Enigmatic ground water enriched in isotopically light lithium

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Deep crustal fluids may involve with earthquake and volcanic activities. The geophysical survey such as seismic and electrical conductivity tomography can visualize distribution of crustal fluids, while they need abundant fluids for the detection. It is therefore expected that geochemical results provide us detailed information about origin of deep-seated fluids. However, admixture with surface water makes it difficult to draw precise conclusions regarding the origins of deep-seated fluids. Because of this, geochemical results of the deep-seated fluids had been limited. Lithium (Li) is relatively unaffected by surface water contamination because the Li contents of deep-seated fluids are much greater than the surface water content. These high Li concentrations result from dramatically elevated leaching of Li from solid phase into fluids at high temperatures, and the fact that subsequent re-uptake of the leached Li from the fluid by the solid phase (which occurs as the fluid cools) takes a considerable time. In addition, the two stable isotopes of Li are ^{6}Li and ^{7}Li, and their relative abundances are about 7.5% and 92.5%, respectively. Furthermore, the difference in the ^{7}Li/^{6}Li ratio between fluid and solid phases varies with the reaction temperature. As a result, the Li isotope ratio provide us information about origin of deep-seated fluids. Based on the Li isotopic results on ground water samples, we have researched the origin of deep-rooted fluids. One of major problems unsolved is that significantly low ^{7}Li/^{6}Li ratios are observed in several ground water samples. The Li isotope composition of fluid phase is currently heavier than that of solid phase. Therefore, the significantly low ^{7}Li/^{6}Li ratios of ground waters require the solid phase other than the crust or mantle. Nishio et al. (2010) reported that the significantly low ^{7}Li/^{6}Li ratios were observed in the southeast flank of Ontake volcano in central Japan. Since 1976, earthquake swarms have occurred beneath the southeast flank of Ontake volcano. Electrical conductivity surveys have shown that these earthquake swarms are associated with the upwelling of deep-seated fluid. Based on the Li and Sr isotopic results of ground water samples around Ontake volcano, Nishio et al. (2010) concluded that the fluid associated with the earthquake swarms beneath the southeast flank of Ontake volcano is not a simple volcanic fluid. However, it is still unknown the origin of significantly low ^{7}Li/^{6}Li ratios. Afterwards, such significantly low ^{7}Li/^{6}Li ratios were observed in ground water samples in the Kobe and Kochi area (unpublished data). Accordingly, I'll discuss about the origin of the significantly low ^{7}Li/^{6}Li ratios observed in several ground water samples.

Reference:

Nishio et al., 2010. Lithium and strontium isotopic systematics of waters around Ontake volcano, Japan: Implications for deep-seated fluids and earthquake swarms. Earth Planet. Sci. Lett. 297, 567-576.

Keywords: lithium isotope, deep crustal fluid, slab-derived fluid, geochemical thermometer

Relationships between crustal stress fields and geological structures on pathways of upwelling deep-seated water at Kii Peninsula, southwest Japan

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The natural and hot springs with $^{3}He/^{4}He$ ratios higher than the atmospheric values are recognized to occur in nonvolcanic regions on the Kii Peninsula in the forearc regions of southwestern Japan arc (Sano & Wakita, 1985; Wakita et al., 1987; Matsumoto et al., 2003; Umeda et al., 2006, 2007), indicating that there are upwelling paths of the mantle-derived fluids in this region. A number of deep groundwater and natural spring water in this region are found to contain the slab-derived deep-seated fluid component, whose isotopic composition is similar to magmatic with the high Li/Cl ratio (>0.001 in wt. ratio) (Kazahaya et al., 2014). The upwelling of the deep-seated water provides significant information to understand the fluid movement in the crust and the water cycle in the subduction system (e.g. Hacker, 2008).
In this study, we present the upwelling of water and gas along the fractures and the relationships between orientations of the veins and the upwelling of the deep-seated water in the Shiotakibashi outcrop located to the north of Median Tectonic Line (MTL). And, we discuss the upwelling process of the deep-seated water at Kii Peninsula by using the relationships between crustal stress field and geological structures.
The Shiotakibashi outcrop along the Ishikawa river at the Kawachinagano city of Osaka prefecture is one of regions where the upwelling of the water and gas containing deep-seated water along the fractures can be observed (Tanaka et al., 2013). In the upwelling points at the outcrop, the patches of fractures that cut the Cretaceous granite belonging to the inner zone are filled by the calcite crystalized from the water. Furthermore, the water and gas are flowing so as to avoid the filled fractures. And, we can observe many mineral veins with several orientations in this outcrop. Mineral veins can provide evidences of the ancient fluid migration along the fractures.
In this study, we measured the strike, dip and width of the veins in a single outcrop of the Shiotakibashi outcrop (~100 veins). On the veins, the fractures that cut the cretaceous granite are filled by the calcite. The veins have thicknesses with a few mm to 2 cm. The most of the veins have NNE-SSW and ENE-WSW striking and dip with high angle while some veins have horizontal dip. The dilation tendency (Ferrill et al., 1999) for the filled fractures in the present stress inferred from the major active faults in the eastern part of the southwestern Japan including the Kii Peninsula (Tsutsumi et al., 2012) indicate that the fractures with upwelling of water and gas have high tendency on the pass ways of deep-seated water. Hence, the present tectonic stress may be feasible for upwelling of the deep-seated water along the fractures for a part of the fractures.
At the map scale, the Cretaceous-Paleogene accretionary complex, Shimanto Belt is exposed in the region located to the south of MTL in Kii Peninsula. The most of deformation structures of the Shimanto Belt have northward plunging thrusts. Based on the relationships between crustal stress field and attitudes of the geological structures, the dilation tendency is high on the geological structures. Hence, we suggest that the geological structures of the region under the present crustal stress are favorable pathways for deep-seated fluids.

