Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SCG68-P01 Room:Convention Hall Time:May 23 18:15-19:30

3-D shear-wave velocity structure of the Japan subduction zone from teleseismic tomography

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So far many researchers have used seismic tomography to investigate the 3-D seismic velocity structure beneath the Japan Islands. However, most of the previous tomographic studies used only the arrival-time data from local earthquakes that occurred in the crust and the subducting Pacific and Philippine Sea slabs under Japan, which could reveal the 3-D structure down to about 200 km depth including the crust and upper-mantle wedge, but could not determine the deeper 3-D structure for the entire subducting slabs and the mantle below the slabs. This problem was resolved by adding data from teleseismic events to conduct a joint inversion of local and teleseismic data (e.g., Zhao et al., 1994). However, so far only 3-D P-wave velocity structure has been studied under the Japan Islands (e.g., Abdelwahed and Zhao, 2007; Zhao et al., 2012), while high-resolution 3-D S-wave velocity (Vs) structure under Japan has not been investigated yet.

In this study, we have attempted to determine a detailed 3-D Vs model of the Japan subduction zone down to 700 km depth using both local and teleseismic data. We used ˜101,200 S-wave arrival times from 1180 local earthquakes that occurred in and around Japan. We have also made great efforts to collect 17,167 S-wave arrival times from 25 teleseismic events (M 6.1 - 8.1) from the original 3-component seismograms recorded by the dense Hi-net seismic network deployed on the Japan Islands.

Main features of our 3-D Vs model are summarized as follows. (1) The subducting Pacific and Philippine Sea slabs are imaged clearly as high-velocity zones, and low-velocity anomalies are visible in the upper-mantle wedge above the slabs. The overall pattern of the 3-D Vs model is quite similar to that of the 3-D Vp model of Zhao et al. (2012). (2) The subducting Philippine Sea slab is well imaged as a high-velocity zone down to 400 km depth under west of Kyushu Island. (3) Beneath the Japan Sea off Shimane Peninsula in western Honshu (the Chugoku District), the Philippine Sea slab is found to subduct aseismically down to ˜500 km depth. These new findings are considered to be very important for understanding the subduction history of the Philippine Sea plate as well as the dynamic evolution of the Japan subduction zone.

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Keywords: teleseismic tomography, 3-D shear-wave velocity structure, Japan subduction zone

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Spatial stress heterogeneity imaging by using difference between reduced stress tensors

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Space variations in stress states are important to understand crustal dynamics and development. Methods for determining the present state of tectonic stress from earthquake focal mechanisms have been proposed (e.g. Angelier 1984; Jour. Geophys. Res. 89, 5835-5848; Michael, 1987; Jour. Geophys. Res. 92, 357-368). Otsubo et al. (2008; Tectonophysics 457, 150-160) proposed a method to separate heterogeneous stresses from earthquake focal mechanism data from spatially varying state of stress, and it shows the spatial heterogeneity in the crust. However estimated state of stress from Otsubo et al. (2008) is spatially discrete, and the discrete information of the stress state is insufficient to illustrate the overview of the heterogeneity.

We propose a technique to image an overview of the stress state in the crust from the difference between the reference stress state and the stress state determined at various locations. The measurement of the difference between the stress tensors determined at various locations is essential to evaluate the stress heterogeneity. A few approaches have been proposed for this stress heterogeneity estimation (e.g. spatial distribution of stress axes directions). However, the difference of stress tensors should not be evaluated based on only their directional attributes. The evaluation of the difference should be achieved based upon all six components of the respective tensors. We introduce the stress difference (SD) defined by Orife and Lisle (2003; Jour. Struct. Geol. 25, 949-957) to calculate the difference between the stress tensors that are represented by three principal stress axes and stress ratio (s2-s3/s1-s3). The difference shows the similarity or dissimilarity between the stress tensors. SD ranges from 0 to 2. SD = 0 for identical tensors, while SD = 2 when the two tensors are negative tensors to each other. Therefore, the spatial distribution of SD can be illustrated as spatial stress heterogeneity.

We apply the technique to natural data from Japan islands that are located in region of subduction zones. The stress imaging technique provides important potential to compare the stress state and spatial geophysical information (e.g. geodesic data, seismic velocity structure and gravity anomaly).

Main part of this research project has been conducted under the research contract with the Secretariat of Nuclear Regulation Authority (Secretariat of NRA).

