P- and S-wave velocity structure in southern Hokkaido deduced from ocean-bottom seismographic and land observations

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The Kuril arc collides with the northeast Japan arc in the southern part of Hokkaido, Japan. Such a collision results in building the Hidaka Mountains and is related to the seismic activity and large earthquake occurrence such as the Urakawa-Oki earthquake (Ms6.8) on March 21, 1982. It is important to image the three-dimensional crustal structure in order to clarify the collision tectonics and understand the patterns of earthquake occurrence and the mechanism of large earthquake occurrence. A group of seismologists from eleven universities operated a dense temporary network of land stations from 1999 to 2001 in and around the Hidaka Collision Zone [Katsumata et al. (2002)]. In addition, we conducted ocean-bottom seismographic observations in 1999 and 2000 in the south off Hokkaido region. Murai et al. (2003) estimated P-wave velocity structure by the 3-D tomographic inversion [Zhao et al. (1992)] of seismic travel time data obtained from networks of ocean-bottom seismographs (OBSs) and land stations in 1999. However their spatial resolution was poor for the deep crustal structure and they could not obtain S-wave velocity structure because of limitation of the number of data. Here we estimate P- and S-wave velocity structure by the tomographic inversion of travel time data from OBSs and land stations in 1999 and 2000.

From the tomographic images, distinct low-velocity anomalies are detected at the western side of the Hidaka Main Thrust (HMT). They are considered to be the crust of the northeast Japan arc. In the eastern side of it, we find high-velocity anomalies, which are considered to be the crust of the Kuril arc obducted towards the west. The low-velocity anomalies appear to reach a depth of the upper boundary of the subducting Pacific plate. These results are similar to Murai et al. (2003). Murai et al. (2003) considered the low-velocity anomalies deeper than 30 km as the delaminated Kuril arc lower crust because the velocity inversion occurs at around 30 km depth. However we cannot image the delamination structure clearly although the velocity inversion is also detected. From the vertical cross section along the subducting direction of the Pacific plate, the depth of the upper boundary of the high-velocity anomalies increases towards the northwest, which represents the upper boundary of the subducting Pacific plate. The low-velocity anomalies beneath the western side of the HMT disappear in the offshore area southeast of Cape Erimo. Moreover many microearthquakes occurred in the low-velocity anomalies whereas the seismic activity was low outside them. These results suggest arc-arc collision has little influence on the offshore area as an extension of the Hidaka Mountains. S-wave velocity structure shows similar features to P-wave velocity structure.

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Keywords: ocean-bottom seismograph (OBS), seismicity, tomography, Hidaka Collision Zone, Hokkaido, 1982 Urakawa-Oki earthquake

Estimation of Crust and Uppermost Mantle Structure by Reflection and Receiver Function Analyses

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In the northern Kinki district, the dense seismic observation network has been operated. We carried out reflection and receiver function analyses with high resolution by using the data obtained from this observation network. In the reflection analysis, we obtained three dimensional distribution of reflection strengths in the northern Kinki district. We found a S wave reflector was dipping to the north and LFEs occurred at a high reflection strengths zone. In the receiver function analysis, we also used the data, which obtained from a dense linear array observation conducted in Kii peninsula and obtained the three dimensional distribution of seismic wave discontinuities beneath the Kinki district. As a result of the receiver function analysis, the continental Moho discontinuity becomes shallow to the southward in the Kii peninsula.

Keywords: Reflection analysis, Receiver function analysis, Fluid, Niigata-Kobe Tectonic Zone

Receiver Function Analysis for Broadband Seismic Stations in Ryukyu Arc

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The S-wavevector receiver function (SWV-RF) has a great advantage that the problem of unclearly seismic images beneath very thick sedimentary basin due to the records include strong effect of reverberation within the sedimentary layer can be overcome (Takenaka and Murakoshi, 2010, AGU). In this study, we applied the SWV-RF from broadband seismic records of the F-net (NIED) and ETOS (JMA) to obtain the seismic structures in Ryukyu Arc. In this presentation, we will describe the estimated seismic structure under each stations in the Ryukyu Arc. Acknowledgement: We have used F-net data (NIED) and ETOS data (JMA), “Japan integrated velocity structure model 2012” provided by Headquarters for Earthquake Research Promotion of Japan (HERPJ).

