Petrographic and geochemical analysis of a portion of the High Cascades along the Klamath River on the California-Oregon border

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INTRODUCTION

The Pacific coast of North America has been a zone of convergence throughout much of the Cenozoic. Some major changes in the manner of plate interaction originated in the Late Oligocene with the subduction of an oceanic spreading ridge under the western edge of the continent, and resulted in the creation of the Cascade volcanic arc in the basic form which we see today (Hart and Carlson, 1987). More recent changes in tectonic environment have also had marked effects on the Cascade Range. The rate of subduction of oceanic plates under the North American continent has been generally slowing down over the past 35 million years, and in particular the rate has decreased from 7 Ma to the present (Hughes, 1990). It is this slowing of convergence, the oblique angle of subduction, and transverse motion related to the Walker Lane belt which may be responsible for the inception of Cenozoic westward clockwise rotation of the southern Cascade Range (Blakely et al., 1997). This rotation is probably the source of the regional east-west extensional stress which has allowed the westward migration of the Basin and Range province into the southern Cascade region over the past 10 million years (Guffanti and Weaver, 1988). The arrival of Basin and Range extension and volcanism has complicated the volcanic history of the Cascade Range. Widespread north-south normal faulting and thinning of the crust associated with Basin and Range extension has allowed primitive basaltic and bimodal magmas to be erupted in the southern Cascade area in addition to the normal calc-alkaline andesitic lavas (Hart and Carlson, 1987).

In order to gain a better understanding of this volcanic history of the southern Cascade Range, a project was conducted during the summer of 1997 through the W.M. Keck Foundation in Geology. This project investigated a small portion of the High Cascade Range on the Oregon-California border. In this paper are presented the results of investigation of a section approximately ten square miles in size, straddling the Oregon-California border and located along the south rim of the Klamath River Gorge. The main focus within this project area was Secret Spring Mountain, a small extinct volcano on the south side of the Klamath River. The investigation involved field mapping of the project area and collection of rock samples for petrographic and geochemical analysis. The goals of this project were the production of an accurate geologic map and stratigraphic column for the area, petrographic and geochemical descriptions of the rock units found within it, and the interpretation of the geologic history.

STRATIGRAPHY AND PETROGRAPHY

The field area is divided into three sections: Secret Spring Mountain, Rock Creek Canyon, and the Topsy Grade. Each of these sections has a distinct stratigraphic column. The section of Secret Spring Mountain consists of six units. This is in contrast to the sections of Rock Creek Canyon and the Topsy Grade Road further to the northeast along the Klamath River Gorge rim, each of which has a more complicated stratigraphic collection with a total of twenty different volcanic units. For the sake of brevity, only the major units will be discussed.

The lowest unit at Secret Spring Mountain and the oldest material in the area is the Secret Spring Tuffaceous Unit (Tvts) (figure 1). This unit underlies the entire mountain, with a total vertical exposure of approximately 100 meters. Much of the unit appears as massive beds 2-10 meters thick, but also has occurrences of fine bedding less than 1 cm in thickness and occassional layers containing rounded clasts, suggesting that both direct air fall and sub-aqueous deposition may be present. Thin-section analysis from one of the more massive sections indicates that the unit consists of approximately 70% tiny groundmass glass fragments, 20% pumice clasts less than 2 mm in diameter, ~6% fragmented andesine phenocrysts, and rare fragmented olivine and magnetite crystals. This underlying tuffaceous material was instrumental in the formation of a landslide which removed a portion of the northern side of Secret Spring Mountain.

The main bulk of Secret Spring Mountain consists of the Secret Spring Olivine Basalt (Tvbs), which geochemical data shows to fall within both the basalt and basaltic andesite ranges (see figure 2). In the central peak area, the maximum thickness of this unit is approximately 100 meters, and is made up of individual flows 2-8 meters

Present and Future Work

Hazlett and others (1997) report data concerning one of the larger landsliding events to occur in the U.S. which indelibly marked the north side of Secret Spring Mountain. Reconnaissance work done at the end of the 1997 field season and a K-Ar age date completed in February, 1998 suggest a possible source for the pyroclastic materials which are so evident on the south side of the Klamath River in the vicinity of Secret Spring Mountain. The likely source is an area of older rock sandwiched between the much younger lavas from the Eagle Rock and Goosenest volcanoes located west of Macdoel, CA (see Figure 1). Williams (1949) mapped much of this area as "Tb" (Pliocene basalts), but new research demonstrates an age variation from at least 20 Ma to 2 Ma. Several exogenous andesite domes in this area are similar in both mineralogy and chemistry to some of the pyroclastics which occur to the north in the vicinity of Secret Spring Mt. Interestingly, these Early Western Cascade andesite pyroclastic extrusives are also similar to 1997-1998 pyroclastic extrusives from Montserrat volcano in the Caribbean region. Further field work will be accomplished in northern California during the summer of 1998. Naturally, completing work on two manuscripts which summarize this Oregon Cascade research is also a top priority.