Keywords: stress inversion, focal mechanism, multiple inverse method, faulting, earthquake, crustal dynamics

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Advanced use of refraction tomography using long-spread reflection seismic data for exploring deep crustal structure

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(1) Recent advances for reflection and refraction survey

We introduce recent advances of data acquisition and processing in the reflection seismic survey. Today's reflection survey exploring deep crustal structures use the long-spread survey line with dense receiver deployment by combining the stand-alone recording systems and the wired telemetry type recording systems. In addition, different kinds of seismic source are used in a survey such as vibrators with high mobility and dynamite explosion on land, and an airgun system in marine. These innovations enabled us to improve the efficiency of simultaneous acquisition of the reflection seismic data and the refraction seismic data. In data processing, there are some remarkable technologies to profile the deep structures with the long-spread seismic data. The deep reflections appeared in a long-offset range are effectively used on the reflection imaging. The advanced refraction tomography are carried out to estimate velocity structures with highly dense traveltime data using both the reflection survey data and refraction survey data. These advances have achieved to reveal the basin structures in a lot of areas in Japan.

(2) Standard specification of data acquisition aiming deep crustal structure

The standard specifications in the simultaneous reflection and refraction survey for deep seismic profiling are briefly reviewed. The thousands of receivers are deployed along a 50 km or longer survey line with 50 m geophone spacing on land and 25 m spacing of receivers on an ocean bottom cable in marine. For the reflection survey, four vibrators are used to generate sweep signal with from 150 to 250 m intervals on land, and the airguns are used with 25 m or 50 m intervals. For the refraction survey, we need high energy seismic source in order to record the high S/N data on the whole line. Three kinds of sources are used with about 5 km shot intervals, the dynamaites with 100 kg or more charge and vibrators with hundreds sweeping on land, and the airgun with 30 or more stacks in marine.

(3) Refraction tomography with dense traveltime data

The velocity distribution in the ground is estimated by the refraction tomography using the traveltime information of first arrival waves, which are picked manually on both the reflection and the refraction data. By updating the velocity model iteratively to minimize the traveltime difference between the observed and the calculated for each source-receiver pair, the reasonable velocity distribution is estimated.

(4) Uncertainty analysis by a initial model randomization

We adopt the Monte Carlo uncertainty analysis by initial model randomization to evaluate the tomography result, because the refraction tomography has a high non-linearity and the solution also has high dependence on initial model selection,. We assumed that the effect on the uncertainty by selection of the initial models is bigger than the effect by pick error of the traveltimes on both the dense reflection data and the high S/N refraction data. By averaging the tomographic results from hundreds of initial models, we obtain statistically optimum solution with the averaged velocity model and the uncertainty distribution by the standard deviation.

(5) Final model update by cascade tomography

The cascade tomography is a practical solution to retrieve fine velocity perturbation around velocity boundaries which are smoothed by averaging the hundreds of tomograms. The averaged model after uncertainty analysis is used as the best initial model for the final tomography, and the velocity model is update slightly in a few iterations. The parts of fine-scale update in the cascade process are well correspondent to the parts of high standard deviation in the uncertainty analysis.

Keywords: reflection seismic, refraction tomography, Mote Carlo uncertainty analysis, cascade tomography

SCG68-P04 Room:Convention Hall Time:May 23 18:15-19:30

Reinterpretation of the lithospheric structure beneath the Hidaka collision zone, Hokkaido, Japan 1.Outline

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An arc-arc type collision between the northeastern (NE) Japan arc and the Kuril arc has formed Hidaka collision zone (HCZ) in south-central Hokkaido Japan. From detailed geologic information, it is known that Kuril arc crust is thrusting westward on the NE Japan arc along the Hidaka Main Thrust (HMT).

To clarify the subsurface structure of the deeper part, several reflection/refraction surveys across the HCZ were carried out in the period from 1994 to 2000 by the group of University of Tokyo, Hokkaido University and Chiba University(e.g. Arita et al., 1998; Tsumura et al., 1999; Ito et al., 2002, Iwasaki et al. 2004). The seismic profiles reveal that distinct east-dipping reflectors are dominant in the eastern side of the HMT. Especially, in the Hidaka94-97 transects, the upper portion of the Kuril lower crust is characterized by numerous east-dipping reflectors, whereas west-dipping reflectors dominate the lower part of the lower crust. From this reflector configuration, the lower crust of the Kuril arc is interpreted to be delaminated by the collision.

Recent results of travel time tomography showed that the existence of east-dipping high velocity zone at the eastern side of the HMT and low velocity zone intruded beneath the high velocity zone. These velocity images well coincide with the feature seen in the reflection profiles in the shallower part. However, it seems that there are some disagreements between velocity images and reflection profiles in the deeper part. Since it was difficult to argue rock composition only from the estimated velocities or from reflection events, we examined to detect reflectors at the deeper extension of lower part of the lower crust by using multi-dip reflection surface (MDRS) method(Aoki et al.,2010). MDRS analysis is an effective tool to emphasize the weak dipping reflections and it provides us new information about a deeper part beneath the HCZ.

