Overview
Convective mass flow in Earth’s mantle drives plate tectonics and determines exchange rates of energy and material with Earth's surface and atmosphere. Geophysical observations provide increasingly detailed constraints on flow patterns in the mantle. For instance, seismic tomography provides imaging of fast regions in the mantle, possibly indicative of descending slabs (e.g. Fukao et al. 2013) and seismic anisotropy observations near the boundary regions of Earth's mantle are most likely related to mass flow induced deformation (Wenk et al. 2011). However, a detailed interpretation of these large-scale observations in terms of mantle flow patterns requires the synergy of geophysical observables with information from mineral physics and large-scale numerical models. Material transport from Earth's surface into the deep mantle occurs by subduction of oceanic lithosphere. Historically, many geoscientists favoured a model of separate convection within the upper and lower mantle based on geochemical arguments, but seismology (van der Hilst et al. 1997), mantle dynamic models (Tackley 2000) and petrology (Walter et al. 2011) provided evidence for subducting slabs penetrating the 660 km seismic discontinuity and descending into the lower mantle.

However, many questions remain, such as why do some slabs stagnate in the upper ~500-1000 km of the lower mantle as indicated by recent seismic tomography studies (Fukao et al. 2013) or if there is a change in thermal or chemical state in the mid-lower mantle around 1500 km depth as suggested by previous work (Cammarano et al. 2010). To understand the structure and dynamics of the lower mantle, knowledge of the deformation behaviour of lower mantle minerals is needed. From laboratory deformation experiments, we can extract properties that determine the behaviour of slabs in the mantle, such as density or yield strength (viscosity) (Marquardt et al. 2015). Further, as a response to stress, crystals deform on preferred slip planes along specific slip directions (together referred to as slip system), leading to a preferred orientation of crystals. This can be measured and combined with single-crystal elastic properties to model seismic anisotropy observations and ultimately link them to patterns of mantle flow (Wenk et al. 2011).

In this project, we will perform deformation experiments on lower mantle phases, particularly cubic CaSiO₃ perovskite (Ca-Pv). In a deeply subducted oceanic slab, Ca-Pv may account for up to 25 vol.% of the transformed basaltic crust and will affect the bulk rheological properties of the lithospheric slab. Previous deformation studies on Ca-Pv have been limited to 49 GPa at 300 K (Miyagi et al. 2009). At this temperature, however, Ca-Pv forms a crystal structure with tetragonal symmetry, whereas at temperatures typical for the lower mantle, it will be cubic (Komabayashi et al. 2007). Cubic Ca-Pv may show a different rheological behavior than its tetragonal form that has been studied before (Miyagi et al. 2009).

Methodology
Only diamond anvil cell (DAC) experiments can simulate the pressure-temperature conditions of the deeper lower mantle. Ca-Pv can be experimentally synthesized from CaSiO₃ wollastonite at pressures of about 20 GPa and temperature of about 1300 K, but is not quenchable...
to ambient conditions. This implies that studies of the physical properties of Ca-Pv need to be performed in-situ and in the same pressure device that is used for synthesis.

To study the deformation behavior at mantle pressures and temperatures, in-situ synchrotron x-ray diffraction (XRD) experiments are performed in a specialized scattering geometry, where the x-ray beam is oriented perpendicular to the DAC’s compression direction (radial XRD, rXRD) (Wen et al. 2011, Marquardt et al. 2015). Until a few years ago, these experiments were mostly limited to high-pressures at room temperature, but can now be conducted at simultaneous high-pressure and high-temperature. Experiments will be performed at synchrotron sources, including the Diamond Light Source (Oxfordshire, UK) and the German Synchrotron Radiation Facility (DESY).

Timeline
Year 1: Doctoral training courses (10 weeks), application for synchrotron beamtime, literature review, planning of experimental campaigns, diamond-anvil cell preparation and laboratory training.

Years 2 and 3: Synchrotron experiments (DLS and DESY), data analysis and interpretation, presentation of research at European 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 and its application to the interpretation of geophysical observables (H. Marquardt, moving to Oxford in April 2018) as well as laboratory deformation (L. Hansen). The supervisory team has been strongly involved in both laboratory and 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 synchrotron rXRD and other techniques. You will 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 (info@depict-group.org)
(Hauke Marquardt will start as an Oxford Associate Professor in Earth Sciences in April 2018).