

Metamorphic P-T evolution and fluid inclusion study of Bodonch, Zereg, Sharga and Altai areas, Southwestern Mongolia

ZORIGTKHUU, Oyun-Erdene^{1*}, TSUNOGAE, Toshiaki¹, Batulzii Dash²

¹University of Tsukuba, ²Mongolian University of Science and Technology

The Altai Orogen in the southwestern margin of the Central Asian Orogenic Belt (one of the largest accretionary and collisional orogen in the world) extends from Russia and East Kazakhstan to the west, through Northern China, to southwestern Mongolia to the east. It contains various volcano-sedimentary rocks that were deformed and metamorphosed under various pressure-temperature (P-T) conditions from greenschist to amphibolite and partly granulite facies. We report first detailed petrological and fluid inclusion data of pelitic schists and mafic rocks from Bodonch, Zereg, Sharga, and Altai areas, southwestern Mongolia, which occupy a significant part of the Paleozoic history of the Altai Orogen in the southwestern margin of the Central Asian Orogenic Belt (or Altaids), and discuss P-T evolution of the area.

Zereg, Sharga, and Altai areas contains mafic to ultramafic rocks and pelitic schists with various mineral assemblages such as amphibole + plagioclase + muscovite + chlorite + calcite, serpentine + olivine + chromium spinel + iron oxide, serpentine + olivine + clinopyroxene + talc, chlorite + muscovite + plagioclase + quartz + ilmenite. In the context of traditional terrain tectonics (Badarch et al., 2002) the belt belongs to the Hovd and Dariv terrains and classified as accretionary wedge and metamorphic belt with uncertain tectonic affinity.

Bodonch area contains pelitic schists and amphibolites with various mineral assemblages such as garnet + kyanite + staurolite + biotite + plagioclase, garnet + biotite + staurolite + cordierite, and amphibole + quartz + plagioclase + garnet + ilmenite.

We performed detailed petrologic, geothermobarometric and mineral equilibrium modelling studies on the rocks from Bodonch area and obtained peak P-T condition of 640-690°C /6.3-10.7 kbar and clockwise path from the area. The peak high-pressure amphibolite-facies condition and clockwise P-T evolution of the area estimated for the first time in this study is consistent with available reports of other localities in the Altai Orogen outside Mongolia. Three categories of fluid inclusions have been observed in quartz: dominant primary and secondary inclusions, and least dominant pseudosecondary inclusions. As quartz in the samples are texturally associated with biotite, kyanite, and staurolite, which were probably formed during peak metamorphism, we regard that the primary fluid inclusions trapped in the quartz grains probably preserve peak metamorphic fluids. The melting temperatures of all the categories of inclusions lie in the narrow range of -57.5 to -56.6°C, close to the triple point of pure CO₂. Homogenization of fluids occurs into liquid phase at temperature range between -33.3 to +19.4°C, which convert into densities in the range of 0.78 to 1.09 g/cm³. The results of this study, together with the primary and pseudosecondary nature of the inclusions, indicate CO₂ was the dominant fluid component during the peak amphibolite-facies metamorphism of the study area. Therefore, this is a rare example of CO₂ -rich fluid inclusions trapped in amphibolite-facies rocks.

Keywords: fluid inclusion, mineral equilibrium modeling, Altai Orogeny, Central Asian Orogenic Belt, Mongolia

Fluid and cooling-driven reaction exsolution in garnet porphyroblasts: near-peak history of UHT granulites, EGB, India

DAS, Kaushik^{1*}, TOMIOKA, Naotaka², BOSE, SANKAR³, ANDO, Jun-ichi¹

¹Department of Earth and Planetary Sciences, Hiroshima University, ²ISEI, Okayama University, Misasa, ³Department of Geology, Presidency University, Kolkata, India

Intergrowth textures in porphyroblastic assemblages of granulites are extremely important to decipher the near-peak evolutionary history of deep continental crust undergoing several pulses of orogenic cycles. Eastern Ghats granulite belt of India evolved through Proterozoic orogenic events has occurrences of aluminous granulites and associated quartzofeldspathic gneisses where garnet porphyroblasts contain nanometer- to micrometer-thick ilmenite needles oriented crystallographically. Such garnet porphyroblasts are presumably a product of dehydration melting reaction(s) of Ti-rich phlogopite during the pre-peak metamorphic stage leading to the UHT peak condition. The high oxygen fugacity condition during this stage promoted the enrichment of possible Ti-bearing andradite component in garnet porphyroblasts in appropriate bulk chemistry. In the subsequent post-peak cooling-dominated history with lowered oxygen fugacity, Ti-bearing components of garnet porphyroblasts decomposed to rhombohedral oxide solid solution (ilmenite-hematite). Transmission electron microscopic study of the garnet porphyroblasts and needle-shaped monomineralic ilmenite solid solution indicates that though there is an overall parallelism of [011]* of host garnet and [011]* of ilmenite, structural coherence between the two phases is progressively lost during growth from thin to thick needles. We argue that cooling from high-temperature peak metamorphic condition promoted growth of ilmenite solid solution through reaction-exsolution process within garnet porphyroblasts. Integrated temperature and fO₂ information during deep crustal evolution can thus be retrieved from the detailed petrographic, SEM, EPMA and TEM studies of high-grade granulites.

Keywords: Oriented ilmenite needles, Garnet porphyroblasts, UHT granulites, Reaction-exsolution, EGB, India

Interpretation for geochemical diversity of the Neogene granitoid plutons in the Izu Collision Zone

SAITO, Satoshi^{1*}

¹Research Institute for Humanity and Nature

Neogene granitoid plutons are widely exposed in the Izu Collision Zone in central Japan, where the northern tip of the Izu-Bonin arc (juvenile oceanic arc) has been colliding with the Honshu arc (mature island arc) since middle Miocene. Three main granitoid plutons are distributed in this area: Tanzawa Plutonic Complex (TPC), Kofu Granitic Complex (KGC), and Kaikomagatake pluton (KP). The TPC and southern part of the KGC were intruded in submarine volcanic piles of the Izu-Bonin arc, while the KP and the northern and central parts of the KGC were intruded in Shimanto metasedimentary rocks of the Honshu arc. In this study, I compile geochemical data of these three plutons (Kawate and Arima 1998; Saito et al. 2004; Saito et al. 2007a,b; Saito et al. in press), and propose a petrogenetic model explaining the geochemical diversity of granitoid plutons in the Izu Collision Zone.

The TPC consists of tonalite and trondjemite and characterized by low K₂O contents (< 2.5 wt %), whereas the KP is characterized by relatively high K₂O contents (3-5 wt %) and composed of granodiorite and monzogranite. The rocks of KGC range from tonalite, trondjemite, granodiorite to granite, and show wide variation of K₂O contents (0.5-7 wt %). Previous petrogenetic studies on the plutons have been suggested that (1) the TPC formed by lower crustal anatexis of juvenile basaltic rocks occurring in the Izu-Bonin arc (Kawate and Arima 1998), (2) the KGC formed by anatexis of hybrid lower crustal sources comprising of both basaltic rocks of the Izu-Bonin arc and metasedimentary rocks of the Honshu arc (Saito et al. 2007b), and (3) the KP formed by anatexis of hybrid lower crust consisting of K-rich rear-arc crust of the Izu-Bonin arc and metasedimentary rocks of the Honshu arc (Saito et al. in press). These studies collectively suggest that the chemical diversity within the Izu Collision Zone granitoid plutons reflects the chemical variation of basaltic sources (i.e., across-arc chemical variation in the Izu-Bonin arc) as well as variable contribution of the metasedimentary component in the source region.

References:

Kawate S, Arima M (1998) Tanzawa plutonic complex, central Japan: Exposed felsic middle crust of Izu-Bonin-Mariana arc. *Island Arc* 7:342-358.

Saito S, Arima M, Nakajima T, Kimura J-I (2004) Petrogenesis of Ashigawa and Tonogi granitic intrusions, southern part of the Miocene Kofu Granitic Complex, central Japan: M-type granite in the Izu arc collision zone. *J Mineral Petrol Sci* 99:104-117.

Saito S, Arima M, Nakajima T (2007a) Hybridization of a shallow 'I-type' granitoid pluton and its host migmatite by magma-chamber wall collapse: the Tokuwa pluton, central Japan. *J Petrol* 48:79-111.

Saito S, Arima M, Nakajima T, Misawa K, Kimura J-I (2007b) Formation of distinct granitic magma batches by partial melting of hybrid lower crust in the Izu arc collision zone, central Japan. *J Petrol* 48:1761-1791.

Saito S, Arima M, Nakajima T, Tani K, Miyazaki T, Senda R, Chang Q, Takahashi T, Hirahara Y, Kimura J-I (in press, published online on Sep 2011) Petrogenesis of the Kaikomagatake granitoid pluton in the Izu Collision Zone, central Japan: implications for transformation of juvenile oceanic arc into mature continental crust. *Contrib Mineral and Petrol*, DOI 10.1007/s00410-011-0689-1.

