SMP43-01 Room:A03 Time:May 24 14:15-14:30

Analysis of metamorphic history recorded in garnet: A combined EBSD and EPMA study

ENAMI, Masaki[1*] ; NAGAYA, Takayoshi[2]

[1]Center for Chronological Research, Nagoya University, [2]Graduate School of Environmental Studies, Nagoya University

Pressure-temperature and deformation histories recorded in garnet grains in metapelites were analyzed with an effective combination of EBSD (Electron Backscatter Diffraction) and EPMA (electron-probe microanalyzer) data.

Sanbagawa metapelite (UKE04N07b):
This sample was collected from the eclogite-unit in the Besshi region, central Shikoku, which experienced the following successive metamorphic pressure-temperature path: prograde eclogite facies stage (1.7-1.9GPa/470-530 ℃) → decompression and hydration reaction stage → prograde epidote-amphibolite facies stage (up to 1.0-1.1GPa/600-630 ℃) (e.g., Kouketsu et al., 2014, IAR, 263-280). The main matrix phases are garnet, biotite, phengite, epidote, albite, quartz, and graphite. The analyzed garnet grain is composed of inner and outer segments formed in the eclogite and epidote-amphibolite facies stages, respectively. The inner segment ($Alm_{67-73}Sps_{3-10}Prp_{4-10}Grs_{16-21}$) contains paragonite and quartz with high residual pressure (up to 0.8-0.9GPa). The outer segment, which has Mn-poorer and Ca-richer composition ($Alm_{56-66}Sps_{0-10}Prp_{4-9}Grs_{26-36}$), mantles the inner segment in a compositional discontinuous change. The analyzed garnet grain seems to have grown as a single crystal, although it records a break in the growth period between the inner and outer segments. The EBSD data, however, implies that the garnet grain is composed of four domains with different crystallographic orientations, respectively, and misfits between these domains are 40-59 degrees. Sets of quartz grains included in garnet on both sides of the domain boundaries sometimes share the same crystallographic orientation (misfits are less than1-6 degrees). The four domains are all composed of inner and outer segments. Thus, the EPMA and EBSD data suggest that the garnet grain studied was formed through the following process: prograde formation of polycrystalline garnet during the eclogite facies stage → resorption around the garnet grain and along the domain boundaries during exhumation → recrystallization of the outer segment and domain boundaries during the prograde epidote-amphibolite facies stage.

Mogok metapelite (S22b):
This sample was collected from an upper-amphibolite and granulite facies region in the Mogok metamorphic belt, northwest of Mandalay, Myanmar. The main matrix phases are garnet, biotite, plagioclase ($An_{43+/-4}$), K-feldspar, quartz, ilmenite, and graphite. Sillimanite occurs as inclusions in garnet. The peak metamorphic conditions are estimated at about 0.8GPa/800 ℃ (Maw Maw Win, personal communication, 2014). The garnet grain is separated into sub-grains of various sizes by resorption during the exhumation and cooling stages. Each sub-grain is mostly homogeneous, and shows a gradual increase of Mn and Fe and a decrease of Mg in the outermost margin ($Alm_{60-70}Sps_{1-3}Prp_{20-33}Grs_{5-7}$). Aggregates of biotite, plagioclase, and quartz fill the sub-grain boundaries, suggesting that the resorption stage progressed under the relatively high-temperature conditions of 0.2-0.4GPa/500-600 ℃. The EBSD analysis shows that the sub-grains share the same crystallographic orientation (misfits are less than 1-4 degrees) and show no rotation or deformation. These data suggest that the sample has not experienced any dynamic deformation causing revolution of garnet grains after the resorption stage, and may have been exhumed under stationary conditions from at least 6-12 km of depths.

Keywords: EBSD, EPMA, garnet, metamorphic history

SMP43-02 Room:A03 Time:May 24 14:30-14:45

Metamorphism of dolomite-bearing eclogite in the Seba eclogitic basic schists, Sambagawa belt, central Shikoku, Japan

KABIR, Md Fazle[1*] ; TAKASU, Akira[1] ; KISHIRA, Naohito[1]

[1]Shimane University

The Sebadani area is located in the Sambagawa metamorphic belt, Besshi district, central Shikoku. The Sebadani metagabbro mass and surrounding Seba basic schists (Seba eclogitic basic schists), and pelitic and siliceous schists occur in the area (Takasu and Makino, 1980; Takasu, 1984). Eclogitic mineral assemblages are sporadically preserved in both the Sebadani metagabbro mass and the Seba eclogitic basic schists (e.g. Takasu, 1984; Naohara and Aoya, 1997; Aoya, 2001). The Onodani eclogites are preserved within the Seba eclogitic basic schists, and they have a complex metamorphic history, with two different eclogitic metamorphic episodes (first eclogitic episode 530-590 ^{o}C/19-21 kbar; second eclogitic episode 630-680 ^{o}C/20-22 kbar) (Kabir and Takasu, 2010). The second eclogitic episode is similar to that of the Seba eclogitic basic schist of Aoya (2001) (610-640 ^{o}C and 12-24 kbar). The pelitic schists intercalated within the Seba eclogitic basic schists also underwent eclogite facies metamorphism of 520-550 ^{o}C and c. 18 kbar (Zaw Win Ko *et al*., 2005; Kouketsu *et al*., 2010).

