikes

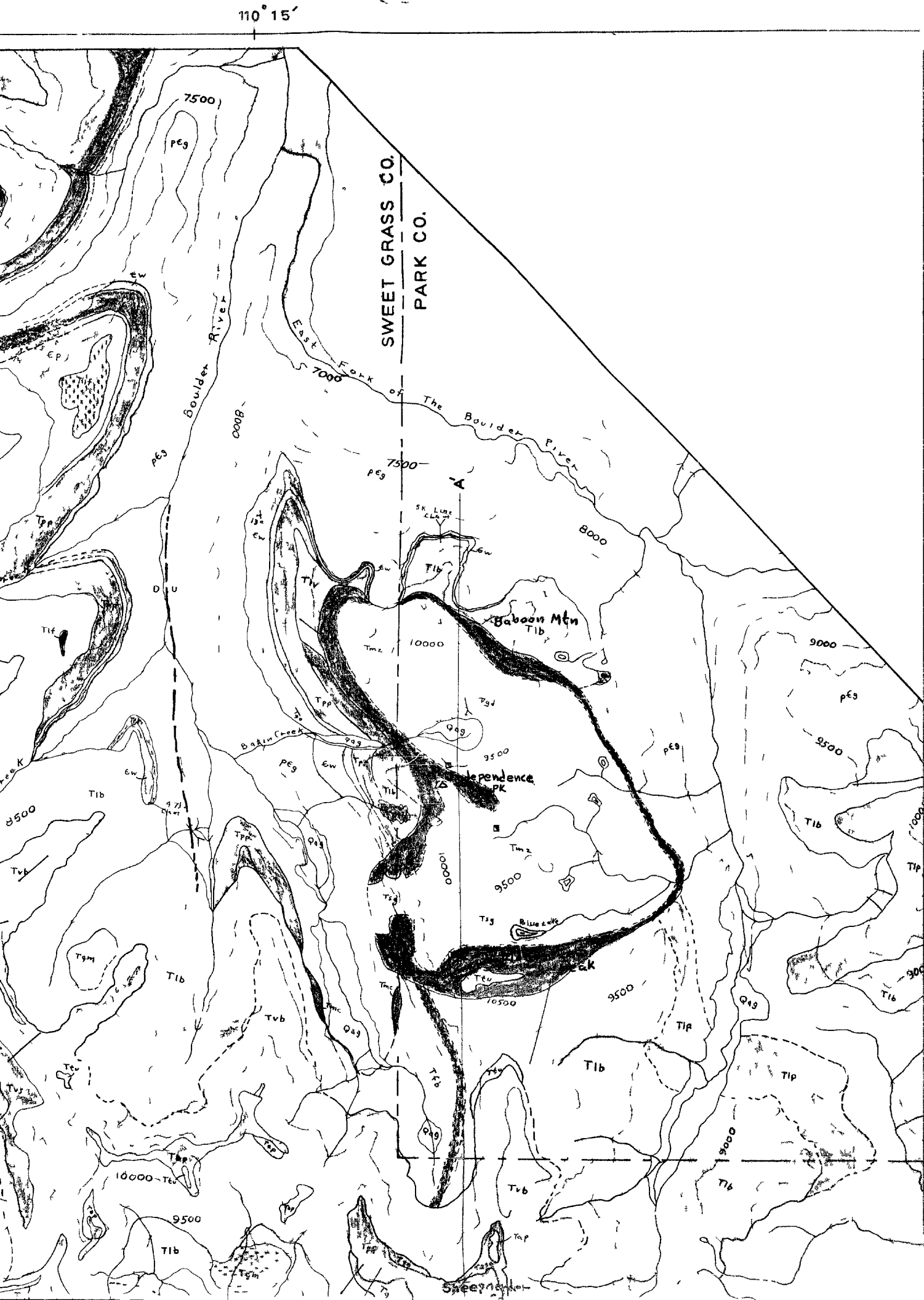
EROSION SURFACE

GROUP III VOLCANICS

Volcanic sandstones well developed bedding - lenticular

Tcg — Volcanic conglomerates

Tep


110° 15'
SWEET GRASS CO.
PARK CO.
East Fork of The Boulder River
Boulder River
Baboon Mtn
Baboon Creek
Bluebird
7500
8000
9000
9500
10000
10500
A
A'

