Japan Geoscience Union Meeting 2014
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SMP46-01 Room:411 Time:April 28 12:00-12:15

Placing time constraints on a P-T-D evolution: insights from Lu-Hf garnet and U-Th-Pb monazite dating

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The best approach for understanding the tectono-thermal evolution of a crustal level is through reconstructing its pressure-temperature-deformation-time (*P-T-D-t*) evolution. Whereas *P-T-D* paths can be inferred from crystallization-deformation relationships, placing absolute time constraints on such paths remains challenging, especially because a link between major element-bearing index minerals and trace element-bearing geochronometers needs to be established.

We present the example of medium-grade metasedimentary rocks (Orlica-Snieznik Dome, EuropeanVariscan Belt) for which results of Lu-Hf garnet and U-Th-Pb monazite dating are linked with prograde and retrograde stages of the *P-T-D* evolution, respectively. On the macroscopic scale, a succession of three metamorphic foliations is recognized: initial subhorizontal S1, intermediate subvertical S2, and late subhorizontal S3. A garnet$\pm$staurolite assemblage is ascribed to the S1 foliation, whereas the S2 fabric is associated with staurolite demise producing a garnet-biotite-sillimanite/andalusite assemblage. Post-S2 garnet and cordierite blastesis is followed by chlorite growth during and after the formation of the S3 foliation. Garnet porphyroblasts show a peculiar zoning pattern with a linear Mn-Ca decrease in the allanite-bearing core, an inner rim of alternating Ca-Y- and P-rich annuli, and a Ca-poor outer rim. Monazite is found as subhedral aggregates at garnet rim, and lone matrix grains close to partially resorbed garnet, staurolite or apatite. Textural observations and modelling of the garnet composition suggest that the inner rim with Ca-Y-rich annuli reflects the allanite-to-monazite transition which occurred close to the staurolite isograd. In this inner rim, a Lu oscillatory zoning pattern coincides with the zone of Ca-Y-rich annuli. Since the inner rim dominates the Lu budget of garnet, the associated Lu-Hf garnet-whole-rock isochron age of 344$\pm$3 Ma is ascribed to *P-T* conditions of the staurolite isograd, i.e. $\sim$5 kbar/575 ℃ in the S1 fabric. A subsequent temperature increase to peak conditions of $\sim$5 kbar/580-625 ℃ in the S2 fabric is indicated by the Ca-poor garnet outer rim that reflects staurolite breakdown. LA-ICP-MS monazite dating yields $^{208}Pb/^{232}Th$ ages defining a dominant group at 313$\pm$2 Ma and a secondary peak at 328$\pm$2 Ma. Based on monazite textures, these relatively young ages are ascribed to fluid influx during retrograde chloritization.

The short time span between prograde garnet growth ($\sim$344 Ma) and existing Ar-Ar cooling ages on micas ($\sim$335 Ma) points to a tectono-thermal event of about 10 Ma. Assumed high heating and cooling rates during this event are explained by the synchronous intrusion of granitoid sheets. Nevertheless, monazite ages indicate that a low-grade overprint occurred more than 20 Ma after peak conditions.

Keywords: P-T-D-t path, prograde garnet zoning, retrograde monazite

SMP46-02 Room:411 Time:April 28 12:15-12:30

Microdiamond - bearing UHP chromitite from the Higo Metamorphic Rcoks, Central Kyushu, Japan

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Microdiamond-bearing ultrahigh-pressure (UHP) chomitite was newly found from a spinifex-textured metaperidotite in the Higo Metamorphic Rocks (HMR) , Central Kyushu, Japan. This is the first finding of microdiamond from Japanese metamorphic rocks and the second finding in Japan following the first one from a mantle xenolith in a Cenozoic lamprophyre dyke in Shikoku[1]. The HMR represents a low P/T metamorphism of Cretaceous in age, however, the precursor HP or UHP metamorphism of ca. 250Ma has been inferred[2]. A great deal of debate has been done on whether or how the Dabie-Sulu UHP terrane extends eastward to the Korean Peninsula and also to Japan. The HMR is one of the candidates[3] for the eastern extension in Japan, but no definitive evidence has been given yet.

Metaperidotites occur in two localities in the HMR: one at Yamato Town in the biotite zone and the other in Matsubase Town in the garnet-cordierite I zone[4]. The metaperidotites from Matsubase Town show distinct spinifex-texture with decimeter-sized elongated olivine (mostly serpentinized) and enstatite. Those from Yamato Town shows either spinifex-texture or granular texture of finer grains (several mm to 1 cm across), and is strongly serpentinized. The metaperidotite bodies occur in mostly pelitic gneisses as small lenticular bodies about several ten meters in size, which are concordant to the gneissosity. The mineral assemblage of the metaperidotite is olivine (mostly serpentinized) + enstatite with secondary tremolite and antigorite. Talc occurs locally along the cleavage of enstatite. A podiform chromitite occurs in such a strongly serpentinized metaperidotite at Yamato Town as a nodular form of about 10 cm in diameter, in which we found many inclusions of microdiamond 1 to 10 μm in size. We have made four thin sections, polished with colloidal silica, from one chromitite sample, and found many microdiamond inclusions in all thin sections. Microdiamonds occur both in chromite and in nickeline, and they are all monocrystalline. Many euhedral to subhedral grains (mostly 1 μm in size) of microdiamond occurs in chromite, making several lines of aligned grains. Identification of diamond was carried out with an energy dispersive X-ray spectroscopy (EDS) analysis (carbon peak) and Raman spectroscopy with a He-Ne laser. We observed a Raman peak at 1333.5 cm^{-1}, which is comparable to the peak (1332 cm^{-1}) characteristic of diamond. They show no evidence of partial or total graphitization. The occurrence suggests that the striations represent healed cracks and that microdiamonds precipitated from a reduced C-O-H fluid[5,6]. Our finding presents a convincing evidence for the hypothesis that the Higo Metamorphic Rocks is an eastern extension of the Dabie-Sulu UHP terrane in Japan. The second implication of our finding is on the nature of UHP chromitite. Microdiamonds are found from several UHP metamorphic terranes[5,6,7], however, microdiamond-bearing UHP chromitite has been found from ophiolites in non-UHP metamorphic terrane[8], making the occurrence of UHP chromitite as an enigma[9]. The Higo UHP chromitite represents a deep subduction product as indicated by spinifex-texture in the host metaperidotite due to high pressure breakdown of antigorite (serpentine), instead of a product of mantle migration10. Therefore the origin of the UHP chromitite requires a specific interpretation in each case.

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Keywords: microdiamond, UHP chromitite, Higo Metamorphic Rocks, Ultrahigh-pressure metamorphic rocks, Spinifex-texture, Dabie-Sulu UHP terrane

SMP46-03 Room:411 Time:April 28 12:30-12:45

Grain Size Grading of Garnet in the Liesegang Metamorphism

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The very puzzling phenomena is that the grain size of metamorphic garnet shows apparently gradational in both basic and politic schists, for bulk chemistries of large grain and small - grain layers are not different with each other and for chemical zonings of large and small grains of garnet display very similar pattern. These facts suggest that the domain structure by diffusion and growth of garnet should be formed in the layer and the spacing of the domain changes gradually across the grain - size layering in the metamorphism.

The layering shows parallel to subparallel against the schistosity plane, suggesting the parameter changes uniaxialy along the normal direction against the schistosity. The length scales of the grain size layering ranges from several to several ten cm, being likely to those of the compositional banding derived from metasomatism. Judging from these facts, it seems that the size grading process in the plate boundary metamorphism is governed by the diffusion, reaction and grain growth mechanism, that is the precipitation mechanism in the Liesegang bands. The precipitation in the Liesegang band is considered as the Cahn - Hillert - Cook process (1), which is characterized by the relation of average grain size, size distribution, width of the layer, and spacing distribution among grains.

In this paper, we would like to investigate these relations of the size grading of garnet in the subduction zone metamorphism.

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Keywords: grain size, grading, Liesegang, metamorphism

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SMP46-04 Room:414 Time:April 28 14:15-14:30

Metamorphism of sodic pyroxene-bearing quartz schists from the Bizan area, Sambagawa belt, eastern Shikoku, Japan

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The Bizan area of the Sambagawa metamorphic belt is occurs in easternmost Shikoku, southwest Japan. The Bizan and Kotsu areas are located in the same tectonostratigraphic horizon, i.e. the Kotsu Formation in eastern Shikoku. The Kotsu Formation in the Kotsu-Bizan area is structurally overlying and underlying by the Kawata Formation and the Kawatayama Formation, respectively. The main rock types in the Bizan area include pelitic, basic and siliceous schists, with minor amounts of psammitic and calcareous schists (Iwasaki, 1963). Faure (1983) suggested a melange zone containing tectonic blocks of serpentinite, metagabbro and garnet-amphibolite (garnet-glaucophane schist) occurs along a ductile shear zone between spotted and non-spotted schist zones. Sodic pyroxene-bearing quartz schists consist mainly of quartz and phengite, with minor amounts of amphibole (Fgl, Mrbk, Rbk, Mkt, Wnc, Brs, Fbrs), garnet, Na-Ca pyroxene (hereafter sodic pyroxene) (aegirine, aegirine-augite and omphacite) and albite. Hematite, chlorite, and epidote occur occasionally. A schistosity is defined by preferred orientation of phengite and quartz.

Garnets are spessartine-rich in composition, show a growth zoning with decreasing spessartine (X_{Sps} 0.82-0.35) and increasing almandine (X_{Alm} 0.01-0.41) and pyrope (X_{Prp} 0.03-0.09) from core to the rim and contain inclusions of phengite (6.84 pfu), epidote, hematite and quartz. The garnets are occasionally replaced by chlorite and biotite along cracks and at the rims. Amphiboles occurring as inclusions in porphyroblastic albite are compositionally zoned, with Fbrs and Brs cores and Rbk rims. Matrix amphiboles are Brs and Mkt core, Fgl mantle and Rbk and Mrbk rims, and contain inclusions of phengite (6.50-6.51 pfu), hematite and quartz. Sodic pyroxenes occurring as inclusions in porphyroblastic albite are aegirine, aegirine-augite and omphacite with X_{Jd} 0.08-0.37 contents. Some of them are compositionally zoned, with aegirine-augite and omphacite cores (X_{Jd} 0.34-0.37) to aegirine-augite and aegirine rims (X_{Jd} 0.34-0.21). Matrix sodic pyroxenes are aegirine-augite (X_{Jd} 0.09-0.27), decreasing X_{Jd} from cores (0.22-0.25) to the rims (0.22-0.17). Some other sodic pyroxenes in the matrix display increasing X_{Jd} from core to the mantle (0.13-0.19) and decreasing towards the rim (0.19-0.12). They contain inclusions of amphibole (Brs, Fbrs, Rbk), phengite (6.66-6.82 pfu), hematite and quartz, and are partially replaced by chlorite along their cleavages. Porphyroblastic albite crystals up to 2 mm across contain inclusions of garnet, amphibole (Brs, Fbrs, Rbk), sodic pyroxene (X_{Jd} 0.10-0.37), phengite (6.57-6.76 pfu) and quartz. Matrix phengites show relatively higher in Si (6.33-6.98 pfu) contents than inclusions.