Keywords: stress, fluid migration, fault, crust, deep low-frequency tremors, subduction zone

Three dimensional attenuation structure beneath the northwestern part of Kii peninsula, central Japan

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Beneath the Kii peninsula which is located above the subducting Philippine Sea (PHS) plate, it is known that there are several interesting seismic phenomena such as an intensive seismic swarm in the shallow crust and occurrence of non-volcanic low frequency earthquakes around the top of the PHS plate at the depths between 30-40km [Mizoue et al.,1983; Kato et al.,2010]. Previous geophysical studies suggested that geofluid is related to the occurrence of such seismic events [Hirose et al.,2008; Kato et al.,2010&2014]. In this study, we determined a 3-dimensinal attenuation structure to obtain a new information about physical properties in the study region because Q value is a sensitive parameter for the existence of fluid or cracks and effect of temperature.
We applied a combined inversion in which source parameters, site effects and Q values are determined simultaneously [Tsumura et al.,2000] for small earthquakes' spectra. Seismic waveforms were observed at the routine Hi-net seismic stations by NIED and temporary dense seismic arrays of arranging east-west direction and north-south direction at the southern and western parts of the Kii peninsula, respectively. We selected 247 earthquakes which were recorded at 113 seismic stations and calculated 8616 spectra for P arrivals of time window 1.28s for taking into account ray distribution.
Derived Qp images show that high attenuation zone(Qp<200) exists at the northwestern part of Kii peninsula in the depths shallower than 15km. This high attenuation zone has the similar horizontal extent as that of seismic swarm's source region. The other region shows moderate Qp(about 400 to 800) except the southern part of the Kii peninsula where Qp is less than 400. For the depths between 15 to 38km, high attenuation zone continued from the shallower part beneath the swarm region, however its horizontal extent becomes small at the deeper than 25km. We found that patch-like high Qp zones were distributed in the region just above isodepth contour 30 to 40km of the PHS plate. These high Qp regions coincide with the region where many low frequency earthquakes occur. In the NW-SE vertical Q cross section at the western part of the Kii peninsula, we can clearly see that the high attenuation zone is located just beneath the seismic swarm region and its distribution corresponds to a low velocity zone estimated from travel time tomography [Hirose et al.,2008; Kato et al.,2014]. From the result of reciever function analysis[Kato et al.,2014] , subducting Philippine sea plate's oceanic basalt is considered to start conversion to eclogite just beneath the swarm region and the high attenuation and low velocity zone may reflect the existence of fluid due to the dehydration proceess. Another feature we should mention is existence of low attenuation zone at the mantle wedge just above the source region of low frequency earthquakes. This low attenuation zone shows higher velocity than surroundings. We'd like to integrate various geophysical data and argue the physical property of these regions.
[References]Hirose et al., J. Geophys. Res., 113, B09315, doi:10.1029/2007JB005274;Kato et al., Geophys. Res. Lett., 37, L15302, doi:10.1029/2010GL043887;Kato et al., EPS, 66:18,2014;Mizoue et al., Bull. Earth Res. Inst., 58,287-310,1983;Tsumura et al., Tectonophysics, 319, 241-260, 2000

Keywords: Q attenuation, seismic swarm, non-volcanic low frequency earthquake, Kii peninsula, southwest Japan

Control of episodic tremor and slip by high-pressurized fluids: a new constraint from ScSp waves

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1. Introduction

High-pressurized fluids are thought to play an important role in controlling episodic tremor and slow slip (ETS) in subduction zones [e.g., Shelly et al., 2006; Audet et al., 2009]. Therefore, constraining the along-dip distribution of ETS is necessary to better understand its source mechanism, and particularly the role played by fluids in ETS generation. Here, we report clear observations of coherent *ScSp* phases with a dense seismic array in western Shikoku, Japan. To reproduce these observations, we performed numerical simulations of elastic-wave propagation using a finite difference method (FDM) that incorporated a three-dimensional structural model. The combination of coherent *ScSp* phases and numerical simulations allows us to investigate the depth dependence of Poisson's ratios within the LVZ, and to quantitatively estimate local changes in fluid pressure in the ETS zone.

