

## Melt focusing and extraction at mid-ocean ridges

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<b>Key words:</b>	Geodynamics, marine geophysics, mathematics, modelling
<b>Research theme(s):</b>	<ul style="list-style-type: none"> <li>• Geophysics and Geodynamics</li> <li>• Geodesy, Tectonics, Volcanology and related hazards</li> </ul>
<b>Eligible courses for this project:</b>	<ul style="list-style-type: none"> <li>• DPhil in Earth Sciences</li> <li>• Environmental Research (NERC DTP)</li> </ul>

### Overview

The concept of plate tectonics on Earth is based on rigid oceanic plates – the lithosphere, moving over a ductile asthenosphere, bounded by the Lithosphere–Asthenosphere Boundary (LAB). 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, Grevenmeyer et al., 2018, Nirmitt 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 LAB, producing heterogeneity in the oceanic lithosphere. Melt that is focused at 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, how the oceanic crust is formed (Fig. 1B, scenarios a-b), or how the LAB initially develops from the crust to the mantle (Kent et al., 2025). Moreover, previous geodynamic models of mid-ocean ridges fall short at coupling magma production, transport and extraction at the ridge axis (Pusok et al., 2022, 2024).

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 IGP 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.

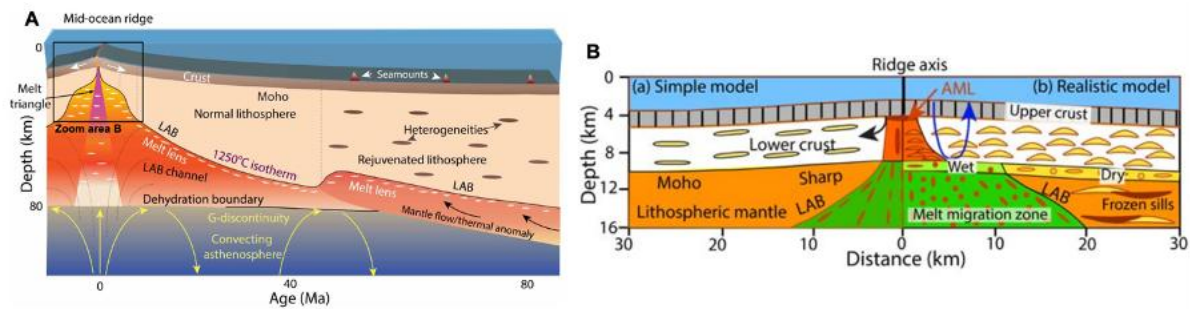


Fig 1. **A.** Schematic showing structures and melt focusing and the LAB at mid-ocean ridges (from Audhkhasi and Singh, 2022). **B.** Schematic showing two end-member models – (a) gabbro glacier model, (b) sheeted sill model – for crustal accretion and formation of Moho close to the mid-ocean ridge axis (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 governing magma/mantle dynamics. The theory describes the interaction between two phases: rock (solid) and melt (liquid) (Katz 2022).

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 (e.g., dunite, melt,  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ ) (Keller et al., 2017). 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., 2024). 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 will 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 (Taylor and Singh, 2002) 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

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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 and basic research; show enthusiasm and ability to take initiative; are meticulous and attentive to details; show flexibility and ability to meet deadlines; able to 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. Attendance is encouraged. There will be opportunities for visits to the IGP Paris for collaboration with Prof. Satish Singh.

## References & Further Reading

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### **Further Information**

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