PROCEEDINGS OF THE TWENTY-SIXTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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Pomona College, Claremont, CA

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OLIVINE BASALT: EARLIEST LAVAS OF THE POWDER RIVER VOLCANIC FIELD, NORTHEASTERN OREGON

LUKE FERGUSON, Pomona College
Research Advisors: Kirsten Nicolaysen and Jade Star Lackey

INTRODUCTION

Miocene Columbia River Basalt (CRB) erupted a large volume of lava – more than 300 flows – and is recognized to be a result of the Yellowstone hotspot. These eruptions occurred mainly from 17.5-16.5 Ma but isolated flows continued until 6 Ma on the west side of the Blue Mountains (Tolan et al., 2009). East of the Blue Mountains, the Powder River Volcanic Field (PRVF) consists of a series of eruptions in the same area that are chemically different from the CRB, yet erupted at a time contemporaneous with the latest CRB eruptions. Interestingly, by this time the Yellowstone hotspot was beginning to cause eruptions in eastern Idaho. The PRVF is subdivided into several different units based on both stratigraphy and composition. A series of 3-4 olivine basalt flows are the oldest, volumetrically largest members of the PRVF (Ferns et al., 2004), and hypothesized to contain the best record of the initiation of PRVF magmatism. This project presents a geochemical analysis of olivine basalt flows in the Miocene PRVF with the ultimate goal to elucidate the eruptive history, formation, and source of the PRVF.

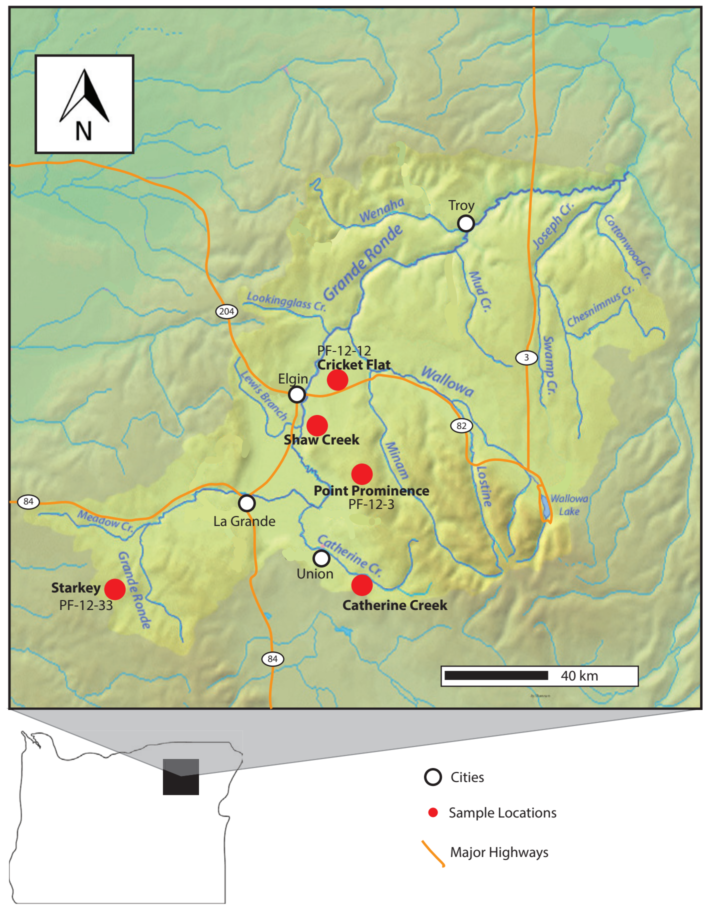

Figure 1. Sample locations for this study, including locations for three important samples.

