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

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1. Dykes & cone sheets

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 (cf. Fig. 1) and seemingly common source (Walker, 1993), 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.

Open questions regarding the emplacement of cone sheets and dykes:

Do they occupy opening or shear mode fractures?

Do they fill pre-existing or actively open new fractures?

Are they fed by the same source magma reservoir?

Do they form as a response of the edifice to deformation?

Do they form in a regime with oscillating stress fields?

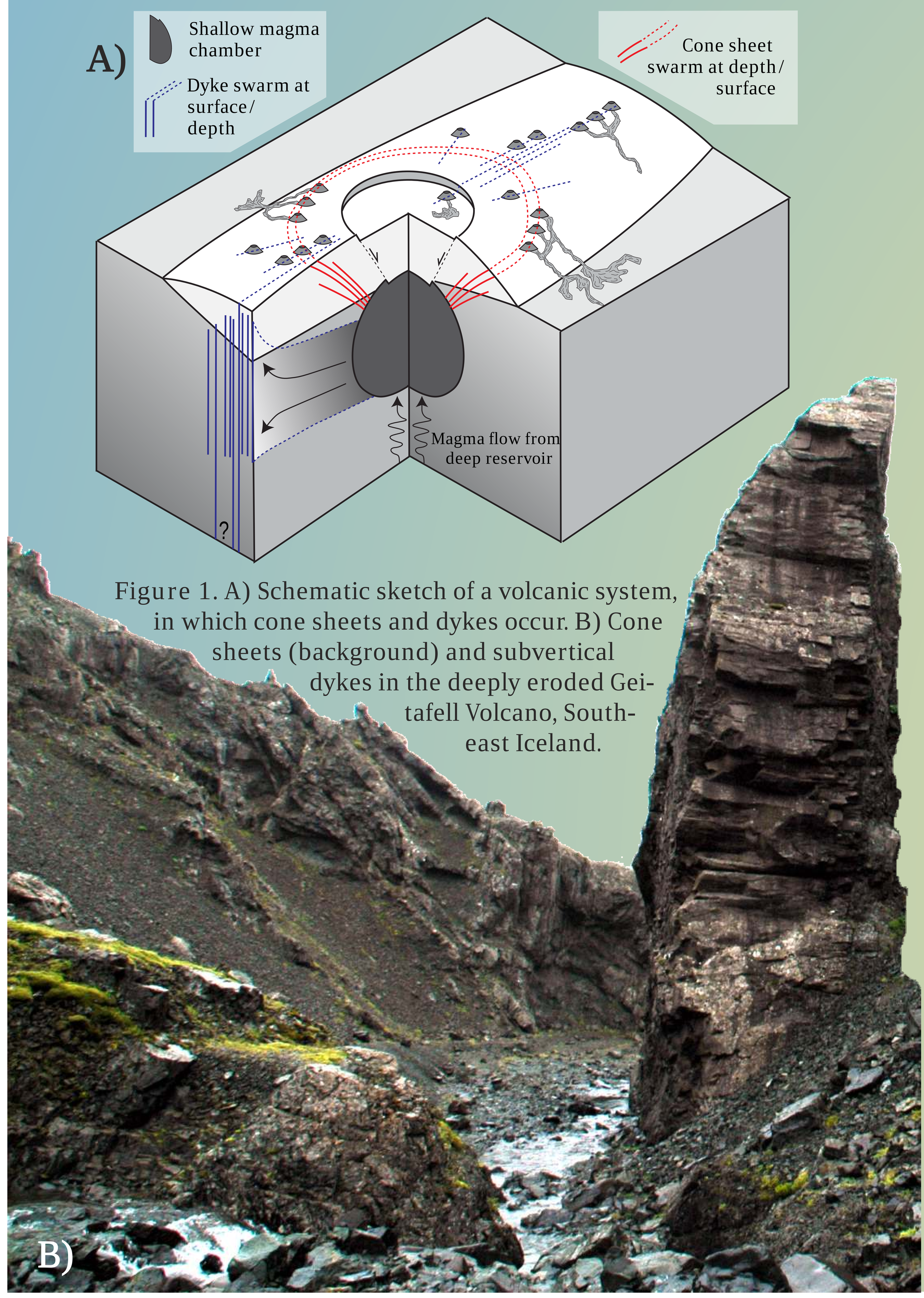

Figure 1. A) Schematic sketch of a volcanic system, in which cone sheets and dykes occur. B) Cone sheets (background) and subvertical dykes in the deeply eroded Geitafell Volcano, Southeast Iceland.