The eclogites exposed 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} 0.27-0.43), phengite (Si 6.5-7.1 pfu). Minor amounts of albite, carbonates (mostly dolomite and few calcite), rutile, titanite, biotite, chlorite and quartz. The schistosity is defined by preferred orientation of phengite, amphibole and epidote. Garnets are almandine-rich in composition, with a compositional zoning of 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 rim. They contain inclusions of epidote, omphacite (X_{Jd} 0.27-0.41), dolomite, titanite and quartz. They also contain symplectite aggregates of barroisite/Mg-katophorite and albite. Omphacites in the matrix are zoned from pale green cores to colorless rims (X_{Jd} 0.27-0.43) and contain inclusions of epidote, and they are partly replaced by amphibole (barroisite/magnesiokatophorite) + albite symplectite. Amphibole in the matrix are zoned, barroisite/Mg-katophorite cores to edenite rims. Dolomites in the matrix are up to 0.5 mm across and they contain inclusions of omphacite, amphibole (winchite, barroisite, magnesiokatophorite), epidote, albite, calcite, rutile and quartz. A chemical zoning in dolomite is well defined by a continuous core-to-rim Mg increasing and Fe and Mn decreasing. Dolomites have mutual contact with eclogitic minerals of garnet, omphacite, barroisitic amphibole and phengite in the matrix.

Texturally abundant dolomites in the Seba eclogitic basic schists exposed in the northeastern part suggest X_{CO2} fluid might stable in the eclogitic facies conditions. Supposing the peak metamorphic conditions are the same as the second eclogitic metamorphic episode of the Onodani eclogites (630-680 ^{o}C and 20-22 kbar), considerable amounts of CO_2 (X_{CO2} 0.02-0.05) were included in metamorphic fluid during the peak metamorphism.

Carbonates are major constituents of the altered oceanic crust and of the sedimentary materials entering the orogenic cycle. Extensive experimental work on phase relationships in carbon-bearing systems reveals that carbonates are extremely stable up to mantle pressures and the transfer of carbon to the mantle wedge at subduction zones is linked to the extent of decarbonation and/or dissolution in aqueous fluids, or to the attainment of a carbonatitic solidus if a thermal relaxation occurs, e.g., upon subduction stagnation. Dolomite is a very common rock-forming mineral still waiting for further exploration and for innovative applications to the reconstruction of dynamic processes in the Earth's interior.

Keywords: Sambagawa metamorphic belt, eclogite, omphacite, dolomite, Seba basic schists

SMP43-03 Room:A03 Time:May 24 14:45-15:00

Unit division and metamorphic conditions of the Northern Chichibu belt in central Shikoku

ENDO, Shunsuke[1*]

[1]GSJ-AIST

There is a general consensus that part of the Northern Chichibu belt underwent the Sanbagawa metamorphism (i.e., Cretaceous high P/T metamorphism). However, the Sanbagawa belt proper represents metamorphosed Late Cretaceous accretionary complex, and thus tectonic implications of the Sanbagawa metamorphism in the Mikabu and N. Chichibu belts (Jurassic to Early Cretaceous accretionary complex) must be reconsidered. For this purpose, it is important to unravel metamorphic history of each unit within the N. Chichibu belt. The present study focuses on the Motoyama district of central Shikoku whereby primary structural relationship among the Sanbagawa, Mikabu and N. Chichibu belts are well preserved. I will report the results of geological mapping and petrological observation on ~200 metabasite samples from the Mikabu and N. Chichibu belts in the Motoyama district.

The N. Chichibu belt in the Motoyama district is composed of three units: the Kashiwagi, Kamiyoshida and Sumaizuku units, following to the unit terminology of Matsuoka et al. (1998). The Kashiwagi unit shows an interfinger relationship with the Mikabu ophiolitic unit, and they can be treated as the Mikabu-Kashiwagi unit. The Kamiyoshida unit overlays the Kashiwagi unit and is overlain by the Sumaizuku unit by south-dipping boundaries.

