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Gas slug ascent through rheologically stratified conduits

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Textural and petrological evidence has indicated the presence of viscous, degassed magma layers at the top of the conduit at Stromboli. This layer acts as a plug through which gas slugs burst and it is thought to have a role in controlling the eruptive dynamics. Here, we present the results of laboratory experiments which detail the range of slug flow configurations that can develop in a rheologically stratified conduit. A gas slug can burst (1) after being fully accommodated within the plug volume, (2) whilst its base is still in the underlying low-viscosity liquid or (3) within a low-viscosity layer dynamically emplaced above the plug during the slug ascent. We illustrate the relevance of the same flow configurations at volcanic-scale through a new experimentally-validated 1D model and 3D computational fluid dynamic simulations. Applied to Stromboli, our results show that gas volume, plug thickness, plug viscosity and conduit radius control the transition between each configuration; in contrast, the configuration distribution seems insensitive to the viscosity of magma beneath the plug, which acts mainly to deliver the slug into the plug. Each identified flow configuration encompasses a variety of processes including dynamic narrowing and widening of the conduit, generation of instabilities along the falling liquid film, transient blockages of the slug path and slug break-up. All these complexities, in turn, lead to variations in the slug overpressure, mirrored by changes in infrasonic signatures which are also associated to different eruptive styles. Acoustic amplitudes are strongly dependent on the flow configuration in which the slugs burst, with both acoustic peak amplitudes and waveform shapes reflecting different burst dynamics. When compared to infrasonic signals from Stromboli, the similarity between real signals and laboratory waveforms suggests that the burst of a slug through a plug may represent a viable first-order mechanism for the generation of infrasonic signals. Furthermore, the presence of a plug seems to be a pre-requisite for the pulsatory behaviour recently observed at Stromboli and the complex interaction between an ascending slug and the liquids promotes magma mingling, therefore controlling the ejecta properties.