Arc-Arc Collision Structure in the Southernmost Part of the Kuril Trench Region -Overview of Results from Integrated Renalyses for Controlled Source Seismiata in the Hidaka Collision Zone-

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The southernmost part of the Kuril trench is known as an arc-arc collision zone. Since the middle of the Miocene, the Kuril forearc has been colliding against the NE Japan arc to form very complicated and unique tectonic environment in the middle part of the Hokkaido Island (the Hidaka Collision Zone (HCZ)). In this region, several seismic reflection/refraction experiments were undertaken (Arita et al., 1998; Tsumura et al., 1999; Ito et al., 2000, Iwasaki et al., 2004). Our integrated reinterpretation for these data sets, which started in 2012, revealed detailed and new structural features and their regional difference within the HCZ.
In the southern part of the HCZ, the crustal delamination associated with the collision was clearly imaged by applying CRS/MDRS method to the seismic reflection data (Tsumura et al., 2014). Namely, the upper 22-23 km crust of the Kuril arc is off-scrapped and obducted along the Hidaka Main Thrust (HMT), while the lower part of the crust is descending down to reach the subducted Pacific plate.
In the northern part of the HCZ, the HMT is also well imaged both by seismic reflection processing and refraction/wide-angle reflection analysis, but the delamination structure as obtained in the southern HCZ is not clearly seen. Around the HMT, the crystalline basement is almost outcropped. In the west of the HMT, several eastward dipping layering is found down to a depth of 7-8 km, probably corresponding to fragments of Cretaceous subduction/arc complexes or deformation interfaces branched from the HMT. The relatively higher velocity in the uppermost crust just east of the HMT represents the base of the obducted middle or (upper part of) lower crust of Kuril arc. The upper crustal structure in the hinterland (the Tokachi Basin) is characterized by 5-7 km thick undulated sedimentary layers which were deformed by faulting in some places.
The most important finding in the northern HCZ is a clear image of the NE Japan arc crust descending eastward to a depth of about 40 km under the hinterland side. Our refraction/wide-angle reflection analysis revealed the very complicated structure above the descending NE Japan arc. Strong dipping reflectors with a velocity contrast of 0.5-1 km/s are distributed in a depth range of 10-35 km in the HCZ west of the HMT. Our result shows that the subducted NE Japan arc meets the Kuril arc 20-40 km east of the HMT at a depth of 20-30 km. Although the Moho of the Kuril arc is not determined, our data provide no evidence for a shallow Moho (< 30 km) as indicated by tomography studies.
The obduction of the upper Kuril crust starts at a deeper crustal level of at least 27-30 km and more easterly (~20 km) of the HMT as compared with the case in the southern HCZ. If the metamorphic rocks outcropped east of the HMT are the same crustal materials shallower than 22-23 km depth as in the case of the southern HCZ, the deeper crustal portion originally situated at 23-27~30 km depth must exist in the western side of the present HMT. The very strong and deep reflectors found west of the HMT might result from the mixture of upper crustal (low velocity) materials of the NE Japan arc and middle/lower crustal (high velocity) materials of the Kuril arc.

Keywords: arc-arc collision, Hidaka, crustal delamination, NE Japan arc, Kuril arc

Major variations in vitrinite reflectance and consolidation characteristics within a post-middle Miocene forearc basin, central Japan

