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Geology of the Eocene volcanic sequence Mt. Baldy-Union Peak area central Garnet Range Montana

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GEOLOGY OF THE EOCENE VOLCANIC SEQUENCE,
MT. BALDY - UNION PEAK AREA,
CENTRAL GARNET RANGE,
MONTANA

by

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ABSTRACT

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Geology of the Eocene Volcanic Sequence, Mt. Baldy - Union Peak Area, Central Garnet Range, Montana

Director: Donald W. Hyndman

Eocene (44-49 m.y.) volcanic rocks in the Mt. Baldy - Union Peak area of the central Garnet Range, Montana, occupy an early Tertiary valley which trends NW-SE and opens into the Clark Fork valley. The volcanic stratigraphy includes a basal assemblage of epiclastic/pyroclastic flows, lahars, volcanic sandstones and lacustrine deposits which may mark the advent of volcanism in the map area. A 70 m-thick section of crystal-poor ash-flow tuffs precedes the earliest flows, a bimodal sequence of olivine basalt and rhyolite porphyry. Above these flows are 250 m of porphyritic hornblende-biotite andesites. In the north, these andesites rest directly on the volcaniclastic sediments. Numerous N-S-trending quartz latite dikes intrude the sequence, notably around Union Peak, and appear to represent the last stage of volcanism in the area.

Reconnaissance geology shows that the olivine basalt is the only unit common to the rest of the Garnet Range. The rhyolite porphyry is found up to 15 km to the south and east, but the more intermediate hornblende andesites and quartz latite are confined to the study area. The restricted distribution of the andesites probably indicates that they erupted from a center within the area, possibly immediately north of Mt. Baldy.

A leucite basalt plug forms a small knob 3 km northwest of Bearmouth. The plug appears to have intruded the Paleozoic sedimentary rocks after the Laramide Orogeny, and was then exposed by erosion prior to eruption of the Eocene volcanic rocks.

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CHAPTER I

INTRODUCTION

This study describes the petrography and field relationships of a sequence of Eocene volcanic rocks in the Mt. Baldy - Union Peak area of the central Garnet Range, Montana, and reconstructs the volcanic history from this information. The study area encompasses approximately 45 sq. km northwest of the old town of Bearmouth, 56 km. east of Missoula on Interstate 90 (Figure 1).

Volcanic units mapped include a basal volcaniclastic sequence containing rounded pebbles of a glassy volcanic rock, the extrusion of which pre-dates the volcanic rocks now seen in the area. An ash-flow tuff overlies the sediments, and may be the pyroclastic precursor of later rhyolite porphyry flows. Basalt and a pyroxene andesite cap the southeastern half of the volcanic sequence. North of Mt. Baldy, hornblende andesites overlie the volcaniclastic rocks, and these are intruded by a quartz latite dike swarm that is most evident in the vicinity of Union Peak.

A small leucite basalt plug outcrops north of Bearmouth. It appears to have intruded Paleozoic sediments and was exposed by erosion prior to Eocene volcanism.

Whole rock geochemical analyses of twenty samples from the map area show distinct variations in major element concentrations with increased silica content.

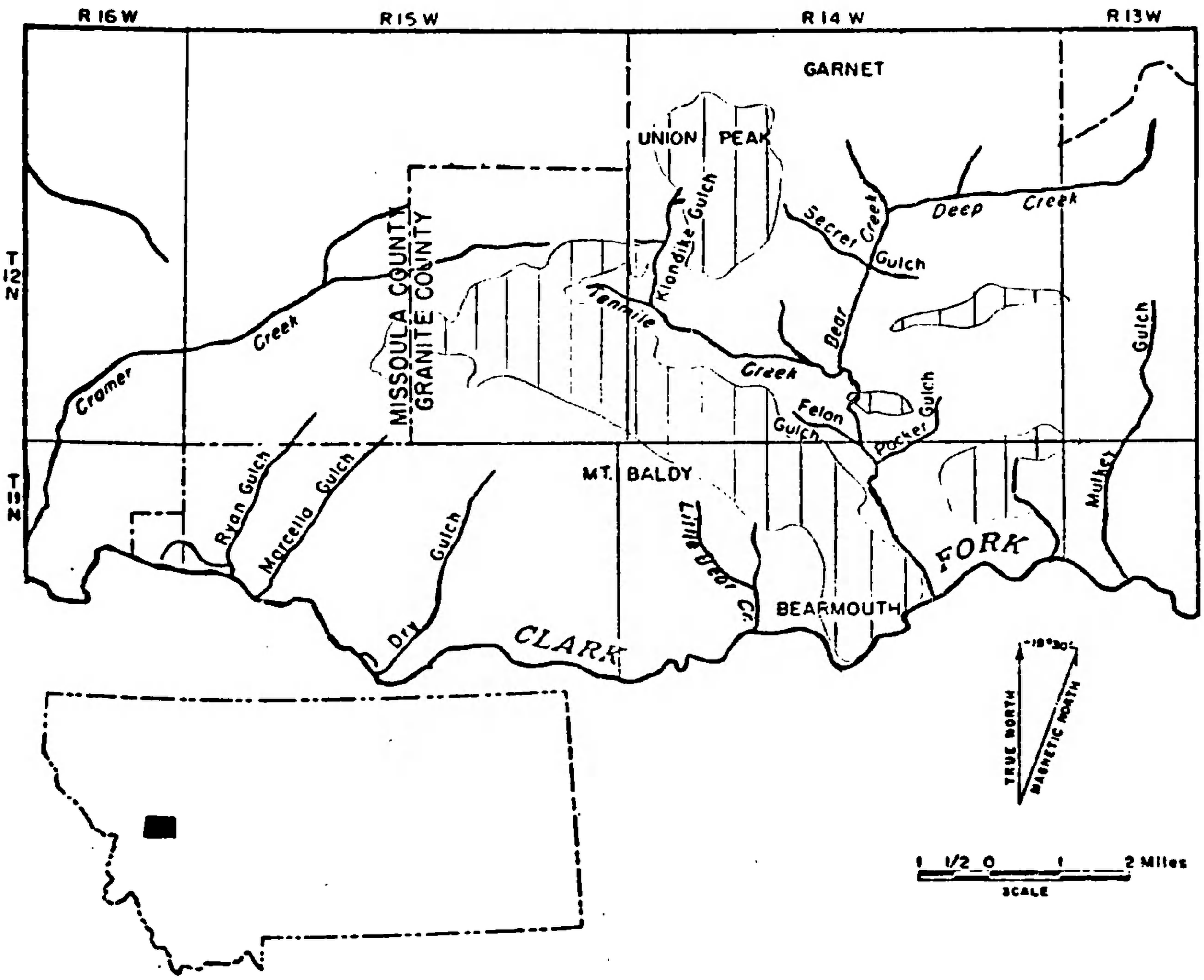

Figure 1. Location map showing Mt. Baldy - Union Peak study area

Geologic Setting

The Garnet Range of west-central Montana is composed of folded and thrust-faulted Precambrian, Paleozoic, and Mesozoic sedimentary rocks (Wallace, 1981). Major structures were formed during the Laramide Orogeny and generally trend N75°W, with tectonic transport in a direction normal to this trend (Kauffman, 1963). Granodiorite stocks and dikes, also associated with orogenic activity, intruded the sedimentary rocks.

The map area lies on the northern edge of the Sapphire Allocthon, a thick 7500 sq. km. section of the crust postulated to have slid eastward as a result of uplift of the Idaho Batholith in the Late Cretaceous (Hyndman et al, 1975). The Bearmouth Thrust Fault, located just south of Mt. Baldy and paralleling the east-west trend of the Clark Fork River (Figure 2), is a segment of the thrust zone which is characteristic of the leading edge of the Sapphire block (Kauffman, 1963; Williams, 1975).

Paleotopography

This study postulates the existence of an early Tertiary paleochannel that trends northwest-southeast at a 45° angle to the Clark Fork River. This paleochannel filled with locally erupted lava, resulting in the present configuration of the volcanic rocks in the map area. Figure 3 is a hypothetical paleotopography map, constructed from elevations of the volcanic-sedimentary rock contact.

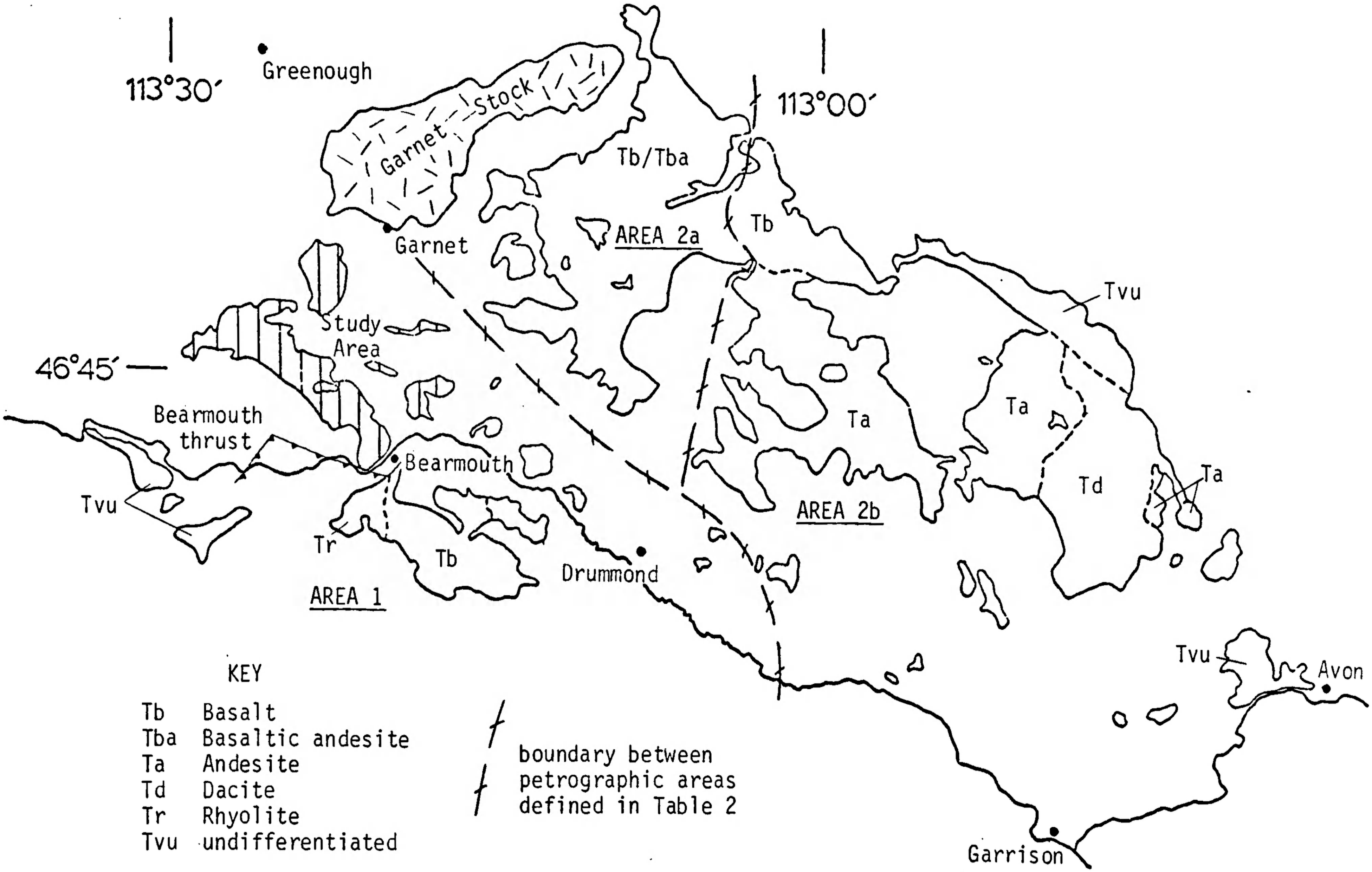

Figure 2. Volcanic geology of the Garnet Range
-boundary between Areas 1 and 2a defines the "topographic divide" of the Garnet Range

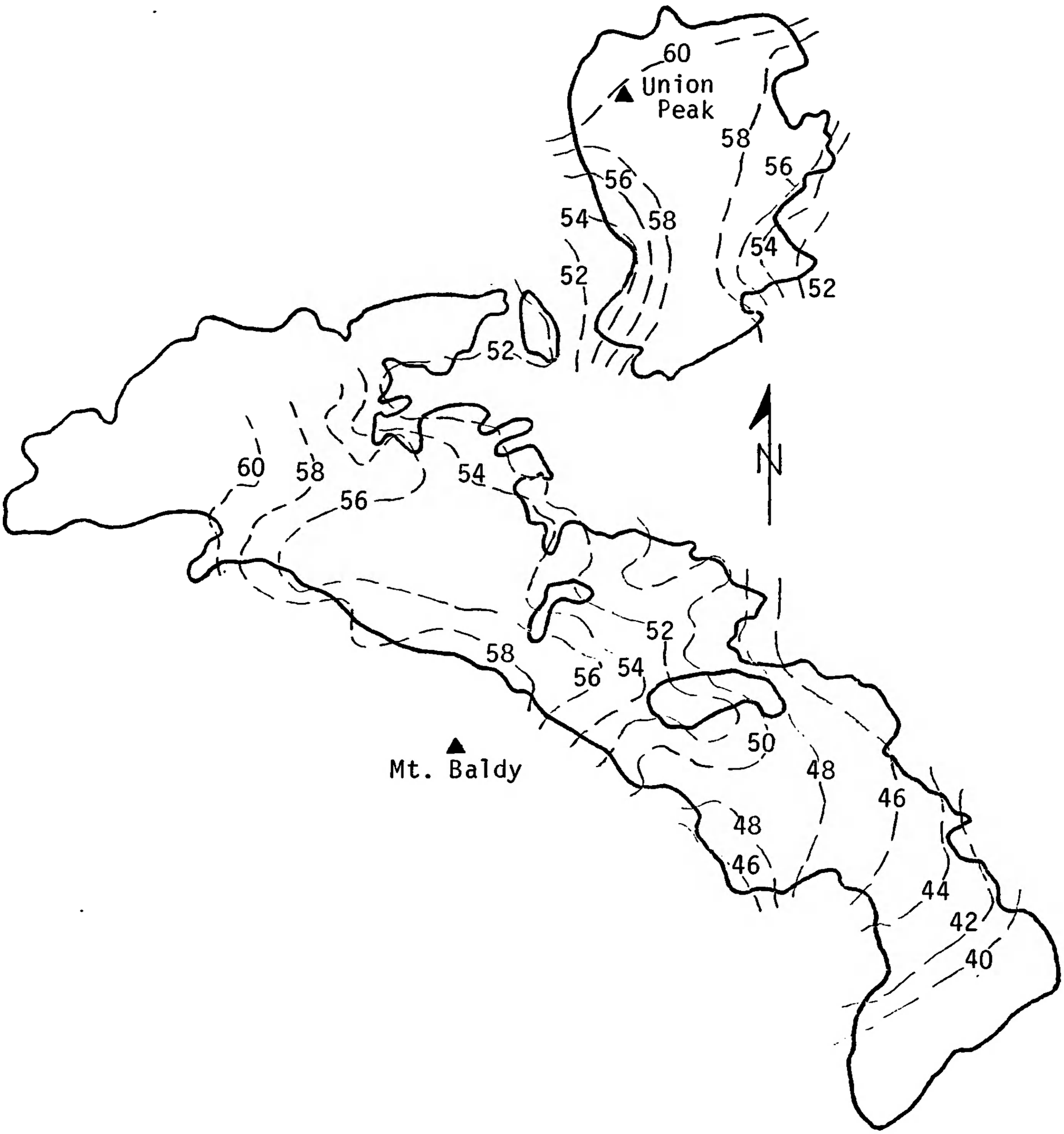

Figure 3. Pre - volcanic topography; map based on intersection of Paleozoic sedimentary rocks and Eocene volcanic rocks (elevations in hundreds of feet above sea level)

Age of the Garnet Range Volcanic Rocks

Potassium-argon ratio determinations of seven samples of the Garnet Range volcanic rocks and one sample of the Garnet Stock granodiorite were compiled during this study (Table 1). Three of the age dates are from rocks within the Mt. Baldy - Union Peak map area. For the volcanic rocks, the age range of 43.7 to 47.7 million years clearly indicates a middle Eocene eruptive sequence. This timing of volcanic activity correlates with the Challis volcanic-plutonic episode in Idaho and with the eruption of voluminous quartz latite flows during Lowland Creek volcanism in west-central Montana (Armstrong, 1974; Smedes and Thomas, 1965).

