Warm memories of the Shikoku Basin recorded within the Nankai inner accretionary wedge

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Paleothermal structure and tectonic evolution of an accretionary wedge is basic information for understanding subduction zone seismogenesis. To evaluate entire paleotemperature profile and evolutionary processes of the Nankai inner accretionary wedge, we performed vitrinite reflectance analysis and detrital zircon U-Pb age dating by using cuttings retrieved from the Integrated Ocean Drilling Program (IODP) Site C0002 located within the Kumano Basin and penetrates the inner accretionary wedge down to 3058.5 m below the seafloor (mbsf).
Both Ro values and the youngest detrital zircon U-Pb ages show a reversal between 2400-2600 mbsf, suggesting the existence of a thrust fault with sufficient displacement to offset both paleothermal structure and sediment age. Taking the reversal at 2400–2600 mbsf into consideration, apparent paleogeothermal gradients of 1700–2400 and 2600–3000 mbsf are calculated to be ~60 (~50–70)°C/km, assuming 1 million years of heating duration time. Geothermal gradient of ~60°C/km is significantly higher than the estimated modern geothermal gradient (~30–40°C/km; e.g. *Sugihara et al.*, 2014). For more precise estimation of paleogeothermal gradient, we collected effects of bedding inclination (subhorizontal to ~60°) and porosity reduction, and as a result, real paleogeothermal gradient of both hanging- and footwall of the presumed thrust fault at 2400–2600 mbsf is ~100°C/km. Such a large paleogeothermal gradient was probably obtained prior to subduction, reflecting large heat flux produced by young oceanic lithosphere and/or hydrothermal circulation within the Philippine Sea Plate. Our results suggest that large geothermal gradient of input sediments might have a potential to affect the up-dip limit of seismogenic zone.

キーワード：ビトリナイト反射率、南海トラフ、付加体、砕屑性U-Pbジルコン年代
Keywords: Vitrinite reflectance, Nankai Trough, accretionary prism, detrital U-Pb zircon age

Heterogeneous distribution of pelagic input sediments in the Japan Trench and its impact on seismic slip propagation

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Large coseismic slip reached to the Japan Trench caused catastrophic tsunami of the 2011 Tohoku Earthquake (e.g. Fujiwara et al., 2011; Ito et al., 2011; Kodaira et al., 2012). Coseismic slip propagation along the shallow portion of the plate boundary fault would be caused by low friction of smectite-rich pelagic clay consisting the fault, as suggested by researches on core samples taken by IODP Expedition 343 (JFAST) (Ujiie et al., 2013; Kameda et al., 2015; Moore et al., 2015). Recently, large heterogeneities in the thickness of incoming sediments are suggested by high-resolution seismic profiles perfomed by JAMSTEC. To reconcile whether the smectite-rich pelagic clay layer even exists in the area of thin incoming sediments, we analyzed lithologies and sedimentation rates of piston cores sampled from horst-graben structures of the Japan Trench.
All of coring sites are located in off-Sanriku area of the Japan Trench, north of the 2011 rupture area. Seven piston cores (PC01-07) were retrieved from seaward trench slope (PC05 and PC06), horst (PC03 and PC04), graben (PC01), and graben edge (PC02 and PC07) during the R/V Shinsei Maru KS-15-3 cruise. Sediment thickness estimated from seismic profiles are ~30-90 m at horst and seaward trench slope sites, and ~130-340 m at graben/graben edge sites, respectively. Visual core descriptions and successive density and magnetic susceptibility measurement by multi-sensor core logger (MSCL) on split core surfaces as well as X-ray CT imaging of whole-round cores have been performed at Kochi Core Center. Ages of tephra layers were estimated by comparing mineral assemblages and refractive indices of volcanic glasses to those of catalog values, and averaged sedimentation rates of each core were estimated.
Core lithologies are mainly diatomaceous clay/silty clay, with including tephra layers. Sedimentation rates of seaward trench slope, horst, graben, and graben edge are estimated to be ~20-40, ~5-20, ~45, ~1 cm/kyr, respectively. According to these sedimentation rates, sediments on seaward trench slope and horst sites have been deposited within the last 160-660 kyr. Our results suggest that entire pelagic sediments, including smectite-rich pelagic clay, have been removed by some reasons in the last 1 million years, where the thickness of incoming sediment is thin. The lack of smectite-rich pelagic clay may contribute to stop rupture propagation of 2011 Tohoku Earthquake at off-Sanriku Japan Trench. More understanding on sediment dynamics of deposition and erosion at trench outer rise is needed to link subduction input and megathrust earthquakes.

Structure of the incoming Pacific Plate subducting into the central part of the Japan Trench: Results from the repeated ocean bottom seismograph observations after the 2011 Tohoku-Oki earthquake

Structure of the incoming Pacific Plate subducting into the central part of the Japan Trench: Results from the repeated ocean bottom seismograph observations after the 2011 Tohoku-Oki earthquake

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Since the occurrence of the 2011 Mw 9.0 Tohoku-Oki earthquake, seismicity within the incoming/subducting Pacific plate has been active near the axis of the Japan Trench and trench-outer rise region. This active intra-plate seismicity, which includes several M7-class earthquakes, is characterized by normal-faulting focal mechanisms with trench-normal tensional axes. Seismicity observations using ocean bottom seismographs have been conducted repeatedly in the Japan Trench area after the 2011 earthquake. These passive seismicity observations would provide structure information of the incoming Pacific Plate subducting into the Japan Trench. Results from the traveltime tomography by using the data consisting of 120 stations and more than 8000 events in total show the seismic velocity changes in the incoming Pacific plate with the approach toward the trench axis. The P-wave velocities within the oceanic mantle reduced from 8.2-8.5 km/s at the 90 km east of the trench axis to 7.5-8.0 km/s beneath the trench axis. The P-wave velocity reduction is observed down to a depth of about 20 km below the oceanic Moho and might relate to the bending-related hydration/alteration of the oceanic plate prior to the subduction. We also investigated anisotropy and Q structures by using the OBS data. We will discuss the structures heterogeneities and their relationships with hydration/alteration of the Pacific plate in the trench-outer rise region by combining the results from these analyses.

キーワード：海洋プレート、アウターライズ
Keywords: oceanic plate, outer rise

古い海洋プレートの沈み込み直前での屈曲断層掘削計画：ロンドン会議の成果

Refinement of scientific objectives, drill sites, and strategies for CHIKYU IODP proposal aimed at Bend-Fault Hydrology in the Old Incoming Plate (H-ODIN): Input from the London workshop

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Hydration due to plate bending-induced normal faults (bend-faults) in the region between the trench axis and outer rise (outer rise) has also drawn considerable attention (e.g., Grevemeyer et al., 2007; Fujie et al., 2013). Ideally, comparing subduction zones in several contrasting geodynamic states (e.g. Old plate vs Young plate, bend-faults being reactivated abyssal hill faults vs. newly formed horst-and-graben faults, etc.) is likely to be the most promising exploration approach to expand our knowledge of bend-fault hydration processes. In order to deepen our understanding of bend-fault hydration, an IODP pre-proposal: Bending fault hydrology of the Old Incoming Plate (H-ODIN) was developed. The IODP workshop, Bend-Fault Serpentinization, was held in London, 2016, sponsored by CHIKYU IODP Board, the UK-IODP, and ECORD. Horst-and-graben bend-fault structures are well developed in the northwestern Pacific subduction system. The Vp/Vs ratio is high at the outer rise area where bend-faults start to be developed (Fujie et al., 2013). Anomalously high heat flow valuesare found to be pervasively distributed in the off-Tohoku outer rise region (Yamano et al., 2014). The off-Tohoku region also provides a rare opportunity to study a place where the local stress state is likely to have changed significantly since the 2011 Tohoku Earthquake (Obana et al., 2011). Microseismic activity detected by OBS is considered to be related to actively deforming bend-faults (Obana et al., 2012, 2014). The questions on the nature of bend-fault hydration are classified into (1) Bend-fault material and structure, and (2) Bend-Fault Stress State and monitoring stress-state and fluid flow. The Japan Trench site seems best for understanding links between bend-induced hydration and the outer rise seismic cycle. (especially optimal now as we are in a rare phase between a giant megathrust event and its potential outer-rise doublet.). We will present more details in the presentation.

キーワード：プレート屈曲断層、海洋掘削計画、地震、水・炭素循環
Keywords: Plate bending induced normal fault, Ocean Drilling Project, Earthquake, Water-carbon circulation

Current Status of Drilling-Related Plans to Study Consequences of Bend-Fault Serpentinization During Plate Bending offshore Nicaragua (Outcome from the June 2016 BFS/H-ODIN Workshop)

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During the last decade, multiple independent geophysical structure studies have revealed that plate bending-induced normal faults in outer rise regions around the world are associated with significant hydration. This bend-fault-linked hydration and Bend-Fault Serpentinization (BFS), with its associated physical and chemical changes, is one of the most significant geological discoveries of the last 15 years. It has the potential to reshape our understanding of Earth's deep water and carbon cycles, the ecology and evolution of species in deep-sea chemosynthetic environments, and even the fundamental mechanism by which slabs bend and unbend, thereby driving Plate Tectonics.

