Noble gas and major element composition of deep groundwater in the fore-arc region of southwest Japan; widespread distribution of fluids dehydrated from the Philippine Sea Plate

*Noritoshi Morikawa[1], Kohei Kazahaya[1], Masaaki Takahashi[1], Akihiko Inamura[1], Hiroshi A Takahashi[1], Michiko Ohwada[1], Masaya Yasuhara[1,2], Tsutomu Sato[1]

1. Geological Survey of Japan, AIST, 2. RISSHO University

Chemical and isotopic studies including analyses of noble gases were conducted on the groundwater in the fore-arc region of southwest Japan (Kii Peninsula and Shikoku Island) where the Philippine Sea Plate is subducting. High $^{3}He/^{4}He$ ratios relative to the atmospheric value (up to 6.7 Ra) were observed throughout the studied area, covering a wider area than documented previously. From the wide distribution of high $^{3}He/^{4}He$ values and the associated ^{20}Ne and Cl^{-} concentrations, Morikawa et al. (2016) infer that aqueous fluids derived from dehydration of the subducting slab are present at depth beneath the entire peninsula. These aqueous fluids may ascend along the major north-dipping boundary faults. The variety of water types documented may be due to water–gas separation and the subsequent incorporation of gaseous species into shallow meteoric groundwater. The observed high $^{3}He/^{4}He$ ratios in the absence of a mantle wedge below the southern part of the Kii Peninsula may reflect the oblique ascent of these fluids along north-dipping boundary faults.
As already reported by Dogan et al. (2006) and Umeda et al (2006), moderately high-$^{3}He/^{4}He$ groundwater has been observed on Shikoku Island, west of the Kii Peninsula, although no sampling point exceeded 4 Ra. By analogy with the Kii Peninsula, incorporation of the ascending fluids along faults accounts for the groundwater of this area, but this moderately high $^{3}He/^{4}He$ ratio (< 4 Ra) is possible to relate the slab configuration. The depth of the slab surface is relatively shallow, and therefore the thickness of the mantle wedge beneath Shikoku Island is less than that below the Kii Peninsula, resulting in a low mantle-He budget around the pathway of the fluids.

References: Dogan et al. (2006) *Chem. Geol.,* **233**, 235-248, Morikawa et al. (2016) *Geochim. Cosmochim. Acta*, **182**, 173-196, Umeda et al. (2006) *Geochem. Geophys. Geosyst.* **7**, Q04009, doi:10.1029/2005GC001210

Keywords: noble gas, groundwater, Philippine Sea Plate, helium, Kii Peninsula

Characteristics of slab-derived fluids beneath Kii Peninsula, southwestern Japan inferred from seismic tomography

*Takuo Shibutani[1], Kazuro Hirahara[1]

1. Kyoto University

1. Introduction

In order to investigate behavior and nature of slab-derived fluids discharged from the Philippine Sea plate subducting beneath Kii Peninsula, southwestern Japan, we carried out linear array seismic observations, receiver function analyses and seismic tomography. We estimated the geometry of the slab and the seismic velocity structure beneath the Kii Peninsula, and discussed the behavior of the fluids with the distribution of low velocity anomalies. We are now understanding relations between the fluids and deep low frequency events and active micro seismicity beneath the northern Wakayama Prefecture.

2. Receiver function analysis

We carried out linear array seismic observations in the Kii Peninsula from 2004 to 2013. We deployed seismometers along profile lines with an average spacing of ˜ 5 km. We applied receiver function analyses and obtained images of S wave velocity discontinuities. We estimated 3D configurations of the continental Moho, the slab top and the oceanic Moho from receiver function images for four profile lines in the NNW-SSE direction which is the dip direction of the Philippine Sea slab and for two profile lines in the NNW-SSE direction that is almost perpendicular to the dip direction.

The continental Moho, the slab top and the oceanic Moho are clearly found in the receiver function images. A new knowledge obtained by the analysis is that the continental Moho dips upward in the southeast direction above the Philippine Sea slab.