Keywords: Hidaka collision zone, delamination, seismic reflection survey, travel time tomography

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Report on the Fujikawa kako fault system ~ Itoigawa-Shizuoka Tectonic Line seismic profiling, FIST.

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A seismic reflection experiment was conducted across the collision/subduction transition zone of the northwestern border of the Philippine Sea Plate just before the completion of the New Tomei EXWY in April in 2012. Its 36-km-long seismic line started from the east of the Fujikawa kako fault system, and ended at the west of the Jumaiyama Tectonic Line crossing the Itoigawa-Shizuoka Tectonic Line. The experiment is named the Fijikawa kako fault system ~ Itoigawa-Shizuoka Tectonic Line seismic profiling, FIST for short. It was composed of the deep and the wide-angle reflection experiments along the whole line, and of the high resolution one across the Omiya and the Agoyama faults in the Fujikawa kako fault system. First of all, we present the shallow structure of the Fujikawa kako fault system revealed by the FIST profiles.

(1) Omiya fault

The high resolution profile indicates that the reflector of the Omiya fault is traceable as a w-dipping reverse fault from the surface (the ridge of the Hoshiyama hills) at about 20 degrees down to 1000m deep, and at about a little less than 40 degrees down to 2000 m deep, although Yamazaki (1992) thought it as a high angle normal fault. Its vertical displacement of 3600-m/s-strata is estimated about 1000 m. The northeastward tilting of the surface along the northeastern margin of the Hoshiyama hills (Nakata et al., 2000) corresponds probably to the drag of the hanging wall of the Omiya fault.

(2) Agoyama fault

Unfortunately there is no information on the Agoyama fault in the profiles. A minor thrust may exist about 1 km east of the Agoyama fault.

(3) Shibakwa fault

The Shibakawa fault is traceable as a west-dipping reverse fault at about 45 degrees down to 3500 m deep, as discussed in Part II. Although the 4200-m/s-strata are displaced vertically at about 1000 m by the fault, the overlying 3600-m/s-strata are only at 500 m. This may suggest that the present main activity of the Fujikawa kako fault system has been shift to the Omiya fault.

The Noshita fault, which runs about 2 km west of the Shibakawa fault, does not belong to the present Fujikawa kako fault system, because it does not displace the strata shallower than the 4200-m/s strata. However it is also a reverse fault, and has the same attitude as the Shibakawa fault. Structurally speaking, the Noshita fault is the westernmost fault of the former system, and belongs to the Fijikawa kako fault system in a broad sense.

We could not find the shallow structure of the faults west of the Noshita fault in the FIST profiles. However several series of very important information on their fault motions is newly collected from the faulted socks of the Neguma and the Tahirotoge-Otoshita faults as follows (Nozaki et al., 2012)..

(4) Neguma fault

The main sense was surely normal in motion, although Matsuda (1961) maintained a reverse sense. This new idea coincides with the fact that the strata of the hanging wall was younger than that of the footwall.

(5) Tashirotoge-Otoshita fault

The main sense was surely left-lateral with reverse in motion, although Matsuda (1961) maintained a thrust motion. This suggests the fault had the same activity as the Itoigawa-Shizuoka Tectonic line.

Keywords: Fujika kako fault system, Itoigawa-shizuoka Tectonic Line, seismic profiling, shallow structure

SCG68-P06 Room:Convention Hall Time:May 23 18:15-19:30

Generation mechanism of shallow earthquakes near Choshi after 2011 Off Tohoku earthquake

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After 2011 Off Tohoku earthquake, numerous earthquakes have occurred near Choshi, eastern Kanto. Especially, two M6-class earthquakes (March 16, 2011 Mw5.8 and March 14, 2012 Mw5.8 from NIED AQUA) occurred at region shallower than 20 km, though small number of earthquakes occurred before the Off Tohoku earthquake. To study generation mechanism of these earthquakes, I determined detailed hypocenters and compared it with other data.

Earthquakes from January 1, 2009 to April 1, 2012 were relocated by Double Difference (DD) method (Waldhauser and Ellsworth, 2000) using arrival time data and relative traveltime difference based on seismic data acquired by NIED Hi-net and other networks. Centroid moment tensor (CMT) solutions were determined by using NIED F-net data based on CMT analyzing method by Matsumura et al. (2006).

Significant seismic cluster can be seen at a region shallower than 20 km in the obtained result. CMT solutions in this cluster are almost normal fault types with E-W tension. At region from 25 to 30 km depth, seismic plane dipping northwestward direction can be seen. This can be regarded as the eastward extension of the upper plane of the Philippine Sea plate (PHS) identified base on small repeating earthquakes (Kimura et al. 2006). CMT solutions in this seismic plane are consistent with slip direction on the PHS. At region from 35 to 50 km, seismic clusters are distributed along a plane dipping westward. These clusters correspond to the Pacific plate and CMT solutions are consistent. Small repeating earthquakes are distributed along this plane, too.

