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

April 2013
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Short Contributions— Northeast Oregon Project

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LAVAS AND INTERBEDS OF THE POWDER RIVER VOLCANIC FIELD, NORTHEASTERN OREGON

NICHOLAS E. BADER, Whitman College
KIRSTEN NICOLAYSEN, Whitman College

INTRODUCTION

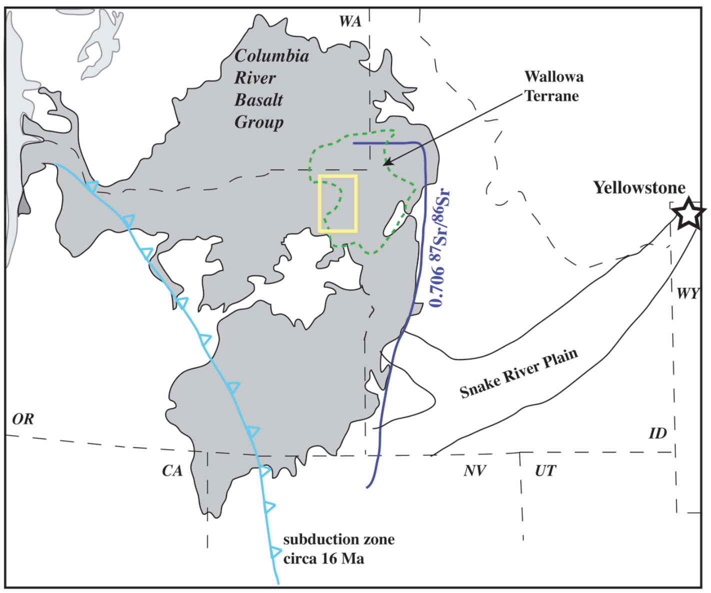

Figure 1. Regional compilation of tectonic boundaries, features and eruptive units significant to Miocene - Pliocene eruptions in northeastern Oregon. The yellow box shows the approximate location of the study area relative to the accreted Mesozoic arc (Wallowa terrane – green dashed line) that forms bedrock beneath the Columbia River Basalt Group (shaded gray) in the study area. To the east the purple "0.706 line" marks the boundary of crystalline Precambrian basement. The younger basalts and rhyolitic centers of the Snake River Plain have been attributed to the track of the Yellowstone hotspot. The blue toothed line marks the location of the Cascade subduction zone circa 16 Ma (Liu and Stegman, 2012). Compiled from Camp and Hanan, 2008; Lund et al., 2008; and Liu and Stegman, 2012.

Northeastern Oregon during the Miocene was center stage for a globally-significant period of volcanism. Between ca. 17.5 to 6 Ma, vast outpourings of basalt covered large parts of Washington, Oregon and Idaho, forming the Columbia River Basalt Group (CRBG; Tolan et al., 2009) and obscuring underlying Mesozoic accreted terranes (Fig. 1). Several models have been proposed to explain the large outpouring of primarily mafic magmas of this Large Igneous Province (LIP) including impact of the Yellowstone mantle plume (Wolff et al., 2008), delamination of lower lithosphere (e.g., Camp and Hanan, 2008), or a slab tear in the subducted Farallon plate (Liu and Stegman, 2012). Eruptions of older LIPs may have changed atmospheric chemistry sufficiently to change global climate and the terminal Permian and Cretaceous mass extinction events have been attributed to LIP emplacement (Wignall, 2001). The eruption of the CRBG in particular may have caused the global spike in atmospheric CO_2 and associated warm temperatures during the Langhian (Sheldon, 2006).

Locally overlying and in some cases contemporaneous with the CRBG are small-volume calc-alkaline to alkaline lavas of the Powder River Volcanic Field (PRVF; Ferns et al., 2010). The distinct mineralogy and geochemistry of these lavas provide an opportunity to evaluate the suitability of the competing models for both CRBG and PRVF genesis. Moreover, contemporaneous volcaniclastic interbeds represent violent eruptive phases interspersed with the CRBG and PRVF. Although the volcanic affinity for these sediments is unknown, they indicate the potential for climate-changing eruptions.