We use geochemical data to test a number of hypotheses: First, the unusually large grain sizes in these flows questions whether these rocks formed as flows or as sills and have since been exposed by erosion. Whether emplaced as sills or flows, one hypothesis is that the influence of the Yellowstone hotspot created the CRB and PRVF magmas (Camp and Hanan, 2008). If this were the case geochemical signatures in the olivine basalt would show that of a hot spot influence and similarities with the CRB. A second hypothesis is that the olivine basalt flows are the result of back arc volcanism associated with the Cascade volcanic arc, as the Cascade volcanic arc was active during the Miocene (Bailey and Conrey, 1992). It is possible that extension related to Basin and Range rifting and a back-arc environment have stimulated the olivine basalt flows and PRVF (Bailey and Conrey, 1992). If this were the case geochemical signatures in the rock would be more similar to a mid-ocean ridge than a hotspot, and less crustal contamination as the extension would create fast pathways through the crust in this location. A third hypothesis is that a tear in the subducting oceanic lithosphere created an opportunity for the edge of the slab to melt (Liu and Stegman, 2012), and a fourth hypothesis is delamination of lithosphere resulted in magma production (Camp and Hanan, 2008).

METHODOLOGY

Thirty-five samples were collected from 5 different locations in the Grande Ronde Valley, of which 8 samples were selected for thin section and petrographic analysis. Sampling targeted map unit Tpb (olivine basalt) mapped by Ferns, et al. (2004), and stretched across most of the southwestern part of the Grande Ronde Valley. Some olivine basalt outcrops were highly weathered but great care was taken to obtain the freshest rocks possible. X-Ray Fluorescence (XRF) revealed whole rock geochemistry for 21 of the most promising samples; some of these analyses were done at Washington State University and some at Pomona College according to methods of Johnson et al. (1997). One sample, PF-12-33, was analyzed at both labs to ensure comparability between results. This resulted in differences to an accuracy of a tenth of a weight percent of 3% error for Na_2O; 2% error for SiO_2, CaO, and Al_2O_3; 1% error for Fe_2O_3; and 0% error for the other major and minor elements. SEM (Scanning Electron Microscope) and EDS (Energy Dispersive Spectroscopy) studies were done at Pomona College using its Hitachi SU-70 Scanning Electron Microscope. Compositional mapping was done to provide a qualitative picture of the composition of individual grains of olivine within the rock, and to determine mineralogy of olivine inclusions. SEM work was done at varying magnifications with a voltage of 20 kV and a working distance of 8.7 mm.

RESULTS

PETROGRAPHY

Samples are mainly fine grained, occasionally verging on medium grained. Glass is minimal and the rocks are characteristically serate (Fig. 2). The groundmass is predominately comprised of coarse, felty plagioclase feldspar laths showing no flow direction and phenocrysts include olivine, clinopyroxene, and an oxide. Vesicles are common and range in size from <100 µm to 5 mm, however most are in the 1 mm size range. Olivine is the major phenocryst in each sample, with a mode of 10-15% and a wide range of sizes, from <100 µm to 3 mm (Figs 2-3). Samples commonly have abundant Fe-oxide inclusions, up to 500 µm in diameter, and 1-5% modal percentage of clinopyroxene. Plagioclase feldspar crystals are up to 2 mm in length, though most are 1 mm or smaller. Olivine and plagioclase feldspar crystals are subhedral to euhedral.

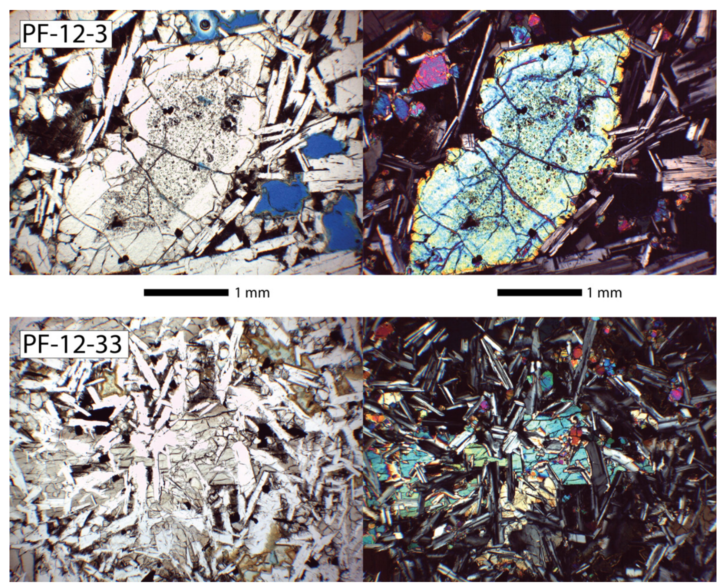

Figure 2. Photomicrographs of thin sections. The left is under PPL, the right is under XPL. PF-3 shows large olivine phenocryst. Vesicles are stained blue. The texture is seriate.

