GEOCHEMISTRY AND PETROGENESIS OF HIGH CASCADE PLIO-PLEISTOCENE VOLCANICS NEAR MT. MCLOUGHLIN, SOUTH-CENTRAL OREGON

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Introduction

During the evolution of most arc systems, the eruption of tholeiitic basalts is followed by calc-alkaline magmatism as melts ascend through a thickening continental block (Miyashiro, 1974). The most distinct geologic feature of the High Cascades is the consanguinity of low-K, calc-alkaline basalts and basaltic andesites with high-alumina olivine tholeiites (HAOT). The purpose of this study is to model the petrogenesis of these two distinct volcanics in the tectonic and structural context of the High Cascades.

Field Observations

The Surveyor Mountain Area, located ten miles south of Mt. McLoughlin, was divided into eight lithologic units based on field, petrographic, and geochemical characteristics. Two main lineaments oriented N40W provided extensive flows of basaltic andesites within this seven square mile area. The Surveyor Mountain Fissure was associated with several monogenetic flows of basaltic andesite overlying an olivine-phyric platform. The second lineament consisted of two exogenous domes associated with basaltic andesites and pyroclastics. The other prominent basaltic andesite unit originated from Kent Peak, a large kipuka surrounded by younger Surveyor flows. Finally, a HAOT flow was also studied in the northern corner of the Surveyor Mountain Area.

Analytical Techniques

Major element analyses of ten oxides were completed at Franklin and Marshall College using X-ray Fluorescence Spectroscopy of fused lithium tetraborate disks. FeO titrations and loss on ignition (LOI) were determined at Carleton College for thirty-five samples. Trace element analyses were completed at Beloit College using Inductively Coupled Argon Plasma Emission Spectroscopy (ICP) of dissolved lithium metaborate glasses. Both techniques used internal monitors and were compared to USGS standards BIR-1, JA-1, and JA-2.

Geochemical Models of Petrogenesis

The petrogenesis of the calc-alkaline and tholeiitic units is best understood by tracing the crystallization and melting sequences of olivine and clinopyroxene phenocrysts. Because they are not affected by crustal anatexis and shallow level contamination, trace element concentrations in mafic minerals accurately reflect changing geologic conditions in a magma chamber. In the Surveyor Mountain Area, these sequences suggest the basaltic andesite units fractionated and partially melted from parental HAOT and calc-alkaline magmas.

Model I: Fractionation and Batch Partial Melting of the HAOT

The HAOT's mantle source can be established using the trace element criteria of Sun and McDonough (1989) (Figure 1). The most likely explanation for the spiked profile is the parental Burton Butte HAOT does not resemble either of its mantle precursors. Mixing with other melts, incorporating crustal wall rock, or fractionation at depth may greatly influence the HAOT's final composition from a parental N-MORB source.

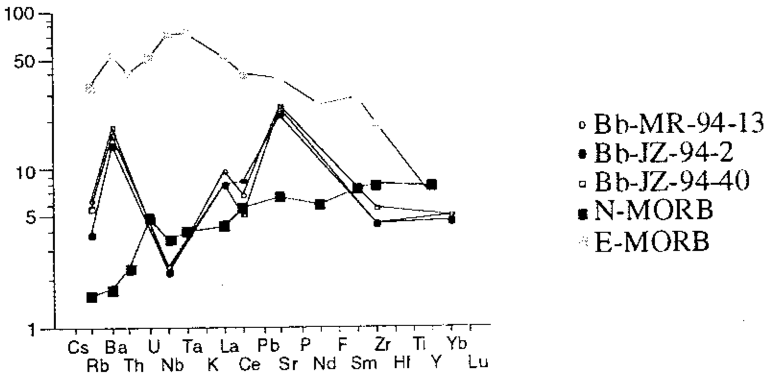

Figure 1: Primitive mantle-normalized spider diagram (After Sun and McDonough (1989))