Aftershocks wihitn 24 hours (hereinafter, aftershocks) from the earthquake on March 14, 2012 (hereinafter, mainshock) are composed of a group of most aftershocks along a plane dipping eastward with dip angle of about 40 degree at a depth from 10 to 15 km and a group of few earthquakes sparsely distributed above the seismic plane. The mainshock is located at the deep extension of the seismic plane and it is likely that this plane corresponds to the fault. In association with the mainshock, small crustal deformations were observed by Geospatial Information Authority of Japan (GSI) GEONET stations. Based on an inversion analysis of the rectangle fault model confinied close to the seismic plane, a tentative fault model with width of 6 km, length of 15 km, and slip amount of 45 cm was obtained. This model can explain the observed horizontal displacements well. The CMT solution of the mainshock is a normal fault type with E-W tension and eastward dipping nodal plane is consistent with aftershock distribution. Before the Off Tohoku earthquake, small number of earthquakes also occurred at a shallow region and they are also normal fault types with E-W tension.

These results indicate that earthquakes shallower than 20 km near Choshi occurred above the interface of interplate shearing on the PHS. E-W tension is dominant at this region before the Off Tohoku earthquake, and it was strengthened after the Off Tohoku earthquake, resulting in numerous earthquakes.

Acknowledgements: Seismic data provided by Japan Meteorological Agency, University of Tokyo, and GSI were used.

Keywords: Shallow earthquake, Centroid moment tensor, detailed hypocenter

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Shallow geologic structure of the Futaba fault, northeast, Honshu, Japan, based on gravity survey

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The Futaba fault is known as a lateral strike slip fault in the Cretaceous period and has a remarkable fracture zone, few hundreds meter wide. The fault trends NNW-SSE and is divided into two branches, western F1 and eastern F2 faults in the northern Abukuma mountains, respectively, and between these faults the Wariyama horst is developed. During early to middle Miocene, E-W extensional stress field caused large normal displacement along the western fault F1 to from a half graben filled with clastic sediments including breccia. In the present, the eastern fault F2 is active, along which left lateral offset with western upheaval ingredient is observed geomorphologically. Thus, the Futaba fault has complicated history of development.

In this study, we conducted gravity survey to clarify the subsurface structure and to model the density structure around the fault. A survey line is east to west across the Wariyama horst and about 12 km long from Shinchimachi, Fukushima Pref., to Marumori, Miyagi Pref. Each interval of observation sites is about 200m in a plain and is about 100m around Futaba fault. The gravity meter of this study is LaCoste and Romberg Model-G824. Error of measurement at each site is less than or equal to 0.02 mGal. The elevation of each site is leveled with an electric level. Errors for leveling are 7mm. We made the normal processing of the data including tidal, drift, terrain, free-air, and Bouguer corrections to obtain Bouguer anomalies, according to the methodology described by Geological Survey of Japan, AIST (2004). We assumed that, applying the empirical equation after Gardner et al. (1974) and Brocher et al. (2005) to P-wave velocity due to a refraction experiment carried out along the same line, the density for the Bouguer and terrain corrections is 2.2 g/cm^3.

The resultant Bouguer anomaly after regional trend correction ranges from 102.5 mGal to 88.6 mGal. The largest value is obtained in the Wariyama horst, where pre-Cenozoic basement is distributed. In the east of the horst, where marine Pliocene formations are exposed, the anomaly decreases to the minimum value gently from the eastern end to west. In the west to the horst, where the main constituent formations are lower to middle Miocene, the anomaly shows two local maximums. They are supposed to be due to concealed half grabens.

We will show the relationship between F1, F2 faults and the main half graben based on the density model.

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Deep seismic profiling across the fore arc of central northern Honshu, Japan: Soma-Yonezawa seismic line

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The 2001 Tohoku earthquake (M9) produced large amount of crustal movements and stress changes. To evaluate the post seismic crustal activity, we have to construct a numerical model, which include lithospheric structures and receiver faults. For the sake of constructing a physical model, we performed deep seismic reflection profiling under collaboration with JAMSTEC. The seismic line starts from volcanic front and ends at the outer rise of the Japan trench. In this paper, we describe the only onshore upper crustal structure obtained by onshore survey. Along the seismic line, the Futaba fault and the western boundary fault of Fukushima basin are distinctive active faults.

