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Deformation driven magma ascent in stratified magma reservoirs: an experimental study

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Mature volcanic systems (e.g., Yellowstone, USA; Campi Flegrei, Italy) are fed by stratified magma reservoirs – small bodies of eruptible, crystal-poor silicic magma are suspended within a larger volume of non-eruptible, crystal-rich mush. Lavas erupted from these systems record geochemical evidence for long-term (10^3 to 10^5 years) deep storage followed by short (<1 to 10^3 years) residences in shallow chambers prior to eruption. Evidence for protracted magma ascent is frequently absent, suggesting deep-seated magmas rise quickly in reservoirs despite the high viscosity and low permeability of crystal-rich mushes. We hypothesize that deformation of a reservoir (by intrusion of new magma, passing seismic waves, tectonic stresses, etc.) allows low viscosity magmas to intrude high viscosity mush, creating mechanical instabilities that focus magma migration and facilitate rapid magma ascent through the reservoir.

To test this hypothesis, we are conducting high-temperature and high-pressure deformation experiments in a gas-medium, Paterson apparatus. Samples consist of a disk of soda lime glass (“magma”) stacked in series with a disk of a composite (“mush”) composed of borosilicate glass and fine quartz sand (44-106 μm). The mush has a crystal fraction of 80%. The stacked magma and mush disks are overlain by permeable ceramics. Sample assemblies are heated to 900°C (above the glass transition temperatures for soda lime and borosilicate glasses) and pressurized to 200 MPa confining pressure. At 900°C the magma viscosity is 10^4 Pa s and the mush viscosity is ~10^{12}-10^{14} Pa s. Following heating and pressurization, samples either dwell at high P-T conditions for extended time or are subjected to axial compression (strain rates of 10^{-5}-10^{-3} s^{-1}; shortening up to 50% of the length of the mush disk) or pore pressure gradients (a pressure difference across the sample of 10-150 MPa, equivalent to 2-30 MPa/mm over the length of the mush disk). After dwelling or deformation, samples are rapidly quenched and decompressed, cut in longitudinal sections and polished. Polished samples are analyzed in an SEM to collect back-scatter electron images and compositional maps. BSE images can be used to look for melt structures (e.g., viscous channels, dikes) that form in the mush during deformation. The compositions of magma (soda lime) and mush (borosilicate) melts are different, therefore compositional maps can be used to look for their respective spatial distributions. In static experiments, no magma intrudes the mush. We expect deformation to facilitate magma intrusion and that the volume of intruding magma will increase with increasing strain rate, strain and pore pressure gradient. These experiments will shed light on the role deformation plays in instigating magma ascent in stratified magma reservoirs.