Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SMP46-P01 Room:Convention Hall Time:May 25 15:30-17:00

Gneissose tonalites and meta-granitoids in the Hase-Ichinose district of the Ina city, central Japan

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Hiji tonalite is exposed along the Median Tectonic Line in the Hase-Ichinose district (Figures A and B). The granitoids exhibit considerable variations in chemical composition and rock texture from place to place. Considering gneissose structures and recrystallizations of minerals, the granitoids can be classified into three types: (1) massive, banding and layered tonalites (2) gneissose tonalites (3) meta-granitoids. These are (1) ordinary granitoids, (2) granitoids deformed at a final stage of the solidification of granitic magma and (3) granitoids deformed and metamorphosed under high temperatures after the solidification of granitic magma. Parts of these granitoids were metamorphosed at about 673K and the Kashio mylonites were formed. The Kashio mylonites are mainly distributed in the yellow region of Figure B.

The Hiji tonalite in the Hase-Ichinose district is characterized by the common occurrence of layered and banded granitoids. Banding structures consist of the alternation of felsic and mafic layers which are poor in continuity. Felsic and mafic layers are often folded locally in a hand specimen scale. Folding layered granitoids is also found in several outcrops. Gneissose tonalites are also common. They are often rich in quartz-feldspar veins which are folded complexly. The quartz-feldspar veins may be deformed under the existence of a small amount of granitic magma. The deformation may be continued even after the solidification of the magma. The problem is whether igneous minerals were recrystallized or not. In this regard, strong schistose texture, plastic deformation of minerals and preferred mineral arrangements are uncommon. The recrystallization under the solid-state condition appears to be slight in most cases.

Meta-granitoids in the study area are called as the Gatsuzozan metamorphic rocks [1, 2]. They are characterized by conspicuous deformations and foliations [2]. However, typical meta-granitoids are rare. Moreover, it is not easy to confirm the recrystallization of minerals because of common occurrences of relic igneous minerals. For example, we examined chemical variations of plagioclase grains for a massive tonalite and a meta-tonalite. The results are shown in Figure C. The compositional variation is small for the meta-tonalite relative to that for the tonalite. The conclusion is however obtained by neglecting a calcium-rich large plagioclase grain for the meta-tonalite.

The original rocks of some meta-granitoids are vein-rich gneissose granitoids. The conclusion is based on the study of the chemical variation of plagioclase grains for a meta-granitoid that is rich in quartz-feldspar veins. The examined rock was exposed in an outcrop near Mt. Gatsuzozan. Plagioclase crystals in the veins exhibit conspicuous chemical zonings, and the chemical variations among plagioclase grains are large. On the other hand the recrystallizations of plagioclases are considerable in the matrix. The data suggest that the quartz-feldspar veins were formed before the metamorphism.

The tectonics of the formation of meta-granitoids took place in almost all the study area. Nevertheless, typical meta-granitoids are uncommon. Complexly zoned plagioclases are common for the granitoids in the study area. The poor recrystallization may be due to the following facts. Deformations took place in limited regions. Driving force to the recrystallization was small because the recrystallization occurred slightly below the solidus temperature of granitic magma.

[1] Ono, 2008, Abst. Ann. Meet. Geol. Soc. Japan, p.243.
[2] Ono, 2009, Abst. Ann. Meet. Geol. Soc. Japan, p.259.

Keywords: gneissose granitoid, meta-granitoid, Hiji tonalite, Gatsuzozan metamorphic rocks, recrystallization, Hase-Ichinose

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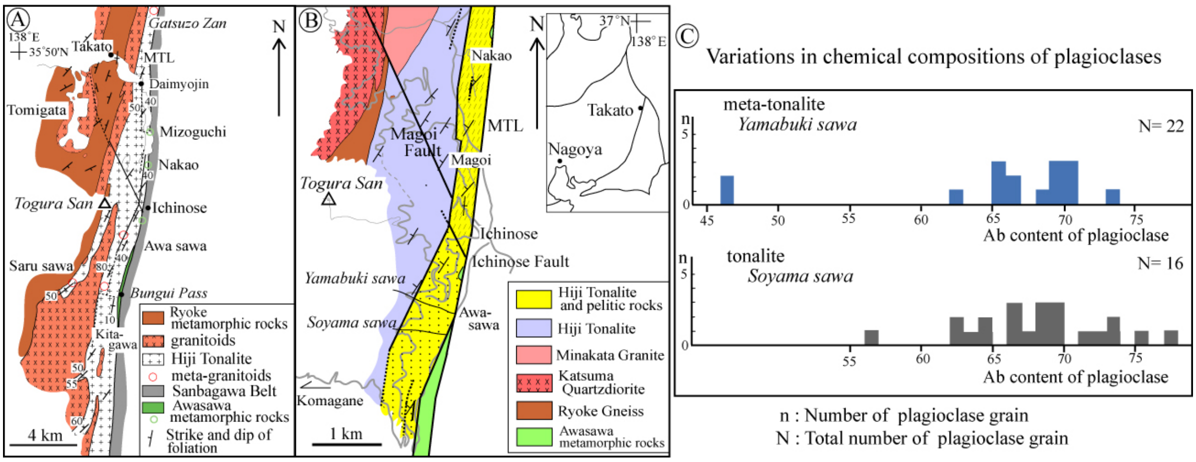

Japan Geoscience Union Meeting 2012
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SMP46-P02 Room:Convention Hall Time:May 25 15:30-17:00

P-T paths of tectonic blocks in the Kamuikotan metamorphic rocks, Etanbetsu-Horokanai district, Hokkaido

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The Kamuikontan metamorphic rocks are known as typical high-P/T type metamorphic rocks formed at convergent plate boundaries at Cretaceous, northern Japan. On these rocks, a number of studies were conducted in 1980s, but since then few studies have been conducted and their tectonics has not been fully interpreted. In the study area, Etanbetsu-Horokanai district, the Kamuikontan rocks are characterized by the paragenesis of lawsonite and glaucophane, and suffered the highest pressure metamorphism (Sakakibara and Ota, 1994) in the Kamuikotan rocks. In this area, while accretionary sediments suffered a high-P/T type metamorphism (prograde rocks), epidote-amphibolite and epidote-garnet amphibolites indicating medium pressure type metamorphism also occur as tectonic blocks, which later suffered the same high-P/T type metamorphism as the sediments did (retrograde rocks, Ishizuka and Imaizumi, 1980; Ishizuka et al., 1983). It is inferred that amphibolite originated from layered gabrro, which is somewhat similar to the Horokanai ophiolite. Further, although blueschist which originated from basalt is classified as prograde rocks by these authors, the amphibolite and blueschist could have been derived from the same oceanic crust, as discussed below. If so, a series of ophiolitic rocks was brought to the subduction channel by tectonic erosion, where the formation of the Kamuikotan rocks proceeded.

We have analyzed mineral assemblages in these rocks (tectonic blocks), and conducted micro-chemical analyses of compositional zoning in amphiboles from these rocks with an EPMA. Among two blueschist samples collected from the Etanbetsu pass, amphiboles from one sample (falling rocks) show a zoning where actinolite core (Al(IV)=0.17-0.33, Na(B)=0.38-0.43) is overgrown by glaucophane rim (Al(IV)=0.003-0.024, Na(B)=1.81-1.86), while ones from the other sample (outcrop rocks) almost uniformely show a composition of winchite. On the other hand, amphiboles in an epidote-amphibolite sample from the Horokanai pass have a zoning where actinolite-actinolitic hornblende core (Al(IV)=0.33-0.71, Na(B)=0.09-0.40) is overgrown by thin glaucophane rim (Al(IV)=0.009-0.079, Na(B)=1.39-1.85). Accordingly, amphiboles in the amphibolite and blueschist have a similar zoning, and thus these rocks could have been derived from the same ophiolitic rocks. For epidote constituting these amphibolite and blueschist, an interesting observation is that some epidote grains were severely fractured often forming microboudins, while the other grains show idiomorphic shape, and not fractured at all. Hence, there may be a possibility that epidote grains were formed at two distinct stages. It is anticipated that the relation between P-T path and deformation stage will be inferred in the future by analyzing pistasite component of epidote.