The Mikabu-Kashiwagi unit was unambiguously affected by the Sanbagawa metamorphism, and the occurrence of metamorphic aragonite (Suzuki & Ishizuka, 1998) suggests peak metamorphic pressures of $>$0.7 GPa at 300 ℃. However, relatively low jadeite content in alkali pyroxene coexisting with quartz, and amphibole compositions (magnesioriebeckite to actinolite) in the presence of epidote suggest that the main stage of metamorphic recrystallization took place at lower pressure conditions.

Although the general trend of southward decrease in metamorphic grade has been inferred from the degree of metamorphic recrystallization and deformation structures, quantitative metamorphic conditions of the Kamiyoshida and Sumaizuku units have not been constrained. The Kamiyoshida unit is characterized by the occurrence of alkaline basaltic volcanic breccia with metamorphic minerals of magnesioriebeckite, calcite and stilpnomelane. Recently, jadeite has been discovered from quartz- and riebeckite-free metaigneous rocks in the Kamiyoshida unit. Decompression P-T path from 0.6-0.7 GPa, 300 ℃ to 0.4 GPa, 210-260 ℃ has been derived from zoned sodic pyroxene with a jadeite core and an aegirine rim (Endo, 2015).

The Sumaizuku unit is characterized by the occurrence of prehnite-pumpellyite-epidote-quartz veins in massive basalt and dolerite. No alkali pyroxene or Na amphibole is found. These observations appear to imply the lack of high-P/T metamorphism on this unit. However, lawsonite-pumpellyite-quartz veins were newly discovered from this unit. Lawsonite in the vein locally forms fine-scale Lws-Qz intergrowths with a prismatic outline, interpreted as pseudomorphs after laumontite. This texture suggests compression to $>$0.3 GPa at 200-250 ℃. It is likely that prehnite-bearing veins formed during a decompression stage.

The N. Chichibu belt has long-term history in the accretionary wedge. Apparently gradual Sanbagawa metamorphism of the N. Chichibu belt may be related to exhumation-related metamorphism caused by underplating of new accretionary units in the Cretaceous subduction zone.

Keywords: Northern Chichibu belt, low-grade metamorphism, pressure-temperature history, jadeite, lawsonite

SMP43-04 Room:A03 Time:May 24 15:00-15:15

Study of geological structure and Paleogene kinematic history of the Fault system along the MTL, the west Shikoku.

KUBOTA, Yasu'uchi[1*] ; TAKESHITA, Toru[1]

[1]Hokkaido University

For the long time span of the Paleogene period, the fault movement along the MTL (Median Tectonic Line) has not been fully clarified. Kubota and Takeshita (2008) inferred that Paleogene kinematic history of the MTL is divided to 63-58 Ma (Ichinokawa phase) and 45-25 Ma (Pre-Tobe phase), the pre-Tobe phase defined by N-S directed shortening, which is responsible for a large-scale folding of the Izumi Group and thrusting. The Okamura Fault, Kawakami Fault, and Iyo Fault distribute parallel to the trend of the MTL, and northern part of the MTL in the west Shikoku. We study the geological structure and the deformation structure of fault fracture zone for these faults.

The Okamura Fault has been recognized as active fault, and as right-lateral strike-slip faults (Ehime Prefecture 2001). And, Aoya et al.(2013) reported the development of left-hand en echelon folds along the Okamura Fault, and this study the folds with wavelength of ˜500m of map scale and ˜10m of outcrop scale. The fault fracture zone develops in alternating beds of sandstone and mudstone in the Izumi Group, The whole fault with ˜25m width has been consisted of foliated cataclasite zone with ˜15m width. Left lateral slip and top to the south movement sense by the observation of foliation structure. Furthermore, cataclasite zone with breccia and develops. It has been weakly foliation and shear band, partially remained bedding plane. The fault gouge 30-45cm thick develops at southern margin of fault fracture zone with foliation and shear band has shown movement sense of right lateral slip predominantly. Furthermore, in this study the deformation conditions had been discussed by the microscope observation of fault rocks. Further, the Kawakami and Iyo Fault had been the development of left-hand en echelon folds of map-scale along the Fault, and fault fracture with cataclasite zone with slip sense of left lateral slip and top to the south.

It indicates that the faults had been formed with movement sense of left lateral slip and top to the south. This movement period has been inferred the Paleogene according to the result of K-Ar age dating of the other faults in north of the MTL (Shibata et al. 1989), accordingly the movement is important data for clarify of Pre-Tobe phase of MTL.

