KECK GEOLOGY CONSORTIUM
PROCEEDINGS OF THE TWENTY-THIRD
ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY
ISSN# 1528-7491

April 2010

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Editor & Keck Director
Franklin & Marshall College

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Students: Adam Curry, Allison Goldberg, Lauren Idleman, Allan Lerner, Max Siegrist, Clare Tochilin

Keck Geology Consortium: Projects 2009-2010
Short Contributions – UNALASKA

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

Project Faculty: *KIRSTEN NICOLAYSEN*: Whitman College
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ADAM CURRY: Pomona College
Research Advisors: Jade Star Lackey and Richard Hazlett

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ALLISON R. GOLDBERG: Williams College
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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

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

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INTRODUCTION

Pumice deposits are records of violent plinian eruptions, typically from highly siliceous volcanoes (Bardintzeff and McBirney, 2000). Plinian eruptions are major socio-economic hazards, both locally due to pyroclastic density flows, lahars, and tephra rain-out, and worldwide due to ash and aerosol inputs into the atmosphere. Makushin Volcano on Unalaska Island, AK, is potentially the most threatening volcano in the Aleutian chain, being located close to Dutch Harbor and Unalaska – the most populated Aleutian communities and the second most economically important fishing port in the United States. This study investigates the stratigraphic and petrologic details from the 7.7 ka (Bean, 1999) Driftwood Pumice deposit, which records Makushin's last episode of extreme explosivity.

The Driftwood Pumice reaches thicknesses of over 1.5 meters, and consists of two identifiable light horizons, capped by two darker layers. The deposit is sandwiched between numerous smaller ash falls, many of which also consist of light-dark tephra couplets, possibly being smaller-scale equivalents of the Driftwood deposit. The repeated occurrences of light tephra overlain by dark tephra suggest a common mechanism for explosive Makushin eruptions.

FIELD DESCRIPTION AND METHODS

Pumice fragments of the Driftwood Pumice are ubiquitous in the topsoil and solifluction depressions throughout Driftwood Valley, which extends ~8-12 km to the northeast from the summit of Makushin Volcano. The Driftwood Pumice is best exposed in the steep walls of river valleys and landslide scarps.

Samples were collected from 19 trenched and measured sites in and around Driftwood Valley. Proximal deposits of the Driftwood Pumice consisted of three identifiable pumice horizons: the Lower Pumice (PL), Main Pumice (PM), and Upper Pumice (PU), as well as a capping ash layer (Mcap) (Fig. 1). Horizons were distinguished by color, grain size, and the proportions of pumice, scoria, and lithic ejecta. Bulk samples were collected from the centers of each of these horizons.

Samples were hand-sieved at 1 phi intervals to calculate average bulk diameter. Weight percent of components were calculated with volumetric estimations and density corrections for finer material (0 to 4 phi). Petrological and geochemical analyses of the ejecta included: 1) petrographic investigation of thin sections of juvenile material from each horizon, 2) Scanning Electron Microscopy (SEM) analyses of mineral and glass compositions, and 3) X-Ray Fluorescence (XRF) whole rock and trace element analyses done at the University of Massachusetts Amherst.

RESULTS

Stratigraphy

Many of the sample sites have two dark and one light ashfall horizons underlying the Driftwood Pumice deposit, with each ashfall separated by a few cm of soil (Fig. 1). Locations with more complete Holocene stratigraphy show numerous ashfall horizons both stratigraphically below and above the pumice, including multiple ash couplets consisting of a light ash layer immediately overlain by dark ash layer, without any intervening soil or other evidence of a depositional hiatus.

The Driftwood Pumice (Fig. 1) contains multiple types of juvenile and accidental ejecta. Juvenile pumice is tan, highly vesicular, and low-density. Juvenile scoria is vesicular with grayish-black glass, and is denser and more crystal-rich than the pumice. Accidental ejecta included vitric and a variety of non-vitric lithics.

The bottom of the Driftwood Pumice deposit (PL) is a relatively thin horizon of vitric lapillistone (76 wt% lapilli, 24 wt% ash) consisting of well-sorted, light brown-beige pumice fragments (avg. dia. ~4 mm) and abundant smaller lithics (22 wt%). The accidental lithic ejecta consist almost entirely of vitric material. There is sharp inverse grading at the very base of the layer, as well as at the top where PL grades into PM.