Keywords: Kamuikotann metamorphic rocks, high-P/T type metamorphism, tectonic blocks, tectonic erosion, compositional zoning in amphibole, pressure-temperature paths

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Analyses of deformation stages and paleostress in the Kamuikotan metamorphic rocks, west of the Asahikawa-city, Hokkaido

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The Kamuikotan belt, distributed in the central Hokkaido, is a representative high-P/T type metamorphic belt that developed on the convergent boundary between the Eurasian Continent and the oceanic plate subducting beneath the edge of the Asian continent in the Cretaceous. In the metamorphic rocks cropping out in the Kamuikotan gorge area in the western part of Asahikawa city, structures such as foliations and folds have been developed well, and many quartz veins intruded. We measured the orientations of these, and found the existence of three deformation stages Okamoto (2011, graduation thesis) has suggested, from analyses of orientations of foliations. The D1 is defined as the stage at which principal foliations in this area (S1) were formed. S1 was folded to form closed east-vergent folds with axes which trend N-S?NNE-SSW and plunge south at low angles (D2). Furthermore, S1 locally formed open folds with axes that are almost vertical and fold axial surface oriented in E-W. These folds overprinted D2 folds (D3). Poles of quartz veins in the outcrop where D2 folds are dominant were distributed symmetrically with respect to the D2 fold axial surface. This indicates that quartz veins intruded in a stress field that formed D2 folds. We also sampled a quartz vein with dominant D3 crenulation folds that was intruded parallel to foliations, and analyzed microstructures of quartz using three methods explained below to infer the paleostress field. We first define the sample coordinates, the X-Y-Z axes, where X trends E-W and plunge east at 15 degrees, Y trends north and plunges horizontally, and Z trends E-W and plunges east and upward at 75 degrees, respectively. Poles of deformation lamellae in quartz grains are relatively rotated towards sigma 3 direction from the direction of c-axis. Estimation of the paleo-sigma 1 and 3 directions can be possible from the distribution of arrows which connect the c-axis and lamellae pole (arrow head) orientations in grains. Arrows converged in the direction that plunge the -X axis at 20-60 degrees in the XZ plane. Kink bands tend to be formed in grains where the c-axes are oriented between the sigma 1 and 3 axes (i.e. orientations of highest resolved shear stress on slip plane), and not to be formed in grains where the c-axes are oriented to the directions of principal stress axes. Based on these facts, we can estimate the directions of principal stress axes from distributions of c-axes orientations in grains containing and not containing kink bands. The c-axes in grains with kink bands showed a girdle distribution with the angular radius of 45 degrees whose center is Y axis, and those in grains without kink bands were concentrated in the direction that plunges -X direction at 20-30 degrees in the XZ plane. Sigma 3-direction can also be estimated from distribution of poles of healed microcracks formed in quartz grains because they are ideally formed perpendicularly to the sigma 3-axis. The highest concentrated area of poles of microcracks plunges -X direction at 40 degrees in the XZ plane. Combining all these results, we could estimate that the paleostress field during the D3 period is such that the sigma 1, 2, and 3 axes trends N-S with no plunge, vertical, E-W with no plunge, respectively. From the measurement of homogenization temperature of fluid inclusions in quartz grains constituting a vein which probably formed during the D3 period, we obtained the values of temperature of 142-176 degrees. We could estimate that the pressure was 1.6-2.1 kbar when fluid inclusions were trapped, using the slope of isochore of pure water (76 degrees/kbar). This pressure value during D3 period is significantly lower than that estimated from fluid inclusions trapped during D2 period by Okamoto (2011, graduation thesis) (about 2.5 kbar). These facts indicate that an uplift of 0.5-1.0 kbar (1.5-3 km) occurred from the D2 period to the D3 period.

Keywords: Kamuikotan metamorphic rocks, deformation stage analyses, paleostress analyses, deformation microstructures in quartz, healed microcrack, fluid inclusion

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SMP46-P04 Room:Convention Hall Time:May 25 15:30-17:00

Wedge extrusion followed by out-of-sequence thrusting and duplexing, and solving knocker problem, the Sambagawa HP-LT sc

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The Sambagawa high P/T metamorphic rocks central Shikoku is regionally mapped, and characteristic major structures performed the exhumation of high grade metamorphic rock is clarified. Our geologic map is expected to be an index map available for researchers of the Sambagawa zone. As noted by Osozawa and Pavlis (2007), the most fundamental structure is the extrusional wedge, rebelled D2-1 in this paper. The S directed extruded wedge consists of a series of normal faults domain at hanging wall of the Asemigawa detachment N directed, and a series of thrust faults domain of the footwall S directed. These faults bound every metamorphic mineral zone, and the thermal culmination of the Asemigawa section is oligoclase-biotite zone, hanging wall of the detachment fault. To the W, we now confirm that the culmination contains a metamorphic ultramafic rocks- amphibolite-eclogite complex. To the E, these extrusional wedge and a series of normal and thrust faults are linearly traceable on regional map, but suddenly discontinuous to the footwall chlorite zone. The disruption is due to the D2-2 Hamegano out-of-sequence thrust, newly found in this paper, and the hanging wall consists of the high grade rocks. The OST divides the chlorite zone into the upper L tectonite consisting of varicolored mafic schist, and the other main pelitic schist regionally distributed. D2 folds at the hanging wall is disjunctive and broken by the movement of brittle OST. The OST is traceable to the W from the Asemigawa area. To the N, the Tomisato syncline is observed as mapped by previous studies, but it exists only on hanging wall, and the structure is discordant to the footwall main chlorite zone. Its S limb, hanging wall of the OST, is extrusional wedge, but the NW limb consists of stacked metamorphic mineral zones, and the syncline is asymmetric. Further to the N, OST and hanging wall duplex is involved in the W plunging D2-3 Oboke anticline. We named the D2-2 duplex stack formed near anticlinal axis, the Tomisato duplex. OST and duplex directed S, as the second expression of metamorphic exhumation, following the first wedge extrusion. The Median Tectonic Line might have played an important role for exhumation as a root, and the high grade rocks, including eclogite, is consequently rootless. The Oboke anticline contains the structurally lowest psammitic schist included in the main chlorite zone. The similar psammitic schist unit of the upper different horizon is newly recognized only at the NW limb of the anticline. The psammitic schist and the Oboke thrust is concordantly folded with the OST and duplex at the Oboke anticlinal axis. Another anticline is to the S, the Nakashichiban area, where the psammitic schist of the same horizon is once again exposed. Metamorphosed ultramafic rocks, amphibolite (mafic schist) except for eclogite, calcareous schist, and piemontite siliceous schist are distributed in every metamorphic zone. The rocks are affected by D1 stretching and W directed shear, but never tectonic melange. Therefore, ultramafic rocks were amalgamated with surrounding rocks before D1, and possible mixing mechanism is sedimentary melange. The eclogite might be derived from metamorphic sole of the Jurassic Mikabu ophiolite as the same fashion.

Keywords: Sambagawa HP-LT metamorphic rocks, exhumation, extrusional wedge, out-of-sequence thrust, duplex, eclogite

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Microstructural analysis of peridotite xenoliths from Kimberley and Lesotho kimberlite pipes in South Africa

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Kimberlite pipes carry peridotite xenoliths derived from the deep upper mantle (70-250 km) beneath Archean cratons. Such xenoliths contain well-developed deformation microstructures. This study presents microstructures of peridotite xenoliths from two kimberlite pipes in South Africa: Kimberley and Lesotho.