2. Experimental setup & goal

We present a series of scaled laboratory experiments that reproduce the emplacement of sheet intrusions into the brittle crust. The aim of the experiments was to identify the parameters that control what type of sheet intrusions form in a volcanic system in the absence of tectonic stresses.

The experimental setup is described in detail by Galland et al. (2006) and illustrated in Figure 2. A cohesive silica flour (with cohesion C) was used as model crust, and vegetable oil as a low viscosity (η) 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).

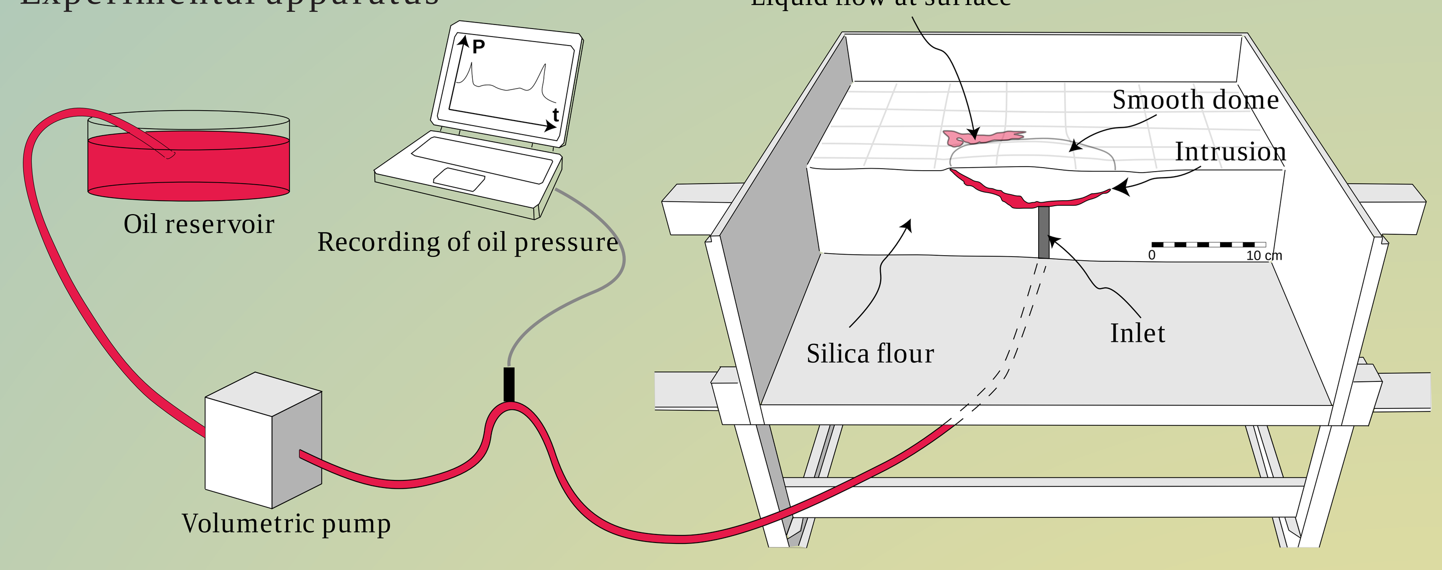

Figure 2. Sketch of the experimental setup for the modelling of magmatic sheet intrusions.

