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.

Acknowledgments

We thank the crew of the R/V Kofu Maru of the former Hakodate Marine Observatory for their cooperation during deployment of OBSs. We thank D. Zhao for permitting us to use his computer program for 3-D tomographic inversion.

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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

The Dense Gravity Surveying Situated in *Senboku Graben* on Takaishi-Sakai Profile which to Cross Uemachi Fault Zone

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1. Summary
Basement investigation is advanced energetically to assume the earthquake response generated in an active fault. In Uemachi Fault zone, located on the central part of Osaka plain, several base investigations have been studied supposing the earthquake which occurs in an active fault energetically too. However, the structural analysis by a gravity survey is not carried out with sufficient point-of-measurement density. Then, the authors have advanced the dense gravity survey in Senboku Area (for example, Ryoki, 2011, *etc*.) In this time, a gravity anomaly was measured densely along mostly Takaishi-Sakai Line in which a seismic prospecting with P wave reflection method was studied by Iwata *et al*. (2013).

2. Target area
The gravity survey line is about 8.3 km distance of east-and-west projection from Takasago, Takaishi-shi to the Handakita-cho, Naka-ku, Sakai-shi. The line intersects some active faults of Uemachi Fault Zone (Nakata *et al*., 1996).

3. Acquisition of geographic information
Latitude, longitude and the altitude of the public-surveying points used the coded data which the Geographical Survey Institute (2013) offered. When it measured on a road, the technique of Ryoki (2015) was applied to refer to them.

4. Result
Fig. 1 shows the measurement result projected in the direction of east and west. The simple Bouguer anomaly has not given geographical feature compensation at Fig. 1. The arrows in the figure show the positions of the active fault by Tanaka *et al*. (1996). Fig. 1 is very as harmonic as P wave profile shown by Iwata *et al*. (2013).

5. conclusion
When Fig. 1 is compared with the profile presented by Nakata *et al*. (1996), a fault structure, which can be presumed from gravity anomaly, consists in the same place as the active fault which is shown with P wave profile. About 0.7 mgal decrease of the eastern throw consists in near -53 km. This decrease forms a low gravity anomaly zone with the Uemachi faults which shows the western throw near -51.5 km. This gravity anomaly can be contrasted with the "bending structure" which shown by Iwata *et al*. (2013), and the base depth of that structure is interpreted as -1750m order. Such a structure is too shown at about 3.5 km southwest (Ryoki, 2014), and it can be seen besides in Ootsugawa profile presented by Iwata *et al*. (2011) though it is narrow. From the above observation fact, it is thought that a Graben is formed here of two structures of eastern throw and western throw. In this paper, this Graben is called "Senboku Graben." The eastern edge of the Senboku Graben is westernmost reversed fault of Uemachi Fault Zone which is divided into three near here. When the form of a gravity anomaly is considered carefully, there is a high possibility that the western edge of the Senboku Graben is also a reversed fault of the eastern throw which accomplishes the eastern edge and a pair.

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Keywords: Osaka Plan, Seismic Reflection Method, subsurface structure, reverse fault, digital geographic information, public-surveying point

