Japan Geoscience Union Meeting 2013
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SMP43-01 Room:303 Time:May 24 09:00-09:15

Nano-granite and glass inclusions in zircon from the migmatite zone of the Aoyama area, Ryoke metamorphic belt, Japan

Tetsuo Kawakami[1*]

[1]Department of Geology and Mineralogy, Kyoto University

Glass inclusions and nano-granite inclusions in Zrn are the important evidence of Zrn growth in the presence of melt. In this contribution, we report the first finding of the nano-granite inclusions [1] in Zrn from the migmatite of the Ryoke metamorphic belt at the Aoyama area, SW Japan.

In the Aoyama area, pelitic-psammitic metamorphic rocks of the upper amphibolite to granulite facies grade are widely exposed. Pelitic-psammitic schists dominate in the northern half (Sil-Kfs zone and low-T part of the Grt-Crd zone), and migmatites dominate in the southern half (mid- to high-T part of the Grt-Crd zone) [2].

The zircon in metatexites and diatexites from the mid-T to high-T parts of the Grt-Crd zone has a thin, bright annulus under BSE image along which tiny inclusions of several microns are aligned [3]. Some of the inclusions with the similar mode of occurrence are identified to be the glass that was included during the Ryoke metamorphism. The nano-granite inclusion is newly found from the same kind of annulus.

The nano-granite inclusions are about 2 um in diameter, which is the largest size among the inclusions found in the bright annulus under a BSE image. Based on the FE-SEM observation and EDS qualitative analysis, nano-granite consists of plagioclase, biotite and other several unidentified minerals or glass ([4] uses the term 'nano-granite' even if it contains some glass portions). In the zircon grains from the same metatexite sample, in addition to the totally glass inclusions, partially solidified glass inclusions with biotite-like mineral developed at the boundary between host zircon and glass are found. The fact that nano-granite and glass inclusions are found from the zircon rim developed at 90.3 +/- 2.2 Ma in metatexite [3] shows that partial melting took place during the Ryoke metamorphism. Composition of partial melts formed during the dehydration melting of micas is being determined using these glass inclusions [5]. It is difficult to quantitatively analyze the melt inclusions in zircon from the Aoyama area because they are too small in size as in the case of other areas [5]. However, the CIPW normative composition (Qtz-Ab-Or) of leucosomes segregated in the boudin necks that is found near the migmatite front of the Aoyama area [6] are plotted in between the compositions of melt inclusions from El Hoyazo and Kerala Khondalite Belt on the cotectic line between primary phase fields of Or and Qtz for P(H2O) = 0.5 GPa. This supports the idea that the leucosome in boudin necks are possible partial melts formed during the prograde metamorphism during Ryoke metamorphism [6].

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Keywords: zircon, nano-granite, migmatite, partial melting, glass inclusion

SMP43-02 Room:303 Time:May 24 09:15-09:30

Behavior of REE-rich minerals during Cl-rich fluid activity under granulite facies metamorphism

Fumiko Higashino[1*], Tetsuo Kawakami[1], Satish-Kumar Madhusoodhan[2], Masahiro Ishikawa[3], Noriyoshi Tsuchiya[4], Geoff Grantham[5]

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

The importance of understanding the role of Cl-rich fluid in the crust is gradually recognized since metamorphic fluid in the granulite facies rocks has been long considered as CO_2-rich in most cases, and the *P-T-t* condition and the scale of its activity are still not clear. Cl-rich fluid and CO_2-rich fluid are possible candidates of low a_{H2O} fluids. Presence of such fluids shifts the wet solidus to the high-T side, and dehydration reactions to low-T (Newton et al., 1998). Cl-rich fluid can coexist with CO_2-rich fluid under high-T condition and is a powerful solvent (Heinrich et al., 2004; Newton and Manning, 2010). In order to understand the fluid-related geological process in the middle- to lower-crust of the continental collision zone, the *P-T-t* condition of Cl-rich fluid activity and the behaviour of REE-rich minerals during Cl-rich fluid infiltration are studied in detail at the Sor Rondane Mountains, East Antarctica where Late Proterozoic to Cambrian granulites are widely exposed.

Among 33 felsic gneiss samples, a Grt-Bt-Sil gneiss from Balchenfjella was selected, since it was best suited sample to constrain the *P-T-t* conditions of Cl-rich fluid activity. This gneiss contains Grt porphyroblasts that have a P-rich core with oscillatory zoning in P. The Grt core includes Cl-poor Bt and fluorapatite. The core of the Grt has been partially resorbed and discontinuously overgrown by a P-poor rim, in which Cl-rich Bt and chlorapatite are included. Coarse-grained, rounded Zrn grains are exclusively included in the rim of the Grt porphyroblast and are also present in the matrix. This mode of occurrence suggests that the Cl-rich Bt and chlorapatite, together with coarse-grained Zrn were formed almost simultaneously. The *P-T* condition of Cl-rich Bt entrapment in the Grt rim is estimated to be ca. 800 ^oC and 0.8 GPa. In comparison, peak metamorphic condition is estimated to be ca. 850 ^oC and 1.1 GPa. These pieces of observation suggest that Cl-rich fluid or melt infiltrated at the core-rim boundary of Grt. In the case of fluid infiltration, the f_{HCl}/f_{H2O} ratio of the fluid in equilibrium with Cl-rich Bt and chlorapatite in the Grt rim are estimated to be ten times larger than that in equilibrium with Cl-poor Bt and fluorapatite in the matrix and the Grt core, because Cl concentration of the melt cannot be high enough to make Bt and apatite as Cl-rich as observed in this study (Higashino et al., 2012).

In this sample, there is a tendency that Mnz is included in the Grt core, and Zrn and Xtm are included in the Grt rim. This implies that Cl-rich fluid carried LREE away and brought HREE and Zr in, and that Zrn included in the Grt rim formed simultaneously with the Cl-rich fluid infiltration. The LA-ICP-MS U-Pb dating of the coarse-grained Zrn included in the Grt rim gave concordia age of 603 +/- 14 Ma. Therefore, Cl-rich fluid infiltrated under the near-metamorphic peak condition of ca. 800 ^oC and 0.8 GPa during the continental collision process. On the other hand, the rim of Zrn present in the matrix gave concordia age of 564 +/- 17 Ma. The field distribution of Cl-rich fluid activity is somewhat linear, located near the large scale ductile shear zones in the Sor Rondane Mountains. Regional distribution of high-grade Cl-rich fluid or melt activity in the Sor Rondane Mountains implies that it is one of the major phenomena in the continental collision processes. The *P-T-t* condition of Cl-rich fluid activity could be successfully determined because we successfully distinguished the Zrn grains formed by the Cl-rich fluid activity from the detailed microstructural study. Therefore, in addition to understanding the Cl-rich fluid activity itself, understanding the formation mechanism of datable accessory minerals is also important to correctly interpret the meaning of the age obtained.

Keywords: chlorine, fluid infiltration, granulite facies, Sor Rondane Mountains, REE

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SMP43-03 Room:303 Time:May 24 09:30-09:45

Thermal anomaly map in low P/T type metamorphic belt -Case study of the Ryoke metamorphic belt in the eastern Yamaguchi

Yu Sugawara[1*], IKEDA, Takeshi[1]

[1]Kyushu University

Low P/T type metamorphic belts show that the slope of their field P-T curves is higher (60-150^{0}C/km) than any steady-state geothermal gradients of continental crust (De yoreo et al., 1991). This suggests that excess heat was supplied by any transport proses to form the low P/T type metamorphic belts. The traditionally proposed process is heat conduction from granitic melts (Hunson and Barton, 1989). Recently, Miyazaki (2007) proposed pervasive melt migration as a heat transport proses. In contrast, Hoisch (1987) proposed hot fluid as source of high geothermal gradient in the crust.

A thermal anomaly map would help evaluate the validity these models. In this study, we provide thermal anomaly map of low P/T type metamorphic belt by using petrological method in the Ryoke metamorphic belt in the eastern Yamaguchi Prefecture.

[Method 1]

We estimated pressure-temperature conditions of one sample from K-feldspar-cordierite zone, seven samples from the sillimanite-K-feldspar zone and four samples from the garnet-cordierite zone by using the garnet-biotite thermometer of Hodges and Spear (1982) and the relative geothermobarometry of Ikeda (2004). Addition of result of Ikeda (2004) enables us to reveal the thermobaric structure of this area. Isotherms are oblique to isobaric lines, suggesting that the crust has thermally heterogeneous at the same depth. We constructed thermal anomaly map that shows difference between metamorphic temperature and steady-state temperature at the depth (dT).

[Result 1]

We divide the study area into two domains where T is larger than 500^{0}C and smaller than 500^{0}C. The former domain contains garnet-cordierite zone, low temperature and pressure part of sillimanite-K-feldspar zone and K-feldspar-cordierite zone.

[Method 2]

We measured areal fraction of the Older Ryoke Granite (ORG) based on the geological map of Nishimura, et al., (1995).

[Result 2]

The areal fraction of ORG is larger in the domain of dT $<$500^{0}C than that of dT $>$500^{0}C. The domain of T $>$500^{0}C elongates subparallel to the gneissosity.

[Discussion]

The areal fraction of ORG being larger in domain of dT$>$500^{0}C suggesting that ORG could not be a heat source of Ryoke metamorphism. We proposed three alternative models.

1: Infiltration of high temperature H2O fluid that is not controlled regionally by the distribution of ORG (Hoisch, 1987).

2: Advection of the small amount of melt has slow flow velocity or long duration (Miyazaki, 2007).

3: Spatially dense injection of thin granitic melts.

The gneissosity subparallel to the long axis of the domain of dT $>$500^{0}C may support the model3.

Keywords: metamorphic rock, Low P/T metamorphic belt, Ryoke belt, Thermobaric structure, Thermal anomaly map

SMP43-04 Room:303 Time:May 24 09:45-10:00

Structure and growth of the lower crust beneath SW Japan: constraints from xenoliths in Cenozoic alkaline basalts

Eri Igata[1*], Iwamori Hikaru[1]

[1]Department of Earth and Planetary Sciences, Tokyo Institute of Technology

Felsic continental crust is thought to be unique to the Earth and is important to constrain material circulation of the crust-mantle system throughout its history. The continental crust is estimated to be chemically stratified; the upper crust is considered to be felsic and the lower crust to be mafic. The crustal materials may interact with the mantle via subduction of crustal materials and/or delamination of the lower crustal rocks. However, lack of a direct evidence of such processes, in particular the latter for the lower crust, prevents us from understanding evolution of the crust-mantle system even in a qualitative sense. The purpose of this study is to constrain a timing of formation and growth mechanism of the lower crust, which will provide fundamental information to discuss evolution of the continental crust and the mantle.

Subduction zones are thought to be a site of continental growth and differentiation. We have conducted detailed analyses of various types of xenoliths in alkali basalt from the Gongen volcano in the Kibi plateau, SW Japan. As we particularly concern the formation and growth timing of it, zircon U-Pb age dating has been conducted, as well as petrology of the xenoliths.

We have collected total 40 xenoliths and observed them using optical microscope and electron probe micro analysis (EPMA). The xenoliths consist of various rock types; peridotite, gabbro, pyroxenite, anorthosite and quartzite. Based on the petrological analysis including EPMA and phase relation study, gabbro, anorthosite and quartzite are likely to have derived from the lower crust. Among the xenoliths, pyroxenite may represent a dense igneous cumulative materials located around the Moho beneath the area. Temperature of the pyroxene cumulate is estimated to be 810 degree C based on olivine-spinel geothermometry [Fabries, 1979]. Anorthosite, in which corundum is observed, exhibits Al-rich bulk compositions. Kyanite and garnet are observed in quartzite xenoliths. The kyanite-bearing quartzite xenoliths, which is estimated to have been formed in granulite facies, exhibits silica-rich and CaO-poor bulk compositions, indicating that sedimentary materials are incorporated into the lower crust of the SW Japan.

To constrain the formation age and the underplating process of sedimentary rocks, we have measured U-Pb ages of zircon crystals in the lower crustal xenoliths. Based on the zircon U-Pb age and petrological analyses, structure and growth process of the lower crust beneath SW Japan is discussed.

Keywords: lower crust, xenolith, south west Japan, zircon U-Pb age

SMP43-05 Room:303 Time:May 24 10:00-10:15

Development of olivine crystal-fabrics in the southern Marian forearc mantle wedge: insights from S. Chamorro Seamount.

Yosuke Kondo[1*], Katsuyoshi Michibayashi[1], FUJII, Ayano[1], Teruaki Ishii[2], FRYER, Patricia[3]

[1]Shizuoka University, [2]Fukada Geological Institute, [3]University of Hawaii

Large serpentinite mud volcanoes form on the overriding plate of the Mariana subduction zone, which extends for approximately 2,500 km in the N-S direction parallel to the Mariana Trench axis. Fluids from the descending plate serpentinize the forearc mantle and enable serpentine muds to rise along faults to the seafloor (Fryer, 2012 Ann. Rev. Marine. Sci.). The seamounts are direct windows into subduction processes at depths far too deep to be accessed by any known technology (Fryer, 2012 Ann. Rev. Marine. Sci.). In this study, we focused on serpentinized peridotites obtained from South Chamorro Seamount in order to understand the forearc mantle wedge structure of southern Mariana forearc. The South Chamorro Seamount is located at 100 km east of Guam island and 85 km west of the Mariana Trench axis. The peridotite samples consist mainly of harzburgites with a few dunite samples. We analyzed olivine crystallographic fabrics and chemical compositions of olivine and spinel grains. As a result, two types of olivine crystal fabrics were obtained: [010]-fiber type (or AG-type) and [100]{0kl} type (or D-type). The chemical compositions show that Cr# (Cr3+/Al3++Cr3+) of spinel is 0.4 to 0.8 and Mg# (Mg2+/Mg2++Fe2+) of olivine is 89 to 92, which are in the range of Olivine-Spinel Mantle Array (OSMA) of Arai (1994 Chem. Geol.). However, no other seamounts have been found to have as wide a range of Cr# in spinel composition as those of South Chamorro Seamount. The equilibrium temperatures induced by olivine and spinel compositions are 700 C for the [100]{0kl} type peridotites and 800 to 850 C for the [010]-fiber type peridotites. Since [010]-fiber olivine fabrics could be developed under melt-bearing high-temperature conditions, such as in the subsolidus regime (e.g., Kohlstedt & Holtzman, 2009 Ann. Rev. Earth Planet.), it is unlikely that they have been developed in the forearc region. Alternatively, the [010]-fiber type peridotites may be derived from the older lithospheric mantle before the formation of the Mariana arc system, whereas the {100}{0kl} type could be related to supra-subduction tectonics or the development of serpentine mud volcanoes.

