Japan Geoscience Union Meeting 2011
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Detailed structure of the locked-sliding transition on the plate boundary beneath the southern part of Kii Peninsula

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The Nankai trough region, where the Philippine Sea Plate subducts beneath the SW Japan arc, is a well-known seismogenic zone of interplate earthquakes. A detailed crustal and upper mantle structure of the subducting Philippine Sea Plate and the overlying SW Japan arc is inevitably important to constrain the physical process of earthquake occurrence. Recently a narrow zone of nonvolcanic tremor has been found in the SW Japan fore-arc, along strike of the arc (Obara, 2002). The epicentral distribution of tremor corresponds to the locked-sliding transition zone. The spatial distribution of the tremor is not homogeneous in a narrow belt but is spatially clustered. Knowledge of lithospheric structure is necessary for an understanding of tremor. However, little is known about the deeper part of the plate boundary, especially the transition zone on the subducting plate. To reveal the detailed structure of the transition zone on the subducting plate, we conducted a deep seismic profiling in the southern part of Kii Peninsula, southwestern Japan. In this experiment, 290 seismometers were deployed on a 60-km-long line in the east-west direction with about 200 m spacing, on which five explosives shots were fired as controlled seismic sources. Charge size of the shots is 200 kg. Each seismograph system consisted of a 4.5 Hz, vertical component seismometer and a single channel data recorder, recording at 250 Hz. We obtained high signal-to-noise ratio data along the entire length of the profile. The most remarkable feature of the record sections is that extremely high amplitude reflections, which are interpreted as a reflected wave from the top of the subducting Philippine Sea plate, can be recognized. To obtain the detailed structure image of the transition zone on the subducting plate, the data recoded on the EW-line were processed using seismic reflection technique. The stacked image shows several features of the deeper part of the crust including the subducting plate boundary at 10-11 sec in two way travel time. Seismic reflection image also shows the lateral variation of the reflectivity along the top of the subducting Philippine Sea Plate.

Keywords: Non-volcanic tremor, transition zone, plate boundary, reflector

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Converted Ps amplitude variations on the dipping slab Moho beneath the Kii Peninsula: 2. Ray parameter dependence

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Receiver functions (RFs) analysis is a very useful method to detect seismic velocity discontinuities beneath a seismic station. One can also evaluate elastic properties at an interface from changes of Ps polarity and Ps amplitude. Ps amplitude depends primarily on the impedance contrast at an interface, but the variation of Ps amplitude on back azimuth (BAZ) of the incoming P wave is affected if the interface is dipping and/or anisotropic rock surrounds the interface. Moreover, difference of incidence angle of incoming P waves also causes the variation of Ps amplitude. Shiomi and Park (2009; AGU FM) defined "standard amplitude (SA)" of a converted phase at a dipping interface beneath a station, based on back azimuth dependence of the Ps amplitude, and applied this analysis to the stations located within the Kii Peninsula, central Japan. However, since precise estimation for an incidence angle to the dipping interface is difficult, ray parameter dependence to the Ps amplitude evaluation was not considered. It becomes a problem for stable estimation of the SAs. In this study, we check ray parameter dependence to the SA estimation, and revise it at each station in the Kii Peninsula.