According to the occurrence of mineral assemblage the Kwata, Kotsu and Kawatayama Formation probably correlate with the albite-biotite zone of the Besshi area (Enami *et al*., 1994). Jadeite content in the sodic pyroxenes are significantly higher in sodic pyroxene-bearing quartz schists (X_{Jd} 0.08-0.37) than those of garnet-aegirine augite-alkali amphibole-quartz schist (X_{Jd} 0.30) in the Bizan area (Iwasaki, 1963) and Asemigawa (X_{Jd} 0.15-0.19), Besshi (X_{Jd} 0.14-0.23) and the Sarutagawa area (X_{Jd} 0.17-0.30) in the central Shikoku (Enami *et al*., 1994). This higher jadeite content in sodic pyroxenes suggests metamorphic conditions in the Bizan sodic pyroxene-bearing quartz schists might be higher in pressure than those of the metamorphic zonation in the albite-biotite zone of the Sambagawa belt central Shikoku by Enami *et al*. (1994).

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Keywords: Sambagawa (Sanbagawa) metamorphic belt, Bizan area, quartz schist, omphacite, aegirine-augite

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SMP46-05 Room:414 Time:April 28 14:30-14:45

Application of the Raman carbonaceous material thermometer to the Chichibu-Sanbagawa belt in the Kanto Mountains, Japan

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The structure and tectonic history of the Chichibu-Sanbagawa belt have been investigated by the lithological structure, radiolarian age, radiometric age, deformation microstructural analysis, and X-ray diffraction analysis of carbonaceous material (CM). The structural discontinuities (nappe boundaries) within the Chichibu-Sanbagawa belt are proposed in several studies (e.g., Shimizu 1988, *J.Geol. Soc. Japan*; Isozaki & Maruyama 1991, *J. Geogr.*; Hirajima *et al*. 1992, *J.Geol. Soc. Japan*). However, the boundary between the Chichibu and Sanbagawa belts and their structural relationship are still under debate. In addition, the thermal structure was not well investigated because the geothermometer that can be applied over the temperature range of the Chichibu and Sanbagawa belts was not available. Recently, several studies proposed the geothermometers applying the Raman spectroscopy. Kouketsu *et al*. (2014, *Island Arc*) analyzed the CMs with a wide range of crystallinity, from amorphous carbon to well-crystallized graphite, in sedimentary and metamorphic rocks and proposed a new Raman CM geothermometer. By using this technique, we evaluate the peak temperatures of the rocks in the Chichibu and Sanbagawa belts in the Kanto Mountains, which is the type locality of these belts.

We investigated the mudstone, sandstone, and pelitic schist taken from the Kannagawa, Sanbagawa, and Ayukawa River districts in the Kanto Mountains, Gunma Prefecture. In the studied area, the accretionary complexes of the Northern Chichibu belt are distributed in the south, crystalline schists of the Sanbagawa belt are distributed in the north, and the Mikabu greenstones are exposed between them. The Chichibu belt is divided into three units: Kamiyoshida, Manba, and Kashiwagi units, in descending structural order (Shimizu & Yoshida 2004, *Island Arc*). The Sanbagawa belt is divided into three metamorphic zones: chlorite, garnet, and biotite zones, in order of ascending metamorphic grade (Yano & Tagiri 1998, *J.Geol. Soc. Japan*). The strata gently dip to the north and the metamorphic grade monotonously increases towards the lower structural level.

The Raman spectra of CM in mudstone and sandstone taken from the Chichibu belt include broad peaks that are characteristic of the amorphous carbon structure. The temperatures of most samples estimated by full width and half maximum (FWHM) of the D1-band are around 260-300 ℃. Several CMs in the rocks near the Mt. Nishi-Mikabo show the temperature higher than 300 ℃.

The intensities of Raman spectra of CM in the Sanbagawa schists are one order weaker than those in the rocks taken from the Chichibu belt. The D4-band, which is the characteristic peak in amorphous carbon, is not observed. Instead, G-band, which is the characteristic peak in well-crystallized graphite, becomes the most prominent peak at higher-grade zone. The metamorphic temperatures are estimated by using the FWHM of D1- and D2-bands and area ratio (R2) of CM Raman spectra. The metamorphic temperatures of the samples are estimated around 360-400 ℃, 420-450 ℃, and 460-510 ℃ in the chlorite, garnet, and biotite zones, respectively.

The temperatures estimated from CM show the gap of several tens of degrees or more between the Chichibu and the Sanbagawa belts. Further sampling and analysis will be proceeded.

Keywords: Raman spectroscopy, Carbonaceous material, Geothermometer, Chichibu belt, Sanbagawa belt, Kanto Mountains

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SMP46-06 Room:414 Time:April 28 14:45-15:00

Fission track and U-Pb zircon ages of psammitic rocks from the Harushinai unit of the Kamuikotan belt, Hokkaido

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In order to discuss exhumation processes and mechanisms for high-*P/T* type metamorphic rocks, it is necessary to obtain correct informations on pressure-temperature-time paths of these rocks from sedimentation to exhumation through maximum burial. We conducted coupled fission-track (FT) and U-Pb dating on detrital zircon grains in two psammitic rock samples collected from the Harushinai unit of the Kamuikotan metamorphic rocks using a Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS). The results indicate that the concordant zircon U-Pb ages greatly vary between 1980-90 Ma. Among them, the youngest U-Pb age cluster (*c.* 110-90 Ma) is dominant, yielding the weighted mean ages of Albian (100.8$\pm$1.1 and 99.3$\pm$1.0 Ma with 2σ errors) for both samples. According to an oscillatory zoning of igneous origin without any overgrown rims in the analyzed zircon, the zircon U-Pb ages were not reset by the high-*P/T* type metamorphism, and hence the youngest U-Pb ages indicate the upper bound of sedimentary ages. On the other hand, the zircon FT data show the spectra with a single peak age at 100-90 Ma, which are comparable with the youngest U-Pb age cluster. The fact indicates that these zircon FT ages were once reset at *c.* 100 Ma due to an intense igneous activity at the provenance, but have not been essentially reset since the sedimentation. The scenario is supported by the temperature conditions slightly less than those of brittle-ductile transition of quartz (*c.* 300 ℃, also closure temperature of zircon FT) estimated from the microstructures in deformed quartz detrital grains constituting the psammitic rocks. Combining these results with the previously reported K-Ar ages of white mica, it is inferred that Harushinai unit was deposited after *c.* 100 Ma, dragged down to the maximum depth, and further affected by a localized thermal overprint during exhumation (*c.* 58 Ma).

Keywords: Kamuikotan metamorphic rocks, zircon, U-Pb ages, Fission track ages, deformation microstructure

SMP46-07 Room:414 Time:April 28 15:00-15:15

Shape evolution of spinel grains in the Horoman Peridotite Complex, Hokkaido

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We present the evolution of spinel grains in the Horoman Peridotite Complex, Hokkaido. For deformation under differential stresses at high temperature conditions, both diffusion processes including diffusion creep and annealing process and dislocation creep will affect shape change of a crystal inclusion (Okamoto and Michibayashi, 2005 JGR). Grain size and grain shape are related to the shape change of the crystal with respect to given temperature and differential stress conditions. We applied this theory to spinel grains in the Horoman Peridotite Complex, Hokkaido. As a result, grain shapes of coarser spinel grains more than 100 micron are dominantly controlled by dislocation creep, whereas those of smaller spinel grains less than 100 micron are influenced by both diffusion processes and dislocation creep. Moreover, we found that grain shapes of the smaller spinel grains can be only explained by post-tectonic annealing process after their intense deformation. Our result will provide a new insight to understand the deformation processes in mantle.

Keywords: spinel, grain shape, diffusion process, dislocation creep, Horoman

SMP46-08 Room:414 Time:April 28 15:15-15:30

Verification of ultra-low strain rate effect from microstructural observation on naturally deformed olivine

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Kitamura et al. (1986) and Ando et al. (2001) reported Fe concentration on dislocation core in naturally deformed olivine. They suggested that compositional heterogeneity is formed by Cottrell atmosphere of solute atoms. This phenomenon is well known in the realm of metallurgical science, and only occurs during dislocation creep at very low strain rate condition. The presence of Cottrell atmosphere has a pinning effect on dislocations and prohibits their movements. As a consequence, plastic behavior of materials is drastically changed in the presence of Cottrell atmosphere. On the basis of this compositional heterogeneity, they demonstrate that the study of ultra-low strain rate effect on olivine plasticity is very important to understand the dynamics of the upper mantle.

With this background, the purposes of the present research are: (1) to confirm whether the Fe concentration on dislocation core is a common phenomenon in deformed olivine grains of mantle-derived peridotite, (2) to verify the deformation condition at which Fe concentration was occurred, from the microstructural observation of each studied peridotite samples, (3) to clarify the exact mechanism of Fe concentration, namely Cottrell atmosphere or pipe diffusion. The studied peridotite samples are xenoliths from basalt (Takashima, Megata, Kurose and Salt Lake), and alpine rocks (Uenzaru and Horoman). The techniques employed for the present study include optical microscopy, EPMA, SEM-EBSD, TEM and ATEM.

The main results are as follows:

1) Fe concentration on dislocation core in all olivine samples is detected, which suggests that it is common phenomenon in mantle peridotite.

2) The mechanism of Fe concentration on dislocation core in olivine grains is preferably Cottrell atmosphere than other phenomena such as pipe diffusion. However we need to carry out more careful and detailed observations to confirm it.

3) The microstructural observations indicate that the all peridotites preserve the deformation characteristics developed at the upper mantle. This fact suggests strongly that the Fe concentration on dislocation core in olivine grains occurred in the upper mantle condition.

Ando et al. (2001) Nature, 414, 893; Kitamura et al. (1986) Proc.Japan Acad., 62, 149.

Keywords: Olivine, Cottrell atmosphere, Dislocation creep

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The relationship between microstructures and metasomatism preserved within coarse granular peridotites derived from Kaap

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Kimberlite was generated in deep upper mantle (70-250km) beneath craton and subsequently ascended to surface rapidly. Peridotite xenoliths, which were entrained by kimberlite, record composition and texture formed in upper mantle beneath the craton. We studied coarse granular peridotites obtained from Kimberley pipe, South Africa, as they have a few studies in terms of microstructural development, presumably because of very coarser grains. We performed mineral crystal-fabric analyses of the coarse granular peridotites in order to understand the structure of the cratonic lithosphere. The peridotites consist mostly of olivine and orthopyroxene with clinopyroxene, garnet and a minor amount of spinel and phlogopite. The crystallization of clinopyroxene appears to be associated with melt metasomatism, whereas that of phlogopite could be associated with hydration metasomatism. Garnet grains occur commonly with kelyphite consisting of fine-grained orthopyroxene, clinopyroxene and spinel, indicating that these peridotites could have been uplifted above the phase boundary between garnet peridotite and spinel peridotite stability fields. Although both foliation and lineation are not commonly identified because of coarse granular texture, olivine crystal fabrics are characterized by a single maximum of [010] with single maxima or weak girdles of [100] and [001]. We found that the intensities of olivine and orthopyroxene crystal-fabrics are correlated to the modal composition of clinopyroxene and phlogopite. It suggests that the melt metasomatism weakened crystal-fabrics, whereas the hydration metasomatism intensified crystal-fabrics. As a consequence, the metasomatism could result in the development of different types of microstructures in the peridotites and may weaken the craton lithosphere.