OLIVINE MAPPING

Figure 3 shows results of olivine grain mapping by EDS. Multiple grain sizes were studied (100 µm, 500 µm, 1 mm) to gain an understanding of the range of the population. All of these grains are from sample PF-12-12. Olivine grains show standard zoning with Fe rich rims and Mg rich cores, illustrated in Figure 3 by the density of red surrounding the grain rims and abundance of green in the grains' cores. This zoning is a result of the fact that Mg has a higher crystallization temperature, and thus crystallizes before the Fe. Inclusions in the olivine are high in Fe and Cr, and to a lesser extent Al. Chromite is the most common inclusion, followed by spinel and what is likely magnetite.

Olivine Zoning

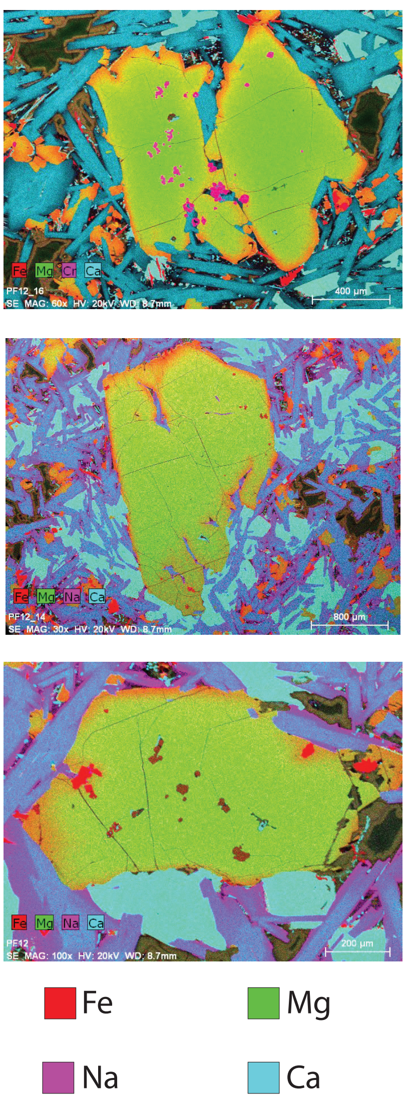

Figure 3. Compositional mapping results of two hours of mapping at 20,000 cps. Fe-rich areas show red and Mg-rich areas show green. Phenocrysts in the center of each image are olivines. Laths surrounding olivine phenocrysts are plagioclase feldspar. All from sample PF-12-12.

GEOCHEMISTRY

Of the 21 samples analyzed for whole rock geochemistry, 5 were determined to be CRB based on chemistry and 4 were determined to be basanite, the younger Tpbo member of the PRVF (see Baez, this volume). Samples have weight percent oxide abundances of: SiO_2 (46.1-51.3), TiO_2 (1.1-1.4), Al_2O_3 (15.6-17.6), FeO* (8.8-10.7), MgO (7.0-8.9), CaO (9.3-11.9), Na_2O (2.4-3.1), K_2O (0.2-0.9) and P_2O_5 (0.2-0.5). In comparison to CRB, the PRVF olivine basalts have high Cr (251-478 ppm) high Ni (135-215 ppm), low Rb (1.5-11 ppm) and low Zr (51-104 ppm). Figure 4 illustrates key geochemical results in this study. Values for Columbia River Basalt were taken from The Western North American Volcanic and Intrusive Rock Database (NAVDAT) (Walker et al., 2006). There are 812 data points in the CRB field, 130 in the field for olivine basalt from Ferns, et al. (2004), and 11 in the field for results from this project. The samples collected in this project geochemically match those collected and analyzed by Ferns and others. In addition, it is apparent that there are geochemical differences between CRB rocks and olivine basalt rocks of the PRVF.