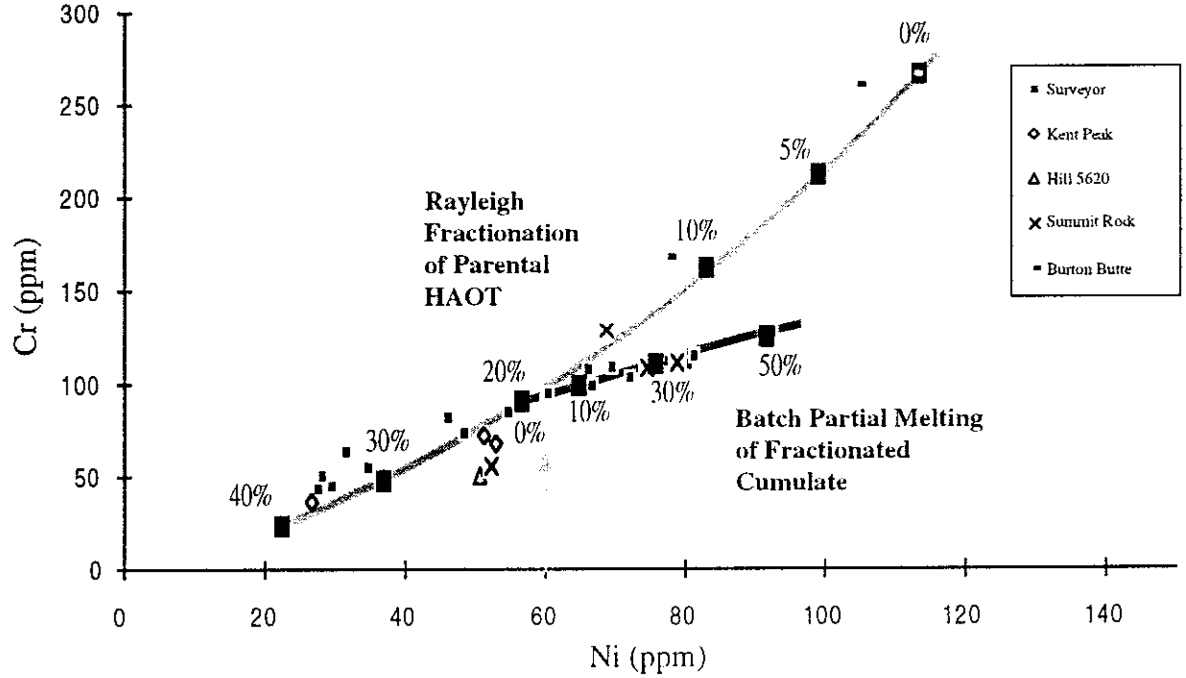

Figure 2: Model I of mafic fractionation and partial melting in the Surveyor Mountain Area. Parent for fractionation curve was HAOT sample JZ-94-2. Parent for batch partial melting curve was 20% fractionation of original HAOT sample. Cumulate composition is modelled for batch partial melting.