Aoya, M.,Noda, A.,Mizuno, K., Mizukami, T., Miyachi, Y., Natsuura, H., Endo, S., Toshimitsu, S. and Aoki, M., 2013, Geology of the Niihama district. Quadrangle Series, 1:50,000, Geological Survey of Japan, AIST, 181p.(in Japanese with English abstract, 3P.);EHIME PREFECTURE 2001. Report on active faults in Ehime Prefecture, a summary-Investigation on the MTL fault systems in the northwestern part of Ehime Prefecture, the northern border of the Ishizuchi Mt. and the southern border of the Sanuki mountain range. pp. 47, Ehime Prefecture. (in Japanese).;Kubota, Y., Takeshita, T., 2008. Island Arc, vol. 17, p. 129-151.;SHIBATA K., NAKAJIMA T., SANGAWA A., UCHIUMI S. & AOYAMA H. 1989. K-Ar ages of fault gouges from the Median Tectonic Line in Shikoku. Bulletin of the Geological Survey of Japan 40, 661-71 (in Japanese with English abstract).

Keywords: Median Tectonic Line, Paleogene, kinematic history

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SMP43-05 Room:A03 Time:May 24 15:15-15:30

Spatio-temporal fluctuation of garnet and cracks

TORIUMI, Mitsuhiro[1*] ; FUKUYAMA, Mayuko[2]

[1]JAMSTEC, [2]Akita Univ.

In the previous papers of JpGU meeting (1), we studied the grain size distribution patterns of metamorphic garnet and albite in the banded metamorphic rocks with grain size grading. The average grain size increases with increasing distance across the banding but normalized distribution patterns of the grain sizes within the individual bands are very similar with each other. The banding structure should be derived from the unidirectional flow of metamorphic fluid with ionic diffusion, therefore suggesting that the growth conditions changed across the bands. It follows that the distribution patterns of grain size of garnet and albite display the summation of multiple simple distribution function such as Ostwald type or simply Gaussian, forming the lognormal to power law type.

In the plate boundary region, the metamorphic rocks also experienced frequent generation of small cracks with fluid and then occupied by minerals. However, the mechanical conditions controlling the crack formation and propagation must be fluctuated in terms of stresses, fluid pressure, temperature, and other parameters. Then, the observed frequency distribution of cracks filled with fluid and also minerals should show the summation of many simple distribution functions and it is approximately lognormal or power law. The fluctuation of the distribution patterns can be simply represented by drifts of mean and variant values with time and space.

In this paper, we would like to discuss the rapid growth of grains and cracks at the case of over - the critical fluctuations by drifts by means of stochastic resonance.

(1) Toriumi M. and M. Fukuyama, 2014, Grain size grading in the Liesegang banding of the plate boundary rocks. Proceeding of JpGU meeting 2014.

Keywords: size distribution, average and variance, spatio-temporal fluctuation, garnet, crack

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SMP43-06 Room:A03 Time:May 24 15:30-15:45

Timescale of metamorphsim and U-Pb ages of the Sanbagawa Metamorphic Complex

MIYAZAKI, Kazuhiro[1*] ; WAKITA, Koji[2] ; DANHARA, Tohru[3] ; IWANO, Hideki[3] ; HIRATA, Takafumi[4]

[1]GSJ AIST, [2]Yamaguchi Univ., [3]Kyoto FT, [4]Kyoto Univ.

Timescale of high-pressure metamorphism is not well known, but is crucial for solid mass transport and fluid flux in the subduction zone. Here, we report timescale of high-pressure metamorphism for the Sanbagawa Metamorphic Complex in the area of 1:200,000 geological map of Matsuyama, western Shikoku, Japan.

We collected psammitic and pelitic rocks from the Iyo and Ozu units of the Sanbagawa Metamorphic Complex, weakly metamorphosed and non-metamorphosed Togano units of the southern Chichibu belt and non-metamorphosed Hanyama unit of the Shimanto belt. The samples are used for zircon U-Pb and phengite K-Ar dating. Histogram of detrital zircon U-Pb ages ($H(t_{zrn})$) of non-metamorphosed Togano unit is similar to $H(t_{zrn})$ of weakly metamorphosed Togano unit, and ages of the youngest cluster of detrital zircon U-Pb ages (t_{zrn-yc}) are 174.7$\pm$1.9 Ma and 181.6$\pm$1.4 Ma, respectively. The $H(t_{zrn})$s of the Hanyama unit, Ozu unit and upper part of the Iyo unit are identical to each other. The t_{zrn-yc}s of the Hanyama and Ozu units, and the upper part of the Iyo unit are 111.3$\pm$2.4 Ma, 110.3$\pm$4 Ma, and 111.2$\pm$2.9 Ma, respectively. This implies that protolith of the Ozu unit and the upper part of the Iyo unit, both units are a part of the Sanbagawa Metamorphic Complex, is the Hanyama unit of the Shimanto belt. On the other hand, the $H(t_{zrn})$ of the lower part of Iyo unit is quite different from those of the above-mentioned 3 samples, and the t_{zrn-yc} is 89$\pm$1.0 Ma. The phengite K-Ar ages (t_{phn})of the upper and lower parts of the Iyo unit are 83.8$\pm$2.1 Ma and 86.9$\pm$2.2 Ma, respectively.