In-situ sampling of rocks and fluid tracers is a key tool to make further progress in our understanding of BFS, its implications for the hydrothermal system(s?) that can develop during plate bending, the extent of deep life within these systems, and the resulting chemical interactions between the downgoing plate and seawater. Offshore Nicaragua is a prime site for drilling-related study of this process because this is the place where ongoing BFS occurs in the the world's shallowest environment (2.9-3.4km water depth).

In June 2016 a group of interested scientists met at the IODP workshop "Bend-Fault Serpentinization, drilling proposals using the D/V *Chikyu*" to assess the best strategy for using scientific drilling to explore BFS at complementary sites at the Middle American Trench offshore Nicaragua and the Japan Trench. The drilling-oriented goals of the workshop were to refine scientific objectives, drill sites, and strategies for scientific drilling in the outer rise region in order to understand the nature of the bend-fault hydration in the incoming plate. We reached a provisional consensus on the best approaches to make the most rapid progress towards better understanding of this frontier area of Earth Science. The workshop discussed deep drilling plans, but it was felt that a staged approach is preferable for effective study of this system. A dual-mode drilling strategy was proposed: (Stage I), D/V JOIDES Resolution or D/V Chikyu drilling through the upper parts of the bend-fault system to better understand the chemistry and shallow fluids, fluid flow, and bend-fault-linked microbial ecosystems, and also assess and improve our current technologies and strategies for drilling through bend-faults, and (Stage II), a MoHole-type drilling strategy to sample an intact crustal and mantle section through 1km below the ~5.5km-deep crust-mantle boundary that has direct relevance to many M2M (MoHole) science objectives. This talk will briefly summarize the known constraints on BFS in this region, and then discuss the proposed strategy for future IODP investigation of this system. Any interested scientists are welcome to join the 'BFS Science Team' and help in the preparation of a full IODP proposal for Fall 2017.

Keywords: Bend-Fault Serpentinization, Outer Rise, Hydrothermal System, Scientific Drilling

Mantle Serpentinization near the Mariana Trench Constrained by Ocean Bottom Surface Wave Observations

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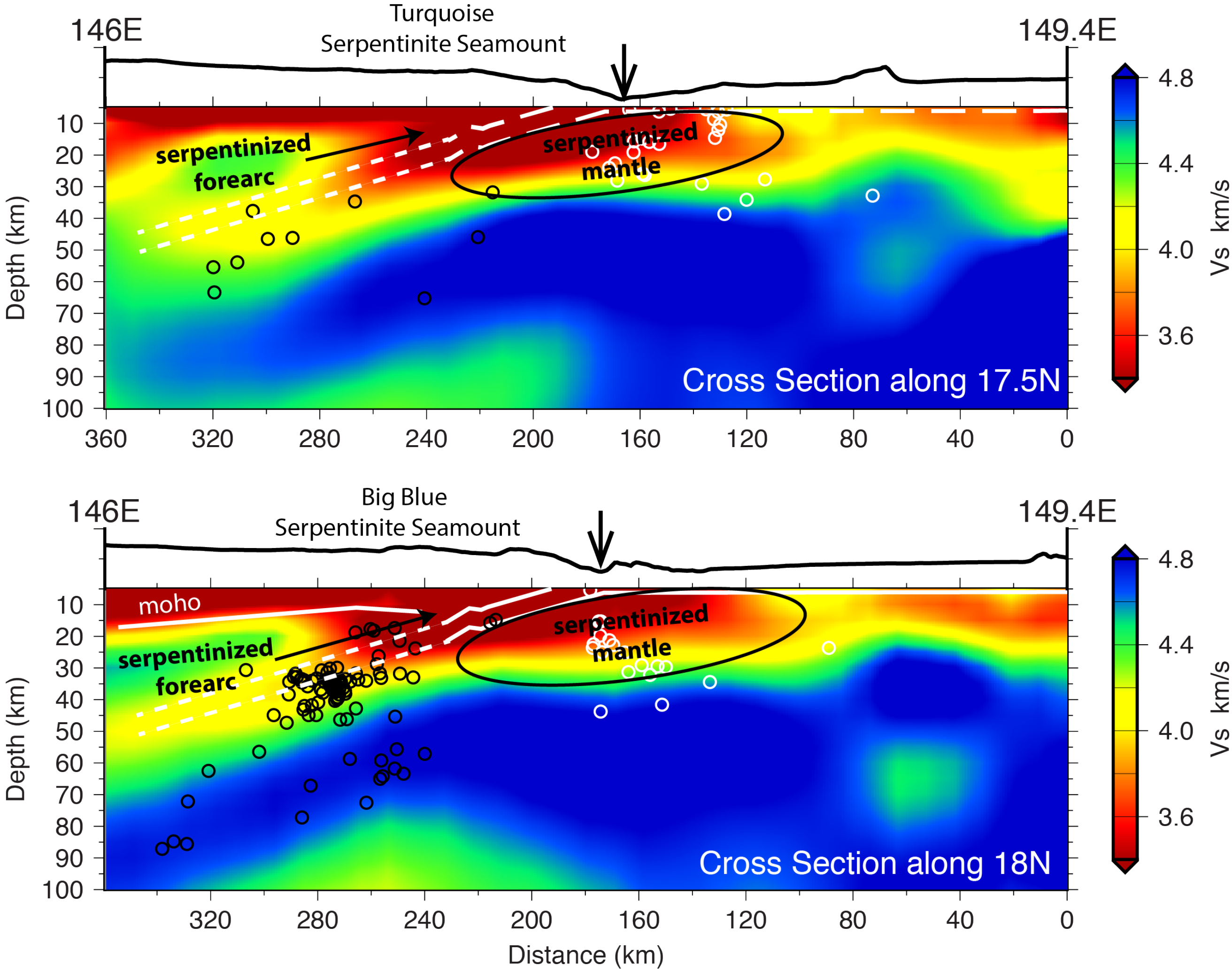
Although water is essential for many subduction processes, the water cycle at subduction zones remains poorly constrained. Serpentinization within the subducting and overriding plates have been observed at numerous subduction zones, with significant percentage variations. Widespread normal faulting on the incoming plate and serpentinite seamounts on the outer forearc in Mariana makes it an ideal place to study serpentinization of the incoming plate and the forearc mantle, and thus helps us to better understand the water budget of subduction zones. We investigate the shear wave structure of the crust and uppermost mantle across the Northern and Central Mariana trench using data collected by a temporary network involving both ocean bottom seismographs (OBSs) and land stations on the arc islands. Rayleigh wave phase velocities (10s –64s) are obtained with three different methods, including ambient noise tomography for short periods, Helmholtz tomography for the intermediate periods and two-plane-wave tomography for long periods. The dispersion curve obtained at each location is then inverted to SV velocities. Linear inversion results show low velocity anomalies around the trench axis, both within the incoming plate mantle and the forearc mantle wedge. The low velocity anomaly extends to about 30 km deep from the seafloor, well correlated with the 600-degree isotherm. The western and eastern boundaries of the anomalies are sharp, and have good correlation with the forearc serpentinite seamount locations and the incoming plate normal faulting earthquake distributions. The mantle shear velocity is as low as 3.2 km/s, indicating ~60% serpentinite component if the velocity reduction is purely caused by serpentinization. We will further apply a Bayesian Monte-Carlo algorithm to avoid the potential biases due to starting models and to better apply a priori constraints.

Keywords: Mantle Serpentinization, Water Budget, Surface Wave


Turquoise
Serpentinite Seamount
146E
149.4E
serpentinized
forearc
serpentinized
mantle
Depth (km)
Cross Section along 17.5N
Vs km/s
4.8
4.4
4.0
3.6
Big Blue
Serpentinite Seamount
moho
Cross Section along 18N
Distance (km)

プチスポットから読み解く沈み込むリソスフェアへの交代履歴
Metasomatic records of lithosphere prior to subduction inferred from petit-spot

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The lithospheric mantle below oceanic regions is directly known only about largely restricted portions (mid-ocean ridges, back-arc spreading centers, and hotspots) where the ultramafic rocks are generally sampled from fracture zones and oceanic core complexes, or as xenolith entrained by magmas. The geochemical mantle has ever been previously recognized only by MORB and OIB as well. Monogenetic petit-spot volcano was first identified as magma squeezed upward at the flexed plate off the Japan Trench due to subduction. The magmas originate from the asthenosphere immediately under the plate, and erupt over a large eruption area (over 800 km of plate motion) but with low volumes of magma production each (Hirano et al., 2006). Such volcanoes have been reported from subduction zones worldwide (e.g., the Japan, Chile, Java, and Tonga trenches) (Hirano et al., 2008; 2013; 2016; Taneja et al., 2016). Xenoliths and xenocrysts entrained in petit-spot lavas provide direct information on lithosphere of subducting plate because the magma ascends along the concavely flexed lithosphere prior to the outer-rise along the trench. Here, we discuss the geochemical interactions between lithosphere and asthenosphere during ascending petit-spot melt using geochemistry of lava and xenoliths/xenocrysts from mantle.

