Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

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The CPO and deformation processes of K-feldspar in the Kawai mylonites from the Ryoke metamorphic belt, SW Japan

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The temperature of brittle-plastic transition for K-feldspar has been considered to be 500-550 degrees. Under higher temperature condition, K-feldspar is deformed by dislocation creep with development of crystallographic preferred orientation (CPO). Some granitic rocks deformed under lower temperature, upper-greenschist to lower-amphibolite facies condition, include bands of K-feldspar fine-grained aggregates. These fine-grained aggregates are considered to be deformed by diffusion or dissolution-precipitation creep based on their microstructures and random crystallographic orientation. However, some granitic mylonites deformed under these condition include fine-grained K-feldspar bands that show clear CPO, requiring to understand more detailed processes. We discuss the formation and deformation processes of fine-grained K-feldspar aggregates in granitic mylonites based on their microstructures and CPO.

Kawai mylonite zone is sinistral mylonite zone developed in the Cretaceous Ryoke metamorphic belt, SW Japan. The studied samples are mylonites deformed under upper-greenschist to lower-amphibole facies condition and are mostly composed of fine-grained quartz bands and porphyroclasts of plagioclase and K-feldspar.

In moderately deformed mylonites including porphyroclasts maore than 30 % of whole volume, fine-grained K-feldspar aggregates develop between and around porphyloclasts. The fine-grained aggregates can be divided into two types based on their microstructures. Most of type 1 aggregates develop between porphyroclasts and are characterized by straight grain boundaries and elongated grain shape. In most case, their long axes are sub-parallel to relative displacement direction of porphyroclasts. Type 2 aggregates show undulose extinction and are characterized by less elongated grain shape with irregular grain boundaries.

Highly deformed mylonites include fine-grained K-feldspar bands that can be divided into type A and B based on the geometrical relationship with K-feldspar porphyroclasts. Type A aggregates are fine-grained bands that include several porphyroclasts and type B aggregates are thin and long tails on porphyroclasts. Type A aggregates show CPOs with the same orientation as the porphyroclasts and their [100] and [010] axes tend to be sub-parallel to XZ plane. The CPOs for most of type B aggregates gradually rotate from the same orientation as the porphyroclast as away from the porphyroclast and their [100] axes tend to be high angle to XZ plane. The axes of the rotation are sub-parallel to Y-axis of mylonites but the sense of the rotation is variable without particular relation with the sinistral shear sense of mylonitic deformation.

The features described above may indicate that fine-grained K-feldspar aggregates were formed by recrystallization along microcracks and kink boundaries within porphyroclasts, inheriting crystallographic orientation of the host grain, and then were deformed by granular flow associated with dissolution-precipitation processes. Further, present samples indicate that clear CPO originated from host grain can survive after large deformation through granular flow.

Keywords: Granitic ultramylonite, K-feldspar, CPO, EBSD, fine-grained aggregates

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SMP046-02 Room:201B Time:May 27 08:45-09:00

Deformation of granitoids in brittle-ductile transition: insights from the Asuke shear zone

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Under brittle-ductile transition, various kinds of fault rocks such as mylonite, cataclasite and pseudotachylyte are formed. It is important to study these rocks to comprehensively understand the processes of inland earthquake generation. Especially, quartz in fault rocks shows various types of recrystallization processes sensitively in response to experienced temperature, pressure and stress; bulging, subgrain rotation, grain boundary migration, which has been investigated experimentally (Hirth and Tullis, 1992). In natural systems, extrapolations of experimental results often give good results to estimate the above parameters (Jerabek et al., 2007; Stipp and Tullis, 2008). Therefore, investigations of quartz texture would give the processes which are experienced during shear deformation. In addition, the slip systems of quartz, induced by plastic deformation, are indicatives of the conditions of shear deformation, and they have been studied from experiments and analyses of natural samples (Reviews in Passchier and Trouw, 1996; Toy et al., 2008). However, a lot of reports for recrystallization processes and slip systems of quartz so far focus on regions where plastic deformation of rocks is dominated. Therefore, studies for mineral textures in brittle-ductile transitions are limited.

Based on the above questions, this study focuses on one of the representative areas of brittle-ductile transition in Japan; the Asuke shear zone, Aichi prefecture. The studied area consists of Inagawa granite as host rock (Kanaori et al., 1991; Sakamaki et al., 2006), and the major mineral constituents in studied rocks are quartz, plagioclase, K-feldspar, amphibole, and biotite. The fault rocks in the Asuke shear zone are basically cataclasite, and partly mylonite on outcrop scale. Under optical microscopy, quartz fine grains less than 1 um are recognized around large quartz grains up to 3 mm. Plagioclase and K-feldspar are fragmentated by brittle deformation, and fine grains in micrometer scales can be recognized. It has been discussed that these grain-size-reduction processes are induced by above dynamic recrystallization (bulging or subgrain rotation in this case) or introductions of clacks (Vernnoij et al., 2006a). Moreover, Vernooij et al. (2006b) suggested that dissolution-precipitation process partly contributes to grain size reduction. Also, it has been argued that dauphine twinning may induce dynamic recrystallization of quartz (Lloyd, 2004; Stipp et al., 2008) or not (Neumann, 2000). These grain-size-reduction processes as well as slip systems can be inferred from analyses of crystallographic preferred orientations (CPOs) and misorientation axes. In this study therefore, we use electron backscatter diffraction (EBSD) and measure relationship of crystallographic orientations between quartz fine grains and host large grains. Then, I will discuss the grain-size-reduction processes of quartz in brittle-ductile transition. Also, surfaces of quartz grains are observed by using scanning electron microprobe (SEM). Grain-size-reduction processes and contributions of fluid will be discussed from their morphologies, together with the EBSD results. In addition to analyses for quartz, deformation mechanisms of feldspars are investigated: The compositions of feldspars between fine grains in micrometer scales and porphyroclasts are determined. EBSD analyses and observations of grain morphologies by SEM for feldspar fine grains are performed. Then, I will discuss deformation mechanisms of feldspar fine grains (in this case, grain boundary sliding or possibility of solution-precipitation creep).

