Modelling magma transport: a study of dyke injection under regional extensional stress

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The propagation of magma-filled cracks is the primary method of magma transport through the Earth's lithosphere. Dykes are widespread and are evidently important in feeding the supply of magma to volcanoes, thus the good understanding of the physics of crack propagation is critical for understanding the methods of magma supply. Dyke injection is also crucial at rift margins to accommodate strain and assist rifting. Scaled analogue experimental models can provide key insights into the mechanics and dynamics of magma transport in different tectonic settings.

In this study, the results from 41 laboratory analogue experiments, comprising the repeated injection of a fluid into an analogue crust (gelatine) under a remote extension, are presented. The experiments were designed to investigate the relationship between successive lateral dyke injections, by examining dyke injection size, amount of extension, injection spacing and injection orientation. A rotation angle defined as the angle between the orientations of each injection and the subsequent injection was also recorded. A cooling fluid (Vegetaline) was chosen as the magma analogue, so that it would solidify after injection to stop successive injections coalescing and preserve their structural relationship. To prevent solidification during the injection, allowing smooth propagation without melting the gelatine, the temperatures and flow rates were optimised at 60℃ and 0.25-0.32 rpm.

The experiments categorise the relationship between the dyke rotation angle and the distance from a previous intrusion under given extensional stress conditions. The results show that the size of the first injection is important. The rotation angle between two injections depends on the ratio of the fluid overpressure and the remote tensile stress. For small first injections, where the overpressure due to the fluid is small, the rotation angle between the injection and the subsequent one is also small. For large first injections, the rotation angle between the injection and a subsequent injection is larger and is dependent on the first injection overpressure, and is inversely proportional to the square of the normalised spacing. For larger normalised injection spacing, the rotation angle will be smaller. The experiments show that the stress field is perturbed the most, and locally becomes more compressive, near the centre of an injection. However, dyke injections at rift margins do not seem to occupy orientations other than rift-parallel, suggesting that the extensional stress is always larger than the amount relieved by dyke injections, or that the dyke intrusion timescale is longer than the time taken for extensional stresses to build up in the crust. The paucity of experimental studies investigating the effects of repeated injection in an extensional environment renders these experimental results a unique exploration of the phenomenon of multiple dyke injections at active rift margins.