

Dynamics that connects massive earthquake and cross section structure of Aomori, Iwate, and Miyagi

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¹none

In convergence zones, high temperature bodies are formed diagonally-on-and-under the plate of low temp. and the bodies are drawn each other. The mantle wedge and the plate, get on the high temp. body that heads westward from the east, head westward. And, they are placed by the high temp. body that heads eastward from the west and compressed. I think this is the main spring and structure in it. I explained in each respect of the theory, experiment, and application.(1)(2)

This time concerns the structural understanding of the north off Miyagi. First of all, I can recognize the feature of Miyagi(Section d-d') again by the comparison with Aomori(Sec. a-a'). Hot4 of the high temp. is extended to the west more and Hot5 is extended to the east more. And, the direction of the main spring is almost horizontally. Moreover, because there is no remarkable hot section in (the wedge in the east coast east)(W), modeling and repro.-experiment in the slip zone of 3.11 were easy. Hot4 that surges from the west has the tendency to be stuck well to the slope in the east part, and stagnates. And, the material accumulates about there. As a result, the land is formed and maintained. However, in the eastern edge, pressure tends to come off to the under east. Because W is pushed from the west true side, flaking-off along the boundary can be expected.

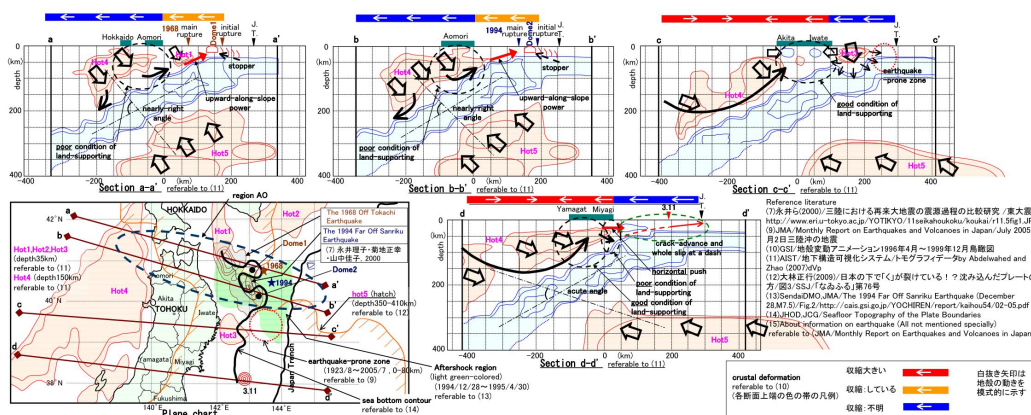
The feature of Aomori is entirely different. Because Hot 4 and Hot 5 do not extend, the angle of the mainspring and the slope is squarely near. And, Hot 4 approaches the slope first and develops along it. Therefore, the land does not develop. Because W is pushed from the under west diagonally, flaking-off deviates from the boundary on the way and pushes up bottom of the sea. Material collects there and Dome develops. Because, on the east side from that place, power to stop the Dome is generated in the reaction from the under east diagonally, flaking-off along the boundary will not happen easily here similarly. Though Sec. a-a' and Sec. b-b' look like, more active slip of climbing up the slope is expected in the former because it has the engine(Hot 1) also in W. Region AO in the Plane chart is peculiar in these reasons.

In comparison with off Miyagi, following matters were mysterious (8). In the large earthquake(EQ) in 1968 and 1994, the position of initial rupture(IR) and main rupture(MR) is mutually away (7). It seems the 1994 EQ destroyed from the shallow to the depth widely (13).

However, according to the above-mentioned structural understanding, it can explain that the characteristic of large EQ in region AO is having the seismic source process that ,on the east side of the Dome, the stopper moves first(IR) and ,west side, the large slip starts(MR).

The temp. structure of Iwate(Sec. c-c') is intermediate as a whole. It is peculiar that there are low temp. bodies under the land and there is huge Hot 3 in W. Hot 3, Hot 4, and Hot 5 pull each other mutually. The underground is pushed from east and west and the land is supported by steady pressure. I think that Sanriku can exist for this. Because Hot 3 is pulled to the under east diagonally, point of W and subducting slab are pushed immediately. This and earthquake-prone zone(9) relate.

(1)MASE/SSJ2010/P3-47 (2)MASE/JpGU2012/SCG67-P06 (3)MASE/SSJ2012/P2-75 (4)MASE/JpGU2013/SSS28-P09 (7)NAGAI et al.(2000)/ERI U-Tokyo (8)MASE/JpGU2014/SSS30-P01 (9)JMA/Monthly Report/July 2005 (13)SendaiDMO,JMA/The 1994 Far Off Sanriku Earthquake



Crustal study of the Northern Scandinavian Mountains from receiver functions analysis and surface wave ambient noise

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The Scandinavian Mountains are a topographic anomaly on the North-East Atlantic passive margin. With heights above 1 km adjacent to the low-lying Baltic Shield (average altitude of 500 m), this mountain range has undergone a rejuvenation by an uplift event during the Neogene. The absence of a crustal root expected from Airy isostasy calculations , the variation of gravity anomaly and the possibility of a low velocity zone in the upper crust suggest variations in density within the crust. This mechanism will explain the (isostatic) equilibrium of the mountain range. With this perspective two passive seismic experiments were deployed in 2007-2009 (SCANLIPS2) and 2013-2014 (SCANLIPS3D) across the Northern Scandinavian Mountains. These 2 experiments allow a better characterization of the crust in terms of Moho depth, Poissons ratio and shear wave velocity. Here we will show a new Moho map compiled from our new results together with previous studies (LAPNET-POLNET, SNSN and NORSAR network) in this region. This map shows a crustal thickening from West to East (40 km to 50 km) without any obvious influence of the transition from the Scandinavian Mountains to the Baltic Shield. From our receiver functions only, inverse modelling does not confirm the presence of a low velocity zone in the upper crust as suggested in previous work in the area using P receiver functions and controlled source experiments. We therefore use Rayleigh waves ambient seismic noise to better constrain the shear wave velocity at the short periods (3- 30 s). Finally a joint inversion of the P-receiver functions and surface wave ambient noise used to build a new 2D crustal model across the Northern Scandinavian Mountains. This new crustal model confirms the assumption of the variation densities within the crust like the source of this topographic anomaly on this passive margin.

Keywords: Scandinavian Mountains, Neogene uplift, variation density, P-Receiver Functions, Rayleigh waves dispersion curve, joint inversion

Seismic velocity structure off the Boso Peninsula, Central Japan, revealed by an ocean bottom seismographic experiment

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Off the Boso Peninsula, central Japan, where the Sagami trough is in the south and the Japan trench is in the east, there is a triple junction where the Pacific plate (PAC), the Philippine Sea plate (PHS) and the North America plate (NA) meet each other. In this region, PAC subducts beneath PHS and NA, and PHS subducts beneath NA. Due to these subductions, numerous seismic events took place in the past, such as the Enpo-Boso earthquake 1677, Genroku-Kanto earthquake 1703, the Taisyo-Kanto earthquake 1923, and the Boso slow slip events. In order to understand these events, it is important to image structure under Kanto region, and many researchers attempted to reveal the substructure from natural earthquakes and seismic experiments.

Because most of the seismometers are placed inland area and the regular seismicity off Boso is inactive, it is difficult to reveal the precise substructure off Boso area only from analyzing natural earthquakes. Although several marine seismic experiments were held, vast area remains unclear off Boso Peninsula. In order to improve the situation, a marine seismic experiment was conducted from 30th July until 4th of August, 2009. The survey line has 216 km length and 20 Ocean Bottom Seismometers (OBSs) were placed on it.

In this study, we analyzed the airgun data acquired from the OBSs by using PMDM (Progressive Model Development Method; Sato and Kenett, 2000) and FAST (First Arrival Seismic Tomography; Zelt and Barton, 1998), then obtained 2-D seismic velocity structure.

According to the previous studies, the P wave velocity of the upper surface of Philippine Sea plate (UPHS) is around 5 km/s, then, we drew the line which represents the UPHS at 5.0 km/s zone. The result shows that the UPHS inclines gently toward east, and the high P-wave velocity area which has 35 km width, locates off southernmost Boso Peninsula, 4 km depth from the sea surface.

The estimated depth of UPHS corresponds to that of Nakahigashi et al. (2012) and Kimura et al. (2009). We also compared our result with other studies and delineated the isodepth contours of UPHS off the Boso Peninsula. We gained a rough image that the 10 km isodepth contour is almost parallel to the Sagami trough, the 15 km isodepth contour runs toward east, and the 20 km isodepth contour runs toward northeast. It indicates that the Philippine Sea plate subducts gently off the Boso Peninsula and it gets sharpened gradually toward the land.

The width and location of the high P-wave velocity area correspond to that of a bump on the UPHS revealed by Tsumura et al. (2009). The velocity is higher than 6 km/s in the center therefore, we concluded that the bump is the buried seamount and our result supports the result of Tsumura et al. (2009).

Acknowledgement

The marine seismic experiment was conducted by R/V Hakuho-maru of Japan Agency for Marine-Earth Science and Technology, and the OBSs were retrieved by Shinchoyomaru of Shin-Nihon-Kaiji co. Ltd. (Present, Fukada salvage co. Ltd.).

