Feedbacks between mineral reactions and mantle convection

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Simple summary

The evolution of the solid Earth and many surface features are controlled by movements deep within. We aim to transform our understanding of those movements through a new understanding of mineral behaviour. Rocks in the mantle, the outer half of the Earth, can flow despite being solid, in the same way that a glacier flows. This flow is driven by contrasts in density, for example dense material sinks. One control on density is mineralogy, so we need to understand the controls on mineral changes. Pressure is key, for example, graphite (a form of carbon) transforms into diamond (a denser form of carbon) with increasing pressure. Pressure increases with depth in the Earth, in the same way as it does in the deep oceans. However, in a flowing system, pressure may not relate simply to depth. Another control on mineralogy is stress (different force per unit area in different directions), which prevails in the mantle as it deforms.

These ideas are illustrated by a simple analogy with clouds. On a calm day, the bases of clouds often appear undisturbed at a particular level, above which water is condensing. On a day of livelier weather, the cloud bases can be disturbed, as the wind wafts them up and down, and it takes time for water to evaporate or condense in response. Thus, looking at the bases of the clouds from a distance tells us something about the on-going dynamics in the atmosphere. Similarly, in the mantle, we have mineral changes at specific levels which we can "see" using seismic waves. In places the levels vary sideways, sometimes explained in terms of varying chemistry. We propose that this may in some places be like the effects on the cloud bases, in which case the observed levels are an imprint of the on-going dynamics.

We aim to understand the pressures and stresses in a flowing mantle and predict their effects on mineralogy. The changing mineralogy will affect density, which in turn affects the flow patterns. Changing mineralogy affects flow, and flow affects mineralogy - this is called feedback. We will undertake four tasks to understand this feedback.

1. New experiments on minerals at mantle conditions (250,000 atmospheres pressure, temperatures up to 1800 C) measuring evolving mineral properties. To understand how the minerals change, we will examine the experimental products to discover the details of structure and chemistry within individual grains. These details will enable us to understand how the atoms have moved around, information needed for the second task.

2. Creation of mathematical models to explain the results of the experiments. The mathematics is required to use what happens in days in the experiments to predict what happens in the mantle over millions of years.

3. Taking those predictions and including them in a numerical model for flow in the whole mantle. This model will be used to predict what happens when large dense objects (tectonic plates) sink into the mantle (e.g under Japan and South America) and find out what effect the mineral changes have. It will also be used to model what happens when hot less dense material (e.g. under Hawaii and Iceland) rises towards the surface.

4. Predictions of mantle mineralogy will be tested using seismic waves from earthquake, which travel at varying speeds as they pass through rocks with varying densities. Seismic waves reflect and refract

due to the sharp mineral changes in the Earth. Calculations will allow us to test how seismic waves can map the features predicted in step 3. We will also collect a large data set of observed earthquake waves from across the planet to image the mineral changes occurring deep within and interpret them in terms of on-going flow patterns.

In summary we will produce new mantle models that we will test using seismic wave observations and use them to produce new insights into how mineral changes and mantle flow (which controls how the Earth evolves) feedback on each other.

News item

https://news.liverpool.ac.uk/2022/07/20/3-3m-to-investigate-earths-mantle-convection/

The research team

We are based at several UK universities with partners abroad.

University of Liverpool

Investigator:	John Wheeler (project lead, micro and mantle scale modelling)
Postdoctoral researchers:	Lucy Xi (microscale modelling)
	and mantle modelling position to be advertised in early 2024
PhD student:	Scott Akhtar-Lewis (silicate analogue experiments)

University of Manchester

Investigator:	Simon Hunt (high pressure deformation experiments)
Postdoctoral researchers:	Joshua Littleton
	and experimental position to be advertised in summer 2024

University of Cambridge

Investigator:	Sanne Cottaar (seismology)
Postdoctoral researchers:	*and seismology position to be advertised in early 2024*

University of Cardiff

Investigator:	Huw Davies (mantle modelling)

University College London

Investigator:	Dave Dobson (high pressure deformation experiments)

Partners

Ingo Steinbach and Raphael Scheidung (Bochum. Germany) advise on microstructural modelling using their OpenPhase software.
Rene Gassmoeller (Kiel, Germany) is an expert developer of the ASPECT mantle convection modelling software and advises on its use.

Funder links

These have dates and other details.
https://gtr.ukri.org/ or
http://gotw.nerc.ac.uk/ and here
https://gotw.nerc.ac.uk/list_split.asp?awardref=NE%2FV018477%2F1