Maximum value of the timescale of high-pressure metamorphism can be defined by the difference between the t_{zrn-yc} and the t_{phn}. The maximum value of the timescale for the upper part of the Iyo unit is 27 Myr, although that for the lower part of the Iyo unit is 2 Myr. Metamorphic zircon rims have grown around detrital zircon grains of the sample from the upper part of the Iyo unit suffered garnet zone metamorphism. Average of U-Pb ages of the metamorphic rims is 94.4$\pm$1.2 Ma. It is inferred that the metamorphic zircon rim have grown at the peak temperature of the Sanbagawa metamorphism. Therefore, difference between the U-Pb age of the metamorphic rim and the t_{phn} should give minimum value of the timescale of the high-pressure metamorphism. The value is 11 Myr.

Results show that the timescale of high-pressure metamorphism ranges from $<$2Myr to 11-27 Myr in the same unit. The upper part of the Iyo unit suffered higher-grade metamorphism than the lower part of the Iyo unit. Numerical simulation of viscous fluids shows that lower viscosity part of metamorphic rocks, in which metamorphic dehydration reaction actively takes place, will be elongated by shear deformation, and intrude into lower-grade metamorphic rocks coming newly in the metamorphic field at deeper part of the subduction zone.

Keywords: Sanbagwa, metamorphism, metamorphic rock, zircon, U-Pb age

SMP43-07 Room:A03 Time:May 24 15:45-16:00

Heat transportation recorded in the southern part of the Hidaka metamorphic belt

SAKATA, Ryugen[1*] ; OZAWA, Kazuhito[1]

[1]School of Science, The University of Tokyo

The earth's continental crust has granitic upper crust and gabbroic lower crust with andesitic average composition, which was developed by various magmatic processes driven by thermal and material transportation through the sub-continental crust-mantle boundary. There are three ways of heat transportation from the mantle to the crust with respective time and spatial scales: heat conduction, solid-state flow of the mantle and the crust, and magmatism. This study aims to evaluate the relative importance of these elemental mechanisms in an exhumed ancient arc crustal section, Hidaka metamorphic belt, Hokkaido, Japan.

Seismic wave tomography has revealed that the lithospheric mantle shows continuity to the shallow crustal level near the Hidaka Main Thrust, where the Horoman peridotite complex is exposed, suggesting shallow uplift of the upper mantle (Kita et al., 2012). The Horoman peridotite complex is shown to underwent isothermal ascent with local heating up to $<$1GPa followed by rapid cooling (Ozawa, 2004), which could have heated the lower crust. Previous studies pointed out that basaltic magma frozen as gabbroic bodies caused crustal partial melting and melt transportation on the basis of geological and geochemical data (Osanai et al., 1991; Owada et al., 2003; Tagiri et al., 1988; Shimura et al, 2006). However, the role of mantle-derived heat and its transportation mechanism are still unclear.

Field survey was conducted along the Nikanbetsu river in the southern end of the Hidaka metamorphic belt. In the study area, a small peridotite body called Nikanbetsu mass is exposed on the west and a large tonalite body on the east. Metamorphic rocks are distributed in between them. The dominant lithology is banded garnet biotite gneiss intercalating $<$100m thick zone of mafic metamorphic rocks, which consists of amphibolite and mafic granulite with many leucocratic veins and layers. The banded garnet biotite gneiss shows remarkable foliation except for the one located near the Nikanbetsu mass.

We applied biotite-garnet Mg-Fe exchange thermometer (Ferry and Spear, 1978) for average chemical compositions of biotite and garnet in the banded garnet biotite gneiss and leucocratic veins including garnet and biotite in the zone of mafic metamorphic rocks. The results show a temperature decrease by ~100 ℃ within ~1km from the east of the peridotite mass to the west of the tonalite body with an exceptionally high value of 750 ℃ around the mafic metamorphic rocks. An application of biotite-garnet thermometer to the core and the rim of the largest garnet and the average value of biotite gives $>$900 and ~750 ℃, respectively. The garnet zoning, occurrence of euhedral plagioclase with normal Na-Ca growth zoning, and weak foliation suggests partial melting of the rock followed by rapid cooling. We also applied two-pyroxene thermometer (Lindslay, 1983) for orthopyroxene coexisting with clinopyroxene in mafic metamorphic rocks with leucocratic veins. The calculated temperature ranges 1000~700 ℃, which is due to a decrease in Wo content from the core to the rim suggesting rapid cooling.

Veins with various structure, morphology, and chemical composition suggest diverse processes during melt transportation, such as brittle failure of the host rock, permeable leakage to and reaction with the host rock, and differentiation and crystallization in the veins. Less differentiated veins may have records of a melt directly migrated from the deep crust, whereas differentiated veins may have records of partial melting of pelitic gneiss.