Keywords: kimberlite, peridotite, garnet, olivine, craton, crystal-fabrics

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SMP46-10 Room:414 Time:April 28 15:45-16:00

Corona-forming reaction in the Lutzow-Holm Complex, East Antarctica at Ongul Island

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[Introduction]

Corona is a microstructure that aggregate of one or several species of mineral surrounds another mineral. This suggests that corona was formed by the reaction between the interior mineral and the matrix minerals (Passchier and Trouw 1996). Estimating this reaction enables us to know which component transferred and how temperature and pressure changed. In this study, we estimated corona-forming reaction by describing the microstructure and chemical composition of a corona in the Lutzow-Holm Complex at Ongul Island.

[Geological Outline]

In the Lutzow-Holm Complex, metamorphic grade increases from amphibolites facies in the northeast to granulite facies in southwest (Hiroi et al., 2006). The granulite facies metamorphic rocks are widely distributed throughout East Ongul Island. The rock types are mainly garnet gneiss and hornblende gneiss (Shiraishi et al., 1994). Ultramafic rocks occur as thin layers in the garnet gneiss. The ultramafic rocks analyzed in this study are composed mainly of hornblende and porphyroblasts of garnet. Corona structure forms around the garnet.

[Microstructure]

In the ultramafic rocks, hornblende-rich domain and plagioclase-rich domain occur. Both domains consist of hornblende, plagioclase, brown biotite and orthopyroxene. The corona consists mainly of green biotite and plagioclase, and occurs around the garnet. Plagioclase in the matrix and the corona has twin and chemical zoning. Garnet porphyroblast (about 15mm diameter) shows concavo-convex shape. In the embayed part of garnet, biotite tends to occur with long axis is at right angles to garnet surface.

[Chemical Composition]

Garnet; Rim shows higher Fe and lower Mg than the interior.

Plagioclase; Ca/(Ca+Na) increases in the order of Pl-rich domain, Hbl-rich domain and corona. Ca/(Ca+Na) in every domain increases from core to rim.

Biotite; Mg/(Fe+Mg) decreases in the order of Hbl-rich domain, Pl-rich domain and corona. Rim in every domain shows lower Al than the core.

Hornblende; Hbl-rich domain shows higher Al and Mg/(Fe+Mg) than Pl-rich domain. The rim of both domains shows higher Al than the core.

Orthopyroxene; Composition is almost homogeneous within the domain.

[Discussion]

The compositional difference between core and rim of each mineral in the matrix can be regarded as growth zoning. We used the rim-composition in each domain to estimate the corona-forming reaction. The average of analyses was used for plagioclase and biotite in the corona and for garnet. The corona-forming reaction employing the compositions of Hbl-rich domain was given as follows.

Grt + 1.10Bt + 3.25Pl + 0.76K + 0.81H2O = 1.91Bt + 3.62Pl

On the other hand, the reaction using the compositions of Pl-rich domain expects garnet as products, which is inconsistent with the observation that garnet was consumed. This suggests that K is supplied from the outside through fluid during corona formation. We also compared volume of left side minerals, that is,

Grt : Bt : Pl = 1 : 1.4 : 2.8

Garnet is minimum in amount. Nevertheless, corona formed around garnet. This suggests that diffusion of component from garnet controlled the rate of the reaction.

Keywords: corona, East Antarctica, Lutzow-Holm Complex

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SMP46-11 Room:414 Time:April 28 16:15-16:30

Possible tectonic models before, during and after mylonitization in the Sor Rondane Mountains, East Antarctica

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The deformational history in the Sor Rondane Mountains (SRMs), eastern Dronning Maud Land (DML), East Antarctica, is divided into 13 stages (D1?D13). The tectonic regime varied frequently from extension (D3?D4) to layer-normal compression and layer-parallel extension (D5), to compression (D6), top-to-the S shearing (D7), top-to-the SE shearing and sinistral strike-slip (D8), compression (D9?D11), and ?nally extension related to dextral shearing (D12?D13). In this paper we discuss change in deformation and P-T conditions before, during and after the D7-D8 mylonitization, using mineral textures, assemblage, compositions and microstructures of D7 and D8 mylonites.

Garnet porphyroclasts of the D7-D8 mylonites include high-Ca mantles and crenulation microfolds defined by sillimanite fibrolites. The high-Ca mantles of garnets and their plagioclase inclusions in the mylonites imply an increase in pressure before the D7-D8 mylonitization. S-tectonites having a dominant planar fabric were formed before the D7-D8 mylonites and after the high-Ca mantles of the garnets. The planar fabric (foliation) of the S-tectonites is produced by fan-shaped arrangement of sillimanite and biotite grains. The sillimanite and biotite grains were formed by breakdown of garnet. Most of the sillimanite and biotite grains have been rotated and folded by the D7-D8 mylonitization. The D7-D8 mylonite foliations are parallel to the planar fabric of the S-tectonites. The S-tectonites indicate a flattening type of strain and resulted from the layer-normal shortening after the increase in pressure and before the D7-D8 mylonitization. kyanite-quartz porphyroblasts and randomly oriented crystals of sillimanite/kyanite and biotite were formed after the D7-D8 mulonitization. The randomly oriented crystals of sillimanite/kyanite and biotite resulted from the breakdown of garnet porphyroclasts of the D7-D8 mylonites. The kyanite-quartz porphyroblasts accompany leucogranite veins cutting the D7-D8 mylonite foliations. The randomly oriented crystals and porphyroblasts imply non-deformational conditions after the D7-D8 mylnitization and D9 folding.

Three possible tectonic models for D7 and D8 mylonite-forming events before the D9 deformation can be considered as follows: extensional tectonic model, positive flower structure model and rotated mylonite model. In the former model, D7 and D8 indicate major extensional tectonic activity in the southern part of the East African and Antarctic Orogen (EAAO) before the Pan-African compressional event, and after the 650-600 Ma peak of metamorphism. In the latter two models, D7 and D8 mylonites may have resulted from the compressional events. In the positive flower structure model, the SRMs are the southern half of the E-trending positive flower structure. The flower structure model needs top-to-the N shear zones to the north of the SRMs. In the rotated mylonite model, the present S-dip of the D7 and D8 mylonites results from the rotation and folding of originally N-dipping reverse (top-to-the S-SE, normal-sinistral shear, present day coordinates) mylonites. The Pan-African compressional event resulted in the formation of upright folds with horizontal axes that curve along the coastline in central to eastern DML during the D9 deformation that took place between 600 and 560 Ma. The coastline-parallel fold axes and subvertical axial-planes correspond to the X-axes and the XY-planes, respectively, of strain ellipsoids that were progressively rotated counterclockwise toward the central parts of a sinistral shear zone. Therefore, the curved fold axes and axial-planes suggest the EAAO acted as a zone of sinistral transpression during the collision of parts of East and West Gondwana.

Keywords: S-tectonite, flattening, mylonitization, Sor Rondane Mountains, Gondwana, East Antarctica

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Significance of multi-stage chloride brine activity- An example from Sor Rondane Mountains, East Antarctica

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It has been gradually recognized chloride brine potentially plays an important role in large-scale mass transfer during high-grade metamorphism without partial melting. This is because brine is a powerful solvent, can coexist with CO_2-rich fluid under the granulite facies conditions and has low-H_2O activity (Newton & Manning, 2010; Heinrich et al., 2004). In natural observation, evidence for the presence of brine is often found as fluid inclusions. In metamorphic rocks under granulite facies conditions, however, brine inclusions are only rarely found (Markl & Bucher, 1998). This is partly because brines have a high mobility due to their low viscosity and low wetting angle (Watson & Brenan, 1987; Holness, 1997).

On the other hand, hydrous minerals such as biotite (Bt), hornblende (Hb) and apatite can record the f_{H2O}/f_{HCl} of the last equilibrated Cl-rich fluid as their mineral compositions. In order to understand the metamorphic fluid activity using these minerals, *P-T* condition under which these minerals equilibrated with a fluid as well as the crystallographic requirements for these minerals to record the fluid composition should be known (e.g., Makino, 2000). However, there still are a lot of unsolved issues about brines, for example, cations transported in the fluid, *P-T* condition and areal scale of brine activity, and its origin (Newton et al., 1998).

In order to understand the multiple brine activities and the cation composition in brines, two meta-mafic gneisses are studied in detail in Brattnipene, Sør Rondane Mountains (SRM), East Antarctica.

In a Grt-Bt-Hb gneiss, Cl-rich Bt is exclusively included in garnet (Grt). Bt, Hb, and cummingtonite (Cum) in the matrix are Cl-poor. These compositional differences imply that Bt included in the Grt formed under the presence of chloride brine and Cl-poor fluid infiltrated after Grt formation. Grt is enveloped by the gneissosity defined by the arrangement of Cum overgrown by Hb, and Bt. Therefore, chloride brine activity predated or was simultaneous with the penetrative gneissosity formation in this area. After considering the effect of Mg-Cl avoidance rule and compositional change during retrogression, the geothermobarometry (Holdaway, 2000; Wu et al., 2004) gave $650 < T < 800$ ℃ and 0.96 GPa for the peak *P-T* condition of this sample. The Cl-rich Bt entrapment was probably predated or simultaneous with the attainment of this *P-T* condition.

In a Grt-Opx-Hb gneiss, ca. 1cm-thick Grt-Hb vein cut the penetrative gneissosity in this area. Cl-content of Hb and Bt, and K-content of Hb decrease with the distance from the vein center and become constant at ca. 1.6 cm from the vein center. Plagioclase present next to the vein has a core (An_{55}) and mantle (An_{68}) which is sharply overgrown by Na-richer rim (An_{51}). Plagioclase in the vein is An_{51} without zoning, and development of Na-richer rim gets thinner with a distance from the vein. Therefore, the Grt-Hb vein was probably formed by NaCl-KCl brine infiltration. This is also supported by the isocon analysis of whole-rock chemistry determined for wall rock of the vein. *P-T* condition of the vein formation is estimated as 720 ℃ and 0.70 GPa (Holdaway, 2000; Wu et al., 2004).

P-T conditions of multi-stage chloride brine activity, cation composition of the brine, and outcrop-scale pathways of the brine are constrained in SRM from these two gneisses. From the pelitic gneisses in SRM, Cl-rich fluid or melt activity with a linear distribution over 200 km has been reported (Higashino et al., 2013). Additionally, this study revealed that the brine activity in SRM is not controlled by the lithology or specific deformational stages. It is clear that chloride brine in SRM was not a result of *in situ* fractionation through the selective consumption of H_2O in the fluid (Kullerud, 1995), but substantial amount of brine was actually moving, and was playing an important role in mass transfer.