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thick and separated by layers of cinder and volcanic breccia of the same thickness. The cinder and breccia are not found farther out on the flanks of the mountain. Petrographically, this unit displays an intergranular to sub-ophitic texture consisting of plagioclase, olivine, and few pyroxene phenocrysts surrounded by a groundmass of tiny plagioclase, pyroxene, and magnetite crystals. The modal composition averages 65% plagioclase, with albite-twinned tabular lath-shaped phenocrysts and occasional oscillatory-zoned crystals. Olivine averages 10% by volume, in euhedral phenocrysts up to 4mm in diameter, usually rimmed by or entirely altered to iddingsite. Pyroxenes make up approximately 20% of the composition, most commonly as clinopyroxene (augite), but some samples contain up to 4% orthopyroxene. Another mineral in the typical assemblage is magnetite. This iron-titanium oxide occurs as euhedral crystals <1/2 mm, either in the groundmass or poikilitically enclosed within olivines and pyroxenes. It is notable that the average phenocryst size increases with higher locations in the stratigraphy, from ~1/2 mm in the lowest levels to ~2 mm in the highest.

There are twenty-three other volcanic units present in the mapping area. These units are divided into two major categories, calc-alkaline and tholeiitic. The tholeiitic units have several common characteristics. In thin section these units are nearly holocrystalline, without tiny aphanitic groundmass crystals between the phenocrysts. Instead, they are texturally ophitic, with anhedral pyroxene crystals surrounding and partially enclosing the tabular plagioclase laths. Olivine is present as euhedral phenocrysts, and spinel as small euhedral crystals poikilitically enclosed within olivines and pyroxenes. In hand sample, the tholeiitic units also display a diktytaxitic texture, consisting of tiny angular vesicles with tabular plagioclase crystals protruding slightly into them.

The calc-alkaline group of units has several contrasting characteristics to the tholeiitic group. These units have an intergranular to subophitic texture. In thin section, they show phenocrysts of plagioclase, olivine, and sometimes pyroxenes surrounded by a groundmass of tiny plagioclase, pyroxene, and magnetite crystals. Glomeroporphyritic clumps of plagioclase, olivine and sometimes pyroxene phenocrysts are common. Olivine phenocrysts are euhedral and ubiquitously partially or entirely altered to iddingsite. Plagioclase is generally present as albite-twinned tabular laths, but sometimes polygonal-shaped crystals with oscillatory zoning are also seen. Augite is the only pyroxene present. Magnetite is often poikilitically enclosed within olivines, and occasionally within augite.

About one kilometer to the northeast of Secret Spring Mountain is Rock Creek Canyon. The stratigraphy between these two locations is disjointed by a northwest-southeast trending normal fault with down-to-the-northeast offset totaling approximately 70 meters. This fault is overlain, however, by the Northeast Amphitheater Diktytaxitic Basalt (Qvbd). This unit is one of the diktytaxitic units, and stratigraphically laps up onto the northeastern flank of Secret Spring Mountain. It does not show any apparent offset where it overlies the normal fault. The two lowest units exposed at Rock Creek Canyon are the Tvbs and Tvts. However, they are both approximately 70 meters lower in elevation than their respective outcrops on the Secret Spring Mountain side of the normal fault. Above these two units, the other twelve units within the area of the canyon can be separated into two groups divided by an angular unconformity. The lower 200 meters of stratigraphy contain one calc-alkaline and three tholeiitic units which all dip 3-5° degrees to the south. The upper 250 meters of stratigraphy within the canyon consists of two tholeiitic and six calc-alkaline units. The lowest units in this upper section lie in angular unconformity with those below, dipping 2-3° to the north.