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Keywords: Off-Boso, Seismic velocity structure, Philippine Sea plate

Compilation of thermochronologic ages of bedrocks in Japan: For understanding the deformation over geologic time

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For understanding of the relationships between stress and strain and separation of elastic and inelastic deformations in the crust of the Japanese Islands, comparison and investigation of deformations over various time scales are significant (e.g., Ikeda et al., 2012; Nishimura, 2014). The authors are attempting to estimate vertical strain rate of the NE Japan Arc over geologic time by using low-temperature thermochronology, as a part of “Crustal dynamics — Unified understanding of intra-island deformation after the great Tohoku-oki earthquake —”. Although vertical deformation in the NE Japan Arc over the geologic time has been investigated in the plains and coastal areas on the basis of the relative heights and formation ages of the marine and fluvial terraces (e.g., Koike & Machida, 2001; Tajikara & Ikeda, 2005; Matsu’ura et al., 2008, 2009), few quantitative data is available in the mountainous regions where higher uplift rates are possible. As the preliminary step toward thermochronometric studies in the mountainous regions in the NE Japan Arc, we compiled previous thermochronometric ages over the Japanese Islands to review previous thermochronometric data in the NE Japan Arc and to understand vertical deformation of the Japanese Islands over the Japanese Islands. We are compiling mainly about fission-track (FT) ages regarding the items, such as author(s) and year of publication, journal, study area, lithology, sample code, latitude, longitude, altitude, apatite FT age and error, zircon FT ages and error. At present, we have compiled >350 apatite FT ages and >600 zircon FT ages from >70 articles including unpublished data. The result of the compilation suggests: 1) still more data have been reported in the SW Japan Arc than in the NE Japan Arc, 2) in the Kitakami and Abukuma regions, pacific coasts of the NE Japan, apatite FT and zircon FT ages of late Cretaceous were reported (Goto, 2001; Ohtani et al., 2004), indicating total denudation since that era is less than 2-3 km, and 3) in the Iide and Echigo mountains along the Japanese Sea coast of the NE Japan, a few apatite FT ages younger than the end of Neogene were obtained (Goto, 2001; Sueoka unpublished data), implying recent rapid uplift and denudation. By following the compilation results, we are planning to apply thermochronometric methods, e.g., FT analyses and (U-Th)/He dating, to the mountainous regions in the NE Japan Arc, especially in the areas where young ages were reported or no age was obtained.

Keywords: thermochronology, data compilation, deformation over geologic time

Formation and development of incipient shear zone in the lower crust: Example from the Hasvik gabbro, Norway

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Gabbroic rock is a major constituent of the lower crust, and it consists mainly of plagioclase and pyroxene. Although dislocation creep of plagioclase has generally been considered to govern the rheology of the lower crust, when the grain size of the constituent minerals is small enough, grain-size-sensitive creep dominates the mechanical behavior of the lower crust. The process of grain-size reduction is a fundamental factor in controlling the strength of the lower crust. Instead of dynamic recrystallization, the nucleation that results from the fracturing and crushing of minerals have to be considered as potentially important processes. In this study, to clarify the initial process of shear zone formation in the lower crust, we describe microstructural and petrological characteristics of shear zones developed in the Hasvik gabbro of the Seiland Igneous Province in northern Norway (e.g., Tegner et al., 1999).

Shear-zone networks are developed in the Hasvik gabbro, and the shear zones are made up of fine (a few tens of microns), equant, but slightly elongate grains of the recrystallized plagioclase, amphibole and pyroxene. On the other hand, in the primary magmatic crystals of plagioclase and pyroxene, intragranular and intergranular fractures are found. Newly crystallized amphiboles are found along the boundaries between magmatic plagioclase and pyroxenes, in the intragranular fractures within pyroxenes, and at the margins of pyroxene porphyroclasts in the shear zones. Recrystallized grains of plagioclase, clinopyroxene, and orthopyroxene have compositions that differ from the magmatic ones, which suggests they formed by nucleation and growth. Based on conventional plagioclase-amphibole thermobarometry (Holland and Blundy, 1994; Bhadra and Bhattacharya, 2007), the shear zones have formed at temperatures and pressures of 750-800 °C, 0.8±0.2 GPa. The observed primary minerals cut by fractures suggest high-temperature fracturing in the absence of high pore pressures, which implies a high strength of the lower crustal gabbros and high stresses at fracturing. The viscously deformed shear zones are characterized by the lack of crystallographic preferred orientation (Okudaira et al., submitted) and a small grain size, suggesting that the mechanism of deformation of the fine-grained plagioclase and orthopyroxene has been diffusion accommodated grain-boundary sliding during and/or after their nucleation and growth.

Keywords: gabbro, lower crust, brittle fracturing, grain-size reduction, grain-size-sensitive creep

Measurements of elastic wave velocity and electrical conductivity in a brine-saturated granite under confining pressures

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Geophysical mapping of fluids is critical for understanding crustal processes. Seismic velocity and electrical resistivity structures have been revealed to study the fluid distribution. However, the fluid distribution has been still poorly constrained. Observed velocity and resistivity should be combined to make a quantitative inference on fluid distribution. The combined interpretation requires a thorough understanding of velocity and resistivity in fluid-saturated rocks. We have studied elastic wave velocities and electrical conductivity in a brine-saturated granitic rock under confining pressures.

A fine grained (100-500 μ m) biotite granite (Aji, Kagawa Pref., Japan) was selected as a rock sample for its small grain size and textural uniformity. Cylindrical samples (D=26 mm, L=30 mm) were heated to 100-600°C to increase the amount of crack (open grain boundary), and filled with 0.1 M KCl aqueous solution. A linear relationship was found between the highest temperature and the crack density parameter, which was estimated from velocities measured at atmospheric pressure. Velocity and electrical conductivity were simultaneously measured by using a 200 MPa hydrostatic pressure vessel. The pore-fluid was electrically insulated from the metal work by using plastic devices. The confining pressure was progressively increased up to 150 MPa, while the pore-fluid pressure was kept at 0.1 MPa. It took 3 days or longer for the electrical conductivity to become stationary after increasing the confining pressure.

Velocity and conductivity showed reproducibly contrasting changes with increasing confining pressure. Elastic wave velocities increased by less than 10% as the confining pressure increased from 0.1 MPa to 50 MPa, while electrical conductivity decreased by an order of magnitude. The changes were caused by the closure of cracks under pressure. The steep decrease in conductivity at low pressures suggests that there are more cracks with smaller aspect ratios. Both velocity and conductivity showed no remarkable changes at higher pressures. An empirical relationship between the normalized conductivity and crack density parameter was obtained. This relationship might be applied to a combined interpretation of seismic velocities and electrical resistivity.

Keywords: seismic velocity, electrical conductivity, resistivity, fluid, crack

Measurements of elastic wave velocity and conductivity in a brine-saturated sandstone under confining pressures

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Geophysical mapping of fluids is critical for understanding crustal processes. Seismic velocity and electrical resistivity structures have been revealed to study the fluid distribution. However, the fluid distribution has been still poorly constrained. Observed velocity and resistivity should be combined to make a quantitative inference on fluid distribution. The combined interpretation requires a thorough understanding of velocity and resistivity in fluid-saturated rocks. We have studied elastic wave velocities and electrical conductivity in a brine-saturated sandstone under different confining and pore-fluid pressures.

Berea sandstone (OH, USA) was selected as a rock sample for its high porosity (~20%) and permeability (~10-13 mD). It is mainly composed of subangular quartz grains, with small amounts of feldspar grains. Microstructural examinations showed that clay minerals (e.g., kaolinite) and carbonates (e.g., calcite) fill many gaps between grains. The grain size is 100-200 micrometers. Cylindrical samples (D=26 mm, L=30 mm) were saturated with 0.1 M KCl aqueous solution. Measurements have been made using a 200 MPa hydrostatic pressure vessel, in which confining and pore-fluid pressures can be separately controlled. An aqueous pore-fluid is electrically insulated from the metal work by using a plastic devices. Elastic wave velocity was measured with the pulse transmission technique (PZT transducers, f=2 MHz), and electrical conductivity the four-electrode method (f=100 mHz - 100 kHz) to minimize the influence of polarization on electrodes.

Confining and pore-fluid pressures work in opposite ways. Increasing confining pressure closes pores, while increasing pore-fluid pressure opens them. For a given pore-fluid pressure, both compressional and shear velocities increase with increasing confining pressure, while electrical conductivity decreases. When confining pressure is fixed, velocity decreases with increasing pore-fluid pressure while conductivity increases. The closure and opening of pores can explain observed changes of velocity and conductivity. In contrast to a granitic rock, a brine-filled sandstone showed only relatively small changes in conductivity. These contrasting behaviors might reflect the difference in pore geometry between two rock samples.

Keywords: seismic velocity, conductivity, resistivity, sandstone, fluid

Grain growth in sintered polycrystalline diopside

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Grain growth kinetics were studied in sintered polycrystalline diopside. The starting material was prepared from two types of diopside single crystals (I :Ca_{0.99}Na_{0.01}Mg_{0.97}Fe_{0.03}Si₂O₆, II :Ca_{0.97}Na_{0.02}Mg_{0.86}Fe_{0.13}Si₂O₆). They were crushed and milled to particle size of <math><1\mu\text{m}</math>. The powders were pressed into cylindrical shape under a uni-axial pressure of 2.0 MPa for 10 minutes. The pellets were then sintered at 1130 - 1280 °C for 2h and 6h. As a result, grain size increased and the porosity decreased with increasing sintering temperature or sintering time. The experimental data can be fit the following relation, $D_f^n - D_0^n = kt$ where n is a constant, D_f and D_0 are the grain size at time $t = t$ and $t = 0$ respectively, and k is a rate constant. For the sintered polycrystalline diopside, the parameter $\log_{10}k$ ($\mu\text{m}^n/\text{s}$) was determined to be -3.3 or -4.8 for $n = 2.59$ or 2.64 respectively.

Keywords: grain growth, sintering, diopside, polycrystalline

Tectonic provinces of the Northern Fossa Magna region depicted by means of the crustal movement and seismic activity

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In the Northern Fossa Magna (NFM), large crustal earthquakes had been occurred in 1847 (the Zenkoji Earthquake) and recently. Understanding the tectonic provinces of the upper crust is important in order to clarify the generation mechanism of the crustal earthquakes. The purpose of this study is revealing the tectonic provinces of the NFM region depicted by means of the regional characteristics of the crustal activity. The author investigated the crustal movement and the depth of the seismogenic layer by analyzing GNSS observation data and hypocenter data, respectively.

Velocity field and strain rate field were estimated by analyzing GNSS observation data of GEONET and University of Toyama, from October 2007 to March 2011. The depth of the seismogenic layer was evaluated using the JMA unified hypocenter catalog from January 2003 to March 2011. Noises and low-frequency events were removed from the catalog with hypocenters that focal depth is shallower than 40 km and magnitude is larger than 0.1. Relocation and declustering process of the hypocenters were not conducted in this study. The depth of the seismogenic layer was evaluated by means of the methods of Ito and Nakamura (1998), the depth which 10%, 50%, and 90% of hypocenter occur are defined as the upper, middle, and lower depth of the seismogenic layer.