Volcanic Geology of the Garnet Range

Volcanic rocks of the Garnet Range have received only cursory examination during reconnaissance geologic mapping of the area. However, recent work by Mejstrick (1982, unpubl.) and others allows for comparisons between this detailed study and the remainder of the Garnet Range volcanic rocks. The Mt. Baldy - Union Peak area is anomalous in that it contains several units found nowhere else in the Garnet Range. A brief description of the rocks is found in Table 2.

Poor exposure complicates the determination of spatial relationships of the volcanic rocks, both in the Mt. Baldy - Union Peak area and in the Garnet Range as a whole. For purposes of comparison they have been grouped into three lithologic packages, with Area 1 including the Mt. Baldy - Union Peak rocks, and Areas 2a and 2b representing further

TABLE 1: Age Dates From Volcanic Rocks Of The Garnet Range*

ROCK TYPE	AGE	MINERALS DATED	LOCATION	REFERENCE
Latite porphyry flow [1]	43.7 ± 2.2 my	K-Ar - whole rock	Sec. 23, T. 11 N, R. 10 W	T. Collmeyer (1982)
Rhyolite porphyry flow [2]	44.5 ± 2.0 my	K-Ar - sanidine	Sec. 21, T. 11 N, R. 14 W	T. Williams (p. 63, 1975)
Andesite flow (glassy) [1]	44.8 ± 2.2 my	K-Ar - whole rock	Sec. 23, T. 11 N, R. 10 W	T. Collmeyer (1982)
Olivine basalt flow [3]	44.9 ± 2.0 my	K-Ar - whole rock	Sec. 14, T. 11 N, R. 14 W	T. Williams (p. 63, 1975)
Olivine basalt flow [3]	46.7 ± 2.5 my	K-Ar - whole rock	Sec. 22, T. 11 N, R. 13 W	T. Williams (p. 64, 1975)
Latite porphyry flow [1]	47.0 ± 2.7 my	K-Ar - plagioclase	Sec. 31, T. 11 N, R. 9 W	T. Collmeyer (1982)
Latite porphyry flow [4]	47.4 ± 1.6 my	K-Ar - biotite	Sec. 7, T. 12 N, R. 14 W	P. Mejstrick (pers. comm., 1982)
Granodiorite	78.7 ± 3.9 my	K-Ar - biotite	Garnet Stock	P. Mejstrick (pers. comm., 1982)

1) Area 2b
2) Area 1; Unit Tr
3) Area 1; Unit Tb
4) Area 1; Unit Tlf

* see Tables 2 and 3 for lithologic distinctions and volcanic stratigraphy

Table 2. AREA 1

Mt. Baldy - Union Peak and the volcanic rocks southwest of the "Garnet divide"

Andesite	- porphyritic hornblende andesite flows - biotite, pyroxene, plagioclase, hornblende phenocrysts - local porphyritic hornblende andesite dikes - basal subporphyritic hornblende andesite flow
Basalt	- subporphyritic olivine basalt - relatively thin flows - spatially associated with rhyolite porphyry
Light-colored intermediate volcanic rock	- porphyritic gray latite dikes - biotite, pyroxene, plagioclase phenocrysts - local latite porphyry flows
Rhyolite	- rhyolite porphyry - quartz, sanidine phenocrysts - crystal tuff (?)
Ash-flow tuff	- crystal-vitric ash-flow(s) - poorly welded - ± air-fall deposits
Volcaniclastic rocks	- epiclastic ± pyroclastic flows and lahars - local thinly interbedded fluvial and lacustrine deposits

Table 2 (cont.). AREA 2

Northeast of the "Garnet divide"

	2a	2b
Andesite	- subporphyritic basaltic andesite gradational to basalt - local hornblende and/or pyroxene andesite flows	- glassy pyroxene andesite flows
Basalt	- porphyritic olivine basalt - greater %age olivine than Area 1 basalts - commonly brecciated and vesicular or frothy - local cinder cones	- porphyritic "feldspar" basalt - less olivine than Area 2a basalts - no associated basaltic andesites
Light-colored intermediate volcanic rock	- local flows similar in appearance to Area 1 latite dikes	- dacite porphyry flows with varied appearance - generally pink to reddish to dark glassy green with biotite, pyroxene, feldspar phenocrysts
Rhyolite	- none	- none
Ash-flow tuff	- none	- dacite porphyry crystal tuff (?)
Volcaniclastic rocks	- local basalt bombs and ejecta	- rare

divisions of the basalt - basaltic andesite - andesite - dacite sequence of the eastern Garnet Range. The division between areas 1 and 2a/2b can be drawn along the current topographic divide of the Garnet Range. Although this may be coincidence, and has no observable petrographic importance, it provides strong permissive evidence for the existence of an equivalent topographic boundary during Eocene time (Figure 2).

Throughout the range, the volcanic rocks generally consist of thin, scattered patches of discrete lithologies. Areal percentages include:

45% basalts or basaltic andesites

35% porphyritic to glassy andesites

15% porphyritic latite or intermediate volcanic rocks

5% porphyritic rhyolite

There are local patches of vesicular, brecciated and/or amygdaloidal basalts/basaltic andesites which are associated with cinder cones, notably in the Wild Horse Parks quadrangle (Mejstrick, pers. comm., 1982). Otherwise, the following field evidence suggests that the rocks were primarily erupted from fissures:

1) The flows are nowhere thicker than 250 meters, and often much less.
2) Thin units cover large areas, as in homogenous, massive basalt flows that can be traced for over three kilometers.
3) There is no discernible center of volcanism.
4) There is a paucity of pyroclastic rocks and general lack of explosive features in felsic units.
5) The different lithologies in the Garnet Range are rarely intercalated.

6) The observed conduits are commonly dikes, with some approaching 2 kilometers in length.

Despite the petrographic distinctions between the areas detailed in Table 2, their coincidence in time and space indicates a single Eocene volcanic episode in the central Garnet Range. Rhyolite and latite ash-flow tuffs and tuff breccias of much lesser extent erupted in the eastern half (Area 2b) of the Garnet Range during Late Oligocene to Early Miocene time (P. Mejstrick, pers. comm., 1982).

CHAPTER II

DESCRIPTIONS OF MAP UNITS

Leucite Basalt (KTap)

A 600 m wide plug of leucite basalt occurs 3 km north of Bearmouth, on the west side of Bear Creek. It is surrounded by the Eocene volcanic rocks, and forms a distinct knob, easily seen from Interstate 90 (Figure 4). Talus and ground cover obscure the periphery of the plug, but the remainder is well exposed. Outcrops at the top of the knob have a consistent foliation that strikes N10°E and dips approximately 75°SE.

In hand specimen the rock has a black granular groundmass containing abundant biotite phenocrysts to 3mm in size and local clinopyroxene xenocrysts(?). The groundmass varies from very fine-grained to medium-grained, generally increasing toward the center of the plug. Thin section examination showed a phaneritic texture of poikilitic anhedra of reddish-brown biotite, blades of clinopyroxene up to 1mm in length, and equant grains of leucite to 0.4mm in diameter. Subequal amounts of leucite and clinopyroxene comprise 85 percent of the rock. Numerous grains of Fe-oxides infuse the biotite, and local grains of plagioclase are found (Figure 5).

The plug does not appear to intrude the volcanic rocks that surround it, as the volcanic rocks show no alteration, brecciation, or any other evidence of intrusion. No included fragments of the volcanic rocks were observed in the plug. It appears that the plug intruded the sedimentary rocks and was denuded by erosion prior to eruption of the lava flows.

Figure 4. Leucite basalt plug as seen from the vicinity of Interstate 90

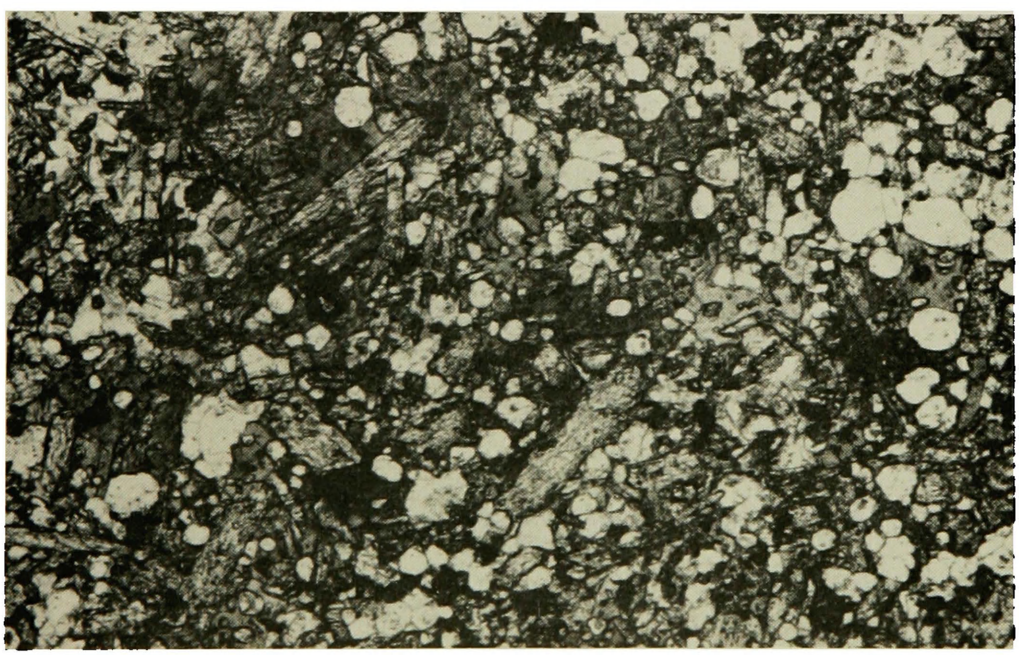

Figure 5. Photomicrograph of leucite basalt (X 12.5). Tabular, hi relief grains are pyroxene; colorless, equant grains are leucite; dark, lo relief grains are biotite

Volcaniclastic Rocks (Tvc)

Roadcuts expose a texturally and lithologically diverse section of tuffaceous sandstones, epiclastic tuff breccias and lahars, lithic-rich ash-flows, and laccustrine deposits. These rocks are generally confined to a 1 km wide band south of and paralleling Cramer Creek and to the Union Peak area, where they reach a maximum thickness of 250 m. Small patches are found as far south as Little Bear Creek. The unit is poorly indurated due to its originally unlithified nature and the devitrification of glass, and its full extent is often masked by ground cover, where subcrop leaves a white gritty soil.

In roadcuts the rocks display wide textural and compositional variability but, with few exceptions, have a chalky, white to light gray matrix of clay and devitrifying pumice fragments and glass shards. There is a crude but distinct bedding between units of different grain size and origin. Beds range in thickness from 1cm to 3m, and are laterally continuous throughout a given exposure. The rocks have been lumped into four categories: (1) epiclastic tuff breccias and lahars, (2) lithic fragment-rich ash-flows, (3) volcanic sandstones, and (4) lacustrine deposits. No stratigraphic relationships are implied by this classification.

Epiclastic tuff breccias and lahars. Poorly sorted, massive, matrix-supported conglomerates compose the majority of the volcaniclastic rocks (Figure 6). Clasts include a pervasive, sub-angular, biotite-plagioclase ash-flow tuff, sub-rounded gray to light red glassy biotite-plagioclase volcanic pebbles, and rounded to sub-rounded pebbles of the

Paleozoic rocks. Most are 1 cm or less in size, but Paleozoic boulders to 1 m are seen in this unit at the base of Union Peak. These clasts probably accumulated when the mudflows, seeking topographic lows, picked up stream material.

Up-section, there are fewer sedimentary cobbles and the ash-flow tuff fragments predominate. Crystals of plagioclase, biotite, hornblende, pyroxene, quartz, sanidine, magnetite, and apatite fill the interstices between the larger clasts. Most crystals are broken and biotite flakes are bent. The matrix material is a very fine-grained, grungy, low-birefringent material, possibly representing volcanic ash and dust altering to clay. Carbonates commonly infuse the groundmass. Field and petrographic evidence supporting a mudflow instead of a pyroclastic origin for most of these rocks includes:

1) Lamination and vertical size grading are absent, and would probably be present in an air-fall tuff.
2) Fresh or devitrified pumice or volcanic glass is generally absent. Such fragile components would not be expected to persist in reworked deposits, and are common components in pyroclastic sequences.
3) Welding or resorption phenomena along grain boundaries is absent.
4) Thin sections display a swirled matrix structure typical of matrix-rich epiclastic breccias deposited by mudflows.
5) No flattening of particles or planar orientation of clasts was observed.

(Gwinn and Mutch, 1965)

The most likely origin for these volcanic conglomerates is deposition as a volcanic mudflow, or lahar. Mechanical action would round fragments of included volcanic material as well as collecting surface debris, and account for the breakage of crystals in the flow. Kauffman (1964) reports the presence of charred wood fragments in volcanic sediments south of Cramer Creek, which would indicate relatively high temperatures for some of the mud-flows.

