SCG07-01 Room:106 Time:May 21 09:15-09:30

Folding of Kitakami granite and exhumation associated with regional-scale flexural slip folding and ridge subduction

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The following abstract after Osozawa, Tsai, Wakabayashi, 2012, appeared in Journal of Asian Earth Sciences, 59, 85-98.

The early Cretaceous granitic plutons intrude the Kitakami zone, northeast Japan, whose southern and northern regions consist of forearc basin and accretionary complex rocks, respectively. All country rock of the Kitakami zone exhibit prominent pressure-solution cleavage and associated folds formed during shortening with a small component of sinistral shear, whereas most plutons show only igneous textures. The Kesengawa granite and some other plutons, however, have foliations that cut the pluton boundaries and are continuous with those observed in surrounding sedimentary rocks. We document a tectonic fold with axial planar foliation in part of the Kesengawa granite. The metamorphic minerals associated with the contact aureole and country rocks of the Kesengawa and other deformed plutons indicate an increase in metamorphic grade toward the pluton showing that deformation of the pluton and country rock took place as the plutons cooled. The Kesengawa pluton and country rocks of the southern Kitakami zone are deformed into regional scale upright folds with parasitic asymmetric folds that verge toward regional anticlinal axes whereas regional scale folds in the northern Kitakami zone are overturned and verge to the east. The Kitakami basement is not bounded by normal or reverse faults, so the style of regional exhu- mation does not resemble the upright or inclined extrusion noted in other regions, nor is the exhumation associated with extensional doming. Instead, the vergence of parasitic folds toward the regional fold hinges indicates flexural slip deformation at least in the late stages of exhumation and exhumation occurred in the cores of regional scale anticlines. The regional shortening of accretionary prism, forearc basin, and older forearc basement was associated with intrusion of adakitic plutons that thermally weak- ened the forearc basin and enhanced the deformation and exhumation. The adakitic magmatism and forearc shortening resulted from subduction of the buoyant Izanagi?Kula ridge, a regional event known as the Oshima orogeny.

Keywords: Kitakami granitic pluton, aplite marker, asymmetric fold, axial planar foliation, biotite, aureole, flexural slip anticline, tilted unconformity, extrusion, exhumation, adakitic magmatism, ridge subduction

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SCG07-02 Room:106 Time:May 21 09:30-09:45

AN OVERVIEW OF SEISMOTECTONIC PROPERTIES OF EASTERN ANATOLIA

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ABSTRACT

Turkey is lying within a region surrounded by 3 main tectonic plates which are Eurasian, African and Arabian plates. The Global Positioning Systems (GPS) show that the Arabian plate is pushing and compressing Anatolia plate at a rate of 1.7?2.4 cm/year, being effective to the east of Anatolia, while the subduction of the African plate along the Hellenic arc pulls the Anatolian block toward SW at a rate of 3.0-4.0 cm/year. The intersection of the two main fault systems (North Anatolian and East Anatolian transform faults) constituting a triple junction point between Erzincan-Bingol-Elazig region is the most tectonically active area in East Anatolia.

The eastern part of North Anatolian Fault Zone is northeast of East Anatolian Fault zone. These two fault zones intersecting around Karliova and is called Karliova Triple Junction. In this region, in the east of Erzincan Yedisu Segment a seismic gap is defined by the previous scientific studies. However, there is not sufficient seismological study in this region to characterize the seismic gap. For this purpose the number of seismic stations have been increased. The number of stations increased 3 fold within the last 5 years with the aim to understand the characteristics of the earthquakes, to study earthquake risk analysis and the mechanism of the faults in the region.

Especially between 2003-2011 there were 3 large earthquakes (2003 Pulumur Mw=6.1; Bingol Mw= 6.4; 2010 Elazig Mw 6.1) in the region. In the same period 2004 Sivrice Ml=5.5; 2005 Karliova Ml=5.7-5.9; 2007 Sivrice-Elazig earthquakes (Ml=5.3-5.9) and 2010 Gokdere-Palu-Elazig (Ml=5.1) earthquakes showed that the region is highly active.

