Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SIT06-01 Room:104 Time:May 22 09:00-09:15

On the space scale of fluid interconnection for the high electrical conductivity of the crust and uppermost mantle

Michihiko Nakamura[1*], Satoshi Okumura[1], Takeyoshi Yoshida[1], Osamu Sasaki[2], Eiichi Takahashi[3]

[1]Dept. Earth Sci., Tohoku Univ., [2]Tohoku Univ. Museum, [3]Dept. Earth & Planet. Sci., Tokyo Inst. Tech.

Our knowledge on the grain-scale fluid distribution is mostly based on microstructures of high-pressure experimental charges in a typically micrometer scale, whereas spatial resolutions of seismic tomography and magnetotelluric observations are both in a kilometer scale, thus there is a gap larger than 7 orders of magnitude. For estimating fluid fraction in the crust and mantle, it is necessary to clarify the critical length scale of fluid interconnection that determines the macroscopic physical parameters. A possible approach to lessen the gap is to observe xenoliths that were directly derived from the depths. For this purpose, we carried out Xray-CT observation of uppermost mantle and lower crust xenoliths from several localities in the world, including Ichinomegata (NE Japan), Eifel (Germany), SanCarlos and Kilbourne Hole (USA). Intergranular pores were observed in all the lherzolite and Hb-gabbro xenoliths from these localities, showing that the rocks were saturated with a free-fluid phase. The pore fluids are localized in interphase boundaries between different mineral phases, as found in the grain-growth experiment in a bimineralic system (Ohuchi and Nakamura, 2006, J. Geophys. Res.). Most of the monomineralic triple junctions are faceted and lack pore fluids, within the resolution limit of CT observation (typically 4-7 micrometer), thus pore fluids do not have larger scale interconnectivity. Although we do not rule out the possibility of presence of thinner, CT-imaginable fluid networks, such thin networks along grain edges and corners, if present, cannot account for the high electrical conductivity as observed for the crust and upper mantle of NE Japan arc. Fluid localization in a larger scale such as meterscale shear zones, or to the contrary, conductive 2D interphase boundaries of wet polycrystalline rocks are required.

Keywords: geological fluids, seismic tomogrphy, magnetotellurics, X-ray CT

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SIT06-02 Room:104 Time:May 22 09:15-09:30

Connectivity of fluids at the mid-crustal depths

Tohru Watanabe[1*]

[1]University of Toyama, Department of Earth Sciences

Geophysical explorations have been conducted to study the composition,structure and dynamics in the Earth's crust. A lot of detailed profiles of seismic velocity and electrical conductivity have been reported.

The observed electrical conductivity is generally higher than those of dry rocks by several orders of magnitude, suggesting that fluids (mostly aqueous fluids) prevail within the crust. The observed spatial variation of seismic velocity and electrical conductivity should thus reflect the distribution of fluids. Based on the velocity variation at the mid-crustal depths, the spatial variation of fluid volume fraction must be no more than a few%.

The observed spatial variation of electrical conductivity is often up to 4 orders of magnitude. This large conductivity change must occur over a narrow range of the fluid volume fraction. If the connectivity of fluid is identical, the conductivity is proportional to the fluid volume fraction. A small change in the fluid volume fraction cannot make a change of orders of magnitude. The observed large change in conductivity requires the increase of connectivity with increasing volume fraction of fluid. Such an increase of connectivity suggests that crustal fluids are generally in a critical state of interconnection.

I think that this critical state of fluid connection is self-regulated. If fluids are fully interconnected, the permeability becomes high enough to expel fluids rapidly. It leads to the decrease of interconnection, and to the decrease of permeability. If fluids are supplied from depths, the fluid is accumulated there to increase the permeability.

Keywords: crust, fluid, connectivity, electrical conductivity, seismic velocity, resistivity

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SIT06-03 Room:104 Time:May 22 09:30-09:45

Electrical conductivity of fluid-bearing rocks

Takashi Yoshino[1*], Akira Shimojuku[1], Xinzhuan Guo[1]

[1]Institute for Study of the Earth's Interior, Okayama Univ.

The electrical conductivity of dry crustal rocks is considerably lower than that of middle to lower crust determined by electromagnetic studies. On the other hand, the electrical conductivity structure of the crust determined by the MT method demonstrates that the regions showing high conductivity anomaly correspond to the root of a fault and hypocenter of an inland earthquake. Although it has been thought that these conductivity anomalies are originated from existence of fluid and melt, the conductivity of a fluid (especially water) under high pressure has not been measured because of its experimental difficulty. Therefore, in order to estimate the amount of fluid from electromagnetic observations, we need many assumptions such as the mixing model of fluid-rock system and given salt concentration. Since the supercritical fluid under high temperature and high pressure can contain high ion concentration, knowledge of fluid composition for typical crustal rocks is required to estimate fluid content from the observed conductivity values. However, electrical conductivity measurement of the fluid-bearing rock has not performed.

This study reports experimental results on electrical conductivity measurement of fluid-bearing rock. In our group, electric conductivity measurement of Quartz-H2O, Quartz-H2O-NaCl, and Albite-H2O systems has been performed as simple analog materials of the crust. We have measured as a function of temperature and the amount of fluid by the pressure of 1GPa. The aqueous fluid phase in samples was sealed using single crystal quartz capsule sandwiched by metal electrodes. First, Quartz-H2O system showed that electrical conductivity rises as the water content increases, and electrical conductivity also tends to increase with increasing temperature (Shimojuku et al. 2012). However, the electrical conductivity values were much lower than the observed ones. Because dominant solute in aqueous fluid in this system is electrically neutral Si(OH)4, the conductivity of fluid phase cannot increase largely. Therefore, to explain the observed high conductivity value, high concentration of ion as an electric charge carrier in aqueous fluid is required. For the system adding NaCl to Quartz+H2O, electrical conductivity showed almost no temperature dependency, but electrical conductivity increases with increasing salt concentration. Next we consider the case that the system contains alkali ion in fluid (Albite-H2O system). Unlike the Quartz+H2O system, temperature dependency was small but electrical conductivity once slightly decreases with increasing temperature then increases again at high temperatures. This trend agrees with the concentration change of a solute with the electric charge in the fluid via temperature. Thus, these observations suggest that even if temperature was low enough, fluid with certain ion concentration can produce the conductivity anomalies in the crust. If crust rock has dissolved into fluid as ionic charge, high NaCl concentration in fluid is not necessary to produce conductivity anomalies in the crust.