Lithic fragment-rich ash-flows. A very few conglomeratic lenses in the volcaniclastic rocks show evidence of having been deposited as pyroclastic flows. Although not obvious in hand specimen, resorbed plagioclase phenocrysts and pumice shards seen in thin section, as well as angular accessory volcanic fragments, seem to indicate a pyroclastic origin. Abundant sub-rounded volcanic and sedimentary clasts would have been derived from the surface over which the flow passed.

Volcanic sandstones. This sub-unit appears gradational from the volcanic mudflows, exhibiting more distinct bedding, greater sorting of clast-sizes between layers, and a consistent sand-sized fraction. Beds range from a few millimeters to 1 m in thickness. They are light gray to white on a fresh surface, and contain 1mm clasts of rounded to sub-rounded volcanic fragments and phenocrysts. The matrix is a white chalky material that is predominantly clay, and the rock as a whole is grain-supported (Figure 6). The consistency of grain size, degree of rounding, lack of matrix support and more pronounced bedding of this unit suggest more thoroughly reworked deposits of volcanic material, probably derived from the surface of the lahars. However, the general absence of

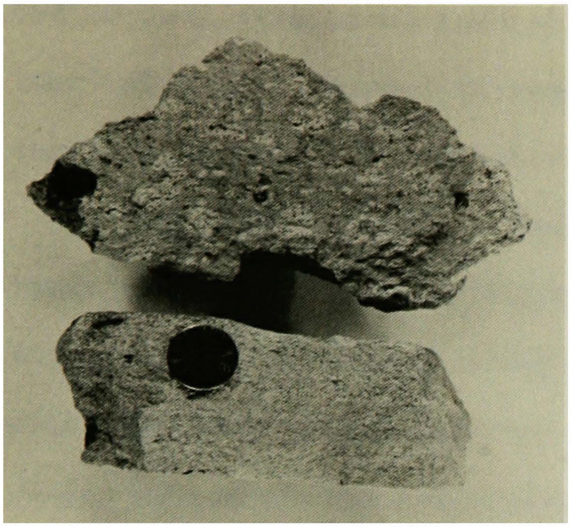

Figure 6. Volcaniclastic sandstone (bottom) and lahar (top)

Figure 7. Roadcut showing volcaniclastic rocks overlain by ash-flow tuff

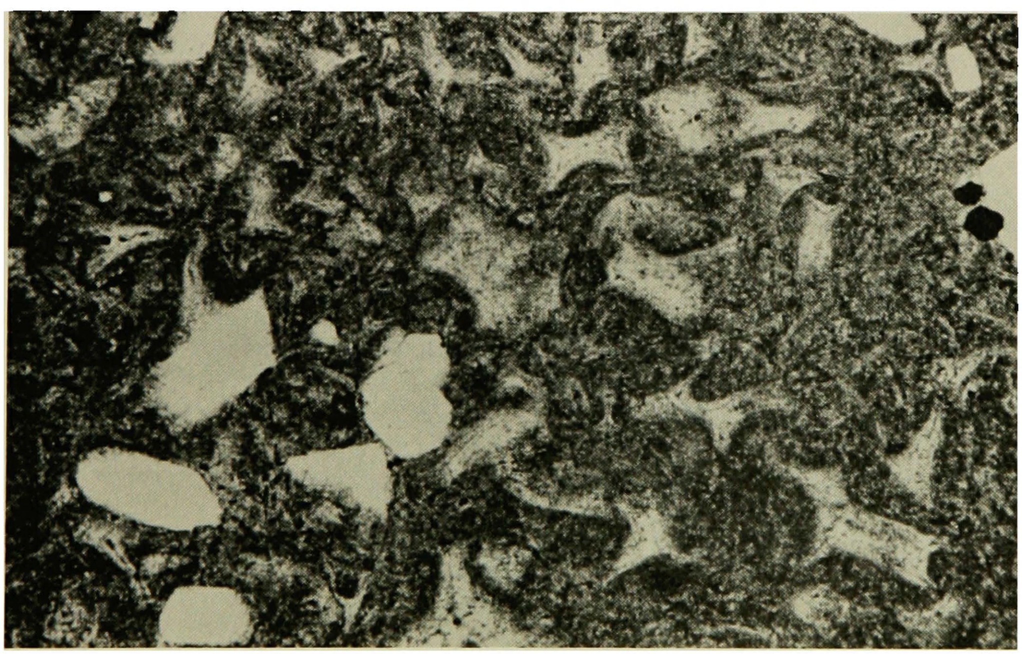

Figure 8. Photomicrograph of ash-flow tuff (X 10) showing colorless plagioclase phenocrysts and vitroclastic groundmass with disseminated Fe-oxides

sedimentary structures such as sorting, scour features, laminar cross-beds, imbrication, or channeling argue against a purely fluvial environment. The flat surfaces of the lahars may have been more prone to sheetwash.

Lacustrine deposits. Small lenticular(?) beds of thinly laminated lacustrine deposits are interspersed throughout the volcaniclastic section. These range from ashy claystone to relatively fissle carbonaceous sediments with indistinct plant fossils. Numerous pelecypods are present in one series of beds. These deposits undoubtedly represent minor hiatuses in the volcanic activity that produced the bulk of the unit.

The volcaniclastic rocks as a whole represent predominantly volcanic material that has been reworked by epigene geomorphic processes (Fisher, 1960) and deposited in low areas where they remained protected from further erosion. The textural and compositional variability of the unit appears to indicate a high degree of local source control.

Ash-flow Tuff (Tft)

The basal volcaniclastic sequence is followed by crystal-vitric ash-flow tuffs, which locally cap the volcaniclastic rocks, but more commonly rest on the Paleozoic bedrock (Figure 7). The most extensive exposures of this unit are found east of Mt. Baldy, between Felan Gulch and Little Bear Creek. The tuff rarely outcrops, instead forming massive talus piles on ridge tops and in gullies. It is common in the vicinity of Union Peak, where the lack of outcrop and high relief preclude accurate mapping of its extent.

Criteria contributing to its identification as an ash-flow include:

1) The retention of heat has partially welded the abundant glass shards. (Smith, 1960)
2) There is complete lack of sorting (lateral or vertical).
3) Phenocrysts are commonly broken and intruded with glass; biotite grains are commonly oxidized to dark red brown and some show deformation resulting from compaction of the tuffs as they cool and lose gas (McBirney and Williams, p. 163, 1979).
4) Rounded surface debris is often incorporated into the base of the flow.
5) The flow forms a nearly level surface over irregular topography, best seen where the basalt overlies the tuff (Smith, 1960).

The tuff appears similar in composition throughout, with only slight variations in texture, being either glassy or slightly grainy with few phenocrysts. This homogeneity and the paucity of accessory fragments may indicate that the flow is a single cooling unit. It is light buff when fresh, but weathers to light pink or yellow, with local patches oxidized to a brick-red color. These oxidized tuffs are most commonly found adjacent to the quartz latite dikes, the intrusion of which could have heated ground water to a temperature sufficient to oxidize iron in the biotite and magnetite.

The tuffs contain less than 5 percent phenocrysts, including sanidine and plagioclase euhedra to 3 mm and biotite grains to 1.5 mm. Lithic fragments are uncommon, usually consisting of less than 4 mm, sub-rounded clasts of the Paleozoic section. In thin section the tuff has a characteristic vitroclastic groundmass comprised of minute crescent-shaped and crudely triangular glass shards (Figure 8). Degree of welding was determined through comparison with photographs in Ross and Smith (1960) and a slight welding is evident, although devitrification has destroyed much of the original texture. Axiolitic intergrowths of cristobalite and feldspar are common, often spreading outward from shard boundaries or localized in bands along parting planes. Phenocrysts of sanidine and faintly zoned plagioclase ($\sim An_{25}$) are generally embayed and broken or cracked. Biotite grains are very dark red and comprise less than 1 percent of the rock. Trace amounts of magnetite and apatite are found, commonly in the feldspar phenocrysts.

Lapilli-sized pumice fragments are found in a small quarry on County Route 12, where stretched tabular pumice fragments as large as 2 cm occur in a slightly welded ash-flow tuff. These may have resulted from the stretching of vesicles by rising magma during late gas-depleted stages of eruption (McBirney and Williams, 1979, p. 130). Discontinuous slickensides found in this lapilli-tuff are probably related to differential movement during transportation and cooling of the unit (McBirney and Williams, 1979, p. 176).

Several small but prominant outcrops of a tuff-breccia are found three kilometers north of Mt. Baldy, near Ten Mile Creek, and east of Union Peak, at the head of Secret Gulch. In sharp contrast to the unbrecciated material, this breccia is as resistant to erosion as any unit in the map area. In these outcrops, sub-angular fragmented clasts up to 2.5 cm in size are supported in a matrix of feldspar phenocrysts and coarsely comminuted partially welded (?) glass. Although its origin is unclear, the partial resorption of fractured clasts and the introduction of feldspar phenocrysts, which dominate the matrix, indicate that the partially cooled tuff was intruded, perhaps explosively, by a "pulse" of fresh lava.

Rhyolite Porphyry (Tr)

Outcrops of the prophyritic rhyolite are common in the area between Little Bear Creek and Bear Creek, and continue south of the map area for 10 km (Maxwell, 1965). North of the Clark Fork River the unit is 200 m thick, but it thins to less than 30 m to the south and east. Contact between the ash-flow tuff and the stratigraphically higher olivine basalt, seen in a roadcut in Little Bear Creek, attests to the discontinuous nature of the rhyolite (Figure 9).

The unit has a massive blocky appearance in outcrop, and is pink to gray in color or brick-red where oxidized. Vesicles and flow-banding are uncommon. It is characterized by 1-3mm sub-rounded to angular fragments of bi-pyramidal smoky and clear quartz and euhedral sanidine phenocrysts in a devitrified aphanitic groundmass. Phenocrysts constitute 40 percent of the rock.

Thin section study revealed common axiolitic texture, which locally results in "pseudo" flow-banding as preferential devitirification proceeded along tiny cracks that formed as the flow cooled. Sanidine phenocrysts are weakly zoned and commonly twinned. Ubiquitous fracturing of quartz may have resulted from the inversion of beta-quartz to alpha-quartz as the flow cooled (Blatt et al, 1972). Trace amounts of sphene, biotite, and iron-oxides are present, as well as rare oligoclase(?) phenocrysts (Figure 10).

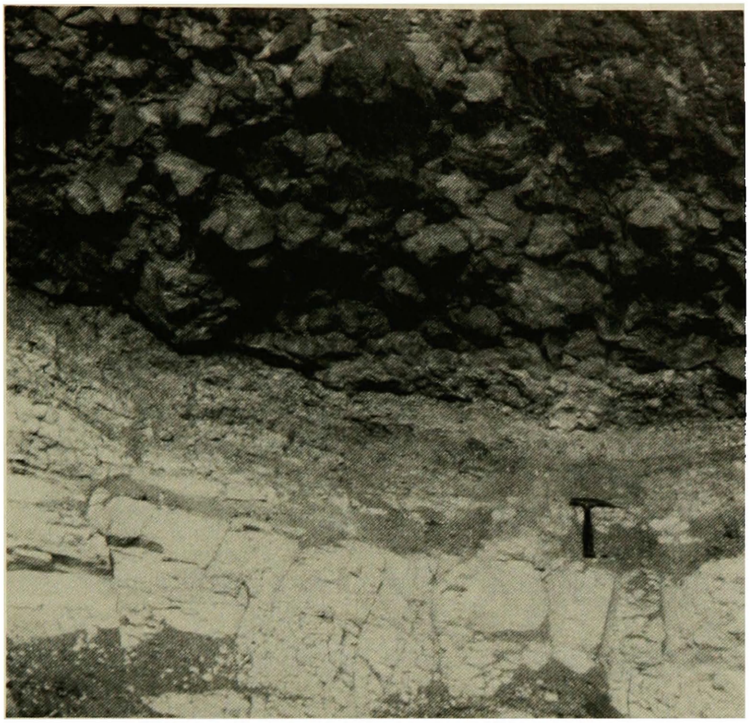

Figure 9. Quarry outcrop showing ash-flow tuff overlain by basalt lahar

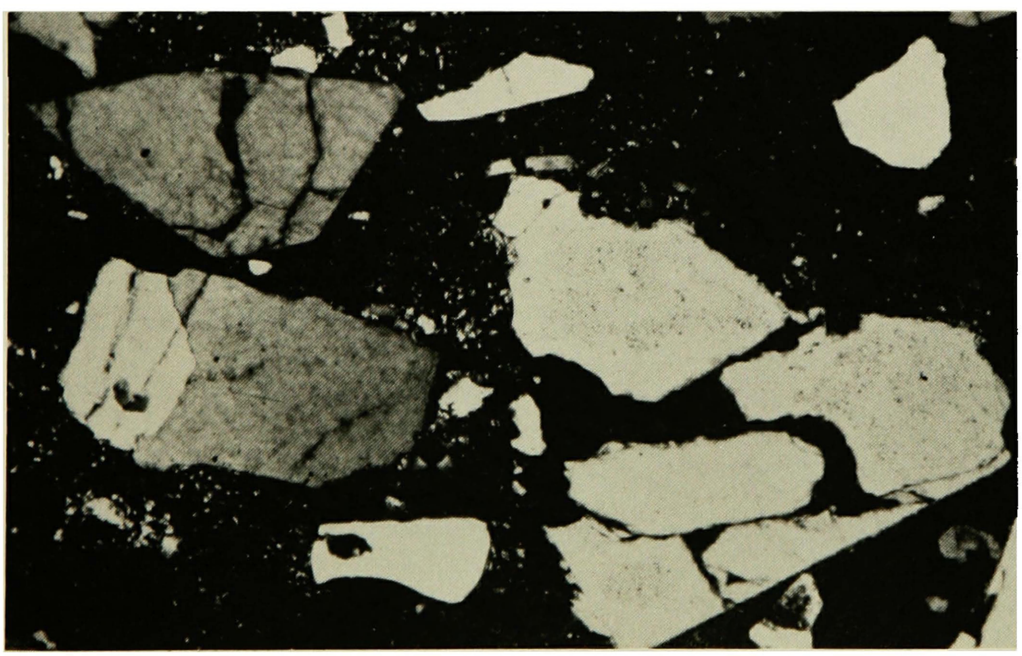

Figure 10. Photomicrograph of rhyolite porphyry (X 12.5) showing fractured quartz and sanidine phenocrysts

The large number of broken phenocrysts in this unit may be indicative of an ignimbrite or ash-flow tuff if they resulted from explosive impacts within the eruptive vent or a high degree of turbulance during movement (McBirney and Williams, 1979, p. 169). Pervasive devitrification has destroyed any evidence of pyroclastic fragments, and deformation of biotite, which would indicate compaction of the glassy matrix as it degassed, is not evident. The unit is thickest at higher elevations, thinning considerably as it drops 300 m in 3 km. A relatively mobile hot ash cloud would presumably thicken towards the lower elevations, whereas the observed pattern would be expected of a thick, viscous flow.