Approximately two kilometers to the northeast of Rock Creek Canyon, the Topsy Grade Road descends from the top of the Klamath Gorge rim down to the river. This section along the gorge reveals yet another different stratigraphy from those at Secret Spring Mountain and Rock Creek Canyon. There are six rock units which outcrop in the area of the Topsy Grade. Three lower calc-alkaline units are stratigraphically overlain by three tholeiitic units. The stratigraphy here is complicated by the presence of three parallel normal faults. These faults trend northwest-southeast, with down-to-the-northeast offset. Total displacement on these three faults ranges from 2 to 70 meters. The Qvbto displays little or no displacement where it overlies these normal faults, indicating an age younger than the latest offset along them. Darren Gravely (1996), has reported an age of 1.1 ± 0.02 Ma for this unit, providing a minimum age limit on the fault displacement.

GEOCHEMISTRY

Twenty-one samples were analyzed at Franklin & Marshall College using XRF techniques to measure major and trace element concentrations. The amount of FeO was determined via a titration technique; the total volatile content was measured as "loss on ignition." Eight samples were analyzed for trace elements in the laboratory at Oregon State University, and four samples were K-Ar dated by Dr. Stan Mertzman of Franklin and Marshall College. Due to the large number of individual units within the field area, it was not possible to conduct analyses for every unit. This includes the units from the Topsy Grade section of the field area, however most of these units have been previously analyzed by Darren Gravely (1996).

Plotting of geochemical data on a Total Alkali and Silica (TAS) diagram provides a classification for the units analyzed (see figure 2). The Tvbs samples fall within the basalt and basaltic andesite range. Other than the Tvbs, there are three basalts, two basaltic andesites, one dacite, one basaltic trachy-andesite, and one sample which falls on the border between basalt and trachy-basalt. When plotted on an AFM diagram (see figure 3), it can be seen that two of the basalts are tholeiitic, and the rest of the samples are all calc-alkaline. It is also apparent from the AFM plot that the Tvbs samples show a distinct evolutionary trend of iron enrichment.

DISCUSSION

Additional information provided by geochemical analysis is the role of fractional crystallization within the Tvbs unit. Major minerals within the calc-alkaline basalts will preferentially acquire particular trace elements as they crystallize, depleting the concentration of these indicator trace elements in the rest of the melt. Therefore if a particular mineral is fractionally removed from the magma before eruption, it may leave a signature of decreasing trace elements. A plot of Ni versus Cr (figure 4) reveals a definite trend of concurrent depletion. Since both of these elements are commonly incorporated into olivine and pyroxene, this may indicate the fractionation of either or both of these minerals (Wilson, 1989). Because MgO is a major component of many olivines and pyroxenes, additional evidence for the fractionation of these minerals is seen in the trend of Cr and MgO (see figure 5) (Wilson, 1989). Petrographic support for these observations is indicated by the abundant presence of phenocrysts of both olivine and clinopyroxene within the Tvbs unit.

K-Ar dating was conducted on three samples from the Tvbs. Two samples from the bottom of the stratigraphy yielded dates of 12.5 ± 0.5 Ma and 13.2 ± 0.8 Ma. A sample from the top of the stratigraphy produced a date of 13.3 ± 0.4 Ma. These dates are highly interesting because they place the eruption of the Secret Spring volcano within a time period previously undocumented for volcanic activity in this area of the High Cascades. These dates belong to the period of Late Western Cascade volcanism, which was superceded by High Cascade volcanism at approximately 7.5 Ma (Priest, 1990). It is believed that Western Cascade volcanism was active throughout the area now occupied by High Cascade volcanics, but the earlier vents and flows were mostly buried by later flows and are rarely found in the eastern portion of the Cascade Range.

CONCLUSIONS

The presence of both calc-alkaline and tholeiitic flows in the area of Secret Spring Mountain indicates the presence of two volcanic regimes which were simultaneously active for some period of time. Calc-alkaline lavas indicate a source related to subduction under the west coast of North America. Tholeiitic lavas are probably the result of Basin and Range extensional tectonics migrating into the area over the past 10 Ma. The absence of tholeiites in the lower stratigraphy but increasingly abundant higher up may be a record of their arrival into this portion of the High Cascades. The Tvbs calc-alkaline unit also shows evidence of fractional crystallization and crustal contamination. These both probably reflect an evolving melt and interactions between it and the country rock as this magma rose through the continental crust.