Keywords: electrical conductivity, fluid, crust

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SIT06-04 Room:104 Time:May 22 09:45-10:00

3D crustal fluid distribution by magnetotellurics around Naruko volcano

Yasuo Ogawa[1*], Masahiro Ichiki[2], Wataru Kanda[1]

[1]Volcanic Fluid Research Center, Tokyo Institute of Technology, [2]Graduate School of Science, Tohoku University

We have carried out wideband magnetotelluric measurements in order to map the distribution of fluids and melts under the volcanic arc in the NE Japan around the Naruko volcano. The area has several Quaternary calderas, such as Naruko, Onikobe, Sanzugawa and Mukaimachi calderas. The area has also high shallow seismicity and has one of the largest intraplate earthquakes, M7.0, in 2008 near the Kurikoma volcano. Thus the area is thought as a good test field to study the relation of fluids and volcanoes and intraplate earthquakes. We have 224 sites in total with average site spacing of ~5km. From the three-dimensional modelling we have imaged (1) subvertical conductors which shallows towards the active volcanic zones under Onikobe, Naruko and Sanzugawa calderas, and (2) seismic activities over the resistive zones above the crustal conductors, which implies earthquake triggering by fluid migration into the brittle crust.

Keywords: geofluid, electromagnetism, Naruko, volcano, earthquake

SIT06-05 Room:104 Time:May 22 10:00-10:15

Possible pathway of geofluid suggested by deep low-frequency earthquakes, scattered phase, and migration of earthquakes

Masahiro Kosuga[1*], Kazuma Masukawa[1]

[1]Graduate School of Sci. and Tech., Hirosaki Univ.

Migration of seismicity, reflected phase, and anomalous deep low-frequency earthquakes are possible seismic evidence of geofluid in the crust. All of these phenomena are observed near the Moriyoshi-zan volcano in Akita Prefecture located to the west of the volcanic front of northeastern Japan. Seismic activity around the volcano became quite high after the occurrence of the great 2011 Off the Pacific coast of Tohoku (Tohoku-oki) Earthquake. Among some earthquake clusters the one to the north of volcano has been the most active from May 2011 to date. The size of this cluster is about 3 km both horizontally and vertically. Since there is only one nearby seismic station to the west of volcano, we deployed temporary stations above the most active cluster on September 2012. Relocated hypocenters using data of temporal observation shows increased depth accuracy by the concentration of hypocenters around a depth of 7 km, whereas the depth of catalog location by the JMA spans from 8 to 10 km. Seismic activity in the most active cluster exhibits clear migration, however, the direction and speed are variable. The activity started near the center in the horizontal location, then migrated to the northeast, and jumped to the west, and migrated again to the south and to the north. This complex pattern suggests repeated injection of geoflud below the cluster, however, the temporal rate of migration is not clear due to insufficient accuracy of hypocenter location for the period before the temporal observation.

A prominent feature of the seismogram is a reflected/scattered phase observed at the station to the west of volcano. The time interval between this later phase and S wave depends on the hypoceneter location, suggesting gently dipping zone of scattereres to the west. This zone probably corresponds to a plane of refection estimated previously from the 1982 earthquake swarm.

The Moriyoshi-zan area is one of the source areas of deep low-frequency earthquakes occurring mainly beneath active volcanoes in the northeastern Japan. The low-frequency earthquakes that occur well below the elastic plastic boundary are interpreted as the events generated by the activity of geofluid. The westward bottom of reflector/scatterers is close to the upper limit of low-frequency earthquakes and the eastward top seems to reach the bottom of earthquake cluster. From this we can image a pathway of geofluid from the upper mantle to the source of cluster. However, to verify this idea, we need to estimate the location and temporal change of reflector/scatterers accurately using arrival times and waveform characteristics of the later phase.

Acknowledgement: We used hypocentral parameters and arrival time data of the JMA catalog that was prepared by the JMA and the Ministry of Education, Culture, Sports, Science and Technology in Japan. I thank the National Research Institute for Earth Science and Disaster Prevention (NIED) and Tohoku University for providing waveform data. This work was supported by JSPS KAKENHI Grant Number 21109002.

Keywords: geofluid, seismic activity, migration, scattering, low-frequency earthquakes

SIT06-06 Room:104 Time:May 22 10:15-10:30

LF-earthquakes, S-wave reflectors and Arima-type Brine: A model for Geofluid circulation in arc crust

Eiichi Takahashi[1*]

[1]Earth and Planetary Sciences, Tokyo Institute of Technology

<Introduction>: Kazahaya et al [2011] reported distribution of "Arima-type brine" in various part of Japan and they proposed that it represents fluid from deep source. "Arima-type brine" is featured by 1) high salinity: >3 times of sea water, 2) high CO2, 3) oxygen and hydrogen isotopes similar to those of island-arc andesite magmas. They proposed that it may have two origins 1) fluids derived from dehydration of subducting oceanic plate, 2) fluids derived from solidifying magma in the lower crust. Because of its vital importance in understanding the nature of deep fluids, I discuss the origin of "Arima-type brine" in the latter case.

<"Arima-type brine" originated from crustal partial melt>: Considering average heat flow and distribution of Quaternary volcanoes in Japanese island arcs, temperature of the lowermost crust would be >800degC and small amount of partial melt would exist almost ubiquitously regardless of the distribution of the Quaternary volcanoes. If partial melting takes place in the lower crust, aqueous fluids derived from subducting plates and those migrating in the mantle wedge should be trapped there and the composition of fluids in the crustal depth should be controlled by melt/fluid equilibrium at the base of the crust. Very high Cl and CO2 featuring "Arima-type brine" can be easily understood by considering melt/fluid element partitioning at the lower crustal depth, because Cl strongly partitions into fluid [2] and its CO2 solubility is high.