We detected a thermal gradient of ~100 ℃/km from the Nikanbetsu mass, suggesting the mass acted as a heat source to affect the adjacent metamorphic rocks through heat conduction. We also detected a thermal gradient of $\gg$100 ℃/km around the zone of mafic metamorphic rocks generated by magma transportation overlapping the much gentler thermal gradient.

Keywords: Hidaka metamorphic belt, pelitic gneiss, peridotite, heat source, partial melting

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SMP43-08 Room:A03 Time:May 24 16:15-16:30

Aqueous fluid activity in the MCT zone and its role in High Himalayan leucogranite formation, Dhankuta, Eastern Nepal

KAWAKAMI, Tetsuo[1*] ; SAKAI, Harutaka[1] ; SATO, Katsushi[1]

[1]Graduate School of Science, Kyoto University

Significant aqueous fluid activity during the prograde to retrograde metamorphism in the footwall side of the Main Central Thrust (MCT) is observed in the MCT zone around Dhankuta, Eastern Nepal. A term 'MCT zone' in this study is used to represent the garnet to the kyanite zones developed in the footwall side of the MCT, where inverted metamorphism is observed. In the MCT zone, several evidences of continuous fluid activities during metamorphism and their movement cutting the schistosity can be observed.

The first and most important is the abundant quartz veins. They are found as sheared lenses in the MCT zone, and asymmetric textures show top-to-the-S sense of shear indicating the deformation during the MCT movement. In the kyanite zone, quartz veins contain mm- to cm-sized crystals of kyanite and minor plagioclase. Garnet and kyanite are coarse-grained only at the vicinity of the quartz veins, and in the staurolite and garnet zones as well, garnet tends to be coarser-grained around the quartz veins. These observations suggest that the aqueous fluid infiltration that formed the quartz veins took place at the prograde to peak stage of the metamorphism in the MCT zone.

Meta-dolostone in the kyanite zone is also a good indicator of H_2O movement. It is commonly almost completely metamorphosed to tremolite schist. In such rocks, radiated aggregates of tremolite form a flat, oval-shaped aggregate are arranged parallel to define the schistosity. Locally, such a tremolite arrangement discordantly cut the schistosity like a vein. In some meta-dolostones, dolomites are still preserved, and veins of tremolite discordantly cut the schistosity as well as stem out parallel to the schistosity. These observations indicate that SiO_2-bearing aqueous fluid infiltrated into the dolostone and reacted with dolomite to form tremolite, calcite and CO_2 along the vein and schistosity.

Tourmaline (Tur) is an important sink mineral of incompatible element B, and thus is often abundant in the environment where water-rock interaction took place. Unusually abundant Tur is locally found in metapelites of the MCT zone. It is localized in aluminous, muscovite-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 garnet with prograde chemical zoning includes abundant Tur crystals. B-bearing aqueous fluid infiltration continued in the post-peak stage as suggested by the presence of Tur-rich vein cross-cutting the schistosity. In the kyanite zone, Tur veins are found cutting the schistosity and/or stem out parallel to the schistosity. In such samples, although the B-rich fluid infiltration postdates schistosity formation, staurolite includes or partly overgrows the Tur crystals formed simultaneously with the Tur-rich vein, suggesting that the Tur vein was formed under relatively high-temperature condition slightly after the peak metamorphism.

These aqueous fluids are likely to have moved upwards through the veins to the MCT and to the Higher Himalayan Crystallines (HHC) where P-T conditions above water-saturated solidus of muscovite-bearing pelitic rocks are estimated. In the hanging wall side of the MCT in the Dhankuta area, patches of Tur-bearing leucogranites are found in the migmatitic Grt-Ms-Bt gneisses. One of these leucogranite samples gave the U-Pb zircon age of 25.9 +/- 2.3 Ma, and other gneiss sample from the same area gave U-Pb zircon age of ca. 17 Ma (Sakai et al. 2014). These ages are well consistent with the ages of High Himalayan leucogranites (HHL, Searle et al. 2010), which is commonly tourmaline-bearing, so segregation and extraction of these B-bearing melts is a likely process of the HHL formation. Therefore, input of aqueous fluids released from or passed through the MCT zone into the HHC can be an important process for the formation of HHL (e.g., Le Fort et al., 1981).

