

Tracking Volatiles at Mount St. Helens From Magma Chamber Residence to Eruption at the Vent

Authors & Affiliations:

Lehigh University: Kimberly Genareau (kig210@lehigh.edu), Dork Sahagian (dos204@lehigh.edu)

University of New Hampshire: Alex Proussevitch (alex.proussevitch@unh.edu), Gopal Mulukutla (gopal.mulukutla@unh.edu)

University of Cambridge: Adam Durant (ajd90@cam.ac.uk)

Arizona State University: Gordon Moore (gordon.moore@asu.edu), David Bell (david.r.bell@asu.edu)

Richard Hervig (hervig@asu.edu)

Topics/Themes: How are volatiles, fluids, and melts stored, transferred, and released through the subduction system?

Summary: As a means to understand a volcano from top to bottom, we propose a geochemical and microtextural examination of eruptive products in order to track the dynamics of magma mixing, devolatilization, and fragmentation from within the magma chamber, through the volcanic conduit, and out of the vent during eruption. We will focus on Mount St. Helens (MSH) due to the extensive petrological and analytical work already performed at this location and the possible selection of the Cascadia subduction zone as a GeoPRISMS focus site for the SCD initiative. The proposed study will directly address one of the primary topics/themes (see above) and will have broad implications for other active volcanoes. In addition to improving the understanding of an active volcanic system, the research described here will also help to clarify the role of various volatile elements in magmatic systems, their effects on magma rheology, and their use as geochemical tracers for H₂O behavior during magma mixing, decompression, devolatilization, crystallization, and fragmentation. This study will focus specifically on Li, B, and S, and how the behavior of these fluid-mobile elements compares with that of H during volcanic processes.

Project Proposal: In order to gain a more comprehensive understanding of volcanic processes and the role of volcanoes in cycling materials between the atmosphere, hydrosphere, and lithosphere, we propose an integrated study of the path of volatiles and their interaction with host magmatic fluids and solids as they are transferred from magma chambers at depth, through a volcanic conduit and vent finally to be deposited on the land surface. This will shed light on eruption drivers and characteristics of eruptions controlled by volatile exsolution, as well as chemical interactions between volatiles, melt, and minerals within the magmatic system.

Products from both the 1980 and the 2004 eruptive events at MSH will be examined in order to build upon the extensive work that has already been conducted on these eruptive stages [1-19]. Examination of the 1980 samples will focus on deposits from the lateral blast, Plinian explosion, and cryptodome. Examination of the 2004 products will focus on ash from the initial phreatic explosions and various stages of lava dome extrusion. Direct comparison between explosive and effusive products will allow better constraint of volatile behavior during different styles of magma ascent. The various analyses conducted will occur simultaneously at the collaborating institutions and will involve a large number of samples (hundreds of individual crystals and ash grains) in order to establish a statistically rigorous dataset that can then be utilized to model volatile behavior in the MSH system. Total time required for the project is estimated at 4-5 years.

Using the OmniPressure Laboratory at Arizona State University, experiments will be performed at various static pressures and temperatures to determine the diffusion and partitioning behavior of the listed fluid-mobile elements (H, Li, B, S) specifically within MSH minerals (focusing on plagioclase and hornblende) and melts, as previous studies have noted enrichment of some of these elements in MSH products [7,9,11,12]. Our experiments will allow quantification of trace element diffusivities in

the various minerals examined, permitting direct calculation of volatile exsolution rates and future use of eruptive products to determine pressure/temperature conditions in the magma based upon trace element concentrations.