With the exception of geochemical work by Bailey and Conrey (e.g., Bailey and Conrey, 1992), previous published work in the PRVF has been primarily restricted to mapping the location and extent of the rock units. Early workers lumped PRVF rocks (as "younger basic lavas") together with the CRBG (Hampton and Brown, 1964). The most recent map,

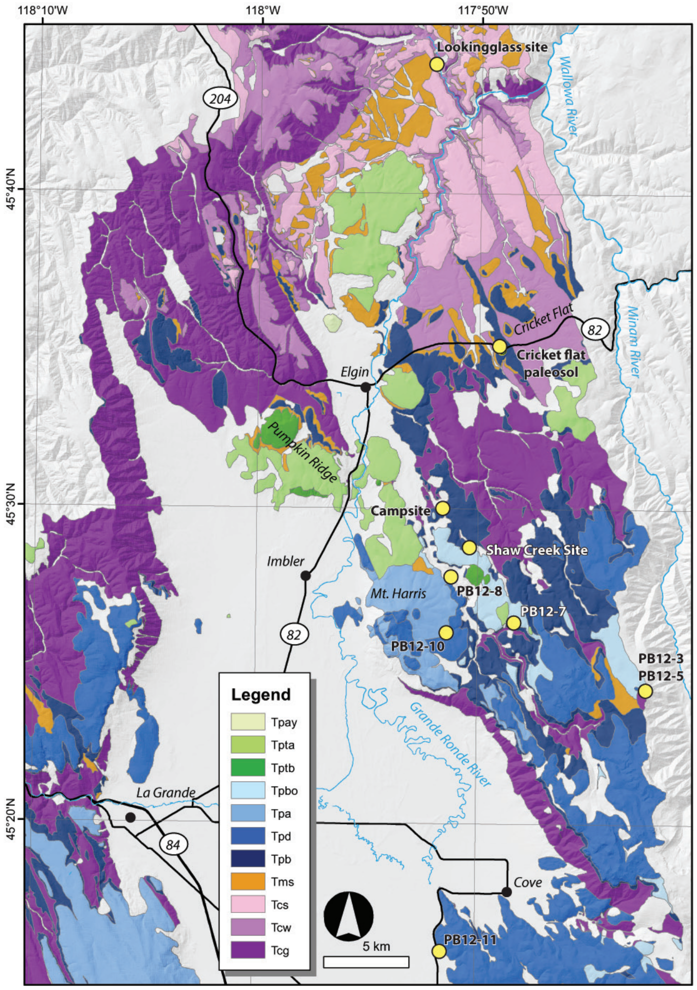

Figure 2: Map of the study area in northeastern Union County, Oregon including some project locations. Sample numbers are from study by Baez (this volume). Purple units are CRBG, blues are Middle-Late Miocene PRVF, and greens are Late Miocene-Pliocene PRVF (the Elgin Volcanic Complex). PRVF units: **Tpb** *olivine basalt;* **Tpa** *andesite and basaltic andesite;* **Tpd** *dacite;* **Tpbo** *basanite and trachybasalt;* **Tpta** *andesite and trachyandesite;* **Tptb** *basaltic trachyandesite;* **Tpay** *andesite and dacite. CRBG units:* **Tcg** *Grande Ronde Basalt;* **Tcw** *Wanapum Basalt;* **Tcs** *Saddle Mountains Basalt. From Ferns, 2010. Gray areas in the east and northwest are mapped as CRBG and Quaternary sediments.*