In addition along Southeast Anatolian border of Turkey, as a result of the compressional tectonism thrust type orogenic structures like Bitlis Suture Zone occured. These structures are also active. The earthquakes of 6 September 1975 Lice (Ms=6.6), 24 November 1976 Caldiran (Ms=7.5), and 23 October 2011 Van (Mw=7.1) earthquakes were destructive and revealed that the faults in eastern Anatolia are capable to generate major events.

The October 23, 2011 Van-Ercis Earthquake (Mw=7.1) was the most devastating resulting in loss of life and destruction. The Van Earthquake activity initiated and caused an increase in seismic activity of the region. Van Earthquake and its important aftershocks fault mechanism solutions show that the region is under compression and reverse faulting is a result of this regime which is effective on the active compressional tectonics of the region.

The earthquakes generated significant amount of data that will be used in seismic tomographic inversion studies to determine a 3D velocity structure. The aim is to determine velocity and crustal structure of Karliova Triple Junction and surrounding area.

This study is supported by B.U Research Fund, with project number 6040.

Keywords: Karliova Triple Junction, Yedisu segment, seismic gap, aftershocks, compressional tectonics

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SCG07-03 Room:106 Time:May 21 09:45-10:00

Inclusion mineralogy in extreme thermal conditions and its implication to the evolution of deep continental crust

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The history of recycling of shallow crustal material to deep crust and its return journey to the shallower depths is recorded in the high-grade metamorphic rocks, in particular those suffered extreme conditions of crustal metamorphism. The study of such rocks provides important information regarding the overall evolution of continental crust and physico-chemical processes operative during orogenesis. However, the record of the early part of this evolutionary history is often blurred due to faster reaction kinetics during the prograde history. The melt-generated at the deep crustal interior and their relative mobility from the protolith is considered to be one of the factors of preservation of near-peak metamorphic assemblages. Nevertheless, our experience shows that major portion of the deep crustal metamorphosed rocks is mostly retrogressed, though some patches of ”preserved” near-peak assemblages do exist. Hence, major information of tectonothermal evolution reconstructed from rocks of particular bulk composition (*e.g.*, aluminous metapelitic granulite) is mostly restricted from peak to post-peak metamorphic conditions.

However, evidences of near-peak to pre-peak metamorphic conditions are rare in granulites, particularly those suffered extreme thermal conditions of metamorphism at deep continental crust. Reconstruction of this prograde history is important to understand the overall tectonic evolution of the deep crust. Careful studies of high temperature to ultra-high temperature granulites, in recent years reveal that the porphyroblastic phases produced at near-peak conditions can include many coexisting to preexisting mineral phases. Detailed microscopic to submicroscopic textural analyses and mineral chemical characteristics of these included phases and intergrowths provide important information regarding the pressure-temperature-fluid conditions of the early metamorphic history *i.e.*, part of prograde to peak metamorphic conditions. Garnet and orthopyroxene porphyroblasts in aluminous granulites and their included phases as well as inclusions in zircon grains proved to be extremely helpful in this regard.

Keywords: Inclusions in porphyroblasts, Retrieving early metamorphic history, HT-UHT granulites

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SCG07-04 Room:106 Time:May 21 10:00-10:15

Intracrystalline plastic deformation of chromite: a case study on dislocation creep mechanisms

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Detailed microstructural observations on natural chromite samples from the Sittampundi Layered Anorthosite Complex (SLAC), southern India reveal intracrystalline plastic deformation. The SLAC was formed in Neoarchaean and was subjected to eclogite facies metamorphism ($>$1000 C and $>$20 kbar), later exhumed in the latest Neoproterozoic-Cambrian. Before this study diffusion creep has typically been considered as the principal deformation mechanism in chromites. We describe three dislocation creep regimes in this mineral that produced distinctive microstructures with increasing temperature. The plastic deformation commences with grain boundary bulging recrystallization in regime 1. At relatively higher temperatures diffusion controlled strain accommodating mechanisms take over. Regime 2 is characterized by formation of new high angle grain boundaries and it corresponds to subgrain rotation recrystallization followed by nucleation of dislocation-free new grains in regions of high strain. At more elevated temperature the dominant accommodating mechanism switches over to recrystallization accommodated dislocation creep in regime 3 from the recovery accommodated one in the earlier regime. This corresponds to grain boundary migration recrystallization. The movement of high angle grain boundaries through strained grains in this creep regime provides high diffusivity paths for the rapid exchange of components which may produce compositional heterogeneity in the recrystallized grains.