The main body of the pumice deposit (PM) consists of a much thicker horizon of large, light brown-beige pumice with sparse, smaller lithic inclusions (5%) that are mostly vitric (60%). The horizon is a moderately well-sorted, generally ungraded, vitric lapillistone (92% lapilli, 8% ash), with an average grain size of ~11 mm. Pumice bombs are commonly larger than 9 cm across.

PM abruptly transitions to a thinner, darker yellow-brown upper horizon (PU) of vitric lapillistone (75% lapilli, 25% ash) consisting of a mixture of light brown pumice, dense, dark-gray to black scoria, and abundant, non-vitric lithics. The PU horizon is very poorly sorted, with great variability in grain size (6-14 mm) between sample locations. Scoria (~12 mm) is larger than pumice (~5 mm) and lithic fragments (~3 mm), with scoriaceous bombs reaching up to 10 cm. The upper contact of PU is poorly defined, with the capping ash (Mcap) filling gaps between the uppermost clasts.

Mcap is a relatively thick, dark brown-grey ash layer that caps the deposit. It is a well-sorted vitric tuff (99% ash, 1% lapilli) consisting of scoria, free plagioclase crystals, mafic minerals, and lithics. The upper contact of the ash is often reworked and is overlain with soil, marking the end of the eruptive
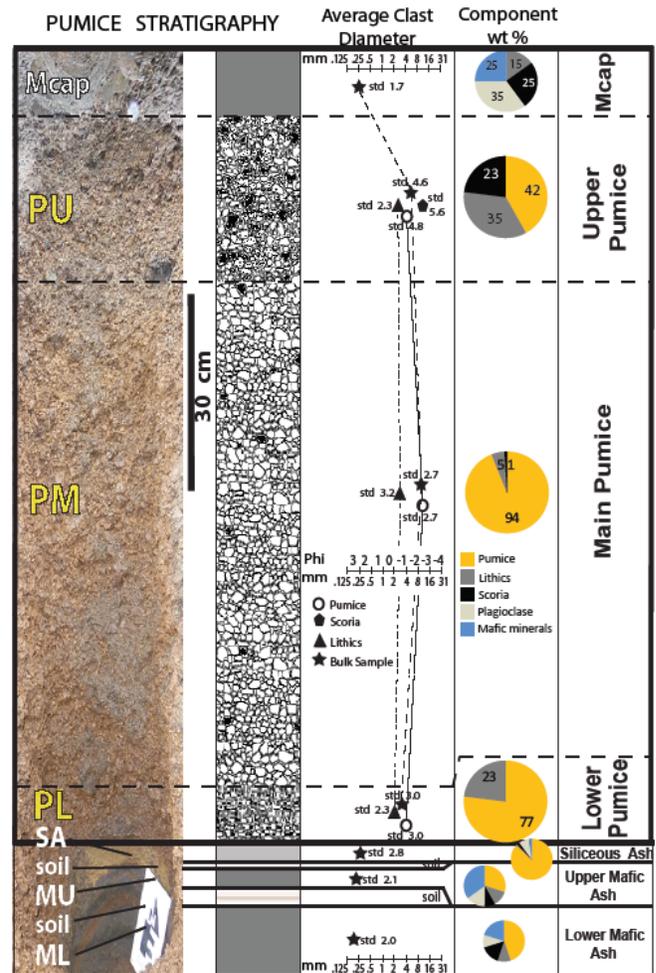

Figure 1. Idealized stratigraphic column of the Driftwood Pumice deposit and common underlying ashes modeled on location 16 in Figure 2. Grain sizes and abundances of each component changed during the eruption.

sequence.

