Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SCG72-01 Room:103 Time:May 22 14:30-14:45

Permeability anisotropy of serpentinite and fluid pathway in subduction zone

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Subduction zones are the only sites where water is transported into the Earth's deep interior. Water that is transported into the mantle affects the physical properties of mantle rocks, including their melting temperature and mechanical strength; consequently, the presence of water is believed to influence arc volcanism and seismicity. Permeability is a key parameter in controlling fluid flow in a mantle wedge. Although the fluid released into the wedge is generally believed to ascend under buoyancy, it is possible that fluid movement is influenced by anisotropic permeability in localized shear zones. The mantle rocks at the plate interface of a subducting slab are subjected to non-coaxial stress and commonly develop a strong foliation. Indeed, the existence of foliated serpentinite is indicated by strong seismic anisotropy in the forearc mantle wedge (e.g., Katayama et al. 2009). Therefore, fluid pathways in the mantle wedge may be controlled by the preferred orientation of highly anisotropic minerals. In this symposium, we present results of permeability experiments of highly foliated serpentinites (Kawano et al. 2011).

We used an intra-vessel deformation and fluid flow apparatus housed at Hiroshima University. Permeability measurements were performed using a steady-state flow, which consists of generating a known pore-pressure gradient across the specimen and measuring the flow rate. Under low confining pressure, all the experiments show similar permeability, in the order of 10-19 m2. However, permeability anisotropy appears under high confining pressures, with the specimens oriented parallel to the foliation having higher permeability than those oriented normal to the foliation. At a confining pressure of 50 MPa, the difference in permeability between the samples with contrasting orientations reaches several orders of magnitude, possibly reflecting the pore tortuosity of the highly sheared serpentinite.

The present experimental data show that the highly foliated serpentinites have a marked permeability anisotropy: consequently, fluid migration is strongly influenced by the orientation of the foliation in the mantle wedge. Serpentine forms in the mantle wedge because of the infiltration of water expelled from the subducting plate, above which deformation is concentrated in a relatively thin layer (e.g., Hilairet and Reynard 2009). In such a case, the water released from the subducting plate migrates along the plate interface. The total flux of fluid expelled from the subducting plate would be expected to result in a thick layer of serpentinized mantle, if the water migrates vertically in the mantle wedge. However, geophysical observations, including seismic tomography and reflection data, have shown that the serpentinized layer is limited to a narrow zone above the subducting plate. These data are consistent with our hypothesis that fluid tends to migrate within the highly sheared serpentinite layer, along the plate interface, rather than vertically upward. The migrating water along the subducting plate boundary may accumulate at the corner of the wedge, which might trigger low-frequency earthquakes due to a pore pressure build-up at the boundary.

Keywords: permeability, serpentinite, fluid migration, subduction zone

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SCG72-02 Room:103 Time:May 22 14:45-15:00

Earthquakes in subduction zones: An important role of aqueous fluids in earthquake generation

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Recent investigations have shown that slab-origin aqueous fluids play an important role in generation of three main types of earthquakes in subduction zones. Studies on spatial distribution of intraslab earthquakes and tomographic imagings of seismic velocity structure within the Pacific slab provide evidence which supports the dehydration embrittlement hypothesis for generation of intermediate-depth intraslab earthquakes. Investigations of detailed seismic velocity structure in and around the plate boundary zones suggest that interplate coupling is mainly controlled by fluid overpressure there or serpentinization of the mantle wedge right above. Seismic tomography studies show the existence of inclined sheet-like seismic low-velocity zones in the mantle wedge not only in Tohoku but also in other areas in Japan, which perhaps correspond to the upwelling flow portion of the subduction-induced convection system. The upwelling flows reach the Moho right beneath the volcanic areas, suggesting that those volcanic areas are formed by the upwelling flows. Aqueous fluids derived from the slab are probably transported upward through the upwelling flows to reach the arc crust, where they might work to weaken the surrounding crustal rocks and finally cause shallow inland earthquakes.

Generation of the 2011 Tohoku-oki earthquake and its induced seismic activities also seem to be closely related with aqueous fluids. We observed a clear temporal change in stress field near the source area after the earthquake which shows nearly complete stress drop by the earthquake, suggesting that the plate interface is very weak. Temporal change in stress field after the earthquake is also observed for inland areas, suggesting that faults for inland earthquakes are weak as well. The weak faults are probably caused by overpressured fluids. Tomographic imagings in the source area of a large (M7.1) intermediate-depth intraslab aftershock provide evidence for reactivation of a buried hydrated fault in the Pacific slab.

