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Differentiation in Sheared Granular Magma

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Recent developments in high definition mineral chemistry at the grain scale are shedding new light on the processes and rates of magma storage, differentiation and eruption. However, the complementary physics and fluid dynamics of magma as a granular material are still based on viscous compaction theory, which may not be relevant in sub-volcanic settings where magma is being deformed by external shear. We present a quantitative model for shear deformation of a crystallised dense magma (>70% solid) with poro-elastic properties where the critical link between the mechanics and associated compositional changes in the melt are governed by dilation (volume increase) of the granular skeleton. Key material parameters governing the dilatancy effect include magma permeability, mush strength, the shear modulus and the contact mechanics and geometry of the granular assemblage. Calculations show that dilation reduces the interstitial fluid (melt) pressure to produce a 'suction' effect. At shear strain rates in excess of the tectonic background, deformation-induced melt flow can redistribute chemical components and heat between regions of crystallising magma with contrasting rheological properties, at velocities far in excess of diffusion or buoyancy forces, the latter of course the driving force behind fractional crystallisation and compaction. Unlike static magmas, there is no 'lock-up' state above which the interstitial melt cannot percolate. Co-mingling of hotter, indigenous melt has the potential to interrupt (or locally reverse) fractionation trends and produce reverse zoning or resorbtion of crystals, mimicking some of the textural effects attributed to magma mixing. Post-failure instabilities include hydraulic rupture of the mush along shear zones with potential for larger scale extraction and redistribution of evolved melt. A novel feature of congested, sub-volcanic granular magma is that the eruption itself helps drive rapid melt extraction, negating the requirement to first segregate large volumes of evolved melt as a precursor.