The dynamics of lateral magma transport in volcanic rift zones

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Introduction:

The majority of the Earth's crust is created at mid-ocean ridge systems, where the rifting process occurs as tectonic plates moving apart leading to magma being generated. Rift zones also occur independent of plate tectonic setting, for example in Hawaii where gravitational and internal stresses of the volcanic edifice produces elongate, lateral zones on the flanks of the volcano which experience repeated and regular intrusions of magma. In these cases, the crust and volcanic edifice growth occurs overhelmingly from within as sheet-like bodies called dykes transport magma from depth into the upper crust. This endogenous growth means only 1 in 10 dykes will breach the surface (Crisp, 1984).

The spectacular fissure eruptions that are formed at terrestrial (on land) volcanic rifts have proved to be extremely hazardous with potentially global consequences, despite their relatively low explosivity. The eruption of Laki in 1783-84 produced a gas-rich plume that was locally responsible for severe fluorine poisoning in grazing livestock and a famine that caused the death of ~20% of the population of Iceland. It also had further-reaching impacts across Europe and North America, causing extreme and unusual weather, a persistent and widespread sulphuric aerosol cloud ("dry fog") and mean surface cooling of -1.3 ºC for 2-3 years (Thordarson and Self, 2003). Eruptions of this magnitude have occurred in Iceland in the recent past and they will occur again, with inevitable disruption to air traffic over large portions of the Northern Hemisphere that would potentially exceed that caused by the eruption of Eyjafjallajokull in 2010 (which resulted in $1.8 billion loss to the airline industry).

Recent fissure eruptions offer the rare opportunity to directly study the dynamics of magma transport in volcanic rift zones (e.g. Figure 1). Geophysical studies have shown that in these regions dyke propagation occurs laterally, producing horizontally propagating, vertical blade-like magma-filled fractures. The 2014-2015 eruption of Holuhraun, Iceland, is arguably the best-monitored basaltic fissure eruption that has ever occurred (Sigmundsson et al. 2014). Independent high-resolution datasets of seismicity, ground deformation and volcanic plume chemistry have been linked with the petrology and geochemistry of erupted products of scoria and lava to constrain the depth from which these magma originate (Hartley et al. in review).

Laboratory experiments using analogue materials proffer the opportunity to answer key questions that remain regarding the transport of the magma in rift zones and the nature of the volcanic plumbing system that feeds volcanic fissure eruptions. Particle image velocimetry (PIV; Figure 2) and digital image correlation (DIC) techniques allows quantification of subsurface fluid flow and host deformation associated with experimental dyke growth (Kavanagh et al. 2015; Kavanagh et al. 2017; Kavanagh et al. in review).

Project Summary (max 700 words inc introduction):

This multidisciplinary project will constrain the dynamics of lateral dyke propagation associated with volcanic rifts, using ancient and recent examples of volcanic fissure eruptions in Iceland and Australia as case studies. The project is divided into three parts: 1) Field sampling of erupted products from a volcanic fissure eruption in Iceland, 2) petrographic and geochemical rock analysis, and 3) laboratory experiments using analogue materials to track the magma flow dynamics within a propagating lateral dyke and associated surface displacement. The results will integrate constraints from geophysical observation of lateral dyke intrusion events, for example the seismicity and surface deformation they produce.

This multidisciplinary project utilizes to full effect the unique combination of expertise in Geology and Geophysics applied to volcanology that is offered by the Liverpool-Manchester DTP. The student will work regualry with supervisors both at the University of Liverpool's Volcanology Group and the University of Manchester's Geoscience Group, being trained in the use of state-of-the-art experimental techniques and cutting-edge microscopy and petrochemical analysis.

This project is suitable for applicants with a degree in Geology, Geophysics or a related discipline and can be tailored according to the applicant's background. Due to the multidisciplinary nature of the project it is not expected that the applicant will be familiar with all techniques, however experience with igneous petrology, coding or working in a research laboratory is desirable.

Image 1 – Example of a recent volcanic fissure eruption in Iceland (photo c/o Haukur Snorrason).

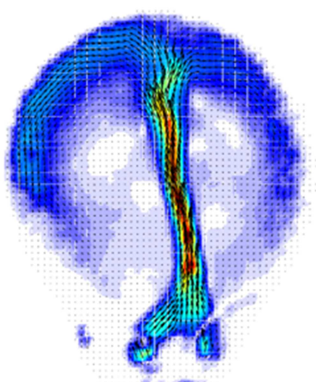

Image 2 Colour-map of flow velocity within a growing experimental dyke analysed using PIV (Kavanagh et al. in review).

References

Crisp, J.A., 1984. Rates of magma emplacement and volcanic output. Journal of Volcanology and Geothermal Research, 20, pp.177–211.

Hartley, M. E. et al., in review. Melt inclusion constraints on petrogenesis of the 2014-2015 Holuhraun eruption, Iceland. Contributions to Mineralogy and Petrology.

Kavanagh, J.L., Boutelier, D. & Cruden, A.R., 2015. The mechanics of sill inception, propagation and growth: Experimental evidence for rapid reduction in magmatic overpressure. Earth and Planetary Science Letters, 421, pp.117–128.

Kavanagh, J.L. et al., 2017. Controls on sill and dyke-sill hybrid geometry and propagation in the crust: The role of fracture toughness. Tectonophysics, 698(C), pp.109–120.

Kavanagh, J.L. et al., in review. Challenging dyke ascent models using novel laboratory experiments: Implications for reinterpreting evidence of magma ascent and volcanism. Journal of Volcanology and Geothermal Research.

Sigmundsson, F. et al., 2014. Segmented lateral dyke growth in a rifting event at Ba´rðarbunga volcanic system, Iceland. Nature, 517(7533), pp.191–195.

Thordarson, T. and Self, S., 2003. Atmospheric and environmental effects of the 1783–1784 Laki eruption: A review and reassessment. Journal of Geophysical Research, 108(D1), doi:10.1029/EO065i026p00410-01.