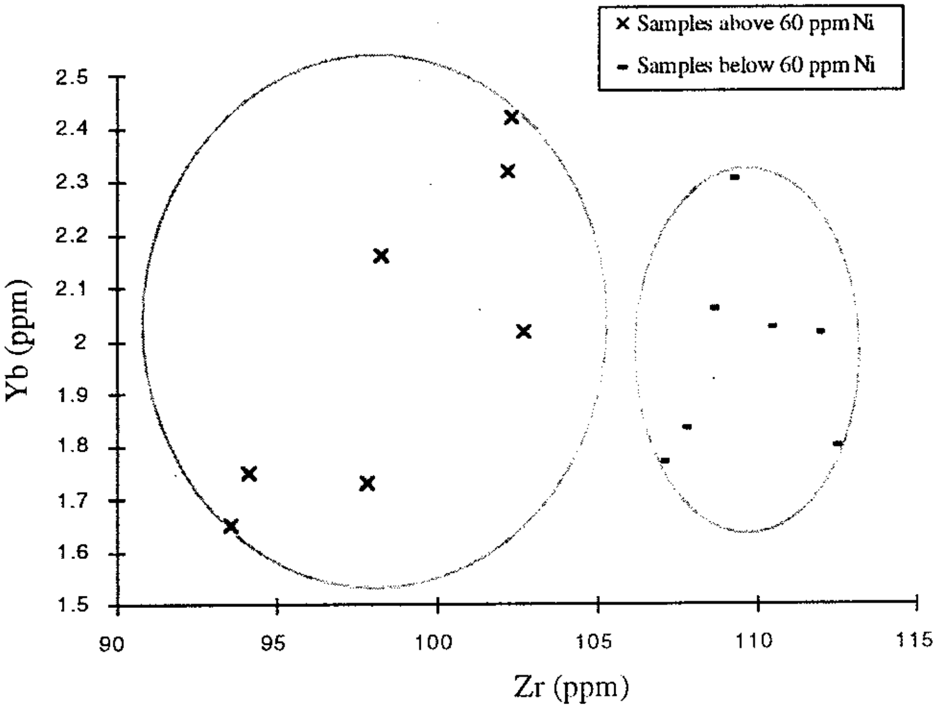

Figure 3: Bivariate plot of Yb vs. Zr for the Surveyor Mountain Basaltic Andesite. Decreasing incompatible concentrations suggest partial melting processes for the cumulate The 60 ppm Ni divide was obtained from Figure 1. The two distinct fields indicate partial melting occurred in the Surveyor Mountain Area.

A liquid line of descent from the Burton Butte sample with the most Cr and Ni was constructed using the Rayleigh fractionation equation (Figure 2):

$$C_L/C_O = F^{(D-1)}$$

where C_L is the concentration of a trace element in the fractionated liquid, C_O the concentration of a trace element in the parental liquid, F the fraction of melt remaining, and D the bulk distribution coefficient. If the HAOT represents a parental unit, at least 20% of the melt must fractionate to produce an average calc-alkaline composition seen in this area. Fractional crystallization alone, however, cannot produce all of the calc-alkaline compositions seen in the Surveyor Mountain Area.

Large intraunit scatter may be accounted for by continued fractionation of the tholeiite or batch partial melting of a fractionated cumulate. A batch partial melting model was used for a cumulate formed by 20% Rayleigh fractional crystallization (Figure 2). The compositions along this curve represent the cumulate composition after a single batch of liquid is released, using the equation

$$C_S/C_O = D_{RS}/[D_{RS} + F(1-D_{RS})]$$

where C_S is concentration of a trace element in the residual solid after melt extraction, C_O the concentration of a trace element in the original unmelted solid, D_{RS} the bulk distribution coefficient of the residual solids, and F the weight fraction of melt. Therefore, units derived from these conditions represent a cumulate erupted after a partial melting event.

Evidence for batch partial melting can be seen in a bivariate plot of Yb vs. Zr (Figure 3). Because both Zr and Yb are typically incompatible elements, a partial melting event should increase their concentration in the liquid phase relative to the remaining cumulate. Because Model I concerns **cumulate** composition after a partial melting event, samples along this curve should have less incompatible trace elements compared to the non-melted volcanics. Selecting fourteen samples from a single flow of SURVEYOR MOUNTAIN BASALTIC ANDESITE and plotting them relative to the 60 ppm Ni divide seen in Figure 2, partial melting must have occurred during the petrogenesis of this basaltic andesite. Zr separated the two groups more effectively than Yb, possibly owing to amphibole or garnet compatibility at depth (Garcia and Jackson, 1979). The wide scatter seen in the partial melting field may also represent sequential batches of elements being removed from the cumulate at depth.

Model II: Fractionation and Batch Partial Melting of Two Magmas

Instead of extensive tholeiitic fractionation, Model II incorporates a two-magma system to explain the compositional range. Although fractionation of two magmas explained compositions seen in the Burton Butte unit on a Cr vs. Ni diagram, the calc-alkaline line of descent did not cover a sufficient compositional range. Trends using the partial batch melting equation also failed to explain calc-alkaline compositions. Therefore, Model II requires possible mixing of the two parent magmas or crustal anatexis to explain the observed calc-alkaline compositions.

Evidence for a two magma system can be seen in Figure 4, which used the rare earth elements Ce and Yb plotted against Zr, an incompatible high field strength element. Depletion of heavy REE relative to light REE most likely indicates a residual garnet source, although hornblende may mimic this effect. The higher the ratio, the more likely a slab-derived garnet is present as a residual mantle phase.

