Japan Geoscience Union Meeting 2013
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SCG68-01 Room:303 Time:May 23 14:15-14:30

Difference of the seismic crustal structure between the northern Yamato Basin and the southern Japan Basin, Japan Sea

Takeshi Sato[1*], Tetsuo No[1], Narumi Takahashi[1], Shuichi Kodaira[1], Yoshiyuki Kaneda[1]

[1]JAMSTEC

The Japan Sea is one of very well studied back-arc basins in the northwestern Pacific. In the eastern margin of the Japan Sea, the fault-fold belts developed by the deformation of the extension by the opening of the Japan Sea during the late Oligocene and the shortening since the late Pliocene (e.g., Sato, 1994). The seismic crustal model, however, has been inadequate to elucidate the crustal evolution process including the deformation in fault-fold belts in this margin and the detailed opening model of the Japan Sea. To understand this process in this margin of the Japan Sea, it is necessary to clarify the crustal structure model, not only in the Japan and Yamato Basins without this shortening, but also in its marginal area, which presumed to show the transition of the structure from the basin toward the island arc. From 2009 to 2012, the seismic survey using ocean bottom seismographs (OBSs), an air-gun array, and a multi-channel hydrophone streamer were undertaken in this margin. For this study, we will present the crustal structure models from the northern Yamato Basin to the coastal of the northeastern Japan Island Arc and from the southern Japan Basin to the coastal area.

The crustal thickness of the northern Yamato Basin is about 16 km and is less than that of a typical continental crust (Christensen and Mooney, 1995) and greater than that of a typical oceanic crust (White et al., 1992). From the velocity gradient, the crust of the northern Yamato Basin is divided to two parts; one is upper part having the steep gentle velocity gradient and the other is the lower part having the gentle gradient. These upper and lower parts have about 5 and 8 km thick, respectively. In this Basin, there is a little in the part of 5.5-6.4 km/s of the P-wave which corresponds to the island arc upper crust. Moreover, the lowermost lower crust in the central part of this Basin has the high velocity as compared to the surrounding area. This high velocity may show that the mantle temperature was slight high during the formation of the Yamato Basin. On the other hand, the crustal thickness of the Sado Ridge where it locates between the northern Yamato Basin and the coastal area is about 23 km. From the distribution of the P-wave velocity, the shallow and deep parts of the crust beneath this Ridge correspond to the island arc upper and lower crusts (Iwasaki et al., 2001).

The crustal thickness of the southern Japan Basin is about 10 km. This crust is thinner than those of the northern Yamato Basin. This crustal structure beneath the southern Japan Basin is similar to a typical oceanic crust (White et al., 1992), except for the lowermost lower crust having the high velocity. Therefore, the difference of the crustal structure between the southern Japan and northern Yamato Basins including those marginal areas may show that of the crustal evolution process during the formation of the Japan Sea.

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SCG68-02 Room:303 Time:May 23 14:30-14:45

Configuration of Moho discontinuity beneath Japanese Islands estimated with seismic tomography

Makoto MATSUBARA[1]*

[1]NIED

1. Introduction

P-wave seismic velocity is up to 7.0 km/s in the lower crust, however, that in the mantle is over 7.5 km/s. There is a large velocity gradient at the Moho discontinuity between the crust and mantle. Zhao et al. (1992) estimated the Moho discontinuity based on the seismic velocity model. Ryoki (1999) gathered the Moho models obtained by reflection and refraction seismology. Katsumata (2010) estimated the Moho discontinuity with tomographic method.

Fine-scale three-dimensional seismic velocity structure beneath Japanese Islands is estimated using data obtained by dense seismic network (Matsubara and Obara, 2011). I can calculate the velocity gradient between the grid nodes. I estimate the configuration of Moho discontinuity with the isovelocity plane with large velocity gradient.

2. Data and method

I calculate the P-wave velocity gradients between the vertical grid nodes between a P-wave velocity from 6.5 to 8.0 km/s with interval of 0.1 km/s. The largest velocity gradient is 0.078 (km/s)/km at velocities of 7.2 and 7.3 km/s. In this study, I define the isovelocity plane of 7.2 km/s as the Moho discontinuity.

3. Result

The Moho discontinuity deepens over 35 km beneath Tohoku backbone range, Kitakami mountains, Eastern Chubu district, northern Kinki district, Chugoku mountains, northern Kyushu district, and eastern Kyushu district. The shallower Moho discontinuity shallower than 30 km depth is distributed beneath the southeastern Hokkaido district, northern and southern Kanto district except Tokyo district, Noto peninsula, southern Tokai, Kinki, and Shikoku district, and southwestern Kyushu district.

The characteristic shallow Moho discontinuity beneath the southeastern Hokkaido district and deep Moho discontinuity beneath the Tohoku backbone range, eastern Chubu district, and eastern Kyushu district are also estimated by Zhao et al. (1992), Ryoki (1999), and Katsumata (2010). The shallow Moho discontinuity beneath the northern and southern Kanto district and deep Moho discontinuity beneath Tokyo is one of the characteristic Moho configuration of this study and is consistent with the model by Katsumata (2010). I can estimate the complex configuration of Moho discontinuity not only along the isodepth line not parallel to the coastal line as well as that parallel to the coastal line same as Katsumata (2010), however, Ryoki (1999) and Zhao et al. (2010) estimated that only parallel to the coastal line. The Moho discontinuity beneath the Chugoku district deeper than 35 km is also one of the characteristic structures of this study, however, that by Katsumata (2010) is shallower than 30 km. My model is consistent with that by Ryoki (1999) and Shiomi et al. (2006). Ryoki (1999) estimated the deep Moho discontinuity beneath the central Chugoku and Shikoku district and Shiomi et al (2006) estimated the Moho configuration deeper than 35 km beneath the Chugoku mountains using receiver function method.

