Japan Geoscience Union Meeting 2015
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Seismic attenuation in the Pacific slab beneath northeast Japan

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Seismic activity and arc-magmatism in subduction zones are considered to relate to water carried with a subducting oceanic plate (e.g., Kirby et al., 1996; Nakajima et al., 2013). It is known that the existence of hydrous minerals, aqueous fluid, and melt contribute to reducing seismic velocity and increasing seismic attenuation. Therefore, investigations of seismic velocity and attenuation structures are important to constrain fluid distribution in subduction zones.

Seismic velocity structure in the Pacific slab beneath northeast (NE) has been investigated by a lot of studies, and characteristic structures, such as the low-velocity subducting crust down to a depth of ˜100 km (e.g., Shiina et al., 2013) and a low-velocity zone along the lower plane of the double-seismic zone (e.g., Zhan et al., 2004), have been revealed. However, seismic attenuation structure in the Pacific slab is not estimated precisely, because conventional tomographic methods are difficult to resolve detailed seismic attenuation in the slab.

To investigate seismic attenuation in the Pacific slab, we calculated the spectral ratio of the direct P waves for a pair of intraslab earthquakes with similar ray paths from shallower earthquake to a common station. Then, we estimated attenuation between the two earthquakes by fitting the Brune's source model (Brune, 1970) and t^* value to the spectral ratio, assuming constant stress drops for all earthquakes. The t^* value estimated here represents a path-averaged attenuation between the two earthquakes.

The results obtained in this study are summarized as follows.

1) In the slab mantle, observed attenuation is higher in the fore arc than in the back arc.

2) Attenuation in the subducting crust is higher than that in the slab mantle.

3) Highly attenuated ray paths are obtained in the Pacific slab near the hypocenter of the 2003 off-shore Miyagi earthquake (M7.1).

These results imply spatial changes in compositions or fluid distributions in the Pacific slab, providing a crucial constraint for the understanding of the seismic properties of rocks in the Pacific slab.

Keywords: Seismic attenuation, spectral ratio, the Pacific slab, intra-slab earthquake

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3-D P-wave anisotropy tomography of the crust and upper mantle beneath Hokkaido

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The velocity of seismic wave depends on the direction of wave propagation, which is called seismic anisotropy. Seismic anisotropy is induced mainly by the lattice-preferred orientation of anisotropic minerals in the mantle, especially olivine which exhibits strong anisotropy. Olivine can changes its type depending on temperature, pressure, and water content. Isotropic seismic tomography determines velocity anomalies in the crust and mantle, but it cannot directly provide us with information on mantle dynamics. Considering seismic anisotropy in tomography can provide such useful information. P-wave anisotropy tomography has been proposed, which can determine azimuthal and radial anisotropy (e.g., Wang and Zhao, 2013). In this work we focus on 3-D P-wave radial anisotropy.

We estimated 3-D P-wave velocity structure and P-wave anisotropy of the crust and upper mantle under Hokkaido using a large number of arrival-time data from local earthquakes recoded by the dense Kiban seismic network. We used P-wave arrival-time data selected from the JMA Unified Catalog and the data reprocessed by staffs of Research Center for Prediction of Earthquakes and Volcanic Eruptions of Tohoku University. Our study region is between 40N˜46N and 138E˜147E. To determine the velocity structure under the entire Hokkaido, our study region also includes northern Tohoku. We set up a 3-D grid and invert for isotropic velocity and radial anisotropy parameter at each grid node. We also compared our results with those of previous studies. One previous study is Wang and Zhao (2013) on P-wave tomography for 3-D azimuthal and radial anisotropy of Tohoku and Kyusyu subduction zones. The other study is Liu et al. (2013) on P-wave azimuthal-anisotropy tomography under Hokkaido.