Keywords: Izu Collision Zone, Granite, Kofu Granitic Complex, Tanzawa Plutonic Complex, Kaikomagatake pluton

Spatial variations in Hf isotopic compositions of Quaternary volcanic rocks in North-eastern Japan Arc

HIRAHARA, Yuka^{1*}, TAKAHASHI, Toshiro¹, MIYAZAKI, Takashi¹, CHANG, Qing¹, SENDA, Ryoko¹, YOSHIDA, Takeyoshi², BAN, Masao³, KURITANI, Takeshi⁴, FUJINAWA, Akihiko⁵, OHBA, Tsukasa⁶, HAYASHI, Shintaro⁶, KIMURA, Jun-Ichi¹

¹JAMSTEC, ²Tohoku Univ., ³Yamagata Univ., ⁴Oosaka-city Univ., ⁵Ibaragi Univ., ⁶Akita Univ.

The dual Quaternary volcanic chains of the North-eastern Japan (NEJ) Arc sit 100 km and 150-170 km above the top of the subducting Pacific Plate. We focus on a particular variation in the isotopic compositions of Quaternary volcanic rocks in the NEJ Arc because isotope data are useful for estimating the influence of subducting components on mantle wedges. In general, slab-derived materials from subducting plates add to mantle wedges, and these materials induce the generation of island arc magma.

In this study, we report a new spatial variation of Hf isotopic compositions in combination with Sr-Nd-Pb isotopes and trace element compositions. Although a high-field-strength elements (HFSE), Hf is one of them, rare earth elements (REE), and large-ion lithophile element (LILE) behave as incompatible elements during mantle-melting processes, they distinctively separate from each other into preferentially partitioned aqueous fluids due to the increased solubility from LILE, REE to HFSE. Therefore, Hf isotopes in combination with other geochemical signatures serve as identification of metasomatic agents in subduction-related magma generation.

On the rear arc (RA) side, we collected samples from the Chokai, Sannome-gata, Moriyoshi, and Kampu volcanoes. On the volcanic front (VF) side, we collected samples from the north area (the Iwate and Akita-koma-ga-take volcanoes), the central area (the Zao and Azuma volcanoes), and the south area (the Nasu and Takahara volcanoes).

The RA volcanic rocks have limited and slightly enriched Sr-Nd-Pb isotopic ratios and trace element compositions as compared to those of mid-ocean ridge basalts (MORB) from the Japan Sea. In contrast, the compositions of the VF samples tend to be more enriched with wide variations. The Sr-Nd-Hf isotopes in the VF rocks tend to be more enriched as one goes from north to south, and the sample with the most enriched isotopic compositions is from the Takahara volcano. In the correlation diagrams of the Sr-Nd isotopic compositions, the trend from the RA to the VF samples appears as a mix of depleted MORB mantle (DMM) and enriched oceanic sediments or continental crust materials. However, the variation in the Hf-Nd isotopes in the VF samples could not be explained by a model of bulk-mixing between DMM and subducted oceanic sediments. Moreover, these isotopic ratios decrease with increasing SiO₂ content. These observations indicate that the variations in the VF samples were formed during processes of magmatic evolution, such as assimilation-fractional crystallization (AFC) or mixing with silicic magma, thus resulting in enriched isotopic compositions. Furthermore, the VF rocks have different Pb isotopic compositions in different area, which indicates that such a varied trend was probably caused by a variety of contaminated crust compositions. In contrast, the Sr-Nd-Hf-Pb isotopic ratios for the RA rocks suggest that their enriched isotopic compositions as compared to MORBs were most likely influenced by the enriched subducting components, and not the crustal material, because the values of the isotopic ratios become constant when their SiO₂ content increases.

Keywords: NE Japan arc, Quaternary volcanic rocks, Spatial variations in isotopic compositions, Hf isotopes

Origin of "black olivines"

HOSHIKAWA, Chihiro^{1*}, MIURA, Makoto¹, ARAI, Shoji¹

¹Earth Sci., Kanazawa Univ.

Rocks of SDW (spinel-rich dunite-wehrlite) suite of the Horoman peridotite complex are characterized by fresh black-colored olivines. The black color is caused by numerous minute inclusions in olivine. The inclusions are homogeneously distributed in olivine grains of the SDW. They are different from the secondary inclusions of magnetite associated with hydrous minerals aligned in olivine both in the SDW dunite and in the MHL harzburgite. The inclusions are abundant in dunites from the central part of the SDW layer, whereas they are scarcely observed in olivines near the contact with the MHL harzburgite. The MHL harzburgite do not contain olivines with such inclusions.

Raman spectroscopy revealed that the numerous minute inclusions consist of magnetite and orthopyroxene. It is very difficult to form such magnetite inclusions by secondary oxidation of olivines. They are possibly subsolidus exsolution products from OH-bearing olivines, precipitated from a hydrous magma. The "black olivine" in dunite can be an indicator for involvement of hydrous melt. Fresh olivines with black colors are frequently found in course-grained dunites.

High-NiO olivine in the dunite enveloping the concordant chromitite from the Wadi Hilti, northern Oman ophiolite

MIURA, Makoto^{1*}, ARAI, Shoji¹

¹Department of Earth Sciences, Kanazawa University

Two types of podiform chromitite, concordant and discordant, are exposed on the same cliff in the mantle section of Wadi Hilti, northern Oman ophiolite. Chromian spinel grains only from the concordant chromitite contain thin lamellae of diopside and enstatite. This indicates that the concordant chromitite has experienced cooling, and probably decompression, for a longer prolonged period than the discordant one. Olivines in the dunite enveloping the concordant chromitite is sometimes extraordinarily high in NiO (up to >0.5wt%), suggesting subsolidus Ni diffusion from the chromitite. This is not the case for the dunite envelope around the discordant chromitite. Ni has moved over about 10cm from the boundary between the concordant chromitite and dunite, which is consistent with the appearance of pyroxenes lamellae in spinel of the concordant chromitite. According to the well-known Ni diffusion coefficient in olivine, the high-NiO olivine in the dunite envelope can constrain the cooling duration of the concordant chromitite. Podiform chromitites are enigmatic in origin, and their origins should be systematically classified to understand concerning mantle processes. Their temporal relationship is a clue to solve this problem.

Keywords: Olivine, Ni diffusion, Podiform chromitite, Oman ophiolite

High temperature oxidation of lherzolite xenolith from Oku district, Oki-Dogo Island, Japan: evidence in olivine

EJIMA, Terumi^{1*}, AKASAKA, Masahide¹, Hiroaki OHFUJI²

¹Department of Geoscience, Graduate School of Science and Engineering, Shimane University, Matsue 690, ²Geodynamics Research Center, Ehime University, Matsuyama 790-8577, Japan

Ejima et al. (2011) reported Fe^{3+} from olivine in lherzolite xenolith from Oku-district, Oki-Dogo Island, Shimane Prefecture, and pointed out two possibilities of generation of Fe^{3+} in olivine: 1) Olivine was incorporated Fe^{3+} at upper mantle condition; 2) Fe^{3+} was generated in olivine by high temperature oxidation in host basalt magma. In order to solve this problem, we investigated a brown zone (about 0.3 mm) distributed at the rim of olivine in the margin of the xenolith in touch with host basalt, using methods of electron probe microanalysis (EMPA), high resolution transmission electron microscopy (HRTEM) and Raman spectroscopy.

The brown zone consisted of forsterite with Fo_{69} (mol%), which is Fe-rich than that at the core part (Fo_{81}) of the xenoliths. No impurity was detected by EMPA, although the Fe-O vibration peaks of hematite and magnetite were detected by Raman spectroscopic analysis. HRTEM observation revealed existence of dislocation cores parallel to (001) of olivine structure, and electron diffraction spots of olivine consisting of the brown zone showed weak streak along the c-axis. However no precipitate such as hematite or magnetite was detected by HRTEM observation. Thus, the Fe-O vibrations observed in Raman spectra can be attributed to very short-range hematite and magnetite structure clusters in olivine, but not to hematite and magnetite phases.

On the basis of the results of the present study, genetic process of hematite and magnetite structure clusters at the rim of olivine in the margin of the Oku lherzolite xenolith in touch with host basalt is considered as follows: 1) a part of Fe^{2+} on the rim of olivine was changed to Fe^{3+} by high temperature oxidation, and vacant octahedral sites were generated; 2) Fe^{3+} in olivine increased with high temperature oxidation, and hematite and magnetite structure clusters were formed in olivine structure; 3) in the region of hematite structure clusters, vacant layers (dislocation cores) parallel to (001) of olivine structure were formed. Therefore, crystallization of hematite and magnetite along the dislocation cores by further high temperature oxidation is expected.