Keywords: peridtite, serpentinite, crystal fabric, [010]-fiber type, [100]{0kl} type, subduction

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SMP43-06 Room:303 Time:May 24 10:15-10:30

Development of an ultramylonite zone within the mafic rocks in the Moho Transition Zone, Oman Ophiolite

keisuke furuhata[1*], Katsuyoshi Michibayashi[1]

[1]Department of Geosciences, Shizuoka University

The purpose of this study is to reveal the process of structural development of a ductile shear zone across the crust-mantle boundary in Oman ophiolite. The ductile shear zone has been developed within the mafic rocks in the Moho Transition Zone, Fizh massif. Ultramylonites are widely distributed, whereas mylonitie does not occur in the shear zone. Weakly and moderately deformed rocks observed in the outside of the ductile shear zone have igneous equigranular textures and partly contain domains of dynamically recrystallized fine grains consisting of plagioclase and minor amphibole. The mean grain sizes of fine-grained plagioclase matrix within ultramylonites are 5-6 microns which are nearly steady state. Plagioclase crystal-preferred orientations (CPO) show (010) [100] pattern and (001) [100] pattern in the weakly and moderately deformed rocks, respectively, and random in the ultramylonites. The change of the CPO patterns suggests a transition from dislocation creep to grain-size-sensitive creep. The modal composition of amphibole is higher in each ultramylonite than those in weakly and moderately deformed rocks. Combined with the whole rock chemical compositions, it suggested that the shear zone has been infiltrated by water, by which element mobilization could occur. As the grain sizes of plagioclase decreased along with the amphibole formation, intense strain localization in the shear zone could take place accommodated with strain softening.

Keywords: ultramylonite, gabbro, mafic rock, shear zone

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SMP43-07 Room:303 Time:May 24 10:30-10:45

Microstructural development of coarse granular peridotite derived from Kaapvaal cratonic lithosphere, South Africa

Masashi Kino[1], Katsuyoshi Michibayashi[1*], Ikuo Katayama[2], Tsuyoshi Komiya[3], Kazutaka Mannen[4], Hiroyuki Kagi[5], Atsushi Okamoto[6]

[1]Department of Earth Sciences, Shizuoka University, [2]Department of Earth and Planetary Systems Science, Hiroshima University, [3]Department of Earth Science & Astronomy, University of Tokyo, [4]Hot Springs Research Institute of Kanagawa Prefecture, [5]Geochemical Research Center, Graduate School of Science, The University of Tokyo, [6]Graduate School of Environmental Studies, Tohoku University

Kimberlite was generated in deep upper mantle (70-250km) beneath craton and subsequently ascended to surface rapidly. Peridotite xenoliths, which were entrained by kimberlite, record composition and texture formed in upper mantle beneath the craton. Peridotite xenoliths from Kimberley pipe, Southern Africa, are divided into two groups: granular type and foliated type. The granular type peridotite has difficulty in identifying any foliation, whereas the foliated type shows distinct foliations. The granular type peridotite has a few studies in terms of microstructural development, presumably because of very coarse grain. In this study, five large samples have been selected among thirty-five samples and several thin sections for three orthogonal planes in each sample have been made after lineation and foliation were identified visually. We performed microstructural analyses and measured major mineral compositions and water contents in minerals in order to reveal microstructural and petrological characteristics of peridotite xenoliths in kimberlite and to interpret cratonic lithosphere. All five samples are garnet harzburgites. They were divided into two groups: Group1 includes two samples containing no clinopyroxene and Group2 includes three samples containing minor amounts of clinopyroxene. The crystallization of clinopyroxene appears to be associated with metasomatism. Rounded garnets were observed in Group1 peridotites, whereas elongated garnets occur in Group2 peridotites. Olivine and orthopyroxene Mg# in Group2 are lower than those in Group1 peridotite. Olivine and orthopyroxene have different compositions between Group1 and Group2 peridotites. Equilibrium temperature and pressure are similar (1000 degree C, 40kbar) among all five samples regardless of the group. With respect to CPO analyses, Group1 olivine fabrics were characterized by a point maximum of [010] and girdle distribution of [100] and [001]. Orthopyroxene fabrics were characterized by a point maximum of [001] and girdle distribution of [100] and [001]. Group2 olivine and orthopyroxene fabrics did not show any dominant concentration. Water contents in garnet are different between two types. Rounded garnet in Group1 had relatively low water contents (10ppm), whereas elongate garnet in Group2 presents high water contents (50ppm). Although both Group1 and Group2 peridotites have similar equilibrated P-T conditions, they showed different mineral compositions of olivine and orthopyroxene. It appears that Group2 peridotite has been affected by metasomatism process. The change of mineral compositions from Group1 to Group2 is attributed to melt infiltration, possibly resulting in different fabrics of olivine and orthopyroxene. With respect to garnet shapes, rounded garnet in Group1 might be facilitated to strain and be transformed elongate garnet in Group2 by water added with melt during metasomatic event. It is generally considered that granular type peridotite represents the steady state mantle process in the cratonic lithosphere. However, this study suggested that granular type peridotites show a variation, resulting from melt infiltration in the cratonic mantle.

Keywords: Kaapvaal craton, Kimberlite xenolith, olivine fabrics, metasomatism, seismic anisotropy

SMP43-08 Room:303 Time:May 24 11:00-11:15

Thermal alteration of the R1 parameter of carbonaceous matters

Masami Murata[1*], Kenichi Hoshino[2]

[1]Grad. School., Kanazawa Univ., [2]Grad. Sch. Sci., Hiroshima Univ.

Burnham and Sweeney (1989) concluded that the vitrinite (VTN) maturation during heating could be treated most simply by considering the following four independent parallel reactions: VTN -> VTN + H_2O, VTN -> VTN + CO_2, VTN -> VTN + CHn and VTN -> VTN + CH_4. Huang (1996) proposed the empirical power law rate model for the evolutions of VTN reflectance controlled more by temperature than time based on his heating experiments of lignite.

The thermal maturity of carbonaceous matters (CMs) may also be represented by the R1 ratio (measured commonly as D/G peak intensity ratio) of the Raman spectra. Muirhead et al. (2012) estimated the kinetic rate of the thermal maturity of CMs indicated by the R1 ratio as $R1 = B + 0.441557 * \exp(-402/T) * t\hat{}(6.04E-5*T+0.011304)$, where t is the duration of heating in seconds, T is the temperature in Kelvin and B the initial ratio of R1 (=0.23 in his study), from his flash pyrolysis experiments of CMs for 5 to 80 seconds heating. However, the CMs taken in his experiments were collected from Murchison meteorite and show quite different Raman spectra from those of CMs in non-metamorphosed pelitic rocks. Also, it should be noted that his R1 ratios may be D/G peak area ratios.

Therefore, we have made heating experiments of CMs in pelitic rocks collected from the Kanoashi Group of Jurassic complex, SW Japan and measured the R1 (D/G peak intensity) ratios before and after the experiments. Reflectances of the CMs indicate their diagenetic temperatures as around 284C. The initial R1 ratios before heating are about 0.5.

Polished rock chips were kept in an Ar purged capsule, and then taken into an electric oven. Unfortunately, the oven is not available for quick heating, it took, for example, 14 minutes to achieve 800C. The experiments have been done under 290, 500 and 800C with different durations. Note that the both 500 and 800C experiments, the same rock chips were used, that is, repeatedly heated, to follow the evolution of the R1 ratios of the individual CMs.

Small peaks between the D and G bands of the Raman spectra appeared in some CMs after short heating (< 10 minutes at 500C and (1) of 800C). However, they disappeared after longer and higher heating experiments. Other two types of the thermal evolution of the R1 ratios could be observed during 500C experiments. The one is that the R1 ratios systematically increased with increasing heating durations (i.e., repeating times), while the other is that the ratios increased after a short time heating and then decreased to the initial ratios and again increased by further heating. On the other hand, the R1 ratios after 800C heating experiments show two types of their evolutions. The one is that the ratios did not exceed 1.5 after heating, while the other did. The latter showed various R1 ratios irrespective of heating durations. Those characteristics of the thermal evolution of the R1 ratio may depend on the difference of the precursors of CMs.

Therefore, it can be concluded that the large grained CMs of which R1 ratios do not exceed 1.5 should be taken to estimate a kinetic rate for the thermal maturation of CMs. The power term on time of a preliminarily estimated kinetic rate of the thermal evolution of the R1 ratios estimated by the present experiments is one order of magnitude higher than that of Muirhead et al. (2012), implying that the rate depends not only on temperature and time but also on the initial R1 ratio. Also, it should be investigated in a future study that there may be maximum value(s) of the R1 ratios as shown by Beyssac et al. (2002), which in turn may also affect the kinetic rate.

Keywords: carbonaceous matters, R1 ratio, Raman

SMP43-09 Room:303 Time:May 24 11:15-11:30

Trace-element analyses of clinopyroxene megacryst in garnet lherzolites from the Bohemian Massif

Kosuke Naemura[1*], Takao Hirajima[2], Kenshi Maki[2], Kazuhito Ozawa[1], Takeshi Hirata[2]

[1]Department of Earth and Planetary Science, The University of Tokyo, [2]Department of Geology and Mineralogy,Faculty of sciences, Kyoto University

High-pressure and ultrahigh-pressure metamorphic rocks in the continetal collision zone contain a number of garnet-bearing ultramafic rocks within the metamorphic rocks of upper crustal compositions. Two different hypotheses has been proposed to incorporate the peridotites in the crustal metamorphic rocks: (1)a high-temperature mantle wedge peridotite was dropped into the subducting crust, and (2)the dry mantle peridotite was entrained in the low-P-T crustal rocks and was transformed to serpentinite/chlorite peridotites that are transformed into garnet peridotite by the subsequent subduction.

To reconcile this controversy, we study garnet peridotites from the two localities in the Bohemian massif (Variscan orogeny), Lom pod Libidem (LPL) and Plesovice quarry (PQ). In both localities, garnet peridotites are enclosed in the high-pressure acidic granulite. The previous researches demonstrated that these garnet peridotite have equilibrated at 1020 C/2.5 GPa and 940 C/2.9 GPa during the UHP metamorphism. The subsequent exhumation partially transformed garnet peridotite into spinel peridotite at 770C/1.5 GPa.

We find clinopyroxene megacrysts, with size up to 3 cm, surrounded by the fine-grained matrix of garnet peridotite assemblages which are variably retrogressed to spinel peridotite ones. The clinopyroxene megacryst contains numerous amphibole inclusion (bleb/lamella) along with phlogopite, olivine, orthopyroxene, apatite,ferrit chromite, and rare huttonite.

The 3 cm-size clinopyroxene from the LPL locality are strongly zoned. Chemical mapping demonstrated it consists of three zones: (1)the core poor in Al_2O_3 (~1.0 wt. %) and Na_2O (0.8 wt. %), (2)the mantle contains highern Al_2O_3 (~2.0 wt. %) and Na_2O (1.2 wt.%) and (3) the rim with higher Al_2O_3 (~3.0 wt. %) and lower Na_2O (0.8 wt.%). The CaO content slightly decreases from the core to the mantle (from 22.0 to 20.5). The trace element analyses of clinopyroxene showed positive anomalies of Pb, Sr, LREE and negative HFSE anamalies, suggesting an involvement of fluid. Rare earth element concentration is very low in the core with moderate LREE/HREE slop with $(Yb/Gd)_N$=9+-5 normalized by CI chondrite. Such an Al-Na-REE poor clinopyroxene are typically observed in the chlorite-bearing peridotite. The mantle REE pattern have a steeper slope of LREE/HREE with $(Yb/Gd)_N$=17+-4 suggesting a coexistence with garnet. The REE contents at the rim become higher in concentration with a slope of $(Yb/Gd)_N$=7+-2, reflecting a re-equilibration in the spinel-lherzolite facies.

The clinopyroxene megacryst at the PQ locality show a similar zoning with the core and the rim. (1)The core is poor in Al_2O_3, Cr_2O_3 and Na_2O (2.0, 0.5 and 1.2 wt.% respectively), and (2)the rim is rich in them (3.6, 0.8 and 1.9 wt.% respectively). The CaO content decreases from the core toward the rim (from 22 to 20 wt. %).The trace element analyses for the megacryst rim showed enrichment in Pb, Sr. LREE and depletion in HFSE. The rim contain high concentration of REE with a steep LREE/HREE {$(Yb/Gd)_N$~20+-6}, suggesting a coexistence with garnet. The coexistence of clinopyroxene rim with garnet suggest a week retrogression that is consistent with the week kelyphitization of garnet.