<Water eruption during the Matsushiro Earthquake Swarm>: More than 60000 earthquakes took place in Matsushiro, central Japan in 1965-1967 [Mogi, 1989]. Matsushiro earthquake swarm is featured by ejection of large amount of saline ground water since 1968 until today. Tsukahara and Yohida[2005] discussed the origin of the ground water eruption associated with Matsushiro earthquake swarm and proposed a model that the water may have derived from mid crustal "S-wave reflector" which is a reservoir for deep crustal fluids. Chemistry of the ground water (including isotopes) ejected from Matsushiro is indistinguishable from that of the "Arima-type brine". The "groundwater eruption" in Matsushiro strongly suggests that "Arima-type brine" may be stored at some crustal level locally in large volume. "S-wave reflectors" found in many areas in Northeast Japan (typically at 10~15km depth, [Hasegawa et al.2005]) may correspond with the deep crustal ground water reservoirs. Very low electric conductivity anomalies found in middle crust of subduction zones [Ogawa,Y. et al, 2007] may also represent reservoirs for high salinity crustal fluids.

<Formation of "S-wave reflectors">: Close correlation has been found between location of the lower crustal DLF earthquakes and the distribution of the middle crustal "S-wave reflectors" in Northeast Japan. If lower crustal DLF earthquakes correspond with the emission of fluids from solidifying magma body, fluids derived from lower crustal magma should have >5wt% SiO2 as well as Cl and CO2. Thus, large amount of silica and carbonate must precipitate from the fluid along ascent due to decreasing temperature and pressure. Deep fluids may be self-sealing as it ascends due to the precipitation of silica and carbonate. Judging from the depth distribution of the "S-wave reflectors" (reflectors situate at shallower depths near volcanoes), the depth of precipitation may be more sensitive to ambient temperature than pressure.

<Summary>: In summary, I propose that known features of the "Arima-type brine" may be explained in a coherent manner by considering melt/fluid equilibrium at deep crustal condition. Shallow crustal process (such as precipitation of silica and carbonate) would determine its final chemistry.

Keywords: Arima type brine, low frequency earthquake, S-wave reflector, Matsushiro earthquake swarm, geofluid circulation

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SIT06-07 Room:104 Time:May 22 10:30-10:45

Genesis of thermal water related to Iwaki-Nairiku earthquake

Kohei Kazahaya[1*], Tsutomu Sato[1], Masaaki Takahashi[1], Yuki Tosaki[1], Noritoshi Morikawa[1], Hiroshi Takahashi[1], Keika Horiguchi[1]

[1]Geological Survey of Japan, AIST

An earthquake (M7) occurred at 6 km depth on April 11, 2011 in Iwaki City, Fukushima, Japan. Thermal waters sprang out at 3 places in Iwaki just after the earthquake. Observed groundwater changes, such as flow rate and water level changes are thought to be due to volumetric strain changes occurred by the earthquake. The newly formed springs are still spouting as of Jan. 2013, and some of their flow rates do not decrease. Iwaki area is placed at a fore arc position of NE Japan and there are no volcanoes there. However, temperature of thermal waters found from bore holes (1000m deep) are up to 80 deg C, and heat source is unknown. The thermal NaCl waters thought to come from basement granite through the faults.

In this study, we analyzed chemical and isotopic compositions of thermal waters around Iwaki, to understand the cause of new springs formation and their origin.

From the analytical results, the thermal waters are classified into NaCl-type, and the stable isotopic composition of water suggests that they are of seawater origin. However, the chlorine concentration of the endmember of NaCl-type water is depleted in Cl, and Cl concentrations varied from 6000 mg/L to 20000mg/L similar to that of formation water found in oil fields. The age of saline water is determined to be from several hundreds thousand years to more than one million years, using Cl-36/Cl ratio of waters and chemical composition of rocks forming aquifers. The origin of NaCl water is possibly implied as 1) formation water from Joban-Oki Basin placed in Pacific Ocean 50 km east from Iwaki, or 2) dehydrated or squeezed water from the sediments of the subducting Pacific slab.

Keywords: Thermal water, Chemical, Isotopic, Iwaki, Earthquake

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SIT06-08 Room:104 Time:May 22 11:00-11:15

Mapping seismic anisotropy and heterogeneity of Japan subduction zone

Dapeng Zhao[1*]

[1]Tohoku University

We determined P and S wave tomography and 3-D P-wave anisotropic structure under the Northeast Japan arc from the Japan Trench to the back-arc area under the Japan Sea using a large number of P and S wave arrival times from local shallow and deep earthquakes recorded by the dense local seismic networks. Arrival times from many suboceanic earthquakes relocated with sP depth phases enable us to determine the 3-D structures under the Pacific Ocean and Japan Sea, which expand the study region from the land area to the whole arc from the Japan Trench to the Japan Sea with a width of more than 500 km. Our results show strong heterogeneities on the top of the subducting Pacific slab under the Pacific Ocean and most large thrust earthquakes occurred in the high-velocity (high-V) areas where the Pacific slab and the overriding plate are strongly coupled. Low-velocity (low-V) zones are imaged in the mantle wedge with significant along-arc variations under the volcanic front. The mantle-wedge low-V zones extend westward under the Japan Sea and are connected with the subducting Pacific slab at depths of 150-200 km under the back-arc. The results indicate that the H2O and fluids brought downward by the subducting Pacific slab are released into the mantle wedge by dehydration and are subsequently transported to the surface by the upwelling flow in the mantle wedge. Significant P-wave anisotropic anomalies are revealed under the Honshu arc. The predominant fast-velocity direction (FVD) is E-W in the mantle wedge while it is N-S in the subducting Pacific slab. The anisotropy in the mantle wedge is the result of deformation caused by the subduction of the Pacific plate and the induced mantle wedge convection, while the special pattern in the middle of the mantle wedge argues for the 3-D mantle flow or the specific alignment of the olivine in partially molten mantle. The N-S (trench-parallel) FVD in the subducting Pacific slab represents either the original fossil anisotropy when the Pacific plate forms or the trench-parallel crystal and shaped preferred orientation in the subducting slab due to the slab bending.

We also performed a detailed 3-D P-wave anisotropic tomography of the crust and upper mantle beneath Southwest Japan using P-wave arrival times from local earthquakes. The Philippine Sea (PHS) slab is imaged clearly as a high-V anomaly which exhibits considerable lateral variations. Significant low-V anomalies are revealed above and below the PHS slab. The low-V anomalies above the PHS slab may reflect the upwelling flow in the mantle wedge and the PHS slab dehydration, and they form the source zone of the arc volcanoes in SW Japan. The low-V zones under the PHS slab may reflect the upwelling flow in the big mantle wedge above the Pacific slab. The anisotropy in the crust and upper mantle is complex. In Kyushu, the P-wave FVD is generally trench-normal in the mantle wedge under the back-arc, which is consistent with the corner flow driven by the PHS slab subduction. The FVD is trench-parallel in the subduting PHS slab under Kyushu.

