Japan Geoscience Union Meeting 2011
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SIT004-P01 Room:Convention Hall Time:May 26 14:00-16:30

Texturing in the Earth s inner core due to preferential growth in its equatorial belt

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We propose an extension of the model by Yoshida et al. (1996), where deformation in the inner core is forced by preferential growth in the equatorial belt, by taking into account the presence of a stable compositional stratification. Stratification inhibits vertical motion, mposes a flow parallel to isodensity surfaces, and concentrates most deformation in a shallow shear layer of thickness proportional to $B^{-1/5}$, where B is the dimensionless uoyancy number. The localization of the flow results in large strain rates and enable the development of a strong texture of iron crystals in the upper inner core. We couple our dynamical model with a numerical model of texture development and compute the time evolution of the lattice preferred orientation of different samples in the inner core. With sufficient stratification, texturing is significant in the uppermost inner core. In contrast, the deeper inner core is unaffected by any flow and may preserve a fossil texture. We then investigate the effect of an initial texture resulting from solidification texturing at the ICB. In the present inner core, the deformation rate in the shallow shear layer is large and can significantly alter the solidification texturing, but the solidification texture acquired early in the inner core history can be preserved in the deeper part. Using elastic constants from ab initio calculations, we predict different maps of anisotropy in the modern inner core. A model with both solidification texturing and subsequent deformation in a stratified inner core produce a global anisotropy in agreement with seismological observations, both in magnitude and geographical distribution, with a weak anisotropy in the uppermost layer and stronger anisotropy in the deeper parts.

Keywords: Inner core, Iron, anisotropy, texturing

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SIT004-P02 Room:Convention Hall Time:May 26 14:00-16:30

Diffusion of Co, Mo in FeNi alloy at high pressure

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Seismic observations have shown that the PKIKP waves propagate faster in the north-south direction than in the equatorial plan (Poupinet et al., 1983), which might be caused by dislocation creep (Van Orman, 2004). On the other hand, observation of the seismic velocity structure at the top of the Earth inner core shows that the the eastern hemisphere is faster than in the western hemisphere (Niu & Wen, 2001), and they proposed that this might be caused by intrinsic chemical heterogeneity during inner core formation or temperature heterogeneity at the base of outer core. Siderophile elements (SEs) can partition into the inner core during the inner core-forming processes and its distribution can cause the chemical heterogeneity. Iron?nickel alloys are the principal constituents of the Earth core, and their chemical diffusion properties are important for understanding physical and chemical processes in the Earth inner core. If we could obtain diffusivity of SEs in Fe-Ni alloy, the chemical heterogeneity in the inner core and creep mechanism might be solved.

In this study, we measured diffusion coefficients of Mo, Co in fcc FeNi alloy at different conditions to determine pressure dependence on diffusivity. We conducted the experiments in four steps: 1) Synthesis of the Fe-Ni alloys of starting materials by piston cylinder (PC) apparatus at 1400 degree C and 1 GPa. 2) Diffusion runs by the piston cylinder at 1 GPa, and the Kawai-type multi-anvil apparatus (KMA) at different conditions of 7 GPa ,15 GPa and 22GPa and at different temperature conditions of 1200, 1400, 1600 degree C for 1~30 hours. 3) Analysis of diffusion profiles by electron probe micro-analyzer (EPMA). 4) Determination of the diffusion coefficient by fitting the diffusion profiles to Crank function using non-linear least squares method.

Our results show that: 1) Pressure has a negative effect on diffusivity of Co and Mo, and activation volumes are similar to those of Pd, Re and Au. 2) Temperature has a large positive effect on diffusivity, and activation energies are larger than those of Pd, Re and Au. 3) Atomic number has no effect on diffusivity of SEs, and diffusion coefficients of different SEs keep in same level. 4) Diffusion can not make the original heterogeneity of inner core became homogeneous.