Previous studies by annealing experiments of olivine in air reported crystallization of laihunite. However, in the olivine of the Oku lherzolite xenolith, laihunite was not detected, and existence of hematite and magnetite structures clusters in olivine are considered instead. Thus, two ways of crystallization of precipitates by high temperature oxidation can be proposed: 1) crystallization of laihunite \rightarrow hematite \rightarrow magnetite with increasing temperature; 2) crystallization of magnetite \rightarrow hematite with decreasing temperature, where the crystallization of laihunite is quite difficult. The latter case corresponds to olivine in the Oku lherzolite xenolith.

We conclude that Fe^{3+} within olivine from the Oku lherzolite xenolith (Ejima et al., 2011) was generated by high temperature oxidation underwent during the transportation from the upper mantle to the surface.

Keywords: olivine, lherzolite xenolith, oxidation state of Fe, high temperature oxidation

A technique for EBSD analyses of phyllosilicates in petrographic sections and determination of polytypes in lepidolite

INOUE, Sayako^{1*}, KOGURE, Toshihiro¹

¹Earth & Planetary Sci., Univ. Tokyo

Applications of Electron backscatter diffraction (EBSD) to obtain crystallographic information of minerals in petrographic thin sections are increasing in mineralogy and petrology. However, platy phyllosilicates that mostly appear with their silicate layers terminated by the surface of the thin section generally do not show sharp EBSD patterns in spite of gentle mechanical polishing using colloidal silica. Transmission electron microscopy (TEM) examination indicated that this is due to crystal bending of phyllosilicates from the surface to a few micrometers in depth, caused by the polishing process (Fig. a). Ion beam etching commonly used to prepare TEM specimens was found to be applicable to remove the surface region with crystal bending (Fig. b and c). As a result, clear and sharp EBSD patterns were acquired from the phyllosilicates (micas, chlorite, etc.) in petrographic thin sections, by which their crystal orientations and polytypes were unambiguously determined. This technique was applied to the determination of polytypes of lepidolite, a lithium-rich aluminous mica whose general composition is expressed as $K(Li, Al)_{2-3}(Si, Al)_4O_{10}(OH, F)_2$.

The mica structure generates six standard polytypes expressed as $1M$, $2M_1$, $2M_2$, $2O$, $3T$ and $6R$. They are divided into two subfamilies: *subfamilies* A and B. $1M$, $2M_1$ and $3T$ are classified into *subfamilies* A, and $2M_2$, $2O$ and $6R$ are classified into *subfamilies* B (Backhaus and Durovic 1984). Using EBSD pattern, it is possible to distinguish the two *subfamilies* (Kogure 2002). We investigated lepidolite from a lithium pegmatite in Myoken-san, Ibaraki, where various polytypes have been reported (Kogure and Bunno 2004). EBSD analyses of lepidolite crystals in petrographic thin sections showed that polytypes with different subfamilies coexist within a single crystal: The outside was $1M$ (*subfamilies* A) and inside was $2M_2$ (*subfamilies* B).

References

Backhaus, K. O. and Durovic, S. (1984) Polytypism of micas. I. MDO polytypes and their derivation. *Clays and Clay Minerals*, 32, 453-463.

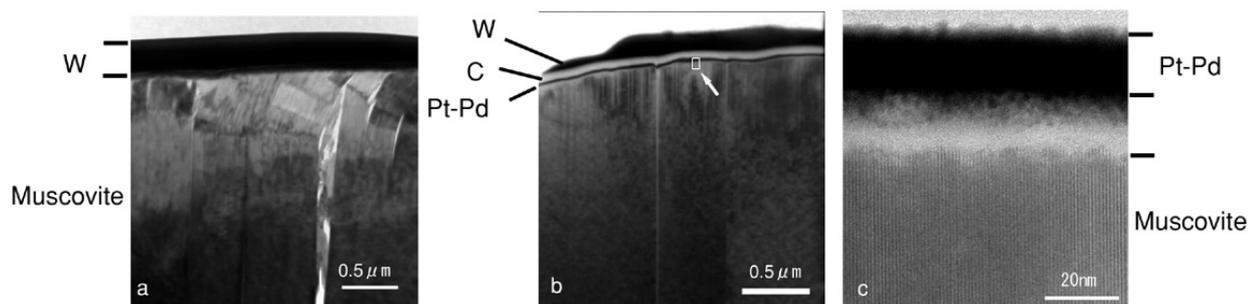
Kogure, T. (2002) Identification of polytypic groups in hydrous phyllosilicates using Electron Back-Scattering Patterns (EBSPs), *American Mineralogist*, 87, 1678-1685.

Kogure, T. and Bunno, M. (2004) Investigation of polytypes in lepidolite using electron back-scattered diffraction. *American Mineralogist*, 89, 1680-1684.

Figure

(a) TEM image of muscovite near the polished surface with colloidal silica. Tungsten (W) was coated for surface protection in the FIB process. (b) TEM image of muscovite near the surface etched by ion milling. Pt-Pd and carbon film were coated after ion milling to identify the specimen surface. (c) High-resolution TEM image of the area marked with square in b.

Keywords: EBSD, phyllosilicates, ion milling, petrographic thin section, polytype, lepidolite



Distribution of cations at two tetrahedral sites in $\text{Ca}_2\text{MgSi}_2\text{O}_7$ - $\text{Ca}_2\text{Fe}^{3+}\text{AlSiO}_7$ series synthetic melilite and its relation

HAMADA, Maki^{1*}, AKASAKA, Masahide¹

¹Shimane Univ.

Synthetic melilites, $\text{W}_2\text{T}_1\text{T}_2\text{O}_7$, were analyzed to determine the distribution of Fe^{3+} between two different tetrahedral sites (T1 and T2), and the relationship between ionic substitution and incommensurate structure in melilite. Melilites on the join $\text{Ca}_2\text{MgSi}_2\text{O}_7$ (kermanite: Ak)- $\text{Ca}_2\text{Fe}^{3+}\text{AlSiO}_7$ (ferrialuminium gehlenite: FAGeh) system were synthesized from starting materials with compositions of Ak_{100} (100Ak), $\text{Ak}_{80}\text{FAGeh}_{20}$ (80Ak), $\text{Ak}_{70}\text{FAGeh}_{30}$ (70Ak) and $\text{Ak}_{50}\text{FAGeh}_{50}$ (by sintering at 1200-1250 °C and 1 atm. The synthetic melilites were analyzed using X-ray powder diffraction, ⁵⁷Fe Mossbauer, and high-resolution transmission electron microscopic methods. The average chemical compositions and end-member components, Ak, FAGeh and Geh ($\text{Ca}_2\text{Al}_2\text{SiO}_7$), of the synthetic melilites were $\text{Ca}_{2.015}\text{Mg}_{1.023}\text{Si}_{1.981}\text{O}_7$ (100Ak), $\text{Ca}_{2.017}\text{Mg}_{0.788}\text{Fe}^{3+}_{0.187}\text{Al}_{0.221}\text{Si}_{1.791}\text{O}_7$ (80Ak), $\text{Ca}_{1.995}\text{Mg}_{0.695}\text{Fe}^{3+}_{0.258}\text{Al}_{0.318}\text{Si}_{1.723}\text{O}_7$ (70Ak) and $\text{Ca}_{1.982}\text{Mg}_{0.495}\text{Fe}^{3+}_{0.449}\text{Al}_{0.519}\text{Si}_{1.535}\text{O}_7$ (50Ak), respectively.

The site populations at the T1 and T2 sites were $[0.788\text{Mg}+0.054\text{Fe}^{3+}+0.158\text{Al}]\text{T}_1[0.056\text{Fe}^{3+}+0.153\text{Al}+1.791\text{Si}]\text{T}_2$ for 80Ak, $[0.695\text{Mg}+0.105\text{Fe}^{3+}+0.200\text{Al}]\text{T}_1[0.112\text{Fe}^{3+}+0.165\text{Al}+1.723\text{Si}]\text{T}_2$ for 70Ak and $[0.495\text{Mg}+0.173\text{Fe}^{3+}+0.332\text{Al}]\text{T}_1[0.281\text{Fe}^{3+}+0.153\text{Al}+1.535\text{Si}]\text{T}_2$ for 50Ak (apfu: atoms per formula unit), respectively. The results indicate that Fe^{3+} is distributed at both the T1 and the T2 sites. The mean T1-O distance decreases with the substitution of $\text{Fe}^{3+} + \text{Al}^{3+}$ for Mg^{2+} at the T1 site, whereas the mean T2-O distance increases with substitution of $\text{Fe}^{3+} + \text{Al}^{3+}$ for Si^{4+} at the T2 site, causing decrease in the *a* dimension and increase of the *c* dimension.