Keywords: Spinel, Plastic deformation, dislocation creep

SCG07-05 Room:106 Time:May 21 10:15-10:30

Precipitation and dissolution of chromite by hydrothermal solutions: new behavior of Cr and chromi

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Chromite is one of typical refractory igneous minerals, precipitated from mafic magmas at relatively high temperatures. Chromites commonly occur in sedimentary, metamorphic and metasomatic rocks, where they are interpreted as relics of an igneous phase and serve as the source of Cr for low-temperature Cr-bearing minerals. We present evidence for nucleation of chromite within hydrothermal solution. We found minute euhedal chromite grains enclosed by uvarovite in a diopsidite, metasomatically replacing layered gabbro of the Oman ophiolite. The uvarovite shows oscillatory concentric zoning in terms of Cr# (= Cr/(Cr + Al)), and the chromite is embedded only in the high-Cr# zones of the uvarovite. Another diopsidite, replacing peridotite in the underlying upper mantle section, contains xenocrystal chromite, which is in part dissolved. These probably indicate that a hydrothermal solution collected Cr by digestion of chromite within the mantle and precipitated chromite with high-Cr# uvarovite within the lower crust upsection. The metasomatic agent involved was CO2- and SO2-bearing hydrothermal solution containing appreciable silicate components, and could carry Cr via carbonate and/or sulfate complexes. The hyrothemal chromite is similar in chemistry to commonly found igneous one (e.g., Cr# = 0.8, Mg/(Mg + Fe^{2+}) = 0.13, TiO_2 $<$0.3 wt% and Fe^{3+}/(Cr + Al + Fe^{3+}) $<$0.2), but its Cr# is clearly different from that (0.6-0.7) of mantle chromite in peridotites and chromitites from the Oman ophiolite. We should re-consider the origin of some chromites in rocks that involved hydrothermal activity in genesis. Even hydrothermal chromitite is possible if chromite grains are effectively concentrated.

Keywords: chromite, hydrothermal solutions, uvarovite, diopsidite, Oman ophiolite

SCG07-06 Room:106 Time:May 21 10:30-10:45

Mantle convection simulation with subducted continental materials as a heat source

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Geological studies have suggested that significant amount of granitic crustal materials have been lost from the surface. According to recent numerical studies, most of the granitic materials subducted at ocean-margin subduction zones from the surface are expected to be conveyed through subduction channels by viscous drag from the surface to 270km depth. In addition, the subducted crustal materials might be trapped in the mid-mantle owing to the density difference from peridotitic materials induced by the phase transition from coesite to stishovite at 270km depth. In other words, strong heat source materials are most likely to be accumulated around the mantle transition zone, at least, near the plate subduction zones.

In this study, we conduct numerical experiments of mantle convection with subducted continental materials as a chemically distinct heat source at the bottom of the mantle transition zone together with a laterally drifting motion of a surface supercontinent. The simulations deal with a time-dependent convection of fluid under the extended Boussinesq approximation in a model of a two-dimensional rectangular box. We found that the addition of the heat source considerably reduces the time scale of continental drift.

