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Vertical versus lateral flux of magma in dykes during crustal extension: new insights from simple laboratory experiments

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During intrusion of buoyant magma into a rift zone, it is a common belief that the magmatic flux will be dominantly vertical and therefore will lead rather readily to volcanic eruptions. Nevertheless, many dykes in active rift zones (such as those in Hawaii, Iceland or the Afar) are blade-shaped (i.e. horizontal length, L, versus vertical height, H, within the plane of the dyke > 1). Therefore lateral (horizontal) fluxes may also be important in such extensional settings. According to the theory of elastic hydraulic fracturing, a fracture ceases to propagate vertically, when the pressure at its upper tip drops to that of the adjacent host rock (driving pressure = 0). On approaching these conditions, lateral propagation may become important. Topographic slopes or oblique tectonic extension may also influence the main directions of magma flux and hence the final aspect ratio L/H of a dyke.

Here we describe some simple laboratory experiments, in which models consisted of silica powder (representing brittle crust) and vegetable oil (representing magma of low viscosity). The latter was hot and buoyant, yet solidified at room temperature. A motor induced the powder to stretch at a steady rate (R), forming a rift that was orthogonal to the extension direction and had a nearly flat floor. Simultaneously, oil intruded from an underlying point source at a preset flow rate (Q). In each of the experiments, a single hydraulic fracture formed. It was blade-like (L/H > 1), oil-filled, sub-vertical and sub-parallel to the rift axis. As it propagated, the oil cut across and/or, at least locally, followed some of the normal fault planes that developed within the rift. Immediately before erupting, the oil tended to fill an open fracture within the powder, very near the rift floor. During these experiments running simultaneous powder stretching and oil injection, the intrusion propagated laterally, faster than it did vertically. In contrast, in other experiments when oil intruded unstretching powders, either pre-rifted (that is once dilation had ceased to be active), or not rifted at all, the L/H ratios of the fractures were close to, or smaller than, unity.

In the experiments, the final aspect ratio of a fracture or dyke reflected the main propagation direction of the oil during intrusion. Therefore, we infer that the faster a crust stretches, the longer are the dykes, magmatic input conditions being invariant. Thus active extensional dilation appears as a process favouring lateral intrusion, instead of eruption, and during which relatively large volumes of buoyant magma can be trapped at depth, possibly limiting those available for eruption. We also show that not one of the classical explanations for dyke-like intrusions, having large values of L/H, applies to our experiments.