# MAGMATIC INCLUSIONS WITHIN AN ANDESITE FLOW AND OTHER CALC-ALKALINE MAGMAS FROM THE HIGH CASCADES, SOUTHERN OREGON

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## INTRODUCTION

Intra-peak lavas within the High Cascades volcanic arc offer an exemplary look at continental arc volcanics. A typical calc-alkaline andesite flow 20 miles north of the California border in southern Oregon contained magmatic inclusions that indicate magma mixing/mingling. Analysis of this flow and other surrounding flows gives evidence to the origin of the inclusions and the nature of volcanism in the area.

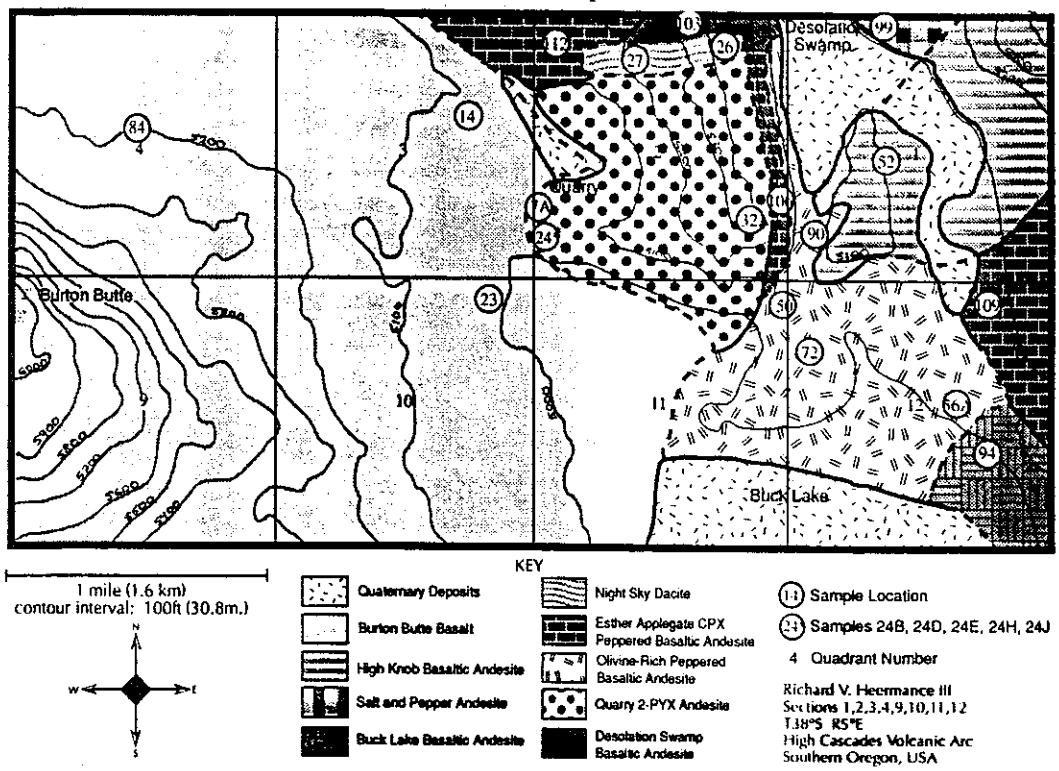
## GEOLOGIC SETTING

The lavas in the area make up a section of the High Cascades volcanic arc just south of the composite-cone Mt. McLoughlin in Southern Oregon. This linear continental margin volcanic arc stretching from British Columbia to Northern California was formed by oblique subduction of the Juan de Fuca plate beneath North America. The predominately calc-alkaline arc is bordered on the west by the Western Cascades and on the east by the Basin and Range. Volcanism of the High Cascades arc began about 7 million years ago (ma) and continues to the present. (Guffanti and Weaver, 1988)

## FIELD OBSERVATIONS

Ten units were sampled, with special attention paid to the inclusions and related flows. (Figure 1) The flows ranged in age from 3 to 0.8 million years (ma), and in composition from basalt to dacite. Nine of the flows were distinctly calc-alkaline, although the westernmost, youngest lava was a tholeiitic basalt similar to the basalts found in the Basin and Range to the east (Hart et al, 1984).

**Figure 1- Geologic Map of Units**




## ANALYTICAL TECHNIQUES

Thirty-one thin sections were studied and twenty-four geochemical analyses were done for the units. Geochemical analyses included x-ray fluorescence, inductively-coupled plasma, loss on ignition, and iron titration. Petrography work involved 1000-point counts on every unit for a modal mineral estimation, Michel-Levy tests for the plagioclase compositions, and crystal size correlation's between the inner and outer parts of the inclusions. Certain critical units were selected for K-Ar dating by Dr. Stan Mertzman.

