Compositional layering within the Large Low Shear-wave Velocity Provinces in the lower mantle

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The large low shear-wave velocity provinces (LLSVP) are thermochemical anomalies in the deep Earth’ s mantle, thousands of km wide and ~1,800 km high. This study explores the hypothesis that the LLSVPs are compositionally subdivided into two domains: a primordial bottom domain near the core-mantle boundary and a basaltic shallow domain extending from 1,100~2,300 km depth. This hypothesis reconciles published observations in that it predicts that the two domains have different physical properties (bulk-sound vs. shear-wave speed vs. density anomalies), the transition in seismic velocities separating them is abrupt, and both domains remain seismically distinct from the ambient mantle. We here report underside reflections from the top of the LLSVP shallow domain, supporting a compositional origin. By exploring a suite of two-dimensional geodynamic models, we constrain the conditions under which well-separated “double-layered” piles with realistic geometry can persist for billions of years. Results show that long-term separation requires density differences of ~100 kg/m^3 between LLSVP materials, providing a constraint for origin and composition. The models further predict short-lived “secondary” plumelets to rise from LLSVP roofs and to entrain basaltic material that has evolved in the lower mantle. Long-lived, vigorous “primary” plumes instead rise from LLSVP margins and entrain a mix of materials, including small fractions of primordial material. These predictions are consistent with the locations of hotspots relative to LLSVPs, and address the geochemical and geochronological record of (oceanic) hotspot volcanism. The study of large-scale heterogeneity within LLSVPs has important implications for our understanding of the evolution and composition of the mantle.

Keywords: Mantle Convection, Primordial Reservoir

Origin of Seafloor, Platetectonics, Pacific arc basin**, Proof of eccentric Moment Force,** Mechanism of Plate rapid change of direction,

Verification by Abduction of "Multi Impact Hypothesis" explaining everything **uniformly.**

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Structure and Dynamics of Earth and Planetary

Mantles Continental movement theory, Ocean Floor expansion theory, Driving force from Plate Tectonics to Plume Hypothesis was Thermal Convection Hypothesis.

We propose Celebrity Hypothesis that Minimizes Moment of Inertia caused by crushing crust Mantle defect and isostatic uplift eccentricity due to Inertial efficiency imbalance as **Plate new Driving Force**.

A Wegenr tried to prove **Continental drifft hypothesis** and prove it based on Continuity of paleontology and geology because Coastal profile of Africa coincides with that of continental North and South America.

Plate tectonics is now almost a fixed theory with empirical observations such as **Ocean Foor Epansion Hypothesis**, **Mantle Thermal Convection Hypothesis,** discovery of Atlantic mid-ocean ridge, discovery of transform faults, reversal of geomagnetism and submarine tape recorder Hypothesis.

However, **Driving force of Continental movement** *that Wegener could not show is **still a mystery** in **Plate Tectonics**.*

Wegener pointed out Effort to explore Origin of Deep ocean floor (-5 km) occupying 70%, Origin of Plate boundary, Origin of plate tectonics.

Arcuate archipelago and Origin of Basin still remain a mystery. A new paradigm capable of unifying all of this was desired.

It is Multi Impact Hypothesis by Abduction and was stated in "Elucidation of Missing link of Earth and Moon" from geophysics and solar system planetary theory.

According to it, in addition to Origins of this Plate Tectonics, Origin of Moon, Origin of Deep ocean floor, Core eccentricity, Origin of Jupiter's Great Red Spot, Origins of Mercury and Pluto, Origin of Asteroid belt and Differentiated Meteorite. It is a proposal of a new paradigm that can unravel Origin of Word.

Furthermore, I could also show Reason for Eccentric Density difference where Moon and Moon's Orbital Energy (theoretically calculated from Collision Energy) and Mantle matter are oriented on Same side.

Abduction is Idea that Correctness of Hypothesis is guaranteed to Extent that Conclusion by a certain Hypothesis can explain Current situation.

It is a big change of thinking and it is called creative reasoning,Abduction.

Using Physically Meaningful Hypothesis, if Idea is correct, a breakthrough progress is obtained.

"Multi Impact Hypothesis":About 4 billion years ago from the birth of the solar system, when CERRA orbital deformed due to Jupiter perturbation and ruptured by the tension of Jupiter and the sun, CERRA and the Earth were differentiated and solidified.

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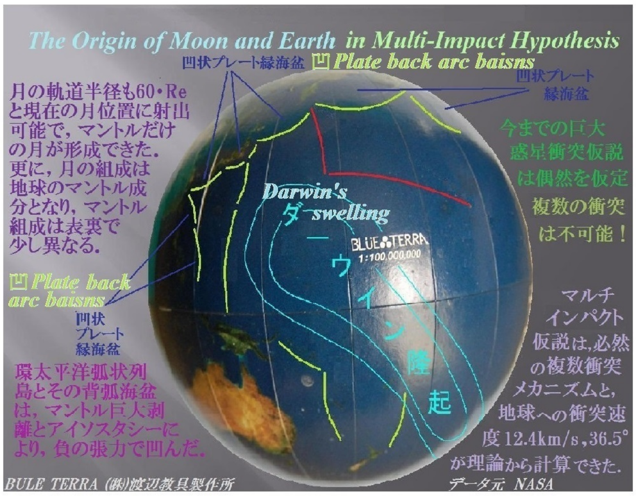
solidified.
When Darwin's rise (convex plate) occurred in Collision Mantle Defect due to isostasy, Plate from which Surrounding crust had peeled recessed and Boundary Crack formed Arcuated Islands, Pacific Rim Arc Island concave arc.
Arcuate archipelago centered on Pacific Ocean and Java Island during Formation of Tacos Sea, a trench arc continuing to Outer side of Arcuate Island indicates that Convex Plate has slipped under Arcuate archipelago concave basin (= Mutual slipping mechanism of Plate).
Plate boundary is caused by cracks when multiple mantle fragments crash into Earth.