Keywords: NaCl-KCl brine, fluid infiltration, continental collision zone, Sor Rondane Mountains

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SMP46-13 Room:414 Time:April 28 16:45-17:00

Rate-limiting process and degree of disequilibrium of garnet-forming reaction

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Water released by dehydration reaction in metamorphic rocks will take a major role in rheology, mass transport, and reactivity of metamorphic rocks. Rate-limiting process of the dehydration reaction can be divided into the following three steps, such as reaction at interface, diffusion, and heat-flow. Garnet is one of the common minerals produced by dehydration reaction in metamorphic rocks. The rate-limiting process of garnet-forming reaction is usually assumed to be diffusion-controlled reaction. However, there are few cases where clear evidences for diffusion-controlled reaction were proposed. In addition, degree of disequilibrium of the diffusion-controlled reaction is not well known. Here, I report evidence of diffusion-controlled reaction and estimation of degree of disequilibrium of garnet-forming reaction in the Tsukuba Metamorphic Rocks.

Garnets in the Tsukuba Metamorphic Rocks are formed by the dehydration reaction of biotite + sillimanite + quartz = garnet + cordierite + K-feldspar + water. Biotite-depleted region surround the irregular shaped garnet. The depleted region of reactant is typically expected for diffusion-controlled reaction, but is rare for natural garnet-forming reaction. Irregular shape of garnet is also expected for diffusional instability of growing interface (Mullins & Sekerka, 1963). These sets of observations strongly suggest that the garnets were formed by diffusion-controlled reaction.

Spherical shape of growing particle under diffusion-controlled reaction becomes unstable due to diffusional instability, but interfacial energy will reduce the instability. Using spherical harmonics function, instability of small perturbation from spherical shape can be evaluated. Assuming interfacial energy of garnet, dominant wavelength in unstable regime is predicted with degree of super-saturation under diffusion-limited reaction. Dominant wavelength of the irregular garnet suggests that degree of super-saturation is less than 0.1. This value can be translated to degree of disequilibrium temperature with entropy change of the garnet-forming reaction. The disequilibrium temperature $\triangle T$ is less than 5 ℃, and is very small. This small value of disequilibrium temperature suggests that spherical or euhedral garnets that are more common than irregular garnets, should be produced near equilibrium condition. Otherwise, such common spherical or euhedral garnets should be produced by interface-controlled reaction associated with influent fluid.

Keywords: garnet, dehydration reaction, disequilibrium, metamorphism, metamorphic rock, metamorphic reaction

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SMP46-14 Room:414 Time:April 28 17:00-17:15

FLUID RELATED ORIGIN OF SILLIMANITE VEINS IN POLYMETAMORPHIC ROCKS FROM THE RYOKE BELT, JAPAN

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In the polymetamorphic area, it is important to distinguish the effect of each metamorphism in order to appreciate the evolution of thermal structure of the area. Some authors have successfully distinguished the regional metamorphism from the postdating contact metamorphism (e.g. Miyake et al., 1992), but studies dealing with a fluid activity during polymetamorphism is not sufficiently available. Veins consisting of fibrous sillimanite (Sil) in a contact metamorphic aureole have been previously interpreted as a result of fluid activity (e.g. Johnson et al., 2003).

In Kasagi area (Kyoto, Japan), Ryoke metamorphic rocks are widely exposed and main lithology is pelitic and psammitic schists and gneisses. Younger Ryoke granites discordantly intrude to the metamorphic rocks and, therefore, the regional metamorphic rocks are overprinted by the heat (Ozaki et al., 2000) and fluid flux from the granites. This area belongs to the Sil zone that is defined by the presence of Sil in the pelitic lithology (Ozaki et al., 2000) whose origin has not been discussed in detail.

However in this area, fibrolite bundles are often observed to cross-cut the gneissosity formed by the regional metamorphism and it seems difficult to explain their formation during the regional metamorphism. In this study, we report the mode of occurrence of Sil veins emanating from the granite into psammitic gneiss and discuss the fluid-related origin of them.

The studied psammitic gneiss containing Sil veins is collected from the Sil zone near the granite intrusion contact. Ryoke granite intrudes discordantly to the gneissosity of this sample, and the Sil vein subparallel to the gneissosity emanate from it. The Sil vein consists of fibrolite and retrograde muscovite (Ms) replacing it. Quartz (Qtz) in the matrix near the vein are coarser-grained and they include fibrolite grains. The amount of fibrolite included in the Qtz decreases as a distance from the Sil vein increases. Fibrolite is present in veins and Qtz grains. Fine, retrograde Ms after fibrolite is present along grain boundaries in the matrix. Although plagioclase (Pl) is a common constituent mineral in the matrix, it is almost completely absent near and in the Sil veins. K-feldspar is absent in the studied sample, but instead, retrograde Ms cutting the schistosity is abundant in the matrix.

Cathodoluminescence (CL) observation of the microstructures around the Sil veins revealed that the brightness of CL signal of Qtz grains increases as the distance from the Sil vein increases. That is, Qtz grains near the vein or including Sil are dark under CL observation. In particular, part of a single Qtz grain including more fibrolite grains appears dark under CL image.

From the observation of microstructural relationships described above, we consider that Sil veins were formed by the fluid released from the Ryoke granite. Formation of fibrous Sil by the action of mobile hydrogen ions on pre-existing minerals has been previously discussed (Vernon, 1979). Moreover, experimental work has shown that Al2SiO5 minerals and Ms can be produced by the action of acidic, aqueous solutions on various common silicate minerals (Burnham, 1967). In this study, fibrolite is present in veins and Qtz grains and the amount of fibrolite crystals included in the Qtz crystals decreases as a distance from the vein increases. Pl is absent in and at the vicinity of the veins. From these pieces of observation, a fluid from the granite would have reacted with the matrix to dissolve Pl and to form coarser-grained Qtz and fibrolite bundles simultaneously. Thermodynamic calculation using SUPCRT92 (Johnson et al. 1992) has revealed that infiltration of the aqueous fluid with low Na+/H+ and K+/H+ ratio can destabilize Pl and stabilize Sil under the presence of Qtz at 3 kbar, 600oC. Therefore, Sil in this study is not regional metamorphic in origin, but is probably a result of fluid infiltration during a contact metamorphism by the Ryoke granite.

Keywords: fibrous sillimanite, Ryoke belt, fluid-related origin, polymetamorphism

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SMP46-P01 Room:Poster Time:April 28 18:15-19:30

Comparison of UHP chromitites from the Higo and Nishisonogi Metamorphic Rocks, Kyushu, Japan.

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We have found microdiamond - bearing ultrahigh-pressure (UHP) chromitites from two metamorphic terranes in Kyushu: the Higo (HMR)[1] and Nishisonogi (NMR)[2] Metamorphic Rocks. This paper describes the similarity and difference between the two UHP chromitites. The HMR are located in west-central Kyushu with an E-W trend. They have undergone low P /T metamorphism, however, precursor HP or UHP metamorphism of ca. 250 Ma has been inferred[3]. The protoliths have affinity to continental shelf deposits[4], consisting mainly of pelitic gneisses and meta-carbonates with minor metabasites and metaperidotites (partly serpentinite). Chromitite occurs very rarely as a nodular form in serpentinized metaperidotites which shows spinifex-texture. The NMR is located in western Kyushu with a N-S trend. They have undergone high P /T metamorphism of epidote-blueschist subfacies. They consists mainly of pelitic and psammitic schists with minor basic schists and serpentinites, some of which show a character of serpentinite melange[5]. Detrital zircon from the pelitic schists show the age of 89-86 Ma[6], whereas zircon from jadeitites in a serpentinite melange does 136 -126 Ma in the core and 84 - 80 Ma in the rim[7,8]. Chromitite occurs as a deformed schlieren-like layer in serpentinite with no reilc minerals. The P-T condition of the HMR has been estimated to be 200 - 600 MPa and 600 - 800 ℃ [3,9,10,11,12,13]. Higher pressure and temperature conditions are reported from the following two samples: a sapphirine-bearing granulite[3,10] as a tectonic block in the spinifex-textured metaperidotite (900 MPa and 950 ℃) and a calc-silicate granulite[13] (900 MPa and 820 ℃) intercalating with garnet - biotite gneiss. We newly estimated the peak P-T condition of Al-spinel and chlorite -bearing metaperidotite as 2.0 GPa and 780 - 990 ℃. In the case of the NMR, the peak metamorphic condition of the crystalline schists is 1.4 GPa and 520 ℃ for a garnet galucophanite[14]. Jadeitites[15] as tectonic blocks in the serpentinite melange shows the peak condition of 1.5 GPa and 500 ℃. Chromite from the HMR has the composition $(Mg_{0.34}Fe^{2+}{}_{0.75}Mn_{0.02})(Cr_{0.81}Al_{0.06}Fe^{3+}{}_{0.04}Si_{0.05)2}O_4$, whereas that from the NMR has similar composition $(Mg_{0.33}Fe^{2+}{}_{0.65}Mn_{0.03})(Cr_{0.84}Al_{0.12}Fe^{3+}{}_{0.04})_2O_4$ in the core and Fe-rich composition $(Mg_{0.06}Fe^{2+}{}_{0.89}Zn_{0.02}Mn_{0.03})(Cr_{0.85}Al_{0.12}Fe^{3+}{}_{0.04})_2O_4$ in the rim. Microdiamonds occur as i*n situ* inclusions in chromite in both chromitites. They are 1 to 10 μm in size in HMR chromite, and those in NMR chromite is much smaller, mostly <1 μm with small number of larger grains. In both chromitites microdiamonds occur in some cases as numerous aligned grains, making diamond - rich zones. Both microdiamonds are identified with Raman spectra. HMR microdiamonds show a broad peak at 1333 cm^{-1}. NMR microdiamond, also shows a broad peak at 1331 cm^{-1} with graphite peak at around 1600 cm^{-1}, suggesting partial graphitization. Both UHP chromitites will be deep subduction origin. HMR can be an eastern extension of the Dabie-Sulu UHP terrane in China, however, NMR is more problematic. No corresponding UHP terrane of ca. 80Ma is found around Kyushu. Our findings of UHP chromitites require reexamination of micro-tectonics in Kyushu, a peculiar location of an arc-arc junction at the continental margin.

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Keywords: microdiamond, chromitite, UHP, Higo metamorphic rocks, Nishisonogi metamorphic rocks, subduction

SMP46-P02 Room:Poster Time:April 28 18:15-19:30

3D imaging of the Mn-caldera shaped zoning of the garnet found from the Sanbagawa metamorphic belt and its origin.

