Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SIT04-01 Room:414 Time:April 28 09:00-09:25

Thermal structure of the NE Japan-Hokkaido subduction system: The effects of 3-D slab geometry and oblique subduction

WADA, Ikuko[1*] ; JIANGHENG, He[2] ; HASEGAWA, Akira[3] ; TAMURA, Yoshihiko[4] ; NAKAJIMA, Junichi[3]

[1]IRIDeS, Tohoku University, [2]Pacific Geoscience Centre, Canada, [3]Graduate School of Science, Tohoku University, [4]Japan Agency for marine-Earth Science and Technology

In this study, we first examine the effects of along-strike variation in slab geometry and oblique subduction on subduction zone thermal structures by comparing 3-D numerical thermal models with a range of generic subduction geometries and parameters with a 2-D reference model. We found that changes in slab dip along a straight margin have modest effects on the mantle flow pattern and thus the thermal field. However, concave and convex ocean-ward margins result in cooler and warmer mantle wedges, respectively, and oblique subduction results in a warmer mantle wedge, compared to the 2-D reference model. We developed a 3-D thermal model for the NE Japan-Hokkaido margin, using a well-constrained 3-D slab geometry model. In general, there is little 3-D effect on the thermal structure of the shallow part (<70 km depth) of the subduction system, where the mantle does not participate in the slab-driven wedge flow. We also found that the 3-D effect is small in the deeper part of the southern half of the system, where the margin is relatively straight and the slab dip does not vary significantly along the margin. These results indicate that 2-D models provide excellent approximations for the thermal structures of the shallow part and the southern part of the subduction system. However, from the northern part of NE Japan to Hokkaido, the mantle flow pattern is affected by the concave ocean-ward margin and oblique subduction, and the wedge is cooler near the NE Japan-Hokkaido junction and warmer in Hokkaido than the 2-D thermal models for the respective regions. We compare the 3-D thermal modeling results with along-strike variations in surface heat flow, arc magma geochemistry, and earthquake distribution in NE Japan and Hokkaido.

Keywords: Tohoku-Hokkaido subduction system, 3-D thermal model, slab geometry, oblique subduction, mantle wedge flow, earthquakes and volcanism

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SIT04-02 Room:414 Time:April 28 09:25-09:40

Effects of a local deepening of slab-mantle decoupling depth on slab surface temperature

MORISHIGE, Manabu[1*] ; VAN KEKEN, Peter E.[2]

[1]JAMSTEC, [2]University of Michigan

In the subduction zone, we generally observe low seismic attenuation in the forearc mantle. In addition, surface heat flow shows low value in the forearc and a sudden transition to high value in the arc. These observations suggest that the forearc mantle is cold and is not involved in the corner flow in the mantle wedge. We can understand it in terms of slab-mantle decoupling depth (D_{dec}). Above D_{dec}, the mantle does not move with the slab just beneath it. Therefore, it becomes cold quickly due to the cooling from the overriding plate and the slab. Below D_{dec}, on the other hand, the mantle moves with the slab. It keeps this part of mantle warm by advection of hot material due to the corner flow. Thus, D_{dec} is a key parameter which strongly affects thermal structure in the subduction zone. Comparison of the observed surface heat flow and the one predicted with 2D numerical model suggests that D_{dec} does not vary much for each subduction zone and is 70-80km, but in each subduction zone D_{dec} may show some degree of along-arc variation. One such example is the junction between Japan and Kurile arcs, where the down-dip limit of thrust type earthquake is locally deepened by around 15km. In this presentation, we investigate the effects of a local deepening of D_{dec} on slab surface temperature.