Keywords: aqueous fluid, quartz veins, tourmaline, partial melting, leucogranite, Himalayas

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SMP43-09 Room:A03 Time:May 24 16:30-16:45

Garnet-hornblende vein formation and mass transfer by brine infiltration during upper amphibolite facies metamorphism

HIGASHINO, Fumiko[1*] ; KAWAKAMI, Tetsuo[1] ; TSUCHIYA, Noriyoshi[2] ; SATISH-KUMAR, Madhusoodhan[3] ; ISHIKAWA, Masahiro[4] ; GRANTHAM, Geoffrey[5]

[1]Kyoto University, [2]Tohoku University, [3]Niigata University, [4]Yokohama National University, [5]Council for Geoscience, South Africa

The importance of chloride brines during metamorphism is being increasingly recognized among various metamorphic fluids. This is because chloride brines can coexist with a CO_2-rich fluid under the granulite facies condition (Heinrich, 2007), has low a_{H2O}, and acts as a powerful solvent not only for metals but also for various oxide and silicate minerals (Newton and Manning, 2010; Tropper et al., 2011). Therefore, chloride brines would play an important role in mass transfer especially when the pressure-temperature (*P-T*) conditions of metamorphism are around the wet solidus, because X_{H2O} in the brine can control the melting/non-melting behavior of the rock (Aranovich et al., 2013).

In the Sør Rondane Mountains (SRM), East Antarctica where Late Proterozoic to Cambrian granulites are widely exposed, Cl-rich hornblende and biotite in mafic gneisses are locally but widely distributed for ca. 200 km (Higashino et al., under review). Formation mechanisms of these Cl-rich minerals can be different if the modes of occurrence of them are different. Therefore, this study deals with the Cl-rich hornblende-bearing garnet-hornblende (Grt-Hbl) vein which discordantly cuts the gneissose structure of a mafic gneiss in the Brattnipene area, and discuss the formation mechanism and mass transfer that accompanied the vein formation.

In the Grt-Hbl vein, Cl contents of hornblende and biotite, K content of hornblende, as well as the development of a Na-richer rim of plagioclase decrease with a distance from the vein center. Whole-rock composition analyses as a function of distance from the vein show mass imbalances around the vein, suggesting that the Grt-Hbl vein was formed through an open system process. Taking into account the possibility of partial melting, distribution of Cl between melt, aqueous fluid and minerals, and microstructural evidences of minerals, the Grt-Hbl vein was shown to have formed by the Cl-rich aqueous fluid infiltration. The Cl-rich aqueous fluid was possibly NaCl brine because whole-rock analyses showed that Na was added to the vein compared to the wall rock. We estimated that the Grt-Hbl vein was formed at ca. 700 ℃ and 0.70 GPa. This means that the NaCl brine infiltrated into the wall rock at the early stage of retrograde metamorphism in this area. The whole-rock analyses and fractional mass change values calculated according to Ague (2001) also revealed that the NaCl brine infiltration caused additions of Si, Ti, Al, Fe, Mn, Mg, Ca, Na, Li, Sc, V, Cu, Zn, Ge, Sr, Y, Ba, Pb, Bi, Th and U to the wall rock. These added elements are similar to those contained in previously reported brines which were present in mineral assemblages implying subduction metamorphism and implying metal segregation in hydrothermal systems (e.g., Heinrich et al., 1992; Philippot and Selverstone, 1991). The Grt-Hbl vein formed by the NaCl brine infiltration as shown in this study is a clear example that brine could move at least a few meters, and was playing a role in mass transfer at ca. 700 ℃ and 0.70 GPa in the lower crust of the continental collision setting.

Keywords: NaCl brine, trace elements, metasomatism, continental collision, Sor Rondane Mountains, Antarctica

Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SMP43-10 Room:A03 Time:May 24 16:45-17:00

Fluid activity during corona formation in ultramafic gneisses of Lutzow-Holm Complex, East Antarctica

IKEDA, Takeshi[1*] ; SHIMADA, Asami[1]

[1]Kyushu University

In Lutzow-Holm Complex, East Antarctica, it is common that symplectic intergrowth of spinel, orthopyroxene and plagioclase occurs between garnet and hornblende in mafic to ultramafic gneisses. This reaction microstructure has suggested that the complex experienced decompression after peak of metamorphism. In contrast, this study found a corona that is composed of biotite and plagioclase around garnet in ultramafic gneisses. This study describes the mode of occurrence and discusses its significance.

Garnet in the centre of the corona shows convavo-convex shape. Some isolated grains of garnet also occur that have colloded form. Biotite and plagioclase constituent of the corona are euhedral, in contrast to the common occurrence of symplectic intergrowth of spinel, orthopyroxene and plagioclase. Chemical composition of these minerals show almost constant range irrespective of distance from the garnet. Grain size of biotite in the corona represents lognormal distribution. The corona has a bulk composition equivalent to the sum of garnet and matrix plagioclase and biotite together with additional K_2O and H_2O.