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Garnets with a complex compositional zoning were found from the northern proximal area of the Western Iratsu body of the Sanbagawa metamorphic belt of the Besshi district, southwest Japan. The studied garnet shows incipient Mn-reverse (increasing) zoning part (defined as core) and subsequent Mn-bell shape (decreasing) zoning part (defined as mantle), which is almost identical to the " Mn-caldera shaped zoning " described by Banno et al. (2004) in the Asemigawa region of the central Shikoku. In order to describe the chemical characteristic sterically, X-ray chemical mapping were performed by each 0.2-0.3 mm depth step, for one very-coarse-grained garnet with ca. 11 mm in diameter. The result clearly shows that the core/mantle boundary has the highest Mn content with euhedral shape, and that the chemical composition continuously changes through the grain. Internal schistosity defined by sigmoidal inclusion arrays cross-cuts the core/mantle boundary. This fact also suggests the continuous growth of garnet from the central part to the outer part. In the same sample, garnets with Mn-bell shape type zoning are also observed, which are relatively fine-grained up to 5 mm. Raman barometry and thermodynamic modeling suggest the climax *P-T* conditions of the studied sample did not reach the eclogite facies, which are consistent with the conditions of the oligoclase-biotite zone of the Sanbagawa metamorphic belt (610 ℃ and 1.0 GPa, Enami, 1994).

Contrary to the simple Mn-bell shape type zoning which grown up with progressive regional metamorphism, " Mn-caldera shaped zoning " could be generated from the crystal nucleation under oversaturated environment (Matsumoto and Kitamura, 2004). Such oversaturation is expected in a rapid increase of temperature. Recently, Aoya et al. (2013) proposed the eclogite nappe covering the large part of the Besshi district. However, the exact boundary between the eclogite nappe and lower grade surrounding rocks is still under the debate. The conjunction of the eclogite nappe and the lower-grade surrounding rocks are thought to have taken place near the peak metamorphic stage of the surrounding rocks (500-600 ℃ and ca. 1 GPa, Aoya et al., 2013). Mn-caldera shaped zoning garnet found in the Besshi district (this study; Xu et al., 1994) are both found from the northern proximal of the hypothesized eclogite nappe. Those Mn-caldera shaped zonings are possibly originated from the conjunction of the eclogite nappe and surrounding crystalline schist, and corresponding rapid heating. Such features of garnet can help to determine the boundary of the eclogite nappe in the Besshi district.

Keywords: garnet, Sanbagawa metamorphic belt, compositional zoning, disequilibrium crystal growth

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Widespread analyses of pressure-temperature trajectory and timing in the Altai Range, Mongolia

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This study performed large-scale petrographical and geochronological investigation in the Altai Range, Mongolia distributed in the Central Asian Orogenic Belt, which is the typical subduction-accretion-collision orogeny on the Earth. Based on the petrographical observation, clockwise and anti-clockwise pressure-temperature trajectories were identified in whole of the studied area (400 km long). U-Th-Pb monazite dating yields c. 350 Ma and c. 260 Ma. Samples with clockwise pressure-temperature path, containing kyanite in garnet and sillimanite in the matrix, commonly have c. 350 Ma monazite in garnet and c. 260 Ma monazite in the matrix. In contrast, samples with anti-clockwise pressure-temperature path containing sillimanite in garnet and kyanite in the matrix have monazites showing (i) c. 350 Ma both in garnet and the matrix, (ii) c. 260 Ma both in garnet and the matrix, and (iii) c. 350 Ma in garnet and c. 260 Ma in the matrix. Ca zoning pattern in garnet shows either continuous or discontinuous zoning. Samples containing single monazite age cluster (either c. 350 Ma or c. 260 Ma) have continuously zoned garnet, in which samples with anti-clockwise pressure-temperature trajectory at both periods show Ca zoning increasing from core to rim or mantle, whereas some samples with unknown pressure-temperature path at both periods show opposite zoning. These features strongly suggest both clockwise and anti-clockwise evolutions occurred at both periods. Discontinuous Ca zoning in garnet is observed in samples that contain c. 350 Ma monazite inclusions in garnet and c. 260 Ma monazite grains in the matrix, and the zoning patterns show a decrease in Ca at the rim for samples with clockwise paths and an increase in Ca at the rim for those with counterclockwise paths. In some cases, c. 350 Ma monazite grains are included in the large garnet cores but c. 260 Ma monazite grains are found in the garnet rims as well as in the matrix. These rocks might be metamorphosed at c. 350 Ma, whereas they did not exhume to the surface and have remained deep crustal level. Subsequent compression and decompression event formed garnet rim and monazite at c. 260 Ma, which should be caused by same tectonic regime to clockwise and anti-clockwise pressure-temperature path at the period. The presence of the regional-scale clockwise and anti-clockwise trajectories and their repetition during less than 100 My have never reported from any other orogenic belts in the world. Further studies may allow to realize the complex tectonic evolution of the Altai Range.

Keywords: P-T trajectory, U-Th-Pb monazite age, Altai Mountains, Mongolia, Central Asian Orogenic Belt

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Temporal change of modal abundance of minerals during formation of arrested charnockite from Sri Lanka

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Charnockite occurs as a number of several-decimeters patches in hornblende-biotite gneiss in central Sri Lanka. This type of charnockite has been called arrested charnockite. Local condition of low-H_2O activity or low-oxygen fugacity could explain the difference of mineral assemblage in local scale. They might be caused by fluid influx and/or partial melting (e.g. Newton et al., 1980; Hiroi et al., 1990; Burton and O'Nions, 1990; Ravindra Kumar, 2004; Endo et al., 2012). The temporal and spatial development of charnockite has been unclear. This study describes variation in modal abundance of hornblende, biotite and orthopyroxene in melanocratic and leucocratic parts from surrounding gneiss to charnockite.

Charnockite and surrounding gneiss have layer structure composed of melanocratic and leucocratic parts. Each part can be traced continuously between the two rock types. Melanocratic parts consist mainly of hornblende and biotite in gneiss, and orthopyroxene added in charnockite. Leucocratic parts are composed of biotite and colorless minerals in gneiss, while biotite is absent in charnockite. Modal abundances of hornblende and biotite have no systematic trend in melanocratic parts of gneiss. Hornblende and biotite decrease drastically and gradually, respectively, while orthopyroxene increases gradually in melanocratic parts of charnockite. Biotite decreases gradually toward charnockite in leucocratic parts in gneiss.

Biotite of leucocratic parts breaks down within gneiss. Orthopyroxene appears in the location of dehydration reaction of biotite and hornblende in melanocratic parts. This suggests that the element released due to break down of biotite in leucocratic layer diffused from leucocratic part to melanocratic part to produce orthopyroxene. It is a possible that hornblende broke down first to produce significant amount of orthopyroxene in melanocratic part. The element released due to break down of biotite in leucocratic part transported to the location of preexisting orthopyroxene in order to grow the crystals. Biotite in leucocratic layers is enriched in Fe as compared with that in melanocratic part. Fe-rich biotite breaks down under lower temperature (or higher activity of H_2O) than Mg-rich biotite. This could explain the decrease of biotite in leucocratic layer in gneiss.

Reference

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Keywords: Sri Lanka, Charnockite, Hornblende-biotite gneiss, modal abundance

SMP46-P05 Room:Poster Time:April 28 18:15-19:30

Thermal structure and water transportation in subduction zones: a comparison between NE and SW Japan

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Northeastern and southwestern Japan are considered to be typical examples of cold and hot subduction zones, respectively. The old Pacifc plate subducts beneath northeastern Japan at high rate and the young Philippine Sea plate subducts beneath southwestern Japan at low rate. These contrasts in the subduction conditions reveals in several aspects including higher activity of arc volcanism and deeper down dip limit of inter-plate earthquake in northeastern Japan, and deep low-frequency tremors at plate boundary of southwestern Japan. We have investigated thermal structure and geophysical and geochemical processes in these subduction zones using a numerical model. The model includes hydration and dehydration of the slab and mantle wedge, melting and solidification of mantle peridotites, permeable flow of melt and aqueous fluids, and temperature-dependent solid flow of mantle peridotites with water- and melt-induced weakening. We will discuss effects of the subduction conditions on the volcanic and seismic activities through the processes, especially water transportation.

Keywords: subduction zones, NE Japan nad SW Japan

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Stress and strain history during the microboudinage for granite intrusion: Mt. Edger granite complex, East Pilbara

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Stress and strain analysis is essential to improving the understanding of deformation process. Microboudinaged columnar minerals can be used as an indicator of stress and strain during the microboudinage for quartzose and calcareous metamorphic tectonites. In this presentation, we discuss the stress and strain history during the microboudinage deduced by the microboudin method with a collaboration of the strain reversal method.

We collected samples of metachert from the Archean Warrawoona greenstone belt around Mt. Edger granite complex, East Pilbara, Western Australia, and identified microboudinaged tourmaline grains embedded within quartz matrix in 10 samples. The result revealed that the samples experienced extensional strain at least -0.56 and differential stress in the range from 3.9 to 11.9 MPa. We obtained stress-strain curves which show increase in differential stress with increasing inverse natural strain (ε_{inv}). The frequency distribution of interboudine gaps between separated grains with respect to ε_{inv} for boudinaged tourmaline grains shows that end of microboudinage occurred immediately after the peak frequency of fracturing. This occurrence commonly appeared in all the 10 samples. These results provided us with keys to discuss a stress-strain history during the microboudinage in relation to evolution of the granite complex. The spectacular implication would be a drop or relaxation in increased differential stress at the end of the microboudinage.

Keywords: microboudin structure, stress, strain, granite complex, Archean

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Time scale for formation of diffusion zoning in response to breakdown reaction

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In high-grade metamorphic rocks, garnet commonly represents an increase in Mn or Fe toward margin. This feature has been interpreted as diffusion zoning owing to garnet-consuming reactions during retrograde metamorphism. In this process, the zoned thickness can be described in terms of distances of internal diffusion and surface retreating. This study preliminaly formulated to express these distances as a function of time and retreating velocity of the surface. Applying the formulation to some high-temperature metamorphic belts yielded that the diffusion zoning with zoned thickness of 0.04 to 0.1 mm was formed by 1 to several million years. This result may be applied to estimate cooling rate provided that the surface equilibrium was mainetained during the formation of diffusion zoning.

Keywords: diffusion zoning, duration time, cooling rate

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Integrated radiometric dating of schist clasts from the Eocene and Miocene conglomerates in Shikoku

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The age that the high P/T type Sanbagawa metamorphic rocks reached at erosion level gives an important constraints for considering exhumation processes of the Sanbagawa metamorphic rocks. It is shown by the oldest age of the conglomerate containing schist clasts derived from the Sanbagawa Belt. Integrated radiometric dating has been carried out for schist clasts from the Paleogene and Neogene conglomerates in Shikoku. The results of K-Ar and fission-track (FT) ages for the schist clasts from the Eocene Hiwadatoge Formation and the Miocene Furuiwaya Formation (Kuma Group) were already reported (Takagi and Sakisaka, 2012; Takagi et al., 2013). We have been doing U-Pb dating of zircon grains from the same clasts for the FT dating using NanoSIMS 50 ion microprobe of AORI. The youngest U-Pb age of zircon grains approximates the sedimentary age of the protoliths of the schist, because the zircon grains in the low-grade metamorphic rocks are detrital origin. The tentative results shown by the youngest peak yield around 110 Ma in all samples. We will report on details of the U-Pb ages at the meeting. FT dating was also carried out for the schist clasts from Eocene Oyamamisaki Formation in the Shimanto Belt where K-Ar ages (78.2-71.4 Ma) of the clasts have been already reported by Yoshikura et al (1991). The FT ages were 67.3 +/- 9.0 Ma and 68.4 +/- 8.2 Ma. From the results of K-Ar phengite ages and FT zircon ages for schist clasts (Table 1), it is suggested that the exhumation rate of the schist eroded at Eocene time is faster than that eroded at Miocene time.