As the results, considerable lateral variation in the crustal activity was revealed in and around the Niigata-NFM region. The strain concentrate zone consisted of the WNW-ESE trend contraction strain more than 0.15 ppm/yr distributes from the north region of Niigata Prefecture to the central region of Nagano Prefecture, and this zone corresponds to the northeastern part of the Niigata-Kobe Tectonic Zone (Sagiya *et al.*, 2000). The displacement direction in the horizontal velocity field changes from eastward in the northwestern part of the Niigata-NFM region to northward in the southern part. The depth of the seismogenic layer shows lateral variation of about 10 km beneath the NFM region, and the inland region with a relatively shallow depth of the seismogenic layer corresponds the location of active volcanoes. Focal mechanisms of the shallow crustal earthquakes in the NFM region show reverse fault type and strike-slip fault type. These different mechanisms indicate that seismotectonic stress varies around this region.

These results suggest the existence of the geodetic and seismological tectonic boundary that trends to NE-SW direction and inclines toward the west. This tectonic boundary is located obviously on the west side of the geological tectonic boundary, the Shibata-Koide Tectonic Line (Yamashita, 1970) and Tsunan-Matsumoto Tectonic Line (Kosaka, 1984), along the eastern margin of the Shin'etsu sedimentary basin. A conclusive model for the tectonic provinces of the Niigata-NFM region shows that the tectonic boundary separates the whole crust into two provinces which having different characteristics in the horizontal velocity field, seismogenic layer depth, and surface geology. The lateral variation in the seismogenic layer along the geodetic and seismological tectonic boundary might be the cause of generating the shallow crustal earthquakes in the NFM region. In order to discuss about the detailed tectonic provinces of the NFM region, it is necessary the crustal activity are evaluated by various observations with high spatial resolution.

Keywords: tectonic province, tectonic boundary, Northern Fossa Magna, strain concentrate zone, seismogenic layer

Seismic survey around the largest slip area of the 2011 Tohoku-oki earthquake

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The slip amount during the 2011 Tohoku-oki earthquake exceeded tens meters at the near-trench region off Miyagi, though few meters caused at off Sanriku (e.g., Iinuma et al., 2012). Such the spatial variation of the coseismic slip seems to reflect the variation of the physical property on the interplate fault, which can be correlated with a seismic velocity structure. In this study, to understand the mechanism of enormous coseismic slip of this megathrust event, we investigate the heterogeneity of the seismic velocity structure around the fault.

Many seismic refraction surveys were carried out at off Miyagi and Sanriku regions. Azuma et al. (2013) found the high-Vp anomaly in the overriding plate, corresponding the backstop block (Tsuru et al., 2002), at the area of 38°38.5N and 20 km from the trench axis (Figure 1). This Vp anomaly overlapped the large slip area during the 2011 earthquake, and they suggested that the heterogeneous structure in the overriding plate controlled the extent and amount of the coseismic slip near the trench based on the 2-D structure model along a seismic profile. It is expected that similar correlation between the seismic velocity and the amount of coseismic slip is broadly observed in the trench slope area, if the coseismic slip was actually controlled by the material heterogeneity, e.g. the distribution of backstop block.

To confirm broad consistency of the previously identified structural variation, we conducted a seismic survey on October 2014 in the gap area where no seismic surveys have been conducted (Figure 1). We set two survey lines, with a length of 180 km, which run slightly oblique against the Japan Trench axis. Along the profiles, 17 and 20 ocean bottom seismometers (OBSs) were deployed. The spacings of the OBSs were 10 and 8 km, along the land-ward and trench-ward profiles, respectively, taking into account the difference in depths to the plate interface. We used an airgun array composed of four guns with a total volume of 100 liters as a controlled source. During the shooting operation, we also collected near-vertical reflection data by a 48-channel hydrophone streamer with a length of 1.2 km.

The obtained wide-angle data showed clear first arrivals within the offset range of 60 km, and later phases interpreted as the wide-angle reflections from the plate interface. Further analyses of the obtained data set will provide a velocity structural model to clarify more detailed distribution of the backstop block and to reinforce the interpretation based on the spatial correlation between the high-Vp block and large coseismic slip area of the 2011 Tohoku-oki earthquake.

Figure 1. Map view of surveyed area. Red lines and yellow plots indicate survey lines and deployed OBSs' positions of this study. Black line indicates the profile of Azuma et al. (2013). Blue arrow represents the high Vp area detected by Azuma et al. (2013). Gray lines were surveyed by Ishihara et al. (2015). Black blocks shows the distribution of sedimentary prism obtained by reflection surveys (after Tsuru et al., 2002). Color-filled contour represents the coseismic slip distribution of the 2011 Tohoku-oki earthquake (Iinuma et al., 2012).

Keywords: crustal structure, 2011 Tohoku-oki earthquake

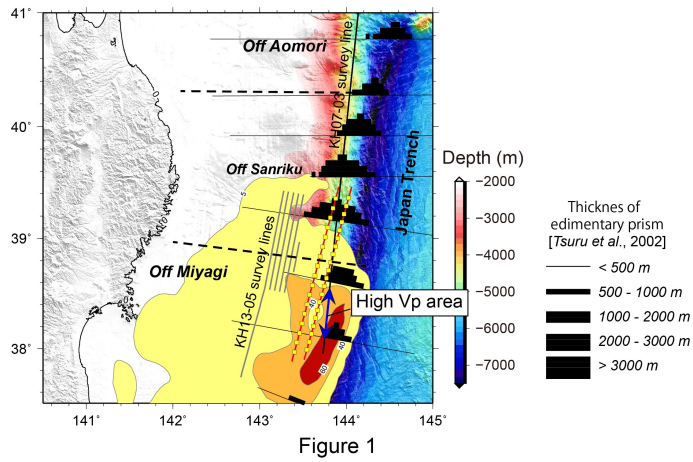


Figure 1

Grain growth of nanocrystalline labradorite

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Plagioclase is a solid solution series that ranges from albite to anorthite endmembers (with respective compositions $\text{NaAlSi}_3\text{O}_8$ to $\text{CaAl}_2\text{Si}_2\text{O}_8$). Plagioclase is a major constituent mineral in the Earth's crust. Its physical and chemical properties are important for establishing the overall rheology of Earth's crust. Previous experimental studies on sintering on plagioclase were mostly concentrated on the endmembers under the high-pressure conditions, thus there are few reports on sintering of plagioclase with intermediate composition.

In this study, sintering of labradorite polycrystalline were performed by using nanoscale powders of natural labradorite, and grain growth kinetics was studied in sintered polycrystalline labradorite. We prepared nanoscale mineral powders from natural crystals of labradorite (Ab38An62) by milling. Sintering experiments were carried out at a temperature of 1100-1210 °C with controlling time after milling and formed mineral powders. Starting materials were characterized by electron probe micro analysis (EPMA). The resultant materials were characterized by X-ray powder diffraction (XRD), secondary electron microscope (SEM) and X-ray fluorescence (XRF) analysis.

Grain growth occurred with increasing sintering temperature or sintering time. The experimental data can be fit the following relation, $D_f^n - D_0^n = kt$ where n is a constant, D_f and D_0 are the grain size at time $t = t$ and $t = 0$ respectively, and k is a rate constant. For sintering, a temperature of 1100-1210 °C with controlled time can provide high dense aggregates of labradorite with an average grain size of 0.5µm, porosity of 3vol% and volume reduction of 60%. In this study, we found that high dense and fine grain polycrystalline Labradorite can be made from nano-sized powders (<100nm) by atmospheric pressure sintering.

Keywords: plagioclase, sintering, grain growth

Effects of seismic velocity anomaly zone below Northeast Japan on displacement of the 2011 Tohoku earthquake

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2011 M9 Tohoku earthquake, Japan, has the 500-km long and 200-km wide source region and large deformation was observed over the Japanese islands. Japan is deployed with dense GPS observation network. Analyzing the spatial features of the crustal deformation data, we can obtain not only information of the source of the Tohoku earthquake but also that of crustal structure. The Northeast Japan arc is formed by the subduction of the Pacific plate below the Eurasian plate. The volcanic front is located along the Ou Range. Studies of seismic tomography has revealed low velocity region below the volcanic front due to the intrusion of hot materials and high velocity region below the Pacific coast due to crustal thinning and ascending of mantle materials. In this study, we construct a finite element model incorporating 3-D crustal structures and examine the effect of crustal heterogeneity on the surface deformation using slip distribution obtained from inversion of the surface displacements due to the Tohoku earthquake. We utilize the large, land-based Japan GPS array as well as seafloor geodetic constraints in the inversion. Our FEM considers a region of 4500 km x 4900 km x 670 km, incorporating the Pacific and the Philippine sea slabs by interpolating models for the Tohoku region and the Nankai trough, as well as the Kuril, Ryukyu and Izu-Bonin arcs. As the geometry of the plate boundaries, we used the model interpolating the existing local plate boundary models. The model region is divided into about 500,000 tetrahedral elements with average dimension ranging from 5-100 km. We also test the role of gravity on coseismic results, with initial results suggesting that gravitational loading is not an important factor because of the shallow dip of the upper Pacific slab. As for the elastic structure, we used PREM model. To represent high and low velocity zone under the Pacific coast and volcanic front, respectively, we introduced 80-km thick region in the model. We also computed with the associated layered structure model to check the effect of crustal heterogeneity. We obtained almost the same slip distribution for both the layered and crustal heterogeneity models, indicating that the deviation of the displacement due to crustal heterogeneity from layered model does not affect slip inversion. Using these results, we calculated surface deformation for models. We compared the two results by patterns of residual displacements, which is obtained by subtracting computed displacements from observed displacements. In the case of layered model, most of Northeast Japan shows eastward residual vectors and the westward vectors can be found along the Pacific coast. These residuals are diminished in the crustal heterogeneity model, so this model better explains the observation. In this way, we can extract information of detailed elastic structure by using broad surface deformation field data. This will allow us to calculate more realistic stress state in the crust.

