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Two-Layered Convection in Earth's Outer Core
- Implications on Earth's Magnetic Reversal -

Overview
A group of researchers from JAMSTEC, Tokyo Institute of Technology(Tokyo Tech), and Japan Synchrotron Radiation Research Institute(JASRI) discovered a new phase transition of iron monoxide (FeO), a major ingredient of the liquid outer core, under high pressure and temperature conditions comparable to those in the Earth's outer core (more than 240 gigapascals (GPa) and 4000 kelvin(K)). A numerical simulation of the core convection incorporating the newly found FeO phase transition revealed that the core flow was disturbed by the said phase transition, resulting in a two-layered convection.

It was commonly held that the outer core convection occurs in a single layer. A two-layered structure of the core convection could therefore provide significant implications to understand the Earth's magnetic field, a magnetic dipole generated by the convection of the molten metal. The Earth's magnetic field plays an important role in protecting our planet from the harmful solar winds and cosmic rays.

The study was carried out by Kei Hirose (Principal Scientist at IFREE[1], JAMSTEC, also Professor at Tokyo Tech), Haruka Ozawa (Technical Scientist at IFREE, JAMSTEC), Futoshi Takahashi (Assistant Professor at Tokyo Tech) and their colleagues, with the cooperation of scientists from JASRI. Their work was published in the November 11th issue of the journal Science.

Title: Phase Transition of FeO and Stratification in Earth's Outer Core
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Background
At the center of the Earth lies the core, which is predominantly composed of iron. The core is about 3,500 km in radius (beginning at a depth of about 2900 km from the surface) and divided into two parts: a liquid outer core (down to a depth of 5,150 km), and a solid inner core, the innermost layer of

the Earth (Fig. 1). The convection of the liquid outer core is believed to create the Earth's magnetic field.

The liquid outer core includes substantial amounts of light elements in addition to iron. The existence of oxygen in the core has been put forward to account for the observed seismic-wave velocities and the density change at the inner core boundary. The structures of light element–bearing phases in the outer core conditions not only impart density variation but may also influence the geodynamic processes that are controlled by core convection. Iron monoxide (FeO), the major oxygen-bearing phase of iron, is estimated to account for 30% of the molten outer core. From seismic-wave observations, the outer core convention has been thought to occur in a single layer; yet the behavior of core materials at high pressure and high temperature, including changes in crystalline structure, has not been considered in this hypothesis. Thus, the nature of the core structure and dynamics remained elusive.
In this study, researchers reproduced the high pressure and temperature conditions of the outer core, and examined the phase change of crystalline FeO and its influence on the core convection.

Results
High-pressure and -temperature experiments were carried out at SPring-8, the large third-generation synchrotron radiation facility operated by JASRI. Crystalline structures of FeO were examined at pressures between 227 and 324 GPa and temperatures up to 4880 K by x-ray diffraction measurements. The results showed that the structure of crystalline FeO changed from a sodium chloride (NaCl)–type (B1) to a cesium chloride (CsCl)–type (B2) at 240 GPa and 4000 K, the condition comparable to those in the middle of the outer core (Fig. 3). Crystalline FeO adopts the B1-type structure at ambient condition and the nickel arsenide (NiAs)–type (B8) structure at high pressure. The existence of the B2–type FeO had been previously unknown.

The crystalline phase transition is assumed to affect the physical properties and flow dynamics of the outer core, and as such the above experiment results were incorporated into a numerical simulation of the outer core convection. The results showed a development of two-layered convection, with the boundary being at the depth of B1/B2 phase transition (Fig.4).

Future perspectives
The study suggests that the phase transition of materials composing the liquid outer core could develop stratified convection, instead of the single layer convection as conventionally thought. The possibility of two-layer convection may offer an explanation to the Earth's geomagnetic reversal; a sudden mixing of the upper and lower regions induced by magnetic and/or kinematic instabilities, which may trigger geomagnetic polarity reversal every 700,000 years on average.