It is difficult to identify the Moho discontinuity of the Eurasian plate where the lower crust of the Eurasian plate contacting the oceanic crust of the Philippine Sea plate using seismic velocity structure since there is no mantle high-velocity material. However, I can detect the Moho discontinuity if there is a mantle material since there is a high-velocity zone. Deep low-frequency tremors are observed beneath the southwestern japan (e.g. Obara, 2002). They occur at the boundary of the partly serpentinized mantle wedge in the Eurasian plate and the oceanic crust at the uppermost part of the subducting Philippine Sea plate (Matsubara et al., 2009). It is possible that the Moho discontinuity on the south side of the tremor zone is the Moho discontinuity within the subducting Philippine Sea plate. The shallow Moho discontinuity shallower than 30 km beneath the southern Tokai and Kinki district is consistent with Shiomi et al. (2008).

Keywords: Moho discontinuity, tomography, Japanese Islands, seismic velocity, 7.2 km/s

SCG68-03 Room:303 Time:May 23 14:45-15:00

Deep seismic reflection profiling across the northern Fossa Magna, central Japan

Hiroshi Sato[1*], Kazuya Shiraishi[2], Tatsuya Ishiyama[1], Naoko Kato[1], Eiji Kurashimo[1], Susumu Abe[2], Mitsuru Inaba[3], Takaya Iwasaki[1], Tomihisa Kawamoto[4], Tetsuya Takeda[5]

[1]Earthquake Research Institute, The university of Tokyo, [2]JGI, Inc., [3]Japan Petroleum Exploration Co., Ltd., [4]INPEX Corp., [5]National Resarch Institute for Earth and Disaster Prevention

The northern Fossa Magna (NFM) is a back-arc rift basin produced in the final stages of the opening of the Sea of Japan. It divides the major structure of Japan into two regions, NE and SW Japan. The Itoigawa-Shizuoka Tectonic Line (ISTL) bounds the western part of the northern Fossa Magna and forms an active fault system that displays one of the largest slip rates in the Japanese islands. The eastern rim is bounded by the Shinanogawa fault system, which produced the Zenkoji earthquake of 1847 (M7.4). We carried out deep seismic reflection and refraction/wide-angle reflection profiling across the northern part of NFM in order to delineate structures in the crust, and the deep geometry of the active fault systems. The seismic data were acquired using four viboseis trucks, explosives (4 locations, 100 kg). We further applied refraction tomography analysis to distinguish between previously undifferentiated syn-rift volcanics and pre-rift Mesozoic rock based on P-wave velocity. The 60-km-long velocity profile suggests 5-km-thick Miocene basin fill beneath in the NFM basin. The thick argillaceous basin fill was strongly deformed by compression since the Pliocene. The shortening deformation is marked by fault-related folds and detachment folds. The middle Miocene over pressured mudstone forms detachments within a basin fill. Geologic reconstruction based on the seismic section suggests that the NFM basin was formed by east dipping normal fault systems. Western edge of the NFM basin is formed by the ISTL and Otari-Nakayama fault. The vertical offset of the Otari-Nakayama fault is several times larger than that of ISTL. Thus, the Otari-Nakayama fault and its northeastern extension, played an important role for the formation of NFM basin. Due to reactivation of normal faults as reverse faults, Miocene major normal faults forms seismogenic source fault. The Shinanogawa fault system, which bounds the eastern rim of NFM basin, is estimated to form a wedge thrust with deep-sited eastward-dipping fault. The distribution of strong seismic intensity area accords well to such wedge thrust geometry.

Keywords: fold-and-thrust belt, source fault, Northern Fossa magna, deep seismic profiling, active fault, 1847 Zenkoji earthquake

SCG68-04 Room:303 Time:May 23 15:00-15:15

High-resolution seismic reflection profiling across the Tsukioka fault, central Japan

Naoko Kato[1*], Tatsuya Ishiyama[1], Hiroshi Sato[1], Shigeru Toda[2], Tsuyoshi Toyoshima[3], Kenta Kobayashi[3], IIZUKA, Genki[2], SHINADA, Kouya[3], IRITANI, Masato[3]

[1]Earthquake Research Institute, The Univ. of Tokyo, [2]Aichi University of Education, [3]Niigata University

To understand the relationship between an active and seismogenic source fault is crucial for estimating seismic hazards. Along the western margin of the Echigo mountains, basin-ward dipping active faults are distributed. To obtain complete image of the active-seismogenic source fault system, we carried out the high-resolution seismic reflection profiling across the eastern margin of the Echigo plain for 8-km-long seismic line. Seismic data were acquired using a vibroseis truck (IVI, Y2400). The sweep signals (8-100Hz; reflection profiling) were recorded with fixed 812 channels deployed at 10 m intervals, off-line recorder (GSR, JGI MS2000). The seismic data were processed using conventional CMP-reflection methods. The obtained seismic section portrays the seismic image down to 2.5 km. The seismic section demonstrates a wedge-thrust system and the deeper extension of the Tsukioka fault merges to the deep-sited east-dipping thrust.