Talus slopes of large, to 2 m, polyhedral blocks occur in a gully south of the leucite basalt plug. These blocks may be related to fracturing of the cooling exposed material as new lava surged beneath it.

Olivine Basalt (Tb)

A subporphyritic olivine basalt is found above the rhyolite porphyry. It forms ridges adjacent to the Clark Fork River, and columnar jointing is evident at a prominent outcrop west of Bearmouth. Except for a small outcrop of relatively coarse-grained basalt characterized by unaltered olivine, which is found northeast of Union Peak, it is rarely found north of Felon Gulch.

Commonly vesicular, the basalt is dark grey to black, and brick-red where frothy. It has a massive, granular speckled appearance, with 0.5 mm grains of plagioclase and relict olivine in an aphanitic matrix. In thin section, the rock has an intergranular texture, with tiny grains of clinopyroxene and magnetite interstitial to crudely laminated plagioclase microlites (An_{70}) and relict olivine euhedra. True olivine comprises less than 1 percent of the rock, with 4 percent olivine pseudomorphs of chlorite, antigorite, Fe-oxides and clay (Augustithis, 1978). Irregular fractures are outlined by the mineraloid iddingsite. Plagioclase microlites constitute 65 percent of the groundmass, with subequal amounts of augite and pigeonite (+2V≈10°). Accessory minerals include Fe-oxides and apatite.

Roadcuts along County Route 12 expose oxidized basalt lahars. The lapilli-tuff found near the Clark Fork River is capped by a mud-flow of rounded basalt cobbles and "palagonite" tuffs (C. Wallace, pers. comm., 1982).

Pyroxene Andesite (Tpa)

On a small ridge immediately south of the leucite basalt plug, a hypersthene-augite andesite flow overlies the rhyolite. It is similar to the basalt, differing only in its lack of iddingsite/antigonite pseudomorphs and the presence of locally common 1-2 mm quartz anhedra. Patches of vesicular, oxidized float were indistinguishable from the basalt.

Outcrops commonly have steep parallel joints which result in thin discontinuous sheets of rock. The joints have variable but high angle dips (>45°) and widely divergent strikes, and may have developed from differential movement of the cooling lava as it filled a gully.

In thin section the rock has a well-developed pilotaxitic texture with 10 percent glomeroporphyritic hypersthene. An equivalent amount of very faint pleochroic green augite occurs as tiny discrete grains, partially resorbed phenocrysts, or reaction rims on the hypersthene. Rare 1 mm plagioclase phenocrysts exhibit pervasive resorption along nearly isotropic zones within the crystal (Pichler and Ziel, 1972; see also Figure 11). Quartz-eyes are rare in thin section but approach 1 percent in outcrop. They are highly resorbed and have indistinct reaction rims of pyroxene. Oriented plagioclase microlites with 1 percent interstial magnetite comprise the remainder of the rock.

This unit commonly outcrops and is remarkably unweathered in thin section. It is possible that the present ridge occupied by the pyroxene andesite represents an inversion of the topography from a gully which was filled with the resistent lava.

Hornblende Andesite (Tha)

This unit rarely outcrops but is distinctive enough to be readily identified in float. It is found at the head of Baldy Gulch, adjacent to a small window of the Paleozoic rocks, near Cramer Creek, where a roadcut exposes the andesite-volcaniclastic contact, and on Union Peak.

The hornblende andesite is pale lavender-gray in color, with sub-lineated hornblende phenocrysts in a grainy, aphanitic groundmass. Vesicles and accidental fragments are scarce but present in all exposures. In thin section, the rock has a pilotaxitic to hyalopilitic texture. Plagioclase microlites comprise 65-75 percent of the rock. Hornblende occurs as tiny 1 mm euhedral phenocrysts that are black in hand specimen, and are pleochroic with Z' = greenish brown and X' = light yellow green. Accessory minerals include apatite, magnetite, and biotite. Hyalopilitic varieties contain as much as 20 percent glass in the groundmass. The flow aligned pilotaxitic andesites contain less glass and the increased orientation may

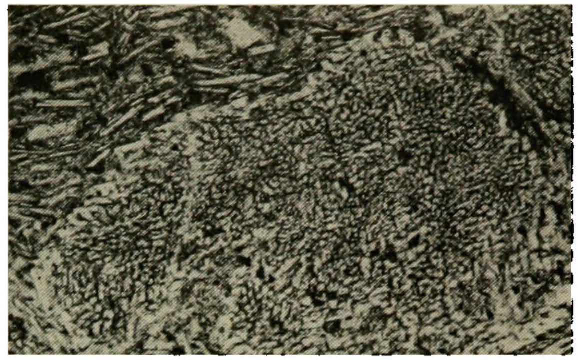

Figure 11. Photomicrograph of geometric pattern of resorption in plagioclase phenocryst (X 40)

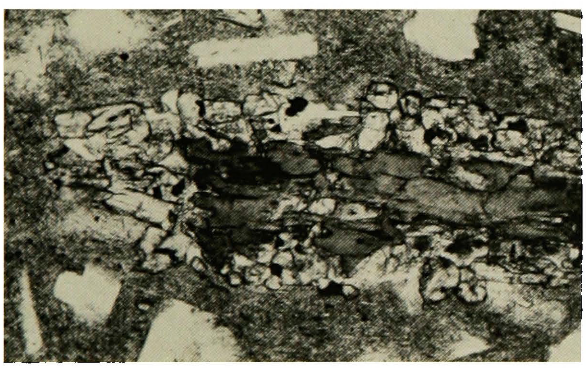

Figure 12. Photomicrograph of hornblende altering to pyroxene and Fe-oxides (X 40)

Figure 13. Photomicrograph of rutilated biotite (X 50)

All photos taken in plain light

indicate that they cooled a greater distance from the source (McBirney and Williams, 1979, p. 179).

North of Dry Gulch, a small outcrop of the subporphyritic hornblende andesite contains 15 percent hornblende in a fine-grained phaneritic matrix. It may represent material that cooled in a dike, although cross-cutting relationships are not exposed.

Porphyritic Biotite - Hornblende Andesite (Tbha)

The porphyritic biotite-hornblende andesite, the most widespread unit in the map area, is found over a 10 km area north of Mt. Baldy. It outcrops locally at ridge tops and in steep-sided gullies. One exception is found south of Baldy Gulch, where a single flow outcrops on a small ridge for 1/2 km. The unit is nowhere capped by the quartz latite that must have erupted from the nearby dike swarm. The contact with the underlying subporphyritic hornblende andesite was mapped on float. That contact appears horizontal, as does most of the flow banding seen in road-cuts. A few dikes of the biotite-hornblende andesite, less than 3 m wide, cut the volcaniclastic rocks.

In outcrop the rock is massive, generally well-jointed, and devoid of accessory fragments. Color varies from dark gray to greenish gray to light gray to brown to brick-red. Glassy varieties are commonly variegated gray and brick-red, apparently by oxidation along fractures. Vesicles are uncommon. The rock has a granular appearance due to the high percentage of plagioclase phenocrysts. Large, to 6 mm biotite phenocrysts that weather to a bronze color are locally common, particularly in the lower levels of the unit, but most phenocrysts are no larger than 3 mm. Weathering of hornblende and plagioclase has left small cavities that commonly fill with secondary minerals having a greenish cast. Fe-stained fractures may enhance flow banding.

Three km north-northwest of Mt. Baldy, a series of 3 cm-wide vertical cracks are filled with a jasperoid material. In the vicinity, lavender-gray glassy andesite contains abundant lineated amygdules of chalcedony.

Thin sections show consistent textures and mineralogy throughout (Figure 12). The rock has a pilotaxitic groundmass, with less common hyalopilitic glassy varieties. Tiny, 0.02 mm, plagioclase microlites may be unoriented in a rock with larger aligned microlites. These were probably too small to be aligned by viscous shear in the flowing lava, or grew to their present size after the lava stopped moving. Phenocrysts average 10 percent plagioclase (An_{27} - An_{36}), less than 1 to 5 percent hornblende, 1-8 percent clinopyroxene, 1 percent biotite, and 0-2 percent hypersthene. The hornblende is commonly rimmed by or completely altered to granular masses of magnetite and clinopyroxene or serpentine-like minerals. Augite ($Z \wedge C = 39°$) is also found as primary interstitial grains and broken, zoned, locally glomeroporphyritic phenocrysts. Hypersthene forms faintly pleochroic pink or yellow subhedral grains. Biotite is pleochroic with Z' = brown and X' = light brown, but is locally oxidized to a dark reddish-brown or yellow. It commonly encloses Fe-oxide grains and may be embayed. Accessory minerals include magnetite, ilmenite, and apatite. Quartz anhedra are rare but constitute 1 percent of some samples.

Distinctive flow features are rarely observed in this unit, probably due to the paucity of outcrop. Laminar flow is common, as are planar fractures that form cracks and joints. The absence of blocky fracturing and autobrecciation may be due to the removal of peripheral features of the flows by erosion. Roadcuts south of Ten Mile Creek exposed "lahar-type" breccias with matrix-supported clasts of sub-angular glassy flow-banded andesite (Parsons, 1969). Weathering of the matrix accentuates the clasts and facilitates identification of the lahars.

Porphyritic Plagioclase-Hornblende Andesite (Tpha)

Several outcrops of hornblende andesite porphyry dikes are found in the dike swarm near Union Peak, and a small patch of float was found south of Felan Gulch, where the rock was apparently intruded into the basalt-rhyolite-ash-flow sequence. Although later than the flows found near Union Peak, crosscutting relationships with respect to the quartz latite dikes are uncertain. Flanking talus slopes prevent observation of the peripheral features of these dikes.

The rock has a distinctive appearance, with abundant 2-5 mm phenocrysts of hornblende and plagioclase, less common biotite and pyroxene, and a massive, fine-grained gray to light brown groundmass. Glassy varieties locally exhibit a banded devitrification pattern. Calcite commonly occurs as a replacement of hornblende and plagioclase(?). Microscopically, the rock has a hyalopilitic to pilotaxitic texture, with up to 10 percent interstitial glass. It contains 70-80 percent plagioclase, as microlites and commonly resorbed and embayed phenocrysts (An_{30} - An_{33}) and 2-4 percent hornblende phenocrysts, which are pleochroic with Z' = brown, Y' = brownish green and X' = light yellow brown. Grains of magnetite and pyroxene locally rim the hornblende (Figure 12). Biotite comprises 1 percent of the rock, is pleochroic with Z' = dark brown and X' = tan and often encloses grains of ilmenite(?) or rutile needles aligned perpendicular to (010) and at 60° intervals (Figure 13) (Deer, Howie and Zussman, p. 209, 1966). These inclusions may have formed as the biotite cooled and lost titanium (B. Bakken, pers. comm., 1982). Accessory minerals include magnetite, apatite, and sphene. Devitrification of glass in the groundmass has rimmed small voids (vesicles?) with axiolitic intergrowths enclosing tiny, .1 mm, recrystallized grains of quartz.

Porphyritic Quartz Latite (Tqlp)

Erosion has exposed a N-S trending subparallel dike swarm that intrudes all of the flows and characteristically outcrops along ridges for up to 1 km. The dikes are most evident in the vicinity of Union Peak, where they intrude a relatively thick section of the volcaniclastic rocks, and dike material forms up to 75 percent of the surface area. Similar intrusive rocks mapped in Lubrecht Forest to the north (Brenner, 1964) and a dacite porphyry (Montgomery, 1958) south of the Clark Fork River may extend this trend.

The porphyritic quartz latite has a distinctive appearance, with subhedral feldspar phenocrysts to 1 cm, small biotite books, and a light gray to gray aphanitic groundmass. Quartz-eyes are common, as are 1-2 mm phenocrysts of hornblende. Small vesicles are locally lined with zeolites(?). In thin section they have a hyalopilitic texture with 65-75 percent groundmass comprised of plagioclase microlites and glass in highly variable ratios. Phenocrysts average 15% plagioclase (An_{25} - An_{32}), 1 percent biotite, 1 percent hornblende, and 0-5 percent embayed quartz anhedra. Accessory minerals include magnetite, apatite, sphene, and the alteration products chlorite and sericite. The biotite is pleochroic, with X' = light yellow brown and Z' = dark brown, and often encloses Fe-oxide grains. The plagioclase phenocrysts are weakly zoned and partially resorbed with incipient melting along nearly isotropic zones within the crystal (Pinchler and Ziel, 1972).

The contact between the quartz latite dikes and the intruded volcaniclastic rocks is commonly marked by a 5-10 cm zone of volcanic conglomerate, with a glassy groundmass containing abundant sub-angular clasts of the Garnet stock granodiorite, Paleozoic sedimentary rocks, crystal-rich ash-flow tuff, and volcaniclastic rocks. Xenocrysts, commonly broken, include clinopyroxene, hornblende, quartz, and slightly zoned plagioclase. These mineral fragments are similar in appearance to components of the granodiorite, and may have resulted from explosive activity as the dike intruded the Garnet stock. Narrow vertical zones of increased vesiculation in the interior of the dikes may have resulted from upward movement of vaporized groundwater along fractures which developed during cooling of the molten rock or from the build up of water during crystallization (Hyndman, pers. comm., 1982).

Latite Porphyry (TlF)

A small flow of crystal-rich latite caps Union Peak where it displays a distinctive "flaggy" morphology. More extensive outcrops of the same unit are found to the northeast at the base of Union Peak. It resembles the quartz latite of the dike swarm in its large, cloudy feldspar phenocrysts and biotite books, but differs in that it contains pyroxene, has a higher percentage of phenocrysts, and weathers to a lavender-gray. It is found as slabs in the float blanketing the Union Peak area.

In thin section the rock has a massive, hyalopilitic texture, with up to 50 percent phenocrysts in a brown devitrified cryptocrystalline groundmass. Broken, angular plagioclase (An_{34} - An_{40}) phenocrysts to 5 mm comprise 35 percent of the rock. 1-3 mm phenocrysts of augite, hornblende with alteration rims of Fe-oxides and carbonate minerals, and biotite altering to Fe-oxides, occur in sub-equal amounts. Local anhedra of serpentine minerals and magnetite appear to be altering from an unknown mineral. Abundant 1 mm irregular cavities in the groundmass probably result from preferential devitrification around vesicles.

