Japan Academy Prize to:

Kei Hirose
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for “Studies on Materials and Dynamics of the Earth’s Deepest Mantle”

Outline of the work:

The principal constituent mineral in the Earth’s lower mantle, extending down to the core–mantle boundary at 2900-km depth, had long been believed to be $MgSiO_3$-rich perovskite. In 2004, Dr. Kei Hirose discovered the transformation from $MgSiO_3$ perovskite to a denser phase (post-perovskite) at the pressure and temperature conditions estimated for the bottom of the mantle. This is the most important discovery in the studies of mantle materials since 1974 when silicate perovskite was discovered. Furthermore, he determined with his co-workers physical properties of post-perovskite and demonstrated that it plays an important role in the dynamics of the lower mantle.

Dr. Hirose has been conducting ultrahigh-pressure experiments on mantle materials using a laser-heated diamond-anvil cell (LHDAC) combined with in-situ X-ray analysis at SPring-8. With his advanced LHDAC techniques, he succeeded in obtaining static high-pressure and -temperature conditions of the deepest part of the mantle and discovered that $MgSiO_3$ perovskite transforms to a denser structure at pressures greater than 120 GPa at 2500 K corresponding to depths >2600-km. This new phase is 1.0–1.2% denser than perovskite and is named post-perovskite. The post-perovskite phase transition was found to occur not only in $MgSiO_3$ but also in natural mantle materials. The finding of post-perovskite made a significant impact among earth scientists, particularly those studying the Earth’s mantle.

In the bottom several hundred kilometers of the mantle called D” layer, large seismic wave anomalies are observed, and people have tried to understand and explain their causes without success. Dr. Hirose and co-workers determined the elastic wave velocities of post-perovskite by first principles calculations and found that the observed seismic anomalies can be well accounted for by the elastic properties of post-perovskite. Based on these Dr. Hirose’s studies, it is now established that the D” layer consists mainly of post-perovskite. Dr. Hirose further examined the transition boundary between perovskite and post-perovskite over a wide pressure and temperature range and demonstrated that the mantle convection is strongly enhanced by this phase transition; that is, relatively low-temperature down-going former oceanic plates become denser due to transition to post-perovskite at shallower levels than in surrounding mantle, whereas higher temperature regions in the lowest mantle become less dense due to the reverse transition at deeper levels, thereby accelerating the convection in the lower mantle. In addition, Dr. Hirose successfully conducted the measurements of electrical conductivity of post-perovskite and perovskite under high pressure-temperature conditions of the deepest mantle using LHDAC. He found that the electrical conductivity increases by three orders of magnitude upon transition from perovskite to post-perovskite. It implies that the D” layer, in which post-perovskite is the principal mineral, has high electrical conductivity as a whole. Presence of such a highly conductive layer just above the molten metallic core would enhance, by electromagnetic coupling, the exchange of angular momentum between the lower mantle and the core. It explains quantitatively the observed decadal variations in length of a day and also the periodic precession of the Earth’s axis of rotation.

The discovery of post-perovskite and the subsequent studies mentioned above have disclosed the materials and dynamics of the deepest part of the lower mantle which has been one of the least known part of our planet. A series of studies carried out by Dr. Hirose has greatly contributed to the advancement of the studies of the Earth's mantle.

Recently, Dr. Hirose together with his colleagues succeeded in generating the ultrahigh pressure-temperature condition corresponding to the center of the Earth (i.e. 364 GPa and ~5500 K). This is another milestone in solid earth science. He determined the crystal structure of iron, the principal component in the core, to be hexagonal close-packed (hcp) structure at such extreme conditions. It suggests that the hcp phase is predominant in the Earth's solid inner core, which has profound implications for its seismic-wave velocity structure, dynamics, and growth history.

Relevant publications

1. K. Hirose, Y. Fei, Y. Ma and H. Mao, The fate of subducted basaltic crust in the Earth's lower mantle. *Nature*, *397*, 53–56, 1999.
2. M. Murakami, K. Hirose, K. Kawamura, N. Sata and Y. Ohishi, Post-perovskite phase transition in $MgSiO_3$. *Science*, *304*, 855–858, 2004.
3. T. Iitaka, K. Hirose, K. Kawamura and M. Murakami, The elasticity of $MgSiO_3$ post-perovskite phase in the Earth's lowermost mantle. *Nature*, *430*, 442–445, 2004.
4. K. Hirose and Y. Fujita, Clapayron slope of the post-perovskite phase transition boundary in $CaIrO_3$. *Geophysical Research Letters*, *32*, L13313, 2005.
5. K. Hirose, R. Sinmyo, N. Sata and Y. Ohishi, Determination of post-perovskite phase transition boundary in $MgSiO_3$ using Au and MgO internal pressure standards. *Geophysical Research Letters*, *33*, L01310, 2006.
6. K. Hirose, Post-perovskite phase transition and its geophysical implications. *Reviews of Geophysics*, *44*, RG3001, 2006.
7. K. Hirose and T. Lay, Discovery of post-perovskite and new view on the core-mantle boundary region. *Elements*, *4*, 183–189, 2008.
8. K. Ohta, S. Onoda, K. Hirose, R. Sinmyo, K. Shimizu, N. Sata, Y. Ohishi and A. Yasuhara, The electrical conductivity of post-perovskite in Earth's D" layer. *Science*, *320*, 89–91, 2008.
9. S. Tateno, K. Hirose, Y. Ohishi and Y. Tatsumi, The structure of iron in Earth's inner core. *Science*, *330*, 359–361, 2010.
10. K. Hirose, Y. Nagaya, S. Merkel and Y. Ohishi, Deformation of $MnGeO_3$ post-perovskite at lower mantle pressure and temperature. *Geophysical Research Letters*, *37*, L20302, 2010.