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Detailed characteristics of the March 12, 2011 Nagano-Niigata earthquake sequence and its seismo-tectonic backgaround

Tetsuya Takeda[1*], Bogdan Enescu[2], Youichi Asano[1], Shoji Sekiguchi[1], Kazushige Obara[3]

[1]National Research Institute for Earth Science and Disaster Prevention, [2]University of Tsukuba, [3]Earthquake Research Institute, University of Tokyo

The Tohoku-oki earthquake (Mw9.0) occurred on March 11, 2011, involving a large number of aftershocks and widespread induced seismicity all over Japan. About 13 hours later, the March 12, 2011 Nagano-Niigata earthquake (M6.7) occurred within the high-strain-rate zone of Japan. Both the Hi-net and F-net focal mechanism solutions of this earthquake revealed a reverse fault mechanism, with a P-axis trending NNW-SSE. The largest Nagano-Niigata aftershock (M5.9) occurred 30 minutes after the mainshock and was characterized by a NNW-SSE compressional reverse fault mechanism, similar to the one of the mainshock. The Tohoku-oki earthquake caused crustal deformation in a widespread area of Tohoku district (e.g. Ozawa et al., 2011). In such changed stress field, the Nagano-Niigata earthquake occurred. It is important to study in detail this earthquake sequence and the underlying tectonic background to understand the physical mechanism of its occurrence. In this work we analyze the Nagano-Niigata aftershocks and obtain a detailed aftershock distribution. Finally, based on these results, we are able to describe the detailed features of the Nagano-Niigata sequence and suggest a physical model for its occurrence.

We describe the features of this earthquake from the obtained aftershock distribution and the detailed 3-D velocity structure (Enescu et al., 2012). The aftershock region consists of two basement-rock blocks, which divide the area into NE and SW parts. The NE block hosts the source fault of the mainshock, with a SE dipping plane. The source fault of its largest aftershock, with a NW dipping fault plane (different from the one of the mainshock) lies within the SW block. The velocity structure of the two blocks is different; the SW block has a higher velocity than the NE block. Such difference indicates a different rock composition, likely related to the tectonic processes that lead to the formation of the two blocks.

These blocks were formed by normal and transform faulting accompanying the opening of the Sea of Japan in the Miocene. The faulting processes are at the origin of the many tectonic blocks that exist below the high-strain-rate zone. Similar with the sequence analyzed in this study, the mainshock and/or aftershock source faults of the 2004 Niigata Chuetsu earthquake and the 2007 Niigata Chuetsu-oki earthquake are divided into multiple areas (e.g. Kato et al., 2005, Yukutake et al., 2008). Therefore, earthquakes occurring within the high-strain-rate zone may break multiple blocks either at the same time or during a short time period. In most cases distinct "block-dependent" behavior could be noticed.

Finally, we discuss why the Nagano-Niigata earthquake was induced by the M9.0 Tohoku-oki earthquake. After the occurrence of the Tohoku-oki earthquake, the seismicity in many volcanic regions all over Japan became active. The activated areas include a volcanic region in Kyushu, very far from the Tohoku-oki source region. This indicates that the triggering is likely caused by dynamic rather than static stress changes (that is, stress change induced by the passage of the surface waves from the megathrust event). The tomography result showed the existence of a high Vp/Vs ratio below the mainshock hypocenter, which suggests fluid existence, same as in volcanic areas. The Nagano-Niigata earthquake may have been induced by a stress transfer due to the very large amplitude surface waves from the Tohoku-oki earthquake, similar with the seismicity activation process in volcanic regions.

Keywords: the high-strain-rate zone of Japan, Nagano-Niigata earthquake, Tohoku-oki earthquake

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SCG68-06 Room:303 Time:May 23 15:30-15:45

Seismic anisotropy at the northern part of Kanto and Tohoku regions

Takashi Iidaka[1*], Kazushige Obara[1], Toshihiro Igarashi[1], Jun Muto[2], Bunichiro Shibazaki[3]

[1]Earthquake Research Institute, University of Tokyo, [2]Tohoku Department of Earth Sciences, Tohoku University, [3]IISEE, Building Research Institute

1) Introduction

Beneath Japan, the Pacific and Philippine Sea plates are descending toward west and north, respectively. The stress distribution of inland of Japan is expected to be complex. The seismicity around Japan is related to the stress field caused by the plate subduction. It is very important to understand the stress field of Japan. The stress field in the shallow crust in Japan has been studied previously, with Kaneshima (1990) reporting that the maximum stress axis in northeastern Japan had a WNW?ESE orientation, parallel to, and potentially controlled by, the subduction direction of the Pacific Plate.

Shear-wave splitting is an ideal tool for determining the orientation and form of the stress field in an area. Shear-wave splitting in the crust is related to the orientation of faults or cracks, and it is thought that propagating cracks are preferentially aligned parallel to the orientation of the maximum stress axis, in turn meaning that the polarization direction should also be parallel to the maximum stress axis [Crampin, 1981]. Then, the shear-wave splitting method was used to understand the stress field in the northern Kanto and Tohoku regions.

2) Data

We analyzed crustal earthquakes at depths of <30 km during this study. Those earthquakes are from Jan. 1, 2000 to Mar. 10, 2011. The dataset consists of earthquakes that occurred before the 2011 Tohoku earthquake. The seismic stations operated by the National Research Institute of Earth Science and Disaster Prevention (NIED), the Japan Meteorological Agency, and the University of Tokyo are used.

3) Results

The shear-wave splitting results for earthquakes prior to the 2011 Tohoku earthquake are laterally variable. However, some interesting characteristics were found of the map of the polarization directions. The polarization directions which were observed at the seismic stations located in the western part of Japan suggested that the polarization direction with WNW-ESE. The direction is consistent with that of regional stress field which are caused by the subduction of the Pacific plate. However, the polarization direction with the north-south direction was found at the easternmost seismic stations of the northern part of Kanto and Tohoku regions. The direction is clearly inconsistent with the direction of the regional stress field. But, the characteristic, that the E-W and N-S polarization directions were observed at the western and eastern parts of the region, respectively, was as same as the result of Iidaka and Obara (2013), which was observed in the southern part of the Tohoku region. The cause of the lateral variation was researched considering the mechanism of subduction.