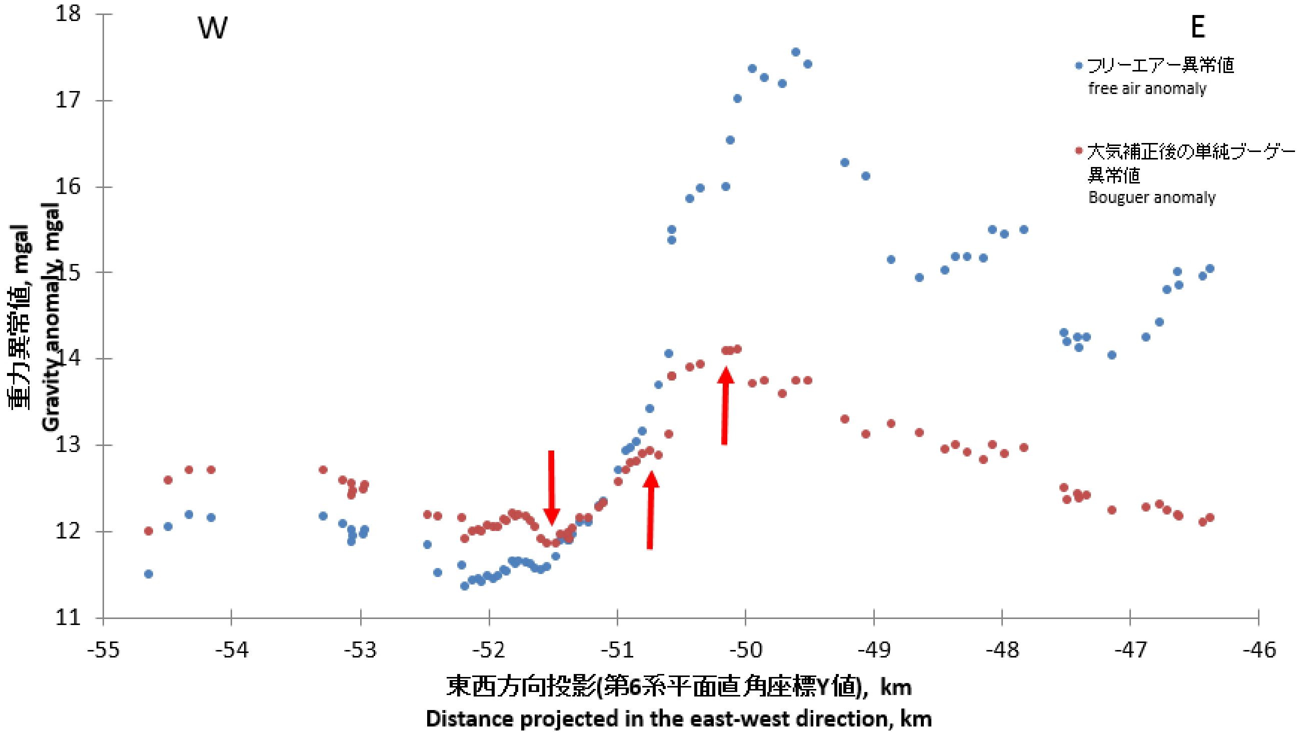

図1　重力異常稠密測定の結果 東西断面
Fig. 1　Profile of gravity anomaly in dense survey East-West ssction

Detecting reflected waves in the triggered seismicity area of Yonezawa, Yamagata-Aizu, Fukushima

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Seismic activity started on March 18, 2011 in the Yonezawa (Yamagata Prefecture) -Aizu(Fukushima Prefecture) area, where seismicity has been very low before. The 2011 Mw 9.0 Tohoku Earthquake on March 11 is supposed to trigger this activation. Studies on focal mechanisms, the time sequence of events, and seismic wave velocity and Qc structures in this area suggested that an inflow of fluids and overpressure subsurface fluids were the cause of the triggering seismicity. Distribution of subsurface fluids, however, has not been known. A boundary of a region containing fluids reflects seismic waves with a large reflection coefficient. Therefore we detected reflection phases in wave records of the events in this area.
Events that have occurred by January, 2015 with M larger than 2 (about 2500 events) were investigated. Wave records were downloaded from the Hi-net Home Page of NIED. Up to now, horizontal components of N.ATKH, the station closest to the active region (epicentral distance range of 3~15km), and N.YNZH, the second closest station (8~25km) were checked as follows. Records contaminated by another event were removed. S wave arrivals were picked. Considering the epicentral distribution, eight profiles were set. The records of events with epicentral distance within 0.5km from a profile were displayed along the profile. S wave arrivals between traces were aligned, and a band-pass filter and AGC were applied. Record sections were made for the same component of each station.
Later phases were detected between 1.5~8s after an S wave arrival at both stations. If we assume they were from horizontal reflectors, most of reflectors were situated at 10-20km in depth. The later phases could be traced over 1~2km along a profile. It seems that the phase may be traced for a longer distance, if the method to display a profile is improved. We are going to improve the profile, and determine the position of reflector (or scatterer).

Keywords: reflected wave, crustal fluid, triggered seismicity

Seismic Reflection Survey at Eastern Edge of Aizu Basin

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We conducted seismic reflection survey at eastern edge of Aizu Basin in Aizuwakamatsu City in September 2015. The Aizu Basin is located between the Western and Eastern Aizu Basin Fault Zones. It is helpful to reveal detailed structure of the fault zones that segment the edge of the Aizu Basin, in order to understand the whole Aizu Basin. Our purpose of the study following the survey in Kitakata City, in the north of the Aizu Basin in September 2014 is to obtain control data to understand the whole Aizu Basin.