Keywords: 2011 Tohoku Earthquake, Crustal deformation, Finite element modeling, Seismic velocity structure, Northeast Japan arc, Active fault

A method to estimate friction coefficient from orientation distribution of meso-scale faults

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Static friction coefficient controls the brittle strength of earth's crust of which deformation is recorded as faults. It is difficult to estimate the friction coefficient of ancient geological faults because fault gouge does not preserve its physical property. This paper proposes a method to determine friction coefficient from orientation distribution of fault planes.

Stress tensor inversion techniques have been applied to geological meso-scale faults to calculate a reduced stress tensor, which is composed of three principal stress orientations and a stress ratio. Angelier (1989) tried to determine all six independent components of stress tensor including magnitudes of principal stresses, assuming that the ratio of normal and shear stresses on observed fault surfaces exceeds the friction coefficient. The assumption allows us to estimate the friction coefficient of meso-scale faults as the slope of linear boundary of distribution of points representing normal and shear stresses on Mohr's diagram. However, there has been remained uncertainty in the estimation since the recognition of the line has been done manually on the diagram.

This study computerizes the estimation of friction coefficient as follows. Meso-scale faults are assumed to slip when they satisfy the cohesionless Coulomb's failure criterion represented by the linear friction envelope. The principal stress axes and stress ratio are presumed to be stable, while the changes in the magnitude of differential stress and the fluid pressure are taken into account. When the two parameters fluctuate to cause faulting, the Mohr's circle moves to leftward (negative direction of effective normal stress). Then, a upper left part of the Mohr's circle is cut off by the friction envelope and the faults corresponding to the part are activated. If such events are repeated with various values of differential stress and fluid pressure, the orientation distribution of activated faults should have concentration around the tangential point between the friction envelope and the Mohr's circle normalized to satisfy $\sigma_1=1$ and $\sigma_3=0$. According to the above-mentioned concept, the new method searches for the direction of linear gradation in the frequency of fault planes on the normalized Mohr's diagram. The slope of friction envelope is given by linear contour lines of frequency of faults.

The method was applied to natural fault-slip data gathered from the Pleistocene Kazusa Group, eastern Boso Peninsula. The strata are composed of sandstones and siltstones. Stress inversion analysis (Sato, 2006) gave a WNW-ENE trending tensional stress. The friction coefficient was determined to be $0.66 \pm 0.05/-0.05$, which is typical value for sandstone.

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Keywords: stress tensor inversion, fault-slip analysis, friction coefficient, orientation distribution

Landward migration of active folding estimated from topographic developments along the eastern margin of the Japan Sea

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The Quaternary tectonics of the Japan arc is characterized by strongly crustal deformation, whose mode and rate are quite different from those of the preceding late Pliocene. The Tohoku district, on the eastern margin of the Japan Sea, lies within a strongly compressive area that has been experiencing large, contractional, crustal deformations, since the late Pliocene (Sato and Amano, 1991). Fold-and-thrust structures (Sato, 1989) and fold-topographic structures with distributed reverse faults (e.g., Okamura et al., 1995) have developed in response to this contractional deformation. Geodetic surveys in the Tohoku district have detected zones with a high rate of horizontal strain (Sagiya et al., 2000). When the contractional deformation continues to the present, the high strain rate zones at the geological and geodetic scales should be overlapped. However, the high horizontal strain-rates recognized at geological and geodetic time-scales are spatially heterogeneous. Rates are consistent in the Niigata region, in the southwestern part of the Tohoku district, but not in the Akita region in the northwestern part of the district. There is, therefore, a need to constrain the spatial differences in the horizontal strain-rate between the geological and geodetic time-scales, in order to understand regional tectonic differences across the district.

We focus here on the erosional and topographic evolution of fold structures developed since the late Pliocene in the Akita and Niigata regions. We measured the distance between the fold hinge lines and the mountain ridge lines. We targeted 44 folds that were activated since the late Pliocene, comprising 12 and 32 folds in the Akita and Niigata regions, respectively. Spatial variations in the normalized deviations are consistent with the systematic eastward migration of fold growth in the area. The topographic behavior indicates that the landward migrating of the fold growth is generally constant.

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Keywords: fold, fault, topography, earthquake, deformation, high strain rate zone

Block-in-matrix fabric by frictional grain-boundary sliding of the Hioki melange of Shimanto belt, Shikoku, Japan

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We report lithology, deformation structures, and clay mineral contents of the Hioki melange, which constitutes part of the youngest (late Oligocene to early Miocene) portion of the Shimanto accretionary complex, Shikoku, Japan. The Hioki melange is comprised essentially of a dark gray shaly matrix that envelops blocks and large rafts of mainly sedimentary rock. Although it is regarded as accreted within a few kilometers below the surface (e.g., Hibbard et al., 1993; Underwood et al., 1993), the deformation process of the melange still remains unclear. The deformation mechanism of the melange is essential information to understand this problem.

The lithology and deformation structures are observed using core samples and outcrops along coastline at Muroto, Kochi, Japan. The core samples were collected at two localities (HK01 and HK02) and are about 40 m length, respectively. The whole of the samples show block-in-matrix fabrics. The ratios of the blocks change irregularly between 0 to 40 %. Furthermore, some fracture zones are observed throughout the samples. Some of these fracture zones contain clay minerals. In the field, block-in-matrix fabrics are also observed throughout the study area. The size of blocks ranges from millimeter to meter scale. There were three shapes in the blocks, which are brecciated, boudinage, and layered blocks. Some blocks are injected by shale. The matrix, which is partly folded, is composed of dark gray shale and some green tuff and dark brown shale. Microscopic observation revealed that the shear displacement of the matrix has been achieved by grain boundary sliding and some pressure solution. Attitudes of bedding plane, cleavage foliation, and major axis of boudinage blocks are parallel in many cases.

Clay mineral contents were investigated by XRD analysis on 23 samples (7 samples for HK01, 5 samples for HK02, and 11 samples for outcrops) throughout the study area. The result shows that illite is the major mineral in all samples. In addition, chlorite is contained in the samples of HK02 and the northern half of outcrop, and kaolin minerals are contained in the fracture zone.

Two possible explanation are concerned for the process of the block-in-matrix fabric of the Hioki melange. One explanation is that this fabric has formed under the condition that the contrast in competence between the sand (block) and the shale (matrix) is relatively high. In this case the sand layers have consolidated and deformed by brittle failure, although the shale layers have deformed by grain boundary sliding. In this case, blocks from same layer should form a line. It is a future problem to confirm. Another explanation is that host strata of the Hioki melange have deposited as mud layer with some boulders. In this explanation, sandstone blocks may have been transported by debris flow and/or submarine landslide. On the other hand, the fracture zones have formed in the consolidated melange, which have been uplifted to shallower part of the accretionary prism.

Keywords: block-in-matrix fabric, grain boundary sliding, Shimanto belt, melange

Changes in seismic velocity and electrical conductivity in a brine-saturated granite under uni-axial compression

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Geophysical observations have shown that fluids exist pervasively within the crust. Fluids are mainly situated at intra-grain cracks and open grain boundaries. Since the opening of cracks strongly depends on the stress state, bulk properties such as seismic velocity and electrical conductivity, which are strongly affected by fluid-filled cracks, should be anisotropic under a stress state. In order to understand the anisotropy in velocity and conductivity under stress, we have been constructing an experimental system for studying the anisotropy in elastic wave velocity and electrical conductivity in a brine-saturated granitic rock under uni-axial stress.

The loading system is composed of a hand press (Maximum load: 20 kN), a load cell and stainless steel end-pieces, which contains ultrasonic transducers for velocity measurements in the axial direction. A fine grained (100-500 μ m) biotite granite (Aji, Kagawa Pref., Japan) was selected as a rock sample for its small grain size and textural uniformity. A cylindrical sample (D=26 mm, L=30 mm), to the cylindrical surface of which ultrasonic transducers are mounted for velocity measurements in the radial direction, is assembled with end-pieces, and then loaded. One compressional wave velocity and two shear wave velocities can be measured in the axial and two radial directions. Electrical impedance can also be measured in the axial and radial directions.

Preliminary runs on a dry rock sample have showed that velocities in the axial direction increased significantly with the axial compression. No significant change was observed in velocities propagating in the radial directions. These observations can be explained by the closure of cracks perpendicular or subperpendicular to the compression axis. Experiments on wet samples will also be reported in this poster.

Keywords: seismic velocity, electrical conductivity, anisotropy, fluid, compression, stress

Detrital zircon chronology of the Upper Cretaceous Atokura Formation in northern Kanto Mtn., Japan

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The Cretaceous sandstones of the Atokura nappe in the northern Kanto Mtns. in central Japan were analyzed for detrital zircon U-Pb chronology by LA-ICP-MS. The results documented two distinct age groups; i.e., 150-300 Ma (Permian to Jurassic) and 1600-2600 Ma (Neoproterozoic to Mesoproterozoic). As there are no correlative candidates for provenance in the neighborhood, the Cretaceous strata of the Atokura nappe were likely exotic. The occurrence of Jurassic granitoids is currently limited to the Hida belt in central Japan, while no Precambrian basement is exposed at all in Japan. Judging from the allochthonous mode of occurrence, the Atokura nappe was derived originally from the back-arc domain of the Cretaceous Japan.

Keywords: Cretaceous, sandstone, detrital zircon, U-Pb age, LA-ICP-MS, Japan

Dislocation creep induced layer structures ? in mafic rocks, Tanzawa Mountain

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Tanzawa plutonic complex is located in the northern part of Izu-Bonin-Mariana (IBM) arc. The complex has been exposed by the collision of IBM arc and Japan islands. The exposed process is related to uplifting of Tanzawa plutonic complex along the Kannawa fault. Mafic rocks near the Tanzawa plutonic complex show metamorphosed and deformed textures. The purpose of this study is to reveal microstructures of metamorphosed mafic rocks occurred near the Tanzawa plutonic complex. They are highly deformed and show well-developed layer structures. The mafic rocks consist mainly of amphibole and plagioclase. Amphibole grains are elongated. Plagioclase grains are polygonal. The mean grain sizes of amphibole are in a range between 30 and 110 micron, whereas those of plagioclase are in a range between 25 and 115 micron. Within the well layered rocks, aspect ratios become smaller, as increasing grain sizes. Crystal-preferred orientations (CPOs) of amphibole and plagioclase were measured by a scanning electron microscope (SEM) equipped with electron back-scattered diffraction (EBSD). Amphibole CPOs show (100) [001] patterns. Plagioclase CPOs show (001) [100] patterns. It suggests that their deformation mechanisms are dominantly dislocation creep. Some elongated amphibole grains have grain boundaries perpendicular to the foliations, which appear to be also an evidence of dislocation creep. Consequently, the mafic rocks could result from dislocation creep during the development of layer structures associated with uplifting of the Tanzawa plutonic complex.