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Takagi and Sakisaka, 2012, 119th Geol. Soc. Japan Congress, Abstracts, p.93.
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Yoshikura et al., 1991, 98th Geol. Soc. Japan Congress, Abstracts, p.434.

Keywords: Sanbagawa belt, schist, radiometric dating

Table1. Phengite K-Ar and zircon fission track ages of schist clasts from the Miocene and Eocene strata in Shikoku.

Series	Formation Name		Sample	Phengite K-Ar age (Ma)	Zircon FT age (Ma)
Miocene	Kuma Group	Furuiwaya Formation	32204-2 psamm.sch.	81.5 ± 1.3	68.7 ± 6.0
			112101-2 pel.sch.	83.5 ± 1.3	64.9 ± 5.8
Eocene	Hiwadatoge Formation		2003-8 psamm.sch.	86.8 ± 1.3	85.2 ± 7.7
	Oyamamisaki Formation		1-B psamm.sch.	78.2 ~ 71.4 (Yoshikura et al., 1991)	67.3 ± 9.0
			1-F psamm.sch.		68.4 ± 8.2

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SMP46-P09 Room:Poster Time:April 28 18:15-19:30

The metamorphic evolution from PrP to LBS facies in a late Paleozoic cold subduction system in Kurosegawa belt

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Introduction: Recent progress of thermal modeling and thermodynamic calculation can help the general understanding of the thermal structure of subducting plate and the total movement of H2O stored in high-pressure type metamorphic rocks from the trench to the upper mantle depth in various subduction settings (e.g., Peacock & Wang, 1999; Hacker et al., 2003). For example, Peacock (2009) indicated that the oceanic plate in the Philippine Sea plate subducting below the Kii Peninsula would suffer the cold HP/LT type metamorphism represented by zeolite facies, prehnite-pumpellyite facies, pumpellyite-actinolite facies, lawsonite-blueschist facies to jadeite-lawsonite-blueschist to 2GPa. However, the natural example recording abovementioned progressive metamorphic evolution has not been recognized yet.

Recently prehnite-pumpellyite facies and lawsonite-blueschist facies units have been recognized in the Otao unit of Kurosegawa belt in Yatsushiro area, Kyushu, Japan (Kamimura et al., 2012). However, the relationship of two metamorphic units has not been verified yet.

In this paper, we propose the progressive change of metamorphic grade from the prehnite-pumpellyite facies to lawsonite-blueschist facies based on petrography and thermodynamic phase analysis in metabasite system.

Petrography and Mineralogy: We confirmed that the prehnite-pumpellyite facies assemblage is predominant in the Tobiishi subunit of (Kamimura et al., 2012), but we newly found pumpellyite-actinolite facies from the western end of this subunit.

In the lawsonite-blueschist facies unit, Hakoishi-subunit of (Kamimura et al., 2012), located to the west of the Tobiishi-subunit, following mineral assemblage with excess chlorite, quartz, albite and phengite are systematically distributed from the east to the west in the subunit:

lawsonite + pumpellyite + aegirine-augite,pumpellyite + Na-amphibole,lawsonite + pumpellyite + Na-amphibole, lawsonite + Na-amphibole + aegirine-augite.

The compositions of sodic pyroxene, pumpellyite and Na-amphibole also show the following systematic trend westwards in the subunit; jadeite component of sodic pyroxene generally increases from XJd=0.12 to XJd=0.50 with XAeg= up to 0.5. Al content of pumpellyite increases from 3.7 to 4.6 p.f.u. for O=24.5 Fe3+/(Al+Fe3+) in Na-amphibole decreases from 0.8 (riebeckite) to 0.15 (glaucophane).

Thermodynamic phase analysis: To evaluate stability relationship among abovementioned mineral assemblages, the phase diagram was construct-ed in the NCFMASH system with PERPLE_X soft-ware package (Connolly, 2005) for 1-10 kbar and 100-400 C. The considered minerals are stilbite, laumontite, prehnite, pumpellyite, ferro pumpellyite, tremolite, ferro tremolite, diopside, hednbargite, clinochlore, daphnite, lawsonite, glaucophane, ferro graucophane, clinozoisite and albite with excess, quartz and water. As the first order approximation, solid solution in each mineral was ignored. The new-ly constructed phase diagram predicts following representative mineral assemblages appear with the increase of the pressure along the high HP/LT path.

lawsonite + pumpellyite + clinopyroxene,pumpellyite + glaucophane,lawsonite + pumpellyite + glaucophane,lawsonite + glaucophane + clinopyroxene.

This metamorphic evolution in the model system is coincident well with the natural observation in the Hakoishi subunits.

Conclusion: Mineral assemblages observed in metabasites of the Tobiishi and Hakoishi subunits and the newly constructed petrogenetic grid suggest the metamorphic grade increases from prehnite-pumpellyite facies to lawsonite-blueschist facies westward ca. 20km in the Otao unit of Kurosegawa belt. The westward increase of Al content in pumpellyite, Na-amphibole, and Na- clinopyroxene also suggest the metamorphic grade increases westward. Thus, this area would become a type locality of a cold subduction system as proposed by the Peacock (2009)s thermal modeling.

Keywords: lawsonite, blueschist, HP/LT type metamorphic rocks, Kurosegawa belt, petrogenetic grid, cold subduction system

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Morphological change of zircon under high temperature metamorphism: Example of the Kiso Ryoke metamorphic rocks

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Zircon is an important key mineral to obtain the age of rocks, however zircon newly grew at each metamorphic cycle and its timing of crystallization should have been recorded as U-Pb age. It is not always fully understood how zircon crystal grows at different metamorphic grade. Williams (2001) demonstrated that the behavior of zircon has been changed accompanying with metamorphic grade in Cooma complex, SE Australia. In low grade, there are detrital zircons but in high grade, overgrown or newly formed zircons are observed. Kawakami et al (2013) reported the behavior of zircon in the upper-amphibolite to granulite facies schist/migmatite transition, Aoyama area, Ryoke metamorphic belt. They concluded that the recrystallization of zircon has been controlled by partial melt. Thus, crystal morphology is quite important for understanding the U-Pb age of zircon.

This study reports morphological change of zircon crystal at different metamorphic grades in the Kiso area, Ryoke metamorphic belt in Central Japan, where metamorphic grade continuously increases from non-metamorphic (Mino belt) to migmatite facies, similar with Cooma complex. The district is located in northeastern part of Mt. Kisokomagatake and the study area is about 43km from north to south, and about 22km west to east. In this district, regional metamorphic rocks (metasediments, quartz schist, basic schist, and carbonate rocks, etc.) and non-metamorphic rocks widely occur. Morikiyo (1984) classified the district into nine mineral zones (I to VII) based on the mineral assemblages.

We have studied total 46 samples from all zones. Mineral assembles of the studied samples indicate the following characteristics features: biotite appears in zone II, albite disappears in zone IIIa, chlorite disappears in zone IIIb and sillimanite appears in zone VIa.

On the basis of the optical microscope and SEM observations, morphology of zircon is divided into 3 groups, such as zones I-II, zones IIIa-V and zones VIa-VII.

Zones I-II: Under the optical microscope, each zircon grain shows different color (purple, pale-pink and colourless). Zircon grains are essentially euhedral, and show variable range of grain size (40-220 um). In SEM observation, the abrasion and cracks are notable in zircon crystal surface. The above observations are consistent that the zircons in these zones are detrital origin that were derived from a variety of different source rocks.

Zones IIIa-V: Surface of zircon in these zones are irregular and rough with small holes which are likely to reflect resorption during the metamorphism. In contrast with the zircons from zones I-II, zircon crystal surface is relatively rough and shows no abrasion and cracks. But, even in the same zircon grain, both resorption surface and non-resorption surface can also be observed. Non-resorption surface is considered to preserve detrital surface (same with zone I-II), and resorption surface possibly reflects metamorphic dissolution or recrystallization (similar to zone VIa-VII). According to BSE images, no obvious new growth zone can be observed in many of zircon grains, but a few grains show sign of new overgrowth zone. Grain size of newly growing zircon is relatively small about 30um.

Zones VIa-VII: Surface of zircon in these zones is relatively smooth, which differs from rough crystal surface in zones IIIa-V. It is assumed that the irregular surface of zone IIIa-V zircons are overgrown and filled by smooth surface as temperature increases to zones VIa-VII. In the highest-grade zone VII, the rough surface is disappeared, and smooth zircon grains are dominated.

Thus in the Ryoke metamorphic rocks from Kiso area, crystal morphology of zircons changes from the dominant detrital signature in the lowest-grade zone through irregular and rough resorption and recrystallization features in the middle-grade zone to the more smooth overgrowth recrystallization in the higher-grade. New zircon grain growth can be found in the middle to higher-grade zone.

Keywords: zircon morphology, regional metamorphism, Ryoke belt

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SMP46-P11 Room:Poster Time:April 28 18:15-19:30

P-T estimates of a metapelite containig garnet zoning from Mefjell, Sr Rondane Mountain, East Antarctica

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The Sør Rondane Mountains, East Antarctica have been considered to be situated in the Gondwana suture zones. Therefore the mountains have attracted interest as a key area for understanding amalgamation process of the supercontinent. The mountains consist of amphibolite- to granulite-facies metamorphic rocks with granitic intrusions, and the timings of the main metamorphism are interpreted as *c*. 640-600 Ma and *c*. 550-500 Ma. Metamorphic rocks from northern and eastern part of the mountains (Balchenfjella and northern part of Austkampane) record a clockwise *P-T* path, on the other hand, metamorphic rocks from central part of the mountains (Brattnipene and eastern Menipa) record anti-clockwise *P-T* path. This suggests each area records a different *P-T* path. However, pre-peak *P-T* conditions of southwestern part of the mountain such as Mefjell have been still not clear.

In this study, we report a garnet porphyroblast with a prograde zoning in a metapelite from Mefjell. The St-bearing Grt-Sil-Bt gneiss mainly consists of garnet, biotite, sillimanite, quartz and plagioclase, with minor K-feldspar, staurolite, apatite, monazite, ilmenite and magnetite. The garnet grain is 12 mm in diameter, with the change of color from reddish in the core to transparent in the rim. The garnet has core-rim boundary defined by Mn-zoning. The garnet is typically almandine-rich, and shows compositional zoning with decrease in spessartine content from the core ($Alm_{63}Sps_{24}Prp_{14}Grs_6$) to the rim ($Alm_{74}Sps_2Prp_{20}Grs_4$), and spessartine content increase again towards the outer-rim ($Alm_{73}Sps_{11}Prp_{20}Grs_6$). The garnet includes staurolite, sillimanite, biotite, chlorite, plagioclase, K-feldspar, quartz, apatite and ilmenite. Garnet-ilmenite and staurolite-garnet geothermometers yield a temperature increase towards rim from 350-400 to 630-700 ℃. Garnet-Al_2SiO_5-quartz-plagioclase geobarometer applied to rim inclusions yields 7.2kbar$\pm$0.9kbar for an assumed temperature of 650 ℃.