These features suggest that K_2O-bearing H_2O fluid infiltrated during corona formation. Absence of the common symplectite in spite of the presense of hornblende in the matrix implies the fluid infiltration preceded the reaction to form symplectite. The shape and size distribution of corona minerals suggest that the corona minerals crystalized in a melt phase of which degree of supersaturation decreased with time. This study concludes that the complex experienced an infiltration of K_2O-bearing H_2O fluid at early stage after peak metamorphism, which caused partial melting and following crystallization with relative rapid cooling rate without significant annealing.

Keywords: corona, metamorphic fluid, Lutzow-Holm Complex

SMP43-11 Room:A03 Time:May 24 17:00-17:15

Interplay of irreversible reactions and deformation: a case of hydrofracturing in the system rodingite - serpentinite

NISHIYAMA, Tadao[1*] ; YOSHIDA, Chisato[1] ; MORI, Yasushi[2] ; SHIGENO, Miki[2]

[1]Graduate School of Science and Technology, Kumamoto University, [2]Kitakyushu Museum of Natural History and Human History

This paper examines hydrofracturing caused by reactions between rodingite and serpentinite during a regional metamorphism. Hydrofracturing is driven by rapid increment of fluid pressure, and therefore will be likely to occur in the contact metamorphic aureole due to rapid and irreversible reactions (Nishiyama, 1989). This paper aims to show the same type of hydrofracturing can occur even in the regional metamorphic terrane.

Rodingites occurs ubiquitously in serpentinite from the Nomo metamorphic rocks, western Kyushu, which is a Cretaceous accretionary complex of greenschist to epidote - amphibolite facies condition (Miyazaki and Nishiyama, 1989). Fukuyama et al. (2014) made geochemical and geochronological studies on these rodingites, and gave U-Pb age of zircons from the rodingites as 108 - 105 Ma. This study classified the rodingites into two types depending on the occurrence and the rock texture: vein type and dyke type. Mineralogy of both types of rodingites are almost the same, consisting of diopside, garnet (grandite), chlorite, vesuvianite and titanite with rare occurrence of epidote and pumpellyite. Both vein-type and dyke-type rodingites are associated with reaction zones between serpentinite. Tremolite veins commonly develop from the reaction zone into serpentinite, representing hydrofracturing associated with the formation of the reaction zone. A conspicuous feature is that perovskite occurs in some reaction zones consisting mainly of diopside and chlorite, whereas titanite is common in rodingites. The reaction perovskite + SiO2 = titanite indicates the condition poorer in SiO2 in the reaction zone. We investigated the reaction relation between rodingites and serpentinites using the singular value decomposition (SVD) technique (Fisher, 1989). Constant solid volume is assumed during the formation of the reaction zone because of lack of ductile deformation in the reaction zone. The condition of constant solid volume is incorporated into the SVD analysis as was firstly done by Yuguchi et al. (2015).

The seven component system CaO - SiO2 - Al2O3 -Fe2O3 - FeO - MgO - H2O is considered. Antigorite (serpentinite), diopside, garnet and chlorite (rodingite), and diopside^R and chlorite^R(reaction zone) are considered. The superscript R denotes minerals from the reaction zone, because they also occur in the rodingite but have different compositions. We took the following strategy to find the reaction relation. First we tried to find reaction relations which hold the conservation of pseudoquarternary components CaO - SiO2 - AF (Al2O3 + Fe2O3) - FM (FeO + MgO) among the mineral assemblage, but we got no reaction relation. Next we omitted CaO as an inert component from the system, and consider reaction relations that hold conservation of pseudoternary SiO2 - AF - FM components, then we got three reactions cosuming CaO and evolving H2O. This strongly suggests increment of fluid pressure associated with the progress of the reactions. We have further examined the system AF - FM, having the following reactions:

1Serp + 22.71Di + 6.79Chl + 4.11CaO + 0.40SiO2 = 26.01Di^R + 10.49Chl^R + 1.43H2O
1Serp + 6.88Di + 3.39Grt + 3.74CaO + 3.32SiO2 = 19.46Di^R + 3.24Chl^R + 5.06H2O
1Serp + 3.24Grt + 0.26Chl + 3.61CaO + 2.74SiO2 = 12.25Di^R + 3.51Chl^R + 5.01H2O
1Serp + 0.34Di + 3.37Grt + 3.62CaO + 2.75SiO2 = 12.95Di^R + 3.23Chl^R + 5.14H2O

All of these reactions consumes SiO2 and CaO, and evolves H2O. This relation holds if we take any linear combination of above reactions. When we consider the perovskite formation from titanite in the reaction zone, reactions in the system AF-FM are preferable, because SiO2 liberated by the titanite breakdown will be consumed by the above reactions in the system AF - FM.

Keywords: rodingite, serpentinite, hydrofracturing, irreversible reactions, singular value decomposition