Metamorphic overprint of the Kamuikotan metamorphic rocks by fluid migration during exhumation around Asahikawa City, central Hokkaido, Japan

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Subduction zone is a place where fluid cycling occurs from surface through the lithosphere to the lower mantle of the Earth. However, for high-P/T metamorphic rocks in intermediated depths of subduction zone, fluid migration associated with metamorphism remains unclear. The Kamuikotan metamorphic rocks in northern Japan are the typical high-P/T metamorphic rocks in the world, formed by subduction during Early Cretaceous to early Eocene (Sakakibara and Ota, 1994). Around Asahikawa City, they have evidence implying thermal overprint which might have been caused by fluid migration. Kamuikotan metamorphic rocks in study area show relatively high geothermal gradient (Sakakibara and Ota, 1994), spatially heterogeneous distribution of K-Ar ages (Ota *et al*., 1993; Ota, 1999; Iwasaki *et al*., 1995) and pervasive development of quartz veins while high-P/T mineral assemblages recording prograde metamorphism were only locally preserved. The purpose of this study is to reappraise the tectonics of the Kamuikotan metamorphic rocks in respect of metamorphic overprint by fluid flow during exhumation. In this study, we conducted petrographic and mineralogical analyses for mafic rocks and Raman spectroscopy of carbonaceous material for pelitic rocks to elucidate the spatial center and effect of the thermal overprint. The mafic rocks contain lawsonite, pumpellyite along the Ishikari River, glaucophane, pumpellyite, actinolite and Na-pyroxene along the branch of Ishikari River, and epidote, actinolite along the Orowen River from north to south. chlorite exists in all of the analyzed metabasites. Six pelitic rocks were analyzed to infer the peak metamorphic temperature by using Raman CM geothermometer (Kouketsu *et al*., 2014). The metamorphic temperature estimated from full width at half maximum of D1-band is approximately 313˚C from the Ishikari River, 300˚C from the branches of Ishikari River, 351˚C from the Orowen River, and 325˚C from the Pankehoronai River areas from north to south. Glaucophane and lawsonite are restrictively distributed in the northern part of this area and the overgrowth of actinolite on alkali amphibole indicates the Kamuikotan metamorphic rocks underwent metamorphic overprint (greenschist facies at 58 Ma; Ota, 1999) during exhumation. It is inferred that the effect of fluid migration was most intense around the Orowen River area within the study area. Further research is needed to determine the origin of fluid.

Keywords: Kamuikotan metamorphic rocks, tectonics, fluid migration, exhumation, metamorphic overprint, Raman spectroscopy

EBSD analysis on coexisting omphacite and diopside found in aragonite-calcite vein form the Horokanai area, Kamuikotan metamorphic belt, Hokkaido

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Ca-Na pyroxenes are common in high pressure metamorphic rocks. While most of them have C2/c space group, omphacite (Omp), the intermediate composition between jadeite (Jd) and diopside (Di), has P2/n space group, because of cation ordering in M1 sites (Mg, Fe and Al), and M2 sites (Ca and Na). Two miscibility gaps are reported between Jd and Omp, and Omp and Di, as a result of the ordering (Carpenter 1980b), which takes place below the critical temperature ˜750˚C (Carpenter, 1980b). In addition, degree of the ordering in Omp decreases as the Fe (II) and Fe (III) contents increase, and finally, Fe-rich Omp has disordered C2/c space group (Carpenter, 1980b; Cámara et al., 1998). Matsumoto & Hirajima (2005) proposed a possible phase boundary between the P and C lattice in eclogite facies rocks (˜700˚C) based on natural and synthetic data of Carpenter and Smith (1981), Cámara et al. (1998) and Boffa Ballaran et al. (1998), i.e., P lattice field for less Fe (III) (< 15%) Omp. However, Carpenter (1980a) reported P lattice space group for Fe (III)-rich (>20%) Omp in an epidote-blueschist collected from the Franciscan Complex. These data suggest the P lattice field also expands with the decrease of metamorphic temperature.
In this study, we report possible space group of coexisting Omp and Di found from a pale green vein in the Horokanai area of the Kamuikotan metamorphic belt. Shibakusa (1989) subdivided the relevant area into three zones, from zone I (Lawsonite-BS facies) to zone III (Epidote-BS facies) with the increase of grade. The host rock of the pale green vein is an epidote amphibolite, collected from the amphibolite block at the Horokanai Pass. The sample is mainly composed of epidote, Ca-amphibole and rutile which are partly replaced by muscovite + chlorite, Na-amphibole and titanite, respectively, suggesting the BS-facies overprinting on the epidote amphibolite as described by Imaizumi (1984). A pale green vein (˜1 cm width), white veins (˜1 mm width) and yellowish green veins (˜1 mm width) are developed in the studied amphibolite. The pale green vein mainly consists of Omp, Di, calcite, aragonite, albite and apatite. White veins consist of calcite, aragonite and albite. Yellowish green veins consist of pumpellyite and chlorite. All aragonites are surrounded by calcites. Furthermore, the composition ranges of vein forming minerals are equivalent to those of zone II or zone III of Shibakusa (1989), thus the vein-forming conditions can be estimated as 250-350 ˚C and 7-10 kbar.
Ca-Na pyroxenes in the pale green vein show the wavy extinction and their grain sizes are of ˜0.5 mm and growth faces dominantly lie parallel/perpendicular to the c axis. EBSD analysis suggests that Omp and Di constituting the hour-glass texture have the same orientation with the phase boundary parallel to the c axis. Three domains are recognized in Omp based on the contrast of back scatter electron (BSE) image, strongly correlated with Al/Ca contents. Their domain boundaries are curved and diffused and banding structures with ˜1 μm width are observed in Omp domain in BSE image. The banding structures with ˜1 μm width are also observed in Di. In spite of the existence of micron-scale zonings in Omp and Di, EPMA analysis gave Jd30-40Acm15-25Di38-55 for Omp and Jd4-8Acm9-15Di77-95 for Di. This compositional gap between Omp and Di is almost identical to those reported by Carpenter (1980a) and Tsujimori (1997) for BS facies (˜300˚C) conditions.
Fe (III) component of Omp analyzed in this work is almost the same as the composition reported by Carpenter (1980a) pointed out P lattice space group for Omp with Fe (III) rich (˜20 %) based on TEM study. However, Kikuchi patterns obtained from our Omp with similar Fe (III) content with the Omp of

Carpenter (1980a) are best fit to C2/c Di. Further study is needed to evaluate the ferric component effect on the space group of the Omp.

Keywords: omphacite, ordering state, Kamuikotan belt

Revisiting of metamorphic zonal mapping in the Etambetsu Pass area, the Kamuikotan belt, Hokkaido.