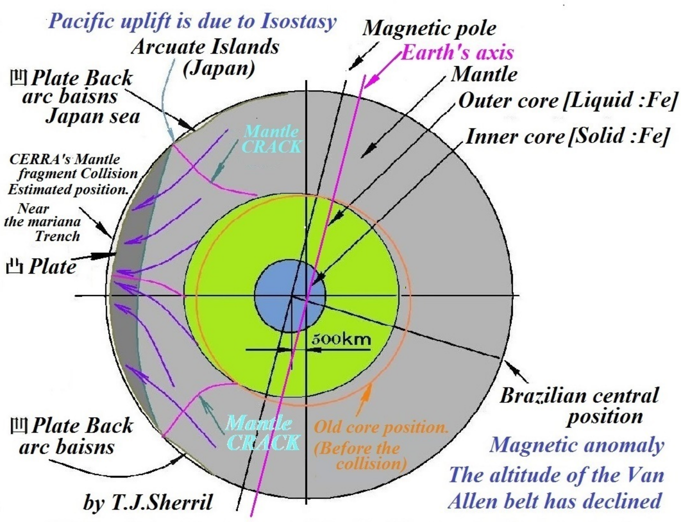
Proof of inertial efficiency eccentric moment driving force
In this Hypothesis, since Earth rotates on its own axis, in Earth where Moment of Inertia becomes uneven (unbalanced) when Missing mantle is isostasic due to collision, Driving force that minimizes Moment of Inertia is generated.
Reason for sudden change in movement direction and Mechanism of rotation axis Inclination
Impact fracture at single mantle collision works on Opposite side of Earth as Ejection pressure from Inside.
Formation mechanism of Diamond mine is indicated by Formation of a kimber-lite pipe.
Collision with Drake Passage is Cause of Diamond mine in Russia Miruuui.
A tilt of 23.5 °was formed on Axis of rotation from the revolving surface due to the couple of collision to high latitude.
There are three rows of curved trajectories parallel to plate movement traces of Hawaiian Islands and Kuril Seamount line
It is a result in Direction of plate movement, which is caused by a sudden change in Rotation Axis.

- Evolution of Earth only once -Demonstrated by history -
Ability to explain all Mysteries as a unified Evolution alone with one Hypothesis is verification by Abduction of "Multi Impact Hypothesis".
It is expected that quantitative simulation becomes possible in more detail from Qualitative Elucidation.

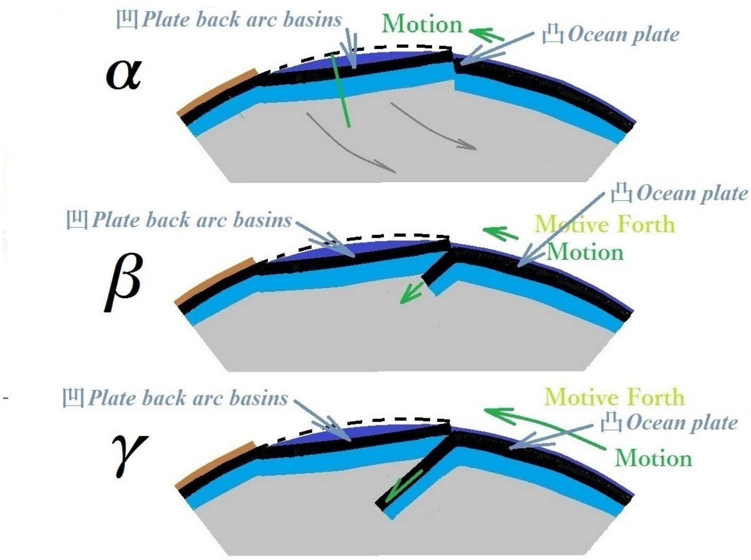
Keywords: Origin of Ocean floor, Origin of the "Moon formation and the Earth's plate tectonics", Proof of inertial efficiency eccentric moment driving force, Origin of the Pacific Rim Arc Isolated Archipelago Back Arc Basin, Mechanism of Slipping Inside Plates, Plate movement direction rapid change mechanism reason, Verification by abduction - by one-time evolution of the earth and empirical history -

