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Gas slug rise in open versus plugged basaltic conduits: the transition from Strombolian to sustained volcanic eruptions

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Strombolian eruptions are characterized by low-energy explosive activity, which may repeat, at fairly regular intervals, for long periods of time. Explosions at the vent are thought to result from the arrival of discrete slugs of magmatic gas that have risen through the magmatic plumbing system. We develop a one dimensional, analytical model of gas slug rise in a volcanic conduit which we use to investigate the controls on the dynamics of Strombolian eruptions.

We consider a partially-filled, cylindrical conduit containing degassed magma, that is initially in magma-static equilibrium with a constant pressure magma reservoir at depth. We introduce a slug of gas at the base of the conduit and consider the temporal evolution of the pressure distribution in the conduit, and the motion of the magma above and below the slug, as the slug rises, decompresses, and expands isothermally. We validate our model against published data for gas slugs rising and decompressing in a vertical pipe [James et al., 2008, Geological Society of London, Special Publications 307, 147-167] by imposing the condition of zero magma-flux at the base of the conduit, and constant pressure at the top; we find excellent agreement. If we impose the more geologically-sound condition of constant pressure at the base of the conduit, we can consider two scenarios of volcanological relevance:

1) Vent plugged with cooler, more-viscous magma. In this case, as the slug rises and expands beneath the plug, it pushes the degassed magma below it down the conduit, consequently, magma re-enters the chamber from the base of the conduit. The slug reaches the viscous plug at the top of the conduit with a significant over-pressure; this may be sufficient to disrupt the plug, causing a Strombolian explosion, or the gas may percolate away. Fresh magma then moves up from the chamber, into the conduit to restore magma-static equilibrium.

2) Open vent. As the slug rises and expands, the volume of magma held in the falling-film that encircles the slug increases. Since this film is supported viscously by the conduit walls, it does not contribute to the magma-static pressure at the base of the conduit which, therefore, decreases, causing fresh magma to flow upwards.

Fresh magma entering the base of the conduit may cause a new slug to form, either through decompression and exsolution, or by tapping a gas-rich layer at an asperity, or at the chamber roof. In either case, scenario 1 (plugged vent) will lead to periodic, Strombolian eruption, whilst scenario 2 (open vent) will lead to sustained eruption at higher discharge rate. A noteworthy feature of the model is that the conduit is recharged with fresh magma following slug rise, even if no magma is erupted at the surface.

We apply our model to the case of Stromboli, and compare model output with monitoring observations. We find that the most important parameters controlling eruption style and vigour are magma viscosity, mass of gas in the slug, and the ratio of slug radius to conduit radius. Our findings potentially impact the dangerous transition from 'touristic' Strombolian activity to more-hazardous paroxysmal activity.