AN ABSTRACT OF THE THESIS OF

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Title: Geology of the Bagby Hot Springs Area, Clackamas and Marion Counties, Oregon

Abstract approved: Redacted for Privacy
Dr. E. M. Taylor

The thesis area is located southwest of Portland, Oregon, in the Western Cascades. In the area are volcaniclastic rocks and lava flows that range in composition from basaltic andesite to dacite. The dominant volcaniclastic rock type is thin intracanyon ash-flow tuff. The dominant lava flows are a thick sequence of basaltic andesites to dacites that account for 60 percent of those found in the thesis area. Within this group is an intracanyon flow of basaltic andesite that contains double phenocrystic stages of clinopyroxene and plagioclase. Quartz is also present and surrounded by a reaction rim of clinopyroxene. This unit is an example of magmatic mixing. The most distinctive unit is a cliff-forming hornblende ignimbrite found in two isolated locations. This unit contains large hornblende crystals, collapsed pumice lumps, and sanidine granite inclusions. There are four andesite intrusions in the thesis area; two are dikes and two are irregular discordant bodies. The most distinctive is Pin Creek andesite with large embayed quartz phenocrysts.

Variation diagrams based on chemical data follow normal trends as expected for calc-alkaline or calcic rocks. Rocks from the thesis area are calcic, due to abundant calcic plagioclase phenocrysts and intense alteration.

The thesis area lies along the western flank of a broad northeast-plunging anticline. All units consistently dip 8 to 11° in a westerly direction or northerly direction depending upon their location with respect to the nose of the anticline. Two distinct groups of faults occur. One group trending north-northwest, the other east-west. It is the northern fault of the east-west-trending group that has served as a zone of crustal weakness for the intrusion of a dike system and the conduit of hot water supplying Bagby Hot Springs.

Bagby Hot Springs lies in a broad, deeply-glaciated valley used primarily for recreational activities. The projected geothermal reservoir temperature of 127°C and the low flow rate do not make this area a good potential reservoir for generation of electricity.

Geology of the Bagby Hot Springs Area
Clackamas and Marion Counties, Oregon

by

Richard F. Dyhrman

A THESIS

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CLACKAMAS AND MARION COUNTIES, OREGON

INTRODUCTION

Location

The area of investigation is located in the western Cascade Mountains 72 km southeast of Estacada, Oregon. This area covers 142 km^2 in the northern half of the 15-minute Battle Ax quadrangle, Clackamas County, Oregon. The northern boundary is the lower slope of Thunder Mountain; the western boundary is the ridge between Nohorn Creek and Hugh Creek; the southern boundary is Whetstone Mountain, Silver King Mountain, and the headwaters of Pansy Creek; the eastern boundary is the Collawash River (fig. 1). The central landmark around which the study is based is Bagby Hot Springs located on the western edge of sec. 26, T. 7 S., R. 5 E.

Geography

There are three major streams in the thesis area. The largest stream is the Hot Springs Fork of the Collawash River into which empty Hugh Creek and Pansy Creek (fig. 2).

The relief exceeds 914.4 m. The lowest elevation is 549.2 m at Alder Swamp near the Collawash River and the highest elevation exceeds 1524.0 m along the ridges.

Accessibility and Exposure

The study area is easily reached from Estacada, Oregon on United

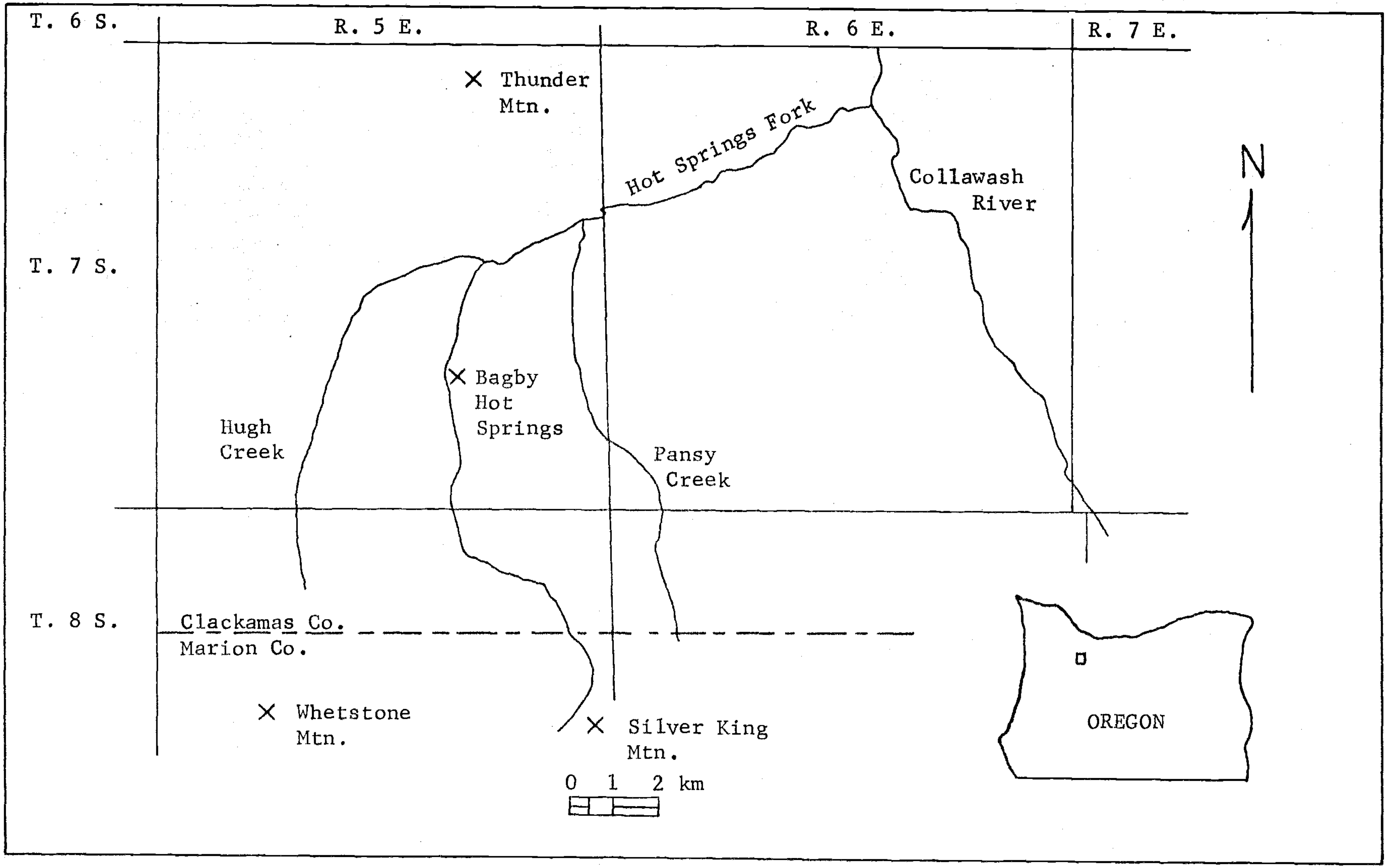

Figure 1. Index map of major drainage systems and geographic points

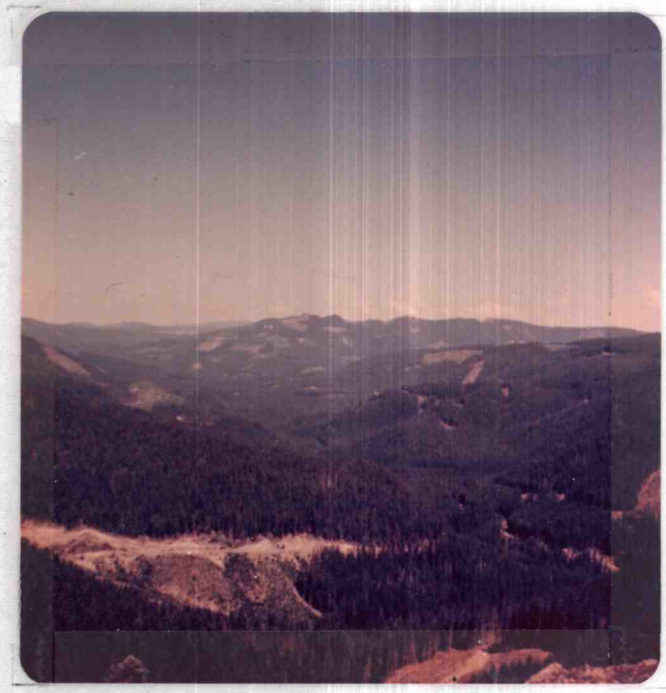

Figure 2. Looking east along the Hot Springs Fork. Nohorn Creek is in the foreground with the Hot Springs Fork joining beyond the first ridge line from the south. Beyond the next ridge, Pansy Creek is coming in from the south.

States Forest Service roads. The western and northern portions of the study area contain numerous logging roads. The best outcrops are along road cuts, beds of major streams, and on ridges above 1219 m. In lower valleys, outcrops are very hard to find and are limited in areal extent due to dense stands of Douglas fir, vine maple, and rhododendron. At higher elevations, outcrops are well-exposed and contacts can be followed because stands of Noble fir and rhododendron are thin.

Methods of Investigation

Field work was conducted during the summer of 1974. Logging roads and trails were found by using an Estacada Ranger District "Fireman's Map". Field studies consisted of detailed mapping of geologic contacts on a Unites States Geological Survey 15-minute topographic map enlarged to a scale of 1:24,000, followed by determination of structural relationships, and gathering of samples for analysis.

The colors of samples on fresh surfaces were described according to the Rock Color Chart distributed by the Geological Society of America (Goddard, 1963).

Samples have been analyzed chemically and petrographically. Weight percentages of FeO, TiO_2, CaO, K_2O, and Al_2O_3 were determined by X-ray fluorescence spectrophotometry, Na_2O and MgO percentages by atomic absorption spectrophotometry, and SiO_2 percentages by visible light spectrophotometry. The chemical analyses were accomplished at the Department of Geology, Oregon State University by Ruth L. Lightfoot and Dr. E. M. Taylor.

In this study, the classification of volcanic rocks is based on weight percent SiO_2. Rocks with less than 52 percent SiO_2 are basalt; 52-58 are basaltic andesite; 58-66 are andesite; 66-74 are dacite.

The volumetric proportions of phenocrystic minerals and total groundmass were visually estimated during study of thin sections. Point-count estimates of groundmass mineralogy were not attempted because of the fine-grained texture of the samples.

Mineral identifications were based upon optical and physical properties observed with a petrographic microscope. Optical properties included optic sign, birefringence, approximate 2V, and extinction. Physical properties included cleavage, form, and twinning. Plagioclase composition was determined using the Michel-Levy method (Kerr, 1959).

Geologic Setting

Two thick stratigraphic units of Tertiary age occur within the study area. The first is a sequence of pyroclastic rocks which includes two mappable flows. The second sequence consists of very thick intracanyon andesite lava flows with small sedimentary interbeds. Above the second sequence are thinner units consisting of sediments, ash flow tuffs, and andesite flows. Quaternary deposits consist of till, alluvium, and landslides.

The pre-Quaternary rocks of the study area were folded and now form the west limb of a broad northeast-plunging anticline. Faults that are not associated with landslides and slump blocks have an east-west or north-northwest trend. Bagby Hot Springs is found along one of the east-west-trending faults.

Bagby Hot Springs consists of eight springs and seepages in five acres (Waring, 1965). Total flow rate is 94 lpm with an average temperature of 58°C (Bowen, 1970). Chemical analysis of the hot spring water was performed by the United States Coast and Geodetic Survey (U. S. Forest Service, date unknown).

Previous Work

Few geological studies in the northern part of the western Cascade Mountains of Oregon have been published. Major contributions have been due to Thayer (1936, 1937) who studied the northern Santiam River area and to Peck and others (1964) who made a regional reconnaisance study.

Thayer (1936, 1937) named formations that are very extensive and lithologically distinctive. Two of these are the Breitenbush Tuff consisting of sub-aerial and sub-aqueous pyroclastic rocks, and the Sardine Series consisting predominantly of andesite flows. Structure of the western Cascade Mountains was outlined in the two publications by Thayer. His sketch maps indicate that the Mehama Anticline passes through or near the study area (Thayer, 1936).

The more recent work by Peck and others (1964) assigns all andesite flows of Miocene age to the Sardine Formation. These same authors mapped all pyroclastic rocks of Oligocene to early Miocene age as part of the Little Butte Volcanic Series. This included Thayer's Breitenbush Tuff. The map published by Peck and others (1964) indicates that only the Little Butte Volcanic Series and the Sardine Formation are present in the study area. Peck and others (1964) mapped an anticline plunging northeast but not reaching the study area. This anticline is probably Thayer's (1936) Mehama Anticline.

STRATIGRAPHY

Rock-stratigraphic units are mapped and described in this study. All unit names are informal. In accordance with the Code of Stratigraphic Nomenclature (American Association of Petroleum Geologists, 1961), the names of specific geographic features in the thesis area have been used in naming mapped units. A generalized columnar section of the rocks of the Bagby Hot Springs area is shown in figure 3.

Blister Creek Tuff and Included Lava Flows

Blister Creek tuff consists of numerous ash-flow tuffs of variable thickness and degree of welding. Outcrops of this unit are extensive throughout valleys in the thesis area, but continuous outcrops of individual ash flows are limited and cannot be traced for long distances. Within Blister Creek tuff there are two lava flows that can be traced across the Hot Springs valley floor and are mapped separately. These two flows are the Pegleg Falls dacite and the Rock Creek felsite.

Blister Creek Tuff

Major outcrops of Blister Creek tuff occur in three locations: eastern end of Hot Springs Fork valley west of the Collawash River, Pansy Basin, and Hot Springs Fork valley south of Bagby Hot Springs. These outcrops cover 11.7, 5.2, and 2.6 km^2, respectively. Two very small outcrops of Blister Creek tuff are found along Nohorn Creek near the Silver Lady mining claim in sec. 21, T. 7 S., R. 5 E. Both outcrops combined account for 0.32 km^2. Total thesis area covered by outcrops of Blister Creek tuff is approximately 19.7 km^2.

