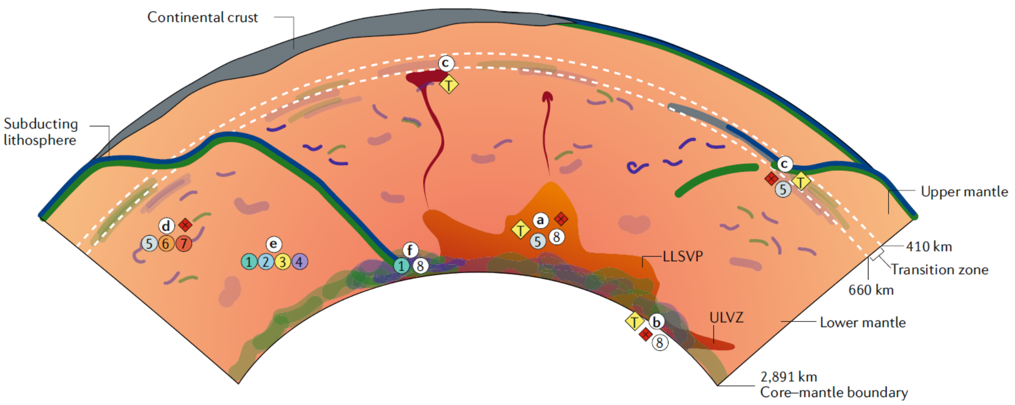
Watching the Mantle Transform: From Snapshots to Movies of Phase Transitions in Earth’s Deep Mantle

Primary supervisor:	**Prof. Hauke Marquardt** **(**https://www.earth.ox.ac.uk/people/hauke-marquardt**)**
Co supervisor(s):	**Prof. Andrew Walker** (https://www.earth.ox.ac.uk/people/andrew-walker)
Key words:	
Research theme(s):	• Geophysics and Geodynamics • Planetary Evolution and Materials
Eligible courses for this project:	• DPhil in Earth Sciences (3-4 years) • Interdisciplinary Life and Environmental Science Landscape Award (ILESLA) • Intelligent Earth (UKRI CDT)

Overview

The Earth’s lower mantle, from 660 km to 2890 km depth, constitutes more than 60% of Earth’s volume and is the largest geochemical reservoir for many elements. Throughout Earth’s history, substantial amounts of material have been exchanged between the mantle and Earth’s surface and atmosphere, affecting the evolution of Earth’s atmosphere and the habitability of our planet. The lower mantle, linking the liquid outer core to the Earth’s upper mantle, also governs mantle dynamic processes. Phase transitions occurring in mantle minerals under pressure and temperature have a pivotal role influence on the propagation of seismic waves through the Earth as well as on large-scale geodynamic processes linking the Earth deep interior to is surface and atmosphere (e.g. Immoor et al., 2022). But even fundamental properties, such as the location of major phase transition boundaries in Earth’s mantle, are poorly constrained.



Cartoon of dynamic processes in the lower mantle and possible effects of phase transitions indicated by numbers (see Marquardt and Thomson, 2020 for details).

Within this DPhil project, you will employ a novel class of time-resolved high-pressure/-temperature experiments that reduce by several orders of magnitude the time for key experiments. This will allow to monitor phase transitions in high-pressure experiments in real time, and makes it possible to “watch atoms move positions” for the first time, transitioning from the age of pictures to movies. The experiments will be used to map lower mantle phase transitions, their impact on physical properties and their seismic signature. They further allow for probing the time-dependence of phase transitions, transforming our understanding of how to scale from laboratory measurements to geophysical processes. This will improve or knowledge of processes in Earth’s lower mantle and their role for planetary evolution.

Methodology

High-pressure dynamic diamond-anvil cells will be combined with time-resolved Synchrotron x-ray diffraction measurements watch phase transitions under pressure and temperature (Jenei et al., 2019). Results will be comprehensively analysed using either classical approaches (EoS) or machine learning techniques (e.g. Trautner et al, 2024). The results will be used to predict the propagation of seismic waves through Earth and can be integrated into large-scale geodynamic models.

Timeline

Year 1: Literature review, planning of experimental campaigns, application for synchrotron beamtime, introduction to methodology.

Years 2 and 3: High-pressure experiments, machine learning data analysis, seismic modelling, presentation of research at national conferences.

Year 4: Data integration, thesis completion, papers for international journals.

Training & Skills

As part of this project you will learn how to prepare dynamic diamond-anvil cells (dDACs), conduct high-pressure experiments using time-resolved XRD at world-leading Synchrotron facilities. You will also receive training in applying machine learning to analyse data and learn how to apply these results to real world seismological data. You will also receive training in presenting scientific results, and writing scientific papers.

References & Further Reading

Immoor et al., (2022). Weak cubic CaSiO3 perovskite in the Earth’s mantle. Nature 603(7900) (2022): 276-279.

Jenei et al. (2019). New dynamic diamond anvil cells for tera-pascal per second fast compression x-ray diffraction experiments. Review of Scientific Instruments 90(6): 065114.

Marquardt, H. and A. R. Thomson (2020). Experimental elasticity of Earth’s deep mantle. Nature Reviews Earth & Environment 1(9): 455-469.

Trautner et al. (2024). Iron Content-Dependence of Ferropericlase Elastic Properties Across the Spin Crossover From Novel Experiments and Machine Learning. Geophysical Research Letters 51(22): e2024GL111276.

Further Information: Contact: **Hauke Marquardt (hauke.marquardt@earth.ox.ac.uk)**