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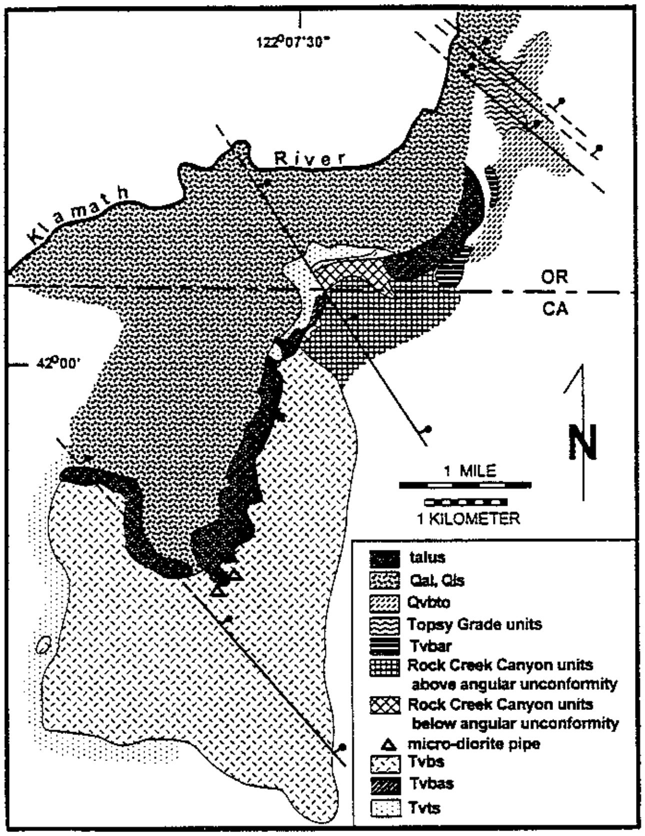

Figure 1. Simplified map of study area.

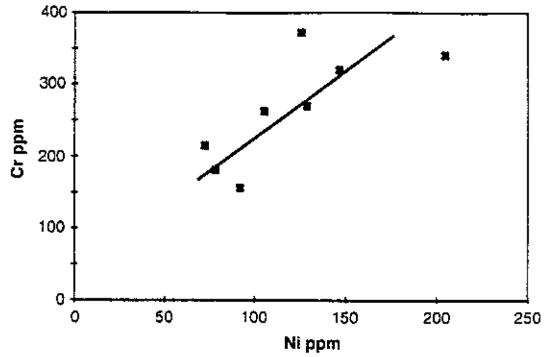

Figure 4. Variation plot of Ni versus Cr.

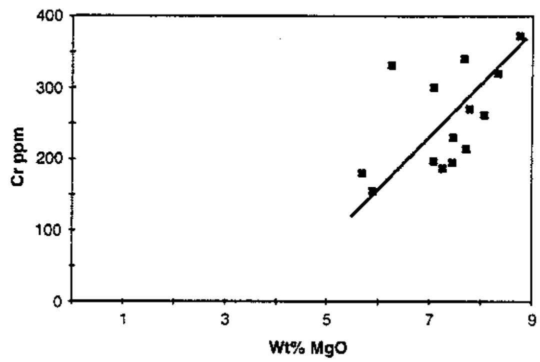

Figure 5. Variation plot of Cr versus MgO.

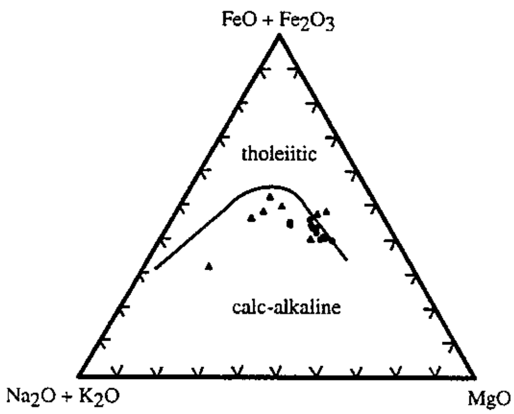

Figure 3. AFM diagram showing distribution of calc-alkaline and tholeiitic lavas. Black circles are Tvbs samples.