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We propose a new metamorphic zonation based on low-variant mineral assemblage in metabasites from the Etanbetsu Pass area of the Kamuikotan belt.
The prograde decomposition of lawsonite (Lws) to epidote (Ep) was reported by Shibakusa (1989) in this area. However, Imaizumi (1984) proposed that the Ep-blueschist (BS) occur as tectonic blocks and it is in tectonic contact with Lws-BS. Furthermore, Sakakibara & Ohta (1994) supported the tectonic contact model based on phengite K-Ar ages of Lws/Ep BSs. As mentioned above, there is no general consensus on the Kamuikotan metamorphism in the relevant area.
This study confirms that the Etanbetsu Pass area can be divided into Ep-free zone (majority of the area) and Ep-bearing area (the northern part of the area), which almost coincident with Zone I (Lws zone) and Zone II (Ep-Lws zone) of Shibakusa, and Biei- Harushinai and Horokanai units of Sakakibara & Ohta, respectively.
In the Ep-free zone, Lws + Na-pyroxene (Napx) ±pumpellyite (Pmp) assemblage is predominant, but Lws + Na-amphibole (Namp) + Pmp or Lws + Namp + Napx assemblages, the diagnostic of the Lws-BS facies, are limited in the northern part, i.e., the proximal area to Ep zone. Spatial distribution of abovementioned mineral assemblages suggest that the Ep-free zone can be divided into Lws+Napx+Pmp sub-area and Lws+Namp one, and this subdivision can be explained by the progress of a following reaction; Pmp + Napx + Chlorite = Lws + Namp + H2O (1) in the Ca-Al-Fe3-(Fe+Mg) system with excess of quartz, albite and phengite, possibly with the progress of the subduction.
In Ep zone, following mineral assemblages are identified; Ep + Namp + Pmp + Lws (7/16), Ep + Lws + Namp and Ep + Namp + Pmp. Those assemblages are stable around the reaction; Ep +Pmp+Chl = Lws +Namp + H2O (2).
Sato et al (2017) proposed that there is a a significant P-T gap between stability fields of two reactions. This suggest the the tectonic contact model of Ep-free and Ep zones in the study area.

Keywords: metamorphic zonal mapping, Lawsonite blueschist, Kamuikotan belt

The extent and variety of exotic rocks identified from the Kebara Formation, NW Kii Peninsula

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The metamorphic zoning in the regional metamorphic belt can be defined as area in which a particular mineral or suite of minerals is predominant or characteristic(s) reflecting the original rock compositions, the pressure and temperature of formation, and the duration of the metamorphism (e.g., Jackson, 1997). If we found rocks with some of different nature to the metamorphic zoning, the earth scientists generally try to consider its reason and it becomes a long term controversy in some case, e.g., the origin of tectonic blocks of blueschist and/or eclogite in direct contact with greywacke or serpentinite in the Franciscan complex (e.g. Colman and Lanphere, 1971).

Metabasites with barroisite (Brs) + epidote (Ep) assemblage, which is stable under higher-*T* (>450 ºC: Kato and Hirajima, 2017), have been recognized in the SW part of the Kebara Formation (KF), the southern margin of the Sanbagawa belt, NW Kii Peninsula, of which peak metamorphic temperatures for pelitic rocks, which are main lithotype of the KF, are <340 ºC estimated by the stability conditions of diagnostic minerals (Tomiyoshi and Takasu, 2009) and by the Raman spectra of carbonaceous material (RSCM) geothermometer (Yoshida et al., 2016). This study describes the mode of occurrence and mineralogy of metamorphic rocks exposed nearby the Brs-bearing metabasites and discusses its tectonic significance.

Brs-bearing rocks are identified from a metabasite layer in N-S striking 30 m-long outcrop. The dominant schistosity in the outcrop strikes ENE-WSW and dips steeply to the south, which is consistent with that of the main schistosity in the KF. No clear fault-bounded contact is observed in the outcrop. Following three rock types are recognized in this layer; A) weakly schistose metabasite rich in relict pyroxene, B) metamorphosed mixtures of volcaniclastic materials and pelagic sediments characterized by distinct schistosity and the high modal amount of phengite accompanying with relict pyroxene, and C) basic schist whose schistosity is mainly defined by the arraignment of amphiboles, Ep and chlorite (Chl).

A/B) type rocks occupy the northern half of the out crop and most of them contain pumpellyite (Pmp) + Chl + Ep assemblage, which is the identical assemblage with the previous report (Kurimoto, 1986), suggesting the Pmp-actinolite facies metamorphism.

C) type rocks mostly occupy the southern half of the outcrop and they can be distinguished into two types based on the composition of amphibole: C1) Brs-Ep schist and C2) glaucophane (Gln)-Ep schist.

C1) type rocks are recognized from two parts; i.e., from more than 2.5 m and 70 cm thick layers. The mineral assemblage and the zoning structure of representable minerals of the 2.5 m thick layer are identical with those in 70 cm layer as reported in Kato and Hirajima (2017).

C2) type rock is recognized from 7 m thick layer exposed to the north of the 2.5 m thick Brs-Ep schist. All analyzed Gln are rich in Al content [$Y_{Fe} = Fe^{3+} / (Al + Fe^{3+}) = 0.00 – 0.30$] with constant Fe-Mg ratio [$Fe^{2+} / (Mg + Fe^{2+})$ ~ 0.40], and some grains are rimmed by actinolite. Ep is Fe^{3+}-rich composition (Y_{Fe} = 0.27 –0.34). Al content of Gln associated with Ep increases with the metamorphic grade (e.g. Hosotani & Banno, 1986), and those of C2 type rock are equivalent to or higher than those in the garnet zone of the Sanbagawa belt in central Shikoku, suggesting the higher-*T* than 350 ºC.

These data indicate that most basic schists in the southern half of the outcrop underwent higher-*T* metamorphism than those of the KF. Such occurrence of these basic schists can be interpreted as tectonic blocks or olistostromes, because the irreversible nature of RSCM geothermometry suggests that the pelitic schist of the KF never experienced temperatures higher than ~350 ºC. Further geological and

geochronological studies are requested to interpret the origin of these exotic rocks, which will shed a light on the material cycling in the shallower part of the subduction zone.

Keywords: exotic rock, Kebara Formation, Sanbagawa metamorphic belt

On the origin of high temperature metamorphism within a magmatic arc: the case of the Cretaceous Ryoke belt (Japan)

