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SCG07-01 会場:106 時間:5 月 21 日 09:15-09:30

北上花崗岩の軸面劈開を伴う褶曲によるエクスヒューム
Folding of Kitakami granite and exhumation associated with regional-scale flexural slip folding and ridge subduction

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Journal of Asian Earth Sciences, 59, 85-98, 2012 に基づく。

北上山地の白亜紀花崗岩から、黒雲母を軸面劈開としてもつ非対称褶曲を発見した。褶曲は大船渡のこの地点以外見られないが、再結晶した黒雲母からなる構造的なフォリエーションは北上山地のみならず、例えば、徳之島の花崗岩でも確認した。片麻岩はこのようにしてできるかも知れない。またフォリエーションができて、花崗岩はエクスヒュームする。なお、大型の線形加速器である ILC が計画されている北上山地の千厩・人首岩体にも、フォリエーションが発達し、両岩体の瓢箪形のくびれは東西圧縮によって生じたブーディンと判断される。構造的な変形部分は弱線として再動、地震を引き起こし、変形した花崗岩地盤は必ずしも安定でない。

キーワード: 北上花崗岩プルトン, アプライトマーカー、非対称褶曲, 軸面フォリエーション、二次的黒雲母, 接触変成、層面滑り背斜, 高角不整合、エクストルージョン、エクスヒューム, アダカイト、海嶺沈み込み
Keywords: Kitakami granitic pluton, aplite marker, asymmetric fold, axial planar foliation, biotite, aureole, flexural slip anticline, tilted unconformity, extrusion, exhumation, adakitic magmatism, ridge subduction

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SCG07-02 会場:106 時間:5 月 21 日 09:30-09:45

AN OVERVIEW OF SEISMOTECTONIC PROPERTIES OF EASTERN ANATOLIA
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.

キーワード: Karliova Triple Junction, Yedisu segment, seismic gap, aftershocks, compressional tectonics
Keywords: Karliova Triple Junction, Yedisu segment, seismic gap, aftershocks, compressional tectonics

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SCG07-03 会場:106 時間:5 月 21 日 09:45-10:00

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

キーワード: Inclusions in porphyroblasts, Retrieving early metamorphic history, HT-UHT granulites
Keywords: Inclusions in porphyroblasts, Retrieving early metamorphic history, HT-UHT granulites

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SCG07-04 会場:106 時間:5 月 21 日 10:00-10:15

クロミタイトの塑性変形：特に転位クリープによる変形
Intracrystalline plastic deformation of chromite: a case study on dislocation creep mechanisms

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スピネルの転位クリープによる塑性変形メカニズムについて、天然試料からの観察に基づいて考察した。

キーワード: スピネル, 塑性変形, 転位クリープ
Keywords: Spinel, Plastic deformation, dislocation creep

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SCG07-05 会場:106 時間:5 月 21 日 10:15-10:30

熱水によるクロマイトの晶出および融解：クロムおよびクロミタイトの新たな振る舞い
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.

キーワード: クロマイト, 熱水, ウバロバイト, ディオプシダイト, オマーン・オフィオライト
Keywords: chromite, hydrothermal solutions, uvarovite, diopsidite, Oman ophiolite

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SCG07-06 会場:106 時間:5 月 21 日 10:30-10:45

沈み込んだ大陸地殻物質の熱源を含むマントル対流計算
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.

キーワード: 大陸地殻, サブダクションチャネル, マントル対流計算, 大陸移動
Keywords: continental crust, subduction channel, mantle convection simulation, continental drift

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SCG07-07 会場:106 時間:5 月 21 日 11:00-11:15

沈み込み帯におけるヒスイ輝石の役割
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, therefor 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

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SCG07-08 会場:106 時間:5 月 21 日 11:15-11:30

スコットランド高地のバロウ型累進変成帯における変成岩の研究
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

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SCG07-09 会場:106 時間:5 月 21 日 11:30-11:45

四国中央部別子地域に分布する三波川変泥質岩中のザクロ石に記録された複合変成履歴
Composite metamorphic history recorded in garnets of Sambagawa metapelites in the Besshi region, central Shikoku, Japan

