Investigating Lava Properties using Experiments, Video Analysis, Infrared Thermometry and Numerical Flow Models

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The thermal and mechanical properties of lava are primary controls on lava flow behavior and are critical parameters in flow simulations. However, these properties are difficult to measure at field conditions or correctly extrapolate from the scale of small-size samples. We address this challenge by conducting controlled experiments using lab-made, meter-scale basaltic lava flows and carefully monitoring their cooling and deformation using high spatial and temporal resolution video and infrared cameras.

Our experimental setup is part of the Syracuse University Lava Project (http://lavaproject. syr.edu) and includes a large furnace capable of melting up to 450 kg of basalt at temperatures well above the basalt liquidus. The lava is poured out of the furnace to produce meters-long flows. To date, we have poured lava on sand, gravel, steel, ice and snow, onto unconfined planes, confined channels, and planes with obstacles. This experimental setup is probably the only facility that allows such large scale controlled lava flows made of natural basaltic material. We record the motion of the lava using a high-resolution video camera placed directly above the flows, and the temperature using forward-looking infrared (FLIR) cameras and thermocouples.

After the experiments, we analyze the images for lava deformation and cooling behavior. To extract a surface velocity field from the videos, we employ the technique of differential optical flow, which uses the time-variations of the spatial gradients of the image intensity to estimate velocity between consecutive frames. An important benefit for using optical flow, compared with other velocimetry methods, is that it outputs a spatially coherent flow field rather than point measurements. We demonstrate that the optical flow results agree with other measures of the flow velocity, and estimate the error due to noise and time-variability to be under 30 percent of the measured velocity.

We compare the observations with numerical forward-models to constrain the thermal and rheological parameters and laws which best describe the lava. Our forward flow models are obtained by solving the Stokes flow equations using the finite- element method. The model domain is an unstructured mesh defined by the geometry of the observed flow. We explore a range of rheological parameters, including the lavas apparent viscosity, the power-law exponent m and the thermal activation energy. We find that for the high-temperature portion of the flow a weakly shear-thinning or Newtonian rheology ($m>0.7$) with an effective activation energy of B=5500J gives the best fit to the data. These results agree well with predictions of the composition-based Shaw (1972) and GRD model (Giordano, Russell and Dingwell, 2008).

In summary, we demonstrate that our experimental lava flows allows for a careful documentation of flow evolution and control over flow variables, which leads to understanding of lava flow dynamics in unparalleled detail.