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Magmatic arcs, located at convergent plate boundaries, are sites of crustal deformation, widespread plutonism and high temperature (HT) metamorphism. Our task is to reveal how these intricate events relate in space and time, and how heat transfers and large-scale tectonics contribute to the genesis of HT conditions within the arc crust.
The Ryoke belt (Japan) is a ca. 800 km-long association of Cretaceous magmatic and metamorphic rocks which gives direct access to the upper-middle crust of a former continental arc setting. Across the belt, a regional HT metamorphic gradient is defined by paragenetic zones that lie parallel to the main foliation of metamorphic rocks and gneissose granitoids. This gradient is opposed to localized contact metamorphic aureoles that are ascribed to later, massive plutons. By summarizing structural/petrological observations and new U–Pb zircon ages obtained in the western (Yanai) and central (Aoyama/Mikawa) parts of the Ryoke belt, we try to constrain the origin of HT metamorphism within this former magmatic arc.
(1) Deformation across the belt was polyphase, with distinct episodes of horizontal extension and shortening (Yanai), or of variable intensity (Mikawa; Adachi & Wallis, 2008).
(2) Metamorphic mineral growth, when correlated with the deformation history, appears to have been polyphase as well. Importantly, pre-tectonic porphyroblasts are observed in both areas. Syn-tectonic assemblages, assuming they were not reoriented by deformation, define the regional gradient while post-tectonic minerals are frequent.
(3) The reported U–Pb zircon ages of HT metamorphic conditions decrease from west (~100 Ma, Yanai) to east (~90 Ma, Aoyama; Kawakami *et al.*, 2013 / ~87 Ma, Mikawa; Nakajima *et al.*, 2013), indicating that the so-called regional metamorphic event was diachronous.
(4) With respect to HT metamorphism, some granitoid intrusions are older; these are usually the shallowest plutons that are not only gneissose but also massive (Skrzypek *et al.*, 2016).
(5) Although some gneissose plutons are broadly coeval with HT metamorphism (Yanai), some others can be significantly younger (Mikawa; Takatsuka *et al.*, 2017).
(6) The latest stage of voluminous plutonic activity was also diachronous and occurred without apparent deformation; its age decreases from west (~80 Ma, Yanai) to east (~70 Ma, Mikawa; Takatsuka *et al.*, 2016).
The upper-middle arc crust clearly experienced heating before, during and after the main phase of regional deformation. The importance of heat advection by granitoids is obvious; we may additionally suggest that the oldest, shallow intrusions potentially acted as a hot lid which facilitated the thermal maturation of the crust. However, we emphasize that regional HT metamorphism is not always spatially and temporally associated with plutonism. This underlines the role of heat conduction, the source of which can be found at the base of the crust where prolonged HT conditions and partial melting are needed to sustain the protracted magmatic activity (105–80 Ma, Yanai; 99–70 Ma, Mikawa). Therefore, there must have been a large-scale process (oblique ridge subduction or lateral mantle upwelling?) which was able to generate diachronous HT conditions along the base of the arc crust. Yet, was it the same process which led to the much younger, magmatic flare-ups associated with relative tectonic quiescence?

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Keywords: magmatic arc, high temperature metamorphism, Ryoke belt

Rising of a high-temperature metamorphic belt due to buoyancy

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Cretaceous Ryoke (plutono-metamorphic) complex (hereafter Ryoke complex) is distributed as the Ryoke metamorphic belt (Ryoke belt) with more than 1,000 km length in Japanese Island. Recently, we found a possible western extension of the Ryoke complex, that is high-temperature metamorphic rocks in the Omuta district, northern Kyushu, Japan. Protolith of the high-T metamorphic rocks in the Omuta district is Triassic high-pressure Suo (metamorphic) complex (Miyazaki, et al., submitted). The lower-grade part of the metamorphic rocks partly preserves schistosity of the Suo complex, although high-grade part consists of migmatite and gneiss. Pressure differences between low-grade and high-grade parts cannot be explained by geologically estimating thickness between both parts, and it is suggested that thinning should be taken place between the low-grade and high-grade parts (Ikeda et al., accepted).

Pervasive occurrence of migmatite implies that melt existed at the peak high-T metamorphism. Because density of melt is lower than solid rock, melt has a buoyance. However, viscosity of felsic melt is very high, and the melt is difficult to easily separate from the solid rock. Therefor, we consider a rising of the high-grade part as that of the mixture of melt and solid rock.

To evaluate the rising of the mixture, we performed numerical simulation, in which the crust and mixture are assumed as host and buoyant viscous fluids, respectively. Without thermal diffusion between host and buoyant viscous fluids, the buoyant viscous fluid rises as a diapir. In the case with thermal diffusion, density of the buoyant viscous fluid increases with decreasing temperature. The buoyant viscous fluid transforms to the host viscous fluid during the rising. After the transformation, the transformed viscous fluid stops to rise. We also simulate the case with continuous production of buoyant viscous fluid. In this case, the buoyant viscous fluid also transforms to the host viscous fluid, and the transformed viscous fluid still rise to shallower depths than the case without the continuous production. The transformed viscous fluid suffers a vertical compression and horizontal extension after the transformation. This implies thinning of the transformed viscous fluid.

The results of numerical simulation suggest that high-T metamorphic rocks with pervasive occurrence of migmatite can rise to a shallow depth when melt production continues. Zircon U-Pb ages of plutonic and volcanic rocks in the northern Kyushu shows that melt generation continued from 112 to 98 Ma. Zircon U-Pb ages of the high-T metamorphic rocks in the Omuta district also suggest that high-T metamorphism and partial melting occurred at 105.1 ±5.3 Ma (Miyazaki et al. submitted). The thinning of high-grade part of the metamorphic rocks in the Omuta district and the above-mentioned age constrains suggest that the high-T metamorphic rocks rose due to buoyancy.

Keywords: high temperature metamorphic belt, rising, Ryoke

New evidence of ultrahigh-pressure metamorphism in the Cretaceous low *P/T* metamorphic terrane, Higo Metamorphic Rock, Central Kyushu, Japan

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This paper reports a new finding of diamond-graphite aggregates (DGA) from the Higo Metamorphic Rock (HMR), a Cretaceous low *P/T* metamorphic terrane, Central Kyushu, Japan. There are three occurrences of DGA. One is inclusions in a chromitite in a spinifex-like textured metaperidotite, which is already reported by Nishiyama, et al. (2014). This time we found another two occurrences of DGA: one from garnets in pelitic gneisses and the other from a garnet-bearing amphibolite. Arai (2010) proposed a mantle migration model for the genesis of microdiamond-bearing chromitites, therefore, the occurrence of the DGA-bearing chromitite in the HMR itself does not reveal that the whole metamorphic terrane has experienced the ultrahigh-pressure metamorphism. Our new finding of DGA-bearing pelitic gneisses and a amphibolite, however, clearly indicate that the HMR has undergone a ultrahigh-pressure metamorphism as a whole prior to the low *P/T* metamorphism of Cretaceous in age. All thin sections of rock samples in which the occurrence of DGA is confirmed are made with Al_2O_3 sheets without using diamond paste to avoid possible contamination of diamond. No carbon coating was used for observation of DGA under a SEM.
DGA-bearing pelitic gneisses are found at three localities around Mt. Kousa (Sakamoto, Taira, and Kawagoe from east to west). They all belong to the garnet-cordierite zone (Obata et al., 1994; Miyazaki, 2004). Garnets in these rocks show doubly zoned structures consisting of black core surrounded by pink mantle, which are distinct even in naked eyes. This type of garnet occurs ubiquitously in the HMR, however, both simply zoned garnets and doubly zoned garnets occur frequently in the same outcrop, depending on the bulk compositions of the host rocks (Ishimaru et al., 2015). DGA occurs as platy grains of 10 mm in size in the garnet cores, but not in the mantles. We confirmed C peaks for the grains with EDS analysis under Au coating on the sections. DGA shows Raman spectra with 1335 cm^{-1} diamond-band together with 1580 cm^{-1} (G band) and 2680 cm^{-1} (S1 band) of graphite. These features are quite similar to those from the Nishisonogi metamorphic rocks (Nishiyama et al., 2017; this meeting), however, the wave number of the diamond-band is slightly shifted to be higher (1335 cm^{-1}) compared to that (1330 cm^{-1}) in the Nishisonogi DGA. The grain size (10 mm) is larger than that (1 mm) of the Nishisonogi DGA. The SEM-SXES (scanning electron microscope combined with soft X-ray emission spectrometer) analysis confirmed coexistence of sp^3 and sp^2 structures in the grains, showing that the grains consist of diamond and graphite. The result is consistent with the Raman spectra. Radial alignment of tiny inclusions of rutile is occasionally observed in the garnet cores, however, coesite has not been identified yet from the inclusions. Quartz inclusions occur in the garnet mantles.
The garnet-bearing amphibolite occurs as a block of 50 ×100 cm in size within pelitic gneisses at a stream near Kawagoe, Tomochi Town. It consists mainly of magnesio-hornblende and biotite with small amounts of plagioclase, quartz, and ilmenite. Garnet ($Alm_{64}Prp_{17}Grs_{18}$) occurs locally as anhedral crystals, several millimeters across, and decomposes into a symplectite consisting of orthopyroxene (En_{47}) + plagioclase (An_{85}) from the periphery. The orthopyroxene contains a small amount of Al_2O_3 (0.02 apfu based on 3 oxygens) and is frequently altered to chlorite. The garnet-hornblende geothermometry gives a temperature of 450 ^{o}C, whereas the garnet-orthopyroxene geothermometry does 640 ^{o}C (at 0.5 GPa) -