The unit was named a crystal-tuff in the field due to the abundance of broken phenocrysts which would result from explosive activity as the rock erupted. However, the high percentage of phenocrysts would increase internal friction in the flow and contribute to fracturing, and the lack of pyroclastic fragments or collapse features argue against it being a tuff. Cross-cutting relationships are unclear.

CHAPTER III

SUMMARY OF VOLCANIC HISTORY

The basal section of volcaniclastic rocks marks the onset of Eocene volcanism in the map area. The rocks represent a gradation in epiclastic-pyroclastic processes, with thick poorly sorted laharic debris flows intercalated with thinner pyroclastic flows and lacustrine deposits. As much as 250 m of the rocks were deposited in a narrow belt trending southwest from Union Peak to south of Cramer Creek. Northwest of Ten Mile Creek, the sharp east-west contact between the Paleozoic rocks and the volcaniclastic section suggests a fault which, if active during volcanism, may have produced a graben-like basin. Within 1 km south of this contact the volcaniclastic rocks dip to the northwest, possibly in response to continued movement along the fault. The lacustrine deposits and volcanic sandstones found throughout the section also suggest a topographic basin.

Rounded clasts of a glassy, biotite-plagioclase volcanic rock and sub-angular fragments of a biotite-feldspar ash-flow tuff are found throughout the volcaniclastic rocks. The clasts of glassy volcanic rock document extrusive activity prior to the formation of these sediments. The sub-angular tuff fragments may indicate that formation of the volcaniclastic rocks was simultaneous with eruption of the ash-flow tuff. Mudflows and sheetwash transported material from the tuff flow to the site of accumulation of the volcaniclastic sediments. Local overlapping of the volcaniclastic rocks by the ash-flow tuff unit continued after deposition of the sediments had ceased (Figure 7).

Erosion incised channels into the volcaniclastic section, as shown by the 150 m difference in elevation along the andesite-volcaniclastic contact south of Cramer Creek.

The ash-flow tuff unit is thickest and most extensive east of Mt. Baldy. The lateral and vertical homogeneity of the unit suggest a single period of eruption. The flow leveled pre-existing topography, incorporating small lithic fragments into its base. As it cooled and became more plastic, joints developed parallel to the direction of movement, partly by contraction, but also by differential rates of internal advance (McBirney and Williams, 1979, p. 176).

Following extrusion of the pyroclastic material, a viscous crystal-rich rhyolite erupted, probably from an area south of Felan Gulch where the unit is thickest (Figure 14). Mapping has shown that most of the unit dips away from this area. The tuff mentioned above may be a pyroclastic precursor of these rhyolite flows, although the spatial relationship between the two units is indistinct at best.

Eruption of the olivine basalt then filled irregularities in the surface of the rhyolite, as much of the basalt is topographically lower than the rhyolite. In some places it directly overlies the ash-flow tuff (Figure 9).

The basalt has the greatest areal extent of any map unit and is found up to 10 km south of the Clark Fork River. It may be contemporaneous with the widespread basalts of the central Garnet Range (P. Mejstrick, pers. comm., 1982). Amygdaloidal basalts and abundant scoria are found at the head of Little Bear Creek, where the unit reaches its highest

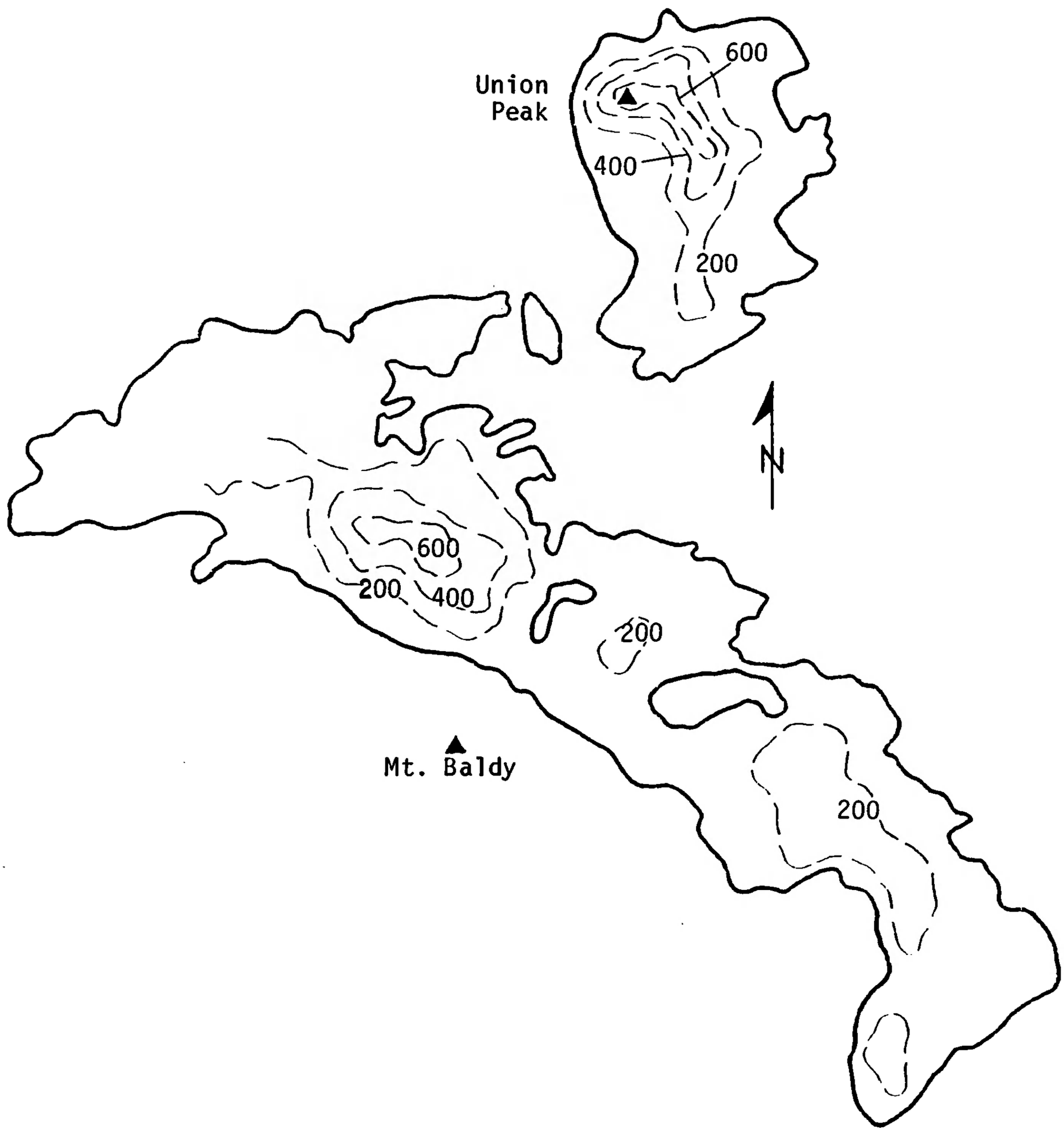

Figure 14. Isopach map of Eocene volcanic rocks of the Mt. Baldy - Union Peak area (in feet)

elevation, but no other evidence of vent facies was found. The concentration of basaltic lahars at the lowest (southeast) end of the map area may have resulted from the channeling of mudflows into an Eocene valley that coincided with the present Clark Fork Valley.

With the exception of the volcaniclastic rocks and small outcrops of the ash-flow tuff, none of the units mentioned above are found north of Mt. Baldy. Consequently, stratigraphic relationships are unclear between these units and the andesite flows which erupted onto the volcaniclastic rocks. The andesite as a whole is topographically higher than the basalt-rhyolite sequence, and a single hornblende andesite dike appears to cut the basalt south of Felan Gulch. Throughout the Garnet Range, andesite and basaltic andesite flows follow eruption of basalt (P. Mejstrick, pers. comm., 1982). For these reasons, I believe the andesite followed eruption of the southeastern basalt-rhyolite sequence.

North and northwest of Mt. Baldy, andesitic volcanism began with the eruption of the thin subporphyritic hornblende andesite. Although discontinuous and of relatively small areal extent, the unit invariably precedes eruption of the voluminous porphyritic andesite. Laminar flow features and a paucity of clasts from the underlying volcaniclastic sediments probably result from a relatively quiescent eruption.

Volcanism continued, producing >300 m of the porphyritic biotite-hornblende andesite flows. The lava was probably extruded from fissures, as evidenced by andesite dikes cutting the Paleozoic and volcaniclastic rocks, the widespread but relatively thin beds, and the lack of voluminous pyroclastic materials. The unit attains its maximum thickness north-northwest of Mt. Baldy, where a small eruptive center may be present

(Figure 12). Andesites in that region are locally glassy, vesicular and amygdaloidal. Small cracks and vesicles are filled with chalcedony, but no brecciation or obvious hydrothermal alteration is seen.

The lack of air-fall deposits associated with this or any other unit, the very minor amount of pumice in the ash-flow tuff, and the predominance of lava flows over pyroclastic deposits may signify a relatively low volatile content for the volcanic system as a whole (Holloway, 1979).

The dikes of porphyritic plagioclase-hornblende andesite are probably associated with the biotite-hornblende andesite flows, but field relationships between the two units are unclear. Their proximity to the numerous quartz latite dikes may indicate a shift in the eruptive center north from Mt. Baldy. The plagioclase-hornblende andesite is compositionally gradational between the andesite flows and latite dikes, perhaps indicating a coincident change in composition.

Many of the quartz latite dikes that cut the layered volcanic rocks now exposed in the map area were probably feeders to stratigraphically higher lava flows which have been removed by erosion. The dikes passed through the volcaniclastic sediments with a minimum of explosive activity, indicating that the sediments were fairly lithified and dry. The dikes graphically illustrate the mode of eruption prevalent in the map area. Local east-west extension(?) created conduits along which lava flowed to the surface. Extrusion of the pyroxene-bearing latite porphyry flow probably preceded most of the lava now seen in the dikes, as it rests directly on the volcaniclastic rocks.

Field relationships show no evidence of volcanic activity in the Mt. Baldy - Union Peak area following intrusion of the quartz latite dikes. Table 3 and Figure 15 summarize the volcanic stratigraphy and age dates of the Mt. Baldy - Union Peak area.

Cross - Sections Showing Field Relationships of Map Units

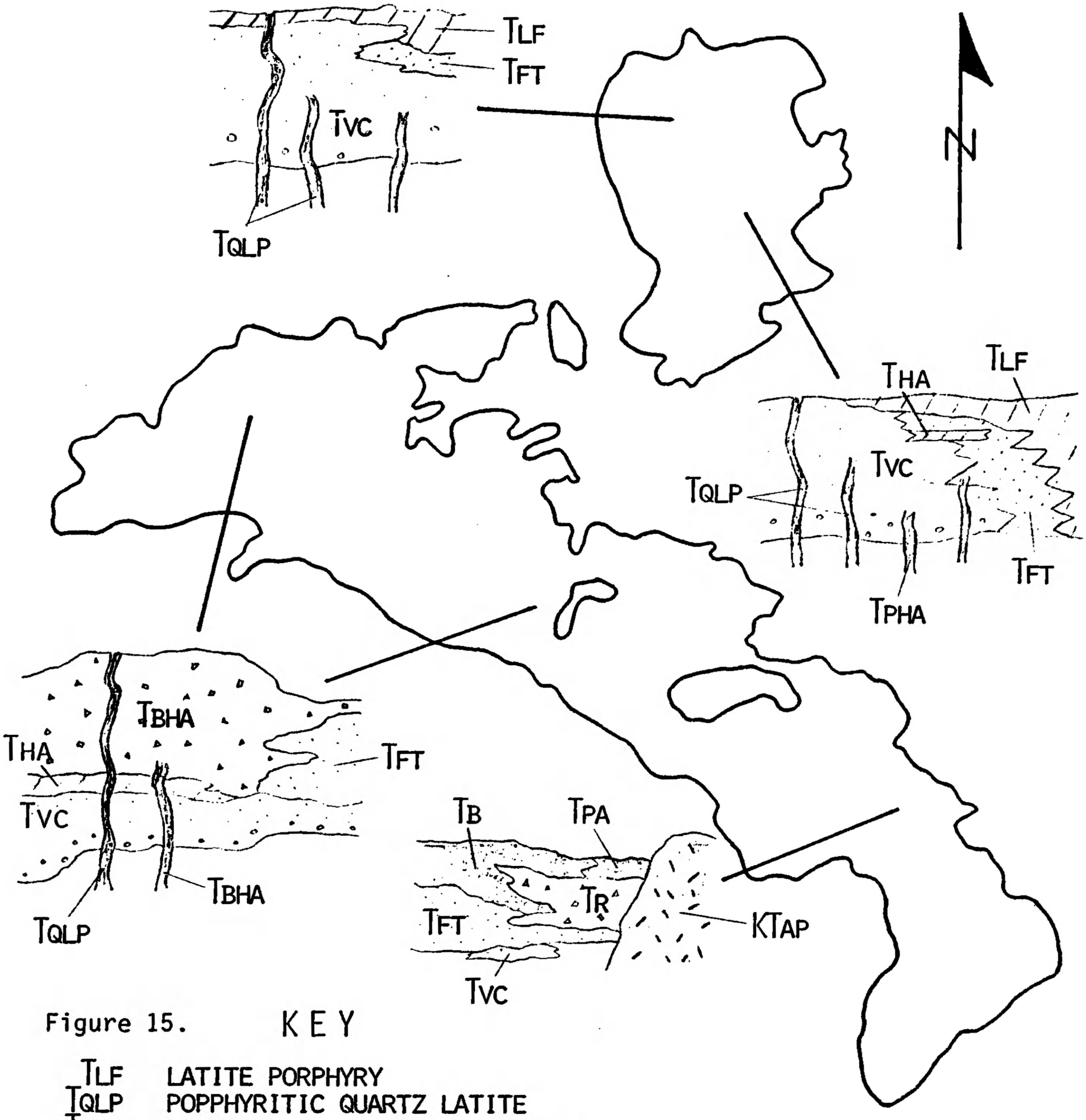

Figure 15. KEY

TLF	LATITE PORPHYRY
TQLP	POPPHYRITIC QUARTZ LATITE
TBHA	PORPHYRITIC BIO - HBL ANDESITE
TPHA	PORPHYRITIC PLAG - HBL ANDESITE
THA	HORNBLENDE ANDESITE
TPA	PYROXENE ANDESITE
TB	OLIVINE BASALT
TR	RHYOLITE PORPHYRY
TFT	ASH - FLOW TUFF
TVC	VOLCANICLASTIC ROCKS
KTAP	ALKALIC PLUG

Table 3.