Keywords: continental crust, subduction channel, mantle convection simulation, continental drift

SCG07-07 Room:106 Time:May 21 11:00-11:15

Role of jadetites in subduction zones: key to understand arc magma source

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Magmas erupted above subduction zones show the characteristic chemical compositions which are reflected mixing in the magma source region among hydrous fluids derived from the subducted oceanic crust, subducted sediments and mantle rocks. In the study of jadeite - quartz rocks within serpentinite melanges in the Yorii area of the Kanto Mountains, Japan, we found high concentrations of Zr and Nb, with low LILE (large ion lithophile elements) concentrations. The jadeite - quartz rocks were formed in the Jurassic subduction zone. Typical arc volcanic rocks are depleted in the HFSE, therefore some material should preferentially take such elements. We considered that jadeite-quartz rocks may have undergone processes that increased HFSE (high field strength elements) concentrations the rocks by subduction related fluids prior to those upward migration to the mantle wedge. Although these jadeite-bearing rocks are rare on the surface, they could be abundant in or above subducted slabs. Jadeite-bearing rocks could be a key to understand the mechanism for mixing and transport of these components.

Keywords: jadeite, Yorii, Jurassic accretionary complex

SCG07-08 Room:106 Time:May 21 11:15-11:30

Tectonometamorphism of the high-grade Barrovian zones of the Scottish Highlands

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The Barrovian zones in Scottish Highland are the type locality for a intermediate P/T metamorphic belt, defined as the root zone of a collision zone (e.g. Miyashiro, 1973). The nature of the collision zone metamorphism has been re-interpreted following the discovery of UHP minerals throughout the world (e.g. Maruyama et al., 1996). It is becoming increasingly realized that the metamorphic zonation of many orogenic belts is a product of retrograde hydration after UHP or HP metamorphism. However, little research has studied the Barrovian zone metamorphism in terms of retrograde hydration at the exhumation stage or UHP metamorphism due to collision. Here we would like to represent our preliminary description of the high-grade Barrow zones from the view- point of retrograde hydration.

Three hundred and sixty four rock samples were collected from the high-grade Barrovian zones (staurolite, kyanite and sillimanite). Mineral textures and assemblage were identified under the microscope, SEM-EDS and EPMA. Inclusion minerals in garnets were also identified using Laser-Raman. In the staurolite zone, staurolite was not recognized in metapelites and amphibolites. In the amphibolites, biotite and garnet occur with chlorite. In the kyanite zone, abundant chlorite occurs in all specimens. Staurolite, kyanite and tourmaline are present in some amphibolites. In the sillimanite zone, sillimanite is scarcely recognized, although Vorhies (2011) identified it.

Chemical zonation of garnets and mineral inclusions in garnets are useful to decipher the P-T trajectory of prograde and retrograde metamorphism. However, most garnets from the amphibolites are strongly deformed and fragmented. The garnets in metapelites are relatively smaller and inclusion-free. Therefore, a P-T path cannot be easily deciphered from the zonation of the garnets. The presence of chlorite with garnet in the whole studied area indicates that retrograde hydration had consumed garnet to form chlorite. Based on pseudo-section analysis, the metamorphic P-T conditions will be discussed.

Post-collision TTG due to subduction of Dalradian under inter-oceanic island arc has a wide distribution Barrovian zone in Scottish highland. UHP-HP records has been overprinted by TTG intrusion. Radiometric ages Dalradian metamorphic minerals range in a long time span from 520Ma to 390Ma (Oliver et al, 2000). Because of thermal effects by TTG intrusion mainly occurred at 430- 380 Ma (Oliver, 2008). Most Collision orogens do not have TTG pluton hence UHP-HP records tend to be remained.

In addition to Abundant tourmaline overgrows evident in Ky zone. Extensive hydration events are ubiquitous over sillimanite to garnet zones, and presumably due to late stage after progressive metamorphism.

Barrovian metamorphism is not progressive at all as described above. There are three stage summarized as follows. First, Barrovian metamorphism in Scottish highland is collisional metamorphism at 520-480 Ma. Second, retrograde hydration at the mid- crastal depth occurred at 480-460 Ma. Third, overprinting of granite contact metamorphism occurred at 430-380 Ma.