Keywords: quartz recrystallization, grain morphology, feldspar deformation, composition, electron backscatter diffraction

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SMP046-03 Room:201B Time:May 27 09:00-09:15

Elastic anisotropy of deformed rocks

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The seismic anisotropy will provide us the information about deformation in the Earth's interior. In order to interpret observed anisotropy, we must understand the relationship between deformed textures and elastic properties. Plastic deformation gives rise to the lattice preferred orientation (LPO) of mineral grains, which leads to elastic anisotropy in deformed rocks. The development of SEM-EBSD has enabled us to measure the orientation of individual mineral grains in a deformed rock. Using the measured orientations and elastic constants of single crystals, we can calculate elastic properties of the deformed rock using Voigt or Reuss averaging schemes. No information about the shape or arrangement of grains is used in these averaging schemes. The Voigt average gives an upper bound, and the Reuss average a lower bound to elastic stiffness. The stiffness of the rock sample should be found within these bounds. When component minerals have similar elastic properties and weak anisotropy, Voigt and Reuss averages are nearly equal. These values can provide a good prediction of elastic properties. However, when component minerals have strong anisotropy, Voigt and Reuss values are far apart (Mainprice and Humbert, 1994). Additional information like the shape and arrangement of grains should be taken into account for a better prediction of elastic properties.

As the arrangement of grains, we focus on a layered structure seen in deformed rocks. For simplicity, we consider an alternation of two compositionally different layers. The two layers are composed of different mineral grains, which are well aligned in each layer. Two layers have different effective elastic constants. The elastic properties are assumed to have the symmetry of orthorhombic systems in both layers. Two layers are assumed to have the same principal axes of elastic tensors. The calculated effective elastic constants show Reuss values in relation to deformation perpendicular to the layers. The calculation gives Voigt values in association in relation to deformation parallel to the layers. In this presentation, we will also compare calculated and measured velocities for serpentinite mylonites.

Keywords: elasticity, anisotropy, deformed rock, LPO, layered structure

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SMP046-04 Room:201B Time:May 27 09:15-09:30

metasomatic instability and constitutional oversaturation

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Migrating interface derived from interdiffusion of ionic species in permeable solution in the plate boundary rocks occurs as wavy boundary between mono- and bi-mineralic bands. Simple examples are found in the banded basic schists of the Sambagawa metamorphic belt. Albite - quartz - calcite bands having wavy interface are commonly sandwiched by thin chlorite bands and sometimes by thin epidote bands. The trails of hematite grains are continuously pervaded into albite - quartz bands from chlorite band, indicating the advancement of interface into chlorite bands.

The wavelength of the interface increases firstly and then reaches the constant level with width of albite - quartz band. It suggests that the preferable wavelength of the interface develops with time, considering the increasing width of albite - quartz band with time. However, the ratios between width of band and wavelength of the interface varies in different rock specimens.

The modeling of the wavy interface development should be constructed in the system of chemical equilibrium of solution with albite, chlorite, quartz and calcite. At the interface chemical equilibrium attains but being apart from the interface, the diffusion of ionic species relevant with chlorite and other minerals should make change in equilibrium concentrations. As the concentrations gradients of ionic species in grainboundary solution makes constitutional oversaturation (1) of one side mineralogy, the interfacial geometry becomes unstable for small waveform perturbation. The selective wavelength in this case is governed by the ratio of oversaturation degree and interfacial energy. In this study, the authors can propose the capillarity effect constitutional oversaturation instability of the metasomatic banding interface. This is called as metasomatic instability which controlled by velocity of interface advance.

Reference

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Keywords: metasomatic instability, constitutional oversaturation, metamorphic banding

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Implication of the residual pressure recorded in quartz inclusions in granet from high T metamorphic terranes

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Quartz inclusions in garnet from metamorphic terranes reveal residual pressure depending on the metamorphic pressure and temperature of their entrainment (Enami et al, 2007). The residual pressure occurs due to the difference in elastic properties of host garnet and quartz inclusions and also due to the pressure and temperature change according to the exhumation path. The residual pressure can be measured by Raman micro-spectroscopy, and the results are consistent with those estimated by a simple elastic model of the sphere-in-hole problem (Enami et al, 2004). This is an important progress in metamorphic petrology, because it represents a new development of metamorphic barometry independent of thermodynamic methods.

However, several problems have remained to be solved in the application of this method. One problem is the applicability of this method to high temperature metamorphic terranes in which low - high transition can occur in quartz. This study aims to solve this problem and examined quartz inclusions in garnet from the Higo Metamorphic Rocks, one of the high T metamorphic terrane of Cretaceous in age in Central Kyushu.

The studied are is Kosa district, Kumamoto Prefecture, which is the same area studied by Maki et al (2004). Here we adopt the metamorphic zonal mapping after Maki et al (2004): biotite zone, garnet - cordierite zone, and orthopyroxene zone from north to south. This study newly defined the muscovite - out isograd and the tourmaline - out isograd in the studied area. The peak metamorphic temperatures are about 600 C at the muscovite - out isograd and about 800 C at the orthopyroxene isograd, which are estimated by the granet - biotite thermometer and the petrogenetic grid (Maki et al, 2004).

We examined eight samples collected from the area between the muscovite - out isograd and the orthopyroxene isograd by Raman micro-spetroscopy. According to Enami et al (2004), we made plots of Dw1 vs Dw2. In the plots we found two kinds of data: one plotted in the first quadrant (both Dw1 and Dw2 are positive) and the other plotted in the third quadrant (both Dw1 and Dw2 are negative). The two kinds of data are taken from the same garnet grain. The latter data has not been reported by Enami et al (2004) who studied mostly high pressure metamorphic rocks. We interpret that the data plotted in the first quadrant show compressive stress and the data plotted in the third quadrant do tensile stress as suggested by Enami et al (2004).

