Understanding the migration and emplacement of Lithium-bearing granitic magmas

Lead supervisor: Dr. Katherine Daniels, Cardiff University

Co-supervisors: Dr. James Lambert-Smith, Cardiff University; Prof. Janine Kavanagh, University of Liverpool

Project Highlights:

- Studying the dynamics and mechanisms of dyke emplacement and the associated damage from the passage of viscous magmas.
- Improving understanding of the Lithium-bearing granitic dykes in Cornwall, their morphology, emplacement mechanisms and association with other economically viable ores (e.g. Sn and W).
- State-of-the-art analogue experimentation to elucidate the fundamental physics governing the emplacement of non-newtonian (shear thickening), granitic-composition dykes.

Overview:

The propagation of fluid-filled fractures is both a complex and ubiquitous problem within the geosciences. Volcanic eruptions are fed by magma-filled fractures, and where magma cannot escape to the surface, successive intrusions form batholithic or laccolithic bodies in the crust. The Cornubian batholith, which is exposed at a number of sites in Cornwall, is enriched in Sn, Cu, W, B, F and As; the ores of many of these elements have been extensively mined in Cornwall. There is currently much interest various intrusions within the Cornubian batholith that are enriched in lithium mica (up to 5.5 wt%).

The fluid dynamics of a propagating fracture can have a major effect on the fracture behaviour. A good knowledge of the dynamics and mechanisms of granitic dyke emplacement and the associated crustal damage from the passage of viscous magmas is important in gaining understanding on the occurrence and location of economically viable lithium concentrations.

Modelling informed by field data collected from exposed outcrops of volcanological phenomena, is a useful way to study volcanic systems, for which access to real-time samples and direct observations is impossible. Analogue laboratory and numerical models can describe and quantify temporal and spatial volcanic and magmatic processes spanning many orders of magnitude. Cornwall offers fantastic exposure against which laboratory analogue experiments and numerical models can be ground-truthed. Granitic dykes are low temperature, crystal-rich fluids, and as such their intrusive behaviour will be strongly controlled by their rheology. Using state-of-the-art equipment in the MAGMA Lab at the University of Liverpool, the student will be able to replicate the intrusion of non-newtonian (shear thickening) dykes into an elastic crust, gaining key insights into the emplacement process of crystallising near-solidus granitic magmas. The student would also be able to look at the formation of sills from dykes by interaction with weak interfaces, and the stacking of sills. Analogue experimental work would be supported by field observations, chemical analysis (SEM, Fluid inclusions) and simple numerical modelling to apply analytical solutions to experimental data where appropriate.

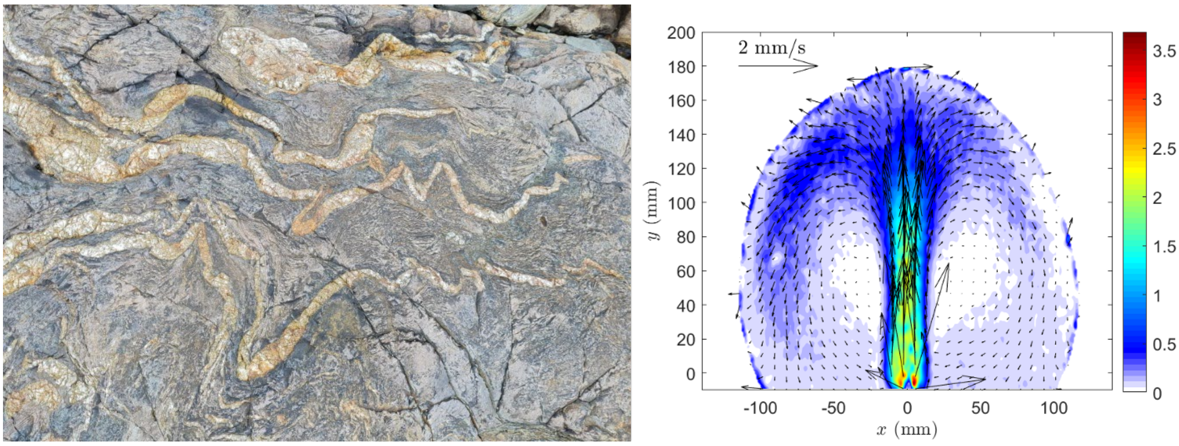

Figure 1: *A) Exposures of thin granitic veins close to the Rinsey Cover roof pendant above the Tregonning Granite. Alt= Rock surface close-up with wavy, pale beige mineral veins contrasting against dark grey base, showing granitic dykes weaving through country rock*
B) Recirculating flow within a viscous dyke shown by PIV. The viscous fluid is silicon oil, injected into a gelatine crust, from Chalk and Kavanagh, 2024. Alt= Velocity field diagram showing viscous dyke flow. Vectors give direction and speed while colour bar shows velocity magnitude from 0 to 3.5.

