Results from the iMUSH Active Source Seismic Experiment

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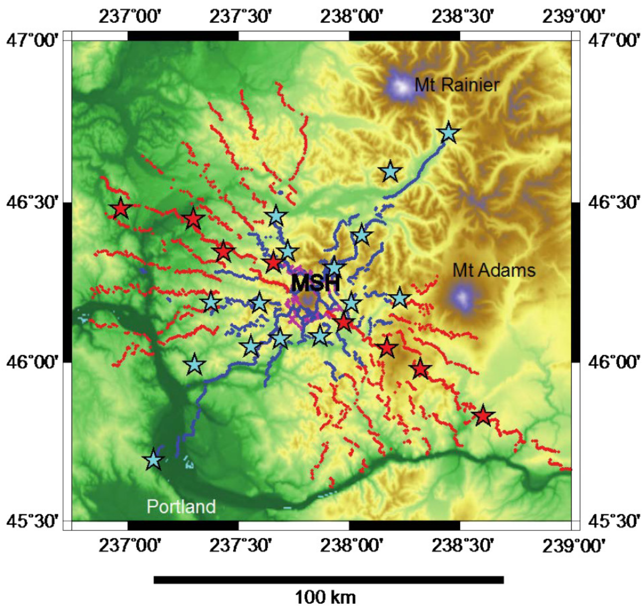
iMUSH (imaging Magma Under Saint Helens) is a U.S. NSF sponsored multi-disciplinary investigation of Mt. Saint Helens (MSH), currently the most active volcano of the Cascades arc in the northwestern United States. The project consists of active and passive seismic experiments, extensive magnetotelluric sounding, and geological/geochemical studies involving scientists at 7 institutions in the U.S. and Europe. The long-term goal of the project is to produce a comprehensive 3D model of the volcanic plumbing system from the surface to the subducting Juan de Fuca slab.

Here we describe preliminary results of the iMUSH active source seismic experiment, conducted in July and August 2014. The active source experiment consisted of fifteen 454 and eight 908 kg weight shots recorded by ~3500 seismographs deployed at ~6000 locations. Of these instruments, ~940 Nodal Seismic instruments were deployed continuously for two weeks in an areal array within 10 km of the MSH summit (Fig. 1-2). 2500 PASSCAL Texan instruments were deployed twice for five days in 2 areal arrays and 2 dense orthogonal linear arrays that extended from MSH to distances > 80 km.

Overall the data quality from the shots is excellent, registering very clear Pg, pre- and post-critical PmP phases, and surprising strong Sg, and SmS signals. The seismograph arrays also recorded dozens of micro-earthquakes beneath the MSH summit and along the MSH seismic zone, numerous other local and regional earthquakes, and at least one low frequency event.

At this point we have completed various types of analysis of the data set: We have determined an average 1D Vp structure from stacking short-term/long-term average ratios, and the 2-D Vp, Vs and Vp/Vs structure from ray-trace inversion and finite-frequency tomography along the two orthogonal profiles (in the NW-SE and NE-SW directions, Fig.s 1-2). We also have made low-fold CMP stacks of the profile data. Below the MSH summit, the 2-D ray-trace inversions have identified a large Vs, and Vp/Vs (Vp/Vs ~ 2) anomaly at 4-10 km depth below sea level. We identify this anomaly as the feeder magma chamber below the shallowest magma chamber at 1-3 km depth below the caldera, imaged previously in local earthquake tomography (Waite and Moran, 2009, Journal of Volcanology and Geothermal Research, 182, 113-209). A low Vp anomaly extending to the Moho dips to the southeast away from the Mt. St. Helens caldera, outlining a likely pathway for melt and fluid migration in the crust. Low frequency events are associated with this anomaly. The PmP phases image the Moho at depths varying from 35-40 km directly beneath the MSH plateau and to the east beneath the backarc. We have also identified a continuous landward dipping reflection from within the uppermost mantle, the source of which is under discussion.