The peak metamorphic pressure and temperature condition of this area is likely to have reached the stability field of high quartz (Obata et al, 1994, Osanai et al, 1998, Yoshimrua, 2004, Maki et al, 2004 and Miyazaki, 2004). Therefore quartz inclusions showing tensile stress may be originally high quartz when they are entrained in the host garnet. The high quartz will transform into low quartz when the host rock crosses the transition curve during the exhumation, and the volume decrease by about 1 per cent associated with the transition may cause tensile stress in the garnet. Quartz inclusions showing compressive stress from the same garnet grain may have been entrained in garnet when the rock crosses the transition curve from high temperature side in the retrograde path. Therefore we assume that quartz inclusions with compressive stress have been entrained at the low- high transition temperature and evaluated the entrainment pressure by combining the residual stress measured by Raman micro-spectroscopy and the elastic model. The result shows 0.35 - 0.5 GPa, independent of sample location in the area. The estimated pressure is higher by 0.1 - 0.3 GPa than the peak metamorphic pressure estimated by Maki et al (2004) and also by Miyazaki (2004), and lower than the pressure by 0.3 - 0.5 GPa recorded in a calc-silicate granulite in the same area reported by Maki et al (2009).

Keywords: garnet, quartz, residual pressure, high T metamorphic terrane, Raman micro-spectroscopy, elastic interaction

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SMP046-06 Room:201B Time:May 27 09:45-10:00

Distinct difference of metamorphic texture between high P/T and low P/T metapelites

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Localization of deformation and reaction will affect macroscopic evolution of metamorphic belt in the crust. To evaluate localization of deformation and reaction, metamorphic textures of metapelites from high P/T metamorphic belt (Sanbagawa Metamorphic Rocks) and low P/T metamorphic belt (Ryoke Metamorphic Rocks) are examined.

Distinct difference of metamorphic textures between high P/T and low P/T metapelites is observed with EPMA mappings of thin sections as follows. Metamorphic differentiation and coarsening of metamorphic minerals progressed well in high P/T metapelites. Quartz-rich layers or lenses are formed in high P/T metapelites. On the other hand, mosaic textures of quartz-rich and Al-bearing mineral domains are developed in low P/T metapelites. Textures of migmatite of low P/T metamorphic rocks are exceptional and complex. Coarsening of metamorphic plagioclase is clear in high P/T metamorphic rocks. Average size of metamorphic plagioclase in higher-grade high P/T metapelites is about 10 times larger than those of lower-grade high P/T metapelites. At the same metamorphic temperature (around 500 ?C), average size of metamorphic plagioclase of high P/T metapelites is about 10 times larger than those of low P/T metapelites. Exceptionally, average size of metamorphic plagioclase in migmatites is much larger than those in the non-migmatitic low P/T metapelites.

It is suggested that quartz-rich layers or lenses in high P/T metapelites were formed by deformation, because these layers or lenses are parallel or subparallel to schistosity. To examine the deformation-associated metamorphic differentiation, deformation of immiscible two-phase viscous fluid is simulated. The results of deformation of the two-phase fluids without viscosity contrast show that coarsening of the each mosaic domain takes place. And multi-layers or elongated mosaic structures are formed by deformation. On the other hand, the results of deformation of the two-phase fluids with viscosity contrast show that branching layered structures or lenses of lower viscosity fluid are formed. These types of structures are developed with strain localizing in low viscosity fluid.

The numerical simulations suggest that formation of quartz-rich layers or lenses in high P/T metapelites is caused by strain localization in quartz-rich domain. On the other hand, coalescence and precipitation-dissolution are important for coarsening of metamorphic minerals with deformation. Because dihedral angle between quartz and water becomes less than 60? at high P/T conditions, fluid network will be formed within quartz-rich layers or lenses, which will enhance reaction-diffusion in high P/T metapelites. The above-mentioned mechanism has a positive feedback, therefore, it is expected that textural evolution due to deformation and reaction in high P/T metapelites will accelerate progress of deformation and reaction.

Keywords: metamorphic rock, metamorphic texture

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SMP046-07 Room:201B Time:May 27 10:00-10:15

Heterogeneous nucleation, Ostwald step rule and Potts model: Implications for precipitation of silica polymorphs

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The rock-forming minerals include several polymorphic minerals such as aluminosilicates, serpentine, carbonates, carbon, and silica. These minerals have been used as indicators of P-T condition and/or fluid compositions, when they formed. It is also well known that metastable phases commonly appear especially during fluid-rock interaction, including aragonite in carbonate sinters, and opals in silica sinters. Okamoto et al. (2010) found that the dominant silica minerals precipitated from aqueous solutions in order of amorphous silica, cristobalite to quartz, and that quartz is dominant in the solutions including minor Al and Na. The formation of less stable phase prior to the most stable phase is called as the Ostwald step rule. The phenomena following the Ostwald step rule is explained by relative differences in growth rate among the polymorphic minerals in the presence of seeds of all phases, but nucleation of these seeds should be considered. In this study, heterogeneous nucleation and the effects of impurity are investigated by a simple microscopic model, Potts model, in Monte Carlo simulation.