Keywords: tracer diffusion, siderophile elements, high pressure

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SIT004-P03 Room:Convention Hall Time:May 26 14:00-16:30

Toward mineralogical interpretation of LLSVP: High-P,T elasticity of deep mantle materials

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Seismological studies have clarified that although most part of the lower mantle is fairly homogeneous, substantial heterogeneities exist at the bottom a few hundred km. They, in particular low-velocity anomalies observed beneath central-Pacfic and Africa often called large low shear velocity provinces (LLSVP), attract great interest, since to clarify nature of them G is a key to understanding of chemical and dynamical properties of the Eath's mantle. Although they would be produced associated with temperature and/or compositional heterogeneities, details are still largely unknown.

Elastic property of possible mantle constituents is one of the most important properties to clarify this issue. So many studies on the high-P,T elasticity of minerals have been perfomed to date. However, those are still limited for some major phases in the lowermost mantle condition, such as Mg-perovskite, post-perovskite, periclase, and Ca-perovskite. We therefore performed new ab initio simulations on the high-P,T elasticity of some other phases, which are expected not to be abundant in the average silicate mantle but to be substantial when considering differentiated materials. We will discuss possible compositional heterogeneity by constructing mineralogical models of the deep mantle based on the obtained elasticity.

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Keywords: LLSVP, elasticity, first principles

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SIT004-P04 Room:Convention Hall Time:May 26 14:00-16:30

Seismological and mineral physical joint modeling on seismic anisotropy above/below D”

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Many studies have reported a $V_{SV} < V_{SH}$ anisotropy in various places of the D” layer. Shear wave splitting in the D” layer beneath the Antarctic Ocean regions was observed by analyzing broad-band seismographs recorded at several recent permanent and temporary seismic stations in Antarctica. The lattice preferred orientation (LPO) of post-perovskite (PPv) and MgO phases are thought to be a major source of the D” anisotropy. However, we detected the anisotropy even above the D” discontinuity in these regions unlike previous studies. Perovskite (Pv) and MgO should be instead considered to explain the anisotropy above the D” layer. Although the deformation mechanisms of the mantle minerals under high-P,T condition are still under debate, mineral physics modeling helps us to know likely LPO directions. In order to clarify the origin of the anisotropy, the seismological and mineral physical (in particular first principle calculations) joint modeling would be an important approach. We first construct new transverse isotropic (TI) shear wave velocity models by the seismic waveform modeling, which have a velocity discontinuity atop the D” layer and some anisotropy even above the discontinuity. Then we calculated the elastic anisotropy of polycrystalline aggregates (Pv + MgO) and (PPv + MgO) in several different LPO directions with a different degree by means of ab initio high pressure elasticities. Preliminary results suggest that a transversely isotropic aggregate (TIA) of Pv with [100] and MgO[100] vertical directions with unexpectedly small LPO can reproduce the observed anisotropy above the D” discontinuity. TIA of PPv[001] is possible to be an origin of the anisotropy below the discontinuity. Although PPv[010] is thought to be the major cause in previous works, our results suggest that only complete TIA of PPv[010] can explain the observations. The most likely case is TIA of MgO[100] model. Though the amount of MgO is much smaller than that of PPv and Pv, significantly small LPO can reproduce the anisotropy, indicating MgO is much anisotropic. We conclude that MgO is highly possible to be an origin of the anisotropy. Regional variations will be also demonstrated.

Research supported by JSPS Grant-in-Aid for Scientific Research Grants 21740330 and the Ehime Univ G-COE program ”Deep Earth Mineralogy”.

Keywords: Anisotropy, Lowermost mantle, Shear wave splitting, Seismic observation, Numerical modeling

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SIT004-P05 Room:Convention Hall Time:May 26 14:00-16:30

X-ray absorption spectroscopy of iron-bearing minerals under high pressure.