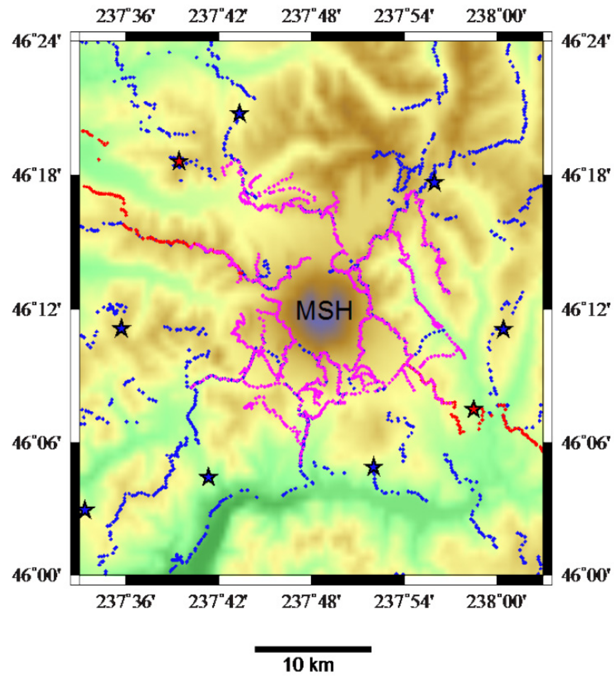


Figure 1 (left). iMUSH active seismic experiment. The ~2450 blue dots are Texans used in the first deployment that recorded 15 shots denoted by blue stars. The ~2550 red dots are Texans from the second deployment that recorded 8 shots denoted by red stars. The ~940 magenta dots are Nodal Seismic instruments which recorded all 23 shots. Approximately 1200 seismographs were hiked into the MSH region (Fig. 2).

Figure 2 (right). Map showing detail of instrument deployments near Mt. St. Helens (MSH). Magenta dots are ~940 Nodal Seismic recorders which recorded continuously for 2 weeks. Deployment teams of foot hiked in the 1200 instruments that were within 7.5 km of MSH. Blue and red dots are Texans deployed during the first and second deployments. Also shown is the inner ring of shots, denoted by blue and red stars, which were ~15 km from the center of MSH.

Imaging Magma Under mount St. Helens (iMUSH): Earthquake-seismic component

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To better understand volcanic activity, it is fundamental to get an accurate representation of magma generation zones and storage regions in the Earth's crust and upper mantle. Illuminating the architecture of the plumbing system beneath volcanoes indicates (1) at which depths and conditions magmas are generated, and (2) the shapes and sizes of pathways and reservoirs along which magma travels towards the surface. Such knowledge will improve predictions on the durations of volcanic crises and on the total volume of erupted material during eruptive episodes. The iMUSH project focuses on Mount St. Helens (WA, USA), whose explosive eruption in 1980 attracted world's attention, and was the first volcano to be thoroughly monitored with modern instruments. Mount St. Helens is active, easily accessible, and has a well recorded past history. iMUSH uses several different methods (active and passive source seismic tomography and scattered wave imaging, magnetotelluric imaging, petrology and geochemistry), involving a large collaborative team, to image the volcano's plumbing system with unprecedented resolution from the subducting plate to the surface. This Nugget describes the earthquake seismic component of the project.

