

Giant Dykes & Deep Time Tectonics; the Role of Dyke Swarms in Driving Precambrian Tectonics (Ref IAP2-18-86)

University of St Andrews, School of Earth and Environmental Sciences

In partnership with **Glasgow University**

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Key Words

1. Dyke, 2. Tectonics, 3. Rift, 4. Structure, 5. Fieldwork

Overview

Throughout Earth's history, intense periods of magma production have led to the intrusion of vast dyke swarms. These dyke swarms are commonly associated with Large Igneous Provinces and provide a record of the magmatic and tectonic processes controlling their formation (Ernst, 2014). However, many Precambrian dyke swarms have been metamorphosed and deformed, meaning their original structure is obscured. Finding a way to unravel the structure and intrusion history of Precambrian dyke swarms is therefore critical to understanding the evolution and interaction of tectonic and magmatic processes in the early Earth. This project examines the Giant Dykes of SE Greenland (Upton & Blundell 1978) and Scourie Dykes of NW Scotland (Davies & Heaman, 2014) to assess how large dyke swarms relate to Precambrian rifting and tectonic plate piercing points.

The Giant Dykes of Tugtutoq, SE Greenland (Fig. 1), represent the most voluminous phase of Proterozoic rift magmatism along the Tugtutoq-Narssarsuaq zone (Upton & Blundell 1978). Mineralogical and geochemical studies highlight the petrogenic history and Ti-Fe deposits associated with this dyke swarm (see Steinfeld et al. 2016). The Giant Dykes present a rare opportunity to study the interaction between intrusion and Precambrian tectonics because they have not been deformed or metamorphosed. However, the mechanics of dyke injection, the formation of pristine mineral layering, and the tectonic history recorded within these intrusions remains unstudied.



Fig. 1 Excellent 3D exposure of dyke swarms in SE Greenland offer excellent opportunities to assess the structure of sheeted intrusions.

Despite first being mapped and studied in the early 1900's, we also know very little about the tectonic setting and intrusion mechanics of the Scourie Dykes (Fig. 2.). Studies using petrology, geochemistry, and geochronology have shown the Scourie Dyke swarm was actually intruded in several phases, with the main period of intrusion occurring between ~2.4 Ga and one at ~2.1 Ga (Davies & Heaman, 2014). Preliminary data collected from the Scourie Dykes by the supervisors of this proposed work has identified small-scale structures and crystal alignments within the dykes that

can be used to determine how they intruded; this information can be used to unravel the tectonic framework for the intrusion of the Scourie Dykes.



Fig. 2 An undeformed Scourie Dyke, Badcall NW Highlands showing primary contact relationships.

This PhD will examine the structural history of the Giant Dyke and Scourie Dyke swarms with a view to relating the mechanics of dyke intrusion and magma flow to tectonic processes in deep time. The resulting data will help the community to pinpoint melt sources during the formation of Large Igneous Provinces, to understand how globally significant dykes swarms record tectonic processes, and unravel the tectonic history of the Precambrian.

Methodology

Magma flow can be interpreted from small-scale structures formed during dyke propagation (e.g. intrusive steps; Magee et al. 2018) and from the alignment of crystals within the intrusion (e.g. sticks align with flow in a stream; Magee et al. 2016), which can be measured through the assessment of Anisotropy of Magnetic Susceptibility data (e.g. McCarthy et al. 2015). Expansion of AMS datasets across the Scourie Dyke and Giant Dyke swarms will provide a basis to develop a tectonic model for their intrusion. This research will allow you to: (1) identify the origin of dyke swarms and tectonic piercing points; (2) determine the role that the dyke swarms played in early crust formation; and (3) test whether intrusion mechanics of dykes were different in the early Earth compared to today.

The successful applicant will be undertaking state-of-the-art research at the University of St Andrews, with regular visits to the University of Leeds (Magee) and University of Glasgow (MacDonald). Whilst a significant portion of this project will involve fieldwork and analysis of crystal alignments, the PhD is designed to be flexible. The successful candidate will be encouraged to pursue their own exciting ideas using the wide range of analytical facilities that are available at St Andrews, Leeds, and Glasgow (see our [School Facilities Website](#)).