Toward the goal, we use time-dependent 3D finite element models to compute mantle flow and temperature. Only mantle wedge is treated as a dynamic entity. We use a simple slab geometry and assume a local deepening of D_{dec} to see its effects. We find that the increase in slab surface temperature at D_{dec} is larger where we assume a deepening of D_{dec}, which produces a warmer region there. It is caused by 3D flow in the mantle wedge due to along-arc variation of D_{dec}. We also calculate surface heat flow from obtained thermal structure, but it does not show significant along-arc variation. These results do not change even when we use a realistic slab geometry which is similar to that of the junction between Japan and Kurile arcs. While the surface heat flow anomaly and deepening of the seismic belt in S. Hokkaido cannot be easily explained by these models, the temperature excursions at the slab surface are significant. These models predict potentially strong variations in the conditions that the fluids leave the slab, which may be visible by various new geothermometers, such as those based on the H_2O/Ce ratio.

Keywords: subduction zone, slab-mantle decoupling depth, slab surface temperature

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SIT04-03 Room:414 Time:April 28 09:40-10:05

Thermal modeling associated with subduction of the Philippine Sea plate in southwest Japan

YOSHIOKA, Shoichi[1*] ; JI, Yingfeng[1] ; MATSUMOTO, Takumi[2]

[1]RCUSS, Kobe University, [2]NIED

By constructing a parallelepiped three-dimensional thermal convection model, we investigated temperature, mantle flow and heat flow distributions associated with subduction of the Philippine Sea (PHS) plate in southwest Japan. We proposed new, realistic, and high-resolution temperature field on the plate interface, and attempted to clarify its relationships with the occurrences of megathrust earthquakes, long-term slow slip events (SSE), and low frequency tremors (LFEs). For this purpose, we newly developed a numerical model to deal with subduction of an oceanic plate with 3D arbitrary geometry. We modeled subduction of the PHS plate by using the up-to-date three-dimensional slab geometry, referring to high resolution P-wave seismic tomography and seismic reflection studies. We also used large number of heat flow data such as BSRs, borehole, heat probe, and Hi-net to constrain calculated temperature field, and took account of complicated subduction history in southwest Japan. The results showed that the interplate temperature was lower by approximately 100^{o}C in western Shikoku where a larger true subduction angle exists than eastern Shikoku. Temperature change due to erosion and sedimentation affected surface heat flow with short wavelength. We also found that the obtained interplate temperature in the Nankai seismogenic zone was wider than that in the Tonankai seismogenic zone. The LFEs occurred near the plate interface with temperatures ranging from 350^{o}C to 450^{o}C at depths of 30 to 40 km. The existence of large temperature gradients from the surface to the inside of the PHS plate was considered to be related to the occurrence of long-term slow slip events beneath the Bungo Channel.

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SIT04-04 Room:414 Time:April 28 10:05-10:20

Slab-wedge mantle boundary preserved in the Sanbagawa belt, SW Japan

WALLIS, Simon[1*] ; MORI, Hiroshi[1] ; NAGAYA, Takayoshi[1] ; KAWAHARA, Hirokazu[1]

[1]Dept. Earth & Planetary Sci., Nagoya Uni.

The Sanbagawa belt of SW Japan is a high-pressure low-temperature subduction type metamorphic belt. The rock types consists of mafic, siliceous and pelitic schists derived from the subducted slab. There are also a series of ultramafic bodies whose origin is disputed: both a slab and wedge mantle origin have been proposed. However, the clear relationship between the distribution of the mantle rocks and metamorphic grade provides strong evidence that they were derived from the wedge mantle. We carried out a detailed study of the Shiragayama body as an example of serpentinized mantle from close to the corner of the wedge. Studies of this region can contribute to our understanding of non-volcanic tremor and fluid flow that occurs in these otherwise inaccessible parts of subduction zones.

Keywords: fore arc mantle, subduction metamorphism, slab mantle boundary

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SIT04-05 Room:414 Time:April 28 11:00-11:25

Phenomenology of Episodic Tremor and Slip

OBARA, Kazushige[1*]

[1]Earthquake Research Institute, UTokyo

Episodic Tremor and Slip (ETS) is a coupling phenomenon composed of continuous weak seismic events and geodetic short-term slow slip event (SSE) in the transition zone between the brittle seismogenic zone and stable sliding regime recognized in southwest Japan and Cascadia. This paper reviews characteristics of ETS and related phenomena to contribute to discussion for subduction process.