Polished sections of hornblende phenocrysts will be chemically mapped using secondary ion mass spectrometry (SIMS) to determine the zoning patterns of volatile elements within these hydrous minerals. In particular, we will examine possible evidence that reveals influx of volatile-rich magmas at depth in the plumbing system, prior to magma ascent into the volcanic conduit. Previous geochemical analyses have shown evidence of Li enrichment in products from both the 1980 and 2004 eruption, and these studies have attributed this enrichment to vapor transport from a deeper magma source [7,9,11,12]. Various hornblende textures will provide information on magma chamber processes and the transition from chamber residence to conduit ascent [1,3]. Hornblendes lacking breakdown textures will permit characterization of magma chamber conditions, but hornblendes that also display a breakdown rim (either as a result of decompression or heating) will signify a transition in the dynamic conditions of the magma, and the behavior of volatile elements in these hornblendes will be particularly useful in deciphering stages of devolatilization during ascent through the conduit or magma mingling at depth in the chamber. We predict that reaction textures will be associated with gradients in rapidly diffusing chemical or isotopic species that can be used, in addition to the experimental studies of breakdown kinetics [1,3], to set timing limits on texture development. Diffusive re-equilibration of Li in minerals due to new magmatic conditions results in large isotopic gradients in $\delta^7\text{Li}$. Changes in B concentration and $\delta^{11}\text{B}$ are expected to be extremely slow, based on rates of B isotope equilibration in tourmaline [20].

Plagioclase phenocrysts and microphenocrysts will be depth profiled using SIMS to examine chemical variations during the final stage of decompression-induced crystal growth within the volcanic conduit [21-23]. In lava samples, this will track magma ascent from the chamber to effusion at the vent. For explosively erupted samples, this will allow quantification of pressure/temperature and devolatilization/crystallization conditions immediately prior to eruption [22,23]. High-resolution (~10 nm per datum) examination of plagioclase compositions during the final stage (<50 μm) of crystal growth will provide information on the physical dynamics during conduit ascent (Fig. 1). A wide range of P-T-t space is accessible using different minerals, chemical or isotopic systems, and by combining high spatial-resolution depth profiling and conventional microbeam lateral traverses.

Using stereo-scanning electron microscopy (SSEM), ash grains will be imaged and a digital elevation model (DEM) will be constructed from the stereo-pair image using specialized software (MeX). Utilizing another software tool (BubbleMaker), bubble volumes are determined from the constructed DEM [24-26]. Work is currently in progress to determine the bubble number densities, bubble size distributions, and role of microlites as sites for heterogeneous bubble nucleation [e.g., 27] in distal ash samples derived from the 1980 eruption at MSH (Fig. 2). Additional samples will be examined from other 1980 tephra deposits in various locations in order to determine the physical parameters that cause volatile exsolution in the shallow conduit to transition to magma fragmentation at the vent, constraining one of the final roles of volatiles in the subduction system. Samples from the initial phreatic phase of the 2004 eruption will allow comparison between different styles of fragmentation mechanisms at the same volcano. In addition to SSEM, selected ash grains will also be imaged with X-Ray Ultra-Microscopy (XuM), which utilizes the X-rays generated by the SEM to pass through objects and project an image onto a target, allowing visualization of components *within an ash grain* [28], including microlites acting as vesicle nucleation sites [e.g., 29].

If the Cascadia subduction system is selected as a GeoPRISMS focus site, the project outlined above can also be applied to other volcanoes within that system in order to determine the role of fluid-mobile trace elements on an *arc-wide scale*. We suggest that Cascadia would represent one of the best candidates for a focus site due to the foundation of work already performed and the use of this previous research (and the work stemming from it) in addressing some of the fundamental goals of the SCD initiative and the GeoPRISMS program.

References Cited:

- [1] Rutherford, M.J., and Devine, J.D. (1988), *J Geophys Res*, 93, 11949-11959.
- [2] Cashman, K.V. (1992), *Contrib. Mineral. Petrol.*, 109, 431-449.
- [3] Rutherford, M.J., and Hill, P.M. (1993), *J of Geophys Res*, 98, 19667-19685.
- [4] Heliker, C. (1995), *J. Volcanol. Geotherm. Res.*, 66, 115-135.
- [5] Cashman, K.V., and Blundy, J. (2000), *Philos. Trans. Royal Soc. London*, 358, 1487-1513.
- [6] Blundy, J., and Cashman, K.V. (2001), *Contrib. Mineral. Petrol.*, 140, 631-651.
- [7] Berlo, K., et al. (2004), *Science*, 306, 1167-1169.
- [8] Cashman, K.V., and Hoblitt, R.P. (2004), *Geology*, 32, 141-144.
- [9] Blundy, J., and Cashman, K. (2005), *Geology*, 33, 793-796.
- [10] Cashman, K.V., and McConnell, S.M. (2005), *Bull. Volcanol.*, 68, 57-75.
- [11] Blundy, J., et al. (2006), *Nature*, 443, 76-80.
- [12] Kent, A.J.R., et al. (2007), *Geology*, 35, 231-234.
- [13] Blundy, J., et al. (2008), *In Sherrod, D.R., et al., eds., USGS Prof. Paper 1750.*
- [14] Pallister, J.S., et al. (2008), *In ibid.*
- [15] Rowe, M.C., et al. (2008), *In ibid.*
- [16] Rutherford, M.J., and Devine, J.D. (2008), *In ibid.*
- [17] Streck, M.J., et al. (2008), *In ibid.*
- [18] Thornber, C.R., et al. (2008), *In ibid.*
- [19] Durant, A. J., et al. (2009), *J. Geophys. Res.*, 114, B03204.
- [20] Büttner, S.H., and Kasemann, S.A. (2007), *Amer. Mineral.*, 92, 1862-1874.
- [21] Genareau, K., et al. (2007), *Amer. Mineral.*, 92, 1374-1382.
- [22] Genareau, K., et al. (2009), *Geology*, 37, 367-370.
- [23] Genareau, K., and Clarke, A.B. (2010), *Amer. Mineral.*, 95, 592-601.
- [24] Proussevitch, A.A., et al. (2007), *J. Volc. Geotherm. Res.*, 164, 112-126.
- [25] Proussevitch, A.A., et al. (in review), *Geophys. Res. Lett.*
- [26] Proussevitch, A.A., et al. (2007), *EOS Trans. AGU Fall Meet*, 5942.
- [27] Proussevitch, A.A., et al. (2007), *J. Volc. Geotherm. Res.*, 164, 95-111.
- [28] Kiely, C., et al. (2007), *Microsc. Microanal.*, 13.
- [29] Gardner, J.E. and Denis, M.-H. (2004), *Geochim. Cosmochim. Acta*, 68, 3587-3597.