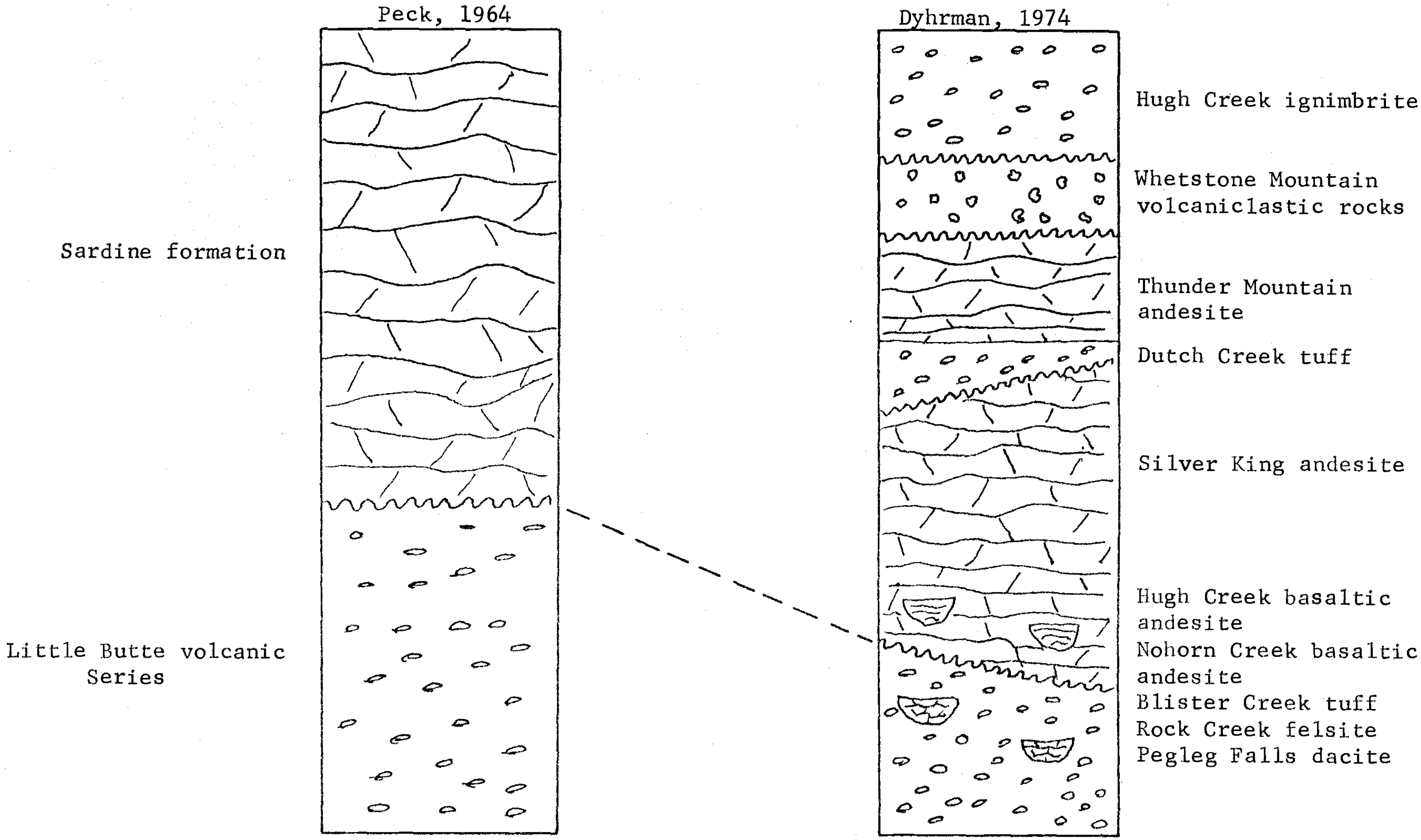

Figure 3. Generalized columnar section of lavas and volcaniclastic rocks of the Bagby Hot Springs area

Silver King andesites overlie Blister Creek tuff. In most areas the contact between these two units is covered by colluvium. Best contact is observed along road S-70 at the Silver Lady mining claim. Figure 4 shows this contact with 1.5 m of Blister Creek tuff below a 1-m layer of oxidized flow breccia and Silver King andesite. Field relations suggest that Silver King andesite is intracanyon to the Blister Creek tuff. Blister Creek tuff in Pansy Basin and southern Hot Springs Fork valley is in fault contact with Silver King andesite. An east-west-trending fault has brought Blister Creek tuff up. The eastern outcrop of Blister Creek tuff along Nohorn Creek was brought up into contact with Silver King andesites by a north-south-trending fault.

Thickness of Blister Creek tuff was not measured because of inadequate contact exposure and because the base of the Blister Creek tuff is not exposed. A field estimate of thickness along a cliff face in Pansy Basin was 152 m.

Peck and others (1964) mapped the rocks cropping out in the western end of Hot Springs Fork valley as part of the Little Butte Volcanic Series of Oligocene and early Miocene age. The Blister Creek tuff was included in this unit.

Outcrops of Blister Creek tuff are cliff formers where individual ash-flow tuffs are densely welded. Poorly welded Blister Creek ash-flow tuffs tend to be slope formers. Outcrops of Blister Creek tuff do not have a distinctive jointing pattern, but when present, it is blocky. Most good exposures are found along road cuts and in stream beds. Stream beds in Blister Creek tuff have a distinctive erosion pattern. A stream will flow through narrow, deep "pot-holes" or wide,

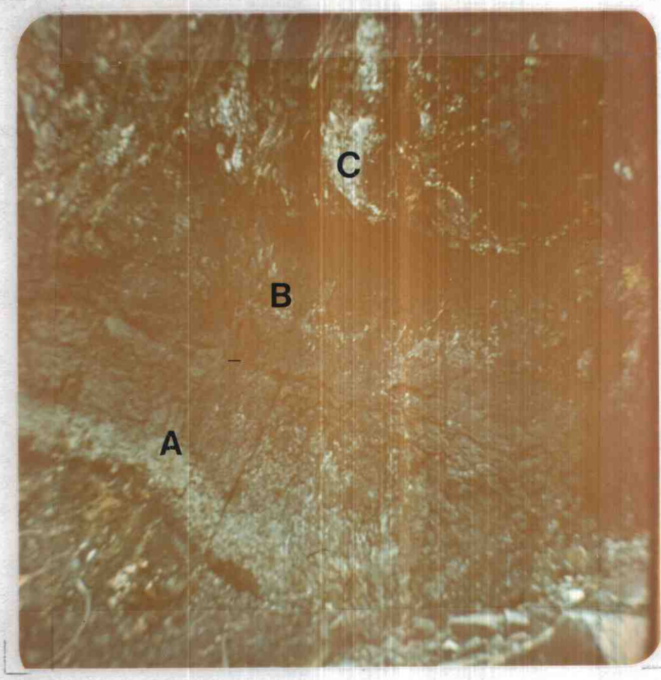

Figure 4. Contact between Blister Creek tuff and Silver King andesite found in SE1/4 sec. 21, T. 7 S., R. 5 E. with:

A. 1-1/2 meters of Blister Creek tuff including carbonaceous layer,
B. 1 meter of oxidized flow breccia, and
C. Silver King andesite flow.

shallow, differentially scoured areas. "Pot-holes" are caused by eddying of the river in poorly-welded zones of the unit. Differentially-scoured areas are in firmly-welded zones. An easily recognized feature of Blister Creek tuff is the color, a shade of light green or light red with light green predominant.

Individual ash flows of Blister Creek tuff are variable in thickness and extent of zonation. Most ash-flow tuffs are approximately 14 m thick and contain three zones. Using Smith's (1960) criteria, the lower and upper zones are nonwelded and of variable thickness. The middle zone is firmly welded and in some outcrops is densely welded. Along road S-70 near Silver Lady mining claim is an outcrop of Blister Creek tuff showing the lower and middle zones (fig. 5). This ash-flow tuff lies on a thin carbonaceous sedimentary bed that is approximately 1.2 m thick. The firmly-welded zone is approximately 6.1 m thick to the top of the road cut.

Hand specimens of Blister Creek tuff contain obvious lithic fragments, pumice lumps, and plagioclase crystals. Lithic fragments are porphyritic andesites that average 1 cm in diameter. Collapsed pumice lumps vary in size with the largest being 2 cm in diameter, and account for 30 to 45 percent of the rock. Pumice lumps are a different shade of light green or dark red than the rest of the rock. Plagioclase crystals in the matrix are approximately 1 mm in length.

Petrographically, the texture of Blister Creek tuff is vitric, ranging from eutaxitic (fig. 6) in firmly and densely-welded zones to vitroclastic in nonwelded zones. Pumice lumps are collapsed in firmly-welded zones and are usually light green in plain light. In all rocks

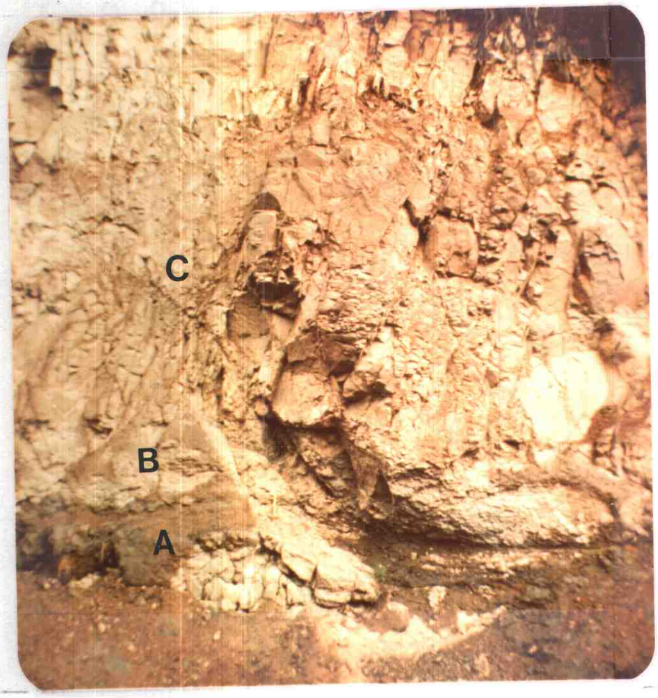

Figure 5. Zonation of Blister Creek tuff found in SE1/4 sec. 21, T. 7 S., R. 5 E. with:
A. 0.6 to 1.2 meters thick carbonaceous sedimentary bed,
B. 1.2 meters of poorly-welded zone, and
C. firmly-welded zone. (Hammer for scale.)

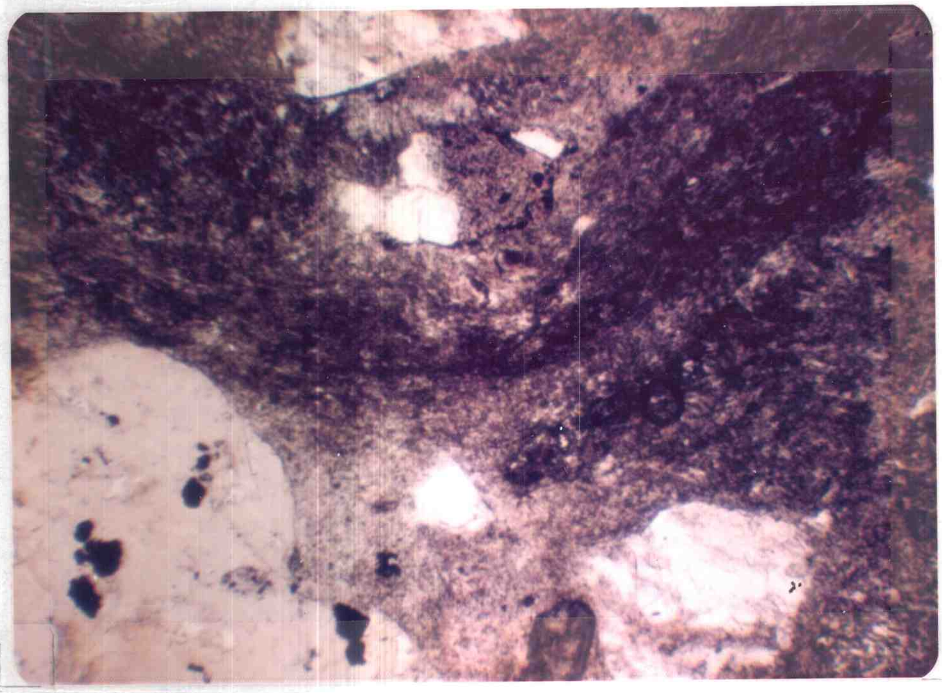

Figure 6. Photomicrograph of Blister Creek tuff eutaxitic texture. Sample No. RD-21-74 found in SE1/4 sec. 12, T. 7 S., R. 5 E.

the pumice is devitrified and in a few, it is spherulitic.

Blister Creek tuff contains a relatively constant proportion of the primary minerals plagioclase, clinopyroxene, and zircon. Plagioclase (An 44 to An 52) accounts for 5 to 35 percent of the unit. Plagioclase crystals are zoned, subhedral to euhedral, and average 1 mm long. Subhedral to euhedral clinopyroxene crystals account for 10 percent of the unit and are less than 1 mm in diameter with an average of 0.5 mm. In many rocks, clinopyroxene is so altered that interference figures cannot be taken, but unaltered clinopyroxene is augite with an approximate 2 V of 60 degrees and a pale green color in plain light. Euhedral zircon grains, 0.2 mm in diameter, are well-disseminated and account for 3 percent of the rock.

Volume of lithic fragments in the unit varies from 5 to 30 percent. Lithic fragments are pilotaxitic with phenocrysts of plagioclase and pyroxene. Plagioclase (An 52) phenocrysts average 1 mm long. Pyroxene crystals are subhedral, very small, and by volume account for a small percentage of the lithic fragments. Groundmass of lithic fragments is composed of devitrified glass, plagioclase microlites, and magnetite. These lithic fragments are porphyritic augite-bearing basaltic andesites.

The matrix of Blister Creek tuff contains devitrified glass, small mineral fragments, and small lithic fragments. A subhedral accidental hornblende crystal 1 mm long was found in a thin section of a sample from Bagby valley. Alteration products found in the matrix are magnetite, chlorite, calcite, and chalcedony. Magnetite and chlorite are associated with the alteration of mafic minerals and calcite and chalcedony are associated with the alteration of plagioclase.

Pegleg Falls Dacite

Pegleg Falls dacite is a lava flow found in sec. 14, T. 7 S., R. 5 E., at Pegleg Falls (fig. 7). This flow is the resistant rock over which Hot Springs Fork flows to make Pegleg Falls. Outcrops of Pegleg Falls dacite are well-exposed in the stream bed and along the banks. The total area covered by outcrops of this unit is 0.323 km^2.

Pegleg Falls dacite is surrounded by ash-flow tuffs belonging to Blister Creek tuff. Contacts are covered by colluvium and alluvium, but the linear distribution of Pegleg Falls dacite suggests an intracanyon relationship with the underlying ash-flow tuff. Exact measurements of thickness were not made, but maximum thickness was estimated to be approximately 12 m.

Because Pegleg Falls dacite lies within Blister Creek tuff, it is assigned the same Oligocene to early Miocene age.

Pegleg Falls dacite is a platy-jointed, reddish-brown cliff former in which fresh surfaces are medium dark gray (N-4). A very few small plagioclase phenocrysts are set in a fine-grained groundmass. Small quartz veinlets are abundant.

Pegleg Falls dacite is pilotaxitic with phenocrysts and sparse clusters of plagioclase and clinopyroxene. The rock contains 12 percent of subhedral to euhedral-zoned plagioclase (An 49) up to 1.5 mm in length. Three percent of the rock consists of subhedral to euhedral clinopyroxene, up to 0.3 mm in length. Clinopyroxene is a nonpleochroic greenish-purple as viewed in plain light.

Groundmass constituents by volume account for 85 percent of the rock. These are plagioclase microlites, very small clinopyroxene, devitrified glass, and magnetite. Magnetite grains are well-disseminated and average 0.5 mm in diameter. Alteration has produced celadonite which fills cavities in the rock.

Vein fillings of quartz occur throughout the rock (fig. 8). Veins are 0.5 mm wide with quartz occurring as anhedral crystals 0.25 mm in diameter. Along vein walls are crystals of biotite less than 0.1 mm in diameter. The small size of veins and lack of alteration throughout the rock suggests a deuteric origin for these two minerals.

Chemical analysis was performed on a sample from Pegleg Falls dacite and weight percent SiO_2 is 68.6 (Appendix 2). Pegleg Falls dacite is a porphyritic clinopyroxene-bearing dacite.

