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Challenges in model validation of multiphase mixtures: scaling requirements for application to volcanic and magmatic systems

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Validation of models for volcanic/magmatic systems requires assessment of the appropriate kinematic and dynamic scaling of multiphase mixtures. We present scaling relations that provides a more complete framework for scaling dilute magmatic systems by explicit consideration of the complexity caused by the feedback between particles (crystal, bubble, or pyroclast) and the continuous phase (liquid or gas). We consider three canonical igneous multiphase systems: magma chambers, volcanic plumes, and pyroclastic surges, and we provide estimates of the proposed scaling relations for published experiments on those systems.

Dilute magmatic mixtures can display a range of distinct dynamical regimes that we characterize with a combination of average (Eulerian) properties and instantaneous (Lagrangian) variables. The Eulerian properties of the mixture yields the Reynolds number (Re), which indicates the level of unsteadiness in the continuous phase. The Lagrangian acceleration of particles is a function of the viscous drag and gravity forces, and from these two forces are derived the Stokes number (St) and the stability number (Rt), two dimensionless numbers that describe the dynamic behavior of the particles within the mixture. The compilation of 17 experimental studies relevant for pyroclastic surges and volcanic plumes indicates that there is a need for experiments above the mixing transition ($\mathrm{Re} > 10^4$) and for scaling St and Rt. Among the particle dynamic regimes present in surges and plumes, some deserve special attention, such as the role of mesoscale structures on transport and sedimentary processes or the consequences of the transition to turbulence on particle gathering and dispersal.

The compilation of seven experimental studies relevant to magma bodies indicates that, in the laminar regime, crystals mostly follow the motion of the melt, and thus the physical state of the system can be approximated an ensemble single phase. In the transition to turbulence, magmas can feature spatially heterogeneous distributions of laminar regions and important velocity gradients. This heterogeneity has a strong potential for crystal sorting. In conclusion, the Re-St-Rt framework demonstrates that, despite numerous experimental studies on processes relevant to magmatic systems, some and perhaps most, geologically important parameter ranges still need to be addressed at the laboratory scale.