3. Seismic tomography

We carried out seismic traveltime tomography with FMTOMO (Rawlinson et al., 2006) in which a robust wavefront tracking (de Kool et al., 2006) is implemented for the theoretical travel time calculation and the ray tracing. We used a velocity model with the 3D geometries of the three discontinuities derived from the receiver function analysis. We also used observed travel times at temporary stations in the dense linear arrays in addition to permanent stations. A dense distribution of the temporary stations contributed to higher resolutions of tomographic images. We used 231,650 P travel times and 210,142 S travel times from 3,445 local events during May 2004 –March 2013. We also applied the four-step approach by Ramachandran and Hyndman (2012) to estimate accurately Vp/Vs ratios.

Results of the tomography show that low velocity anomalies (> 5 % in both P and S wave velocities and high Vp/Vs ratio > 1.8) are located in deep low frequency events areas at 30 –40 km depths on the Philippine Sea slab and that another strong low velocity anomaly (> 10 % in P wave velocity and low Vp/Vs ratio < 1.6) is widely distributed in the lower crust beneath the northern Wakayama Prefecture where small to micro earthquake activity is very high in the upper crust (Figure 1). The first feature can be due to discharged H_2O from hydrous minerals in the oceanic crust at 30 –40 km depths. The second feature can be explained by a mechanism that fluids upwelling from the low velocity anomaly in the lower crust increase the pore pressure in existing cracks in the brittle upper crust. The low Vp/Vs ratio in the low velocity anomaly beneath the northern Wakayama Prefecture might indicate that the low velocity body is deposited silica.

We used waveform data from permanent stations of NIED; JMA; ERI, Univ. of Tokyo; Nagoya Univ. and DPRI, Kyoto Univ.