In this study, we used 333 seismic stations. The followings are our criteria for the selection of local earthquakes. (1) Earthquake epicenters are located between 40N˜46N and 138E˜147E ; (2) The focal depths are $<$350 km; and (3) the event epicenters are located beneath the land of Hokkaido or the Pacific Ocean within 20 km from the coastline. As a result, our data set contains about 170,000 P-wave arrival times from 2030 local earthquakes.

The grid interval is 0.2 degree in the latitude and longitude directions, and the grid nodes are set up at depths of 8, 25, 40, 65, 90, 120, 150, 180, 200, 250, 300 and 350 km. The starting velocity model for the 3-D tomographic inversion is the 1-D J-B model, whereas we have added +4% high-velocity anomaly to the subducting Pacific slab. The results of this work are summarized as follows.

(1) Prominent low-velocity anomalies are revealed under Mt. Tarumae, Tokachi, and Usu active volcanoes, which may contain high-temperature melts associated with slab dehydration.

(2) Low-velocity anomalies exist in the mantle wedge beneath the volcanic front and back-arc area. The vertical-velocity is greater in the low-V zones, which is similar to that beneath Tohoku and Kyusyu.

(3) The horizontal-velocity is greater in the subducting slab, similar to the radial anisotropy results in Tohoku and Kyusyu.

(4) There is little azimuthal anisotropy in the low-velocity body under Mt. Usu (Liu et al., 2013), but our study shows very strong radial anisotropy. This result suggests the existence of upwelling flow in the mantle wedge beneath Mt. Usu.

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Keywords: Tomography, Anisotropy, Hokkaido, Subduction zones, Mantle wedge

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P and S wave attenuation tomography of the Southwest Japan arc

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We determined the first high-resolution P- and S-wave attenuation (Qp and Qs) tomography of the crust and upper mantle under the entire Nankai subduction zone from the Nankai Trough to the Japan Sea using a large number of high-quality $t*$data measured from P- and S-wave spectra of local earthquakes. The suboceanic earthquakes used in this study were relocated precisely using sP depth phases and ocean-bottom-seismometer data. The overall pattern of the obtained Q models is similar to that of velocity models of the study region. Our present results show that high-Q (i.e. weak attenuation) anomalies in the upper crust generally correspond to plutonic rocks widely exposed in the Nankai arc. Some of the low-Q (i.e. strong attenuation) anomalies in the upper crust along the Pacific coast are associated with the Cretaceous-Cenozoic accretionary wedge. Obvious low-Q anomalies exist in the crust under the active arc volcanoes. Most of the large inland crustal earthquakes are located in or around the low-Q zones in the crust. The subducting Philippine Sea slab is imaged clearly as a landward dipping high-Q zone. Prominent low-Q anomalies are revealed in the mantle wedge under the volcanic front and back-arc area, which reflect the source zone of arc magmatism caused by slab dehydration and corner flow in the mantle wedge. Significant low-Q anomalies exist in the fore-arc mantle wedge, which reflects a highly hydrated and serpentinized fore-arc mantle wedge due to abundant fluids released from dehydration of the young and warm Philippine Sea slab.

Keywords: Southwest Japan, subduction zone, Seismic attenuation, slab, fluids

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Geofluid migration process inferred from a 3-D electrical conductivity model beneath Tohoku district.

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We carried out long-period MT observation using the state-of-the-art equipments. The MT impeadance responses were inverted into 3-D electrical conductivity model using WSINV3D (Siripunvaraporn et al, 2005). The 3-D model delineates vertical continuous conductive zone from subducting Pacifc plate surface to lower crust below Ou backbone range. The conductive body indicates saline fluids and/or melt pathway from the subducting slab surface to lower crust. The resistivity of the lower crust conductor is 1 Ωm or more conductive and saline fluids and/or melt volume fraction is estimated to be 7 vol. % at minimum. Other resistivity profile in the across-arc direction indicates that conductive body separated from Pacific plate surface at 80-100 km depth and assumes an overturned form towards backarc direction. The head of the conducting body attains to the lower crust just below Mt. Gassan. This suggests the backarc volcanisms are caused by saline fluids and/or melt overturn rising towards backarc direction.