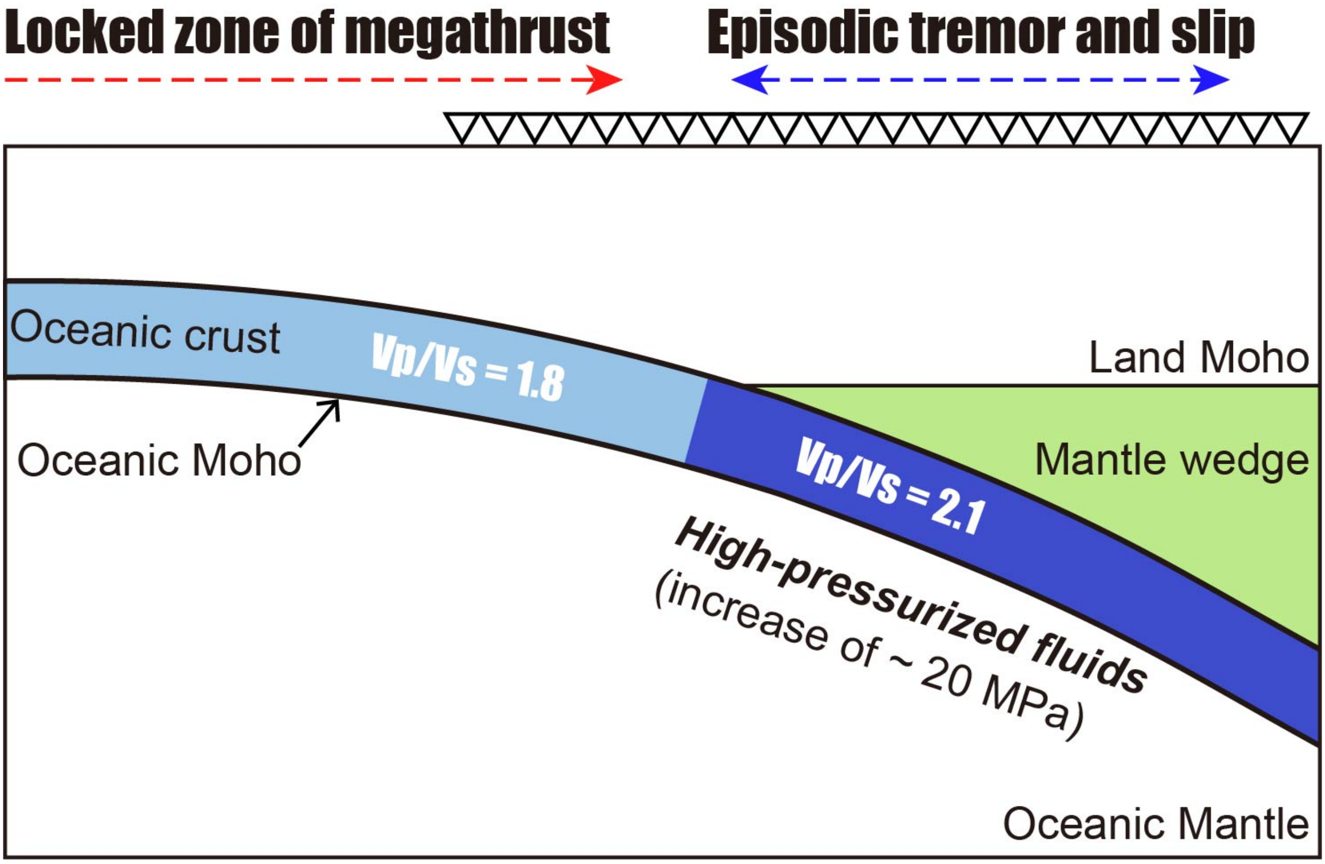
2. Data and Method

We deployed a dense linear seismic array from October 2011 to April 2013 on western Shikoku Island, SW Japan. We also used permanent stations near the array from the Hi-net network, operated by the National Research Institute for Earth Science and Disaster Prevention [Okada et al., 2004], and stations of the Japan Meteorological Agency. During the deployment period, we visually inspected seismograms of Mw ≥6 deep earthquakes with focal depths greater than 90 km and epicentral distances D < 25°. Using the transverse components of rotated seismograms from the array, we shifted the *ScS* phases relative to the arrival at the station having the highest S/N ratio by cross-correlating the *ScS* phase from the station with other *ScS* waveforms to achieve the maximum correlations. The vertical component data at each station were then time shifted by the corresponding time lags, relative to the station.