In the Potts model, each spin (molecule) in a lattice has one of q states (phases). Each lattice site i has a spin si taking values in the range of 1 to q, and the energy of a configuration s is given by the Hamiltonian, H = - $[J]_{si,sj}$ - $[h_a M_a]_a$ (eq. 1) , where M_a is the number of spins of the spin type a. The first term is the sum of nearest-neighbor pairs of spins with the symmetric interaction energy (surface energy), and the second term describes the effect of external fields ha acting on spin type a (bulk free energy). To evolve the system, we employed discrete-time Metropolis dynamics. Here, we consider spins of four states (1-4) in a 30 x 30 square lattice in two dimensions and periodic boundary conditions. We set T = 0.80, and impose the external fields as ha = 0.1 x (a ? 1), indicating that state 4 is the most stable. When we set the diagonal elements of the interaction matrix to unity and the other elements to zero, any metastable phase does not appear. The sequential nucleation of metastable phases following the Ostwald step rule is realized when we introduce a non-diagonal interaction, $J_{a,\ a+/-1}$ = F1 $>$ 0 (attractive), between neighboring phases, and all other non-diagonal interactions have $J_{a,\ b}$ = F2 $<$ 0 (repulsive) (Sanders et al. 2007). The successive nucleation of metastable phases in order of 1, 2, 3 and 4 appears with F1 = 0.1 and F2 = -1.0. We also find that phase i nucleated in phase i-1. This result is qualitatively same to the occurrences of the silica minerals in the pure Si solution of Okamoto et al. (2010): homogeneous nucleation of opal-A from the solution, heterogeneous nucleation of opal-C upon opal-A and that of quartz on opal-C. A new phase preferentially nucleates on the next-less-stable phases, as they are probably more structurally similar to new phase than are other phases.

The effect of impurities was introduced as -$[J_{pa}]$, that is the interaction between the impurity, p, and spin a into equation 1 following Sear (2005). To consider the case of silica, we propose that an interaction between phase 4 and an impurity equals 1, and that interactions between other states and an impurity are zero. The simulation results reveal that the evolution of the system varies with increasing number of impurities. When the number of impurities is small, nucleation of the most stable phases occurs via the formation of metastable phases. In contrast, with a larger amount of impurity, phase 4 is able to nucleate directly. The direct nucleation of quartz in the solution with small amounts of impurities (Okamoto et al. 2010) indicates the strong interaction between quartz and these cations.

References:

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Sanders DP. (2007) Phys Rev B, 75, 132101.
Sear PS (2005) J. Phys. Condens. Matter 17, 3997-4004.

Keywords: polymorphic minerals, Ostwald step rule, heterogeneous nucleation, Potts model

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Zircon behavior in the upper amphibolite facies metamorphic rocks from the Aoyama area, Ryoke metamorphic belt, SW Japan

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Recent researches on zircon behavior showed that zircon can crystallize at various stages of metamorphism. In order to interpret the results of the U-Pb zircon dating, it is essential to understand how zircon behaves and responds to the metamorphic processes (Harley et al. 2007). However, zircon-forming, zircon-consuming and zircon-modifying reactions are controlled by the whole-rock composition, pressure-temperature conditions, and fluid-melt-rock interactions. This complexity leaves zircon behavior in metamorphic rocks still unraveled. This research aims to describe the mode of occurrence of zircon in the upper amphibolite facies metamorphic rocks exposed in the western part of the Aoyama area (west of the Kachiji fault), Ryoke metamorphic belt, SW Japan (Yamaguchi and Kawakami, 2008), and to understand the behavior of zircon during the high-temperature metamorphism.

In the Aoyama area, upper amphibolite facies pelitic schists and pelitic-psammitic migmatites are widely exposed and the metamorphic grade increases from the north to the south (Takahashi & Nishioka, 1994; Kawakami, 2001). The metamorphic conditions of the study area estimated by the geothermobarometry were about 610 ^{o}C, 3 kbar in the north and about 715 ^{o}C, 6 kbar in the south. Kawakami and Suzuki (2008) reported the CHIME monazite age of the Ao granite that is intruded to the south of the Aoyama area to be 79.8+/-3.9 Ma.

Eighteen pelitic-psammitic metamorphic rock samples from the study area were examined under SEM-EDS and about 250 grains of zircon were described in detail. As a result, at the north of the study area, zircon grains larger than 20 um in diameter were abundant than in the south.

In order to confirm whether this trend is controlled by the whole-rock Zr composition or not, the remaining half of the chips that was used for the thin section preparation were powdered and analyzed by the XRF analysis. As a result, most of the whole-rock Zr was resided in the zircon grains larger than 20 um in the north, whereas zircon grains larger than 20 um occupied only 20-30 % of the whole-rock Zr in the south.

Based on the result above, a hypothesis is made that most of the coarse-grained zircon in the north larger than 20 um would be detrital. In contrast, at the south, zircon is likely dissolved and may have newly nucleated during the metamorphism, so that Zr may be resided in zircon smaller than 20 um and in other minerals.

In order to check this hypothesis, zircon U-Pb dating by LA-ICPMS was carried out. As a result, zircons (> 20 um) in the north showed the Proterozoic to the Jurassic discordant ages both in the core and the rim. These ages would represent detrital ones. On the other hand, zircon grains in the south showed the Cretaceous discordant ages. This may represent the partial resetting of the old, detrital zircons during the Cretaceous or the Tertiary time. Therefore, it is likely that in the study area, detrital zircon grains including coarse ones dissolved and partially reset during the Ryoke metamorphism and/or during the contact metamorphism by the Ao granite and the Kabuto granodiorite intrusions postdating the Ryoke metamorphism. To confirm that new zircon grains nucleated in the south of the study area during the Ryoke metamorphism or not, the dating of tiny grains and thin overgrowths of zircon and check of the REE patterns of them are important.

Keywords: high-temperature metamorphism, zircon, U-Pb dating, laser ablation ICPMS, zirconium, Ryoke metamorphic belt

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SMP046-09 Room:201B Time:May 27 10:45-11:00

Heterogeneous distribution of garnet in the Sanbagawa metamorphic rocks in Kanto Mountains

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Occurrence of garnet in the Sanbagawa metamorphic rocks from Nagatoro area, Kanto Mountains, east Japan, was investigated in detail.