In the profile of the 2014 survey, we can see flexure caused by the Eastern Aizu Basin Fault. There, we conducted the survey at Ikkimachi-Tsuruga, Aizuwakamatsu City, where is about 10km to the south of the survey area in 2014. The length of the survey line is about 860m. The western half of the survey line is relatively flat, but the eastern half of the survey line inclines toward the west and is overlaid by the Okinajima Debris Avalanche Deposit. To the north of the survey line, a 6m displacement is recognized from the surface of the deposit, and it is deduced that the displacement is caused by the Eastern Aizu Basin Fault.

We used a portable vibrator ElViS III by GEOSYM with S-wave. Spatial intervals of shot points are 2m, seep frequency is 20 to 160Hz, and sweep duration is 7s. We used single horizontal component geophones with GS32CT (f_o=10Hz) by Geospece, and the intervals are slao 2m. We deployed 96 geophones simultaneously, and moved 48 geophones at a time.

We cannot obtain obvious event at the eastern half of the survey line, and it is possible that it is caused by the debris avalanche deposit. Inclined event toward west can be seen at the western half of the survey line, and structure like flexure also can be seen. We cannot determine that the structure is caused by the Eastern Aizu Fault, but it is possible that the fault is located relatively more western than that deduced from the topography.

Keywords: Aizu Basin, active fault, seismic reflection survey

The 1997 Kagoshima earthquake fault cuts through the north-dipping Shimanto Supergroup

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The 1997 Kagoshima earthquake (M6.6; the 1st event) occurred in southern Kyushu, Japan, subsequently involving another earthquake (M6.4; the 2nd event) in the vicinity two months later. The both focal mechanisms show lateral fault type with a tensional axis of NW-SE direction, which is consistent with their aftershock distributions. This source area has shown no active fault identified. The western offshore of the events is located at the northern margin of the Okinawa trough, where backarc spreading is on-going; however the seimogenic background of the events still remains unknown. Here we understand the seismotectonics in this area based on the analyses of aftershock data and seismic reflection data.
We have early aftershock data (29Mar1997 - 19Jun1997) of the Kagoshima University and the catalogue (2001 - 2009) of NIED Hi-net, the nation-wide dense network in Japan. We relocated the hypocentres using a common velocity structure to compare aftershock distribution through the terms of both datasets. The relocated hypocentres show existence of seismic gap areas throughout the dataset terms. There is a large seismic gap close to the mainshock, which is consistent with large coseismic slip area. Also other seismic gaps like narrow band are observed.
Next we analysed the seismic survey data. We have the dataset of the seismic survey conducted in 2000, of which the survey line runs in the direction of NNW-SSE across the 1st event fault. We applied the developed Multi-Dip CRS method that is powerful tool to clarify seismic image and delineate fine reflections. The obtained seismic crosssection shows that north dipping reflectors are dominant; especially there is a remarkable reflector in the depths of 8-10km in the north of the fault. The north dipping reflectors become obscure around the source fault.
The relocated aftershocks are superimposed with the crosssection. The aftershocks distribute vertically but include seismic gaps which correspond to the narrow band gaps described above. Interestingly the seismic gaps are located in the extension of the north-dipping reflectors, implying that the north dipping structure in the subsurface may control the aftershock activity.
We interpret the results as follows. The common dip direction would indicate that the north dipping structure is related with the Shimanto Supergroup formed in the Cretaceous. The seismic section shows that near-vertical fault plane cuts through the Shimanto Supergroup, that is, the rupture occurred on the plane suitable to the present stress field, almost independent of the existing Cretaceous structure. In addition, the fault would be relatively recently formed since the fault displacement on surface has not been confirmed. Thus the 1997 event may be seismic activity that is attributed to the eastward block movement following the recent backarc spreading of the Okinawa trough.

Keywords: Seismic Reflection Survey, The 1997 Kagoshima earthquake

3D seismic velocity structures at the off-Boso Peninsula

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1. Introduction

In the Kanto region, the North American plate, the Philippine Sea plate (PHS) and the Pacific plate are mutually interrelated. Thus various seismological events have occurred along the Sagami Trough, for example, the 1923 Kanto earthquake and the Boso slow slip events (e.g., Ozawa et al., 2003). To reveal the process of these events, it is required to obtain the detailed structure at the Off-Boso area. The purpose of this research is to estimate 3D seismic velocity structure at the Off-Boso peninsula.