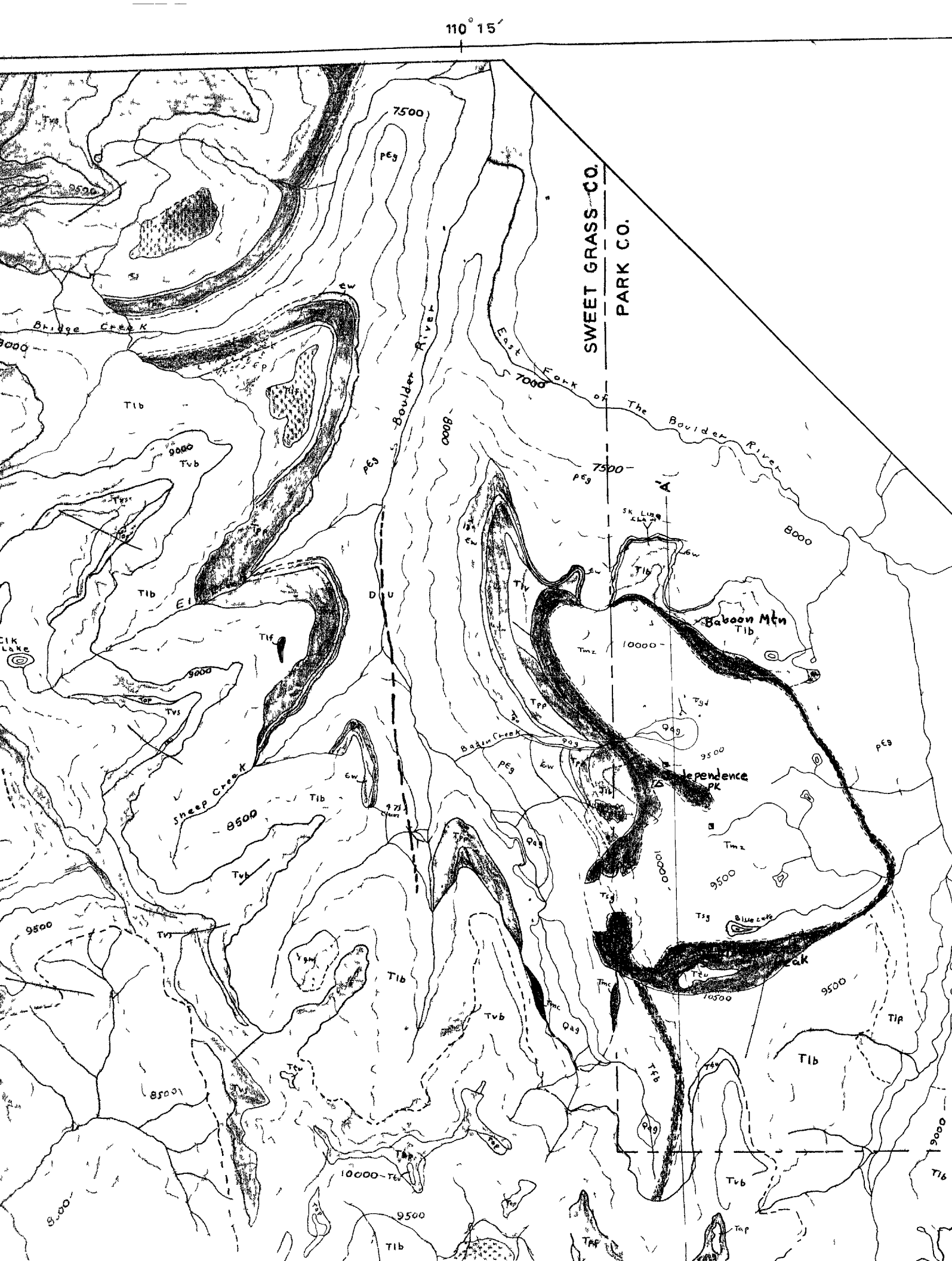
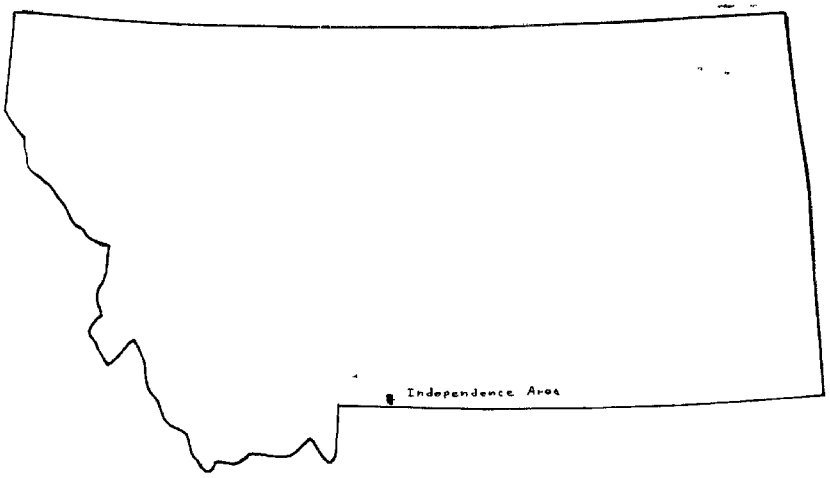
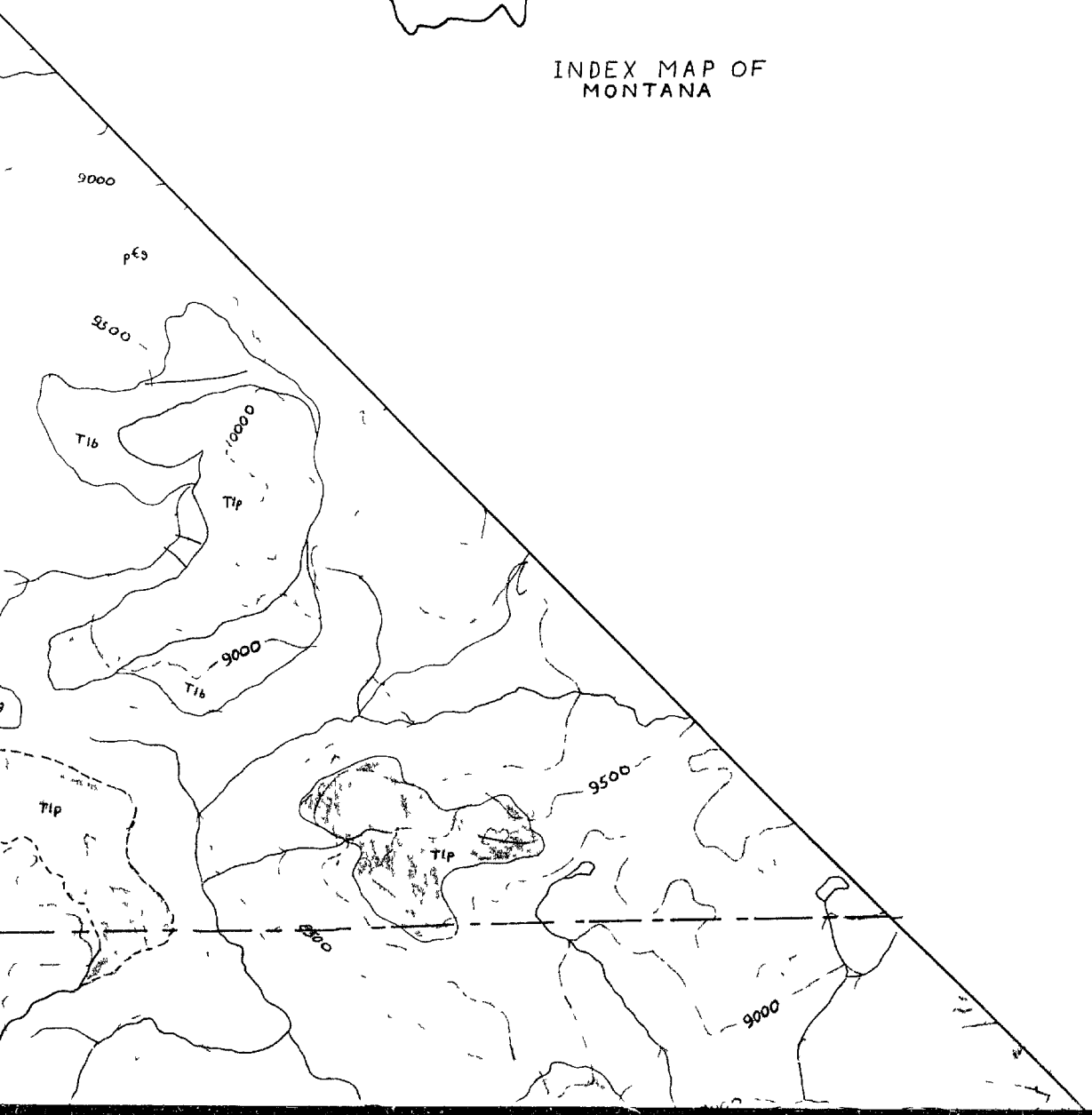

110° 15'
SWEET GRASS CO.
PARK CO.
Boulder River
East Fork of The Boulder River
Bridge Creek
Sheep Creek
Baboon Mtn
Tlb
Tvb
Tlf
Tvs
Tpp
Tmz
Qag
Tsg
Tvu
Tlp
peg
Ew
7500
8000
8500
9000
9500
10000
A
A'

PLATE 4



INDEX MAP OF
MONTANA



EOCENE

PALEOCENE (?)