Garnet have been known to occur in the Nagatoro-area pelitic rocks, which contributed to the definition of the metamorphic zonation in the area. The occurrence , or texture, of the garnet grains have, however, not been described in detail. Textural observation of garnet is becoming more and more important, since garnet grains with different texture has now been reported from the Sanbagawa metamorphic rocks in Shikoku.

In this study, pelitic samples were taken from the high-grade zone area in the Sanbagawa belt exposed in the Kanto Mountains. Most garnet grains found in the pelitic schists were smaller than 0.1 mm in diameter, and were either included in the albite porphyroblasts (referred as albite-spot, hereafter) or among muscovite grains. The heterogeneous distribution is similar to the type-B garnet found in Shikoku (Inui, 2010). The average size of the albite-spot seemed to be larger in samples with garnet than in those without garnet. The shape of the garnet grains included in the albite-spots were mostly euhedral, whereas about half of the garnet grains within muscovite layers had round shape. Many of the rounded grains had aspect ratios larger than 2. Such grains often accompanied chlorite ”tails” at their either end, which suggests that the grains have been resorbed after their euhedral growth. The overall texture suggests that the euhedral garnet grains in albite-spots are perfectly preserved, on the other hand, the long and round grains among muscovites are partly preserved. It is likely that garnet grains formed in the other parts of the rocks are mostly resorbed and are lost. It infers mechanism that resulted in the heterogeneous distribution of the garnet in the schists. The correlation of the size of garnet grains and the distance to its nearest neighbor suggested that the initial garnet growth was controlled by the velocity of material transfer in the rocks.

The heterogeneously distrubuted garnet grains in the Nagatoro area were compared to the similar garnet in the Asemigawa River area and the origin of the garnet will be discussed.

Inui, M. (2010) Two types of garnet in Sanbagawa pelitic schists along Asemigawa River, central Shikoku Journal of Mineralogical and Petrological Sciences, 105, 274-279.

Keywords: garnet, Kanto Mountains, Nagatoro, grain size distribution, heterogeneous distribution

Japan Geoscience Union Meeting 2011
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High-Mg cores of the garnets in the Sambagawa pelitic schists from the Besshi district, central Shikoku, Japan

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Pelitic schists adjacent to the Seba metagabbro consist mainly of garnet, phengite, epidote and quartz with small amounts of amphiboles (Na-Ca and Ca-amphibole), albite, chlorite, biotite and carbonaceous matter. Rutile, titanite, ilmenite, calcite, paragonite, hematite and zircon are occasionally present as accessory minerals. A schistosity is defined by preferred orientation of coarse-grained phengite (3.5 mm).

Garnets in the pelitic schists occur as euhedral to subhedral grains up to 3 mm across. The garnets are optically zoned, from pale red-colored cores to colorless rims. The garnets have almandine-rich composition (XAlm=0.50-0.60) with variable amounts of the grossular (XGrs=0.18-0.31) and pyrope (XPrp=0.08-0.24) components. Two zones (almandine-pyrope rich core and almandine rich rim) were identified based on chemical composition. The cores are abundance of rich in pyrope, decreasing toward the core-rim boundary (XPrp=0.24-0.18) and they show antithetic zoning of XAlm (0.50-0.56). The boundary between the core and the rim shows a sharp chemical discontinuity. In the rim, XAlm (0.56-0.58) and XPrp (0.09-0.13) increase, XSps (0.02-0.01) decreases, and XGrs (0.29-0.31-0.28) increases and then decreases slightly. The garnets contain inclusions of epidote, Ca-amphibole (Mg-hornblende), phengite (Si=6.53-7.27 pfu), paragonite, albite (An 0-3), chlorite, calcite, ilmenite, rutile, titanite and zircon. The garnets also contain polyphase inclusions of Mg-hornblende+paragonite+quartz; epidote+paragonite; epidote+paragonite+quartz and epidote+albite. Garnets are partly replaced by aggregates of amphibole (Mg-hornblende), phengite (Si=6.47-6.52 pfu), epidote and albite (An 0-3) and symplectites of Ca-amphibole (Mg-hornblende) and albite (An 0-5) with rare quartz. The margins of the garnets are occasionally replaced by chlorite, phengite and biotite, or by biotite and calcite aggregates.

Amphiboles occur in the matrix as subhedral to anhedral prismatic grains up to 2 mm long. Some amphiboles in the matrix are zoned from winchite, barroisite cores to Mg-hornblende rims.

According to the petrography and chemical compositions of the minerals the pelitic schists are adjacent to the Seba metagabbro mass probably suffered high-pressure metamorphic condition. The chemical discontinuity between the core and the rim of the garnets is formed in the different metamorphic conditions for the core and the rim. Similar zoning of garnets have been reported by Higashino and Takasu (1982), Takasu (1984) and Nomizo (1992) from the Besshi district. Takasu (1984) reported similar garnet from the Seba metagabbro mass, the core of garnet undergone an eclogite facies metamorphism at higher temperature conditions (720-750 C, 12-24 kbar) and the rim together with the surrounding Seba eclogitic basic schists (610-650 C, 7-24 kbar).

Reference:

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Keywords: pelitic schist, high-Mg garnet, Sebadani, Sambagawa

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SMP046-11 Room:201B Time:May 27 11:15-11:30

Metamorphism and thermal structure of subduction zone: a case study on the Sanbagawa pelitic rock

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The thermal structure of the present subduction zones has been a focus of geophysical studies regarding the origin of arc magma, transportation of volatile component such as H_2O and CO_2 into the deep mantle, and origin of the subduction zone earthquakes. Many studies employing numerical modeling have been done for the aim estimating the thermal structure of the subduction zone. The results contributed semi-quantitative understanding of the thermal structure of the subduction zone, however, diversity of the results among the models is not negligible to be applied to the natutal system.