3. Results and Discussion

Based on comparisons of transverse and vertical component waveform data, we found clear, coherent signals arriving before *ScS* on the vertical components of most stations in the array. The travel time differences between *ScS* and *ScSp* increase along the direction of subduction. This means that the *ScS-to-ScSp* conversion point deepens to the northwest, indicating in turn that the converted waveforms propagate from the top of the subducting PHS Plate. Then, we simulated the propagation of synthetic *ScSp* waveforms using the JIVSM model [Koketsu et al., 2012]. However, the calculated *ScS-ScSp* travel time differences were systematically smaller than predicted by our observations. To improve the goodness of fit, we partitioned the LVZ into shallower and deeper parts around the upper corner of the mantle wedge, because the travel time difference between the observed and simulated waveforms was larger at the northern stations, toward which the LVZ is subducting. This change gave two different *S*-wave velocities in the LVZ. We conducted a grid search over the three-parameter space defined by two velocities, and the layer thickness *h* of the LVZ. To quantify the fit, we averaged the cross-correlation coefficients between observed and simulated *ScSp* phases. From the grid search results, the Vp/Vs ratio must be higher beneath the mantle wedge corner than at shallow depths, regardless of the assumed LVZ thickness. In the best model, Vp/Vs ratios within the subducting oceanic crust increase by 0.3 beneath the mantle wedge corner, where ETS has been observed. This high-Vp/Vs layer indicates the presence of high-pressurized fluids confined at ETS source depths. Based on extrapolation of laboratory measurements [Peacock et al., 2011], we infer that the observed changes in Vp/Vs ratios correspond to an increase in fluid pressure of ~20 MPa relative to the updip, locked zone (Figure 1).

Keywords: episodic tremor and slow slip, ScSp phase, high-pressurized fluid



Dynamics of rock fracture permeability explored through MEQs

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For the success of unconventional geothermal reservoirs (i.e. EGS), maintaining conduits with high-fluid-throughput is desirable. Hydraulic stimulation for such reservoirs is recognized as one of the most general ways to improve or maintain their crustal permeability, which is known as the key parameter controlling crustal fluid flow [*Ingebristen and Manning*, 2010]. During the hydraulic stimulation, in-situ microearthquakes (MEQs) data are basically recorded to capture the underlying active processes and the permeability evolution within the reservoir [*Majer et al.*, 2007], and these MEQs are in general regarded as signals that somehow represent permeability change in a fractured reservoir. If we have an insight into quantitative linkage between the permeability change and MEQ, such an insight is definitely useful for mapping in-situ permeability evolution in a reservoir. However, it remains ambiguous how much the fracture permeability is enhanced by a MEQ.

In the present study, we explore a linkage between fracture permeability change and MEQs. For this purpose, we first prepared heterogeneous aperture distributions for rock fractures with various combination of fracture length (m), l, and shear displacement (m), d, according to the method of *Ishibashi et al* [2015]. Through the analyses of these aperture distributions, scale dependencies of fluid flows through joints, i.e. fractures without shear displacement, and faults, i.e. fractures with shear displacement of d (m), are predicted as followings. Both joint and fault aperture distributions are characterized by a scale-dependent geometric mean and a scale-independent geometric standard deviation of aperture. Changes in the geometric means of joint and fault apertures (mm), $e_{\mathrm{m,\ joint}}$ and $e_{\mathrm{m,\ fault}}$, with fracture length (m), l, are approximated by $e_{\mathrm{m,\ joint}} = 1.3\times10^{-1} l^{0.10}$ and $e_{\mathrm{m,\ fault}} = 1.3\times10(d\ /l)^{0.59} l^{0.71}$, whereas the geometric standard deviations of both joint and fault apertures are approximately 3. Fluid flows through both joints and faults are characterized by formations of preferential flow paths (i.e., channeling flows) with scale-independent flow areas of approximately 10%, whereas the joint and fault permeabilities (m^2), k_{joint} and k_{fault}, are scale dependent and are approximated as $k_{\mathrm{joint}} = 9.8\times10^{-13} l^{0.16}$ and $k_{\mathrm{fault}} = 2.3\times10^{-6}(d\ /l)^{1.18} l^{1.08}$. By coupling these scaling laws with the concept of moment magnitude [*Hanks and Kanamori*, 1979], quantitative change in mean aperture ($e_{\mathrm{m,\ fault}}/e_{\mathrm{m,\ joint}}$) and fracture permeability ($k_{\mathrm{fault}}/k_{\mathrm{joint}}$) are successfully linked with moment magnitude of MEQs (M_w) during hydraulic stimulation for a reservoir as $e_{\mathrm{m,\ fault}}/e_{\mathrm{m,\ joint}} = 1.0\times10^{0.35Mw}$ and $k_{\mathrm{fault}}/k_{\mathrm{joint}} = 116.4\times10^{0.46Mw}$. Validity of the equation will be discussed through comparisons with some data of real field development/experiments (e.g., EGS system in Basel and Soultz-sous-Fôret).

In summary, such linkages may enable rough inverse-mapping of evolving fracture permeabilities using in-situ MEQ data. This mapping will facilitate new insights into transport phenomenon within the Earth’s crust and it relevant to engineering and scientific applications such as the development of geothermal or hydrocarbon reservoirs and clarification of earthquake mechanisms.