670 °C (at 1 GPa). This indicates that the rock was initially equilibrated at 450 °C and then heated up by about 200 °C, forming the symplectite. The DGA occurs as granular materials 100 mm across in this symplectite. It does not occur in garnets. EDS analysis of the sample coated with Au reveals C peaks. Raman spectra shows a 1335 cm^{-1} diamond-band together with 1580 cm^{-1} (G) and 2680 cm^{-1} (S1) bands of graphite. Although the diamond band shows a slightly higher wave number, other features are the same as those of DGA in the pelitic gneiss. The SEM-SXES method also shows coexistence of sp^2 and sp^3 structures, indicating that this material is a mixture of diamond and graphite.
Our new finding of DGA from four localities in two types of rocks confirms that the HMR has undergone the ultrahigh-pressure metamorphism and that the Cretaceous low *P/T* metamorphism has superimposed on it.

Keywords: Higo Metamorphic Rock, ultrahigh-pressure metamorphism, diamond-graphite aggregate, Raman spectrometry, Soft X-ray emission spectrometry

Inverted Metamorphism across the Main Central Thrust constrained by metamorphic P-T condition, western Himalaya, India

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Evolutionary signatures of active mountain building tectonic process as a consequence of collision between Indian plate and Tibetan plate are well preserved in the Himalayan metamorphic rocks. Southward thrusting of high grade metamorphic rocks (amphibolite to granulite facies) of Greater Himalayan Sequence (GHS) over low grade (greenschist facies) Lesser Himalayan Sequence (LHS) cause an inverted metamorphic field gradient across Main Central Thrust (MCT) (Arita, 1983; Vannay and Hodges, 1996). A geological map of the study area along Madhmaheswar Ganga valley, Rudraprayag district, Uttarakhand, India is prepared. In order to understand the inverted metamorphism in the study area, it is important to analyze how *P-T* conditions inferred from the phengite chemistry and garnet zoning pattern change with increasing structural level across the MCT. In this study area, hangingwall block of north-easterly dipping MCT mainly consists of paragneiss with intrusive body of leucogranite within the lower GHS (~1.5 km thickness) and footwall is generally termed as MCT Zone (~4 km thickness) comprised of augen gneiss and micaceous quartzite with some intercalations of amphibolites. An inverted Barrovian sequence is persistent from biotite zone through garnet zone upto kyanite zone where garnet-in isograd lies just beneath the MCT.

In this study, chemical analysis including garnet line profile and elemental map for major elements such as Ca, Fe, Mn, Mg and composition of matrix minerals is carried out by electronprobe microanalyser. Further, we have employed average *P-T* method (Holland & Powell, 1994) by using Thermocalc program (ver. 3.36) for thermobarometry. Garnets from uppermost MCTZ and lowermost GHS are characterized by growth zoning with consistently decreasing X_{Mn} content (from core to rim) suggesting the grain growth during burial with increasing *P* and *T* (Spear *et al.*, 1990). On the other hand, most of the garnet porphyroblasts in the lower GHS exhibit flat profile of X_{Mn} with little increase of it at rim. So, this kind of diffusional zoning profile signify retrograde reaction during exhumation and cooling of the lower GHS rocks (Florence & Spear, 1991). Higher rate of diffusion of major elements at higher elevated temperature than that of growth zoning cause homogeneous distribution of these elements. Tschermak substitution $[(Mg, Fe2+)^{vi}, Si^{iv}=Al^{vi}, Al^{iv}]$, between solid solution end members of dioctahedral micas is good indicator of metamorphic condition (Guidotti, 1984). In low grade metamorphic rocks, phengite composition changes from celadonite-rich mica towards idealized muscovite composition with increasing temperature (Guidotti and Sassi, 2002). Decrease of octahedral Fe+Mg content with increasing tetrahedral Al content in the order of 1 a.p.f.u. (11 oxygen basis), towards structural high, indicate the extent of tschermak substitution from biotite zone to kyanite zone. However, there is an abrupt decrease of Fe+Mg and Si content at the base and top of the MCTZ which could support the presence of Munsiari thrust and MCT, respectively. Peak *P-T* condition of 594 ±19 °C and 9.4 ±1 kbar is estimated from garnet + quartz + chlorite + plagioclase + biotite + muscovite ±ilmenite assemblage in uppermost MCTZ rocks. In contrast, lowermost GHS experienced peak *P-T* condition of 687 ±31 °C and 11.9 ±1.2 kbar attained by the peak metamorphic assemblage of garnet + quartz + plagioclase + muscovite + biotite ±kyanite ±ilmenite ± rutile. Thus, it is estimated that a steep inverted pressure gradient of 16.4 ±1.3 kbar km^{-1} persist between uppermost MCTZ sample and lowermost GHS sample which could suggest that MCT activity exhumed GHS from deeper level than MCTZ rocks. Further, it has to be determined whether very low Si

concentration in phengites in direct proximity to the major thrusts correlate with the effect of low-*P* or high-*T*.

Keywords: Himalayan metamorphic rocks, Main Central Thrust, Inverted metamorphism, Tschermak substitution, Peak P-T conditions

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Metamorphic process of the Tromso Nappe in the Scandinavian Caledonides based on P-T-t history of felsic gneiss