Keywords: East Antarctica, Sør Rondane Mountain, pressure and temperature conditions

SMP46-P12 Room:Poster Time:April 28 18:15-19:30

Syn-metamorphic fluid infiltration and petrogenesis of leucogranites in the MCT zone in Eastern Nepal

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Syn-metamorphic fluid activity in the continental collision zone is of great importance especially for the petrogenesis of leucogranites and mass transfer through the fluid/melt extraction. Tourmaline (Tur) is a common accessory mineral in the crust having a wide stability field [1]. It is the most important sink of B in metapelites [2, 3, 4]. Although B behaves incompatibly under the absence of its sink minerals and is transported in fluid, once the *P-T-X* condition permits, it can be precipitated as Tur and other borosilicates in the site of fluid/rock interaction. Therefore, Tur can be a good tracer of B-bearing fluid [4]. Since Tur is a polar mineral, different concentrations of cations are incorporated at opposite poles of the crystal as a function of temperature up to 650^{o}C, and this interpolar element partitioning in Tur can be used as a geothermometer [2, 5].

We have investigated the mode of occurrence of Qtz veins and Tur-rich veins in the MCT zone around Dhankuta, Eastern Nepal. In this area, pelitic schists are widely exposed and subordinate amounts of metamorphosed dolostone, quartzite and mafic rocks are intercalated with them. The metamorphic grade decreases from the Ky zone through the St zone to the Grt zone as the distance from the MCT increases toward the south.

Qtz veins are abundant in metapelites of this area. They are mostly deformed by the ductile deformation with top-to-S sense of shear during the activity of the MCT, and are found as lenses. In the Ky zone, Qtz veins contain mm- to cm-sized crystals of Ky and minor Pl. Grt and Ky are coarse-grained only at the vicinity of the Qtz veins, and Ky tends to be formed exclusively around the Qtz veins. This suggests that the fluid activity that formed the Qtz veins took place around the peak metamorphism of the Ky zone, and Si, Al, Na and Ca were mobile in the fluid. Preliminary *P-T* estimate of this fluid activity using Grt-Ky-Pl-Bt-Qtz assemblage gave ca. 8kbar and ca. 600^{o}C. In the St and Grt zones as well, Grt tends to be coarser grained around the Qtz veins. Therefore, these veins are the evidence for the externally derived fluid that infiltrated during the prograde to peak metamorphism of each zone.

Unusually abundant Tur is locally found in metapelites of the MCT zone. It is localized in aluminous, Ms-rich layers and can be formed through the input of external B into the appropriate whole-rock composition for Tur growth. Such a B-bearing fluid infiltration continued from the prograde stage because Grt with prograde chemical zoning includes abundant Tur crystals. B-bearing fluid infiltration continued in the post-peak stage as suggested by the presence of Tur-rich vein cross-cutting the schistosity. Interpolar Ca/Na partitioning of Tur [5] gives 530-590^{o}C for the temperature of the Tur-rich vein formation. A potential source of external fluid could be lower grade metasediments underlying these metamorphic zones, because syn-metamorphic dehydration reactions of hydrous minerals can supply not only H_2O but also B in the fluid.

B-bearing fluid infiltration during the prograde to post-peak metamorphism in the MCT zone is important for the petrogenesis of the Higher Himalayan (HH) and North Himalayan leucogranites whose source region and petrogenesis remain highly controversial [6]. Observation in this study supports the fluid-fluxed melting of the MCT zone or Higher Himalayan Crystallines (HHC) [7]. Tur-bearing leucogranite veins in the HHC just above the MCT could be a potential product of such a fluid fluxed partial melting that took place near the MCT.

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Keywords: fluid, tourmaline, boron, inverted metamorphism, partial melting, continental collision zone

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Geochronology of the metamorphic rocks from the Masora, Antananarivo and Betsimisaraka domains, east-central Madagascar

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In a previous reconstruction of Gondwana supercontinent, Madagascar is located within the interior of the supercontinent (e.g. Jacobs and Thomas, 2004). Therefore, Madagascar is one of the most significant areas to understand the process of Gondwana supercontinent formation. However, it is still controversial whether the central part of Gondwana supercontinent was formed by young arc-arc collision and amalgamation (Stern, 1994), or was reworked of old continent (e.g. Collins and Pisarevsky, 2005; Tucker et al., 2012). In this study we estimated the age of protolith formation by applying LA-ICP-MS zircon dating method to metaigneous rocks and the age of metamorphism by applying EPMA monazite dating method to metasedimentary rocks, to understand the geochronological characteristics of the composed domains in east-central Madagascar.

East-central Madagascar is divided into Masora, Betsimisaraka and Antananarivo domains from east to west based on the geology and geochronology (Tucker et al., 2011). The Masora domain is mainly composed of the felsic metamorphic rocks with subordinate amounts of the metasedimentary rocks. Two metasedimentary rocks gave ages ranging from ca. 520 to 510 Ma. This age range is consistent with the age obtained from the meta-granitoid (ca. 530 to 510 Ma, Smith et al., 2008) and from quartzite (ca. 540 to 520 Ma, De Waele et al., 2011) by U-Pb zircon dating method. The felsic metamorphic rock gave igneous age at ca. 3300 Ma. This age is consistent with the age obtained from the migmatized gneiss (Tucker et al., 2011).

The Antananarivo domain is mainly composed of the felsic metamorphic rocks with subordinate amounts of the metasedimentary rocks. This domain is divided into east and west on the basis of the metamorphic condition and structural geology. The east and west areas are bounded by the low-angle ductile shear zone of top-to-west sense. Monazites from the metasedimentary rock in the east gave ages ranging from ca. 500 to 480 Ma. In the west monazites from the two types of the metasedimentary rocks gave ages ranging from ca. 540 to 500 Ma (Martelat et al., 2000) and ca. 630 to 540 Ma (Jöns and Schenk, 2011) and from the meta-granitoid gave age ranging from ca. 560 to 540 Ma (Grégoire et al., 2009). Therefore, the metamorphic age in the east is relatively younger than in the west. The felsic metamorphic rocks are geochemically classified into two types, which gave individual igneous ages of ca. 2700 Ma in the east and ca. 760 Ma in the west, respectively. The intermediate metamorphic rocks are exposed in the west and gave igneous age at ca. 550 Ma.

The Betsimisaraka domain is mainly composed of the metasedimentary rocks. Monazites from the metasedimentary rocks gave ages of ca. 500 Ma. This age is younger than the ages reported from the quartzite at ca. 550-520 Ma (Tucker et al., 2011) and rim ages from the metasedimentary rock at ca. 550 Ma (Collins et al., 2003) by U-Pb zircon dating method.

As a consequence east-central Madagascar was metamorphosed between ca. 550 and 500 Ma. Both the east of the Antananarivo and Betsimisaraka domains was metamorphosed at the youngest age around ca. 500 Ma. In previously reported geochronological results the oldest igneous activity was at ca. 2500 Ma in the Antananarivo domain (e.g. Kröner et al., 2000) Therefore the ca. 2700 Ma igneous age is new and the oldest igneous age in this domain. The east of the Antananarivo domain was older than the west and the oldest part of this domain. The age transition zone was possibly exposed between the Masora, Betsimisaraka and the west of the Antananarivo domains. The age and geological relationship in Archean domain was recently reported from the Dhawar Craton in southern India (Peucat et al., 2013). The existence of the ca. 2700 Ma igneous activity in the east of the Antananarivo domain could be the significant evidence of the continuity between India and Madagascar since Archean.

Keywords: Gondwana supercontinent, east-central Madagascar, LA-ICP-MS U-Pb zircon dating, EPMA monazite dating

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Deformation microstructures of a Kamila amphibolite mylonite and their formative temperatures

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The Kohistan complex and the Kamila amphibolite belt in the northern Pakistan are considered to represent a Cretaceous island arc crust and a part of its lower crust, respectively. Here we report deformation microstructures of a Kamila amphibolite mylonite sample and their formative temperatures.

The amphibolite mylonite sample studied is composed of 100 μm to 1 mm thick alternating layers of hornblende + pyroxene, plagioclase, and hornblende + plagioclase + quartz, intercalating a 3 mm thick layer of garnet + quartz + plagioclase. Composite planar fabrics of a top-to-south sense of shear are developed in this sample; C plane defined by compositional layering (= foliation), S plane defined by lenticular domains of plagioclase aggregate clockwise oblique to the C plane, and C ′ plane anticlockwise oblique to the C plane.

Hornblende + pyroxene layers contain pyroxene porphyroclasts of grain sizes ≈ 200 μm scattered in matrix mainly composed of hornblende grains with grain sizes ≈ 30 μm. Hornblende exhibits a strong crystallographic preferred orientation with (100) and [001] subparallel to foliation and lineation, respectively. Orthopyroxene porphyroclasts are elongated subparallel to foliation, and are accompanied by asymmetric tails mainly composed of hornblende indicating a top-to-south sense of shear. In addition, pyroxene porphyroclasts are surrounded by fine-grained (≈ 10 μm) hornblende and quartz, suggesting a breakdown reaction of pyroxenes (orthopyroxene + clinopyroxene + H2O = hornblende + quartz), which is a retrograde reaction from granulite facies to amphibolite facies.

Plagioclase layers are composed of dynamically recrystallized plagioclase grains of An_{47-54} in composition. Lenticular domains of plagioclase are likely porphyroclasts in origin. Plagioclase grains are polygonal in shape, and weakly aligned clockwise oblique to foliation, which also suggests a top-to-south sense of shear. Plagioclase exhibits a distinct crystallographic preferred orientation with {131} and <1-12>clockwise oblique to foliation and lineation, respectively by ≈ 20 degrees. But {131} and <1-12>are aligned subparallel to the S plane, suggesting the dominance of {131}<1-12>during the dynamic recrystallization of plagioclase.

We applied three pyroxene geothermometers to the chemical compositions of orthopyroxene and clinopyroxene porphyroclasts, which yielded temperatures around 850 degrees C. We also applied a hornblende-plagioclase geothermometer to the average chemical compositions of hornblende and plagioclase in hornblende + plagioclase + quartz layers, and obtained a temperature of ≈ 610 degrees C. Thus, the amphibolite mylonite studied likely experienced a peak metamorphism of granulite facies at ≈ 850 degrees C, and subsequently a retrograde metamorphism of amphibolite facies at ≈ 610 degrees C, during which it was sheared by top-to-south thrusting.

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The tectonics evolution of metamorphic and igneous rocks embedded in the serpentinite melange from the Kurosegawa Tecton

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This study focuses petrology of the Kurosegawa Tectonic Zone, which is characterized by serpentinite melange in the Jurassic Chichibu Belt, in SW Japan. The serpentinite melange contains several blocks including high-pressure/low-temperature metamorphic rocks, high-temperature metamorphic rocks and granites. A small amount of age data obtained in previous study suggests that all rock types were formed before the Jurassic. However, detailed petrological and geochronological works on the blocks have been never performed so far. In this study, we carried out regional-scale geological, geochemical and geochronological analyses on the blocks in serpentinite from the western part of Kyushu to the eastern part of Kii peninsula.