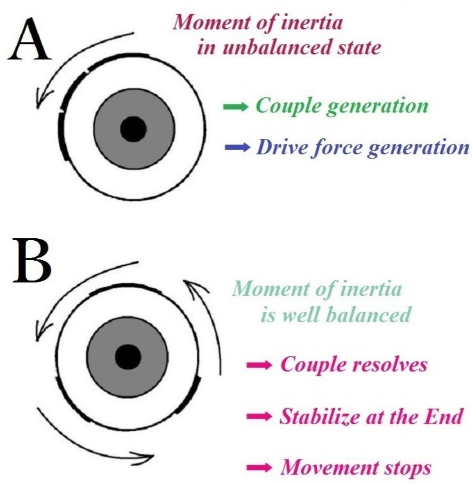
Origin of the Earth,Plate-tectonics,Ocean-floor, by Abduction in Multi-Impact Hypothesis CERRA





Origin of plate tectonics and the Pacific arcuate back-arc basin





Phase Transformation Mechanism Responsible for Deep-focus Earthquakes by The Multi-Phase-Field Methods

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One of the possible mechanisms for deep-focus earthquakes is the faulting associated with phase transformation from olivine to spinel under high pressure. Burnley et al. (1991) conducted deformation experiments of Mg_2GeO_4 under conditions at confining pressures of 1~2 GPa, temperature of 900~1500 K and strain rates of 2×10^{-5} ~ 2×10^{-3} s^{-1}. The spinel is observed like microscopic lenses in place of microcracks. They form perpendicular to the maximum compressive direction, which is called “anticracks.” They connect with each other, eventually, cause the faulting. Spinel anticracks can be formed by intracrystalline nucleation and nucleation at grain boundaries. As the mechanism, it has been advocated that they form by nucleation whose crystal orientation is random, martensitic transformation or along the dislocation. However, we don’t know which is a dominant mechanism forming spinel anticrack. So, to reveal how spinel anticracks are formed, we have studied the transformation mechanics by the Multi-Phase-Field (MPF) method. The MPF method is a phenomenological model based on continuum mechanics and has widely used in material sciences. We can reveal temporal change of material morphology by MPF method, that is, easily follow crystal interfaces with probability. We developed the numerical model taking into account of both intracrystalline nucleation and nucleation at grain boundaries. Furthermore, to constrain physical conditions of the numerical model, we also conducted experiments by a Griggs type piston-cylinder apparatus using solid NaCl as a confining medium based on Burnley et al. (1991) to observe microstructure of a deformed sample. We compressed Mg_2GeO_4 as an analogue material under conditions at confining pressure of 1.2 GPa, temperature of 1200 K and strain rate of 2.0×10^{-4} $s^{-1}$where Burnley et al. (1991) reported faulting by anticrack mechanism. As a result of the experiment, the sample was ductile deformed. According to the microstructural observation on the deformed sample, there are many bands composed of very-fine grained materials. The particle size is very small and there are small faults in the vicinity, so we think that superplastic deformation in these fine-grained portions might cause faulting, as proposed by Burnley et al. (1991). Also, compared to hydrostatic experiment in which fine grain materials were observed but phase transformation didn’t occur, we inferred that phase transformation is difficult to occur without differential stress. Therefore, we modified the conditions of numerical model to consider superplastic deformation and particle size, finally, built up new numerical model.

Keywords: Deep-focus earthquakes, Phase Field, Griggs type piston-cylinder apparatus

Stability of anhydrous phase B, $Mg_{14}Si_5O_{24}$, at the mantle transition zone conditions

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Stability of anhydrous phase B, $Mg_{14}Si_5O_{24}$, has been determined in the pressure range of 14-21 GPa and in the temperature range of 1100-1700°C with both normal and reverse experiments at high pressures and high temperatures. Our results imply that anhydrous phase B is stable at the *P-T* conditions corresponding to the shallow depth of the mantle transition zone and it decomposes into periclase and wadsleyite at greater depth. The decomposition boundary of anhydrous phase B into wadsleyite and periclase has a positive phase transition slope and can be expressed by the following equation, P(GPa)= $7.5 + 6.6 \times 10^{-3}T(°C)$. Configuration disorder might account for an increase of entropy for anhydrous phase B at high-temperature conditions. It is suggested that MgO-rich conditions can be available in the deep mantle during hydrous melting of peridotite and the reduction of subduction carbonates by the metal-saturated mantle at depth > 250 km. Anhydrous phase B might become an important phase in the area where SiO_2 activity is low. We propose that the paragenesis of directly touched ferropericlase-olivine inclusions in natural diamonds might be the retrogression products of anhydrous phase B via the decomposition reaction Anh-B = Olivine + Periclase during the transportation of host diamonds from the deep to the surface. Our experimental results put a constraint on the origin of such diamonds at a depth less than 500 km. On the cooling of the magma ocean during the early history of the Earth, a distinctive layer that was concentrated with hydrogen and other elements such as Fe, Ca, Mn substituting Mg might exist with the crystallization and accumulation of anhydrous phase B at depth equivalent to the upper part of the mantle transition zone.