The existence of incommensurate structure in all synthetic melilites at room temperature was confirmed by Mossbauer and $\text{CuK}_{\alpha 1}$ X-ray line profile analyses. The Mossbauer spectra of the melilites consist of two doublets assigned to Fe^{3+} at the T1 site and two or three doublets to Fe^{3+} at the T2 site, which imply the existence of multiple T1 and T2 sites with different site distortions, respectively. The existence of two T1 sites is not influenced by ionic substitution. Conversely, the splitting of T2 sites becomes more remarkable with the substitution of $\text{Fe}^{3+} + \text{Al}^{3+}$ for Si^{4+} which results in the increase of volume and site distortion of the T_2O_4 -tetrahedra.

Incommensurate structure in melilite has been interpreted rather statically, based on the crystal structure of kermanite, that the incommensurate structure is caused by the misfit between the tetrahedral sheet and the polyhedral sheet. However, as found in this study, effect of ionic substitution at the T1 and T2 sites on the formation of incommensurate structure is also significant. The first factor is the site distortion arising from the distribution of cations with different ionic radii in the T1 and T2 sites. Even though the cation sites are symmetrically equivalent in the average structure, each tetrahedron which is occupied by different cation(s) has variant volume. The second factor is the site distortions caused by the difference of adjacent coordination polyhedra around tetrahedra. Therefore, in Ak-FAGeh melilite solid solutions, the site distortions caused by the ionic substitution at the tetrahedral sites play important role on the formation of the incommensurate structure.

Keywords: synthetic melilite, incommensurate structure, X-ray powder diffraction method, Electron diffraction, Mossbauer spectroscopy

Study on classification of terrestrial impact structures and concentration of impact-related carbon light elements

MIURA, Yasunori^{1*}

¹Visiting (Univs.)

Terrestrial impact structures indicating remnants of the surface activity are classified largely as follows:

1) Type 1 impact structure: Impact crater structures formed at crystalline igneous and sedimentary rocks on large continental crust are almost this type remained at present continents. Eject direction from target rocks is opposite direction for ejecta with vapor.

2) Type 2 impact structure: Impact structures formed at sedimentary and limestone basement rocks of sea (ocean) - water is buried and broken by plate-movements, which should be checked precisely by drilled and physical explorations. Soft or porous target rocks of the type II impact produce comparatively penetration of ejecta or light gas vapor in the progress direction.

The type 2 structure is classified to sea-bottom and lands by remained sites of impact remnants. Sea-bottom type 2 structure can be explored due to young formation, but land type 2 remained at lands is classified more at lowlands remained structures (Akiyoshi and Takamatsu), and at highland remained at the summit (Santa Fe, USA etc.).

The Santa Fe impact structure which has been explored by research scientists of the University of New Mexico in 2011 fall during my stay at the UNM University, is to be classified as highland type 2 structure because we found new limestone breccias with impact-related carbon-bearing micro-materials by our FE-ASEM works in this study.

Terrestrial elemental concentration of mineral deposits formed at high temperature, can be formed at impact breccias to produce high contents of carbon and rare-earth elements, as well as previous igneous magmatic melting on the Earth planet.

The present idea of impact concentration can be checked at the Apollo lunar breccias samples with the elemental concentration, which will be applied significantly to other planets and Asteroids for next new exploration of resources and rock-minerals.

Keywords: impact structure, classification, impact carbon-bearing materials, ocean impact, concentration reservoir, limestone breccias

Fluor-wagnerite as a petrogenetic indicator: first occurrence from the Eastern Ghats Granulite Belt, India

DAS, Kaushik^{1*}, TOMIOKA, Naotaka², BOSE, SANKAR³, ANDO, Jun-ichi¹

¹Department of Earth and Planetary System Sciences, Hiroshima University, ²ISEI, Okayama University, Misasa, ³Department of Geology, Presidency University, Kolkata, India

Accessory mineral phases in deep-crustal granulites often preserve plethora of information regarding the pressure-temperature-fluid evolution of the crust undergoing orogenesis. Their presence in different bulk compositions in granulites offer significant inputs to reconcile the *P-T* histories, as minor components present in these accessory phases may play crucial effects on the topology of petrogenetic grids. One such minor component is fluorine which is accommodated within accessory minerals and hydrous minerals in metapelitic granulites of 'appropriate' bulk compositions. Apatite is one of the common minerals that contain fluorine. On the other hand, wagnerite is rare phosphate mineral reported from some metapelitic granulites in different regional granulite terranes of the world.

The Eastern Ghats Belt of India evolved in phases in response to Proterozoic orogeneses in the span of c. 1.80-0.50 Ga. The high-temperature to ultrahigh temperature (UHT) granulites of this belt were retrogressed after emplacement to mid-crustal level as deduced from *P-T* history. Metamorphic fluid played an important role throughout this journey and its presence is characterized from mineralogical, theoretical and fluid inclusion analyses. Although wagnerite was previously reported from this belt, its composition is hydrous as presence of vapor fluid was interpreted to be responsible for its stability at the retrogressive stage of evolution. We report for the first time, presence of fluor-wagnerite in peak metamorphic porphyroblastic assemblages as well as retrograde matrix assemblages from Eastern Ghats Belt and explore its implication for the different stages of evolution of the lower crust. Fluor-wagnerite crystals develop inside garnet porphyroblasts of aluminous granulites as well as in the quartzofeldspathic matrix. Based on EPMA data and Micro-laser Raman analyses, we document an unusual high-Mg-F-rich chemistry of the mineral. Abundance of F over H₂O implies brine-rich nature of the fluid which was earlier inferred from F-rich nature of phlogopite crystals from this belt. Apatite is characteristically absent in the primary assemblages containing wagnerite, except a very late occurrence decomposing the matrix wagnerite grains. We propose that, given the 'suitable bulk and fluid chemistry', fluor-wagnerite can occur as a common accessory mineral in lower-mid crustal rocks, and fluorine should be taken into consideration while reconciling the *P-T* grid in the higher temperature side of biotite-dehydration melting curve.

Keywords: Fluor-wagnerite, UHT granulites, EGB, India

Petrology of eclogitic garnet-clinopyroxene rocks from Namakkal, southern India

IINUMA, Minako^{1*}, TSUNOGAE, Toshiaki¹, M. Santosh²

¹Univ. Tsukuba, ²Kochi Univ.

We report new petrological data of eclogitic garnet-clinopyroxene rocks from two new localities in Namakkal region within the Palghat-Cauvery suture zone, which corresponds to the Gondwana suture zone in southern India. The eclogitic rocks from Pavithram comprise garnet and clinopyroxene with accessory orthopyroxene, hornblende, plagioclase, and quartz. The garnet is often mantled by orthopyroxene + plagioclase corona, suggesting decompression from high-pressure stage possibly along a clockwise P-T path. This is a common reaction texture of magic granulites in this region. In contrast, clinopyroxene in garnet-clinopyroxene rocks from Vadugappatti is mantled by garnet + quartz corona, suggesting the progress of reaction: clinopyroxene + plagioclase => garnet + quartz probably due to near-isobaric cooling. The two contrasting textures in garnet-clinopyroxene rocks from this region might indicate the occurrence of discrete metamorphic blocks with different P-T history within the suture.

Magmatic process of synplutonic mafic dykes in Ryoke belt at Shodo Island, southwest Japan

KOIZUMI, Naoko^{1*}, OKIUDAIRA, Takamoto¹, SUDA, Yoshimitsu²

¹Osaka City University, ²Meiji University

Various synplutonic mafic dykes in igneous rock complex are widely distributed throughout the Tanoura Peninsula of the southern part of Shodoshima Island, in the Ryoke belt, southwest Japan. The common mineral assemblages are plagioclase + amphibole + biotite, sometimes quartz. Plagioclase phenocrysts (~ 3 mm) are observed in all dyke samples, these modes vary according to each samples (0.2 to 14 vol.%). Plagioclase phenocrysts have An-rich core (> An₈₀) and Ab-rich rim, these cores show partial dissolution shape indicate the magma mixing. An-rich core often contain inclusions of amphibole and/or biotite. Therefore, it suggest that the mafic end member of magma mixing is a low temperature hydrous basaltic magma. Ab-rich rim of plagioclase groundmass show similar Anorthite content. This observation suggest that both assemblage might be crystallized from the mixed magma during end stage.

Ratageski et al. (2005) performed the experiment of partial melting of mafic intrusion in lower crust. On the major oxides variation diagrams for SiO₂ contents, the experimental melt composition area by Ratageski et al. (2005) are located on the extension line of whole rock compositions of this study trend. This observation suggests that the felsic end member of magma mixing have similar composition for this experimental melt. Kutsukake (2002) proposed that the origin of the Ryoke tonalities were formed by the magma which generated the partial melting of amphibolites. This results also consistent with this study.

Mantle origin mafic magmas were acted as the heat source of the Ryoke granitic magmatism. It is quite possible that felsic magma and mafic magma mixed at the lower crust.