Distribution and Volume Estimate

Isopach maps (Fig. 2) were generated using Arc-GIS surface interpolations of measured thicknesses and phantom points which were extrapolated from field measurements. Consideration of tephra fallout patterns from published studies (eg., Palladino and Agosta, 1997; Rosi et al., 1999) and prevailing Aleutian wind patterns (Naval Research Laboratory, 1998) aided isopach reconstructions. For all Driftwood Pumice horizons, the axis of maximum deposition is to the northeast, though the axis of maximum deposition for each stratigraphic horizon rotates counterclockwise by ~20° through the course of the eruption. PL has a limited dispersal area that

uniformly thins, reaching a zero-line ~13 km from the Makushin summit at its furthest extent. The main PM horizon is over 35 cm thick at the zero line for PL and reaches thicknesses of ~15-20 cm over 25 km away in the towns of Dutch Harbor and Unalaska. The upper PU horizon has a distribution area similar to PL, though thins more sporadically.
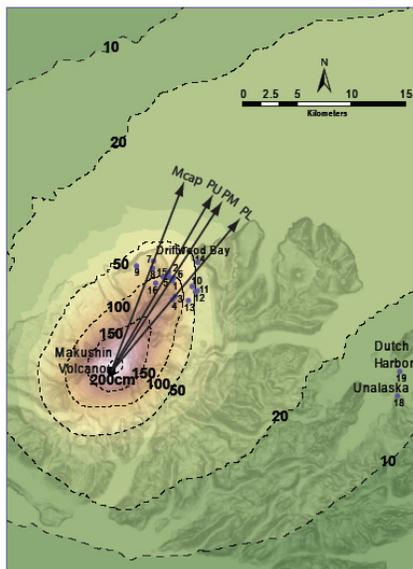

Figure 2. Combined isopach map for the Driftwood PL, PM, and PU horizons. The maximum deposition axes of each horizon are shown, trending more northerly as the eruption progressed. Well-constrained isopach contours are shown with solid lines and interpolated isopach contours are shown with dashed lines, with wider dashes indicating increasing uncertainty. Sample locations and the towns of Dutch Harbor and Unalaska are shown.

Using the isopach maps and the exponential thinning model of Pyle (1989), the total volume of material erupted is calculated to be 0.3 -0.9 km³. The volume of the Mcap ash was not included in this calculation, making it possible that the volume of erupted material exceeded 1 km³. These estimates give the Driftwood Bay eruption a Newhall and Self (1982) Volcanic Explosivity Index of 4-5, which would correspond to a plinian eruption with a column height of 10-25 km and a duration of ≥ 12 hours - an eruption on the scale of the 1980 Mt. St. Helens eruption.

Petrography and Geochemistry

Pumice from PL and PM display little variation in overall mineral abundances and rock texture. Pumice from both horizons is vitrophyric and mineral-poor, with plagioclase (2%), clinopyroxene (<1%), orthopyroxene (<1%), and Fe-Ti oxide (1%) phenocrysts and glomerocrysts set in a vesicle-rich matrix of hyalopilitic-holohyaline glass. Very little olivine is present in PM, and none occurs in PL. Scoria from the upper PU horizon are texturally similar to pumice from the other horizons, but is more mineral-rich, with relatively abundant plagioclase (5-8%), clinopyroxene (1%), orthopyroxene (2%), Fe-Ti oxides (1-5%), and scarce olivine (<<1%) phenocrysts. Fe-sulfides and apatite are trace minerals present in all horizons. The matrix glass is dacitic, ranging from 67-69 wt% SiO_2 in PL and PM, and becoming more mafic in PU (64-67 wt% SiO_2) (Fig. 3). Numerous populations of plagioclase and olivine were identified based on grain habit and composition (Fig. 3). The most abundant plagioclase is moderately-calcic (An_{45-55}), occuring as anhedral and euhedral phenocrysts and glomerocrysts. Small, euhedral, more sodic (An_{35}) plagioclase phenocrysts occur only in the basal PL. Highly-calcic plagioclase phenocrysts are present in low abundances in PM and PU. These include distinctly zoned plagioclase, with embayed cores of An_{70-90} and thick euhedral overgrowth of more typical An_{45-55}, as well as highly embayed, unrimmed plagioclase (An_{85-90}). Another distinct population occurs as unzoned, euhedral, high-Ca phenocrysts (An_{80}) with only exceedingly thin (<10 μm) more-sodic rims (An_{60}). This population is present mostly in the upper PU horizon, systematically becoming scarcer down the stratigraphic section, with only a single grain being present in PL samples. Olivine in PM is relatively Fe-rich (Mg_{63}), and is encased by thick orthopyroxene reaction rims. In PU, the most abundant olivine occurs as Mg-rich (Mg_{75}), euhedral phenocrysts with very thin (<10 μm) orthopyroxene reaction rims (Fig. 3).