Keywords: Anhydrous phase B, phase relations, Clapeyron slope, diamond inclusions, Raman spectra

Numerical simulations on the formation and behaviors of slabs in 2-D spherical annulus

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We developed a numerical model of thermal convection of highly viscous fluid in a two-dimensional spherical annulus, aiming at (i) classifying the morphologies and dynamic behaviors of subducting slabs, (ii) comparing the shapes of slabs obtained in our simulation models with those estimated from seismic tomography to offer the constraints on the plate velocities and the properties of the 660 km discontinuity from fluid-dynamical viewpoints.
In this study, we consider a time-dependent convection of fluid under the extended Boussinesq approximation. The viscosity of mantle material is assumed to be exponentially dependent on temperature and pressure (or depth). We also have included the exothermic olivine to spinel phase transition at around 410 km depth and the endothermic post-spinel phase change at around 660 km depth. The plate subduction is modeled by downward flow of cold and viscous fluid along with a conduit which guides the descending slab from surface to the mantle transition zone. We take into account the effect of trench migration, by imposing the migration of the conduit with respect to the deep mantle.
We found that our model successfully reproduces the diverse morphology of subducting slabs which can be well compared with those of natural slabs, by carrying out calculations with systematically varying the velocities of subducting slabs and trench migration, the Clapeyron slope at around 660 km depth, and the viscosity jump between the upper and lower mantle. In particular, the dynamic behaviors of slabs around the mantle transition zone can be classified into five types depending on the combinations of varying parameters: (1) Penetrating, (2) Accumulating, (3) Floating, (4) Long-term Stagnation, and (5) Short-term Stagnation.
A careful comparison of the slab morphologies in our numerical experiments with those of natural slabs in selected subduction zones enabled us to estimate the rate of trench migration with respect to the deep mantle, given that both the duration of subduction and rate of two-plate convergence are properly known. This implies that the morphology of slabs can be used to settle a reference frame of motions of surface plates, which is of crucial importance in determining their absolute velocities from the relative ones. Such comparison could also offer fluid-dynamical constraint on the properties of the 660 km discontinuity.

Keywords: subducted slab, stagnant slab, mantle convection, numerical simulation

Fabrication of highly-dense and fine-grained olivine aggregates with various crystallographic preferred orientation patterns in natural peridotite rocks

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Olivine is the most abundant mineral in the Earth’s upper mantle and it is considered to orient crystallographically in response to the mantle flow. Six types of fabrics have been identified in mantle peridotite: A, B, C, D, E and AG type. Physical properties of olivine such as elasticity, plasticity, thermal conductivity, thermal expansion and electron conductivity are known to be anisotropic so that geophysical observations showing directional dependence in the mantle are often attributed to the result of crystallographic preferred orientation (CPO) of the mineral. However, most of our current understanding of the effects of CPO on physical properties of bulk rocks is essentially based on the properties of single crystals.
To measure CPO effect on the bulk rock properties directly by room experiments, it is required to prepare polycrystalline materials with ideally controlled CPO
Olivine particles synthesized from source oxide powders and natural mineral particles prepared from milling natural olivine crystals were used in this study. To fabricate olivine aggregates with CPO, an external strong magnetic field (12 T) was applied to the olivine fine particles which were dispersed in the solvent. The alignment of certain crystallographic axes of the particles with respect to the magnetic direction was anticipated due to magnetic anisotropy of olivine. The dispersed particles were gradually consolidated on a porous alumina mold, which was covered with a solid-liquid separation filter, during drainage of the solvent. The consolidated aggregate was then isostatically pressed and vacuum sintered. Uni-axially aligned *c*-axes and *b*-axes olivine aggregates that correspond BC-type and AC-type peridotite were obtained from the aggregates aligned under static and rotated magnetic field, respectively.
Tri-axially aligned olivine aggregates corresponding to A-, B-, C- and E-type peridotite were obtained from a modulated rotation magnetic field.

Keywords: crystallographic preferred orientation, olivine, mineral aggregate

High-resolution 3-D S-wave structure beneath North America using phase and amplitude of surface waves

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Majority of surface wave tomography have employed the phase information, which reflects the average phase speed perturbation along a propagation path. To the contrary, the use of amplitude anomalies of surface waves has been limited in tomographic studies, due to a variety of uncertain factors such as source mechanism, local amplification at receiver, elastic focusing/defocusing and anelastic attenuation. In the interstation analysis, the source term can be canceled out, so that we can focus on the effects of the elastic focusing/defocusing as well as the receiver amplification factors, with an appropriate correction for anelastic attenuation. In the framework of ray theory, the amplitude anomalies affected by the focusing/defocusing reflect the second derivatives of phase speed across the ray path, and thus the amplitude data are more sensitive to shorter-wavelength structure than the conventional phase data.

In this study, we employ a fully non-linear waveform fitting technique to measure interstation phase speeds and amplitude ratios simultaneously, based on a global optimization method. This technique is applied to observed seismograms of the high-density transportable array deployed in the United States (USArray) in the past decade, and a large-number of interstation phase speed and amplitude ratio data are collected. The typical interstation distances for measured dispersion data are less than 1000 km, which is much shorter than the average path length used in conventional single-station analysis and can be of help in improving the lateral resolution of the regional tomography models.

