Japan Geoscience Union Meeting 2014
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SIT40-P01 Room:Poster Time:May 1 18:15-19:30

# An overview of seismic coupling and crustal deformation on the basis of geofluid and shallow slow earthquakes

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Due to the use of broadband seafloor seismometers near the trench and dense inland networks of highly sensi-tive seismic stations, very low-frequency events (VLFEs) have been observed in the shallow transition zone near the trench of subduction plate boundaries as well as the deep one. Following the 2004 Sumatra Earthquake, the Japanese government has established the Dense Oceanfloor Network system for Earthquakes and Tsunamis (DONET) along the Nankai Trough. In the Tonankai district, M8-class megathrust earthquakes will probably occur in the near future; DONET-I has now operated since August 2011. In this study, we perform numerical simulations of multiscale earthquake cycles, including a megathrust earthquake and VLFEs, on a 3-D subduction plate boundary, in order to understand the change in VLFE activity after megathrust earthquakes and hydraulic pressure gauge data.

In our simulation, the motion equation for a subduction plate boundary is described by a quasi-dynamic equi-librium between the shear stress (due to reverse dip-slip on the discretized faults) and the frictional stress based on a rate- and state-dependent friction (RSF) law. To perform multiscale earthquake cycle simulations, we as-sumed single large asperity and numerous small asperities arranged along the strike direction, where the large asperity generates megathrust earthquakes and a chain reaction of numerous small asperities generate a migra-tion of slow earthquakes along the strike direction.

From our simulation results, we concluded as follows: (i) For a megathrust earthquake in which the coseismic slip penetrates to the trench, plate coupling in the postseismic stage will be strong in the region from the central part of the source region to the shallower part toward the trench, which will cause the shallow VLF after-events to be quiescent or to occur infrequently in isolation. On the outer rim, shallow VLF after-events will be reac-tivated earlier than they will be in the center because of weak plate coupling. (ii) Since leveling change due to slow earthquakes at DONET is expected to be local and incoherent in the same node because of the short dis-tance between their sources and the (DONET) receiver, it is useful to remove an average from original data in the same node in order to extract a signal.

Keywords: megathrust earthquake, subduction zone, seismic quiescence, high pore pressure, seafloor observation, rate- and state-dependent friction law

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SIT40-P02 Room:Poster Time:May 1 18:15-19:30

# Three-dimensional seismic attenuation structure beneath Kyusyu

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The Philippine Sea (PHS) plate is subducting beneath Kyusyu and a clear volcanic front is formed through the middle of the arc. Furthermore, there is a volcanic gap between Aso and Kirishima volcanos. Seismic attenuation provides additional insights into subduction-zone dynamics, because higher-temperature environments or the existence of fluids may have different effects on seismic attenuation from on seismic velocity. Therefore the estimate of seismic attenuation is very important to understand arc magmatism and mantle dynamics in subduction zone. This study estimates seismic attenuation structure beneath Kyushu using a large number of high-quality waveform data. Data and method

We used 5195 earthquakes that occurred from April 2003 to December 2013 by applying the method of Nakajima et al. [2013] to waveform data recorded at a nation-wide seismograph network in Japan. We determined the corner frequency of earthquakes by using the spectral ratio method of S-coda waves. Then, we determined a whole-path attenuation term ($t*$), site-amplification factors and spectrum level simultaneously by a joint inversion. Finally, these $t*$values (N= 75207) were inverted to obtain three-dimensional attenuation structure.

The obtained results show several interesting feature. First, the subducting PHS slab is imaged as a low attenuation zone. Second, an inclined high-attenuation zone that is interpreted as mantle upwelling flow is served in the back-arc mantle. However, the inclined high-attenuation zone is less developed in the volcanic gap between Aso and Kirishima volcanos. This correspondence suggests the important role of mantle-wedge processes in the genesis of arc magmas.