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Zircon grains have a potential to retain UHP minerals as inclusions, such as Coe and Jd, from the later stage overprint (e.g., Tabata et al., 1998). Therefore, the comprehensive study on Zrn is a potential tool to determine the exact spatial distribution and the formation timing of UHP belt. The Scandinavian Caledonides formed by continental collision between Laurentia and Baltica during the Ordovician to the Devonian, and are composed of a stack of several nappes. The Tromsø Nappe is traditionally ascribed to the Uppermost Allochthon (i.e., the uppermost tectonostratigraphic unit in the Caledonian nappe stack), containing abundant eclogites and ultramafic rocks within the host felsic gneisses, schists, marbles and calcsilicate rocks. UHPM conditions were reported from eclogites at two localities (Tonsvika and Tromsdalstind) as well as Dia–bearing gneiss hosting UHP eclogite at Tonsvika (e.g., Ravna & Roux, 2006; Janák et al., 2013). However, the country rocks hosting eclogites and peridotites have not been investigated in detail with respect of P-T conditions except of older work by Krogh et al. (1990). Therefore, we carried out petrological and Zrn geochronological study on felsic gneiss from Holmevatn, where Cr-rich eclogite and garnet peridotite were investigated previously (Ravna et al., 2006; Janák et al., 2015), recording P-T conditions up to 2.8 GPa and 800°C, close to UHPM. Felsic gneiss shows an augen texture characterized by cm–size Pl porphyroclasts in the gneissose matrix mainly composed of micas, mm–size Grt and Qtz. Si–content and Mg# of Ms are homogeneous in each grain (6.14–6.41 for O=22 basis and 0.60–0.74, respectively). X-ray mappings of representative Grt grains show a zoning structure, such as Ca–poor (Grs9–15) and inclusion–rich (including Ky) inner–core, Ca– and inclusion–poor outer–core and Ca–rich rim (Grs18–26). The Ca–rich rim is absent from the most grains of Grt. Outline of inner core shows an irregular shape, suggesting that some garnet was partially resorbed before the outer–core formation stage. Most Pl grains show a zoning from Ca–rich (An26–33) core to Ca–poor (An15–25) rim. The Zrn grains also show zoning structures composed of oscillatory zoned core, thin dark mantle and bright rim in CL image, and include Qtz, Ms, Bt and Ap in the core. The LA–ICPMS U–Pb Zrn dating gives the concordant ages of 2800–950 Ma for the core and 490–430 Ma for the rim. The Zrn core shows high Th/U ratio (> 0.10), the HREE over LREE and Ce positive and Eu negative anomaly, suggesting the magmatic origin (e.g., Hoskin & Ireland, 2000). The Zrn rim shows low Th/U ratio (< 0.10), depleted HREE and negative Eu anomaly, suggesting the metamorphic origin in the Pl stability field. The age spectra of the Zrn core are similar to those of the East Greenland Caledonides (e.g., Watt et al., 2000), suggesting the studied rock could be derived from the Laurentia but also detrital zircons from the Laksefjord and Gaisa Nappes indicating Baltican origin (e.g. Gee et al. 2017). The Zrn rim ages overlap with the previous report of Corfu et al. (2003) using ID–TIMS (e.g., U–Pb Zrn age of 452.1 +/- 1.7 Ma from eclogites and U–Pb Ttn ages of 451–448 Ma). Zr–in–Rt thermometry and GASP barometry give 640–700°C and 1.5–1.7 GPa for the Grt and Pl cores. The same thermometry and Grt–Hbl–Pl–Qtz barometry give 550–570 C and 1.1–1.2 GPa for the rim pairs. The P–T conditions of the Grt core stage are similar to those of D1 stage in metapelite reported by Krogh et al., (1990). Above mentioned results from conventional thermobarometry and zircon composition suggest that felsic gneiss probably did not experience UHPM, but crystallization of metamorphic zircon during exhumation cannot be excluded (e.g. Kohn et al., 2015). Moreover, all analyzed inner–rims of garnet (Grs18–20) show no Eu anomaly, suggesting formation in the absence of Pl,

at eclogite facies conditions.

Keywords: Caledonian Orogeny, U-Pb zircon age, REE pattern

Amorphous SiO_2 phase in a pseudomorph after coesite in garnet of a Su-Lu ultrahigh-pressure eclogite

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Coesite has been identified in continental collision-related metamorphic rocks and serves as a critical indicator of ultrahigh-pressure (UHP) metamorphism. Coesite grains and their pseudomorphs effectively preserve geological and mineralogical information, which is useful for understanding the exhumation process of UHP belts. Although the pseudomorphs after coesite included in robust phases are generally composed of polycrystalline α-quartz grains, occurrences of K-feldspar in these pseudomorphs have also been reported. The mineralogical data of polyphase pseudomorphs are insufficient, and their origins are not well understood.
By using a Focused Ion Beam (FIB) system, Transmission Electron Microscopy (TEM), and Raman spectroscopy, pseudomorphs after coesite in a garnet of a Sulu UHP eclogite obtained from Yangzhuang, Junan region, eastern China, were carefully examined in this study. Anomalous pseudomorphs consisting of amorphous SiO_2 (APSI) and K-bearing fibrous phases were noted; the existence of an APSI phase in UHP rocks has not been reported previously. In this presentation, we report on the crystal chemical features and nano-textural characteristics of the pseudomorph.
The eclogite sample includes garnet porphyroblasts mostly 1 mm in diameter or larger. These garnet grains are composed of inner and outer segments with the boundary marked by discontinuous changes in the grossular content. The pseudomorphs occur within only the outer segment of the host garnet, and radial cracks have developed in the garnet around them. These pseudomorphs are divided into darkly colored and transparent areas under plane-polarized light, which are dominant mainly at the core and in the marginal parts, respectively. The transparent area is composed of fine-grained α-quartz crystals. The darkly colored area consists of fine-grained aggregates of an SiO_2 phase and a fibrous phase including K and Mg. The Raman spectra of the SiO_2 phase in the darkly colored area do not show definitive Raman bands. The fibrous phase has a broad Raman spectrum and does not show a distinctive Raman band.
The TEM observation of a cross-section of the pseudomorph shows that the internal structure consists of a worm-like SiO_2 phase and fibrous parts. The selected area electron diffraction (SAED) analyses of most parts of the worm-like SiO_2 phase did not show diffraction spots, suggesting a non-crystalline state. In addition, the SAED analysis of fibrous minerals shows weak ring patterns with corresponding d-values of approximately 4.8, 4.3, and 2.5 Å. According to these d-values and Energy Dispersive X-ray Spectrometry (EDS) analysis data, the fibrous minerals were identified as polycrystalline sheet-silicates (KFSS). This study also discusses the origin of the pseudomorph consisting of APSI and KFSS phases and implications on the behavior of metamorphic fluid during the retrograde stage

Keywords: Pseudomorph after coesite, Amorphous SiO2 phase, Su-Lu UHP eclogite, TEM observation

Spacial distribution of garnet associated with foliation in the Sanbagawa metamorphic rocks, Kanto Mountains, Japan

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Reconstruction of the local thermal structure within metamorphic rocks are important since the thermal structure shows the deformation regime during the exhumation of the terrain. The deformation regime of the Sanbagawa metamorphic rocks of the Kanto Mountains have long been controversial, whether it is one plastic continuous body or it is composed of several parts separated by faults or thrusts. One of the key must lie in the area where apparent isograd is outcropped. Most of the Nagatoro area is categorized as the zone I by Hashimoto et al. (1992), which is the lowest metamorphic grade zone and is equivalent to the Chlorite Zone defined in the Shikoku Area of the Sanbagawa Metamorphic Belt. Zone I is defined by the mineral assemblage without garnet. Appearance of garnet is the index of zone II, which is the second lowest metamorphic grade zone defined in this area. Several outcrops in this area are known as being the zone II rocks since they show the mineral assemblage including garnet. Hashimoto et al. (1992) interpreted the appearance of garnet as being the result of the brittle structural deformation such as faults and thrusts. In that case, the local occurrence of garnet means that the area shows discontinuity in metamorphic grade, and the discontinuity results from juxtaposition of different grade rocks through some thrusting. However, raman spectrometry of the carbonaceous material indicated no gap in the metamorphic temperatures between the samples with and without garnet from the same outcrop. In this study, spacial distribution of garnet within an outcrop several tens of meters long was determined. Mineral assemblage was quartz, plagioclase, muscovite, chlorite. Not all the samples had garnet, calcite, titanite, and zoisite. Carbonaceous material was also included in many of the samples. 36 of the 55 samples included garnet in its mineral assemblage. Garnet grains were small, most of them with diameters 50 to 100 micrometers. Most of the garnet grains were euhedral and were found within the relatively mafic layers within the pelitic metamorphic rocks which were mostly composed of muscovite. Chlorite was often associated with garnet.