The measured interstation phase and amplitude data are inverted simultaneously for phase speed maps as well as local amplification factor at each receiver location. The phase speed maps derived from both phase and amplitude measurements exhibit better recovery of the strength of velocity perturbations, particularly for the smaller-scale heterogeneities. The spatial distributions of local amplification factors in the longer period are correlated well with the velocity structure in the upper mantle, indicating that the effects of local amplification can be isolated well from those of focusing in our joint inversion of phase and amplitude data.

Isotropic and anisotropic 3-D S wave speed models of North American continent are then obtained from the phase speed maps. Our isotropic 3-D S wave models from phase and amplitude data for Rayleigh waves emphasize local-scale tectonic features associated with conspicuous lateral velocity gradients; e.g., fast anomaly in the Colorado Plateau surrounded by slow anomalies, and slow anomaly in the New Madrid Seismic Zone encompassed by faster regions. Such local tectonic features with the size of about 200 km can hardly be identified in the conventional surface wave tomography, and thus the interstation amplitude ratio data can be of great help in improving the lateral resolution of velocity models in the upper mantle. Radial anisotropy models derived from the phase speed maps of Rayleigh and Love waves using only phase data, are also constructed. The results show faster SH wave speed anomaly than SV in the tectonically active regions in the western and central U.S., while the model exhibits faster SV wave speed anomaly than SH in the eastern region below 75 km depth.

Keywords: upper mantle, surface wave amplitude, North American Continent

Dvelopment of S wave buffer rod for DAC-GHz experiments.

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I have been develping GHz ultrasonic technique for diamond anvil cell (DAC) in a recent a few years. Last year, I reported the development of P wave GHz buffer rod. Then, I conducted development of GHz S wave buffer rod as well. Simultaneopusly, I have examined how to get a good signal through P wave buffer rod. The solution is combination wiping by aceton, alcohole, and ammonia water. I have started the measurement for the specimen squeezed in DAC. In the poster, I will show those effort.

Keywords: GHz ultrasonics, diamond anvil cell, Shera wave, mantle, elasticity, high pressure

P and SH wave upper mantle velocity structure beneath South China

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There is widespread intracontinental orogen and magmatic province in Mesozoic South China. Study of upper mantle velocity can bring light on the distribution and movement of material in deep earth of this region. Triplication waveform of P and SH from 5 to 30 degree recorded by CDSN(Chinese Digital Seismic Network) are used to obtain P and SH wave upper mantle velocity structure by comparing with synthetic waveform. There is low velocity layer above 410 in both P and S waveform, and 410km discontinuity is broadened. Low P and low S velocity and high Vp/Vs may be result of partial melting related to plate subduction.

Keywords: triplciation, upper mantle , partial melting

Tidal Dissipation of the Solid Earth with an Internal Structure Including a Low-Viscosity Layer

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Tidal dissipation in the solid Earth is one of the important geophysical phenomena. Because tidal dissipation in a solid body depends on its internal structure, especially its viscosity structure, the dissipation can be a constraint on the interior. If the viscous structure can be constrained, it may provide one of the useful clues to learn the mantle dynamics.

The tidal response of the solid Earth, particularly the dependence of the theoretical Love number on the tidal period and viscosity structure, has been investigated in a few previous studies already. As a result, it has been considered that the presence of a low-viscosity layer inside the mantle, especially at its bottom part, is important for successfully interpreting the frequency-dependence of the observational Love number derived geodetically.

On the other hand, based on a similar idea to that of the above-mentioned research, the authors examined the dependence of the tidal quality factor on the frequency and the internal structure, assuming that such a low-viscosity layer exists also in the mantle of the Moon. This result also indicates that, as well as the Earth, the frequency-dependence of the quality factor obtained from the selenodetic observation can be explained if a low-viscosity layer exists at the base of the mantle. In addition, the characteristic timescale corresponding to the viscoelastic property of this layer is discovered to be very close to the main tidal periods. That is, it also implies a possibility that the viscosity which leads to efficient tidal heating in the layer is controlled through self-regulation.

Returning the viewpoint to the Earth tide with considering the implication from the lunar tide, it is unknown whether the above low-viscosity layer of the Earth possesses viscosity which is consistent with the dominant tidal periods. The previous research on the Earth have mainly illustrated the frequency-dependence of the complex Love number. Indeed, the uncertainty of the viscosity of the layer was systematically taken into consideration also in the previous analysis. However, the viscosity structure dependence of the quality factor obtained from the complex Love number was not explicitly specified. It is meaningful to survey this point in terms of both geophysics and comparative planetology.

Therefore, in the present study, in order to quantitatively estimate the effect of the low-viscosity zone at the bottom of the mantle on the tidal dissipation of the solid Earth, especially on the quality factor, the viscoelastic tidal deformation was calculated for several actual tidal periods. The typical reference structure for the density and elastic profiles is given in here based on the observation of seismic observation. Also, concerning the viscosity profile, for the sake of simplicity in order to roughly understand the dependence on the layered structure, just the four layers of a lithosphere, asthenosphere, mesosphere, and low-viscosity layer are set from the top to the bottom. Among them, only the viscosity of the low-viscosity layer is adjusted whereas those of the remaining three layers are uniform and constant. In the computation of the complex Love number in finding the quality factor, the stress-strain relation follows the rheological law of the Maxwell material. Then, the viscosity of the layer was estimated by comparing this theoretical value of the quality factor with the observational value.

