

Mantle transition zone structure from novel seismic inference

Primary supervisor:	Prof Paula Koelemeijer (https://www.earth.ox.ac.uk/~univ4152/index.html)
Co supervisor(s):	Prof Andrew Walker (https://www.earth.ox.ac.uk/people/andrew-walker) Prof Hauke Marquardt (https://www.earth.ox.ac.uk/people/hauke-marquardt)
Key words:	Mantle structure and dynamics, Seismology, Inverse methods, Temperature and composition of the Earth
Research theme(s):	- Geophysics and Geodynamics - Planetary Evolution and Materials
Eligible courses for this project:	- MSc by Research in Earth Sciences (2-3 years) - DPhil in Earth Sciences (3-4 years) - Interdisciplinary Life and Environmental Science Landscape Award (ILES�A) - Intelligent Earth (UKRI CDT)

Overview

The mantle transition zone, between 410 and 660km deep, is a crucial region that strongly controls mantle convection (Goes et al., 2023). At these depths, mineralogical changes occur that profoundly alter the density and viscosity of the material. These phase transitions affect convective flow depending on the Clapeyron slope of the transition, e.g. flow is hindered by the ringwoodite-bridgmanite transition at 660km depth, but enhanced at higher temperature by the garnet-to-bridgmanite reaction. Depending on the local mineralogy and temperature, these phase transition may occur both, with a competing effect on convection.

Seismic images of this complex region show that ancient oceanic plates sinking into the Earth's interior exhibit different behaviours when they reach the transition zone. They may pass through unaffected, bend, break or simply stagnate. Equivalent variations are observed for rising mantle plumes, which may pond, deflect or branch out. To understand mantle convection and its effects on Earth's surface, we have to unravel what causes these variations in plume and slab morphology and how they link to temperature and composition.

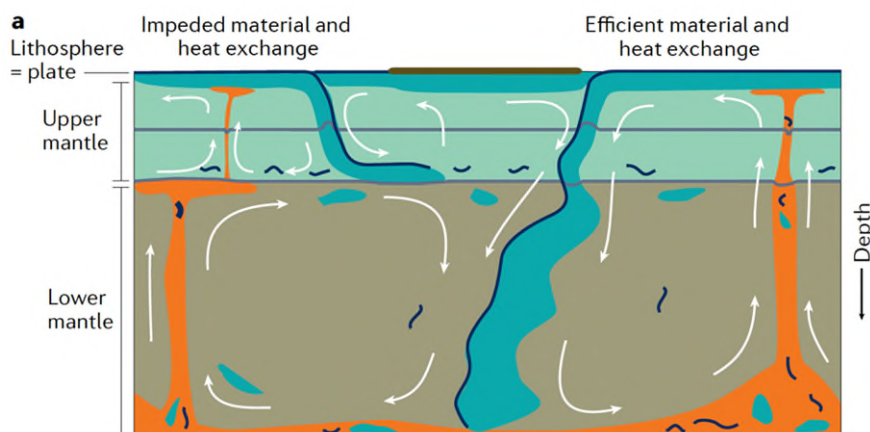


Fig.1: Cartoon illustrating modes of mantle convection with limited or efficient flow across the mantle transition zone due to solid-solid phase transitions. Figure taken from Goes et al., 2023.

Seismic imaging provides the strongest observational constraints on mantle transition zone structure and dynamics. However, current imaging approaches are insufficient, typically ignoring trade-offs between parameters and over-simplifying the underlying physics. A key issue is that seismic data are sensitive to 3D variations in bulk structure (seismic velocity) as well as topography on seismic discontinuities. Critically, data uncertainties and their impact on the images (and therefore interpretations) are not routinely calculated. It is vital to improve on this to further our understanding of this complex region.

Methodology

In this project, we will address the issues above by using an inference framework based on the Backus-Gilbert SOLA method (Zaroli, 2016; Zaroli et al., 2017). This allows us to obtain seismic models with both resolution and uncertainty, allowing robust, quantitative interpretations. To obtain estimates on regional scales, we will develop a finite-frequency SOLA framework (Latallerie et al., 2025) for body-wave observations, building on recent work imaging the MTZ under Indonesia (Serra et al., 2025). We will extend this framework to constrain both velocity and discontinuity topography by combining relevant body-wave phases (sensitive to velocity) with reflected waves sensitive to topography (*precursors*).

Firstly, the student will spend time compiling multi-frequency measurements of body-wave phases and characterising their uncertainties. Subsequently, the student will compute 3D finite-frequency kernels and design target kernels based on the data coverage. The student will then construct SOLA models and analyse the 3D model resolution to assess the robustness of the images. Finally, we will characterise the scale lengths and amplitudes of velocity and topography variations and interpret these in terms of thermal and compositional variations.

Timeline

Year 1: Doctoral training courses, literature review, seismic data collection / measurements.

Years 2 and 3: Seismic data measurements, setting up inference problem and development of workflow, experimenting with kernel size and resolution-uncertainty trade-offs, development of seismic velocity models.

Year 4: Interpretation of results and integration of seismic constraints with mineral physics data, thesis completion, writing of papers for international journals and presentation of results at international conferences.

Training & Skills

The successful candidate will join the vibrant seismology group at the University of Oxford, and benefit from interactions with existing PhD students, postdocs and faculty who work on similar topics.

The PhD student will receive training in computational methods and the processing of seismic data sets, as well as inverse methodologies and interpretations. In addition, they will be mentored on how to prepare scientific results at (inter)national conferences, how to write manuscripts for publication in international journals and how to communicate their science to a general audience.

In addition to the training in these transferable skills and research skills, the student will be provided with advice on funding applications and career support.



References & Further Reading

Goes, S., Yu, C., Ballmer, M.D. *et al.* Compositional heterogeneity in the mantle transition zone. *Nat Rev Earth Environ* **3**, 533–550 (2022). doi:10.1038/s43017-022-00312-w

Latallier, F, C. Zaroli, S. Lambotte, A. Maggi, A. Walker & **P. Koelemeijer** (2025). Towards surface-wave tomography with 3D resolution and uncertainty. *Seismica*, Vol. 4(2), doi:10.26443/seismica.v4i2.1407

Serra, E., C. Zaroli, S. Lambotte & **P. Koelemeijer**. Inference of the ratio between S and P-wave velocity anomalies and its uncertainty with an application to South-East Asia. *In revision for Geophys. J. Int*, available via [EarthArXiv](#), doi:10.31223/X56X5G.

Zaroli (2016). Global seismic tomography using Backus-Gilbert inversion. *Geophys. J. Int.*, 207(2), 876-888.

Zaroli, **Koelemeijer** & Lambotte (2017). Toward seeing the Earth's interior through unbiased tomographic lenses. *Geophys. Res. Lett.*, 44. doi:10.1002/2017GL074996.

Further Information

Contact: Paula Koelemeijer (paula.koelemeijer@earth.ox.ac.uk)