Keywords: seismic attenuation structure, Philippine Sea Plate, Kyusyu

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# 3D Electrical Resistivity Imaging beneath Kyushu by Geomagnetic transfer function data

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The Kyushu island in the Southwest Japan Arc has many Quaternary active volcanoes in relation to the subduction of the Philippine Sea Plate (PSP). The volcanoes exist along the volcanic front of N30$^o$E-S30$^o$W, whereas the volcanoes are densely located in the northern and southern regions of the island. The Kyushu island has a non-volcanic region in the central region of the island between the two volcanic regions. We performed three-dimensional (3D) inversion analyses to obtain a litospheric-scale electrical resistivity model beneath the entire Kyushu island using the Network-Magnetotelluric (MT) data. The electrical resistivity model, however, has a limited resolution in a horizontal direction because of the sparse Network-MT data in several areas of Kyushu. Thus data of geomagnetic variations are used anew to improve the uncertainty of the electrical resistivity structure in a horizontal direction. Data of geomagnetic variations were obtained at the entire Kyushu island and several islands off the western coast of Kyushu from 1980's to 1990's [e.g., Handa et al., 1992; Shimoizumi et al., 1997; Munekane et al., 1997]. In this study, accessible data of geomagnetic variations around Kyushu are compiled. Geomagnetic transfer functions for the data of geomagnetic variations in the northern Kyushu are re-estimated using the BIRRP code [Chave and Thomson, 2004] in order to enhance the quality of the transfer functions and their error estimation. The transfer functions at about 150 sites, which are 12 periods between 20 and 960 s, are obtained with improving quality at the entire Kyushu island. The induction vector representation [Parkinson, 1962] is generally used to delineate the lateral variation of electrical resistivity structure because the vectors point to current concentration in conductive anomalies. Induction vectors determined using the improved transfer functions have the following specific features. First, the vectors on the northern and central Kyushu do not point to the Pacific ocean off the eastern coast of Kyushu but point to the East China Sea of the shallow sea off the western coast of Kyushu. Second, the induction vectors on the southern Kyushu point to the Pacific ocean in the eastern part and point to the East China Sea in the western part at short period, whereas the vectors are arranged along a direction parallel to a direction of the coast line at longer period (>300 s). These results are consistent with the previous work [Handa et al., 1992; Shimoizumi et al., 1997; Munekane, 2000]. It is considered that the complex behavior of the induction vectors are influenced by conditions of the Earth's mantle relating to the igneous activities. Then we applied three-dimensional (3D) inversion analyses for geomagnetic transfer functions using the WSINV3DMT inversion code [Siripunvaraporn and Egbert, 2009]. The electrical resistivity of a starting model is based on values of the 3D electrical resistivity model estimated by using the Network-MT data. In this presentation, we will mainly describe features of the 3D electrical resistivity structure using the geomagnetic transfer functions and them of the 3D electrical resistivity structure using only the Network-MT data [Hata et al., 2013].

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# Influence of confining and pore-fluid pressures on velocity and conductivity of a fluid-saturated rock

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Pore-fluid pressure in seismogenic zones can play a key role in the occurrence of an earthquake (e.g., Sibson, 2009). Its evaluation via geophysical observation can lead to a good understanding of seismic activities. It is critical to understand how pore-fluid pressure affects seismic velocity and electrical conductivity. We have studied the influence of pore-fluid pressure on elastic wave velocity and electrical conductivity of water-saturated rocks.

Measurements have been made using a 200 MPa hydrostatic pressure vessel, in which confining and pore-fluid pressures can be separately controlled. An aqueous pore-fluid is electrically insulated from the metal work by using a specially designed device (Watanabe and Higuchi, 2013). Elastic wave velocity was measured with the pulse transmission technique (PZT transducers, f=2 MHz), and electrical conductivity the four-electrode method (Ag-AgCl electrodes, f=100 mHz-100 kHz) to minimize the influence of polarization on electrodes.

Berea sandstone (OH, USA) was used for its high porosity (19.1%) and permeability (~$10^{-13}$ $m^2$). It is mainly composed of subangular quartz grains. Microstructural examinations show clay minerals (e.g., kaolinite) and carbonates (e.g., calcite) fill many gaps between quartz grains. A small amount of feldspar grains are also present. The grain size is 100-200 micrometers. Cylindrical samples have dimensions of 25 mm in diameter and 30 mm in length. Their axes are perpendicular to sedimentation bed. Elastic wave velocity is slightly higher in the direction perpendicular to the axis than in that parallel to the axis.