Based on the above information, we propose a following thermal history for the Bohemian garnet peridotites. Both the LPL and PQ peridotites were stable at chlorite-stability field at the initial thermal history. The alumina-poor composition in clinopyroxene suggests the rocks were originally chlorite-bearing peridotites at $T<700C$ (or very low-T spinel peridotite), and the increse of Al, Na and the decrease of Ca toward the rim suggests a heating during the subduction history, which finally transformed chlorite peridotite into garnet peridotites. Both peridotite were partially transformed to spinel peridotite, but the retrogression is more severe in LPL peridotite while PQ peridotite preserve the garnet-peridotite even at the rim of clinopyroxene.

Keywords: orogenic peridotite, continental collision, Bohemian massif, subduction, clinopyroxene megacryst

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SMP43-10 Room:303 Time:May 24 11:30-11:45

Evolution of Archean high-pressure granulites from the Namakkal Block,southern India

George Paul Mathews[1*], TETSUMARU, Itaya[2], KENJI, Horie[3], TOMOKAZU, Hokada[3], SATISH-KUMAR, Madhusoodhan[4], KRISHNAN, Sajeev[1]

[1]Centre for Earth Sciences,Indian Institute of Science,Bangalore,India, [2]Research Institute of Natural Sciences,Okayama University of Sciences,Okayama,Japan, [3]Geoscience Group, National Institute of Polar Research,Tachikawa,Tokyo,Japan, [4]Department of Geology,Faculty of Science,Niigata University,Niigata,Japan

The Namakkal Block of Southern Granulite Terrain is bounded by Salem- Attur Shear Zone to its North and Cauvery Shear Zone to its South. Major litho-units are meta-gabbro, charnockites, granites, hornblende-gneiss, pyroxene granulites, ultramafics and iron formations. Here we describe the high-pressure granulites /retrogressed eclogites (meta-gabbro) from three key localities which are found along the verge of shear zones.

The meta-gabbros exposed in the Devannur-Mahadevi area are located in the southern part of Namakkal Block.They are associated mainly with iron formations, two-pyroxene granulites and websterites. Mg-rich garnet porphyroblasts coexist with the magnesium rich clinopyroxenes porphyroblasts, changing partially to amphiboles and plagioclase along the grain boundaries and fractures. Garnet contains clinopyroxene and quartz inclusions. On the other hand, garnet inclusions in clinopyroxene are not observed. Both garnet and clinopyroxene have exsolution lamellae of rutile or Ilmenite, which formed during retrogression and exhumation. Rutile is also present in the matrix assemblage. It is noted that orthopyroxene is totally absent. The pressure and temperature condition of the peak mineral assemblage (Grt+Cpx+Qtz) are about21 kbars 900oC, respectively that are determined through isochemical phase diagram.

Retrogressed eclogites/high-pressure granulites are also reported from the Sittampundi area located in the southwest of Namakkal Block, where the opx free meta-gabbroic rocks are associated amphibolites and layered anorthosite. Sajeev et al. (2009) found relict omphacite inclusions in garnet porphyroblasts and described the eclogite facies conditions (about 25 kbar and 1020oC). Amphibole and plagioclase are the retrograde phases in these samples. The U-Pb zircon age from the high-pressure granulites gives 2490 Ma (Sajeev et al., unpublished). The high-pressure granulites are also found in several places towards the North of Namakkal Block. The most notable occurrence is at Kanjamalai near Salem town. The U-Pb zircon ages from the associated rocks also yield 2490 Ma (Anderson et al., 2012, George et al., unpublished). These rocks with geological and textural similarity in the southern localities contain orthopyroxene. Moreover, these samples also have significant variation in the mineral chemistry with high iron content. The pressure and temperature of meta-gabbros are estimated to be about 19Kbar and 800oC, respectively.

Thus, the mineral chemistry and geochronological studies of the high-pressure granulites in a traverse from North to South suggest that the Namakkal block had undergone late Archean metamorphism. Hence, the region possibly represents various levels of a subducted basaltic oceanic crust, with the lower crust to the South and the middlecrust to the North. A comprehensive geochemical study, including Rb-Sr and Sm-Nd isotopes as well as zircon SHRIMP age dating are underway, which will be significant in discussing the geotectonic architecture of Namakkal Block of Southern Granulite Terrain in late Archean.

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Keywords: High-pressure granulite, Namakkal Block, Subduction zone metamorphism, Late Archean, Oceanic crust

SMP43-11 Room:303 Time:May 24 11:45-12:00

Metamorphic age of the eclogites from the Lake Zone, SW Mongolia

Otgonkhuu Javkhlan[1*], Akira Takasu[1], Md Fazle Kabir[1], Dash Batulzii[2], Yondon Majigsuren[2]

[1]Shimane University, Japan, [2]Mongolian University of Science and Technology, Mongolia

The Alag Khadny metamorphic complex in the Lake Zone, SW Mongolia, which is located in the central part of the Central Asian Orogenic Belt, consists mainly of orthogneisses and minor micaschists interleaving marbles including lenses of garnet-chloritoid schists of the Maykhan Tsakhir Formation. Eclogites occur as lenses and boudins in the matrix of orthogneisses and minor micaschists. The peak metamorphic conditions for the eclogites were estimated to be high *P/T* conditions of T=590-610^{o}C and P=20-22.5 kbar (Stipska *et al*., 2010), in contrast the pressure conditions of the garnet-chloritoid schists (P=10-11 kbar) are distinctly lower than those of the eclogites, whereas temperature conditions (T=575-585^{o}C) are similar (Otgonkhuu *et al*., 2012).

We discovered the amphibole-rich veins (up to 5 mm in width) are developed in the eclogite bodies. Two types of amphibole-rich veins are distinguished based on the mineral assemblage, i.e. amphibole-sodic plagioclase-phengite (Amp-NaPl-Ph) vein and amphibole-quartz (Amp-Qz) vein. Amp-NaPl-Ph vein consists mainly of amphibole (barroisite), sodic plagioclase, phengite with minor amounts of titanite and quartz. Amp-Qz vein consists of quartz and amphibole (tremolite).

Amphiboles in the Amp-NaPl-Ph vein occur as subhedral prismatic crystals and they are up to 0.5 mm long. They show compositional zoning from barroisite (Si=6.97-7.20 pfu, Na_B=0.52-0.68 pfu, K_2O=0.37-0.46) cores to Mg-hornblende and/or edenite (Si=6.56-7.41 pfu, Na_B=0.22-0.48 pfu, K_2O=0.18-0.74) rims with rarely actinolite (Si=7.50-7.57 pfu, Na_B=0.07-0.35 pfu, K_2O=0.10-0.26) outer-most rims. Whereas the amphiboles in the Amp-Qz vein occur as subhedral prismatic crystals, up to 3 mm long in the matrix of quartz. They show compositional zoning from tremolite (Si=7.58-7.62 pfu, Na_B=0.31-0.42 pfu, K_2O=0.09-0.14) cores to Mg-hornblende rims (Si=7.27-7.49 pfu, Na_B=0.17-0.44 pfu, K_2O=0.04-0.19) with rare actinolite (Si=7.50-7.67 pfu, Na_B=0.09-0.42 pfu, K_2O=0.06-0.16) outer-most rims. Sodic plagioclases (An=1-14) in the Amp-NaPl-Ph vein are of anhedral grain, intercalated with amphiboles and phengites. Phengites (Si=6.64-6.92) in the Amp-NaPl-Ph vein occur as subhedral crystal, up to 0.5 mm across.

The geothermometer of amphibole-plagioclase (Holland and Blundy, 1994) and the geobarometer of Si content of phengite (Massonne and Schereyer, 1987) have been applied for the approximate *P-T* conditions of Amp-NaPl-Ph vein developed in the eclogites. The cores of barroisite and intercalated plagioclase with highest anorthite component (An=14) suggest temperature conditions of 540-580^{o}C. Si contents of phengite (6.64-6.92 pfu) suggest pressure conditions of $>$10 kbar.

We obtained K-Ar ages of the Amp-NaPl-Ph vein [603 +/-15 Ma (amphibole) and 612 +/-15 Ma (phengite)] and Amp-Qz vein [602 +/-15 Ma (amphibole)], and we interpret the ages of c. 600 Ma as exhumation age of the eclogite bodies. The obtained ages of the eclogites are distinctly older than $^{40}Ar/^{39}Ar$ phengite ages of c. 540 Ma from the eclogites and garnet-chloritoid schists (Stipska *et al*., 2010), which are located about 2 km east from the present localities of the veins. These suggest that the eclogites were once exhumed at c. 600 Ma from the high-P conditions and juxtaposed with the garnet-chloritoid schists, and the amalgamated sequence of metamorphic rocks was then exhumed together to shallower crustal levels at c. 540 Ma.

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Keywords: K-Ar age, Amphibole-rich veins, Eclogite, Lake Zone, Mongolia

Japan Geoscience Union Meeting 2013
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SMP43-12 Room:303 Time:May 24 14:15-14:30

Jadeite-bearing garnet glaucophane schists from the Sambagawa metamorphic belt in the Bizan area, eastern Shikoku, Japan

Md Fazle Kabir[1*], Akira Takasu[1], Mayuko Nakamura[1], Yuki Kondo[1], Masaaki Kainuma[1]

[1]Department of Geoscience, Shimane University, Japan

Discovery of jadeite-bearing garnet glaucophane schists from the Bizan area offers a new locality of eclogite facies metamorphic rocks and extension of the distribution of eclogites to the easternmost part of the Shikoku Island. The Bizan area of the Sambagawa metamorphic belt is located in the Tokushima Prefecture of eastern Shikoku, Japan and it is mainly composed of pelitic schists, basic schists and siliceous schists with minor garnet glaucophane schists. Faure (1983) suggested that a melange zone containing tectonic blocks of serpentinite, metagabbro and garnet-amphibolite (garnet-glaucophane schist) occurs within a ductile shear zone between spotted and non-spotted schist zones. Jadeite-bearing garnet glaucophane schists are newly found in the melange zone.

Jadeite-bearing garnet glaucophane schists consist mainly of garnet, jadeite, amphibole (glaucophane and barroisite), epidote, phengite, paragonite, chlorite, albite, rutile, titanite, calcite and quartz. The porphyroblastic garnets are almandine-rich composition and display prograde growth zoning with decreasing X_{Sps} (0.23-0.02), increasing X_{Alm} (0.47-0.66) and slightly increasing X_{Prp} (0.01-0.03) from core to rim. The cores of the garnets contain inclusions of barroisite, epidote, muscovite (Si 6.04-6.15 pfu), chlorite, calcite, titanite and quartz and polyphase inclusions of barroisite +/- epidote +/- chlorite + titanite + quartz assemblage. The rims of garnet contain inclusions of glaucophane, epidote, phengite (Si 6.49-6.73 pfu), paragonite, chlorite, rutile and quartz and polyphase inclusions of jadeite +/- glaucophane +/- epidote + chlorite + titanite + quartz. Impure jadeite inclusions are present throughout garnet grain (X_{Jd} 0.49-0.75, X_{Aeg} 0.19-0.47). Glaucophanes in the matrix contain inclusions of phengite, epidote, chlorite, titanite and quartz and they are partly replaced by barroisite. Phengites (Si 6.61-6.67 pfu) in the matrix contain inclusions of glaucophane, epidote and chlorite. Some large grains of epidotes and chlorites contain inclusions of matrix minerals such as glaucophane, phengite, epidote, titanite and quartz.

The metamorphism of the garnet glaucophane schists is divided into three events based on petrography and chemistry of constituent minerals, i.e. (i) precursor metamorphic event (muscovite inclusions in the garnet cores), (ii) first high-pressure metamorphic event of eclogite facies, and (iii) second high-pressure metamorphic event (large epidote and chlorite in the matrix).

Chloritoid-bearing garnet glaucophane schists lack of jadeite represent multy-stage metamorphic evolution (Kabir *et al*., 2012; Takasu *et al*., 2012; Kabir *et al*., 2013). *P-T* conditions of prograde stage are estimated as 450-500^{o}C and 9-11 kbar (epidote-blueschist facies metamorphic conditions) using inclusion mineral assemblage in garnet core. The peak metamorphic conditions of eclogite facies (550-600^{o}C and 17-19 kbar) are obtained from inclusions minerals in the rims of the porphyroblastic garnets and schistosity-forming matrix minerals. *P-T* pseudosection in the MnNCKFMASH model system and garnet compositional isopleths also consistent with the obtained prograde and the peak metamorphic conditions. Prograde and peak metamorphic conditions of the garnet glaucophane schists are similar to those of newly found lawsonite eclogites in the Kotsu area, eastern Shikoku (Tsuchiya and Hirajima, 2012), probably suggesting both of them have similar metamorphic evolution. Large grains of epidotes and chloretes in the matrix, which contain minerals of the peak metamorphic stage suggest another high-pressure prograde metamorphism occurred and the metamorphism is correlated with the Sambagawa metamorphism in the Besshi area, central Shikoku (Aoya, 2001; Kabir and Takasu, 2010a, b). Both jadeite-bearing and chloritoid-bearing garnet glaucophane schists are considered to experience similar high-pressure metamorphic history.