The calculation result demonstrate that, like the Moon, the relaxation time of the low-viscosity layer is close to the tidal periods with respect to the deformation of the Earth. It is basically the same as the previous result that the numerical value matches with the geodetic observation if adding the influence of the low-viscosity layer. What is further clarified in this work is that the Maxwell relaxation time of the viscosity satisfying the frequency-dependent quality factor for the semidiurnal and diurnal tides, which is particularly prominent at the Earth tide, approaches the tidal period. In other words, a similar implication to that of the Moon described above were obtained here also in the case of the Earth.

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Keywords: Tidal Dissipation, Solid Earth, Internal Structure, Low-Viscosity Layer

Upper mantle structure beneath the Ontong Java Plateau from measurements of body wave differential travel times

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The Ontong Java Plateau(OJP) is a single largest oceanic plateau in the world, and thought to emplaced at 120Ma. To reveal the origin of the OJP, we have to know the structure beneath the OJP. Richardson et al. (2000) showed that S-velocities are 2-3 % lower than global average above a depth of 300 km beneath the OJP.
In this study we investigated upper mantle structure beneath the OJP by using PP-P differential travel times for PP waves of which bounce points are located on the OJP and the surrounding region. We analyzed waveform data of events from 2012 to 2013 recorded by IRIS and F-net stations.
We follow a method of Obayashi et al. (2004) to obtain PP-P differential travel time residuals. First a band-pass filter from 5 to 10 second was applied to the waveform data. To calculate PP-P differential residuals, we synthesized PP waves from P waves by applying the Hilbert transform, attenuation operator, and multi reflection/conversion effect in the crust beneath the bounce points. To calculate the multi reflection/conversion effect, we used crust structure model CRUST1.0 (REFERENCE). We then calculated PP-P differential residuals with respect to differential times predicted from the iasp91 model (Kennett and Engdahl, 1991) by cross-correlation of the observed and synthetic PP waves. Distribution of the obtained PP-P differential residuals indicated that the residuals are consistently negative for PP waves of which bounce points are located on the OJP. The average PP-P residual for such PP-waves is -1.6 second, which suggests P-velocities faster than that of iasp91 beneath the OJP, while we cannot constrain a depth range of the fast anomalies from the present study. Assuming that the average residual is due to uniformly fast structure above a depth of 300 km, P-wave velocity beneath the OJP is 1.7% faster than that of the iasp91 model.

Keywords: Ontong Java Plateau, body wave

Mechanical coupling between the plate and lowermost mantle controlled by the subducted lithosphere strength

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Hotspot volcanoes are regarded as an indication of mantle plumes that originate from the deep mantle. Relative migration between the hotspot tracks suggests much slower horizontal motion of the deep mantle layer than that of the surface plates. Viscosity increase in the lower mantle is often attributed to the cause of the slow motion in the deep mantle. Numerical modeling on subducted lithospheres integrated into a mantle convection system showed that the lithosphere penetrating into the lower mantle is not assimilated thermally to the surrounding mantle, so that the subducted lithosphere should work as a substance to transmit viscous stress from the deep mantle. This implies that motion of the deep mantle layer is strongly coupled with that of the surface plate.

We performed numerical simulation of an integrated lithosphere-mantle convection system in which the subducted lithosphere penetrates into the core-mantle boundary region. We investigated effects of yield strength and viscosity reduction due to the grain-size reduction or interconnection of ferro-periclase generated at the 660-km phase transition. The viscosity in the lower mantle was controlled as the value fit to the range inferred from geoid anomalies. In addition to them, depth-dependent thermal expansivity was also considered.

When the viscosity reduction is not incorporated, viscous resistance in the deepest mantle substantially controls the lithosphere motion in the case with the yield strength of 300 MPa. The large yield strength causes that the plate motion averaged in time is maintained to be less than 5 cm/yr, except in the cases with the viscosity of the lowermost mantle less than 10^{22} Pa s. Furthermore, the horizontal motion in the lowermost region is equivalent to half value of that of the surface plate. When the yield strength is set to 200 MPa, the viscosity increase in the lower mantle generates periodic slab folds by sharp bending. This substantially absorbs difference in the motion between the surface and the lowermost mantle. The slab folding generates a lump of the subducted lithosphere, which has large negative buoyancy. Toppling of the slab lump colliding the core-mantle boundary induces episodic acceleration of the slab descent motion. At this time, the plate motion exceeds 10 cm/yr. The slab is regarded as a stress guide between the surface and lowermost mantle in spite of the deformation. The slab interaction with the CMB region would therefore appear to the surface as significant fluctuation of the plate motion. Although the slab folds are generated when the depth-dependent thermal expansivity is introduced with the yield strength of 300 MPa, the decoupling between the surface and lowermost mantle motion is not enough to explain the stationary hotspot.

When viscosity reduction beneath the 660-km phase boundary is introduced, the viscous resistance of the deep mantle is not transmitted to the surface. The viscosity of the uppermost lower mantle controls the speed of the plate motion in the range of 5 to 10 cm/yr, which is consistent with the observation. On the contrary, the speed of the deep mantle flow is reduced to about 1/5 of the surface plate motion. Slab deformation induced by the viscosity reduction is therefore an important mechanism to weaken the coupling between the plate and deep mantle and to regulate subducting plate motion.