Keywords: Shear-wave splitting, crust, subduction

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Quaternary strain rates distribution and crust-upper mantle structure of the southern Northeast Japan

Tatsuya Ishiyama[1*], Hiroshi Sato[1], Naoko Kato[1], Makoto MATSUBARA[2], Tetsuya Takeda[2], Takaya Iwasaki[1], Toshifumi Imaizumi[3]

[1]ERI, University of Tokyo, [2]NIED, [3]Department of Geosciences, Tohoku University

We estimated spatial distributions of intraplate permanent strain rates accommodated by active faults and fault-related folds in southern Northeast Japan during the late Cenozoic time, based on combinations of recently obtained deep to shallow seismic re?ection data, and rates of fault slip determined by offsets of geomorphic features or stratigraphic horizons identified of drilled shallow boreholes across fault and/or fold scarps. Tectonic setting of the northeastern Japan in late Cenozoic times, underlain by westward subducting old and cold Pacific plate, is characterized by north to northeast trending active thrust sheets that deform Neogene deposits. Although previous studies indicated that active reverse faults are predominant in this region, revised active fault mapping after the 2011 Tohoku-oki earthquake (M9.0) and its normal-fault aftershock sequence indicate that active normal faults are widely distributed on the southeastern flank of the coastal mountains along the Pacific coast and continental shelf off the southern Northeast Japan. Estimated strain rates accommodated by active faults and folds are an order of 10-8/yr for each structures, that are in general 10 to 100 times higher than previous estimates only from surficial Quaternary active fault data and historical seismicity. Contrastingly, geodetic strain rates observed before the 2011 Tohoku-oki earthquake shows 10 times higher than those estimates in this study. Most of these active thrusts are reactivated normal faults originally formed during Miocene in extensional stress regimes. Trench-normal, spatial distributions of the longer-term permanent strain rates is characterized by a distinctive trend that strain rates in back-arc are apparently 10 times higher than in fore-arc region, quite similar to those estimated based on late Cenozoic folded/faulted strata. Most of these active thrusts are reactivated normal faults originally formed during Miocene in extensional stress regimes. Longer-wavelength, late Quaternary uplift and subsidence overprinting these short wavelength strains, estimated by fluvial incision rates based on tephrostratigraphy, and borehole stratigraphy in alluvial plains, indicate relatively uniform, moderate uplift rates in fore-arc and west of the volcanic front, and very fast subsidence rates in back-arc. Late Cenozoic major tectonic records in southern Northeastern Japan after Miocene Japan Sea opening are, in summary, mainly characterized by Quaternary strong compression and coeval fast subsidence in back-arc region. Crust-upper mantle structures of the southern Northeast Japan based on seismic tomography, seismic reflection and refraction profiles indicates crustal thickening beneath the Ou backbone Range probably associated with magmatic underplating during late Cenozoic volcanisms. Back-arc subsidence is underlain by thinned crust and low P-wave velocity anomaly in the upper mantle imaged by seismic tomography, suggesting that downwelling of the mantle lithosphere may be driving present-day surface fast subsidence.

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How elastic is the island arc crust?

Takeshi Sagiya[1*]

[1]Nagoya University

The earth's crust is usually treated as elastic in the many studies. The term elasticity refers to a physical property of materials that recover their original shape after they are deformed. The elastic theory is very useful in data analysis and interpretation in seismology and geodesy. On the other hand, elasticity of the crust is nothing but a first order approximation. It has not been thoroughly tested in which time scale, in which spatial scale, and to what extent the crust is elastic. These issues have important implications associated with tectonic loading of crustal faults, evaluation of seismic potential, and topographical as well as geological structure development. As an example, we have found that there is significant inconsistency between geodetic and geologic deformation rates around active fault zones in central Japan such as the Atotsugawa Fault and the Itoigawa-Shizuoka Tectonic Line. Geodetically estimated fault slip rate is larger than geologic estimates by a factor of 2 to 3 there. Such an observation strongly suggests that there exists significant amount of inelastic deformation, and a large part of the inelastic deformation should be accommodated within the crustal blocks. Currently available geologic data about crustal strain rate are mostly related to fault offset and do not take deformation of the whole block into account. Thus it is important to develop appropriate methods to estimate long-term deformation rate of crustal blocks. One possibility is to examine cumulative deformation of strata based on seismic exploration and boring. Another possibility is to translate seismological properties such as attenuation and/or scattering coefficient into inelasticity. These possibilities should be investigated and derived results should be integrated into comprehensive modeling of deformation process of the Japanese island arc.

