The dynamics of cone sheet emplacement and construction of volcanic edifices

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Introduction:

Magma is transported through the crust in fractures called dykes that cut across rock layers. Dykes are important in all stages in the life of a volcano; they transport magma from depth but may stall during ascent or reach the surface to feed eruptions. They are capable of transporting magma substantial distances, and can potentially transport magma from one volcanic centre to another. Dyke emplacement occurs before, during and after surface eruptions are evident; but, the majority of dykes do not erupt, and so dyke arrest is an important process that helps build long-lived volcanic centres from within. Understanding the state of stress within a volcanic edifice and the surrounding area, the nature of the volcanic plumbing system itself and overall controls on magma flow are fundamental to improve our ability to forecast when and where the next volcanic eruption will be.

Cone-sheets are thin, arcuate dykes that confocally dip into the crust to create an overall conical shape. They have been used to infer the nature of the magma chamber(s) at depth, but this relies upon the hypothesis that the dykes originate from a single magma reservoir (e.g. Figure 1). The Ardnamurchan central complex, NW Scotland, exposes the deeply eroded base of an ancient volcanic edifice that formed ~58 Ma in association with the British Palaeogene Igneous Province. Structural studies of this world-famous field area have largely shaped our understanding of cone sheet emplacement; and yet contrasting models exist to explain the origin of the Ardnamurchan cone sheets, as either from a single, elongate magma reservoir (e.g. Burchardt et al. 2013) or due to lateral emplacement by regional dykes from an adjacent volcanic system (e.g. Magee et al. 2012).

Recent volcanic eruptions fed by cone sheet have been associated with volcanoes that have a caldera; where previous events have resulted in a topographic depression due to subsidence into a partially drained magma chamber. Inversion models based on the ground deformation that is caused have supported the model that radial dykes are sourced from a magma chamber that is directly beneath the volcanic edifice and caldera (Chadwick et al. 2010; Figure 1). Laboratory models have shown that the unloading caused by caldera-forming events can effect the subsequent pathways of dyke propagation and the overall stress budget of a volcano, and in doing so may favour cone-sheet emplacement (Corbi et al. 2016). However, cone sheets are often observed in ancient volcanic systems. This suggests they are a common feature in long-lived volcanic centres, and are not only associated with calderas.

Project Summary:

This project will use a multidisciplinary approach to study the dynamics of cone sheet emplacement. Using field sites in Scotland and Ireland as case studies, you will analyse the crystal shape and magnetic fabrics preserved within cone sheets and use laboratory experiments to interpret ther host-deformation and magma flow patterns.

The fundamentally contrasting models of cone sheet emplacement, as either centrally or laterally sourced, are expected to produce contrasting magma flow trajectories and different structural deformation of the intruded host rocks. Cone sheets from the British and Irish Palaeogene Igneous Province (BIPIP) will be studied by sampling their crystalline magma and intruded host rocks. The samples will be analysed for their rock fabrics using petrographic imaging techniques, such as scanning electron microscopy

(SEM), and rock magnetism, including Anisotropy of Magnetic Susceptibility (AMS) and Anisotropy of Anhysteretic Remanent Magnetization (AARM).

To test the cone sheet emplacement models and aid the interpretation of the field-based evidence, experimental cone sheets will be created in the laboratory using scaled analogue materials (e.g. Galland et al. 2014; Corbi et al. 2016). Imaging and analytical techniques such as digital image correlation (DIC), particle image velocimetry (PIV) and laser scanning will be used to document the coupled host-deformation and fluid flow trajectories (Kavanagh et al. in review; Figure 2) as the cone sheet developes.

This project is suitable for applicants with a degree in Geology, Geophysics or a related discipline. Field experience and/or knowledge of working in a research laboratory is desirable.

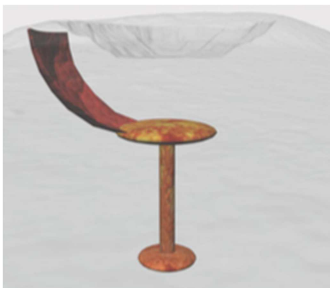

Image 1– 3D representation of the sub-caldera plumbing system that fed to 2005 eruption of Fernandina, Galapagos (Chadwick et al. 2010).

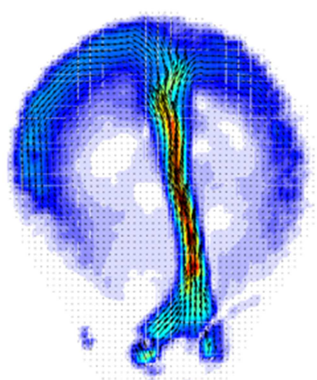

Image 2 Colour-map of flow velocity within a growing experimental dyke analysed using PIV (Kavanagh et al. in review).

References

Burchardt, S. et al., 2013. Ardnamurchan 3D cone-sheet architecture explained by a single elongate magma chamber. *Scientific Reports*, 3: 2891, doi: 10.1038/srep02891.

Chadwick, W.W. et al., 2010. The May 2005 eruption of Fernandina volcano, Galápagos: The first circumferential dike intrusion observed by GPS and InSAR. *Bulletin of volcanology*, 73(6), pp.679–697.

Corbi, F. et al., 2016. Understanding the link between circumferential dikes and eruptive fissures around calderas based on numerical and analog models. *Geophysical Research Letters*, 10.1002/(ISSN)1944-8007.

Galland, O. et al., 2014. Dynamics of dikes versus cone sheets in volcanic systems. *Journal of Geophysical Research*, 10.1002/2014BJ011059.

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*.

Magee, C. et al., 2012. An alternative emplacement model for the classic Ardnamurchan cone sheet swarm, NW Scotland, involving lateral magma supply via regional dykes. *Journal of Structural Geology*, 43, pp.73–91.