The Futaba fault is located along the Pacific cast of southern part of Northern Honshu and continues at least 100 km. Based on tectonic morphological research, its central part show the active tectonic features. Due to the effect of M9 Tohoku Oki earthquake 2011, the evaluation of Coulomb stress changes on the fault surface is concerned for the assess of seismic hazards. To investigate the deep geometry of seismogenic source fault and basic crustal structure, we performed deep seismic reflection profiling along the 60-km-long seismic line across the Futaba fault. The seismic data were obtained using four vibroseis trucks and 2500 channel recorders. The seismic section portrays the half graben filled by1000-m-thick lower Miocene fluvial sediments, suggesting that the Futaba fault reactivated as a west dipping normal fault during the early Miocene associated with opening of the Sea of Japan. On the hanging wall of the Miocene normal fault, Mesozoic metamorphic rocks are cropping out forming a narrow range parallel to the fault. On the footwall of this range, footwall shortcut thrust is clearly identified by the deformation of Plio-Pleistocene sediments on the seismic section. The deeper extension of the Futaba fault can be traced down to 4.5 seconds (TWT) and sub-horizontal reflectors are developed around 6-7 seconds (TWT). The dip angle of the Futaba fault in the seismogenic zone is about 45 degrees. The footwall shortcut thrust was formed at the shallow high-angle part of the Futaba fault as a low-angle (30 degrees) reverse fault. The formation of half graben is limited along the northern part of this fault system. The footwall shortcut thrust was developed along a 40-km-long segment only accompanied with the Miocene half graben. The southern segment of the surface trace of the Futaba fault suggest a straight geometry may represent a change in dip angle.

The western boundary fault of Fukusghima basin (WBF) is marked as an eastern margin of the back-arc rift basin in early Miocene. Later, due to arc perpendicular compression, it reactivated as a reverse fault. For the deeper extension of this fault is recognized as west-dipping reflectors at moderate angle down to 3 sec (TWT).

Keywords: Futaba fault, seismogenic source fault, seismic reflection profiling, P-wave velocity structure, western boundary fault of Fukushima basin, northern Honshu

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Crustal structure beneath the Boso Peninsula revealed by seismic refraction/wide-angle reflection profiling

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The Philippine Sea plate (PHS) is being subducted beneath Boso Peninsula, and Neogene fore-arc sediments and accretionary complex are widely exposed on land, providing an exceptional opportunity for the research on the structure and tectonic processes of the fore-arc region. In this study, we aimed to understand geological structure of the fore-arc area and geometry of the upper boundary of the subducting PHS.

In Boso peninsula, seismic reflection and refraction survey was conducted in 2002 along a 150-km-long seismic line trending NNE-SSW (Sato et al., 2003). A near vertical seismic reflection section portrays the fore-arc basin structure north of the Mineoka belt and the geometry of PHS. However, ambiguity remains with the geologic structure of the south of Mineoka belt and deep geometry of PHS slab.

In this study, seismic data were analyzed by refraction and wide-angle reflection methods to construct P-wave velocity model. The obtained P-wave velocity profile suggests that the Mineoka belt is marked by higher velocity zone (4 km/s) than that of Neogene sediment cover. The accretionary prism, south of the Mineoka belt, shows lower velocity ($Vp < 6$ km/s) down to the plate interface.

In the north of the Mineoka belt, thick (< 5 km) Neogene fore-arc sediments are identified as low velocity zone (1.7-3.1 km /s). The pre-Neogene rocks under fore-arc sediments show high velocity ($Vp = 4.8$-5.1 km/s). The pre-Neogene upper crust suggests higher velocity ($Vp = 5.9$-6.1 km/s) in the northern part of the seismic line and decrease to the south. The northern part corresponds to the Sambagawa metamorphic belt and the Ryoke belt, the Chichibu and the Shimanto belt are in the central part. We compared the seismic reflection profiling which was obtained by Ito et al. (2009) with our profiling to estimate the structure of basement. A thin Cretaceous sediment cover ($Vp = 4.3$ ˜ 4.8 km/s) occurs in the northern most part of the seismic line.

The Mineoka belt is estimated the past plate boundary between past subducting Pacific plate and current subducting PHS because the Mineoka belt and the accretionary complex do not show high velocity like the shimanto belt.

Using ray-tracing method, upper surface of PHS slab and Moho discontinuity of the overriding plate were mapped. In the southern end of this section, the upper boundary of PHS is located about 10 km in depth and shows 15 degrees of northward dipping. The thickness of PHS is estimated as 10 km. The depth of Moho of overriding plate is 23 km in northern part and slightly decreases its depth toward south. The upper surface of downgoing slab is traced down to about 30 km. The contact area between the upper boundary of PHS and the crust of overriding plate is coincide with the area of larger slip deficit on the PHS obtained by geodetic observation (Sagiya, 2004).