Keywords: Sambagawa metamorphic belt, Bizan area, garnet-glaucophane schist, eclogite, jadeite

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SMP43-13 Room:303 Time:May 24 14:30-14:45

Two stages of orthopyroxenite formation in the slab-mantle wedge interface

Shunsuke Endo[1*], MIZUKAMI, Tomoyuki[2], WALLIS, Simon R.[3], TAMURA, Akihiro[2], ARAI, Shoji[2]

[1]Institute of Geology and Geoinformation, AIST, [2]Kanazawa University, [3]Nagoya University

The slab-mantle wedge interface is a site of intensive chemical-mechanical interactions between mantle and crustal rocks in the presence of a slab-derived agent (fluid/melt). Mantle rocks that suffered from Si-metasomatism probably play important roles in subduction interface processes such as mechanical coupling and recycling of volatile and incompatible elements, although the detailed petrological structure of the subduction interface and its spatial-temporal evolution are not well-understood.

We focus on the two important processes of orthopyroxenite formation along the slab-wedge mantle interface. One is metasomatic replacement of peridotite via the reaction Ol + SiO2 (slab partial melt or solute-rich fluid) = Opx (R1). This process can occur at high-T conditions such as seen at forearc depths of infant subduction zones or subarc depths of matured subduction zones. The other is dehydration of Si-enriched serpentinite via the reaction Tlc + Atg = Opx + H2O (R2). This reaction takes place at low-T eclogite facies conditions and may be responsible for the maximum depth of decoupled slab-forearc mantle interface.

Natural records of these reactions have been discovered in the Western Iratsu body of the Sanbagawa belt, which consists of metabasaltic and minor ultramafic domains. This mafic-ultramafic complex represents an important natural laboratory to study slab-mantle interactions in an evolving subduction zone environment. Dunite is the major rock type of the ultramafic domain and grades into Opx-rich rocks (orthopyroxenite with a harzburgitic zone at the contact with dunite) at the mafic-ultramafic boundary. In addition, Opx-rich veins crosscut the whole sequence.

The earlier orthopyroxenite is mainly composed of coarse-grained orthopyroxene (Opx1: up to 1.3 wt% Al2O3) that include rounded olivine crystals and texturally primary multiphase solid inclusions (MSI). Olivine enclosed in Opx1 in the orthopyroxenite is enriched in Ni (up to 1.1 wt% NiO, Fo88-89) with respect to this mineral in adjacent dunite (up to 0.35 wt% NiO, Fo88-89), suggesting the progress of R1. Cores of Cr-spinel in the Opx1-bearing rocks and dunite show identical compositions (Cr#=0.83-0.87, Mg#=0.20-0.29, TiO2$<$0.4 wt%) that are indicative of a highly depleted forearc mantle origin. These observations, in conjunction with previously constrained P-T-t history of the body, suggest that the Opx1-bearing rocks were formed by reactions between a slab-derived melt and the dunitic mantle wedge during the earliest stage of the subduction zone development. MSI in Opx1 probably represent remnants of residual melt/fluid after the progress of R1. LA-ICPMS analyses of MSI and the host Opx1 reveal that the residual melt/fluid (and also metasomatic agent) is rich in LILE, U, Th and LREE and only minor fraction of them resides in Opx1. Therefore, the metasomatic formation of orthopyroxenite permits transportation of the reactive slab-derived agent into the mantle wedge and recycling of the slab-derived incompatible elements.

The later orthopyroxene-rich vein consists of euhedral prismatic Al-poor orthopyroxene (Opx2: Al2O3$<$0.04 wt%) in association with antigorite, chlorite and tremolite. The mineral assemblage and the composition and morphology of Opx2 suggest Opx2-bearing veins were formed via R2 in the eclogite facies conditions. Before the dehydration veining, dunite and/or Opx1-bearing rocks must have suffered from hydration to form antigorite and talc by influx of H2O-rich fluid. Opx2 is significantly lower in HFSE (Nb, Ta, Zr, Hf, Ti) and higher in fluid mobile elements (Li, B, Cs and Rb) than Opx1, supporting this interpretation.

Keywords: orthopyroxenite, metasomatism, mantle wedge, Sanbagawa belt

SMP43-14 Room:303 Time:May 24 14:45-15:00

The importance of slab-mantle coupling at 80 km depth in subduction zones

Simon Wallis[1*]

[1]Dept Earth Planet. Sci., Nagoya University

Subduction zones are complicated regions with fluid flow, earthquakes, melting and metamorphism, and ductile deformation, all interacting. One of the major controls on these processes is temperature. Thermal modeling suggests that the temperature of subduction zones is largely determined by the balance between cooling due to inflow of cold lithosphere and heating due to the flow of hot mantle towards the slab due to induced convection in the wedge mantle. Understanding this flow in the mantle wedge has been a major topic of research in the geodynamics of subduction zones.

Direct evidence for solid-state flow in the mantle wedge is provided by heat flow patterns across convergent margins. Few margins are very well characterized and the arc region is associated with local heat sources such as magmatic intrusions that are a cause of large scatter in the data. Nevertheless, the available data suggest mantle convection occurs at depths greater than around 70 to 90 km irrespective of the age of the slab.

Flow in the mantle wedge is thought to be restricted to regions where there is strong coupling between the downgoing slab and overlying mantle. Shallow levels in subduction zones are more weakly coupled. As a result of the decoupling, the corner of the wedge mantle undergoes cooling and hydration to form a cold nose.

Thermal modeling predicts a kink should exist in the thermal structure along the subduction boundary corresponding to the depth at which strong coupling between the mantle and slab become effective. The study of subduction-type metamorphism provides information on the P-T conditions close to the subduction boundary and can potentially be used to identify this type of kink in the thermal structure and, hence, to constrain the depth of strong coupling in ancient subduction settings. The Sanbagawa belt is a rare example of where this has been proposed and suggests induced flow at a depth of around 65 km.

The available evidence suggests the depth of coupling is roughly the same in all subduction zones. This common depth of coupling can help explain the common depth to the slab beneath volcanic arcs. The mechanism responsible for a change from weak to strong coupling is, however, not well known. Dehydration of antigorite and other weak hydrous phases may play a role. However, the temperature at the onset of the thermal kink is different for different subduction zones and so such a mechanism cannot explain the common depth.

The Sanbagawa belt preserves a series of peridotite bodies derived from the mantle wedge, which have experienced metamorphism at depths from 30 to greater than 100 km. The boundaries of these bodies are, therefore, fossil examples of the subduction boundary. This area is ideal for studying the controls on the coupling.

Keywords: subduction zone, wedge mantle, coupling, slab

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SMP43-15 Room:303 Time:May 24 15:00-15:15

Metamorphism of the Eastern Iratsu mass in the Sambagawa metamorphic belt, Besshi district, central Shikoku, Japan

Akira Takasu[1]*, Katsuchika Nishioka[1], Kabir, Md F.[1]

[1]Shimane University

Based on petrography and chemistry of the constituent minerals metamorphic P-T pass is revised as 1)granulite facies met (amphibolite-epidote amphibolite facies), 2) high T eclogite facies met, 3)low-T eclogite facies met, 4) epidote amphibolite met (Sambagawa met).

Keywords: Sambagawa metamorphic belt, Iratsu, granulite, eclogite

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SMP43-16 Room:303 Time:May 24 15:15-15:30

Hydrofracturing, fluid flow, and rhythmic precipitation of carbonates in marble: An example of orbicular marble

Tadao Nishiyama[1*], Kensaku Urata[2]

[1]Graduate School of Science and Technology, Kumamoto University, [2]Osaka University of Economics and Law

The Hirao Limestone at Hirao-dai, Kita-kyushu City, is considered to be a Paleozoic limestone bed metamorphosed by Cretaceous granites, and now consists of completely re-crystallized limestone (marble) with little fossil evidence (Fukuyama et al., 2004, 2006; Urata, 2009). We newly found a peculiar zone with orbicular structure in the marble, and refer it as an orbicular marble hereafter. The orbicular marble occurs as a narrow zone of about 1 meter width, extending about 20m straight from north to south. In parallel to the zone occurs several veins of dolomite with various width ranging from several millimeters to 5 centimeters in the marble. The zone contains a lot of angular fragments of marble, several centimeters to 10 centimeters in size, surrounded by alternating thin layers of dolomite and calcite. The resulting structure looks concentric orbicules. The number of alternating layers is typically more than 10. The thickness of each thin layer is variable, ranging from 1 mm to 6 mm. The interstices between orbicular marbles are filled with dolomite. The angular fragments sometimes show jig-saw puzzled structure with neither clay nor fine-grained crushed materials between the fragments. The contact between the zone of orbicular marble and the country rock (massive marble) is sharp and shows no obvious displacement.

The occurrence of the orbicular marble zone suggests that the zone was originated as a tensile fracture caused by hydrofacturing and that fluid flew through the fractured zone and precipitated dolomite and calcite around the fragments formed by fracturing. The absence of clay and gouge strongly supports hydrofracturing rather than faulting for the origin of tensile fracture.

We will present here a qualitative model to explain alternate precipitation of dolomite and calcite. The precipitation reaction of calcite is written as (e.g. Fein and Walther, 1989)

Ca2+ + CO2(aq) + H2O = CaCO3 + 2H+ (1)

Assuming similar reaction for dolomite, we get

0.5Ca2+ + 0.5Mg2+ + CO2(aq) + H2O = Ca0.5Mg0.5CO3 + 2H+ (2)

In the fluid, the following two reactions occur together with the above two reactions(Fein and Walther, 1989):

H2O + CO2(aq) = HCO3- + H+ (3)

H2O = H+ + OH- (4)

The charge balance equation holds for these reactions:

2mCa2+ + 2mMg2+ + mH+ = mHCO3- + mOH- (5)

Here m stands for molality. Reaction rates for the formation of calcite and dolomite can be modelled as:

dnCc/dt = k1[KCcaCa2+aCO2(aq)aH2O - aH+]A/V (7)

dnDo/dt = k2 [KDoaCa2+aMg2+aCO2(aq)aH2O - aH+]A/V (8)

All the reactions are assumed to be 1st order. KCc and KDo represents equilibrium constant for calcite and dolomite, respectively, and k1 and k2 are rate constants. A/V stands for specific area(area / solution volume). Assuming ideal dilute solution, activity is equal to molality.

Equation (5) gives

aMg2+ = - aCa2+ + K (9)

We assume K = (aHCO3- + aOH- - aH+)/2 is a positive constant. Then equation (8) becomes

dnDo/dt = k2 [KDoaCa2+(- aCa2+ + K)aCO2(aq)aH2O - aH+]A/V (10)

Antivity of H2O is almost unity in the dilute solution, then qualitative behavior of the solutions can be discussed in an aCa2+ vs. aH+ plane under constant aCO2(aq), by using nullclines of (7) and (10). The two nullclines intersect at a certain point with positive values of aCa2+ and aH+, which represents an equilibrium point. Precipitation of dolomite and calcite occurs interchangeably while the solution changes its composition around the equilibrium point.

Keywords: periodic precipitation, hydrofracturing, fluid flow, dolomite, calcite, orbicular marble

SMP43-17 Room:303 Time:May 24 15:30-15:45

Viscous flow and thermal evolution of metamorphic belt

Kazuhiro Miyazaki[1*]

[1]GSJ AIST

Evolution of internal structure of metamorphic belt under viscous flow and thermal diffusion was evaluated using a virtual metamorphic belt. The virtual metamorphic belt consists of two phases viscous fluids. Thickness of the virtual metamorphic belt is set at 3 km and periodic boundary condition (9 km long) is adopted. Two phases viscous fluids is sandwiched by top and bottom solid plates. Viscosity of two phases fluids is set at 10ˆ23 and 10ˆ21 Pa s, respectively. Simple shear deformation is induced by the top and bottom moving-plates. Shear velocities of these plates are 1 cm/y and -1 cm/y, respectively. Thermal boundary conditions are given by constant temperatures at both plates (600 and 800 ?C). Heat conductivity of the both viscous fluids is set at 2.5 W/m/K.

Thermal structure within the virtual metamorphic belt shows a simple vertical thermal gradient during deformation. Thermal structure will be steady-state under the given thermal boundary conditions during 0.1 M yr.

When residential time is shorter than sufficient progress of diffusional relaxation and hydration reaction at lower temperatures, metamorphic rocks record peak metamorphic temperature. Therefore, thermal structures of metamorphic belt may represent spatial distribution of peak temperature. Spatial distribution of peak temperature of each element of the virtual metamorphic belt is mapped. The result shows that thin layers of which peak temperature is higher or lower than surrounding area were formed. Very large apparent thermal gradient is observed in the virtual metamorphic belt. These thermal structures are not formed without viscosity contrast between two phases. Therefore, the thin layers are formed by selective elongation of low viscosity phase under shear deformation.

Large thermal gradient perpendicular to schistosity is observed in many metamorphic belts. The above-mentioned selective-elongation of low viscosity phase is one of explanation for the large thermal gradient observed in the metamorphic belt.

Keywords: Metamorphic belt, viscous flow, thermal structure

SMP43-18 Room:303 Time:May 24 15:45-16:00

metamoprhic banding-moving Liesegang patterns in the plate boundary

mitsuhiro toriumi[1*], Mayuko Fukuyama[2]

[1]JAMSTEC, [2]Akita university

Recent studies of parallel metamorphic bands in plate boundary rocks revealed that the band front advances accompanied with metasomatic instability by Toriumi and Fukuyama (2012) during the large scale hydration metamorphism of the plate boundary rocks, judging from waveform interface between band and matrix. The chemical reactions at the front are dissolution of matrix minerals and precipitation of metasomatic minerals together with grain boundary fluid lens partially connected and networked together with neighboring fluid lenses. Advancing fronts of the bands should be controlled also by diffusion of ionic species of constituent minerals through the network of the fluid lenses.

In the plate boundary metamorphic rocks of Sanbagawa and Alpine and also Franciscan have abundant albite bands and spots. These bands and spots of albite contain commonly inclusion trails of matrix mineral grains, indicating replacement of albite after matrix.

