Iron spin crossovers in Earth’s lower mantle studied by novel high-pressure-/temperature experiments (DEEP-MAPS ERC)

Supervisory Team

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Key Words

Mineral physics, deep Earth, material cycles, mantle dynamics, phase transitions, seismology, mantle structure

N.B. Funding from the European Research Council means that applicants of all nationalities are eligible for this project. If/when Brexit occurs, the project will be supported by the UK Government under identical rules

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 the 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 pivotal for interpreting the thermal evolution, geochemical properties, and dynamics of the Earth’s interior.

Seismic wave velocity measurements on mantle minerals in the diamond-anvil cell. The diamond-anvils are illuminated by the probing green laser light.

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 incorporated in lower mantle minerals 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 crossovers extend over several hundreds of kilometres depths and the effects of these spin crossovers on the physical properties of the mantle and seismic wave velocities are not understood in detail.

This project will focus on resolving the impact of the iron spin crossovers on mantle physical properties and geophysical observables by combining traditional seismic wave velocity measurements in the laboratory with novel experimental capabilities at large-scale synchrotron research facilities (Diamond Light Source, UK and DESY, Germany). This will permit to quantify the effects of the iron spin crossovers on seismic wave propagation at realistically high pressures, temperatures and seismic frequencies. The new measurements will be combined with the seismological record to enhance our understanding of the current state of the lower mantle and, ultimately, its role in the evolution of our planet. This DPhil is part of the ERC-funded project DEEP-MAPS.

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 will be measured in the laboratory using laser-based techniques (Brillouin spectroscopy). Complementary x-ray diffraction measurements will 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 (e.g. Kurnosov et al., 2017). In addition to this new approach, the implementation of laser-heating capabilities in the diamond-anvil cell at Diamond Light Source (Oxfordshire, UK) now allows for density measurements at both the pressure and temperature conditions of the lower mantle. Finally, the project will take advantage of very recent developments at DESY Synchrotron (Germany), where elastic properties can now be studied for the first time at seismic frequencies in the diamond-anvil cell (1 Hz) (Marquardt et al. 2018). The laboratory data will be incorporated in seismic velocity models of the lower mantle and compared to real seismological observations.

## Timeline

**Year 1**: Doctoral training courses (optional), application for synchrotron beamtime, literature review, planning of experimental campaigns, sample synthesis and characterisation (e.g., microscopy, EPMA, XRD) and laboratory training.

**Years 2 and 3**: Sample preparation (polishing, FIB), preparation of diamond-anvil cells, Brillouin spectroscopy, synchrotron experiments (DLS and DESY), 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 are leaders in high-pressure mineral physics and its application to the interpretation of geophysical observables (H. Marquardt) as well as deep Earth seismology (T. Nissen-Meyer, P. Koelemeijer). The supervisory team has been strongly involved in synchrotron-based research in the past.

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

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