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The Glass Bead Game: experimental sintering of rhyolitic ash reveals complex behaviour of irregular multiphase particles

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Sintering of magmatic particles profoundly influences the permeability, strength and compaction of fragmented magma in conduits and pyroclastic deposits. It involves initial rounding and agglutination of particles, with formation of inter-particle necks, followed by progressive viscous collapse of pores. The sintering behaviour of ash particles within tuffisite veins, which may mediate shallow outgassing in silicic eruptions, is of particular interest. Experimental studies on homogeneous synthetic glasses[1] have shown sintering rates to be time, temperature and grainsize-dependent, reflecting the influence of melt viscosity and pore-melt interfacial tension. A key objective is to reconstruct the temperature-time path of naturally sintered samples, so here we investigate the sintering of natural, angular ash fragments, to explore whether similar simple relationships emerge for more complex particle morphologies and internal textures.

A glass-rich ballistic rhyolite bomb from the Cordón Caulle 2011-2012 eruption was ground and sieved to create various grainsizes of angular ash particles. The bomb contains 70 wt.% SiO_2, 0.25 wt.% H_2O, and $\sim$30 vol.% crystal phases, as phenocrysts and microlites of plagioclase and pyroxenes. Particles were spread thinly over a sapphire surface in an N2-purged heated stage, and heated to 900, 1000 and 1100 °C, corresponding to melt viscosities of 105.4-107.7 Pa.s. Images were collected every 10-600 s during isothermal sintering over tens of minutes to hours. Quantitative image analysis using ImageJ allowed quantification of evolving particle size and shape (diameter and roundness) and inter-particle neck width. The rate of particle rounding was expected to be highest for smallest particles, and to decrease through time, but unlike synthetic glass bead experiments, no simple trends emerged.

When the temporal evolution of particle roundness was tracked, some particles showed an unexpected, systematic increase in rounding rate with time (type A), whereas others showed the expected decrease (type B), or an increase followed by a decrease (type C). The relationship between evolving particle roundness and diameter showed similarly diverse trends, and no distinction could be made between type A, B and C based on initial roundness, size or other characteristic. The development of inter-particle necks was quantified via measurements of the rate of neck width evolution. These rates proved broadly similar for different grain sizes at a given temperature, suggesting that the initial grain size was not the primary controlling factor on neck width growth.

Our results highlight both the complexity of sintering in multiphase magmas with irregular particle shapes, and the difficulty of adequately using two-dimensional imagery to characterise evolving three-dimensional morphologies. Future work should employ tomographic techniques to characterise four-dimensional sintering, and analyse large particle populations to overcome the stochastic effects of variable particle texture and morphology.

[1] Vasseur J et al. 2013, GRL 40, 5658–5664.