3. Results

Our experiments resulted in sheet intrusions either comparable to dykes or cone sheets. Dykes were subvertical, elliptical and branched into a "boat"-shaped intrusion at very shallow depths (Fig. 3A). Cone sheets had an inverted cone shape, the rim of which flattened towards the surface, resulting in a cocktail-glass shape at depth and a trumpet-shape closer to the surface (Fig. 3B). A few experiments produced hybrid intrusions, which exhibited a dyke connected to a conical sheet intrusion (Fig. 3C).

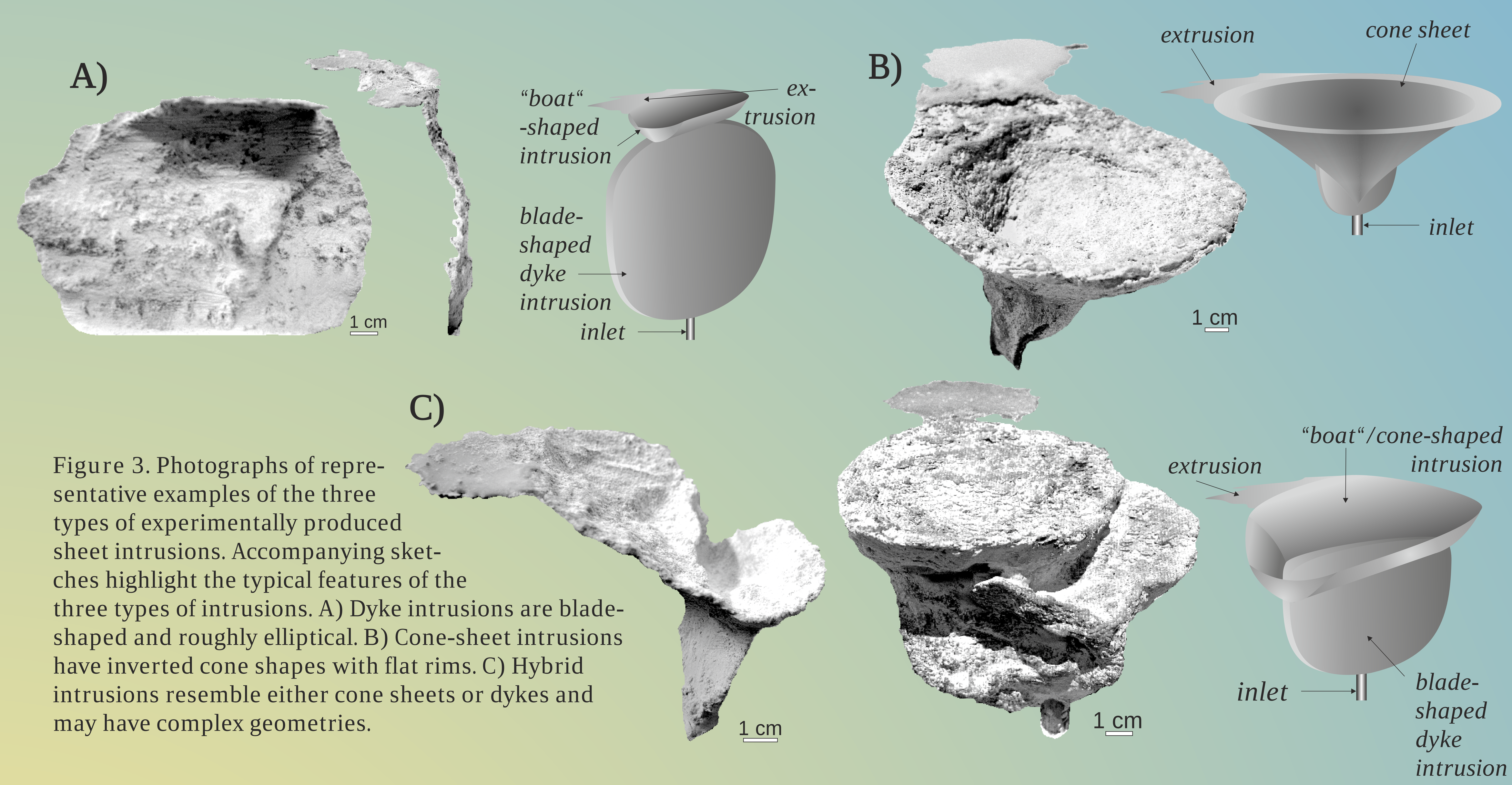

Figure 3. Photographs of representative examples of the three types of experimentally produced sheet intrusions. Accompanying sketches highlight the typical features of the three types of intrusions. A) Dyke intrusions are blade-shaped and roughly elliptical. B) Cone-sheet intrusions have inverted cone shapes with flat rims. C) Hybrid intrusions resemble either cone sheets or dykes and may have complex geometries.