The peridotite xenoliths of Kimberley kimberlite pipe consist of lherzolite, harzburgite and dunite. The lherzolites consist of olivine, orthopyroxene, garnet and clinopyroxene. The harzburgites consist of olivine, orthopyroxene, garnet and a minor amount of clinopyroxene. A small amount of phlogopite occurs in both rocks. These rocks are texturally divided into two types: coarse granular (granular type) and extensively sheared peridotites having obvious foliations (foliated type). The granular type peridotites show equigranular textures with slightly curved grain boundaries. The foliated type peridotites show porphyroclastic textures, which consist of coarse-grained porphyroclasts and very fine-grained neoblast matrix. These peridotites display no visible evidence of extensive metasomatism, but show some secondary serpentine alterations along grain boundaries. Major-element compositions of minerals were determined by an electron probe microanalyzer (EPMA). Mineral chemistries for the Lherzolites and the harzburgites indicate that these mantle rocks were equilibrated at similar P-T conditions regardless of their texture types. Olivine crystal-preferred orientations (CPOs) were measured in highly polished XZ thin sections using a scanning electron microscope (SEM: Hitachi S-3400N) equipped with electron back-scattered diffraction (EBSD: Oxford-HKL Channel5). The peridotite xenoliths show various olivine CPO patterns.

The peridotite xenoliths of Lesotho kimberlite pipe are grouped into two types: coarse granular type and small-grained elongated type. Olivine CPOs show intense concentrations of [010] axes normal to the foliation, with girdles of [100] and [001] axes within the plane of the foliation (AG type). In particular, the small-grained elongated peridotites show strong concentration of [010] axes. This CPO pattern may result from axial shortening. The coarse granular peridotite shows higher equilibrium temperatures than those for the small-grained elongated peridotites. It suggests that the cratonic mantle beneath Lesotho may contain a domain where the coarse peridotites alternate with the small-grained elongated peridotites at around 150 km deep.

Keywords: Kimberlite, Peridotite xenoliths, microstructure, crystal fabric analysis

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Strain localization in the Konoyama mylonite zone,SW Japan

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In a shear zone, grain size of minerals gradually decreases towards the center of the shear zone, and fine-grained minerals developed as a localized high-strain zone at the shear zone center. The difference between grain sizes of minerals in the shear zone center and the shear zone margin resulted from the difference in (1) strain rate, (2) stress, and (3) duration of deformation. Therefore, we should clarify which is the most important factor to localize the strain in the shear zone center. However, in general, duration of deformation cannot be estimated by a conventional geochronological analysis. In shear zone rocks, if metamorphic minerals crystallized during shearing are different in different lithologies, the formation temperature of different lithologies would be different. Thus, strain localized with decreasing temperature with time. In this case, the formation period of them would be different.

In the Ryoke metamorphic belt, there are many ductile shear zones with different scale. The Konoyama mylonite zone (e.g., Takagi et al., 1988; Ishii et al., 2007) is one of the shear zones, and developed around Mt. Konoyama, Kishiwada, SW Japan. In the area, deformed granodioritic rocks from protomylonite, through mylonite, to ultramylonite can be observed. In this study, to clarify whether the formation temperature of deformed rocks is different in different lithologies, we analyzed mineral assemblages and mineral chemistry for deformed rocks with different degree of strain magnitude.

We found some interesting observations as follows: (1) There is no chlorite and muscovite in protomylonites and mylonites, but present in ultramylonites; (2) The recrystallized biotite in ultramylonites shows lower Ti and higher Al than those in protomylonites and mylonites, although the difference is small. These observations suggest that the formation temperature of ultramylonites is slightly lower than those of protomylonites and mylonites, and the formation period of ultramylonites and protomylonites/mylonites is different. This implies that strain localization in the Konoyama mylonite zone occurred retrogressively.

Ref: Takagi, H., Mizutani, T. and Hirooka, K. (1988) Jour. Geol. Soc. Japan, 94, 869-886; Ishii, K., Kanagawa, K., Shigematsu, N. and Okudaira, T. (2007) Jour. Struct. Geol., 29, 1083-1098

Keywords: mylonite, shear zone, biotite

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Petrology and geochronology of metamorphic rocks in the Bayankhongor area, the central part of Mongolia.

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Mongolia is situated in the Central Asian Orogenic Belt (e.g. Mossakovsky et al., 1993), which extends from the Siberian craton, Baltica craton, North China craton and Tarim craton. It is composed of subduction-accretion complexes and developed from c. 1000 Ma to c. 250 Ma (Windley et al., 2007). Metamorphic rocks are partly distributed in the central and western part of Mongolia. Metamorphic history would be a key for understanding the tectonic evolution of this area, however detailed study on metamorphic rocks has not been well-documented, including geochronology. In this study, we report petrology and U-Pb monazite and zircon ages on metamorphic rocks occurring in the Bayankhongor area.

The Bayankhongor area is situated between Gobi-Altai range and Hangay range in the central part of Mongolia. The area is mainly composed of granitic gneisses (biotite gneiss and clinopyroxene-biotite gneiss), amphibolites and pelitic gneisses. Pelitic gneisses are classified into garnet-biotite gneiss, garnet-sillimanite-biotite gneiss and garnet -cordierite-biotite gneiss. Garnet in garnet-cordierite-biotite gneiss is replaced by cordierite and biotite, indicating decompression process. Sillimanite in garnet-sillimanite-biotite gneiss is replaced by andalusite, which also indicates later stage metamorphism under the lower pressure condition. Amphibolites are classified into garnet-amphibolite, clinopyroxene-amphibolite and amphibolite. Garnet in garnet-amphibolite is replaced by plagioclase and hornblende, which qualitatively imply decompression as well as pelitic gneisses. Thus, metamorphic rocks in the Bayankhongor area widely recorded amphibolite- to upper amphibolite-facies metamorphism with subsequent decompression.

In the presentation, we show additional data including mineral chemistry, P-T estimations and U-Th-Pb in situ dating and discuss metamorphic evolution of the Bayankhongor area. Based on the interpretation of those data, we suggest its implication for the tectonic process related to the development of the Asia continent.

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Windley et al. (2007) Tectonic models for accretion of the Central Asian Orogenic Belt. Journal of the Geological Society, London, 164, 31-47.

Keywords: metamorphic rock, P-T condition, U-Pb dating, Bayankhongor Area, Mongolia

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A primary and secondarily-modified microstructure of kelyphites in garnet pyroxenites from the Ronda peridotite, Spain

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Kelyphite as a breakdown product of garnet may contain in its internal microstructure thermal and recrystallization history that rocks had followed because of its relatively high reactivities coming from its fine-grained nature. I re-investigated a once-well studied and published complexly-zoned kelyphite in a garnet pyroxenite layer in the Ronda peridotite, Spain (Obata, 1994). The zoning has been reported to consist of Zone I (Opx+Pl+Sp) adjacent to garnet, Zone II (Ol+Pl+Sp) and Zone III (Ol+Pl) adjacent to primary aluminous Cpx (Obata, 1994). A steady state-reaction and diffusion model has been proposed to account for a simultaneous generation of such zoned structure by a reaction between garnet and primary Cpx (Obata, 1994) in the plagioclase-lherzolite facies condition. However more simple structured kelyphite that consists of Opx+Pl+Sp+Cpx occurs in other pyroxenite layers from the same body. An important fining in sample R127 is the occurrence of trace amount of Cpx in both Zones I and II, thereby casting a doubt to the modeling that assumed a single-stage metasomatic reaction in the plagioclase-lherzolite facies as proposed in Obata (1994). Through more careful comparative studies of these samples, the author came to a conclusion that the simple structured kelyphite is a primary one and the complex zoning that Obata described is a secondarily modified one through later fluid-aided metasomatic reactions. The zone II and III are reaction products developed between a reactant pair of Zone I and the primary Cpx. From the presence of a small amount of Cpx in Zone I, It is concluded that first kelyphitization forming Zone I took place in the seilad subfacies of the spinel-lherzolite facies (OHara, 1967) and that late modification producing Zone II and III took place in the plagioclase-lherzolite facies. It is considered from the fact that these reactions are metasomatic, some metamorphic fluids acted as agents of the reactions. Kelyphitization of garnet occurred also in the host garnet peridotites. It is therefore possible to explore the fluid activities through comparative studies of kelyphitization between different lithofacies with close spatial associations.