Keywords: rock fracture, permeability, surface topography, microearthquake

Bidirectional replacement zoning developed in metasomatic reaction of olivine and its implication for development of mesh zoning of serpentinites

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Serpentnization reaction, which occur though a coupled process of mass transfer, surface reaction, and volumetric expansion, affects both chemical and physical properties of oceanic lithosphere. Mesh texture characterizes most serpentinized peridotite. Mesh rims are considered to be formed via precipitation from a fluid bringing Mg, Fe, and Si into the rock from external resources (e.g., Andreani, 2004, 2007), or replacement reaction after/before mesh core formation (e.g., Beard et al., 2009; Schwarzenbach et al., 2016); However, it is difficult to interpret the processes of mesh texture development and related volumetric changes and mass transfer from texture.
In this study, we conducted hydrothermal experiments using mineral powder of plagioclase and olivine, and found Al-rich serpentine (Al-serpentine) which has a characteristic chemical zoning was formed around contacts between olivine and plagioclase via metasomatic reaction of Si and Al, while lizardite + brucite + magnetite was formed at far from the boundary. Al content in Al-serpentine once decreases from core to rim, and increases. At the center of chemical zoning which has relative low Al content, and a clear outline is observed in its texture. It could be interpreted that the outline preserves an outline of pre-existed olivine, therefore it suggests reaction front propagated both inside and outside direction of olivine. The chemical zoning was formed due to changes of Si and Al concentration in reacting fluid which may occur via metasomatic reaction front propagation. Hydration reaction proceeds toward inside direction requires removal Mg, Fe, and Si to fluid on serpentinization. The removed components from olivine and Si and Al from plagioclase were transported to pore and precipitated at outside.
This experiment used mineral powder (25-53μm) and initial porosity is ~40%; therefore, our experimental results represent an analogue of serpentinization in natural hydrothermal systems with a high porosity such as serpentinization of highly fractured peridotite. It is usually considered that mesh core and rim were formed in another stage. Our result showed a large mass transfer were required on iso-volumetric serpentinization which proceeds toward inside, and reaction towards inside proceeds to make mesh core and reaction towards outside proceeds to make mesh rim, simultaneously; therefore, mesh rim and core could be formed in same stage. On that, the thickness of mesh core represents the thickness of olivine that has been replaced while mesh rim was enlarged with volumetric expansion.

Keywords: serpentinization, mass transfer, mineral replacement, metasomatism, hydrothermal experiment

Seismic velocity and seismicity in the subducting crust of the Pacific slab beneath the eastern part of Hokkaido

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Fluid in subduction zones is considered to play important roles for genesis of intermediate-depth earthquakes (e.g., Kirby et al., 1996) and arc magmatism (e.g., Nakajima et al., 2013). The subducting crust located at the uppermost part of the oceanic plate involves a large amount of water in form of hydrous minerals, and released fluid by dehydration reaction of the hydrous minerals lowers seismic velocity (Hacker et al., 2003). Therefore, it is important to reveal the detailed seismic velocity structure in the subducting crust to understand seismogenesis and water circulation in the subduction zones.
At the western side of the Hidaka mountain range, distinct later phases are often observed for intermediate-depth earthquakes in the Pacific slab (e.g., Shimizu and Maeda, 1980; Abers, 2005). The later phases that are recorded for earthquakes occurred near the upper boundary of the Pacific slab are interpreted as guided waves propagating in the subducting crust (Shiina et al., 2014).
In this study, we estimated P- and S-wave velocities in the subducting crust beneath the eastern part of the Hokkaido by using travel times of the guided waves. The number of earthquakes that guided-P and the guided-S waves were identified in this study were 315 and 275, respectively. Then, we obtained P-wave velocity of 6.5-7.5 km/s, S-wave velocity of 3.6-4.2 km/s, and Vp/Vs of 1.80 at depths of 50-100 km. The P- and S-wave velocities at depths shallower than 80 km are lower than those expected for the fully-hydrated MORB (e.g., Hacker et al., 2003), and the low-velocity anomalies can be explained by the existence of 1 vol% of aqueous fluid.
The P-wave velocity obtained at depths of <80 km beneath the eastern Hokkaido is coincident with that observed in Tohoku (Shiina et al., 2013), while the P-wave velocity at depths of 80-100 km are faster than that estimated in Tohoku district. It is expected that temperatures around the upper boundary of the Pacific slab beneath the eastern Hokkaido are higher than beneath Tohoku, as a result of an oblique subduction of the Pacific slab (e.g., Kita et al., 2010; Abers et al., 2013; Wada et al., 2015). High temperatures beneath eastern Hokkaido may affect location of dehydration reactions of hydrous minerals and fluid migration paths from the subducting crust to the mantle wedge. Therefore, the differences in P-wave velocities between the eastern part of Hokkaido and Tohoku at depths of 80-100 km may be caused by the differences in the amount of fluids trapped in the crust.