Keywords: amphibolite, Tanzawa, amphibole, plagioclase, CPO

Brittle and ductile textures preserved in Kashio mylonite along the Median Tectonic Line, Sakuma-cho, Shizuoka

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Kashio mylonite exposed along the Median Tectonic Line in the central Japan is one of the most famous fault rocks in Japan. The purpose of this study is to reveal microstructural development of Kashio mylonites in the Urakawa area, Sakuma-cho, Shizuoka Prefecture. Kashio mylonite occur along the Ohchise-gawa River and Shippei-sawa. In this study, four Kashio mylonites were classified into three types: protomylonite, mylonite, and ultramylonite. The whole rock chemical compositions show that they were derived from the igneous rocks such as tonalites. Two protomylonites have larger (~4mm) plagioclase and amphibole porphyroclasts and show composite planar structures. The plagioclase porphyroclasts were fractured but partly dynamically recrystallized into fine-grains. All quartz grains were dynamically recrystallized into fine (about 40 micron) grains. One mylonite consists of very fine-grained quartz (about 20 micron) and plagioclase bands with small amount of plagioclase porphyroclasts. One ultramylonite consists of very fine-grained matrix of quartz, plagioclase and K-feldspar (about 10 micron). Ultramylonite were fractured such as cataclastic rocks after the mylonitization. Crystal-preferred orientations (CPO) of quartz were measured in the four mylonitic samples. Quartz CPO patterns suggest that prism $\langle a \rangle$ slip system is dominant, whereas the ultramylonite have a weak cross girdle pattern of c-axis. It suggests that the ultramylonite was progressively developed during deformation under the retrogressive condition. As a result, these mylonitic rocks have undergone three stages of the deformation event. The first stage of deformation occurred in the ductile regime of plagioclase, resulting in the fine-grained plagioclase and Y-maxima CPO patterns of quartz c-axes. The second stage of deformation occurred in the brittle regime of plagioclases, resulting in fracturing within plagioclase porphyroclasts and the weak cross girdle CPO pattern of quartz c-axis in the ultramylonites. Finally, the third stage of deformation occurred in the brittle regime of both quartz and plagioclase, resulting in the development of cataclasis. The results support that the Kashio mylonites have been deformed during progressive retrogression associated with the development of Median Tectonic Line.

Keywords: Median Tectonic Line, Kashio mylonite, CPO, ductile regime, brittle regime

Thickness of seismogenic layer within the crust on the Japan Sea side

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¹NIED

1. Introduction

We investigate the depth of the seismogenic layer in order to estimate the lower limit of the seismogenic fault plane since this depth is related to the size of the earthquake caused by the active fault. We have index D10 and D90 as the upper and lower limit of seismogenic layer, respectively. D10 is defined as the depth above which 10 % of the whole crustal earthquakes occurred from the surface. D90 is the depth above which 90 % of the crustal earthquakes occurred from the surface. The difference between the D10 and D90 is the thickness of the seismogenic layer.

2. Data and method

NIED Hi-net has a catalog of hypocenters determined with one-dimensional velocity (1D) structure (Ukawa et al., 1984). We construct the system to relocate the hypocenters from 2001 to 2013 with magnitude greater than 1.5 on the Japan Sea side shallower than 50 km depth with three-dimensional velocity (3D) structure (Matsubara and Obara, 2011). We estimate the D10 and D90 from the hypocenter catalog with 3D structure.

3. Result

The many earthquakes determined shallower than the 5 km with 1D structure are relocated to deeper with 3D structure and the earthquakes deeper than 15 km are relocated to about 5 km shallower. D10 becomes deeper and D90 becomes shallower with 3D structure.

From Akita to Niigata prefecture, D90 is deeper than the other area and D90 beneath the Japan Sea is much deeper than the inland area. The thickness of the seismogenic layer in this area is also thick from 8-16 km. On the west side of the area, D90 is very shallow as 11-16 km and the thickness of the seismogenic layer is also thin as 2-7 km from Toyama to Tottori.

4. Discussion

Omuralieva et al. (2012) relocated the JMA unified hypocenters with 3D structure. D90 became shallower than that from the JMA catalog. Very deep D90 beneath the northern Hokkaido and from Akita to Niigata is consistent with our result.

5. Conclusion

Using 3D structure, the depth of shallow earthquakes is relocated to deeper and that of the deep earthquakes is relocated to shallower than D10 deepens, D90 shallow, and the thickness of the seismogenic layer becomes thinner. The thickness of the seismogenic layer is thick beneath the region from the Akita to Niigata prefecture on the northeastern Japan Sea side, however, that is very thin beneath the region from Toyama to Tottori prefecture on the west side of the Japan Sea coastal area.

Keywords: seismogenic layer, D90, D10, seismic fault

P-wave velocity structure at shallow depths around the northern limit of the 2011 Tohoku earthquake

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Before 2011 Tohoku earthquake, some seismic surveys had been conducted within the co-seismic slip area of the earthquake. However structures may have been changed after the earthquake due to the co-seismic slip. We need to compare the structures of the same area of different times in order to reveal changes caused by the 2011 Tohoku earthquake. Therefore, a refraction-reflection seismic survey was conducted in 2013 at the same area of the 1999 and 2001 surveys. Seven 100 km long profiles were surveyed parallel to the Japan Trench. Forty-four OBSs were deployed and hydrophone streamer was towed behind the shooting vessel. Air-gun array was used as controlled seismic sources. Because the area of 2013 survey includes the co-seismic slip area of the 2011 Tohoku earthquake, the changes of structure may be revealed by comparing results of 1999 and/or 2001 survey with that of the 2013 survey. Especially the profiles include the northern limit of the co-seismic slip area of the 2011 Tohoku earthquake in their north, so it may be possible to put constraints on the northern limit.

We could identify some differences on the seismic reflection sections and in the recorded waveforms between the 2001 and 2013 surveys. It is, then, expected to reveal some structural changes before and after the 2011 Tohoku earthquake.

We constructed 1-D V-p structures to about 2km depth beneath the seafloor for each OBS station by applying the Tau-P method. Then we constructed 2-D V-p structure models by referring to the 1-D V-p structures for profiles so that the models explain travel times of shallow P-wave arrivals.

Keywords: the northern limit of the 2011 Tohoku earthquake, controlled source seismic survey, ocean-bottom seismometer(OBS)

Seismic basement structure in and around the northeastern Kanagawa Prefecture inferred from the seismic interferometry

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1. Introduction

Detailed information on seismic basement structure is required for understanding the formation process of the Kanto sedimentary basin. In this study, we investigated the seismic basement structure in and around the northeastern Kanagawa Prefecture by the pseudo reflection seismic profiles from the seismic interferometry of local earthquake waveforms, with other geophysical information from geophysical exploration and deep borehole observation.

2. Data and Analysis

Twenty-seven thousand seismic waveforms of the local earthquakes recorded by SK-net, K-NET, and MeSO-net, were analyzed in this study. Following Yoshimoto et al. (2009), we analyzed the SH displacement waveforms of moderate size earthquakes. After the calculation of the autocorrelation functions of each SH displacement waveform with a length of 10s from the S-wave onset, autocorrelation functions from all events were stacked at each station to obtain the reflection response of S-wave for shallow underground structure.

3. Result

We found clear reflective surfaces in the pseudo reflection seismic profiles. As for the Atsugi-Yokohama survey line, it was found that significant reflective surface is inclined to the east from 2s to 6s in two-way traveltime. We interpreted this reflective surface as the top of the Shimanto belt, comparing the geological information at Sagami-hara borehole (Ozawa et al., 1999). The observation stations located at the north of the Tama River show very reflective surface compared with those located above the Shimanto belt. Since this reflective surface is observed at the vicinity of Koto borehole and Fuchu borehole, we interpreted this reflective surface as the top of the Chichibu belt.

The boundary of the Shimanto belt and the Chichibu belt is found to be located nearly along the Tama River, slightly shifting to the south near the northeastern Yokohama City. The top of the Shimanto belt in the south side of this boundary was found at 6s in two-way traveltime in the mid-eastern Yokohama City, and it is about 1s deeper than the top of the Chichibu belt in the north side. It was also found that the Shimanto belt becomes shallower toward the west in western Yokohama City (in and around Asahi-ku and Totsuka-ku). These results are consistent with the seismic traveltime analysis (Yokohama City, 2000). As for the top of the Chichibu belt, its depth was estimated to be nearly horizontal in the east of Chofu, Tokyo, however, it becomes suddenly shallower at the westward of Fuchu.

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Seismic reflection profiling off-Tottori and Fukui, SW Japan, for seismic and tsunami hazards in the Sea of Japan

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To estimate Tsunami and seismic hazards along the coastal area of Sea of Japan, more detailed survey to identify source faults are needed. A research project funded by MEXT named "the integrated research project on seismic and tsunami hazards around the Sea of Japan" began in FY 2013. To obtain the information of source faults, we performed deep seismic reflection profiling off-Fukui and Tottori area in the southwestern part of Honshu, Japan. Multi-channel seismic reflection data were acquired along four seismic lines in off-Fukui area and five seismic lines off-Tottori in the area within 50 km distance from the shoreline. Total length of seismic line is 190 km in off-Fukui and 280 km in off-Tottori. We used two vessels; a gun-ship with 3020 cu. inch air-gun and a cable-ship with a 2-km-long, streamer cable with 168 channels and 1050 cu. inch air-gun. The survey area consists of stretched continental crust and marked by densely distributed syn-rift normal faults. The thickness of Neogene basin fill is 5 km in off-Tottori and 3 km in off-Fukui. The rift basin fill along the arc-parallel normal faults were strongly deformed in late Miocene by basin inversion. The gently dipping Pliocene sediments cover the folded strata unconformably. Some of the Miocene reverse faults displaced late Pliocene sediments. Latest fault system is high-angle faults, whose displacement is preserved in topographic features. Judging from the pattern of reflection the fault system is strike-slip faults.