Considering these evidences, it is confirmed that the metamorphic band is just the precipitation band behind the diffusion front of solution penetrating the network of fluid lenses of the rock. In this case, we will propose the simple band formation model by albite replacement after chlorite in the basic metamorphic schists in the greenschist facies and low pH conditions as follows:

Mg2Al3Si3O10(OH)5 + 13H+ = 2Mg2+ + 3Al3+ + 3H4SiO4 + 3H2O

Na+ + Al3+ + 3H4SiO4 = NaAlSi3O8,aq + 4H+ + 8H2O

NaAlSi3O8,aq = NaAlSi3O8,s (albite)

In this system, ionic concentrations of every species are governed by the following reaction-diffusion equations;

Ci,t = Di Ci.xx + Ri(Cj) (i,j = Na+, Mg2+, Al3+, H+, NaAlSi3O8,aq)

where Di and Ri are the diffusion constant and reaction term, respectively. These reactions comprise the system of inhibitor (H+) and activator (Na+) of ionic solutes with respect to precipitation of albite and dissolution of chlorite. Thus, it should have precipitation pattern like general Liesegang patterns (Izak and Lagzi, 2005). In this presentation, we would like to propose the dynamic Liesegang type metasomatism in plate boundary hydration metamorphism in the wide range of spatio-temporal scales.

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Keywords: metamorphic band, reaction-diffusion equation, Liesegang, plate boundary

SMP43-P01 Room:Convention Hall Time:May 24 16:15-17:30

Thermodynamic equilibrium for fluid-dominant metamorphic systems

Tatsu Kuwatani[1*], mitsuhiro toriumi[2]

[1]Graduate School of Frontier Sciences, University of Tokyo, [2]IFREE, JAMSTEC

Classical metamorphic petrology has generally considered chemical equilibrium only among solid phases, but not among solid phases and aqueous species in the intergranular fluid (aqueous solution). It has been implicitly assumed that the chemistry of fluid is entirely buffered by the coexisting minerals. On the other hand, hydrothermal chemistry has modeled that the generation and extinction of the minerals are mostly controlled by the aqueous chemistry in the coexisting water. In most cases, however, the formulation in hydrothermal systems has treated minerals only as pure components but not as solid solutions (e.g. Reed 1983; Henley 1984). In this study, we develop the unified thermodynamic model that seamlessly integrates both the classical concept of metamorphic petrology and the concept of hydrothermal chemistry. The incorporation of the amount of water and chemistry of the aqueous species into the theory of the metamorphic equilibria enables us to investigate the water-rock interaction in metamorphism and metasomatism. In the numerical modeling, the rock shows a wide variety of mineral assemblages according to the amount of water, or the water/rock ratio, even in the same pressure, temperature and bulk-composition conditions. With the increase of water, the number of phase decreases and eventually the system becomes bimineralic or monomineralic. The present model will be the basis for the future study of the various reaction textures such as the formation of the metamorphic banding and the pseudomorphic replacement.

SMP43-P02 Room:Convention Hall Time:May 24 16:15-17:30

Change of modal abundance of mafic minerals during formation of arrested charnockite in Sri Lanka

Yukiko Yamasaki[1*], IKEDA, Takeshi[1], MOTOYOSHI, Yoichi[2], HIROI, Yoshikuni[3], PRAME, Bernard N.[4]

[1]Kyushu University, [2]National Institute of Polar Research, [3]Chiba University, [4]Geological Survey of Sri Lanka

Arrested charnockite occurs as a number of patches with lenticular to ovoidal shapes in hornblende-biotite gneiss in central Sri Lanka. Yamasaki et al. (2012) tentatively proposed the following reactions to produce orthopyroxene based on compositional difference of hornblende and biotite between charnockite and surrounding gneiss.

Ti-rich biotite + quartz = Ti-poor biotite + orthopyroxene + ilmenite + alkari feldspar + H_2O

Ti-rich hornblende + quartz = Ti-poor hornblende + orthopyroxene + ilmenite + anorthite + albite + alkari feldspar + H_2O.

These reactions suggest that orthopyroxene is produced under the condition of low-H_2O activity in the interstitial fluid. However, it is still unclear where the formation of charnockite began and how the reactions proceeded with time. Although gneissic structure in the surrounding gneiss becomes obscure at interior of charnockite, it can be traced into the near-boundary charnockite. Therefore information before charnockitization have been possibly preserved in charnockite. This study describes variation in modal abundance of hornblende, biotite and orthopyroxene in both rock-types.

Modal abundance of hornblende and biotite in gneiss decreases with decreasing the distance from charnockite. The modal abundance of hornblende and biotite at a point 12cm apart from charnockite is 7.9% and 6.9%, respectively, which decreases to 5.0% and 5.5%, respectively, at the boundary. This abundance decreases discontinuously to 1.7% and 4.1%, respectively, in the charnockite next to the boundary, and further decreases to 0.06% and 1.9% at the interior of the charnockite. The amount of orthopyroxene in charnockite is almost constant at 3.3%.

Biotite occurs both in leucocratic and melanocratic parts in gneiss, in contrast, biotite is absent in leucocratic part in charnockite. Orthopyroxene occurs in melanocratic part or its extension.

Provided that the small amount of hornblende and biotite in central part of charnockite were due to progress of orthopyroxene-forming reaction, the amount of orthopyroxene increases toward the center of charnockite. This prediction contradicts the observation. If the amount of hornblende and biotite before charnockitization tends to decrease toward the present center of charnockite, similar progress of the orthopyroxene-forming reaction in the charnockite would leave hornblende and biotite of which amount decreases toward the centre. This hypothesis is consistent with the fact. This indicates that the orthopyroxene-forming reaction initiated at the hornblende- and biotite-poor part, i.e., leucocratic part.

Keywords: Sri Lanka, arrested charnockite, hornblende-biotite gneiss

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Microstructure of corona of garnet amphibolites from the Lutzow-Holm Complex, East Antarctica

Asami Shimada[1*], Takeshi Ikeda[1]

[1]Kyushu University

Corona is a microstructure that any mineral or its aggregate surrounds another mineral. This suggests that corona was formed by the reaction between the interior mineral and the matrix minerals. Estimating this reaction, enables us to know which component transferred and how temperature and pressure changed. Microstructure of constituent mineral in the corona also provides duration of reaction and strain of rocks. In this study, we described the microstructure, crystal size distribution of biotite in the corona and chemical composition of constituent minerals of a corona from the Lutzow-Holm Complex, East Antarctica.

Geological outline

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

Microstructure

In the matrix, hornblende-rich domain and plagioclase-rich domain occur. Both domains consist of hornblende, plagioclase, brown biotite, and orthopyroxene. Garnet porphydroblast (about 15mm diameter) occurs in the hornblende-rich domain and locally shows concavo-convex shape (around 0.5mm). Garnet (long axis 0.10-0.45mm) that is rounded and irregularly shaped locally occurs at the extension of embayed part. The corona consists mainly of plagioclase and green biotite, and occurs around the outer edge of garnet. Crystal size of green biotite increases with increasing the distance from garnet. In immediate proximity to garnet, biotite occurring at the embayed part of garnet has the long axis that orientates at right angles to garnet.

Crystal Size Distribution

We measured area of all biotite grains(about 3300 grains) in the corona, using image analysis soft(image J) and calculated projected area diameter. We obtained the crystal size distribution for three domains(1,2,3 domains according to the distance from garnet) identified by naked eye. The mode of crystal size distribution is smaller than average and gently decrease on the coarse-grained side as compared with the fine-grained side. The crystal size distribution of 2and 3 is similar to lognormal distribution. 2 has high standard deviation relative to 3.

Chemical composition

Garnet has homogeneous interior and trim that shows higher Fe and lower Mg than the interior. Orthopyroxene in the corona has higher Al and lower Si and Fe+Mg than orthopyroxene in the matrix. Plagioclase in the matrix shows chemical zoning Xan=0.38˜0.46 from core to rim. In contrast, plagioclase in the corona has chemical zoning Xan=0.65˜0.84. Biotite in the corona has higher Al and lower Si, Ti and K+Na than biotite in the matrix.

Discussion

The crystal size distribution of biotite in the corona resembles to lognormal distribution, suggesting that biotite maintained continuous nucleation and growth with reduced rate of nucleation, during corona formation. Thus this suggests that recrystallization didn't take place significantly despite high temperature condition. Bulk composition of the corona, estimated from mode and chemical composition of minerals, has higher K and lower Fe than bulk composition of the matrix, deduced from chemical composition of garnet, hornblende and plagioclase. This suggests that K is supplied from the outside and Fe is leached through fluid during corona formation.

Keywords: East Antarctica, Lutzow-Holm Complex, corona

SMP43-P04 Room:Convention Hall Time:May 24 16:15-17:30

SHRIMP U-Pb zircon dating of garnet gneiss from the Lutzow-Holm Complex at Langhovde, East Antarctica

Mutsumi Kato[1*], Yoshikuni Hiroi[1]

[1]Graduate School of Science, Chiba University

The Lutzow-Holm Complex of East Antarctica is one of Pan-African metamorphic terranes that formed as a part of the East Gondwana supercontinent amalgamation. The LHC is considered to have experienced a typical clockwise pressure-tempereture-time path, as indicated by the presence of relict kyanite and staurolite inclusions within garnet and plagioclase in sillimanite-rich pelitic granulites and the development of reaction textures characteristic of near-isothermal decompression in mafic to ultramafic rocks (e.g., Hiroi et al., 1991). The timing of peak regional metamorphism within the sillimanite stability field is constrained to be 520-550 Ma by SHRIMP U-Pb dating on zircon (Shiraishi et al., 1994).

Hiroi et al. (2008) found magmatic andalusite in garnet-bearing pegmatite for the first time from the granulite facies Langhovde area of the LHC. The andalusite-bearing pegmatite intrudes garnet-biotite-sillimanite gneiss, and between them, garnet gneiss that does not contain both andalusite and sillimanite is sometimes formed. In order to constrain the timing of andalusite formation, we performed an ion microprobe (SHRIMP) dating of zircons in the garnet gneiss, and obtained an apparent population of U-Pb ages at ca. 525 Ma, that is almost contemporaneous with the timing of peak metamorphism in the LHC. We discuss the significance of the zircon U-Pb age from the garnet gneiss.

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Keywords: antarctica, granulite, Langhovde, andalusite, zircon, Lutzow-Holm Complex

SMP43-P05 Room:Convention Hall Time:May 24 16:15-17:30

Palaeo stress analysis using microboudinage structures of tourmaline within metacherts in East Pilbara Terrane

Taroujirou Matumura[1*], OKAMOTO, Atsushi[3], KIMURA, Nozomi[2], MASUDA, Toshiaki[2]

[1]Graduate school of science nd technology, Shizuoka University, [2]Institute of geosciences, Shizuoka University, [3]Graduate school of environmental studies, Tohoku University

Granite emplacement is the key process for generation of continental crust during Archaean. We analysed microstructures of tourmaline grains embedded within metacherts in the aureole around the Mount Edgar Granitoid Complex in east Pilbara, Western Australia. The aim of this study is to evaluate stress and strain with respect to progressing deformation in the aureole during the metamorphism in relation to the granite emplacement. The shape preferred orientation of tourmaline grains on the foliation surface revealed that the intensity of lineation depicted by the value of k ranges from 0.6 to 5.4. Higher values of k occur in an area which is previously called sinking zone by several authors. As many tourmaline grains exhibit microboudinage structures, we performed the microboudine analysis for palaeostress analysis. The estimated palaeodifferential stress ranges from 3.9 to 9.2 MPa. The sample with the highest palaeodifferential stress came from the locality $<$10 m from the contact between the granite and the greenstone belt. The palaeodifferential stress in the sinking zone is 7.2-9.2 MPa, while that far from the contact is 3.9 MPa. We discuss the relationship between the palaeodifferential stress and the k value in the poster.

Keywords: microboudinage structure, granite-greenstone belt, metachert, differential stress

SMP43-P06 Room:Convention Hall Time:May 24 16:15-17:30

Modeling shear wave anisotropy in forearc regions: implications for distribution of antigorite and olivine CPO fabrics

Takayoshi Nagaya[1*], WALKER, Andrew M.[2], WOOKEY, James M.[2], KENDALL, Michael J.[2], Simon Wallis[1]

[1]Earth & Planet. Sci., Nagoya Univ., [2]Sch. Earth Sci., Bristol Univ.

In the upper mantle it is generally thought that the crystal preferred orientation (CPO) of olivine forms by plastic deformation related to solid-state mantle flow. The presence of olivine CPO is one of the main causes of the seismic azimuthal and polarization anisotropy observed in the upper mantle. This link means seismic anisotropy can be used to investigate the flow patterns in the mantle. An important proviso is that there has to be good knowledge of the distribution and type of olivine CPO.

Thermodynamic modeling combined with results of deformation experiments can be used to predict the distribution of different types of CPO patterns in the forearc mantle (e.g. Kneller et al 2008). However, it has also been proposed that topotactic growth of olivine on aligned antigorite may also be an important process in the formation of B-type olivine CPO (Nagaya et al., 2012). This mechanism predicts B-type Ol CPO may be much more widespread in the wedge mantle than CPO formed by deformation alone.

Many forearc regions show an unusual pattern of seismic anisotropy with the fast direction perpendicular to the plate movement direction. One explanation of this observed seismic anisotropy is that the wedge mantle of these regions is characterized by a B-type olivine CPO patterns that characteristically have an a-axis concentration parallel to the intermediate principle axis of strain. The anisotropy observed in NE Japan (s-wave splitting with a time delay of ˜0.1 sec) can be explained by the presence of B-type olivine CPO (Katayama and Karato, 2006).

