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Rheology contrast in the shallow conduit and eruption dynamics at Stromboli: insights from analogue experiments

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Strombolian eruptions result from the bursting of large individual gas pockets (slugs) in a low-viscosity magma. Scaled experimental investigations of the processes involved have generally been carried out in single Newtonian liquids, and have explored the dynamics of slug expansion, burst and their control on the generation of geophysical signals. Such studies provide a thorough first order investigation of the mechanisms involved, but little attention has been given so far to the processes of slug expansion and burst in more complex fluids. Observations at Stromboli show that obstructions in the conduit (due to, e.g., partial wall collapse or fall back in the vent of ejecta) can generate a viscous impedance within the upper portion of magma, leading to more violent eruptions. Petrological and textural data also suggest the presence of different magma rheologies due to degassing driven crystallisation.

Here we use laboratory experiments to investigate the role of a vertical contrast in magma rheology on the dynamics of slug expansion and burst, and the resulting geophysical signals. The analogue materials used are silicon oil (μ = 0.1 Pa*s) capped with castor oil (μ = 1 Pa*s) to give a viscosity contrast of 10. Vertical pressure gradient is scaled by reducing the pressure at the top of the experimental apparatus with a vacuum pump. Pressure variations are measured at the top and bottom of the apparatus and correlated with high-speed imagery of the experiments and the results compared with control experiments using single liquid. The thickness of the viscous plug was varied along with the gas volumes and the gas pressure at the liquid surface (1 kPa, 3 kPa and 300 Pa).

Our results show that the thickness of the viscous plug strongly controls slug expansion and systematically changes the magnitude of the associated pressure transients, favouring a more impulsive and energetic pressure release compared with the control experiments. The intrusion of slugs in the viscous plug leads to complex flow configurations: small slugs can enter the viscous plug either partly or wholly before bursting. Large slugs lead to complex interaction between the two liquids: the intrusion of the low-viscosity liquid into the high-viscosity one provides a preferential pathway for the slugs. The viscous plug generates an annulus of variable thickness acting as a narrowing of the tube. Furthermore, higher gas volumes can induce both instabilities in the falling film and the disruption of the viscous annulus, clots of which are brought to the top by the slug.