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Fluid-rock interaction in deep portions of subduction plate boundaries

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Fluid-rock interaction at deep portions of subduction plate boundaries is a key to understand roles of fluid on deformation and mass transfer during subduction and accretion. In the Upper Cretaceous Shimanto accretionary complex of eastern Kyushu, the melange composed of basaltic slices in the argillaceous matrix and the coherent clastic rock occur three times, representing the repetition of ocean plate stratigraphy associated with the duplex underplating at a depth of ~ 13 km and temperatures of 340-400 ℃. One well-exposed basaltic slice consists mainly of massive basalt, pillow basalt, and dolerite in which argillaceous rocks are intercalated with the dolerite in the uppermost part of the slice. The argillaceous matrix commonly shows pressure solution cleavage in which muscovite and carbonaceous material occur as insoluble residue. The argillaceous rock less than 20 cm from the upper boundary of the basaltic slice is highly bleached in association with the modal increase in albite and consumption of muscovite and carbonaceous material, while that intercalated with the dolerite shows various degree of bleaching. Plagioclase phenocrysts in the dolerite near the upper boundary are replaced to muscovite. Mass-balance estimated from isocon method indicates that the bleached argillaceous rock and the uppermost dolerite are depleted in fluid-mobile elements such as Sr and Ba relative to surrounding rocks. Deformation is concentrated into the uppermost dolerite, which is marked by elongated phenocrysts. These results suggest that the albitization of argillaceous rock by infiltration of Na-rich fluid and the deformation accompanying with fluid-dolerite interaction occurred during the melange-forming process. Infiltration metamorphism during incorporation of basaltic slices in the argillaceous melange matrix may play an important role on mass transfer in subduction plate boundary.

Keywords: fluid-rock interaction, subduction plate boundary, argillaceous rock, dolerite, albitization

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Mechanism of overpressure development in the Kazusa Group

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Abnormally high pore pressure zone may affect many properties and processes in underground, and thus it is important to study the mechanism of developing the high pore pressure zone. In mudstone formations of the Kazusa Group at the Boso peninsula, high porosity anomaly of approximately 5 to 20 % is observed, and this anomaly is suggested to have been generated by an abnormally excess pore pressure. However, the development process of the high pore pressure is still unknown. In general, pore pressure anomalies can develop through normal sedimentation-compaction process under some conditions of permeability and storage capacity, and/or sedimentation rate. In this study, we investigated how much pore pressure and porosity anomalies can develop just only by normal sedimentation-compaction process in the case of the Kazusa Group mudstone formation. Firstly we obtained effective pressure dependencies of permeability and porosity for siltstone specimens from the Kazusa Group by using laboratory experiments, and then carried out 1-D numerical simulation of pore pressure development during sedimentation-compaction processes using the parameters from the experiments.

