Understanding Earth’s Lower Mantle Structure and Composition Through Laboratory Seismology

**Supervisory Team**
- Prof. Hauke Marquardt (https://www.earth.ox.ac.uk/people/hauke-marquardt/)
- Ass. Prof. Paula Koelemeijer (https://www.earth.ox.ac.uk/~univ4152/)

**Key Words**
Mineral physics, deep Earth, material cycles, mantle dynamics, seismology, spin crossover, mantle structure

**Overview**
The Earth’s lower mantle, ranging from 660 km to 2890 km depth, constitutes more than 50% 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 Earth’s upper mantle, is also a key component controlling mantle dynamics. Quantitative knowledge of the chemistry, mineralogy and temperature of the lower mantle is thus of key importance for interpreting the thermal evolution, geochemical properties, and dynamics of the Earth’s interior.

With the exception of the lowermost 200-300 kilometers, the lower mantle has traditionally been assumed to be chemically homogenous, a conclusion based on the absence of geophysical evidence to the contrary (although there is some debate in geochemistry). Recent evidence, from both laboratory work and geophysical measurements, suggests that chemical and/or physical properties change throughout the lower mantle (Ballmer et al., 2015, Marquardt et al. 2015, Rudolph et al. 2015, Kurnosov et al. 2017).

In the mid-lower mantle, iron in the main lower mantle minerals bridgmanite and ferropericlase undergoes a change of electronic configuration, i.e. a spin crossover, that markedly affects its physical properties (Lin et al., 2013). However, at temperatures relevant to the mantle, the crossover extends over several hundreds of kilometres depths. The effects of this spin crossover on seismic wave velocities are not understood in detail (e.g. Trautner et al., 2023). Another important phase transition in the mid-lower mantle, affecting seismic wave velocities, is the tetragonal to orthorhombic distortion in SiO₂ stishovite (e.g. Wang et al., 2023).

This project will focus on resolving the impact of these spin and phase transitions on geophysical observables by combining traditional seismic wave velocity measurements in the laboratory and novel experimental capabilities at large-scale synchrotron research facilities (Diamond Light Source, UK and DESY, Germany), with seismological modelling. The models will be compared to the seismological record to prospect for signs of these transitions in the deep mantle and thereby enhance our understanding of the current state of the lower mantle and, ultimately, its role in the evolution of our planet.

**Methodology**
Direct constraints on the chemical and mineralogical composition of Earth’s lower mantle are derived through a comparison of seismic wave velocity models with synthetic mineral physics-based velocity models calculated from laboratory elasticity measurements (e.g. Kurnosov et al., 2017). Seismic wave velocities are calculated from the elastic moduli (bulk and shear modulus) and densities of lower mantle minerals determined in diamond-anvil cells at pressures of the lower mantle. The elastic moduli can be measured in the laboratory using laser-based techniques (Brillouin spectroscopy). Complementary x-ray diffraction measurements allow for density determination. In this project, a novel multi-sample approach will be employed at Oxford that allows for significantly improved measurements of small effects (such as those caused by the iron spin crossover) on seismic wave velocities and densities at high pressures.
In addition to this new approach, the implementation of laser-heating capabilities now allows for density measurements at both the pressure and temperature conditions of the lower mantle. The laboratory data will be used as input parameters for synthetic seismic models that predict the propagation of seismic waves through Earth. Comparison to the seismic record will allow to derived constraints on the structure, compositions, and dynamics of Earth’s deep mantle.

**Timeline**

**Year 1**: Doctoral training courses (10 weeks), application for synchrotron beamtime, literature review, planning of experimental campaigns.

**Years 2 and 3**: Sample preparation (polishing, FIB), preparation of diamond-anvil cells, Brillouin spectroscopy, synchrotron experiments (DLS and DESY), seismic modelling, presentation of research at national conferences.

**Year 4**: Data integration, thesis completion, papers for international journals, presentation of research at an international conference.

**Training & Skills**

The supervisory team in Oxford are leaders in high-pressure mineral physics (H. Marquardt) as well as deep Earth seismology (P. Koelemeijer).

As part of this project you will learn how to prepare diamond-anvil cells and conduct high-pressure experiments using a variety of techniques (XRD, optical spectroscopy). You will further be trained in how to plan and carry out laboratory as well as synchrotron experiments, using world-leading research facilities. You will also receive training and guidance in how to model and interpret data, how to present scientific results, and how to write scientific papers for publication.

**References & Further Reading**


**Further Information**

Contact: Hauke Marquardt, hauke.marquardt@earth.ox.ac.uk (Professor of Earth Sciences).