Keywords: Crustal structure, Boso Peninsula, seismic velocity structure, seismic refraction analysis, fore arc structure, Philippine Sea plate

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A numerical model of deformation in an evolving thrust wedge: A case study of the Shogawa anticlinorium

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Frontal structures of thrust systems show large variety (Vann et al.,1986). Recently, it has been revealed that there are wedge-shaped reverse faults in the Neogene sediments in Japan (Sato and Hirata, 2000; Ishiyama et al., 2004 etc.). In order to understand the relationship between active thrusts that can be observed at the surface and concealed main faults, it is significant to clarify the conditions that define the shape of the frontal structure of thrust systems.

To reveal the structural development process and conditions of the wedge thrust, we use the distinct element method (DEM). First, in order to examine the validity of DEM, we performed comparative experiments with Particle Flow Code in two dimensions (PFC2D) and analogue experiments with sand box. The obtained results suggest that the both results are in good agreement. We performed the numerical simulation using PFC2D from simple model to complicated one. Using a simple model, we found that the Young's modulus is strongly influenced by the structure development. In addition, it was confirmed that the formation of detachment, the presence of the layer structure is essential.

Based on above-mentioned results, we constructed a "Sanjo model" which was referring to the geological structure of Shitada hills in Sanjo city, Niigata Prefecture, the presence of the wedge thrust has been confirmed by Kato et al. (2010). Through the numerical simulation, when considering the sediment load during the thrusting, wedge thrusts do not develop. It is due to the sediment loads prevent the development of large amplitude of folding above main detachment. Following the actual subsurface data of Sanjo area, we put a western limit for the detachment. An improved model shows the development of fault-related fold above the detachment, including wedge thrusts. These results suggest that the existence of a tip for detachment is important to produce a wedge thrust. In addition, when the side of the hills in the model was eroded, the development of the thrust has been confirmed.

In the Sanjo model, in spite of the boundary condition is given by constant strain, slip on faults occur intermittently and accommodate on several faults in the sediment layers. With the progress of shortening deformation, the area of shortening deformation becomes wider associated with the propagating a slip on the detachment. This is consistent with the geologic records of fault activity in the Yoshinoya fault (Kobayashi et al., 1995). Further, it was found that there is a difference in time of the activity floor and roof thrust in the thrust wedge. Compared to the amount of slip on a main fault, the amount of slip on a fault near the surface was significantly to be small.

Keywords: fault-related fold, wedge thrust, active blind thrust, distinct element method, detachment, Shogawa anticlinorium

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Structural geology of the Shogawa anticlinorium in the Shitada Hill, Niigata, northern Japan

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We investigate the Shogawa anticlinorium of the Shitada Hill, Niigata, northern Japan. Geological structures of Plio-Pleistocene formations of the Shitada Hill are characterized by NNE-trending overturned anticlines and synclines with ESE-dipping axial surfaces. These folds are associated with ESE-dipping listric reverse faults. Geometry of these folds and faults shows they are fault-propagation folds. By the multiple inverse method (Yamaji, 2000; Otsubo and Yamaji, 2006; Sato and Yamaji, 2006; Otsubo et al, 2006), three stress states are separated from fault-slip data as foliows: 1) WNW-ESE horizontal maximum principal stress and vertical minimum principal stress axes, 2) WNW-ESE horizontal maximum principal stress and NNE-SSW horizontal minimum principal stress axes, and 3) vertical maximum principal stress and WNW-ESE horizontal minimum principal stress axes. The WNW-ESE horizontal maximum principal stress and vertical minimum principal stress axes suggest the Shogawa anticlinorium was formed as buckle folds. The WNW-ESE horizontal maximum principal stress and NNE-SSW horizontal minimum principal stress axes were formed transverse strike-slip faults. On the basis of detailed geological mapping, fault-slip and paleocurrent analyses, we also conclude that the anticlinorium began uplifting no earlier than the deposition of the lower part of the Uonuma Formation, i.e., $<$ 2 Ma.

Keywords: Shogawa anticlinorium, fault-propagation fold, minor fault analysis, pareostress, paleocurrent analysis, Niigata sedimentary basin

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Seismogenic source faults in the eastern part of the Japan sea based on seismic survey

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Previous studies of the crustal structure in the Japan Sea were part of the ODP Legs 127 and 128 (e.g., Tamaki et al., 1992), seismic reflection surveys for oil exploration (e.g., JNOC, 1987), and inferences from ocean-bottom seismometer (OBS) observations (e.g., Nishizaka et al., 2001; Sato et al., 2006). Despite the damages associated with large earthquakes and tsunamis in the eastern Japan Sea, such as the 1964 Niigata earthquake (M 7.5), the 1983 Nihonkai-Chubu earthquake (M 7.8), and the 1993 Hokkaido Nansei-Oki earthquake (M 7.8), the seismogenic zone in the Japan Sea are not well studied because crustal structure data are insufficient.