Melt fractionations are required at the mid- or lower depth of lithosphere, given that bulk compositions clearly show fractionation trends of olivine in the absence of phenocrysts, in spite of raising lherzolitic xenoliths and xenocrystic olivines from deepest approximately 45 km (Yamamoto et al., 2015). Depth of the fractionation could be correspond to the σ_3 rotation from extensionally lower to upper compressional lithosphere due to the concave flexure prior to outer rise (Valentine & Hirano, 2010). The high levels of carbon dioxide derived by petit-spot magma recently explains the low seismic velocity and high electrical conductivity of oceanic asthenosphere as the source mantle. Experimentally equilibrated petit-spot melt, adopted 10 wt % CO_2 before emission (Okumura & Hirano, 2013), with harzburgite at the lower lithosphere implies the stagnation of ascending melt at the depth (Machida et al., 2017). Subducting lithosphere is likely metasomatized by the carbon-rich melt just prior to its subduction. The conventional theory about subducting lithosphere requires revision in light of recently obtained petit-spot data.

Transition of stress state of the oceanic lithosphere from shallower-half compression to shallower-half extension in outer rise

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1. Introduction
Recent studies revealed that hydration progresses in shallower part of the oceanic lithosphere from outer rise to the trench (within 100-200 km from the trench) [e.g., Contreras-Reyes *et al*., 2008, *JGR;* Fujie *et al* ., 2013, *GRL*]. In addition, high and variable heat anomalies were found in outer rise (within 150 km from the trench) [Yamano *et al*., 2014, *EPSL*]. These studies proposed that these phenomena are caused by water infiltration and circulation due to bending-related normal faulting and fracturing. The initiation and development of bending-related faulting depends on stress evolution of the oceanic lithosphere in outer rise. In addition, the stress state may control the easiness of the water infiltration. Thus, understanding the stress evolution of the oceanic lithosphere in outer rise will give us useful clues to clear the mechanism of these phenomena.

2. Origin of lithospheric stress
Stress in the oceanic lithosphere has history since it was generated at the oceanic ridge. Thermal stress due to cooling of the oceanic lithosphere is the main origin of stress in the oceanic lithosphere where is far away from the trench. Its stress state is characterized by shallower-half compression and deeper-half extension, and it well explains focal mechanism and seismicity rate of oceanic intraplate earthquakes [Sasajima and Ito, 2015, *SSJ fall-meeting*].
On the other hand, bending stress due to flexure in outer rise is shallower-half extension and deeper-half compression. Thus, transition of the stress state may occur around outer rise. In this study, we focus on this stress transition.

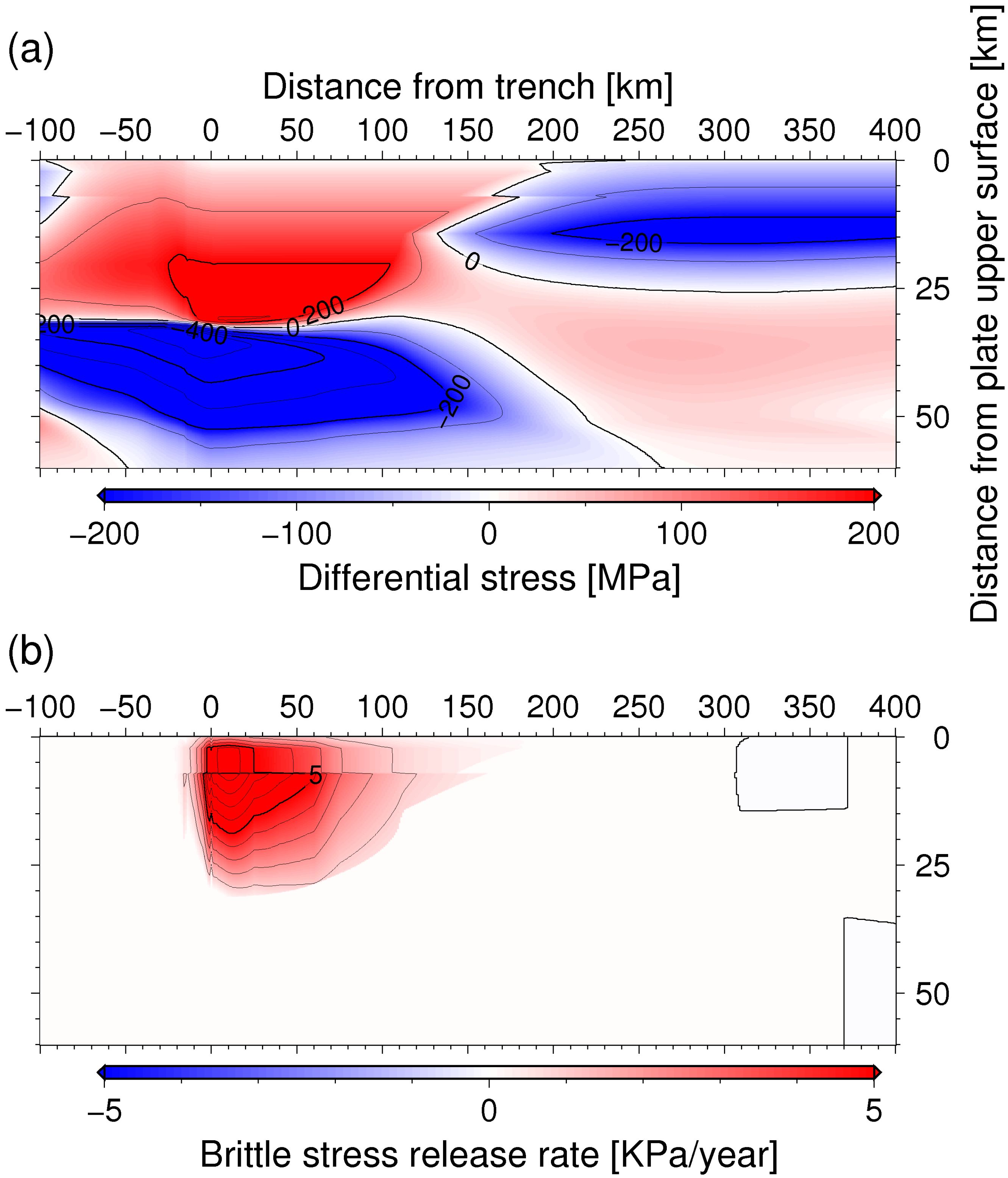
3. Simulating stress evolution
In order to clear the stress transition in outer rise, we modeled stress evolution of the oceanic lithosphere in the Lagrangian description since it was generated at the oceanic ridge. The target of this study is the Pacific plate around the Japan Trench (120-130 Ma). The model describes differential stress of 1D column of the oceanic lithosphere by time integration of elastic stress generation, brittle stress release, and ductile stress relaxation. Dominant components of elastic stress generation are thermal stress in young age and bending stress in outer rise.

4. Results
Figure 1 (a) shows cross-section of modeled stress evolution of the oceanic lithosphere around the outer rise. Until the oceanic lithosphere reaches to 200 km from the trench, shallower-half stress state is compression due to residual thermal stress. The transition from compression to extension occurs during 125-175 km from the trench. The transition initiates at the shallower-most portion, and it expands to deeper portion. Figure 1 (b) shows modeled brittle stress release rates. Although bending deformation initiated at about 300 km from the trench, no normal faulting is expected during 175-300 km from the trench because of residual compressional stress. Thus, the thermal stress delays initiation of bending-related normal faulting.

5. Discussion
The horizontal location of the stress transition from compression to extension (125-175 km from trench) is consistent with the offshore-end (i.e., initiation) of observed hydration and heat-flow anomalies. It corresponds to the initiation of bending-related normal faulting, which may cause the water infiltration into the oceanic lithosphere. In addition, the stress transition from compression to extension likely promotes the water infiltration. Thus, we propose that the residual thermal stress is also important factor to control these phenomena in addition to the bending stress.

Figure 1. Cross section of the oceanic lithosphere. Horizontal axis indicates distance from the trench along the plate upper surface. The right side of figures is offshore. Vertical axis indicates distance from the plate upper surface along the depth direction. (a) Modeled differential stress (extension is positive (red)). (b) Modeled brittle stress release rates (normal faulting is positive (red)).