2. Methods and data

We applied the Double-Difference tomography (Zhang and Thurber, 2003) to arrival data obtained by steady observation stations and ocean bottom seismometers (OBSs). Data from the OBSs improve resolutions in the oceanic area. We used the unified catalog of the Japan Meteorological Agency for the period between August 2009 and March 2012. After several iterations, travel time residuals reduced from 183 msec to 83 msec for P wave, from 328 msec to 131 msec for S wave. As results of checkerboard resolution tests, our results can resolve 10 km scale in horizontal direction and 5~10 km scale in depth direction for P wave.

3. Results

Our results show subducting PHS in the direction of northwest for P and S wave velocity structures. The PHS seems like a flat form under the Off-Boso. We estimated geometry of the upper surface of the PHS by tracing the Moho which is estimated from the velocity structures. As a result, we can estimate a rough trend of the geometry under the oceanic area. The isodepth contour of 10km runs in parallel with the Sagami Trough. On the other hand, the isodepth contours of 20km and 30km have curved forms toward northeast.

It is pointed out that there is a serpentinized mantle in the mantle wedge of the PHS (e.g., Kamiya and Kobayashi, 2000). So we investigated distribution of this serpentine area. The serpentine area distributes under northeast of the Off-Boso, and the boundary of this area has strike of NW-SE, but it locally curves toward south beneath Mobara city. This geometry is similar to that proposed by Nakajima et al. (2010), but our results moves northward compared with the result by Nakajima.

Acknowledgements

We thank captains and crew of KH09-3 cruise and aftershock observation cruise of the 2011 off the Pacific coast of Tohoku Earthquake. We used the unified catalog of the Japan Meteorological Agency. This research was supported by KAKENHI (25287109).

Keywords: seismic tomography, Off-Boso, Philippine Sea plate, serpentinize

P-wave anisotropic tomography of the 2011 Tohoku-oki earthquake area

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On 11 March 2011, the great Tohoku-oki earthquake (Mw 9.0) occurred in the boundary between the subducting Pacific slab and the overlying Okhotsk plate. To clarify the generating mechanism of such a huge earthquake, it is important to study the detailed structure of the subduction zone.

In the crust and mantle, the velocity of seismic waves depends on the direction of wave propagation, which is called seismic anisotropy. A major cause of seismic anisotropy is that the crystal lattice of minerals such as olivine is selectively oriented in a specific direction due to mantle convection. Measuring shear-wave splitting is a good method to study seismic anisotropy, but the measurements have a poor depth resolution. In this work we adopt P-wave azimuthal anisotropy tomography which can determine 3-D variations of seismic anisotropy.

We inverted a large number of high-quality arrival-time data of local earthquakes for P-wave azimuthal anisotropy parameters, and estimated the 3-D velocity structure and azimuthal anisotropy in the 2011 Tohoku-oki Earthquake area beneath the Tohoku forearc. Our study region is in the range of 36N~41N and 139E~145E, and we used 516 seismic stations. The grid interval for the isotropic tomography is 0.3 degrees in the latitude and longitude directions, and the lateral grid interval is 0.4 degrees for the anisotropic tomography. In the subducting Pacific slab, the grid nodes are set up at depths of 5, 25 and 50 km from the slab upper boundary. In the crust and mantle wedge, the grid nodes are set up at depths of 10, 25, 40, 65, 90, 120, 160 and 200 km. We used P-wave arrival-time data selected from the Japan Unified Earthquake Catalogue. The data set used in this study contains many aftershocks of the 2011 Tohoku-oki Earthquake.

The results of this work are summarized as follows.
(1) The predominant FVD (fast velocity direction) is NW-SE in the mantle wedge, which reflects preferred orientation of mantle minerals (such as olivine) caused by the corner flow induced by the subduction of the Pacific plate.
(2) The predominant FVD is nearly N-S in the subducting Pacific slab, which reflects the anisotropy induced by fossil fabric formed at the spreading mid-ocean ridge. This feature of anisotropy is consistent with the previous studies (Wang & Zhao, 2008; Huang et al., 2011).
(3) The interplate megathrust zone exhibits complex FVDs, which may reflect a complex stress field in and around asperities where the interplate plate coupling is strong.