## PETROGRAPHY

*Desolation Swamp Basaltic Andesite* This oldest unit in the study area outcrops in large, 30 foot cliffs, has platy (4-6 cm.) joints and dips westerly. This porphyritic lava is 20 percent phenocrysts dominated by 2-3 mm plagioclase (An29) crystals. Olivine is also present as a phenocryst, while clinopyroxene, orthopyroxene and magnetite are present only in the groundmass.

*Quarry 2-pyroxene Andesite* This course-grained unit outcrops extensively as a ridge and hillside, with platy jointing (1-2 cm plates) dipping westerly. Outcrops are up to 100 feet high, and the lava contains plagioclase (An20, 81%), orthopyroxene (12.3%), clinopyroxene (1%), and magnetite (2.7%). Rare glomeroporphyritic clumps are present. Spheroidal mafic inclusions make up 1 percent of the flow. This unit was dated at 2.45±.05 ma (Mertzman, 1995).

*Quarry Inclusions* These fine grained basaltic andesite inclusions are spheroidal and between 2 and 12 cm in diameter. Mineralogically they constist of plagioclase (An33, 80%), orthopyroxene (14.7%), clinopyroxene (2.4%), and magnetite (2.7). The micro-vesicular texture gives the inclusions 25-30 percent vesicularity. Phenocrysts are plagioclase up to 4 mm in length and orthopyroxene less than 1 mm in length. Magnetite and orthopyroxene euhedral to subhedral crystals accumulate near the edges of the inclusions, while towards the center (>5 cm from rim) these minerals are sparse, anhedral crystals found only within the groundmass. Crystal size decreases systematically away from the center of inclusions, with the average crystal size towards the center being 1.8 mm by 0.91 mm (area=1.74 $mm^2$) and near the rims being 1.6 mm by 0.69 mm (area=1.23 $mm^2$). The plagioclase phenocrysts within the inclusions are more calcic than those in the host, and show resorbtion. Normal zoning of plagioclase and phenocrysts crossing inclusion-host boundaries is common.

*Night Sky Dacite* This distinctive dacite overlies the Desolation Swamp Basaltic Andesite and the Quarry 2 Pyroxene Andesite at their contact. It outcrops as a 150 m. wide, 1300 m. long, less that 30 m. thick flow of extremely platy (.5-1 cm) gray dacite and massive black glass. Phenocrysts are only 5 percent of the lava, and consist of individual 1-2 mm plagioclase (An26) crystals and glomeroporphyritic clumps of plagioclase, orthopyroxene, and magnetite. The groundmass shows trachytic texture of acicular plagioclase crystals, and consists of 50 percent glass. Mertzman (1995) dated this unit as 2.47±.05 ma.

*Esther Applegate CPX Peppered Andesite* This lava outcrops extensively throughout the section mostly as severely weathered boulders. Mineral assemblages are plagioclase (An20, 79%), orthopyroxene (5.6%), clinopyroxene (4.7%), and magnetite (5.8%). The unit contains 5% phenocrysts, some of which are 2-3 mm clumps of plagioclase and pyroxene. Often found weathered to a red/purple groundmass from a normally gray groundmass.

*Olivine-Rich CPX Peppered Basaltic Andesite* This dark gray, porphorytic unit is distinctive by its large, 4-8 mm glomeroporphyritic clumps of clinopyroxene, orthopyroxene and olivine. These phenocrysts, however, make up less than 5% of the rock. It outcrops in place and makes up a valley floor and small hill.

*Buck Lake Basaltic Andesite-* This porphyritic flow outcrops as a hill in the southeast corner of the study area. It is interpreted as younger than the above units, and consists of plagioclase (An20, 1-4 mm, 78%), olivine (1 mm, 5.3%), Orthopyroxene (12%), and magnetite (5%). The flow contains 10-15% phenocrysts.

*Salt and Pepper Andesite-* This fine-grained unit has a sugary texture and rare clumping of pyroxene and An27 plagioclase (1-2 mm). No clinopyroxene or olivine are present, but magnetite is present in the groundmass.

*High Knob Basaltic Andesite-* This unit consists of plagioclase (An42, 80%), clinopyroxene (17%), and magnetite (3.9%). Acicular plagioclase give this fine-grained unit a sugary appearance. It was dated at 0.9±.05 ma (Mertzman, 1991).

