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Survival of the fastest: Fracture healing vs gas exsolution rate in open-vent systems

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Open-vent silicic systems often exhibit cyclic transitions between effusive and explosive activity. For instance, Santiaguito volcano, Guatemala, exhibits a 25-40 minute cycle of quiescent effusive activity intermittently cut by short explosive bursts. These explosive events are characterised by localised, through-fracture gas escape. Repeatable geophysical signals (deformation and seismic) of the cyclic activity, suggest that the source mechanism remains the same (i.e. non-destructive) and at a constant depth of about 300 m. Here, we surmise that the competition between gas exsolution rate and strength/ permeability recovery through fracture healing dictates the cyclic behaviour observed at Santiaguito.

By utilising a novel experimental technique, we first investigate the mechanics and kinetics of fracture healing in silicate melts. In these tests, two rods are placed end-on in contact with one another at different temperatures (and hence viscosities) for different amounts of time. Thereafter, the amount of healing is monitored as a strength recovery of the contact interface, with respect to the nominal tensile strength of the glass. We find that healing initiates after a characteristic onset time proportional to the relaxation timescale of the melt. Additionally, we demonstrate that fracture healing is governed by two successive stages of: 1) viscous deformation along the fracture plane, defined as the wetting regime; 2) diffusive exchange across the fracture interface, defined as the diffusive regime. Importantly, healing shuts down the permeability of a fracture plane, leaving a trail of unconnected pores. We surmise that this texture forms in the early stages of the process, during the wetting stage.

Then, considering that pressure begins to build immediately following an explosion, we apply a linear pressurisation model. This suggests that the repose time of open-vent silicic systems is governed by both the healing and pressurisation rates, and typically only partially heal between explosive events. We find that hotter systems (lower viscosity) can sustain faster pressurisation rates before rupture, due to increased healing efficiency, while colder systems tend to allow more persistent degassing.

Finally, in order to apply these results to Santiaguito, we determine the tensile strength, at different temperatures (hence viscosities), of a wide range of samples from this volcano. We find that the maximum tensile strength varied, depending on porosity and temperature, from 4 to 15 MPa. Given the average repose time, we surmise that, the pressurisation rate of this system must be between 0.07 MPa/min for the higher viscosity and 0.15 MPa/min for the lower viscosity end members of the system. At these pressurisation rates, the system recovers $\sim$10 to 30% of its maximum tensile strength (1.5 and 4.5 MPa, respectively) between explosive events.