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Keywords: Tomography, Anisotropy, Tohoku, Subduction zone, Mantle wedge

Shear wave anisotropy in shallow subsurface around the Alpine fault, New Zealand, estimated by seismic interferometry

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Deep Fault Drilling Project (DFDP) aims to provide new geophysical and geological insight for the central Alpine fault system. After the drillings in two phases (DFDP-1 and DFDP-2), seismometers have been deployed at the depth of 81 and 400 m within the DFDP-1 and DFDP-2 boreholes, respectively, to detect micro earthquakes around the Alpine fault. Additionally, we newly installed two surface seismometers above the DFDP boreholes. Using the borehole and surface seismometers, we examined shear wave anisotropy in shallow subsurface close to the Alpine fault. We applied seismic interferometry to regional earthquake waveforms observed at the bottom and surface sensors to estimate shear wave anisotropy between the two sensors. First, we corrected instrument responses and orientations of sensors and upsampled waveforms. Then, we computed cross-correlation functions of coda waves of 25 and 16 regional earthquakes for DFDP-1 and DFDP-2 sites, respectively. The cross-correlation functions show clear wave packets in the frequency range of 3-6 Hz. The peak times indicate average shear velocity of 880 and 550 m/s in DFDP-1 and DFDP-2 site, respectively. We estimated shear wave polarization anisotropy from peak time variations of cross-correlation functions of rotated horizontal waveforms. We obtained similar shear wave anisotropy in both boreholes with fast shear wave directions parallel to the Alpine fault. The fault parallel fast direction is consistent with orientation of foliation in hanging wall mylonite, suggesting structural anisotropy is predominant. Compering anisotropy in two other boreholes in the footwall sides may provide deeper understanding of shallow subsurface anisotropy and information about structural evolution and stress state around the Alpine fault.

Keywords: Alpine fault, Shear wave anisotropy

Imaging of Crustal Structure across the Red River shear zone (Northern Vietnam) from Seismic Linear Array Observations

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The Red River fault is the first order tectonic structure running from the southeastern margin of the Tibet plateau to the South China Sea that separates the South China block to the north and the Indochina block to the south. Hence, understanding the Red River fault structure is critical for evaluating the hypotheses of the tectonic evolution of Southeast Asia and the extrusion mechanism along the Red River fault caused by the continent-to-continent collision between the Indian and Eurasian plates.
Using a 250 km long profile of 25 broadband seismic stations across the Red River fault in northern Vietnam has provided a high-resolution P receiver function section which interpreted in term of crustal architecture and composition. Results reveal distinct features of crustal structures across Red River shear zone. The Moho depth is ranging from 28 to 32 km, with an average of about 30 km. It deepens in the south of the Red River fault, but shallower and flater in the north. The Vp/Vs ratio is lower and stable values in the north of Red River fault but highly variable in the south, suggesting that the crust in the south of Red River fault might be effected by the interaction of micro blocks in Northern Vietnam which separated by the major faults (Ma River fault, Da River fault, Son La fault, Red River fault). The shear wave velocity profile pointed out a sharp variation of the lower crust and uppermost mantle beneath the Red River shear zone, suggesting that the Red River shear zone is a lithospheric structure.

Keywords: Red River shear zone, Receiver Function, Crustal Structure, Seismic Linear Array across Red River shear zone

Focal Mechanisms and Seismicity in the Region of Induced Earthquakes of Song Tranh Dam, Vietnam

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Vietnam is located in South East Asia and bounded by the Pacific and Mediterranean-Himalaya seismic belts on its eastern, western and southern sides, respectively. The dynamic tectonic processes in this region cause the territory of Vietnam and adjacent areas to have intensive differential movement, making the regional tectonic structure very complicated. The tectonics have led this territory to have moderate seismic activity and complicated geological structures, such as the Lai Chau-Dien Bien fault zone, Red River fault zone, and others. Southern Vietnam was considered to be a region with low seismicity, compared to the North. However, the sequence of earthquakes that occurred at Song Tranh Dam during the last several years surprised many scientists because the southern region of Vietnam was not expected to have major tectonic activity. This region where many induced earthquakes are now occurring is associated with the filling of a new reservoir. There have been four M4 earthquakes (maximum earthquake was 4.7 in November, 2012), so it is one of the most active induced earthquakes examples in the world. It is important to determine the strong motion attenuation relations for this area since damaging earthquakes may be expected in the near future. We collect and process data from 5 seismic stations around Song Tranh dam, include more than 300 events larger than 1.5 and more than 2000 seismic waveforms to determine arrival times and locate the earthquakes in the Song Tranh dam region. In this study we use time domain analyses to determine focal mechanisms. We use software of Dreger and Ford (2011) modified for the Song Tranh Dam region. Induced earthquakes processed by this software include events withmagnitudes larger than 3.5 and recorded on 4 or more stations.