Fieldwork will consist of one short field season in NW Scotland followed by one long field season in Scotland and another in SE Greenland. Detailed structural mapping using airborne drone and tablet mapping methods will focus on the identification of magma flow indicators and structures that inform on intrusion architecture including contact relationships, broken bridge structures, petrofabrics, and mineral layering. Geological mapping will also be used to direct targeted rock core sampling campaigns.

The Magnetics, Minerals, Magma and Ore “M³Ore” Laboratory at St Andrews (Fig. 3) will provide primary support for this project. Equipped with a new KLY-5a Kappabridge and rock magnetic experimental suite, the facility has the unique functionality to measure both in-phase and out-of-phase Anisotropy of Magnetic Susceptibility (AMS) simultaneously using an automated 3D rotator apparatus. In this study, AMS will be used to accurately measure subtle magnetic fabrics in rock samples that inform on the structure and internal architecture of the sampled igneous intrusion. AMS and field data will be coupled with petrographic data to model magma transport and emplacement mechanisms in the context of the broader tectonic setting in both field areas.



Fig. 3 The M³Ore Lab is equipped with (top left) a KLY-5a Kappabridge with CSL cryostat and CS4 Furnace, (top right) a 3D automated rotator, and (bottom) a selection of hand held susceptibility meters, an impulse magnetiser, isothermal demagnetiser, and Molspin magnetometer.

A possible set of objectives and an example timeline are provided below:

Objectives

- 1) Conduct new, high-resolution mapping and structural analysis of the dyke swarms, using cutting-edge digital mapping techniques, to efficiently record structural data from the dykes and host rocks and to identify structures related to magma flow;

- 2) Analyse rock fabrics, identified through petrography and anisotropy of magnetic susceptibility (AMS), to interpret magma flow patterns and later deformation events;
- 3) Measure new, high-resolution geochronological dates for different dykes to establish order and duration of intrusion events;
- 4) Integrate data to produce a conceptual model on the relationship between tectonic processes and dyke swarm evolution through time.

Timeline

Year 1

Familiarisation of the project through background reading and induction from supervisors.

A reconnaissance field campaign, accompanied by supervisors, along the extent of the Scourie Dyke swarm in NW Scotland.

Training in digital & drone mapping, 3D structural modelling and rock magnetic experiment methodology as well as literature review.

Extensive field campaign to the Scourie Dykes in Spring, digital mapping and sample collection.

Commence rock magnetic & petrological analyses.

Year 2

Second extensive field campaign in Greenland including high-resolution mapping and sample collection.

Ongoing rock magnetic experiments and petrography.

Selection and processing of samples for geochronology.

Write-up of first paper with tutelage from supervisors.

Year 3

Completion of data analysis.

Leeway for final, short field campaign or follow up data collection (geochronology, rock magnetism, or other)

Write-up of second paper on Greenland data.

Year 3.5

Write-up and submission of thesis and additional papers.

Training & Skills

This project benefits from four advisors who have specific skill sets in key aspects of the proposed project. Primary advisor Will McCarthy focusses on rock magnetism and the architecture of igneous rocks, external collaborator Craig Magee (Leeds) is a specialist in sill and dyke intrusion mechanics, John McDonald is an isotope geochemist with in-depth knowledge of Proterozoic NW Highland geology, and Adrian Finch is a mineralogist with over 20 years of experience working in SE Greenland.

You will receive bespoke training in: (1) digital (i.e. tablet-based) and traditional (i.e. pen and paper) mapping techniques (all supervisors); (2) rock magnetic

techniques, including AMS, high and low temperature susceptibility experiments (McCarthy and Magee); (4) transmitted light petrography (all supervisors); and (6) geochronology (MacDonald and Finch). Training will be largely one-to-one, working closely with supervisors. Over the course of the PhD you will gain many transferable skills such as scientific writing, statistics and data analysis, problem-solving, as well as time management and developing independent research planning skills. Formal, delivered training courses, as part of the fulfilment of DTP transfer requirements, will also be undertaken. At the end of the PhD, you will become a confident and independent researcher with transferable skills applicable to both academic and non-academic jobs. We will also provide training and support in moving your career beyond the PhD.

References & Further Reading

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Further Information

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