ETS is interpreted as a stick slip on the plate interface accompanied by seismic swarm at small patches surrounded by the SSE plane because of coincidence of their sources and linear relationship between the duration of tremor episode and the moment of SSE estimated geodetically for each episode. ETS is distributed in a narrow belt-like zone along the strike of the subducting plate. ETS zone is divided into several segments in which episodes recur at each regular recurrence interval. However ETS is not ”characteristic earthquake” because the rupture area and recurrence interval are fluctuated. Sometimes we observe rupture propagation through a couple of segments. The segment is usually bounded by gap which is considered as not a barrier but an easily sliding portion because of the existence of multi-segment migration.

ETS activity has depth dependent property. At the deeper part of the ETS zone minor episode frequently occurs, on the other hand major episode occurs infrequently at the shallower part. Large ETS usually initiates from the deeper part and migrates upward then activates at the shallower part. This might be caused by gradual change in frictional property with increasing the depth. At the downdip edge of the ETS zone tremor episode easily occur due to weak strength and stress concentration from stable sliding zone. Each small episode transfers the stress to the updip side. Finally a small episode can propagate to the updip edge then develop as a large ETS episode.

The activity style of ETS in southwest Japan and Cascadia is very similar; however there are some differences. One is the existence of deep very low frequency earthquake (VLF). In Japan the VLF earthquake is usually associated with ETS but has not been detected in Cascadia. It might depend on the detection capability or difference in inhomogeneity of the plate interface because the distribution of VLF earthquake in southwest Japan is more localized compared to that of tremor.

The other difference is the existence of long-term SSE. It is detected at the updip side of ETS zone in the Bungo Channel and Tokai in southwest Japan but not detected in Cascadia. The long-term SSE with duration from several months to years activates tremor at the adjacent limited region in the ETS zone. On the other hand, the tremor activity at the downdip part is not affected. Similar long-term SSE has been detected in Alaska and Mexico, where tremor activity was recently detected at the downdip side of the source fault of the long-term SSE. The tremor is seems to be activated during the SSE period like as in southwest Japan. The long-term SSE in Tokai is located above the anomalously high Vp/Vs region in the slab. In Mexico, a ultra slow speed layer was found in the long-term SSE source region. Therefore, the anomalous structure might be a cause of the long-term SSE. ETS and long-term SSE are quite different in the slip velocity. It might reflect the difference in the frictional property. In Tokai, the source region of the long-term SSE and ETS is bounded by the inland Moho discontinuity. Therefore, ETS occurs at the interface between the subducting plate and overlying mantle wedge.

ETS has not been recognized besides in southwest Japan and Cascadia; however ambient tremor has been detected in some regions. We expect that the ambient tremor is triggered by small SSE which is not detected by the current observation. Understanding detail relationship between tremor and SSE based on improvement detection capability is important to reveal the mechanism of ETS.

Keywords: slow earthquake, non-volcanic tremor, slow slip event, subduction zone, plate interface

SIT04-06 Room:414 Time:April 28 11:25-11:40

Enhancement of slow earthquakes by geometrical irregularity of subducting oceanic crust

KATO, Aitaro[1*] ; OBARA, Kazushige[1] ; TAKEDA, Tetsuya[2]

[1]ERI University of Tokyo, [2]NIED

Along the worldwide subduction zones, slow earthquakes commonly occur on the deep extension of major tectonic boundary which hosts megathrust earthquake rupture. Slow earthquakes silently release stress to the adjacent seismogenic zone, raising the likelihood of promoting unstable fast slip. However, what controls the transitional variations in fault-slip behaviors from fast to slow modes on the deep extension of megathrust fault remains controversial. Here we use a high-resolution receiver function and seismic tomography illustrated by dense seismic arrays to analyze the structural elements in the subduction complex and fore-arc mantle wedge beneath the Shikoku Island, Japan, where episodic tremor and slow-slip events (ETS) have been most intensive for over a decade.

