Geophysical Research Abstracts
Vol. 15, EGU2013-2447, 2013
EGU General Assembly 2013

Frictional melting and stick-slip behavior in volcanic conduits

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Dome-building eruptions have catastrophic potential, with dome collapse leading to devastating pyroclastic flows with almost no precursory warning. During dome growth, the driving forces of the buoyant magma may be superseded by controls along conduit margins; where brittle fracture and sliding can lead to formation of lubricating cataclasite and gouge. Under extreme friction, pseudotachylyte may form at the conduit margin.

Understanding the conduit margin processes is vital to understanding the continuation of an eruption and we postulate that pseudotachylyte generation could be the underlying cause of stick-slip motion and associated seismic “drumbeats”, which are so commonly observed at dome-building volcanoes. This view is supported by field evidence in the form of pseudotachylytes identified in lava dome products at Soufrière Hills (Montserrat) and Mount St. Helens (USA). Both eruptions were characterised by repetitive, periodic seismicity and lava spine extrusion of highly viscous magma.

High velocity rotary shear (HVR) experiments demonstrate the propensity for melting of the andesitic and dacitic material (from Soufrière Hills and Mount St. Helens respectively) at upper conduit stress conditions (<10 MPa). Starting from room temperature, frictional melting of the magmas occurs in under 1 s (« 1 m) at 1.5 m/s (a speed that is achievable during stick-slip motion). At lower velocities melting occurs comparatively later due to dissipation of heat from the slip zone (e.g. 8-15 m at 0.1 m/s). Hence, given the ease with which melting is achieved in volcanic rocks, and considering the high ambient temperatures in volcanic conduits, frictional melting may thus be an inevitable consequence of viscous magma ascent.

The shear resistance of the slip zone during the experiment is also monitored. Frictional melting induces a higher resistance to sliding than rock on rock, and viscous processes control the slip zone properties. Variable-rate HVR experiments which mimic rapid velocity fluctuations in stick-slip behavior demonstrate velocity-weakening behavior of melt, with a tendency for unstable slip.

During ascent, magma may slip and undergo melting along the conduit margin. In the process the shear resistance of the slip zone is increased, acting as a viscous brake halting slip (the “stick” of stick-slip motion). Sufficient buoyancy-driven pressures from ascending magma below eventually overcome resistance to produce a rapid slip event (the “slip”) along the melt-bearing slip zone, which is temporarily lubricated due to velocity-weakening. New magma below experiences the same slip event more slowly (as the magma decompresses) to produce a viscous brake and the process is repeated. This allows a fixed spatial locus that explains the repetitive drumbeat seismicity and the occurrence of “families” of similar seismic events. We conclude that stick-slip motion in volcanic conduits is a self-driving, frictional-melt-regulated force common to many dome building volcanoes.