Confining and pore-fluid pressures work in opposite ways. Increasing confining pressure closes pores, while increasing pore-fluid pressure opens them. For a given pore-fluid pressure, both compressional and shear velocities increase with increasing confining pressure, while electrical conductivity decreases. When confining pressure is fixed, velocity decreases with increasing pore-fluid pressure while conductivity increases. The closure and opening of pores can explain observed changes of velocity and conductivity.

Effective confining pressure is defined by the difference between confining and pore-fluid pressures. Velocity increases with increasing effective confining pressure, while conductivity decreases. However, neither velocity nor conductivity is unique function of the effective confining pressure. For a given effective confining pressure, conductivity significantly increases with increasing confining pressure. Velocity also increases with increasing confining pressure, though it is not so significant. Increasing pore-fluid pressure can compress clay minerals to increase pore space. This might explain observed conductivity change.

Keywords: pore-fluid pressure, seismic velocity, electrical conductivity, geofluid

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# A study on grain boundary brine in halite rocks using electrical conductivity measurements

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Intercrystalline fluid can significantly affect rheological and transport properties of rocks. Its influences are strongly dependent on the style of distribution. When a fluid fills grain boundaries in a rock, it will significantly reduce the strength of the rock. The fluid distribution is mainly controlled by the dihedral angle between solid and fluid phases. The grain boundary wetting is expected only when the dihedral angle is 0o. The dihedral angle of the halite-water system was studied through microstructural analyses of quenched materials (Lewis and Holness, 1996). The dihedral angle is 50˜70o at P<200 MPa and T<300 oC. However, deformation experiments (e.g., Watanabe and Peach, 2002) and cryo-SEM observations (e.g., Schenk et al., 2006) on halite rocks have indicated the coexistence of grain boundary brine with a positive dihedral angle. In order to understand the nature of grain boundary brine, we have conducted electrical impedance measurements on synthetic wet halite rocks over a wide range of pressure and temperature.

Wet halite rock samples (9 mm diameter and 6 mm long) are prepared by cold-pressing (P=140 MPa, 40 min.) of wet NaCl powder and annealing (T=180oC, P=180 MPa, 160 hours). Grains are polygonal and equidimensional with a mean diameter of 50-100 ?m. The porosity is less than 1 %. The volume fraction of brine is estimated to be 11.1% by the thermo gravimetric analysis. Microstructural observation shows that most of brine is enclosed inside halite grains. Electrical impedance is measured in the axial direction of a sample by a lock-in-amplifier (SRS, SR830) with a current amplifier (SRS, SR570). The cylindrical surface of a sample is weakly dried and coated with RTV rubber to suppress the contribution of surface conduction. A conventional externally heated, cold-seal vessel (pressure medium: silicone oil) is used to control pressure and temperature.

Electrical conductivity of wet halite rocks is higher than that of NaCl by orders of magnitude even at the conditions of the dihedral angle larger than 60 degrees. The conduction through brine dominates the bulk conduction. This is also supported by the quick conductivity change in response to the change in pressure. Brine is interconnected over a whole range of pressure and temperature.

No remarkable change in conductivity is observed around the condition of the dihedral angle of 60 degrees. Although the interconnection of triple-junction tubes might drastically change at the dihedral angle of 60 degrees, its influence on the bulk conductivity is masked by more conductive paths. A triple-junction tube is so stiff that it cannot give observed conductivity changes in response to changes in pressure. The dominant conduction paths are not triple-junction tubes. Grain boundary brine must be the dominant conduction paths.

Electrical conductivity decreases with increasing pressure. Larger change is observed for lower temperatures. A simple model of fluid tube with elliptical cross-section shows that the thickness of a fluid tube decreases by less than 10%. The observed large change in conductivity suggests that the conductivity of brine is strongly dependent on the fluid thickness. When the thickness is comparable to the molecular size, the mobility of ions must be sensitive to the thickness. The observed large change in conductivity might be caused by the decrease in ionic mobility.

