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Director, Keck Geology Consortium
Pomona College

Dr. Jade Star Lackey
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Carol Morgan
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Symposium Proceedings Layout & Design
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Keck Geology Consortium
Geology Department, Pomona College
185 E. 6th St., Claremont, CA 91711
(909) 607-0651, keckgeology@pomona.edu, keckgeology.org

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JOHNNY RAY HINOJOSA, Williams College
Research Advisor: Reinhard A. Wobus

INTRODUCTION

The Powder River Volcanic Field (PRVF) located within and around the Grande Ronde Valley of northeast Oregon, is characterized by calc-alkaline to alkaline eruptions during the mid-Miocene to Pliocene (Fig. 1). Previous studies of the area have focused on compositions of high-alumina olivine tholeiites (Bailey, 1990) and extensive bedrock mapping (Ferns et al., 2010) leaving much of the alkaline rock suite chemistry and magma chamber conditions unexplored.

The regionally dominant mid-Miocene Columbia River Basalt Group (CRBG) underlies the PRVF and is compositionally sub-alkaline, tholeiitic and strongly enriched in FeO. Geochemistry of most CRBG flows of the Grande Ronde and Wanapum Members indicate little or no crustal contamination. In contrast, the PRVF includes rock types mapped by Ferns as trachyandesite, trachybasalt, and basaltic trachyandesite. One possible model is that elevated alkaline components indicate an evolved magma that may have assimilated older crust. The original parent magma had to ascend through the accreted Wallowa Terrane of the Pacific Northwest before eruption in the PRVF.

The Wallowa Terrane in NE Oregon contains remnants of Permian ophiolitic and volcanic island arc rocks and a late Triassic and adjacent marine basin. According to Kays et al. (2002), the Permian arc rocks include former spilitic basalts and keratophyres with elevated Na₂O and depleted K₂O. The Upper Triassic Martin Bridge formation of the Wallowa Terrane underlies most of the PRVF and also provides a possible source of elevated alkaline components, with shallow-water peritidal evaporitic sediments that are succeeded by deeper and predominantly subtidal deposits (Stanley et al., 2008).

Other lithologic components pertinent to a crustal assimilation model for the PRVF are the Mid Permian
to Late Triassic Cougar Creek Complex and Late Triassic to Mid Cretaceous Cornucopia Stock. The Cougar Creek Complex is a compositionally diverse suite of dikes and plutons that are interpreted as the roots of the Wallowa arc terrane (Kurz et al., 2012). The Cornucopia stock is a small composite intrusion comprising five distinct intrusive units, including peraluminous trondhjemites (Johnson et al., 1997). The stock was emplaced in metasedimentary and metavolcanic rocks of the Wallowa terrane, further complicating the compositional variance underlying the PRVF. Both the sedimentary and igneous components beneath the PRVF could have contributed to the PRVF magma contamination by assimilation.

This report focuses on the petrography and mineral chemistry of several units from the PRVF with the intent of constraining the petrogenesis of a suite of sodic lavas erupting after the CRBG in a back-arc, extensional setting. Electron microprobe analysis of hornblende and Fe-Ti oxides has been used to provide data for geothermometry calculations based on Rutherford (2003) and Ghiroso and Evans (2008).

**FIELD SITES**

**METHODS**

Nine samples were collected while camping approximately 10km south of Elgin, OR, within the PRVF during July 2012. Field work included locating outcrops from prior bedrock mapping by Ferns et al. (2010), creating GPS waypoints, taking samples by sledge and rock drill, and assisting other members of the research group with their own fieldwork. My focus was locating and sampling mapped units previously described as trachyandesite (Tpta), trachybasalt (Tpbo) (Ferns et al., 2010), and basaltic trachyandesite (Tptb), although one sample of basalt was also analyzed from the lowest unit of the PRVF. My report on the alkaline rock types will discuss geochemistry and provide magma chamber temperature values for samples that contain the appropriate mineralogy.

**PRVF Sample Description**

Rocks of the PRVF vary from basalt to dacite, but only the compositionally intermediate alkaline rocks are described here. $^{39}$Ar/$^{40}$Ar ages for the field are reported in Ferns et al. (2010).