Whole rock major and trace element geochemistry shows minor, yet systematic variations throughout the stratigraphic section. Whole rock SiO_2 varies
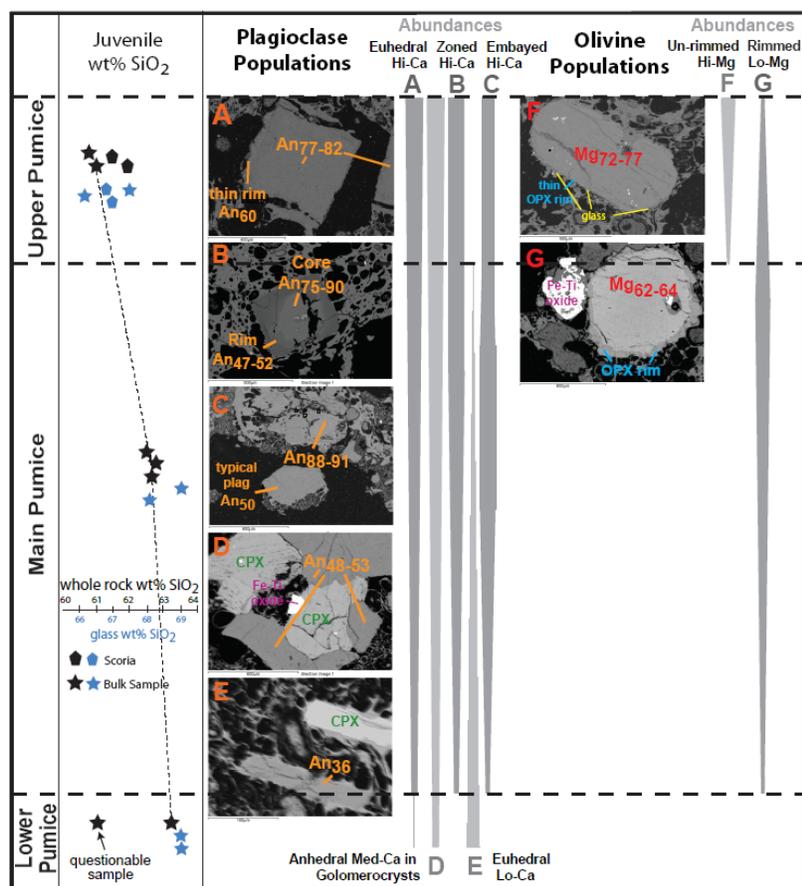
Figure 3. Variations in whole rock (black) and average glass (blue) SiO2 content and the relative abundances of plagioclase and olivine populations with backscattered electron images of phases in juvenile material throughout the deposit. Euhedral mafic plagioclase and olivine with thin rims (A and F) are more abundant in PU, likely being xenoliths with short residence times in a siliceous magma chamber. Zoned, thickly rimmed, and/or heavily embayed mafic xenocrysts (B, C, and G) are most abundant in the PM and PU horizons, likely having had long residence times in a siliceous chamber. Medium-Ca plagioclase in glomerocrysts (D) and phenocrysts are present throughout the deposit, increasing in PM and PU. Euhedral small, low-Ca plagioclase (E) present in PL are likely equilibrium crystals that grew from the most evolved melt in the upper magma chamber.

a few weight percent throughout the section (Fig. 3), with PL being the most felsic (~63% SiO_2), PM being intermediate (~62.5% SiO_2), and PU being the most mafic (~61-62% SiO_2). Trace elements show linear relationships in a number of bivariant plots, (Fig. 4) with PL being the most enriched in incompatible elements, and PU having the highest concentrations of compatible elements.

DISCUSSION

The stratigraphy, petrography, and geochemistry of the Driftwood Pumice indicates that the stratigraphy represents an inverted profile through a magma chamber with the lowest PL horizon derived from the upper, most-fractionated part of the magma chamber, and the stratigraphically higher PM and PU horizons sampling progressively deeper into the chamber. This magma chamber may have been compositionally zoned with a slightly more felsic top. Plagioclase (~An_{50}), clinopyroxene, and orthopyroxene were crystallizing throughout the entire chamber.