GROUP III VOLCANICS

Tcg — Volcanic conglomerates

Tep — Epiclastic volcanic breccias
Volcanic mud flows
conglomerates
Sand stones

Undifferentiated pyroclastic breccias lava flows, and tuff breccias

Tap — Latite lapilli tuff

Volcanic mud flows

Conglomerates agglomerates

Tlb — Latitic lithic tuff breccias

Independence Volcano Intrusive Complex
granodiorite
monzonite
Syenogabbro
latite intrusive breccia

Tmh — Mill Creek plug
labradorite
latite porphyry

Tlp — Melano latite plug

EROSION SURFACE

GROUP II VOLCANICS

Latite porphyry flows
with quartz & hornblende
EROSION SURFACE

GROUP I VOLCANICS

Lithic and vitric tuffs
well bedded to
massive light gray
to tan tuffs

Tlc — Trachyrhyolite flows

Tlb — Lithic tuff breccia
many volcanic
fragments with
light matrix

Buffalo Pass
and Sheep
Creek plugs
latite porphyries

Local lava flows
of basalts and
melanolatites

Tla — Quartz latite
of Buffalo
Fork Lava

Tfb — Pyroclastic flow breccias
aphanitic gray green
latite matrix with
volcanic phenocrysts

Anderson Creek
basalt and trachy
rhyolite lava
flows just South
of map area

Monument Conglomerate
Precambrian boulder conglomerate
UNCONFORMITY

Quartz Latite Porphyry Sills
intruded into lower and
upper Cambrian sediments
UNCONFORMITY

TERTIARY

PALEOCENE (?)