Unit	Volcanic Stratigraphy	Age Dates
TlF	- caps Union Peak - probably remnant of flows extruded from quartz latite dike swarm	47.4 ± 1.6 m.y.
Tqlp	- N-S-trending dike swarm centered around Union Peak - intrudes every unit in the map area	
Tpha	- isolated dikes in Union Peak area - possible gradation between Tbha unit and Tqlp unit	
Tbha	- restricted to northwestern half of map area - flows thickest immediately north of Mt. Baldy - flows overlie volcaniclastic rocks but topographically higher than bimodal sequence	
Tha	- Thin flow precedes eruption of porphyritic biotite-hornblende andesite	
Tb/Tpa	- possibly related to voluminous basalt - basaltic andesite flows found northeast of the map area - filled irregularities in the rhyolite flows	44.9 ± 2.0 m.y. 46.7 ± 2.5 m.y.
Tr	- viscous flow created irregular topography - crystal tuff(?) - restricted to southeastern half of map area	44.5 ± 2.0 m.y.
Tft	- possibly erupted from area between Bear Creek and Little Bear Creek - flattened pre-existing topography - possibly pyroclastic precursor of the rhyolite porphyry	
Tvc	- contains clasts of pre-map unit volcanic rock - represents a gradation in epiclastic-pyroclastic processes - possibly shed from ash-flow tuff unit.	

CHAPTER IV

CONCLUSION

The Mt. Baldy - Union Peak study area is located on the western edge of the fissure-erupted basalts, basaltic andesite, andesites, and dacites which comprise the middle Eocene volcanic rocks of the Garnet Range. The map area contains a sequence of highly variable lithologies that erupted into an early Tertiary paleochannel that probably drained southeast toward the present town of Bearmouth.

In the southeast half of the map area, eruption of a felsic pyroclastic unit may have shed material to the northwest, where volcaniclastic sediments accumulated in a northeast-southwest-trending valley in the Paleozoic sedimentary rocks. A rhyolite porphyry that overlies the pyroclastic unit probably erupted locally, whereas patches of olivine basalt and pyroxene andesite may have overlapped from a source of voluminous basalt - basaltic andesite flows northeast of the map area (Mejstrick, 1982, pers. comm.).

Volcanic activity at the southeast end of the map area probably ceased after eruption of the felsic sequence. The overlying hornblende andesites are restricted to the northwest half of the map area. They may have originated immediately north of Mt. Baldy, where they are thickest. If so, this shift in the eruptive center was coincident with the change from felsic to intermediate-composition lavas.

The porphyritic plagioclase-hornblende andesite dikes are only found locally but they mark an interesting textural and chemical gradation between the porphyritic biotite-hornblende andesite flows and the quartz latite dikes. Detailed sampling of the andesites for geochemical analysis will be necessary to show trends indicative of magma differentiation.

The quartz latite dike swarm trends north-south and is most evident in the Union Peak area, although it intrudes every volcanic unit in the map area. Work by Brenner (1964) and Montgomery (1958) indicates that similar intrusive units extend out of the map area. This may also be true for the structural environment responsible for the perferred orientation of the dikes. Additional field work is necessary to establish relationships between different map units and their associated eruptive centers.

Distinct linear trends in major-element geochemistry probably result from expected chemical variations in the wide range of rock types. However, the intimate temporal and spatial relationship of the units suggests a common origin.

BIBLIOGRAPHY

Armstrong, R.L., 1974, Geochronometry of the Eocene volcanic-plutonic episode in Idaho: Northwest Geology, v. 3, p. 1-15.

Augustithis, S.S., 1978, Atlas of textural patterns of basalts and their genetic significance: Elsevier Scientific Publishing Co., Amsterdam.

Boyd, F.R., 1961, Welded tuffs and flows in the rhyolite plateau of Yellowstone Park, Wyoming: Geol. Soc. America Bull., v. 72, p. 387-426.

Brenner, R.L., 1964, The geology of the Lubrecht experimental forest, Missoula Co., Montana: Unpublished M.S. Thesis, Univ. of Montana, 90 p.

Chadwick, R.A., 1970, Volcanism in Montana: Northwest Geology, v. 1, p. 1-20.

Deer, W.A., Howie, R.A. and Zussman, J., 1966, An introduction to the rock-forming minerals: Longman Group Ltd., London, 528 p.

Eichelberger, J.C., 1974, Magma contamination within the volcanic pile: Origin of andesite and dacite: Geology, v. 2, p. 29-33.

Fisher, R.V., 1961, Proposed classification of volcaniclastic sediments and rocks: Geol. Soc. America Bull., v. 72, p. 1409-1414.

Foster, R.J., 1960, Tertiary geology of the central Cascade Mountains, Washington: Geol. Soc. America Bull., v. 71, p. 99-126.

Gwinn, V.E., 1960, Geology of the Drummond area, central western Montana: Montana Bur. of Mines and Geol., Special Publication 21.

_____ and Mutch, T.A., 1965, Intertongued upper Cretaceous volcanic and non-volcanic rocks, central western Montana: Geol. Soc. America Bull., v. 76, p. 1125-1144.

Hyndman, D.W., in prep., Petrology of Igneous and Metamorphic Rocks: 2nd ed., McGraw-Hill Book Co., New York.

Iagmin, P.J., 1972, Tertiary volcanic rocks south of Anaconda, Montana: unpublished M.S. Thesis, Univ. of Montana, 49 p.

Kauffman, M.E., 1963, Geology of the Garnet-Bearmouth area, western Montana: Montana Bur. of Mines and Geol., Memoir 39, 40 p.

Kuno, H., 1967, Origin of andesite and its bearing on the island arc structure: Bull. Volcano., v. 32, p. 141-176.

LaPointe, D.D., 1973, Geology of a portion of the Eocene Sylvan Pass volcanic center, Absaroka Range, Wyoming: unpublished M.S. Thesis, Univ. of Montana, 60 p.

Maxwell, J., 1965, Structure map and cross sections, southeast Drummond area: Billings Geol. Soc. 16th Annual Field Conf., 188 p.

McBirney, A. and Williams, H., 1979, Volcanology: Freeman, Cooper and Co., San Francisco, Calif., 397 p.

Montgomery, J.K., 1958, Geology of the Nimrod area, Granite Co., Montana: unpublished M.S. Thesis, Mont. State Univ., 61 p.

Pardee, J.T., 1918, Ore deposits of the northwestern part of the Garnet Range, Granite Co., Montana: U.S. Geol. Survey Bull. 660-F, p. 159-240.

Parsons, W.H., 1969, Criteria for recognition of volcanic breccias: Geol. Soc. America Memoir 115.

Peacock, M.A., 1931, Classification of igneous rock series: J. Geol., v. 39, p. 54-67.

Pichler, H. and Zeil, W., 1972, Cenozoic rhyolite-andesite association of the Chilean Andes: Bull. Volcano., v. 35, p. 424-452.

Rubel, D.N., 1971, Independence volcano - a major Eocene eruptive center, northern Absaroka volcanic province: Geol. Soc. America Bull., v. 82, p. 2473-2492.

Ross, C.S. and Smith, R.L., 1961, Ash-flow tuffs: Their origin, geologic relations, and identification: U.S. Geol. Survey Prof. Paper 366, 81 p.

Smedes, H.W., 1962, Lowland Creek volcanics, an upper Oligocene formation near Butte, Montana: J. Geol., v. 70, p. 255-266.

_____ and Prostka, H.J., 1972, Stratigraphic framework of the Absaroka Volcanic Supergroup in the Yellowstone National Park region: U.S. Geol. Survey Prof. Paper 729-C, 33 p.

Smith, R.L., 1960a, Ash-flows: Geol. Soc. America Bull., v. 71, p. 705-841.

_____, 1960b, Zones and zonal variations in welded ash-flows: U.S. Geol. Survey Prof. Paper 354-F, p. 149-159.

Streickeisen, A., 1967, Classification and nomenclature of igneous rocks: N. Jb. Miner. Abst., v. 107, p. 144-240.

Wallace, C.A., Klepper, M.R. and French, A.B., 1978, Preliminary reconnaissance geologic maps of the Garnet Range, western Montana: U.S. Geol. Survey OF Map no. 78-418.

_____ and Scarborough, D.M., 1977, Preliminary reconnaissance geologic maps of the Garnet Range, western Montana: U.S. Geol. Survey OF Map no. 77-529.

Weber, W.M. and Witkind, L.J., 1979, Geologic map of the south half of the Nevada Lake quadrangle, Lewis and Clark and Powell Counties, Montana: U.S. Geol. Survey OF Map no. 79-446.

Wilcox, R.E., 1944, Rhyolite-basalt complex on the Gardiner River, Yellowstone Park, Wyoming: Geol. Soc. America Bull., 55, p. 1047-1080.

_____, 1979, The liquid line of descent and variation diagrams: in Yoder, H.S., Jr., ed.: The evolution of the igneous rocks, fiftieth anniversary perspectives, p. 205-232.

Williams, H., Turner, F.J. and Gilbert, C.M., 1954, Petrography: W.H. Freeman and Co., New York, 406 p.

William, T.R., 1976, Geothermal potential in the Bearmouth area, Montana: unpublished M.S. Thesis, Univ. of Montana, 81 p.

_____, Harakai, J.E., and Armstrong, R.L., 1976, K-Ar dating of Eocene volcanic rocks near Drummond: Northwest Geology, v. 5, p. 21-23.

APPENDIX I

GEOCHEMISTRY

Volcanic rocks of the Mt. Baldy - Union Peak area range in composition from basaltic andesite to rhyolite. Table 4 contains 20 whole rock chemical analyses from the study area. All are X-ray fluorescence analyses performed by the Department of Geology, Washington State University. The composition of average calc-alkaline basaltic andesite, hornblende andesite, dacite, and rhyolite are included for comparison (Hyndman, 1982, p. 269).

Analyses of the olivine basalt indicate a composition closer to a basaltic andesite. This may be due to the degree of weathering and alteration of the olivine phenocrysts, resulting in an increase of SiO_2 and depletion of FeO.

Two of the hornblende andesites (GR-66a and 79A) appear dacitic in composition. They are not spatially related, and may represent more silicic pulses in the eruption of this unit or local hydrothermal alteration. The high SiO_2 percentage of quartz latite sample GR-155A may result from the numerous quartz anhedra in the sample.

The rocks as a whole are anomalously high in K_2O compared with Hyndman's (1982) average calc-alkaline volcanic rocks. This trend is similar to that seen in the Eastern Absaroka eruptive belt (Rubel, 1971) and probably resulted from generation of the rocks in an environment that lead to high K_2O content. No model is proposed, although the proximity of the leucite basalt plug hints of contamination of the volcanic rocks by an early alkalic system.

The percentage of major elements such as FeO^{tot}, Al_2O_3, CaO, MgO, and TiO_2 show distinct inverse relationships with silica percentages (Figure 16). Elements which show these linear trends may be considered to have a common derivation along the liquid line of descent (Wilcox, 1979). However, major-element variations for the widely variable lithologies in the study area should yield linear trends simply indicative of their chemical differences. More extensive chemical studies of the change in composition between units is necessary to establish differentiation trends and comagmicity.

Figure 17 is a combined plot of CaO and $Na_2O + K_2O$ versus SiO_2. The value of SiO_2 at which these two trends intersect, the Peacock Index, has been used by Turner and Verhoogen (1960, p. 48) to differentiate between magmatic suites. This alkali-lime index for the Mt. Baldy - Union Peak rocks is approximately 54% SiO_2, or alkali-calcic. This index may be artifically low, due to the high percentage of K_2O in these rocks.

Figure 18 is an A-F-M diagram showing the lack of Fe-enrichment in the Mt. Baldy - Union Peak volcanic rocks. This trend is typical of the calc-alkaline association (Hyndman, 1982).

Normative mineralogy of the samples was determined using a ClPW computer program from Dartmouth College. The results are shown in Table 5, and Figure 19 shows a plot of normative quartz-orthoclase-plagioclase for the map units. The K-rich nature of the rocks is evident in the relatively high percentage of normative orthoclase.

Table 4. Geochemistry

Sample #	Unit	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MNO	CaO	MgO	K_2O	Na_2O	P_2O_5
44A	Tft	79.52	11.58	0.11	0.33	0.37	0.01	0.43	0.25	4.46	2.93	0.02
54A	Tha	57.45	17.97	0.83	3.01	3.45	0.09	5.92	3.00	3.17	4.61	0.49
56A	Tbha	60.95	16.12	0.78	2.81	3.21	0.04	4.99	2.65	4.06	3.89	0.05
66A	Tbha	67.18	15.71	0.54	1.84	2.10	0.02	3.75	0.93	3.30	4.24	0.39
79A	Tha	66.07	16.25	0.57	1.86	2.13	0.02	3.53	1.51	3.41	4.36	0.29
82A	Tb	56.30	16.50	1.72	3.63	4.16	0.08	5.61	4.11	2.86	4.55	0.49
88A	Tb	59.35	16.05	0.69	2.93	3.36	0.06	5.95	4.96	2.58	3.80	0.29
94A	Tr	78.10	12.29	0.10	0.15	0.17	0.01	0.15	0.21	5.15	3.61	0.05
98A	KTap	50.50	10.99	2.38	4.09	4.68	0.13	9.48	8.04	6.48	2.21	1.03
101A	Tpa	61.82	16.30	1.00	2.85	3.27	0.08	4.48	2.77	2.96	4.23	0.25
108A	Tbha	60.12	14.15	0.86	3.04	3.48	0.15	5.87	4.55	3.43	3.79	0.56
114A	Tlf	63.35	17.19	0.66	2.20	2.52	0.06	3.58	2.15	4.13	3.83	0.35
121B	Tbha	59.13	13.93	0.92	2.86	3.28	0.08	6.63	5.24	3.46	3.87	0.59
150A	Tbha	58.80	14.90	0.82	2.87	3.29	0.09	6.07	5.30	3.65	3.70	0.51
155A	Tqlp	73.04	14.33	0.32	0.83	0.95	0.03	1.49	0.86	4.85	3.18	0.12
157A	Tqlp	67.57	16.07	0.52	1.52	1.75	0.04	2.65	1.48	4.37	3.78	0.25
172B	Tft	76.44	12.78	0.11	0.24	0.27	0.02	0.15	0.28	6.98	2.68	0.04
172C	Tft	80.79	10.70	0.10	0.08	0.09	0.00	0.30	0.30	5.22	2.39	0.03
181A	Tpha	62.73	16.75	0.72	2.20	2.52	0.06	4.44	2.15	3.98	4.04	0.42
204B	Tft	76.21	13.43	0.12	0.25	0.29	0.02	0.70	0.58	6.09	2.30	0.01
*basaltic andesite		53.40	17.60	0.90	3.30	6.10	0.17	9.30	4.80	0.75	2.80	0.17
*hornblende andesite		59.20	16.90	0.70	2.90	3.30	0.13	6.40	3.50	1.80	3.70	0.23
*dacite		65.10	16.30	0.70	2.20	2.60	0.11	4.30	1.60	2.10	4.20	0.19
*rhyolite		74.40	13.20	0.30	1.10	1.00	0.07	1.30	0.37	3.70	4.10	0.06