Keywords: island arc crust, elastic deformation, plastic deformation, strain rate, seismic potential

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SCG68-09 Room:303 Time:May 23 16:30-16:45

Simulation for coseismic and postseismic deformation in the Japan region due to the 2011 Tohoku earthquake with finite e

Akinori Hashima[1*], Andy Freed[2], Hiroshi Sato[1], Takuya NISHIMURA[3], David Okaya[4], Tatsuya Ishiyama[1], Makoto MATSUBARA[5], Takaya Iwasaki[1], Thorsten Becker[4]

[1]Earthquake Research Institute, the University of Tokyo, [2]Purdue University, [3]The Geospatial Information Authority of Japan, [4]University of Southern California, [5]National Research Institute for Earth Science and Disaster Prevention

The 2011 Tohoku earthquake, Japan (M9) remarkably characterizes earthquake generation system in the northeastern Japan arc and greatly affects the plate subduction system in the Japan region. For the rational prediction of earthquake activities and crustal deformations in these situations, we have to quickly construct a realistic model for the physical property structure under the Japan region and simulation model of crustal deformation based on the structure. In this region, two plate subduction system is formed due to the Pacific and Philippine sea plates. Thus, the deformation problem in this region is essentially three-dimensional. To solve a problem of this kind, it is necessary to model with finite element methods with which we can incorporate realistic structures. Currently, it is very important to reveal how the Tohoku earthquake generated the stress field change and how the stress field will change with time. Therefore, for the purpose of realistic prediction of earthquake activity in the Japan region after the Tohoku earthquake, we simulated the coseismic and postseismic deformation of the Tohoku earthquake with a three-dimensional crustal structure using the finite element method.

The most basic structure for simulation of time-dependent deformation in the Japan region is the geometry of the plate boundaries and elastic/viscoelastic material structure. First, we take a modeling space of 4500 km x 4900 km x 600 km. This space corresponds to the region from Kuril islands to Mariana islands and Ryukyu islands. So far, studies on earthquake activity have proposed a plate boundary model under Japan (e.g., Nakajima & Hasegawa, 2006; Nakajima et al., 2009; Kita et al., 2010; Hirose et al., 2008). For the Kuril, Izu-Bonin and Ryukyu arc, Hayes et al. (2012) made Slab1.0 plate boundary model. We constructed geometry of plate boundary structure for the whole region by interpolating these two models. Detailed seismic velocity structure under the Japan region has already been obtained by observation of densely aligned Hi-net seismograph network (Matsubara et al., 2011). At this stage, however, we simply assume uniform thickness of 30 km in the continental side, and 70 km in the oceanic plate and the slabs as the first version structure.

Then, we set boundary conditions. In this type of problem we have to give not only boundary conditions for the outer surface of the model space but also we have to give relative displacement on the two sides of the fault surface (fault slip) of the source region of the Tohoku earthquake. Under these conditions, we ran numerical computation and solve the deformation problem. In this study, we show results for the deformation in the above first-order structure.

From the computational results, we can identify the structural parameters that mainly constrain the behavior of the model, which make us to construct a rational plan for observation of these parameters. Then, we can update the deformation model with the new results and construct more effective observation plans. Establishing such a cycle of observation and modeling is required for studies of prediction of the earthquake activity and crustal deformation.

Keywords: Japan islands, Community model, 2011 Tohoku earthquake, Stress field, Crustal structure, Finite element modeling

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SCG68-10 Room:303 Time:May 23 16:45-17:00

Change in the stress field in the inland area of NE Japan after the 2011 Tohoku-Oki earthquake

Keisuke Yoshida[1*], Akira Hasegawa[1], Tomomi Okada[1], Junichi Nakajima[1], Takeshi Iinuma[3], Yoshihiro Ito[1], Tadahiro Sato[1], Youichi Asano[2], Group for the aftershock observations of the 2011 Tohoku Earthquake[4]

[1]RCPEVE, Tohoku University, [2]National Research Institute for Earth Science and Disaster Prevention, [3]International Research Institute of Disaster Science, [4]Group for the aftershock observations of the 2011 off the Pacific coast of Tohoku Earthquake

We have reported that the principal stress orientations changed after the 2011 Tohoku-Oki earthquake even in the inland areas far from the source area (Yoshida et al., 2012). A typical example of such areas with changed stress orientations is central Akita Prefecture. We investigated amply the stress field in the inland area of Tohoku to further confirm the above results and to know in detail the areas where the principal stress orientations changed after the 2011 Tohoku-Oki earthquake. In order to considerably increase focal mechanism data, we picked P-wave initial-motion polarity data from original seismic waveform records observed at many temporary seismic stations that are deployed in this area both before and after the Tohoku-Oki earthquake. Then we determined focal mechanisms of those events. The number of well-determined focal mechanisms is 2835 and 4291 before and after the 2011 Tohoku-oki earthquake, respectively. These numbers almost doubled the previous dataset. First, we estimated the spatial variation of the stress fields in NE Japan before and after the Tohoku-Oki earthquake in each 50 km spaced grid by applying the stress tensor inversion method. The results show that the estimated principal stress orientations significantly changed after the earthquake in three regions; northeast Miyagi Prefecture, central Akita Prefecture and southeast Tohoku near Iwaki city. The estimated orientations correspond to those of the static stress change caused by the coseismic slip of the Tohoku-Oki earthquake.

Then, we estimated again the stress fields in those regions before and after the Tohoku-Oki earthquake in more detail. We relocated hypocenters using the double-difference location method in the three regions, and applied the stress tensor inversion method to those data by subdividing the regions. Although the change in the stress fields near Iwaki city was not significant due to the existence of the depth variations of stress fields, the stress fields changed significantly in NE Miyagi Prefecture and central Akita Prefecture. This suggests that the stress magnitudes in NE Japan are very low because the static stress changes are only about 1-3 MPa of differential stress. Another possibility is that the stress fields in NE Japan are spatially very heterogeneous with the scale < 10 km.

To confirm whether the stress magnitude has such a low value, we investigated the effect of the tidal stress on earthquake rate. Tidal stresses were calculated including both the solid earth and ocean loading to focal mechanisms estimated above. The phase distribution exhibits a strong influence of tidal shear stress increments in NE Japan both before and after the Tohoku-Oki earthquake. Statistical test shows that it is significant (Schuster, 1897). Using the formula by Dieterich (1987), which was obtained through numerical simulations based on rate- and state-dependent friction law, we estimated the effective normal stress from the phase distribution. Assuming a = 0.004-0.01, the effective normal stress is estimated as 1.0-2.5 MPa. This value is roughly consistent with the value estimated using the change of the stress field after the 2011 Tohoku-oki earthquake.