Keywords: salt, grain boundary, water, electrical conductivity

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# Estimation of the maximum burial depth of siltstones from the Kazusa Group by laboratory experiments

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To evaluate maximum burial depth of sedimentary formations is important for many topics in earth science and engineering such as estimating uplift and erosion of sedimentary basins. As a one of effective methods of the evaluation, a laboratory-based method for determining the maximum effective stress have been proposed. This method is based on a conventional method to evaluate preconsolidation stress (maximum effective stress experienced) of soil. However, this method cannot be necessarily applied to sedimentary rocks in simple ways, because sedimentary rocks have experienced not only mechanical compaction but also other processes such as cementation between grains, which should affect the mechanical properties of the rock. Thus applicability of this method to sedimentary rocks should be examined for several sedimentary basins. We performed laboratory experiments to measure porosity of siltstone specimens collected from several formations of the Kazusa Group, Boso peninsula, Japan, and tried to estimate the maximum burial depth based the results. We then compared the results with differences of burial depth ($\Delta Depth$) among locations of collecting samples which were estimated from geological setting, and examined the applicability of this method for estimation of the maximum burial depth in this site.

We collected rock blocks from Umegase (UMG), Otadai (OTD), Kiwada (KWD), Ohara (OHR), and Katsuura (KTR) Formations (in the descending order of stratigraphic horizon), and prepared cylindrical specimens of approximately 40 mm in diameter and 30 mm in length from these blocks. The porosity of these specimens was measured under different confining pressure (up to 35 MPa) and constant pore pressure (1 MPa) by using an intra-vessel deformation fluid-flow apparatus at Toho University. We used water as a pore fluid, and the measurements were performed at room temperature. Porosity under each effective pressure (the difference between confining pressure and pore pressure) was estimated by measuring volume of water drained from a specimen when confining pressure was loaded. The relation between measured porosity and effective pressure could be bilinear in log?log scale. The maximum effective stress experienced ($P_{e,B}$) of the tested rocks was determined from the intersection point of the two straight lines of the compaction curve. The maximum burial depth ($D_{max}$) was obtained by $D_{max}$ = $P_{e,B}$ / [($\rho_r$ - $\rho_w$)g], where $\rho_r$, $\rho_w$ and g are density of rock, water and gravity acceleration, respectively.

In the case of UMG, OTD and KTR, porosities decrease as the burial depth increases. Porosities of OHR and KWD, however, were relatively high although their burial depth is relatively large. There was a linear correlation between $D_{max}$ and $\Delta Depth$ except for OHR, but the slope of the relationship was less than one (approximately 0.27). Therefore, further investigation is necessary to examine the applicability of this methods to this site. $P_{e,B}$ of OHR was less than that of other specimens, which supports the possibility that pore pressure in this formation was approximately 5 to 12 MPa higher than hydrostatic conditions.

Keywords: porosity, maximum burial depth, maximum effective stress experienced, Kazusa Group, overpressure, laboratory rock experiment

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# Experimental constraints on the serpentinization rate under the antigorite-stable P-T condition

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Water transport into the Earth's interior can be limited by the rate of serpentinization reaction proceeding at slow spreading ridges and along bending related faults (Iyer et al., 2012). Moreover, the distribution of $H_2O$ in the mantle wedge may be controlled by the extent of progression of the reaction between the slab-derived fluid and the hanging wall mantle, as suggested by theoretical models (Iwamori, 1998). Previous hydration experiments for kinetic studies have been vigorously conducted at relatively low P-T condition (up to ca. 400 ℃ and 0.3 GPa) where the low T serpentine variety lizardite or chrysotile is stable. In contrast, antigorite is expected to be the dominant serpentine variety under the higher P-T condition corresponding to the deep oceanic lithosphere and the mantle wedge.

