2009-2010 PROJECTS

SE ALASKA - EXHUMATION OF THE COAST MOUNTAINS BATHOLITH DURING THE GREENHOUSE TO ICEHOUSE TRANSITION IN SOUTH EAST ALASKA: A MULTIDISCIPLINARY STUDY OF THE PALEOGENE KOOTZNAHOO FM.
  Faculty: Cameron Davidson (Carleton College), Karl Wirth (Macalester College), Tim White (Penn State University)
  Students: Lenny Ancuta, Jordan Epstein, Nathan Evenson, Samantha Falcon, Alexander Gonzalez, Tiffany Henderson, Conor McNally, Julia Nave, Maria Princen

COLORADO – INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO.
  Faculty: David Dethier (Williams)  Students: Elizabeth Dengler, Evan Riddle, James Trotta

WISCONSIN - THE GEOLOGY AND ECOHYDROLOGY OF SPRINGS IN THE DRIFTLESS AREA OF SOUTHWEST WISCONSIN.
  Faculty: Sue Swanson (Beloit) and Maureen Muldoon (UW-Oshkosh)
  Students: Hannah Doherty, Elizabeth Forbes, Ashley Krakto, Mary Liang, Ethan Mamer, Miles Reed

OREGON - SOURCE TO SINK – WEATHERING OF VOLCANIC ROCKS AND THEIR INFLUENCE ON SOIL AND WATER CHEMISTRY IN CENTRAL OREGON.
  Faculty: Holli Frey (Union) and Kathryn Szramek (Drake U.)
  Students: Livia Capaldi, Matthew Harward, Matthew Kissane, Ashley Melendez, Julia Schwarz, Lauren Werckenthien

MONGOLIA - PALEOZOIC PALEOENVIRONMENTAL RECONSTRUCTION OF THE GOBI-ALTAI TERRANE, MONGOLIA.
  Faculty: Connie Soja (Colgate), Paul Myrow (Colorado College), Jeff Over (SUNY-Geneeseo), Chuluan Minjin (Mongolian University of Science and Technology)
  Students: Uyanga Bold, Bilguun Dalaibaatar, Timothy Gibson, Badral Khurelbaatar, Madelyn Mette, Sara Oser, Adam Pellegrini, Jennifer Peteya, Munkh-Od Purevtsersen, Nadine Reitman, Nicholas Sullivan, Zoe Vulgaropoulos

KENAI - THE GEOMORPHOLOGY AND DATING OF HOLOCENE HIGH-WATER LEVELS ON THE KENAI PENINSULA, ALASKA
  Faculty: Greg Wiles (The College of Wooster), Tom Lowell, (U. Cincinnati), Ed Berg (Kenai National Wildlife Refuge, Soldotna AK)
  Students: Alena Giesche, Jessa Moser, Terry Workman

SVALBARD - HOLOCENE AND MODERN CLIMATE CHANGE IN THE HIGH ARCTIC, SVALBARD, NORWAY.
  Faculty: Al Werner (Mount Holyoke College), Steve Roof (Hampshire College), Mike Retelle (Bates College)
  Students: Travis Brown, Chris Coleman, Franklin Dekker, Jacalyn Gorczynski, Alice Nelson, Alexander Nereson, David Vallencourt

UNALASKA - LATE CENOZOIC VOLCANISM IN THE ALEUTIAN ARC: EXAMINING THE PRE-HOLOCENE RECORD ON UNALASKA ISLAND, AK.
  Faculty: Kirsten Nicolaysen (Whitman College) and Rick Hazlett (Pomona College)
  Students: Adam Curry, Allison Goldberg, Lauren Idleman, Allan Lerner, Max Siegrist, Clare Tochilin

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LATE CENOZOIC VOLCANISM IN THE ALEUTIAN ARC: EXAMINING THE PRE-HOLOCENE RECORD ON UNALASKA ISLAND

Project Faculty: KIRSTEN NICOLAYSEN: Whitman College
RICHARD HAZLETT: Pomona College

GEOCHEMICAL INVESTIGATION OF THE RED CINDER PEAK AREA OF MAKUSHIN VOLCANO, UNALASKA, ALASKA

ADAM CURRY: Pomona College
Research Advisors: Jade Star Lackey and Richard Hazlett