Keywords: Barrovian zone, UHP, Overprinting

SCG07-09 Room:106 Time:May 21 11:30-11:45

Composite metamorphic history recorded in garnets of Sambagawa metapelites in the Besshi region, central Shikoku, Japan

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Sedimentary rocks are one of the main components of subducted slabs, in which dehydration and recrystallization processes significantly control the chemical compositions of metamorphic fluids, and consequently driving the geochemical evolution of the wedge-mantle in trench-arc systems. As such, the elucidation of metamorphic history of metapelites or metapsammite is important to help reveal mass transfer processes in the subduction zones. In the Besshi region of the Sambagawa belt, the eclogite assemblage of garnet + omphacite + quartz occurs sporadically in metabasalt-metagabbro complexes of the high-grade zone. On the other hand, the evidence of high-pressure (e.g., omphacite) from the metasedimentary rocks is rare, and it has been assumed that the sedimentary rocks had not subducted deep underground. However, there is a possibility that most evidence for high-pressure metamorphism was recrystallized and disappeared during the retrograde metamorphism because metasedimentary rocks contain abundant hydrous minerals. Therefore, we focused on garnets, which are expected to preserve information from prograde metamorphism. We analyzed the chemical zoning of garnet grains, and measured the residual pressure of quartz inclusions in garnets by Raman spectroscopy.

In the metapelites in the Besshi region, garnet grains commonly show ”composite zoning”, defined by a slight increase in spessartine in the mantle part and an increase in grossular in the rim part. Garnet grains showing ”Mn bell-shaped normal zoning”, which is the most common garnet zoning type of Sambagawa metapelites are less common in the Besshi region. These data imply that the metapelites in the Besshi region had experienced different metamorphic histories compare to those in other areas. In addition, some quartz inclusions in the core to mantle part of the composite zoned garnets preserve high residual pressures, corresponding to those of eclogite samples. This high residual pressure is converted into metamorphic pressure of around 1.5-2.0 GPa in the temperature range of 300-600 ^{o}C, following the numerical calculation of the quartz Raman barometer. This pressure condition is significantly higher than those of the common Sambagawa metapelites, estimated using a conventional geothermobarometer, and this pressure corresponds to the estimation for eclogitic metabasites. In addition, omphacite rarely occurs as inclusions in the composite zoned garnets; equilibrium condition was estimated at 1.7-1.9 GPa/470-530 ^{o}C using the garnet-clinopyroxene-phengite geothermobarometer. These results indicate that most metapelites containing composite zoned garnet in the Besshi region had been subducted to the high-pressure corresponding to the eclogite facies with metabasic rocks. On the other hand, quart grains preserving a lower residual pressure than those in the core part were found in the rim part of the garnet. This low residual pressure corresponds to a metamorphic pressure of around 0.8-1.2 GPa in the temperature range of 300-600 ^{o}C. This garnet rim part probably grew at the epidote-amphibolite facies metamorphism that recrystallized the Sambagawa metamorphic rocks and formed the regional thermal structure of the Sambagawa belt.

The prograde metamorphic history of the Sambagawa metapelites in the Besshi region was discussed, through comparison of the chemical zoning of garnet and the distribution of residual pressure of quartz inclusions. These data suggest that (1) more sedimentary lithologies had been subducted deep underground corresponding to the eclogite facies condition than conventionally expected, and (2) sedimentary rocks are an important source to supply fluids and/or light elements to the mantle in past and also present subduction zones.

Keywords: Sambagawa belt (Sanbagawa belt), metapelite, Raman spectroscopy, garnet, quartz, residual pressure

SCG07-10 Room:106 Time:May 21 11:45-12:00

P-T-t evolution of pelitic gneiss in the Lhenice shear zone (Moldanubian Zone of the southern Bohemian Massif).