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The Earth's mantle contain significant amount of iron. Iron in the mantle is observed to undergo high-spin to low-spin transition and change of valence state in the lower mantle condition, which affect seismic velocity and oxidation state of mantle minerals. Experimental evidences of the spin transition have been suggested from a small change of compression property or disappearance of satellite peak in X-ray emission spectrum. Change of the valence state has been observed by electron or Mossbauer microscopy for the recoverd samples. These method is not conventional and take much time for measuring. Therefore, we have been charenging with another experimental method, X-ray absorption spectroscopy (XAS). This method can be combined easily with diamond anvil cell (DAC) for in situ measurement at high pressures. The X-ray absorption experiments under high pressure were performed at the BL-3A in KEK-PF (Tsukuba, Japan). The beam line is suitable for XAS with DAC because high intensity monochromatic X-ray of around 7keV from insertion device was focused with collimator and exposed to tiny area of the sample. The absorption of the samples were measured by transmission geometry with two ionization chambers. Several samples such as iron oxides, olivine and garnet were used as standard material to check the absorption edge to 20-30 GPa. We compressed also $(Mg_{0.87}Fe_{0.13})O$ sample to 74 GPa for detect a spin transition. We found that the balance state is distinguishable even at pressures under the right conditions. The details of experiments and analisis will be presented.

Keywords: X-ray absorption, diamond anvil cell, mantle

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SIT004-P06 Room:Convention Hall Time:May 26 14:00-16:30

Numerical investigations of the effects of spatial variations in physical properties on the mantle convective patterns

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We performed a linear stability analysis on the onset of thermal convection of fluid in the presence of spatial variation of physical properties such as viscosity, thermal expansivity and conductivity. The viscosity of the fluid is exponentially dependent on temperature, while thermal expansivity and conductivity are linearly dependent on pressure (or depth). The planar layer model geometry is employed. The top and bottom boundary conditions for velocity are taken to be either free-slip or rigid surface while the temperature are fixed on the boundaries. Velocity and temperature distributions are solved for infinitesimal perturbations for given horizontal wave number. We seek for the condition for the onset of convection by changing the values of Rayleigh number and wave number. Then, we examine the influence on incipient convection patterns of the magnitude in spatial variation in physical properties.

Our analysis successfully reproduced the transition in flow patterns into the 'stagnant lid' regime where a thick and stagnant lid of cold fluid develops at the top surface because of the very strong temperature dependence of viscosity. These flow patterns are quite similar to those obtained in finite-amplitude convection. Moreover, we found that the presence of spatial variation in thermal expansivity and conductivity, together with the strong temperature dependency in viscosities, changes the convective planform and moderately affects the onset of stagnant lid regime. In the presentation, the details of numerical results would be shown and discussed for describing the nature of the stagnant lid convection.

Keywords: mantle convection, linear stability analysis, temperature-dependent viscosity, pressure-dependent thermal expansivity, pressure-dependent thermal conductivity, stagnant-lid convection

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SIT004-P07 Room:Convention Hall Time:May 26 14:00-16:30

Fe distribution between (post-)perovskite and ferropericlase

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Thermochemical properties in the Earth's deep mantle is still not completely understood. Fe distribution in major lower mantle phases of (post-)perovskite and ferropericlase is of particular importance, because Fe has several substantial effects on density, elasticity, electric and thermal conductivity. Many high-pressure experiments have tackled this issue to date, but the results at the moment seem less converged both experimentally and theoretically. This is originated mostly in multiple complexities related to the valence state, spin state, and incorporation mechanism of Fe. These lead to pressure-induced charge disproportionation reaction and high-to-low spin transition of Fe, all of which need to be considered for understanding the behavior of Fe comprehensively. In this study, we conducted ab initio density functional computations of the Fe distribution in several complex, more realistic situations including multiple phase and also Al-bearing cases. Although we will report details in the presentation, the calculations so far indicate strong effects of the disproportionation of Fe in Pv and spin transition in Fp. They are more remarkable than expected and have opposite contributions. We anticipate that the predicted behaviors should be observed experimentally.

