EARTHSCIENCES

# Melt focusing and extraction at mid-ocean ridges

| | |
|---|---|
| **Primary supervisor:** | **Dr. Adina Pusok** |
| **Co supervisor(s):** | **Prof. Richard Katz**<br>**Prof. Satish Singh (IPG Paris, France)** |
| **Key words:** | Geodynamics, marine geophysics, mathematics, modelling |
| **Research theme(s):** | ● Geophysics and Geodynamics<br>● Geodesy, Tectonics, Volcanology and related hazards |
| **Eligible courses for this project:** | ● DPhil in Earth Sciences<br>● Environmental Research (NERC DTP) |

## Overview

Oceanic plates are formed at mid-ocean ridges (MOR), which are underwater mountain chains where tectonic plates separate. MORs are also places where most of global magmatism and crustal production occurs. Melt extraction from a partially molten mantle is among the fundamental processes shaping the planet's solid surface today (Fig. 1A).

Seismic surveys (e.g., Qin et al., 2020, Audhkhasi and Singh, 2022, Dhabaria and Singh, 2024) and observations from ophiolites provide valuable insights on the structure of the oceanic crust and lithosphere. The general view is that melting initiates in the mantle close to the MOR axis due to plate separation. These melts then migrate upwards towards the surface until they encounter a permeability barrier, and then are focused either towards the ridge axis or freeze off-axis at the lithosphere–asthenosphere boundary (LAB), producing heterogeneity in the oceanic lithosphere. Melt that is focused towards the ridge axis is extracted to form the oceanic crust, which consists of a basaltic upper crust and a gabbroic lower crust, separated from the mantle by a discontinuity known as the Moho (Fig. 1B).

Despite decades of observations, it remains unclear what are the physical and chemical properties of the Moho and the LAB or how the oceanic crust is formed (Fig. 1B, scenarios a-b). Moreover, most models of MORs neglect magma production, transport and extraction despite the obvious importance of magmatism to the mid-ocean ridge system. In contrast, the project supervisors are leaders in the coupled modelling of magma and mantle dynamics (Katz, 2022, Pusok et al., 2022, 2025).

This project aims to develop new theory and models of mantle melting, melt migration, crustal accretion and evolution at mid-ocean ridges to understand the formation of the LAB and Moho and test hypotheses derived from observations. Collaboration with Prof. Satish Singh from IPG Paris will help ground geodynamic models with the most recent seismic observations. Prof. Singh is leading the MohoLAB project that aims to collect geophysical data of unprecedented quality and volume from the East Pacific Rise, giving us an entirely new view of the LAB and Moho. The project will be a joint effort between the research groups in Oxford and Paris, and between geodynamic and seismic modelling.

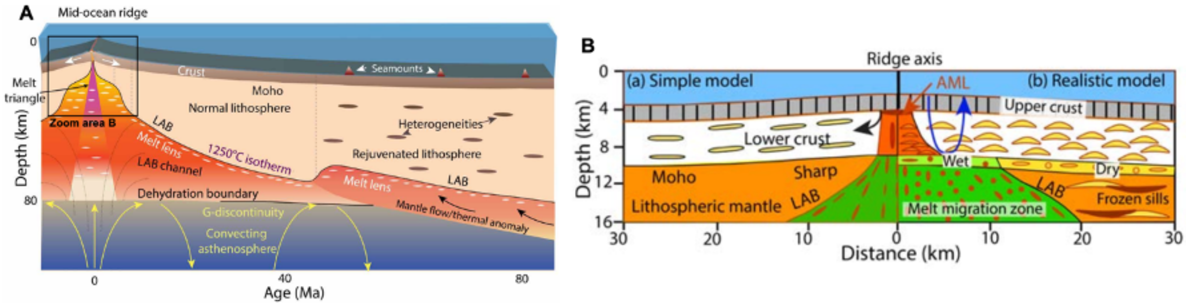


*Fig 1. **A.** Schematic showing structures and melt focusing and the LAB at mid-ocean ridges (from Audhkhasi and Singh, 2022). **B.** Schematic showing two end-member models – (a) gabbro glacier model, (b) sheeted sill model – for crustal accretion and formation of Moho close to the mid-ocean ridge axis (from S. Singh).*

## Methodology

The PhD student will develop theoretical and computational models to simulate melt transport, focusing and extraction at MORs. The theory will be based on two-phase flow of partially molten rock (Katz 2022). The theory describes the interaction between two phases: 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, and could include multiple thermochemical components. One goal is to develop a model of large-scale flow beneath MORs (Pusok et al., 2022) coupled with an axial melt extraction model (Li et al., 2023, Pusok et al., 2025). The student will test the sensitivity of results with varying parameters (e.g., spreading rate, bulk and volatile concentrations, rheological parameters) to constrain the melt and solid streamlines, focusing distance, depth of the freezing, etc. The simulations will be run on the university high-performance computing cluster.

The student may also use seismic modelling methods to help validate geodynamic models against observations of MORs and oceanic lithosphere. This method involves determining seismic and thermodynamic properties of rocks and melts to help compute synthetic seismograms (Singh et al., 2019).

## Timeline

**Year 1:** Training in mathematical and numerical model development (using python and PETSc) to investigate mid-ocean ridge dynamics. Literature survey and preparatory coursework. Identification of questions and hypotheses, project planning.

**Years 2 and 3:** Development of theory and models of MORs that couples large-scale flow and magma production with an axial extraction model. 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 scientific computing to develop models of two-phase flow, and in seismic wave propagation and synthetic seismogram modelling. 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 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. There will be opportunities for visits to the IGP Paris for collaboration with Prof. Satish Singh.

## References & Further Reading


Audhkhasi, P. and Singh, S. (2022). Discovery of distinct lithosphere-asthenosphere boundary and the Gutenberg discontinuity in the Atlantic Ocean. Sci. Adv. 8, eabn5404, doi:10.1126/sciadv.abn5404.

Dhabaria, N. and Singh, S. (2024). Seismic evidence of an extremely thin crust along a 70 Ma slow-spreading crustal segment in the equatorial Atlantic Ocean. Geology, doi:10.1130/G52480.1.

Katz, R. (2022). The Dynamics of Partially Molten Rock. Princeton Univ. Press, 1st edition.

Li, Y., Pusok, A.E., Davis, T., May, D., Katz, R. (2023). Continuum approximation of dyking with a theory for poro-viscoelastic–viscoplastic deformation. Geophys. J. Int., doi:10.1093/gji/ggad173.

Pusok, A., Katz, R., May, D. and Li, Y. (2022) Chemical heterogeneity, convection and asymmetry beneath mid-ocean ridges. Geophys. J. Int., 231(3):2055–2078, 2022. doi: 10.1093/gji/ggac309.

Pusok, A.E., Li. Y., Davis, T., May, D.A., Katz, R.F., (2025). Inefficient melt transport across a weakened lithosphere led to reduced magmatism in the Turkana Depression. GRL, 18, doi: 10.5194/gmd-18-6219-2025.

Qin, Y., Singh, S.C., Grevemeyer, I., Marjonovic, M., and Buck, R.W. (2020). Discovery of flat seismic reflections in the mantle beneath young Juan de Fuca Plate, Nature Communications, doi:10.1038/s41467-020-17946-3.

Singh, S., Belahi, T., and Fuji, N. (2019). Visco-elastic full waveform inversion of wide-angle data: Application to ultra-long offset data from the Mentawai basin, Indonesia, EAGE Workshop.


## Further Information


Contact: Adina Pusok (adina.pusok@earth.ox.ac.uk)