We find out that deformed oceanic crust with irregularity of surface geometry horizontally lies in the ETS zone, where low seismic velocity zone with high Poisson's ratio that we interpret as high pore-fluid pressure. Step-like discontinuous alignments of intra-slab seismicity support the flat-subduction of the oceanic crust with faulting structure. In contrast, at depths shallower than the ETS zone, the low velocity anomaly within the oceanic crust is weak and dipping towards the NW, implying less amount of high-pressured fluid in the tilting oceanic crust. In addition, lithology of the overlying plate changes to partially serpentinized mantle wedge in the ETS zone. Locally flat-geometry of the subducting oceanic crust combined with the contact of serpentine enhances accumulation of high-pressurized fluids along the plate interface, leading to segregation between slow and fast slip modes at the deep transition zone of mega-thrust fault.

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SIT04-07 Room:414 Time:April 28 11:40-12:05

Deformation experiments on serpentinite at high PT conditions with implications for the mechanisms of slow earthquakes

OKAZAKI, Keishi[1*] ; HIRTH, Greg[1] ; PROCTOR, Brooks[1] ; KATAYAMA, Ikuo[2] ; TAKAHASHI, Miki[3]

[1]Department of Geological Sciences, Brown University, [2]Department of Earth and Planetary Systems Science, Hiroshima University, [3]Geological Survey of Japan, AIST

To understand the spatial and temporal distribution of earthquakes and deformation in subduction zones, it is important to constrain the rheological properties of metamorphic rocks (i.e., altered mantle, oceanic crust and sediments), and how they evolve during metamorphic reactions following hydration, carbonation and dehydration of the down-going slab. Especially, antigorite (the high-temperature serpentine polytype) serpentinite, the dominant metamorphic phase in hydrated mantle material at the condition of mantle wedge, is the key metamorphic rock to understand the generation mechanism of slow earthquakes and slab-mantle coupling at the plate interface in subduction zones.

Deformation experiments on antigorite serpentinite were conducted within and above the thermal stability field of antigorite using a gas pressure-medium apparatus and a solid pressure-medium apparatus to understand how dehydration reactions influence the mechanical behavior of antigorite serpentinite. At 400 ℃, within the stability field of antigorite, antigorite serpentinite shows stable sliding and a positive velocity dependence of shear stress (i.e., friction coefficient). Shear stress increased with increasing confining pressure, while the friction coefficient decreases from 0.55 to 0.37 with increasing confining pressure from 200 MPa to 1500 MPa. These results indicate that antigorite serpentinite deforms by brittle and semi-brittle processes in subduction zones.

During the experiments using a gas pressure-medium apparatus at a confining pressure of 200 MPa and temperatures close to the dehydration temperature of antigorite (450-550 ℃), antigorite serpentinite shows a slow stick-slip behaviour, which is characterised by relatively long durations and small stress drops during slip, while this type of behaviour was not observed at higher temperatures when the antigorite becomes completely dehydrated. Stick-slip in this temperature range is consistent with the temperature range where slow earthquakes occur at the corner of the mantle wedge in southwest Japan and Cascadia. The scaling law of slow stick-slip in the antigorite serpentinite gouge is distinct from that of regular earthquakes and a theoretical duration estimated from the apparatus stiffness, but similar to that of slow earthquakes.

We also conducted deformation experiments in which temperature was increased above the thermal stability of antigorite to simulate a prograde metamorphism in subduction zones, similar to the experiments by Chernak and Hirth (2011) but with a general-shear geometry. With increasing temperature from 400 ℃ to 700 ℃ during deformation, differential stress decreased and reached 120 MPa. Recovered sample suggest that the strain localizes within shear fractures and limited dehydration occurred during the experiments.