Keywords: mafic dyke, magmatic process, geochemistry, mineral chemistry

Petrogenesis of olivine-clinopyroxene rocks: an example from the Takashima xenolith suite, northern Kyushu

MUROI, Ritsuko^{1*}, ARAI, Shoji²

¹Dept. Earth Sci., Kanazawa Univ., ²Nat. Sci. Tec., Kanazawa Univ.

Olivine-clinopyroxene rocks (dunite, wehrlite, olivine clinopyroxenite and clinopyroxenite) very frequently occur as ultramafic xenoliths in volcanics and as plutonic rocks in ophiolites. Dunites and olivine-clinopyroxenites can be formed by cumulates during fractional crystallization, but wehrlites, intermediate in mode and very frequently observed, cannot be formed in the same work. Olivine-clinopyroxene rocks containing green clinopyroxene from the Takashima xenolith suite, northern Kyushu, show a gradual variation ratio of olivine to clinopyroxene from dunite to clinopyroxenite. The olivine-clinopyroxene rocks from Takashima are examined to understand their formation processes. They have recrystallization textures formed at subsolidus conditions, leading to change of Mg# ($=\text{Mg} / (\text{Mg} + \text{total Fe})$ atomic ratio) of olivine and clinopyroxene. Based on compositions and modal amounts of olivine and clinopyroxene from high temperature magmatic values, the igneous Mg# of olivine and clinopyroxene is recalculated to be 0.927-0.902 for dunites, 0.869-0.854 for wehrlites, and 0.886-0.876 for clinopyroxenites. Relationships between the Fo content and the NiO content of olivine and the Cr/(Al+Cr) atomic ratio of spinel suggest that these rocks were basically formed by crystal accumulation in fractional crystallization. The Takashima dunites and clinopyroxenites are cumulates by fractional crystallization. Intermediate wehrlites are a mixture of accumulated crystals of olivine with high Mg#s and olivine-clinopyroxene precipitated crystals with lower Mg#s from evolving intercumulus melt. These crystals were homogenized structurally and compositionally through subsolidus recrystallization.

Keywords: olivine-clinopyroxene rocks, wehrlite, fractional crystallization, intercumulus melt, Takashima xenolith suite

Modification of continental lithosphere by the Miocene alkali basaltic activity recorded in gabbroic xenoliths in Shingu

NOGUCHI, Wataru^{1*}, MIZUKAMI, Tomoyuki¹, ARAI, Shoji¹, TAMURA, Akihiro²

¹Graduate School of Natural Science and Technology, Kanazawa University, ²Frontier Science Organization, Kanazawa University

Miocene alkali basaltic dikes in the Shingu area, Ehime Prefecture, brought up abundant crustal and mantle fragments. They bear the information of the petrological structure beneath the region at the beginning of subduction of the Philippine Sea plate. We provide results of petrological examinations on the xenoliths and discuss the chemical diversities in magmas at the east Eurasian continental margin.

The gabbroic xenoliths in the Shingu can be classified into three groups: Amph-bearing gabbro (A type), brown Cpx-bearing gabbro-pyroxenite (B type) and gabbronorite (C type). The microtextures of the A-type gabbro are almost granoblastic with local subhedral Pl. The Hbl-Pl thermometry indicates the lowest equilibration temperature among the Shingu mafic and ultramafic xenoliths. Therefore, they probably formed a part of the lower crust beneath the Shingu. The B type gabbro-clinopyroxenite has petrographical features similar to the Group2 xenoliths that are considered as cumulates from an alkali basaltic magma. The C type gabbronorite contains granular Cpx with abundant exsolutions of Opx and brownish interstitial Cpx with no exsolution. High temperature crystallization (1250°C) and re-equilibration (1050-1100°C) are estimated for the gabbronorite, indicating that they were located at a mantle depth. Mineral chemistry of exsolution-rich Cpx in gabbronorite (C type) is richer in Cr and Mg and has a lower abundance of REE than Cpx in groundmass of the host alkaline basalt and the B-type gabbros whereas Pl is richer in alkaline elements. The major and trace element mineral chemistry of the interstitial Cpx is similar to the B type Cpx. These textural and chemical features indicate that the C type gabbronorite were modally metasomatized by an alkaline magma that have crystallized the B-type cumulates.

In order to explain the silica-saturated and Cr-rich but highly alkaline nature of the magma for the C type gabbronorite, we consider assimilation of Opx in lithospheric mantle by ascending alkali basaltic magma. Model calculation including Opx assimilation and subsequent fractionation of Cpx largely reproduces the chemical signatures of Cpx in gabbronorite. The significantly HFSE-enriched geochemical character implies a separation of carbonatite melt in the magmatic evolution. Considering the highly potassic nature of the C type, the original alkaline magma was formed by a low degree of partial melting of mantle probably at the earliest stage of the alkaline magma activity in the SW Japan. Such a silica-undersaturated magma modified the lithospheric structure beneath SW Japan by removing Opx from peridotite in mantle and by crystallizing gabbronorite at around the Moho.

Osmium isotopic and major element compositions of the fresh harzburgite from the Hayachine-Miyamori ophiolitic complex

YOSHIKAWA, Masako^{1*}, OZAWA, Kazuhito², SUZUKI, Katsuhiko³, SHIBATA, Tomoyuki¹

¹IGS, Kyoto Univ., ²Univ. Tokyo, EPS, ³IFREE, JAMSTEC

The Hayachine-Miyamori ophiolitic complex in the Kitakami Mountains, northeastern Japan is located in the Hayachine Tectonic Belt, which is one of the oldest geological terrane in Japan and consists of ultramafic tectonite and cumulate members corresponding to the lower ultramafic sections of ophiolites (e.g. Ozawa, 1984; Ehiro, 2000). Peridotites in this complex are extensively serpentinized (most of them consists of > 60 % serpentine; Ozawa, 1988). The tectonite member is divided into two suites on the basis of spinel Cr-number ($Cr\# = 100 \times Cr / (Cr + Al)$): aluminous spinel ultramafic suite (ASUS; $Cr\# < 40$) and chromite-bearing ultramafic suite (CSUS; $Cr\# > 40$; Ozawa, 1988). The Sm-Nd isotopic data with trace element compositions of clinopyroxenes of this complex suggest that the complex experienced partial melting events around 450 Ma ago with influx of three agents derived from the subducting slab (Ozawa and Shimizu, JGR, 1995; Ozawa, JGR, 2001; Yoshikawa & Ozawa, GR, 2007).

We found a least serpentinized boulder of spinel harzburgite (73003) belonging to CSUS and determined a bulk-rock major element compositions and $^{187}Re/^{188}Os - ^{187}Os/^{188}Os$ isotopic ratios. The sample 73003 is characterized by high CaO and low Al_2O_3 contents than other orogenic peridotites. Similar feature was observed from the Victoria peridotite xenoliths (Yaxley et al., 1991). Yaxley et al. (1991) proposed carbonatite metasomatism for the high CaO and low Al_2O_3 of the xenoliths from the following lines of evidence; (1) replacement of primary orthopyroxene by clinopyroxene and olivine, which may be attributed to the reaction between orthopyroxene and CO_2 -rich melt to produce clinopyroxene and olivine, (2) presence of accessory apatite, which can be produced by reaction from primary olivine + diopside + carbonatite melt to secondary orthopyroxene + haloapatite, (3) high bulk-rock CaO/ Al_2O_3 value and extreme large ion lithophile element (LILE) enrichment without concomitant TiO_2 enrichment. CSUS peridotites have petrological and geochemical features consistent with (2) and (3), although the replacement of orthopyroxene by clinopyroxene + olivine has not been observed in CSUS peridotites. The modal abundances of clinopyroxene in CSUS peridotites, however, are as high as or even higher than in ASUS peridotites which have lower Cr# ratios indicating less degree of melting than CSUS peridotite. It suggests addition of clinopyroxene by influx of a CaO-rich agent. On the basis of the above observations, we infer that CSUS peridotites underwent influx of a silicate-carbonatite melt most probably from subducted slab.

The $^{187}Os/^{188}Os$ isotopic ratio (0.1235) of sample 73003 is consistent with those of present average abyssal peridotite (0.1238, $n=96$; Rudnick & Waker, Lithos, 2009) and the Izu-Bonin fore-arc mantle peridotites (0.1193 - 0.1273; Parkinson et al., Science, 1998). The Re-depletion age of this sample is around 500Ma. This age is consistent with the K-Ar amphibole ages (480 - 520 Ma) of the Matsugadaira-Motai metamorphic rocks which have been interpreted as formed at the subduction zone (Kanisawa et al., GKK, 1992). The Os isotopic results thus strongly support open-system melting at subduction zone as presented by the previous studies.