Keywords: lower mantle, Fe distribution, charge disproportionation, spin transition

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SIT004-P08 Room:Convention Hall Time:May 26 14:00-16:30

Improvement of a semi-dynamical numerical model of a subduction zone in a 3D sphere and its applications

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In this presentation, we present a semi-dynamical subduction zone model in a three-dimensional spherical shell and its applications. The approach we take to enable one-sided subduction at a given angle is to impose velocity on the top surface and in a small three-dimensional region around the shallow plate boundary. The velocity imposed in the region around the plate boundary is determined based on the idea that mass conservation inside the region is satisfied. We can also easily incorporate trench migration kinematically in the model. The advantage of the model is that it allows us to use constraints from as many as possible observations, such as surface plate velocity, shape of the trench and subduction angle in the shallow part, which makes it easier for us to compare the results with observations. Therefore, the model is useful for studying a specific subduction zone where the plate kinetics are well constrained.

As applications of the model, two cases are considered. First, mantle flow around a slab edge is considered, and we find that the effect of Earth curvature on mantle flow is small by comparing our model with a similar one in a rectangular box. If, however, we model a broader area or deeper processes, the effect of Earth curvature may become large and hence important. Second, the case with non-Newtonian rheology is considered using the improved model. One difficulty that may arise in considering non-Newtonian rheology is the treatment of the singularity near the edge of the region around the plate boundary. The effect of the singularity is, however, suppressed by ramping the velocity imposed around the region. The calculation with non-Newtonian rheology may be useful particularly if we study seismic anisotropy.

Keywords: subduction zone, non-Newtonian rheology, 3D sphere, mantle flow

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SIT004-P09 Room:Convention Hall Time:May 26 14:00-16:30

Metastable postspinel and post-garnet transitions in pyrolite: an implication for multiple seismic discontinuities

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Postspinel and post-garnet transformation experiments were carried out at pressures between 22 and 27 GPa at a temperature of 1873 K using synthesized polycrystalline sample with pyrolite comoposition which consists of ringwoodite and majorite garnet. We observed that three discontinuous transitions occur in the ringwoodite + majorite garnet polycrystalline sample: (1) disproportionation of MgSiO3-rich perovskite (MPv) with small amount of alumina and CaSiO3-rich perovskite from majorite garnet at about 22 GPa; (2) postspoinel transition producing alumina-free MPv and magnesiowustite at about 23 GPa; (3) transition of alumina-rich majorite into alumia-rich MPv that should be accompanied by formation of an aluminous phase at 27 GPa. The presence of the observed transitions in three steps in metastable pyrolite is very different from the equilibrium transitions studied in previous studies: postspinel transition is sharp and postgarnet transition proceeds gradually in a binary loop in MgSiO3-Mg3Al2Si3O12 system. The equilibrium transition can explain features of 1D earth models such as PREM: the sudden increase of velocities at 660 km depth corresponds to the postspinel tranisition and the increase of the velocities with steeper gradient between 660 and 720 km to gradual transition of majorite garnet. The results of the present study suggest that the metastable transformations in pyrolite explain the regionally observed splitting of 660 km discontinuity, especially beneath subduction zones: the postspinel transition causes the discontinuity near 660 km depth (which can be deeper than 660 km depth because of low temperature of subducting slab); the shallower and deeper discontinuities might be caused by the metastable transformations of majorite garent.