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The Moldanubian Zone of the Bohemian Massif is a unique metamorphic belt, as both ultrahigh-pressure (UHP) and ultrahigh-temperature (UHT) metamorphic rocks are exposed together. The occurrences of UHP metamorphic rocks have been reported from several areas of the Moldanubian Zone (e.g. Becker and Altherr, 1992; Becker, 1996; Kotkova et al., 1997; Vrana and Fryda, 2003; Nakamura et al., 2004; Kobayashi et al., 2008; Faryad, 2009; Naemura et al., 2009a, b, 2011; Kotkova et al., 2011). Recently, multiple equilibrium stages were identified from Grt-rich gneiss at Ktis in the Lhenice shear zone, located along the western margin of the Blansky les massif (Kobayashi et al., 2011). The characteristic matrix mineral assemblage of the Grt-rich gneiss is Crd + Sil + Bt + Grt +/- Spl with Qtz + Kfs +Pl. Ky is only identified as an inclusion phase in the rim of Grt. Tiny CO_2-N_2 fluid inclusions are abundant in the core of Grt but are free from in the rim. The geothermobarometory, based on the mode of occurrence of constituent minerals and the zoning pattern of Grt, depicts the following developing history of the host rock, such as a prograde stage defined by the assemblage of Grs-rich Grt core (Grs=27) + Pl (An_{11-15}) under 1.5-2.3 GPa at 700-900 ^oC (Stage 1), a subsequent Grt-rim forming stage represented by Ca-poor Grt (Grs_5) + Pl (An_{12-19}) + Ky/Sil at 730-830 ^oC and 1.0-1.3 GPa (Stage 2), and a following decompression stage by the outermost rim of Grt (Grs_2) + Sil + Crd +/- Spl at 740-850 ^oC and 0.6-0.8 GPa (Stage 3) (Kobayashi et al., 2011). To evaluate ages of multiple equilibrium stages, chemical Th-U-Pb isochron method (CHIME) Mnz age dating was carried out for Grt-rich gneiss. Mnzs included in the core of Grt show bimodal grain size; coarse-grained (1 mm in diameter) and fine-grained (10 micrometer in diameter). Mnzs included in the rim of Grt have fine-middle grained size (10 micrometer to 0.5 mm in diameter). Mnzs in the matrix have middle-coarse grained size (0.5 mm to 3 mm in diameter). Most of middle-coarse grained Mnzs show a chemical zoning; relatively low Th constant in the core and high Th content in the rim. The Mnz grains included in the core of Grt give an average age of 337.2+/-4.2 Ma. The Mnz grains included in the rim of Grt give that of 336.5+/-5.1 Ma. The Mnz grains in the matrix give 334.9+/-3.9 Ma. Similar ages around 340 Ma are reported by U-Pb zircon ages of high-pressure granulite (e.g. Aftalion et al., 1989; Kroner et al., 2000; Slama et al., 2008) in the southern part of the Bohemian Massif. These results suggest that the studied rock experienced very fast exhumation from stage 1 to stage 3. Furthermore, felsite inclusions are found from the core and rim of coarse-grained Grt. Felsite inclusions are composed mainly of micrometre- to submicrometre-scale spherulitic and granophyric intergrowths of quartz and feldspar (alkali feldspar or plagioclase). These features of the inclusions are similar to those of "nanogranites" which are felsic inclusions enclosed within Grt in high- to ultrahigh-temperature pelitic migmatites and/or granulites as reported by Cesare et al. (2009) and Hiroi et al. (2011). Cesare et al. (2009) concluded that nanogranites are the crystallized anatectic melts which were trapped by peritectic minerals growing during partial melting. The felsite inclusions in this study suggest that partial melts formed during early high-pressure metamorphic stage (stage 1) and trapped by garnet have undergone nonequilibrium crystallization under specific conditions of continuous rapid cooling.