Rock Creek Felsite

Rock Creek felsite is a highly-altered andesitic or dacitic flow. This unit is bleached white and appears flow banded in the field. Outcrops of Rock Creek felsite occur in the stream bed of Hot Springs Fork and on both sides of the river. Major outcrops occur along road S-70 east of Rock Creek in sec. 13, T. 7 S., R. 5 E. The total area covered by this unit is approximately 0.323 km^2. Rock Creek felsite lies in, and is surrounded by, Blister Creek tuff. Although contacts are covered by colluvium and till, the linear distribution of this unit suggests an intracanyon relationship with the underlying ash-flow tuff. Measurement of thickness was not made because of covered contacts, but field estimate was 9 m.

Figure 7. Hot Springs Fork flowing over the resistant Pegleg Falls dacite (NE1/4 sec. 14, T. 7 S., R. 5 E.).

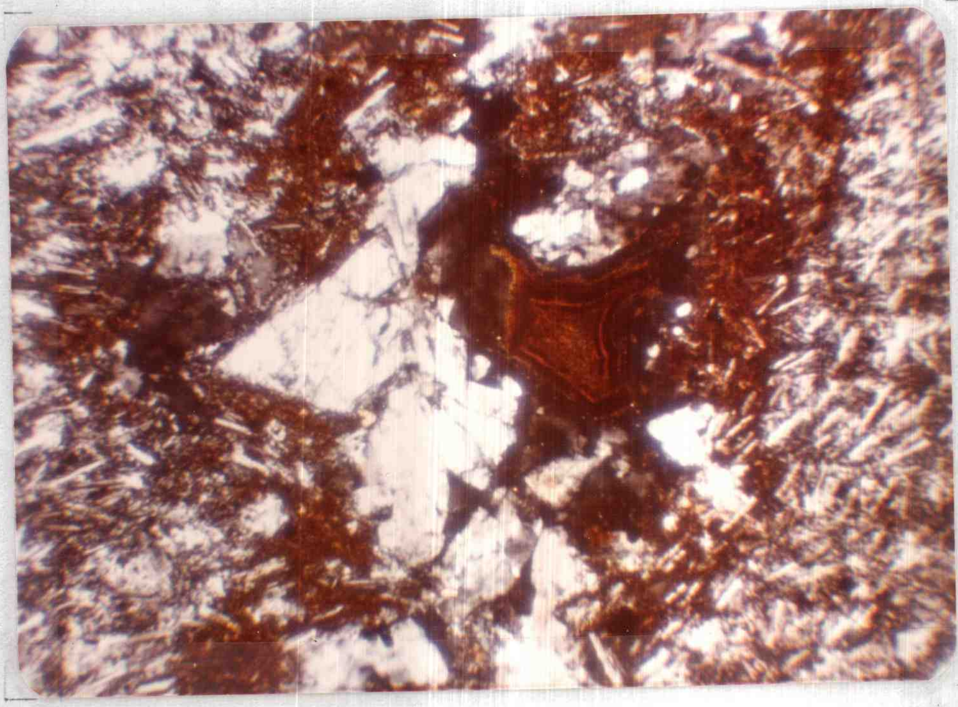

Figure 8. Photomicrograph of deuteric quartz with yellow biotite grains in the Pegleg Falls dacite (Sample No. RD-28-74).

Rock Creek felsite is a cliff former with major outcrops along road cuts and in stream beds. It is very light colored due to hydrothermal bleaching (fig. 9). Hand samples of Rock Creek felsite are very pale orange (10 YR 8/2). The only mineral obvious to the unaided eye is pyrite that is approximately 0.5 mm in diameter.

Because Rock Creek felsite lies within Blister Creek tuff, it is assigned the same Oligocene to early Miocene age.

The original texture and mineralogy of Rock Creek felsite is hard to determine due to alteration, but appears to be pilotaxitic with phenocrysts of plagioclase and pyroxene that account for 30 percent of the rock. Plagioclase has been totally replaced by calcite and chalcedony, preserving the original rectangular shape (fig. 10). Large calcite and chalcedony pseudomorphs after plagioclase are 1 mm long with an average of 0.5 mm, and account for 15 percent of the rock. Fifteen percent of the rock is 0.5 mm-in-diameter pyroxene phenocrysts that are altered to chlorite and magnetite. Pyroxene identification was based upon the eight-sided cross section of altered phenocrysts. The groundmass has been extensively replaced by alteration minerals. Present in the groundmass are grains of calcite, chalcedony, magnetite, chlorite, biotite and devitrified glass. Calcite and chalcedony are abundant and produced by alteration of plagioclase microlites. Biotite occurs in small light brown to dark-brown pleochroic crystals less than 0.1 mm in diameter.

Based upon inferred primary mineralogy, this unit is classified as a porphyritic pyroxene andesite. Intense alteration has obscured the original composition of this rock; consequently, chemical data were not obtained.

Figure 9. Outcrop of hydrothermally-bleached Rock Creek felsite in NE1/4 sec. 13, T. 7 S., R. 5 E. (Hammer for scale.)

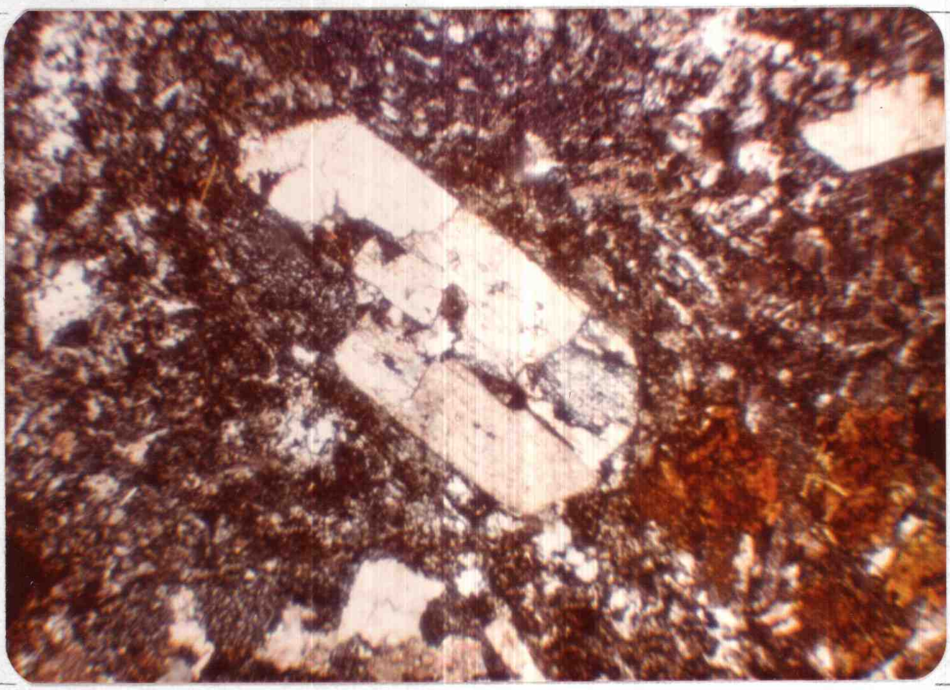

Figure 10. Photomicrograph of plagioclase phenocryst replaced by calcite and chalcedony (Sample No. M 999).

Silver King Andesite, Nohorn Creek and Hugh Creek Basaltic Andesites

Silver King andesite is a thick sequence of intracanyon basaltic andesite to dacite flows, breccias of variable thickness, and small sedimentary lenses of volcanic sands and gravels. Nohorn Creek and Hugh Creek basaltic andesites are two lava flows surrounded by Silver King andesite. These units have distinct colors, jointing patterns, and lithologies which allow them to be mapped separately from the Silver King andesite.

Silver King Andesite

Silver King andesite covers approximately 85.5 km^2 along major ridges and on mountain peaks in the southern end of the thesis area and contributes most of the volcanic rock found in alluvial deposits along major stream beds in this area.

Silver King andesite flowed down valleys cut into Blister Creek tuff. As noted in the description of Blister Creek tuff, the best exposed contact relationship between these two units is in the major road cut along road S-70. Figure 4 shows this contact where 0.61 m of oxidized Silver King andesite flow breccia is underlain by Blister Creek tuff. Because Silver King andesite is so extensive, many units lie on it. These units are Dutch Creek tuff, Thunder Mountain andesite, Whetstone volcaniclastic rocks, and Hugh Creek ignimbrite. Because of the limited exposure of upper and lower contacts, the thickness of Silver King andesite could not be measured. Field estimates of total thickness exceeded 304 m.

Peck and others (1964) assigned the red platy andesite flows that crop out in the thesis area to the Sardine Formation of middle to late Miocene age. This includes the Silver King andesite.

Outcrops of Silver King andesite are cliff formers and are extensively quarried for road gravel (fig. 11). Silver King flow breccias are usually slope formers, but a pinnacle of flow breccia along a ridge crest above a large clear cut in sec. 4, T. 8 S., R. 5 E., is one notable exception. Joint patterns in Silver King andesite are blocky to platy with platy jointing predominant (fig. 12). A few very small outcrops have well-developed columnar jointing. Hand samples of Silver King andesite are characterized by large phenocrysts of plagioclase and pyroxene. Colors of Silver King andesite vary from a brownish red to a reddish green, with brownish red predominant. Most samples on weathered surfaces have the brownish-red tint while fresh samples vary from dark greenish gray (5 GY 4/1) to dark gray (N-3).

Petrographically, most Silver King andesite is pilotaxitic. All rocks are porphyritic with phenocryst abundance ranging from 15 to 55 percent. Mineralogy among flows is relatively constant. Primary minerals are plagioclase, clinopyroxene, orthopyroxene, and olivine. Phenocryst abundance of plagioclase varies from 10 to 50 percent. Plagioclase occurs in 1- to 4-mm-long, zoned euhedral crystals with a variable composition of An 52 to An 71. Subhedral to euhedral clinopyroxene 0.5- to 2-mm-long account for 3 to 10 percent of rocks studied. The clinopyroxene is pale purplish brown under plain light with an approximate 2V of 60 degrees. This is characteristic of augite. Grains of orthopyroxene are subhedral, average 0.5 mm in diameter and account for 2 to 10

Figure 11. Typical Silver King andesite flow. This unit is extensively quarried for road gravel (SW1/4 sec. 33, T. 7 S., R. 5 E.)

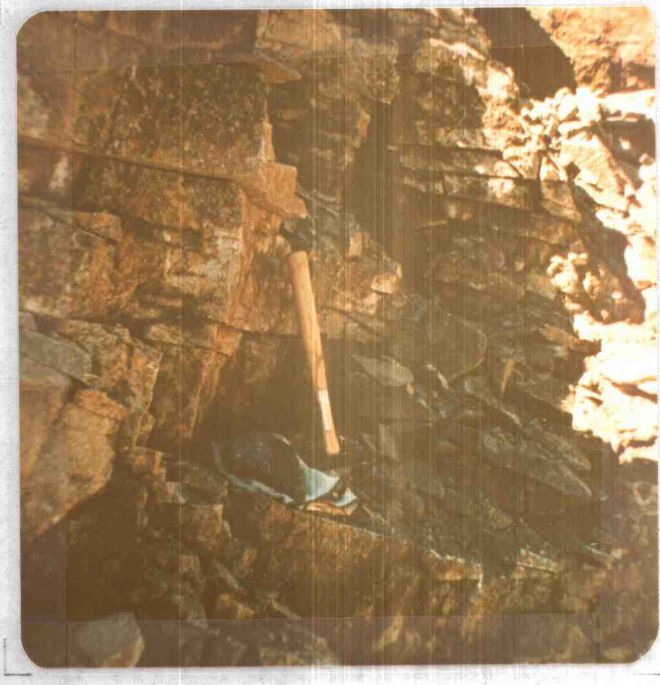

Figure 12. Typical platy jointing and reddish color of Silver King andesite with hammer for scale (NW1/4 sec. 5, T. 7 S., R. 6 E.).

percent of the rocks. These grains are optically negative with a large 2V and pink to pale green pleochroism. Olivine is anhedral, crystal average 0.75 mm in diameter, and vary from 0 to 5 percent of the rock.

Groundmass constituents are magnetite, hematite, plagioclase, pyroxene, devitrified glass, and the alteration products chlorite and celadonite. Magnetite is well-disseminated with an average crystal diameter of 0.75 mm. Hematite is common and produces the brownish red of weathered outcrop surfaces. The most noticeable alteration product in thin section is celadonite which has stringers of magnetite throughout (fig. 13). Chlorite is not common in Silver King andesite.

Chemical analyses of Silver King andesite disclose a range of SiO_2 from 54 to 70 percent (Appendix 1). The most common SiO_2 composition for this unit is 56 percent. These rocks are porphyritic, pilotaxitic olivine and hypersthene-bearing augite basaltic andesites and porphyritic pilotaxitic augite-bearing dacites.

Nohorn Creek basaltic andesite

Nohorn Creek basaltic andesite is a distinctive black vesicular lava flow which crops out in two locations: along Hugh Creek in sec. 28, T. 7 S., R. 5 E. and along Nohorn Creek in sec. 28, T. 7 S., R. 5 E. These outcrops cover 0.65 and 0.16 km^2 respectively. Best exposures are in road cuts along road S-741 up Hugh Creek valley and along road S-70A next to Nohorn Creek.

Peck and others (1964) assigned the rocks cropping out along Hugh Creek and Nohorn Creek to the Sardine Formation of middle to late Miocene age.

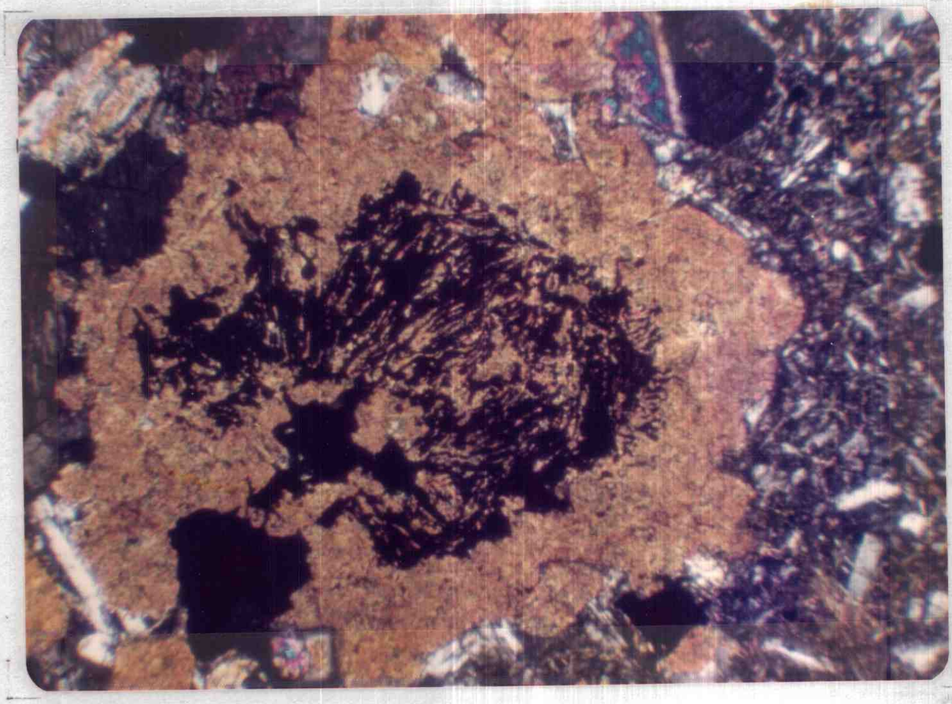

Figure 13. Photomicrograph of celadonite with magnetite stringers. (Sample RD-26-74 from SW1/4 sec. 21, T. 7 S., R. 5 E.)