MISSISSIPPIAN

Mm — Madison Formation
thin bedded to massive
coarsely crystalline
limestone

DEVONIAN

Dj — Jefferson Formation
gray to brown limestone
and dolomite

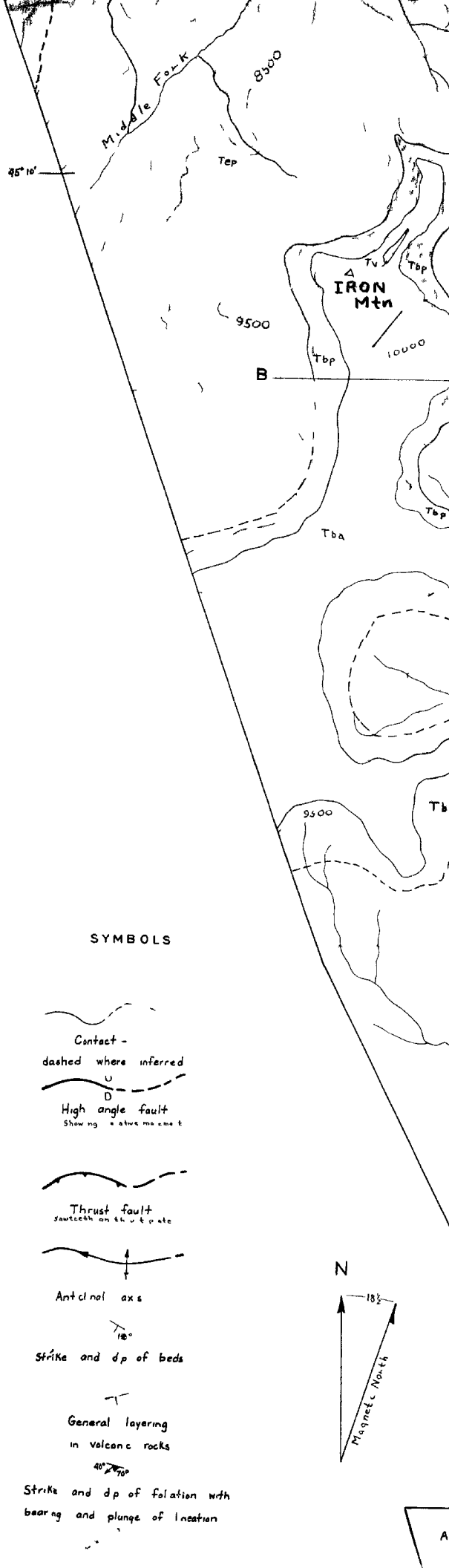
ORDOVICIAN

Bighorn Formation
massive tan rough
weathering dolomitic
limestone

UNCONFORMITY

UPPER CAMBRIAN

Grove Creek-
Snowy Range Formations
limestone Flat pebble
conglomerate



SYMBOLS

Contact -
dashed where inferred

U
D
High angle fault
Showing relative movement

Thrust fault
sawteeth on the upper plate

Anticlinal axis

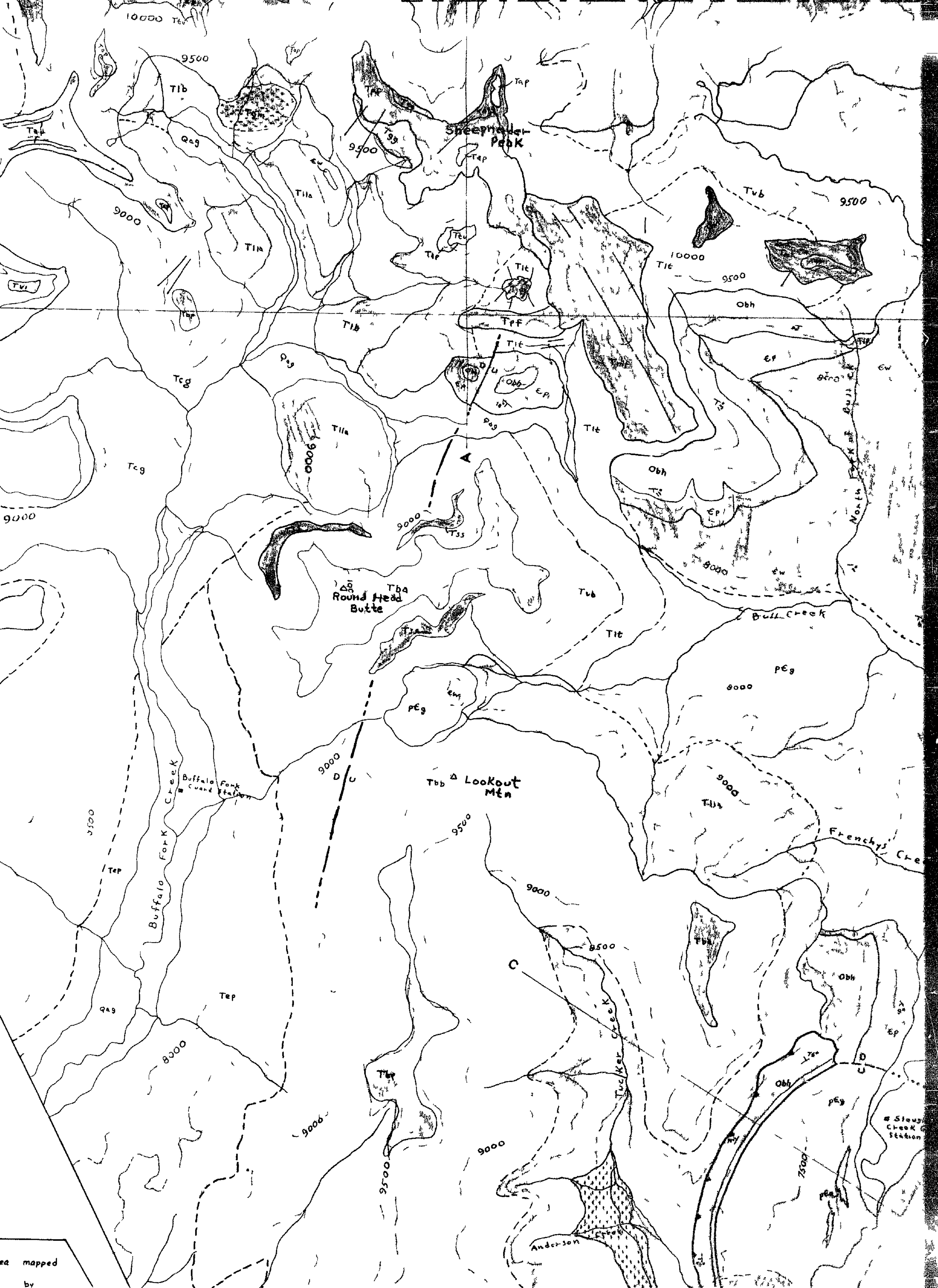
18°
Strike and dip of beds

General layering
in volcanic rocks

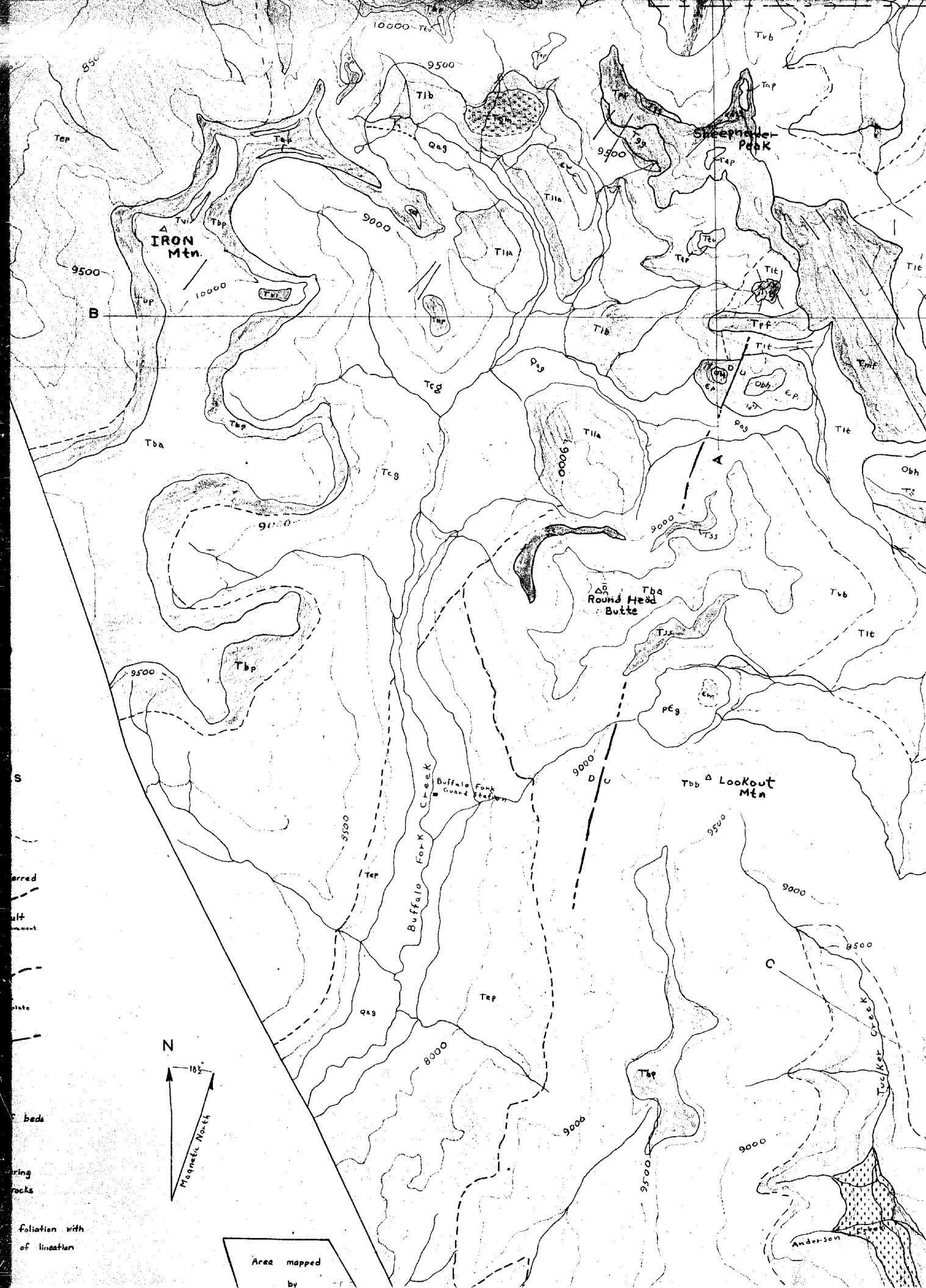
40° 70°
Strike and dip of foliation with
bearing and plunge of lineation