It has also been one of the motivations of metamorphic geology that analysis of prograde metamorphism of a suite of metamorphic rocks in a metamorphic belt yields information of the the subduction geotherm. Recent advance in decoding metamorphic P-T condition enabled revealing true peak P-T condition and prograde P-T path excluding extensive retrograde hydration. Therefore, now, we can discuss the subduction geotherm of past subduction zone in a context of metamorphic geology.

In this presentation, we review nature of the thermal structure in the subduction zone, and prograde- and progressive-metamorphism, at first. Then a case study on the Sanbagawa pelitic rock is demonstrated with implications to the mantle-wedge dynamics and the material transportation.

Keywords: subduction zone, thermal structure, metamorphic rock, exhumation

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SMP046-12 Room:201B Time:May 27 11:30-11:45

Wedge extrusion followed by major out of sequence thrusting accompanying duplexing, the high P/T Sambagawa blue schist

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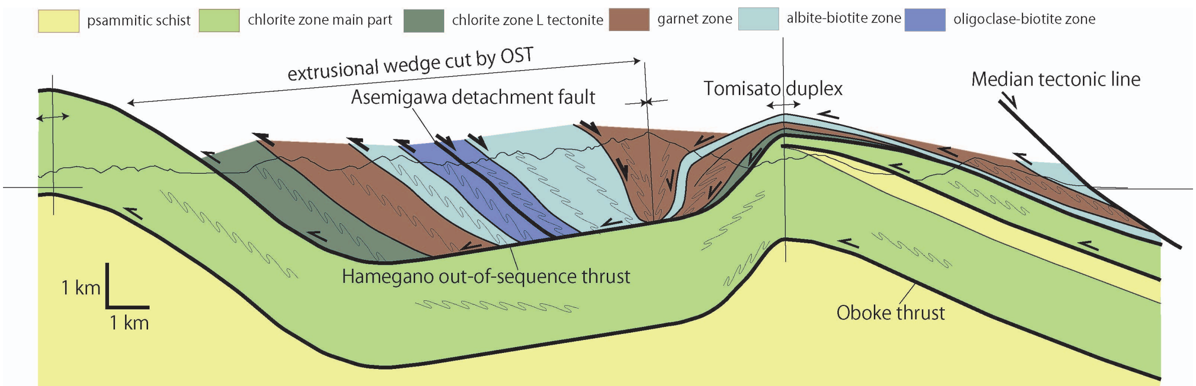
I am seeking for a sponsor, like museum, city or town office, who kindly publishes the colored geological map, very wide, my studied area. Map file is pc based, and only 200,000 Yen for 500 copies is needed.

The Sambagawa high P/T zone of Besshi area is regionally mapped, and characteristic major structures performed the exhumation of high grade metamorphic rock is clarified. As noted by Osozawa and Pavlis (2007), the most fundamental structure is a D2 extrusional wedge. The southeastward wedge consists of a series of normal faults domain at hanging wall of the Asemigawa detachment, and a series of thrust faults domain of the footwall. These faults bound every metamorphic mineral zone, and the thermal culmination of the Asemigawa section is oligoclase-biotite zone, hanging wall of the detachment fault. To the NW, we now confirm that the culmination is an eclogite body, constituting an axis of the extrusional wedge. To the SE, these extrusional wedge and a series of normal and thrust faults are linearly traceable on regional map, but suddenly not continuous to the chlorite zone and disrupted. The disruption is due to the Hamegano out-of-sequence thrust, newly found in this paper, and the Besshi unit is divided into two units. The OST divides the chlorite zone the upper L tectonite consisting of varicolored mafic schist, and the other lower pelitic schist. D2 folds at the hanging wall is disjunctive and broken by the movement of brittle OST. The OST is clearly traceable to the NW from the Asemigawa area. To the NE, a syncline is observed as mapped by previous studies, but it exists only on hanging wall, and the structure is discordance with not-folded or obscured footwall chlorite zone. Its SE limb, hanging wall of the OST, is extrusional wedge, but the NW limb consists of duplexing metamorphic mineral zones, and the syncline is lithologically asymmetric. Further to the NE, OST and hanging wall duplex is involved in NW plunging anticline. We named the duplex stack formed near anticlinal axis of OST, the Tomisato duplex. OST and duplex moved SW, as a final expression of metamorphic exhumation, following the wedge extrusion. The Median Tectonic line might have played an important role for exhumation as a root, but most of the Besshi unit, including eclogite body, is consequently rootless. Interestingly, the chlorite zone rocks hanging wall of the OST include a psammitic schist, only at the NW limb of anticline. The schist is lithologically similar to that of the Obaoke unit, the structurally lowest unit. The Oboke unit and thrust is also concordantly folded with the OST and duplex, for the anticlinal axis. Another anticline is to the SW, Nakashichiban area, where the psammitic schist of Obaoke unit is once again exposed.

Metamorphosed ultramafic rocks, including eclogite, are distributed in every metamorphic zone. The metamorphic minerals constitute D1 foliation overprinted by D2 deformation. Therefore, ultramafic rocks were amalgamated with surrounding rocks before D1. Two possibilities of mixing mechanism are expected; sedimentary or tectonic melange process, and we prefer in this case tectonic slicing during D0 at deeper subduction zone, by considering eclogite metamorphism.