Keywords: mantle convection, plate motion, lower mantle, subducted slab, rheology

Detection of Hadean crustal material in the deep Earth and Moon

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Because of the tectonic erosion associated with plate subductions, the Hadean crustal material may have been brought down to the deep interior of the Earth (Kawai et al., 2009, 2013; Isozaki et al., 2010; Dohm and Maruyama, 2015; Maruyama and Ebisuzaki, 2017; Maruyama et al., 2017). The primordial material may have physical properties different from those of the surrounding mantle rocks, hence it could be detected using seismic tomography.

Significant lateral variations of S-wave velocity (Vs) are revealed in the lunar mantle by tomographic imaging (Zhao et al., 2008, 2012). A correlation between the Vs tomography and the thorium abundance distribution is found. The area with a high thorium abundance exhibits a distinct low Vs zone which extends down to a depth of ~300 km below the Procellarum KREEP Terrane (PKT), which may reflect a thermal and compositional anomaly beneath the PKT. The distribution of deep moonquakes shows a correlation with the tomography in the deep lunar mantle, similar to earthquakes which are affected by structural heterogeneities in the terrestrial crust and upper mantle. The occurrence of deep moonquakes and seismic-velocity heterogeneities implies that the lunar interior may contain a certain amount of fluids and so still be thermally and dynamically active at present. Because there is no plate tectonics in the Moon, the Hadean crustal material may have been preserved near the lunar surface till today. However, due to the mantle overturn that happened at the early stage of the Moon, part of the Hadean crustal KREEP material may have sunk to the deep mantle, which may have become heat sources for the lunar mantle activities and so caused the deep moonquakes around them.

The processes happened in the Moon may have also taken place in the deep Earth. Due to the plate subductions, the Hadean crustal KREEP material may have sunk to the deep mantle of the Earth, which may have become heat sources for mantle plumes and super-plumes. Prominent low seismic-velocity (low-V) anomalies are clearly revealed in the deep mantle beneath the surface hotspot regions such as south-central Pacific, East Africa, Hawaii and Iceland (Zhao et al., 2013; Zhao, 2015). Some of the low-V anomalies could be caused by the Hadean crustal KREEP material.

References

Dohm, J.M., S. Maruyama (2015) Habitable trinity. *Geoscience Frontiers* 6, 95-101.

Isozaki, Y., K. Aoki, T. Nakama, S. Yanai (2010) New insight into a subduction-related orogen: A reappraisal of the geotectonic framework and evolution of the Japanese Islands. *Gondwana Res.* 18, 82-105.

Kawai, K., T. Tsuchiya, J. Tsuchiya, S. Maruyama (2009) Lost primordial continents. *Gondwana Res.* 16, 581-586.

Kawai, K., S. Yamamoto, T. Tsuchiya, S. Maruyama (2013) The second continent: Existence of granitic continental materials around the bottom of the mantle transition zone. *Geoscience Frontiers* 4, 1-6.

Maruyama, S., T. Ebisuzaki (2017) Origin of the Earth: a proposal of new model called ABEL. *Geoscience Frontiers*. http://dx.doi.org/10.1016/j.gsf.2016.10.005.

Maruyama, S., M. Santosh, S. Azuma (2017) Initiation of plate tectonics in the Hadean: Eclogitization triggered by the ABEL Bombardment. *Geoscience Frontiers*. http://dx.doi.org/10.1016/j.gsf.2016.11.009.

Zhao, D. (2015) *Multiscale Seismic Tomography*. Springer, 304 pp.

Zhao, D., J. Lei, L. Liu (2008) Seismic tomography of the Moon. *Chinese Sci. Bull.* 53, 3897-3907.

Zhao, D., T. Arai, L. Liu, E. Ohtani (2012) Seismic tomography and geochemical evidence for lunar mantle heterogeneity: Comparing with Earth. *Global Planet. Change* 90, 29-36.
Zhao, D., Y. Yamamoto, T. Yanada (2013) Global mantle heterogeneity and its influence on teleseismic regional tomography. *Gondwana Res.* 23, 595-616.

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Grain growth kinetics in pyrolite composition: Implications for grain-size evolution of lower-mantle slab