We conducted marine seismic surveys from 2007 to 2012 to study the crustal structure of the seismogenic zone of the eastern Japan Sea. We used a multichannel seismic system and the ocean-bottom seismographs (OBS) of the research vessels of the Japan Agency for Marine-Earth Science and Technology. The survey areas covered regions from the coast of the Sea of Japan to the Yamato Basin and the Japan Basin. Seismic data were acquired along 47 lines. The data suggests that the crustal structure in the south (from off Yamagata to Noto Peninsula) and the north (from off Akita to Nishi-tsugaru) is different. These differences are critical to understand the relationship between the spatial distributions of seismogenic zones and strain concentration areas.

In the southern part (from off Yamagata to Noto Peninsula), the active structure includes the continental shelf, the Mogami Trough, and the Sado Ridge. These areas represent island-arc crust as deduced from the P-wave velocity and the seismic refraction/wide-angle reflection imaging using OBSs. In particular, the upper-crust P-wave velocity changes because of the changes in the active structure. Large earthquakes (e.g., the 2007 Niigata-ken Chuetsu-oki earthquake, the 1964 Niigata earthquake, and the 1833 Shonai earthquake) in this area occurred in the island-arc crust. On the other hand, the Yamato Basin represent transitional crust between island arc crust and oceanic crust. These two areas are not much deformed.

In the northern part (from off Akita to Nishi-tsugaru), the strain concentration area in the eastern margin of the Japan Sea is divided into three zones. The most eastern of the three zones is along the continental shelf and the Nishi-tsugaru Basin. The crustal structure of this zone is that of an island arc crust and is similar to the southern part. In contrast, the structure of the strain concentration area near 139E corresponds to transitional crust. The 1983 Nihonkai-Chubu earthquake occurred in this region. In particular, the western margin of the hypocentral region exhibits remarkably well formed anticlines and east-dipping reverse faults. In addition, several seismic lines imaged an east-dipping strong reflector that corresponds to a reverse fault. The area of the strong reflector is located in the boundary of the transitional crust and island arc crust that becomes even thicker toward the east; furthermore, the reflector matches the distribution of the earthquake aftershocks very well (Nosaka et al., 1987). Therefore, this reflector is probably the source fault of the 1983 earthquake. The other strain concentration area is also located in the southeastern part of the Japan Basin (between the Matsumae Plateau and the Yamato-tai) about 100 km to the west of the source region of the 1983 earthquake. The crust structure in this area is located near the boundary of the transitional crust and oceanic crust. This area contains reflectors that connect deformation structures, and parts of them reach the lower crust and the Moho. The Japan Basin in the west of the strain concentration area consists of typical oceanic crust without reverse faults and folds.

Keywords: Japan sea, Seismic survey, 1983 Nihonkai-Chubu earthquake, 1964 Niigata earthquake, Multi-channel seismic reflection survey, Ocean bottom seismograph

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High resolution seismic reflection profiling across the Iiyama fault, central Japan

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We collected and processed shallow high-resolution seismic reflection data in order to resolve shallow structures and to understand structural linkage between active faults and folds recognized at ground surface and deeper, complicated fold and thrust structures along the Iiyama fault, northern Fossa magna. We deployed more than 200 seismic channels, 10-Hz geophones, and Enviro-Vib (IVI, Inc) as a seismic source along about 5-km-long seismic line. Common midpoint stacking by use of initial velocity analysis successfully illuminates subsurface geometries of active fault-related fold to 1-1.5 two-way time. Detailed seismic reflection analyses including refraction and residual statics, migration, deconvolution, and time-space variant bandpass filters, and depth-conversion by use of stacking velocities enable to obtain subsurface depth section of these active structures.

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Calculated P-wave velocity for xenoliths from the lower crust beneath Shikoku

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Mafic and ultramafic xenoliths (olivine gabbro, melanocratic gabbro, melanocratic hornblende-pyroxene gabbro,leucocratic gabbronorite, leucocratic norite,clinopyroxenite, olivene clinopyroxenite) occur in alkali basalt at Kochi, southwest Japan. The constituent minerals of xenoliths were analysed chemically to obtain the equilibrium P-T conditions and the seismic velocities. Calculated temperatures using two-pyroxene thermometry give values of 960C and 1060C for melanocratic gabbro and clinopyroxenite, respectively. Modal compositions of xenolith samples were analyzed, and then compressional wave velocities (Vp) were calculated using elastic dataset of minerals. The calculated Vp of most of the melanocratic gabbroic rocks (7.1-7.4 km/s) is significantly higher than Vp of the lower crust beneath Shikoku. Combining the calculated velocities of the xenoliths with the P wave velocity structure beneath Shikoku of the southwest Japan arc, we infer that leucocratic plagioclase-rich gabbronorite is the main constituent rock type of the lower crust.