キーワード：海洋リソスフェア、熱応力、曲げ応力、アウターライズ
Keywords: Oceanic lithosphere, Thermal stress, Bending stress, Outer rise


(a)
Distance from trench [km]
–100 –50 0 50 100 150 200 250 300 350 400
0
25
50
Distance from plate upper surface [km]
–200
0
200
–400
0
–200
–200 –100 0 100 200
Differential stress [MPa]
(b)
–100 –50 0 50 100 150 200 250 300 350 400
0
25
50
5
–5 0 5
Brittle stress release rate [KPa/year]

Well-log characterization of hydration and dehydration processes in oceanic lithosphere: from mid-ocean ridges to subduction zones

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Hydration and dehydration of oceanic lithosphere are known to be central to understand geodynamics processes from mid-ocean ridges, to intraplate tectonics and magmatism, to seismogenesis and material cycles facilitated by subduction zones. Recent and proposed drilling efforts at various subduction zones particularly highlight the significance of lithosphere hydration by faults evolved in incoming plate (e.g. “Bend-fault serpentinization (BFS) and Bend-Fault Hydrology in Old Incoming Plate (H-ODIN)”). Although undertaking sub-meter to sub-centimeter scale observations on cored materials has been much desired approach in investigating the nature of lithosphere, drilling through faulted lithosphere and deeper crust has been, indeed, a challenging task throughout the history of scientific drilling, let alone obtaining continuous core materials with high to perfect recovery rates. Borehole informatics using downhole physical properties logging has been a known strategy to complement our understanding of drilled intervals with no core recovery in establishing the most optimal downhole lithostratigraphy model in hard rock drilled sites. Using case studies from the mid-ocean ridge and interaplate volcanic settings, we introduce that (1) downhole physical properties logging can also be utilized to further characterize lithosphere hydrogeology and associated alteration processes over time; and (2) microresistivity imagery logging profiles not only enable us to conduct detailed mapping of the orientation and distribution of hardly-recovered in situ fracture networks, but also to estimate void space abundances in crustal material and the determination of complex lithology-dependent void geometries. Together with petrological and rock magnetic evidences in terrestrial serpentinized lithosphere, we propose that sub-meter scale well-log characterization of drilled holes in the faulted lithosphere in incoming plate will enable us, at multiple scale, to delineate where seawater can permeate and serpentinization takes place, in turn, where microbes are possibly reside.

Keywords: oceanic lithosphere, hydration, serpentinization

The Permeability Structure of Oceanic Crust and Implications for Subduction Zone Hydrology

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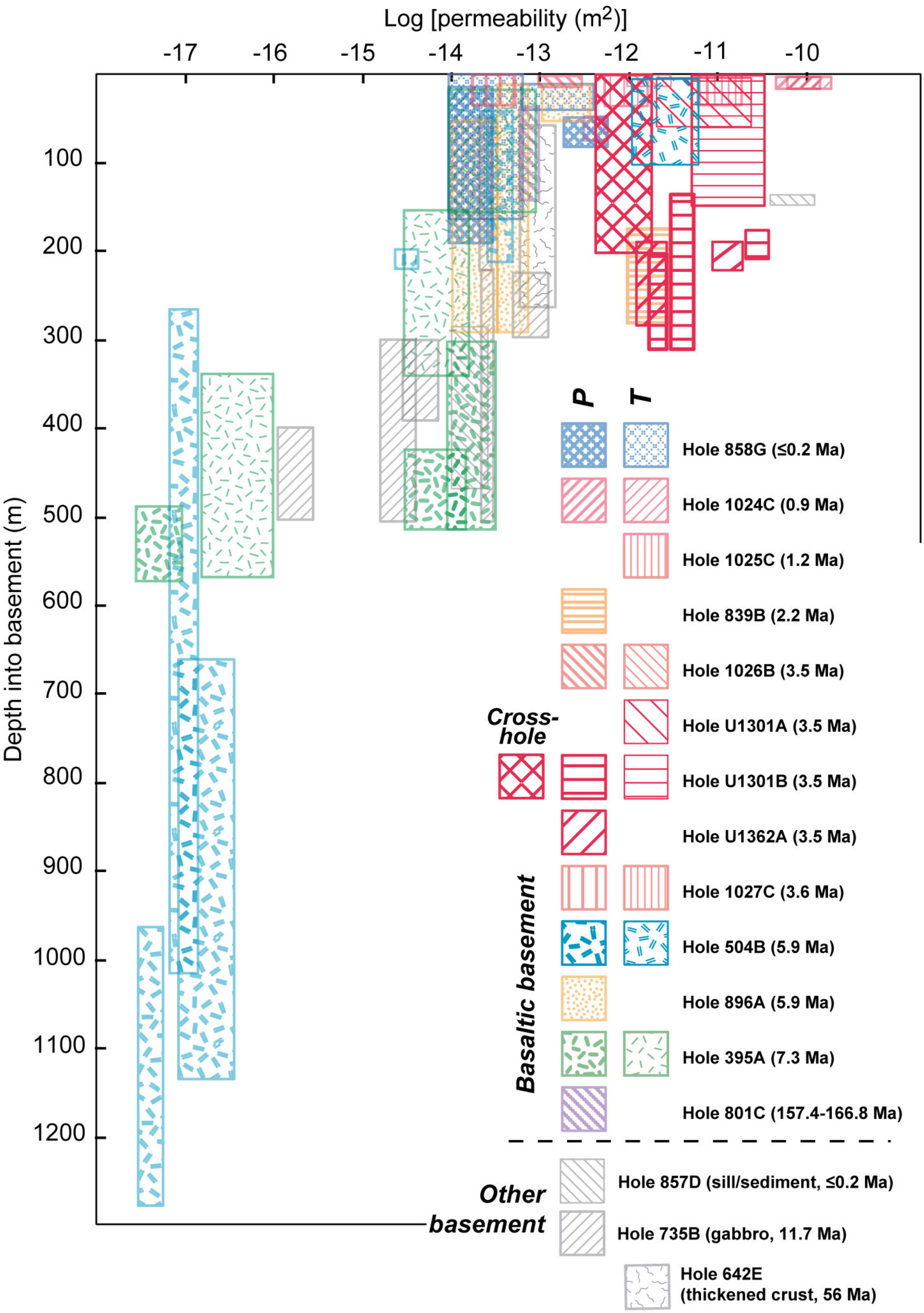
We review investigations of the permeability structure of the oceanic crust with a specific focus on implications for hydrogeological processes in incoming plates at subduction zones. Direct determinations of permeability require sampled materials or boreholes, so the cores and holes of DSDP, ODP, and IODP have been crucial to our understanding of ocean crustal permeability. Important techniques have included wireline logs, borehole temperature profiles, in-situ packer experiments, long-term records obtained with CORK sealed-hole hydrological observatories, and comparison of such in-situ results with constraints from numerical simulations.

Early DSDP packer measurements in 6-7 Ma off-axis settings suggested a simple layered permeability structure for upper oceanic basement in young ridge flanks, with a few hundred meters of permeable uppermost pillow lavas underlain by much less permeable deeper pillows and sheeted dikes. In ODP and IODP, there have been important new results on several fronts. Packer measurements and borehole flow permeability estimates have been completed in holes in oceanic crust spanning a wider range of age (0-12 Ma and 160 Ma; see attached figure). Permeability at larger spatial scales has also been estimated at some of these sites using other direct and indirect techniques including (a) analyses of the response of pressures recorded in sealed-hole CORK experiments to seafloor tidal loading and co-seismic deformation, and (b) numerical simulations of the nearly isothermal uppermost basement temperatures observed in paired ridge-flank CORK sites where there is considerable basement relief and large variation in sediment thickness. Combined results indicate the following: (1) Permeabilities of uppermost basement in sedimented young oceanic crust are very high. (2) Permeabilities of uppermost basement in young crust seem to decrease systematically as the crust ages, consistent with the evolution of seismic velocities in Layer 2A. (3) Permeabilities within oceanic crust seem to display a scale dependence, possibly as the result of the highly heterogeneous distribution of the permeable network within oceanic basement. (4) Lateral fluid fluxes are very high, but the inter-connected “effective porosity” that contributes to high permeability and fluxes is quite low; this has significant implications for fluid residence times and reactions with host rock depending on position within the network. (5) Lateral fluid flow directions in young crust must have a signficant component subparallel to the ridge axes and dominant tectonic structures, contrasting with earlier conceptual models configured as sections normal to structural strike.

Clearly, if relatively young oceanic crust is being subducted, as at Nankai, Central America, and Cascadia, its high permeability must be considered a signficant factor in the hydrology of the subducting slab (and, therefore, seismicity, volcanic activity, and related processes), even before accounting for the effects of plate-bending faults that, depending on geometry, may cross or reinforce large-scale lateral permeability provided by ridge-parallel tectonic fabric. Permeability data are much sparser in oceanic crust older than 10 Ma, but the few data points also indicate high permeability where fault zones or structural discontinuities are encountered. There is almost no data from deeper oceanic crust, and the nature and hydrologic significance of deep reflectors that penetrate the ocean crust and extend into the upper mantle remain to be determined. Plate-bending faults could augment permeability in subducting ocean crust of any age, and this effect could be particularly important when older, otherwise less permeable

crust is subducted.

