How does magma move through sill-complexes?

Dr Craig Magee (SEE), Dr William McCarthy (University of St Andrews), Prof. Douglas Paton (SEE),

Contact e-mail: c.magee@leeds.ac.uk

Overview

Understanding how magma intrusion controls the location of volcanoes and pre-eruption warning signals is critical to hazard assessment. Textbooks suggest volcanoes are underlain by dykes, where magma predominantly moves vertically through the crust (Fig. 1A). However, recent studies champion a new idea where the lateral extent of volcano plumbing systems is greater than their vertical extent, with magma primarily transported in a network of sub-horizontal sills (i.e. a sill-complex) as opposed to dykes (Fig. 1A) (Magee et al. 2016). The Karoo Sill-complex (South Africa), spanning an area the size of Spain, and the Ferrar Sill-complex (Antarctica), which extended horizontally for >4000 km, provide excellent examples of volcano plumbing systems that channelled magma laterally through the crust prior to eruption (Leat et al. 2008; Svensen et al. 2012; Magee et al. 2016). Recognising that sill-complexes can play a major role in magma transport questions our current understanding of volcanology, which centres on vertical, dyke-dominated systems.

Field observations and seismic reflection data, which provide 3D ultrasound-like images of Earth's subsurface, have allowed the broad structure of sill-complexes to be constrained and shown how individual intrusions are emplaced (e.g. Magee et al. 2016). However, we do not know how entire sill-complexes are built and transport magma over large areas without freezing. It has been suggested that hot but solidified sections of sill-complexes allow later magma injections, focused into channels (Fig. 1B) (Holness & Humphreys, 2013) or along sill boundaries (Fig. 1C) (Annen et al. 2015), to flow further and gradually extend the sill-complex. The aim of this project is to test these ideas by investigating how magma moves through sill-complexes, with a view to understanding how magma flow pathways influence the distribution, construction, and eruption of volcanoes.

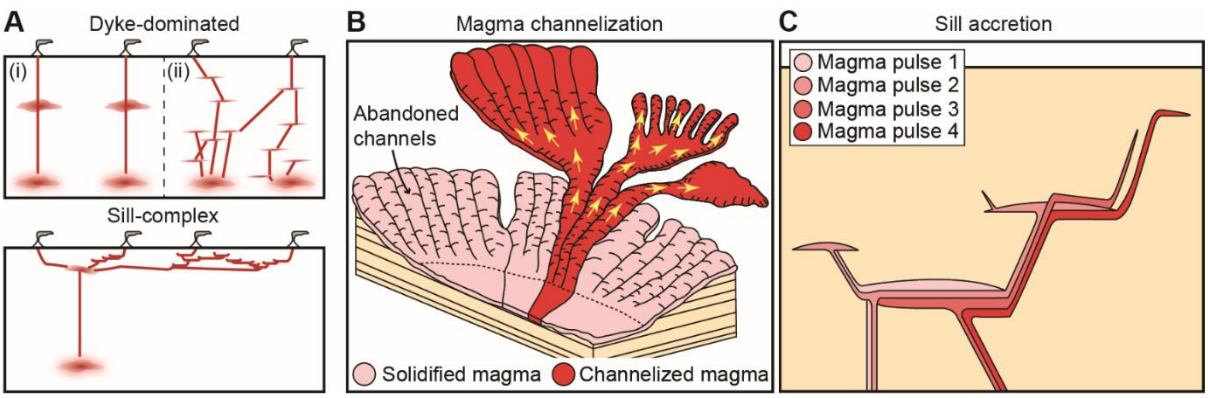

Figure 1: (A) Cartoons showing the difference between dyke- and sill-dominated plumbing systems. (B) Channelization of magma promoting extension of a sill-complex (Magee et al. 2016). (C) Stacking of sills where early intrusions provide heat for later injections, allowing them to flow farther.