Olivine is the dominant mineral in the mantle, but forearc mantle of subduction zones also consists of significant amounts of hydrous minerals, in particular antigorite, that have much high anisotropy (for olivine Vp=24%, Vs=18%; for antigorite Vp=46%, Vs=66%). Relatively thin layers of antigorite-rich rock may therefore also have a strong influence on the seismic anisotropy. S-wave splitting with large-time delays greater than 1 second seen in the Ryukyu arc may be due to the presence of antigorite with a CPO that has a strong alignment of the c-axes perpendicular to a steeply dipping subduction zone (Katayama et al., 2009).

Modeling seismic anisotropy is a potentially useful way to place constraints on the types and distribution of different CPO patterns in the forearc mantle. We develop an approach used by Kneller et al. (2008) including a 3D analysis of ray paths and apply it to investigate proposed models of antigorite and olivine CPO distribution in the wedge mantle of NE Japan and the Ryukyu arc. The anisotropy of antigorite has only recently been determined and it has not yet been incorporated in such models. Our model combines two recently developed Matlab toolkits: MTEX (Hielscher & Schaeben, 2008; Mainprice, 2011) and MSAT (Walker & Wookey, 2012). We apply this model to the Ryukyu and NE Japan subduction zones and examine its potential to constrain the distribution region and type of olivine and antigorite CPO in these two wedge mantle.

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Keywords: antigorite, olivine, crystal preferred orientation (CPO), topotaxy, MTEX & MSAT, seismic anisotropy

SMP43-P07 Room:Convention Hall Time:May 24 16:15-17:30

Minerals on the verge of fracturing: fluid inclusions observed in minerals within kink bands

Takaki Matsuki[1], Mutsuko Inui[1*]

[1]School of Science and Engineering, Kokushikan University

Sambagawa metamorphic belt is a high pressure intermediate type metamorphic belt exposed along the south-west Japan. The peak pressure condition of the metamorphism is known at least to be 0.4 to 0.5 GPa at the lowest metamorphic grade rocks (chlorite zone). Outcrops of the chlorite zone rocks of the Sambagawa metamorphic belt in Chichibu, Saitama prefecture, often show abundant veins. Veins are the evidence of how the rocks have cracked and deformed during exhumation, most likely at the seismic depth. This study first investigated the orientation of veins and kink-bands found in an outcrop of the chlorite zone rocks. The similarity of their orientation indicated that at least some of the kink-bands are possibly the predecessor of the cracks and veins. Several kink-bands gradually changed into veins, which seems to support the view. Observation of the thin sections of the rocks in and out of one of the kink-bands revealed that quartz contained fluid inclusions in a large amount within the kink-band (between the two axial planes of the kink-band). Most of the fluid inclusion bubbles were were aligned in the similar orientation as the axial plane. More than a hundred lines of fluid inclusion bubbles were observed in a 0.5 $*$ 0.5 mm2 area between the two axial planes of the kink, whereas very few fluid inclusion was observed in quartz outside the kink-band. It is possible that the alignment of the fluid inclusions in quartz shows the beginning of the brittle deformation in rocks quenched. Kink bands observed in the outcrops of the Sambagawa metamorphic rocks in Chichibu (Saitama, Japan) may exhibit the minerals on the verge of fracturing.

Keywords: Sambagawa metamorphic belt, crack, vein, kink band, fluid inclusion

SMP43-P08 Room:Convention Hall Time:May 24 16:15-17:30

On the genesis and evolution of serpentinite melange in the Mitsuishi-Horaisan area of the Kamuikotan Zone, Hokkaido.

Hayato Ueda[1*], Yu Kano[1], Mio Miura[1]

[1]Hirosaki Univ.

The Mitsuishi-Horaisan area is one of the typical localities of serpentinite melange with high-grade metamorphic rocks in the Kamuikotan high-P/T metamorphic zone. It is thus expected that the serpentinite melange records condition and evolution of deep subduction zone. Here we discuss genesis and evolution of the serpentinite melange.

Pre-Tertiary in this area comprises an array of high-P/T accretionary complex, ophiolite, and serpentinite melange from NE to SW. These together are overlain by Miocene sediments, and tightly folded to form an anticline. Foliation of serpentinite melange matrix does not show any structure of the fold axis, and thus are probably formed during or after the folding.

Amphibolite blocks consist of garnet-epidote amphibolite and epidote amphibolite. The latter also occasionally contain pseudomorphs and trace relics of garnet. Amphiboles commonly show a compositional zoning from (I) actinolite core via (II) hornblende or barroisite mantle and (III) actinolite rim 1, to (IV) sodic amphibole rim 2. Stage I amphiboles contain relic inclusions of titanite. Stage II amphiboles co-occur with rutile +- ilmenite, garnet or its pseudomorphs, oligoclase or albite and muscovite +- biotite. Stages III and IV amphiboles are associated with titanite, albite, phengite, and chlorite. Sodic pyroxene also occurs in the stage IV. This zoning suggest heating from the greenschist (I) to amphibolite (II) facies and subsequent cooling via the greenschist facies again (III) to the blueschist facies(IV). Geothermobarometry on garnet amphibolites suggested conditions of 560-670 degC, ~1.1 GPa for the stage II.

The amphibolite blocks are commonly mantled by actinolite or tremolite rocks with chlorite or talc, regarded as reaction rind in contact with serpentinites. Sodic amphiboles rimming tremolite suggest that the contact reaction (i.e. fragmentation of amphibolites and juxtaposition with ultramafic rocks) precedes the stage IV.

Ultramafic rocks are primarily classified into (a) antigorite rock, (b) peridotite and massive serpentinites with mesh texture of low-temperature serpentines, and (c) foliated serpentinite mainly of chrysotile. Some massive serpentinite contains antigorite, which generated prior to low-temperature serpentinization, implying that olivine co-existed with antigorite in early stages. Antigorite rocks occasionally contain diopside in addition to common occurrences of carbonates. These occurrences suggest that peridotite first heterogeneously hydrated to produce antigorite peridotite and antigorite rocks. This stage is compared to the amphibolite stages II-III. Low-temperature serpentinization may have occurred in or after the amphibolite stage IV.

Metamorphic sequence of the amphibolites is characterized by early heating under high geothermal gradient from the greenschist (I) to amphibolite (II) facies, juxtaposition with serpentinite (II-III), and subsequent cooling without significant decompression (III-IV) to the blueschist facies. The stage IV condition is common with the major Kamuikotan schists. Contemporaneously, peridotite first experienced a high-temperature hydration mixing with amphibolite fragments at depths of 30-40 km. Later, olivine was extensively hydrated to be mesh textures of low-temperature serpentines during or after the stage IV.

In Hokkaido, subduction zone jumped from the Oshima Belt in the west to the Kamuikotan Zone in the earliest Cretaceous as the Horokanai Ophiolite was emplaced. Amphibolites in serpentinite melanges are the first products since the new subduction zone initiated. It is difficult to explain high thermal gradients and subsequent near-isobaric cooling for amphiboltes in the scheme of thermally stable subduction zone. Whereas subduction initiation and transition to more matured low subduction geotherm potentially explain them. If so, serpentinite blocks in the study area could be fragments of the very juvenile wedge mantle being hydrated for the first time.

SMP43-P09 Room:Convention Hall Time:May 24 16:15-17:30

Tectonic blocks in the Kamuikotan metamorphic rocks with distinct P-T paths, Etanbetsu-Horokanai district, Hokkaido

Ayumi Okamoto[1*], Toru Takeshita[1]

[1]Hokkaido University

The Kamuikotan metamorphic rocks are known as typical high-*P/T* type metamorphic rocks formed at a convergent boundary. One the other hand, in the study area, the Horokanai ?Etanbetsu district, while accretionary sediments suffered a high-*P/T* type metamorphism, amphibolites formed by an intermediate-*P/T* type metamorphism also occur as tectonic blocks, which later suffered the same high-*P/T* type metamorphism as the sediments did (Watanabe et al., 1986). In order to argue about the metamorphic history and tectonics of these amphibolites, it is important to estimate the temperature and pressure changes (*P-T* paths) during metamorphism strictly. Furthermore, it is necessary to analyze deformation structures, which recorded a motion of metamorphic rocks. Accordingly, in this research, we have analyzed mineral assemblages in these amphibolites, and conducted micro-chemical analyses of compositional zoning in amphiboles from these rocks with an EPMA. Further, we have analyzed the pressure and temperature conditions which the amphibolite experienced based on a thermodynamic calculation (i.e. pseudosection). As a result, amphiboles which constitute the amphibolites can be divided into 7 types in terms of compositional zoning in amphiboles. Type I amphibole is characterized by the compositional zoning from actinolite core to glaucophane rim. Therefore, it can be inferred that greenschist facies metamorphism was overprinted by blueschist facies metamorphism. Here, we inferred that no cooling was experienced in the amphibolites during the poly-metamorphism, because neither pumpellyite nor lawsonite which is expected to form at high pressure and low temperature conditions was not formed. Therefore, it is thought that this sample only experienced the pressure increase without cooling during the poly-metamorphism. Type II amphibole is characterized by the compositional zoning in amphiboles from magnesiohornblende core indicating amphibolite facies metamorphism through actinolite mantle indicating greenschist facies metamorphism to glaucophane rim indicating blueschist facies metamorphism. Therefore, a *P-T* path such as pressure increase after cooling is suggested. Type III is characterized by the compositional zoning in amphiboles from tschermakite core to glaucophane-magnesioriebeckite rim. It is inferred from compositional zoning in garnet that both temperature and pressure increased in the garnet amphibolite, which was followed by blueschist facies metamorphism inferred by the compositional zoning in amphibole. Therefore, in this area, there are at least three different types of amphibolites which show different *P-T* paths. Since these three types of amphibolites show different overall paleo-geothermal gradients based on the compositions of amphiboles, we inferred that the paleo-geothermal gradient decreased from low-*P/T* (or intermediate-*P/T*) type to high-*P/T* type during the poly-metamorphism, which is best represented by the compositional zoning of type II amphibole. These facts could indicate that the paleo-subduction zone was cooled, and three different types of amphibolites which may have been formed at different paleo-geothermal gradients in different ages, were later assembled as tectonic blocks with different temperature-pressure-time paths in the Horokanai-Etanbetsu district.

Keywords: the Kamuikotan metamorphic rocks, high-P/T metamorphism, tectonic blocks, pressure-temperature path, compositional zoning in amphiboles

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Serpentinite textures and mode of hydration along the ancient subduction zone beneath the Horokanai Ophiolite, Hokkaido,

Takechika Kasai[1*]

[1]Hirosaki-Univ.

Along convergent plate boundaries, the mantle peridotites are serpentinized as water fluids are supplied from the subducted slab. Because serpentinites are less frictional than peridotites, it might play an important role on the deformation characteristics and seismic activities. However, there are still poor observations on the ways how water is supplied and how hydration proceeds in deep subduction zones.

Serpentines of mantle origins occur in contact with a metamorphic rock of oceanic plate origins crop out in the Horokanai area located 30km to the northwest of Asahikawa, Hokkaido. It is prospective that contact relations between, and element transports across the plate boundary of a deep part of the subduction zone is preserved. In this study, field mapping and sampling were made mainly along two routes, which traverse the boundary between the serpentines and the metamorphic rocks. By optical and electron microscopy, occurrences of serpentinites and related minerals and reaction textures are here described.

The serpentinite body is dominated by low-temperature serpentinites occasionally with relic olivine, opx, spinel, and rarely cpx. Antigorite more commonly occurs in parts close to the metamorphic rocks, accompanied by reaction rocks such as talc and/or carbonate rocks. In olivine-antigorite serpentinites, antigorite typically occurs penetrating olivine and opx along with their grain boundaries. Trace amounts of talc instead of antigorite occurs along the grain boundaries between olivine and opx in an antigorite-free peridotite. These occurrences suggest that percolation along grain boundaries was a major mode of water supply in the mantle, as well as by hairline cracks indicated by antigorite serrate veins.

Some antigorite serpentinites also contain diopside and tremolite useful to estimate metamorphic temperature. Several types of reaction textures are observed: (a) opx is surrounded by tremolite corona with secondary olivine at their tips, and (b) simplectic Ol + Cpx + Atg + Mag pseudomorphs presumably after tremolite. Retrogressive hydration from amphibole peridotite to antigorite serpentinite is supposed by these textures. Water supply might have been heterogeneous and intermittent because textures of incomplete hydration are not uncommon.

SMP43-P11 Room:Convention Hall Time:May 24 16:15-17:30

Compositional zoning and inclusions of garnet in Sanbagawa metapelites from the Asemigawa area, central Shikoku

Tomoki Taguchi[1*], Masaki Enami[2]

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

Chemical zoning and inclusions in garnets record valuable information for estimating the pressure-temperature (P-T) history of metamorphic rocks. Metamorphic garnet grains in Sanbagawa metapelites usually record a bell-shaped profile of Mn (normal zoning), suggesting that they were formed by nucleation and continuous growth with increasing temperature during the Sanbagawa metamorphism (Sakai et al., 1985). In contrast, garnet grains in metapelites around eclogite bodies in the Besshi area usually have composite zoning, showing discontinuous growth between the grain's core and mantle boundary, and are reported as resorption-overgrowth zoning by Takasu (1986). In the Asemigawa area, some rare garnet grains in metapelites show reverse zoning (Itaya, 1978) and sector zoning (Inui, 2010) in addition to the normal zoning.