Keywords: stress field, static stress change, focal mechanisim, tidal triggering, stress magnitude, frictional strength

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SCG68-11 Room:303 Time:May 23 17:00-17:15

IBM arc petrology, arc evolution and andesite problem

Yoshihiko Tamura[1*]

[1]IFREE, JAMSTEC

Modern magmatism at the intra-oceanic Izu-Bonin-Mariana (IBM) arc is bimodal, with basalt and rhyolite predominating (Tamura & Tatsumi, 2002); and turbidites sampled during Ocean Drilling Program (ODP) Leg 126 in the Izu-Bonin arc, which range in age from 0.1 to 31 Ma, are similarly bimodal (Gill et al., 1994), suggesting that the bimodal volcanism has persisted throughout much of the arc's history. Moreover, such bimodal magmatism is not unique to the Izu-Bonin arc, with the 30-36.5 degrees S sector of the Kermadec arc, another example of an intra-oceanic arc, also exhibiting it (Smith et al., 2003; 2006; Wright et al., 2006).

Closer inspection of the IBM arc remarkably reveals the presence of a significant volume of middle crust with seismic velocities of 6.0-6.8 km/s throughout the entire arc (Calvert et al., 2008; Kodaira et al., 2007a,b; Kodaira et al., 2008; Kodaira et al., 2010; Takahashi et al., 2007; Takahashi et al., 2008; Takahashi et al., 2009). This is remarkable because these velocities are characteristic of a wide range of intermediate-felsic plutonic/metamorphic rocks (Christensen & Mooney, 1995; Behn & Kelemen, 2003, Behn & Kelemen, 2006) and are similar to the mean velocity of andesitic continental crust, such material would not be expected to be present on the basis of the bimodal volcanism.

One possible way to understand this phenomenon is to investigate arc crustal sections exposed on land, but in the IBM arc, remnants of this old crust have never been found at the northern end of the arc, where it is colliding with the Honshu arc (Izu collision zone) (e.g. Tani et al., 2010; Tamura et al., 2010). Tamura et al. (2010) suggest that IBM arc middle crust in the collision zone was partially melted during the collision and then intruded into the overlying upper crust of the Honshu and IBM arcs. This resulted in the complete loss of chronological information, original mineralogy and possibly their original composition, and thus any information related to their original source. 'Ultra-Deep Drilling into Arc Crust' is the best way to sample unprocessed juvenile continental-type crust in order to observe the active processes that produce the nuclei of new continental crust, and to examine the nature of juvenile continental crust being generated at intra-oceanic arcs.

Keywords: IBM arc, andesite, oceanic arc

SCG68-12 Room:303 Time:May 23 17:15-17:30

Report on the Fujikawa kako fault system˜ Itoigawa-Shizuoka Tectonic Line seismic profiling, FIST. (2) Deep structure

Tanio Ito[1*], Ken-ichi Kano[2], Yasutaka Ikeda[3], Noriko Tsumura[4], Shintaro Abe[5], Kenji Nozaki[4], Satoshi Yamakita[6], Tetsuya Takeda[7], Kiyoshi Kato[8], Go Sato[1], Jiro Komori[1], Takaya Iwasaki[3], Hiroshi Sato[3], Toshiki Watanabe[9], Akira Fujiwara[10], Susumu Abe[10], Kei Odawara[11], Yoshiki Matsuura[12]

[1]Teikyo Heisei University, [2]Shizuoka University, [3]University of Tokyo, [4]Chiba University, [5]AIST, [6]Miyazaki University, [7]NIED, [8]Komazawa University, [9]Nagoya University, [10]JGI, [11]Hot Springs Research Institute of Kanagawa Prefecture, [12]Geebec

It is difficult to interpret the deeper part of the FIST profiles processed by the conventional method, although the profiles contain many events. Therefore we try to visualize both the velocity heterogeneities and the dominant event patterns by the following techniques.

1. To overlay the velocity structure obtained by tomographic analyses on the profiles.
2. To distinguish and classify the dominant event patterns in the MDRS (Multi-dip reflection surface) profile as follows:

1) Skeltonization of the events.
2) Classification in average dips of events and degrees of average event-lengths in skeltonization attributes.

Thus we successfully recognize the following five subsurface domains of A to E.

A: Foreland of the Fujikawa kako fault system.

Horizontal or subhorizontal events are dominant down to about 4000 m deep.

B: Fujikawa kako fault system (in a broad sense)

W-dipping reverse faults, the Omiya, the Agoyama, the Shibakawa, and the Noshita faults are arranged from east to west. W-dipping events are dominant down to about 6000 m deep parallel to the faults. The velocity structure suggests that the main activity in the four faults have been migrated eastward from the Noshita to the Omiya faults.

C: Between the Noshita and the Neguma faults

W-dipping events are dominant down to about 5000 m deep between the Noshita and the Neguma faults. Although both the Noshita and the Neguma faults are dipping west at about 45 degrees, the former is a reverse fault and the latter is a normal one.

D: Between the Neguma and the Tashirotoge-Otoshita faults

An open syncline is inferred from the velocity structure between the Neguma and the Tashirotoge-Otoshita faults.The W-dipping Neguma fault is cut at about 3000 m deep by the high angle W-dipping Tashirotoge-Otoshita fault which displaces the 5000-m/s-strata reversely at about 2500 m..