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Forearc basin sediments near the oceanward margin preserve tectonic information related to plate subduction. The post-middle Miocene Boso forearc basin, central Japan, records major differences in structure, paleo-maximum temperature, and consolidation state between below (Miura Group) and above (Kazusa Group) the Kurotaki Unconformity, which formed at ca. 3 Ma. Many fault systems below the unconformity are characterized by a disaggregation-band-like inner fabric that apparently formed soon after sedimentation, whereas there are few of this type of fault system above the unconformity. Vitrinite reflectance values (Ro) are 0.38%-0.44% and 0.16%-0.22% below and above the unconformity, respectively. The consolidation yield stress (p_c) in the Miura Group (23.7 MPa in the Anno Formation; 31.0 MPa in the Amatsu Formation) is much greater than that in the Kazusa Group (7.5 MPa in the Umegase Formation; 7.6 MPa in the Ohtadai Formation). These clear differences in vitrinite reflectance and consolidation characteristics above and below the unconformity are attributed to a change in the convergence direction of the Philippine Sea Plate, which resulted in the Miura Group being uplifted and eroded by ~2000 m before sedimentation of the Kazusa Group. The forearc basin, especially near the trench-slope break, records structural and physical properties reflecting the plate-tectonic environment and the development of the trench-slope.

Keywords: Forearc basin, Boso Peninsula, Vitrinite reflectance, Consolidation test

Crustal structure and opening process on the back-arc basin in the southwestern margin of the Japan Sea

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The Japan Sea is one of very well studied back-arc basins in the northwestern Pacific. Based on geophysical, geological, and petrological results, it is suggested that the back-arc opening of the Japan Sea was taken from the Early Oligocene to the Middle Miocene (e.g., Tamaki et al., 1992). From 3.5 Ma, in the eastern and southwestern margins, the crustal shortening by a strong compression occurred (e.g., Sato, 1994, Itoh et al., 1997). The deformation such as active faults and folds has developed in these margins because of these opening and shortening (e.g., Okamura et al., 2007). Recently, in the eastern margin of the Japan Sea, it was found from the result that the deformation zone affected by the shortening and back-arc opening is distributed on the rifted island arc crust, and on a structural boundary between this arc crust and the thicker oceanic crust in the northern part only by the seismic survey (No et al., 2014, Sato et al., 2014). This result shows that the back-arc opening process and the crustal structure formed by this opening may have connection with this deformation process. Although the southwestern margin of the Japan Sea seems to have the region of the complex formation process, we have little information about the crustal structure formed by back-arc opening, and the detailed opening process in this margin. To obtain this information, the active-source seismic survey using ocean bottom seismographs (OBSs), and multi-channel streamer system (MCS) was undertaken from the arc to the back-arc basin of the southwestern margin of the Japan Sea off Echizen-misaki cape, Fukui Prefecture in 2015.
This seismic survey using 54 OBSs and a tuned air-gun array (7,800 cu. inch) was conducted from the continental shelf off Echizen-misaki cape, Fukui Prefcture, Oki Trough, Oki Ridge, Yamato Basin to the Kita-Oki Bank, in the southwestern margin of the Japan Sea. This survey line has about 270 km length. In record sections of several OBSs and land stations, not only the first arrived phases but also later phases reflected from interfaces in the crust and uppermost mantle are visible.
The Oki Ridge has about 20 km of the crustal thickness. The upper part of the crust with P-wave velocity of 5.4-6.2 km/s corresponding to the continental upper crust has about 10 km. This shows that the Oki Ridge may have the character of the continental crust. On the other hand, the crust in the Yamato Basin and Oki Trough has 13 and 15 km thick, respectively. These are thinner than that the Oki Ridge. The Yamato Basin and Oki Trough do not have the character of the typical continental crust. The upper part of the crust in the continental shelf area has 10 km with a lateral variation. This crust may have the continental crustal type because the P-wave velocity distribution is similar to that of the continental upper crust in Korean Peninsula (Cho et al., 2006). And, this variation may correspond to the distribution of the deformation. This crustal structure in the southwestern margin of the Japan Sea off Fukui differs from that in the northern part of the eastern margin (No et al., 2006). This might show that the southwestern margin off Fukui is different from the northern one on the back-arc opening process.