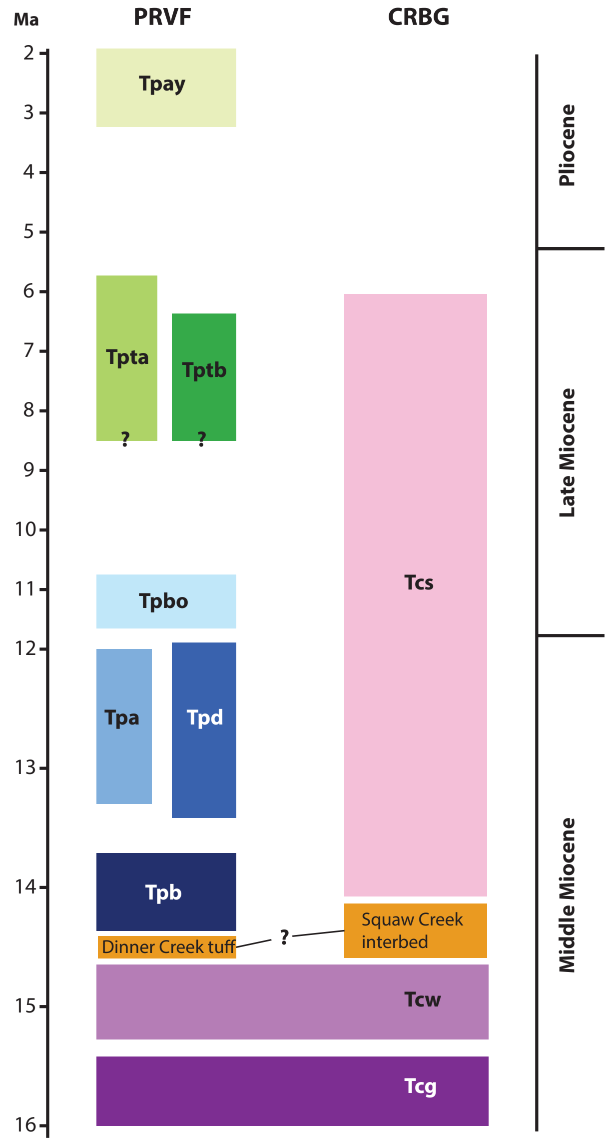

Figure 3. Approximate timeline for the major units of the PRVF and the CRBG in our area. Ages are approximate; colors and units are as in Fig. 2. Dinner Creek Tuff and the Squaw Creek interbed are part of the undifferentiated Tms (Tertiary sediments) of Figure 2. Ages from Ferns et al. (2010), Barry et al. (2010), and Ferns and McClaughry (in press).

covering Union County, includes a compilation of geochemical data from the PRVF, revealing a remarkable variety of compositions including basalts, dacites, basaltic trachy-andesites, and basanites (Ferns et al., 2010, Fig. 2 and 3). The meaning of this geochemical variety has not yet been incorporated into a broader model for the formation of the CRBG and PRVF.

In some cases fossil soils (paleosols) can be identified in the silicic interbeds that indicate periods of relative stability between eruptive phases. Paleosols are useful because they are affected by environmental conditions at the Earth's surface at the time of their formation. After controlling for diagenetic alteration, paleosols can therefore allow us to reconstruct paleoclimates (Sheldon and Tabor, 2009), paleoenvironments (Kraus, 1999) or paleotopography (Takeuchi, 2007) depending upon the variables held constant by the analysis. Furthermore, paleosols may prove invaluable to reconstructing the timing and duration of eruption hiatuses (Barry et al., 2010).

Because most soils are in actively eroding landscapes, the global distribution of paleosols is sparse compared to the distribution of modern soils. However, widespread aggradation in the volcanically-active Cenozoic landscapes of eastern Oregon has preserved numerous paleosols. Especially well-studied examples include the late Eocene and Oligocene paleosols of the Clarno and John Day Formations (e.g. Retallack et al., 2000). Numerous paleosols have also been preserved between flows of the CRBG (Sheldon, 2003). Paleosols from these volcanic landscapes are particularly useful for geochemical analysis because the composition of the parent material can be measured accurately rather than inferred. Furthermore, because the paleosols are stratigraphically bracketed by datable volcanic units, unusually precise age determination is possible.