We also compare our results with mechanisms for tectonic earthquakes in the region (Hung Nhuong Tavi and Tra Bong faults). The results show a difference in focal mechanism between tectonic earthquakes and induced earthquakes which may be related to the increased fluid pressure from filling of the reservoir. To confirm this result, we will need to process the many smaller events with magnitude less than 3.0, which have occurred around Song Tranh Dam.

We used a genetic algorithm method to estimate the local velocity structure. We applied this method to determine a layered model for the Song Tranh dam region. Our results obtained a new 1D model of 7-8 layers. The shallow P wave velocity of 4.6 km/s is slower than 5.9 km/s for previous studies in northern VietNam. For a deeper layers from 6 to 12 km, P wave velocity becomes larger, 5.4 km/s -5.9 km/s. The Vp/Vs shows relatively higher values of 1.75-1.77 for the depth around 12 km. When layer thickness changes from 21 km to 28 km, the P wave velocity increases and changes from 6.5 km/s to 7.3 km/s, however, Vp/Vs ratio decreases from 1.77 to 1.67. Finally, the depth of the Moho surface changes from 28 to 35 km and the P wave velocity changes from 7.8 to 8.2 km/s, with Vp/Vs value of about 1.78. Earthquakes still occur at Song Tranh dam (a recent M3.3 occurred on August,26 th 2015), and more than a thousand earthquakes with magnitude less than 1.5 have not yet been processed. We continue to update the seismic analyses with information from smaller earthquakes to improve our results.

Keywords: Song Tranh Dam, VietNam, Focal Mechanism , Induced Earthquake, Velocity structure

Did the temporal crustal structure change cause the Oct. 2011 Kurobe Dam seismicity?

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1. Introduction
After the March 2011 Tohoku-Oki earthquake, seismicity activation was observed wide range of beneath the Hida mountain area. However, another significant seismicity occurred around the Kurobe dam reservoir in October 2011. It was initiated by M3.9 earthquake followed by two magnitude larger than 5.0 quakes and the activity lasted for a couple of weeks. No active earthquake faults have been recognized, and no significant seismic activities or magnitude larger than 5 events have been observed previously except the one observed in 1960s right after the reservoir impounding. In the previous study, we discussed the fault zone around Kurobe and mechanism of seismic activity [Sato *et al.*, 2015]. This time, we discuss the crustal structure change around Kurobe.
2. Method
To investigate the temporal structural change in the study area, we calculated the autocorrelation function (ACF) and shear wave splitting analysis. For the both analyses, Kuroyon station (E.KYJ) located the north of Kurobe dam reservoir was used. ACF is calculated each day using the vertical component of the continuous waveform from 2010 to 2012. Shear wave splitting is calculated using the event that occurred within 50km from Kurobe in 2011 and incident angle less than 35°.
3. Results and Discussion
The obtained ACF showed that the relative seismic wave velocity reduction in 2011 compared to other periods. Especially, significant reduction was observed during the period of May to June 2011. It might be caused by the static and dynamic stress changes around the area. The noises observed in the ACF is consistent with dynamic stress increase. In addition, shear wave splitting analysis results showed the 90°-flips in shear wave polarizations. It indicates the presence of high pore-fluid pressure and suggests the penetration of water. In conclusion, the seismicity observed beneath the Kurobe dam October 2011 might be induced by the pore pressure increase due to the opening crack which is promoted by the successive seismicity followed by the M9.0 Tohoku earthquake.