Keywords: receiver function, Ryukyu arc, crustal structure

Geometry of plate boundary beneath the southern Ryukyu Trench subduction zone deduced from passive seismic observation

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In the Ryukyu Trench subduction zone, many large earthquakes occurred historically. Recent seismic and geodetic studies indicate that the occurrence of very low frequency earthquake [Ando et al., 2012] and slow slip events [Heki and Kataoka, 2008; Nishimura, 2014] in the southern Ryukyu subduction zone. In addition, plausible seismogenic zone of the 1771 Yaeyama earthquake (Mw 8.0) is located near the trench [Nakamura, 2009]. These results suggest that the interplate coupling is not so weak and it is possible for the large interplate earthquake to occur in this region. However, the plane geometry is uncertain due to the sparse seismic observation network. To investigate the subducted plate geometry, we have conducted the passive seismic observation around the southern Ryukyu Trench using 6 land stations and 30 ocean bottom seismographs (OBSs) from Nov. 2013 to Mar. 2014, as a part of “Research project for compound disaster mitigation on the great earthquakes and tsunamis around the Nankai trough region”.

First, we conducted event detection from continuous seismic records and picked their first arrivals of P and S waves. We could detect microearthquakes about three times of Japan Meteorological Agency (JMA) catalogue during same periods. Second, we performed a seismic tomography to estimate the precious hypocenter locations. To improve the spatial resolution beneath the Island arc, we also used the first arrival data of JMA catalogue from 2013 to 2014. Then, we estimated the focal mechanisms of relocated earthquakes and searched the small repeating earthquakes according to the catalogue of Igarashi (2010). Finally, we estimated the depth variation of the subducted Philippine Sea plate beneath the Ryukyu arc by following assumptions: 1) low-angle thrust-type earthquakes and small repeating earthquakes occur along the plate boundary, 2) landward dipping high velocity layer indicates the slab mantle and the thickness of oceanic crust is about 7 km. The consistency of our plate geometry model and the result of active source survey [Arai et al., 2015] indicated the validity of above assumptions. In the western Ishigaki Island, we set our model as same as slab1.0 model [Hayes et al., 2012] because their model satisfied our assumptions.

Our plate model indicates local variation between Ishigaki to Miyako Islands, whereas plate geometry western Ishigaki seems to be smooth. In this area, plate boundary estimated shallower than slab1.0 model. Especially, plate boundary seems to have a convex structure beneath the Tarama Island. The difference in E-W direction also appeared in the seismicity pattern. Microearthquakes within oceanic crust in forearc region is active in only the eastern side, whereas the long-term slow slip located mainly western Ishigaki Island [Nishimura, 2014]. Besides, low-angle thrust-type earthquakes and small repeating earthquakes estimated in this study located the outside of the active area of long-term slow slip. Our tomographic result of P-wave velocity model also indicated that the landward mantle is strongly serpentinized, which might be corresponding to the occurrence of slow slip events.

Keywords: The Ryukyu Trench, Geometry of the plate boundary, Seismicity, Seismic velocity structure