PETROLOGIC AND VOLCANIC HISTORY OF POINT TEBENKOF IGNIMBRITE, UNALASKA, ALASKA

ALLISON R. GOLDBERG: Williams College
Research Advisor: Reinhard A. Wobus

40Ar/39Ar DATING OF LAVAS FROM MAKUSHIN VOLCANO, ALASKA: EVIDENCE FOR XENOCRYST CONTAMINATION

LAUREN M. IDLEMAN: Colgate University
Research Advisor: Martin S. Wong

ERUPTION DYNAMICS OF THE 7.7 KA DRIFTWOOD PUMICE-FALL, MAKUSHIN VOLCANO, ALASKA

ALLAN H. LERNER: Amherst College
Research Advisor: Peter D. Crowley, Amherst College

GEOCHEMICAL VARIATION IN PRE-CALDERA AND HOLOCENE LAVAS FROM MAKUSHIN VOLCANO, UNALASKA ISLAND, ALASKA

MAX T. SIEGRIST: Beloit College
Research Advisor: Jim Rougvie
PALEOMAGNETIC EVIDENCE AND IMPLICATIONS FOR STRUCTURAL
BLOCK ROTATION ON UNALASKA ISLAND

CLARE TOCHILIN: Whitman College
Research Advisors: Kirsten Nicolaysen and Robert Varga

Funding provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)

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INTRODUCTION

This project presents a geochemical analysis of Pleistocene volcanic deposits of the Red Cinder Peak area of Makushin Volcano, Unalaska Island, AK. This analysis aims to understand the petrogenesis of the Point Tebenkof Ignimbrite (PTI) and several lava flows from the northeast flank of Makushin Volcano shown in Figure 1. Comparison of the ~42 m thick ignimbrite to younger Makushin caldera-forming events is significant from a hazards point of view because it constrains the conditions that have led to large, caldera-forming eruptions at Makushin in the past, exemplified by the PTI. Any future eruptions of similar magnitude could potentially threaten the residents of the nearby town of Unalaska (including Dutch Harbor) as well as disrupt air traffic downwind of the Aleutian Islands. Geologically, this project is significant because the Holocene eruptive history of Makushin Volcano and its satellite vents have been well characterized (Nye et al., 1986; McConnell et al., 1997; Roach, 1997; Bean, 1999; Begét et al., 2000), but the Pleistocene eruptive and petrogenetic history of Makushin is much less studied.

METHODOLOGY

Red Cinder Peak and Pt. Tebenkof comprise the western wall of Driftwood Bay and Valley (Fig. 2 of Nicolaysen and Hazlett, this volume). Keck colleague Allie Goldberg and I collected ~ 40 samples from a stratigraphic sequence of 12 pre-Holocene lava flows and established field relations of these deposits (Fig. 1). At the bottom, the basal contact of the Point Tebenkof Ignimbrite, here named, was not visible due to beach cobbles. Lithic, vitric, scoria, and pumice samples were collected from various levels within the ignimbrite. Whole rock analyses were done at Washington State University according to the methods of Johnson et al. (1997) using a ThermoARL x-ray fluorescence spectrometer (XRF) and an HP4500+ inductively-coupled plasma-mass spectrometer (ICP-MS). Values of δ^{18}O for individual olivine and plagioclase crystals were measured at University of Oregon using laser fluorination (Valley et al., 1995). Pb isotope analysis was conducted at the University of British Columbia’s Pacific Centre for Isotopic and Geochemical Research using a Nu
Plasma multi-collector inductively coupled plasma-mass spectrometer (MC-ICP-MS) according to the methods of Weis et al. (2006). Analytical precision at two standard deviations is as follows: XRF achieved ±0.09 wt. % for all major elements, ±2.3 ppm for all trace elements; ICP-MS achieved ±0.07 ppm for all trace elements except Sr (±10.8 ppm); δ18O achieved ±0.14 ‰; and Pb isotopes achieved ±0.0046. Error bars are left out of all figures except those with δ18O based on symbol size relative to analytical precision.

RESULTS

STRATIGRAPHY

The feature herein called Red Cinder Peak is labeled on maps as Red Cinder Dome, implying that all flows are related to such a satellite dome. Peak is used here because the feature is not a volcanic extrusive dome but a point resulting from glacial erosion. The sampled flows in Figure 1 most likely originated from the main vent of Makushin or a buried satellite vent.