References

Huang, Z., D. Zhao, L. Wang (2011) Seismic heterogeneity and anisotropy of the Honshu arc from the Japan Trench to the Japan Sea. Geophys. J. Int. 184, 1428-1444.

Huang, Z., D. Zhao, L. Wang (2011) Shear-wave anisotropy in the crust, mantle wedge and the subducting Pacific slab under Northeast Japan. Geochem. Geophys. Geosyst. 12, Q01002.

Wang, J., D. Zhao (2012) P wave anisotropic tomography of the Nankai subduction zone in Southwest Japan. Geochem. Geophys. Geosyst. 13, Q05017.

Zhao, D. (2012) Tomography and dynamics of Western-Pacific subduction zones. Monogr. Environ. Earth Planets 1, 1-70. (www.terrapub.co.jp/onlinemonographs/meep/list.html)

Zhao, D., T. Yanada, A. Hasegawa, N. Umino, W. Wei (2012) Imaging the subducting slabs and mantle upwelling under the Japan Islands. Geophys. J. Int. 190, 816-828.

Keywords: seismic tomography, P-wave anisotropy, subduction zone, Pacific slab, Philippine Sea slab, slab dehydration

SIT06-09 Room:104 Time:May 22 11:15-11:30

A three-dimensional electrical conductivity model in the subduction zone of Tohoku district, northeastern Japan

Masahiro Ichiki[1*], Yasuo Ogawa[2], Songkhun Boonchaisuk[2], Tomotsugu Demachi[1], Hiromi Fukino[5], Satoshi Hirahara[1], Yoshimori Honkura[2], Hiroshi Ichihara[3], Toshiki Kaida[1], Wataru Kanda[2], Toshio Kono[1], Takao Koyama[4], Masaki Matsushima[5], Takashi Nakayama[1], Syuichi Suzuki[1], Hiroaki TOH[6], Makoto Uyeshima[4]

[1]Graduate School of Science, Tohoku University, [2]Volcanic Fluid Research Center, Tokyo Tech, [3]IFREE, JAMSTEC, [4]Earthquake Research Institute, Univ. of Tokyo, [5]Graduate School of Science, Tokyo Tech, [6]Graduate School of Science, Kyoto University

We acquired magnetotelluric (MT) data at 65 sites in Tohoku district, northeastern Japan for the aim of three-dimensional (3-D) electrical conductivity distribution in the wedge mantle. Typical observation duration was three months at each site, and MT response functions from 10 to 20000 s in period have successfully collected with fine quality. The site location was arranged with ca. 20 km distance. We integrated the MT data observed on the seafloor in Japan Sea using the ocean bottom electromagnetometers (OBEM) (Toh et al., 2006) into these inland data, and estimated a conductivity model.

The MT phase response functions at some sites show over 90 degrees at longer periods than 5000 s and suggest that 3-D conductivity distribution beneath those sites. The distribution of phase tensor ellipses (Caldwell et al., 2004) shows more clearly the degree of lateral heterogeneity or dimensionality. The phase tensor ellipses of the sites in Akita and Iwate Prefectures have major axes aligned with NW direction. The direction is almost parallel to the Pacific plate motion. On the other hand, the major axes around Naruko and Kitakami river have random directions and the ellipticity of the phase tensor ellipses are very large (over 10).

We carried out the 3-D inversion using WSINV3DMT code (Siripuvaraporn et al., 2005) and gave a prior model composed of subducting slab (10^{-4} S/m) and seafloor bathymetry. The plate boundary information by Kita et al. (2010), Nakajima et al.(2009) and Nakajima and Hasegawa (2006) was used. Before inverting the observation data, simple checker board resolution tests were performed to estimate a resolution. We tested the three models composed of cubes with the same size (60, 40 and 20 km on side) and 1 S/m conductivity in the wedge mantle of 0.01 S/m. Each cube with 40 and 60 km on side was imaged using the synthetic data, while the adjacent cubes sticking together were imaged in the model composed of cubes with 20 km on side. Furthermore, any cubes beneath no observation site were not imaged at all using the synthetic data. The east-west profile (across the Japan Arc) of the obtained model shows that conductive region appears from 20 km to just above the subducting slab beneath the Tohoku backbone range. The basic images are well consisted with the seismic tomographic model (Nakajima et al., 2001), provided that conductive and low velocity zone should corresponds with each other. Obtained the final 3-D model, we plan to estimate the mantle geotherm and fluid distributions in the wedge mantle using seismic tomographic and electrical conductivity models.

Keywords: electrical conductivity, subduction zone, magnetotellurics

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SIT06-10 Room:104 Time:May 22 11:30-11:45

Hydration-dehydration processes in active subduction zones, and their geophysical signature

Bruno Reynard[1]*

[1]ENS Lyon, CNRS

Seismological and magneto-telluric methods are potential tools for imaging fluid circulation when combined with petrophysical models. Recent measurements of the physical properties of rocks, in particular serpentinites, have permitted to refine hydration of the mantle and fluid circulation in the mantle wedge from geophysical data.

In the slab lithospheric mantle, serpentinization caused by bending at the trench is limited to a few kilometers below the oceanic crust (<5 km). Double Wadati-Benioff zones, 20-30 km below the crust, are explained by deformation of dry peridotites, not by serpentine dehydration. It reduces the required amount of water stored in solid phases in the slab (Reynard et al., 2010).

In the cold (<700C) fore-arc mantle wedge above the subducting slab, serpentinization is caused by the release of large amounts of hydrous fluids in the cold mantle above the dehydrating subducted plate. Low seismic velocities in the wedge give a time-integrated estimate of hydration and serpentinization. Serpentinization reaches 50-100% in hot subduction, while it is below 10% in cold subduction (Bezacier et al., 2010; Reynard, 2012).

Electromagnetic profiles of the mantle wedge reveal high electrical-conductivity bodies. In hot areas of the mantle wedge (> 700C), water released by dehydration of the slab induces melting of the mantle under volcanic arcs, explaining the observed high conductivities. In the cold melt-free wedge (< 700C), high conductivities in electromagnetic profiles provide "instantaneous" images of fluid circulation because the measured electrical conductivity of serpentine is below 0.1 mS/m (Reynard et al., 2011). A small fraction (ca. 1% in volume) of connective high-salinity fluids accounts for the highest observed conductivities. Low-salinity fluids (< 0.1 m) released by slab dehydration evolve towards high-salinity (> 1 m) fluids during progressive serpentinization in the wedge. These fluids can mix with arc magmas at depths and account for high-chlorine melt inclusions in arc lavas.

