Fail or not to fail? Reservoir mechanics and ground deformation before large magnitude eruptions of intermediate magmas

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The current knowledge base on ground deformation prior to the eruption of intermediate magma is skewed towards small magnitude eruptions. The long-term (order of years) pre-eruptive ground deformation of a future large magnitude intermediate eruption similar to the caldera-forming Great Tambora eruption in 1815 is thus poorly understood.

Here, we explore a potential long-term pre-eruptive geodetic signature of a growing magma reservoir of intermediate composition using numerical mechanical modelling.

We start by exploiting cyclic ground deformation data from the currently active Soufrière Hills volcano to constrain the pre-eruptive subsurface stress history of a comparably small magmatic system of intermediate composition. We first define a reservoir failure criterion based on rock tensile strength under the simple assumption of elastic mechanical behaviour of surrounding rocks. Given observed pre-eruptive deformation amplitudes and petrologically deduced storage conditions, the results indicate that invoking mechanical elasticity is problematic to explain cyclic eruptive behaviour at SHV over the past decade. Time-dependent stress relaxation must play a first order role.

Up-scaling to match magmatic conditions prior to the Great Tambora eruption demonstrates a first order influence of edifice load, topography, and mechanical heterogeneity of encasing rocks on the stress distribution and the resultant deformation field upon reservoir growth. Again time-dependent stress relaxation is found to control growth of an intermediate magma reservoir of substantial size and thereby inhibiting pre-mature failure upon recharge.

The modeling also shows that a dynamic failure criterion is more plausible compared to a static criterion based on rock tensile strength to characterize reservoir failure at lithostatic pressures of between 100 and 220 MPa, i.e., within a pressure window constrained petrologically for many recently erupted intermediate magmas. Combining the numerical results with published thermal and petrological constraints on reservoir evolution, we deduce a limiting permissible volumetric strain rate upon reservoir recharge of 10^{8} s^{-1}. Growth of a large body of eruptible magma of intermediate composition may be favoured at strain rates $<10^{8}$ s^{-1}, whereas pre-mature reservoir failure may occur at strain rates $>10^{8}$ s^{-1}. The associated long-term pre-eruptive ground uplift of the pre-1815 Tambora volcano by the incremental growth of a relatively short-lived (compared to silicic) intermediate magma reservoir is predicted at well below 1 cm/year. The results may be useful for assessing the long-term pre-eruptive signs of future large magnitude eruptions