Keywords: kelyphite, garnet, reaction zone, fluid, Ronda peridotite

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Fault kinematics along the Itoigawa - Shizuoka Tectonic Line in western Yamanashi

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Fault kinematics of the Itoigawa - Shizuoka Tectonic Line (ISTL) in western Yamanashi is discussed based on structural observations and analyses of fault rocks.

In the eastern foothill area of Mt. Ho-oh, the ISTL forms the boundary between the Kaikoma-Ho-oh granite with an intrusion age of ca 15 Ma on the west and the sediments of the Momonoki Subgroup in the Miocene Koma Group on the east. It strikes NNW in the northern and southern subareas, but NNE in the central subarea, and dips 45-60 degrees toward W. The microstructures of the mylonitized granite near the ISTL indicate reverse faulting toward SE during its mylonitization. Based on the temperatures during its mylonitization inferred from quartz microstructures and c-axis fabrics and the cooling history of the granite pluton inferred from K-Ar ages (Sato et al., 1989), this reverse faulting likely occurred at 12-13 Ma. Cataclasites along the ISTL have structures indicative of sinistral faulting, while gouges along the ISTL show structures indicative of reverse faulting.

In the Hayakawa River area located ca 20 km southward away from the Mt. Ho-oh area, the ISTL forms the boundary between the slates of the Eocene to Miocene Setogawa Group on the west and the volcaniclastic rocks of the Kushigatayama Subgroup in the Miocene Koma Group on the east. It strikes NNW and steeply dips toward W. Asymmetric structures in the Setogawa slates near the ISTL indicate reverse faulting toward ESE during cleavage development at ca 15 Ma and the subsequent sinistral faulting after the cleavage development. Based on the temperatures during these two stages of faulting inferred from vein quartz microstructures and c-axis fabrics and the cooling history of the Setogawa slates inferred from fission-track ages of detrital zircon (Yamagiwa et al., 1997), the reverse faulting likely changed to the sinistral faulting at ca 13 Ma. Cataclasites along the ISTL have structures mostly indicative of sinistral faulting, while gouges along the ISTL show structures mostly indicative of reverse faulting. K-Ar ages of gouges (Tanaka et al., 1997) suggest that this reverse faulting occurred after 7 Ma.

In summary, three stages of faulting along the ISTL are recognized in both areas in western Yamanashi; initial reverse faulting associated with granite mylonitization and slate cleavage development, secondary sinistral faulting associated with the formation of cataclasites, and final reverse faulting associated with the formation of gouges. These three stages of faulting occurred in this sequence, and accordingly the pressure and temperature during faulting decreased. However, the ages described above suggest that the change from the initial reverse faulting to the secondary sinistral faulting occurred ca 1 Ma earlier in the Hayakawa River area than in the Mt. Ho-oh area. This is likely because the collision of the Izu arc with the Hoshu arc started from the south and propagated northward with time.

Keywords: Itoigawa - Shizuoka Tectonic Line, western Yamanashi, fault kinematics

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Two burial-exhumation cycles of tectonic blocks from the northern Montague fault zone, Guatemala

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The Motagua fault zone (MFZ) of central Guatemala is a sinistral suture between the Maya Block (North American Plate) and the Chortis Block (Caribbean Plate). High-P tectonic blocks occur in serpentinite-matrix melanges exposed immediately north and south of the MFZ. The northern MFZ (NMFZ) melange hosts warm-subduction related blocks of epidote eclogite and garnet amphibolite, whereas the southern MFZ (SMFZ) melange includes cool-subduction related blocks of lawsonite eclogite and blueschist. Both the NMFZ and SMFZ eclogites give indistinguishable Sm-Nd garnet-omphacite isochron ages of around 140-130 Ma (Brueckner et al. 2009), but K-Ar phengite ages of the NMFZ high-P blocks (77-65 Ma) are significantly younger than those of the SMFZ high-P blocks (125-116 Ma) (Harlow et al. 2004). Further petrological study especially on the NMFZ high-P blocks is needed to interpret the available age data, and hence to understand the tectonic evolution of this region. We present detailed petrological data of garnet amphibolite from the NMFZ melange exposed at Estancia de La Virgen.

Single garnet crystals in the studied sample consist of four distinct growth zones (Grt1, Grt2, Grt3 and Grt4) and grossular inclusions. Compositions of the four garnet generations are: Grt1 (Alm_{44-52} Sps_{5-13} Prp_{5-6} Grs_{28-41}), Grt2 (Alm_{37-43} Sps_{8-16} Prp_{1-2} Grs_{41-51}), Grt3 (Alm_{48-53} Sps_{3-4} Prp_{3-6} Grs_{38-41}) and Grt4 (Alm_{50-58} Sps_{2-3} Prp_{8-10} Grs_{30-38}). Grt1 occurs as highly corroded cores of the garnet crystals, and contains inclusions of epidote, omphacite (Jd_{28}), titanite and actinolite, indicating the first subduction-related metamorphism in the eclogite facies (M1). The second growth zone (Grt2) hosts inclusions of chlorite, hornblende/actinolite, albite/oligoclase, allanite/epidote, zoisite, K-feldspar, indicating relatively low-P/T metamorphism in the transitional greenschist/amphibolite facies (M2). Grossular (Grs_{72-86} Adr_{6-22} Sps_{1-7}) is exclusively present as discrete crystals included in an intermediate zone within Grt2. The third garnet generation (Grt3) is recognized as a skeletal/dendritic overgrowth on Grt2. Grt3 hosts abundant aqueous fluid inclusions in addition to an almost identical inclusion paragenesis as Grt2. Metamorphism associated with Grt3 growth (M3) could be related to a pulse-like hydrothermal event. The last garnet generation (Grt4) resulted from second subduction-related metamorphism (M4). The early phase of M4 took place in the garnet-unstable conditions, and is recorded as relic inclusions within matrix amphibole. This early M4 assemblage includes glaucophane, actinolite, pumpellyite, phengite (Si=3.58-3.70 apfu) and paragonite, indicating high-P/T type metamorphism in the transitional pumpellyite-actinolite/blueschist facies. The inclusion paragenesis within Grt4 is identical with the matrix assemblage that consists of edenite/barroisitic hornblende, albite/oligoclase, epidote, phengite (Si=3.38-3.45 apfu), chlorite, titanite and quartz. The matrix amphibole was slightly replaced first by glaucophane + actinolite and then by actinolitic hornblende during final exhumation. P-T conditions during Grt4 growth are estimated to be ~550 deg.C, 1.1 GPa, and thus the K-Ar system of phengite have been closed after the thermal peak of M4.

By combining the available information, we presume that the NMFZ high-P blocks underwent, at least, two subduction-exhumation cycles with three main tectono-metamorphic phases: 1) the first subduction-related metamorphism (~140-130 Ma), 2) subsequent thermal events at shallow crustal levels, and 3) the second subduction-related metamorphism (~77 Ma) at the transitional oceanic to continental subduction setting.

References: Brueckner et al. (2009), EPSL 284, 228-235; Harlow et al. (2004), Geology 32, 17-20.