Crustal deformation in Hokkaido after the 2003 Tokachi-oki earthquake using GNSS data

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The Tokachi-oki earthquake ($M_w = 8.0$) occurred on the plate interface along the Kurile trench on 26 September 2003. Large interplate earthquakes like this are generally accompanied by the postseismic deformation. Postseismic deformation of this earthquake is well observed by GNSS. It is proposed that afterslip and viscoelastic relaxation are dominant mechanisms for the postseismic deformation. Afterslip is aseismic slip that occurs in and around the slip area of the mainshock. It lasts for several days to several years. Viscoelastic relaxation is the crustal deformation caused by flow of viscoelastic material due to the change of stress distribution. It lasts for several years to several decades and its effect is more widely distributed than that of afterslip [e.g. Scholz, 2002]. The effect of viscoelastic relaxation should be eliminated from the observed data when we infer the interplate coupling, especially its healing process after the mainshock, so an estimation of that is important. Theoretically, we can use a difference of relaxation times between two mechanisms to eliminate it, but we don't know when it actually starts to play a dominant role in postseismic crustal deformation.

Several previous studies, such as Miyazaki et al. (2003), Ozawa et al. (2004), and Baba et al. (2006) inverted the observed displacement data and inferred the afterslip distribution of this earthquake. Tanaka (2007) showed that the effect of viscoelastic relaxation is detectable in the observed data by a forward calculation. However, all of them use the data observed for only 2 years after the event, so we analyze the crustal deformation data for 7 years after the event observed by GNSS at the GEONET stations and investigate the effect of both afterslip and viscoelastic relaxation. We, here, describe the feature of the observed deformation after the Tokachi-oki earthquake.

Before the calculation of the deformation velocity after the event, we eliminate linear trends and the significant coseismic displacement of 3 earthquakes occurred near Hokkaido on 15 November 2006, 11 September 2008 and 5 June 2009 [Kimura & Miyahara, 2013]. We estimate the velocity by piecewise linear approximation. The horizontal velocity is estimated every year. The vertical velocity is estimated every year for first 3 years after the earthquake and every 2 years for the remaining period.

The observed data in the Tokachi, the Kushiro and the Nemuro regions were affected by double Kushiro-oki earthquakes on 29 November and 6 December 2004 ($M = 7.1, 6.9$, respectively). The postseismic deformation of these earthquakes lasted for 2 years in the eastern Tokachi, the Kushiro and the Nemuro regions near the hypocenter. In the western Tokachi region, the postseismic deformation lasted for 1 year. From 3 years after the Tokachi-oki earthquake, vertical velocity in the Tokachi and Kushiro regions was larger than that of in the stations near Cape Erimo, so we propose that the effect of viscoelastic relaxation was increasing there relatively and/or afterslip area moved to northeast.

In the Douou region, that is northwestern region of hypocenter, from 4 years after the mainshock, spatial decay of horizontal velocity is notably smaller than that in the northern and northeastern regions.

From examining the data analysis, we concluded that viscoelastic deformation started to play a dominant role in postseismic deformation after 3 years following the mainshock. We assumed a 2-layers structure model consisting of an elastic layer overlying a viscoelastic half-space and estimated the thickness of the first layer and the viscosity of the half-space by grid search. As a preliminary result, we obtained 60 km and 8.0×10^{18} Pa s for the elastic thickness and the half-space viscosity, respectively. The viscoelastic model almost explains the deformation in the northwest and southeast region of Asahikawa.

Acknowledgments: We used the GNSS data(F3 solution) provided by GSI.

Keywords: postseismic crustal deformation, viscoelastic relaxation, 2003 Tokachi-oki earthquake, GNSS

Moho discontinuity beneath the Japanese Islands inferred from grid search analysis of receiver functions

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Information on seismic velocity and seismic velocity discontinuities is important to clarify the characteristics of the seismogenic zone. In particular, investigation on the crustal structure and the crustal thickness is the key to understanding the stress concentration and strain accumulation process. Recent travel time inversion analyses have elucidated 3D velocity structures in the whole areas in the Japanese Islands. However, very few studies have paid attention to velocity discontinuities due to the limitation of spatial resolution. A receiver function analysis can extract velocity discontinuities at any depth. In this study, we applied the grid search analysis of receiver functions to estimate the depths of Moho discontinuity beneath the Japanese Islands.

We first searched for the best-correlated velocity structure model between an observed receiver function at each station and synthetic ones for 10 seconds from the direct P arrival. Synthetic receiver functions were calculated from many assumed one-dimensional velocity structures that consist of a sediment layer and one or two velocity discontinuities from the ground surface to the depths of 50 km. We considered only the positive S-wave velocity steps. Observed receiver functions were stacked without considering backazimuth or epicentral distance. Telemetric seismographic network data covered on the Japanese Islands and several temporal dense seismographic stations are used. We selected events with magnitudes greater or equal to 5.0 and epicentral distances between 30 and 90 degrees based on USGS catalogue.

As a result, we clarify spatial changes of the depths of Moho discontinuity. They tend to increase in mountain regions and become shallow toward the surrounding areas with some undulations in most part of the Japanese Islands. This grid search analysis extracts the oceanic Moho of subducting plates in some areas near the Pacific coastline and beneath the south western Japan. This result suggests that velocity gaps of the subducting plates are larger than that of the overriding plate. We also show the Itoigawa-Shizuoka Tectonic Line (ISTL) is the boundary of the velocity structure in the Japanese Islands. The uppermost mantle along the ISTL shows relatively low P-wave velocities compared to the neighborhood areas. The southwestern Japan side is covered in the relatively high velocity and low V_p/V_s in the crust. On the other hand, the northeastern Japan side has heterogeneities of velocity perturbations. Low S-wave velocity and high- V_p/V_s areas exist just beneath the Moho discontinuity. This may be the reason the depths of Moho discontinuity interpreted from depth-converted receiver functions are deeper than the estimation from tomographic imaging and travel time of the refracted seismic waves in several areas.

Reassessment of the stress history in the eastern Boso Peninsula, central Japan

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There are numerous mesoscale faults in the Neogene to Quaternary Awa and Kazusa Groups in the eastern Boso Peninsula (Kinugasa et al., 1969). The counterclockwise change of the Philippine Sea plate motion was argued on the basis of the stress history reconstructed by fault striation analyses in the peninsula (Angelier and Huchon, 1987; Yamaji, 2000). However, there has been no consensus on the timing of N-S or NE-SW compression. The timing was said to be about the late Pliocene by Kinugasa (1969), before 3-2 Ma by Angelier and Huchon (1987) and before 1.2 Ma by Yamaji (2000). In this research, we reinvestigated the stress history by using a recent technique of paleostress analysis (the Hough-transform-based inversion method: Yamaji et al., 2006; Sato, 2006).

We investigated mesoscale faults cropping out along the east coast of the Boso Peninsula and collected about 1,400 fault-slip data in the Awa and Kazusa Groups. The result of the fault striation analysis is as follows; a vertical axial compression, N-S extension and NW-SE extension were detected from the upper Katsuura Formation to the Umegase Formation. In addition to the above-mentioned three stresses, we detected NE-SW compression from the Amatsu Formation to the Kurotaki unconformity and an early stage extension from the Amatsu and Kiyosumi Formations. The clarified stress history is summarized as follows; the early stage extension before ~3 Ma, the NE-SW compression at 3-2 Ma, the NW-SE extension at 2-0.8 Ma, the N-S extension after 0.8 Ma and the vertical axial compression at the present.

The most important discovery of this study is that the compression was episodic from 3 to ~2 Ma. In this presentation, we discuss the relationship between the paleostress and the past position of the TTT junction.

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Keywords: Boso Peninsula, stress history, fault striation analysis

Analysis of fault rocks along Median Tectonic Line in Tsukide, Itaka town, Matsusaka city, Mie prefecture

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Median Tectonic Line (MTL) is extended more than 800 km in the East-West direction in Southwest Japan, and it is the largest fault, which defines the boundary between Sambagawa belt belonging to the Outer Zone of Southeast Japan and Ryoke belt belonging to the Inner Zone of Southeast Japan. Cracks are initiated when the accumulated strain exceeds the strength of rocks, and we call the displacement along cracks faulting, which could generate earthquakes. However, it is difficult to directly observe presently occurring fault movement in the underground. Therefore, it is very important to observe the outcrop of faults, which were active in the past for understanding the development of fractures along faults. In this study, we described geological map around the MTL, which is distributed in Tsukide, Itaka town, Matsusaka-city, Mie-prefecture, and carried out rock descriptions. Then, we showed brittle fracture formed by faulting along the MTL, and the development of geological structures related to the faulting.