Teleseismic waveforms recorded at the NIED Hi-net, F-net and AIST seismic stations in the Kii Peninsula are used. We select earthquakes with high signal-to-noise ratio observed from October 2000 to August 2010 with magnitudes 6.0 or greater. Checking distribution of BAZs and incidence angles of every teleseismic waveforms observed at each station, we confirm that 80% of the selected event is located in the south ($120^o \leq$BAZ$\leq 250^o$) of stations. Ray parameters of 10% of the events are larger than 0.077, which corresponds to 37^o of incidence angle to a horizontal interface. In the case of dipping interface, Ps amplitude change with BAZ becomes larger when incoming P waves have larger ray parameters. Since events located in the west or northeast of stations are fewer than other directions, the contribution of events with large ray parameter is not small in these directions. The Philippine Sea slab is subducting to west at the eastern Kii Peninsula and to north at the southern Kii. Therefore, the Ps amplitudes tend to become large for earthquakes occurred in these direction. This means the Ps amplitude may be overestimated when we do not take ray parameter dependence into account. In order to avoid this contamination, we first select events with ray parameter from 0.055 to 0.077. Moreover, we apply amplitude correction coefficients, which are numerically evaluated by the difference of converted phase amplitudes by a horizontal Moho discontinuity. We clearly confirmed that the Ps amplitudes decreases from 11% to 7% of the primary P wave as the oceanic Moho deepens to ~40 km, and the amplitudes becomes a constant, at 5-7% of the primary P wave. According to the P-T diagram of the Kii Peninsula region, we say that the Ps amplitude decrease likely reflects a phase transition from lawsonite blueschist to lawsonite-amphibole eclogite as water is released to the overlying layer, and this metamorphic fluids likely influence the occurrence of low-frequency nonvolcanic tremor. On the one hand, the regionality of standard amplitude distribution within the Kii Peninsula became unclear. To understand what happens along the subducting slab interface, it is important to construct models to explain the observed SA distribution as the next step.

I use the teleseismograms observed at AIST groundwater observation stations. I thank J. Park who provide me a source code for RF stacking analysis.

Keywords: Receiver function, Converted phase amplitude, Ray parameter, Kii Peninsula, Oceanic Moho, Philippine Sea plate

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Distinct trapped waves of oceanic mantle earthquakes and their relationships to the inter-plate structure

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We have investigated the Hi-net (high sensitivity seismograph network Japan operated by the NIED) seismograms of the intraslab earthquakes occurred within the subducting oceanic mantle of the Philippine Sea plate beneath the Kii Peninsula, southwest Japan. On their seismograms, distinct later phases (X phases) were found within 2-3 seconds after initial P-wave arrivals. Main features of the X phases are as follows: (1) The X phases are observed only in and around the southwestern part of Gifu Prefecture. (2) Amplitudes are a little larger than those of the initial P-waves. (3) Vertical and radial components are dominant. (4) Dominant period is approximately 2-4 Hz and apparent velocity is approximately 8.0 km/s. On the basis of these features, the X phases could not be interpreted as trapped waves within the oceanic crust or direct waves observed by the oceanic crust events (e.g. Fukao et al., 1983; Hori et al., 1985), and pPmP or sPmP phases (Miyoshi and Ishibashi, 2007).

To examine the origin of the X phases, we calculated P-SV seismic wave field in the two-dimensional structure. The structure was constructed on the basis of Kubo et al.(2002) and Miyoshi and Ishibashi (2004). The source was assumed as a point source represented by double-couple model. As an example, we simulated the seismic wave field of the oceanic mantle event located 55 km depth beneath the Kii peninsula along two profiles, profile A (N20E direction from the source) and profile B (N50E direction from the source).

Our results could reproduce successfully the features of the observed seismograms. Along the profile A, distinct later phases were simulated within 2-3 seconds after initial P-wave arrivals at approximately 150 to 200 km epicentral distances. Using cross-sections of the wave field and snapshots of the strain field, we interpreted the later phases are SP converted waves, P-waves converted from S-waves at the plate interface or the oceanic Moho discontinuity, and trapped within the oceanic crust. The trapped SP converted waves propagate through a contact zone between the oceanic crust and the lower island-arc crust and arrive at stations. On the other hand, no distinct later phases were simulated within 2-3 seconds after initial P-wave arrivals along the profile B. In this case, SP converted wave are not trapped within the oceanic crust, because the oceanic crust mostly contacts with the island-arc lower crust along the profile B. As a conclusion, observed X phases could be explained by SP-converted waves generated near the source and propagate within the oceanic crust. Then, the trapped SP phases are only observed above the contact zone between the oceanic crust and the lower island-arc crust. Based on this point, we infer the Isewan-Kohoku slab (Miyoshi and Ishibashi, 2008) contacts directly with the island-arc crust.