We re-examined the metamorphic P-T history of the metapelites in the Asemigawa area, based on the zoning of garnets, composition and parageneses of garnet inclusions, and residual pressure recorded by quartz grains inclusions in garnets. Thirty-four samples were collected from different metamorphic zones of the garnet (Grt), lower albite-biotite (Ab-Bt), oligoclase-biotite (Ol-Bt), and upper albite-biotite zones along the Asemigawa region from south to north.

Most garnet grains show normal zoning. However, garnet grains from the lower Ab-Bt zone have composite zoning. The composite zoning of garnet is defined by the discontinuous variation in Mn content at the core-mantle boundary. The two types of zoned garnet grains have different inclusion assemblages, as follows: (1) Normal zoning: Qtz (quartz), Ttn (titanite), and micro multi-phase inclusions of Pg (paragonite) + Phg (phengite); and (2) Composite zoning comprising (a) Core: Rt (rutile), Ttn, Cz (clinozoisite), Gln (glaucophane), and (b) Rim: Qtz and Ttn.

Quartz inclusions in the garnets in samples from the Grt, Ol-Bt, and upper Ab-Bt zones preserve a residual pressure compatible to that of the epidote-amphibolite facies. In contrast, the samples from the lower Ab-Bt zone record higher residual pressure than those from the other zones.

These results suggest that the metapelites in the lower Ab-Bt zone were likely recrystallized under relatively higher-pressure metamorphic conditions than others in the Asemigawa area.

Keywords: garnet, compositional zoning, residual pressure, quartz-Raman barometer, Sanbagawa metamorphic belt

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Preliminary 2-D thermal modeling of Proterozoic granulite: a case study of structurally controlled exhumation

Kaushik Das[1*], Tomoeki Nakakuki[1], Sankar Bose[2]

[1]Hiroshima University, [2]Presidency University, Kolkata, India

Deep continental crustal rocks undergone granulite-grade of metamorphism are exposed at the orogenic belts. Mesoproterozoic Eastern Ghats Granulite belt is one such polymetamorphosed and polydeformed terrain. The unique character of this belt is the occurrence of ultrahigh temperature metamorphosed granulites on a regional-scale where the peak metamorphism is estimated to be in excess of 1000 ^{o}C at ~8-10 kbars. The reason(s) for such extreme thermal conditions at the deeper parts of the Proterozoic orogen and an appropriate geotectonic setting for such extreme high heat flow are still eluding the geoscientists. Moreover, the exhumation processes and rates of exhumation are one of the least studied areas for the deep interiors of such extremely hot orogen.

Proper structural and petrological assessments, particularly exhaustive analysis of pressure-temperature-deformation-time evolutionary history of Eastern Ghats Granulite belt pave the path to look for exhumation histories. This belt is known to be anisotropic and domainal in terms of isotopic signatures and tectonothermal histories. The domain 2 of this orogenic belt presents the best-studied section showing an overall anticlockwise P-T path evolution with three to four deformation and metamorphic events in an overall possible accretionary orogenic set-up. Regional-scale structural studies along the Vishakhapatnam-Araku transect of domain 2 show imprints of superposed deformation at high angle producing domal structures. Three such large-scale domes are arranged from south-east (Madudavada mega-sheath) to north-west (Anantagiri dome and domal structure near Araku).

The present study is based on the occurrence of aluminous granulite with sapphirine-spinel-aluminous orthopyroxene-cordierite-sillimanite-garnet-biotite-quartz-feldspar near the boundary of the "Maduravada mega-sheath". Fe-Mg compositional profiles of porphyroblastic garnet adjacent to orthopyroxene, and that with adjacent retrograde biotite (fluorine-Ti-Mg-rich) show development of zoning only in the latter case. Geothermometric calculations indicate formation of biotite at ~875 ^{o}C during the early cooling, followed by the formation of compositional zoning in adjacent porphyroblastic garnet. In an earlier study, we estimated an anomalously fast cooling rate from this zoning profile of garnet *i.e.*, 12 to 25 ^{o}C/Ky, which is several order higher than the normal thermal relaxation rates reported from younger orogenic belts. In the present study, we have tried to formulate a preliminary two-dimensional numerical thermal model using rapid upheaval of deep crust in a compressional tectonic setting through a domal structure having near-vertical foliation planes. The model calculation is based on an initial thermal condition similar to that of known old continental crust having a steady-state geotherm on 100 km wide area with depth of 35 km. An already perturbed geotherm of 900 ^{o}C at the lowermost part is then folded up in an antiformal parabolic shape, more or less in the fashion of a diapiric upheaval. The 2-D conductive cooling is then assumed and cooling rates have been calculated at different places from the boundary of the upheaved portions, i.e., 0 to 1.25 km at a depth of 5 km from the surface. We use a finite volume method with an implicit time integration to solve the thermal conduction equation with a radiogenic heat source decaying with the depth. The initial cooling rates of ~10-20 ^{o}C/Ky is estimated to be achieved near the boundary with non-linear subsequent decay, similar to the recorded cooling rate from the Fe-Mg zoning profile in the studied rock. The thermomechanical consequence of such deep crustal flow process in presence of partial melt in the overall perspective of the Proterozoic orogen is being checked, in addition to the plausibility of such high degree of thermal relaxation rate.

Keywords: Deep crustal UHT granulites, Anomalously high thermal relaxation rate, 2-D thermal model and crustal flow

SMP43-P13 Room:Convention Hall Time:May 24 16:15-17:30

Subduction conditions estimated from the P-T paths for the Sambagawa metamorphic rocks

Kazuhiko Ishii[1*]

[1]Graduate School of Sceiences, Osaka Prefecture University

Petrologically derived P-T conditions for high P/T-type Sambagawa metamorphic rocks show lower P/T ratio than numerically modeled typical steady state temperature distribution along the surface of subducting slab. To explain this discrepancy, several authors have proposed the idea of subduction of very young slab that may involve a subduction of spreading ridge (Iwamori, 2000; Aoya et al., 2003; Okudaira & Yoshitaka, 2004). I examined the thermal effects of ridge subduction on both subduction- and exhumation-stage PT-path by a two-dimensional thermal calculation. The results show that PT-path for eclogite and lower-grade metamorphic rocks can be reproduced by a subduction and exhumation of rocks just before the ridge subduction.

Garnet-bearing ultramafic rocks in the Higashi-akaishi perodotite show progressive PT-path up to UHP condition with high dP/dT ratio (Enami et al., 2004). A numerical calculation shows that this PT-path can be explained by a mantle wedge dragged down by the subducting oceanic slab with older age (>20 Ma) and fast (>10 cm/yr) subduction rate.

These two results indicate that UHP and lower-grade metamorphisms are occurred different time and different subduction conditions.

Keywords: plate subduction, Sambagawa metamorphic rocks, P-T path, thermal modeling

SMP43-P14 Room:Convention Hall Time:May 24 16:15-17:30

Reaction and structural development of antigorite serpentinite in the Higashi-akaishi ultramafic body, Sambagawa belt

Hironori Yokoyama[1], Tomoyuki Mizukami[2*]

[1]Depart. Earth and Environ. Studies, Grad. Sch. of Natural Sci., Kanazawa Univ., [2]Earth Science Course, School of Natural System, College of Science and Engineering, Kanazawa Univers

Serpentinization of mantle wedge is a key process controlling fluid flux across subduction boundaries. In order to model progressive serpentinization and its effect on subduction system, it is important to understand mechanism of the fluid-rock reactions in open system. For direct information on the kinetic reactions, we made field observations on antigorite (Atg) serpentinite in the Higashi-akaishi ultramafic body in the Sambagawa belt.

Schistosed Atg serpentinite develops at the lower half of the body. Modal proportions of Atg to olivine (Ol) show a bimodal distribution representing an interlayering between Ol-rich (5-20% Atg) and Atg-rich (30-60% Atg) layers. Such layering can be seen in scales of several mm to 20 meters. Each layer is generally distinctive but local gradual decrease of Atg proportion in a single unit indicates the direction of fluid transport from bottom to top. Veins and network structures of Atg connect these strongly foliated parallel layers with the hydrous mineral.

Brucite (Brc) and magnetite (Mag) are found in highly serpentinized layers. However, there is no concentration of Brc and Mag in the outcrops and strain shadows are filled by Atg or carbonate indicating extraction of Mg and Fe is minor during serpentinization. Mineral chemistry of Atg and Ol suggests re-distribution of Ni and Fe during serpentinization. These observations indicate that Atg formation is owing to an additional SiO2 dissolved in aqueous fluids. Minor Brc and a small amount of Mag can be explained by a reaction involving SiO2.

These observations indicate that discontinuous layers with high concentrations of Atg represent fluid pass ways supplying SiO2 and H2O required for serpentinization of peridotite. Syn-deformational serpentinization causes strong schistosity defined by parallel alignment of platy Atg. Such foliated layers probably enhanced channelized fluid flow and, as a result, formation of Atg. This positive feedback is considered as a major mechanism to increase the amount of Atg in the Ol-rich Higashi-akaishi body. It is also indicated that contributions of interconnecting channels were important for advancing of serpentinization front into the mantle wedge.

Keywords: serpentinization, structural development, reaction

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U-Pb zircon age of low-pressure/high-temperature metamorphic rocks from the Kurosegawa tectonic zone, South-west Japan.

Aya Yoshimoto[1*], Yasuhito Osanai[1], Nobuhiko Nakano[1], Tatsuro Adachi[1], Kazuhiro Yonemura[1], Hideo Ishizuka[2]

[1]Kyushu University, [2]Kochi University

The Kurosegawa Tectonic Zone distributed from Kyushu to Kanto Mountains, characterized by serpentinite melange. The serpentinite melange contains various types blocks such as sedimentary rocks, granite, high-temperature amphibolite- to granulite-facies rocks and high-pressure/low-temperature metamorphic rocks.

The variation of U-Pb detrital zircon age clusters in pelitic schist from Itsuki area in Kyushu, Toba area in Kii Peninsula, and quartzite from Anan area in Shikoku are mostly similar in each area. These results might indicate that the pelitic schists and the quartzite from three areas were derived from similar hinterland.

Meanwhile, the U-Pb zircon ages of garnet-clinopyroxene granulite from Tsubokinohana area and amphibolite from Hashirimizu area in Kyushu are 447+/-3 Ma and 449+/-4 Ma, respectively. According to texture and Th/U ratios of analyzed zircon grains, the estimated U-Pb zircon ages from low-pressure/high-temperature metamorphic rocks may indicate protolith ages of these metamorphic rocks. In addition, the U-Pb zircon age of glaucophanite, which represent to form the gabbro, from Engyoji area in Shikoku shows 447+/-5 Ma. This U-Pb zircon age may also indicate protolith age. At present, protolith ages of metamorphosed mafic rocks in the Kurosegawa Tectonic Zone are considered to concentrate between the Silurian and the Cambrian.

Keywords: Kurosegawa Tectonic Zone, U-Pb zrn age

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The Kiroko greenstone melange of the Atokura Nappe in the Yorii-Ogawa district, central Japan

Akira Ono[1]*

[1]None

The Atokura Nappe is distributed in the Yorii-Ogawa district of the northeastern margin of the Kanto Mountains. The Kiroko greenstone melange is exposed in the southern margin of the Atokura Nappe. The greenstone melange is composed of Kiroko metamorphic rocks, serpentinite and various tectonic blocks. The tectonic blocks are considered to be captured by the Kiroko metamorphic rocks and serpentinite in the course of their rises toward shallow crust. K-Ar datings for the Kiroko greenstone melange were carried out for two samples by the present writer. The Kiroko-M sample is a greenstone. The Iyo-mus sample is a biotite-garnet-muscovite schist which is exposed in Iyo, East Chichibu village.

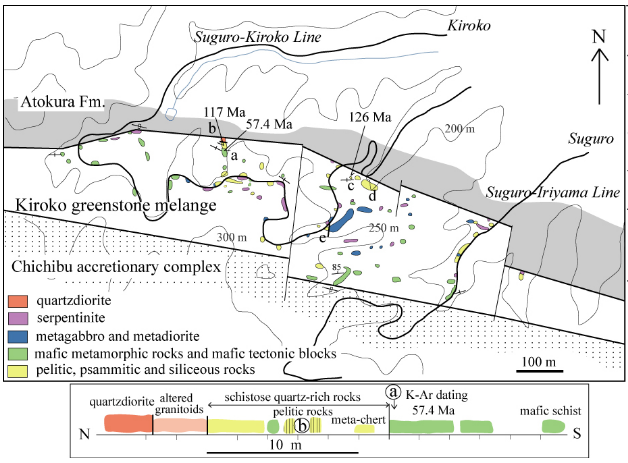
The Kiroko-M sample was made from several hand specimens. Lenticular portions with various colors such as pale-green, gray, white and black are observed for the hand specimens (Figure 1). The lenticular portions are of about 1-3cm in length and less than 5mm in thickness. Radiolarians are rich in white siliceous parts although they are also common for other portions. Black pelitic lenses are composed of fine actinolite, chlorite, white mica, quartz and carbonaceous material. The small white mica has a great impact on the K-Ar age of the Kiroko-M sample.

Pelitic metamorphic rocks of the Kiroko greenstone melange were previously described as slates or mudstones. Recrystallizations of minerals are good in spite of the low metamorphic temperature. Preferred orientation of muscovite is clear in many cases. The sizes of muscovite grains depend on each rock sample. It is very small in some cases. Two kinds of muscovite with respect to grain sizes are observed for all the studied samples. Larger muscovite grains are considered to be detrital ones. Secondary minerals are hardly observed although quartz veins are present frequently.