Keywords: tomography, slab-derived fluids, Kii Peninsula

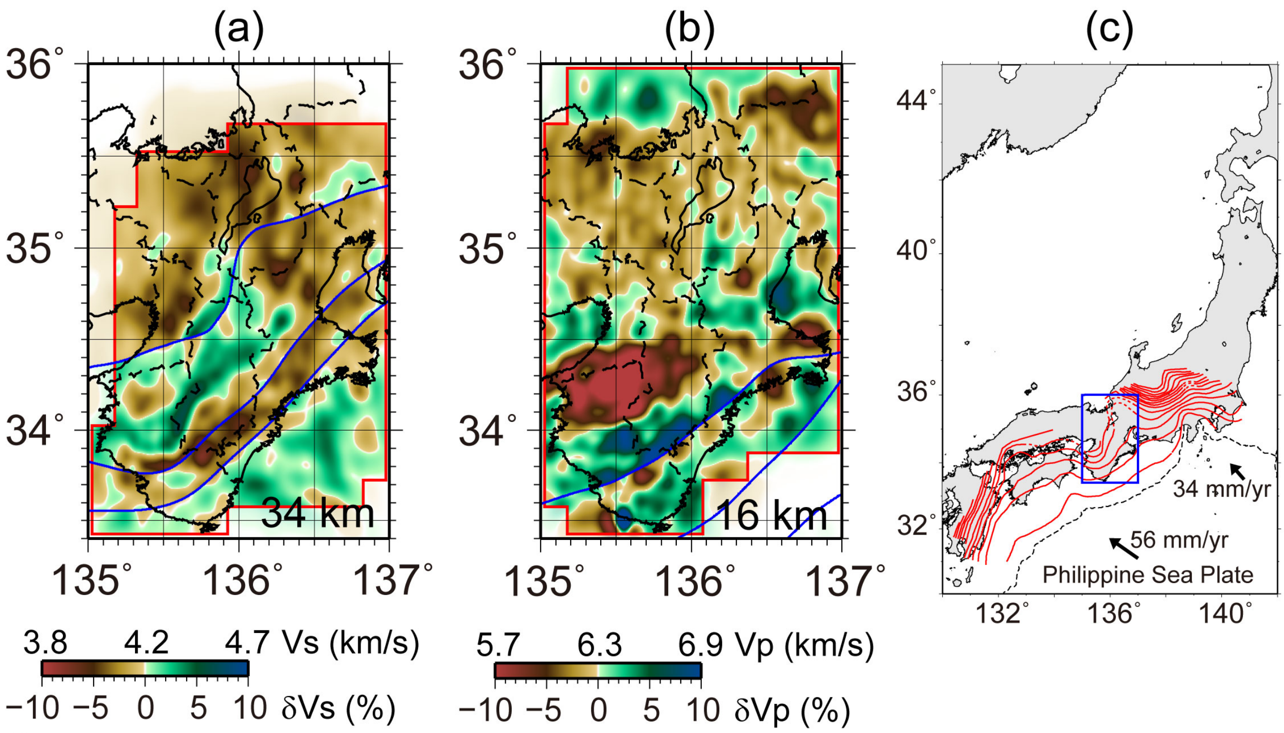


Figure 1
Heterogeneous distribution of seismic wave velocity in and around Kii Peninsula.
(a) Perturbation of S wave velocity at 34 km depth from the reference velocity of 4.23 km/s. The blue lines denote the continental Moho, the slab top and the oceanic Moho from the north to the south. The broken lines indicate prefectures' borders.
(b) Perturbation of P wave velocity at 16 km depth from the reference velocity of 6.28 km/s.
(c) A map showing the location of our study area (blue rectangle). The broken lines indicate Nankai and Sagami troughs. The red lines show contours of the Philippine Sea slab. The arrows indicate velocities of the Philippine Sea plate.

Major components and salinity of slab-derived fluids: insights from fluid inclusions in jadeitites and jadeite-quartz rocks

*Miki Shigeno[1], Yasushi Mori[1], Tatsuhiko Kawamoto[2], Tadao Nishiyama[3]

1. Kitakyushu Museum of Natural History and Human History, 2. Kyoto University, 3. Kumamoto University

Slab-derived fluids play important roles in mass transfer in subduction-zone channels between the subducting slab and the mantle wedge (e.g., Bebout, 2013). High salinity of the slab-fluids probably enhances the mobility of elements such as Pb in subduction-zone channels (Keppler, 1996). Salinity is important to affect solubility and fluid-rock partitioning of elements. Jadeitites and albitites occur as tectonic blocks in serpentinite mélanges intercalated to high-pressure and low-temperature metamorphic rocks. Therefore, fluid inclusions of them are expected to record information of the fluid composition in serpentinized mantle-wedge. Especially, jadeitites have index minerals of metamorphic conditions such as jadeite, quartz, albite and analcime. Jadeitites have been noted on relationships to fluids in subduction-zone channels; they are products of direct precipitation from aqueous fluids (P-type) and/or of fluid-induced metasomatism of a protolith (R-type) (e.g., Harlow et al., 2007, Tsujimori & Harlow, 2012). Albitite-rinds around quartz-bearing jadeitites are developed by metasomatism during retrogression (Shigeno et al., 2012b).