The plate interface is the source region of interplate earthquakes included slow events and a material and mechanical boundaries in the subduction zones. It is a quite important problem for seismotectonics to reveal the detail plate boundary structure. Using the SP trapped wave detected in this study and guided waves of the oceanic crust events (Fukao et al., 1983; Hori et al., 1985), we can infer the structure near plate boundary in detail.

Keywords: later phases, trapped waves, oceanic crust, Philippine Sea plate

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Multiple collision and subduction structure of the Izu-Bonin arc revealed by active source seismic data

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Since the middle Miocene, the Izu-Bonin arc has been colliding with the Honshu arc in central Japan. This collision process is responsible for an extremely complex crustal structure of the Izu collision zone. Geological studies suggested that Koma, Misaka, Tanzawa and Izu blocks were accreted onto the Honshu arc at different ages in the process of collision (e.g. Amano, 1991). In recent years, collision and subduction structure in the Izu collision zone has been revealed by seismic experiments which were performed in 2003 and 2005 as a part of Special Project for Earthquake Disaster Mitigation in Urban Areas (Sato et al., 2005; Sato et al., 2006; Arai et al., 2009). They showed a wedge-like structure of the Tanzawa block and its delamination from the subducted slab in the eastern part, and the aseismic slab subducted beneath the collision zone in the western part. Based on refraction/wide-angle reflection analysis of 2005 Odawara-Yamanashi profile in the western part, this study aims to reveal the whole structure formed by the multiple collision and subduction and to establish the model of crustal deformation process.

A 75-km-long seismic line in NW-SE direction crossed several collision boundaries such as the Sone-Hills Faults, the Tonoki-Aikawa Tectonic Line and the Kozu-Matsuda Faults. Seismic waves from 115 shots were recorded at 1642 stations with an average interval of 50 m. Data quality was so good in the whole profile that not only P wave first arrivals but also P wave reflections and S wave first arrivals were recorded. Refraction tomography analysis (Zelt and Barton, 1998) and forward modeling using ray tracing method (Iwasaki, 1988; Cerveny and Psencik, 1983) were applied to the data set to construct P and S wave velocity models.

The obtained structural models showed strong crustal heterogeneities associated with the multiple collision and subduction processes. One of the important features characterizing the collision structure is that the Sone Hills Faults, located at the northern end of the Izu-Bonin arc, has a southeastward dip, which contrasts with northwestward dips of the Tonoki-Aikawa Tectonic Line and Kozu-Matsuda Faults. Multiple collision and subduction structure of the Misaka, Tanzawa and Izu blocks is summarized as follows.

1)The Misaka blocks is obducted onto the Honshu arc along the southeastward dipping Sone Hills Faults, and forms a pop-up structure bounded by reverse faults on both sides.

2)The Tanzawa block is characterized by crustal stacking bounded by northwestward dipping boundaries.

3)Crustal delamination occurred in the middle crust of Misaka and Tanzawa. The delaminated middle/lower crust of the Izu-Bonin arc was accreted at the bottom of the Honshu crust or subducted deep into the mantle.

4)The whole crustal block of Izu was subducted beneath the Tanzawa block without delamination in the upper and middle crustal level.

5)There exists a northwestward dipping reflector at the depth of 25-35 km beneath the Misaka and Tanzawa blocks, which is interpreted to be the top of the subducted lower crust of the Izu-Bonin arc.

6)Due to a small velocity contrast inferred from amplitude modeling, it is expected that a low velocity layer does not exist at the top of the slab beneath the collision zone, which contrasts with the case of the Nankai subduction zone where the oceanic crust is subducted.