The stratigraphy of Red Cinder Peak is subdivided into four subsections, based on stratigraphic location (Fig. 1). Section 1 is the ignimbrite at the base of the exposure, and section 2 includes the four basaltic-andesitic flows directly overlying the PTI. Flow BCA is dated at 139 ka (see Idleman, this volume). Sections 3 and 4 are basaltic andesite and andesite lava flows whose stratigraphic relationships are obscured by lack of horizontal continuity. The top flow of Section 4, EAR, outcrops just below glacial till of the last glacial maximum.

The Pt. Tebenkof Ignimbrite is an andesitic, dominantly lapilli ignimbrite which is pumice-poor and scoria-rich. The PTI records many distinct eruptive phases, and the main phase marks the appearance of mingled scoria clasts in which a dark matrix surrounds lighter colored pumice. The ignimbrite is topped with an ~8 m section of co-ignimbrite ashfall grading from tan to brick red. A detailed description of the PTI can be found in Goldberg, this volume.

PETROGRAPHY

All lavas contain phenocrysts of dominantly plagioclase+ clinopyroxene ± olivine ± orthopyroxene. Sieve textures and zoning in plagioclase crystals are prominent in flows above the PTI, but very few sieve textures or zoning occur within the ignimbrite’s phenocrysts. Sieving occurs either in the middle of the crystal on the edges, or throughout the crystal. Cumulophyres of different combinations of plagioclase, pyroxene, and occasionally olivine are prevalent in
the post-ignimbrite flows, while the ignimbrite has few cumulophyres and crystals in general.

**GEOCHEMISTRY**

PTI samples (including lithic, vitric, scoria, and pumice samples from different layers) have normalized weight percent oxide abundances of SiO$_2$ (59.86-61.24), TiO$_2$ (0.97-1.114), Al$_2$O$_3$ (16.26-16.93), FeO* (7-7.86), MgO (2.11-2.66), CaO (5.16-5.98), and K$_2$O (1.16-1.57). The PTI is a compositionally homogeneous ignimbrite up to the co-ignimbrite ash fall (not sampled). Subsequent flows have ranges of SiO$_2$ (49.66-63.72), TiO$_2$ (0.79-1.29), Al$_2$O$_3$ (15.11-18.87), FeO* (6.11-10.19), MgO (1.73-8.99), CaO (4.31-11.89), and K$_2$O (0.63-2.21), normalized wt. %. These post-ignimbrite flows display much more heterogeneity than the ignimbrite. All samples except SEB and SEA fall into the tholeiitic geochemical field of Miyashiro (1974), which agrees with the previous geochemical analyses of Makushin (Nye et al., 1986; Bean, 1999).

Figure 2a-d shows trace element abundances of each stratigraphic section using the primitive mantle normalization of Sun and McDonough (1989) compared to the same author’s NMORB values and average DSDP 183 (Plank and Langmuir, 1998). Nearly all samples from this study follow a typical island arc pattern, with BCC showing the only noticeable variation, including several dips below normal mid-ocean ridge basalt (NMORB) values. Figures 2e and 2f show the PTI compared to Holocene caldera-forming tephras of Bean (1999) and mainly Holocene flank vent lavas of Roach (1997).

![Figure 2. Primitive mantle-normalized spider diagrams showing samples in the present study compared to NMORB (Sun and McDonough, 1989), and DSDP 183 (Plank and Langmuir, 1998).](image)
Figures 3 and 4 show the behavior of Th/La, Ba/La, Sm/La and $^{207}$Pb/$^{204}$Pb. Both Th/La and Ba/La are positively correlated to $^{207}$Pb/$^{204}$Pb, (Fig. 3a and 3b). In both instances the present samples plot between the MORB values and the DSDP 183 values. Furthermore, samples from this study plot between MORB and DSDP 183 values on a Ta/La vs. Sm/La plot (Fig. 4).

Olivine $\delta^{18}$O values range from 4.32-5.48, and plagioclase $\delta^{18}$O values range from 4.67-6.25 (Fig. 5a). Most samples plot below the arc mantle source value, and $\delta^{18}$O values increase with stratigraphy. $\Delta^{18}$O$_{\text{OL-PLAG}}$ values plot above the magmatic equilibrium lines indicating disequilibrium between the minerals and the melt (Fig. 5b).