The eruption was likely triggered by the injection of mafic magma into a crystal-poor mush of more evolved magma. The mafic magma carried phenocrysts of more calcic plagioclase (~An_{80}), and more magnesian olivine (~Mg_{75}). The mafic injection mixed incompletely with the siliceous host, introducing minerals that were in disequilibrium with

the siliceous glass matrix around them (Fig. 5). This mixing produced linear trends among both major and trace elements (Fig. 4). PL is the least contaminated siliceous host, derived from the top of the chamber, with more mafic mixing in PU, derived from the base of the chamber. Mafic phenocrysts from the more primitive injection are dominantly found in PU. The thin reaction rims on olivine and plagioclase show short residence times of these minerals in a more siliceous magma, suggesting an eruption shortly following the mafic injection.
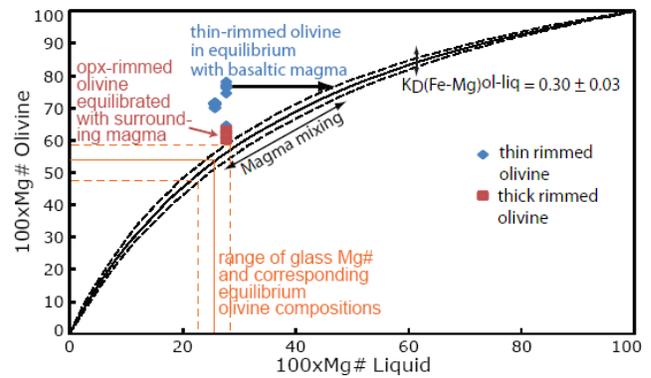

Figure 5. Olivine equilibrium curve after Rhodes et al. (1979) showing that the low-Mg, thickly pyroxene-rimmed olivine population is nearly equilibrated with the liquid (glass), whereas the high-Mg, thin-rimmed olivines are in significant disequilibrium. The solid curve is based on an Fe-Mg partition coefficient of 0.30 +/- 0.03 between olivine and glass. Mg#=Mg/(Mg+Fe) in cation fractions.

PL represents the initial stage of the eruption, with magma from the upper chamber or conduit erupting through a vitric dome – interpreted here as the effusive end product of a previous eruption. The limited dispersal, small average grain size, and high abundance of vitric lithics shows a relatively weak initial eruption that cleared the vent area. PM represents the main phase of the eruption, broadly dispersing relatively large pumice with little accidental ejecta, showing a powerful eruption through a relatively stable vent. PU represents the closing stage of the eruption that tapped into deeper magma. This magma was mixed with a greater mafic component, as shown by thinly rimmed, high Mg olivine, euhedral calcic plagioclase, and more mafic bulk composition than the previously deposited PL and PM layers. The limited, somewhat spotty dispersal area and ejection of large, dense scoriaceous bombs suggests that the eruption style during this period transitioned to a strombolian-type eruption. The marked increase in accidental lithic ejecta in PU is consistent with the transition to a strombolian, more mafic eruption, as a decrease in eruptive pressure could cause the destabilization and collapse of some of the vent area. The capping ash layer (Mcap) likely represents the fallout of an ash-rich tephra cloud after the explosive stages of the eruption. The repeated light-dark ash couplets that bracket the Driftwood Pumice indicate that the Driftwood eruption punctuated a cycle of

Figure 4. Linear relationships between trace element abundances throughout stratigraphic horizons are consistent with magma mixing trends. PU experienced the most mixing with an end-member enriched in compatible elements, while PL experienced the least, representing an incompatible-enriched magma.

similar, albeit less violent, eruptions each triggered by a similar magma mixing process.

Numerous other studies have cited mafic injections into with more evolved magma chambers as common eruption triggers (eg., Sparks et al., 1977; Miller et al., 1999). This study provides evidence that this process is responsible for Makushin's last very powerful eruption, and is a typical cause for much of its Holocene activity.

ACKNOWLEDGEMENTS

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