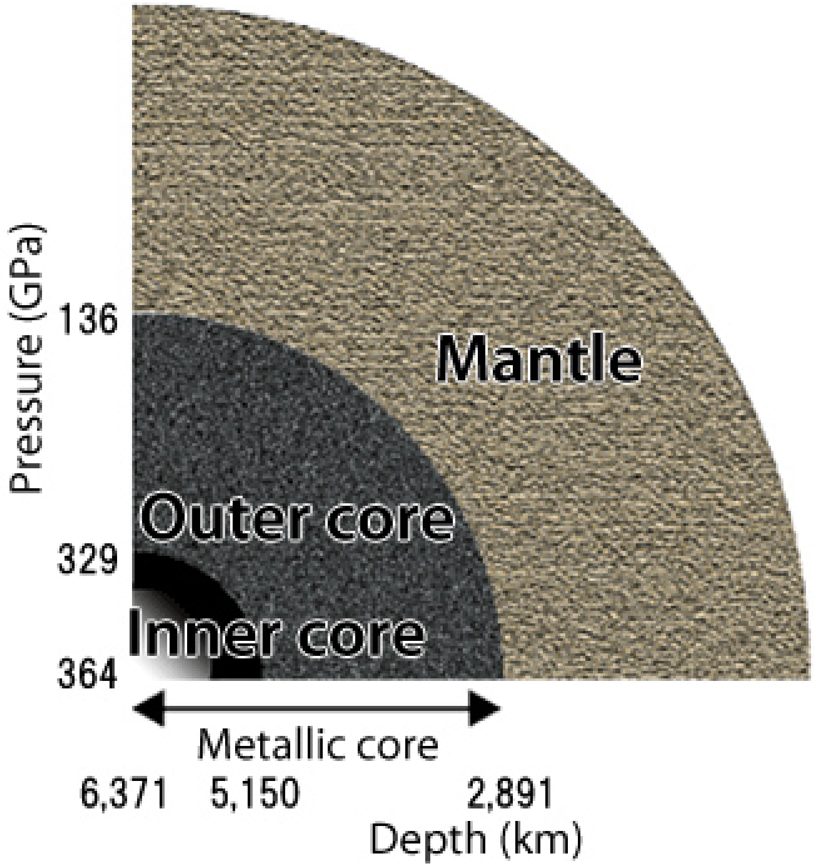

Figure 1. Cross-section Diagram of the Earth

Figure 2(A,B). Laser-heated diamond anvil cell
The diamond anvil cell (DAC) is a high-pressure apparatus in which a sample is compressed to high pressures by two opposing diamond anvils (C). It is capable of reproducing extremely high pressures and temperatures of the Earth's interior.