Occurrence of garnet was not at random, but seemed to form groups with lenticular or tabular distribution. The lens (if it was a lens) was subparallel to the foliation, which is known to be subparallel to the lithologic boundary in this area. Spacial distribution of garnet occurrence seemed to form lenticular or tabular groups subparallel to the lithology.

Chemical analyses of garnet using EPMA showed that the garnet grains were normally zoned, exhibiting euhedral growth of the crystal. Mn (spessartine) content was quite high (<50 Xsps). Some of the grains lacked part of the outermost rim, indicating resorption of garnet grains, but not in large amount. No evidence of large retrograde metamorphism was found. It is explained that the garnet grains started to grow during the last stage of the prograde metamorphism. Those cores were formed and started to grow but the growth did not last long because the grains are all so small compared to the proper garnet grains from the garnet zone.

The sharp euhedral chemical zoning profile indicates that the garnet grains were not kept hot for long time. Spacial distribution of garnet was probably controlled by the lithology parallel layers, namely the bulk rock chemistry.

Reference

Hashimoto et al. (1992) Journal of the Geological Society of Japan. 98, 953-965.

Keywords: lithology, Sanbagawa metamorphic belt, temperature

Estimation of maximum metamorphic temperature from Al/Si-order parameter in sillimanite

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The polymorphs of Al_2SiO_5 (andalusite, kyanite, sillimanite) are valuable for metamorphic rocks as indicators of pressure and temperature. Moreover, crystal structure and micro-texture of sillimanite can provide more detailed information about thermal history. For example, Raterron *et al.* (2000) observed the micro-textures in sillimanite, which were formed by the partly transformation to mullite ($Al_2(Al_{2+2x}Si_{2-2x})O_{10-x}$, x ≅0.17–0.59) at high temperatures. Furthermore, Zen (1969) and so on suggested that Al/Si-distribution in TO_4 tetrahedra of sillimanite should become continuously disordered with adding temperature. Although this Al/Si-disordering, in particular, has a possibility of a powerful geothermometer, the quantification of Al/Si-order parameter has been never succeeded. Recently, Igami *et al.* (JpGU, 2016; 2017) successfully determined the Al/Si-order parameter from micrometric region by HARECXS (High Angular Resolution Electron Channeling X-ray Spectroscopy, *e.g.* Soeda, 2000) method using TEM-EDS and obtained the relationship between the Al/Si-order parameter and temperature. In this study, HARECXS experiment was applied to natural sillimanite from metamorphic rocks, and the maximum metamorphic temperature of analyzed sillimanite was estimated.

Analyzed samples were sillimanite from Rundvågshetta, Lützow-Holm Complex, East Antarctica (sample No. RVH92011102A), and that from Mt. Riiser-Larsen, Napier Complex, East Antarctica (sample No. TH96123009). Both regions are assumed to be the UHT metamorphic regions (*e.g.* Kawasaki *et al.*, 2011; Hokada, 2001). No characteristic textures were observed in these sillimanite by optical microscope and SEM. Ultrathin sections were prepared from these sillimanite using focused ion beam (FEI Quanta 200 3DS or Helios NanoLab 3G CX), and then observed and analyzed by TEM-EDS (JEOL, JEM-2100F, JED-2300T).

In RVH92011102A, no characteristic textures were observed, and HARECXS analysis showed that the Al/Si-order parameter converged on ~ 0.88. In TH96123009, on the other hand, abundant anti-phase boundaries (APBs) were observed, and HARECXS analysis showed that the Al/Si-order parameter slightly converged on around 0.90, but widely distributed ranging from ~ 0.6 to ~ 0.9.

Generally, Al/Si-order parameter are assumed to have the lowest value at the peak temperature and to become somewhat higher during cooling. The HARECXS results of RVH92011102A implies that the peak temperature is > 1000 ℃ by comparison with those of experimentally heat-treated sillimanite (Igami *et al.*, 2016; 2017). This temperature is consistent with previous estimates (*e.g.* Kawasaki *et al.*, 1993; 2011; Harley, 1998; Fraser *et al.*, 2000). On the other hand, the lowest Al/Si-order parameter obtained from the HARECXS results of TH96123009 is ~ 0.65, and this value implies that the peak temperature is much higher than RVH92011102A. However, this low Al/Si-order state is thought not to be formed by stoichiometric disordered sillimanite and to be formed by the transformation from mullite + SiO_2 to sillimanite, because mullite has similar framework with sillimanite and its Al/Si-distribution is disordered. The APBs observed in TH96123009 is also thought to be formed at the same time. Therefore, the peak temperature of this sillimanite is assumed to be above the transition temperature between sillimanite and mullite + SiO_2, ~1200 ℃. This result provides further constraint on previous estimates, > 1100 ℃ (Harley and Motoyoshi, 2000; Hokada, 2001).

Keywords: sillimanite, Al/Si-order parameter, geothermometer, Napier Complex, HARECXS, TEM

Pressure dependence of structural evolution of CM: Implication for fast graphitization in subduction zone

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We report here new kinetic experiments in the pressure range of 0.5 to 8 GPa at 1200˚C for 10 min to 24 hours. Natural CMs extracted from sedimentary rocks in the Shimanto accretionary complex (SM) and Hidaka metamorphic belt (HMB) changed their morphology and crystallinity with increasing pressure. The time-pressure relations of each crystal parameter by X-ray diffraction and micro-Raman spectroscopy demonstrated sigmoidal transformations from an amorphous to a graphitic structure, suggesting the pressure-induced recrystallization at constant temperature (1473 K). Utilizing the relationship between log rate constant (ln*k*) and pressure (atm), we obtained the activation volumes of −22˜− 44 cm^3/mol during graphitization using a power rate model and a Johnson-Mehl-Avrami-Kolmogorov model. Combining the activation volumes and data on Nakamura et al. (2017), the structural evolution of CM based on experimental kinetic model can be expressed by three different factors of pressure *P*(MPa), metamorphic temperature *T* (K) and duration *t* (min):
$f(P, T, t) = C_{min} + (C_{max} - C_{min}) / \{1+[((-22P+286686)/RT)/t]^h\}$,
where C_{min} and C_{max} are the maximum and minimum values of each parameter, respectively, *A* is the intercept of the Arrhenius plot, *R* the gas constant, and *h* is the reaction rate of the sigmoid function (named as the “Hill coefficient”). It is thus possible to calculate the progress of graphitization at any *P-T-t* conditions during metamorphism. Utilizing the kinetic model, we tried to compare the experimental model based crystallinity of CM with natural metamorphic *P-T-t* conditions. In the case of Hidaka metamorphic belt, the natural CMs along the field *P-T* path of HMB proceeded structural evolution of CM from around 350 ˚C and form a graphite at around 450 ˚C. On the other hand, calculated structural evolution of CM started to recrystallize at around 400 ˚C, and form graphite at over 500 ˚C in a duration of ca.10 million years. Although there still exist some factors for fully understanding the natural structural evolution of CM to graphite, the experimental kinetic model can be applicable as a thermal indicator in a wide range of *P-T* conditions between 0.5 and 2 GPa at 400˜800 ˚C. The most important implication of our finding is that natural CM in crust has proceed fast recrystallization from an amorphous to a graphitic structure by temperature and pressure compared with the laboratory at 1 atm. Our data provide a new kinetic model for not only geothermometry but also geospeedometry and geobarometry in subduction zone.