The rock samples used in the experiments were collected from outcrops at Umegase Formation (Fm.), Otadai Fm., Kiwada Fm., Ohara Fm. and Katsuura Fm. of the Kazusa group. The collected samples were shaped into a cylindrical shape about 40 mm in diameter and about 30 mm in height. The measurements were performed using an intra-vessel deformation fluid-flow apparatus at Toho University. Distilled water was used for pore fluid and confining pressure was applied by using oil. Permeability and porosity of siltstones were measured at room temperature and under effective pressures from 2 to 35 MPa. To obtain porosity under effective pressure, we measured a volume of water discharged from the specimen when confining pressure was applied. We measured permeability by monitoring flow rate through the specimen under the condition of constant pore pressure differences at the both side of the specimen. Measured porosity ranged from approximately 34 to 42 %, except for the specimens of Ohara Fm., porosity of which was up to 55 %, higher than others. Permeability ranged from 10^{-20} to 10^{-16} m^2. We obtained the effective pressure dependencies of porosity and permeability for each specimen by fitting normal consolidation domains of the experimental results with some functions. We then simulated developments of pore pressure and porosity anomalies during sedimentation of silt(stone) layer up to the thickness of 3000 m. By using finite difference method, we discretized a differential equation modeling pore pressure developments by sedimentation-and-compaction, and diffusion in the vertical direction of pore pressure. The conditions for the simulation are as follows: the lower boundary of the calculation domain is impermeable, and pore pressure is constant at the upper boundary of the sediments. The sediment layer is initially 54 m in the thickness, and the initial pore pressure is hydrostatic (no pore pressure anomaly). Skempton's constant is 0.9. The sedimentation rate is constant, and we used three values, 4.0, 9.49, 40.0×10^{-4} m/year, estimated from the previous studies at the Kazusa Group. The results of the numerical simulations suggested that, pore pressure anomaly was increased as the depth was increased, and when the sedimentation rate was 9.49×10^{-4} m/year, developed maximum pore pressure and porosity anomaly ranged from 3 to 12 MPa and 0.5 to 6 %, respectively. As the sedimentation rate was increased, the anomalies were increased, and pore pressure and porosity anomalies were increased up to 18 MPa and 8 % when the sedimentation rate was 40.0×10^{-4} m/year. These results indicate that, when considering conditions for the Kazusa Group, pore pressure anomaly of more than 10 MPa and porosity anomaly of several percentages can develop.

Keywords: the Kazusa Group, overpressurization, permeability, laboratory permeability measurement, numerical simulation

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Dehydration effect on frictional instability: Experimental study using gypsum hemihydrate

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Subduction zone seismicity can be controlled by water. For example, dehydration embrittlement of subducting slab is thought to generate intermediate depth earthquakes and their epicenters concentrate in "the upper plane earthquakes belt." The lower boundary of "the upper plane earthquakes belt" is possibly related to the stability of anhydrous phase after dehydration [1, 2]. Besides, the presence of serpentinized mantle wedge or excess pore pressure derived from hydrous slab may explain the distribution of asperities possibly inducing plate boundary earthquakes [2, 3]. In this way, hydrous minerals in subducting slab physicochemically transport water into deeper part of the Earth at subduction zone; the water probably has relationship with seismicity. Nevertheless, it has not concretely resolved yet how water has elementary microscopic effects on the macroscopic seismicity.

Many hydrated minerals such as serpentinites [4] exhibit mechanical instability such as dehydration weakening. Especially for gypsum, previous researches clarified that the condition of brittle-ductile transition and dehydration reaction can be achieved easily in laboratory [5, 6], so that gypsum is thought to be a good rheological analogue for hydrous slab. Thus, in this research, we investigate a following problem on the hypothesis that hydrous mineral dehydration microprocess affects frictional characteristics and rheology. The problem is how dehydration of hydrous minerals controls frictional properties and rheology of seismogenic zone by friction experiments of simulated gypsum gouges.

In this study, simulated gouge sample of gypsum hemihydrate, bassanite, between precut gabbro pistons was deformed in gas-medium apparatus at confining pressures of 10 − 200 MPa and temperatures up to 180 ℃. From the results at room temperature, the magnitude of stress drops proportion to confining pressure explains the depth distribution of seismicity in subduction zones. At 200 MPa, 70 ℃ corresponding to non-dehydration condition, samples exhibited stick-slip behavior and the strength of the samples became larger. On the other hand, at 200 MPa, 110 ℃ and higher, likely corresponding to condition for stable anhydrite phase, stick-slip behavior was found to be diminished with the reduction in mechanical strengths with strain. Microstructural observations clarified opening shear planes (R_1) oblique to shear direction in non-dehydrated samples, while the number of shear planes decreased and another sets of shear planes parallel (Y) or orthogonal (X) to the direction against shearing were formed in dehydrated samples. Cleavages were turned parallel to shearing by shape preferred orientation of the gouge particles and most of deformation was covered along them as mechanically weaker planes. The generation of excess pore pressure generated by dehydration of hydrous minerals, low permeability of the surroundings and connection of internal shear planes or cleavages may have significantly reduced the strength of rock. Because the phase after dehydration, anhydrite, is known to show higher frictional strength than the hemihydrate, bassanite [7], existence of excess pore pressure rather than the change in frictional properties may induce weakening during or after the dehydration. Hence, this implies that the dehydration weakening process is possibly related to formation of aseismic or stable sliding zones.