Silver King andesite overlies and underlies Nohorn Creek basaltic andesite. Contacts are covered, but field relationships suggest that Nohorn Creek basaltic andesite is intracanyon to Silver King andesite. The field estimate of maximum thickness was 24 m.

Nohorn Creek basaltic andesite forms a bench along Hugh Creek, narrowing the mouth of Hugh Creek valley. This unit is light brown with blocky jointing and is different from the brownish-red color and predominantly platy jointing of the Silver King andesite which surrounds it (fig. 14). Dominant features of hand specimens of Nohorn Creek basaltic andesite are vesicles, dark gray (N-3) color, and large phenocrysts of plagioclase and pyroxene. Phenocrysts of plagioclase are 4 mm long, phenocrysts of pyroxene are 3 mm long, and vesicles average 2 mm in diameter.

The primary minerals of Nohorn Creek basaltic andesite are plagioclase, clinopyroxene, and orthopyroxene. Nohorn Creek basaltic andesite contains 25 percent of euhedral, zoned plagioclase (An 54) phenocrysts. Phenocrysts of clinopyroxene are euhedral and account for 10 percent of the rock. The clinopyroxene possesses an approximate 2V of 60 degrees and is probably augite. Phenocrysts of orthopyroxene are subhedral and account for 5 percent of the rock. The orthopyroxene has a high 2V and pink-brown pleochroism and is probably hypersthene. Groundmass constituents are plagioclase microlites, disseminated magnetite, devitrified glass, and celadonite. Small rims of hematite also occur in association with hypersthene.

Chemical analysis of Nohorn Creek basaltic andesite disclosed a weight percent SiO_2 of 57.7 (Appendix 2). This unit is a porphyritic

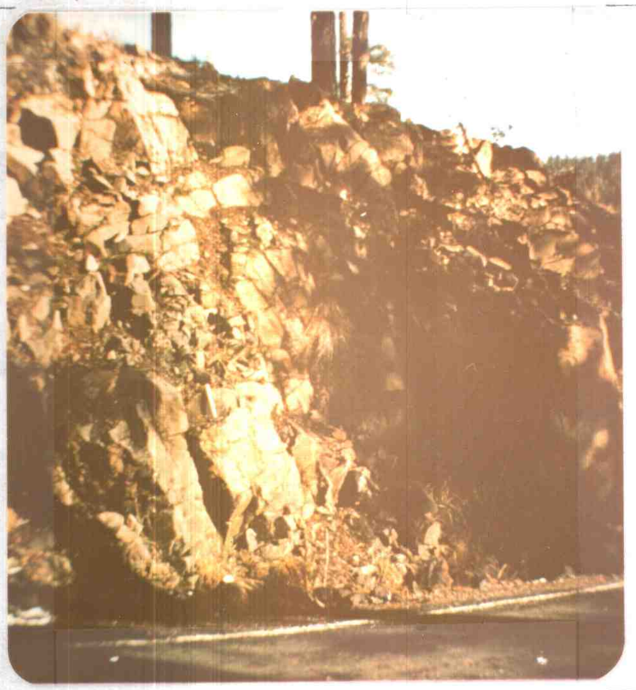

Figure 14. Nohorn Creek basaltic andesite with blocky jointing along road S-741 in SE1/4 sec. 28, T. 7 S., R. 5 E. (Hammer for scale.)

hypersthene-bearing augite basaltic andesite.

Hugh Creek basaltic andesite

Hugh Creek basaltic andesite is a lava flow that crops out in bold cliffs on northwest- and west-trending ridges extending from the main north-trending ridge between Hugh Creek and Hot Springs Fork in sec. 33, T. 7 S., R. 5 E. and sec. 4, T. 8 S., R. 5 E. The total area covered by both outcrops is approximately 0.65 km^2.

Hugh Creek basaltic andesite is underlain by Silver King andesite. Contacts are covered by talus and vegetation, but joint patterns and long, linear ridges formed by this unit suggest a deeply incised intra-canyon relationship. Estimates of thickness made in the field were 61 m.

The rocks the author terms Hugh Creek basaltic andesite were all assigned by Peck and others (1964) to the Sardine Formation of middle to late Miocene age.

Outcrops of Hugh Creek basaltic andesite are dark gray and stand out in contrast to the red soils and rocks of Silver King andesite. Jointing is columnar and well-outlined in vertical and horizontal patterns on the cliff faces (fig. 15). Hand specimens of Hugh Creek basaltic andesite are dark gray (N-3) and are very fine-grained with a few small phenocrysts. Phenocrysts of Plagioclase and pyroxene are less than 1 mm in length.

Petrographically Hugh Creek basaltic andesite is pilotaxitic with phenocrysts which account for 30 to 35 percent of the rock. Hugh Creek basaltic andesite is unique in that two stages of primary phenocrysts are present. The two minerals with distinct phenocryst assemblages are plagioclase and clinopyroxene. One plagioclase variety is represented by anhedral grains 2.5 mm long with a composition of An 54 and has been attacked by groundmass (fig. 16). The second variety is subhedral with an average grain length of 0.5 mm with a composition of An 71 and has not been attacked by groundmass. In both varieties, the phenocrysts are zoned. Phenocrystic abundance of plagioclase is 5 percent, divided equally between the two varieties. Ten percent of the rock consists of nonpleochroic subhedral greenish-brown clinopyroxene crystals up to 1.5 mm in diameter. This variety of clinopyroxene has an approximate 2V of 60 degrees and is considered augite. Fifteen percent consists of anhedral clinopyroxene crystals up to 4 mm long. This variety is altered to magnetite and chlorophaeite with only small cores remaining which have incline extinction and high birefringence (fig. 17). Olivine and quartz are present in only one aspect. Olivine grains are 0.5 mm in diameter and account for 5 percent of the rock. Olivine is altered to a greenish-gray fibrous serpentine mineral. The rock contains less than 1 percent anhedral quartz phenocrysts that are 0.5 mm in diameter (fig. 18). Quartz phenocrysts are surrounded by a ring of small clinopyroxene crystals that in turn are surrounded by a zone of devitrified glass. Groundmass constituents are smaller crystals of the same minerals along with magnetite and chlorophaeite. Magnetite and chlorophaeite are well-disseminated throughout the rock and do not exceed 0.2 mm in diameter.

The two types of plagioclase with a wide range of composition and two types of clinopyroxene could be accounted for by some form of magmatic contamination. This contamination could be by assimilation or

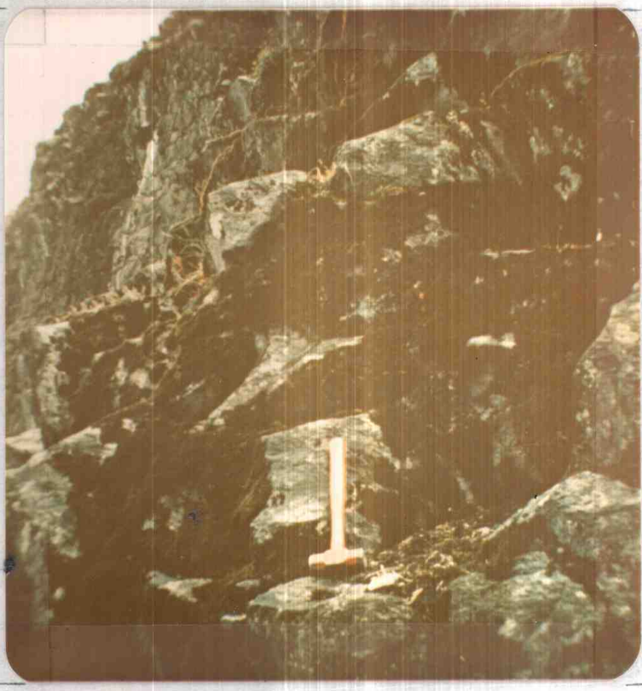

Figure 15. Hugh Creek basaltic andesite with columnar jointing outlined in the cliff face. Found in SE1/4 sec. 33, T. 7 S., R. 5 E. (Hammer for scale.)

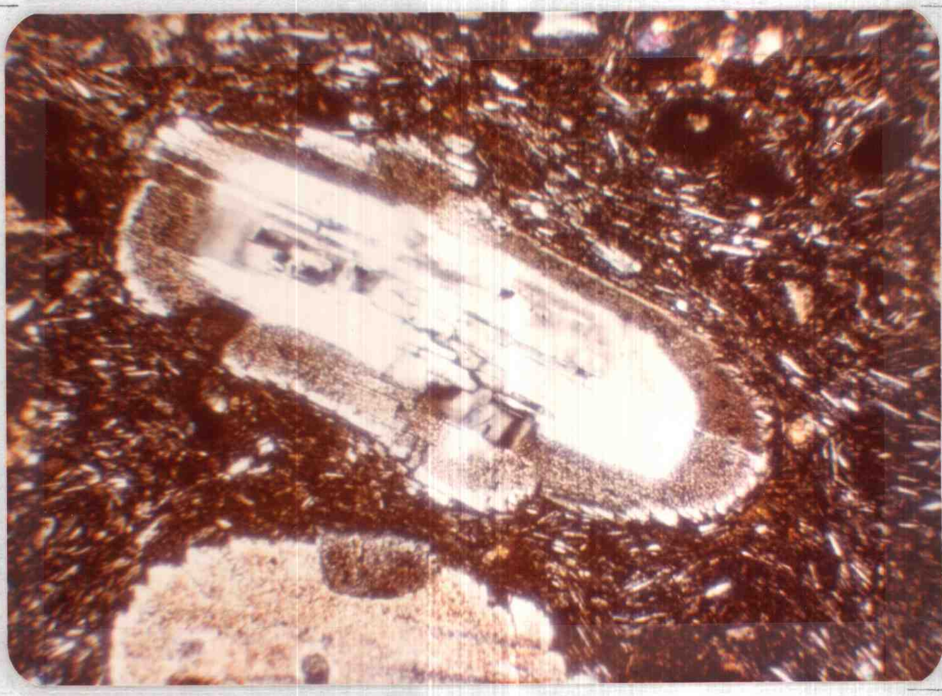

Figure 16. Photomicrograph of plagioclase (An 54) phenocryst that was being attacked by the groundmass (Sample No. RD-5-74 found in sec. 4, T. 8 S., R. 5 E.).

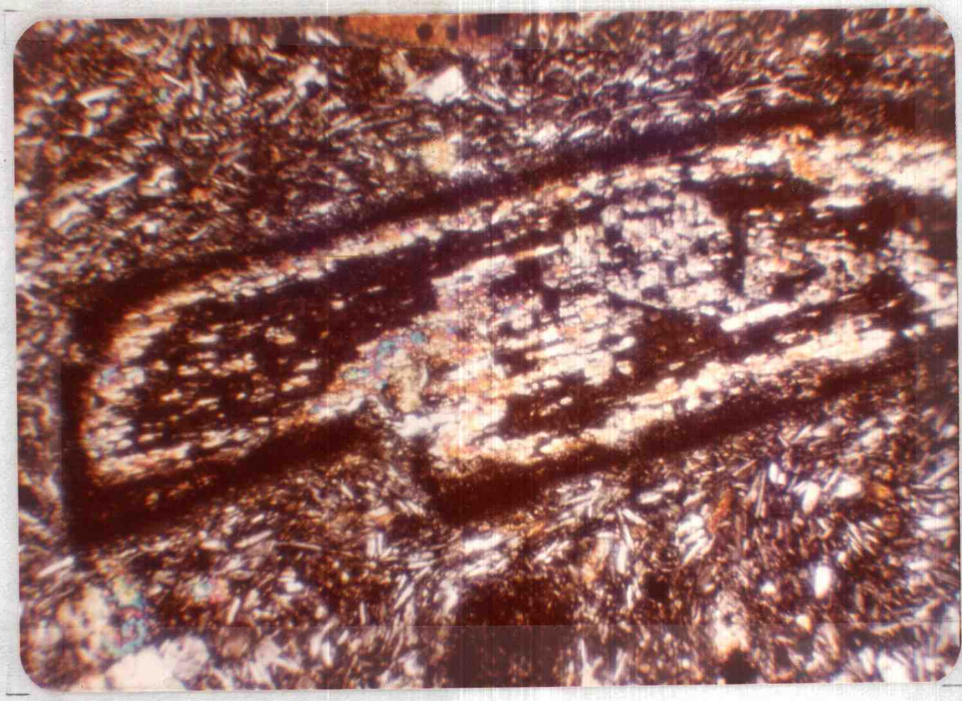

Figure 17. Photomicrograph of highly-altered clinopyroxene phenocryst of Hugh Creek basaltic andesite. Alteration products are chlorophaeite and magnetite (Sample No. RD-3-74 found in SE1/4 sec. 33, T. 7 S., R. 5 E.).

Figure 18. Photomicrograph of quartz phenocryst with a reaction rim of clinopyroxene found in Hugh Creek basaltic andesite (Sample No. RD-3-74 found in SE1/4 sec. 33, T. 7 S., R. 5 E.).

mixing of magmas. Because magmas are generally at a temperature just above their solidus, assimilation would be incomplete and xenoliths would be present. There were no xenoliths observed in Hugh Creek basaltic andesite. This leaves mixing of magmas. Olivine is completely replaced indicating an unstable environment. Double varieties of minerals, reaction rims, and imbayed crystals represent the complete mixing of a basaltic and more silicic magma sometime before eruption. Phenocrysts from the silicic magma are: altered plagioclase (An 54), the more abundant - larger-altered clinopyroxene, and the quartz with the reaction rims. Phenocrysts from the mafic magma are: plagioclase (An 71), nonaltered clinopyroxene, and highly-altered olivine.

Chemical analyses of the Hugh Creek basaltic andesite disclosed an SiO^2 composition of 55 percent (Appendix 2). This unit is a porphritic pilotaxitic olivine-bearing augite basaltic andesite.

Dutch Creek Tuff

General Statement

Dutch Creek tuff is a very soft, poorly exposed, and nonwelded ashflow tuff. When found in road cuts, this unit is very light in color with abundant lithic fragments and large relatively undeformed pumice lumps (fig. 19). This unit produces a sandy soil that contains pumice lumps. Dutch Creek tuff is located along road S-53 just south of the northern boundary of the thesis area in sec. 1 and 2, T. 7 S., R. 5 E. Total area covered by this unit is 0.66 km^2.

Dutch Creek tuff is underlain by Silver King andesite and overlain by Thunder Mountain andesite. Contact relationships are not well-exposed,

Figure 19. Dutch Creek tuff outcrop found in NW1/4 sec. 1, T. 7 S., R. 5 E. showing the white pumice lumps and the dark lithic fragments. (Hammer for scale.)

but the lens-shape of this unit suggests that it lies in a depression cut into the Silver King andesite. The upper contact with the Thunder Mountain andesite also appears to be unconformable. At the base of Thunder Mountain, Dutch Creek tuff wedges out against Silver King andesite. Thickness of Dutch Creek tuff is variable due to its shape, but a field estimate of maximum thickness was 61 m.

Peck and others (1964) assigned the rocks that crop out at the base and east of Thunder Mountain to the Sardine Formation of early to late Miocene age.

