Illuminating the architecture of crustal magmatic systems in the Cascade region

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White paper proposal for the Cascade region; MARGINS program

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Summary:

In order to: (1) resolve major tectonic controls on volcanism along the Cascade arc, and (2) determine the configuration of crustal magma transport and storage, including the extent and characteristics of highly crystalline magma bodies (crystal mushes; potential sources zones for explosive silicic magmas), we propose that a variety of high-resolution seismic and MT methods should be used to image the crust and upper mantle in strategic locations in Cascadia. Our first choice would be to focus data gathering efforts on Mount St. Helens (MSH), with potential of a follow-up survey of Mount Hood as (a) both volcanoes have erupted within the last 250 years, (b) the volcanoes are close to urban centers (Portland, OR; Columbia River shipping channels), (c) there is a wealth of detailed geologic, petrologic, and geophysical information on Holocene MSH, (d) the arc magmatic front shifts abruptly westward from Mount Hood to MSH, associated with forearc basaltic volcanism in the Portland metropolitan area, (e) previous surveys using both seismic tomography and MT data have outlined interesting regional structures in the upper-to-lower crust that require further investigation.

Project:

Intermediate arc magmas (andesites, dacites) have compositions closely similar to estimates of the bulk continental crust, but such intermediate magmas are difficult to interpret unambiguously because of complex processes of differentiation, mixing, and assimilation involved in their formation. At a basic level, it is important to have a clearer understanding of where arc magmas stall in the crust, in what volumes, and why magma storage differs from one volcano to another. Armed with this information, geochemists could develop more tightly constrained and quantitative interpretations of the processes of crystallization, assimilation, melt extraction, and mixing in the middle and lower crust; geophysicists could more accurately interpret the apparent granitoid-dominated mid-crustal seismic velocities in arcs; and volcanologists could infer the magma recharge times, lengthscales, and depths recorded by geodetic, seismic, and other monitoring signals.

Imaging of crustal magmatic architecture will be challenging in the Cascades due to the generally low eruptive fluxes of volcanic centers (which is suggestive of compact magmatic systems), but this concern is countered by the extensive infrastructure (roads, power, telecommunications) available to support an intensive geophysical study; the wealth of previous work on the geology, eruptive history, petrogenesis, and upper crustal geophysical imaging for MSH; and already established close working relations between land managers (US Forest Service) and the volcano monitoring community (USGS, Pacific Northwest Seismographic Network). Moreover, easy access to the greater MSH – Mount Hood region would permit numerous low-cost concurrent and follow-on studies by research groups of diverse affiliation.

Specific questions to address include: 1) Is there a well-defined zone in the deep crust where parental magmas stall and assimilation and differentiation take place? 2) Is this zone localized to the base of the crust, suggestive of a density control on magma storage, or is it more extensive? 3) What lies above this deep zone: dikes feeding to the seismically imaged shallow crustal reservoir, or a more vertically integrated mush column that may approach trans-crustal extent? 4) MSH mainly erupts dacites, and many of these carry Pleistocene zircons (Claiborne et al. 2010) suggestive of the presence of a long-lived evolved crustal intrusive complex or mush body. However, during the period 1950 to 1750 years ago, multiple basalt types erupted through the MSH conduit system (Mullineaux 1996, Clynne unpublished). Local earthquake tomography studies have only been able to penetrate ~7-8 km below MSH and show evidence for only a relatively small magmatic reservoir or widened conduit (Waite and Moran 2009). Is there a sizeable silicic mush body beneath the volcano or not? 5) Some interpretations posit that MSH dacites are mainly melts of the deep crust (e.g., Smith and Leeman 1987; Pallister et al. 1992; Pallister et al. 2008), so can a region of deep crustal melting be recognized and how large is it? 6) MSH sits atop the St Helens seismic zone, and seismic refraction profiling to the north (Parsons et al. 1998) suggests that the seismic zone marks the buried eastern edge of the Paleocene Siletzia basaltic seamount province. How does this terrain boundary influence magma storage and transport? 7) Magneto-telluric (MT) imaging reveals a mid-crustal conductor in the southern Washington Cascades that merges with high conductivity at the shallow MSH conduit system. To the north, the crustal conductor reaches the surface in anticlinal exposures of Eocene sediments, elsewhere concealed by the Oligocene and Miocene volcanic section (Egbert and Booker 1993; Stanley et al. 1996), but in the MSH – Mount Adams region it has been interpreted as a widespread body of magma (Hill et al. 2009). Which is it? 8) MSH marks a pronounced westward step in the Cascades volcanic front, moving northward, associated with enigmatic forearc basaltic volcanism in the Portland area. Regional P- and S-wave tomography are suggestive of a discontinuity in the subducting slab beneath that area (Schmandt and Humphreys 2010) that might account for the shift in volcanism. Can the slab be better imaged in the northwest Oregon – southwest Washington area to investigate the presence of a discontinuity, with implications for generation of MSH magmas by slab-edge melting? 9) When MSH last erupted, the volume of magma released exceeded what would be inferred by its deflation. This difference could signify recharge counterbalancing withdrawal, or it could result from expansion of bubbles in non-erupted mushy magma (Mastin et al. 2008). Can high-resolution geophysical techniques resolve bubbly magma?

We propose deploying a dense network of broadband seismometers and MT receivers radially around MSH, and extending several tens of kilometers in both the E-W and N-S directions, coupled with active source experiments. The seismic data will be used for receiver function analyses; local earthquake (Vp and Vs), teleseismic body-wave, noise-correlation, and active-source tomography inversions; and shear-wave splitting studies. The MT data will be used to construct full 3-D conductivity models. A complementary active seismic tomography and scattered wave imaging experiment will illuminate the crustal structure and Moho details. We also suggest that lines connecting both volcanoes across the Columbia River would be important to better image the fundamental transition that occurs in the area. This depths-to-daylight study of dangerous volcanic systems would provide dividends for both science and for society.

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