Deep Connections: Does $CaSiO_3$ Perovskite Link Slab Recycling, Mantle Flow, and Surface Volcanism?

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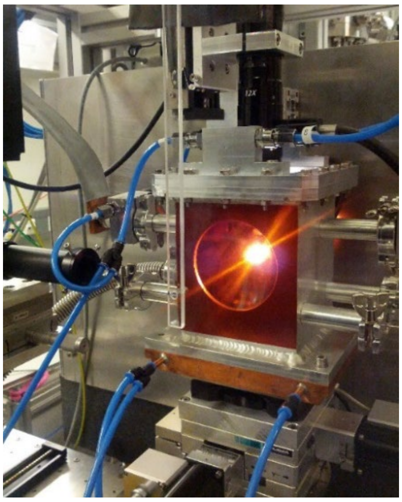
Key words:	
Research theme(s):	• Geophysics and Geodynamics • Planetary Evolution and Materials
Eligible courses for this project:	• DPhil in Earth Sciences (3-4 years) • Interdisciplinary Life and Environmental Science Landscape Award (ILESLA)

Overview

Subduction of oceanic crust is the main process to recycle chemical elements into Earth's deep mantle, and considered a key process to sustain a habitable planet. $CaSiO_3$ perovskite (CaPv) is a major mineral in deep subducted oceanic crust (slabs). Recent works have shown that CaPv has unique physical properties among the mantle minerals, including seismic properties and viscosity. Its characteristically low seismic wave speeds promise the ability to map CaPv, and hence subducted oceanic crust, throughout Earth's mantle using seismic data. Among others, it has been proposed that CaPv explains the unique seismic properties of the Large Low Velocity Provinces in Earth's lower mantle (e.g. Thomson et al, 2019), continent-sized enigmatic structures that have puzzled geophysicists for decades and have been linked to surface volcanism. Moreover, the very low viscosity of CaPv has been linked to key geodynamic mantle processes, including slab dynamics (Immoor et al., 2022).



However, CaPv can exist in two different crystal structures, cubic or tetragonal, depending on pressure, temperature, composition, and stress. The physical properties between cubic CaPv (c-CaPv) and tetragonal CaPv (t-CaPv) are largely different and the seismic signature of CaPv, as well as its quantitative impact on large-scale geodynamics is entirely dependent on its stable crystal structure at depths. No consensus has been reached as to whether c-CaPv or t-CaPv exists throughout Earth's mantle.

Figure shows experimental setup for high-pressure/-temperature experiments on $CaSiO_3$ at a Synchrotron Facility.

This project is motivated by controversy around the position of the cubic-tetragonal phase boundary of Davemaoite in the lower mantle, which is pivotal to (1) understand its role in explaining seismic observables in the lower mantle and thereby tracing deep subduction, as well as (2) quantifying its importance for understanding slab dynamics and slab delamination. The results from this project will allow for exploring the effects of the transition on large-scale material transport in future geodynamic models. These results will impact our understanding of slab subduction into Earth's deep interior, and hence global material cycles.

Methodology

Here, we propose to use novel experiments pioneered in our group to experimentally measure the properties of CaPv in Earth's mantle. The experiments will use Diamond-Anvil Cells (DAC) at high-pressure and -temperature, combined with time-resolved X-ray diffraction (XRD) recorded in-situ at Synchrotron radiation facilities, such as DESY (Germany) and DLS (UK). Based on these new experimental data, we will construct synthetic seismic tomography models of the Earth and model seismic wave propagation through these models. The outcome will be detailed knowledge on the effects of the cubic to tetragonal transition in CaPv on full seismic waveforms, informing attempts to prospect for the transition in real-world seismograms.

Timeline

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

Years 2 and 3: High-pressure/-temperature experiments, data analysis, geophysical modelling, presentation of research at international conferences.

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

Training & Skills

As part of this project you will learn how to prepare diamond-anvil cells, conduct high-pressure/-temperature experiments using time-resolved XRD at Synchrotron sources. You will also receive training in data analysis and how to apply laboratory data to interpret real world geophysical observations (e.g. Trautner et al., 2023). You will also receive training in presenting scientific results, and writing scientific papers.

References & Further Reading

Immoor, J., L. Miyagi, H. P. Liermann, S. Speziale, K. Schulze, J. Buchen, A. Kurnosov and H. Marquardt, Weak cubic CaSiO3 perovskite in the Earth's mantle. Nature 603(7900) (2022): 276-279.

Thomson, A., W. Crichton, J. Brodholt, I. Wood, N. Siersch, J. Muir, D. Dobson and S. Hunt. Calcium silicate perovskite's acoustic velocities can explain LLSVPs in Earth's lower mantle. Nature 572 (2019): 643-647.

Trautner, V. E., S. Stackhouse, A. R. Turner, P. Koelemeijer, D. R. Davies, A. S. J. Méndez, N. Satta, A. Kurnosov, H.-P. Liermann and H. Marquardt, Compressibility of ferropericlase at high-temperature: Evidence for the iron spin crossover in seismic tomography. Earth and Planetary Science Letters 618 (2023): 118296.

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