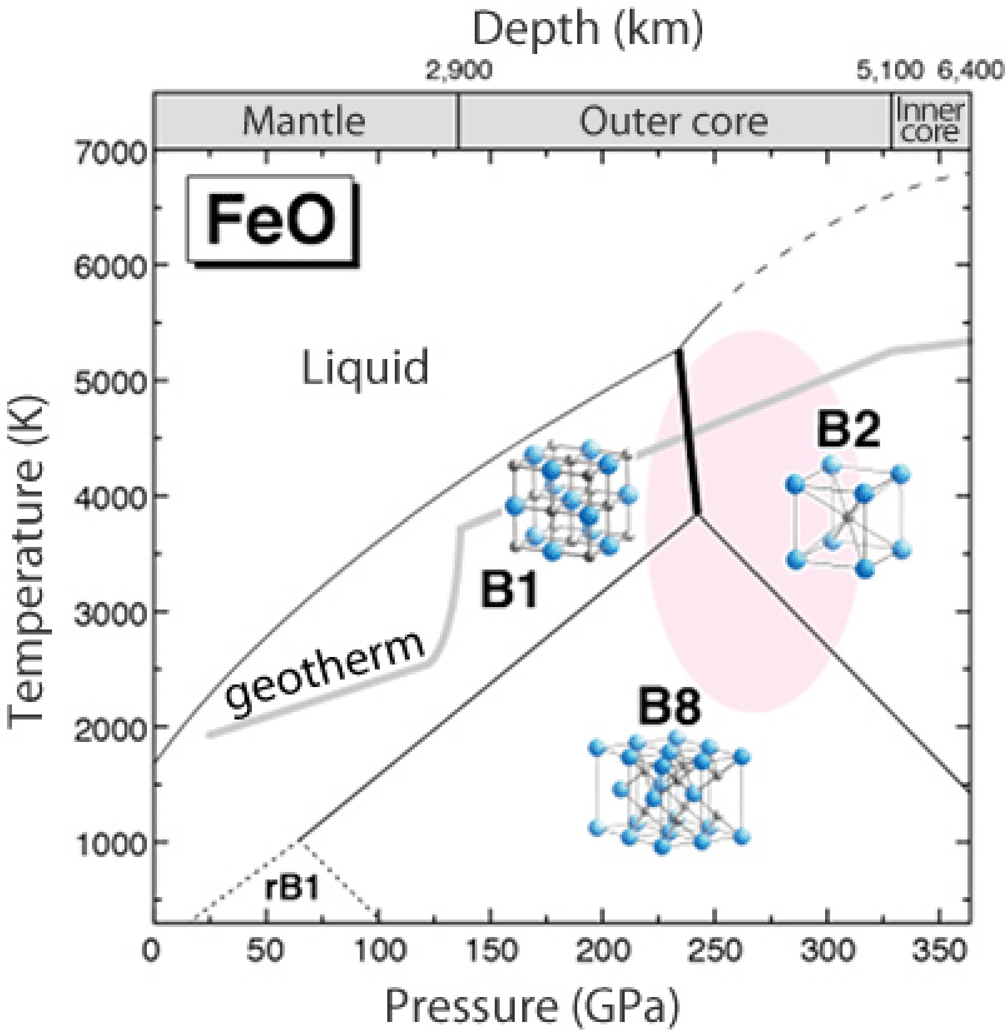

Figure 3. Phase diagram of FeO : sodium chloride (NaCl)–type (B1), cesium chloride (CsCl)–type (B2), nickel arsenide (NiAs)–type(B8) and rhombohedrally distorted B1 (rB1) phase from Fei & Mao(1994). The red shaded area indicates the temperature and pressure area reproduced in the experiments. The solid line represents the melting curve from Fischer & Campbell (2010). The inferred temperature profile inside the Earth is shown in gray.

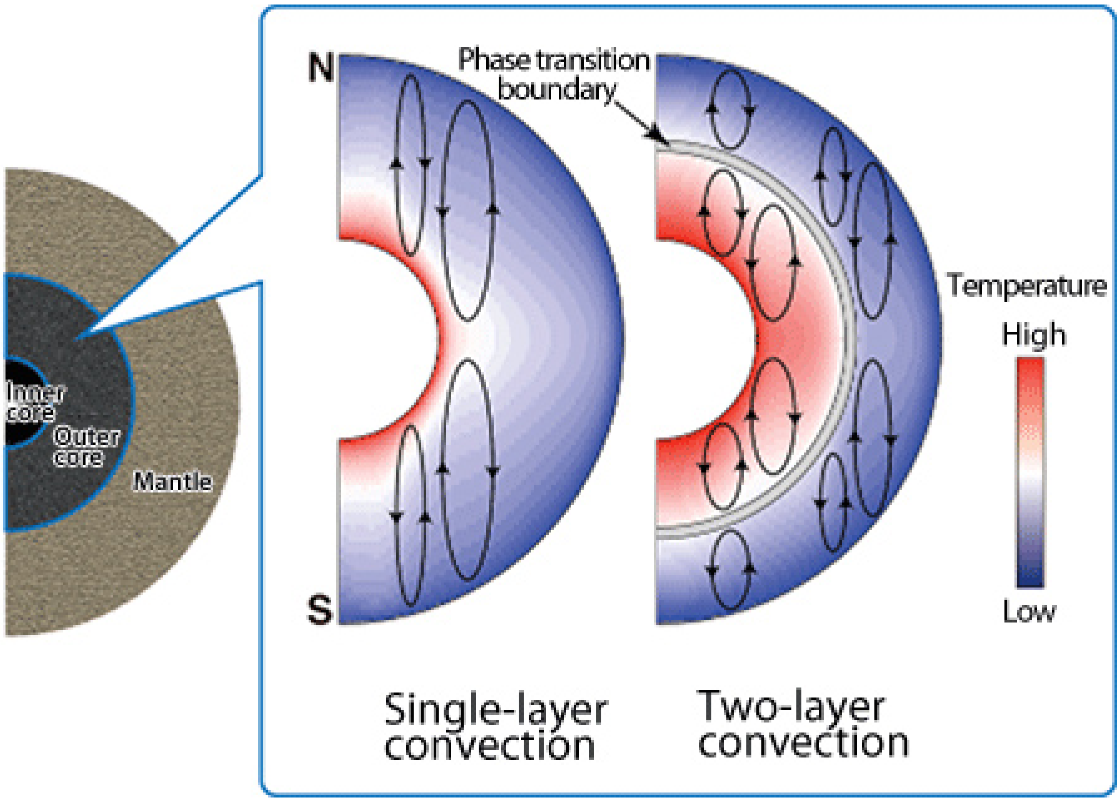

Figure 4. Meridional cross-section of the simulated core flow
The convection without the FeO phase transition (left) and the convection with the phase transition (right).

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