High electrical conductivities up to 1 S/m in the hydrated wedge of the hot subductions (Ryukyu, Kyushu, Cascadia) reflect high fluid concentration, while low to moderate (< 0.01 S/m) conductivities in the cold subductions (N-E Japan, Bolivia) reflect low fluid flow. This is consistent with the seismic observations of extensive shallow serpentinization in hot subduction zones, while serpentinization is sluggish in cold subduction zones.

Bezacier, L., et al. 2010. Elasticity of antigorite, seismic detection of serpentinites, and anisotropy in subduction zones. Earth and Planetary Science Letters, 289, 198-208.

Reynard, B., 2012. Serpentine in active subduction zones. Lithos, http://dx.doi.org/10.1016/j.lithos.2012.10.012.

Reynard, B., Mibe, K. & Van de Moortele, B., 2011. Electrical conductivity of the serpentinised mantle and fluid flow in subduction zones. Earth and Planetary Science Letters, 307, 387-394.

Reynard, B., Nakajima, J. & Kawakatsu, H., 2010. Earthquakes and plastic deformation of anhydrous slab mantle in double Wadati-Benioff zones. Geophysical Research Letters, 37, L24309.

Keywords: subduction, fluids, serpentine, seismic velocity, electrical conductivity

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SIT06-11 Room:104 Time:May 22 11:45-12:00

Mantle physico-chemical conditions beneath the Japan arcs constrained by chemical composition of volcanic rocks

Hitomi Nakamura[1*], Hikaru Iwamori[1]

[1]Tokyo Institute of Technology

Chemical compositions of arc magmas in subduction zones are thought to reflect several processes, such as fluid contribution derived from subducting slabs, mantle melting, and crystallization and fractionation at crustal level. By using isotopic systematics, the amount and origin of slab-derived fluids beneath the Japan arcs have been quantified with a fairly good accuracy, which give a "Geochemical Map" regarding the distribution of slab-derived fluid, as well as melting P-T condition, in the mantle wedge [1,2]. In this study, we try to construct "Geochemical Map" regarding the mantle physic-chemical condition beneath the Japan arcs, based on such approaches.

Considering the amount of slab-derived fluid and its origin, we forward estimated the chemical compositions of slab-derived fluid, fluid-added mantle and subsequently generated magma. Then we can inversely evaluate the melting condition by optimizing the prediction with the observed magma compositions. In this model, there are several uncertainties involved in this estimation, such as compositional range of subducting materials, partition coefficients among melt-water-solid, which have been considered to evaluate the fitting accuracy [2].

As a result, we have obtained the melting conditions (melting degree; proportion of sp- and gt-lherzolites) together with fluid contribution, all of which have been quantified with uncertainties. For instance, in the mantle wedge beneath central Japan, relatively low degrees of dominantly garnet-lherzolite (plus minor spinel-lherzolite) melting at near-solidus has been identified [2]. These calculations suggest that the melting conditions can be inferred with a fairly good resolution (melting degree ~ 5 %; proportion of sp- and gt-lhs. ~ 10 %), especially when coupled with fluid contribution determined independently by isotopic systematics. Based on this modeling, we discuss the mantle condition beneath Japan arcs and its global implications.

[1] Nakamura and Iwamori, 2009, Gond. Res., [2] Nakamura and Iwamori, 2013, CMP

Keywords: mantle, subduction, slab, fluid, volcano, temperature

SIT06-12 Room:104 Time:May 22 12:00-12:15

Elemental partitioning between high Mg andesite and aqueous fluids as functions of pressure and salinity

Tatsuhiko Kawamoto[1*], Kenji Mibe[2], Ken'iti Kuroiwa[1], Tetsu Kogiso[3]

[1]Institute for Geothermal Sciences, Kyoto University, [2]Earth Research Institute, University of Tokyo, [3]Graduate School of Human and Environmental Studies, Kyoto University

1. Introduction

Silicate melts and aqueous fluids are major fluids in subduction zones. Elemental partition among minerals and these fluids is a key to understand the elemental transfer from subducting slab to mantle wedge [1-3]. Partition between minerals and melts is relatively well known, while partition between aqueous fluids and melts remains to be investigated.

2. Experimental

Synchrotron radiation X-ray fluorescence analysis is conducted to know elemental distribution between aqueous fluids and high magnesian andesite melt under high-temperature and high-pressure (HTHP) conditions. We put Cs, Ba, La, Sm, Gd, Ho, and Yb-doped high-Mg andesite with water or a saline solution (2.5 mol NaCl and 2.5 mol KCl per 1 kg water) in a metal tube + single-crystal-diamond lids and brought it under HPHT conditions. We achieved HTHP conditions with SPEED 1500 Kawai-type large-volume press installed at BL04B1, SPring-8, Japan. Incident X-ray is a white beam with energy ranging from 20 keV to 150 keV. During heating at a given pressure, synchrotron X-ray radiography technique allows us to observe a melt globule surrounded by aqueous fluids through the diamond windows [4, 1]. SR-XRF spectra are collected from the melt globule and the aqueous fluid using an SSD detector placed with 6 degrees to incident X-rays.

3. Results

A series of experiments has been carried out at pressures of 0.5, 1, 1.5, 2 and 2.2 GPa. The spectra show characteristic X-ray peaks of the doped elements superimposed on a continuous X-ray background. At 1 GPa, no characteristic X-ray peak from any doped element is observed in Cl-free fluids and all the doped elements are partitioned into melts. At 1.5 GPa and greater pressures, only Cs is found in Cl-free fluids, with one exception of small X-ray peak of Ba at 2 GPa. In contrast, X-ray peaks of Cs and Ba are observed in saline solutions at 1 GPa. In addition to Cs and Ba, a small peak of La is also found in the saline solutions at 1.5 GPa and greater pressures. The other elements (Sm, Gd, Ho, Yb) are found only in melts at all conditions.