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Gravity anomaly and density structure in western Shikoku region

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In Shikoku region, metamorphic belts parallel to the trench axis of the Nankai trough are developed and deep low-frequency tremors and slow slips occur on the surface of the subducting Philippine Sea plate. We conducted gravity survey along three profiles, one along E-W direction and two along NNW-SSE directions. We repot here gravity anomaly on the three profiles and in western Shikoku.

The gravity data we analyze here include 132 new measurement data along the profiles and data measured by other institutes (Honda et al., 2013; Geospatial Information Authority of Japan, 2006; Geological Survey of Japan, 2004: Gravity Research Group in Southwest Japan, 2001). We adopt the density of 2,300 kg/m3 for the Bouguer correction and terrain correction. We calculate the terrain correction using the method of Honda and Kono (2005) with 50 m mesh digital elevation map data.

The gravity anomaly in western Shikoku region is highest in the Pacific Ocean side and becomes lower toward the Seto inland sea as a long wavelength trend. Some variations in the gravity anomaly with short wavelength, which are reflect shallow geological structures, are included in the long wavelength trend. The gravity anomaly, however, differs by about 5-10 mgal even in the same metamorphic belt, suggesting that the difference reflects the difference of deep density structures. In this study, we construct a density structure model from the surface to the Philippine Sea plate and examine how much modification of structure boundaries and/or densities is needed to satisfy the observed gravity anomaly.

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Keywords: gravity anomaly, density structure, western Shikoku, metamorphic belt, Philippine Sea plate

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Geophysical characteristics between Okino-erabu Island and Okinawa trough (Preliminary results of GH12 cruise)

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Back-arc basins are extensional basins formed behind subduction zones by seafloor rifting or seafloor spreading. Back-arc seafloor spreading process is considered as similar to those of mid-ocean ridges. Likewise, back-arc rifting process is considered as similar to mid-ocean rifting but is not clear because there are few examples of the back-arc rifting in the present. The Okinawa Trough is a back-arc rifting basin of the Ryukyu arc, extending between the southwest Kyushu and north Taiwan. Several evidences of magmatic activity such as dike intrusions and hydrothermal activities were found in the trough. However, it is still not clear when these magmatic activities were initiated and how they proceed during seafloor rifting.

We carried out marine geophysical survey during GH12 cruise by R/V Hakurei from July 20 to 31. The survey area is between Okino-erabu Island and Okinawa trough in the middle of the Ryukyu arc. Sea surface geophysical mapping (bathymetry, magnetics and gravity) was conducted during the survey. We present preliminary results of the morphological and geophysical characteristics of the area.

Lower Bouguer anomaly (-40 to 20 mgal) is observed at Yoron basin, southwest area of Okino-erabu Island, and 30 km northwest area of Iheya Island. Comparing with the seafloor morphologies, these Bouguer anomalies suggest the presence of thick sediments in the area. Sediment thickness of these areas gradually increases to the east. On the other hand, higher Bouguer anomaly ($>$20 mgal) is observed at north to northeast of Iheya Island and Okino-erabu spur. The highest Bouguer anomaly corresponds to the shallow area extending from Iheya Island. This shallow area including Iheya Island shows weak positive to negative magnetization. These geophysical observations may attribute to the pre-Neogene basement rocks which constitutes Iheya Island. In contrast, Yoron Island and Okino-erabu Island also are characterized by lower Bouguer anomaly and weak magnetization. Yoron Island is also constituted by pre-Neogene basement rocks, therefore the geophysical difference may come from the depth to the basement rocks. Positive magnetic anomaly with moderate Bouguer anomaly is observed at Igyo-sone. Similar features accommodating with shallow topography can be observed toward southwest and form a chain. Considering the location and the trend of these anomalies, this may come from the magmatic activity related pre-volcanic Island-arc of Ryukyu-arc, continuing from Kume Island. Several sea knolls are observed at western end of the survey area. These structures are considered to belong to present volcanic arc from its location, but remarkable geophysical features are not found.

Above preliminary interpretations suggest that the magmatic activity of Ryukyu-arc is limited to the west of Iheya Island. Although the transition of magmatic activity between pre- and present volcanic-arc is not clear in our survey area, several magmatic activities related to the back-arc rifting, such as Iheya knolls and Iheya minor ridge, are located just west to our survey area. Regional scale survey from Island-arc to back-arc is important to understand the back-arc rifting process.

Keywords: Seafloor morphology, magnetic anomaly, gravity anomaly, Okinawa trough