4. Discussion

Plotting all the experiments with respect to two dimensionless parameters, a geometrical aspect ratio P1 = h/d, and a dynamic ratio P2 = ηv/Cd, our results organize consistently in log-log space (Fig. 4). A line with a positive slope and corresponding to a transition separates a dyke regime from a cone sheet regime. The hybrid intrusions plot right at this transition. Dykes systematically form at high values of P1, i.e. from magma sources that are much deeper than they are large. In contrast, cone sheets preferentially form from shallow sources and are favoured at large values of P2, i.e. for fast injection rates. Hence, both types of intrusions can occur in the same system. Furthermore, The empirical law that describes the relationship between P1 and P2 may be applied to natural magmatic plumbing systems where sills, dyke tips and magma reservoirs plot in the two regimes (Fig. 5).

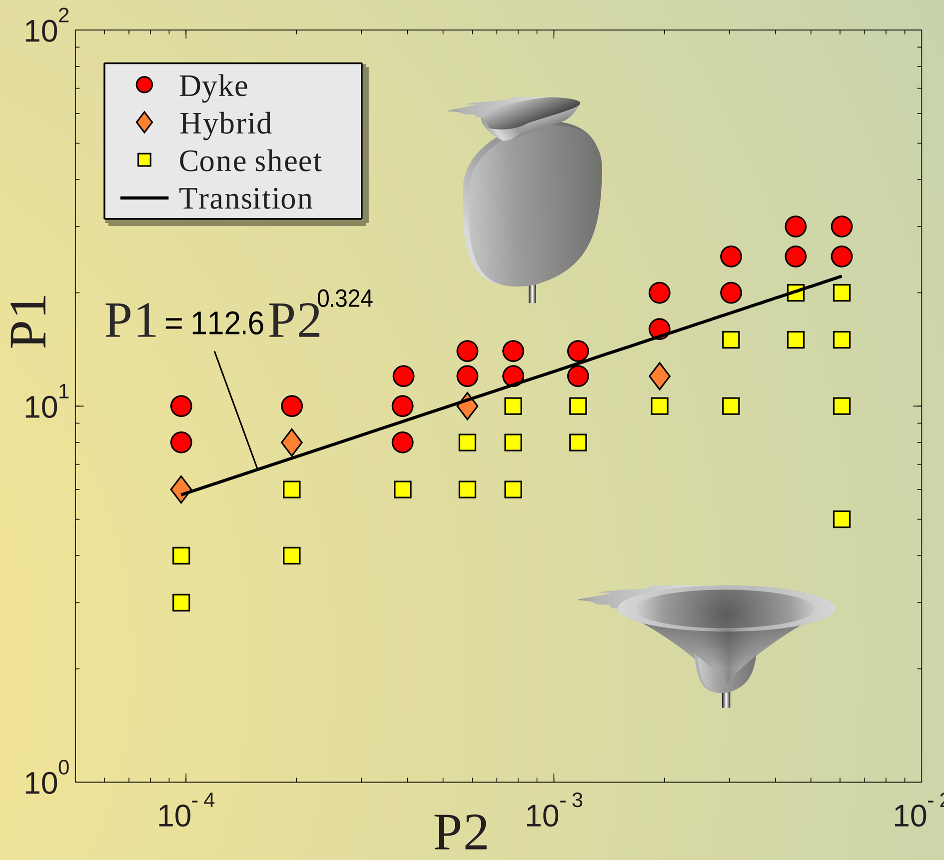

Figure 4. Experimental results plotted in a diagram P1=h/d vs. P2=ηv/Cd. The observed intrusion geometries define two regimes, a dyke and a cone-sheet regime. The hybrid intrusions plot at the transition between both regimes.