DISCUSSION

Although the relatively large grain size and holocrystalline matrix led us to consider whether some olivine basalt (Tbp) rocks might have intruded as sills, this hypothesis can be dismissed. In thin section vesicles were large and abundant in every sample; gas exsolution is difficult under pressure and vesicles are not seen in sills. Results from the x-ray intensity mapping by EDS show that growth zoning in the olivine grains follows the standard pattern with Fe-rich rims and Mg-rich cores. This indicates simple, in situ crystallization of olivine. In some cases, olivine has chromite inclusions, potentially signaling early crystallization of this population of olivine. The plagioclase feldspar is also normally zoned (reciprocal change from high Ca and low Na cores to high Na and low Ca cores) implying growth as the liquidus temperature decreased. Preservation of subhedral to euhedral habit and the rim of the olivine suggest a change in temperature and or/magma composition due to mixing immediately preceding eruption.

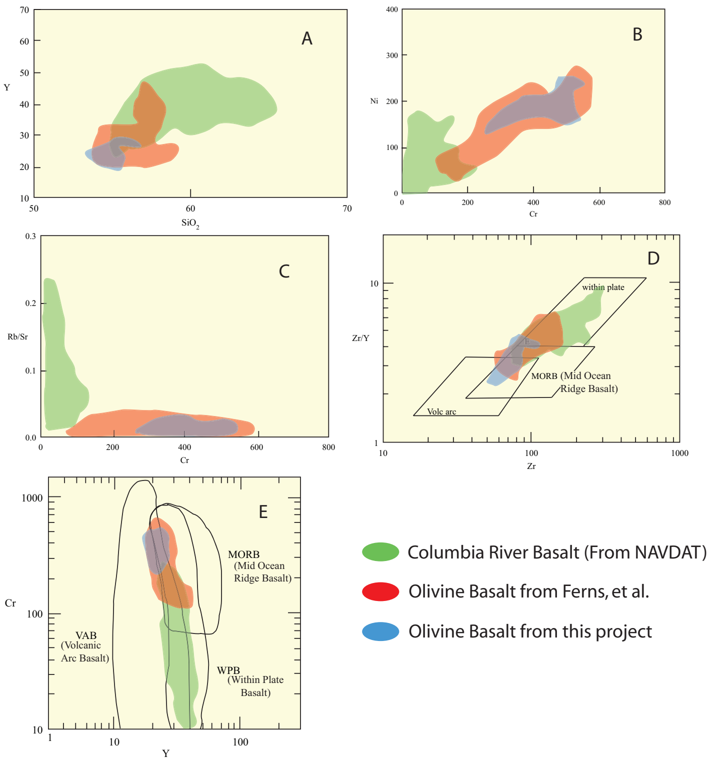

Figure 4. Whole rock geochemistry of the PRVF basalts compared to those analyzed by Ferns, et al. (2004) and the CRB. CRB results are averages from all units. (a) SiO_2 vs. Y (b) Cr vs. Ni (c) Cr vs. Rb/Sr (d) discrimination basalt diagram from Pearce and Norry (1979) and (e) discrimination basalt diagram from Pearce (1982). CRB data are from the NAVDAT (navdat.org) database.

