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Spine growth mechanisms: friction and seismicity at Mt. Unzen, Japan

Adrian Hornby (1), Jackie Kendrick (1), Takehiro Hirose (2), Sarah Henton De Angelis (1), Silvio De Angelis (1), Kodo Umakoshi (3), Takahiro Miwa (4), Fabian Wadsworth (1,5), Don Dingwell (5), and Yan Lavallee (1)

(1) Earth, Ocean and Ecological Sciences, University of Liverpool, Liverpool L69 3GP, (2) Kochi Institute for Core Sample Research (KCC), JAMSTEC, Kochi, Nankoku 783-8502, Japan, (3) Graduate School of Fisheries Science and Environmental Studies, Nagasaki University, 1-14 Bunkyo-machi, Nagasaki 852-8521, Japan, (4) Institute of Seismology and Volcanology, Kyushu University, 2-5643-29 Shin'Yama, Nagasaki, Japan, 855-0843, (5) Dept. for Earth and Environmental Science, LMU Munich, Theresienst. 41, 80333, Munich, Germany

The final episode of dome growth during the 1991-1995 eruption of Mt. Unzen was characterised by spine extrusion accompanied by repetitive seismicity. This type of cyclic activity has been observed at several dome-building volcanoes and recent work suggests a source mechanism of brittle failure of magma in the conduit. Spine growth may proceed by densification and closure of permeable pathways within the uppermost conduit magma, leading to sealing of the dome and inflation of the edifice. Amplified stresses on the wall rock and plug cause brittle failure near the conduit wall once static friction forces are overcome, and during spine growth these fractures may propagate to the dome surface. The preservation of these features is rare, and the conduit is typically inaccessible; therefore spines, the extruded manifestation of upper conduit material, provide the opportunity to study direct evidence of brittle processes in the conduit. At Mt. Unzen the spine retains evidence for brittle deformation and slip, however mechanical constraints on the formation of these features and their potential impact on eruption dynamics have not been well constrained.

Here, we conduct an investigation into the process of episodic spine growth using high velocity friction apparatus at variable shear slip rate (0.4-1.5 m.s-1) and normal stress (0.4-3.5 MPa) on dome rock from Mt. Unzen, generating frictional melt at velocity >0.4 m.s-1 and normal stress >0.7 MPa. Our results show that the presence of frictional melt causes a deviation from Byerlee's frictional rule for rock friction. Melt generation is a disequilibrium process: initial amphibole breakdown leads to melt formation, followed by chemical homogenization of the melt layer. Ultimately, the experimentally generated frictional melts have a similar final chemistry, thickness and comminuted clast size distribution, thereby facilitating the extrapolation of a single viscoelastic model to describe melt-lubricated slip events at Mt. Unzen. To that end we apply state of the art 2-phase rheological models to estimate the dynamic apparent viscosities acting on the slip plane during a given slip event. Physical parameters of individual slip events in the conduit are constrained through calculation of seismic moments from earthquake swarms recorded during spine growth at Unzen. The combination of experimental data and viscosity modelling for frictional melt with seismic analysis provides a model for material response during slip in the upper conduit at Unzen. This model may have applicability to other eruption modes and volcanoes and further our understanding of cyclic eruptive activity during lava dome formation.