*Hyndman (in prep), p. 269

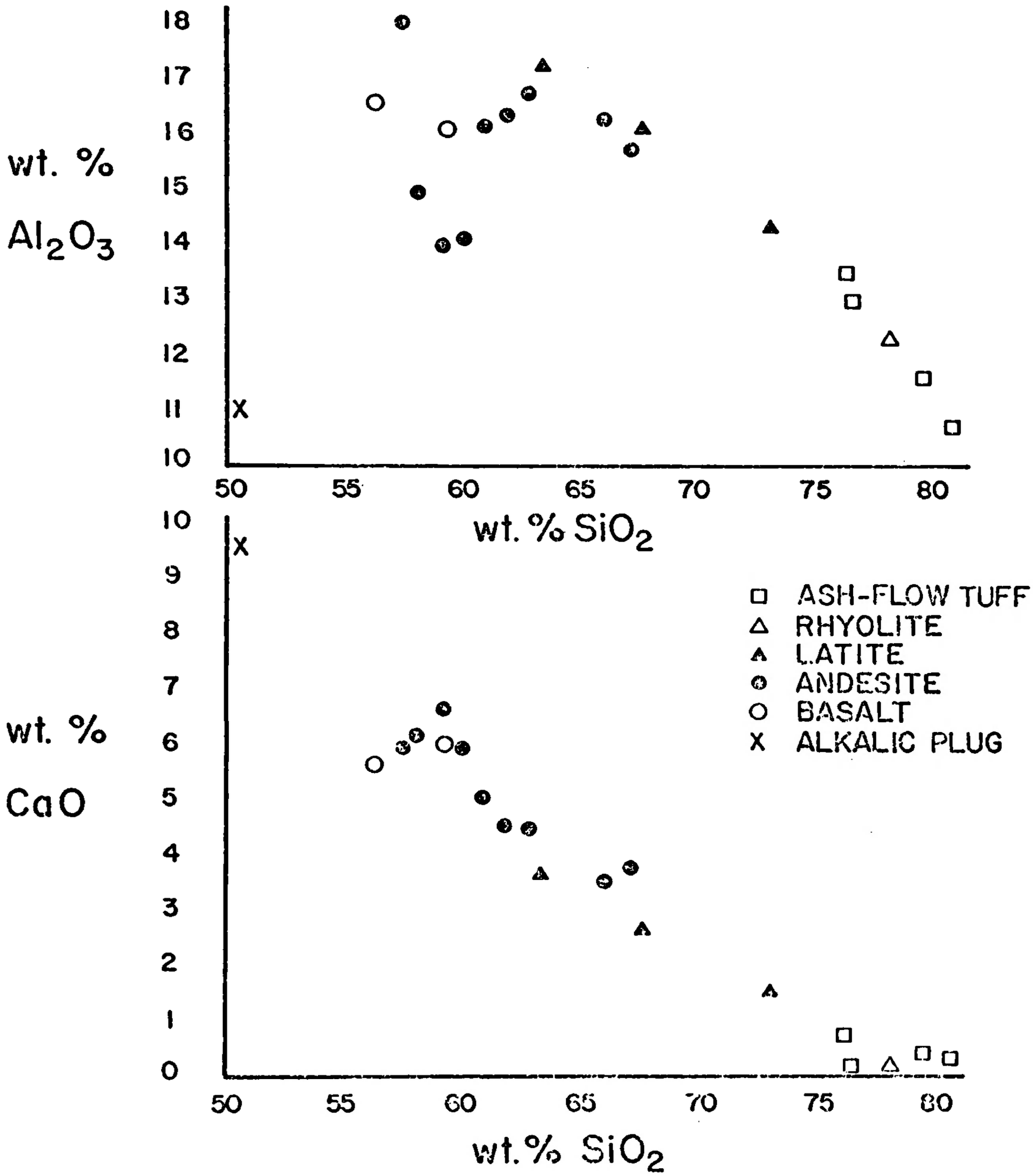

Figure 16. VARIATION DIAGRAMS

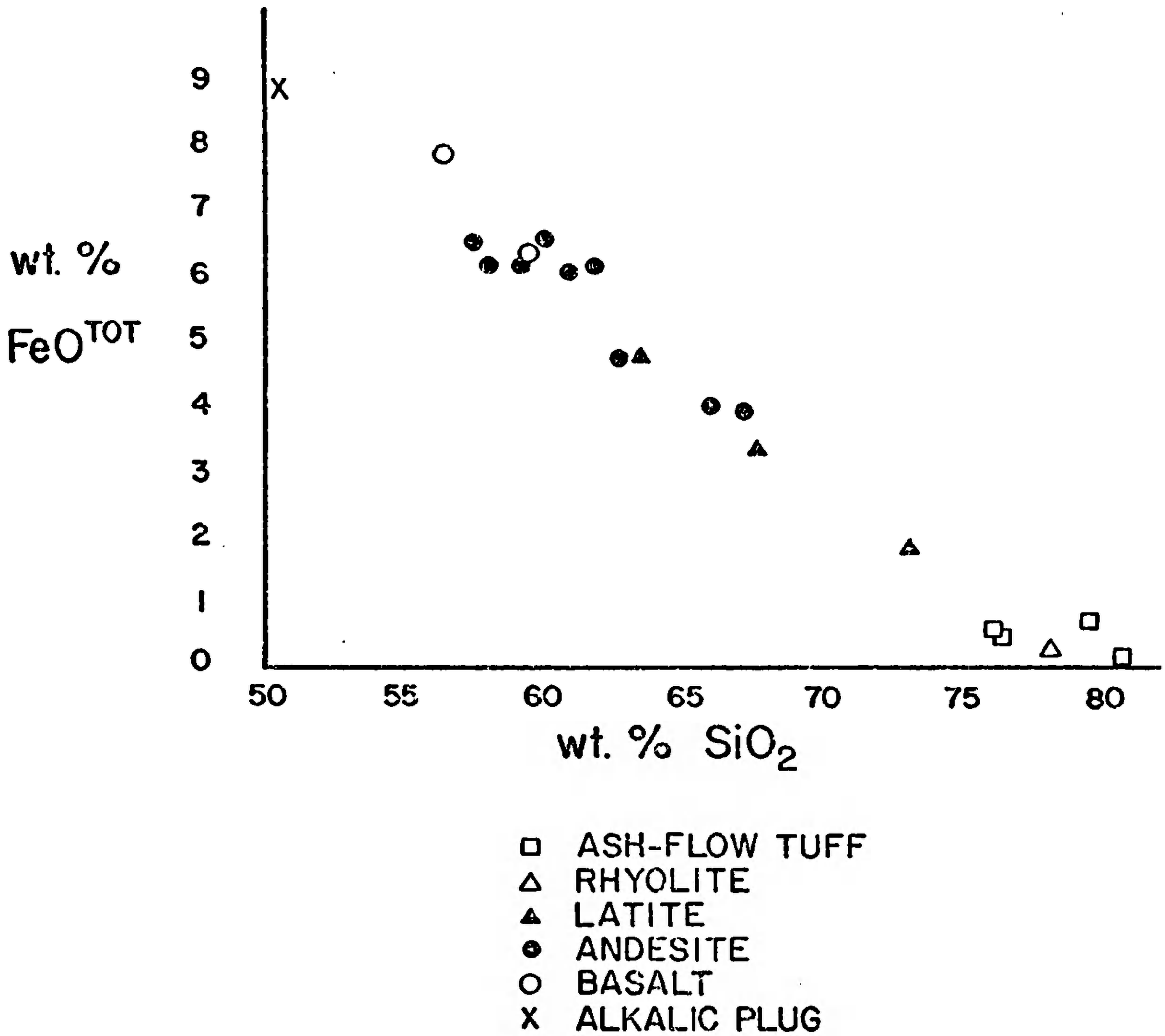

Figure 16 (cont.). VARIATION DIAGRAM

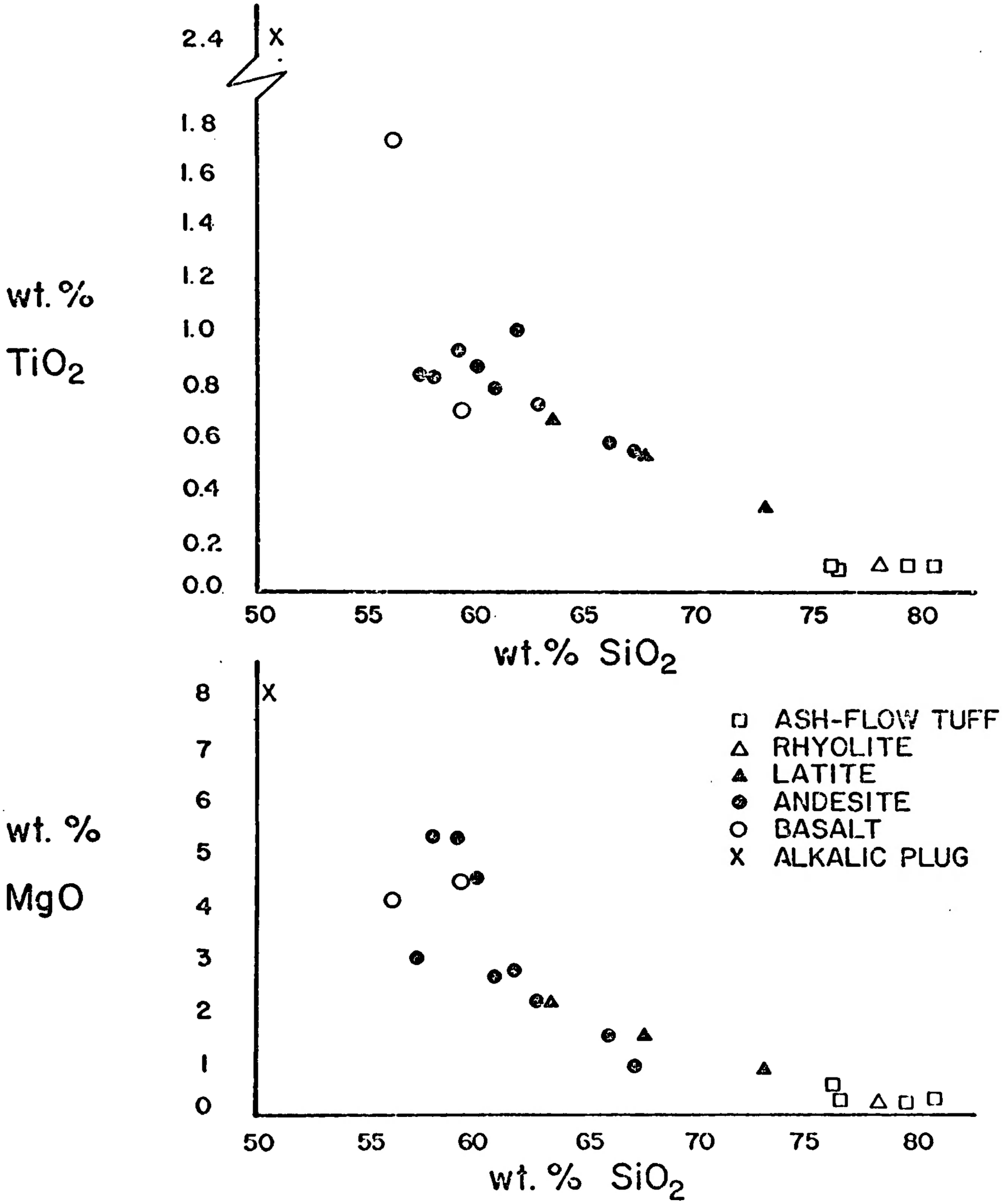

Figure 16 (cont.). VARIATION DIAGRAMS

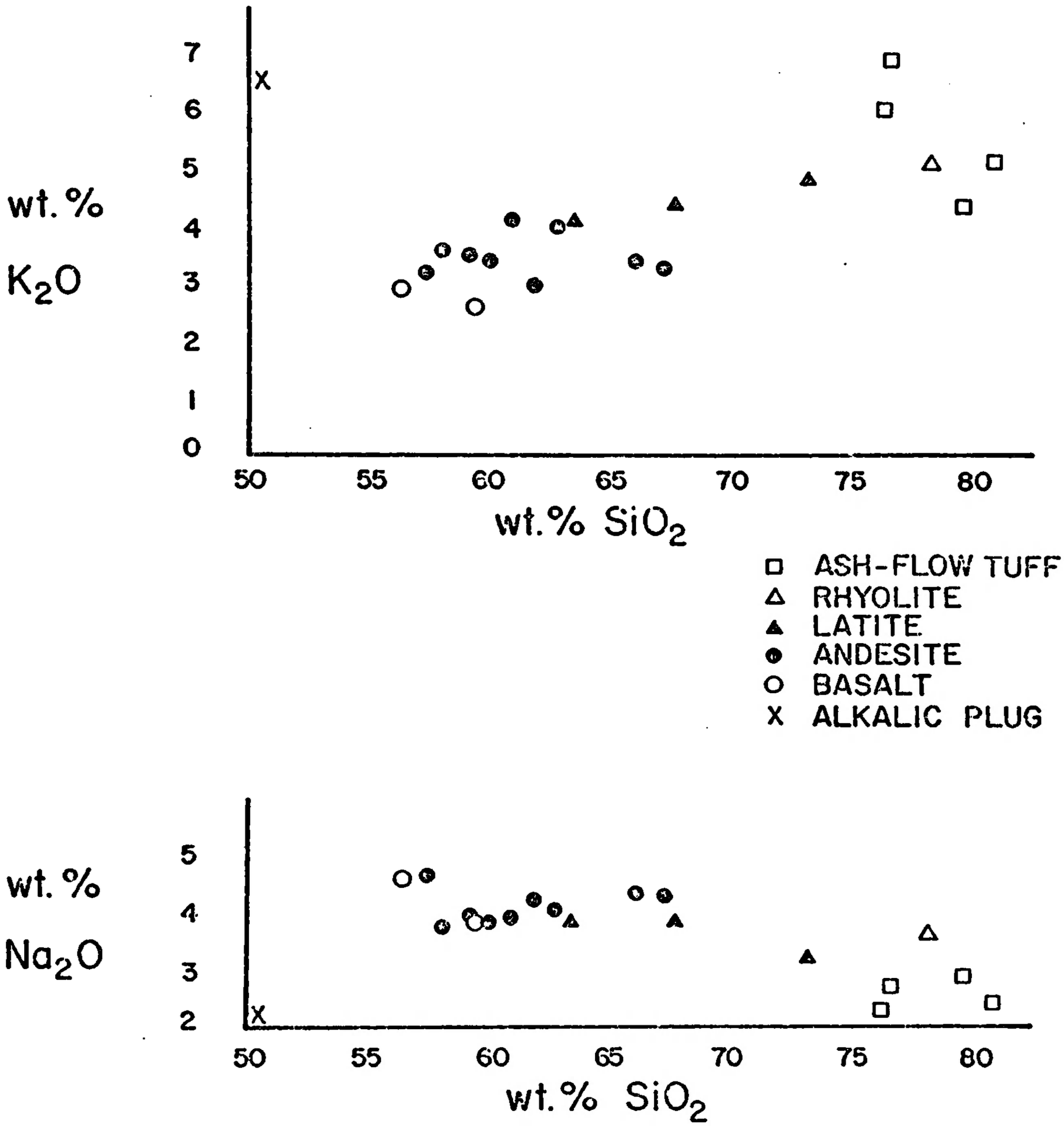

Figure 16 (cont.). VARIATION DIAGRAMS

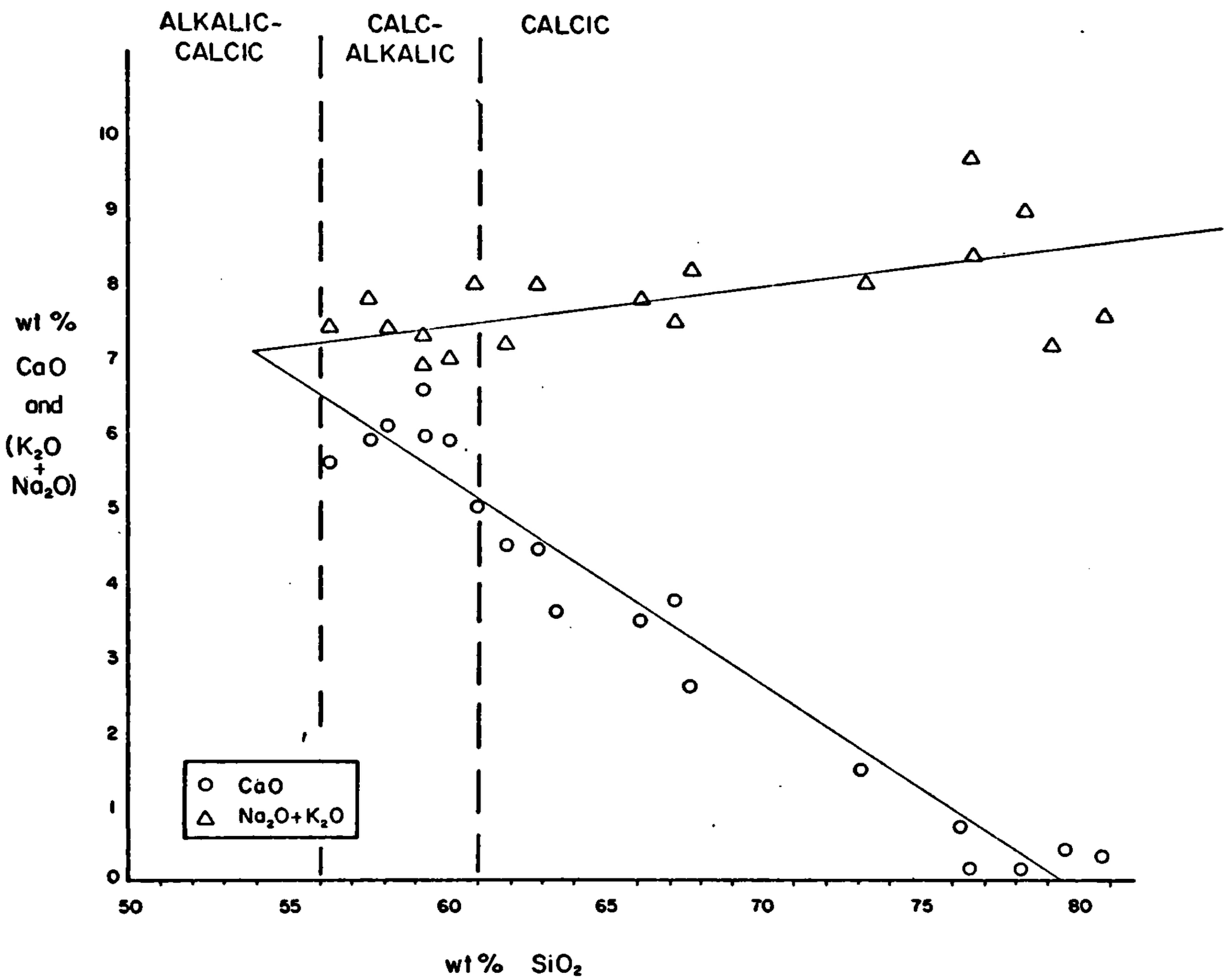

Figure 17. Determination of Peacock Index - utilizing variation diagram for CaO and (K_2O + Na_2O) vs. SiO_2 for volcanic rocks of the study area.

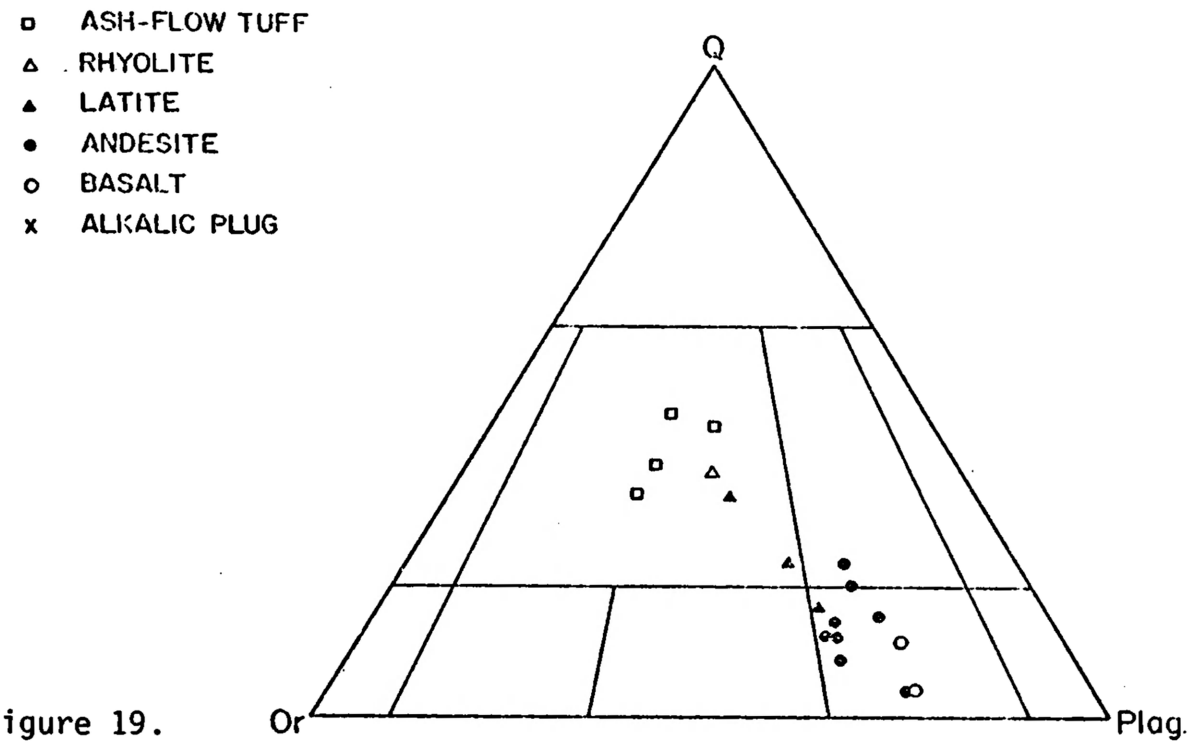

Figure 19. PLOT OF NORMATIVE QUARTZ-ORTHOCLASE-PLAGIOCLASE FOR MAP UNITS

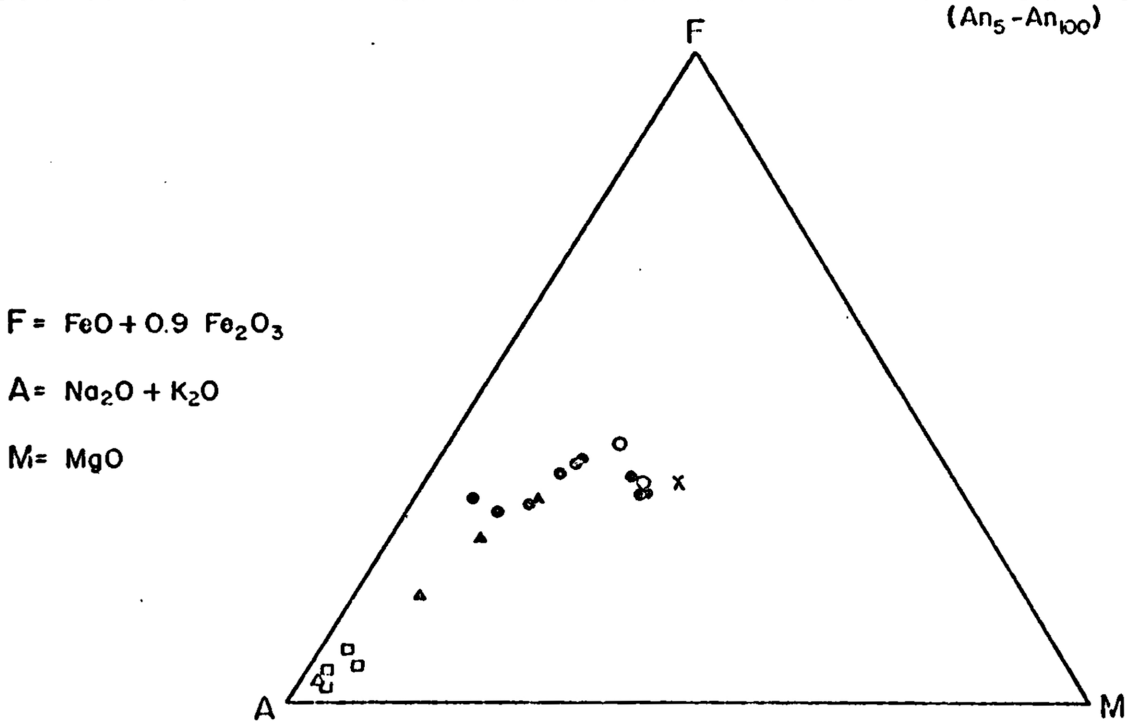

Figure 18. A-F-M PLOT OF ROCKS OF THE STUDY AREA

Table 5.

Normative Mineralogy

Unit:	Tft	Tha	Tbha	Tbha	Tha	Tb	Tb	Tr	KTap	Tpa
	44A	54A	56A	66A	79A	82A	88A	94A	98A	101A
Q	47.17	3.40	10.99	23.40	19.96	3.37	9.34	39.69	—	13.92
Or	24.37	17.92	22.85	18.49	19.10	16.07	14.23	28.29	35.49	16.64
Ab	24.33	39.61	33.27	36.10	37.11	38.86	31.86	30.14	4.11	36.02
An	1.85	18.16	13.85	13.36	13.93	15.37	17.85	0.39	0.86	15.86
Ne	—	—	—	—	—	—	—	—	7.14	—
Di		6.88	6.69	1.87	0.87	8.07	7.94	—	36.51	3.68
Hy	1.04	9.13	7.73	3.59	5.97	11.41	14.69	0.71	—	9.37
He	—	—	—	—	—	—	—	—	—	—
Ol	—	—	—	—	—	—	—	—	6.72	—
Mt	0.27	2.51	2.33	1.52	1.54	3.01	2.38	0.12	3.30	2.35
Il	0.18	1.38	1.29	0.89	0.94	2.85	1.12	0.16	3.84	1.65