Keywords: exhumation, polygenetic garnet, Guatemala, subduction

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SMP46-P11 Room:Convention Hall Time:May 25 15:30-17:00

Geologic structure of the Sanbagawa Metamorphic Rocks in western Shikoku and deformation pattern of viscous fluids

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The Sanbagawa Metamorphic Rocks are high-pressure metamorphic rocks formed at depth deeper than lower crust. During exhumation, it is expected that the metamorphic rocks should suffered large-scale deformation. I created geological map of the Sanbagawa Metamorphic Rocks in the Iyo-Nagahama district, western Shikoku, and compared the geologic structure and patterns of viscous fluid under simple shear deformation.

The Sanbagawa Metamorphic Rocks in the Iyo-Nagahama district can be divided into Uchiko and Iyo units 1). The Uchiko unit is mainly composed of pelitic schist, and the Iyo unit is mainly composed of mafic schist. The Iyo unit can be also divided into lower, middle and upper subunits. The lower subunit is composed of mafic, siliceous, pelitic and psammitic schists. The middle subunit is mainly composed of thick mafic schist. The upper subunit is composed mainly of mafic and pelitic schists. The lower and middle subunits suffered metamorphism equivalent to that of chlorite zone in central Shikoku. In both subunits, mineral assemblage of epidote + glaucophane + albite + chlorite + quartz occur in mafic schist, and no garnets appear in pelitic schist. In the upper subunit, albite porphyroblast occur in pelitic and mafic schists, and garnet appears in pelitic schist. Therefore, metamorphic grade in the Iyo unit increases toward upper structural levels. Phengite K-Ar ages obtained by this study and previous study 1) yield 78.7+-2.0-88.1+-2.2 Ma for the Iyo unit, and 90.6+-2.3-94.6+-2.4 Ma for the Uchiko unit.

An E-W trending antiform develops in the Iyo unit at central part of the district, and the schistosity dips gently to north at northern side of antiform, and dips gently to south at southern side of the antiform. Recumbent fold with a few km wavelengths is inferred by detailed mapping of red-colored siliceous schist of the middle subunit of the Iyo unit in western part of the district. Folds with sub-horizontal axial plane also develop at outcrop scales in the Iyo unit.

Pressure and temperature in high P/T metamorphic rocks, such as the Sanbagawa Metamorphic Rocks, drastically increase in perpendicular to schistosity. Formation of this type of P-T structure may require tectonic displacement under simple shear. I examined structural evolution of viscous fluids with different viscosity under simple shear deformation. The system consists of high viscosity fluid (10ˆ23 Pa s) and low viscosity fluid (10ˆ21 Pa s). Both fluids are sandwiched by solid plates. Layering structures slightly oblique to shear direction are assumed as initial configuration. Shear deformation were induced by two plate moving to the opposite direction with 1 to 10 cm/y. Results show that folds with a few cm to few km wavelengths are formed during evolution of patter under simple shear deformation. Although the comparison of the results with natural observation is insufficient, the results suggest that tectonic displacement of metamorphic rocks formed at different P-T and formation of large-scale folds may take place simultaneously under simple shear deformation.

1) Banno, Y., et al. (2010) Geology of the Ozu District. Quadrangle Series, 1:50,000, Geological Survey of Japan, AIST, 58p.

Keywords: Sanbagawa Metamorphic Rocks, Geologic structure, viscous fluids, metamorphsim, deformation, fold

SMP46-P12 Room:Convention Hall Time:May 25 15:30-17:00

Protolith and tectonic environment of blueschist from the Kurosegawa tectonic zone, South-west Japan.

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Blueschists from the Kurosegawa tectonic zone are distributed from central Kyushu to Kanto mountains. These rocks are usually embedded in the serpentinite melange. Blueschist is layered and can be divided into two layers; blue and green layers. Coexisting minerals of the blue layer are crossite-glaucophane, lawsonite, and less amount of sodic pyroxene. Secondary minerals that can be found in the blue layer are epidote, pumpellyite, actinolite and chlorite. Mineral assemblage of the green layer is similar to that in the blue layer. However, chlorite and actinolite aof the green layer are more abundant than that of the blue layer, which might be due to hydration during retrograde metamorphism.

It is also noted that the green layer is enriched in LIL elements in comparison with the blue layer affected by the retrograde metamorphism, and then we used the data only from the blue layer for later discussion.

Based on several discrimination diagrams using HFS and REE elements of the blueschists, their protoliths can be divided into following four types of basalt: (1) N-MORB type, (2) E-MORB type, (3) OIB type, (4) T-MORB type.

Rb-Sr isotopic analysis (using blueschist samples from Kyushu, Shikoku ,and Kii peninsula) yields a whole rock isochron age of 269 +/- 8Ma (SrI=0.70513 +/- 0.00018). Zircon U-Pb ages were also determined to be an inherited age (430-490Ma) of pelitic schist from Itsuki area in Kyushu and as a protolith age (480-520Ma) of gabbro from Engyoji area in Shikoku. Therefore, the Rb-Sr isochron age of 269Ma might reflect the timing of the blueschist-facies metamorphism from the Kurosegawa tectonic zone.

Results of these studies suggests that the formation process of Kurosegawa tectonic zone was possibly prior to continental collision of the North China craton and South China craton during the age of early Triassic (ca. 230-220Ma).

In addition, Nd-Sm isotopic analysis (using blueschist samples from Itski area in Kyushu) yields a whole rock isochron age of 804 +/- 64Ma (NdI=0.511781 +/- 0.00073). Therefore, blueschists in Kurosegawa tectonic zone were formed by subduction of the oceanic plate that was located in front of the South China craton.

Keywords: Kurosegawa tectnic zone, blueschist

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An Outline of High-Pressure Metamorphic Rocks from Bantimala and Barru Complex in South Sulawesi, Indonesia

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Accretionary and metamorphic complexes regarded as Cretaceous subduction complexes of Indonesia are distributed in Central Indonesia include of West and Central Java, South Kalimantan and South Sulawesi. The widely dispersed rocks of the pre-Tertiary basement in the Indonesian region comprise variably metamorphosed accretionary complexes, imbricated terranes, melange, turbidite and broken formations, and ophiolite (Parkinson et al., 1998). These accretionary and metamorphic complexes in South Sulawesi are recorded on the restricted area namely Bantimala and Barru Complex.

Bantimala Complex is a tectonic assemblage of slices and blocks consisting of sandstone, shale, conglomerate, chert, siliceous shale, basalt, ultramafic rocks, schist and schist breccia with the ages of components range from Jurassic to middle Cretaceous (Wakita et al., 1996). The metamorphic rocks are intercalated with melange deposits and mainly consist of high-pressure metabasites and low-pressure metamorphosed clastic sequence rocks. The melange includes clasts and blocks of chert, sandstone, basalt, limestone and schist embedded within a sheared shale matrix (Wakita et al., 1996). K-Ar ages of phengite on garnet-glaucophane rock yields 125-139 Ma and 107-119 Ma, 118-130 Ma on mica rich intercalated with garnet-glaucophane rock, 108-120 Ma and 109-121 Ma for mica-quartz schist intercalated with hematite bearing glaucophane schist (Wakita et al., 1994, 1996) and 134-140 Ma for eclogite (Parkinson et al., 1998). Miyazaki et al. (1996) estimate the peak pressure of the Bantimala eclogites were 18-24 kbar at 580-640 ^{o}C. Parkinson et al. (1998) suggest the pressure and temperature for eclogites and garnet-glaucophane rocks were 18-24 kbar at 580-620 ^{o}C and jadeite-garnet-quartz (coesite) rock were $>$27 kbar at 720-760 ^{o}C.

High-pressure metamorphic rocks in the Bantimala Complex mainly crop out as river boulders. Mafic rocks (eclogite) are the most common comparing to pelitic lithologies such as glucophane schist and garnet-glaucophane-phengite schist. Rarely garnet-jadeite-quartz rock crops out as 3 m wide river boulders in Bantimala River. Meanwhile, the Barru Complex is located approximately 30 km north of the Bantimala area. Metamorphic rocks in this area are crop out more restricted area with most common lithologies are variably of garnetiferous quartz-mica schist and serpentinized peridotite. Wakita, et al. (1994) reported phengite K-Ar age determination from quartz-mica schist of 106 Ma.

