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Dynamics of dikes versus cone sheets in volcanic systems

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Igneous sheet intrusions of various shapes, such as dikes and cone sheets, coexist as parts of complex volcanic plumbing systems likely fed by common sources. How they form is fundamental regarding volcanic hazards, but yet no dynamic model simulates and predicts satisfactorily their diversity. Here we present scaled laboratory experiments that reproduced dikes and cone sheets under controlled conditions (Galland et al., 2014). Our models show that their formation is governed by a dimensionless ratio ($\Pi 1$), which describes the shape of the magma source, and a dynamic dimensionless ratio ($\Pi 2$), which compares the viscous stresses in the flowing magma to the host-rock strength. Plotting our experiments against these two numbers results in a phase diagram evidencing a dike and a cone-sheet field, separated by a sharp transition that fits a power law. This result shows that dikes and cone sheets correspond to distinct physical regimes of magma emplacement in the crust. For a given host-rock strength, cone sheets preferentially form when the source is shallow, relative to its lateral extent, or when the magma influx velocity (or viscosity) is high. Conversely, dikes form when the source is deep compared to its size, or when magma influx rate (or viscosity) is low. Both dikes and cone sheets may form from the same source, the shift from one regime to the other being then controlled by magma dynamics, i.e. different values of $\Pi 2$. The extrapolated empirical dike-to-cone sheet transition is in good agreement with the occurrence of dikes and cone sheets in various natural volcanic settings.

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