Keywords: Carbonaceous material, Graphitization, Chemical kinetics, HPHT experiments

Progressive mélange formation during subduction: The Makimine mélange in the Shimanto accretionary complex of eastern Kyushu, southwest Japan

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Mélanges are commonly observed in accretionary complexes. However, the origin of mélange has remained controversial. Detailed field and microstructural studies of the Makimine mélange in the Late Cretaceous Shimanto accretionary complex of eastern Kyushu have revealed the progressive mélange formation during north-northwest directed subduction at the thickly sedimented convergent margin. The mélange preserved the ocean plate stratigraphy composed of basalt slabs in the argillaceous matrix, brown tuff, and mixed sandstone and mudstone, in ascending order. The mélange was imbricated at least two times possibly due to a duplex underplating after subduction. Early deformation in the mélange was recorded in the upper part of thrust sheets and is marked by mixing and layer-parallel shear of partially lithified sandstone and mudstone, resulting in the sandstone blocks in the mudstone matrix with mud intrusions and disaggregated sandstone blocks. These features suggest the deformation under elevated pores pressure beneath the décollement. Late deformation in the mélange occurred in middle to lower parts of thrust sheets and is characterized by stretching, and layer-parallel extension and shear of lithified sediments under the operation of pressure solution creep, resulting in development of stretching lineation, boudined layers, and composite planar fabrics with pressure solution seams. Basalt slabs were incorporated into the mélange during late deformation. Kinematic indicators consistently show the north-northwest directed shear from early to late deformation that is perpendicular to the general strike of the mélange. Overall, the mélange recorded the margin-perpendicular subduction-related deformation, with its distribution and deformation mechanisms spatially and temporary changed with depth.

A recipe of serpentinite melange in Mitsuishi Horaisan, Hokkaido.

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Serpentinite melanges are thought to originate from interfaces between wedge mantle and subducting oceanic slab. However, it is still not clear whether the observed fabrics represent original structures or significantly modified during later exhumation stages. We discuss on structural evolution of the Horaisan serpentinite melange, one of the typical in Kamuikotan Zone of Hokkaido.
The Horaisan melange contains numerous blocks of amphibolites, antigorite rocks, and massive serpentinized peridotite. Peak metamorphic conditions (~650 degC, 1.1 GPa) of garnet amphibolite blocks suggest high-temperature subduction. Since the melange structurally underlies an ophiolite accompanied with boninite, amphibolites may represent fragments of subducted slab under hot wedge mantle (i.e. dismembered metamorphic sole). We reconstruct how the melange developed based on field and microscopic observations as follows.
Stage 1 (Ep-amphibolite facies): Amphibolitized oceanic slab subducted beneath wedge mantle. High strain concentrated inside the slab resulted in strong schistosity, whereas the hanging wall peridotite scarcely deformed.
Stage 2 (Ep-Ab amphibolite facies): Amphibolites partially underwent retrograde recrystallization. Antigorite crystallized in peridotite to varying extent. Amphibolites were dissected by anastommosing shear bands and thus became blocks. Peridotites in contact with amphibolite blocks are altered to be actinolite rinds. Peridotites were also dissected by shear zones consisting of tremolite and/or antigorite schist. Slab and block interiors of amphibolite and peridotite were not deformed in this stage.
Stage 3 (blueschist facies): Trace Na-amphiboles crystallized at interstices of amphibolites and actinolite rinds without any deformation. No information specifically of this stage were identified in peridotites. Since coherent blueschist units underplated, the melange might have already detached from the subduction interface.
Stage 4 (very low grade): Peridotites pervasively underwent low-temperature serpentinization. Heterogeneous cataclastic shear differentiated foliated and massive serpentinite. Low-temperature reaction rims wrapped amphibolite blocks without significant deformation.
Summary: The sites of major strain shifted from amphibolite in stage 1, reaction rims (actinolite rinds) in stage 2, and low-temperature serpentinite in stage 4. Originally, the melange might have been a stack of blocks and slabs of peridotite and amphibolite separated by thin and anastomosing shear zones in early stages 1 to 2. Block-in matrix fabric with foliated serpentinite matrix is a feature not of plate interface but of later reorganization after exhumation and cooling.

Keywords: serpentinitei melange, subduction zone, actinolite rind

Peridotite ultramylonites derived from Prince Edward Transform fault, Southwest Indian Ridge: evidence of hydrous shearing in the lithospheric mantle