The evidence from mineral chemistry analysis, suggests that the Grt-Jd-Qtz rock passed through Jd + Qz stability field during metamorphic evolution. Peak metamorphism of eclogite is represented by garnet rim and omphacite in the matrix. Grt?Cpx thermometer (Krogh, 1988., Pattison & Newton, 1989., and Ravna, 2000) yield a temperature of 720-820 ^{o}C for pressure of 25 kbar on the sample of eclogite 110310T03F. The occurrence of glaucophane inclusions in the core and mantel of garnet indicate the former stability field in the blueschist area. Retrogression observed in the eclogites is represented by replacement of omphacite by actinolite-tremolite-winchite-barroisite amphiboles.

Moreover on the retrogression stage, three types of eclogite are recognized. All of the types are contain garnet and omphacite bearing assemblages. The difference between each type is secondary phase minerals that present during retrogression. Type I of eclogite is dark green eclogite with rich of omphacite in the matrix and less of amphibole or minimally affected by the secondary hydration. Type II of eclogite is bluish colored rich of glaucophane and less of omphacite in the matrix. Omphacite grains in this eclogite are restricted as inclusions on garnet or other minerals. Type III of eclogite is light green-bluish colored dominated by mostly amphiboles in the matrix that ranges in composition from actinolite to barroisite. In these rocks, omphacite is partially to completely replaced by amphiboles.

Keywords: high-pressure metamorphic rocks, eclogite, Bantimala Complex, Barru Complex, South Sulawesi, Indonesia

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Metamorphic conditions of blueschists and greenschists in the Toudaoqiao area, in Inner Mongolia, NE China

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Blueschists and related metamorphic rocks are exposed in the Toudaoqiao area of the Honghuaerji-Yimin district in Inner Mongolia, northeastern China (Ye et al., 1994). These metamorphic rocks occur along Tayuan-Xiguitu fault, located between the Ergun block and the Xing'an block, and those are situated in the eastern parts of the Central Asian Orogenic Belt (Sengor et al., 1993).

Zhao et al. (2011) reported that blueschists occur together with greenschists, pelitic schists and siliceous schists in this area. The blueschist consists of amphibole (Gln, Mg-rbk and Win), epidote, albite, phengite (Si=6.7-7.0 p.f.u.), quartz, titanite and hetamite, and the metamorphic conditions are in the epidote-glaucophane facies (380-450^{o}C, 11-14kbar).

In this study we describe barroisite-bearing blueschists and greenschists. The barroisite-bearing blueschists consist mainly of amphibole (Mg-rbk, Gln, Win, Ktp and Brs), epidote, albite, phengite (Si=6.7-7.2 p.f.u.), chlorite, quartz, calcite and titanite with minor amounts of hematite. The amphibole is of subhedral prismatic crystal with size up to 0.2 mm long. It contains inclusions of amphibole (Ktp and Brs) as a relic of the precusor metamorphic event. The amphibole is zoned with winchite core (Na_B=0.54-1.48 p.f.u.) to magnesioriebeckite rim (Na_B=1.52-1.81 p.f.u.), and it is partly replaced by chlorite, calcite, titanite and quartz. The zoning texture suggests the prograde stage is in the winchite stability field followed by the magnesioriebeckite/glaucophane stability field. The peak metamorphic stage is characterized by the rim of amphibole (Mg-rbk/Gln) and coexisting minerals (epidote+albite (An$<$0.38)+phengite (Si=7.2 p.f.u.)+hematite+titanite+calcite), suggesting the epidote-glaucophane schist facies metamorphic event. The retrograde stage is represent of chlorite, calcite, quartz and titanite, which replace the amphibole, probably suggests the greenschist metamorphic event. The peak stage mineral assemblage is same as the previously described blueschist, and the metamorphic condition are T=390-450^{o}C, P=13-15kbar.

The greenschists consist mainly of amphibole (Act, Mg-hbl, Ts, Ed and Hs), epidote, chlorite, albite, phengite (Si=6.7-6.9 p.f.u.), quartz, calcite and titanite with minor amounts of hematite. The amphibole is mainly classified as actinolite ($Na_B$$<$0.34 p.f.u.), and it is of euhedral to subhedral prismatic crystal, with size up to 0.5 mm long. It is commonly zoned with magnesiohornblende (Ti=0.14-0.26 p.f.u.) core and actinolite ($Na_B$$<$0.16 p.f.u.) rim, and its core contains inclusions of amphibole (Ts, Ed, Hs and Mg-hbl (Ti$<$0.10 p.f.u.)) and titanate. Actinolite (Na_B=0.10-0.34 p.f.u.) and chlorite occur along cleavages of the zoned amphibole. The core of the amphibole and its inclusions (Ts, Ed, Hs and Mg-hbl) as relic of the precusor high tempreature metamorphic event. The peak metamorphism is represented by actinolite+chlorite+epidote+albite (An$<$0.2)+phengite (Si=6.9 p.f.u.)+quartz+hematite, suggesting low-temperature and high-pressure metamorphic condition.

Reference

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Keywords: high P/T metamorphism, blueschist, greenschist, Tayuan-Xiguitu fault, NE China

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Geochemistry of the HP-UHP metamorphic rocks, Makbal complex, northern Kyrgyz Tien-Shan

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Geochemistry of the HP-UHP metamorphic rocks, Makbal complex, northern Kyrgyz Tien-Shan

A.A. Bakirov[1], K.S. Sakiev[1], M. Tagiri[2], A.B. Bakirov[1], A. Takasu[3], R.T. Orozbaev[4], A.A. Togonbaeva[1] and J.-I. Kimura[5]

The Makbal UHP complex occurs in the western part of Kyrgyz Range of the Northern Tien-Shan and consists of quartzite and muscovite-quartzite, garnet-muscovite-quartz and chlorite-muscovite-quartz schists, marbles, amphibolites with relicts of eclogites and UHP talc-garnet-chloritoid schists (Tlc-Grt-Cld). The coesite has been found in quartzites and Tlc-Grt-Cld schists, and they experienced UHP metamorphism ($P>29$ kbar and $T<600$ ^{o}C), whereas the eclogites and garnet amphibolites are experienced mainly HP metamorphism with different peak P-T conditions (Tagiri et al., 2010). UHP Tlc-Grt-Cld schists are conformably intercalated in thick quartzite layers. Eclogites occur as imbricated lenses within these host UHPM rocks.

A phengite K-Ar age of 509+13 Ma (Tagiri et al., 2010), CHIME monazite age of 481+26 Ma (Togonbaeva et al., 2009) and 498+7 Ma for the UHP Tlc-Grt-Cld schist and paragonite K-Ar age of 482+17 Ma (Tagiri et al., 1995) and zircon SHRIMP U-Pb ages 509+7 Ma and 502+10 Ma (Konopelko et al., 2011) has been reported for the eclogite. The granitic rocks discordantly intruded in the Makbal complex are dated as 399+10 Ma (Tagiri et al. 2010).

