

Fractured Earth: Segmentation of the mid-ocean ridge system

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Co supervisor(s):	Prof. Richard Katz
Key words:	Geodynamics, marine geophysics, mathematics, modelling
Research theme(s):	• Geophysics and Geodynamics • Geodesy, Tectonics, Volcanology and related hazards
Eligible courses for this project:	• DPhil in Earth Sciences • Environmental Research (NERC DTP)

Overview

Mid-ocean ridges (MORs) are underwater mountain chains where tectonic plates separate and new seafloor is constantly created. The ~70,000-km-long global MOR system is actually a series of discontinuous segments, offset by lateral fractures (Carbotte et al., 2016). The most prominent ridge discontinuities are the oceanic transform faults which typically offset the ridge axis by tens to hundreds of kilometres, and leave scars—known as fracture zones—that can cross an entire ocean basin. In the current understanding of plate tectonics, transform faults are assumed to be conservative two-dimensional strike-slip boundaries, where the lithosphere is neither created nor destroyed. However, recent observations suggest that this assumption is incorrect (Grevemeyer et al., 2021). Moreover, shorter discontinuities (non-transform offsets or NTOs) displacing the ridge axis by only a few kilometres to tens of kilometres also show more complex magmatic and tectonic features.

It is thought that the style of discontinuity is controlled by a combination of magma supply, tectonic extension, lithospheric plumbing system and strength of the lithosphere (Sibrant et al., 2021). However, much of the classification of ridge discontinuities is based on studies of fast-spreading ridges dominated by robust magma supply, which adds limitations to our current understanding. Previous numerical and analogue models also tend to exclude magma from the dynamics, leaving open questions regarding how discontinuities respond to the thermal and mechanical structure of mid-ocean ridges, which is controlled by magma supply and extension.

This project aims to develop new theory and models of segmentation at mid-ocean ridges to understand how transform faults and NTOs interact with the mantle melting and focusing at the ridge axis, and test hypotheses derived from observations. The student will develop computational tools for 3-D modelling to investigate the dynamics of the most prominent fracture system on Earth.

Methodology

The PhD student will develop theoretical and computational models to couple melt generation and migration with formation of discontinuities at MORs. The theory will be based on two-phase flow of partially molten rock (Katz 2022), which describes the interaction between rock (solid) and melt (liquid). The computation is based on numerical solutions of a

system of partial differential equations comprising conservation of mass, momentum, and energy conservation for two phases.

The student will first expand existing computational tools (FD-PDE framework, Pusok et al., 2022, 2025) into 3–D and create robust tests for these new computational tools. One goal is to develop a model of magma generation, migration and extraction coupled with brittle–ductile rheology of rocks (Li et al., 2023, Pusok et al., 2025). The student will then investigate the relative importance of factors controlling segmentation of mid-ocean ridge axis. The simulations will be run on the university high-performance computing cluster.

Timeline

Year 1: Training in mathematical and numerical model development (using python, C and PETSc) to expand the generic computational tools (FD-PDE framework) into 3–D. Literature survey, identification of questions and hypotheses, project planning.

Years 2 and 3: Development of 3-D models of MORs that include magma production, transport and segmentation of the lithosphere. Analysis of numerical simulations, writing of model results.

Year 4: Hypothesis testing by comparison with available geophysical and geochemical data. Prepare papers for publication and conference presentations. Thesis writing and completion.

Training & Skills

The student will be trained in theory and scientific computing to develop models of two-phase flow in 3–D. They will learn skills and knowledge relevant to other disciplines such as geophysics, petrology, rock mechanics. The student will also learn through weekly project meetings with the supervisors and by attending geophysics seminars.

Students with a background in geodynamics, (geo)physics, applied mathematics, computer science or engineering are encouraged to apply. We seek applicants who are keen to learn and work on fundamental problems; show enthusiasm and ability to take initiative; are meticulous and attentive to details; show ability to meet deadlines; work in a team with interdisciplinary expertise; present and convey scientific ideas in a concise and clear manner. Other courses on professional skills are available through the University.

References & Further Reading

Carbotte, S. M., Smith, D. K., Cannat, M. and Klein, E. M. (2021). Tectonic and magmatic segmentation of the global ocean ridge system: a synthesis of observations'. Geological Society, London, Special Publications 420, doi:10.1144/SP420.5.

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Further Information

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