Keywords: Izu collision zone, Seismic wave velocity structure, Refraction/wide-angle reflection analysis, Misaka Mountains, Tanzawa Mountains, Izu Peninsula

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Shear-wave splitting in the Tokai region

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In Tokai region, the Philippine Sea plate is descending to the N-W direction. The configuration of the subducting slab has been revealed by the seismic tomography and refraction/reflection studies. Those studies suggested that the top of the slab was not smooth. The subducting ridges were detected. The asperity is one of the important topics to know the mechanism of the inter plate earthquakes. There are many discussions for the relationship between the subducting sea mount and asperity. The Tokai region is one of the good fields to know the relationship. The configurations of the subducting ridges have been revealed by the refraction and reflection studies. If the effect of the subducting ridge to the stress pattern is large, it will be detected by the shear wave splitting at the seismic station just above the ridge. We did temporal seismic observation with about 70 seismic stations in Tokai region. The shear wave splitting is researched using the array.

The spatial variation of the sear wave splitting values was obtained. But, we could not find any close relationship between the topography of the subducting ridge and spatial variation of shear-wave splitting. It is expected that the effect of the subducting ridge to the stress pattern in the crust seems to be small.

Keywords: anisotropy, Tokai, asperity

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Crustal structure in Japan inferred from receiver functions and comparison with those of travel time tomography

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Investigation on the crustal structure and configurations of the subducting plates is the key to understanding the stress and strain concentration process. Recently, many researchers have elucidated crustal structures in the Japansese Islands from travel time tomography analyses. However, they show different features in some areas. In this study, we estimated the seismic velocity structure and seismic velocity discontinuities of the crust and uppermost mantle beneath the Japanese Islands by using receiver function analyses, and compared them with existing results of seismic velocity structures estimated from travel time tomography.

We first searched for the best-correlated velocity structure model between an observed receiver function at each station and synthetic ones by using a grid search method. Synthetic receiver functions were calculated from many assumed one-dimensional velocity structures that consist of four layers with positive velocity steps. Observed receiver functions were stacked without considering backazimuth or epicentral distance. We further constructed the vertical cross-sections of depth-converted receiver function images transformed the lapse time of time series to depth by using the estimated structure models. Receiver function amplitudes were projected and stacked at each cross-section. 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 catalogues.

As a result, we clarify spatial distributions of the crustal S-wave velocities. Average S-wave velocities from the ground surface to 5 km deep indicate thick low-velocity layers in several plain and basin areas. Although the velocities are slower than those of tomography models, the spatial patterns are corresponding with basement depth models. The velocity perturbations in the crust are consistent with tomography models. There are low-velocity zones corresponding to volcanoes in the upper crust and around the crust-mantle boundary. In the lower crust, our results show low-velocity structures in the Niigata-Kobe Tectonic Zone. From depth-converted cross-sections, we can detect the upper boundary and the oceanic Moho of the subducting plates that dipped toward northwest. High velocities near the southern coastline of the Japanese Islands correspond to the oceanic Moho of the subducting Philippine Sea plate. We also estimated the tops of the mantle depths in the overriding plate from the velocity discontinuities of layered structures and depth-converted cross-sections of receiver function images. It is deep beneath the mountain region of the land area and becomes shallow toward the surrounding seas in most part of the Japanese Islands. The tendency of depth changes is consistent to the patterns of the Moho discontinuity proposed previously, but the depths are deeper than those results in several regions. We will be able to resolve detailed whole structures by considering difference of both images.

Keywords: Receiver function analysis, Crustal structure, the Japanese Islands

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Crustal Vp, Vs, and thickness estimations via vertical and radial receiver functions