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Keywords: dehydration weakening, phase transition, hydrous mineral, gypsum

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Spatial variation of magmatic temperatures and water contents in western Java Island, Indonesia: estimation from mineral

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Across-arc variations of magmatic temperatures and water contents in West Java were investigated from whole-rock chemistry, petrography, and phenocryst mineral compositions. Volcanic rocks were collected from eight volcanoes in the region. To determine these properties, the pyroxene thermometer by Brey and Kohler (1990) and the plagioclase-melt hygrometer by Putirka (2008) were applied. Rocks in this region range from basalt to andesite with some exceptions: dacite from Guntur and latite from Dago. Silica contents range from 53-58 wt% in Papandayan, 51-63 wt% in Guntur, 50-57 wt% in Galunggung, 57-61 wt% in Cikuray, c. 57 wt% in Tangkuban Parahu, 56-57 wt% in Dago, 49-57 wt% in Tampomas, and 55-61 wt% in Ciremai, respectively. Although a majority of rocks belong to medium-K series, potassium content varies by location, increasing with the distance from the trench. Basalt and basaltic andesite from Galunggung, one of the frontal volcanoes, are classified as low-K series, and part of rocks from rear-arc volcanoes, Tampomas, Tangkuban Parahu, and Dago, are assigned to high-K series. To equalize effects of differentiation, samples with similar silica contents (c. 57 wt%) are selected to apply the geothermometer and the hydrometer. Pyroxene rims indicate a temperature range from 900-1050 ℃ (970-1000 ℃ in Papandayan; 900-1020 ℃ in Guntur, 970-1020 ℃ in Galunggung, 970-1020 ℃ in Cikuray, 940-1050 ℃ in Tangkuban Parahu, 970-980 ℃ in Tampomas, and 950-1020 ℃ in Ciremai). The temperature estimates of cores range from 900-1030 ℃ (970-1000 ℃ in Papandayan, 930-950 ℃ in Guntur, 950-1030 ℃ in Galunggung, 960-1010 ℃ in Cikuray, 990-1030 ℃ in Tangkuban Parahu, 950-1030 ℃ in Tampomas, and 900-940 ℃ in Ciremai). Water content of plagioclase rims ranges from 0.5-1.6 wt % and each volcano exhibit narrow range (1.0-1.2 wt% in Papandayan, 1.6 wt% in Guntur, 0.9-1.2 wt% in Galunggung, 1.6-1.8 wt% in Cikuray, 0.5-0.7 wt% in Tangkuban Parahu, 0.7 wt% in Dago, 1.1-1.3 wt% in Tampomas, and 1.2 wt% in Ciremai). The water contents estimated from core composition show no distinct difference from those of rims, ranging from 0.6-1.4 wt% (1.3-1.5 wt% in Papandayan, 1.1-1.4 wt% in Guntur, 0.6-1.0 wt% in Galunggung, 1.1-1.4 wt% in Cikuray, 0.8-1.1 wt% in Tangkuban Parahu, 0.6-0.8 wt% in Dago, 0.9-1.2 wt% in Tampomas, and 1.0 wt% in Ciremai). Neither temperature nor water content is correlated with the distance from the trench; lateral variations are not distinct in terms of these properties. In many samples, pyroxene crystals exhibit reverse-zoning with increasing Mg-number, and the estimated temperatures at rims are higher than those of cores, implying recharge of hot magmas into colder magma reservoirs.

Keywords: across-arc variation