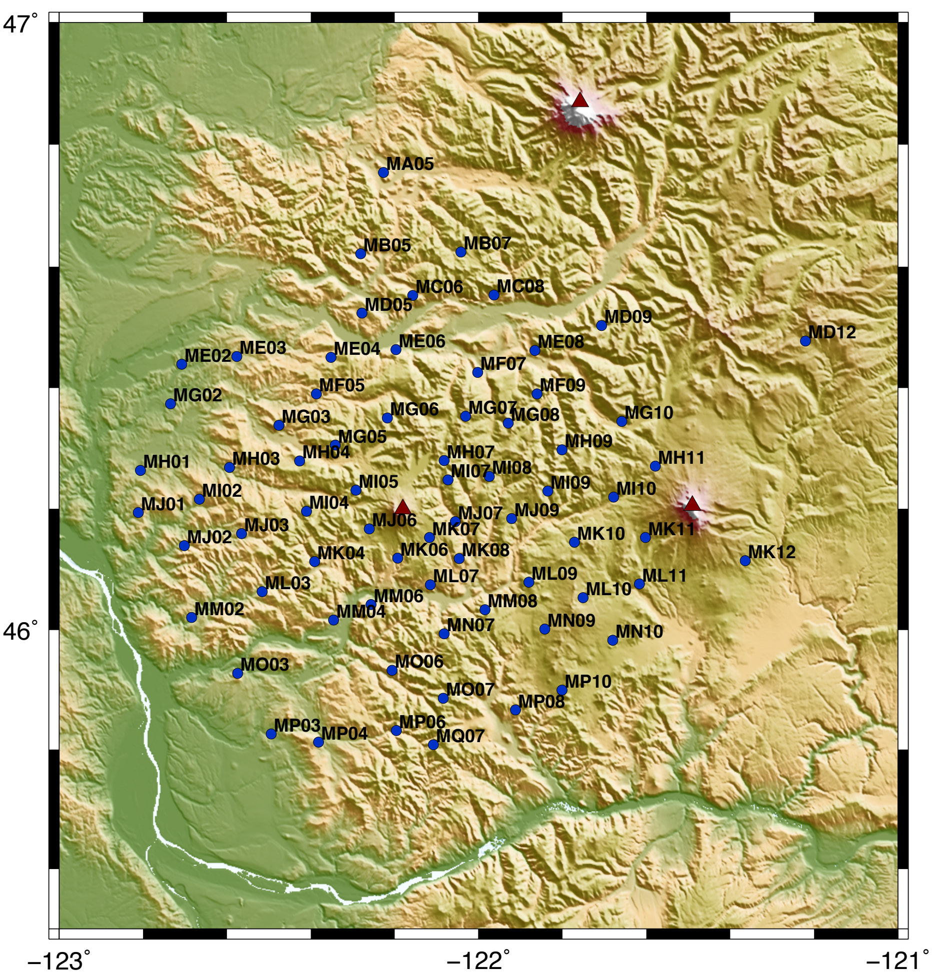

Figure 1. The iMUSH Broadband array. The 70 stations are distributed within 50 km of the summit of Mount St. Helens from the Cascadia foothills to Mount Adams. Triangles show volcanic centers.

In the summer of 2014, seventy broadband seismometers were deployed in a 50 km radius around the summit of the volcano (Fig. 1). These stations will remain for two years to record signals from local earthquakes associated with the volcano, long-period tremor, and teleseismic signals from around the world. Many of the signals will be used for imaging the crust and mantle wedge, with targets including the slab presumed to be subducting beneath the array, the mantle melting region, the Moho and how it is influenced by the ascent of melt from the mantle, and the crustal architecture beneath the volcano. Crustal signals refine our understanding of magma plumbing and crustal differentiation beneath this active arc, and various volcano-related sources will help us understand the deformation associated with active volcanism. This is the largest dense array over a volcano at this scale anywhere in the world, so should play an important role in addressing GeoPRISMS science goals associated with magmatic processes.

As of summer 2015 we have one year of data from nearly all of the stations and are rapidly accumulating a comprehensive set of high-quality P-wave travel-time picks from the 600 local earthquakes recorded to date. This effort will continue through the planned two years of recording. We have also picked the times at these stations from last summers 23 shots that were part of the iMUSH active-source experiment (see Levander nugget). These data sets, along with P-wave picks from the permanent network stations will be inverted for earthquake hypocenter locations and 3-D structure beneath MSH using struct3DP, which calculates travel times by 3-D eikonal-equation solver. We will follow up with inversions from S-wave picks and using double difference tomography applied to cross-correlation-derived differential travel-times of P and S waves from pairs of nearby events recorded at a given station. In parallel, ambient-noise tomography is providing initial estimates of shear-velocity structure of the crust, showing a strong influence of pre-arc basement structure on wave speeds. These data will be integrated with receiver functions to provide structural models of the crust and uppermost mantle of the volcano and its surroundings.

As seismological results emerge and the dataset becomes complete, deeper imaging and higher-resolution imaging are planned. These results will compliment the active source work by providing fully 3-D models and resolution to greater depths, though with lower resolution for the shallow structure, and will be integrated with magnetotelluric imaging to better understand volcanic plumbing and architecture. When completed, the iMUSH dataset and models will provide some of the most thoroughly integrated and highest-resolution images of a volcanic system anywhere, from subducting slab to surface.