These observations suggest that aqueous fluids expelled from the subducted slab play an important role in the generation of three main types of earthquakes in subduction zones.

Keywords: Subduction zone, aqueous fluids, interplate earthquake, intraslab earthquake, shallow inland earthquake

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SCG72-03 Room:103 Time:May 22 15:00-15:15

Runaway slip to the trench due to rupture of highly pressurized megathrust, Tsunamigenesis of the 2011 Tohoku earthquake

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The gigantic 2011, March 11 Mw 9 Tohoku earthquake is examined from the viewpoint of the pre-seismic forearc structure, the seismic reflection properties of amegathrust around the usual up-dip limit of the seismogenic zone, the thermal state of a shallow subduction zone, and the dehydration of underthrust sediments. At the Japan Trench the Pacific Plate is subducting westward beneath the northeast Japan at a dip angle of 4.6. The middle and lower slopes dip eastward at angles of ˜2.5 and ˜8.0, respectively. The forearc prism beneath the middle and lower slopes is inferred to be in extensionally and compressively critical states, respectively, based on the presence of clear internal deformation features and on the occurrence of aftershock earthquakes. The rapid uplift of the forearc that caused the 2011 Tohoku tsunami may have been associated with this internal deformation of the prism. The critical state of the prism indicates that the effective basal friction of the plate boundary megathrust is <0.03 for the middle prism and >0.08 for the lower prism. The megathrust, especially under the middle slope, is characterized by a prominent reflector with negative polarity; i.e., a landward-increasing wave amplitude. This observation suggests that the megathrust hosts highly pressurized fluids. Underthrust sediments in this part of the Japan Trench are dominated by pelagic and siliceous vitric diatomaceous silt with clay. The dehydration kinetics of opal-A to quartz, the clay transformation of smectite?illite, and the thermal structure of the Japan Trench suggest that maximum dehydration of the sediments would take place at 50?60 km horizontally from the deformation front, where the temperature along the megathrust is 100?120. The zone of maximum dehydration coincides with the prominent seismic reflector that has negative polarity. We hypothesize a possible free slip along thisportion of the megathrust during the 2011 Tohoku earthquake, caused by anomalously high fluid pressure resulting from fluid accumulation over centuries.

SCG72-04 Room:103 Time:May 22 15:30-15:45

Diagenesis and dehydration of subducting oceanic crust within seismogenic subduction zones

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Seismogenic plate-boundary faults at accretionary margins may lie within or close to the subducting oceanic crust, composed of basaltic rocks, in contact with the overriding plate of a lithified accretionary prism (Kimura and Ludden, 1995; Park et al., 2001; Matsumura et al., 2003). Therefore, diagenesis and dehydration of the oceanic crust within the seismogenic zone (normally defined as a temperature condition from ~100-150 to 350-450^{o}C; Hyndman et al., 1993) is supposed to have a great influence on the interplate mechanical behaviors where great earthquakes occur. Our previous work showed that basaltic basement at the top of the oceanic crust is remarkably hydrated prior to reaching the trench axis, and pointed out a possibility to be a significant source of fluid in the seismogenic zone (Kameda et al., 2011). The aim of this work is to provide complementary dataset on the state and pathways of diagenesis in the subducting oceanic crust to verify the argument presented in the previous paper. In particular our focus is on a more validate quantification of the dehydration processes within the seismogenic zone. In this work, we analyzed 5 pillow basalt samples exposed in the Cretaceous to Tertiary accretionary complex, the Shimanto Belt, southwest Japan. Based on the vitrinite reflectance measurement of terrigenous sediments accompanied by these rocks, they are estimated to have been subjected to burial diagenenesis at 150-300 ^{o}C. X-ray diffraction (XRD) analyses of the bulk samples revealed that they contain ~25wt% of hydrous clay minerals. Moreover, clay-fraction XRD exhibited a successive conversion of smectite (saponite) into chlorite as a function of diagenesis grade. In this talk, we will present an improved model of the dehydration behavior of subducting basaltic crust inferred from these data, and address its potential influence on the evolution and physical states of the seismogenic-plate boundary faults.