Keywords: Hida Mountains, Ambient noise, Autocorrelation function, Shear wave splitting

Results of 2015 seismic survey for the research project on seismic and tsunami hazards around the Sea of Japan

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To estimates Tsunami and seismic hazards along the coastal area of Sea of Japan, more detailed survey to identify source faults is needed. A research project funded by MEXT named "the integrated research project on seismic and tsunami hazards around the Sea of Japan" began in FY 2013. To obtain the information of crustal structure, we performed seismic reflection profiling off-Maizuru area in the southwestern part of Honshu, Japan. The location of seismic line was designed to connect to the Shingu-Maizuru deep seismic survey across the Southwest Japan arc (Ito et al., 2006). Multi-channel seismic reflection data were acquired along seismic line off-Maizuru. The length of seismic line is 67 km. We used a gun-ship with 1950 cu. inch air-gun and towed a 2-km-long, streamer cable with 168 channels. On land we deployed 4.5 Hz geophones at 100 m interval and formed a 17-long-seismic line. All air-gun shots were recorded on this seismic line. Seismic section of marine part portrays the image down to 2 to 3 seconds. Based on seismic facies, we can divide it into three units. Lowest unit is marked by poor seismic reflection and considered to correspond to pre-Neogene rocks. Middle unit is characterized by northward-dipping coherent reflectors and corresponds to Miocene mainly sedimentary rocks. The top unit, above 0.5 sec (TWT), covers the lower units with unconformity. This unit corresponds to Quaternary Tottori-Oki Group (Yamamoto et al., 1993). Reverse fault is observed in the northern part of the seismic section. The reverse faulting is a result of reactivation of normal fault associated with the formation of the Sea of Japan. Along this seismic line, the revers faulting does not show the deformation of the Quaternary unit. In the middle part of the seismic line, a high angle fault displaced the top unit. Beneath the land section, subhorizontal reflectors is observed between 4.5 to 5.5 second (TWT). It seems to be a northward extension of the mid-crustal reflectors in the Shingu-Maizuru seismic section (Ito et al., 2006).

Keywords: Sea of Japan, crustal structure, seismic reflection survey

Fault distribution on the southwest offshore area of Okinawa Island

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This is a part of the project “Comprehensive evaluation of faults information on offshore Japan”, by the Ministry of Education, Culture, Sports, Science and Technology (MEXT). The project consists of three themes, 1) Collecting seismic survey data and building a database of offshore faults, 2) Interpreting distribution of active faults using seismic data collected, and conducting the seismic re-processing by leading-edge seismic technology for the seismic data obtained in previous decades, 3) Building the fault models for a simulation of strong motion and tsunami disaster, based on the interpreted faults. Our purpose of study is to reveal the detailed structural characters of active faults in the southwest offshore of Okinawa Island by 3D seismic interpretation.
3D reflection seismic data provide us the ability to map structural features in detail up to a resolution of a few tens of meters over thousands of square kilometers. Landscapes of seismic attributes such as amplitude, dip and coherence (discontinuity) attributes are often revealed to detect great detail of geological structures. We carried out the interpretation of fault distribution with the seismic attribute to highlight faults such as seismic discontinuities, using 3D seismic data which were acquired by JOGMEC.
The Ryukyu island arc system is located at a convergent plate margin where the Philippine Sea Plate is subducting under the Eurasia Plate. In the southwestern Ryukyu arc, the subduction is oblique to the trench, while in the northeastern Ryukyu arc, the Philippine is subducting perpendicular to the trench. The Oblique subduction causes compressive or extensional stresses in the forearc depending on the sense of arc curvature and the relative motion of the plates.
Discontinuity attribute shows slightly-swing lineaments with northeast-trending on the seabed surface where is located on a continental slope of the Ryukyu trench side. Based on that geometry features, numerous normal faults with 5 to 30 km length, and NNE-trending, were recognized in the study area. Those faults trend to converge toward the Kerama Gap which is considered to be left-lateral fault and the one of two major structural boundaries of the Ryukyu Arc, which indicates those faults have been developed when the Kerama Gap was formed. Although the fault density is high and the fault traces are crooked in this area, the time-slice of the discontinuity attribute shows clear the spatial relationships between those faults. In contrast, it is hard to identify clearly fault segments which are interpreted on seismic section by only 2D seismic data due to a sparse data density and a limitation of 2D seismic survey itself. Seismic attributes help us to identify subtle faults and can lead to better understanding in the description and analyses of fault system geometry such as trace-length, fault-displacement and connectivity of fault.

Keywords: active fault, Kerama Gap, 3D seismic reflection survey