E: From the Tashirotoge-Otoshita fault, across the Itoigawa-Shizuoka Tectonic Line, to the Jumaiyama Tectonic Line

This domain is characterized by the left lateral with reverse faults, all of which are W-dipping at high angle.

A relatively dense event zone (DEZ) of about 2 km thick is dipping westward at about 20 to 25 degrees from about 5 km deep (beneath the Omiya fault at surface) to about 10 km deep (beneath the Neguma fault at surface). The lower boundary is considerably prominent due to the contrast with the wide poor-event domain beneath it. Although there are not any continuous reflectors along the lower boundary, it is reasonable that the boundary corresponds to the upper surface of the Philippine Sea plate judging from the seismicities obtained by Hi-net of NIED. The reason why typical reflectors are not seen along the upper surface is that there is no strong impedance contrast between the Philippine Sea plate and the overlying strata of the Honshu arc. In reality both are originally the same materials derived from the Izu volcanic arc.

The deeper part of the Omiya fault probably merges into the upper part of the DEZ at about 6000 to 7000 m deep. The deeper parts of the Shibakawa and the Noshita faults may reach a gently e-dipping event zone at about 5000 m deep. The zone corresponds to 5300 m/s contour. The relationships between the deeper parts of the faults in Domain E and the subducting PHS are not clarified.

Keywords: Fujikawa kako fault system, Itoigawa-Shizuoka Tectonic Line, Philippine Sea Plate, seismic survey, MDRS

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Reinterpretation of the lithospheric structure beneath the Hidaka collisionzone, Hokkaido, Japan 2 Biratori-Obihiro Line

Takaya Iwasaki[1*], Noriko Tsumura[2], Tanio Ito[3], Hiroshi Sato[1], Eiji Kurashimo[1], Naoshi Hirata[1], Kazunori Arita[4], Katsuya Noda[5], Akira Fujiwara[5], Susumu Abe[5], Shinsuke Kikuchi[6], Suzuki Kazuko[7]

[1]ERI., the University of Tokyo, [2]Graduate School of Science, Chiba University, [3]Teikyo-Heisei University, [4]The Hokkaido University Museum, Hokkaido University, [5]JGI, Inc., [6]JAPEX, [7]Schlumberger Ltd.

The Hidaka region in the central part of Hokkaido Island, Japan is known as an arc-arc collision zone where the Kuril Arc (southern part of eastern Hokkaido) has been collided against the NE Japan Arc (western Hokkaido) since the middle Miocene. This collision is a controlling factor for the formation of the Hidaka Mountains, the westward obduction of the middle/upper part of lower crustal rocks of the Kuril Arc (the Hidaka Metamorphic Belt) and the development of the foreland fold-and-thrust belt. A series of seismic reflection/refraction surveys from 1994 to 2000 revealed the collision and deformation processes occurring in this region (e.g. Arita et al., 1998; Tsumura et al., 1999; Ito et al., 2002). As indicated by Tsumura et al. (2013, this symposium), the high quality of these data sets has large potentiality to provide more clear collision image and new geological finding with the use of more advanced processing and interpretation techniques including CRS/MDRS method.

This paper focus on the reanalysis for the data sets from ”the Hokkaido Transect Project from 1998 to 2000”, which was multidisciplinary effort intended to clarify the structural deformation process associated with the arc-arc collision. The element of the active source experiment in this project was composed of a 227-km seismic refraction/wide-angle reflection profile running middle part of Hokkaido and three seismic reflection lines from the hinterland to the foreland (Biratori-Obihiro) crossing the Hidaka Mountains.

The previous study for these data sets, mainly based on the forward modelling by the ray-tracing technique, revealed the collision structure in the upper and middle crustal levels beneath the Hidaka Mountains, and a thick sedimentary package developed beneath the fold-and-thrust belt (Iwasaki et al., 2004).

Generally, refraction/wide-angle reflection method and near-vertical reflection profiling are complimentary to each other. Therefore, simultaneous evaluation for these two kinds of data set is expected to yield significant improvement for structural modelling and its geophysical/geological interpretation. In the present analysis, seismic tomography analysis was applied to a combined set of a large amount of near vertical reflection data and the refraction data. This analysis was mainly undertaken to confirm the validity of the upper 20-km crustal structure deduced from the previous result (Iwasaki et al. 2004) and quantitatively evaluate the resolving power of the data sets and the reliability of the structure model. The obtained image is well consistent with the previous result, showing a thick (4-5 km) undulated sediments in the hinterland, the outcrop of crystalline crust beneath the Hidaka Metamorphic Belt with higher Vp and Vp/Vs, probably expressing the obduction of the middle/lower crustal materials, and an enormously thick (>8 km) sedimentary package beneath the foreland. The CRS /MDRS processing for the reflection data provided clearer images of the base of the obducting lower crustal part of the Kuril Arc and shallow structural packages within the fold-and-thrust belt. Furthermore, it succeeded in imaging eastward dipping events around 25-35 km depth beneath the Hidaka Mountains. These reflectors, which were not imaged by the previous conventional CDP processing, are situated below the offscrapped and thrust-up part of the Kuril Arc crust, probably representing the lower crustal part and uppermantle of the NE Japan Arc. In several record sections of the wide-angle data, we can recognize weak later phases at a rather distant offsets (> 80-100 km). Their travel times are explained fairly well by the eastward dipping lower crust and Moho of the NE Japan Arc as indicated by the CRS/MDRS imaging.