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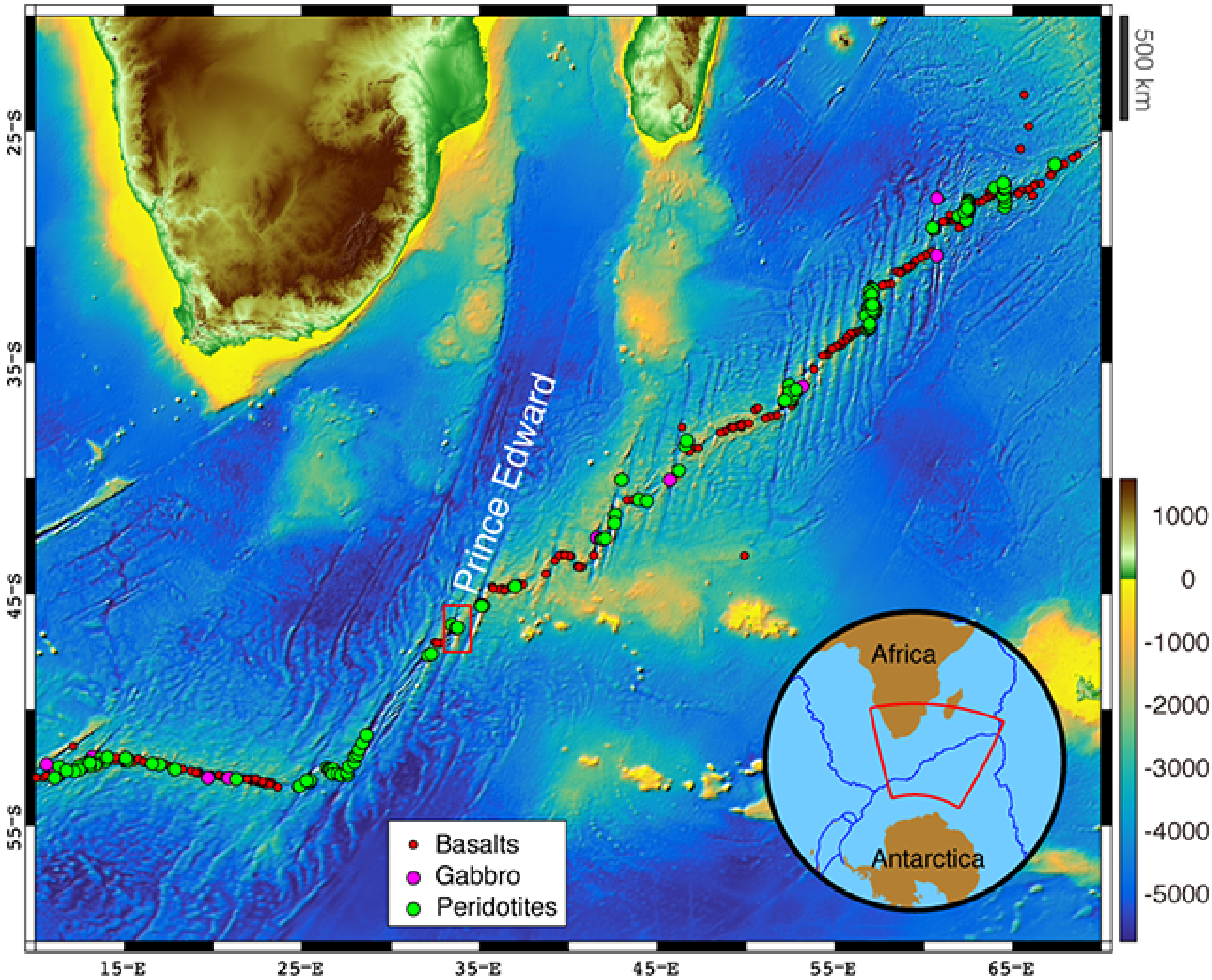
Southwest Indian Ridge (SWIR) is located to the southwest of Rodriguez Triple Junction where three Indian ocean ridges meet, and one of the slowest spreading ocean ridges in the world. We analyzed microstructure of 21 peridotites samples derived from Prince Edward transform fault on SWIR by PROTEA5 cruise in 1983. Peridotites contained olivine, orthopyroxene, clinopyroxene and spinel. Some samples also contained amphibole. Analysis of major elements indicated the origins of most samples were mantle. Compositions of amphibole were in the range of tremolite and magnesiohornblende. Based on microstructures provided by observation of thin sections, 21 samples was categorized into 4 groups: ultramylonites mainly consist of extremely fine grained matrix (3~5μm), heterogeneous tectonites consisting of coarse-grained crystals and fine-grained matrix, cataclasite and strongly serpentinized peridotites. Amphibole was in matrix or existed as porphyroclasts, so that amphibole could be generated before deformation of peridotites. Boudin structures of pyroxene and spinel were in some of the heterogeneous tectonites. Crystallographic preferred orientations of peridotites with amphibole were B- and E-type, whereas those of samples without amphibole were A- and D-type. These results suggest mantle flow under transform fault is affected by water, and possibly water moves into mantle from transform fault.



25°S
35°S
45°S
55°S
15°E
25°E
35°E
45°E
55°E
65°E
500 km
Prince Edward
Basalts
Gabbro
Peridotites
Africa
Antarctica
1000
0
-1000
-2000
-3000
-4000
-5000

Petrophysical characteristics of peridotites in Hayama-Mineoka belt of Cirmum-Izu serpentinite zone and their similarities to IBM fore arc peridotites

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We present petrophysical characteristics of serpentinized peridotites obtained from Hayama belt in Miura peninsula and Mineoka belt in Boso peninsula. The peridotites are dominantly harzburgites with minor lherzolite. Olivine grain sizes within the peridotites are ranged from coarser grains (>3mm) to medium grains (~1mm) and show undulose extinctions as well as kink bands. Orthopyroxene grains have exsolution lamellae. The chemical compositions of both olivine and spinel are in the range of the olivine-spinel mantle array of Arai (1994). Spinel Cr# can be divided into two groups: high Cr# (0.5-0.6) and low Cr# (0.3-0.4). Olivine crystal-fabrics in these peridotites were also divided into two groups: D type (Fablic Index Angle (FIA): 71°-84°) and A (AG) type (FIA: 34°-59°). Moreover, the two groups of olivine crystal-fabrics are directly related to chemical compositions of spinel: D type with the high Cr# and A type with the low Cr#. The peridotites of D type with high Cr# are similar to those in Izu-Bonin forearc peridotites. The peridotites of A type with low Cr# have similar physico-chemical properties to abyssal peridotites or those in Oman ophiolite. With the other geological evidences such as older basalt occurrences, we argue that the peridotites of A type with low Cr# might be possibly derived from the oceanic crust before subduction initiation.

Keywords: Cirmum-Izu serpentinite zone, Hayama-Mineoka belt, peridotite

Global seismicity dynamics - dimension reduction analysis of global seismicity

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Huge amounts of global seismicity data along the plate boundaries are very critical to understand the global mechanics of the plate motion together with relative velocity and subduction geometry. Especially, the continuous time series of seismicity of the subduction zone is of great importance to reconstruct the dynamical behavior within the several to several tens year global plate motion. In this paper, I would like to propose the new global seismicity dynamics based on the data-driven machine learning method using truly global seismic data stored in the international seismic database of USGS and ERI.
Recent studies of global seismic activity in the subduction zones reveals the repeating nature of the intermediate sized earthquakes, correlation of slow slip events, low frequency tremor, and normal earthquake , and correlated truncation of several asperities of the plate boundary. Further, it has been suggested that there is some degree of correlation between differential stress acting on the plate boundary and b value of the plate boundary seismicity, supporting that the correlation between buoyancy force of the plate and b value of seismic statistics appears weak. In the region of low b value statistics, the giant earthquake occurred a little bit frequently rather than the other region.
The global surveys of plate boundary seismicity were concerned with mainly the relations among occurrence of giant earthquake, slab characteristics, and the plate motion or the subduction geometry. It suggests that the physical model of subduction is possibly reconstructed by several to several tens examples of plate boundary characteristics. However, it seems to be obvious that huge amounts of seismicity data along the plate boundary zones including many seismicity time series now accumulating with time are most important data to reconstruct the global mechanics of plate motion.
In this paper, I would like to clarify the mechanical behavior of the truly global seismicity in the plate dynamics using the whole seismic data of the plate boundary. The method used here is the dimension reduction in which the observed seismicity vectors defined by time dependent number density of seismic spikes in the given volume of the plate boundary zone of the whole earth are uniquely projected on the low dimensional principal subspace of characteristic base vectors. Those characteristic base vectors are classified into two types; one is the aftershock seismicity of the world wide giant earthquakes, and the other is the strong correlation of plate boundary deformation. In this study, it is suggested that the mode of the latter changed repeatedly within ten years from quite period to murmured one.

Keywords: global seismicity analysis, dimension reduction, correlative plate motion