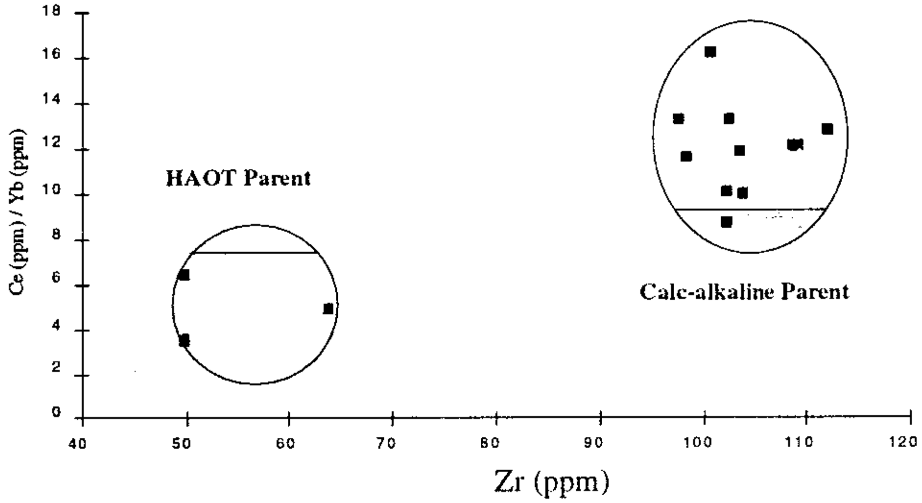

Figure 4: Evidence for a two-magma system in the High Cascades. Overlap may be due to residual garnet at depth. See text for explanation.

Because they are based on idealized conditions, these models must be framed in a geologic context. The structural complexities of the High Cascades produced magma chambers at high, intermediate, and shallow depths. Lithospheric fractures also allowed variable rates of melt ascent and erupted magmas from various reservoir depths. The following hypotheses relate the importance of such geologic complexities to liquid lines of descent.

Hypothesis I: Single Parent, Multi-Level Eruptions

The hypothesis is based on Model I, where a single HAOT magma fills an intermediate- and shallow-depth reservoir or a zoned magma chamber. The tholeiitic melt initially fractionated plag±olv±opx±cpx and assimilated crustal wall rock in both chambers. At any calc-alkaline composition, the deeper chamber received a new injection of magma which partially melted the cumulate in the lower reservoir. All melt increments ascended to the upper reservoir where they were subsequently fractionated. Compositional variations occurred if eruptions tapped at different depths (mantle, upper reservoir, lower reservoir), if eruptions tapped at different stages in the fractionation/partial melt sequence, or if the magma ascended at different rates.

Several lines of evidence for this hypothesis can be seen in the Surveyor Mountain Area. First, the petrography of the calc-alkaline unit suggests a history of crystallization, resorption, and disequilibrium. Zoned plagioclase phenocrysts, olivine phenocrysts rimmed by orthopyroxene, and abundant pseudomorphs attest to such conditions. Second, the variety of cogenetic lithologies within a limited area suggests a dynamic, single magma chamber. Finally, two groups of clinopyroxene- and olivine-driven fractionation indicates a variable rate of ascent.

Hypothesis II: Multi-Parent, Multi-Level Eruptions

The second hypothesis represents a continuation of the first, except petrogenesis is complicated by two parental magmas. The upper and lower reservoirs were filled with a residual garnet calc-alkaline parent and an immiscible HAOT, fractionating and partially melting both magmas at intermediate to shallow depths. During these processes, the reservoirs were contaminated by HAOT injections. Such mixing may also have preceded eruptions of the calc-alkaline material as volatiles were released. Although there was no solid lithologic or geochemical evidence for mixing in the Surveyor Mountain Area, several calc-alkaline eruptions near Crater Lake and Burton Butte showed two immisible liquid phases. Mixing also seems likely in the structurally complex High Cascades, where various melts pool in different reservoirs.

Conclusion

The complexity of the Surveyor Mountain Area cannot completely eliminate either of these two hypotheses; I believe the compositional variety of the calc-alkaline and tholeiitic units requires both. Unfortunately, these theories are highly oversimplified: neither considered the importance of anatexis in the shallow reservoirs nor mixing of more evolved magmas. Such variables must be considered to explain the compositionally diverse volcanics of the High Cascades.

To better understand Plio-Pleistocene volcanic activity in the High Cascades and the role of these variables in the formation of calc-alkaline and tholeiitic volcanics, additional petrogenetic constraint is necessary, because the tectonic and structural complexity of the High Cascades easily masks petrogenetic processes from the deep mantle to the shallow crust. This study requires isotope data and electron microprobe analyses of the mafic phenocrysts to better constrain compositions. Additional samples of the Johnson Creek Olivine-Phyric platform would also be highly instructive. Through its wide variety of small-scale petrogenetic processes, the Surveyor Mountain Area attests to the complexity of arc systems and their need for further study.

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