Keywords: seismogenic zone, dehydration, oceanic crust, saponite

SCG72-05 Room:103 Time:May 22 15:45-16:00

10 years of ACORK: Continuous pressure from the decollement zone at Nankai Trough off Muroto

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During the KR22-12 cruise, three dives were completed using ROV KAIKO onboard R/V KAIREI during Dec. 20-25, 2011, to retrieve pressure data and interstitial fluid samples from ACORKs at ODP Holes 808I and 1173B situated landward and seaward of the deformation front in the Nankai Trough off Muroto. With 3-year-long and a 4-year-long new data records from 808I and 1173B, respectively, we now have over 10-year-long continuous pressure records since June 2001 at both sites. Most of pressure data from multiple depths show systematic variations in pressure with depth, and in tidal signal amplitudes. Transient changes were observed at the time of several nearby earthquakes, including ones during the recent 3 to 4 years at the time of Mar. 11 Tohoku earthquake, followed by a long-lasting pressure change starting on Mar. 23, 2011.

Gas-tight fluid sampling operations were successfully carried out from the hydraulic port attached to the swellable packer inserted within the ACORK head. The swellable packer was set in order to isolate the decollement zone that lies roughly 20 m below the bottom of casing at 922 m below the seafloor. We observed shimmering water venting through the port, and the flow rate was measured using a ball-type flowmeter. Fluid samples looked muddy-colored, probably due to the stain from the casing steel. Geochemical as well as microbial analyses are planned as a post-cruise activity, and a full analysis of the relationship between the Tohoku earthquake and the pressure transients is underway.

Keywords: ACORK, Nankai Trough, pore pressure, decollement

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SCG72-06 Room:103 Time:May 22 16:00-16:15

Experimental demonstration of high-temperature fluid generation during coseicmic fault slip

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The generation of a high-temperature hydrous fluid by frictional heating crucially affects on the fault-slip behavior. Thermal pressurization is widely known dynamic weakening mechanism, by means of which fluid pressure generated by shear-related heating reduced the fault strength during seismic slip. In the case of Taiwan Chelungpu fault, anomaly of fluid-mobile trace elements (Sr, Cs, Rb and Li), and Sr isotope ratios was reported, and it was attributed to fluid-rock interaction at high temperature (>350C) and being an evidence that thermal pressurization occurred during 1999 earthquake. However, the anomaly in trace elements and isotopes have not been demonstrated and verified experimentally. So, we here performed high-velocity frictional experiments on simulated fault gouge under wet condition, and analyzed the trace elements and Sr isotope of the samples after the experiments with an inductively coupled plasma spectrometer.

We used a rotary shear testing apparatus at the Kochi Core Center. The pore pressure and normal stress can be controlled during experiments. A series of experiments was performed at a 14-15 MPa normal stress, 2-5 MPa pore pressure and 0.2-0.4 m/s slip velocity with several displacements between 14.7-29.3 m. With increasing slip, the shear stress decreased, and the temperature reached at 300C. We found distinct depletion of Li in the sample experienced 300C. Because Li is known as fluid-mobile element and significantly mobilizes into fluids above 300C, the change of Li concentration in the sample indicate fluid-rock interactions at high temperatures. Therefore, our experimental results verify that trace element compositions can be good proxy for generation of high-temperature fluid during coseismic slip.

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SCG72-07 Room:103 Time:May 22 16:15-16:30

Along-trench variation of the water contents within the incoming plate offshore north-eastern Japan

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The dehydration process and the expelled water from the subducting oceanic plate are expected to affect various subduction zone processes, including the arc volcanism, generation of the intermediate-depth earthquakes and the regional variation in the seismic coupling of plate interface. To better understand these subduction zone dynamics, it is essential to clarify the amount of water that is being subducted within the incoming oceanic plate into the subduction zone.

In the northern Japan trench subduction zone, a number of great interplate earthquakes, such as the 2011 Mw 9.0 Tohoku-oki earthquakes, have repeatedly occurred. However, the distribution of rupture zones of these interplate earthquakes shows distinct regional variations. It has been suggested that the along-trench variation in the distribution of large interplate earthquakes are well correlated with the along-trench variation in the outer trench seafloor roughness. Recently, seismic structure studies in the middle and south America trench have suggested that the seafloor roughness including seamounts and bending-related faulting is closely associated with the oceanic plate hydration. Thus, there is a possibility that the along-trench variation of the large interplate earthquakes in the northern Japan trench subduction zone is associated with the amount of water that is being subducted within the incoming plate.