Keywords: Hidaka Collision Zone, Kuril Arc, Delamination, NE Japan Arc

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

Koichi Asamori[1*], Dapeng Zhao[2]

[1]Japan Atomic Energy Agency; Department of Geophysics, Tohoku University, [2]Department of Geophysics, Tohoku University

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

SCG68-P02 Room:Convention Hall Time:May 23 18:15-19:30

Spatial stress heterogeneity imaging by using difference between reduced stress tensors

Makoto Otsubo[1*], Ayumu Miyakawa[1], Atsuki Kubo[2]

[1]Geological Survey of Japan, AIST, [2]Faculty of Science, Kochi University

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

Kazuya Shiraishi[1*], Susumu Abe[1], Hiroshi Sato[2], Takaya Iwasaki[2]

[1]JGI, Inc., [2]Eathquake Research Institute, the University of Tokyo

(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

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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

Noriko Tsumura[1*], Takaya Iwasaki[2], Tanio Ito[3], Kazunori Arita[4], Eiji Kurashimo[2], Hiroshi Sato[2], Naoshi Hirata[2], Katsuya Noda[4], Akira Fujiwara[4], Susumu Abe[4], Shinsuke Kikuchi[5], Katsuko Suzuki[6]

[1]Chiba Univ., [2]ERI, Univ of Tokyo, [3]Teikyo Heisei Univ., [4]JGI Inc., [5]JAPEX, [6]Schlumberger

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

SCG68-P05 Room:Convention Hall Time:May 23 18:15-19:30

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

Ken-ichi Kano[1*], Yasutaka Ikeda[2], Tanio Ito[3], NOZAKI, Kenji[4], Satoshi Yamakita[5], Tetsuya Takeda[6], Shintaro Abe[7], Takaya Iwasaki[2], Kiyoshi Kato[8], SATO,Tsuyoshi[3], Hiroshi Sato[2], Toshiki Watanabe[9], Akira Fujiwara[10], ABE, Susumu[10], Kei Odawara[11], MATSUYRA, Yoshiki[12]

[1]Shizuoka University, [2]University of Tokyo, [3]Teikyo-Heisei University, [4]Chiba University, [5]Miyazaki University, [6]NIED, [7]AIST, [8]Komazawa University, [9]Nagoya University, [10]JGI, [11]Onken, Kanagawa Prefecture, [12]Geebec

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

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

Hisanori Kimura[1*]

[1]National Research Institute for Earth Science and Disaster Prevention (NIED)

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

Kyoko Terui[1*], Shin Koshiya[2], SAKURAI, Syohei[2], Hiroshi Sato[3], Tatsuya Ishiyama[3], Naoko Kato[3], Susumu Abe[4], Motonori Higashinaka[4]

[1]Iwate Univ., [2]Iwate Univ., [3]ERI, Univ. of Tokyo, [4]JGI, Inc.

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.

SCG68-P08 Room:Convention Hall Time:May 23 18:15-19:30

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

Hiroshi Sato[1*], Tatsuya Ishiyama[1], Naoko Kato[1], Motonori Higashinaka[2], Eiji Kurashimo[1], Shin Koshiya[3], Takaya Iwasaki[1], Susumu Abe[2]

[1]Earthquake Research Institute, the University of Tokyo, [2]JGI, Inc., [3]Iwate University

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

Yoshitaka Nakayama[1], Hiroshi Sato[1*], Takaya Iwasaki[1], Susumu Abe[2], Tanio Ito[3]

[1]Earthquake Research Institute, The universoty of Tokyo, [2]JGI, Inc., [3]Tekyo-Heisei University

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

Shigehiro Kitamura[1], Hiroshi Sato[1*], Naoko Kato[1], Tatsuya Ishiyama[1]

[1]Earthquake Research Institute, The university of Tokyo

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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SCG68-P11 Room:Convention Hall Time:May 23 18:15-19:30

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

Koya Shinada[1], Tsuyoshi Toyoshima[1*]

[1]Niigata University

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

SCG68-P12 Room:Convention Hall Time:May 23 18:15-19:30

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

Tetsuo No[1*], Takeshi Sato[1], Shuichi Kodaira[1], Hiroshi Sato[2], Tatsuya Ishiyama[2], Narumi Takahashi[1], Yoshiyuki Kaneda[1]

[1]JAMSTEC, [2]ERI, Univ. of Tokyo

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

Tatsuya Ishiyama[1*], Naoko Kato[1], Hiroshi Sato[1], Eiji Kurashimo[1], Shin Koshiya[2], Tsuyoshi Toyoshima[3], Kenta Kobayashi[3], Shigeru Toda[4], Kyoko Terui[2], Genki Iizuka[4], Mizue Moriyama[2], Shiori Abe[5], Kazuya Shiraishi[6], Susumu Abe[6]

[1]ERI, University of Tokyo, [2]Faculty of engeneering, Iwate University, [3]Department of Geology, Faculty of Science, Niigata University, [4]Aichi Educational University, [5]Department of Geosciences, Chiba University, [6]JGI, Inc.

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

Masahiro Ishikawa[1*], Noritsugu Takahashi[1], Hideo Ishizuka[2]

[1]Yokohama National University, [2]Kochi University

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

Yoshihiro Hiramatsu[1*], Akihiro Sawada[1], Tomoyuki Mizukami[1], Suguru Urano[1], Kazuki Horino[1]

[1]Department of Earth Sciences, Kanazawa University

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.

Acknowledgments: We thank the Geospatial Information Authority of Japan, Geological Survey of Japan, and The Gravity Research Group in Southwest Japan for providing gravity data.

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)

Taichi Sato[1*], Hirokuni Oda[1]

[1]Institute of Geoscience, Geological Survey of Japan, AIST

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