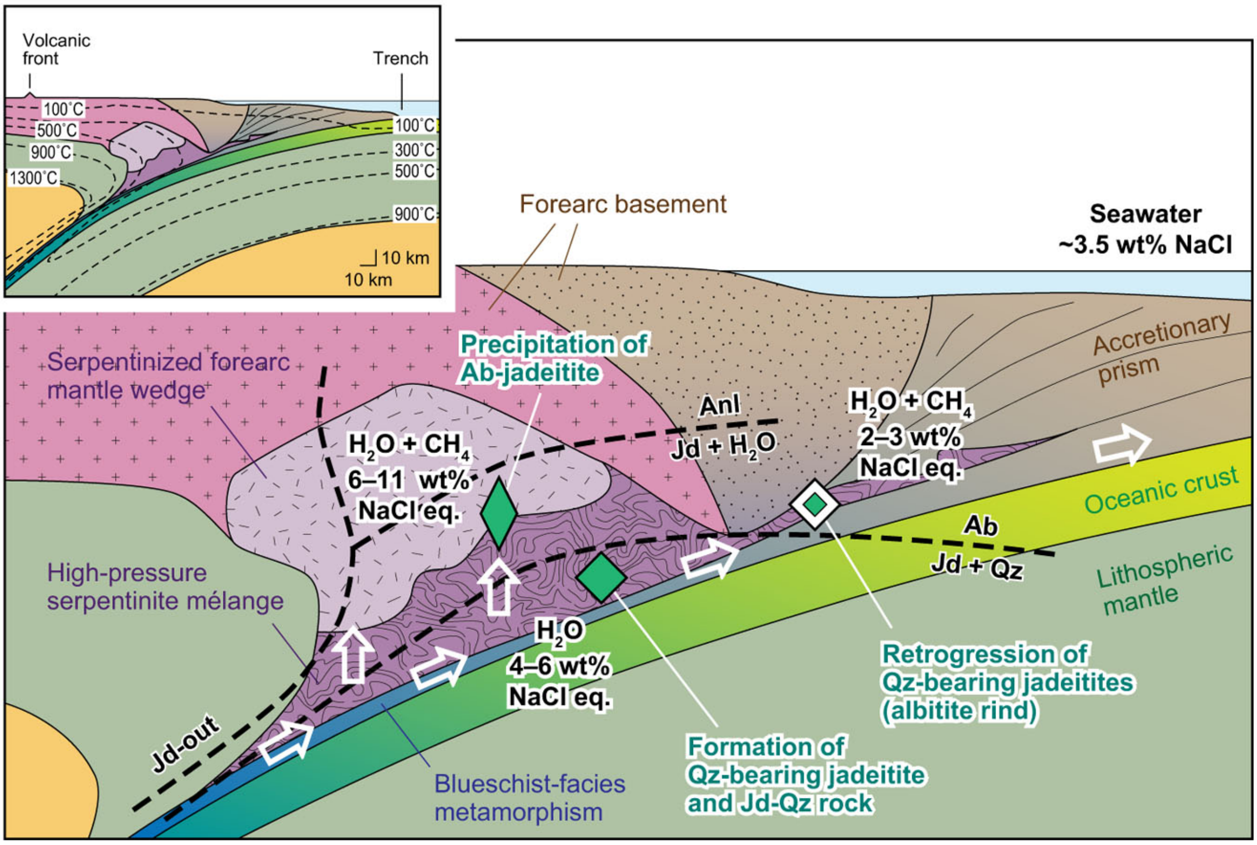
We investigated major components and salinity of fluid inclusions (liquid + gas bubble) in jadeite-quartz rocks (Kamuikotan, Yorii), quartz-bearing jadeitite with albitite rind (Nishisonogi), albite-jadeitites (Itoigawa, Oya) in Japan. The quartz-bearing jadeitite from Nishisonogi is a pale blue-green rock including quartz inclusions in the core of jadeite crystals (Shigeno et al., 2005). Investigation of mineral-inclusions of zircon revealed that the quartz-bearing jadeitite from Nishisonogi and the jadeite-quartz rock from Yorii were R-type (Mori et al., 2011, Yui & Fukuyama, 2015). The jadeite-quartz rocks show green-grey color and consist of subhedral jadeite and quartz. The albite-jadeitites are pale grey rocks, and show signature of P-type jadeitites such as euhedral jadeite crystals and interstice of albite.

Major components and salinity of fluid inclusions were examined by Raman spectrometry and by freezing point depression using heating/freezing stage. Raman spectrometry showed that primary fluid inclusions in jadeite-quartz rocks, quartz-bearing jadeitite and albitite rind of quartz-bearing jadeitite are H_2O liquid and vapor. In albite-jadeitite, primary fluid inclusions are H_2O liquid and vapor with CH_4. The modes of salinity of jadeite-quartz rocks, quartz-bearing jadeitite, albitite rind of quartz-bearing jadeitite are less than 6 wt% NaCl eq. The modes of salinity of fluid inclusions in albite-jadeitites are more than 6 wt% NaCl eq. Many secondary fluid inclusions are H_2O + CH_4 and tend to show higher or lower salinity than each mode.

These results and reaction curves are summarized in Fig.1. These results indicate that salinity distribution of slab-derived fluids and their difference depend on distance from surface of subducting slab. They are possible to explain different appearance, origin and metamorphic conditions (mineral assemblages) of two types of jadeitite as well as contents of fluid inclusions and salinity.

Fig. 1. Schematic model showing the major components and salinity of slab-derived fluids and the formation of jadeite-quartz rocks, quartz-bearing jadeitite with albitite rind, albite-jadeitites in forearc mantle wedge. The figures are not to scale. Modified from Harlow et al. (2015). Mineral abbreviations: Ab = albite, Anl = analcime, Jd = jadeite, Qz = quartz.