In this study, we mapped (i.e. investigated lithology) five valleys in high resolution using a 50 m scale, which extend approximately 150m in N-S direction, in the area spanning 900m in E-W direction, including the MTL. As a result of field study, it has been found that the MTL dips north at high angles. We showed that around the MTL four kinds of rocks are structurally overlain in order of the Sambagawa pelitic schist (50m+), pelitic schist derived from chert-laminite (90m), cataclasite (80m), and protomylonite derived from Ryoke Granitoids (15m+). We sliced the cataclasite samples and the protomylonite ones, and observed them under a microscope. Then, we observed the gradual alteration of plagioclase to muscovite, and chlorite deposited in cracks from the fluids which percolated along brittle fractures. We classified deformed granitic rock samples into four groups: not fractured, weakly, moderately, and strongly fractured rocks based on the degree of cataclasis. The schistosity of Sambagawa metamorphic rocks in the study area strike East-West directions, and the boundaries between Sambagawa metamorphic rocks and Ryoke Granitoids are also traced in the East-West directions. Therefore, we can show that the MTL generally strikes the East-West directions. Minor faults in Sambagawa metamorphic rocks strike NE-SW and dip north at moderate angles. Therefore, they are interpreted to be Riedel shears formed in relation to large-scale, left-lateral shear along the MTL in the East-West direction. Based on our detailed geological mapping in this area, it has been found that the trace of the MTL is displaced by 70m in the North-South direction in the center of this area, which could indicate a fault jog (step). Faults generally exhibit non-monotonous structures (fault jog) such as bending, echelon arrangement, and junction. Fault jogs are the end areas or the stop areas of fracturing, and it is considered that there are asperities which indicates the area greatly slipped just adjacent to them (e.g. Sugiyama et al., 2003). In the future study, we must investigate the structures of fault jog in detail. Further, we showed that the rocks are strongly fractured near the MTL, and are moderately fractured far from the MTL. The degree of alteration of plagioclase conforms to this result. From these results, it can be inferred that the fracturing along the MTL propagated from the rocks in direct vicinity to the MTL to the remote ones, and the cataclasite zone grew over time.

Keywords: Median Tectonic Line, fault rock, cataclasite

Characteristics of island arc deformation due to steady plate subduction

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Steady plate subduction elastically brings about permanent lithospheric deformation in island arcs, though this effect has been neglected in most studies based on dislocation theory. We investigate the characteristics of the permanent lithospheric deformation using a kinematic model, in which steady slip motion is given along a plate interface in the elastic lithosphere overlying the viscoelastic asthenosphere under gravity. As a rule of thumb, long-term lithospheric deformation can be understood as a bending of an elastic plate floating on non-viscous fluid, because the asthenosphere behaves like water in a long term. The steady slip below the lithosphere-asthenosphere boundary does not contribute to long-term lithospheric deformation. Hence, the key parameters that control the lithospheric deformation are only the thickness of the lithosphere and the geometry of the plate interface. Slip on a plate interface generally causes substantial vertical displacement, and the gravity always tries to retrieve the original gravitational equilibrium. For a curved plate interface gravity causes upward bending of the island arc lithosphere, while for a planar plate interface gravity causes downward bending. Larger curvature and thicker lithosphere generally causes larger deformation. When the curvature changes along the plate interface, internal deformation is also involved intrinsically, which modifies the deformation field due to gravity. Because the plate interface generally has some curvature, at least near the trench, upward bending of the island arc lithosphere, which involves uplift of island arc and subsidence around the trench, is always realized. On the other hand, the deformation field of the island arc lithosphere sensitively depends on lithospheric thickness and plate interface geometry. These characteristics obtained by the numerical simulation are well consistent with observed topography and free-air gravity anomalies in subduction zones, where a pair of topography and gravity anomaly, high in the arc and low around the trench, exists without exceptions all over the world, while there are large variety in the amplitude and horizontal scale.

Keywords: island arc, crustal deformation, viscoelasticity, gravity anomaly

Structure of the PHS in the southernmost area of the Southern Japanese Alps using dense seismic array records

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The southernmost area of the southern Japanese Alps is located within a focal region of the anticipated Tokai earthquake and at the western edge of the Izu collision zone. The structure of the subducting Philippine Sea Plate (PHS) in this area, however, remains enigmatic. To investigate the structure of the subducting PHS as well as the physical property of the oceanic crust, we deployed a temporary, dense array consisting of 34 portable seismic stations extending 50 km in the southernmost area of the southern Japanese Alps. The seismic line started from Umegashima, Aoi-ku, Shizuoka city, and ended at Haruno-cho, Tenryu-ku, Hamamatsu city in Shizuoka prefecture. We applied receiver function and seismic tomography to the observed data, and discussed lateral variations of the plate interface and physical properties of the subducting oceanic crust in the studied area.

The analysis in this study is as follows.

1. We estimated velocity discontinuities by applying receiver function analysis to the seismic waveforms recorded by both the present array and five Hi-net stations near the array for teleseismic events with epicentral distance from 30 to 90 degrees.

2. We estimated seismic velocity structures by applying the double-difference tomography method (Zhang and Thurber, 2003) to the arrival time data. We used seismic waveforms of 354 local earthquakes retrieved at both the seismic array deployed by the present study and permanent seismic stations (45 stations) around the array.

3. To investigate seismicity in the studied area, we relocated the earthquakes from January 2004 to October 2014 applying the double-difference relocation (Waldhauser and Ellsworth, 2000) using the final velocity model estimated by seismic tomography.

We interpret the configuration of the PHS in the receiver function image. As overall character, the plate interface beneath the seismic array gradually becomes shallow toward the northeastern side. The plate interface interpreted in the present study well matches with those proposed by Matsu'ura et al. (1991), Kato et al. (2010), and Ito et al. (2013) at the both edges of the section. For example, Hirose et al. (2008) delineated the smooth plate interface of the PHS. However, the interpretation in this study suggests that the plate interface of the subducting PHS is not simply smooth, but has a convex, complex structure in the studied region. Interestingly, this complex configuration well correlates with the spatial distributions of intraslab earthquakes. A likely explanation is bucking deformation of the PHS due to the effect of collision and subduction. Subduction of a sea mountain beneath the seismic line as seen in the southwest part of the studied area (e.g., Kodaira et al., 2004) is another possible explanation. The reason is under discussion.

From the center to the southwestern side of our seismic section, oceanic crust is characterized by relatively low Vs with a high Vp/Vs ratio. The oceanic crust in this area does not host any significant seismicity. In contrast, at the northeastern side of our seismic section, a low Vp/Vs ratio seems to be present within the oceanic crust, and hosts active seismicity therein. A plausible explanation of the low Vp/Vs ratio within the oceanic crust is that intra-oceanic island arc crust is subducting beneath the northeast side of our seismic section. We suggest that different amount of water trapped within the subducting oceanic crust beneath the studied area may control lateral variations of activity level of non-volcanic tremors or deep low-frequency earthquakes at down-dip extension.

Keywords: southernmost area of the southern Japanese Alps, Philippine Sea Plate, receiver function, seismic tomography, intra-oceanic island arc crust, deep low-frequency earthquakes

Holocene vertical movement history in northern Sanriku coast, NE Japan, related to megaquake cycle

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The 2011 off the Pacific coast of Tohoku Earthquake (The 2011 EQ below) was associated with the distinct subsidence along the Pacific Coast of NE Japan in addition to inter-seismic rapid subsidence by the asperity (coupling) of Eurasia (North American) plate and Pacific plate (Ozawa et al., 2011). Especially, the southern Sanriku coast which largely subsided has been reversely uplifting as an after-slip movement, recovering one fourth of coseismic subsidence (GIS, 2014). If after-slip movement continues at the same speed, the coast will start inter-seismic subsiding by the reinforcing interplate coupling after relatively short recovery of coseismic subsidence (Ikeda, 2014). According this scenario, the vertical movement of northern Sanriku coast out of the 2011 EQ source area is possibly controlled by the similar megaquake cycle. We reconstructed the vertical movement history in the southern Sanriku coast based on the mapping of Holocene emerged coastal topographies and ages, and examined the megaquake cycle managing the history considering the geodetic subsidence measured at the tide-gauge station.

Tephrochronologically age-determined MIS 5e marine terrace height of 30 m shows average uplift rate of 0.2 mm/yr in geological long term. Holocene emerged coastal topographies and dates present three times of rapid uplift events; about 1,000 years ago just before B-Tm ash fall, before 3,300 years ago and before 4,800 years ago. Records of Hachinohe tide-gauge station in the past 60 years indicate the mean subsidence rate of 2 mm/yr. We built the vertical movement diagram synthetically explaining the above results.

Emergences of coastal topographies suggest three sudden uplift events which are named E1, E2 and E3 in chronological order. Assuming that the geodetic subsidence (2 mm/yr) continued during 1,000 years between E3 and the present, E3 was associated with 6-7m uplift. Setting that the gradient of straight line connecting heights of emerged topographies attained just after uplift events satisfies the long-term uplift rate of 0.2 mm/yr, E2 was accompanied by 5-6 m uplift 3,800 years ago, and E1 by 4-5 m 6,200 years ago. These abrupt uplift phenomena is likely generated by a near-shore faulting (Miyachi, 2012), which is not sufficiently testified by geophysical exploration yet. Correlating these uplift events with the ongoing after-slip uplift event after 2011 EQ, plate-boundary megaquakes associated with distinct coseismic subsidence necessarily occurred off the northern Sanriku coast, namely from the northern Japan Trench to the southern Kuril Trench, just before those uplift events. Such megaquakes are estimated to occur at least three times in Holocene.

Keywords: Holocene, Emerged coastal topography, Vertical movement history, After-slip movement, northern Sanriku coast, megaquake

Crust and upper mantle structure of the New Madrid Seismic Zone: Insight into intraplate earthquakes

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The New Madrid Seismic Zone (NMSZ) is seismically the most active region in the Central and Eastern United States and an ideal area to study intraplate earthquakes. A sequence of at least three large earthquakes ($M > 7.0$) occurred here in 1811-1812, and palaeo-seismic records show evidence of large earthquakes about 500 years apart in the past 2000 years. The distribution of local earthquakes recorded since 1974 delineates three linear faults in the NMSZ: (1) the NE-trending Cottonwood Grove-Blytheville Arch fault along the central Reelfoot rift, (2) the NW-trending Reelfoot Fault, and (3) the NNE-trending New Madrid North Fault. The activation of these mid-continent faults and their controls on duration of the seismic activity remain poorly understood. One of the fundamental questions is: what makes the NMSZ different from the surrounding intraplate areas in North America, especially the areas within the same geologic settings?