Keywords: Bohemian Massif, Gneiss, Monazite age, Partial melting, Fast exhumation, Rapid cooling

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SCG07-11 Room:106 Time:May 21 12:00-12:15

Variation and significance of chemical zoning pattern of garnet in Nove Dvory eclogoite, Moldanubian Zone of the Bohemia

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Nove Dvory eclogite recorded extremely high-P/T conditions, 4.5-4.9 GPa/1100oC (Nakamura et al., 2004). In spite of such high-T conditions, various zoning patterns of garnet are identified from the eclogite, i.e., homogeneous, pyrope-increasing with constant grossular content, pyrope-decreasing with constant grossular content, and grossular-increasing with constant almandine content (Nakamura et al., 2004). The preservation of such zonings infers the short duration of UHP metamorphism and subsequent granulite facies overprinting (Nakamura et al., 2011). The present study found a new type of garnet zoning from a Nove Dvory eclogite, i.e., grossular increasing and almandine decreasing type. Studied samples, collected from an outcrop with 1.5 x 3.0 m in a vertical cliff, can be classified into kyanite-bearing and kyanite-free eclogite. kyanite-free eclogites are characterized by higher modal amount of garnet, ca. $>$ 60 vol %. Another main UHP phase is omphacite along with minor apatite. Pargasitic amphiboles are commonly identified as primary inclusions in several garnet grains. Garnet and omphacite were decomposed to kelyphite and symplectite, mainly composed of plagioclase, biotite, amphibole, spinel, corundum and K-feldspar, with various degrees. Main UHP minerals in kyanite-bearing eclogites are also garnet and omphacite with subordinate amount of kyanite and apatite with or without SiO2 phase. Break-down products of garnet and omphacite are plagioclase, biotite, spinel amphibole, clinopyroxene, and orthopyroxene suggesting that the host eclogite experienced a granulite facies overprinting during the exhumation. The both types of eclogites contain garnets showing the new zoning type, but they show following distinct chemical characters, i.e., garnet is almandine-richer and omphacite is jadeite-richer in the kyanite-free eclogite than those in the kyanite-bearing eclogite. The new type garnet grains in the kyanite-free eclogite vary their compositions from Alm35-43Prp30-35Grs30 in the core to Alm35Prp30Grs35 in the rim, instead those in the Ky-bearing eclogite vary their compositions from Alm30Prp40-45Grs25-30 in the core to Alm20-25Prp30-33Grs45-50 in the rim. These zoning patterns are generally identified in coarse-grains with $>$ 2 mm in diameter. The core composition of fine-grained garnet ($<$2mm in diameter) is almost identical with the rim composition of coarse-grains. Most of garnet grains decrease their grossular content to partially developed outer most rim, to Alm33Prp33Grs33 in the kyanite-free eclogite and to Alm25-32Prp30-33Grs35-45 in the kyanite-bearing eclogite. Jadeite and Ca-tschermakite content of omphacite inclusions in garnet of the kyanite-free eclogite are 0.43-0.48 an d 0.02-0.04, respectively, and those of the kyanite-bearing eclogite are 0.25-0.38 and 0.04-0.05, respectively. There was a controversy on the origin of eclogite, high-P cumulate (Medaris et al., 1995) or low-P gabbro (Obata et al., 2006). These chemical characters obtained by this study also suggest that the studied eclogite has experienced the subduction as pointed out by Nakamura et al. (2004), and that compositions of garnet and omphacite in both types of the eclogite reflect differences in bulk compositions of the protolith. Thus, the protolith of kyanite-bearing eclogite should be derived from more primitive rock and that of the kyanite-free eclogite should be more differentiated one. The peak P-T conditions of the studied kyanite-bearing eclogite was estimated to be 4.1-4.3 GPa and 900-940oC by garnet-clinpyroxene-kyanite-SiO2 phase geobarometer of Nakamura and Banno (1997) and garnet-clinopyroxene geothermometer of Nakamura (2009), and the equilibrium temperature of kyanite-free eclogite was estimated to be 1070-1080oC assuming the pressure within 4.1?4.3GPa. These estimates are lower than those of Nakamura et al., (2004), i.e., 4.5-4.9 GPa and 1050-1150oC, probably caused by the serious comoisition modification of omphacite.

