Beyond empiricism: Quantitative models for the permeability of heterogeneous magmas

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Measurements abound for the permeability of volcanic rocks, high temperature magmas, synthetic analogues for magma and rock, and 3-dimensional domains of porous media simulated numerically. Despite a wealth of data, the dominant approach to parameterisation has been empirical, and scarcely goes beyond the power-law models for percolating systems. Here we propose a suite of methods to bring the data for these complex systems in line with theoretically grounded percolation models. To do this we create numerical samples using variations on theme of overlapping spheres filling volumes. In order to create a wide range of possible geometries, we can either define the spheres as the pore phase, or the inter-sphere volume as the pore phase, such that one option is the inverse of the other. In either case, we simulate fluid flow through the pore phase until steady state, to determine the Darcian and inertial permeability tensors. We compare these results with derived, fully theoretical percolation theory and find good agreement without fitting parameters. In order to render this useful for understanding permeability in volcanic scenarios, we compare these validated models to a large database of compiled published permeability data. This approach allows us to group the permeability of magmas into three universality classes, which each have just one dimensionless solution: (1) initially granular magmas, such as variably welded ignimbrites or tuffisites, and (2) bubbly magmas, such as pumice.