Geophysical Research Abstracts
Vol. 20, EGU2018-760, 2018
EGU General Assembly 2018

Can we predict seismogenic failure of single-phase magmatic liquids?

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During ascent through the shallow crust, high viscosity magma fractures repeatedly, producing seismicity that can be used to both track magma movement and help forecast eruption times. Predictive tools (e.g. Failure Forecast Method (FFM), and variations thereof) have been developed in which the acceleration of acoustic signals toward failure is thought to follow a power law, such that the singularity defines the critical point at which the acoustic signals run away and coincides with failure. Unfortunately, forecast methods are not universally successful, possibly due to a few key processes that remain under-explored. We located the viscous-to-brittle transition in magma using scaled laboratory deformation experiments in which acoustic emissions were tracked *in situ*.

A high-load (<300 kN), high-temperature (<1050 ˚C) uniaxial press was used to deform both synthetic and natural single-phase magmatic liquids at constant strain rates, while recording acoustic emissions simultaneously. The ratio between the relaxation time of the liquid, λ_r (s), and the time of deformation, λ (s), also known as the Deborah number (De), was used to define the deformation behaviour of each experiment. This dimensionless quantity is <<0.01 for purely viscous behaviour and >0.04 for brittle behaviour with a single major stress drop at the moment of failure. In between these regimes, viscous flow was interrupted by small stress drops, which we refer to as transitional. We detected no acoustic emissions for De<0.001. At 0.001<De<0.01, formation of microcracks and subsequent healing characterised the macroscopically viscous deformation behaviour. The frequency of the acoustic emissions was consistent at 70 kHz–1 MHz for all waveforms independent of De, but the average amplitude increased with increasing De.

Using the timings of acoustic events, we calculated the highest probability for the normalised forecast error, which is the ratio of the predicted failure time over the observed failure time, by applying the Maximum-Likelihood method to the TROL (Time-Reversed Omori Law) for a large range of initial parameters. In addition, we compared the TROL to an exponential and linear model by assessing the Bayesian Information Criterion (BIC). We found that predicting failure can be five orders of magnitude off compared to the observed failure time. Moreover, the BIC showed that the linear model is preferred over the TROL and exponential model for all De, which indicates that precursory signals in single-phase liquids do not follow a power law. This may be another key reason for erroneous failure forecasts in homogeneous materials including single-phase magmas and may help interpret poor predictions of eruptive behaviour at some active volcanoes. This also highlights a major shortcoming in the widely used FFM and points toward a need for novel forecasting tools.