Keywords: Os isotopic composition, Hayachine-Miyamori ophiolitic complex, whole rock compositions, metasomatism by silicate-carbonatite melt

Rare earth element composition of the Yakushima granitic body, Kagoshima Prefecture

KAWANO, Yoshinobu^{1*}

¹Faculty of Geo-environmental Science, Rissho University

The Miocene Yakushima pluton intruded into Shimanto Super Group in Yakushima Island, Kagoshima Prefecture. The pluton consists of four members with granitic dike: Yakushima main granite (YMG), core granodiorite (CGD), core cordierite granite (CCG), marginal facies granite (MFG) and late granite dike (LGD). Anma et al. (1998) revealed geotectonic and petrological features of the pluton, and suggested that the YMG has different origin from other members. Furthermore, Kawano et al. (2007) discussed relationships between Sr initial isotopic ratios and origin of YMG.

In this study, rare earth elements of the Yakushima pluton are measured and REE characteristics for each rock facies are revealed. The rocks of the CGD and CCG have higher ratios of La/Lu and LREE/HREE than those of other rock facies. Negative Eu anomaly in the CGD and CCG is not recognized, it is suggested that fractionation of plagioclase was not performed. The rocks of the YMG have lower ratios of La/Lu and LREE/HREE than those of the CGD and CCG. Some samples from the YMG indicating remarkable negative Eu anomaly have lower Sr initial ratios of 0.702 to 0.704. Whereas samples having higher Sr initial ratios of 0.705 to 0.707 show no Eu negative anomaly. The former is exposed to the central part of the YMG, it is shown that fractionation of plagioclase is progressing in the central part. The MFG has no Eu negative anomaly, however, LGD is characterized by Eu negative anomaly and lowest ratios of La/Lu and LREE/HREE among the pluton.

From these REE features, it can be considered that the YMG and MFG, the CGD and CCG, and the LGD were derived from the different origin, respectively. Moreover, REE pattern of the YMG is complicated and possibly was formed by mixture of the magma presumed from SrI.

Keywords: Yakushima, Granite, Rare earth element

Magma process of the granitic rocks around the Chichibu mine, Saitama Prefecture

TAKAHASHI, Miori^{1*}, KAWANO, Yoshinobu²

¹Geo-environmental Science,Rissho University, ²Geo-environmental Science,Rissho University

Chichibu granitic body in the western Saitama Prefecture is composed of quartz diorite and tonalite (Ishihara et al., 1987). The body is divided into two main bodies, namely Chichibu south body and Chichibu north body, accompanied with some small body (Hara et al., 2010). Radiometric ages of the Chichibu granitic body were dated 6.3 to 5.9 Ma (Ueno and Shibata, 1986;Saito et al., 1996). In this study, modal and chemical compositions and mineral chemical compositions of the granitoids from the north and south bodies, and the magma process of the Chichibu south body is examined.

The marginal part of the Chichibu south body has large amount of biotite, whereas the central part shows large amount of amphibole. With the increase in SiO₂ value, an A.S.I value increases in the less than 0.80 to 1.1 range, and the Chichibu south body has feature of I-type granites. The A.S.I value becomes low in the central part of the Chichibu south body, and the value becomes higher in marginal part. The rocks of the Chichibu south body are rich in a LIL element and deficient in a HFS element. From these features of trace elements, it can be considered that the Chichibu south body was formed by Island arc magma activity.

In conclusion, the following magma processes can be considered. The magma crystallizing plagioclase and amphibole was intruded into sedimentary layers of the Chichibu area. Then, it reacted to the surrounding sedimentary rocks at marginal of the Chichibu south body. A marginal part becomes locally peraluminous magma and it crystallized biotite. As a result, crystallizing of amphibole continues in the central part. It can be considered that amphibole increased in the central part of the Chichibu south body, and biotite increased relatively in the marginal part of the body.

Keywords: Chichibu body, granitic rocks, magma process

Alkali rhyolite found in Mt. Haguro, Tochigi Prefecture, central Japan

SHIMIZU, Ryuichi^{1*}, KAWANO, Yoshinobu¹

¹Rissho University

Rhyolite occurred in Mt. Haguro, Tochigi Prefecture, is reported K-Ar whole rock age of 14.2±0.4 Ma (Yoshikawa, 1998). Yoshikawa (1998) shows phenocrysts of the Haguro rhyolite are comprised of quartz, plagioclase and biotite.

In this study, bulk and mineral chemical compositions of the Haguro rhyolite is revealed. Chemical compositions of the rocks were ranged 77 to 79 wt% of SiO₂ and 7 to 9 wt% of Na₂O+K₂O, and alkali feldspars are found in the phenocrysts of the rhyolite. Therefore the Haguro rhyolite is alkali rhyolite.

In N-MORB normarized incompatible element patterns, Sr is dominantly depletion. Furthermore, in chondrite normarized REE patterns, negative Eu anomaly is shown. Additionally in bulk major chemical compositions, Ca is poor. These behaviors of chemical elements suggest that plagioclase was fractionated from original magma.

Keywords: Utsunomiya city, Miocene, Alkali rhyolite

Exsolution textures in alkali feldspar from the Ohgi tonalite

TAKAYA, Masaki^{1*}, Norimasa Shimobayashi¹, MIYAKE, Akira¹

¹Kyoto Univ.

Electron petrographic study of exsolution textures is performed on alkali feldspar in porphyritic granitic rocks from the Ohgi tonalite, which is one of the Late Cretaceous-Paleogene granitoids in the San'yo zone, Southwest Japan, distributed between Kyoto and Shiga Prefecture. Alkali feldspar occurs as subhedral to anhedral prismatic crystals (ca. 200 μm in long) in matrix of the orthopyroxene-bearing porphyritic granitic rocks described by Takaya et al. (2009). Most of the crystals are partially or wholly altered. The unaltered alkali feldspar whose the chemical composition is $\text{Or}_{57-71}\text{Ab}_{24-38}\text{An}_{1.8-3.1}\text{Cn}_{0.4-3.4}$ containing up to 1.8 wt % in BaO displays the chemical zoning in Cn component; the composition in core is high, toward the margin Cn content decreases and rim is almost free in Cn. Various exsolution textures can be observed in the crystals in accordance with the chemical zoning in Cn component.

The core part is clearly composed of several parts on the basis of the textural feature; one characterized by the presence of the relatively-coarse exsolution lamellar intergrowth and the other by the fine exsolution lamellar intergrowth with no coarse lamellae. TEM observation of the coarse intergrowth (bulk composition: $\text{Or}_{58-61}\text{Ab}_{34-37}\text{An}_{2.1-2.5}\text{Cn}_{2.9-3.3}$) reveals that the interface between lamellae is linear and sharp, and the periodicity of the intergrowth is irregular, the fact of which implies that the coarse intergrowth was formed due to nucleation and growth mechanism. In the fine lamellar intergrowth (bulk composition: $\text{Or}_{57}\text{Ab}_{38}\text{An}_{2.2}\text{Cn}_{2.6}$), in contrast, the interface between lamellae is sharp and wavy, and the periodicity of the intergrowth is regular, suggesting that the fine intergrowth was formed by proceeding with spinodal decomposition mechanism. In the rim, on the other hand, the apparently-homogeneous regions can be occasionally observed in addition to the coarse lamellar intergrowth. TEM observation in this region (bulk composition: $\text{Or}_{62}\text{Ab}_{36}\text{An}_{1.9}\text{Cn}_{0.5}$) was clarified to be a presence of the fine lamellar intergrowth whose texture is similar to that of the fine lamellae in the core, that is, the fine lamellar intergrowth in the Cn-poor rim suggests to be formed by spinodal decomposition.

These electron petrographic observations reveal that two distinct exsolution textures, each of which was formed by the different mechanisms (nucleation and growth and spinodal decomposition), are coexisting in a single crystal of alkali feldspar, which can be explained by a small difference in the Or component (almost same Cn) even by a simple cooling process. Furthermore, it is suggested that Or-rich limb in spinodal curve shifts to Or-poor side by increasing with Cn content because the bulk composition of the lamellar intergrowth formed by spinodal decomposition is Or-richer at low Cn content in comparison with high Cn content. This present tendency is concordant with that suggested by Lagache and Catel (1992) and Viswanathan (1992).

Keywords: alkali feldspar, exsolution texture, spinodal decomposition, nucleation and growth, celsian, Ohgi tonalite

Mineralogy of anorthite megacrysts from Take-shima, Kagoshima Prefecture, Japan

MATSUI, Tomoaki^{1*}, ARAKAWA, Yoji², KIMATA, Mitsuyoshi², HOSHINO, Mihoko³, ECHIGO, Takuya⁴, NISHIDA, Norimasa²

¹Kagoshima Univ., ²Univ. Tsukuba, ³AIST, ⁴NIMS

Anorthite megacrysts of about about 1 cm in maximum diameter are found as phenocrysts in the basaltic lavas from Take-shima, Kagoshima Prefecture, Japan. Take-shima is an island located about 40 km SSW of the southern tip of Satsuma peninsula. The island lies at the northeast edge of Kikai caldera, which measures 17 x 20 km², and is one of the large calderas in southern Kyushu (Matsumoto, 1943). Most of the caldera except for three islands, Take-shima, Satsuma-Iou-jima and Shin-Iou-jima, lies below the sea level. The anorthite megacrysts occur in the basalt which is supposed to erupt from Magomeyama, pre-caldera volcano in Take-shima. Similar anorthite megacrysts have been found in the basalt from Satsuma-Iou-jima (Ono et al., 1981). The purpose of this work is to understand the mineralogical significances of anorthite megacrysts from Take-shima, and reveal the genetic mechanism behind these megacrysts.