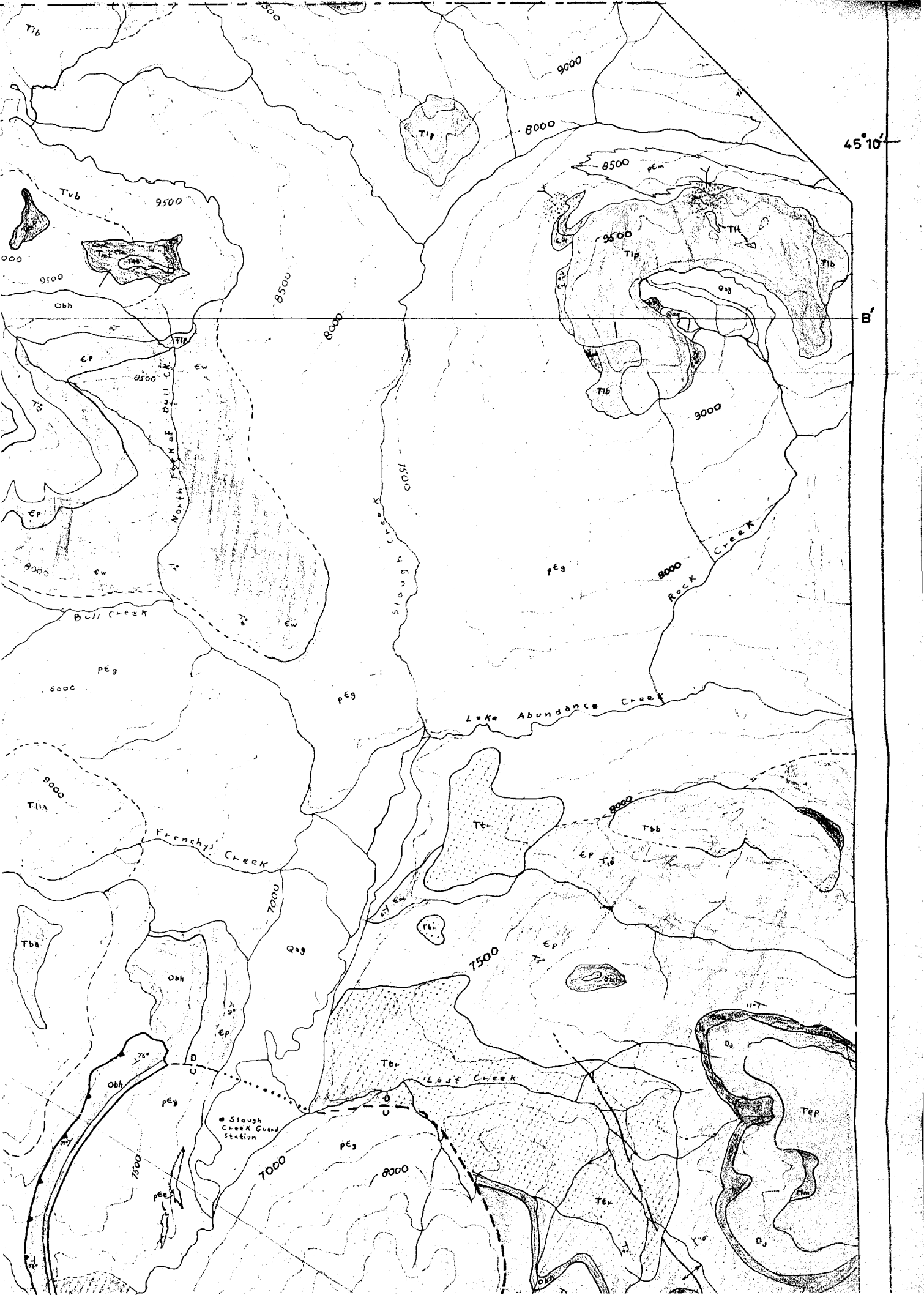
N
18½
Magnetic North

A



Sheepeater Peak
Round Head Butte
Lookout Mtn
Buffalo Fork Creek
Buffalo Fork Guard Station
Bull Creek
North Fork of Bull Creek
Frenchys' Creek
Tucker Creek
Anderson Creek
Slough Creek Guard Station
Tlb
Qag
Tlla
Tcg
Tap
Tgg
Tlt
Tpf
Tvb
Obh
Tep
Tba
Tbb
Tss
pЄg
Єw
Єp
D U
A
C
D
10000
9500
9000
8500
8000
7500
Area mapped by


IRON Mtn.
Sheepmaker Peak
Round Head Butte
Lookout Mtn
Buffalo Fork Guard Station
Buffalo Fork Creek
Tucker Creek
Anderson
B
C
N
18½°
Magnetic North
Area mapped by
Tep
Tbp
Tba
Tcg
Tvb
Tlt
Tlla
Tllb
Tpf
Tsp
Tsg
Tvl
Teu
Obh
Qag
pEg
9500
9000
10000
8000


45°10'
B'
Tlb
Tlp
Tvb
Tmf
Tmg
Obh
Ep
Ew
pEg
Qag
Tbb
Tbr
Tep
Tlla
Dj
Mm
9500
9000
8500
8000
7500
7000
North Fork of Bull Ck
Bull Creek
Slough Creek
Rock Creek
Lake Abundance Creek
Frenchys Creek
Lost Creek
Slough Creek Guard Station