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四国中央部別子地域に分布する三波川変成帯には，地下約 30 km 以深の深部で形成される鉱物組合せ（オンファス輝石＋ザクロ石＋石英）を保持するエクロジャイトが点在する大規模な変塩基性岩体があり，地下深部の情報が比較的良好な状態で保持されている．一方，それらの岩体の周りに広く分布する変泥質岩からは，高圧の証拠となるオンファス輝石の報告が極めて稀である．そのため，深部まで沈み込んだ岩石は海洋プレート起源の変塩基性岩のみであると考えられてきた．ただし，堆積物起源の変泥質岩は含水鉱物を多く含み，後退変成作用時の影響を受けやすいため，深部まで沈み込んでいたとしても，その情報が消えてしまっている可能性もある．変泥質岩はマントル物質とは著しく異なる全岩組成を有しており，また三波川帯の大部分を占めているため，堆積物がどのくらいの深部までどの程度の量が沈み込んでいたかを確認することは，マントルの地球化学的進化を考える上でも，また変成帯の上昇プロセスを議論する上でも極めて重要である．本研究では，累進変成作用時の変成履歴を比較的よく保持していると考えられるザクロ石に注目し，その化学組成累帯構造と包有されている石英が保持している残留圧力を分析し，別子地域の変泥質岩の変成履歴を検討した．

別子地域の変泥質岩中に含まれるザクロ石の化学組成累帯構造を分析した結果，多くのザクロ石は三波川帯で一般的とされている Mn がコアからリムへ単調に減少する「Mn ベル型累帯構造」ではなく，マントル部分で Mn が微増し，リムで Ca が増加する「複合累帯構造」を示した．これは，この地域の変泥質岩が他の地域のものとは異なる変成履歴を経験した可能性を示唆している．さらに，そのようなザクロ石に包有されている石英が保持している残留圧力を測定した結果，エクロジャイト中に包有されている石英の残留圧力と同程度の高い値を示す石英が多くの変泥質岩から見出された．高い残留圧力を保持している石英はザクロ石のコアからマントル部分に含まれている事が多く，石英ラマン圧力計の数値計算によるとこの残留圧力値は，300 ºC から 600 ºC の範囲では 1.5-2.0 GPa の圧力条件に相当する．これは，従来の変泥質岩で見積もられている温度圧力条件（緑簾石-角閃岩相程度）よりも有意に高い圧力条件である．また，ごく稀にではあるが，複合累帯構造を示すザクロ石中からオンファス輝石が見出され，Garnet-clinopyroxene-phengite 地質温度圧力計を用いると，1.7-1.9 GPa/470-530 ºC の平衡条件が見積もられた．これらの結果から，別子地域の多くの変泥質岩は，塩基性岩と共にエクロジャイト相程度の地下深部まで沈み込んだ可能性が示唆された．一方，ザクロ石のリム付近に含まれる石英の残留圧力はコアーマントル部よりも有意に低い値を示し，残留圧力値から推定される変成圧力は，300 ºC から 600 ºC の範囲では 0.8-1.2 GPa 程度である．これは，ザクロ石がエクロジャイト相程度の高圧条件下で成長したのち地表に上昇する際，その時沈み込んできたスラブとカップリングし，緑簾石-角閃岩相程度の条件下で再びザクロ石が成長した時期の記録であると考えられる．

ザクロ石の成長に伴う化学組成の変化とそこに含まれる石英の残留圧力の分布を比較する事で，今まで復元が難しかった変泥質岩の累進変成作用時の変成履歴を明らかにした．そして，別子地域の変泥質岩の多くはエクロジャイト相程度の地下深部まで沈み込んでいた可能性が高い事が明らかになった．これらの結果は，従来の想定よりも多くの堆積物が地下深部まで沈み込み，マントルに水や元素を供給する重要な供給源になっている事を示唆している．

キーワード: 三波川帯, 変泥質岩, ラマン分光法, ザクロ石, 石英, 残留圧力
Keywords: Sambagawa belt (Sanbagawa belt), metapelite, Raman spectroscopy, garnet, quartz, residual pressure

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ボヘミア山塊に産する泥質片麻岩の変成温度圧力時間履歴
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 (UH*P*) and ultrahigh-temperature (UH*T*) metamorphic rocks are exposed together. The occurrences of UH*P* 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 ^{o}C (Stage 1), a subsequent Grt-rim forming stage represented by Ca-poor Grt (Grs_5) + Pl (An_{12-19}) + Ky/Sil at 730-830 ^{o}C 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 ^{o}C 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.