We carried out whole-rock geochemistry analyses on major, trace and REE abundances for the eclogites, Qtz-Grt-carbonate rocks, Tlc-Grt-Cld schists, quartzites, garnetite and one clinopyroxene-biotite rich rocks (lamproite?) from the Makbal Formation. The classification diagrams, using major and trace elements, classify the eclogites as tholeiitic basalts. Tlc-Grt-Cld schists, garnetite and Qtz-Grt-Carb rocks plot in the same field. In the conventional tectonic discrimination diagrams, the eclogites plot in the field of MORB and VAB. Similarly, the Tlc-Grt-Cld schists and Qtz-Grt-Carb rocks show also same compositions in these diagrams as eclogites. However, Tlc-Grt-Cld schist have very low content of CaO (<2 wt%), Na2O (<0.1 wt %) and relatively high MgO (<18 wt %), which is not comparable with basaltic composition. Togonbaeva et al. (2010) pointed out the similarities of the eclogite and Tlc-Grt-Cld schists compositions, and they suggested that the Tlc-Grt-Cld schist is the mixture between eclogite protoliths (basaltic) and quartzites (pelitic) compositions.

Chondrite and primitive mantle normalized diagrams of REE and some trace element abundances show relatively similar pattern for the eclogites, Qtz-Grt-Carb rocks and Tlc-Grt-Cld schists, except some REE enrichments in Tlc-Grt-Cld schists. Eclogites and Tlc-Grt-Cld schists are depleted in incompatible elements (Rb, Ba, Sr, K, Ca), however enriched in Pb.

Here, we propose the possible metasomatic origin of Tlc-Grt-Cld schist in the Makbal complex, similarly to whiteschists formation in Dora-Maira Massif (DMM), Western Alps. Two main genetic hypotheses were proposed for the origin of whiteschists in DMM, i.e. sedimentary (highly Mg-meta-evaporite; Schreyer, 1977) vs. metasomatic (Mg-rich fluid into shear zones; Compagnoni & Hirajima, 2001; Schertl & Schreyer, 2008). We suggest that the origin of Tlc-Grt-Cld schist could be related to Mg-metasomatism on the basaltic protoliths of eclogites, at least prior to peak UHP conditions. This process can be responsible for the modification of some major and trace elements in the eclogites to more Mg-rich and Ca- and Na-poor, similarly to whiteschist in DMM. The metasomatic origin supported also by field relations of these rocks and their similar geochronological data.

References: Tagiri et al. (1995), Island Arc; Tagiri et al. (2010), JMPS; Togonbaeva et al. (2009), JMPS, Togonbaeva et al. (2010) JAMS Annual Meeting, Matsue; Compagnoni & Hirajima (2001), Lithos; Konopelko et al. (2011), Gondwana Research; Schreyer (1977), Tectonophysics; Schertl & Schreyer (2008), Eur. Jour. Miner.

Keywords: geochemistry, UHP metamorphism, metasomatism, Makbal, Tien-Shan, Kyrgyzstan

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Grain-boundary diffusion coefficient based on variation of quartz grain sizes in metacherts around a contact aureole

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Grain-boundary diffusion coefficient is the most important parameter for considering metamorphic and deformation processes. Grain-boundary (or bulk) diffusion coefficients have been estimated experimentally (Farver and Yund, 1990, 2000) or naturally (Joesten, 1983). According to Farver and Yund (2000), the temperature dependence of silicon (bulk) diffusion in the novaculite is described by the Arrhenius parameters: D0 = 3.7 x 10ˆ-10 m2/s and Q = 137+/-18 kJ/mol, and D0 = 6.2 x 10ˆ-9 m2/s and Q = 178+/-38 kJ/mol for the hydrothermal and dry experiments, respectively. On the other hand, variation of the quartz grain sizes in nodular chert in the Christmas Mountains contact aureole was matched by a normal grain growth model in which the temperature dependence of the Arrhenius function along temperature-time history calculated by an one-dimensional thermal modeling. Assuming the grain boundary width of 1 nm, the data permit an estimate of the coefficient for the grain-boundary diffusion of oxygen in quartz as D = 8.07 x 10ˆ-10 exp(-210 x 10ˆ3/RT). Therefore, there is significant difference between the coefficients for a quartz aggregate estimated experimentally and naturally.

In this study, we evaluate the grain-boundary diffusion coefficient by the same scheme of Joesten (1983). We collected metachert samples from the contact aureole around the Hanase-Bessho quartz diorite (Kiji et al., 2000) at the Hanase Pass, Kyoto. Photomicrographs are taken under optical microscope and scanning electron microscope. The grain boundaries are traced using drawing software (Canvas), and grain sizes as equivalent diameter of circles are estimated by ImageJ. The quartz grain sizes vary systematically with the distance from the quartz diorite. We calculated temperature-time history using a one-dimensional thermal model. Based on Arrhenius plot of the observed quartz grain sizes and calculated temperatures, we estimated the activation energy 140+/-16 kJ/mol that is comparable with the value for silicon bulk diffusion estimated by Farver and Yund (2000) for hydrothermal experiment. Furthermore, using the value estimated here, we obtained the value of D0 = 5 x 10ˆ-12 m2/s.

References: Kiji, M., Ozawa, H. and Murata, M. (2000) Cretaceous adakitic Tamba granitoids in northern Kyoto, San'yo belt, Southwest Japan. Jour. Mineral. Petrol. Sci., 29, 136-149.

Keywords: grain-boundary diffusion coefficient, quartz, normal grain growth, contact aureole, termal model, grain size

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Unstable boundary formation behind the growth front in sealing of open crack

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Unstable boundary formation behind the growth front in sealing of open cracks

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Plate boundary quartoze metamorphic rocks contain abundant sealed open cracks and shear cracks that are occupied mainly by quartz with minor amount of albite and chlorite. Apparently the sealed cracks can by classified into two types: one is the comb type and another is the granular type. The latter displays rapid increase of grain size toward the center of the sealed cracks and the grain size proportional to the width of the sealed cracks as indicated by Toriumi and Hara (1995).

The growth front in the sealing the cracks is considered to be parallel to the wall surface and it faces fluid phase in the cracks. The boundary behind the growth front is characterized by wavy interface, showing the various wavelengths of periodicity. This type of unstable boundary should be formed by the instability of growth front during precipitation of constituent minerals in active open cracks. The wavelength of the unstable boundary increases with increasing grain size. The comb type sealed cracks show narrow wavelength but the granular type ones do wide wavelength. In this study, the relationship between the unstable boundary and the instability of growth front during the sealing of cracks.

Crack geometries and deformation by the crack-seal mechanism in the Sambagawa metamorphic belt, Toriumi, M and E. Hara, Tectonophysics 245, 249-261, 1995.

Keywords: unstable boundary, crack sealing, instability of growh, plate boundary metamorphism

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Fabric analyses of glaucophane and lawsonite in low-grade blueschist from Diablo Range, California

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Deformational microstructures of glaucophane and lawsonite in a lawsonite blueschist from New Idria serpentinite body, Diablo Range are studied to understand rheological behaviors of subducting oceanic crust. Glaucophane deforms by recovery and dynamic recrystallization possibly accommodated by dislocation creep, based on developments of crystal-preferred orientations (CPOs), small grain size and irregular or curved grain boundary. Euhedral or subhedral grains with angular or straight grain boundary of lawsonite suggest its deformation mechanism as rigid body rotation. Both minerals in glaucophane-rich layer (GR) show stronger CPOs, higher aspect ratios and lower angle to foliation (stronger shape-preferred orientation, SPOs) than those in lawsonite-rich area (LR), denoting that strain is mainly localized into the GR. In addition, stronger fabrics are observed in the GR rather than in the LR on the basis of fabric analyses (M=0.20, J=18.0 for glaucophane and M=0.21, J=9.6 for lawsonite in the GR, and M=0.18, J=16.0 for glaucophane and M=0.15, J=7.8 for lawsonite in the LR). All results of this study therefore indicate that rheological behaviors of subducting oceanic crust are mainly controlled by glaucophane rather than lawsonite.