Methodology:

The project will follow a number of different research streams, producing a varied PhD project.

1) Fieldwork and sample analysis: The student conduct their own fieldwork in Cornwall, collecting samples that will subsequently be used for fluid inclusion and SEM analysis, as well as mapping outcrops to gain and understanding of the physical properties and characteristics of granitic dykes. The samples obtained will be prepared and analysed in the Electron Microbeam facility and fluid inclusion laboratory, both at Cardiff University.
2) Laboratory analogue experimentation: The student will spend periods of time working in the MAGMA Laboratory at Liverpool University, using state-of-the-art equipment to conduct, record and image analogue experiments of shear thickening magmas intruding an elastic crust. This will include particle image velocimetry (PIV) and digital image correlation (DIC).
3) Application of numerical and analytical solutions to interrogate laboratory analogue experimentation.

Possible Timeline

Year 1: Literature Review; Fieldwork; Scoping visit to Liverpool to prepare for laboratory analogue experiments; development/construction of apparatus; Field data analysis.

Year 2: Extended visit to Liverpool for laboratory analogue experimentation; Conference attendance and presentation; Possible visit to British Lithium and logging of drilled cores from the Cornish granite.

Year 3: Application of analytical and numerical solutions to analogue laboratory data; Fluid inclusion analysis; Conference attendance and presentation; Thesis writing.

Training and skills:

This PhD project offers a varied research training experience with elements of field and laboratory work. The student participating in this PhD project would be trained in all the necessary chemical and analytical techniques, including fluid inclusion analysis and SEM. The student would be inducted into the MAGMA Lab and given the appropriate training to use the laboratory equipment necessary for the analogue experimentation. The student would also be given training in numerical analysis and coding, and core logging.

In addition, TARGET researchers will participate in a minimum of 40 days training over the 3.5 years of study composed of:

- an annual one-week workshop dedicated to their year group, and tailored to that cohort's needs in terms of skills development – *for the first three years of their study*;
- an annual all-TARGET workshop with cross-year interactions, advanced training and opportunities to specialise in particular areas – *all years of study*;
- a number of one-day workshops;
- additional online events and in-person workshops attached to relevant conferences.

Partners and collaboration (including CASE):

This project spans two TARGET institutions, providing additional access to expertise and facilities. Although not currently CASE-funded, this project is closely aligned to the research interests of companies currently prospecting for Lithium in Cornwall. It is possible the student will have the opportunity to study and sample drill core from a Cornish lithium-bearing ore body that has been collected by British Lithium, and for the student to spend time seconded to their offices. This would give the student an understanding of the exposure and knowledge of the economically viable ores (Li, Sn and W) of significant interest in Cornwall.

Further reading:

- Kavanagh, J.L., Menand, T., Daniels, K.A., 2013. Gelatine as a crustal analogue: Determining elastic properties for modelling magmatic intrusions. Tectonophysics, 582, 101-111. https://doi.org/10.1016/j.tecto.2012.09.032.
- Chalk, C.M., and Kavanagh, J.L., 2024. Up, down, and round again: The circulating flow dynamics of flux-driven fractures. Physics of Fluids, 36, 036622. https://doi.org/10.1063/5.0187217
- Williams, K.M., Kavanagh, J.L., Dennis, D.J.C., 2022. Focused flow during the formation and propagation of sills: Insights from analogue experiments. Earth and Planetary Science Letters, 584, 117492. https://doi.org/10.1016/j.epsl.2022.117492

Further details:

Please contact Dr. Katherine Daniels (DanielsK4@cardiff.ac.uk) if you have any questions. Please visit https://target.le.ac.uk/ for additional details on how to apply.

Katherine Daniels: https://profiles.cardiff.ac.uk/staff/danielsk4

James Lambert-Smith: https://profiles.cardiff.ac.uk/staff/lambert-smithj

Janine Kavanagh: https://www.liverpool.ac.uk/people/janine-kavanagh

MAGMA Lab: https://www.liverpoolmagmalab.org/about