Lithology

Dutch Creek tuff is a nonwelded slope former that stands out against the darker soils and rocks of the Silver King andesite and Thunder Mountain andesite. A jointing pattern is not evident in this unit. Hand specimens are yellowish-gray (5 Y 7/2) and contain abundant lithic fragments, pumice lumps, and crystals of plagioclase, hornblende, and quartz. Lithic fragments are subangular to subrounded with the largest 5 cm in diameter and account for 10 percent of the rock. Lithic fragments consist of euhedral plagioclase crystals 3 mm long and pyroxene crystals 0.2 mm long. Twenty percent of the rock is white (N-9) devitrified pumice lumps that are 5 cm long. Primary minerals are plagioclase crystals 3 mm long, hornblende crystals 2 mm long, and quartz crystals 1 mm long that account for 10 percent, 10 percent, and 15 percent of the rock respectively. The overall mix of dark constituants and light constituants gives hand samples of Dutch Creek tuff a salt and pepper appearance.

Thin sections of mounted grains of plagioclase and hornblende were studied. Plagioclase (An 19) occurs in zoned euhedral crystals. Hornblende crystals are euhedral with green to brown pleochroism.

The composition of the magma before eruption can be estimated by analysis of pumice lumps. Dutch Creek tuff pumice has an SiO_2 content of 72.9 percent (Appendix 3) and is equivalent to a porphyritic hornblende dacite.

Thunder Mountain Andesite

General Statement

Thunder Mountain andesite consists of a series of lava flows and flow breccias of variable thickness. Thunder Mountain andesite crops out on the northern and northwestern ridge tops and along the southern boundary of the thesis area. The northern outcrops appear to be isolated, but they join together to the northwest beyond the thesis area. Many outcrops have slumped to a low position in the valleys.

Silver King andesite and Dutch Creek tuff underlie Thunder Mountain andesite. Contact relations are obscure due to vegetation and talus, but field relationships suggest that the basal Thunder Mountain flow lies in small depressions in Silver King andesite and Dutch Creek tuff while the upper flows are sheetlike. Overlying the Thunder Mountain andesite are the sedimentary rocks of Whetstone Mountain. The relationship between these two units will be discussed under the section involving Whetstone volcaniclastic rocks. Total thickness of Thunder Mountain andesite was not measured because of limited vertical exposure, but the thickness of individual flows averaged 7.6 m.

Jointing ranges from blocky to columnar (fig. 20). Where outcrops are deeply weathered, columnar jointing produces hoodoos that are characteristic of this unit. Hoodoos are not as well developed in blocky jointed outcrops.

Rocks of the ridge tops in the thesis area where Thunder Mountain andesite crops out were assigned by Peck and others (1964) to the Sardine Formation of early to late Miocene age.

Lithology

The dense interior of Thunder Mountain andesite forms cliffs and the associated flow breccia forms gentle slopes. Hand specimens are characterized by phenocrysts of plagioclase and pyroxene in a vitric groundmass. Tabular plagioclase crystals are smaller than 2 mm in length and equidimensional pyroxene crystals are smaller than 1.5 mm in diameter. Color of hand samples is medium dark gray (N-4).

The texture of Thunder Mountain andesite is hyalopilitic and porphyritic. Total phenocryst abundance varies from 35 to 45 percent. The rock contains 20 to 30 percent strongly-zoned, euhedral phenocrysts of plagioclase (An 52 to An 56) that do not exceed 2 mm. Clinopyroxene phenocrysts are augite with an approximate 2V of 60 degrees. Augite is euhedral, 1.5 mm long, and accounts for 5 to 10 percent of the rock. Orthopyroxene has parallel extinction, low birefringence, and the pink pleochroism of hypersthene. Hypersthene is subhedral, crystal average 1 mm long, and accounts for 5 to 10 percent of the rock. Groundmass constituents are small, well-disseminated magnetite grains, plagioclase microlites, divitrified glass, and celadonite.

Figure 20. Columnar jointing of Thunder Mountain andesite that weathers to form characteristic hoodoos. Found in sec. 36, T. 6 S., R. 5 E.

Chemical analyses were performed on selected samples from Thunder Mountain andesite (Appendix 3). Weight percent of SiO_2 varies from 54.0 to 59.8. Thunder Mountain andesite ranges from porphyritic hypersthene augite-bearing basaltic andesite to porphyritic hypersthene augite-bearing andesite.

Whetstone Mountain volcaniclastic rocks

General statement

Whetstone Mountain volcaniclastic rocks are epiclastic volcanic tuffs and breccias. The lower part of the Whetstone Mountain section is composed of thickly-bedded breccia and the upper part is composed of thinly-bedded tuff. Whetstone Mountain volcaniclastic rocks are located along the eastern edge of Whetstone Mountain in sec. 21, T. 8 S., R. 5 E. The total area covered is 0.16 km^2. This unit is thicker and differs from the small fluvial gravel and mud lenses that occur between ash flows and lava flows of Blister Creek tuff and Silver King andesite.

Whetstone Mountain volcaniclastic rocks are underlain by the southern part of the bench-forming Thunder Mountain andesite. The contact between these two units is covered by a thick stand of trees and colluvium. The field estimate of maximum thickness was 46 m.

Peck and others (1964) assigned the rocks that crop out below Whetstone Mountain to the Sardine Formation of middle to late Miocene age.

Lithology

Whetstone Mountain volcaniclastic rocks are light green cliff formers that appear similar to the platy and blocky Silver King andesite.

Platy jointing occurs in the tuff and is produced by the splitting of bedding into irregular slabs 1 cm to 5 cm thick (fig. 21). Blocky jointing occurs in the breccia and is produced where the bedding is thicker.

The breccia contains subangular to subrounded lithic and pumice fragments in a fine matrix which does not have any evident internal sedimentary structures. Pumice and lithic fragments account for 50 and 10 percent of the breccia, respectively, and range in diameter from less than 1 mm to 7 cm with an average of 1 cm. The breccia zone grades into the tuff zone where the clasts of the breccia become subordinate to the sandy matrix. The tuff zone consists of laminae 1 cm thick which grades into 0.5 mm layers of finer material. The third dimension of laminae appear to be lenticular. Cross-lamination is found in occasional lamina, but most do not have current structures. Pumice and lithic fragments in the tuff account for 60 and 8 percent respectively. The breccia is a light olive gray (5 Y 6/1) and the tuff is light greenish-gray (5 GY 8/1).

Pumice fragments are 0.25 mm in diameter in the tuff and in both zones the pumice is devitrified. Lithic fragments are not altered and have a pilotaxitic texture with magnetite in a devitrified glass groundmass. Mineral fragments present in both zones are plagioclase, quartz, and zircon. Plagioclase (An 36) occurs in 10 percent of the rock as subhedral grains 0.2 mm long. Each plagioclase grain has altered zones that are now calcite. Five percent of the rock is subhedral quartz grains 0.2 mm in diameter. Zircon grains are less than 0.2 mm in diameter and account for one to three percent of the rocks.

Figure 21. Platy jointing produced along bedding planes of Whetstone Mountain volcaniclastic rocks in sec. 21, T. 8 S., R. 5 E. (Brunton compass for scale.)

Matrix material is composed of well-disseminated magnetite and devitrified glass, cemented by quartz and calcite. The cementing materials appear to have been derived predominately from alteration of plagioclase and devitrification of glass. Calcite is concentrated in 0.5-mm-thick veins throughout the rocks. Alteration of the few mafic minerals present has produced a fibrous, pleochroic green, chloritic material with gray-green interference colors.

Deposition

Outcrop and hand specimens of Whetstone Mountain volcaniclastic rocks do not have significant primary sedimentary structures upon which to base paleocurrent studies. The only structure evident is the vertical grading of coarse fragments in the breccia, upward to sand-size fragments, which in turn, grade into 1-mm-thick, very fine-grained sediments. Fossil remains and carbonaceous materials were not found in hand samples or thin sections of the rock. The lack of sedimentary current structures and organic remains, along with excellent grading, suggests that Whetstone Mountain volcaniclastic rocks were deposited under lacustrine conditions.

Hugh Creek ignimbrite

General statement

Hugh Creek ignimbrite is a distinctive unit with large hornblende crystals and collapsed pumice lumps. This unit crops out in two locations which will be referred to as Hugh Creek section and North Dickey Peak section. Hugh Creek section is near the head of Hugh Creek valley along road S-741 in sec. 17, T. 8 S., R. 5 E. and extends north along the ridge between Hugh Creek and Nohorn Creek. North Dickey Peak section is on North Dickey Peak in sec. 5, T. 8 S., R. 6 E., and is continuous along the northeast-trending ridge that is just outside the thesis area. Hugh Creek and North Dickey Peak sections cover 1.3 and 0.65 km^2, respectively.

Both sections of Hugh Creek ignimbrite are underlain by Silver King andesite. Contacts are covered by thick stands of vegetation and colluvium, but the linear distribution along ridge tops suggests an intracanyon relationship where this unit lies in valleys cut into the Silver King andesite. This intracanyon relationship combined with the present topography accounts for the small size and scarce outcrops of this unit. Field estimates of thickness varied, but the maximum was 122 m.

Peck and others (1964) assigned the rocks cropping out on North Dickey Peak and at the headwaters of Hugh Creek to the Sardine Formation of middle to late Miocene age.

Lithology

Outcrops of Hugh Creek ignimbrite are cliff formers with large talus slopes at the base. Both sections have blocky jointing and vary from light to dark brown. Using Smith's (1964) criteria, Hugh Creek ignimbrite can be classified as partially welded. Other welding zones were not found, particularly a nonwelded base.

Hand specimens of the Hugh Creek section are dominated by hornblende crystals and parallel lens-shaped pumice lumps (fig. 22). The pumice lumps are softer so they weather faster than the groundmass.

Twenty percent of the rock consists of moderate yellowish-brown (10 YR 5/4) pumice lumps that reach 10 cm in length. The groundmass is dusky yellowish brown (10 YR 2/2). On fresh surfaces, Hugh Creek section is dark gray (N-4). Hornblende crystals reach 3 mm in length and account for 5 percent of the rock. The Hugh Creek section is eutaxitic (fig. 23) with subhedral to euhedral matrix minerals. Major constituents of the Hugh Creek section are devitrified pumice lumps, hornblende, augite, plagioclase, quartz, and lithic fragments. Devitrification has produced zones of chalcedony around the pumice. Hornblende is pleochroic green with an approximate 2V of 70 degrees. Augite phenocrysts average 0.5 mm in diameter and account for 5 percent of the rock. Forty percent of the rock consists of zoned plagioclase (An 60) fragments that do not exceed 2 mm in length. Lithic fragments are porphyritic with subhedral plagioclase (An 43) phenocrysts in a predominantly devitrified glass and magnetite groundmass.

Hand specimens of the North Dickey Peak section do not contain the large lens-shaped pumice lumps, but they contain large hornblende cyrstals and more lithic fragments than the Hugh Creek section. Twenty percent of this unit is composed of pumice lumps which are 1 cm in diameter. Hornblende crystals are 3 mm long and account for 15 percent of the rock. Five percent of the rock consists of subangular to subrounded lithic fragments that average 0.5 cm in diameter. Fresh and weathered surfaces of the North Dickey Peak section are a pale yellow brown (10 YR 6/2). Petrographic texture is eutaxitic with subhedral to euhedral groundmass minerals. Major constituents of the North Dickey Peak section are devitrified and spherulitic pumice lumps, hornblende,

Figure 22. Parallel lens-shaped pumice lumps of Hugh Creek ignimbrite (SE1/4 sec. 8, T. 8 S., R. 5 E.).

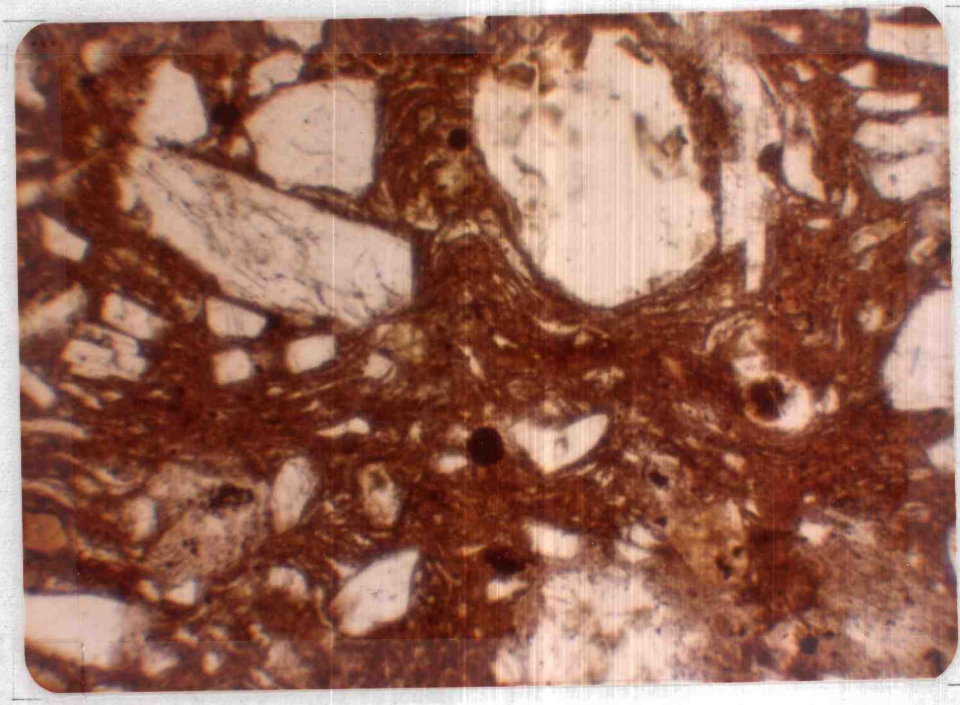

Figure 23. Photomicrograph of Hugh Creek section eutaxitic texture (Sample No. M-997 found in SE1/4 sec. 8, T. 8 S., R. 5 E.).

plagioclase, zircon, and lithic fragments. Hornblende phenocrysts are pleochroic green with an approximate 2V of 70 degrees. Twenty-five percent of the rock is zoned plagioclase (An 47) crystals 1.5 mm long. Zircon grains are well-disseminated throughout the rock and are 0.2 mm in diameter. Lithic fragments account for 5 percent of the rock and are similar to those found in the Hugh Creek section.

Alteration products in rocks from both sections are similar and are derived from mafic mineral grains. The Hugh Creek section contains chlorite and magnetite while the North Dickey Peak section contains celadonite and magnetite.

Chemical analysis of the pumice from Hugh Creek ignimbrite provides the best available estimate of the original composition of the magma. Weight percent SiO_2 is 55.8 (Appendix 3). This chemical analysis did not account for volatiles in the magma; however, hornblende crystals would indicate the presence of high water vapor pressure (Macdonald, 1972). Hugh Creek ignimbrite is equivalent to a porphyritic hornblende-bearing basaltic andesite.

The Hugh Creek ignimbrite contains white, lens-shaped hypidiomorphic granite inclusions 6 cm long (fig. 24). These inclusions contain 40 percent subhedral sanidine grains averaging 1.5 mm in diameter with a small 2V that is almost zero. The sanidine was probably produced by the transformation of orthoclase in a granitic body that was intruded by magma. During the eruption, pieces of the granitic body were broken off, heated, and extruded with the magma so that cooling was rapid and the sanidine was quenched. Other than sanidine, major constituents are quartz, biotite, plagioclase, zircon, and magnetite. Thirty percent of the rock consists of subhedral quartz crystals 1 mm in diameter. Five percent of the rock consists of euhedral biotite crystals 0.2 mm long and subhedral plagioclase (An 12) crystals 1 mm long. Zircon and magnetite are well-disseminated throughout the rock and are 0.2 and 0.5 mm in diameter, respectively.