4. Discussion

NaCl and KCl in aqueous fluids have large effects on elemental partition between melts and fluids as Keppler suggested [5]. He measured distribution coefficients between saline solution and andesitic melt based on quenched experiments and reported D Ba and D La at 0.3, 1, 1.5 and 2 GPa. The present observation is qualitatively consistent with reported values in his measurement [5]. Elliott and his colleagues suggested two slab-derived components: a melt component and a fluid component in order to explain trace element characteristics of basalts and basaltic andesites in the Mariana arc [6]. Both components are characterized by enrichment of alkali and alkali earth elements. The fluid component shows rare earth element abundances relatively similar to MORB, while the melt component shows more light rare earth element rich pattern (Figure 3 in [6]). Such features can be consistent with a Cl-rich aqueous fluid and a melt that can be formed through a separation of a slab-derived supercritical fluid during its migration to the surface [1-3]. If this is the case, the melt should be characterized by less abundance of alkali elements and more abundance of alkali earth and rare earth elements than the aqueous fluid. The aqueous fluid and melt components suggested as slab-derived components in the Mariana arc show features consistent with a Cl-rich aqueous fluid and a melt formed through a separation of a slab-derived supercritical fluid [1]. In order to address this hypothesis, more data sets of elemental partition under HTHP conditions are required. Chemical fractionation of slab-derived supercritical fluids may play an important role in subduction zone magmatism.

References

[1] Kawamoto et al. (2012) PNAS
[2] Bureau and Keppler (1999) EPSL
[3] Kawamoto (2006) Rev Mineral Geochem
[4] Mibe et al. (2004) GCA
[5] Keppler (1996) Nature
[6] Elliott, et al. (1997) JGR

SIT06-12 Room:104 Time:May 22 12:00-12:15

Keywords: melt, H2O, high temperature and high pressure, XRF, synchrotron X-ray, magma

SIT06-13 Room:104 Time:May 22 12:15-12:30

Behaviors of Li and B and their isotope ratios in subduction zone processes: Perspectives from a geochemical forward mod

Jun-Ichi Kimura[1*]

[1]IFREE/JAMSTEC

7Li/6Li and 11B/10B stable isotope ratios have been used as tracers of slab derived fluids in the arc magmas. Temperature dependent isotopic fractionation releases heavier fluids from the subducted slab, hence leaves righter residual solids in the slab. As slab fluid dehydration undergoes in the prograde metamorphism with increasing pressure and temperature, fractionation profiles of these isotopes from the slab is not simple. Moreover, release of Li and B from the slab is controlled by varying mineral assemblages in the prograde metamorphism so that adding further complexities in the element behaviors thus isotopic fractionation. Several works have dealt with the models in elemental behaviors of Li and B and their isotopes for slab dehydration. However, entire dehydration profiles of the subducted slab sediment and altered oceanic crust have not yet been studied. Moreover, interactions between slab fluids and overriding mantle peridotite form arc magmas and are also the factor that alters element abundances of Li and B and their isotopic ratios found in the arc magmas. This work examines the elemental and isotopic behaviors of Li and B and 7Li/6Li and 11B/10B in the slab and released fluids under prograde metamorphism and reactions between the released slab fluids and mantle to form arc magmas. A geochemical forward mode Arc Basalt Simulator ver.3 modified from Kimura (2012) (EarthChem Library http://www.earthchem.org/library) was used for the modeling and results presented in comparison to the reported values from arc magmas. The model calculations reasonably reproduced across arc variations of the Li and B isotope ratios found in the arc magmas. Calculated fluid compositions would also be useful in predicting the non-volcanic slab-derived fluid compositions potentially observed in the fore arc settings.

Keywords: Li, B, isotopes, subduction zone, arc magma

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SIT06-14 Room:104 Time:May 22 12:30-12:45

Noble gas and halogen recycling at the Izu-Ogasawara subduction zone

Hirochika Sumino[1*], Deborah Chavrit[2], Lisa Jepson[2], Aya Shimizu[3], Jun-Ichi Kimura[4], Ray Burgess[2], Chris J. Ballentine[2]

[1]GCRC, Graduate School of Science, University of Tokyo, [2]SEAES, University of Manchester, [3]Tokyo Metropolitan Industrial Technology Research Institute, [4]IFREE, JAMSTEC

Recent findings of subducted halogens and noble gases with seawater and sedimentary pore-fluid signatures in exhumed mantle wedge peridotites and eclogites from the Sanbagawa-metamorphic belt, southwest Japan [1,2], as well as seawater-derived heavy noble gases (argon, krypton, and xenon) in the convecting mantle [3], challenge a popular concept that the water flux into the mantle wedge is controlled only by hydrous minerals in altered oceanic crust and sediment (e.g., [4]). Serpentinized lithosphere of subducting oceanic plate would transport noble gas and halogens acquired from pore-water in the overlying sediment [1,2,5]. To verify whether and how such subduction fluids modify the composition of the mantle beneath subduction zones, we determined noble gas and halogen compositions of olivines in arc lavas of the northern Izu-Ogasawara subduction zone and IODP sediments and basalts recovered from northwestern margin of the Pacific plate.

MORB-like $^{3}He/^{4}He$ and halogen ratios of the Izu arc olivines indicate insignificant contribution to the mantle wedge of radiogenic ^{4}He and pore fluid-like halogens both observed in the subduction fluids in the Sanbagawa samples exhumed from a depth ranging from 30 to 100 km [1,2]. On the other hand, systematically higher contribution of atmospheric argon in volcanic front lavas than in rear-arc lavas of the Izu-Ogasawara subduction zone suggests progressive decrease in flux of subducted argon from the slab according with distance from the Izu-Ogasawara Trench. Distinct halogen and heavy noble gas elemental ratios of altered oceanic basalts indicate their minor contributions to the Izu arc magma and the Sanbagawa subduction fluids. On the contrary, high I/Cl ratios of oceanic sediments well explain elevated I/Cl ratios of the Sanbagawa subduction fluids compared to sedimentary pore fluids [1].

The significantly smaller contributions of subducted noble gas and halogen in the Izu-Ogasawara arc than those in the Sanbagawa belt may result from a difference in P-T condition of the subducted slabs. A hotter mantle wedge than those of mature subduction zones is proposed for the Sanbagawa subduction system [6], in contrast the Pacific slab subducting in the Izu-Ogasawara subduction zone is relatively cold and would therefore lose relatively little water at equivalent depths to other slabs [7]. This implies a relatively small amount of the pore water subduction fluids would be released from the Pacific slab at a sub-arc depth (150-200 km) resulting in further subduction to great depths in the mantle.