Keywords: Slab-derived fluid, Salinity, Fluid inclusion, Jadeitite, Albitite



In situ X-ray diffraction studies of hydrous aluminosilicate at high pressure and temperature

Ryota Abe[1], Yuki Shibazaki[2], Shin Ozawa[1], Itaru Ohira[1], Hiromu Tobe[1], *Akio Suzuki[1]

1. Department of Earth and Planetary Materials Science, Faculty of Science, Tohoku University, 2. Frontier Research Institute for Interdisciplinary Sciences, Tohoku University

Water is transported into the deep Earth’ s interior by hydrous minerals in the descending slabs. Previous studies showed that hydrous aluminosilicate would be stable in the mid-ocean ridge basalt and the sedimentary layer of subducting slab. Discovery of phase egg in the diamond inclusion also supports that hydrous aluminosilicate could exist in the earth’ s deep interior. Topaz-OH ($Al_2SiO_4(OH)_2$) is stable in the pressure range of 8-12 GPa and transforms to Topaz-OH II and Al-phase D under high pressure condition. However, the phase relation of $Al_2SiO_4(OH)_2$ has not been clarified yet.
In order to determine the phase relation of hydrous alminosilicate experimentally, we have conducted an in situ X-ray diffraction study at high pressure and temperature using Kawai multi-anvil high pressure apparatus and intense X-ray of synchrotron radiation at SPring-8. The truncated edge length of the anvil is 3 mm. The pressure medium was made of ZrO_2 and Co-doped MgO. We used a TiB_2 tube heater with a Boron epoxy window for the X-ray path and the W3%Re–W25%Re thermocouple for monitoring temperature of the experiments. Pressure was calculated from the equation of state of gold.
We found that hydrous phase of δ-AlOOH and stishovite were stable in the pressure range of 22-30 GPa and the temperature range of 800-1500 ℃. Al-phase D was found at 24 GPa, 1500 ℃ coexisting with phase egg. Al/Si ratio of Al-phase D was approximately 1.85, which was less than ideal composition.

Keywords: hydrous alminosilicate, synchrotron X-ray diffraction, lower mantle, subducting slab

In situ observation of wet solidus from xenoliths and its control on rheological structures of lithospheric mantle beneath Ichinomegata, NE Japan

*Yuto Sato[1], Kazuhito Ozawa[1]

1. Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo

A fundamental question about lithosphere-asthenosphere boundary (LAB) is what causes the rheological contrast between lithosphere and asthenosphere. Two major proposed solutions for this problem are: (1) abrupt appearance of interstitial melt (e.g. Hirschmann 2010, Green 2010) and of hydroxyls (e.g. Karato 2010, 2012) in the top of asthenosphere. In order to address this issue in the arc environment, where hydrous upper mantle is expected, we investigate depth variations of deformation microstructures and presence or absence of fluid/melt phase in mantle xenoliths from Ichinomegata volcano, where reliable estimates of derivation depths of the xenoliths are available.
Ichinomegata volcano is a 60-80 ka mar (Kitamura 1990) located on Oga peninsula, in a back-arc side of NE Japan. In this area, active subduction of the Pacific Plate beneath the North American Plate has been supplying water to the overlying wedge mantle (e.g. Kumagai et al. 2014). Mantle xenoliths were found in andesitic-dacitic pyroclastic rocks (Katsui et al. 1979). They are either plagioclase- (and/or spinel-pyroxene symplectite after plagioclase) bearing or plagioclase-absent spinel peridotites (Takahashi 1978, 1986). We examined three plagioclase peridotites and six spinel peridotites to identify phases and microstructures along grain boundaries and their distributions.
Interstitial phases were examined with FE-SEM. Fluid phase is identified by the presence of fluid inclusions in olivine and etch pits on the interphase boundaries. Melt phase is identified by the presence of interstitial glass containing vesicles with growth textures of contacting olivine. Two equigranular and tabular granular plagioclase peridotite containing pargasite, one granular spinel peridotite, and one porphyroclastic spinel peridotite are shown to have fluid phases. Two porphyroclastic spinel peridotites, one porphyroclastic spinel peridotites containing amphibole as inclusion in clinopyroxene, and one equigranular spinel peridotites are shown to have melt phase according to above criteria. The chemical compositions of glasses and their petrographic features are consistent with those reported by Takahashi (1986). The samples with interstitial melt recorded a rapid heating event (referred as "preheating" by Takahashi (1986)), and exhibit homogeneous Ca distribution in olivine suggesting persistence (>1000 yrs) of "preheating" forming interstitial melt.
The xenolith samples were compared in terms of the rock textures, depths, and temperatures before xenolith extraction, which are based on pressure-dependent thermometers of T_{BKN} and $T_{Ca\text{-}in\text{-}Opx}$ (Brey and Köhler 1990) from chemical compositions of pyroxenes rims (see our companion presentation). There are systematic correlations between the presence of fluid/glass with rock textures, phase assemblage, and pressure and temperature conditions. Fluid phase is found in equigranular samples registering low pressure and temperature (0.7-1.2 GPa and 831-1016 ˚C), and melt phase in porphyroclastic samples registering high pressure and temperature (1.2-1.6 GPa and 1045-1084 ˚C). The boundary between the disappearance of the presence/absence of melt and fluid is ca. 1.2 GPa and 1000 ˚C, which are almost the same as the wet peridotite solidus experimentally determined by Grove et al. (2006). The coincidence of textural transition from equigranular to porphyroclastic and that of intergranular phases from fluid to melt during high temperature "preheating" stage suggests that the appearance of interstitial melt at high-temperature at wet solidus might govern the rheology of hydrous wedge mantle. The wet solidus may have migrated according to the thermal state beneath the LAB, which might represent dynamics of the