Strike and dip of beds

General layering in volcanic rocks

40° 70°

Strike and dip of foliation with bearing and plunge of lineation

Zones of strong hydrothermal alteration

Adit

Vertical shaft

Magnet

ORDO-VICIAN

CAMBRIAN

PRECAMBRIAN

UPPER CAMBRIAN

MIDDLE CAMBRIAN

PRE-BELTIAN

Bighorn Formation
massive tan rough weathering dolomitic limestone

UNCONFORMITY

Grove Creek-Snowy Range Formations
limestone flat pebble conglomerate

Pilgrim Formation
light gray limestone

Par[illegible] Formation
[illegible] limestones

Meagher Formation
gray limestones, green shales

Wolsey Formation
dark gray shales some limestone

Flathead Formation
light tan to white medium grained sandstone

UNCONFORMITY

Pegmatites
quartz feldspar pegmatites

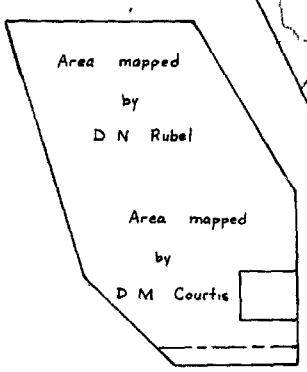
pem

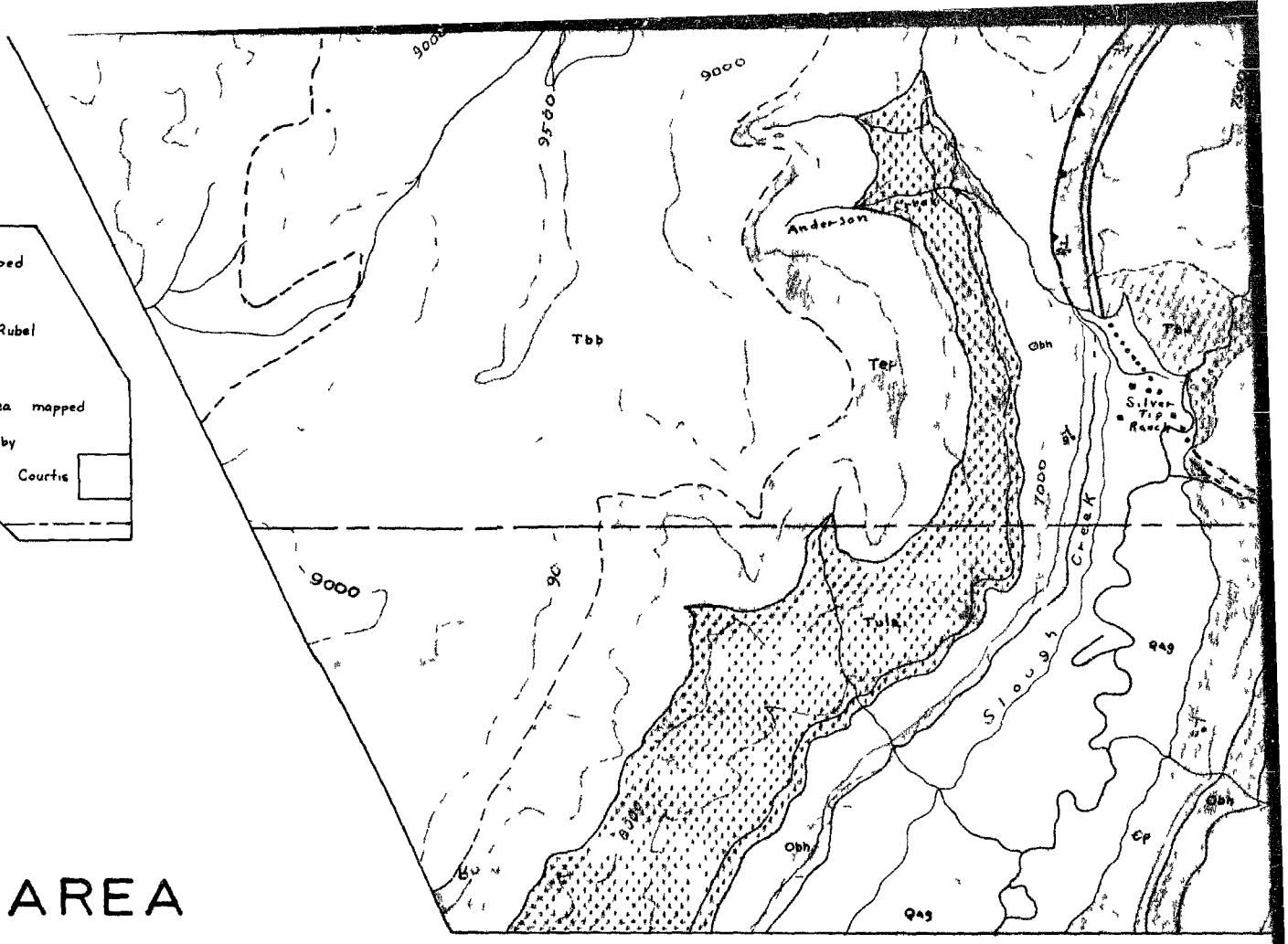
Migmatites
Banded hornblende and biotite migmatites

pmg

Granitic gneiss
Quartz feldspar gneiss and lesser hornblende gneiss and amphibolite

GEOLOGIC M
OF THE INDEPENDEN
SWEET GRASS AND PA
MONTANA





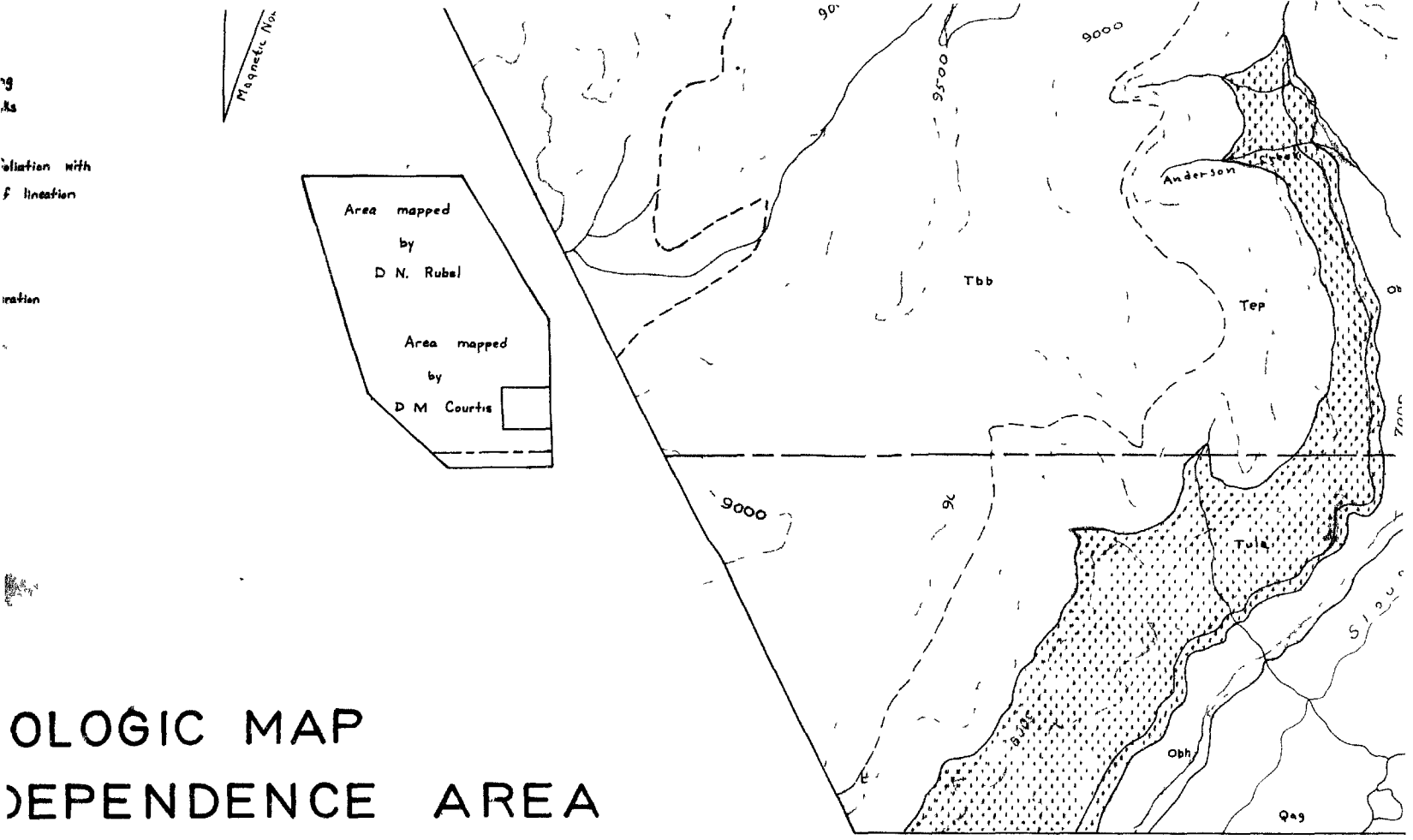
AP
NCE AREA
RK COUNTIES,

Base From USGS Mount Cowan, Mount Wallace, Mount Douglas, and Cutoff Mountain Topographic Sheet

