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MAGNETIC FIELD AND PLATE TECTONICS ON SUPER EARTHS

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Abstract

D" layer's significance in the Earth's tectonics was just confirmed by Hirose and Lay in 2007[1]. For half a century, few people foresee the significance of Core-Mantle Boundary (CMB) dynamics in the geosystem. But as Lay et al [2] said on Nature, the CMB is about to replace the transition zone between Earth's upper and lower mantle as the region most likely to hold the key to a large number of geophysical problems.

1. Introduction

The story begins at the discovery of Post-perovskite (pPv) in 2004 [3], by Iitaka and Hirose's group. Ppv is a high-pressure phase of magnesium silicate (MgSiO3). It is composed of the prime oxide constituents of the Earth's rocky mantle (MgO and SiO2), and its pressure and temperature for stability imply that it is likely to occur in portions of the lowermost few hundred km of Earth's mantle. The ppv phase has implications for the D" layer that influences the convective mixing in the mantle responsible for plate tectonics. And Postperovskite is much more effective in conducting heat. In 2005 and 2006 Ono and Oganov published two papers[4,5] predicting that ppv should have high electrical conductivity, perhaps 2 orders of magnitude higher than perovskite's conductivity. In 2008 Hirose's group published an experimental report confirming this prediction [6].

2. Experiments and Hypothesis

At the Earth's infancy, there is no postperovskite, and the Earth's core is pure liquid, hence the magnetic field is very feeble. Later, when the Earth cools down, post-perovskite formed, and accelerates the mantle convection, increase volcanic activities, expediate continental growth. Without postperovskite, the growth of the Earth's continent should be much slower, and volcanic activity would not be so active. Postperovskite strengthened the Earth's magnetic field, letting it prevent the cosmic ray from damaging the biosphere. As remarked by Lay et al[2], Mantle plumes from D" layer could be very helpful to mantle convection. Lay's group detected that a hot mantle plume from CMB may be responsible for the volcanic island chain of Hawaii. Such a high heat flow supports the view that the upwelling mantle plumes formed near the core-mantle boundary would be very helpful to mantle convection, and the flow of mantle material led to the slow turning movement of the surface plate. In Zhang et al [7], our paper suggests that D" layer played a very significant role in the core-mantle electromagnetic coupling, and if this layer continue thickening, the core-mantle coupling would be able to accelerate the Earth's rotation!

3. Discussions

Let us consider the situation on Super Earth. In Diana et al [8], Super-Earth is predicted to have a temperature of at least 4000 K and a pressure of 10 Mbar at its CMB. Therefore, because of the extremely high pressure, perovskite would all transform into post perovskite, to form the D" layer on super earth. See the phase diagram of MgSiO3 based on the MgO pressure scale in Tateno et al [9]. What is the next polymorph of MgSiO3? This mineral should dissociate into CsCl-type MgO and cotunnite-type SiO2 at pressures and temperatures expected to occur in the cores of the gas giants and in terrestrial exoplanets. But, according to the phase diagram of MgSiO3 in Umemoto et al [10], at the CMB condition of a 10Mearth super earth, MgSiO3 remains ppv phase. In addition, deeper than the CMB, in the core, there would be dissociation. Combining the Earth's history, study of the Earth's Deep Interior (SEDI) and the MgSiO3, we suggest that ppv CMB will develop much earlier in the super Earth than Earth itself. Because in the Earth's CMB, the pressure is just 120GPa, at this pressure, ppv can be only formed under 2500k. It needs 1-2 billion years' cooling after the birth of the Earth to meet such a low temperature. But for a 10Mearth Super Earth, the CMB pressure reaches 1000GPa, hence ppv can form at any temperature. Hence, the D'' layer of the super earth would be much more developed than the Earth, and a even deeper layer could be mainly featured by cotunnite-type SiO2, which have electrical conductivity close to metallic values. This indicates:

First, according to Zhang et al [7], this indicates a very strong core-mantle coupling in the super earth. The strong coupling between core and mantle would inevitably influence the fluid motion of the outer core, thus influence the core magnetohydrodynamical (MHD) dynamo, leading to a strong magnetic field;

Second, uprising mantle plumes can easily break the thin crust, which is a precondition for plate tectonics. Subduction zones form where the lithosphere is already ruptured, such as at transform faults or fracture zones. The transition from stagnant lid to plate tectonics also requires lithospheric rupture to nucleate subduction. It is not clear what this would have been for Earth, maybe a meteor impact. But for a super earth, the unprecedented mantle plumes have such ability.

References

[1] Hirose K., Lay T.: Discovery of Post-Perovskite and New Views on the Core-Mantle Boundary Region, Elements, 4(3), 183-189, 2007.

[2] Lay T., Williams Q., Garnero E.J.: The Core-mantle boundary layer and deep Earth dynamics, Nature, 392, 461-468, 1998.

[3] Iitaka T., Hirose K., Kawamura K., Murakami M.: The elasticity of the MgSiO3 post-perovskite phase in the Earth's lowermost mantle, Nature 430, 442-445, 2004.

[4] Oganov A.R., Martonak R., Laio A., Raiteri R., Parrinello M.: Anisotropy of Earth's D'' layer and stacking faults in the MgSiO3 post-perovskite phase, Nature 438, 1142-1144, 2005.

[5] Onoa S., Oganov A.R., Koyama T., Shimizu H.: Stability and compressibility of the high-pressure phases of Al2O3 up to 200 GPa: Implications for the electrical conductivity of the base of the lower mantle, Earth and Planetary Science Letters, 246(3-4), 326-335, 2006.

[6] Ohta K., Hirose K., Lay T., Sata N., Ohishi Y.: Phase transitions in pyrolite and MORB at lowermost mantle conditions: Im-plications for a MORB-rich pile above the core-mantle boundary, Earth and Planetary Science Letters, 267(1-2), 107-117, 2008

[7] Zhang W., Sun Y., Neil K., Lei Y., Li Z.: The D'' layer's key position in the long-term electromagnetic core-mantle coupling and observational evidence, The European Physical Journal P, 126, 31, 2011

[8] Valenciaa D., Connella R.J., Sasselov D.: Internal structure of massive terrestrial planets, Icarus, 181,545-554, 2006

[9] Tateno, S., Hi-rose, K., Sata, N. and Ohishi, Y.: Determination of post-perovskite phase transition boundary up to 4400 K and implications for thermal structure in D''layer, Earth and Planetary Science Letters, 277(1-2), 130-136, 2009

[10] Umemoto K., Wentzcovitch R.M., Allen P.B.: Dissociation of MgSiO3 in the Cores of Gas Giants and Terrestrial Exoplanets, Science, 311, 983, 2006