Ap	0.04	1.00	0.99	0.79	0.58	0.99	0.57	0.10	2.03	0.50
C	0.76	—	—	—	—	—	—	0.40	—	—

	108A	114A	121B	150A	155A	157A	172B	172C	181A	204B
Q	9.67	16.07	6.45	6.07	34.44	23.21	36.33	48.99	13.69	40.21
Or	18.93	23.29	18.98	20.11	26.91	24.48	38.70	28.43	22.39	33.67
Ab	31.79	32.82	32.26	30.98	26.82	32.18	22.59	19.78	34.54	19.33
An	10.72	14.77	9.68	12.37	6.21	10.92	0.45	1.19	15.06	3.19
Ne	—	—	—	—	—	—	—	—	—	—
Di	13.08		17.29	12.60	—	—	—	—	3.33	—
Hy	10.83	8.92	10.38	13.19	3.37	6.02	1.06	0.95	7.15	2.04
He	—	—	—	—	—	—	—	0.03	—	—
Ol	—	—	—	—	—	—	—	—	—	—
Mt	2.47	1.83	2.31	2.33	0.68	1.26	0.20	—	1.83	0.20
Il	1.40	1.10	1.49	1.33	0.52	0.86	0.18	0.16	1.19	0.20
Ap	1.11	0.71	1.16	1.01	0.24	0.50	0.08	0.06	0.85	0.02
C	—	0.49	—	—	0.91	0.58	0.41	0.41	—	1.15
Unit:	Tbha	Tlf	Tbha	Tbha	Tqlp	Tqlp	Tft	Tft	Tpha	Tft

Key to Plate 2

Pre-Cenozoic Sedimentary Rocks

Cretaceous	Kk	Kootenai Fm.
Jurassic	Jm	Morrison Fm.
	Je	Ellis Group
Permian	Pp	Phosphoria Fm.
Penn.	ℙg	Quadrant Fm.
Miss.	ℙa	Amsden Fm.
	Mm	Madison Group
Devonian	Dj	Jefferson Fm.
	Dm	Maywood Fm.
Cambrian	Cr	Red Lion Fm.
	Ch	Hasmark Fm.
	Cs	Silver Hill Fm.
Pre-Cambrian	pCp	Pilcher Fm.
	pCg	Garnet Range Fm.
	pCmc	McNamara Fm.

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*see Plate 1 for key to Eocene volcanic rocks and Cretaceous intrusive rocks

Scale 1 : 24,000

— No vertical exaggeration —

Structure in the pre-Cenozoic rocks after Kauffman (1963)