1 ½ 0

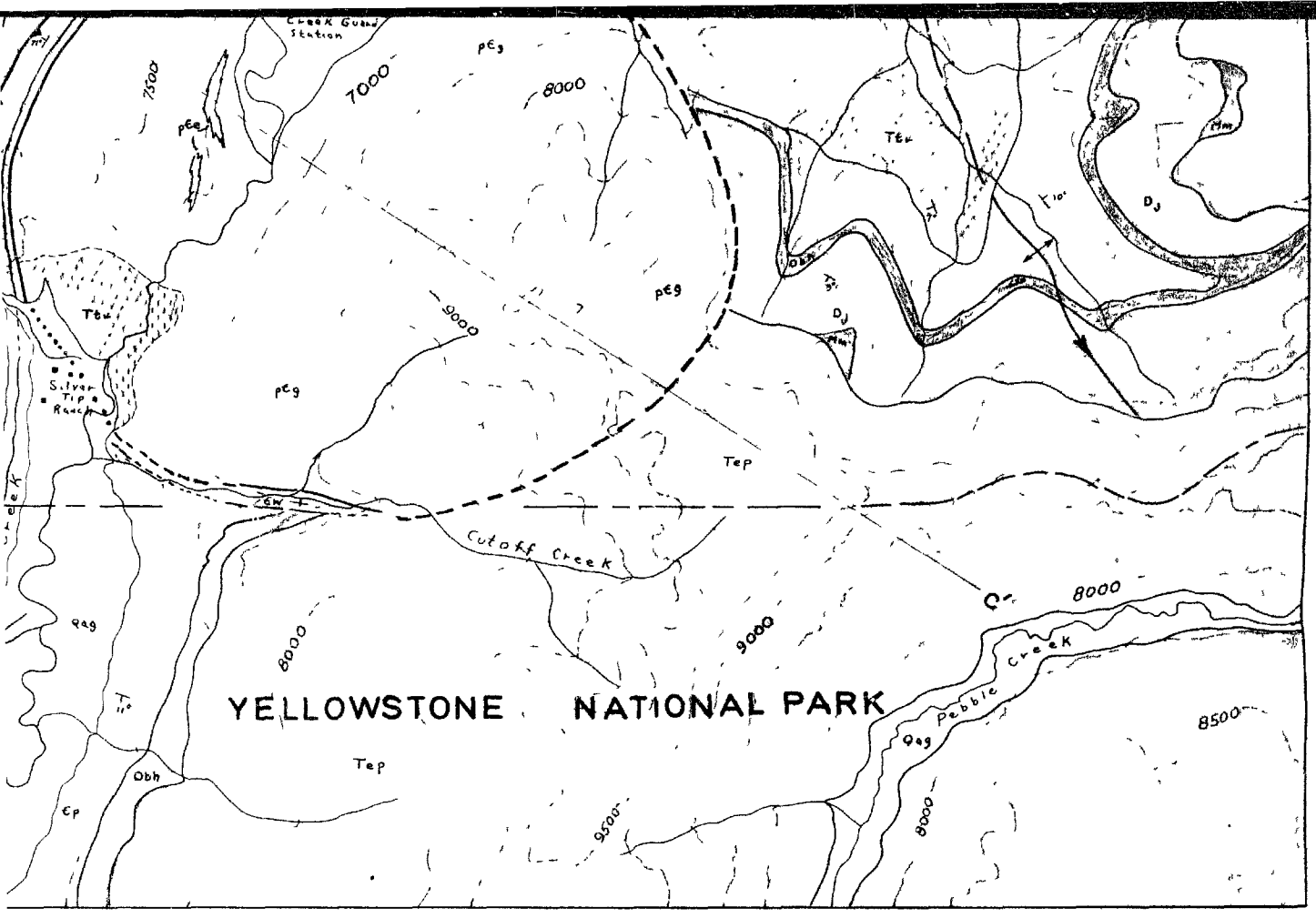
Datu

110° 15'



OLOGIC MAP
DEPENDENCE AREA
S AND PARK COUNTIES, MONTANA

110° 15'