Keywords: Ocean crust permeability, Subduction zone hydrogeology, Plate-bending faults


Log [permeability (m2)]
-17
-16
-15
-14
-13
-12
-11
-10
Depth into basement (m)
100
200
300
400
500
600
700
800
900
1000
1100
1200
P
T
Hole 858G (≤0.2 Ma)
Hole 1024C (0.9 Ma)
Hole 1025C (1.2 Ma)
Hole 839B (2.2 Ma)
Hole 1026B (3.5 Ma)
Cross-hole
Hole U1301A (3.5 Ma)
Hole U1301B (3.5 Ma)
Hole U1362A (3.5 Ma)
Basaltic basement
Hole 1027C (3.6 Ma)
Hole 504B (5.9 Ma)
Hole 896A (5.9 Ma)
Hole 395A (7.3 Ma)
Hole 801C (157.4-166.8 Ma)
Other basement
Hole 857D (sill/sediment, ≤0.2 Ma)
Hole 735B (gabbro, 11.7 Ma)
Hole 642E
(thickened crust, 56 Ma)

A review of hydrothermal heat transport models explaining high heat-flow anomalies observed near the Japanese Islands

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Recent heat flow surveys have revealed that heat flow near the subduction zones is deviated from thermal models of the oceanic plate with the corresponding plate age. At the Nankai Trough and the Japan Trench, high heat flow anomalies are observed. We review physical characteristics of two distinct thermal models that have been proposed to explain the observed high heat flow anomalies.

Heat flow near the Muroto area of the Nankai Trough is more than twice that expected from plate models with the corresponding plate age 15 Ma (*Yamano et al.*, 2003), and that near the Kumano area (~150 km east of the Muroto area) is <50% higher than that expected from plate models with the corresponding plate age 20 Ma (*Kinoshita et al.*, 2008). To explain the high heat flow observed at the Muroto area, *Spinelli and Wang* (2008) constructed a thermal model including hydrothermal circulation. The uppermost ~500 m of the oceanic plate is highly permeable, and they assume that this part is also permeable after subduction. Hydrothermal heat transport within the aquifer upwells heat and decreases temperature, so that an isotherm of 150°C is shifted 50 km landward.

Heat flow within 150 km seaward of the Japan Trench is, on average, ~40% higher than that expected from plate thermal models with the corresponding plate age 135 Ma (*Yamano et al.*, 2008, 2014). Within this area, *Fujie et al.* (2013) have observed a high V_p/V_s layer at the uppermost part of the oceanic plate that is thickened toward the trench axis. Being inspired by this observation, *Kawada et al.* (2014) constructed a thermal model, in which a permeable aquifer is thickened toward the trench axis. Results show that hydrothermal circulation pumps up heat below the thickening aquifer to raise the heat flow above it. Its effect on the temperature structure of the subducted oceanic plate is minor.

We compare these two existing thermal models in a physical point of view. *Spinelli and Wang*' s (2008) model requires very high permeability, and we can call it the high-permeability-aquifer model. To account for the observed high heat flow at the Nankai Trough, preferred permeability is around 10^{-9} m^2 (nearly the upper bound of measured values; *Fisher*, 1998). This high permeability is required because heat and fluid are transported a long journey (several tens of kilometres) along the subducted aquifer. Thus, temperature reduction at depth is significant in this model. The efficiency of this hydrothermal heat transport is, at a first order, proportional to the aquifer permeability. Thus, according to this model, moderately high heat flow along the Kumano area of the Nankai Trough can be interpreted as having moderately high aquifer permeability (10^{-10} m^2, according to *Spinelli and Harris*, 2011). On the other hand, if this model is applied to the Japan Trench, where the oceanic plate of 135 Ma is subducting, the expected permeability is beyond the measured range.

Kawada et al.' s (2014) model involves the thickening of the aquifer, and we call it the aquifer-thickening model. This model, by contrast, requires moderate permeability. For example, to account for the high heat flow observed seaward of the Japan Trench, 10^{-12} m^2 is sufficient. Around this permeability value, its effect on the temperature structure of the subducted oceanic plate is minor. Interestingly, further increasing in the aquifer permeability results in little impact on the resulted heat flow at the seafloor. This is because the amount of heat pumped up by this mechanism, which mainly comes from the base of the thickening aquifer, is bounded by the thickening rate of the aquifer. The amount of heat pumped up by this mechanism is directly related to the thickening rate instead. It is unclear whether this model can be applied to the Nankai Trough, because there is no supporting information from structural observations at present.

キーワード：南海トラフ、日本海溝、熱流量、熱モデル、沈み込み帯
Keywords: Nankai Trough, Japan Trench, Heat flow, Thermal model, Subduction zone

The nature of actively deforming Wharton Basin and its role in the subduction processes, offshore northern Sumatra

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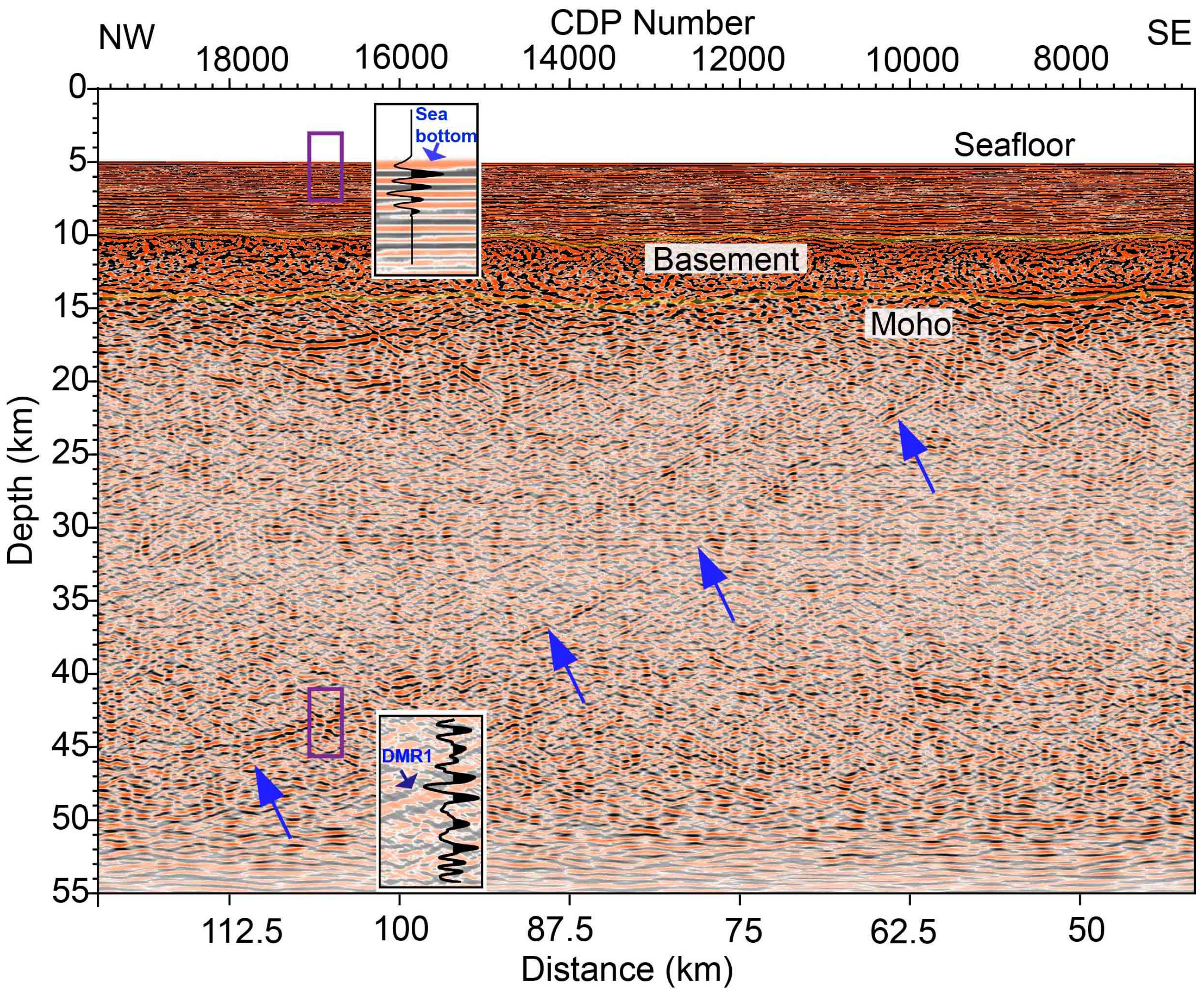
The Wharton Basin is one of the most actively deforming ocean basins on Earth, which was confirmed by the occurrence of the 2012 Mw=8.6 strike-slip earthquake, along with its Mw=7.2 foreshock and Mw=8.2 aftershock. The seismological and geodetic data suggest that the Mw=8.6 earthquake ruptured several faults, oblique to each other, down to the base of the lithosphere. Using ultra-deep seismic reflection technique, we have imaged faults down to 45 km depth in this region, indicating that deformation in the Wharton Basin is indeed on the lithospheric scale. We find that the oceanic mantle there consists of two layers; an upper serpentinized layer where a large number of small earthquakes occur and a lower pristine layer where great earthquakes initiate and large stress drops occur. We also find that the boundary between these two layers corresponds to the second Benioff zone (Qin and Singh, 2015) of the Sumatra subduction. Using multibeam bathymetry and high-resolution seismic data, we have also imaged a large number of right-lateral shear zones, which along with the left-lateral, re-activated N-S fracture zones, form a conjugate system of faults accommodating ongoing deformation (Singh et al., 2017). The shear zones are formed by sets of en echelon normal faults, whose strike defines the direction of principal stress in the region. These shear zones and associated normal faults become much more pervasive in the outer rise region of the Sumatran trench, indicating a complex interaction between the bending stress and the principal compressive stress. The pattern of active faults and the occurrence of the great 2012 earthquakes suggest the possible creation of a nascent plate boundary between India and Australia in the northern Wharton Basin.

