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Rheological controls on the eruption style and size of historical eruptions from Mt. Ruapehu, New Zealand

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The physical state of a magma controls a range of igneous processes, from crystal and bubble growth, the ability to exsolve gas, drive convection, and eventually whether the magma erupts or stalls. During magma ascent, crystallisation and bubble expansion significantly alter the physical state of a magma. Therefore, a quantitative assessment of magma rheology through time could help to explain the style, duration and size of eruptions. The aim of this work is to determine the rheology of magma from storage to eruption using existing constitutive equations. An assessment of the changing rheological properties of magma could provide insights into the generation of seismicity, deformation, and gas efflux; all signals that are regularly monitored at active volcanoes.

Regular eruptions have occurred at Mt. Ruapehu, New Zealand since 1830, yet all have been small volume (< 0.001 km^3). This work combines melt inclusion volatile contents with geochemistry to track the physical state of the magma from its source region (300 MPa) to eruption. In doing so, we hoped to explain the size and style of Ruapehu eruptions.

The rheology of Ruapehu magma has been determined using a combination of thermodynamic models and rheological calculations. We used a thermodynamic model (MELTS) to determine the composition of three, representative Ruapehu magmas from 300 MPa to $\sim$ 30 MPa. The outputs of the model agreed with experimental data and provided the crystal and bubble (assuming no gas loss) content, along with the melt content and composition. We calculated the melt viscosity, and the relative effect of bubbles and crystals, to quantify the rheology of the magma during ascent (under assumed equilibrium conditions). The crystal content at which a yield strength would develop, and therefore the point at which a magma would likely stall, has been constrained to $\sim$ 0.3, which is marginally higher than the crystal content of erupted scoria.

Historical eruptions from Ruapehu were H_2O-undersaturated and as a consequence, crystallisation and bubble growth were suppressed until the magma reached saturation, at $\sim$ 100 to 50 MPa. From this work, we suggest that small-volume magmas (< 0.001 km^3) at Ruapehu are more likely to erupt compared to magmas of a similar composition that are H_2O-saturated. This partly explains the propensity for small-volume phreatic and phreatomagmatic eruptions at Ruapehu (in the presence of Crater Lake).