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Rheology of crystallizing lava: an experimental approach

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The viscosity of magmas is a key parameter in magma transport processes and volcanic eruptions. In nature, magmas are transient. Changes in P-T conditions force the magma to chemically and physically evolve, resolving a transient viscosity of the melt, overprinted by the complex rheological effects of the suspended fraction (crystals and bubbles). Such a dynamic understanding of transient rheology escapes our ability to fully assess the extent of volcanic hazards (e.g., lava flow reach out). To date, rheological studies provide a static view on individual contributions (e.g., chemical composition of the interstitial liquid vs physical effects of the suspended phases), without consideration of the feedback involved in the thermodynamic process underlying the evolution of the magmatic system. Alternatively, thermodynamic calculators provide a static view of mineral assemblage equilibrium, disregarding kinetic information on the physical evolution of the system during crystallization. Here, we assess the adequacy of combining rheological, petrologic and thermodynamic models in a transient system (such as lava flow dynamics) by comparing their outcome to dynamic rheological experiments on crystallizing and flowing natural melts with various (andesitic to basaltic) compositions. We optimized previous experimental methods for the concentric cylinder apparatus to measure the dynamic apparent viscosity of a magmatic suspension undergoing cooling and crystallization. The spindle is left in situ during quenching of the experimental products, to preserve the complete developed texture of the sample. Experiments are carried out in air or under controlled oxygen fugacity in order to avoid extensive oxide crystallization. Below the liquidus we record a transient evolution of the system; when crystals nucleate and when crystals grow. Thermodynamic equilibration is then reached after some hours. With each further cooling increment equally complex rheological response (overprint by non-Newtonian behavior) is observed. Quantification of the evolving mineralogical assemblage as well as the crystal fraction and distribution reveal that the steady state flow conditions are reached upon completion of crystallization at equilibrium (under a given T increments). Comparatively, the apparent viscosity at each investigated temperature is calculated as a function of the crystallization sequences (via MELTS), the residual liquid composition (via GRD model) and the characteristics of the solid fraction, presenting the discrepancies of employing static models in a dynamic system.