Keywords: Sambagawa high P/T zone, extrusional wedge, out-of-sequence thrust, duplex, exhumation, D2

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SMP046-13 Room:201B Time:May 27 11:45-12:00

Tectonics of the Kamuikotan metamorphic rocks distributed in the western part of Asahikawa-city, Hokkaido, Japan

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We have studied the tectonics of the Kamuikotan metamorphic rocks, central Hokkaido, which were developed in the Sorati-Yezo Belt convergent boundary between the Eurasian continent and the subducting oceanic plate in the Cretaceous. The Kamuikotan metamorphic rocks are known as typical high?P/T type metamorphic rocks, where P is pressure, T is temperature, respectively. In this study, we investigated the western part of the Kamuikotan gorge area, the western part of Asahikawa-city. The rocks in this area were characterized by a peculiar P-T path and mineral assemblages different from any other metamorphic rocks in the Kamuikotan metamorphic belt. First, we analyzed the tectonics of the Kamuikotan metamorphic rocks from geological and petrological approach (i.e., field work, chemical composition analyses of both minerals and whole rocks). Based on field work, it has been found that the protolith stratigraphy in this area is composed of a typical accretionary stratigraphy (basaltic rocks, limestone, chart and mudstone in ascending order), which was repeated by thrust. Further, three deformation stages (D1, D2 and D3) have been revealed by the overlapping relationships among folds. D1 is characterized by main schistosity (S1), D2 is characterized by east-vergent close folding (F2), and D3 is characterized by crenulation cleavages (S3). Next, we analyzed the P-T path from blueschist to greenschist facies, and further to the surface of the earth for a mafic schist that includes Na-amphibole surrounded by actinolite. We constrained the range of P and T by the pseudosection method. As a result, it has been found that the P-T range lies on the reaction line between pumpellyite and epidote on condition that pumpellyite, epidote and albite coexist. (P is 3.6-4.5 kbar, T is 280-29oC or P is 3.4-4.7 kbar, T is 275-30oC. This difference in P and T is from amphibole model.) Further, we estimated the formation temperature of epidote in equilibrium with pumpellyite from the pistacite component (0.27-0.31) (Nakajima et al., 1976), which yielded the temperature range of 296-31oC. In the same way, we estimated the formation temperature of chlorite from the chemical composition (Inoue et al., 2009), which yielded the temperature range of 121-24oC if all Fe is Fe2+, and that of 109-220oC if some Fe is Fe3+ (Vidal et al., 2005). In addition, we estimated isochore from homogenization temperatures of fluid inclusions in quartz (101-13oC) that coexisted with chlorite used for the estimate of formation temperature. Integrating all these results, we analyzed P-T path. First, from blueschist facies, temperature increased and pressure decreased to reach or pass through the reaction line between pumpellyite and epidote. Next, pressure decreased toward the isochore of fluid inclusions at constant temperature of c. 300 oC inferred from deformation microstructures in quartz indicating brittle-ductile transition. Furthermore, temperature and pressure decreased toward the formation temperature of chlorite. Finally, we have speculated that the increase of temperature from blueschist to greenschist facies could have been caused by fluid infiltration in the rocks.

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SMP046-14 Room:201B Time:May 27 12:00-12:15

A clockwise P-T path deduced from metapelites and aluminosilicates-bearing veins from the Tseel terrane, SW Mongolia

burenjargal ulziiburen[1*], Atsushi Okamoto[1], Noriyoshi Tsuchiya[1]

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The Tseel terrane of the Central Asian Orogenic Belt, SW Mongolia, contains a record of amphibolite-facies (locally granulite-facies) metamorphism related to several igneous activities. In the central part of the Tseel area, the andalusite (And) + sillimanite (Sil) + kyanite (Ky)-bearing quartz veins occur, whereas only sillimanite occurs in host pelitic gneisses, that contain garnet + biotite + plagioclase + quartz. Textural relations indicate that aluminosilicate polymorphs formed in the order of And-Ky-Sil. Garnet in a sample of gneiss collected from near an aluminosilicates-bearing quartz vein shows compositional zoning, characterized by decreases in Ca and Mn from core to rim, and increases in Fe and Mg, along with minor retrograde zoning at the outermost rim.

We calculate P?T conditions by garnet-biotite geothermometry and garnet-biotite-plagioclase geobarometry based on compositional zoning in garnet, assuming constant compositions for biotite and plagioclase, to roughly constrain the P?T path during garnet growth. This approach is based on the following assumptions: (1) biotite, plagioclase and quartz coexisted with garnet; (2) the compositional ranges of biotite and plagioclase during garnet growth were retained in the thin section; and (3) intracrystalline diffusion was negligible within the crystals. For individual samples, we selected the biotite compositions with highest and lowest Mg/Fe2+ ratio and plagioclase compositions with anorthite content, X_{An}. The P-T estimates along the garnet zoning is carried out for four cases as follows: (1) highest X_{An}, highest MgFe^{2+}Bt; (2) highest X_{An}, lowest Mg/Fe^{2+}Bt; (3) lowest X_{An}, highest Mg/Fe^{2+}Bt; and (4) lowest X_{An}, lowest Mg/Fe^{2+}Bt.

We obtained the decompression P?T path from the kyanite stability field (530-570 C and 6.0-9.6 kbar) to the sillimanite stability field (590-620 C and 2?6 kbar), with slight increase in temperature. Although garnet does not record the P-T conditions at the burial stage, the occurrence of aluminosilicates indicates the change from the andalusite stability field to kyanite stability field. These observations suggest that the metamorphic rocks in the Tseel terrane experienced a clockwise P?T path, although the peak pressure remains unknown.

Microthermometry was based on analyses of fluid inclusions in quartz in an aluminosilicates-bearing quartz vein collected from the locality of sample 0701c. Heating and cooling experiments were performed for the primary inclusions within quartz to measure the homogenization (Th) and ice melting (Tim) temperatures. The values of Th are scattered over the range 110?240 C, with most between 160 and 200 C (mean value, 171 +/- 28 (1?) C). The values of Tim range from ?4.0 to ?9.6 C, with a mean value of ?6.8 +/- 1.3 (1?) C, corresponding to salinity of 10.2 +/- 1.6 wt.% NaCl equivalent. Microthermometric analyses of fluid inclusions reveal that the aluminosilicates-bearing quartz veins formed in the kyanite stability field (530-600 C and 6.0-8.5 kbar). Abundant fluid supply along fractures would have enhanced the formation of coarse-grained kyanite in quartz veins.