In order to constrain the serpentinization rates of peridotite under the antigorite- stbale conditions, we conducted piston-cylinder experiments at 580 ℃ and 1.3 GPa. Four types of starting materials were prepared from the crushed powder of a San Carlos lherzolite xenolith: 1) olivine (Ol), 2) orthopyroxene (Opx) + clinopyroxene (Cpx), 3) Ol + Opx, and 4) Ol+ Opx + Cpx + spinel. These systems were abbreviated as OL, OPX+CPX, OL+OPX, and LHZ, respectively. The starting materials were reacted with 15 wt% distilled water for 4-15 days. The formation of serpentine + talc + magnetite was observed in all the systems except for OL. Based on Raman spectroscopy results and crystal shapes, the synthesized serpentine mineral was identified as lizardite with 6?9 wt% $Al_2O_3$, rather than antigorite. The high $Al_2O_3$ content in the system possibly stabilized the aluminous lizardite at the experimental temperatures. Low silica activity precluded olivine reaction in the OL system, whereas olivine reacted with the SiO2 com-ponent in orthopyroxene to form lizardite and talc in the other systems. The reaction progress followed an interface-controlled rate law. The growth rate, $G$, was estimated to be $2.31 \pm 0.37$, $1.23 \pm 0.20$, and $2.78 \pm 0.64$ $\mu$m/day in the OPX+CPX, OL+OPX, and LHZ systems, respectively. As an example, we applied the hydration rates of peridotites, which were obtained experimentally, to a reactive-transport model for the convecting mantle wedge hydartion. In the case of grain-scale pervasive flow, the mass flux ratio of water fixable in the hanging wall peridotites to that supplied from the dehydrating oceanic lithosphere was calculated to be $2.7 \times 105$ - $1.5 \times 108$. This indicates that the water is completely fixable in the convecting mantle wedge and carried down to the stability limit of serpentine as soon as it is supplied from the slab. Aqueous fluid may penetrate all the way through the serpentine stable layer and reach the hot center of the mantle wedge only when the fluid migrates via crack-like pathways with a spacing $>$270-15000 m, which is not consistent with observations of natural serpentinites.

Keywords: hydration, serpentine, fluid, subduction zone, mantle wedge

SIT40-P08 Room:Poster Time:May 1 18:15-19:30

# Diffusive kinetic isotope fractionaion of water in silicate glasses

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Oversaturation of dissolved volatiles in an ascending magma leads to bubble nucleation and growth, which depend on volatile solubility and diffusivity, and drives explosive volcanic eruptions in the Earth. It is thus important to clarify the behaviors of volatiles in silicate melts in understanding the mechanism and dynamics of volcanic eruptions.

Hydrogen isotopes record the degassing processes of hydrous magmas due to isotopic fractionation between dissolved and exsolved water. The degree of hydrogen isotopic fractionation is correlated with the water content in natural volcanic rock samples; Deuterium is more deficient in water-poor samples, and the degree of D-deficiency increases as the water content decreases. This trend has been interpreted to reflect the transition of degassing model from that in a closed-system to in an open-system. However, these two extreme degassing schemes do not take the diffusive transport of water in magmas into account, which should be included in a realistic degassing model, because the timescale of diffusion is not necessarily negligibily small compared to that of degassing during magma ascent. Moreover, diffusion of water in silicate melts may cause kinetic isotope fractionation between silicate melt and explosive fluid phases because $H_2O$ is likely to diffuse faster than HDO, of which effect can be overprinted in the D/H ratios of natural samples. The hydrogen isotopic fractionation during water diffusion in silicate melts, however, has not yet been fully determined. In order to determine the isotopic fractionation factor of hydrogen due to water diffusion in silicate melts, we performed diffusion experiments of water in $SiO_2$ and synthetic rhyolite glasses in a D-enriched systems(H/D=10, 5 and 1).

The experiments were performed for $SiO_2$ and rhyolite glasses at 850 ℃ and water pressure of 50 bar in sealed silica tubes and at 650 ℃ and water pressure of 500 and 1000 bar in a hydrothermal furnace developed at Tohoku University. Concentration profiles of H and D in run products were measured with the ion microprobe (Cameca ims-6f at Hokkaido University) to evaluate diffusion coefficients of water (including $H_2O$ and HDO) in glasses. The obtained diffusivity (a diffusion coefficient divided by a water content) in $SiO_2$ glass at 650 and 850 ℃ were consistent with the values reported in previous studies (Davis and Tomozawa, 1995; Berger and Tomozawa, 2003). The D/H ratios along the diffusion profile were also analyzed for $SiO_2$ glasses with the ion microprobe. The D/H ratio first decreases, but apparently increases along the profile. The decrease of D/H ratio may imply the kinetic isotope fractionation during diffusion. However, the increase of D/H ratio cannot be explained simply by diffusion and may reflect the change of instrumental mass fractionation with water content (Hauri et al., 2006), which should be precisely determined to correct the profile of hydrogen isotopic ratio.

Keywords: eruption dynamics, silicate glass, water, diffusion, hydrogen isotope, isotopic fractionation

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# Development of high-precision geobarometer

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Fluid inclusions in mantle-derived minerals can serve as a messenger from deep Earth. If $CO_2$ is a dominant phase of the fluid, the relationship between intensity ratio and frequency separation of the Fermi diad bands in the Raman spectra of $CO_2$ can be used for determination of density of the inclusions.