These results suggest that the dehydration of antigorite can form weak zones within the mantle wedge along the plate interface in subduction zones, even if the extent of the dehydration reaction is limited. In addition, slow instabilities of the slip interface can be caused by the dehydration of antigorite within the weak zone in the antigorite serpentinite layer, which can result slow earthquakes.

Keywords: antigorite, serpentinite, semi-brittle flow, slow earthquakes, dehydration, hydrothermal condition

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SIT04-08 Room:414 Time:April 28 12:05-12:20

Metasomatic fault-zone weakening of subduction plate boundary faults

HIRAUCHI, Ken-ichi[1*] ; SPIERS, Christopher[2]

[1]Shizuoka University, [2]Utrecht University

Fluid influx along faults triggers stress-induced dissolution and precipitation processes, leading to syntectonic growth of weak phyllosilicates. In subduction zones, slab-derived Si-rich fluids may infiltrate into the forearc wedge and transform primary mantle minerals into hydrous phases such as serpentines and talc, changing the mechanical and seismogenic properties of subduction plate boundary faults. However, it remains unclear how frictional strength and sliding stability of the plate boundary faults evolve via Si-metasomatism.

Hirauchi et al. (2013, *Geology*) performed frictional sliding experiments on antigorite (70%) plus quartz (30%) gouges at a pore fluid pressure (P_f) of 200 MPa, an effective normal stress (σ_{eff}) of 200 MPa, temperatures (T) of 20, 300, 400, and 500 ℃, and sliding velocities (V) of 0.1-30 μm/s, using a hydrothermal ring shear machine. At temperatures of 300-500C, the gouges exhibited a peak friction coefficient (μ) of 0.40-0.62, followed by strain weakening towards a quasi-steady-state μ of 0.25-0.47. The weakening was mainly due to the development of through-going, talc-rich boundary shears. The steady-state μ of the gouges decreased systematically as the talc-rich layer widened.

At central California, there are several boundary faults that separate serpentinite bodies from shale-matrix melanges of the Franciscan accretionary complex. The serpentinite body is overprinted by anastomosing development of crack-seal veins of talc, serpentine, and calcite, suggesting that intense water-rock interaction took place in connection with faulting. The serpentinite along the faults represents a cataclastic shear zone that records brittle deformation, consisting of angular fragments that are suspended in fine-grained, randomly-oriented talc matrix. Frictional sliding experiments conducted at P_f = 40, 80, and 120 MPa, σ_{eff} = 60, 120, and 180 MPa, T = 20, 150, and 300 ℃, and V = 0.3-100 μm/s showed that the serpentinite has friction coefficients that agree with Byerlee's law (μ 0.6), while the cataclasite is much weaker with friction coefficients as low as 0.2. Examination of the velocity dependence of friction revealed that the serpentinite exhibits both velocity-weakening and velocity-strengthening behavior, whereas the cataclasite is velocity strengthening under all conditions investigated.

Our results demonstrate that in the lowermost part of the forearc wedge, where silica-saturated fluids infiltrate from the dehydrating slab, metasomatically produced talc will form in the intensely sheared serpentinite, causing a much larger weakening effect than expected for serpentines, even if the total amount of talc formed is minor ($<$10 vol%). The continued reaction with Si-rich fluid will also result in a transition from seismic to aseismic behavior of the plate boundary faults.