Objectives

To study how magma moves through sill-complexes, you will combine observations and data from fieldwork, rock magnetic analyses, petrological studies, and interpretation of seismic reflection data. You will work with the Institute of Geophysics and Tectonics (IGT) and Institute of Applied Geophysics (IAG) at the University of Leeds, and with Dr William McCarthy at the M^3ORE Laboratory in the University of St Andrews. Existing analytical facilities and expertise at both Leeds and St Andrews will support this research. Four broad objectives have been identified for the project, but these are flexible and dependent on your research interests:

1) Map the Loch Scridain Sill-complex on the Isle of Mull, focusing on constraining the geometry of sills and host rock deformation structures generated by magma emplacement. The Loch Scridain Sill-complex is an ideal laboratory to test how sill-complexes are intruded because it is well-exposed, easily accessible, and contains magma channels (Holness and Humphreys, 2003). Depending on your research interests, there is scope to study other sill-complexes (e.g. the San Rafael Sill-complex, Utah, USA).
2) Analyse the Anisotropy of Magnetic Susceptibility (AMS) of oriented samples at the M^3ORE Laboratory at the University of St Andrews. This technique allows alignments of minerals within rocks to be measured, which can be linked to the rotation of crystals within a flowing magma (e.g. sticks in a stream align with flow); AMS and complementary rock magnetic experiments will thus be used to map magma flow pathways.
3) Apply quantitative textural petrology techniques, such as Crystal Size Distribution (CSD), to evaluate how crystals grew, interacted, and how long they resided in the system. These techniques will help distinguish the construction history of the sill-complex.
4) Interpret seismic reflection data from around the world, particularly from a 3D seismic dataset in the Rockall Basin offshore Ireland (see Magee et al. 2014), which image entire sill-complexes in 3D. By mapping the structure of sills across these datasets, magma flow indicators (e.g. intrusive steps) can be identified and used to reconstruct magma flow pathways in 3D.

Outcomes

This work will identify how magma moves through and builds sill-complexes, addressing a pressing need to understand their impact on volcano distribution, interaction, and eruption warning signals. The research will also shed light on: (i) how sill-complexes localise mineral and metal accumulations; (ii) magma volumes and storage conditions during continental break-up and Large Igneous Province formation; and (iii) the role of sill-complexes, which can form independent of plate tectonics, in shaping geological processes on other planetary bodies. There will be ample opportunities to communicate results through publication of scientific papers, presentation at both UK and international conferences, and through public engagement.

Training

You will receive extensive training in: (1) field mapping, using both traditional (i.e. pen and paper) and digital (i.e. tablet-based) techniques (Magee, McCarthy); (2) rock magnetic techniques, including AMS and mineral magnetic property characterisation experiments (McCarthy, Magee); (4) transmitted light petrography and quantitative textural analyses (Magee); and (5) interpreting seismic reflection data (Magee, Paton). Training will be largely one-to-one, working closely with supervisors.

You will be become a member of the relevant cross-institute research groups within the School of Earth and Environment, including Volcanology, Tectonics, and Basin Structure. You will have access to bespoke training workshops hosted by the Faculty that range from courses in numerical modelling, through to project management, to preparing for the viva (http://www.emeskillstraining.leeds.ac.uk/).

Through training (e.g. scientific writing, statistics and data analysis, problem-solving, time management, and developing independent research planning skills), you will become a confident and independent researcher with transferable skills applicable to both academic and non-academic jobs.

Student profile

You should have an interest in structural and igneous geology and be enthusiastic about integrating different techniques to unravel how magma moves through the crust. You should be keen to conduct fieldwork, specifically geological mapping.

References

Annen, C., Blundy, J.D., Leuthold, J. and Sparks, R.S.J., 2015. Construction and evolution of igneous bodies: Towards an integrated perspective of crustal magmatism. *Lithos*, *230*, pp.206-221.

Holness, M.B. and Humphreys, M.C.S., 2003. The Traigh Bhan na Sgurra Sill, Isle of Mull: flow localization in a major magma conduit. *Journal of Petrology*, *44*(11), pp.1961-1976.

Leat, P.T., 2008. On the long-distance transport of Ferrar magmas. *Geological Society, London, Special Publications*, *302*(1), pp.45-61.

Magee, C., Jackson, C.L. and Schofield, N., 2014. Diachronous sub-volcanic intrusion along deep-water margins: Insights from the Irish Rockall Basin. Basin Research, 26(1), pp.85-105.

Magee, C., Muirhead, J.D., Karvelas, A., Holford, S.P., Jackson, C.A., Bastow, I.D., Schofield, N., Stevenson, C.T., McLean, C., McCarthy, W. and Shtukert, O., 2016. Lateral magma flow in mafic sill complexes. *Geosphere*, *12*(3), pp.809-841.

Svensen, H., Corfu, F., Polteau, S., Hammer, Ø. and Planke, S., 2012. Rapid magma emplacement in the Karoo large igneous province. *Earth and Planetary Science Letters*, *325*, pp.1-9.

Related undergraduate subjects

Earth science
Earth system science
Geological science
Geology
Geophysical science
Geophysics
Geoscience
Physical science