K-Ar dating was carried out for two pelitic rocks, Kiroko-P and Suguro-P. The results are 117Ma and 126Ma, respectively (Figure 1). Considering the common occurrences of detrital muscovite grains, the measured K-Ar ages are considerably older than cooling ages of metamorphic minerals.

Mid-Cretaceous granitic and metamorphic rocks are tectonic blocks of the early Paleogene Kiroko greenstone melange. The Kiroko metamorphic rocks and serpentinite exhumed to the shallow crust where mid-Cretaceous granitic and metamorphic rocks were distributed. The mid-Cretaceous granitic and metamorphic rocks were largely transported toward an oceanic plate before 60Ma and were situated at the margin of the Paleogene forearc region where the exhumation of high-pressure type metamorphic rocks took place. Similar tectonic shortenings occurred after 60Ma in the forearc region of Southwest Japan. The formation of the Atokura Nappe is an evidence for the tectonic contraction.

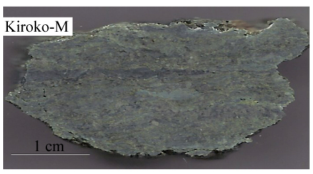
Keywords: greenstone melange, Atokura Nappe, slate, K-Ar dating, detrital white mica



	Sample	Age (Ma)	^{40}Ar rad (scc/g x10^{-5})	^{40}Ar rad (%)	K (%)
(a)	Kiroko-M	57.4± 1.4	0.047 0.046	83.5 75.7	0.21 0.20
(b)	Kiroko-P	117 ± 2.9	1.60 1.64	96.6 96.7	3.45 3.45
(c)	Suguro-P	126 ± 3.0	0.963 0.973	94.2 93.7	1.91 1.92
(x)	Iyō-mus	109 ± 2.7	3.04 3.01	95.1 94.1	6.94 6.92

M: mafic schist, P: pelitic rock, mus: muscovite

$\lambda_\beta = 4.962 \times 10^{-10}$/yr , $\lambda_\varepsilon = 0.581 \times 10^{-10}$/yr
^{40}K/K=0.01167 atom% Geospace Science CO.,LTD.



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SMP43-P17 Room:Convention Hall Time:May 24 16:15-17:30

Zircon LA-ICP-MS U-Pb dating of metamorphic rocks from Sor Rondane Mountains, East Antarctica.

Ippei Kitano[1*], Yasuhito Osanai[1], Tatsuro Adachi[1], Nobuhiko Nakano[1]

[1]Kyushu University

Sor Rondane Mountains, East Antarctica, has been considered to locate inside of the collision zone between West Gondwana and East Gondwana (e.g., Meert, 2003; Jacobs and Thomas, 2004). This area is composed by greenschist- to granulite-facies metamorphic rocks and various plutonic rocks that intrude to metamorphic rocks (Osanai et al., 1992). The Sor Rondane Mountains has been divided into Northeastern (NE) terrane and Southwestern (SW) terrane, based on variety of the constituent rocks and metamorphic process (Osanai et al., in press). The NE terrane consists of unit A and unit B. Metamorphic rocks from the unit A are amphibolite-facies, and from the unit B are granulite-facies (unit B). Metamorphic rocks from unit B show the ages of magmatism at 1130-890 Ma and 800-790 Ma (partial melting), granulite-facies metamorphism at 750-700 Ma and 640-600 Ma, and amphibolite-facies metamorphism (retrograde) at 580-520 Ma (Osanai et al., in press). By contrast, the SW terrane has granulite-facies metamorphic rocks in unit C, greenschist- to amphibolite-facies metamorphic rocks in unit D, and metatonalite (unit D'). Metamorphic rocks of the unit C, D and D' show the ages of syn-magmatism and magmatism at 1190-950 Ma, magmatism at 770-750 Ma (e.g., Nakano et al., 2012), metamorphism at 700 Ma (Hokada et al, 2013), granulite-facies metamorphism at 640-600 Ma, amphibolite-facies metamorphism (retrograde) at 580-520 Ma (Osanai et al., in press). Amount of geochronological data has been reported from the Sor Rondane Mountains. However, their collected areas were limited mainly in central part and eastern part. In this study, we analyzed 25 samples (2 samples from unit A, 12 samples from unit B, 5 samples from unit C and 6 samples from unit D) mainly from the unknown areas to reveal more detailed tectonic evolution of the Sor Rondane Mountains.

In the unit A, zircon ages in metapelites (Grt-Bt gneiss) yield 1070-780 Ma from detrital zircon and 640-630 Ma from metamorphic rim. Those in metamorphosed felsic or intermediate rocks (Hbl-Bt gneiss) yield 1180-1030 Ma, which is interpreted as the ages of magmatism. In the unit B, range of zircon ages in metapelites (mainly Grt-Bt gneiss and Opx-Bt gneiss) is 610?2900 Ma. Especially, the age cluster of 660?610 Ma are interrupted as metamorphic age, and other age groups were analyzed from detrital zircon. Metamorphosed felsic or intermediate rocks (Bt gneiss) consists 1050-840 Ma igneous zircon age and 670-570 Ma metamorphic zircon age. In the unit C, zircon ages in metamorphosed felsic or intermediate rocks (Hbl-Bt gneiss and Bt gneiss) yield 1000-920 and 870-730 Ma with minor 730-710, 570 Ma. Zircon ages at 1000-920 and 870-730 Ma are interpreted as magmatic age, on the other hand, ages of minor 730-710, 570 Ma may be interpreted as metamorphic age. Zircon ages of metamorphosed mafic rocks (Grt-bg. Bt amphibolite) yield 810-760 Ma as magmatism age, and 640 and 610-570 Ma as metamorphic age. Those in calcsilicate metamorphic rock (Hbl-Cpx rock) yield ca. 760 Ma. In the unit D, detrital zircon ages in metapelites (Grt-Bt gneiss and Ep-Chl-Ms schist) are dated at 1120-930 Ma. The variety of zircon age clusters in metamorphosed felsic or intermediate rocks (St-bg. Grt-Bt gneiss and Bt-Hbl gneiss) is 1150, 1050-1010, 950-800 Ma and 720 Ma. Zircon ages, ranging 1150?800 Ma, are interpreted as magmatism age, in contrast, zircon age of 720 Ma may be interpreted as metamorphism. Range of detrital zircon ages in calcsilicate metamorphic rock (Bt-Ep-Hbl rock) is 980-780 Ma.

In comparison with geochronological data of the NE terrane and the SW terrane, the detrital age cluster of >1800 Ma is recognized in unit B, characteristically. Difference in detrital zircon ages suggests that these two terranes would be derived from different hinterlands. We also could recognize that both terranes have similar igneous ages from felsic, intermediate and mafic metamorphic rocks.

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Electron microprobe age dating of monazite from the meta-sedimentary rocks, central-eastern Madagascar

Takashi Ichiki[1*], ISHIKAWA, Masahiro[1], OSANAI, Yasuhito[2], NAKANO, Nobuhiko[2], ADACHI, Tatsuro[2]

[1]Yokohama National University, [2]Kyushu University

Madagascar is situated within the interior of the Neoproterozoic East African Orogen (EAO; Stern, 1994) that marks the join between East and West Gondwana. The Betsimisaraka Unit exposed on the eastern margin of EAO experienced Neoproterozoic-Early Paleozoic metamorphism and deformation. Monazites from biotite gneiss in the Betsimisaraka Unit, sillimanite-biotite gneiss and kyanite-biotite-muscovite schist, and garnet-sillimanite gneiss in the Antananarivo Block were dated by the field emission Electron microprobe. The ages and zoning characteristics varied between the samples, but the U-Th-Pb monazite data confirm that at least Early Paleozoic (Cambrian) metamorphic events are recorded in the area.

Monazites from the Betsimisaraka Unit are subhedral to anhedral, and occur both as inclusions within biotite porphyroblasts and the matrix. Analyzed grains gave ages from 400 to 610 Ma with the 500 Ma age being dominant. Compositional zoning in monazites from samples in the Masora Block demonstrates complex growth relationships. Monazites are subhedral to anhedral, and yield two distinct ages. The cores of monazite grains give ages of ca. 930 Ma whereas the rims of grains generally give ages of ca. 500 Ma. A second sample from the Masora Block contained subhedral to anhedral monazite grains both within biotite and matrix minerals. Analyzed grains gave ages ranging from 450 to 550 Ma with the 510 Ma age being dominant. Discontinuous zoning in monazites from sample in the Antananarivo Block demonstrates complex growth relationships. Monazites are anhedral and yield two distinct ages. The cores of monazite grains give age of ca. 2500 Ma whereas the rims of grains generally give ages of ca. 490 Ma.

The occurrence of monazites suggests that Cambrian-Ordovician history is preserved within metamorphosed equivalents in the central-eastern Madagascar. The monazite data support the previous monazite ages in central-southern Madagascar reported by Giese et al. (2011) and requires re-evaluation of tectonic model of Gondwana formation along the eastern margin of EAO.

Keywords: Gondwana, central-eastern Madagascar, EPMA monazite dating, meta-sedimentary rocks

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Some characteristics of isochemical kelyphite in garnet peridotites, Czech Bohemia

Masaaki Obata[1*], Kazuhito Ozawa[2], Kosuke Naemura[2], Akira Miyake[1]

[1]Kyoto University, School of Science, [2]The Univ. Tokyo, School of Sciences

Isochemical kelyphite that is formed by isochemical breakdown of garnet has been known to occur in olivine-free mafic xenoliths such as garnet pyroxenites or granulites in volcanic rocks. We reported an occurrence of isochemical kelyphite (kelyphite II:Opx+Sp+Plagioclase) from garnet peridotite from Czech Boldanubian Zone (Obata et al, Mineralogy and Petrology, 2013). This presentation illustrates some important petrographic characteristics and discuss their significance. It occurs within ordinary kelyphite (kelyphite I: Opx+Cpx+Sp), which indicates the formation of kelyphite I preceeded kelyphite II.The characteristics of the Czech isochemical kelyphite (kelyphite II) are as follows. (1) kelyphite II is asymmetric, i.e., it develops only on one side of garnet. (2) mineralogical transitions zones are defined between kelyphites I and II. (3) another thin hydrous kelyphite (kelyphiteIII: Amp+Sp+Pl) separates the kelyphite II and relict garnet. (5) while no topotaxic relationship is found between pyroxene and spinel in the kelyphite I, a good topotaxic relationship occurs in the middle of the kelyphite II. These are new features that have not been recognized from previous isochemical kelyphites (from xenoliths) and are considered to bear important information regarding the processes of transformation from kelyphite I to kelyphite II formations and they are expected to occur in other orogenic peridotites. A preliminary report of such isochemical kelyphite is also presented from the Ronda peridotite, Spain.

Keywords: kelyphite, symplectite, garnet peridotite, Czech, Bohemia

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Talc flow layer tectonics :a new concept of globe

Yoshimasa Iida[1*]

[1]non

Many of the theories of plate tectonics are disputable. It is not comprehensible that the low velocity layer in the upper mantle is interpreted as the partial melting. The caldera chain (Iida, 2011b) was proposed as a new concept of magmatism that is possible to be in place of the existing concepts consisting of the hot spot, plume, and subduction zone magmatism. According to the new concept, all magmas except the kimberlite are expected to be generated in the crust or uppermost mantle, and the upper mantle is considered to be much cooler than the current theory.

Talc could be stable in the considerable depth. It is estimated that the talc bearing flow layer (TFL) underlying the plates is the cause of the plate drift and isostasy. The North American ice sheet centered in the Hudson Bay is surrounded by a belt of large lakes. The belt rose in the ice age by the outward migration of the flow material from the center, and turned to sink with the melting of ice sheet. Such a reverse movement of surrounding zone indicates the relatively thin flow layer underlying the crust.

The considerable portion of oceanic plate is serpentinized prior to subduction. The dehydration of serpentine metamorphoses both the plate itself and adjacent mantle into TFL that migrates upward along the lower surface of the plate represented by the lower side of the double seismic plane. Such metamorphism and two-way movement makes the speedy subduction possible. The plate bends and then becomes straight again to subside. It is considered that such plastic deformation is realized by the fractured and surpentinized rocks and surrounding mobile TFL.

The TFL below the oceanic plate migrates toward the mid-oceanic ridge to become the raw materials for the plate. In the subduction zone the oceanic plate enveloped by TFL subsides with the density difference that is the power source for the whole system. The mid-oceanic ridge is in the passive tension field where the oceanic plate is formed by the magma generated with the pressure reduction. The ridge ranges at right angles to the tension direction. The continent is cut by the caldera chain (CC) that moves irregular in shape. In order to fit the shape the ridge is dislocated by the transform faults. The CC that split the Pangaea has migrated for 600 million years from south to north. The current tip of the CC is located at the eastern end of the Gakkel ridge in the Arctic sea.

The zonal geologic structure parallel to the trench is common in the edge of continental crust adjacent to the subduction zone. The caldera tends to be formed in the soft and thin crust rather than hard and thick crust. Accordingly the CC tends to be formed in parallel with the trench. When the large scale CC which magma originates from the TFL is formed along the edge of the continent, the CC becomes the cutting line for the separation of the marginal part. The TFL in the surrounding area flows into the gap to supply the material for the new oceanic crust. The island arch and the marginal sea are formed with such process. The CC concentrically migrates in the new oceanic crust due to its thinness, the marginal sea spreads itself. The movement of the TFL toward the marginal sea makes the TFL below the island arch thin to depress the land. The transgression happened in Japan in the mid-Miocene at the time of the Japan sea spreading could be explained by the process.

The TFL and the CC are the individual tectonics severally. These two are proposed as the new concepts that are totally different from the existing concepts of the earth.

Keywords: continental drift, caldera chain, island arch, marginal sea