Qin, Y., and Singh, S. C. (2015). Seismic evidence of a two-layer lithospheric deformation in the Indian Ocean, *Nature Communications*, 6:8298 doi:10.1038/ncomms9298.
Singh, S.C, Hananto, N., Qin,Y., Leclerc, F., Avianto, P., Tapponnier, P.E Carton, H., Wei, S., Nugroho, A. B., Gemilang, W.A., Sieh, K., Barbot, S., 2017, The discovery of a conjugate system of faults in the Wharton Basin intraplate deformation zone, *Science Advances*, **3**, 1-8, e1601689.

Keywords: outer rise, intraplate deformation, subduction, earthquakes, bend faults, shear zones


NW
CDP Number
SE
18000
16000
14000
12000
10000
8000
Sea bottom
Seafloor
Basement
Moho
DMR1
Depth (km)
0
5
10
15
20
25
30
35
40
45
50
55
112.5
100
87.5
75
62.5
50
Distance (km)

Insights on Structure and Deformation in the Input Section of the Sumatra Seismogenic Zone: Preliminary Results from International Ocean Discovery Program (IODP) Expedition 362

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The Sunda Trench where the Indo-Australian Plate subducts beneath the Sunda and Burma Plate, is an active seismogenic zone which generated the 2004 Mw 9.2 mega-earthquake and devastating tsunami offshore Northern Sumatra, characterized by a large shallow slip near the trench and an extremely thick (>4 km) incoming section at the deformation front. To investigate the nature and impact of the incoming section on seismogenic processes, the International Ocean Discovery Program (IODP) Expedition 362

drilled into the Indo-Australian Plate ~225 km distance from the trench at 2 primary sites offshore Northern Sumatra during August to October 2016. Here, we report preliminary results from shipboard structural observation on the recovered cores.

The lithostratigraphic sequence of the oceanic plate acquired from Site 1480 consists of Unit I: subsurface calcareous and silty clay (~26.4 m), Unit II: silty clay and sand of the Nicobar Fan sequence (~26.4-1250 m), Unit III: pelagic gray-green to reddish-brown tuffaceous claystone and chalk (~1250-1327 m), Unit IV: basaltic lava flows and volcaniclastic/tuffaceous sandstone (~1327-1350 m), Unit V: chalk and calcareous claystone with magmatic intrusion/extrusion with abundant mineral veins (~1350-1420 m), and Unit VI: basaltic basement cut by veins (1420 m~). Units I and II exhibit little deformation as observed from the continuously near-horizontal bedding dips (<10°), except for several localized horizons of syn-sedimentary normal faults in Unit II and intervals of slumping and folds. The bottom of Unit II (~460 m interval) was particularly undeformed, possibly reflecting the most distal portion of the fan deposit. A distinct concentration of normal faults was observed in Unit III, characterized by primarily two sets of thin anastomosing normal faults which randomly cross-cut each other. Sand injections and lighter-colored diagenetic spots also occur in the sediments, and the normal faults generally cut through the sand injections but generally leave the diagenetic spots uncut. The flattened geometry of the diagenetic spots overprinting the normal faults and the high conjugate angle (>90°) and curvy geometry of the faults may imply that the normal faulting occurred before significant compaction. Concentrated deformation in the pelagic section may have occurred in an active ridge environment at that time and thermal subsidence followed by rapid sedimentation of the Nicobar Fan, but the actual mechanism is yet to be revealed.

Ongoing post-cruise research will further examine the internal structure, paleo-stress state, and material properties at these horizons of localized deformation in the input section, and ultimately investigate how they would evolve upon entering the subduction zone through comparison with current stress states and active fault systems.

キーワード：国際深海科学掘削計画、スマトラ沖地震発生帯、インド・オーストラリアプレート
Keywords: International Ocean Discovery Program, Sumatra Seismogenic Zone, Indo-Australian Plate

Measurements of thermal conductivity of a basalt core sample retrieved from subducting oceanic crust in Nankai subduction zone under high temperature

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Knowledge of rock thermal conductivity is a key to understand thermal structure in active seismogenic zones such as the Nankai Trough subduction zone, SW Japan. To estimate thermal conductivity at the oceanic crust surface in the seismogenic zone, we measured the thermal conductivity of a basalt core sample retrieved from subducting oceanic basement at a depth of ~573 mbsf in input site C0012 of the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) under high temperature (maximum 160°C). The high temperature condition corresponds to that at the oceanic crust surface in the updip limit of the Nankai seismogenic zone (~7 km below the seafloor). Thus, we set our high temperature condition of the thermal property measurements up to 160°C at atmospheric pressure for a dry basalt core sample, and up to 100°C for a wet basalt core sample at the same pressure condition.
As results of the experiments, thermal conductivity of the dry basalt core sample under high temperature and atmospheric pressure gradually increased with increasing ambient temperature. The thermal conductivity of the wet sample also showed an increasing trend, but the value measured at 100°C might be strongly influenced by the evaporation of pore water, and consequently revealed a sharp increase between 80 and 100°C. The thermal conductivity of the wet basalt was ~1.62 W/mK at room temperature. Under atmospheric pressure condition we could not measure the thermal conductivity of the wet basalt at 160°C, but we estimated the value to be ~1.77 W/mK based on both measured thermal conductivity of the dry basalt sample and literature thermal conductivity data of pore water at the same temperature 160°C. Generally, for other rock types such as sandstone and granite, however, their thermal conductivity decreases with increasing temperature, in contrast to the thermal conductivity of the oceanic basalt increased with increasing ambient temperature.
The thermal conductivity at ~7km also depends on the in situ pressure condition. We will also show our estimation of the thermal conductivity at ~7km in Nankai subduction zone not only for high temperature but also for high pressure effects.

キーワード：熱伝導率、高温条件、玄武岩
Keywords: thermal conductivity, high temperature, basalt

Heat flow distribution along the Nankai Trough floor: Correlation with the structure of the incoming oceanic crust

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Surface heat flow observed on the floor of the Nankai Trough should reflect the thermal structure of the incoming Philippine Sea plate (Shikoku Basin). Detailed measurements along the trough axis revealed that heat flow on the trough floor in the central part (between 135°E and 136°E) is extremely high and variable, much higher than the value corresponding to the seafloor age. On the east of 136°E, heat flow steeply decreases eastward to the value consistent with the age with no appreciable scatter. In the area west of 134.5°E, the observed heat flow is more or less normal for the age and shows low scatter. This peculiar heat flow distribution is well correlated with the structure of the Shikoku Basin oceanic crust. The high and variable heat flow area in the central part corresponds to the youngest part of the Shikoku Basin, which was formed by spreading in the NE-SW direction, whereas the neighboring areas with less scattered and lower heat flow were formed by E-W spreading. Other geophysical data, e.g., seismicity, crustal thickness, and basement topography, also show significant variations around the boundaries between the two spreading directions, indicating that the crustal structure changes across the boundaries. The high heat flow in the central part can be attributed to vigorous fluid circulation in a permeable layer (aquifer) in the subducted oceanic crust, which efficiently transports heat upward along the plate interface (Spinelli and Wang, 2008). It is probable that the permeability structure of the oceanic crust changes at the boundaries between the E-W and NE-SW spreading, which yields variations in vigor and/or pattern of fluid circulation, resulting in the observed high to normal heat flow transitions across the boundaries. Another feature of the heat flow distribution in the central part, high variability, appears to arise from the crustal structure as well. The central part is characterized by large basement relief and heat flow values have negative correlation with sediment thickness; heat flow tends to be high on basement highs. Similar correlation cannot be recognized in the areas formed by E-W spreading. It suggests that the high heat flow variability in the central part may also be due to fluid circulation in the permeable layer. These results indicate that the structure of the Shikoku Basin originated from its spreading history has a large influence on physical/chemical conditions along the plate interface (seismogenic zone of large thrust earthquakes and slow erathquakes) through fluid and heat transportation in the oceanic crust.