- Trachyandesite: 5.9 ± 0.9 Ma
- Basaltic Trachyandesite: 6.54 ± 0.14 to 7.26 ± 0.11 Ma
- Trachybasalt: 10.85 ± 0.18 to 11.6 ± 0.4 Ma
- Dacite: 11.08 ± 0.18 to 13.38 ± 0.24 Ma
- Olivine Basalt of Little Catherine Creek: 13.3 ± 0.8 to 14.4 ±0.2 Ma

*Discussed in this report

Trachybasalt: Sample PH-12-8, from the top of Mt. Grey, 7km east of Mt. Harris, is dark bluish gray to black, aphyric, and shows a conchoidal fracture. It has a trachytic fabric defined by andesine sodic (An$_{30-35}$) with intergranular clinopyroxene and opaques. Partly altered olivine phenocrysts 0.3 – 0.7mm long are about Fo$_{85}$ as determined optically.

Basaltic Trachyandesite: Samples PH-12-2B, -2M, and 3 were collected on Forrest Capital timberland about 10km SSW of Elgin. From lower to higher in a section of three flows, they are aphyric and range from bluish gray with a distinct flow parting to light gray with no obvious fabric or rock cleavage. In thin section, fabrics range from non-directional aphyric to trachytic and faintly porphyritic with totally altered olivine phenocrysts up to 0.5mm in a groundmass of plagioclase, pyroxene, and opaque minerals. Samples PH-12-9 and PH-12-10, from Pumpkin Ridge and Pumpkin Butte 6km SW of Elgin are porphyritic with sub – to euhedral black phenocrysts of oxyhornblende up to 5mm long. In thin section most of the hornblende phenocrysts either have altered rims (PH-12-9) or are totally altered (PH-12-10). The least altered amphiboles are pleochroic from reddish-brown to tan; some contain cores of clinopyroxene. Smaller phenocrysts of calcic clinopyroxene (2V ~ 60˚ with positive optic sign) are fresh and variably twinned and/or zoned; some show hourglass extinction indicative of titanium. Andesine defines a pilotaxitic groundmass with intergranular clinopyroxene and opaques.

Trachyandesite: Sample PH-12-11 was collected on Bean Coffin Road 7km SW of Elgin. It is light gray, aphyric, and non-directional at all scales; unoriented andesine, clinopyroxene and opaques comprise this very fine-grained rock.
Olivine Basalt: Sample PH-12-6 is an olivine basalt belonging to the basal Little Catherine Creek group of the PRVF. It has a vesicular texture and contains about 10% partly altered olivine phenocrysts (Fo$_{80}$) in an intergranular fabric with clinopyroxene, andesine, and opaques.

**GEOCHEMISTRY**

Whole rock geochemistry by XRF was performed on all samples at Washington State University at Pullman. The samples show a calc-alkaline trend on an AFM diagram (Fig. 2) except for PH-12-6, which plots as a tholeiitic basalt. The samples show an alkalic trend when total alkalis are plotted vs. silica on a Le Bas diagram (Fig. 3). Geochemical results show high Na$_2$O (from 4.44 - 5.18%) and relatively low K$_2$O (1.03 – 1.93%) in all of the samples from the PRVF except for the basalt of Little Catherine Creek (PH-12-6), the oldest unit. The trachybasalt and basaltic trachyandesite samples PH-12-9 and PH-12-10 are nepheline normative; other analyzed samples (except PH-12-6) are quartz normative. All PRVF samples except the basalt of Little Catherine Creek show elevated concentrations of some of the large-ion lithophile elements. Sr ranges from 1223 to 2723 ppm, Ba from 394 to 1073 ppm and Sr/Y = 68 – 170 (as opposed to 17 in the basalt).

![Figure 2. Alkalis – FeO$^+$ - MgO diagram of analyzed samples, after Irvine and Baragar, 1971.](image)

![Figure 3. Total alkali-silica diagrams showing composition of PRVF samples from (a) this study and (b) PRVF from Ferns (2010); and (c) CRBG samples from Ferns (2010), all after Le Bas et al., 1986.](image)

Elevated concentrations of alkaline elements in the PRVF are due especially to high Na$_2$O relative to K$_2$O.