[1] Sumino et al. (2010) Earth Planet. Sci. Lett. 294, 163-172. [2] Sumino et al. (2011) Mineral. Mag. 75, 1963. [3] Holland & Ballentine (2006) Nature 441, 186-191. [4] Schmidt & Poli (1998) EPSL 163, 361-379. [5] Kendrick et al. (2011) Nature Geosci. 4, 807-812. [6] Mizukami & Wallis (2005) Tectonics 24, TC6012. [7] van Keken et al. (2011) J. Geophys. Res. 116, B01401.

Keywords: noble gas, halogen, subduction zone, Izu-Ogasawara arc, pore fluid

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SIT06-15 Room:104 Time:May 22 14:45-15:00

Experimental study on the hydration rates of peridotites in the mantle wedge condition

Takayuki Nakatani[1]*, Michihiko Nakamura[1]

[1]Department of Earth Science, Graduate School of Science, Tohoku University

Although hydration of mantle wedge is a key process in understanding the nature of magmatism in subduction zones, the hydration rate of peridotites has been poorly constrained. Two extreme cases can be considered in terms of equilibration degree between the fluid and rocks. The first is the equilibrium case, in which the hydration rate is fast and H2O is fixed as hydrous minerals as soon as the fluid is supplied. The other is the disequilibrium case, in which the fluid ascends without hydrating solid matrices. Based on a numerical model, Iwamori (1998) showed that distribution of H2O in subduction zones is significantly affected by the extent to which the fluid-rock interaction proceeds. The hydration rate of mantle rocks is thus a primary parameter in the control of H2O transport in subduction zones. In order to obtain the hydration rates of peridotites under mantle wedge conditions, we have conducted hydration experiments using a piston-cylinder apparatus at 580 degC and 1.3 GPa for 4-20 days. Starting materials were prepared from the crushed powder (75-125 micrometer in diameter) of a San Carlos lherzolite xenoliths. The starting materials were put in Ag capsules with 15 wt% distilled water.

In the experimental condition, antigorite (high-T serpentine) is expected to be the stable serpentine phase (Ulmer and Trommsdorff, 1995). We found with Raman spectroscopy, however, that the synthesized serpentine mineral was not antigorite but lizardite (low-T serpentine), which is consistent with its platy shape. The high Al2O3 content (6-9 wt%) in the serpentine mineral probably stabilized Al-lizardite to higher temperature (Caruso and Chernosky, 1979). The degree of reactions was obtained by measuring the area fractions of relict minerals on BSE images of polished surfaces of the run charges. The degree of reaction basically followed an interface controlled rate law. The migration velocity of reaction front, G, was estimated to be 1.23 - 3.18 micrometers per day.

By using these values and the estimated range of porous flow velocities, we obtained the nondimensional time for local chemical equilibration. It is inferred that the mostly complete hydration reaction can be established in the porous flow. This result indicates that slab-derived water should be fixed quickly in the convecting mantle wedge mainly as serpentine and carried down to ca. 150 km, i.e., the stability limit of antigorite or aluminous lizardite.

Keywords: mantle wedge, aqueous fluid, hydration, serpentinite

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SIT06-16 Room:104 Time:May 22 15:00-15:15

Evidence for multi-stage infiltration of aqueous fluids in a block-emplaced serpentinite along the San Andreas Fault

Stephen Kirby[1]*, Masaoki Uno[2]

[1]U. S. Geological Survey, [2]Tokyo Institute of Technology

A structural and petrological study of a tectonically-emplaced serpentinite sliver along the San Andreas Fault in California was initiated with the aim of understanding the geological history and emplacement mechanisms of such bodies that are common in the California Coast Ranges and along the San Andreas diffuse plate boundary. This particular serpentinite melange in Redwood City, California is largely composed of cm- to m-scale tectonite blocks that reflect the internal deformation and complex history of interaction with geofluids during perdiotite alteration and ascent from the mantle. These tectonite blocks commonly exhibit a core-and-mantle internal structure that indicates that tectonic blocks have not come to mineralogical equilibrium . Innermost core structure often consists of partially-serpentinized Ol/OPx/Cpx peridotite rimmed by layers of greater degrees of serpentinization. These tectonite blocks are typically rimmed with green sheared lizardite indicating that high fluid pressure was present during the last stage of emplacement. We also observed chrysotile filled reticulate arrays of vein fillings that often cross cut the sheared lizardite. We discuss these and other observations in the context of the tectonic and fluid environments of the San Andreas Fault System that originated during Tertiary plate reorganization from subduction to continental transform tectonics.

Keywords: serpentinite, mantle, vein filling, hydrothermal alteration, San Andreas Fault, metamorphism

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SIT06-17 Room:104 Time:May 22 15:15-15:30

Dehydrated fluid and seismic deformation in deep subduction zone

Kazuaki Okamoto[1*], MIyuki Arakawa[1], Yoshihiro Mizuno[1], Urara Tanaka[1]

[1]Saitama University, [2]The United Graduate School, Tokyo Gakugei University

Dehydrated fluid in deep subduction zone causes various geological phenomena such as earthquake, and arc volcanism. It has been considered that there is a correlation between the double seismic zone and metamorphic dehydration reaction in deep slab. The location of the upper limits of the upper seismic plane correspond to metamorphic facies boundary where H2O contents change in subducting crust; numerous earthquakes from 60 to 110 km depths in the lawsonite-blueschist facies, many earthquakes in the lower crust of the slab from 110 to 150 km depths in thelawsonite-amphibole eclogite facies and few earthquakes in the lawsonite eclogite facies. Recent petrological researchs have revealed that both blueschist and lawsonite eclogite are stable in the same pressure and temperature condition because chemical variation including water content creates both lawsonite-amphibole eclogite and lawsonite eclogite in different portion of subducted crust. Partial melting would occurred in eclogite in deep subduction zone if warm slab is subducted. In descending slab, the eclogite would reach wet solidus defined as phengite-, through zoisite-, and amphibole-decomposition reactions with increasing temperatures. The lowerplane of the double seismic zone, is considered to be related to dehydration reaction in the slab. Metamorphic olivine has been described in vein from serpentinite mylonite. The vein was created by dehydration reaction to decompose antigorite under shear deformation. In the cold slab beneath Tohoku arc, the reaction has a negative slope in P-T space and forms olivine+orthopyroxene+fluid. In the warm slab beneath SW Japan, the reaction has a positive slope in P-T space and forms olivine+talc+fluid. The above these dehydration reactions are well-described in the serpentinite from high P/T metamorphic belt from Spain, and Italy, respectively.