Keywords: Japan Sea, back-arc basin, crustal structure, opening process

Multi-disciplinary approaches toward understanding the fault slip behaviors from surface to depth: a case study of the Chihshang Fault in eastern Taiwan

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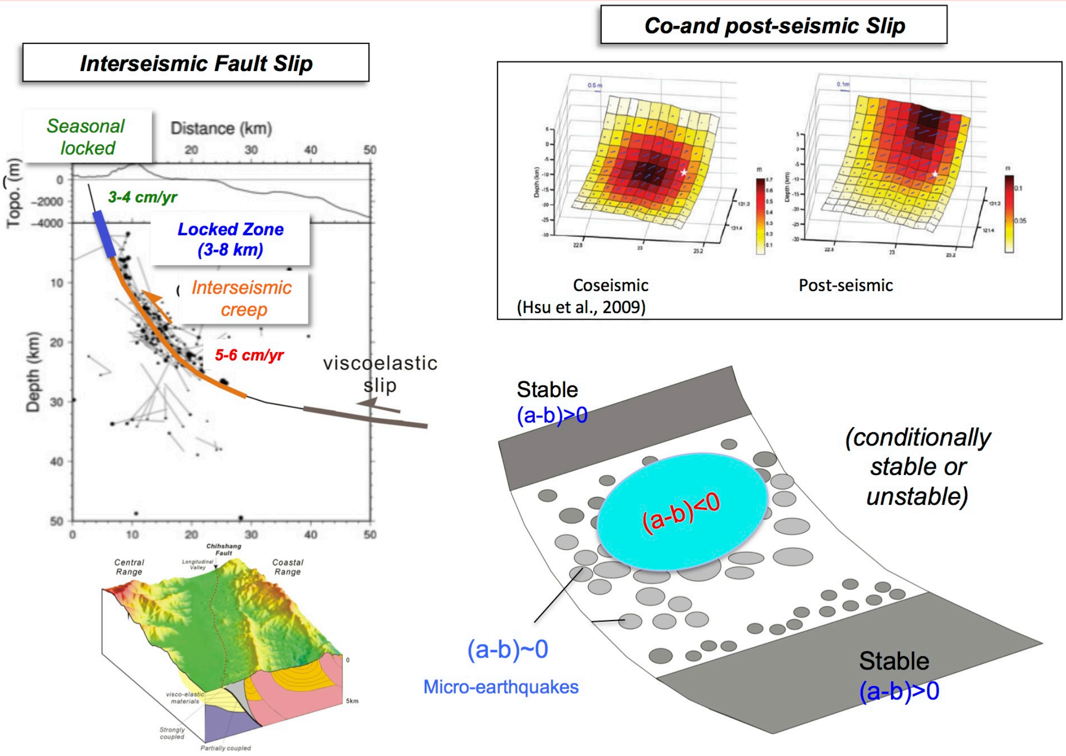
Based on a multi-disciplinary approach, including geological survey, geodetic GPS and leveling measurements, seismology, frictional properties modeling, kinematics dislocation modeling, hydraulic experiments and analyses and geophysical surveys, we aim at better characterizing the slip behaviors of an active fault from surface to depth and their spatial and temporal variations. Our case study is the Chihshang Fault, which we treat as an example of an on-land mega-thrust at the converging plate suture between the Philippine Sea plate and Eurasia. The geometry of the Chihshang Fault is characterized by a 35-km-long, 25-30-km deep patch, which exhibits a listric shape with dip angle of about 60-70° at the shallow kilometers and of about 20-30° at the depth of 20-30 km. GPS and leveling data indicate that the Chihshang Fault is creeping at a rather high rate of about 3-5 cm/yr for mostly the whole patch during the interseismic peripod. According to seismological studies, the slippage on the fault is accompanied by abundant micro-seismicity distributed on the fault patch at the depths of 5 to 25 kilometers. Amongst this seismicity, repeating earthquakes were observed at some places, especially near the northern edge of the fault patch. It seemed that these numerous interseismic micro-earthquakes had released a substantial part of the strain accumulated on the fault induced by the plate convergence or the attachment of the Luzon arc to the Chinese continental margin. However, the 2003 Mw=6.8 Chengkung earthquake suggests otherwise. How the strain accumulated to produce the Chengkung earthquake is still under investigation. But we do observe a significant decrease of surface fault creeping rate of about 25%, starting about 3-4 years before the Chengkung earthquake, which is also suspected to be due to effect of 1999 Mw=7.5 Chi-Chi earthquake (e.g., stress transfer). It is worthy note that the creep meters data along the surface fault zones at Chihshang site revealed a clear seasonal variation, implying a dry-season lock with no or very little slip. Numerical modeling by applying frictional instability laws suggested this seasonal slip/stress perturbation in relation with rainy season is confined within the upper hundreds of meters level, with a positive value of frictional property (a-b). We tend to interpret that this frictional property is related to the unconsolidated alluvial deposits, which cover the Longitudinal Valley for a thickness estimated to be about 3-5 hundreds meters. Indeed the propagation of the Chengkung earthquake co-seismic slip had decreased drastically in the uppermost 1-2 kilometers. And the accumulated strain in the upper segment of the fault has been released by rapid post-seismic slip following the earthquake. This is also consistent with the dynamic effect on the frictional property of the fault.