Fault Distribution and Structural Characteristic in the Nansei Islands

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As a part of “the Comprehensive evaluation of offshore fault information project” by the Ministry of Education, Culture, Sports, Science and Technology, JAMSTEC has carried out collecting seismic reflection data from various institutes and private companies and reprocessing data to obtain high resolution seismic profiles by state-of-the-art data processing methods.
Interpretation of faults on a seismic survey profile is a simple work, but in order to map out the distribution of a fault, the spatial distribution of the fault must be assigned from subsurface structures interpreted on each seismic profile and geomorphologic features. The distribution of displacement along faults is frequently recognizable in the landscape, therefore it is a well-approved method to map out the location of active faults from the geomorphologic features. In this project, we utilize both the seismic profiles and high resolution bathymetric data. The seismic profiles enable us to determine the actual location of displacement of the fault in the subsurface, and the high resolution bathymetric map tells the extension and direction of the fault. This interpretation process led the result of a brief and advanced offshore fault mapping.
The Ryukyu Arc is located in the Eurasian plate and extends from Kyushu, Japan to the Taiwan collision zone. At the Ryukyu Trench, the Philippine Sea plate is subducting beneath the Eurasian plate, and the backarc basin called the Okinawa Trough is formed by crustal extension behind the subducting system.
In offshore of Yonaguni-jima, Iriomote-jima, and Ishigaki-jima, a forearc basin forms a flat terrace. The thickness of basin sediments increases westwards due to a normal fault striking at SE, and dipping NE. In the southeast offshore of Ishigaki-jima, a reverse fault striking at NNE, and dipping NW up-rifts the basin sediments and forms boundary of the west end of the basin. In the south offshore of Miyako-jima, there are several reverse faults striking at NE, and dipping NW develop and up-lift the basement exposing at the sea floor with thin sediments. In the south margin of the forearc basin, accretional wedges develops by thrust faults, and there is remarkable east-west trending steep slope continuously exists exposing the basin sediment layers on the slope face. This could happened if some lateral displacement due to the movement of the Philippine Sea plate had effected slope stability on the wedge, and then the mass sediment body had collapsed. In offshore from Miyako-jima to Kerama Gap, the forearc basin sediments distribute with relatively thin layer, and the entire basin and basement is uprifted by thrust faults. In offshore of Okinawa-jima, a gentle slope composed of thick sediment layers forms from the edge of island shelf towards the trench. There are three large step-like terraces developed along the trench with small to large scale trust faults.
The southern Ryukyu Arc consists of the edge of continental crust, and the terrace of the arc was eroded to naturally flat surface. Normal faults, which cut perpendicular to the axis of the arc, are developed such as Miyako Saddle and Kerama Gap, and these gaps play structural transmit zone in both the trench and the trough geology.
In the Okinawa Trough, there are hundreds of meter cliffs developed along west side of island arc with northeast-southwest trend. In the southern Okinawa Trough, widely knowns as the present trough’s growing stage, east-west trending rift valleys exist at the trough bottom, and the subsurface structure displays spreading system such as great number of normal faults developing

towards the axis of the valley. In the central Okinawa Trough, there are series of NE-NW normal faults, and the edge of the rotated block appears as ridges or small cliffs.
In this session, we will briefly report the structural interpretation on seismic profiles and discuss structural characteristic based on the fault distribution.

Keywords: offshore fault, seismic reflection survey, Ryukyu Arc, Okinawa Trough, Ryukyu Trench

The one dimensional S-wave velocity structure inversion using Rayleigh admittance

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A cabled seafloor network with 20 stations (DONET: Dense Oceanfloor Network System for Earthquake and Tsunamis) has been constructed on the accretionary prism at the Nankai subduction zone of Japan between March 2010 and August 2011, which means that the observation period became more than 4 years. Each station contains broadband seismometers and absolute and differential pressure gauges. In this study, we estimated the Rayleigh admittance at the seafloor for each station, i.e., an amplitude transfer function from pressure to displacement in the frequency band of microseisms, particularly for the fundamental Rayleigh mode of 0.1-0.2 Hz. The pattern of the transfer function depends on the S-wave velocity structure at the sediment beneath stations (Ruan et al., 2014, JGR). Therefore, we estimate one-dimensional S-wave velocity structure beneath each station, and investigate lateral variation of the accretionary prism in the Nankai subduction zone.
We used the Rayleigh wave records of earthquakes with magnitude greater than 6.5 and within an epicentral distance of 30º. At each station, the velocity seismogram was converted to the displacement seismogram by removing the instrument response. The pressure record observed by the differential pressure gauge was used in this study because of a high resolution of the pressure observation. In the frequency domain, we estimated the amplitude transfer functions of displacement/pressure for each event, smoothed it using a Parzen window with a frequency band of 0.01 Hz, and stacked them over all of the used events. For inversion, we employed a simulated annealing technique to estimate one-dimensional S-wave velocity structure, in which the predicted admittance was calculated through a software of DISPER80 (Saito, 1988).
Because we used a broad frequency range (0.03-0.15 Hz), the velocity structure down to 10-20 km depths could be estimated. In particular, at depths from the seafloor to 5 km, the error of the estimated velocity was small compared with those at deeper depths. At some sites, it seems that the obtained S-wave velocity structure shows a low velocity layer within the accretionary prism. In the presentation, we will show other characteristics of the obtained velocity structures.