In this study, we installed new Raman spectrometer that was improved spectral resolution. And we also measured its precision of frequency separation ($\Delta$ ). As a result of this study, we determined that the error of $\Delta$ is $\pm$ 0.003 $cm^{-1}$ ($1\sigma$) . Converted into the error of density, this value is $\pm$ 0.0025 g / $cm^{-1}$ .

Keywords: fluid inclusion, carbon dioxide, Raman spectroscopy, mantle xenolith, geobarometer

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# Applications of rapid and precise 11B/10B isotopic analysis to water and rock samples

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Boron isotope ratio is a powerful tracer in the fields of geochemistry, biochemistry, and environmental chemistry. Boron isotope ratios are determined by TIMS or MC-ICP-MS with precisions of better than 0.1 % RSD, but a large inter-lab discrepancy of 0.6 % is still observed for actual carbonate samples (Foster, 2008). Here, we are trying to determine B isotope ratio by MC-ICP-MS with a simple and common analytical techniques using a quartz sample introduction system with a PFA nebulizer, and compared to recently developed precise B isotope ratio analysis techniques by TIMS in positive ion detection mode determined as Cs2BO2+ ions with sample amount of $<$100 ng (Ishikawa and Nagaishi, 2011) and by MC-ICP-MS (Foster, 2008, Louvat et al., 2011).

In this year, our developed B analytical method above for carbonate and water samples are applied to rock samples. Resultant analytical reproducibility (twice standard deviation) was +/-0.04 % with a consumption of 50 ng B for several geochemical reference rocks issued from GSJ. Their relative differences from the standard were consistent with those determined by the positive TIMS within analytical uncertainty. Current potential B isotopic analysis by MC-ICP-MS will be discussed.

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# Water migration with a subducting slab and the dynamic effects on whole mantle convection

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Existence of liquid water is a characteristic of the earth. The water of interior of the Earths involved with the subducting plate reduces density and viscosity of the crustal and mantle rocks. These effects are essential to emerge the solid Earth activity such as, plate tectonics and island arc volcanism. Although the most of subducted water circulates through upper mantle, there is a possibility that portion of the water penetrates into lower mantle. Where does the water migrate? How much does the water affect mantle dynamics through the rock rheology and property? We performed numerical mantle convection simulation to investigate the water cycle and dynamic effects on the whole mantle convection.

In this study, we use the numerical model based on the model (Tagawa et al., 2007; Nakakuki et al., 2010) including the subducting oceanic plate driven dynamically. This model includes migration of water with the plate motion. We consider influences of reducing density and viscosity due to the water on the mantle flow (Karato and Jung, 2003). The maximum water content in the upper mantle is determined using phase relations of the basalt and the peridotite (Iwamori, 2004; 2007). We use various values of the maximum water content of rocks in the lower mantle, because it has been not clearly defined. We also treated the following physical properties as varying parameters: friction coefficient at the plate boundary, amount of the water injection at the trench, density-water dependence coefficient, and maximum water content in the lower mantle. Addition to we calculated dislocation creep by non-newtonian fluid or newtonian fluid.

A part of subducted water associate with the subducting oceanic plate is absorbed into peridotitic rocks and transported to about 150 km deep mantle. After that, dehydration with the serpentine decomposition occurs, and transported to deeper mantle by hot nominally anhydrous minerals (NAMs). The amount of dehydration at the 660 km phase boundary depends on the maximum water content of lower mantle, when the slab penetrates into lower mantle. The ejected water forms thin and high-water-content layer over the 660 km phase transition. As a result, the buoyancy of this layer induces instability, so that hydrated plumes are generated. We propose that this mechanism is important for the water cycle in the upper mantle. On the other hand, considerable portion of the water is transported into lower mantle with subducting slab, although notable water capacity of the lower mantle much smaller than that of the upper mantle, and reach core-mantle boundary. We have not yet observed notable water influence on mantle convection at lowermost mantle because of the small water concentration. Also, the hydrated materials do not rise to surface with hot plumes generated at the core-mantle boundary.

Keywords: mantle convection, plume, transition zone, water transport