キーワード：南海トラフ、四国海盆、熱流量、海洋地殻、流体循環、基盤地形
Keywords: Nankai Trough, Shikoku Basin, heat flow, oceanic crust, fluid circulation, basement topography

Along-trough variation in the seismic structure of the incoming Philippine Sea plate just seaward of the Nankai Trough

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Rupture of large-thrust earthquakes along the Nankai Trough is known by always initiating from off the Kii Peninsula. The segmentation boundary between the 1944 Tonankai (Mw=8.1) and the 1946 Nankai (Mw=8.4) earthquake rupture is locate on the Kii channel, off the Kii Peninsula. Activity of the nonvolcanic deep low-frequency tremors and very low-frequency earthquakes observed around the down-dip limit of the coseismic rupture zone of the last Tonankai and Nankai earthquakes is not homogeneous, and the belt-like tremor zone is divided into several segments bounded by gaps [Obara, 2010]. Largest gap is recognized around the Kii channel between the Shikoku Island and Kii Peninsula.
Our recent integrated result of first-arrival tomography based on the 2012 and 2014 wide-angle OBS data shows dramatic along-trough variation in P-wave velocity just beneath the basement of the incoming Philippine Sea plate. Variations in P-wave velocity from ~4km/s to more than 5km/s can be recognized south off the Cape Muroto, Shikoku Island and the Shima Peninsula, about 50-60km and 20km seaward of the deformation front, respectively. Such dramatic velocity change correspond with the structural boundary observed as variation in the configuration of the basement reflection in the time-migrated section, and the boundary of the plate age of about 20-21.5Ma proposed based on magnetic lineation by Okino [2015]. Similar along-trough structural variation in the incoming Philippine Sea plate can be recognized along two seismic profiles across the central Shikoku Basin far south from the trough axis [Nishizawa et al., 2011]. Furukawa et al. [this meeting] also find out the similar structural change around the eastern margin of the northern Shikoku Basin along several seismic profiles across the Izu-Ogasawara arc [Takahashi et al., 2015]. The low P-wave velocity of the oceanic layer 2 formed at backarc region is concerned to be related to high porosities and arc-related mineralogies [e.g. Dunn and Martinez, 2011]. Seismic velocities decrease in the oceanic crust may also indicate high water contents, which may be one of the causes of the low-frequency seismic phenomena around the down-dip limit of the Nankai Trough subduction seismogenic zone. This structural characteristic is thought to continue northwards to the subducting Philippine Sea plate beneath the southwest Japan, and may cause the segmentation of an earthquake rupture, and heterogeneous activity of the nonvolcanic deep low-frequency tremors and very low-frequency earthquakes.
This study is part of ‘Research project for compound disaster mitigation on the great, earthquakes and tsunamis around the Nankai Trough region’ funded by MEXT, Japan.

Crustal structure of the eastern Nankai Trough from Full Waveform Inversion of the dense Ocean Bottom Seismometers data

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The Nankai Through region is one of the best sites providing an excellent natural laboratory for studying factors controlling segmentation of the earthquake rupture zones in subduction systems. The area has a ~1300 year historical record of damaging earthquakes and is constantly under intense multidisciplinary scientific investigation. For this purpose enormous number of data are acquired in this region. Among them high quality seismic datasets, including multi-channel reflection seismic (MCS) and wide-angle reflection/refraction seismic (WARR) acquired using Ocean Bottom Seismometers (OBS), provide a great potential for seismic imaging.

Crustal-scale velocity models from 2D marine WARR surveys are usually built using ray-based methods. However their ability to resolve complex structures is limited by factors such as: OBS spacing, width of the Fresnel zone or interpreter's ability to distinguish and associate the picked phases with the model interfaces. From the other hand rapid development of the Full Waveform Inversion (FWI) methodology during last decade allows for automation of the crustal velocity model building in the unprecedented resolution, given that the sufficiently dense acquisitions are used. Additionally, potential of FWI stimulates not only development of the imaging algorithms –but also new acquisition technologies including growing pools of OBS instruments available to the academic community making it possible to acquire dense WARR OBS data in 3D.

Here we present multiscale, layer-stripping strategy for the semi-automatic, high resolution, crustal-scale imaging using FWI. We develop practical workflow including: (i) preprocessing focused on the improvement of the data coherency and boosting low frequencies; (ii) thorough and early stage QC starting from the analysis of the traveltime error in the initial model; (iii) final model validation procedures using source estimation, evaluation of the data fit with Dynamic Image Warping, correlation with PSDM image and the interpretation of crustal phases by the ray-tracing. We successfully apply this workflow to the 2D OBS dataset from the eastern Nankai Through acquired by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) involving 100 OBS uniformly deployed along a 100-km long profile recording air-gun shots extended along 140-km long profile with a 100 m spacing.

As a result we obtain velocity model of the complex subduction zone with clearly delineated shallow and deep structures. In particular in the backstop we observe large-scale stacked thrust sheets covered by sediments of forearc basin. These structures spatially extend to the area of accretionary prism forming Kodaiba and Tokai thrusts. Further into seaward direction we can point sequence of smaller thrusts delineating active wedge covered by slope basins and the thick layers of sediments in the trench. We observe local thickening of the oceanic crust corresponding to the subducting oceanic ridges as well as a sharp low-velocity zone (LVZ) atop the oceanic crust, which represent a damage fault zone created by one of these ridges colliding with the backstop. The top of the LVZ corresponds to a splay fault along which the co-seismic slip can occur during the next large earthquake in the area.

We show that with FWI one is able to retrieve a detailed information on the subduction zone structure that can be used as an input for other studies (e.g. geodynamical modeling). High resolution velocity models accompanied by image from MCS data increase interpreter's ability not only in terms of structural interpretation but also help to understand formation processes. Our study presents great potential of the FWI as a semi-automatic method for better imaging of complex crustal targets being beyond the reach of the WARR or towed-streamer surveys. Further tests of FWI with decimated acquisitions reveal that even datasets with 5km OBS-spacing have potential to deliver satisfactory results in terms of imaging overall crustal structure.

Keywords: subduction zone, crustal-scale imaging, full waveform inversion, velocity model building, OBS data, Nankai Trough

人工地震探査による日本海溝アウターライズ東麓における海洋性地殻構造
Crustal structure beneath the eastern foot of the Japan Trench outer rise by airgun-OBS survey

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海洋性地殻の地震波速度構造は，比較的均質性が高いと考えられるが，海洋性地殻下部から最上部マントルにかけて複雑な構造をもった反射面が認められることがある．こうした地殻深部やマントルにみられる不均質構造の要因の一つとして，海洋プレートの形成・発達過程が考えられる．たとえば，千島海溝沖の北西太平洋の最上部マントルに認められる反射構造は，プレート運動に伴って形成されたリーデル剪断と解釈されている（Kodaira et al., 2014）．本研究では，日本海溝アウターライズの東麓において実施したエアガン−海底地震計（OBS）構造探査の波形記録を解析し，この領域の地殻・マントル内の地震波反射構造を詳細に明らかにすることを通して海洋プレートの形成・発達過程を考察する．

本研究で用いるエアガンーOBS 探査データは, 2010 年に北西太平洋において取得されたもので， 6 km 間隔で23台のOBSを設置した測線沿いに，エアガン発振を0.2 km 間隔で1199 回行った．得られたOBS記録を見ると，初動振幅が顕著に小さくなるシャドウゾーンが認められた．シャドウゾーンが現れ始めるまでの初動は海洋性地殻第３層からの屈折波(Pg)と解釈されることから，海洋性地殻深部のモホ面の直上にシャドウゾーンの原因となる構造が存在すると推察される．こうしたシャドウゾーンは測線南側のOBS の記録でより広く認められ，地殻深部の構造が測線に沿って大きく変化することが示唆される．こうしたOBS記録の特徴を再現するよう，P波速度構造を2 次元波線追跡法により構築した結果，海洋性地殻第３層下部に低速度層が存在し，その厚さが測線に沿って変化していると仮定することで，観測記録の特徴をおおむね再現することができた（大友・他，SSJ，2016）．

