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Densification kinetics of glassy and crystalline volcanic ash and subsequent predictability associated with its fragmentation

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Explosive volcanism is one of the most catastrophic material failure phenomenon. During magma ascent fragmentation produces particulate magma which, if deposited above the glass transition of the interstitial melt, will sinter viscously. In-conduit tuffisites, conduit wall breccias and ash deposited from exceptionally hot pyroclastic flows are scenarios in which sintering by viscous flow is possible. Therefore, understanding the kinetics of sintering and the characteristic timescales over which magma densifies are critical to understanding the degassing timeframe in conduits and deposits. Viscous sintering is accompanied by a recovery of material strength toward that of a pore-free magma. Understanding damage mechanisms and seismic behaviour prior to failure of sintered volcanic products are also crucial for the application of micromechanical models and material failure forecasting laws.
Powdered standard glass (NIST 717a) and natural volcanic ash have been used to explore sintering mechanisms at ambient pressure conditions and temporal evolution of connected and isolated pore-structure. We observed that sintering under low axial stress is essentially grain-size, surface tension and melt viscosity controlled. We found that the timescale over which the bulk density and the strength approaches that of pore-free melt at a given temperature is dependent on the grain-contact surface area, which can be estimated from the particle shape, the packing type and the initial total porosity. Granulometric constraint on the starting material indicates that the fraction of finer particles controls the rate of sintering as they cluster in pore spaces between larger particles and have a higher driving force for sintering due to their higher surface energy to volume ratio. In a volcano, newly formed sintering material will then further contribute to magma-plugging of the conduit and its mechanical properties will affect magma rupture and its associated precursory signals. This consideration permitted us to explore the effect of sintering on the stress required for dynamic macroscopic failure of synthesized samples at conditions relevant to volcanic conduits.
Sintering and densification results in a non linear increase in strength and micromechanical modelling shows that the pore-emanated crack model explains this trend as a function of pore fraction and size. We also assessed the ability of precursory microseismic signals to be used as a failure forecast proxy according to drastic changes in porosity (∼40 to 0%) and material strength (>102 MPa). Homogeneous single-phase liquids to heterogeneous multi-phase (pores in glasses, pores and crystals in other volcanic rocks) liquids display different microseismic patterns preceding bulk sample failure, somewhat mimicking the range of seismic precursory signals observed at volcanoes with magma of similar viscosity and mechanical characteristics. Defect-free glass for example will rapidly accumulate a huge amount of strain energy as it requires to exceed an elevated strength for failure (∼500–700 MPa) and suddenly release it via localised microfracturing. Microseismic acceleration associated with defect-poor rocks/magmas display trial or occasionally little forewarning with the implication that seismic-based failure prediction may be difficult to make in real-time monitoring.