Past work on these paleosols has provided a terrestrial record of paleoclimate in Oregon. The Clarno and John Day paleosols record the dramatic cooling at the Eocene-Oligocene transition (Retallack and Bestland, 1999). The CRBG paleosols have also been used reconstruct Miocene climate change, although no high-resolution chronology has been attempted. For example, paleosols from the Picture Gorge Basalts corroborate theories of a Middle Miocene thermal maximum around 16 Ma, possibly brought on in part by elevated greenhouse gas concentrations associated with the eruption of the Grande Ronde basalts (Sheldon, 2006).

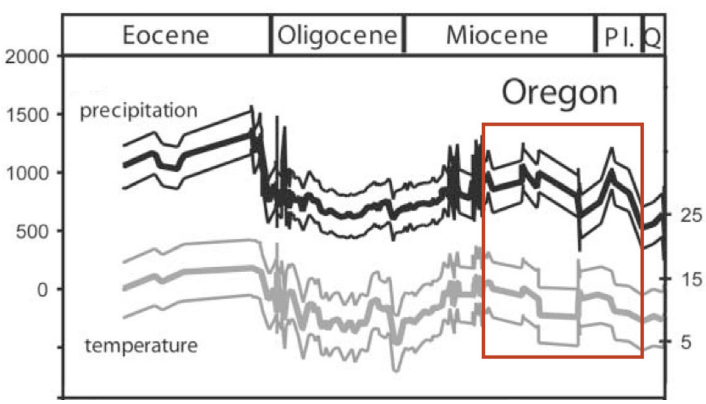

Figure 4. Terrestrial paleoclimate in Oregon from paleosols, (Figure modified from Retallack, 2007). The climate record is sparse within the red box, the period covered by the PRVF eruptions.

The terrestrial paleoclimate record from Oregon paleosols is good for the late Eocene, Oligocene, and Early Miocene, but it becomes sparse in the Middle Miocene and thereafter (Fig. 4), when the PRVF was being deposited. Paleosols from the PRVF are therefore potentially useful for filling this gap. However, thus far no paleosols have been described from the PRVF, although Carson (2001) noted the Cricket Flat paleosol in a field trip guide.

For this project, we investigated the lavas of the PRVF and their interbeds and paleosols. Our primary goals were: (1) to assemble enough geochemical and age control on the rocks of the PRVF to assemble a conceptual model of the origin and evolution of the PRVF; and (2) to use interbeds and paleosols to interpret paleoenvironment at the time of the emplacement of the PRVF.

Seven students participated in this project. Six students were selected and funded through the Keck Geology Consortium; a seventh student from Whitman College was added to the trip using Whitman funds. Students flew from their home cities into Walla Walla on 11 July 2012 for a week of orientation, background, and local and regional field trips before we drove to our field campsite south of Elgin, OR (Fig. 2). The first two days in our field area were spent with Mark Ferns (Oregon Department of Geology and Mineral Industries), whose extensive background in the PRVF made him an invaluable resource. With Ferns, we toured our area, looking at characteristic localities for the PRVF units and sedimentary interbeds. For the remaining two weeks of our field project, students identified research projects that aligned with their interests and took the lead on their research. Due to logistical and safety considerations, students could not work on their projects every day; instead, each student spent part of their time helping other students with their own projects. Upon our return to Walla Walla, students worked for several days on sample preparation and curation, GIS maps, stratigraphic columns, and beginning the writing process. Students also spent a full day at the GeoAnalytical Lab at Washington State University in Pullman running geochemical samples for their projects. The Keck students flew back to their home cities on 7 August 2012.

STUDENT PROJECTS

Figure 5. PRVF team includes (front row, left to right) Michael Baez, Luke Ferguson, Mark Ferns, Ricardo Lopez-Maldonado, Johnny Ray Hinojosa, Nick Bader, (back row) Kirsten Nicolaysen, Rebecca Rodd, Michelle Evertz, and Anna Mudd.