Thin section were made from fragments with anorthite megacrysts, and observed under a high-magnification polarizing microscope, Nikon ECLIPSE E600 POL. A polarizing stereoscope, MEIJI TECHNO EMZ-5POL-2 was also employed to study microstructure and optical property throughout the megacryst in the same view. For mineral identification, X-ray powder patterns were obtained using a RIGAKU Ultima IV Protectus, X-ray diffractometer with monochromated CuK α radiation (40 kV, 40 mA) at Faculty of education, Kagoshima University. Software PDXL was used for mineral identification. Refinement of cell parameters was carried out using a single-crystal diffractometer, Rigaku R-AXIS RAPID at the Chemical Analysis Center, University of Tsukuba. Chemical analyses were carried out using a JEOL JXA-8530F EPMA (20 kV, 1.0 x 10⁻⁷ A for qualitative analyses; 20 kV, 1.0 x 10⁻⁸ A for quantitative analyses and BSE image observation) at the Chemical Analysis Center, University of Tsukuba. ZAF online full matrix corrections were used for quantitative analyses (Reed, 1996). Compositional maps were obtained using a HORIBA XGT-5000 X-ray analytical microscope (50 kV, 1.00 mA) at the Chemical Analysis Center, Kagoshima University.

The megacryst, reaching a maximum size of about 1 cm in diameter, are mainly found as phenocryst in augite-bearing olivine basalt. The anorthite megacrysts show slight optical zoning. Zonal arrangement of opaque minerals and micro-bubble inclusions are common in the specimens. Moreover they often contain several corroded inclusions of olivine, and albite twins occur in every specimen. Though powder X-ray diffraction pattern of the megacryst shows that an ordered P-1 anorthite is the most likely candidate, single-crystal X-ray diffraction data suggests the structure with $c = 0.7$ nm cell. X-ray analytical microscope and electron microprobe studies reveals that the megacryst is chemically homogeneous, whereas BSE image shows a slight oscillatory zoning. It indicates Anorthite content of the megacryst is about 94 mol%. Because a trifling amount of Fe and excess Si are detected by EPMA, minor end-members of FeAl₂Si₂O₈, CaFeSi₃O₈ and []Si₄O₈ are incorporated into the present megacryst.

Though further investigation is required for completely understanding the formation of the anorthite megacryst from Take-shima, this new work provides fundamental information about the history of magmatic system related to anorthite megacryst formation under island arc. The presence of oscillatory zoned micro-bubble inclusions implies the oscillation in pressure, temperature or vapor pressure occurred at a certain narrow range around the melting point of anorthite. The textural feature seems to be consistent with limited chemical zonation observed in BSE image. Both the above implication and the presence of corroded olivine inclusions as a nucleus lead to the megacrystallization of chemically almost homogeneous anorthite in host magma, which offers a good example of Ostwald ripening in nature.

Keywords: anorthite, megacryst, Take-shima, oscillatory zoning, Ostwald ripening

The stable region of sibirskite and parasibirskite

KANO, Masahiro^{1*}

¹Graduate School of Natural Sci., Tec., Okayama Univ.

1. Introduction

Many type of novel minerals from high temperature type of gehlenite-spurrite skarns were found in the Fuka area, Okayama prefecture, Japan. At the last stage of the formation of the skarn, many borate minerals were also formed. The minerals at the first stage of the borate minerals was takedite ($\text{Ca}_3\text{B}_2\text{O}_6$) (Kusachi et al., 1995), and various secondary hydroborate minerals were formed after that. Sibirskite (CaHBO_3) (Kusachi et al., 1997) and parasibirskite (Kusachi et al., 1998) was formed at this stage. These hydroborate minerals were considered as a polymorph each other. The synthesis of sibirskite was reported by the Sun et al. (2011), and parasibirskite was reported by the Schafer (1968a) etc. In this study, we attempted to define the stable region of the sibirskite and parasibirskite by the synthetic experiments.

2. Sibirskite and parasibirskite

Sibirskite is hydroborate CaHBO_3 . It occurs in many places of Russia, and Fuka is the third place of occurrence. It is white with vitreous luster in hand specimen, and colorless in thin section. In Fuka mine, It occurs as aggregates of prismatic crystals up to 0.1 mm long and 0.02 mm wide, in association with takedaite, frolovite and calcite. The cell dimensions and the space group determined are $P2_1/a$, $a=8.643(6)$, $b=9.523(2)$, $c=3.567(3)$ Å, $s=119.23(3)^\circ$ and $Z=4$ (Kusachi et al., 1997).

Parasibirskite is a polymorph of sibirskite, and it is a new mineral found at Fuka mine. It is white with weak pearly luster in hand specimen, and colorless in thin section. In Fuka, it occurs subparallel aggregates of tabular crystals up to $40 \times 20 \times 3$ μm in size, in association with takedaite, olshanskyite, sibirskite, frolovite and calcite. The cell dimensions and the space group are $P2_1/a$, $a=6.722(4)$, $b=5.437(2)$, $c=3.555(2)$ Å, $s=93.00(5)^\circ$ (Kusachi et al., 1998).

3. Result

3-1 Synthesis from takedite

In Fuka mine, the sibirskite and parasibirskite were formed by hydrothermal alteration of takedite. So, these minerals were synthesized from natural takedite by boric acidic water alteration and changing the quantity, temperature, pressure and synthesis period. The reaction formula is $\text{Ca}_3\text{B}_2\text{O}_6 + \text{H}_3\text{BO}_3 \rightarrow 3\text{CaHBO}_3$

At 350°C and 400°C condition, calcibolite (CaB_2O_4) was synthesized or not identified because the XRD peak so low. Sibirskite and parasibirskite were formed when synthesizing it for 7 days at 1000 kg/cm³ and 300°C, and only sibirskite was formed for 14 days.

3-2 Stable temperature and pressure region for sibirskite and parasibirskite

To examine the stable region of sibirskite and parasibirskite, the mixing samples of these minerals with water were synthesized under the hydrothermal condition. The temperature were changed from 200°C to 450°C by the step of 50°C, and the pressure were changed from 500 kg/cm³ to 1500 kg/cm³ every 500 kg/cm³.

Parasibirskite was decomposed to form the sibirskite by 14 days duration time with over 250°C of synthetic temperature. At 1500 kg/cm³ and 400°C, and 450°C, sibirskite and parasibirskite were decomposed to form the Shimazakiite ($\text{Ca}_2\text{B}_2\text{O}_5$) (Masubara et al., 2011). Moreover, at below the 200°C of synthetic temperature, the XRD peaks of sibirskite and parasibirskite were nearly not changed.

4. Discussion

The sibirskite and parasibirskite that occurred in Fuka mine were considered as formed by the hydrothermal alteration of takedite. In this study, those minerals were also synthesized from takedite by the 500, 1000 and 1500 kg/cm³ with 300°C. However, the parasibirskite were decomposed by 14 days of synthesis time. So, those were considered as the minerals of first stage and partially unstable one. From the result of 3-2 experiments, the stable region of sibirskite were limited with 350°C to 400°C with 1500 kg/cm³, with 400°C to 450°C with 500 kg/cm³. At the outer of stable region, the mineral is changed to the Shimazakiite. The lower limit of sibirskite and upper limit of parasibirskite were considered as 200°C.

Keywords: sibirskite, parasibirskite, synthesis

Occurrence of the Komanakigawa Fault and hydrothermal alteration of rocks around the fault

YUHARA, Masaki^{1*}, Keisuke Miyazaki¹

¹Sci. Fukuoka Univ.

The Kokura-Higashi Fault constituting northern part of the Kokura-Tagawa Tectonic Line is considered as an active fault (The Research Group for Active Faults of Japan, 1980), and the timing of activity and its style in Quaternary were analyzed (Watanabe, 1989; Senda, 1990; Takatsu, 1996; Watanabe et al., 2002). However, presumption of timing of activity at the the Tagawa Fault constituting northern part of the Kokura-Tagawa Tectonic Line was performed only by the analysis of fracture system in the Neogene volcanic and sedimentary rocks (Hikosan Collaborative Research Group, 1992). Sako and Yuhara (2004) analyzed the fracture system, which develops in the Soeda Granodiorite around the Tagawa Fault in Hikosan River valley, southern area of Soeda Town, and clarified the formation history of fractures before the Neogene. However, the Tagawa fault could not be found. The fault continuous along the Komanaki River, which is regarded to branch from the Tagawa Fault, was found by subsequent geological survey. In this paper, we report the occurrence of fault rocks and the hydrothermal alteration of rocks around the fault.