Keywords: active fault, creep, earthquake, frictional property

Chihshang Fault in eastern Taiwan



Tomography of the source zone of the 2016 South Taiwan earthquake

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On February 6, 2016, a *M*w 6.4 earthquake occurred in Kaohsiung City, southern Taiwan, at a depth of 17 km (hereinafter we call it the 2016 South Taiwan earthquake). It caused 116 fatalities and widespread damage to infrastructures, especially in the Tainan city. To clarify the generating mechanism of this damaging earthquake, we conducted seismic tomography for high-resolution 3-D *V*p, *V*s and Poisson’s ratio (σ) structures in the epicentral area. We used 91,703 *P*- and 51,718 *S*-wave arrival times from 7,038 local earthquakes (0.6≤*M*≤5.8) recorded at 41 seismic stations operated by the Central Weather Bureau in South Taiwan during 2000-2011.

Our tomographic images reveal significant variations of up to 6% for *V*p and *V*s, and 10% for Poisson’s ratio in the crust and uppermost mantle beneath South Taiwan. In the upper crust (depth≤ 10 km), the most remarkable feature is low-*V*p, low-*V*s and high-σ anomalies in areas with known active faults in the southwest and easternmost parts of Taiwan. In contrast, high-*V*p, high-*V*s and low-σ anomalies become dominant in the lower crust. The hypocenter of the 2016 South Taiwan earthquake is located in a boundary zone where seismic velocity and Poisson’s ratio change drastically in both the horizontal and vertical directions. Furthermore, the hypocenter is underlain by a vertically elongated high-σ anomaly at depths of 23-40 km, which may reflect ascending fluids from the upper (or uppermost) mantle.

The low-*V* and high-σ anomalies in the upper crust coincide with areas of low heat flow (Hsieh et al., 2014), negative Bouguer gravity anomaly (Yen and Hsieh, 2010), and low magnetotelluric resistivity (Bertrand et al., 2012), which may reflect crustal fluids contained in the young fold-and-thrust belt and the dehydration of the subducting Eurasian plate (slab). The South Taiwan source zone also corresponds to an area of the maximum stress loading rate induced by erosion (Steer et al., 2014). These results suggest that the 2016 South Taiwan earthquake was triggered by the ascending fluids from the Eurasian slab dehydration, invading into an active fault with a high loading rate.