DISCUSSION

The trace element patterns of these Pleistocene volcanics are typical of island arc settings (Fig. 2). The relative abundance of large ion lithophile elements (LILE) compared to high field strength
elements (HFSE) shows the influence of fluids in melt generation, as LILE are more fluid-mobile than HFSE. The similar values of HFSE of NMORB and my samples are best explained by a similar depleted mantle source. The only exception, flow BCC, has several HFSE values, Nb, Ta, Zr, Dy, Y, Yb, and Lu, lower than MORB, suggesting an even more depleted mantle source. That BCC in general has lower abundances than other samples implies its production by a higher degree of partial melting.

Figure 2e and 2f show that the PTI is enriched relative to the Roach (1997) Holocene flank vents, and only slightly depleted relative to the Bean (1999) Holocene caldera forming events. Because these trace element values track with SiO$_2$ abundance, the spider plot implies that the PTI reached a lower degree of fractionation of a similar parent magma compared to the Holocene caldera-forming eruptions prior to the catastrophic eruption of the PTI. That the samples in the present study are more akin to the samples of Bean (1997) than to Roach (1997) indicates that the PTI likely erupted from the main Makushin plumbing system rather than a satellite vent.

Kelemen et al. (2003) and Singer et al. (2007) discuss the positive correlation within the Aleutians of $^{207}$Pb/$^{204}$Pb with sediment flux as well as Th/La and Ba/La. $^{207}$Pb/$^{204}$Pb values increases to the east as does the calculated sediment flux (Kelemen et al., 2003; Singer et al., 2007). Th is high in marine sediments, low in the mantle, and relatively insoluble in fluids compared to Ba. Therefore, Th is used as a proxy for sediment melt, and Ba is used as a proxy for a fluid phase added to mantle peridotite melts. These flows show a wider range of Th/La than Ba/La, but the Ba/La values are closer overall to the DSDP 183 value (Fig. 3). This might suggest a consistent fluid release mechanism and a variable amount of sediment melting within the subduction zone. Figure 4, after Plank (2005), shows variable degrees of mixing between Pacific sediments and Aleutian MORB and helps explain the variation of the sample suite. BCC, NWD, and BCF3V are influenced most by subducted sediment, while EAR and DB9M8 are least sediment-influenced (Fig. 4).

The oxygen isotopes recorded in olivine and plagiooclase crystals show a gradual increase of $\delta^{18}$O values going up stratigraphy (Fig. 3a). BCF-1S-1, BCB-2S, and BCB-3S (scoria from the first 3 layers of the ignimbrite, respectively) show the lowest olivine $\delta^{18}$O values, while SEA and SEB show the highest olivine $\delta^{18}$O values. Low $\delta^{18}$O phenocrysts can only be produced through magma that has somehow incorporated surface water, most likely through assimilation of hydrothermally altered crustal rocks (Bindeman et al., 2001). $\Delta^{18}$O$_{OL-PLAG}$ values shown in Figure 5b show that plagioclase and olivine crystals in BCB-2S, BCF-1S-1, BCC, SEB, and SEA were not in equilibrium with the magma in which they grew. Because distribution coefficients dictate that plagioclase should have higher $\delta^{18}$O than olivine in a given magma, it is notable that SEB contains a plagioclase $\delta^{18}$O value lower than its olivine $\delta^{18}$O value. Figure 5 provides evidence for assimilation of hydrothermally altered crustal rocks, disequilibrium magma chambers, and possible magma mixing in sample SEB. This disequilibrium due to magma mixing is further supported by the prevalent sieve and zoning textures throughout the post-ignimbrite flows in addition to the magma mingling suggested by mottled scoria within the ignimbrite.

CONCLUSIONS

The volcanic rocks of Red Cinder Peak are derived from the main Makushin plumbing system rather than composing a satellite vent, and therefore the term Red Cinder Dome should not be used. Although most flows show similar trace element patterns (Fig. 2), much geochemical variability exists, especially regarding BCC. BCC seems to be more extensively melted from a more depleted source, but it also shows high Th/La ratios, indicating sediment melt. Most samples show some degree of sediment influence, but whether this is in the form of a sediment melt or aqueous fluids is to be determined. Given the similarities in spider diagrams, the cause of the PTI cannot be related to fundamental factors controlling such patterns, such as the mantle source or degree of partial melting. More likely, the PTI was caused by factors present in the petrography and
δ¹⁸O values, specifically crustal assimilation of low-δ¹⁸O rocks, disequilibrium between minerals and melt, and magma mixing.

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**REFERENCES**


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