Keywords: Subducting crust, Seismic velocity, Guided wave, Upper plane seismic belt

Three-dimensional numerical modeling for subduction thermal regime, slab dehydration, and mantle flow beneath Kanto to Tohoku, Japan

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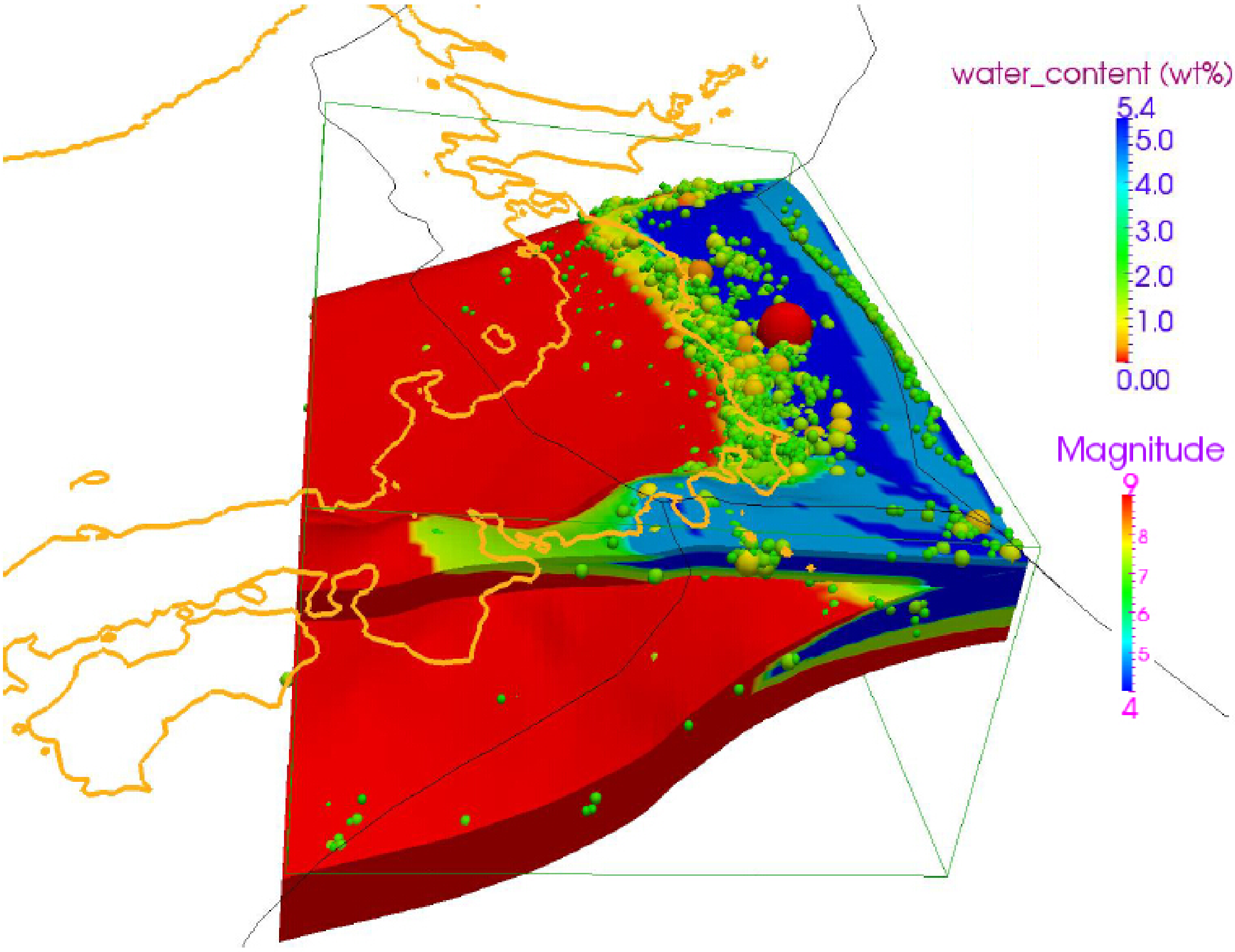
To better understand thermal regimes of the interplate and slab-slab contact zone undergoing subduction upon convergence such as in Kanto to Tohoku, Japan, we developed a parallelepiped three-dimensional thermal convection model to simulate simultaneous subduction of the overlapped Philippine Sea and the Pacific plates. We investigated the interactive slab thermal regime and mantle flow associated with such a unique geodynamic process, using simplified and realistic models. Results showed that: (1) cold anomaly was found to exist predominantly on the slab contact zone, resulting in a cold triple-plate junction corner immediately above the zone with an estimated temperature colder by approximately ~300°C beneath Kanto than Tohoku. As a result, delay in slab dehydration takes place and accounts for the distribution of low seismic velocities in the slab contact zone; (2) a relative subduction direction that yields the obliquity or asymmetry of the thermal structure in the slab contact zone, which corresponds to thermally controlled clustered seismicity on the southwestern half of the slab contact zone probably due to the delayed slab dehydration; (3) induced flow in the continental mantle was related to the straight component of subduction velocity of the lower oceanic plate more than to slab thickness. Interaction between the two oceanic plates determined the induced poloidal and toroidal convections in the continental mantle. In the sandwiched mantle wedge, the mantle flow induced by the Pacific plate is predominant, and reaches depths of 30~100 km beneath Kanto, which is shallower than Tohoku, and attributable to the double subduction; (4) thermal regime and dehydration of MORB near the upper surface of the subducted Pacific plate is considered to control distribution of seismicity beneath Tohoku and Kanto.