The inclusions are cut by veins 0.2 mm wide that contain calcite, chlorite, and chalcedony (fig. 25). Of the three vein minerals, calcite is dominant.

Stratigraphic importance

Hugh Creek ignimbrite, with its large lens-shaped pumice lumps and hornblende phenocrysts, would make an excellent marker bed. Other than in the thesis area, hornblende tuffs have been found in two locations. Peck and others (1964, p. 34) wrote about an unusual hornblende tuff cropping out near High Camp. An outcrop was located near Battle Ax Mountain by Craig White, University of Oregon graduate student (Hammond, verbal communication, 1974).

Intrusions

Pin Creek andesite

Pin Creek andesite lies in the eastern end of Hot Springs Fork valley in sec. 7, T. 7 S., R. 6 E. and is the largest intrusive body found in the thesis area. It is an irregularly-shaped mass that penetrates Blister Creek tuff and creates a hill 122 m high. Excellent exposures are found in cuts along road S-70 and in the stream bed of Hot Springs Fork, but tend to be obscured under a thick blanket of landslide

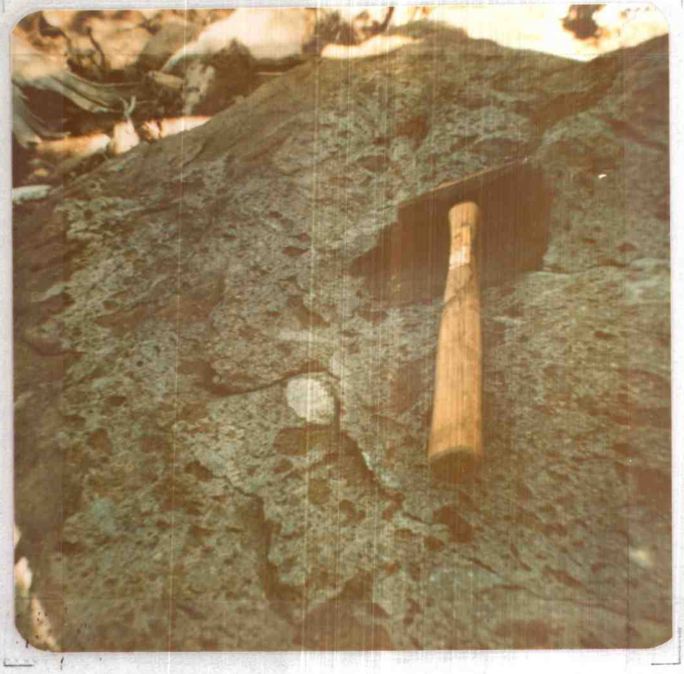

Figure 24. Hugh Creek ignimbrite with white granitic inclusion. Found in SE1/4 sec. 8, T. 8 S., R. 5 E. (Hammer for scale).

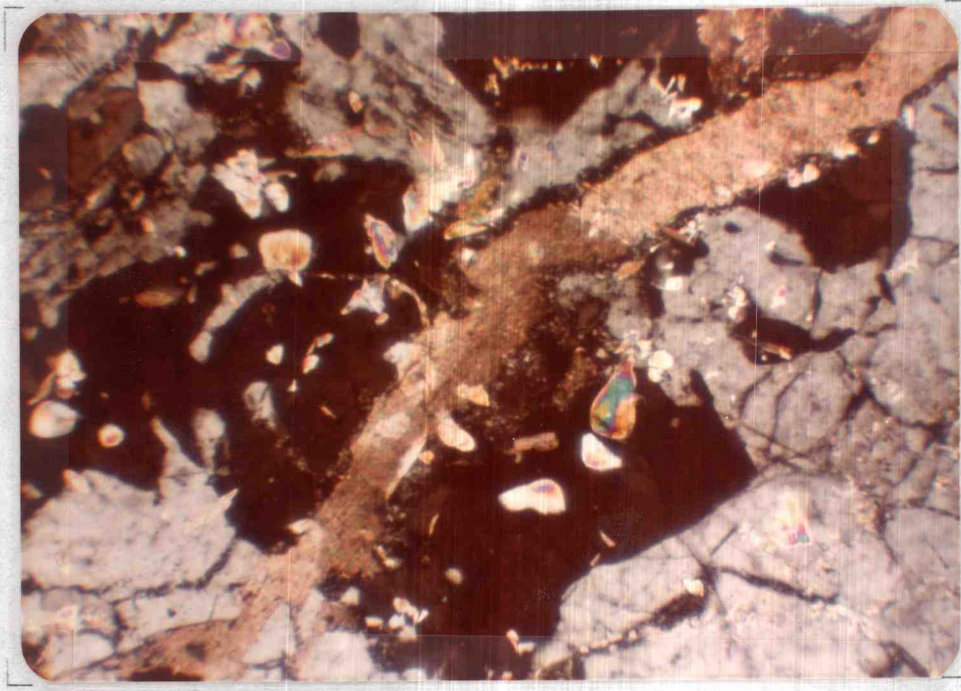

Figure 25. Photomicrograph of vein containing calcite, chalcedony, and chlorite in Hugh Creek section (Sample No. M-997 found in SE1/4 sec. 8, T. 8 S., R. 5 E.).

debris and till. Total area covered by Pin Creek andesite is approximately 0.32 km^2.

Contacts between this intrusion and Blister Creek tuff are covered by till and landslide debris. Field relationships suggest that an irregular, discordant body cuts through Blister Creek ash-flow tuffs and therefore, must be younger than early Miocene.

Lithology

Pin Creek andesite is a cliff former which can be distinguished from the surrounding ash-flow tuffs by the different jointing pattern. Jointing is in the form of irregular blocky, horizontal columns which produce a stair-step effect.

The most distinctive feature of the Pin Creek intrusion is the presence of quartz phenocrysts, 4 mm in diameter. Primary quartz is rare in rocks found in the thesis area. Small hornblende phenocrysts, 1 mm long, are also present. The color of rocks from this unit is greenish-gray (5 GY 6/1).

Phenocrysts make up approximately 45 percent of the Pin Creek andesite. Phenocryst minerals are quartz, plagioclase, and hornblende. Eight percent of the rock is anhedral quartz which is embayed (fig. 26). Zoned plagioclase (An 44) phenocrysts are 2 to 4 mm in length and account for 30 percent of the rock. Seven percent of the rock is altered, subhedral to euhedral, hornblende grains that are 1 mm long and identifiable only by their six-sided shape. Groundmass constituents are very fine-grained calcite, chlorite, magnetite, zircon, and devitrified glass. Zircon and magnetite grains are well-disseminated throughout the

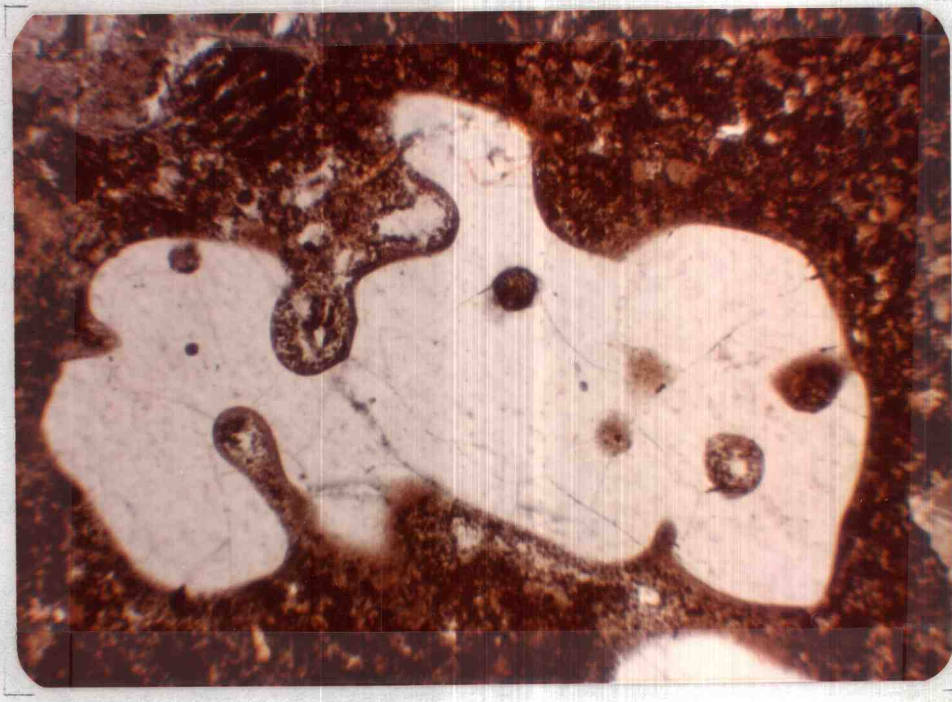

Figure 26. Photomicrograph of embayed quartz phenocryst in Pin Creek andesite (Sample No. M-998 found in SE1/4 sec. 7, T. 7 S., R. 6 E.).

rock while calcite and chlorite are associated with altered hornblende. Calcite occurs also as fine grains throughout the groundmass.

Chemical analysis of the Pin Creek andesite discloses an SiO_2 content of 63.9 percent (Appendix 4). This analysis does not account for water vapor or other volatiles in the magma. Pin Creek andesite is a hornblende and quartz-bearing andesite porphyry. Presence of quartz in a low silica rock is anomalous. This phenomena can be accounted for by primary crystallization of the magma under very high water vapor pressure (Tuttle and Bowen, 1958), as the presence of hornblende would indicate, or by the assimilation of a silicic body of the magma so that the quartz is xenocrystic.

Whetstone Mountain andesite porphyry

Whetstone Mountain andesite porphyry is a large, round intrusive body lying in and above Thunder Mountain andesite along the southwestern border of the thesis area, 0.8 km due north of Whetstone Mountain in sec. 16, T. 8 S., R. 5 E. Whetstone Mountain andesite porphyry extends down into East Gold Creek drainage out of the thesis area and covers approximately 0.08 km^2 within the thesis area. Contacts between Whetstone Mountain andesite porphyry and Thunder Mountain andesite are obscure, but field relationships suggest a resistant, discordant circular body cutting Thunder Mountain andesite and therefore, younger than late Miocene.

Lithology

Whetstone Mountain andesite porphyry has a light greenish-gray color that stands out from the surrounding dark gray flows. Jointing is irregular and blocky, similar to that of the Thunder Mountain andesite. Hand samples have a light gray (N-7) color. Phenocrysts of plagioclase and pyroxene are visible in a fine-grained groundmass.

The rock is porphyritic with phenocrysts of plagioclase, clinopyroxene, orthopyroxene, and olivine. Forty-five percent of the rock consists of zoned euhedral plagioclase (An 54) phenocrysts of variable size with the largest 3 mm long. Clinopyroxene phenocrysts up to 4 mm long are euhedral and account for 3 percent of the rock. The clinopyroxene phenocrysts have an approximate 2V of 60 degrees and are brownish-purple in plain light; this is characteristic of augite. Ten percent of the rock is pleochroic-green chloritic material surrounding cores of pleochroic-pink orthopyroxene. The entire length of orthopyroxene grains, including the altered zones, does not exceed 1 mm. Two percent of the rock consists of anhedral olivine grains 0.4 mm in diameter.

Groundmass constituents are small pyroxene crystals, plagioclase microlites, magnetite, chlorite, and devitrified glass. Well-disseminated magnetite grains are less than 0.5 mm in diameter.

Whetstone Mountain andesite porphyry has an SiO_2 content of 59.3 percent (Appendix 4). This rock is an olivine- and augite-bearing orthopyroxene andesite porphyry.

Silver Lady Andesite

Silver Lady andesite is a small dike emplaced into Silver King andesite near the Silver Lady mining claim. This dike is well-exposed along road S-70. Total length of the dike that can be followed is approximately 0.8 km with a trend of N 45 W. The width in the road cut is 1.5 m. Contacts between Silver King andesite and this dike are vertical and sharp. The dike possesses distinct horizontal columnar jointing and is light green which stands out against the brownish-red of Silver King andesite.

Because Silver Lady andesite is emplaced into Silver King andesite, it is younger than late Miocene.

Lithology

Hand specimens of Silver Lady andesite exhibit phenocrysts of plagioclase and pyroxene 4 mm and 2 mm in length, respectively. Fresh surfaces are medium gray (N-5).

The texture of Silver Lady andesite is hyalopilitic with phenocrysts of plagioclase and clinopyroxene. Plagioclase (An 40) occurs in zoned euhedral crystals that account for 40 percent of the rock. Fifteen percent of the rock is clinopyroxene that has the optical properties of augite. Groundmass constituents are magnetite, small pyroxene, zircon, and devitrified glass. Magnetite and zircon are well-disseminated throughout the rock in grains averaging 0.25 mm to 0.1 mm in diameter, respectively. Alteration of primary minerals has produced chlorite, calcite, and chalcedony. Chlorite is disseminated throughout the rock while calcite is associated with feldspar phenocrysts.

Chemical analysis of Silver Lady andesite revealed a weight percent SiO_2 of 59.9. Silver Lady dike is an augite andesite porphyry.

Pasola Mountain andesite porphyry

Pasola Mountain andesite porphyry crops out as a thick dike emplaced into Silver King andesite near Pasola Mountain and Bull of the Woods trail, U.S.F.S. No. 550, along road S-708, in sec. 32, T. 7 S., R. 5 E. This dike also crops out on the east side of Pansy Basin in sec. 30, T. 7 S., R. 6 E. Total length of the dike is approximately 1.21 km with a trend of N 85 W and total width is 6.1 m. Contacts between this dike and Silver King andesite are sharp. Pasola Mountain andesite porphyry stands out due to its light tan color and the pseudo-horizontal columnar jointing (fig. 27).

Because Pasola Mountain andesite porphyry is emplaced into Silver King andesite, it is younger than late Miocene.

Lithology

Pasola Mountain andesite porphyry is very distinctive due to its light olive-gray (5 Y 6/1) color, horizontal columnar jointing, and phenocrysts of plagioclase and altered mafic minerals. Plagioclase phenocrysts are 5 mm long and the mafic minerals are 1 to 2 mm long.

The primary phenocrysts in Pasola Mountain andesite porphyry are plagioclase, orthopyroxene, and augite. Thirty-five percent of the rock is zoned euhedral plagioclase (core An 37). Orthopyroxene is the smaller mafic phenocryst and accounts for 15 percent of the rock. This mineral is pleochroic red and is anhedral due to alteration to celadonite around the edges. Five percent of the rock is euhedral augite phenocryst that averages 2 mm in length and is light green under plain light.