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Receiver function analysis is one of the effective tools to investigate crustal seismological structure. Here, we present a grid search technique using three seismic phases, Ps, PpPs, and PpPp, observed at teleseismic P coda portion in radial and vertical components, in order to simultaneously determine crustal properties, such as vertically-averaged P and S wave velocities (Vp and Vs), and Moho depth. Using a nonlinear waveform analysis, called simulated annealing, source wavelet of teleseismic P wave can be estimated by using records in vertical component observed at an array of seismometers. Deconvolving individual vertical component by the resulting source wavelet, PpPp phases recorded in vertical component can be extracted. Ps and PpPs phases can be extracted by calculating conventional radial receiver function. The frequency bands are 0.2-1.0 Hz for Ps converted phase, and 0.1-0.5 Hz for PpPs and PpPp reflected phases. The time-to-depth conversion of receiver function is performed by using 1D JMA velocity model. As a result, in addition to seismic images produced by using Ps and PpPs phases, seismic images with PpPp phase also successfully display the continental Moho, the oceanic Moho and the top slab surface of the Philippine Sea slab. This allows us to obtain reliable crustal properties by a grid search over three parameters, Vp, Vs, and thickness. Moreover, we demonstrate that seismic images could be improved by applying the estimated crustal properties, representing crustal lateral variations, to the conversion of time-to-depth domain receiver function.

Keywords: receiver function, Moho, seismic wave speed, Vp/Vs

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Crustal structure of the central part of East Antarctica from broadband seismic deployments and gravity surveys

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The Antarctica's GAmburtsev Province / GAmburtsev Mountain SEISmic experiment (AGAP / GAMSEIS) was an internationally coordinated broadband seismic deployment in the middle part of East Antarctic continent during the International Polar Year (IPY 2007-2008). More than 50 broadband seismographs were deployed over huge highland on the ice sheet from the crest of the Gambursev Subglacial Mountains (GSM; including Chinese station Dome-A (79.6S, 77.4E)) to the region around Japanese station of Dome-F (77.4S, 39.6E). The broadband seismic studies from the recorded teleseismic events provide new information of fine crustal structure and constrain on the origin of GSM, and more broadly on the structure and evolution of the East Antarctic craton and the subglacial environment. The GSM has the most enigmatic tectonic features as one of the Earth frontiers. Buried beneath the thick ice sheet, the mountains are characterized by peak elevations reaching 3000 m above sea level. Until recently, only limited constraints were available on the crustal structure of the GSM and surrounding region but new data from GAMSEIS allows more detailed investigation. The gravity measurements with land-type gravity meters were conducted by the Japanese Antarctic Research Expedition (1992; JARE-33, 1997; JARE-38, and 1998; JARE-39) over the inland traverse routes from Syowa Station (69.0S, 39.6E) to Dome-F. Free-air and Bouguer anomalies based on gravity disturbance along the routes were obtained by use of both surface elevation and bedrock elevation from radio-echo sounding. A density model of crustal structure between Syowa and inland plateau was derived based on the P-wave velocity model from active source refraction surveys and of the P-wave receiver function inversions. A crustal structure of the southern part of the inland plateau was derived from only gravity data. The Bouguer gravity anomalies were calculated by assuming the layered density model of the crustal structure to fit the observed Bouguer anomalies. Decrease in Bouguer anomalies about -200 mgal from Syowa toward Dome-F indicated crustal thickness about 45km beneath the Dome region. Analyses on S-wave receiver functions and Rayleigh wave phase velocities for GAMSEIS data provided estimates on crustal thickness beneath the GSM and surrounding region. The cratonic crust surrounding the GSM was 40-45 km thickness, which agrees with the crustal thickness from gravity surveys by JAREs and was consistent with average Pre-Cambrian crustal thickness found globally. Beneath the GSM, in contrast, the crust thickness was determined almost 55-58 km and provides isostatic support for the high mountain elevations. It is considered that the thicker crust beneath the GSM may reflect the old continental feature associated with Proterozoic and/or Paleozoic orogenic events in East Antarctica. Accordingly, the whole crustal model from the Luzow-Holm Bay (around Syowa) to Dome-F and GSM were obtained for the first time by combining the results of both broadband seismic studies by GAMSEIS and gravity surveys by JAREs. The cross section over 3,000 km length in the middle part of Antarctic continent was achieved to provide predominant information on tectonic evolution of Gondwana super-continent in Earth history.

Keywords: Antarctic continent, broadband seismometer, polar frontier, array deployment, International Polar Year, gravity measurement