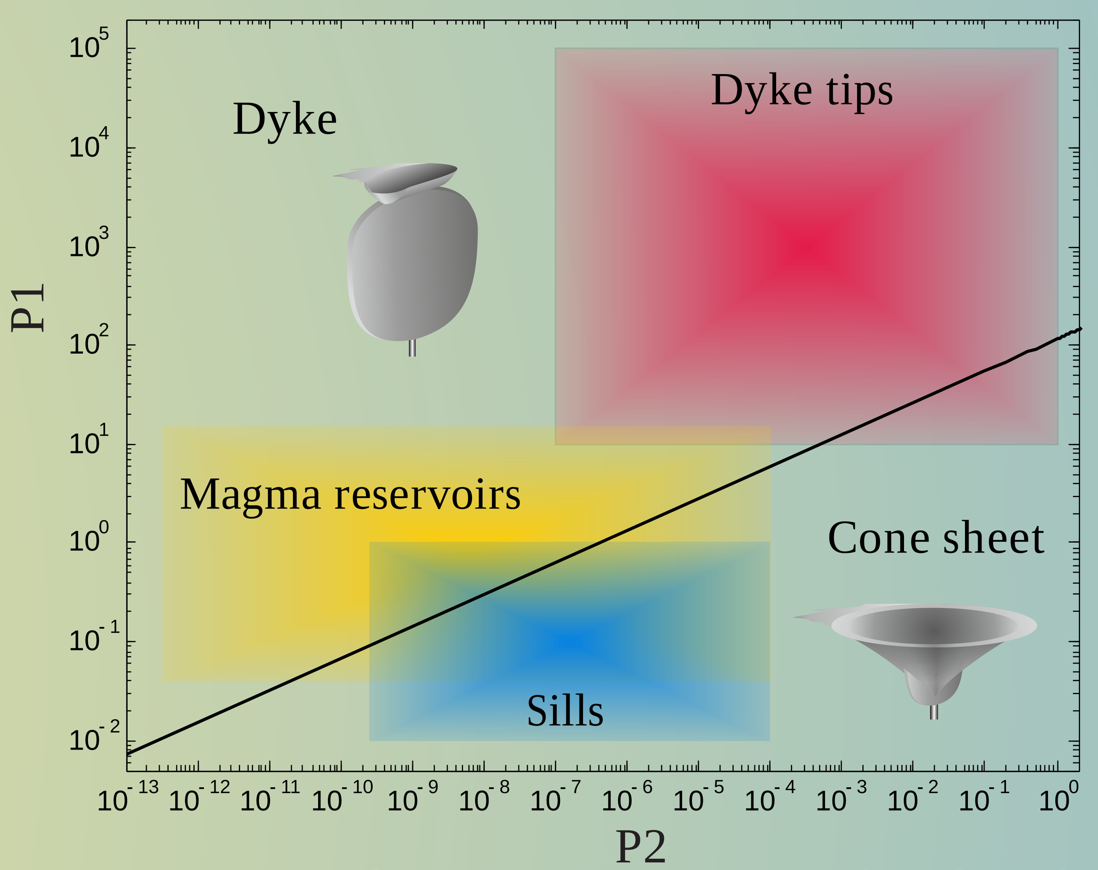

Figure 5. Graph comparing our experimental results with characteristic geological values of P1 and P2. Geological values of dyke tips (red), magma reservoirs (orange), and shallow sills in sedimentary basins (blue) plot in the dyke and/or cone-sheet regimes, respectively.

References

Galland, O., Cobbold, P. R., Hallot, E., de Bremond d'Ars, J. & Delavaud, G. Use of vegetable oil and silica powder for scale modelling of magmatic intrusion in a deforming brittle crust. Earth Planet. Sci. Lett. 243, 786-804 (2006).

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