*Burton Butte Basalt* This represents the youngest and most voluminous unit in the area. It is a diktytaxitic high alumina olivine tholeiite basalt outcropping in blocky flows from cinder cones at the top of Burton Butte. Vesicularity varies from 10-20% depending on the region of the flow. The unit consists of olivine (1 mm) and plagioclase (An32, 0.5-1 mm) phenocrysts along with rare glomeroporphyritic clumps (4-6mm) of these two minerals. The dark gray groundmass contains magnetite (3.9%), plagioclase, and olivine. Iddingsitization of all or part of olivine crystals is common.

## GEOCHEMICAL DATA

The units ranged from basalt to dacite, using the Na2O+K2O vs SiO2 Rock classification by Cox et al., 1979. (Figure 2) An AFM diagram places the units into a calc-alkaline suite, with the exception of the Burton Butte Basalt, which is uniquely tholeiitic for the area. (Figure 3) The spider diagram of trace elements vs chondrite normalized samples shows abundances of Ba, Sr, U,and Th with depletion of Nb, K, and Rb. Another factor relating the units is clear fractionation of magnetite, olivine, pyroxene, and plagioclase. (Figure 4)

## DISCUSSION

Geochemical data indicates the lavas are relatively low K calc-alkaline lavas, with the exception of Burton Butte. The lavas possibly were produced from more primitive melts of the mantle wedge, caused by thermal events from subduction, and subsequently contaminated by the lower crust. Low relative K and Rb abundances give a lower crustal signature. High abundances of Ba and Th are also indicators of crustal contamination. (Wilson, 1989)

The inclusions indicate possible mixing of two separate magmas, probably within the lower crust at low pressures, and could have formed by a variety of mechanisms. One method, corresponding to other flows within the cascades, is that the inclusions are the basal mafic magma of a zoned magma chamber, which through turbulance and vesiculation mingled with the overlying andesite layer. (Bacon, 1986) Another interpretation is that the inclusions are from an injection of unrelated magma. This latter interpretation is more plausible since the source lava is unknown for the inclusions, and proving fractionation of the andesite from the inclusions is difficult due to possible mixing of the magmas as well. The possibility of assimilated zenoliths is unlikely due to the following evidence for liquid formation within the host: 1. Plagioclase phenocrysts are shared by both inclusions and hosts, indicating transfer between two fluids. 2. Decreasing crystal size towards toward the rim of inclusions implies rapid crystalization of minerals near the rim due to chilling from contact with the lower temperature andesite, and slower cooling of the magma towards the center of inclusions. Sheroidal shape and microvesicular texture also hint of magmatic formation. Intense resorbtion of phenocrysts implies that temperature and pressure conditions were not stable for the higher temperature basaltic andesite within the andesite, causing the minerals to begin to transform into more stable states.

The Burton Butte Basalt is clearly an anomalous feature in the area, and exists as evidence for the migration of the Basin and Range extension into the High Cascades arc. Because the majority of the units addressed by this paper are distinctly calc-alkaline, this issue is not discussed in great depth here, but is addressed by Jon Zook, 1995, within this abstract volume.

Figure 2

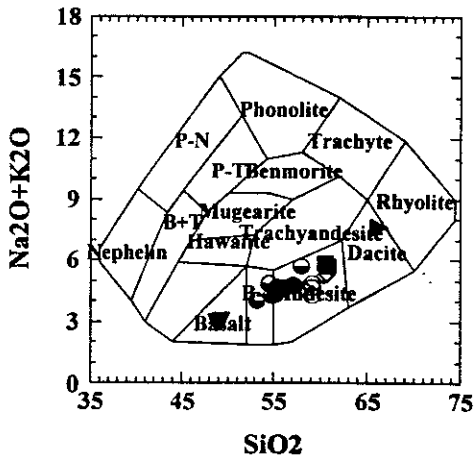
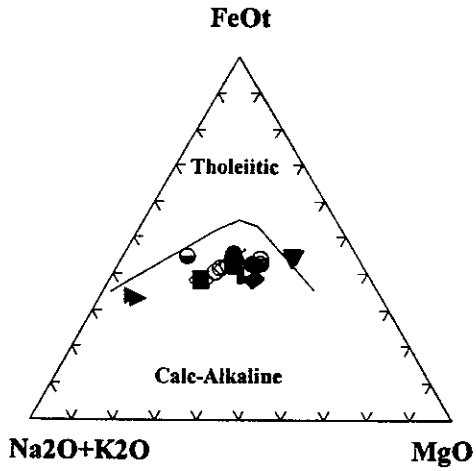



Figure 3




## CONCLUSION

The units from this section of the High Cascades Volcanic Arc represent calc-alkaline magmas erupted during the late Cenozoic period. Mixing of two separate lavas created distinctive inclusions within one large flow. Other units are related by fractionation and similar geochemical signatures. The Burton Butte Basalt represents a later intrusion of tholeiitic magma, most probably related to Basin and Range extension, into the otherwise calc-alkaline volcanic arc.