Preliminary mineral chemistry for samples PH-12-9 and PH-12-10 was obtained using the SEM at Williams College. Backscatter images at 15.0 kV revealed ilmenite exsolution lamellae in magnetite grains in PH-12-10 (Fig. 4). Further examination of the polished thin section revealed the composition of minerals within reaction rims around euhedral amphibole phenocrysts (Fig. 5). The rims contain extremely
small grains of titano-magnetite, apatite, amphibole, clinopyroxene, and plagioclase. Whereas amphiboles in PH-12-10 had a relict core of the original grain, PH-12-9 grains are totally consumed by reaction and are pseudomorphs retaining only their shape with nothing surviving from the original phenocryst.

Microprobe analysis was conducted using the Cameca SX-50 electron microprobe at the University of Massachusetts, Amherst. The same samples previously examined on the SEM at Williams were analyzed on the microprobe. Magnetite grains with ilmenite lamellae in PH-12-10 were targeted for precise chemical composition. Oxyhornblende cores were studied in the same sample. Clinopyroxene grains were analyzed in PH-12-9 and PH-12-10 to attain a precise chemical composition, which clusters closely around En 45%, Wo 47%, and Fs 8% (diopside).

GEOTHERMOMETRY

Fe-Ti oxides from the two samples were targeted specifically to use as a geothermometer according to the methods of Ghiorso and Evans (2008). The method relates temperature to compositionally dependent long-range cation order by looking at the precise Fe-Ti oxide compositions. Once the mineral chemistry was acquired from the electron microprobe, oxide weight percentages were put into two geothermometry calculators. The first was a program derived from Ghiorso and Evans (2008) using calculations based on symmetry-breaking phase transitions at elevated temperatures. Comparisons of magnetite and ilmenite mineral chemistry produce a magma chamber temperature. The second calculation was based on work done by Anderson and Lindsley (1988) using oxide weight percentages of magnetite and ilmenite to calculate percentages of ulvospinel and rhombohedral phase ilmenite. Chemical comparison of the two minerals yields a temperature range for the magma chamber. Results from these calculations yielded temperatures of 743.2˚, 743.3˚, 747.9˚, 752.5˚, 796.7˚, and 805˚ C. The numbers create an acceptable range between 740˚ - 800˚ C for the basaltic trachyandesite magma chamber for sample PH-12-9.

DISCUSSION

Breakdown of the oxyhornblende phenocrysts in basaltic trachyandesite can be attributed to decompression of the hydrous amphiboles during magma ascent from the storage zone at depth (Rutherford, 2003). Reaction rims from decompression are generally thinner (5-50µm) than those from heating during magma mixing (Browne and Gardner, 2006). Morphology and mineralogy of the rims from the PRVF are more comparable to experimental results that produced thinner rims from
decompression. The one discrepancy is the presence of orthopyroxene in the experimental results versus clinopyroxene found in the PRVF samples.

Elevated concentrations of Na$_2$O in the alkalic rocks allow a more specific classification of the PRVF samples in this report: e.g., mugearite (sodic trachybasalt) and benmoreite (sodic trachyandesite). The most plausible model for the genesis of such sodic volcanics involves continental assimilation that incorporates material from previous island arc complexes within the Wallowa Terrane. The Cougar Creek Complex contains a broad compositional base of silicic and mafic magmas that exhibit trace element characteristics of a subduction-modified strongly depleted mantle source (Kurz et al., 2012). The Cornucopia stock includes sodic intrusive rocks such as trondhjemite and tonalite.

Basanite in the PRVF immediately preceded the eruptions of the sodic trachy-lavas of this report and provides further evidence supporting contamination by crustal assimilation. The basanite shows elevated Na$_2$O similar to the sodic trachy-lavas (Baez, 2013, this volume) and contains xenoliths with compositions like some leucotonalites analyzed in Johnson et al. (1997) from the peralumious trondhjemite in the Cornucopia stock.

Additionally, certain trace elements in the PRVF also indicate a significant contribution from continental crustal rocks. What is especially distinctive about the PRVF samples are the low Y and Nb values and extremely high Sr. The basanite and the sodic trachy-lavas all show similar distinctive amounts of those trace elements. Chemical analysis of the high-Al tonalite-trondhjemite-granitoid (TTG) suite of the Cornucopia stock reveals the same trace element patterns; that correlation helps establish a relationship between PRVF and prior igneous activity in the region. A mantle plume initiated by the waning stages of the CRBG hotspot could thus have interacted with a variety of compositionally different lithologic components to produce the enriched sodic PRVF lavas.

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REFERENCES