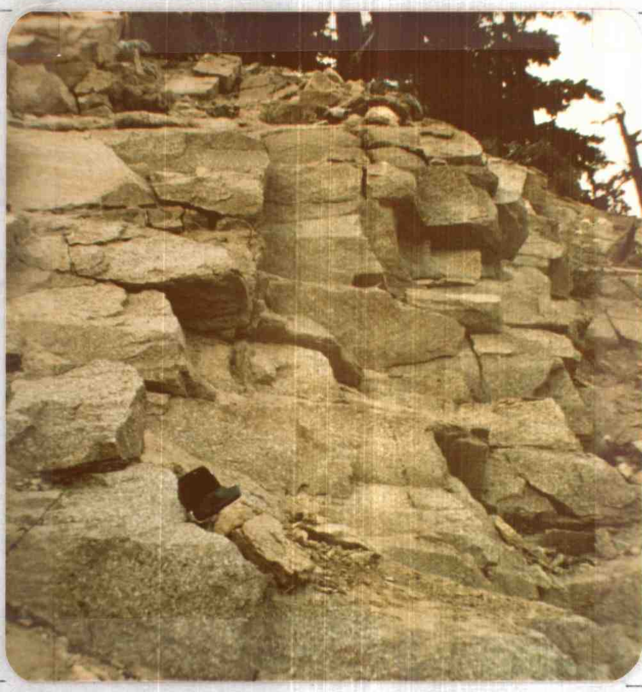

Figure 27. Pseudo-horizontal columnar jointing of Pasola andesite porphyry found in NW1/4 sec. 32, T. 7 S., R. 6 E. (Camera case for scale).

Groundmass constituents are plagioclase, magnetite, pyroxene, devitrified glass, and celadonite. All groundmass minerals are less than 1 mm in diameter and disseminated throughout the rock.

Chemical analysis of Pasola Mountain andesite porphyry reveals a weight percent SiO_2 of 62.8 (Appendix 5). This rock is an augite-bearing orthopyroxene andesite porphyry.

Quarternary deposits

Alluvium

Recent stream sediments are found on the floors of major valleys. Deposits range in size from a thin veneer on stream banks to an extensive network of sand and gravel bars at the confluence of the Hot Springs Fork and the Collawash River. Grade sizes range from clay to subangular and rounded volcanic boulders 30 cm in diameter.

Till

Major valleys are blanketed with a widespread and thick layer of till and outwash. The till deposits consist of angular unsorted voccanic boulders, cobbles, and sand in a very fine matrix. Two very large medial moraines are found in Bagby Valley. These glacial deposits are the result of late Pleistocene glaciation of the western Cascades.

Colluvium

Colluvium is extensive throughout the thesis area and has obscured many outcrops and contact relationships. These deposits are generally in the form of landslides, slumps, and talus at the base of prominent cliffs. Slide and slump activity is concentrated where Blister Creek tuff and hydrothermally-altered rocks crop out. These rocks are soft and possess abundant secondary clay minerals which add to the mobility of the rocks when they are wet. Many of these clays swell when wet, indicative of smectite. In many locations in the thesis area, Blister Creek tuff has dips into the major glaciated valleys which adds to the sliding activity.

STRUCTURE

General statement

Structural relations in the thesis area are difficult to interpret due to the lack of exposed strata on which to take attitudes and the lack of stratigraphic marker beds with which to determine location, orientation, and displacement of faults. Where attitudes can be measured, dip is consistently between 8 to 12° to the north or northwest, and strike varies from east-west in the northeast section to northeast-southwest in the northwest and southwest sections of the thesis area.

Although the major stratigraphic units are separated by unconformities, the attitudes of all units are uniform and indicate erosion-produced unconformities rather than tectonic unconformities.

Folds

The thesis area lies along the western limb of a broad northeast-plunging anticline that is an extension of the anticline outlined by Peck and others (1964) and the Mehama anticline of Thayer (1936). Based upon attitudes taken inside the thesis area and reconnaissance work outside the thesis area, the anticlinal axis is located to the east and southeast of the thesis area and is not shown on the geologic map (pl. 1).

Hammond (verbal communications, 1974) indicated that small undulating folds occur along the limbs of major western Cascade folds. The anomalous attitudes taken in SE 1/4 sec. 21, T. 7 S., R. 5 E., and the center sec. 21, T. 8 W., R. 5 E. could be caused by these smaller folds or bed rotation associated with slump activity. Other than these two attitudes, there is no indication of small folds occurring on the limbs of the major fold.

Faults

In the thesis area, four faults have been recognized; two have distinctive north-northwest trends and two have east-west trends. The two northwest-trending faults can only be traced 1.6 km. They are of unknown displacement and are found in the road cut along road S-70 at the Silver Lady mining claim. Of the two faults, the western appears to be the largest and has brought Blister Creek tuff and Silver King andesite into fault contact. The two east-west faults can be traced 6.4 to 8.0 km and are of unknown displacement. The southern fault has a N 80 E trend that cuts Pansy Basin, crosses Pansy Ridge, and is lost along the western side of Hot Springs valley. In both valleys, Blister Creek tuff has been brought up in fault contact with Silver King andesite. The northern fault has a N 80 W trend. It cuts all the north-south valleys and ridges. This fault is marked by the 0.53-km-wide saddles it produces on the ridge tops. This fault serves as a conduit for hot water and served as a zone of crustal weakness for the intrusion of dikes. Pasola Mountain dike crops out at two locations along this fault. Based upon their similar trends and eastward convergence, these faults probably merge east of the thesis area.

Hammond (verbal communications, 1974) believes that two generations of major faults are represented in the western Cascade Mountains. The oldest faults have an east-west trend and the youngest have a north-northwest trend. The two small faults near the Silver Lady mining claim could be related to the younger group, while the two large, east-west-trending faults might belong to the older group. However, for these faults, no local evidence of relative age exists.

In the thesis area are many faults of small displacement and length that are associated with slumping. These faults are also represented on the geologic map the same as tectonic faults (pl. 1).

COMPARATIVE PETROLOGY

Rocks in the thesis area vary from basaltic andesite with silica as low as 54 percent to dacite with silica as high as 72.9 percent (Appendix 1, 2, 3 and 4). The predominant rock type is platy jointed basaltic andesite to andesite flows in which the silica content ranges from 54 to 63.9 percent. The second most common rock type is dacite tuffs and flows whose silica content ranges from 66 to 72.9 percent. This suite of rocks has a Peacock (1931) alkali-lime index of 61 to 62 which is in the calcic suite. Rocks belonging to the calcic suite commonly possess a high alumina content. The basaltic andesite to andesite members have an alumina content that in some instances exceeds 19 percent and is never below 16.5 percent (fig. 28). Except for slight variations, especially noticeable in Na_2O (fig. 28), the basaltic andesites and andesites in the thesis area belong to the same chemical trends (fig. 28, 29, and 30). The silicic samples (RD-15, M-984, and M-1000) tend to be more scattered, especially along the Na_2O, K_2O, and CaO curves. The distinct scatter in Na_2O and CaO curves is the result of higher calcium plagioclase than expected, as is true of RD-15 (An 71), or plagioclase alteration to calcite as is observed in M-984 and M-1000. Variation diagrams for the remaining metal oxides follow chemical trends considered to be normal for calcic and calc-alkaline rocks (Carmichael and others, 1974).

Peck (1964) obtained a Peacock index of about 60 for the rocks of the western Cascades. The difference in the two indices could be caused by several factors: (1) high calcium plagioclase in unusual abundance,

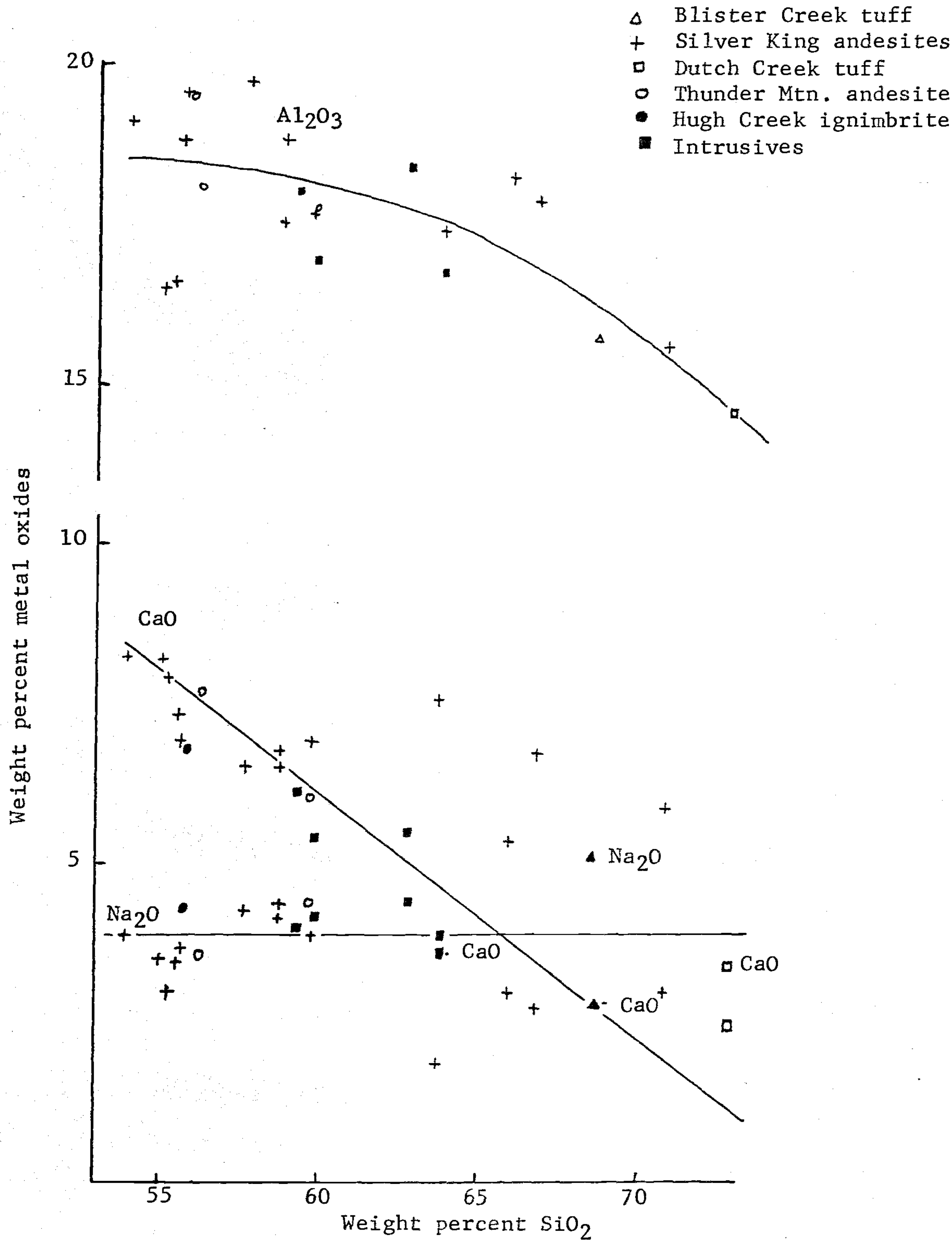

Figure 28. Harker variation diagram for rocks from Bagby Hot Springs area, Al_2O_3, CaO, and Na_2O

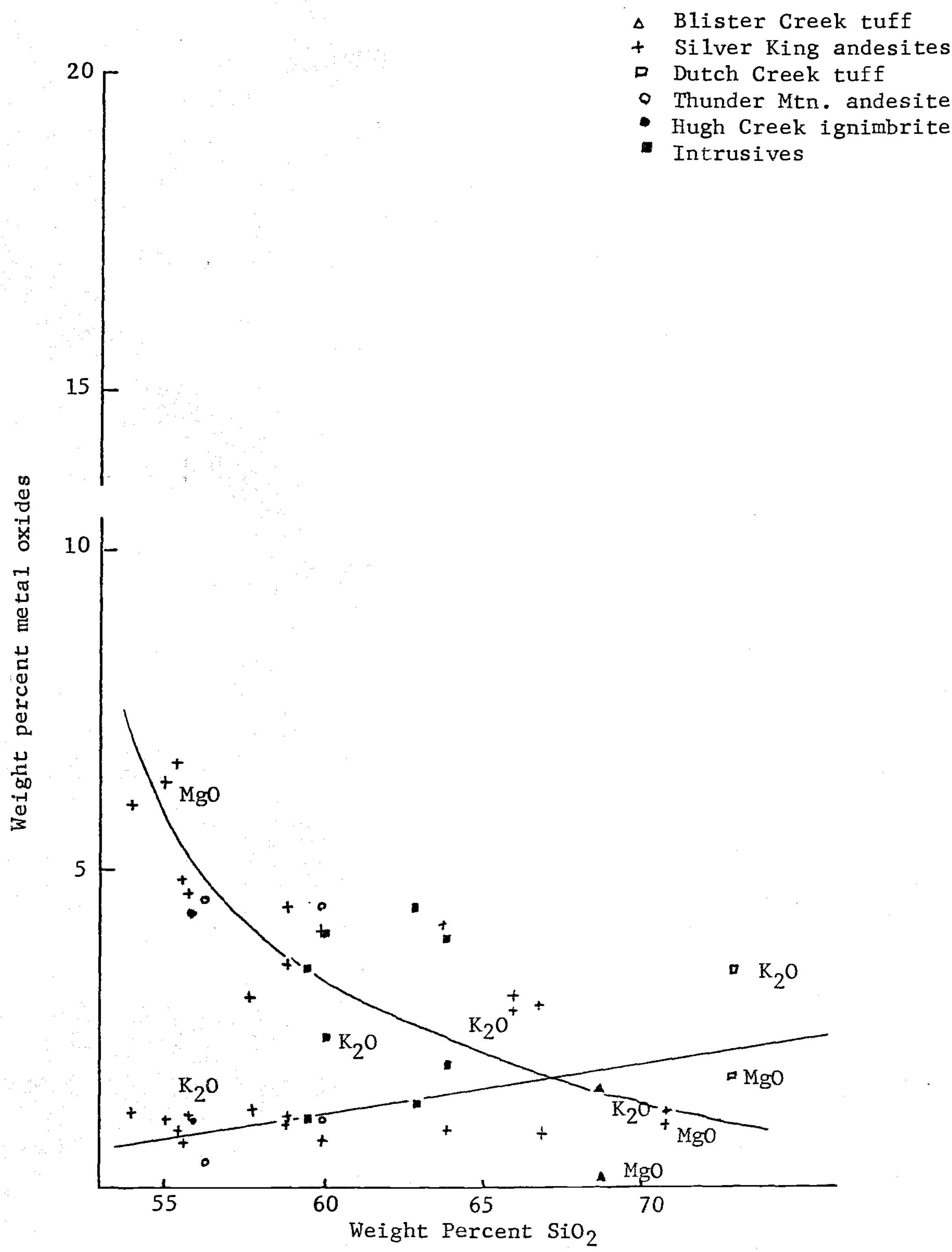

Figure 29. Harker variation diagram for rocks from Bagby Hot Springs area, MgO and K_2O