Keywords: UHP eclogite, Bohemian Massif, Garnet, Compositional zoning

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Rare-earth and trace element characteristics of pseudomorphs after lawsonite in Tlc-Grt-Cld schists of Makbal Complex

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Lawsonite [CaAl2Si2O7(OH)2.H2O] is a critical hydrous mineral that formed at high-pressure (HP) and low-temperature (LT) metamorphic conditions in oceanic subduction zones. It can be stable in a wide pressure-temperature (P-T) range with reaching ultrahigh-pressure (UHP) conditions (up to 300 km depth) as suggested by experimental data (Pawley, 1994; Schmidt, 1995) and thermodynamic modeling (Clarke et al., 2006; Wei & Powell, 2006). However, most of natural occurrences of lawsonite and its pseudomorphs are reported mainly from the blueschist facies metamorphic rocks and their presence in a HP-UHP eclogite-facies rocks is rare (Tsujimori et al., 2006). Lawsonite pseudomorph is identified because of their square to lozenge shape and its breakdown products (mainly epidote, paragonite, chlorite, kyanite). Despite such reports, the reactions behind the formation of lawsonite pseudomorph are not clearly resolved, and in fact, the origin of Ep + Pg + Chl assemblages after lawsonite is debated (Shelly & Bossiere, 1999).

We present a potential way to confirm the previous existence of lawsonite using trace element compositions of the clinozoisite in the multiphase solid inclusions (MSI) of clinozoisite + paragonite + chlorite in garnets of talc-garnet-chloritoid (Tlc-Grt-Cld) schists in Makbal complex. Lawsonite can contain considerable amounts of trace and rare-earth elements (REE) and therefore the pseudomorphic minerals (especially epidote/clinozoite) may inherit the trace element pattern after lawsonite (Spandler et al., 2003). With this scenario in mind, we have performed LA-ICP-MS trace element analysis on the clinozoisite in MSI. The outline of MSI (up to 0.1 mm in size) shows idiomorphic-prismatic shapes and mainly consist of Czo +/- Pg +/- Qtz +/- Ky +/- Mrg, Czo + Pg +/- Chl and Czo + Cld +/- Pg +/- Chl. The estimated/reconstructed bulk compositions of MSI indicate that MSI can be originated from former lawsonite, which can be stable under peak UHP stage.

The trace element compositions of clinozoisite in MSI of clinozoisite + paragonite + chlorite and host garnet were analyzed in-situ on polished thin-sections using LA-ICP-MS at Kyoto University. The spot size was 35 micrometer. The acquisition time for background and samples were 60 sec and 180 sec, respectively. NIST610 and BCR2G glasses are used as external standard, whereas 44Ca as internal standard. Iolite software package is used for data reduction (Paton et al., 2011).

The results show low Sr (710-880 ppm) and moderate contents for LREEs (49-76 ppm for La). The sample/chondrite and sample/primitive mantle normalized diagrams show that trace and REE pattern of clinozoisite in our study is very similar to lawsonite pattern previously reported worldwide (Spandler et al., 2003; El Korh et al., 2009; Martin et al., 2011).

This new data suggest that lawsonite was stable along with garnet, chloritoid, talc and glaucophane at peak-UHP stage and it was decomposed to Czo + Qtz +/- Ky +/- Pg +/- Chl during the isothermal decompression, overstepping the following mineral reactions, such as Lws = Zo + Ky + Qtz + H2O, Gln + Lws = Zo + Pg + Chl + H2O and Grt + Lws = Zo + Cld + H2O. According to petrogenetic grid for NCKFMASH system (Wei & Powel, 2006), these mineral reactions combined with Carp = Tlc/Chl + Ky and Cld = Grt + Ky reactions define the P-T conditions for lawsonite decomposition as 16-22 kbar and 510-590 oC. The micro-cracks radiating from MSI may imply the possible pathway of fluids released due to the breakdown of lawsonite during decompression.

We suggest that the identifying trace element compositions of constituent minerals of MSI that regarded as pseudomorphs after lawsonite can be effective tool in confirmation of the previous existence of lawsonite.

Keywords: lawsonite, trace elements, UHP metamorphism, Makbal, Kyrgyzstan