キーワード: ボヘミア山塊, 片麻岩, モナザイト年代, 部分溶融, 急上昇, 急冷
Keywords: Bohemian Massif, Gneiss, Monazite age, Partial melting, Fast exhumation, Rapid cooling

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ボヘミア山塊 Moldanubian 帯 Nove Dvory 産エクロジャイト中のざくろ石組成累帯構造の多様性とその意義
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.

キーワード: UHP エクロジャイト, ボヘミア山塊, ざくろ石, 組成累帯構造
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

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.

キーワード: lawsonite, trace elements, UHP metamorphism, Makbal, Kyrgyzstan
Keywords: lawsonite, trace elements, UHP metamorphism, Makbal, Kyrgyzstan

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片状組織を有するアンチゴライト蛇紋岩の強度
Strength of foliated antigorite serpentinite

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The trench parallel seismic anisotropy is demonstrated by recent seismological data. This phenomenon is tried to be explained by lattice preferred orientation (LPO) of plastically deformed antigorite serpentinite potentially existed in the mantle wedge and along the subducting oceanic plate. The rocks with LPO have generally well-developed foliation and lineation. In fact, naturally deformed antigorite serpentinites normally have such structure with LPO. The foliated rocks show a great amount of anisotropy of mechanical behavior. In this research, the anisotropic strength behavior of foliated antigorite serpentinite is studied through deformation experiment. In addition we observe the microstructures of recovered samples to clarify the plasticity of antigorite serpentinite.

We have conducted constant strain rate experiments on foliated antigorite serpentinite, collected from Happo ultramafic complex. This foliated antigorite serpentinite has a LPO characterized by [010] and (001) density maximum subparallel to lineation and foliation, respectively. The starting samples were cylinder with ca. 5 mm in diameter and ca. 8 mm in length. They were grouped in three types, as that the foliations were oriented at 0, 30 and 90 degrees with respect to the axial stress. The angle between the axial stress direction and foliation is named as orientation angles, B. The direction of lineation in the cylinders of B = 0 and 30 degrees was oriented parallel to maximum shear stress. Experimental conditions were 500 C of temperature and 1 GPa of confining pressure with a constant strain rate of ca. 1.7 x 10^{-5} /s.

Our mechanical data demonstrate that the strength of foliated antigorite serpentinite exhibits significant anisotropic behavior. Based on the microstructural observations of the recovered samples, the plastic deformation of antigorite serpentinite is proceeded probably by (001)[010] slip. We do not now get any evidence of the other slip systems rather than (001)[010]. This fact suggests that the deformation of antigorite serpentinite can not satisfy the von Mises criterion for creep. If this is true, the antigorite serpentinite can not be deformed to large strain by dislocation creep, which means that LPO does not develop during deformation. Therefore the idea of antigorite serpentinite with LPO existed in the mantle wedge and along the subducting oceanic plate can not be explained by deformation origin.

Keywords: foliated serpentinite, antigorite, anisotropy, plasticity

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Structural Constraints on the Evolution of the Neoproterozoic Jabal Gerf Nappe Complex (Southeastern Egypt), Arabian-Nub
Structural Constraints on the Evolution of the Neoproterozoic Jabal Gerf Nappe Complex (Southeastern Egypt), Arabian-Nub