Keywords: slab dehydration, dual subduction, numerical simulation, thermal regime


water_content (wt%)
5.4
5.0
4.0
3.0
2.0
1.0
0.00
Magnitude
9
8
7
6
5
4

Geo-fluids distribution in mantle inferred from the electrical conductivity and simulated thermal structures beneath Kyushu

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The Kyushu Island, at which the oceanic Philippine Sea Plate subducts into the mantle beneath the continental Eurasia Plate, is characterized by the northern and southern volcanic regions and the central non-volcanic region. Magmatism in the subduction zones is triggered by the addition of the oceanic slab-derived aqueous fluids (water) to the mantle, because solidus of the mantle rock falls by the addition of the aqueous fluids and partial melting of the mantle occurs. Thus the determination of geo-fluids (the aqueous fluids and the melts) distribution is essential to understand the magmatism in the Kyushu subduction zone including the non-volcanic region between the two volcanic regions.
We obtained an electrical conductivity structure (model) beneath the entire Kyushu Island using three-dimensional inversion analyses and found three conductive anomalies, which indicate the different intensity and spatial extent for the three regions, at the mantle in the model [Hata et al., 2015]. The difference is considered to originate in the content of geo-fluids in the mantle. We determined the temperature and melt fraction distributions (structures), as a function of a fixed water content, inferred from the electrical conductivity structure beneath the Kyushu Island by using petrological laboratory-derived results [Hata and Uyeshima, 2015]. The laboratory-derived results are the relation between electrical conductivity and temperature for four nominally anhydrous minerals (Olivine, Orthopyroxene, Clinopyroxene, and Garnet) and hydrous basaltic melt in solid and liquid phases of the mantle, and the relation between melt fraction and temperature for mantle rocks (peridotites) under a condition of isobaric hydrous mantle melting.
In this study, we aim to determine the content of both geo-fluids in the mantle beneath the Kyushu Island. Thus we use a fixed thermal structure, which is a simulated thermal model associated with the subduction of the Philippine Sea Plate [e.g., Yoshioka et al, 2008]. Then we determine the geo-fluids distribution by integrating the simulated thermal structure of the mantle, field-derived electrical conductivity structure of the mantle, and laboratory-derived electrical conductivity of the four mantle minerals and the basaltic melt. We will describe our approach to determine the content of the geo-fluids and show the water content distribution and the melt fraction distribution in the mantle beneath the Kyushu Island.

Dynamics of heat and material transportation during subduction initiation in the Setouchi Volcanic Belt

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Kowledge of subduction initiation is critical for better understanding dynamics of plate tectonics, but is difficult to obtain because of its episodic and transient nature resulting in incomplete and fragmental records. The key issue is elucidation of heat and material transportation in a subduction zone during the subduction initiation. The aim of this study is clarify spatial and temporal changes of thermal state and material distribution involved in volcanisms of the Setouchi Volcanic Belt to scrutinize subduction initiation by exploiting its excellent records of the processes of subduction initiation.

The Setouchi Volcanic Belt (SVB) in the Southwest Japan arc has a record of igneous activities which show temporally and spatially continuous distributions in the forearc region in the Miocene period. The SVB is characterized by the occurrence of primitive volcanic rocks such as high-Mg andesite (HMA) and basalt. Previous studies in the Shodoshima Island and Osaka argued that HMA magmas are generated by highly wet melting of the wedge mantle involving slab melt from the subducting young and hot Shikoku Basin in the early stage of subduction initiation (Furukawa & Tatsumi, 1999; Shimoda & Tatsumi, 1999; Tatsumi et al., 2006). However, there are several issues that must be addressed: (1) HMAs are very poor in water; (2) the estimated melting conditions for HMA and basaltic magmas are very disparate: hydrous and 1050 to 1150 ℃ vs. less hydrous and 1300 ℃, which are supposed to have been close in time and space in the mantle; and (3) the proposed magma genesis is highly dependent on data in a particular and restricted domain (< 20 km in width) in spite of the wide extension of SVB (600 km in width) consisting of several domains with higher concentration of volcanisms.

There are three sectors of higher frequency of volcanic rock distribution in the SVB on the scale of about 100km scale, each of which may correspond to a separated domain of magma generation. We selected north-eastern part of the Shikoku (NE Shikoku), as study area, where magma genesis has not scrutinized yet. We measured whole rock composition of lavas by using XRF, LA-ICP-MS, and ICP-MS and mineral chemical compositions of phenocrysts with EPMA, and obtained K-Ar ages for samples collected from this sector in the SVB.

