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Dykes versus cone sheets in volcanic systems – two sides of the same coin?

Steffi Burchardt (1), Olivier Galland (2), Erwan Hallot (3), and Regis Mourgues (4)

(1) Uppsala University, Department of Earth Sciences, Uppsala, Sweden (steffi.burchardt@geo.uu.se), (2) Physics of Geological Processes, University of Oslo, Sem Seilandsvei 24, Blindern, 0316 Oslo, Norway, (3) Géosciences Rennes, UMR CNRS 6118, Université de Rennes1, Campus de Beaulieu, F-35042 Rennes Cedex, France, (4) L.P.G.N. CNRS UMR 6112, University of Maine, Faculty of Science, 72085 Le Mans, France

Subvertical dykes and inclined cone-sheets represent the two main types of magmatic sheet intrusions in volcanic systems. Despite their coexistence in the same volcanoes and seemingly common source, the intrusion dynamics of dykes and cone sheets has often been addressed through distinct models, such that we cannot predict under which condition either of the two forms.

We present a series of scaled laboratory experiments that reproduce the emplacement of sheet intrusions into the brittle crust. A cohesive silica flour was used as model crust, and some vegetable oil as a low viscosity magma. The experiments comprised the injection of the oil at constant flow rate into the flour through an inlet. Through 46 experiments, we varied independently the depth (h) and the diameter (d) of the inlet, as well as the injection velocity (v). Our experiments produced sheet intrusions exhibiting either dyke or cone sheet morphologies. Dykes were characterized by a sub-vertical, slightly elliptic shape that often split into two branches to form a “boat”-shaped intrusion at very shallow depths. Cone sheets resembled inverted cones with rims that flattened from depth to the surface. Some of experiments produced hybrid intrusions with a dyke-like lower part feeding complex conical sheet intrusion higher up.

Combining our systematic parametric study with a dimensional analysis, we show that the formation of dykes and cone sheets is controlled by two dimensionless parameters. One is geometrical ($\Pi_1 = h/d$) and the other is dynamical ($\Pi_2 = \eta v/Cd$), where η is the viscosity of the vegetable oil and C the flour cohesion. In a plot of Π_1 vs. Π_2, the experiments organise into two distinct fields, separated by a transition line that can be described by a power law. The hybrid intrusions produced in our experiments fall along the transition line in between the dyke and cone-sheet regimes. These results show that at high Π_1 values, dykes are favoured and originate from magma sources that are relatively deep in relation to their size. In contrast, cone sheets preferentially form from shallow sources and are favoured at large Π_2 values, i.e. for fast injection rates.

These results compare fairly well to relevant geological data from magmatic sheet intrusions in various geological settings. Cone sheet and dyke emplacement can thus be explained by a single, unified mechanical model for sheet intrusions.