Luke Ferguson (Pomona College) studied the olivine basalt at the base of the PRVF sequence (Tpb, Fig. 2 and 3), comparing the olivine basalt composition to the distinctly different CRBG. Luke concludes that the olivine basalt seems to require greater extents of melting of upper mantle peridotite than the CRB and that either lithospheric delamination or tearing of the descending Farallon slab may facilitate melting of upper mantle.

Michael Baez (Cal. State Fullerton) collected basanites (Tpbo) and some crustal xenoliths to perform petrographic and geochemical analysis (Fig. 2). The basanite in the PRVF is enigmatic, especially since it overlies andesites and dacites. Michael hoped to answer several questions: Is the basanite an influx of new magma from the same source as the olivine basalt? What is the extent of modification due to assimilation of crustal material? He concludes the basanite is fundamentally different from both the CRBG and the older olivine basalt of the PRVF and attributes these differences both to greater extents of mantle melting and to assimilation of crust of the accreted Wallowa terrane and Cretaceous intrusions.

Johnny Ray Hinojosa (Williams College) studied some of the youngest units of the PRVF: the trachyandesite (Tpta), trachybasalt (Tpbo), and basaltic trachyandesites (Tptb). These alkaline lavas are unusually sodic composition, and though they may be related by fractionation to the underlying basanites, Johnny Ray concludes that assimilation of material from the Wallowa Terrane is also likely. Using electron microscopy on exsolved ilmenite in magnetite revealed that the basaltic trachyandesite had a minimum eruption temperature of ~740-800°C.

Ricardo Lopez-Maldonado (University of Idaho) and Anna Mudd (College of Wooster) studied the Cricket Flat paleosol (Fig. 2). Both Ricardo and Anna were responsible for field description and stratigraphic measurements. Ricardo studied the geochemical record of pedogenesis using major element analysis via XRF, to answer questions about ancient weathering rates. Anna isolated clay minerals and used XRD and SEM to characterize the clay mineralogy of the paleosol in an effort to characterize the soil processes at work during the time of the soil formation, and thus during the eruption of some of the early PRVF units.

Rebecca Rodd (UC Davis) collected oriented cores and made paleomagnetic measurements for two outcrops in the PRVF. Rebecca attempted to determine the direction of the magnetic field during eruption of the Cricket Flat olivine basalt (Fig. 2, 3). Second, she compared magnetic inclination for andesite-dacite lavas but across a ravine with observed differences in lava orientation, in order to understand post-eruption tectonic movement at the Shaw Creek location in the PXRF (Fig. 2). Inclinations did not support interpretations of late Miocene to recent extensional faulting but declinations were markedly different than expected. The simplest explanation is that the magnetic field was reversed or undergoing an excursion at the time of emplacement of the flows.

Misha Evertz (Whitman College) studied a thick silicic interbed in the CRBG exposed near Lookingglass Creek north of Elgin (Fig. 2). Misha described and sampled the section, and collected fossils, thin sections, and geochemical samples in order to interpret the environment of deposition for the sequence, and attempted to identify possible vent sources for the volcaniclastic material.

SCIENTIFIC ACCOMPLISHMENTS

Analysis of several mapped lava units of the PRVF indicate fundamentally different magmatic sources and different extents of partial melting compared to the older Grande Ronde and Wanapum Formations of the Columbia River Basalt Group. In part, the compositions require greater contributions from more than one type of mantle source and local assimilation of accreted arc terranes and/or Cretaceous plutons. Paleomagnetic analyses of some PRVF lavas returned expected inclinations of ~65° though anomalous declinations suggest a geomagnetic reversal or excursion at the time of eruption.

The Cricket Flat paleosol is a newly-described paleosol from Cricket Flat east of Elgin, Oregon. Geochemistry and clay mineralogy from this soil suggests that the basal olivine basalt of the PRVF was erupted in a warm temperate climate with wet and dry seasons.

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