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Simulating and interpreting igneous textures: from crystallization kinetics to pluton dynamics

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Solidification of natural magmas involves crystal nucleation and growth, surface energy-driven annealing, and mechanical crystal-melt interactions. These processes dictate rheology of the evolving magma suspension and are recorded in the resulting igneous texture. We developed a set of high-resolution thermokinetic and thermomechanical algorithms, which predict the formation of igneous texture in cooling magma bodies using variable crystal nucleation and growth kinetics and explore rheological and mechanical consequences of solidification. Crystal nucleation and growth in a static three-dimensional regime using constant, linearly increasing, exponential, and Gaussian functions for the rates of nucleation and growth yield equigranular to seriate textures. The simulated crystal size distributions suggest that the role of Ostwald ripening has often been overestimated. Textures resulting from homogeneous nucleation have clustering index substantially lower than previously reported, whereas preferential heterogeneous nucleation causes initially equigranular textures to evolve to porphyritic, bimodal and spherulitic types. The corresponding crystal size distributions become concave-up curved, often attributed to mixing of crystal populations. One-dimensional model of cooling and crystallization of a horizontal melt sheet (laccolith or a single intrusive pulse) predicts significant variations in the style of magma chamber evolution and solidification. Small magma chambers crystallize by two opposite and gradually progressing solidification fronts; large magma chambers containing high-viscosity magmas crystallize gradually and uniformly by rapidly proceeding crystal interlocking whereas those filled with low-viscosity magmas form an asymmetric footwall solidification front underlying the convecting crystal mush. These thermal, mechanical and kinetic models serve to develop a genetic classification of intrusive bodies that should facilitate interpretation of internal dynamics in natural magma chambers.