Keywords: 2016 South Taiwan earthquake, Seismic tomography, Crustal fluids

Tectonic Features and Megathrust System Offshore South Taiwan

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Located in the Taiwan-Luzon convergent belt, offshore southern Taiwan is one of the ideal natural laboratories to study magatrust faults. Morphotectonic features offshore southern Taiwan suggests that the width of the collisional wedge decreases southward and connects to the northernmost part of the Manila subduction system. Reflection seismic profiles across the southernmost Taiwan collisional belt reveal not only fold-thrust belt in the frontal (western) part of the collisional wedge, but a magatrust system with splay faults, which is also supported by OBS velocity profiles. In order to better understand this megathrust system and its variations from south to north, as the tectonic processes changes from subduction in the area offshore south Taiwan to collision on land Taiwan, we analyze a series of large-offset deep seismic reflection profiles that ran across this megathrust fault system. Decollement has clearly been observed below the lower slope domain of the accretionary wedge. The range of the decollement increases from south to north, inferring that the continental materials have been carried into the subduction zone and the subduction angle decreases from south to north. The crustal velocity model derived from OBS data suggests the possible existence of tectonic underplating beneath this collisional belt. The existence of the megathrust system represents this area have high potential of seismic and tsunami threat.

Keywords: offshore southern Taiwan, collisional belt, OBS

Interpretation of seismic waveform at regional distance for determining focal depth: a case study in Sulawesi Island, Indonesia

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Sulawesi Island, one of the five largest islands in Indonesia, has high seismic activities due to complex tectonic structures related to some active faults (e.g., Palu Koro, Matano and Hamilton faults) and subduction zones. Reliable focal depths of crustal earthquakes are necessary to understand seismotectonics of the crustal layer in Sulawesi Island and its vicinity. However, due to the sparse seismic network, direct P- and S-wave arrival times are not precise to estimate the focal depths in the study area. To obtain more precise focal depths, this study analyzed waveforms of some swarm earthquakes in four areas of interest in Sulawesi Island and considered the effect of sedimentary layer on seismic wave propagation which yields more reflected phases in seismograms. We have selected swarm crustal earthquakes with 5-30 km focal depth range and ≤3.5 deg for station-event distance. In this study, we focused on preliminary depth phases by comparing synthetic and observed seismograms. We calculated the envelope of the seismograms in order to find different peaks of reflected phases clearly. Synthetic seismograms were generated using the reflectivity method with crustal velocity model derived from CRUST 1.0 and IASP 91 and different thickness of sedimentary layers. By the comparison, we could estimate possible pairs of focal depth for crustal earthquakes and apparent thickness of sedimentary layer along the path from each earthquake. Our study showed that the existence of ocean basins and sedimentary layer led to more complex seismograms in the study area. Therefore, we need to consider the waveform complexity for focal depth determination.

Keywords: Crustal earthquakes, Sulawesi Island, Reflected phases, Synthetic seismograms

Morphology of the stagnant slab from the northern Okhotsk arc to the northeastern Japan arc and its geodynamic implications

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The slab morphology as revealed by the seismic tomography is supposed to have much information on the physical properties of mantle transition zone, viscosity structure, geologic history and e.t.c. Incorporating the results of seismic tomography and the geologic history around the northeastern Japan arc with 2D numerical geodynamic models, Honda (2016) concluded that the stagnant slab there is the accumulated slab from the time when the ridge plate boundary between the Izanagi and Pacific plate subducted there around 60 Ma. The similar subduction history can be expected also around the northern Okhotsk arc. However, the slab morphology of each region is quite different, that is, the significant slab stagnation around the northeastern Japan arc versus the slab penetration around the northern Okhotsk arc. Honda (2016) also noticed that the slab stagnation around the northeastern Japan zone requires steeper Clapeyron slope than that estimated by the experiments. In this presentation, I seek the consistent answer to these problems based on the dynamics of hot subslab mantle under the Pacific plate (Morishige et al., 2010; Ismail-Zadeh et al. 2013), because it gives the additional force to support the negative buoyancy of the slab in addition to the endothermic phase change at 660 km and it shows the along-arc variations. An example of results is shown in the figure. Upper figures are derived from the seismic tomography following the procedure described in Honda (2016). The lower figures are derived from the numerical models described in Honda (2016).