Our estimation of a primary magma for HMAs in the north-eastern Shikoku, which is based not only on whole rock major element compositions but also on chemical zoning of phenocrysts, is more magnesian (> 11.6 wt% MgO) than that of the previous study. Geothermometer of Sugawara (2000) combined with liquidus drop after Méderd & Grove (2008) and alpha MELTS program (Ghiorso et al., 2001; Asimow et al., 2003) constrains melting condition of the primary magma as 1GPa and 1200-1240 ℃ with 1.5-0.9 wt % H_2O. The pressure and temperature are close to the basaltic magma generating conditions proposed by Tatsumi (1982). Because of the similarity of major element compositions, the generation conditions of the HMA magma could be common throughout the SVB. By contrast, the whole rock trace element compositions and K-Ar ages show spatial and temporal variations, which suggest variability in timing and extent of supply of a slab-derived component (marked by high LILE/HREE) and/or an enriched mantle component (marked by high HREE abundance). There is a tendency that these components were added in a later stage in a given area.

We argue that achievement of temperature over 1200℃ just beneath the crust for generation of HMA and basalt magmas with temporal changes of source material and involvement of slab-derived fluid components were caused by several local mantle upwellings. Such upwelling induced by the subduction initiation might have entrained slab and/or enriched source components at the leading edge of subducting slab.

Keywords: subduction initiation, high-Mg andesite, The Setouchi Volcanic Belt

Deformation and metasomatic histories of Pinatubo peridotite estimated from microstructural observation

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Deformation microstructures of olivine in naturally deformed peridotites are useful for examining the rheological properties and deformation history in the upper mantle. Particularly, slip system of deformed olivine is especially well known as an indicator for the deformation conditions, such as temperature, stress, pressure or water content. Here, we try to estimate the deformation history of deformed peridotite by means of the microstructural observation and slip system determination. Two types of amphibole-bearing harzburgite samples (namely P-3 and P-4) collected from Pinatubo volcano were analyzed using optical microscope, SEM, EBSD, TEM and STEM. Kawamoto et al. (2013) suggests that these peridotites were affected by the intense metasomatism. We report the relationship between the deformation history and metasomatic reaction.
Pinatubo peridotites are composed of relatively coarse olivine grains with several mm in size, and partly fine orthopyroxene and amphibole aggregate with tens to hundreds μm in size. The fine grained aggregate in P-4 is more than in P-3. The grain boundaries of the coarse grains exhibit irregular shapes. And these grains show the undulose extinction and well-developed subgrain boundaries. The coarse olivine grains contain a lot of fluid inclusions. Additionally, the fine olivine grains exist along the secondary inclusions within some coarse olivine grains.
The LPO patterns of the coarse olivine grains in the both samples imply the dominant activation of [100]{0kl} slip system, which is developed under high temperature, low pressure and dry deformation conditions. On the other hand, the dominant slip systems obtained from the direct characterization of dislocations by TEM are [100](001), [001](010) or [001](100), which activate under moderate to high water content condition. The discrepancy of the obtained slip systems is probably caused by the overprinting due to the changing of deformation conditions. Dislocation microstructures are more easily modified by later deformation events than LPOs.
We conclude from the characterization of microstructures in combined with the result of Kawamoto et al. (2013) that Pinatubo peridotite experienced deformation and metasomatic events in the following manner. Pinatubo peridotites have originally deformed under high temperature, low pressure and dry conditions in the back-arc region. Then, they have moved to the fore-arc region due to the corner flow, and have been affected by the fluid-related metasomatism. Finally, they have undergone the annealing process within the upwelling magma.
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Keywords: Olivine, Deformation, Metasomatism, Slip system

Dynamics of back-arc spreading

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To understand the dynamics of back-arc spreading, we perform 2D numerical simulations. This model is 1200 km depth and 4000 km width and is composed of continental crust, oceanic crust, upper mantle, mantle transition zone and lower mantle. Each rock types have a visco-plastic rheology prescribed by the temperature and pressure dependent linear viscosity, the effective frictional coefficient and the maximum yield stress. We focused on the effects of three parameters, the slab strength (the maximum yield stress), the Clapeyron slope of the 410 km phase transition and the strength of boundary between subducting and overriding plates (the effective frictional coefficient of the oceanic crust).
Most results show periodic change in slab geometry and back-arc spreading rate and their period changes with the parameters. The result for a low maximum yield stress (200 MPa) shows tightly folded slab geometry. The result for a high maximum yield stress (800 MPa) shows relatively flat slab geometry and continuous back-arc spreading. As geological observations show that most back-arc basins formed by 10-20 Myr spreading and the tightly folded slab has not been reported by seismic tomography, we think that the result for a moderate maximum yield stress (500 MPa) reproduce the processes in subduction zones well. We compare the results of simulations with the slab geometry and the history of back-arc spreading in the Izu-Bonin-Mariana subduction zone, and discuss the condition for the start and end of back-arc spreading.

Keywords: subduction zones, slab-mantle interaction, numerical model