Keywords: metastable transformation, pyolite, multiple seismic discontinuities, 660 km detph

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SIT004-P10 Room:Convention Hall Time:May 26 14:00-16:30

Electrical conductivity measurements of hydrous minerals under high pressure

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The electrical conductivity measurements of hydrous minerals (including natural talc rocks and serpentinites, synthesized $Mg(OH)_2$ and $Mg(OD)_2$, and synthesized dense hydrous magnesium silicates) were conducted using an impedance analyzer under high pressures generated by a 1000-ton Kawai- type multi-anvil high pressure apparatus. The electrical conductivity anisotropy of deformed natural talc rocks and serpentinites was investigated in the frequency range of 10^{-3}-10^{6} Hz and temperature range of 500-1000 K along three directions: the direction parallel to lineation of oriented minerals (X direction), the direction perpendicular to lineation on the foliation plane (Y direction), and the direction perpendicular to the foliation (Z direction) at 3 GPa. The electrical conductivities of $Mg(OH)_2$, $Mg(OD)_2$ and phase A polycrystals were measured in the frequency range of 10^{-1}-10^{6} and temperature range of 500- 750 K at 3 GPa, 3 GPa and 10 GPa, respectively. For talc rocks and serpentinites, the electrical conductivities parallel to the X direction and the Z direction are the highest and the lowest, respectively. The electrical conductivity anisotropy for the talc rocks is stronger than that for the serpentinite. The electrical conductivity anisotropy of natural deformed talc rocks and serpentinites strongly depends on the crystal structure and orientation of minerals during deformation. The electrical conductivity increases in orders of talc, serpentine, phase A (similar with serpentine), deuterium brucite and hydrogen brucite, indicating the dependence of the electrical conductivity on water contents in the structures. The activation enthalpy of talc rock is the lowest (0.59 eV) in the X direction and the highest (0.68 eV) in the Z direction. The activation enthalpies of the serpentinite in different directions show the consistent value, 0.74 eV, for the experiments using Mo electrodes. In the case of using Ni electrodes, the activation enthalpies are 0.70 eV, 0.66 eV and 0.68 eV for the measurements in X, Y and Z direction respectively. The higher electrical conductivity and the lower activation enthalpy of the serpentine using Ni-NiO buffer are attributed to the higher fO_2 of Ni-NiO buffer. The activation enthalpies of $Mg(OH)_2$, $Mg(OD)_2$ and phase A are 0.86 eV, 0.81 eV and 0.68 eV respectively. Furthermore, grain interior conductivity, grain boundary conductivity and electrode reaction can be recognized from the impedance arcs. Relationship between logarithm of electrical conductivity of grain boundary and reciprocal temperature shows the linear relationship as well as the grain interior conductivity. The total electrical conductivities are reduced by the grain boundary conductivities.

Keywords: Electrical conductivity, Talc rocks, Serpentinites, Brucite, Phase A, Anisotropy

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SIT004-P11 Room:Convention Hall Time:May 26 14:00-16:30

Adjoint tomography of East Asia

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We use spectral-element and adjoint methods to image upper mantle P-wave and S-wave speed heterogeneities in East Asia. We take one chunk from global mesh of spectral-element method and compute synthetic seismograms with accuracy of about 10 second. The study area involves the convergent boundaries of the Pacific, Indo-Australian and Philippine-sea plates and the slab subuducted from the boundaries show a complex morphology. We use GAP-P2 mantle tomography model (Obayashi et al., 2009) as an initial 3D model and try to use as many broadband seismic stations available in this region, including Ocean Bottom Seismographs deployed in Philippine sea, as possible to perform inversion. Before accumulating finite frequency adjoint kernels for seismic velocity structure, we estimated influences of the initial 3D model on the focal mechanism and hypocenter location. We chose earthquakes occurred at various locations and depths in this region from Global CMT catalog. We picked up time windows for P and S waves that give decent match between data and synthetics for 3D model and determine the best fit solutions for source mechanism and hypocenter. We found that the redetermined solutions do not differ much from the Global CMT solutions, which shows that he Global CMT solutions can be used as initial solutions in the inversion. We then use the time windows for P and S waves to compute adjoint sources and calculate adjoint kernels for seismic velocity structure. Our first result of the inversion will be shown at the meeting.

Keywords: mantle, tomography, spectral element method, adjoint method