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Experimental insight into the Explosive-Effusive eruption transition at Tungurahua volcano, Ecuador

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Tungurahua volcano (Ecuador) has seen increased eruptive activity since 1999 and has severely threatened the local population. This activity includes several pyroclastic density currents generating eruptions, including the voluminous August 2006 activity, which consisted of a series of explosive events terminated by the effusion of a lava flow. A similar explosive-effusive event has occurred in December, 2010. The understanding of such bimodal-volcanism is crucial to forecasting and explaining eruption dynamics seen at Tungurahua.

Field-density measurements were performed on 300 samples revealing a wide range of porosities (1-60%) in terms of the explosive material, in contrast to 1-3% for effusive lava products. Petrographically, material erupted effusively differs from that erupted explosively with a crystal fraction of 20-30% instead of 10-20 %, respectively. Preliminary volatile content investigations using TGA (FTIR measurement are currently being performed) indicate highly degassed erupted products.

Rheological behavior of ascending magma is a chief determinant of eruptive style. The viscosity of magma is strongly dependent on temperature and chemical composition of the melt as well as on the presence of crystals and bubbles, which induce strain rate dependence. Rheologically, crystallization is especially important as it modifies the composition of the interstitial melt while adding rigid particles. The varied eruptive style at Tungurahua represents an excellent opportunity to characterize the evolution of the rheological properties of the magma as it ascended and crystallized. Here, we combine geothermobarometry and rheology measurements using a concentric cylinder rheometer, a dilatometer, a uniaxial deformation press and a fragmentation apparatus to map the flow behavior of magma through its ascent from the magma chamber until eruption.

The temperature-pressure conditions of the magma reservoir have been investigated using two-pyroxene geothermobarometry. Magma chamber conditions have been constrained to 1010-1040 oC and ~2-6 kbar. The deeper magma proxy is envisaged as crystal poor (up to 10%) and thus, has a composition similar to that of the bulk. Chemically, eruptive products during 2006-2008 have been highly homogeneous (57% SiO2), and display a similar, near-identical non-Arrhenian temperature dependence of viscosity.

The rheological effects of crystallization were studied in two steps: we first characterized the temperature dependence of the viscosity of the interstitial melt and then, compared it to the apparent viscosity of natural magmas (containing crystals and bubbles). Due to variation in crystal content, the interstitial melt composition (dacitic with 63-67% SiO2) varied and thus viscosities were different for each sample. The strain-rate dependence of the multiphase magma (15-35% crystals, 2-30% pores) viscosity has been determined using a uniaxial deformation apparatus. Interstitial melt evolution due to crystallization caused a relative viscosity increase of approximately 2-3 log units. Moreover, the presence of crystals in the magma caused an additional 5 log unit increase and as well as strong shear thinning effects. Results indicate that the Aug. 2006 effusive phase displays a higher viscosity and a stronger dependence to strain rate than magma erupted explosively. This is consistent with an evolved interstitial melt as well as crystallinity.

The fragmentation dynamics at Tungurahua have been investigated using a modified shock-tube apparatus. Porosity is a key parameter controlling the fragmentation threshold, which is defined as the amount of over-pressure required to achieve full fragmentation. The August 2006 explosive material was characterized as having a fragmentation threshold of ~3 MPa, while the August 2006 effusive material requires 6-10 times more overpressure in order to fully fragment. We suggest that the effusion at the terminus of the explosive phase in

August 2006 resulted from the late and slower ascent of a more-viscous magma with increased crystallinity and lesser bubble content, thus diminished stored energy to drive explosive eruption.