Volcanic pseudotachylyte and self-driven stick-slip motion

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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 During dome growth, the driving forces of the buoyant magma may be superseded by controls along conduit margins; where brittle fracture and sliding can lead to formation of lubricating cataclasite, gouge and, under extreme friction, pseudotachylyte.

High velocity rotary shear (HVR) experiments demonstrate the propensity for melting of the andesitic and dacitic material (from Soufriere Hills and Mount St. Helens respectively) at upper conduit stress conditions (less than 10 MPa). Starting from room temperature, frictional melting of the magmas occurs in under 1 s (less than 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 to 15 m at 0.1 m/s). Given the ease with which melting is achieved in volcanic rocks, and considering the high ambient temperatures in volcanic conduits, frictional melting is a highly probable 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. 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.

When a melt layer forms at the conduit margin the shear resistance of the slip zone is increased, acting as a viscous brake and 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.

This view is supported by field evidence in the form of pseudotachylytes identified in lava dome products at Soufriere Hills (Montserrat) and Mount St. Helens (USA). Both eruptions were characterised by repetitive, periodic, fixed-source seismicity and lava spine extrusion of highly viscous magma. We conclude that stick-slip motion in volcanic conduits is a self-driving, frictional-melt-regulated force common to many dome building volcanoes.