Keywords: S-wave velocity structure, seafloor observation

Crustal structure of Thailand from receiver function and ambient noise tomography studies

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Thailand located in inner shelf of Eurasia plate. Tectonic evolution and crustal structure knowledge in Thailand is relatively poor. Major tectonic provinces of Thailand can be divided into 2 terranes, Indochina (IC) in east and Shan-Thai (ST) in west. In this study, 40 seismometers of Thailand Meteorological Department (TMD) and 4 of Mahidol University were used for data analysis. Two seismological methods, receiver function (RF) and ambient noise tomography (ANT), were applied to the data. For receiver function, we obtain total number of 1684 RFs. The crustal thickness and Poisson’s ratio of Thailand were measured from the stacking amplitude of predicted arrival time. In average, Poisson’s ration of crust in Thailand is lower than global average indicate more felsic composition in crust. Crustal thickness of Thailand is ranging from 31 –42 km with increasing trend from west to east across ST to IC. In comparison, crust of IC is thicker and have higher Poisson’s ratio than ST. From ANT, cross-correlation function were calculated from three components seismogram of 4 years long data set. Rayleigh and Love wave group velocity dispersion were measured using frequency time analysis (FTAN) scheme. Due to data quality and station geometry observed period of dispersion curve are in between 6-24 second. Two dimensional tomographic inversion was used to construct the travel time tomography of group velocity at each frequency. Results of ANT clearly show that shallow crust of IC have lower velocity than ST. The lower velocity value may be refer to thick clastic rock deposited in uppermost crust of IC. Combining with a result from receiver function, lower crust of IC should have high mafic composition. Isostatic model suggest that dominated tectonic process in present day of ST is crustal thickening by the stacking of upper crust, while IC is thinning by the erosion.

Keywords: Receiver function, Ambient Noise , Mafic lower crust, Poisson's ratio

Seismic attenuation and seismogenic layer in the crust beneath the Kyushu Island

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The spatial distribution of the seismogenic layer is one of the important parameter for seismic hazard analysis. The focal depths of inland seismicity are restricted to the upper several tens kilometers of the crust and are varied depending on the tectonic settings. Previous studies reported the negative correlation between the depth of the seismogenic layer and heat flow [e.g., Sibson, 1982; Ito, 1990; Tanaka and Ito, 2002]. Recently, increasing studies suggest that fluids play an important role in triggering earthquakes [e.g., Terakawa et al., 2010]. At present, it is widely believed that the spatial distribution of seismogenic layer is controlled by temperature and pore fluid pressure (and strain rate). However, quantitative estimates of the two parameters are difficult. Instead, in this study, we compare the spatial distribution of seismogenic layer and seismic wave attenuation, which is sensitive to temperature and existence of fluid. This is expected to provide us new insight into physical properties of the crust and control parameters of inland seismogenesis.

Attenuation of seismic wave energy is caused by two factors: scattering and intrinsic absorption. The former is the scattering of seismic wave energy due to random heterogeneities in seismic wave velocity and the density of the medium, while the latter is the conversion from seismic wave energy to heat energy by internal friction due to anelasticity of the medium. Quantifying scattering and intrinsic attenuation is important to understanding the structure of the lithosphere in terms of seismotectonic features. In this study, we separately estimate scattering and intrinsic attenuation by applying the multiple lapse time window analysis (MLTWA) technique [Hoshiba et al., 1991]. This technique is based on a comparison between observed and calculated seismic wave energy density obtained using radiative transfer theory in several successive lapse time windows.