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The Jabal Gerf mafic-ultramafic complex (? 40 km diameter) is the largest Neoproterozoic thin-skinned stacked ophiolitic nappe in the entire Arabian-Nubian Shield (ANS). It is situated in Gerf (Southeastern Desert/Aswan) tectonic terrane near the intersection between the NNE-trending Hamizana Shear Zone and the Allaqi-Heiani ophiolitic belt which decorates a segment of the Allaqi-Heiani-Sol Hamed-Onib-Yanbu Suture Zone. The complex comprises metaultramafic melange (locally highly sheared), island arc assemblage (mafic metavolcanics and volcaniclastic metasediments) and layered gabbros. This college is separated along WSW- (SW-) propagated thrust sheets and intruded by syn-to post-tectonic granitoids (sheared tonalite and granodiorite) and dykes. Superimposed and overprinting relations between structural fabrics encountered within this college reveal the effect of at least three phases of Neoproterozoic deformations (D1-D3). D1 formed very tight, intrafolial and transposed folds F1, with NW-SE (NNW-SSE) axial surfaces and NW-moderately-plunging axes (25o-35o N40o-60oW), non-penetrative axial planar foliations S1 (//So) and mineral lineation L1, which resulted from early NW- to NNW- oriented shearing and thrusting. D2 progressively overprinted D1 and was dominated by top-to-the-WSW thrusting and thrust-related folds F2, and penetrative crenulation foliations S2, which are mostly coincident with shearing planes of thrusts (i.e. S2=Sth), as well as mineral-, stretched-, pencil-like-lineations L2. F2 folding axes and L2 lineations are nearly coaxial plunging with axes (38o-42o N20o-25oW). D3 was attenuated phase, producing symmetric open folds with steeply plunging NE- (NNE-) axes F3, non-penetrative foliation S3 and kink axes L3. F3 and L3 are also coaxial, plunging 50o-55o N 25o-35oE. Following the D3, the Jabal Gerf mafic-ultramafic complex and granitoids were affected by a subsequent brittle phase D4 resulted in the formation of NNW-, WNW, NE-, NNE- and E-oriented right- and left-lateral-strike-slip faults. On the strain ellipse model, these faults represent en echelon second order Reidel shear (R1), conjugate Reidel shear (R2) and secondary synthetic shear (P), reflecting an activation of a horizontal principal stress from the SSE direction, most probably due to the movement along the Hamizana Shear Zone.

キーワード: Gerf Nappe, Neoproterozoic deformations, Allaqi-Heiani belt, Southeastern Desert, Arabian-Nubian Shield
Keywords: Gerf Nappe, Neoproterozoic deformations, Allaqi-Heiani belt, Southeastern Desert, Arabian-Nubian Shield

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Post-accretionary Extensional Fault-zone Evolution in Ablah Group Volcanosedimentary Sequence, Western Arabian Shield
Post-accretionary Extensional Fault-zone Evolution in Ablah Group Volcanosedimentary Sequence, Western Arabian Shield

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ABSTRACT

The N-oriented Ablah Basin, in northwestern Asir tectonic terrane in Arabia, is affiliated to the marine post-accretionary depositional basins (MPADBs) of the Arabian-Nubian Shield (ANS). In this basin, a sequence of interbedded sandstone (grading into siltstone)-mudstone-dolostone was deposited synchronized and almost immediately after the Nabitah Orogeny (680-640Ma). This sequence is intercalated with rhyolite that is persistent along strike for distances up to hundreds of meters. The whole succession displays amazing post-accretionary structures produced by an earlier E-W shortening event and encompassing shear zones and shear zone-related folds, and thrusts and thrust-related folds, as well as other transpressive structures. Besides, E-W (to ENE-WSW) striking extensional normal faults are observed. The faults formed during a latest N-S (to NNW-SSE) lengthening event affected the entire Ablah Basin near the end of the Neoproterozoic. The present study highlights results obtained from outcrop investigations of these extensional faults that dip towards the S (to SSE) direction and vary in extension from few millimeters to several meters. Remarkable competence contrast between sandstone, mudstone, dolostone and rhyolites resulted in more complicated fault zones because of the development of secondary localized zones and segmentation-induced fault boudins and host rock lenses. Faults show geometries varying from simple fault cores to complicated fault cores showing a variety of principal deformation elements, such as clay-rich gouge, clay smear, and secondary quartz and carbonate veinlets. Other elements including fault splays, overlapped structures, segmented linkages and slip zones with fault-parallel fabrics are also detectable inside fault cores. Slip zones accommodate the bulk of slip within fault cores. It is suggested that the extensional faults evolved under imposed stress by linkage of pre-existing fractures initiated and nucleated during the earlier E-W shortening event, post-dating the final assembly and suturing between Eastern and Western Gondwana.

キーワード: Ablah Group, Arabian-Nubian Shield, Volcanosedimentary Sequence, East and West Gondwana, Accretion
Keywords: Ablah Group, Arabian-Nubian Shield, Volcanosedimentary Sequence, East and West Gondwana, Accretion