High-pressure experimental study of light elements in Earth’s core

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Project background

Comparisons of the density between the Earth’s core and pure iron indicate that the Earth’s core is less dense than pure iron by about 7 %, giving rise to an idea that the Earth’s core consists of iron(+some amounts of nickel) and light element(s). Potential light elements are silicon, oxygen, sulphur, carbon, and hydrogen due to their cosmochemical abundances (Fig. 1). Dissolution of light elements into an iron-rich core strongly depends on how the core is formed. The Earth was formed by accretion of meteorites at 4.6 billion years ago. During the accretion stage, the Earth was subjected to extensive melting, which is called the magma ocean stage. The light elements in the Earth’s core should reflect the thermodynamic conditions of the last equilibration between liquid silicate and liquid iron, i.e., at the bottom of the magma ocean. As such, the identification of the kinds and amounts of the light elements in the core places constraints on the formation process of the Earth. The composition of the core and nature of the 'light element' has been a major unresolved issue in Earth Science for the past 60 years. The solution of this problem should have immediate implications for the origin, formation, and evolution of the Earth. The outcome of this project is also influential in the origin of the geodynamo generating the magnetosphere, which is important for the surface environment and life.

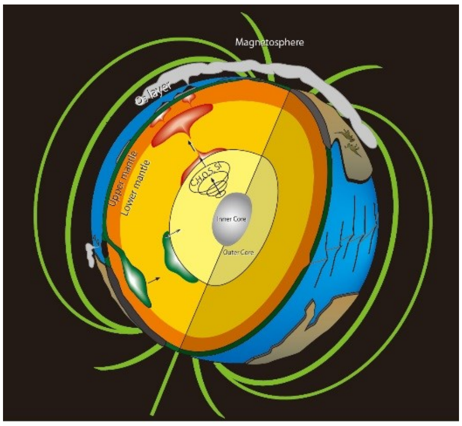

Fig. 1. Earth system

Mineral physics approaches to this problem include establishment of phase diagrams of iron-bearing systems and construction of pressure-volume (density)-temperature (PVT) equation of state (EoS) of materials. The primary supervisor has set up a cutting-edge diamond anvil cell (DAC) laboratory at the University of Edinburgh (UoE) (Fig. 2) which can now accurately replicate pressures and temperatures corresponding to Earth’s core conditions. Also chemical analysis on recovered samples is also possible to investigate element partitioning between the phases. The successful candidate will learn those techniques and advance our knowledge of light elements in the core by constructing phase diagrams of iron-alloys and PVT EoS of the candidate phases.

Fig. 2. Diamond anvil

Key research questions

1. What are the thermodynamic properties of iron and iron-light elements alloy under core P-T conditions?
2. What are the light elements dissolved in the Earth’s core?
3. How was/is the origin, current state, and evolution of the Earth’s core?
4. Do other terrestrial planets’ cores involve the same light elements as in the Earth’s core?

Methodology

The successful candidate is expected to conduct high-P-T experiments in a DAC together with various analytical methods which include synchrotron X-ray diffraction. Simultaneous high-P-T in-situ XRD study allows us to determine the stable structure and unit-cell volume for a material at a given thermodynamic condition. The student will also analyse the chemical composition of the sample at the UoE. He/she will then learn thermodynamic calculations based on experimental data.

The timetable is:

0-12th month: First he/she will read literatures and learn some basic physics. Then he/she will conduct laser-heated DAC experiments at synchrotron facilities at Diamond Light Source in Oxford to determine the phase relations of a given system (Fe+light elements).

13-24th month: He/she will continue the laser heating experiments and start chemical analysis of the samples. Also he/she will start external resistive heating experiments to establish P-V-T EoS of solid phases. He/she may attend a meeting such as EGU.

24-36th month: He/she will continue the experiments and do some thermodynamic calculations to model the systems investigated in the previous years. He/she will also attend meetings such as EGU and AGU and start writing papers.

36-42nd month: He/she will assemble all the information to provide a new view of the Earth's core and publish it. He/she will write a thesis.

Training

We will provide the successful candidate with a comprehensive training to be a specialist and to acquire generic transferable and professional skills. Through the synchrotron high-P-T experiments, he/she will know how to prepare and conduct the cutting-edge experiments. Also we will encourage him/her to write papers for leading journals so that he/she will acquire professional knowledge of the research field, will be able to describe the importance of his/her research, and will know the way how scientific review process works.

Requirements

A student with background in physics, chemistry, mineralogy and/or petrology is preferable. Basic knowledge of thermodynamics, solid state physics, and/or geophysics is beneficial. It should be noted that many of the experiments will be conducted at synchrotron facilities some of which are in Oxford, Hamburg (Germany), Grenoble (France), Chicago (USA), and Hyogo (Japan).

Further reading or any references referred to in the proposal

1. Poirier, J-P., Light elements in the Earth's outer core: a critical review. Physics of the Earth and Planetary Interiors, 85, 319-337, 1997.
2. Wade, J. and Wood, B.J., Core formation and the oxidation state of the Earth. Earth and Planetary Science Letters, 236, 78-95, 2005.
3. Thermodynamics of melting relations in the system Fe-FeO at high pressure: Implications for oxygen in the Earth's core. Journal of Geophysical Research -Solid Earth, 119, DOI: 10.1002/2014JB010980.

A project summary

This project will conduct high-pressure and -temperature experiments in a diamond anvil cell to explore thermodynamic properties of Earth's core.