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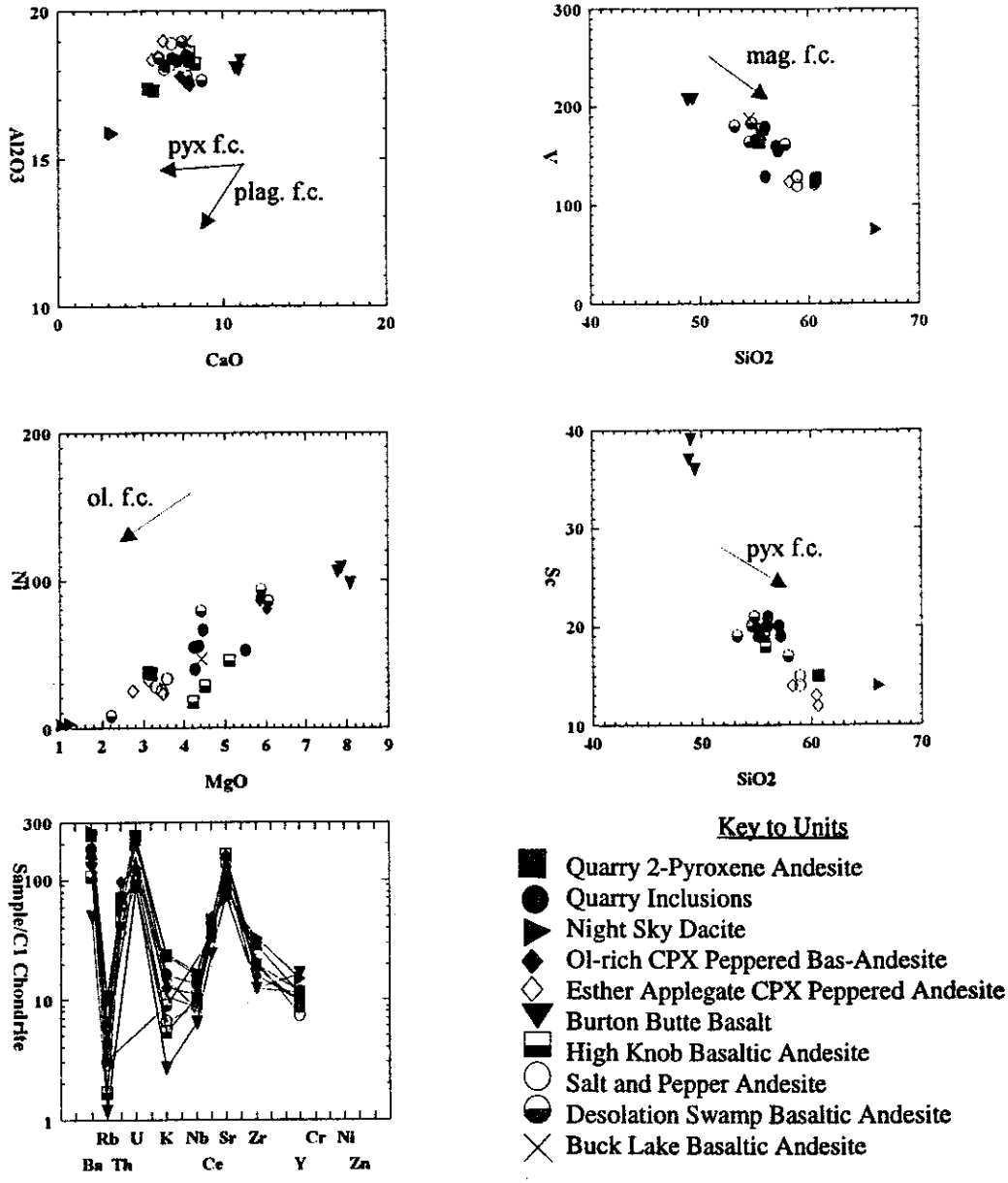
Figure 4




Geochemical plots showing fractionation trends. Al2O3 vs. CaO shows fractionation of plagioclase and pyroxene. MgO vs. Ni shows olivine fractionation. V vs. SiO2 shows magnetite fractionation, representative of a continental margin volcanic arc, and Sc vs. SiO2 shows pyroxene fractionation through the calc-alkaline lavas. Notice how the tholeiitic basalt sits apart from this trend.