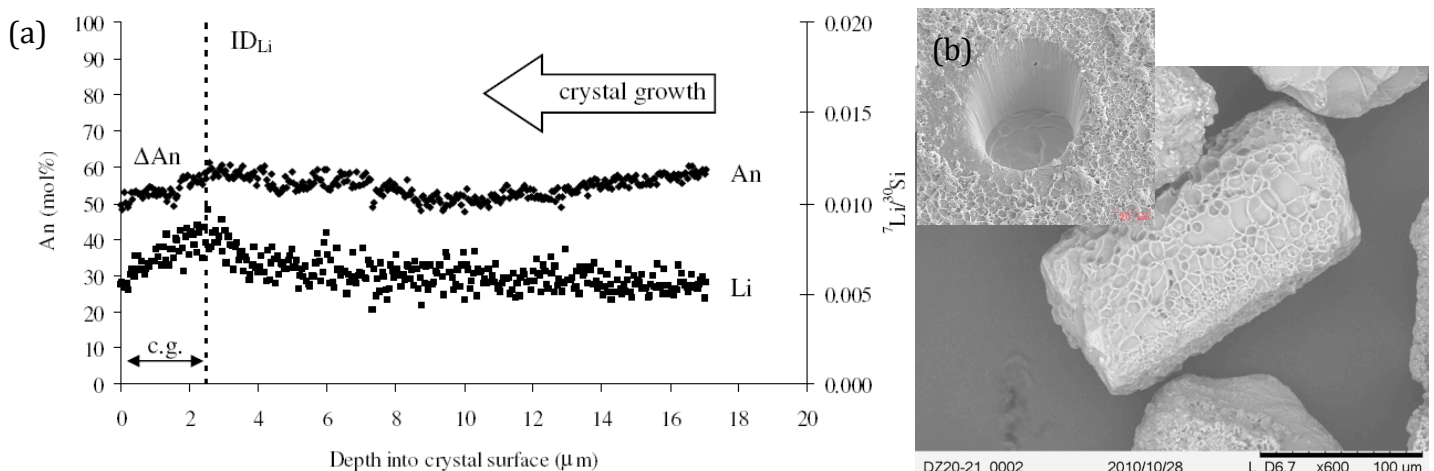


Fig. 1 (a) SIMS depth profile into plagioclase phenocryst derived from an explosive eruption of Soufrière Hills Volcano, Montserrat, which was used as the field area for development of this particular SIMS technique [21]. The final few micrometers of crystal growth (c.g.) shows decreasing anorthite content (ΔAn) and decreasing Li, which is marked by an inflection (ID_{Li}), both of which result from decompression and volatile exsolution in the volcanic conduit during ascent [22,23]; (b)

secondary electron image of microphenocryst derived from distal ash samples of the Mount St. Helens 1980 eruption, similar to samples that will be selected for SIMS depth profiling with the inset image providing an example of a depth profiled crater in a crystal surface.

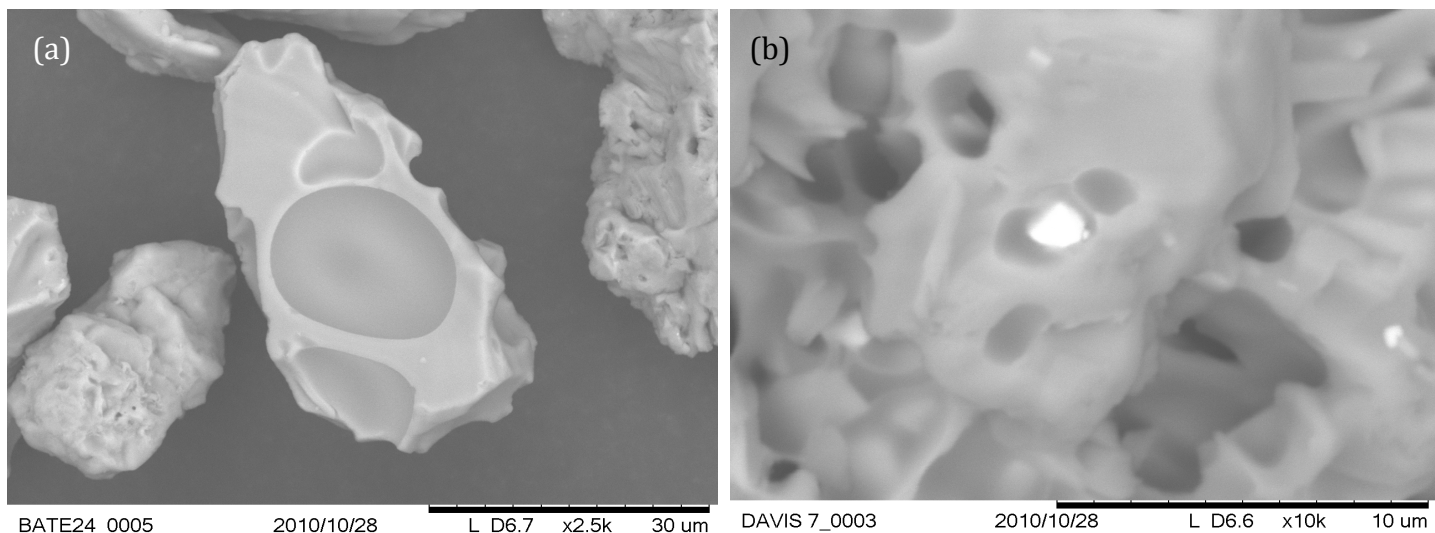


Fig. 2 Secondary electron images of ash particles derived from distal deposits of the 1980 Mount St. Helens lateral blast: (a) A single ash grain $\sim 50 \mu\text{m}$ in length displaying vesicle walls. Grains like these will be used to create a digital elevation model from stereo-pair images in order to reconstruct the original vesicle volume at the moment of fragmentation; and (b) a $\sim 1 \mu\text{m}$ -sized vesicle nucleating on a magnetite microlite. Nucleation sites within individual ash grains can be imaged using X-Ray Ultra-Microscopy (XuM).