In 2010, to clarify the regional variation in the seismic structure and regional variation in the amount of water containing within the incoming plate, we conducted an extensive wide-angle seismic reflection and refraction survey along a trench-parallel profile using OBS and air-guns. We obtained P-wave and S-wave velocity structure models by traveltime inversion techniques and a seismic reflection section by Prestack depth migration. All the obtained seismic structure models including Vp/Vs show significant along-trench variations. As expected, in the region where the seafloor bathymetry is rough (between 38 and 39 degrees north), seismic velocities within the oceanic crust and oceanic mantle are low and Vp/Vs is high. This suggests that water infiltration and/or the hydration of the incoming oceanic plate is high in the region where the seafloor is rough, and indicates that the amount of water that is being subducted within the incoming plate varies significantly along trench axis in this region.

Keywords: outer rise, seismic velocity, water contents, hydration, wide-angle seismic survey, OBS

SCG72-08 Room:103 Time:May 22 16:30-16:45

Estimation of velocity structure in the oceanic crust of the Pacific slab beneath northeast Japan form PS converted wave

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Seismic tomography (e.g. Nakajima et al., 2009) and receiver function analysis (Kawakatsu and Watada, 2007) have revealed the existence of the low-velocity oceanic crust at the uppermost part of the Pacific slab beneath the northeastern Japan arc. However, these methods cannot estimate a detailed spatial variation in seismic velocity in the oceanic crust.

It is known that P-to-S converted phases at the plate interface are often observed in seismograms of intraslab earthquakes. Matsuzawa et al. (1986) examined arrival times and amplitudes of PS converted phases and suggested the existence of a low-velocity layer at the top of the slab down to a depth of at least 150 km. Here we estimate P-wave velocity structure in the oceanic crust using PS converted waves recorded at a nation-side seismic network.

In this study, we identify PS converted waves using theoretical travel times and particle motions of the waveforms, and read arrival times of the waves. We then estimate P wave velocity in the oceanic crust assuming the geometry of the Pacific plate and seismic velocities in the mantle wedge, arc crust and descending plate. As a result, we obtain P-wave velocity structure of 6.5-7.0 km/s in the fore-arc side and of 7.5-8.5 km/s in the back-arc side. We consider that these velocity variations are related to phase transition in the oceanic crust.

Keywords: PS converted wave, oceanic crust, Pacific slab

SCG72-09 Room:103 Time:May 22 16:45-17:00

Fluids dehydrated from the subducting oceanic crust and non-volcanic seismic swarms

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A non-volcanic seismic swarm is often assumed to be tied to fluid movements, based on earthquake mi-grations obeying a diffusion equation. However, seismological observations that relate to the presence and driving force of fluids are not well documented. One of the most intensive non-volcanic seismic swarms in Japan is located in the Wakayama district, SW Japan, and quite distant from the present volcanic front.

It is important to fully describe the crustal heterogeneity originating in crustal fluids. We have deployed a very dense seismic array with a length of about 100 km at the western edge of the Kii Peninsula. The dense seismic observations were conducted from December in 2010 to June in 2011. The linear array consists of 86 seismometers with 1 Hz natural fre-quency, those continuously recorded three-component signals. Both P- and S-wave arrival times from local earthquakes including some low-frequency earth-quakes (LFEs) were manually picked from waveforms observed by both dense temporary stations and per-manent stations. The dense and well-covered ray-paths from local and teleseismic events afford us precious opportunities to investigate the fine-scale seismic structures.

The most striking feature of the fine seismic image is low-velocities with low Poisson ratios beneath the seismic swarm region. This low-velocity feature is also supported by the receiver functions. In addition, the corner of mantle wedge is characterized as low veloci-ty, leading to an inverted inland Moho at depth of about 30 km. This low velocity mantle seems to ex-tend to deeper depths.

At depths shallower than 40 km, a depth-section of receiver functions shows that the oceanic crust, of which the top and bottom (plate interface and oceanic Moho) are outlined by strong negative and positive amplitudes, respectively, is subducting at a dip angle of approximately 15-degree. In contrast, the polarity of the plate interface changes from negative to positive at depths greater than 50 km. The dip-angle of the oceanic crust increases with depth. We interpret the transitions of the polarity as indicating the onset of eclogitization of the oceanic crust. The subducting oceanic crust beneath LFEs is characterized by low-velocities and high Poisson ratios, which are commonly observed at Tokai or Shikoku regions.

We propose that fluids dehydrated from the sub-ducting oceanic crust could infiltrate into the mantle wedge and crust, leading up to the intensive non-volcanic seismic swarms in Wakayama and high-helium isotopes widely observed in the Kii Pen-insula.

Keywords: seismic swarm, crustal fluid, non-volcanic, velocity structure, receiver function, dehydration