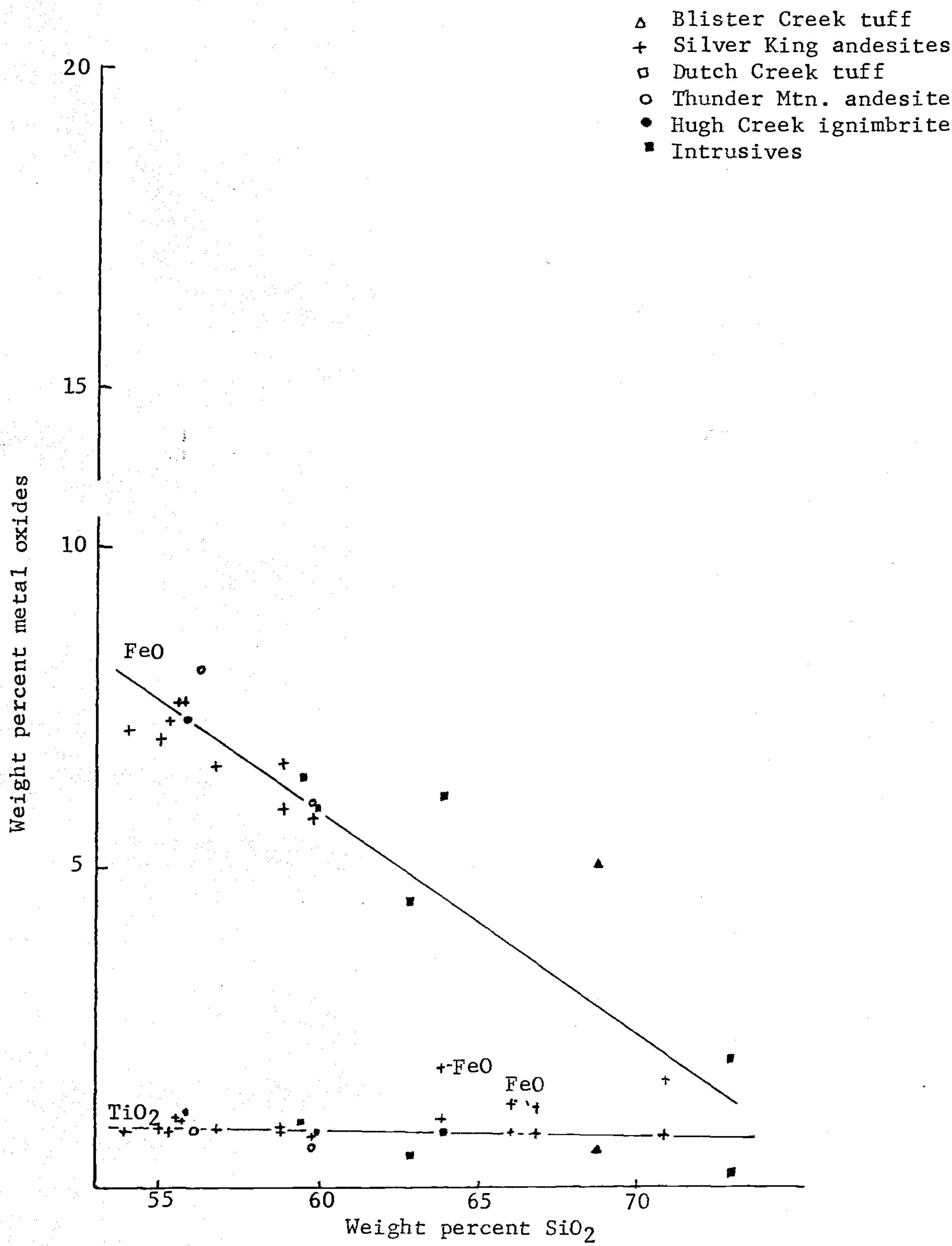

Figure 30. Harker variation diagram for rocks from Bagby Hot Springs area, FeO and TiO_2

and (2) inadequate sampling. Most of the rocks in the thesis area are in the basaltic andesite to andesite range as depicted for rocks of the western Cascade Mountains (Peck and others, 1964, fig. 31). Peck's (1964) data also depicts a hiatus in SiO_2 composition at 65 percent. This hiatus is not as apparent in analyzed rocks from the thesis area. Fresh samples of Blister Creek tuff would probably produce data bridging the range of silica in which this hiatus occurs, but they were not analyzed because fresh pumice lumps were not available.

Phenocrystic mineral assemblages vary with the silica content of the rocks in the thesis area. The low silica rocks that range from 54 to 63.9 percent contain phenocrysts of hypersthene, augite, and labradorite. Olivine phenocrysts are present in this group of rocks, but are not common. The higher silica rocks that range from 66 to 72.9 percent contain phenocrysts of augite, hornblende, and andesine. Even in high silica rocks, phenocrystic quartz is rare in the thesis area. The phenocrysts of most rocks in the thesis area appear to have been stable with respect to the groundmass chemistry and various eruptive and intrusive environments. The notable exceptions are Pin Creek andesite and Hugh Creek basaltic andesite. Pin Creek andesite is a low silica rock (63.9 percent) possessing embayed quartz phenocrysts. This signifies disequilibrium with the groundmass. Hugh Creek basaltic andesite is an example where two magmas mixed, both possessing different phenocrystic assemblages. In this unit, one clinopyroxene and plagioclase type is in disequilibrium and highly altered while the other is not. This unit also contains primary quartz surrounded by a clinopyroxene reaction rim, which represents an arrested reaction between the quartz and the groundmass.

BAGBY HOT SPRINGS AND GEOTHERMAL POTENTIAL

Bagby Hot Springs

Bagby Hot Springs is located where a fault trending N 80 W cuts the deepest and widest valley in the study area. To reach the springs requires a 2.4 km hike up the valley on U.S.F.S. trail No. 544 from road S-70. Present use of the Hot Springs is limited to recreational activities that encompass a bath house, picnicking facilities, and the start of an extensive trail network that includes the major mountain peaks from Silver King Mountain to Battle Ax Mountain. Due to the proximity of metropolitan Portland, this trail network is popular and well-used. The area encompassing this trail network has not been developed for logging or any other commercial endeavor.

Bagby Hot Springs consists of a number of springs and seeps. The largest spring yields 91 lpm at 58.9° C (U.S. Forest Service, date unknown) (fig. 31). This rate and temperature is low when compared with other western Cascade hot springs northeast and southeast of Bagby. Most of these hot springs lie along a north-south line (Bowen and Peterson, 1970). Bagby is approximately 12.9 km west of this line.

Geothermal

For a geothermal prospect to be considered economical, certain requirements must be met that deal primarily with temperatures (Grose, 1972). The minimum reservoir temperature for generation must exceed 200' C and it must not exceed 300' C to prevent scaling and corrosion of the plumbing and generation equipment. Along with the temperature re-

Figure 31. Largest of the springs at Bagby, used for supplying hot water to the bath house (NW1/4 sec. 26, T. 7 S., R. 5 E.).

quirement, the effluent flow rate must be sufficient to recharge the reservoir.

The evaluation of a geothermal prospect also includes the estimated reservoir temperature. This temperature can be estimated by using chemical data from a hot spring. One of the primary indicators of temperature at depth is silica content. Bagby Hot Spring water contains 80 ppm SiO_2 (Appendix 5). Using this value and the graphs published in Fournier and Rowe (1966), the reservoir temperature is estimated at 127° C. If the silica content of hot springs water is less than the solubility of amorphous silica at the pool temperature, then the silica content is likely to be increased by dissolving silica from near surface deposits (Fournier and Rowe, 1966). When silica content is low for the water temperature, as it is at Bagby, the reservoir temperature will be overestimated.

Basing the geothermal appraisal strictly on low flow rate and temperature, both surface and estimated subsurface, Bagby Hot Springs is not a good resource for electrical power generation.

GEOLOGIC HISTORY

In Oligocene to early Miocene time, the Bagby Hot Springs area received a thick sequence of ash-flow tuffs with interbedded lava flows, now forming the Blister Creek tuff. These units were all deposited in an intracanyon relationship which represents a hiatus of time between successive eruptions to allow development of drainage systems.

In middle to late Miocene time, the thesis area continued to receive volcanic products. First was a thick sequence of basaltic andesite to dacite flows forming the Silver King andesite. The gravel lenses between flows point to intracanyon relationships for these flows and intermittant volcanism. After this time of intermittent volcanism, much of the area was subjected to intense hydrothermal alteration. The second volcanic episode is represented by the intracanyon tuff of Dutch Creek followed by Thunder Mountain andesite. The Thunder Mountain andesite is sheet-like and represents continuous volcanism. Following the continuous volcanism was a time of volcanic inactivity in which lakes and drainage systems developed. Deposition of volcanic debris into these lakes from the surrounding terrain produced the Whetstone Mountain volcaniclastic rocks. The last eruptive cycle represented is in the form of Hugh Creek ignimbrite.

In Pliocene time, the Bagby Hot Springs area was folded, faulted, and intruded. Folding was in the form of a broad northeast-plunging anticline. Although some of the folding could have been contemporaneous with the extrusion of Oligocene and Miocene rocks, there is no positive evidence in the form of tectonic unconformities in the thesis area. Two distinct groups of faults exist, but relative age between these groups is unknown. This folding and faulting provided the crustal weakening for the emplacement of the intrusive bodies.

During the Quaternary period, the area was subjected to intensive stream erosion, glaciation, and mass wasting. Glaciers created cirques and basins in the southern part of the area. Following the retreat of the glaciers, landslides occurred due to slope instability of Blister Creek tuff along the steep-walled glacial valley.

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APPENDICES

Appendix 1. Chemical analyses of Silver King andesite.

Sample	57	13	58	26
SiO_2	54.0	55.5	55.7	58.8
Al_2O_3	19.1	18.7	19.5	18.7
FeO	7.2	7.6	7.6	5.9
CaO	8.2	7.3	6.8	6.5
MgO	6.0	4.7	4.2	3.5
K_2O	1.23	0.7	1.22	1.15
Na_2O	3.7	3.9	3.6	4.4
TiO_2	0.86	1.13	1.01	0.81
Total	100.29	99.53	99.63	99.76

BH 57 Hyalopilitic porphyritic augite- and hypersthene-bearing basaltic andesite: elevation 1024 m, SW1/4 sec. 25, T. 7 S., R. 5 E.

BH 13 Hypersthene-bearing basaltic andesite porphyry: elevation 1097 m, SE1/4 sec. 8, T. 8 S., R. 5 E.

BH 58 Hyalopilitic olivine- and hypersthene-bearing augite basaltic andesite porphyry: elevation 1024 m, SW1/4 sec. 25, T. 7 S., R. 5 E.

BH 26 Pilotaxitic porphyritic hypersthene-augite andesite: elevation 975 m, SW1/4 sec. 21, T. 7 S., R. 5 E.

Appendix 1 (continued)

Sample	55	15	984	12
SiO_2	58.8	63.8	66.0	70.8
Al_2O_3	17.5	17.4	18.2	15.6
FeO	6.7	1.8	1.3	1.7
CaO	6.7	7.6	5.4	5.8
MgO	4.4	4.1	1.8	1.0
K_2O	1.0	0.96	2.87	1.25
Na_2O	4.2	2.9	3.0	3.0
TiO_2	0.93	1.05	0.9	0.81
Total	100.23	99.61	99.47	99.96

BW 55 Hyalopilitic porphyritic augite-bearing hypersthene andesite: Elevation 1012 m, NW1/4 sec. 5, T. 7 S., R. 6 E.

BH 15 Porphyritic hypersthene- and augite-bearing andesite: elevation 1219 m, NE1/4 sec. 16, T. 8 S., R. 5 E.

BH 984 Porphyritic augite- and olivine-bearing andesite: elevation 732 m, SE1/4 sec. 21, T. 7 S., R. 5 E.

BH 12 Porphyritic hypersthene- and augite-bearing dacite: elevation 927 m, SW1/4 sec. 33, T. 7 S., R. 5 E.

Appendix 2. Chemical analyses of Nohorn Creek basaltic andesite (63), Hugh Creek andesite (3 & 5), and Pegleg Falls dacite (28).

Sample	3	5	63	28
SiO_2	55.0	55.3	57.7	68.6
Al_2O_3	16.0	16.6	19.7	15.7
FeO	7.0	7.3	6.6	5.2
CaO	8.2	7.9	6.5	2.7
MgO	6.4	6.7	3.0	0.2
K_2O	1.13	0.98	1.2	1.66
Na_2O	3.5	3.0	4.3	5.2
TiO_2	0.98	0.93	0.91	0.65
Total	98.71	98.71	99.91	99.91

BH 3 Pilotaxitic porphyritic olivine-bearing augite basaltic andesite: elevation 975 m, SE1/4 sec. 33, T. 7 S., R. 5 E.

BH 5 Pilotaxitic porphyritic olivine-bearing augite basaltic andesite: elevation 975 m, NW1/4, sec. 4, T. 8 S., R. 5 E.

BH 63 Vesicular pilotaxitic porphyritic hypersthene-bearing augite basaltic andesite: elevation 853 m, SE1/4 sec. 28, T. 7 S., R. 5 E.

BH 28 Pilotaxitic porphyritic devitrified augite-bearing dacite: elevation 640 m, NE1/4 sec. 14, T. 7 S., R. 5 E.

Appendix 3. Chemical analyses of Dutch Creek tuff (54), Thunder Mountain andesites (1 & 16), and Hugh Creek ignimbrite (47).

Sample	47	16	1	54
SiO_2	55.8	56.2	59.8	72.9
Al_2O_3	19.5	18.1	17.7	14.6
FeO	7.3	8.5	6.0	2.1
CaO	6.7	7.7	6.0	1.6
MgO	3.8	4.5	3.4	1.7
K_2O	1.08	0.34	1.1	3.45
Na_2O	4.3	3.6	4.4	2.5
TiO_2	1.2	0.96	0.73	0.25
Total	99.68	99.90	99.13	99.10

Bhb 47 Lithic-bearing crystal-rich welded tuff: elevation 1097 m, SE1/4 sec. 8, T. 8 S., R. 5 E.

BAb 16 Porphyritic hypersthene-bearing augite basaltic andesite: elevation 1219 m, SW1/4 sec. 16, T. 8 S., R. 5 E.

1 Hyalopilitic porphyritic augite-bearing hypersthene andesite: elevation 1341 m, sec. 36, T. 6 S., R. 5 E.

54 Porphyritic lithic-bearing vitric tuff: elevation 1268 m, NW1/4 sec. 1, T. 7 S., R. 5 E.

Appendix 4. Chemical analyses of intrusives.

Sample	17	2	43	23
SiO_2	59.3	59.9	62.8	63.9
Al_2O_3	18.0	16.9	18.4	16.7
FeO	6.9	5.9	4.5	6.2
CaO	6.2	5.4	5.5	3.6
MgO	3.4	4.0	2.7	1.8
K_2O	1.16	2.36	1.25	1.94
Na_2O	4.0	4.2	4.4	3.8
TiO_2	1.11	0.88	0.57	0.83
Total	100.07	99.54	100.12	98.77

Battle Ax 17 Augite-bearing hypersthene andesite porphyry: elevation 1292 m, SW1/4 sec. 16, T. 8 S., R. 5 E.
Whetstone Mountain andesite porphyry.

BAG 2 Hyalopilitic porphyritic augite andesite: elevation 732 m, SE1/4 sec. 21, T. 7 S., R. 5 E.
Silver Lady andesite.

BW 43 Hyalopilitic augite-hypersthene andesite porphyry: elevation 1439 m, NW1/4 sec. 32, T. 7 S., R. 6 E.
Pasola Mountain andesite porphyry.

BW 23 Embayed quartz andesite porphyry: elevation 585 m, SE1/4 sec. 7, T. 7 S., R. 6 E.
Pin Creek andesite.

Appendix 5. Chemical analysis of Bagby Hot Springs water from United States Forest Service, Mount Hood National Forest (date unknown) in parts per million.

Silica	80.0
Sodium	51.0
Sulfate	45.0
Carbonate	36.0
Chloride	13.0
Calcium	3.4
Hydroxide	1.0
Potassium	1.0
Fluoride	0.8
Magnesium	0.1
Arsenic	0.01
Lithium	0.026
Strontium	0.014
Nickel	0.004
Silver	None
Gold	None