Keywords: Kurosegawa Tectonic Zone, U-Pb zre age

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Metamorphism of the NE side of the Seba eclogitic basic schist in the Sambagawa metamorphic belt, central Shikoku, Japan

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The Sebadani area belongs to the albite-biotite zone and is located in the central part of the Besshi district. The Sebadani area is composed of the Sebadani metagabbro mass and surrounding Seba basic schists, pelitic and siliceous schists occur as intercalation within the Seba basic schists (Takasu and Makino, 1980; Takasu, 1984). Eclogitic mineral assemblages are sporadically preserved in both the Sebadani metagabbro and the Seba basic schists (Seba eclogitic basic schists) (e.g. Takasu, 1984; Naohara and Aoya, 1997; Aoya, 2001). The Onodani eclogites preserved within the Seba basic schists have a complex metamorphic history, undergoing three different metamorphic episodes (Kabir and Takasu, 2010). The first and second eclogite facies metamorphism is estimated as 530-590 ℃ and 19-21 kbar and 630-680 ℃ and 20-22 kbar, respectively. The second metamorphic event is similar to that of the Seba eclogitic basic schist of Aoya (2001) (610-640 ℃ and 12-24 kbar). The pelitic schists intercalated within the Seba eclogitic basic schists also underwent eclogite facies metamorphism of 520-550 ℃ and *c*. 18 kbar (Zaw Win Ko *et al*., 2005; Kouketsu *et al*., 2010).

The eclogite in the northeastern part of the Seba eclogitic basic schists consist mainly of garnet, epidote, amphibole (glaucophane, barroisite, taramite, Mg-taramite, Mg-katophorite, edinite), omphacite (X_{Jd} 0.27-0.41), phengite (Si 6.5-6.9 pfu). Minor amounts of albite, dolomite, rutile, titanite, biotite, chlorite and quartz. The schistsity is defined by preferred orientation of phengite, amphibole and epidote. Garnets are almandine-rich in composition, increasing almandine (X_{Alm} 0.54-0.60), pyrope (X_{Prp} 0.07-0.13) and decreasing spessartine (X_{Sps} 0.10-0.03) from core to the rim and contain inclusions of epidote, omphacite (X_{Jd} 0.27-0.41), dolomite, quartz and titanite. They also contain inclusions of barroisite/Mg-katophorite and albite symprectite. Amphibole in the matrix are zoned, barroisite/Mg-katophorite cores to edinite rims. Some other amphiboles in the matrix are parallel to the schistosity and occasionally occur as randomly oriented. The cores of these amphiboles are resorbed barroisite, glaucophane in the mantle and barroisite/edenite in the rim.

Based on the mineral paragenesis of the eclogites the metamorphism is divided into three events. The first eclogitic metamorphic event is deduced from symprectites of barroisite/ Mg-katophorite and albite after omphacite inclusions in garnet. The prograde stage of the second eclogitic metamorphic event is represented by the inclusions minerals within the mantle and rim of garnets consisting of epidote, barrosite and dolomite. The peak eclogite facies stage is defined by garnet rim and omphacite inclusins within the garnets with schistosity forming minerals of barroisite, omphacite and phengite. Garnet and omphacite rim-rim pairs yielded 530-570 ℃ and >11-14 kbar, and garnet and omphacite inclusion within garnet yields 520-560 ℃, >11-12 kbar (Ellis & Green, 1979 ; Bannno, 1986). THEMOCALC (Holland & Powell, 1998) average *P-T* calculation for garnet + omphacite + barroisite + phengite assemblage obtained 590-610 ℃ and 19-20 kbar. The retrograde stage is defined by symprectite of barrosite and albite after omphacite. The third metamorphic event is defined by zoned amphibole in the matrix.

The estimated matamorphic temperatures of the eclogites are lower than that of the second high-pressure metamorphic event of the Onodani eclogite and similar to that of the omphacite-bearing metapelites from the NW part of the Seba eclogitic basic schists (Kouketsu *et al*., 2010). This suggests a metamorphic thermal gradient existed within the Seba eclogitic basic schists.

Keywords: Sambagawa (Sanbagawa) metamorphic belt, Seba basic schist, eclogite, glaucophane, P-T path, thermal gradient

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Metamorphic history of garnet amphibolite from the Neldy Formation, Makbal district in the Kyrgyz Northern Tien-Shan

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The Kyrgyz Tien-Shan Mountains extend from east to west, separating the Kazakhstan plate to the north and the Tarim plate to the south. They are divided into three tectonic units; the Northern Tien-Shan, the Central (or Middle) Tien-Shan and the Southern Tien-Shan. In the Northern Tien-Shan there are two HP and UHP metamorphic complexes, Makbal HP and UHP in the western part, and Aktyuz HP in the eastern part of the complexes. The Makbal complex in the Kyrgyz Northern Tien-Shan is located in the western segment of the CAOB.

The metamorphic rocks exposed in the Makbal district are divided into the Akdzhon and the Scharkyrak Groups based on their metamorphic conditions. The Akdzhon Group contains rocks of the HP and UHP metamorphic conditions, whereas the Scharkyrak Group underwent greenschists facies metamorphism. The Akdzhon Group is divided into two contrasting metamorphic formations, the structurally lower Makbal Formation and the upper Neldy Formation.

The Neldy Formation is mainly composed of garnet-phengite schists and chlorite-carbonate rocks, along with minor metaquartzites and marbles. Amphibolites and garnet amphibolites occur in the garnet-phengite schists as lenses or blocks up to 50 m across. Eclogites preserved in the cores of the garnet amphibolite bodies. Garnet amphibolite consists mainly of amphibole (magnesiohornblende, ferropargasite, ferrotschermakite, tschermakite, barroisite, actinolite), garnet and chlorite, with minor amounts of quartz, epidote and albite. Accessory minerals are paragonite, titanite and calcite. A schistosity is defined by preferred orientation of amphibole.

Garnets in the garnet amphibolite are rich in almandine (X_{Alm} 0.35-0.64), with variable amounts of spessartine (X_{Sps} 0.00-0.20), grossular (X_{Grs} 0.27-0.61) and pyrope (X_{Prp} 0.01-0.07) compositions. Garnet displays a compositional zoning, in which decrease X_{Sps} (0.20-0.04), increases X_{Alm} (0.35-0.60), X_{Grs} (0.31-0.62) and slightly increase X_{Prp} (0.01-0.03) from the core to the rim and contain inclusion of paragonite, titanite, chlorite, epidote and amphibole (actinolite, magnesiohornblende). The garnets are partly replaced by chlorite and aggregates of amphibole (ferrotschermakite, barroisite), chlorite and quartz along the cracks. Amphiboles in the matrix are zoned with magnesiohornblende and barroisite cores to ferrotschermakite and tschermakite rims and contain inclusions of titanite and quartz.

Based on the texture and mineral composition, we consider that the prograde stage probably stable in the epidote-amphibolite facies condition due to the existing of barroisitic amphibole and epidote along with garnet, paragonite, albite and chlorite. The tschermakitic rim of matrix amphibole suggests that the peak stage probably stable in the amphibolite facies conditions. The expecting metamorphic condition of the garnet amphibolite from the Neldy Formation corresponding with peak *P-T* conditions of 610-620 ℃ and 14-16 kbar for the garnet amphibolite from the Makbal complex (Rojas-Agramonte *et al*., 2013).

References:

Rojas-Agramonte Y., Herwartz D., Garcia-Gasco A. *et al*., (2013) Contrib Mineral Petrol, 166, 525-543.

Keywords: Garnet amphibolite, metamorphic history, amphibolite facies, Makbal complex, Neldy Formation, Kyrgyz Tien-Shan

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The stress-strain history of metamorphic sole: the case study of Greece, Turkey, Oman and Andaman islands

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Metamorphic sole is formed by intra-oceanic thrusting and is found in some locations around the world. Greece, Turkey, Oman and Andaman islands are Tethys type ophiolite exposured area. The microboudin method, which is palaeostress analysis, is based on the proportion of boudinaged mineral grains with respect to applied differential stress. In this study, we used columnar minerals bearing metacherts from four areas and examined the value of palaeodifferential stress. The microboudin method revealed the value of palaeodifferential stress is 3.3˜24.8 MPa and we got stress-strain curve by using strain reversal method. The stress-strain curve indicate the stress history. Palaeodifferencial stress increased until the end of deformation in all samples. This result show that peak P-T condition and peak differencial stress are not simultaneous.

Keywords: microboudin, metamorphic sole, palaeodifferential stress, Tethys, stress-strain history

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Late Cretaceous and Paleogene nappe tectonics in the forearc regions of Southwest Japan

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Nappe tectonics occurred at many times in the Paleogene and late Cretaceous forearcs of Southwest Japan. Upper parts of the crust moved toward trench by the nappe tectonics (Figures A and B). Actually the Atokura and Ryoke Nappes are observed in the northern margin of the Kanto Mountains although most of the nappes were eroded. The Atokura Nappe is mainly composed of Permian granites, mid-Cretaceous granitic and metamorphic rocks, late Cretaceous Atokura Formation, early Paleogene Yorii Formation and late Cretaceous pyroclastic rocks. The Ryoke Nappe mainly consists of late Cretaceous granitic and metamorphic rocks. The Permian granitoids are geological bodies of the Kinshozan-South Kitakami Belt. The mid-Cretaceous granitic and metamorphic rocks were geological members of the Higo-Abukuma Belt. The late Cretaceous granitic and metamorphic rocks were distributed in or near the Ryoke Belt. These various rocks were located in the early Paleogene forearc (Figure B) and were removed by nappe tectonics (Ono, 2011, Abs. Geol. Soc. Japan, Meeting, p. 196).

It is important to reveal the tectonics of the lower crust when the upper crust of about 5km in thickness was moved as a nappe toward trench. The author postulates that the lower crust moved toward mantle. The surface layer of the crust moves as a nappe and the lower crust flows towards the mantle. A thrust is assumed near the base of the lower crust. Figure C shows directions of the movements of crustal materials. Tectonics like this has been repeated in late Cretaceous and Paleogene and almost all the mid-Cretaceous Higo-Abukuma metamorphic rocks were eliminated. The Ryoke Belt was also partly removed after the nappe tectonics.

The tectonics described above is consistent with the geological structure near the Median tectonic Line where the Ryoke Belt is directly in contact with the Shimanto Belt in the central part of the Kii Mountains. In this context, Ryoke granitic and metamorphic rocks are in contact with Sanbagawa metamorphic rocks from surface to lower crust according to the crustal section of Southwest Japan (Ito and Sato, 2010, Journal of Geography, 119, p.235). It is difficult to find a crustal layer which was situated in the deep parts of the Higo-Abukuma and Kinshozan-South Kitakami Belts in the crustal section.

Keywords: Southwest Japan, Forearc, Late Cretaceous and Paleogene, Nappe tectonics, Lower crust