Keywords: Subduction zone, Blueschist, Lawsonite eclogite, Dehydrated fluid, Earthquake faulting, Metamorphic olivine

SIT06-18 Room:104 Time:May 22 15:30-15:45

Elastic anomaly of anorthite at high temperature and high pressure

Kyoko N. Matsukage[1*], Yu Nishihara[1], Fumiya Noritake[2], Katsuyuki Kawamura[2], Noriyoshi Tsujino[3], Moe Sakurai[4], Yuji Higo[5], Eiichi Takahashi[4]

[1]Geodynamics Research Center, Ehime University, [2]Graduate School of Environmental and Life Science, Okayama University, [3]Institute for Study of the Earth's Interior, Okayama University, [4]Department of Earth and Planetary Sciences, Tokyo Institute of Technology, [5]Japan Synchrotron Radiation Research Institute

To understand the elastic properties of subducted crustal minerals at P-T conditions of crust and upper mantle, we performed in situ measurement of the elastic wave velocities of anorthite at temperatures up to 1373 K at less than 2.0 GPa and up to 273 K at 2.0-7.0 GPa. A fine grained polycrystalline anorthite was synthesised by using gas pressure apparatus installed at magma factory in Tokyo Tech. The experiments were performed using the SPEED-1500 apparatus installed on beam line BL04B1 at SPring-8. Pressure was generated by eight 26 mm tungsten carbide anvils with 11 mm truncated edge length. A Co-doped semi-sintered MgO octahedron with an 18 mm edge length was used as a pressure medium. The sample was enclosed in a BN sleeve container, and was placed in the central part (hot spot) of the furnace. Platinum foils (2.5 um in thickness) were inserted at the both side of the sample for determination of sample length by using X-ray radiographic imaging techniques. An Al_2O_3 rod (5.3 mm in length and 2.0 mm in diameter) was used as buffer rod which transmit ultrasonic wave to the sample. Temperature was measured by a W97Re3-W75Re25 thermocouple. MgO was used as a pressure marker, and it was mixed with BN to prevent grain growth at high temperatures. The ultrasonic signals were generated and received by 10 degree Y-cut $LiNbO_3$ transducer of 50 um in thickness and 3.2 mm in diameter. We used the ultrasonic wave of the frequencies 30-60 MHz with 3-5 cycles. Diffracted X-ray from the sample was measured simultaneously with the measurement of elastic wave velocities. A solid-state detector connected to a multi-channel analyzer combined with incident white X-ray beam was used for data collection. The X-ray diffractions were collected at a fixed 2 theta angle (= 2.961 degree).

In this study, we found temperature induced elastic anomaly. That is increase of elastic velocities and elastic moduli with increasing temperature in the range of 500-900 K at pressure of ~1 GPa. Based on the phase relation, it considered that this elastic anomaly is occurred in the high-temperature I(-1) phase stability field. Here we suggest a hypothesis that the tilting behavior of corner shared TO_4 tetrahedra in three dimensional frameworks causes the elastic anomaly of anorthite at higher temperature more than 500 K. In general, elasticity of solid materials depends on the bond length of atoms; the materials are hardened with decrease of bond length. Noritake et al (unpublished data) found that T-O-T angle increases and bond length of Si-O decreases with increasing temperature for high temperature I(-1) structure, although that is constant for low temperature structure (= P(-1)). This structure changes reasonably explains that the elastic wave velocities of anorthite increase with increasing temperature in the range of 500-900 K. Above 900 K, effect of the thermal expansion may reveal the reduction of elastic constants.

We also found pressure induced elastic anomaly. Elastic wave velocities of anorthite have a negative correlation with density at pressure more than 4.0 GPa. We consider that the pressure induced elastic anomaly is also caused by the tilting of TO_4 tetrahedra. Plagioclase feldspars are one of most abundant minerals of subducted crustal rocks on the Earth. Plagioclase may survive in subducted slab at higher pressure as a metastable phase if the temperature of the slab is low. Therefore we consider that plagioclase feldspar might be one of the causes for low velocity anomaly of slab.

Keywords: plagioclase, anorthite, elastic wave velocity, elastic anormaly, subducted slab, crust

SIT06-19 Room:104 Time:May 22 15:45-16:00

Rheological behaviors of subducting oceanic crust: Implications from experimentally deformed blueschists

Daeyeong Kim[1*], Shintaro Azuma[1], Katsuyoshi Michibayashi[2], Ikuo Katayama[1]

[1]Department of Earth and Planetary Systems Science, Graduate School of Science, Hiroshima University, [2]Institute of Geosciences, Shizuoka University

Investigations on deformation mechanism of blueschist can be helpful for delineating rheological behaviors of subducting oceanic crust. We deformed natural blueschists under pure and simple shear regimes using Griggs-type solid-medium apparatus and conducted fabric analyses of rock-forming minerals. Mechanical data of pure shear experiments display larger increase of yield stress at low confining pressure (0.5 to 1 GPa) rather than that at high confining pressure (1 to 2 GPa), implying that pressure-sensitive creep at low pressure (0.5?1 GPa) shifts to pressure-insensitive creep at high pressure (1?2 GPa). Microstructures of glaucophane and lawsonite deformed at simple shear experiments suggest that brittle fracturing are dominant at 1 GPa, but plastic flow of constitute minerals become important at 2.5 GPa. In addition, EBSD data indicate angle between slip plane and shear direction corresponding to angle of strain marker at 1 GPa and to angle of strain ellipsoid at 1.5?2.5 GPa. Our experimental data indicate, therefore, that deformations of glaucophane and lawsonite in the subducting oceanic crust are mostly controlled by brittle deformation at 1 GPa and ductile deformation at higher confining pressure (1.5?2.5 GPa); consequently, brittle-ductile transition zone likely occurs at ˜1.0?1.5 GPa in our experimental conditions.

Keywords: Blueschist, Glaucophane, Lawsonite, Griggs-type solid-medium apparatus, oceanic crust