We determined a 3-D P-wave velocity model of the crust and upper mantle down to 400 km depth to investigate structural heterogeneity and its influences on the generation of intraplate earthquakes in the NMSZ. We used 4871 high-quality arrival times from 187 local earthquakes and 30,846 precise travel-time residuals from 1041 teleseismic events recorded by the Earth-Scope/USArray Transportable Array. Our results show that, beneath the Reelfoot rift, a significant low-velocity (low-V) zone exists in the upper mantle down to 200 km depth, with a large volume of 200 km x 200 km x 150 km. The origin of the low-V zone may be related to the passage of the Bermuda hotspot and the stalled ancient Farallon slab materials foundering in the mantle transition zone. This low-V zone may have relatively low shear strength and act as a viscously weak zone embedded in the lithosphere, being apt to concentrate tectonic stress and transfer stress to the seismogenic faults in the upper crust, leading to the large intraplate earthquakes in the New Madrid Seismic Zone.

Keywords: New Madrid, earthquake, crust, mantle, velocity structure

The property of fault zone and fault activity of the Shionohira Fault, Fukushima Prefecture, Japan

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Co-seismic surface ruptures trending NNE-SSW direction were formed from Tabiuto-Nameishi to northwestern Ishizumi-Tsunaki in Tabito-cho, Iwaki City, Fukushima Prefecture, by the April 11, 2011 Fukushima-ken Hamadori Earthquake. This earthquake was characterized by the westward dipping normal slip faulting, and the maximum displacement was about 2 m (e.g., Kurosawa et al., 2012). These surface ruptures were newly named the Shionohira Fault by Ishiyama et al. (2011).

Before the 4.11 earthquake, the N-S trending several faults were described in this area as the Itozawa Fault in Active Faults in Japan, New Edition (The Research Group for Active Faults of Japan, ed., 2011). The surface ruptures of 4.11 earthquake are corresponding to a part of the Itozawa Fault (western trace of the Itozawa Fault by Tsutsumi and Toda, 2012). The geomorphological features of active faults were not found in the northward of the Gozaisyo highway. On the other hand, the N-S trending lineament are recognized from the south of the Tabiuto-Nameishi to the boundary between the Fukushima and Ibaraki Prefectures, though surface ruptures did not appear in this area. The authors study the differences of active and non-active sections by the 4.11 earthquake, and here the authors show the results of observation of fault outcrops along the Shionohira Fault.

A lot of new fault outcrops were formed by the 4.11 earthquake, however most of them are composed of foot-wall with fault plane, and the structures of hanging-wall are difficult to observe. Only a few outcrops have basement rocks of the hanging-wall and hoot-wall with fault plane. Three of these outcrops (Kyodo-gawa, Shionohira and Betto) were selected to investigation. In addition, a fault outcrop (Nameishi-minami) located in about 300 m south to the southern tip of the surface ruptures was investigated. We carried out observations of outcrops, polished slabs and thin sections, and X-ray diffraction (XRD) to the fault materials.

As a result, the fault zones originated from schists were investigated at Kyodo-gawa and Betto. The thick fault gouge is cut by a fault plane by 4.11 earthquake in each outcrops. The fault materials originated from schists are fault bounded with (possibly Neogene) weakly deformed sandstone at Shionohira. The thin fault gouge is found along the fault plane by 4.11 earthquak. A small-scale fault zone with thin fault gouge are observed in Nameishi-minami. According to XRD analysis, smectite was detected in the gouges from Kyodo-gawa, Shionohira and Betto, while it was not contained in the gouge from Nameishi-minami.

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Keywords: Shionohira Fault, active fault, fault gouge, property of fault zone, X-ray diffraction, Fukushima-ken Hamadori Earthquake

Deformation process of the Miocene Misaki assemblage at Cape Muroto, Shikoku, Japan

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We report the geologic structure of the Misaki assemblage, which constitutes part of the youngest portion of the Shimanto accretionary complex, Shikoku, Japan. It is interesting to compare the deformation process of this strata with that of the present Nankai accretionary complex. We divided the Misaki assemblage into ten lithofacies, and described lithologic map and geologic cross section of the study area.

The northern part of the study area consists mainly of hemipelagic calcareous mudstone and deformed sandstone and mudstone. In contrast, the southern part of the study area consists of folded turbidite and conglomerate. These strata dip to the west more than 70° and are intruded by Miocene igneous rocks. Many minor faults are observed in the study area.

These lithologic and structural data suggests a deformation process of the Misaki assemblage as follows: (1) deposition of ocean plate stratigraphy, (2) offscraping by frontal thrusts, (3) intrusion of igneous rocks along one of the thrusts, and (4) tilting of the whole strata.

Keywords: accretionary complex, Shimanto belt, Muroto, fault

Interseismic plastic deformations at ancient crustal seismogenic zones in the Hidaka metamorphic belt and Napier Complex

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Pressure solution-precipitation structures are characteristically abundant in pseudotachylyte-producing fault zones in the Hidaka metamorphic belt, Hokkaido, northern Japan (Toyoshima et al., 2004; Wada et al., 2005). The zones occurred at the lowermost part of upper continental Hidaka crust. Pseudotachylytes formed under granulite-facies conditions (lower continental crustal conditions) occur at Tonagh Island in the Napier Complex, Eastern Antarctica (Toyoshima et al., 1999). Seismic faulting (pseudotachylytes-producing faulting) and plastic deformation (formation of ultramyylonite) alternated under lower continental crustal conditions in Tonagh Island (Toyoshima et al., 1999). I illustrate interseismic deformations related to the Hidaka and Tonagh pseudotachylytes as examples of ancient seismogenic zones in upper and lower crust, respectively.

Modes of occurrence of the Hidaka pseudotachylytes indicate that seismic slip with pseudotachylyte generation and slow plastic deformation (pressure solution with precipitation) occurred alternatively and repeatedly in the same fault zones and fault surfaces (Wada and Toyoshima, 2006, 2007). Pressure solution-precipitation is likely one of the principal deformation mechanisms for interseismic plastic deformation and time-dependent strength recovery of fault zones (Wada and Toyoshima, 2006, 2007). The pressure solution-precipitation processes lead to increase in number of grain-to-grain contact and in real contact areas of the fault surfaces, resulting in healing of the fault zones (Wada and Toyoshima, 2007). Very thin and sharp shear zones filled with very fine-grained materials cut the pressure solution-precipitation structures and are cut by pseudotachylytes-producing faults. The shear zones are deformation structures formed immediately before seismic faulting in the upper Hidaka crust.

Granulite-facies ultramyylonites are characteristically abundant in and along the Tonagh pseudotachylyte-producing fault zones. There are two different types of the granulite-facies ultramyylonites in microstructures of recrystallized plagioclase grains: type 1 and 2. Type 1 ultramyylonites have polygonal medium grains of plagioclase with smooth grain boundaries and very weakly undulose extinction. Type 2 ultramyylonites include very fine grains and elongated fine grains of plagioclase with strongly undulose extinction and irregular grain boundaries. Type 2 ultramyylonites occur along granulite-facies pseudotachylytes-generating fault surfaces and have been cut by fault veins of pseudotachylyte. Some of the granulite-facies pseudotachylytes became type 1 and 2 ultramyylonites, which have also been cut by other granulite-facies pseudotachylytes. These may also be conspicuous difference between dynamic recrystallization mechanisms of plagioclase immediately before and after seismic faulting.

Keywords: pseudotachylyte, pressure solution, ultramyylonite, plastic deformation, interseismic deformation, time-dependent strength recovery

Study on heterogeneous structure beneath the Beppu-Haneyama fault zone

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The Beppu-Haneyama fault zone is the active fault zone in Japan, running from the Beppu Bay to western part of Oita prefecture. In the Beppu area, the seismogenic layer is thin (about 10km). Since the structure beneath this layer could affect the thickness, we need to get acquaintance of subsurface structure. This study estimated the heterogeneous structure of this fault zone from distribution of the reflectors based on seismological analysis.

We analyzed the data observed at seismic stations deployed by Kyushu and Kyoto Universities, NIED and JMA. For simplicity, we assumed homogeneous velocity structure to analyze the observed data. Normal move-out (NMO) processing was applied to detect reflectors. Seismic section normal to the strike direction of the fault zone reveals that reflective zone of the depth about 25km, which could correspond to the Moho discontinuity. Since numerous reflected waves beneath the seismogenic zone were detected. The distribution of the reflectors generating these reflected phase might relate to the thickness of the zone.

Keywords: Beppu-Haneyama fault zone, heterogeneous structure, reflector

Anomalous seismic wave intensity distribution in the Tokyo Metropolitan area.

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The intensities of seismic waves observed at the dense seismic array of the Tokyo Metropolitan Seismic Observation network (MeSO-net) inside the Kanto basin, display unusual distribution patterns. In several occasions, the highest intensities are not observed in the area above an earthquakes hypocenter but appear sifted more than 20 km away. In order to understand the source of this unusual intensity distribution pattern, it is crucial to understand how the waves attenuate before they reach the surface. The attenuation of seismic waves along their path is represented by the t^* attenuation operator that can be obtained by fitting the observed seismic wave spectrum to a theoretical spectrum using an ω^2 model. In order to create a high quality dataset, only 1449 earthquakes that are recorded with intensity greater than 0 in the Japan Meteorological Agency (JMA) intensity scale are selected from the JMA unified earthquake list from April 1st 2008 to October 2nd 2013. A grid search method is applied to determine the t^* values by matching the observed and theoretical spectra. The t^* data were then inverted to estimate a 3D Q structure with grid points set at a 10 km spacing. We implemented the 3D velocity model estimated by Nakagawa et al., 2012 and in addition we set the initial Q values at 100 for the 0 km grids and to 400 for the grids below them. The obtained model suggests average Q values of 50~100 inside the Kanto basin. Furthermore, a low Q zone is observed in the area where the Philippine Sea plate meets the upper part of the Pacific sea plate. This area is located at approximately 40 km depth, beneath the north-east Tokyo and west Chiba prefectures and is represented by Q values <300. Earthquakes occurring on the Pacific plate pass through this low Q area inside the Philippine sea plate and are attenuated significantly. The estimated attenuation distribution at the MeSO-net station for these earthquakes implementing our 3D Q model greatly coincides with the observed seismic wave intensity distribution. Stations where our model predicts high attenuation display low intensity values whereas stations where our model predicts low attenuation display high intensities. The implementation of our findings could help towards a better understanding of the damage area of future earthquakes and mitigate the disaster of the affected areas.

Keywords: Attenuation, Tomography, MeSO-net