Keywords: subduction zone, serpentinite, metasomatism, fault

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SIT04-09 Room:414 Time:April 28 12:20-12:45

Coupled mass transport and serpentinization at crust/mantle boundary: Insights from hydrothermal experiments

OKAMOTO, Atsushi[1*] ; OYANAGI, Ryosuke[1] ; TSUCHIYA, Noriyoshi[1]

[1]Graduate School of environmental Studies, Tohoku University

Serpentinization commonly proceeds by a supply of water passing through crust, and thus a large mass transport could occur during serpentinization reactions. Especially, silica activity is known as a control of the reaction paths and rate during the hydrothermal alternation of peridotites [1, 2]. However, it is still unclear the role of mass transport on reaction paths, overall hydration rate and volume change during serpentinization. In this study, we conducted two types of hydrothermal experiments on serpentinization. First one is the metasomatic-reaction experiments between olivine (Ol) ? quartz (Qtz) zones as analogue of boundary of mantle and crustal rocks. Second one is the hydrothermal experiments with sintered olivine (analogue of low porosity rock). Both types of experiments were carried out at 250 ?C and vapor-saturated pressure (= 3.98 MPa) in alkaline aqueous solution.

In the Ol-Qtz metasomatic experiments (up to 46 days.), composite powders, which was composed of Qtz zone and Ol zone was set in inner tubes and then loaded into autoclave. After the experiments, the mineralogy and H2O content of the products were evaluated as a function of the distance from Ol/Qtz boundary. The reaction products after olivine are serpentine (Srp), brucite (Brc), magnetite (Mgt) and smectite (Smc) (instead of talc). The products systematically change from the Smc+Srp to Srp+Brc+Mgt with increasing the distance from the Ol/Qtz boundary. The H2O content of the products is low at the Ol/Qtz boundary (i.e., 3.9 wt.% after 46 days), and increases toward the margin of the tube (12 wt.% at ˜30 mm from the Ol/Qtz boundary).

The detailed mass balance calculation between 25 to 46 days reveals the characteristic nature of the metasomatic reactions and porosity change as follows. Near Ol/Qtz boundary (Smc+Srp zone), smectite was formed by supply of silica in two ways; hydration of olivine and dehydration of serpentine. In contrast, at the zone far from the boundary (Srp+Brc zone; >20 mm from O/Qtz), the production rate of serpentine and brucite are constant without any silica supply. At the transition zone between Smc+Srp and Srp+Brc zones, a large amount of serpentine is formed by consumption of both brucite and olivine, which results in a largest porosity reduction (˜30 %). In the Smc+Srp zone, dehydration and porosity reduction occurs simultaneously, implying a possible raise of fluid pressure. Silica metasomatic reactions causes a significant variation not only in mineral assemblage but also in porosity and fluid pressure, which will characterize the dynamic change of mechanical properties at crust/mantle boundary.

In the hydrothermal experiments of the sintered olivine, the starting olivine aggregate (initial porosity <˜10 %, covered by Pt jacket), which was made by hot press at 1200 degreeC, 1 GPa and 4 days, was emplaced in the alkaline water. After 3 days, we recognized the progress of serpentinization reaction to produce serpentine and brucite. An interesting finding of this experiment is that brucite did not formed in pores of the core sample, but it was formed only at the top of the cylindrcial core of the sample. This result is quite different from with our previous experiments with using olivine powder (initial porosity is ˜50 %) [3], in which brucite and serpentine was formed uniformly. The result of our present study of the sintered olivine suggests that, when the rock porosity is low and volume expansion is difficult, brucite is segregated into open space (c.a. open fracture) during serpentinization; which may also affects on the formation of the local weak zone within the mantle peridotite.

[1] Frost, B. R., & Beard, J. S., 2007. Journal of Petrology, 48, 1351?1368.
[2] Ogasawara, Y., Okamoto, A., Hirano, N., & Tsuchiya, N, 2013. Geochim. Cosmochim. Act, 119, 212?230.
[3] Okamoto, A., Ogasawara, Y., Ogawa, Y. and Tsuchiya, N., 2011. Chemical Geology, 289, 245-255.

Keywords: serpentinization, hydrothermal experiments, silica metasomatism, porosity change, hydration, mass transport