Scale 1/31680

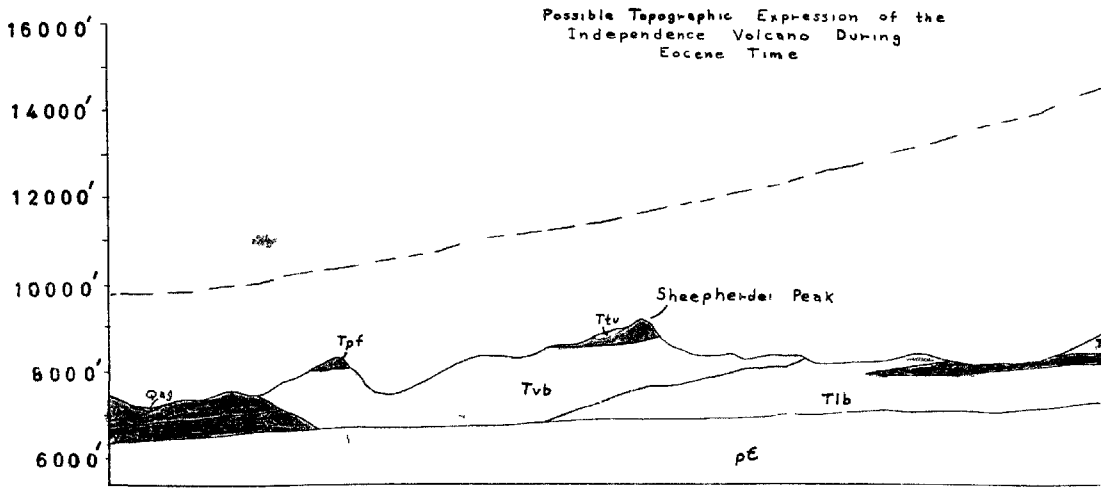
0 1 2 3 Miles

CONTOUR INTERVAL 500 FEET

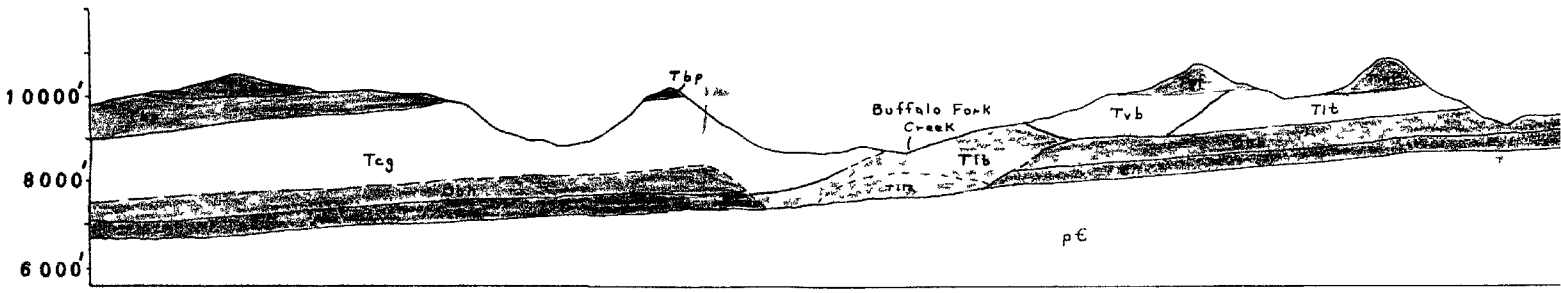
Datum is mean sea level

Geology By D N Rubel, Assisted by F Fisher and M Paradis Mapped during Summers of 1959, 1960, 1961 and 1962

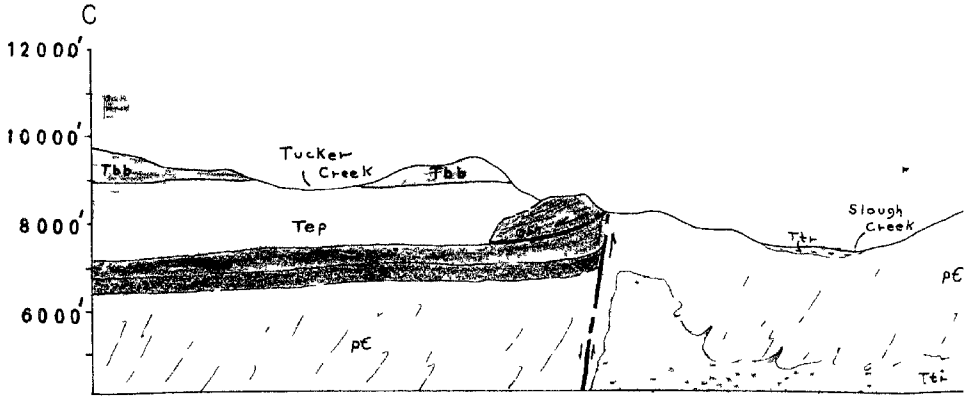
A



B



C



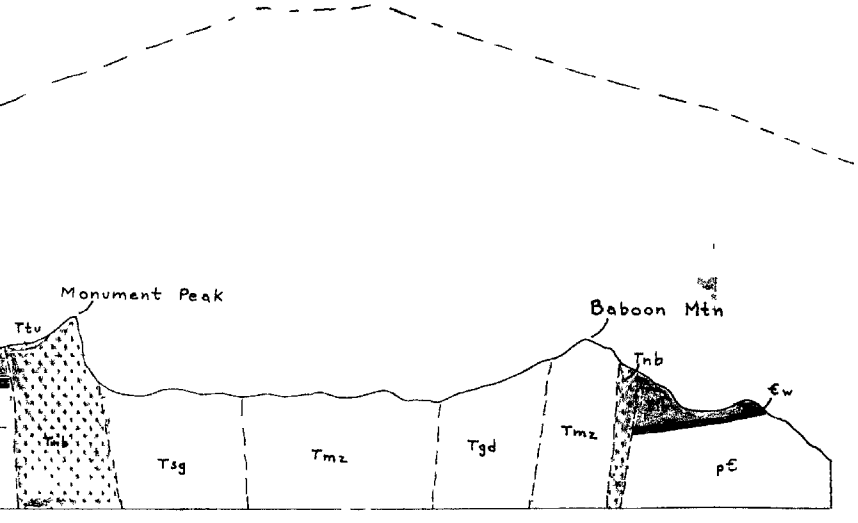
Scale

0 1/2 1

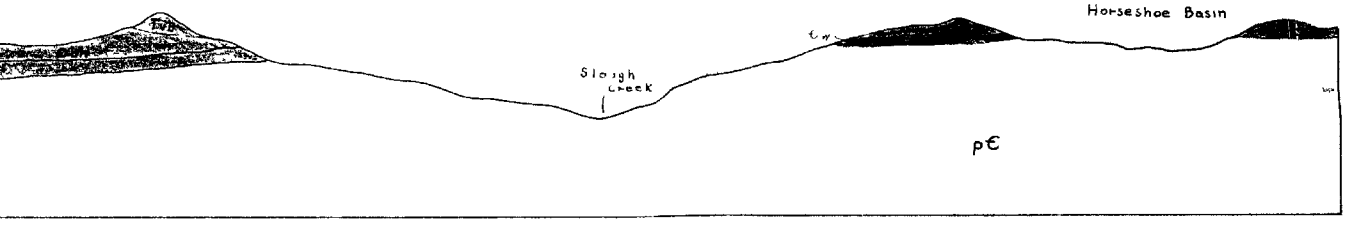
Vertical Sections Not

GEOLOGIC SECTIONS OF
AREA, MO

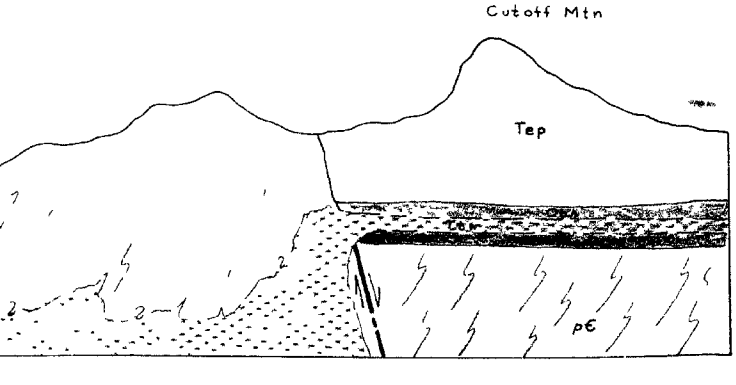
A′



B′



C′



2 miles

aggerated

THE INDEPENDENCE
NTANA