Estimated structures of scattering and intrinsic attenuation in the crust beneath the Kyushu Island show strong spatial variations that depend mainly on the tectonic setting. The seismic attenuation structures are compared with local cut off depth of inland earthquakes, “D90” defined as the depth above which 90 % of the earthquakes occur [Matsumoto et al., 2015]. Regions with high attenuation geographically correlate with shallow seismogenic layers. We will discuss quantitative relation between intrinsic and scattering attenuations and local depths of seismogenic layers.

Study on heterogeneous structure beneath the Beppu-Haneyama fault zone 2

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The Beppu-Haneyama fault zone is the active fault zone in Kyushu, running from the Beppu Bay to western part of Oita prefecture. In the Beppu-Haneyama area, there are many faults and some volcanoes exist between the fault zones. This suggests that the sub-surface structure is heterogeneous in this area. For example, the thin seismogenic layer (about 7km) and the seismic velocity anomaly. Here we developed a method for estimating the complex structure in the area. We modeled the structure of this fault zone as a structure composed by a background heterogeneity and strong scatterers.

We analyzed the 18 seismic events observed at 29 seismic stations deployed by Kyushu and Kyoto Universities, NIED and JMA. We estimated background structure by comparing the observed envelope with theoretical curve based on multiple scattering model. Then, the ripples in the observed envelope were extracted by comparing the envelope with the theoretically expected curve. We estimated the distribution of scatterers based on travel time of the ripples. At 4Hz, the strong scatterer located around the fault zone, the seismic velocity anomaly and the tectonic lines. At 8Hz, scatterer are distributed in the Kuju volcano area.

In conclusion, we could estimate the complex heterogeneity beneath the Beppu-Haneyama fault zone. This method can be applied to the heterogeneous structure of other area, and it is expected to image the structure.

Keywords: Beppu-Haneyama fault zone, Short wavelength heterogeneity

Shear wave splitting caused by triggered seismicity near the Moriyoshi-zan volcano in the Akita Prefecture, northeastern Japan

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We measured shear wave splitting parameters from earthquakes near the Moriyoshi-zan volcano in the Akita Prefecture. Seismic activity in the area was triggered by the 2011 Off the Pacific coast of Tohoku Earthquake, and is characterized by long duration more than four years, migration of hypocentral location, and distinct scattered waves that appear after S-wave, which suggests the contribution of geofluid to seismogenesis. We analyzed seismograms of more than 2000 earthquakes observed at two temporary stations near the source area of triggered seismicity. The splitting parameters obtained by the analysis are the polarization of fast S-wave and the delay time between the fast and slow waves. We used a grid search to find the parameters that give two identical pulses with orthogonal polarization, one delayed with respect to the other. The result shows clear difference between two stations. The polarization is NW-SE and the delay time is around 0.015 s at a station located just above the earthquake cluster (Moriyoshi station). On the other hand, the polarization is nearly N-S and the delay time is close to 0 s at a station situated about 5 km to the north of the cluster (Array station). Rose diagrams of polarization and histograms of delay time show the difference between the two stations is significant. The slitting parameters at the Array station have a common characteristics to a permanent station located about 10 km WSW of the cluster. Because the ray paths to the Moriyoshi station traverse the source location of triggered seismicity, the anisotropy observed at the station is probably caused by the seismic activity of triggered earthquakes. We then investigated temporal variation of the splitting parameters to find no significant change in delay time, but slight change in polarization. Since we started the temporal observation about 16 months after the initiation of triggered seismicity, we cannot specify the time when the anisotropic feature was formed. One possible scenario is that the fracturing at the early stage of triggered seismicity resulted in the formation of anisotropy.

Keywords: shear wave splitting, anisotropy, triggered seismicity