Keywords: relative contrast, glaucophane, lawsonite, blueschist, subducting oceanic crust

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SMP46-P19 Room:Convention Hall Time:May 25 15:30-17:00

Origin of compositional gradient recorded in metamorphic reaction rims

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Localized occurrence of product minerals in reaction rims strongly suggests that the formation of the rim has been rate-controlled by diffusion. It has been a general consensus that the disequilibrium state during the rim formation was quenched, and that the chemical potential gradients were preserved in the rims, which was recognized as presence of compositional gradients of product minerals. This study propose alternative model to explain the compositional gradient occurring in the metamorphic coronas. In retrograde stages, migration distance (mean free path) decreases with descending temperature. The metamorphic reaction would cease when the migration distance sinks below the spatial distance between the reactant minerals. Each of reactant minerals that are chemically isolated could attain the local equilibrium. That is, the diffusion profiles maintained during the reaction would modify to homogenize after the reaction ceased. The continuous reaction produces the product minerals that change their composition progressively during descending temperature. Migration of components within crystal is much slower than that along grain boudary by a factor of 5 to 6. This suggests that compositional heterogeneity in product minerals would be likely to preserve even if local equilibrium was maintained among minerals within the migration distance.

Keywords: reaction rim, compositional gradient, fractional crystallization

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Raman spectra of carbonaceous material in low-grade thermally-metamorphosed accretionary complex

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Sedimentary rocks contain a trace amount of initially poorly ordered carbonaceous material (CM), which transforms into well-ordered graphite with increasing metamorphic grade. Previous study has demonstrated that peak metamorphic temperature (T) can be estimated by an area ratio R2 (=D1/[G+D1+D2]) of peaks recognized in Raman spectra of CM. This geothermometer can be used at temperature range of 330-650^{o}C (e.g., Bayssac et al., 2002; Aoya et al., 2010). Herein, we present Raman spectra from a suite of samples with different metermorphic temperatures which are estimated by a vitrinite reflectance method: Miocene Hota complex (50^{o}C) (Yamamoto et al., 2005), Cretaceous Shimanto complex (150^{o}C and 230^{o}C) (Mukoyoshi et al., 2006) and Jurassic Ashio complex (300^{o}C). First-order Raman spectrum of CM often decomposed into four peaks of a Raman shift (G peak at about 1580cm-1, D1 peak at about 1350cm^{-1}, D2 peak at about 1620cm^{-1}, D3 peak at about 1500cm^{-1}). In our amorphous CM (coal) samples we recognized other three peaks on the D1 peak around 1150 cm^{-1}, 1220 cm^{-1} and 1450 cm^{-1}. These peaks has been also reported in (e.g., Bar-Ziv et al., 2000; Zaida et al.,2007; Potgieter-Vermaak et al., 2011).

The first-order Raman spectrums of our coal samples, in particular low-temperature samples, are hard to fit with decomposed four peaks using the LabSpec program due to the influence of faint shoulders on D1. Therefore, there is no clear correlation between T and average R2 ratio in each sample. However, the Rama spectrums can be fit with the above seven peaks. The correlation between R2 and T can be described by the following exponential equation:

$T\ (^oC) = 8.6*\exp(7.0*R2)\ (R^2=0.98)$

In addition, when we use an area ratio of D1/[decomposed seven peaks] which is referred to as R6 in this study, the correlation between R6 and T is given by

$T\ (^oC) = 10.9*\exp(11.9*R6)\ (R^2=0.99)$

These correlations can be used for a potential geothermometer for low-grade metamorphosed sediments, in the temperature range of 50-300^{o}C.

Keywords: raman spectroscopy, vitrinite reflectance, carbonaceous material, accretionary complex, geothermometry

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Structural change of carbonaceous material inferred from Raman spectra in low- to high-temperature metamorphic rocks

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We report the structural change of carbonaceous material (CM) from the samples metamorphosed at temperatures from 165 to 655 ^{o}C based on Raman spectroscopic analysis. 10 samples were selected from contact and regional metamorphic rocks of the Kasuga, Daimonji, and Shirataki areas and 9 samples were collected from accretionary complexes of the Kitagawa, Kure, and Nobeoka areas.

The shapes of CM Raman spectra show a change from broad and complex to sharp and simple ones with increasing metamorphic temperature. The D ("Defect")-bands dominate in the low temperature range and the G ("Graphite")-band increases in importance with temperature increase. These changes can potentially be used to construct a CM Raman geothermometer. However, there is no study defining a methodology for decomposing the CM Raman spectrum that is applicable to low to high temperature samples, and it is difficult to discuss the sequence of the development of CM. In particular, there has been little discussion of how peak decomposition of CM Raman spectra in the low temperature range should be carried out. In this study, several band combinations for the Raman spectrum of CM metamorphosed at the low temperature range were tested and parameters for each band were compared.

These studies show that the Raman spectrum of CM can be divided into four groups by the metamorphic temperature range: low-grade CM (150-280 ^{o}C), medium-grade CM (280-400 ^{o}C), high-grade CM (400-650 ^{o}C), and ordered graphite ($>$ 650 ^{o}C).

Low-grade CM: The Raman spectrum of low-grade CM is best considered to consist of four D-bands (D1-, D2-, D3-, and D4-bands). The G-band is not clearly distinguishable in this temperature range. The shape of low-grade CM Raman spectra is qualitatively similar to those for amorphous carbon.

Medium-grade CM: The G-band first appears clearly in samples metamorphosed at temperatures of around $>$ 280 ^{o}C. The D4-band disappears at around 340 ^{o}C and the prominence of the D3-band gradually decreases with increasing temperature. The peak positions of G-, D1-, and D2-bands and intensity ratio with D1- and D2-bands show changes in the temperature range of medium-grade CM. This observation indicates that CM transforms from amorphous carbon to disordered graphite in this temperature range.

High-grade CM and ordered graphite: Most band parameters become almost constant in the Raman spectra of high-grade CM. These changes suggest that the transition of CM from amorphous carbon to disordered graphite is complete at around 400 ^{o}C. A lot of CM grains in the highest temperature sample metamorphosed at 655 ^{o}C show spectra with only a G-band present and no recognizable D1- or D2-bands. This result indicates that CM grain reaches fully-ordered graphite at temperatures around 650 ^{o}C.

The above results are an important first step in establishing a reliable CM Raman geothermometer in low to high temperature range covering the transition of CM.

Keywords: Carbonaceous material, Raman spectroscopy, geothermometer, amorphous carbon, graphite

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Low grade graphitization of deformation in Regional metamorphism

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Graphitization in regional metamorphism is affected by various factors; thermal, pressures, time, shear stress, precursor materials, hydrothermal and catalyst(Large, 1994; Itaya,1980). Especially, it is well known that elastic deformation in graphitization is the one of the most important factors for acceleration of graphitization(Bustin,1995).

This study aims to verify how tectonic deformation influences graphitization process in the upper sequence of Hidaka metamorphic rocks (Zone1-2). The upper sequence of Hidaka Metamorphic belt is located in East side of Hidaka Mountains, Hokkaido, Japan. These metamorphic rocks are divided into metamorphic zoning from Zone1(Ms-Chl)to Zone2(Ms-Bt) by Osanai(1987) and ten stage(D0-D9) based on the nature and sequence of deformation by Koyasu(2006MS).

Degree of graphitization in deformed rocks that record elastic deformation (D2-D7 stage) was no variation, although these rocks with brittle fracturing (D8-D9 stage) compounded to low grade graphitization with bimodal distribution in Koikakusyusatunai river route. High-grade crystalline graphite is distributed in matrix of metamorphic textures, on the other hand, low-grade crystalline graphite is distributed in vein like texture in Raman mapping.

These poorly crystalline graphite may deformed under the influence of brittle deformation process in later stage rather than in ductile deformation of peak metamorphic temperature. Moreover, these processes occurred in small crashed zones.

Bimodal distribution of graphitization in thin section scale may be common process in regional metamorphism. Relationship between deformation and graphitization will be discussed.

Keywords: Graphitization, Hidaka metamorphic belt, Micro-raman spectroscopy, XRD, HRTEM