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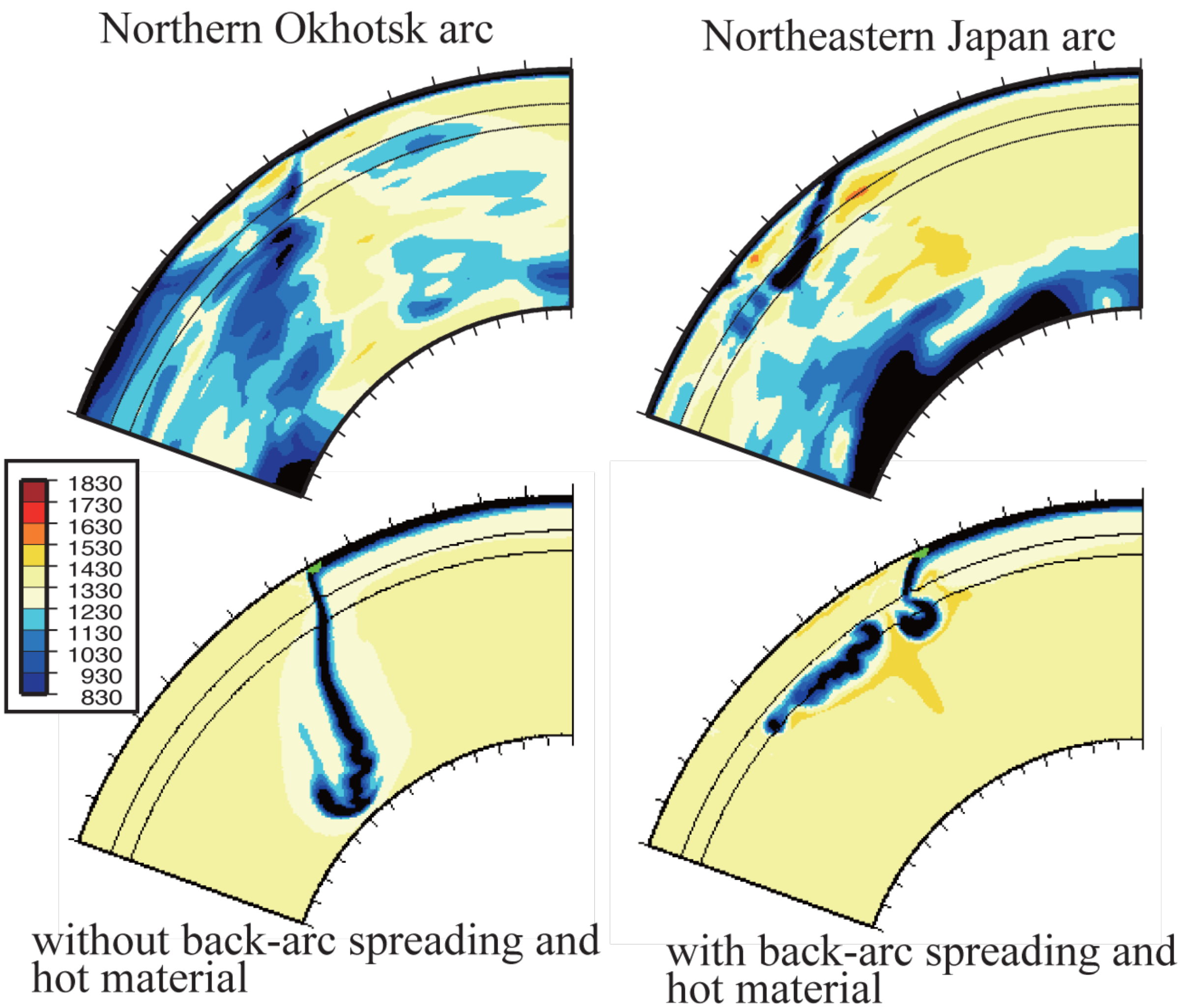
Keywords: subduction zone, stagnant slab, geodynamics, Okhotsk, northeast Japan


Northern Okhotsk arc
Northeastern Japan arc
1830
1730
1630
1530
1430
1330
1230
1130
1030
930
830
without back-arc spreading and hot material
with back-arc spreading and hot material