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Viscosity of lower-mantle slab largely depends on grain size in constituent minerals. It consists of bridgmanite (Brg), ferro-periclase (Fp), Ca-perovskite (Capv), and majoritic garnet (Mjgt) in the case of pyrolite composition. The grain-size evolution of lower-mantle slab is mainly controlled by grain growth process after the significant grain-size reduction due to the post-spinel transformation. Grain growth kinetics can be described by $d^n - d_0^n = kt$ (d: grain size, d_0: initial grain size,n: grain growth exponent, k: Arrhenius-type rate constant, t: time). In the multiphase system, Zener pinning is an important process and grain growth of the primary phase is controlled by Ostwald ripening of the secondary phase, which can be described by $d_I/d_{II} = \beta / f_{II}^z$ (d_I: grain size of primary phase, d_{II}: grain size of secondary phase, f_{II}: volume fraction of secondary phase, β and z: Zener parameters). In the present study, we conducted grain growth experiments in pyrolite composition under lower mantle conditions, and discuss the grain-size evolution of lower-mantle slab.
Annealing experiments in pyrolitic material were conducted at 25-27 GPa and 1600-1950°C for 30-3000 min using a Kawai-type apparatus at Kyushu University. FE-SEM was used for microstructural observations and chemical analysis. Four phases of Brg (~70 vol%), Fp (~15 vol%), Mjgt (~13 vol%), and Capv (~2 vol%) were observed in recovered samples annealed at 25 GPa. To avoid the effects of the eutectoid texture on the kinetics, we took the grain growth data only from the sample exhibiting relatively homogeneous polygonal texture. Both secondary phases of Fp and Mjgt are homogeneously distributed in the Brg-dominant sample after the polygonal texture was achieved. The grain size ratio of d_{Brg}/d_{Fp} and d_{Brg}/d_{Mjgt} are almost constant during the grain growth and estimated to be ~1.7 and ~1.2, respectively. These microstructural observations imply that the Brg grain growth is pinned by the secondary phases, and the rate is controlled by Ostwald ripening kinetics. We obtained n values of 6.2, 3.3, and 3.1 for Brg, Fp, and Mjgt, respectively. The averaged n value of ~4.2 is consistent with the multiphase grain growth model when the secondary phase grows by Ostwald ripening process (n=4, grain-boundary diffusion controlled). When assuming the n-value of 4, the activation enthalpies for Brg, Fp, and Mjgt are estimated to be ~410, ~240, and ~500 kJ/mol, respectively, implying that the rate-controlling species are different between Ostwald ripening processes of Fp and Mjgt, and the Brg grain growth is controlled by both processes. If we treat Fp and Mjgt as a secondary phase ($d_{II=Fp+Mjgt}$) ignoring Capv, the activation enthalpies are almost the same between the primary and secondary phases. The grain size ratio of $d_{I=Brg}/d_{II=Fp+Mjgt}$ is ~1.5 with the $f_{II=Fp+Mjgt}$ of 0.3, which is almost consistent with the previous systematic study in the olivine-enstatite system (Tasaka and Hiraga, 2013). On the other hand, three phases without Mjgt were present at higher pressure of 27 GPa, in which the grain size was slightly larger probably due to the smaller proportion of the secondary phases (~77 vol% of Brg).
On the basis of the results obtained above, we estimated grain-size evolution of lower-mantle slab assuming that Zener parameters are the same as the previous study (Tasaka and Hiraga, 2013). The grain size of Brg in a pyrolitic composition with ($f_{II=Fp+Mjgt}$=0.3) and without ($f_{II=Fp}$=0.2) bearing Mjgt is estimated to be ~5-650 μm and ~50-900 μm, respectively, at 800-1600°C in 10^8 years. When considering an olivine-like ($f_{II=Fp}$=0.3) and a perovskitic ($f_{II=Fp}$=0.1) compositions, the Brg grain size decreases to ~40-720 μm and increases to ~80-1270 μm, respectively. Thus, the grain size in lower-mantle slab is likely kept smaller than 1 mm, suggesting that grain-size sensitive creep is dominant. Viscosity variations in lower-mantle slab will be discussed considering a dynamic grain-growth effect.

A revisit on initial temperature at the core-mantle boundary in a coupled core-mantle evolution model

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An initial temperature at the core-mantle boundary (CMB) is an important constraint for thermal evolution of Earth's mantle and core because this temperature strongly affects the size and onset timing of growing inner core, primordial heat in early Earth's core and thermal and chemical state in the deep mantle. In a previous study, we found ~6000 K as the initial CMB temperature in a coupled core-mantle evolution model to match constraints of thermal evolution of Earth's core [Nakagawa and Tackley, 2010]. However, in recent suggestions from high P-T physics and theoretical model of thermal evolution of Earth's core, the initial CMB temperature seems to be less than ~5000 K [Andrault et al., 2016; Nakagawa, in revisoin]. Since our core evolution model is based on a simplified analytical formulation [Buffett et al., 1992; Buffett et al., 1996] and more complicated formulation that can fit the density structure derived from seismological analysis and applicable for high thermal conductivity of iron alloy is proposed [Labrosse, 2015], we reassess the initial CMB temperature that can find the best-fit core evolution scenario. Because of thermostat effects on thermal evolution [e.g. Nakagawa and Tackley, 2010; Nakagawa and Tackley, 2012], the initial CMB temperature may not be sensitive to the scenario of thermal evolution of Earth's core and mantle but the heat flow across the CMB found in this study (9 to 10 TW) is slightly lower than the lower-bound value (11 TW). On the magnetic evolution, the low thermal conductivity is still more preferable than high thermal conductivity due to existence of adiabatic shell with high thermal conductivity that suppress a convective region of Earth's core. In the presentation, we will attempt to an implication for detectability of geoneutrino based on thermal and chemical evolution modeling of Earth's mantle and core.

Keywords: core-mantle boundary temperature, thermal evolution, Earth's metallic core