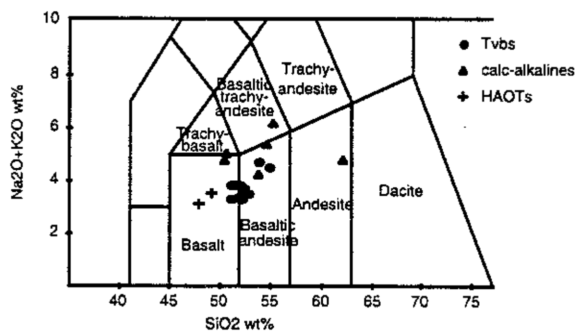

Figure 2. Total alkali and silica classification of units. After Le Bas et al. (1986).

Petrology and Geochemistry of Miocene to Quaternary Volcanics in the High Cascades of Southern Oregon

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INTRODUCTION

The Cascadia Subduction Zone consists of the Farallon Plate and the remnants of it: the Juan de Fuca Plate in the north, and the Rivera, Gorda and Cocos Plates in the south (Alt and Hyndman, 1988). Convergence between the North American and Juan de Fuca Plates has been occurring over the past 40 million years, producing temporally and compositionally varied suites of arc-related volcanics. Geophysical evidence suggests that the Juan de Fuca Plate splits around 30 miles depth into three eastbound descending tongues causing the curvature of the Cascade Range volcanoes in Washington (Baldwin and Orr, 1992).

The development of subduction-related continental margins may be understood by studying the temporal changes in lava composition and the ways in which compositions correspond to localized environments in subduction zones. Because this project focuses on the off-axis basaltic and basaltic andesite lavas extruded in the past 8 million years, it will be significant to understanding the evolution of the arc since its composite cones were formed, and thus could provide insight into how volcanic arcs evolve when the relative movement of their plates change. In the summer of 1997, eight undergraduates mapped 64 square approximately 10 miles west of Keno, OR and collected representative samples for further petrologic and geochemical analyses (Figure 1).

FIELD OBSERVATIONS

The area mapped consists of a north-south oriented strip immediately north of the Klamath River Gorge west of Keno, Oregon (sections 6, 7, 18, 19, 30, and 31 of T40S R6E, and sections 5, 6 and 7 of T41S R6E). The terrain is mainly low-relief, but there is a one-mile section of the Klamath River Gorge that has 300 meters of steep relief, hindering access to rock exposure. The land is covered with coniferous forest and in some areas, thickly overgrown with manzanita. Portions of the area are heavily logged. Most units are voluminous, however separate flows are identifiable in the north. Relative stratigraphy is difficult to determine, and relies largely on K-Ar dates provided by Mertzman because extensive young flows of high-alumina olivine tholeiites (HAOT's) cover unit contacts (Figure 2).

ANALYTICAL TECHNIQUES

Thirty samples were selected for petrographic analysis based on freshness and unit representation. Preparation of rock powders and petrographic analysis were completed at the Colorado College. The analyses include modal analyses based on a 1200 point count, and plagioclase composition determined by the Michel-Levy method. Geochemical analyses were completed by two different institutions. INAA was completed on ten samples by the Oregon State University Radiation Center, and Loss on Ignition and ICP procedures for major and several trace elements were completed on sixteen samples by ACTLABS. All K-Ar age data was provided by Dr. Stanley Mertzman (Mertzman, personal communication, 1997-98).

PETROGRAPHY

Pyroclastics Two different K-Ar dates have been produced by this unit: 17.6 +/- 0.7 and 21.6 +/- 0.4 Ma. The outcrop pattern is an anomaly, but because it is within a slump block and the area of occurrence is only a hill one-eight mile in diameter, petrographic analysis was not completed. The hill contains three distinct lithologies. The bottom-most unit is a coarse-grained, lithic rich, non-welded tuff, which crops out massively. This tuff contains, among unidentifiable lithic fragments, angular obsidian fragments, and pumice clasts up to fifteen cm in diameter. Sanidine phenocrysts are also present. The middle unit is a fine-grained , non-welded pink and gray tuff which also crops out massively. Mineralogy is similar, but hard to identify. Gray pumice clasts in this unit are on the scale of several cm in length. The capping unit is a partially welded tuff, which outcrops in a bouldery style. This unit contains stretched vesicles and elongated pumice clasts which form a linear fabric.

White Tuff The field occurrence of this unit is restricted to the northern side of the river, just above the rim where it is seen in contact below a basaltic andesite dated at 15.0 +/-0.4 Ma. Outcrops are only found in low