The P-T path during the exhumation in the Tseel area cannot be explained by subduction of old slab, but is well consistent with the geothermal gradient along the interface between the slab and the arc crust just after the ridge subduction (after c. 1 Myr). The intrusion of granitoids and mafic dikes and high temperature metamorphism of the Tseel terrane would be caused by the subduction of young oceanic lithosphere during the evolution of CAOB in the Devonian ages.

Keywords: Tseel terrane, aluminosilicates, garnet, clockwise P-T path, ridge subduction

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SMP046-15 Room:201B Time:May 27 12:15-12:30

Multi-events metamorphism of the eclogites in the Lake Zone, southwest Mongolia

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Early Cambrian eclogites have been described from the Chandman district in the Lake Zone, southwest Mongolia (Hanzl and Aichler, 2006; Takasu et al., 2008; Stipska et al., 2010). The Alag Khadny metamorphic complex consisting of metamorphic rocks and ultramafic bodies is exposed for about 10 km across and 4 km wide, and it occurs between the ophiolite complex and migmatized metamorphic rocks in the Lake Zone. Several lenticular-shaped bodies of eclogites and amphibolites (max. 2 km x 0.8 km) occur in the matrix of orthogneisses and minor pelitic gneisses.

Eclogites consist mainly of garnet, omphacite (Jd $<$ 46 %), and amphibole with subordinate amounts of epidote, phengite, paragonite, plagioclase, biotite, K-feldspar, rutile, titanite, quartz, calcite, hematite, ilmenite and zircon. The eclogites experienced three metamorphic events i.e. the precursor metamorphic event (M1) of HT-amphibolite facies; HP metamorphism (M2) of the eclogite facies; and HP-metamorphism (M3) of the epidote-amphibolite facies.

Garnets occur as porphyroblast and they show a prograde zoning. The core of the garnets contain polyphase and single grain inclusions of high TiO2 (up to 1.32%) taramite, taramite+quartz, Fe-pargasite, tschermakite, plagioclase (An$<$19)+biotite+epidote. Those inclusions indicate relatively high-temperature metamorphism of amphibolites facies conditions (M1).

The prograde stage of the first HP metamorphic event (M2) is characterized by polyphase and single grain inclusions in the garnets such as barroisite+taramite+epidote+quartz, barroisite+Mg/Fe-hornblende+quartz, plagioclase (An=3-5)+epidote, chlorite, calcite, and rutile. The peak eclogite facies conditions of 560-680 C and 22-25 kbar (Ravna, 2000; Ravna and Terry, 2004) estimated by the compositions of garnet+omphacite (Jd$<$46)+phengite (Si=6.58-7.11) assemblage. The retrograde stage of eclogite facies is characterized by symplectite of sodic plagioclase (An=1-11)+amphibole and/or Na-poor clinopyroxene (Jd=2-25). These mineral assemblages give 450-560 C and 4-11 kbar (Holland and Blundy, 1994; Holland, 1983).

The second HP metamorphism of the epidote amphibolites facies (M3) is characterized by prograde zoned amphiboles with winchite, actinolite, tremolite core and barroisite rim. They contain inclusions of garnet, omphacite and symplectite of clinopyroxene+sodic plagioclase suggesting that the amphiboles crystallized after the M2 metamorphism. The cores of the amphiboles indicate 300-400 C and 3-8 kbar, whereas the rims indicate $>$400-600 C and 3-12 kbar (Otsuki and Banno, 1990). Taramite/tschermakite outermost rim is occasionally developed.

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Stipska, P. et al., 2010. Journal of Metamorphic Geology, 1-19.
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Keywords: eclogite, Alag Khadny metamorphic complex, Lake Zone, Mongolia

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SMP046-16 Room:201B Time:May 27 12:30-12:45

Deformation of Lake Shorelines and Mid Crustal Flow in Tibet

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The mid crust beneath Tibet is generally thought to be highly mobile low viscosity material. A low viscosity layer of mid crustal material can account for the relatively flat nature of the high plateau?high elevation but low relief?and injection of mid crust into low lying regions around the Tibetan Plateau is thought to be one of the main processes involved in the expansion of the Plateau. Mechanical modeling shows that many of the first order features of the Tibetan Topography can be explained by the presence of a mid crust with a viscosity of 10ˆ19 Pa s or less. However, there has been no independent quantitative estimate of the effective viscosity of the mid crust. Lake shorelines offer a way to achieve this.

Despite its low rainfall, Tibet contains a large number of lakes due to the lack of water outlets from the central plateau. Many of these lakes are surrounded by well-preserved paleo shorelines. The presence of these shorelines shows that the lakes were once much larger than they are now. One of the largest lakes in Tibet is Lake Nam Co, which lies 150 km to the north of Lhasa. This lake shows good development of plaeo-shorelines and is of a suitable size to investigate properties of the mid crust. When there is a drop in the water level of a lake, it reduces the weight on the underlying crust and resulting in a buoyancy force that tends to uplift the substrate. The maximum uplift possible is determined by the ratio of the densities of water to rock: approximately 1 m of uplift for every 3 m decrease in the water level. The reason for the uplift is the inflow of mobile rock at depth. Re-equilibration will not be instantaneous?it will take time for crustal flow to occur. The time scale for this crustal flow depends mainly the geometry of the lake basin and the viscosity of the crust. The geometry is well-known and viscosity can then be estimated from measurements of the amount of uplift and the time that it took for the uplift to occur. Shorelines are palaeo-horizontal markers and, therefore, any uplift can be recognized by careful measurement that reveals present day deviations from horizontal. Preliminary results of age dating and surveys of shorelines using kinematic GPS show the potential of this methodology for obtaining good first order estimates of the mid crustal viscosity.

Keywords: Tibet, Lake shorelines, Crustal Flow, Mid crustal viscosity