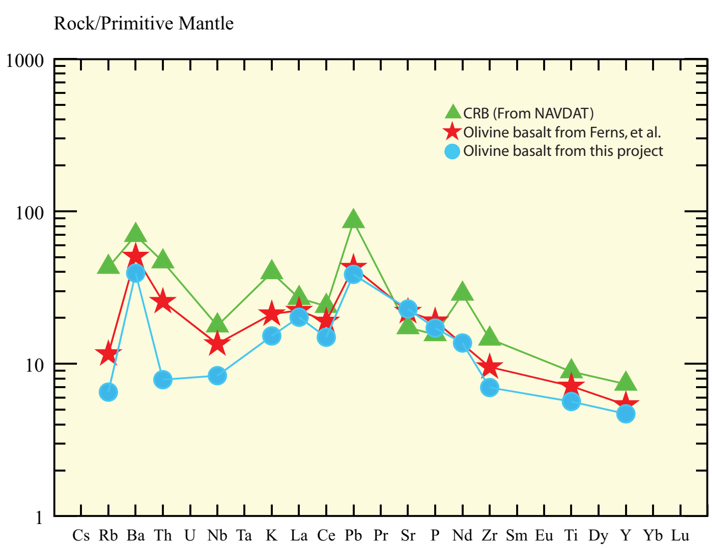

Figure 5. Trace element comparisons of average PRVF lavas and those of Ferns et al. and CRB (see Fig. 4 for sources). Values normalized to primitive mantle values of Sun and McDonough (1989).

The strong anti-correlation of Cr and Rb/Sr (Fig. 4c) between CRB lavas and PRVF lavas suggests that the CRB lavas are considerably more enriched, and contain higher proportions of crust than the later olivine basalt flows. The much higher Ni and Cr are likely from olivine in the olivine basalt (Tpb) samples, whereas CRB samples typically lack olivine. Discrimination diagrams for basalts from Pearce and Norry (1979) and Pearce (1982) show that the olivine basalt samples tend toward more typical mid-ocean ridge basalt signatures while CRB values are more similar to established within plate basalt values. These results suggest that the olivine basalt PRVF lavas have greater affinity with a source resulting from more extensive partial melting of mantle.

The spider diagram (Fig. 5), which is created from the same data as Figure 4, shows that PRVF basalts are more primitive, but show similar minor element inflections consistent with broadly the same decompression melting regime as the CRB lavas, which tend to have higher concentrations of the trace elements. Figure 5 suggests that the CRB and olivine basalt (Tpb) have the same mantle source, but again that the PRVF olivine basalt was created by a higher degree of partial melting.

According to Wolff, et al. (2008) a singular, centralized crustal magma system that fed the majority of CRB lavas was at least partly hosted in transitional to cratonic crust. This required lateral transport of magma to vent sites. This hypothesis is attractive in that it places few constraints on the geometry of the Yellowstone plume. Possibly this lateral travel, of up to 300 km, has led to CRB rocks exhibiting more of a crustal influence, while PRVF olivine basalt exhibits less. Camp and Hanan (2008) argue that the CRB lavas erupted due to delamination triggered by the Yellowstone plume. Liu and Stegman (2012), propose that CRB volcanism is a result of a tear in the Farallon slab. Earlier volcanism was sourced from the base of the slab, and then melting evolved upwards. The fact that the Yellowstone hotspot is no longer near the Grande Ronde Valley during PRVF eruptions suggests that decompression stimulated melting rather than heat addition. Both the delamination model of Camp and Hanan (2008) and the slab tear model of Liu and Stegman (2012) would offer the necessary decompression of primitive mantle. The delamination model of Camp and Hanan (2008) requires the effect of a mantle plume to produce the volume of melt seen in the CRB. It is possible that following the large volume CRB eruptions and passage of the Yellowstone hotspot further delamination occurred due to the low density mantle and this decompression led to PRVF volcanism. Alternatively, the slab tear model (Liu and Stegman, 2012) does not require hotspot interaction for magma production.

CONCLUSIONS

The lavas of the olivine basalt (Tpb) unit contain significant olivine (10-15%) and minor plagioclase feldspar and Cpx in a holocrystalline matrix. The lavas are high in Cr and Ni and contain inclusions of chromite and to a lesser extent spinel. Rims on olivine indicate mixing or temperature drop immediately preceding eruption. The low concentrations of large ion lithophiles suggest that the olivine basalt (Tpb) rocks do not contain a significant amount of subduction zone fluid. PRVF olivine basalt lavas exhibit similar trace element patterns but lower overall values of incompatible trace elements as well as significantly higher Cr and Ni indicating a higher degree of partial melting than for CRB lavas, although the mantle source may not be appreciably different. The high degree of melting at a time when the mantle hotspot is already interpreted to be stimulating eruptions along the Oregon-Idaho border south of the PRVF may indicate that back-arc extension or a slab window (Liu and Stegman, 2012) allowed mantle melting and eruption of a primitive basalt.

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