LAB region hypothetically assumed above hydrous wedge mantle.

Keywords: wedge upper mantle, petrology, rheological structure, LAB

Effects of temperature, melt, and volatile on polycrystal anelasticity: Toward the application to subduction zone

*Hatsuki Yamauchi[1], Yasuko Takei[1]

1. Earthquake Research Institute, The University of Tokyo

Recent progress in the experimental approach to the polycrystal anelasticity shows that the reduction of seismic velocity and Q by partial melting occurs in two stages: reduction just before partial melting and that at the onset of partial melting [Yamauchi and Takei 2016]. This new experimental result significantly affects the interpretation of the upper mantle seismic structures. We present a new anelasticity model derived from these new data, together with some applications to the oceanic mantle. The new model is sensitive to the volatiles, which play important roles in subduction zones.
We measured elasticity, anelasticity, and viscosity of polycrystalline aggregates at near-solidus temperatures ($0.89 =< T/T_m =< 1.01$; T_m = solidus temperature), by using organic polycrystals (borneol + diphenylamine binary eutectic system, eutectic temperature T_m = 316 K) as partially molten rock analogue [Yamauchi and Takei 2016]. The results showed that the high-frequency part of the attenuation spectrum was significantly enhanced just below the solidus temperature ($0.94 < T/T_m < 1$) in the absence of melt. In this temperature range, viscous deformation was also enhanced. These changes are called subsolidus effects. The onset of melting at $T = T_m$ caused further enhancement of the elastic, anelastic, and viscous deformation. These changes are called direct effects of melt. When the samples can produce very small amounts of melt (Φ= 0.4 –0.5%) at $T = T_m$, the direct effects of melt were negligibly small, but the subsolidus effects were large. Therefore, due to the subsolidus effects, a region without melt or with a very small amount of melt can be detected as low V and low Q region. We performed a detailed parameterization of the subsolidus effects and presented a new anelasticity model.
The new model successfully explained the steep reduction of shear wave velocity just below the solidus temperature observed near the Pacific ridge [Priestley and McKenzie 2013]. Because the model includes the nondimensional parameter T/T_m, the solidus depression by volatiles affects the prediction of seismic velocity and attenuation under a given T. So far, the application of this model to the upper mantle is limited to the oceanic mantle, where melt fraction is expected to be very small (Φ<< 1%) even beneath the ridge axis. In the subduction zone, melt fraction in the mantle wedge can be larger, and the direct effects of melt may not be negligible. Although the direct effects of melt on elasticity and viscosity are understood well, the direct effect on anelasticity has a large uncertainty. Hence, further experimental study is needed before the application to the subduction zone. Although Yamauchi and Takei [2016] showed that the direct effect of melt on anelasticity is non-negligible for Φ> 1%, quantitative assessment is difficult, because the samples with Φ> 1% used in this previous study had a connected network of solidified melt at $T < T_m$. We are planning an improved experiment to clarify the direct effect of melt on anelasticity, particularly, the effect of melt connection on anelasticity.

Keywords: anelasticity, partial melting, seismic attenuation, seismic low velocity, melt network