一方，OBS による広角反射法地震探査記録に地震波干渉法を適用して合成した稠密な仮想観測点における地震波形に反射法的処理を施すことで，海洋プレート内反射構造のイメージングを試みたところ，地殻深部からモホ面程度の深度に相当する垂直往復走時9秒付近に連続性の良い反射信号を抽出することに成功した（大友・他，JpGU，2016）．これを，2 次元波線追跡法による屈折波のフォワード解析で得られた構造モデルと対応させると，イメージされた反射面は，モホ面ではなく，地殻最深部に分布する低速度層上面からの反射波である可能性がある．そこで，屈折法解析から得た構造モデルをもとに理論波形計算を行い，理論波形に対して反射法的処理を施すことで，低速度層上面からの反射波がイメージングされるのかを調べてみた．観測波形記録に対して施したのと同様の手順で地震波干渉法および反射法的処理を行って得られた反射断面上には，往復走時で9秒，9.7秒付近に反射面がイメージされ，浅い側の反射面が低速度層上面からの反射波に対応することがわかった．この往復走時が，実際の観測記録から得られた反射断面に認められる反射面の走時が低速度層上面反射のものと整合的であることから，実際の探査によって低速度層上面からの反射波が捉えられている可能性が高い．

実際の反射断面上では，この低速度層上面からの反射波は測線の南側で顕著である一方で，北側では不明瞭になっている．このことを，OBSで観測される初動のシャドウゾーンが測線南側でより広く現れる傾向と対応すると考えると，海洋性地殻深部にある低速度層は，層の厚さが測線に沿って変化しているのではなく，層内の速度が南部側ではより低速度で上面における速度コントラストが大きくなっていることが示唆される．

今後は，走時インヴァージョンとともに詳細な波形モデリングを行い地殻内部の地震波速度分布を詳しく検討するとともに， OBSデータの反射法的処理におけるデコンボリューションなどの波形処理の微調整を行うことにより，反射断面の品位の向上も進める予定である．

Seismic structure beneath the petit-spot area and its implications

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The nature of the sedimentary layer on the top of the incoming oceanic plate is one of key controlling factors on the interplate coupling after plate subduction. In the northwestern Pacific margin off NE Japan, the Pacific plate is generally covered with a sedimentary layer consisting of mainly pelagic sediments of a few hundreds meter thick. However, locally thin sediments areas have been found by existing seismic reflection profiles. One of such thin sediments areas is located at the outer rise of the central Japan Trench and the size is roughly 50km square. This area is known as one of petit spot volcano sites; more than 80 petit spot volcanos are expected in this area (Hirano et al., 2006, 2011).

In 2014 and 2015, we conducted OBS-airgun surveys along a 600 km long 2-D seismic survey line crossing the petit spot area. We deployed 88 OBSs at intervals of 6 km and shot a tuned airgun array of R/V Kairei. We applied a traveltime inversion to model P-wave velocity (Vp) structure and found Vp just beneath the shallowest reflector beneath the seafloor is lower in the petit spot area than that in the other areas. To image the detailed seismic structure of the shallow sedimentary layers, we calculated receiver functions using the active-source seismic data. The receiver function analysis is a technique to image P-to-S conversion interface just beneath each OBSs. At most OBSs, only one P-to-S conversion interface is imaged at the expected time of the basement (top of the oceanic crust). But, in the petit spot area, we observed several P-to-S conversion interfaces. Since the deepest interface at the petit spot area is approximately equal to the basement in other areas, we infer that shallower P-to-S conversion interfaces are located within the sedimentary layer and that these interfaces might be related to the intrusion of sills, because we can expect pervasive sill intrusions beneath the petit spot area based on the observation at the outcrop of a petit spot in the central America (Buchs et al., 2013) and on the petit spot model proposed by Hirano et al. (2006).

The seismic coupling between the overlying plate and the subducting plate is probably affected by the nature of the sedimentary layer of the incoming plate, meaning that the subduction of petit spot area might cause the spatial variation in the interplate coupling after subduction. Although each petit spot volcano itself is very small, existing seismic reflection data suggest that the whole petit spot area, roughly 50 km square, is probably characterized by pervasive sill intrusions. Since the size of this petit spot area corresponds to the coseismic rupture area of M7 ~ M8 interplate earthquakes in the subduction zone of the Japan Trench, the subduction of petit spot areas might be one of the causes for a spatial variations in the distribution of interplate earthquakes in this subduction zone.

キーワード：構造探査、日本海溝、プチスポット火山
Keywords: controlled-source seismic survey, Japan Trench, petit spot volcano

Towards electrical resistivity imaging around outer-rise bending normal faults off the Japan trench

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Hydration in the oceanic crust and uppermost mantle beneath the outer-rise area is thought to be main source of aqueous fluid in the subduction zone (e.g. Ranero et al., 2003). Thus the mapping of hydrating fluid in outer rise areas is essential to understand dynamics, earthquakes and volcanic activities in subduction zones. Imaging of electrical distribution is useful to detect hydration beneath the outer-rise area because electrical resistivity reflects amount, composition and connectivity of fluid, temperature, and serpentinization. Recent developments of control source electro-magnetic (CSEM) investigation methods allow us to obtain high resolution images of resistivity distribution beneath the outer-rise area (Naif et al., 2015). Thus CSEM experiments is being planned in an outer-rise zone in Tohoku-oki area (incoming Pacific plate near the NE Japan arc). In this study, we introduce a present resistivity model based on natural source EM (magnetotelluric) surveys in this area. The model shows that surface conductive layer is thicker beneath the EM station closer to the Japan trench compared to the farther station (40 and 60 km from Japan trench, respectively). Sensitivity tests indicate that the observed data require the variation of thickness of conductive layer. Thus resistivity imaging is effective to investigate hydration in the outer-rise zone in the Tohoku-oki area. Because CSEM investigations can image more detailed resistivity distribution, high resolution mapping of hydration will be realized in this area. Thus we plan CSEM experiments around the Magnetotelluric survey line in mid 2017. The details of CSEM survey plan will be introduced in the presentation.

蛇紋岩の弾性波速度に対する間隙水の影響とアウターライズ領域での蛇紋岩化の再検討

Effect of pore water on elastic wave velocity of serpentinites and implication for serpentinization at outer-rise region

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近年の海底地震波探査からアウターライズ領域において地震波の低速度領域が観測されている (e.g., Fujie et al., 2013; Shillington et al., 2015)。この地震波の低速度はマントル領域まで達するため、アウターライズ断層から海水が供給され蛇紋岩が形成していると解釈されている(e.g., Ranero et al., 2003)。カンラン岩の地震波速度は蛇紋岩化率の増加とともに低下することが実験から報告されており(Christensen, 2004)、観測された速度と比較することでマントルの蛇紋岩化率が見積もられている。しかし、蛇紋岩には反応に伴う体積膨張により多くの空隙が発達しており (Macdonald and Fyfe, 1985)、そのような空隙には水で満たされている可能性が高い。そこで本研究では様々な空隙率をもつ蛇紋岩の弾性波速度に対する間隙水の効果を調べ、アウターライズ領域における蛇紋岩化を再評価した。

実験試料には嶺岡帯に産出する蛇紋岩と、南マリアナ海溝、トンガ海溝の海底からドレッヂされた蛇紋岩を用いた。それらは低温型蛇紋石であるリザーダイト・クリソタイルから主に構成される。これらの試料は、画像解析から蛇紋岩化率が86–100%であった。空隙率は気相置換法によって測定し、嶺岡帯試料では0.3–4.4%、海底ドレッヂ試料は9.6–26.7%であった。実験には広島大学設置の容器内変形透水試験機を用いて、パルス透過法により弾性波速度を測定した。実験は乾燥条件に加え、含水条件では間隙水圧を10MPa一定に制御した条件で測定を行った。封圧は200MPaまで加圧し、温度は室温で測定した。

弾性波速度は封圧の増加に伴って増加し、乾燥条件での封圧200MPaの速度はChristensen(2004)の密度と速度の関係とほぼ一致した。含水条件ではP波速度は乾燥条件の速度より低封圧下では8%程度、高封圧下では3%程度速い速度を示した。これは空隙が水で満たされることで岩石の体積弾性率が増加し、P波速度が上昇すると考えられる。一方で、S波速度は空隙率が低い試料では水の効果は見られないが、空隙率が高い試料では7%程度低下した。これは剛性率に対しては流体の効果は小さいが、密度が増加するためにS波速度が低下したと考えられる

これまでの研究では、最上部マントルの速度異常から蛇紋岩化率は20%程度と見積もられているが、蛇紋岩の空隙率を10%とし、その空隙が水で満たされる場合、蛇紋岩化率はこれまでの見積もりより低くなり15%程度となる。このようにマントルでの蛇紋岩の分布ならびに割合を評価するには、岩石中の空隙率を正確に把握する必要がある。

キーワード：蛇紋岩、間隙流体、弾性波速度、アウターライズ領域
Keywords: Serpentinite, Pore fluid, Elastic wave velocity, Outer-rise region