This fault can be traced more than 3 km along the Komanaki River from Yakatabaru, Soeda Town. Yuhara and Miyazaki (2007) called it Komanakigawa Fault. The Komanakigawa Fault makes the boundary of the Soeda Granodiorite distributed in the east side and the Tagawa metamorphic rocks distributed in the west side. The pelitic schist of the Tagawa metamorphic rocks in maximum width of 11m and the Soeda Granodiorite in maximum width of 12.5m are whitened by hydrothermal alteration.

The Komanakigawa Fault strikes N14° to 42°E and dips 78°W to 88°E. This fault has fault gouge with maximum width of 90cm and cataclasite with maximum width of 200cm. The striations observed in cataclasite are almost horizontal. There are white and dark gray fault gouge and cataclasite. Andesitic dykes correlated to the Kitakamoto Formation intruded along the fault. Considering occurrence in field and under microscope, white fault gouge and cataclasite were formed by destruction of whitened rocks. This suggests that the hydrothermal alteration took place at least two times before and behind faulting.

In the whitened granodiorite, most of biotite and hornblende are altered, and plagioclase is replaced by small altered minerals. In the whitened pelitic schist, most of biotite and plagioclase are altered. Those altered minerals are illite, siderite, kaolinite, calcite and montmorillonite.

MgO, CaO and Sr contents of the Soeda Granodiorite decrease and As, Ni and S contents increase by hydrothermal alteration. In the whitened pelitic schist, there is decrease of MgO and CaO contents.

Keywords: Kokura-Tagawa Tectonic Line, Komanakigawa Fault, Soeda Granodiorite, Tagawa metamorphic rocks, Hydrothermal alteration

Electrical and magnetical properties of the sea-floor hydrothermal deposits

NAKAYAMA, Keiko^{1*}, Mana Yasui¹, Wenting Liu², Meguru Nishiyama², Akira Saito², Atsushi Yamazaki²

¹Waseda University, Research Institute for Science and Engineering, ²Waseda University, Graduate School of Creative Science and Engineering

The newly discovered sea-floor hydrothermal deposits in the Japanese EEZ are growing concern as the crucial future mineral resources and to comprehend the reserved amount of the mineral ores are among the key issues for the developments. Electrical and Electromagnetic exploration technologies are prevailing for the onshore mineral deposits due to the significant differences of the electrical properties between the ores and host rocks, but newly improved technologies are demanded for the ocean bottom applications. The electrical and magnetic properties such as resistivities, chargeabilities and magnetic susceptibilities of the ocean bottom samples from Bayonnaise Knoll and Izena Cauldron are measured and combined with the analysis with X-ray Diffractometry(XRD), X-ray Fluorescence Analysis(XRF) and inductively-coupled plasma mass analysis(ICP-MS). Mineral compositions are determined also with visual and reflecting microscope observations. As comparison samples, the KUROKO black ores which are thought to be the same origin as the ocean bottom hydrothermal deposits are obtained from Koshiji and Kosaka mineral deposits and analyzed in the same way.

The resistivities and chargeabilities are measured with the samples saturated with 0.3 ohm-m water to get the ocean bottom properties. The resistivity values from the Izena samples range from 0.1 to several ohm-m, while those from Bayonnaise and Kuroko range from 1 to several 10s of ohm-m, while chargeability values are found to be high for those two areas. Also no practical differences are found for the IP-values between the above two areas. As the results of the XRF analysis, the average iron content of Izena samples is found to be about 28.8%, which is 6 time higher than that of Bayonnaise and KUROKO (average 4.7%). Bayonnaise samples also contain 35.6% of zinc. Crystalline minerals of Bayonnaise analyzed using XRD showed the same tendency as KUROKO, containing more sphalerite(ZnS) than Izena samples. The mineral contents of Izena samples are distinct from Bayonnaise samples for containing much more pyrite and also containing marcasite and sphalerite, the resistivity of which is usually higher than those of pyrite or other sulfide minerals. The general order of the resistivity values of the ore minerals are from low to high values of pyrite, chalcopyrite < galena < marcasite < sphalerite. The results of our resistivity measurements show good agreements with the mineral composition obtained from the XRD analysis and the differences between those 2 areas can be explained. From the results of ICP-MS analysis, Au and Ag contents are practically no differences between Bayonnaise Knoll and Izena Cauldron, but associate with the contents proportional to Zn and Pb. The magnetic susceptibilities of the ore samples from Izena Cauldron are higher and proportional relation to the Fe contents. The hexagonal pyrrhotite crystals are observed in the samples which show high permanent magnetism.

From the inspection of the core samples, the width of the mineralization and altered zones is minimum of several cm, and the massive or conglomerate minerals were obtained. From the observation under a reflective polarization microscope, the ores with the various crystal-grain sizes were confirmed, it seem to be due to the difference process of the crystallization condition under the ocean bottom such as the concentration of elements, temperature, pressure and redox status. The depth of all the samples used are from shallower than 10m from the ocean bottom, and more samples from deeper layers are needed for the total understanding of the sea-floor hydrothermal deposits.

Keywords: sea-floor hydrothermal deposit, resistivity, chargeability, magnetic susceptibility, chemical composition, mineral composition

Oxygen isotope study of vein type gold deposit at the Tsagaan Tsahir Uul in the Bayankhongor belt, Mongolia

HAYASHI, Ken-ichiro^{1*}

¹Graduate School of Life and Environmental Sciences, University of Tsukuba

The Bayankhongor metallogenic belt, ~700 km southwest of the capital city, Ulaanbaatar, is the second productive gold-field in Mongolia. Production of this gold-field is not well known, but is estimated at about 50 kg/yr. Most gold is recovered from alluvial deposits, however primary sources of alluvial gold in the district are not well understood. The Tsagaan Tsahir Uul (TTU) gold deposit is located at the southeastern part of the Bayankhongor metallogenic belt, and is possible source of alluvial gold. The geology of the TTU deposit consists of Proterozoic tonalitic gneisses and marble-bearing schists, Proterozoic granitoid (647 Ma) and Permian small dioritic stocks (250 Ma) and Permian lamprophyre dikes (352 Ma). Gold mineralization in the TTU deposit is accompanied by quartz veins hosted in migmatized schist and granite.

There are two types of quartz veins. First group is 15 gold-bearing quartz veins that have NNW to NS direction with length of 0.2 to 2.8 km. The width of these veins is between 0.2 and 0.5 m. Quartz veins consist mostly of crustified bandings of milky quartz, with associated silver-black bands. The other vein is barren quartz-carbonate vein with ~4 km length and from 5 to 50 m width. This vein cuts quartz veins mentioned above. The veins composed of brecciated fragments of quartz and fracture filling carbonate-quartz matrix. Ore minerals in quartz vein are pyrite, chalcopyrite, galena, sphalerite, tetrahedrite, arsenopyrite and native gold. The fluid inclusions found in gold-bearing quartz veins were two-phase and some of them contain CO₂, with homogenization temperature range from 160-290°C. Oxygen isotope of quartz veins were analyzed by CO₂-laser ablated BrF₅ fluorination technique. The delta¹⁸O values of quartz vein range between 11.3 to 17.9 per mil, compared to -9.4 to -6.4 per mil for the quartz-carbonate vein. Calculated delta¹⁸O values of fluid from the delta¹⁸O of quartz using fractionation factor between quartz and water and homogenization temperatures (200 and 125°C, respectively) of fluid inclusion are 1.3 to 6.2 per mil for gold-bearing quartz veins and -27.3 to -24.2 per mil for quartz-carbonate vein. These data suggest two veins were formed completely different processes. Oxygen isotopic values of fluid suggest, the origin of gold-bearing fluid is metamorphic fluid from deep crust and migrated along the big fault system. Fluid responsible for quartz-carbonate vein was dominated by meteoric water, and this vein was probably formed at shallow level.

Based on the tectonic setting of the deposit, the TTU deposit possibly belongs to orogenic type gold deposit (Groves, 1998). The geological, mineralogical and geochemical features of TTU deposit are similar to those of worldwide orogenic gold deposits.

Keywords: orogenic gold, oxygen isotope, Tsagaan Tsahir Uul

Relationship between seismic velocity and permeability on granular rock model

YAMABE, Hirotatsu^{1*}, TSUJI, Takeshi¹, Toshifumi Matsuoka¹

¹Graduate School of Engineering, Kyoto University

Fluid flow in a rock pore is of great importance in subsurface development, e.g., petroleum engineering and carbon dioxide capture and storage. Permeability, which shows how easily fluid can pass through rock mass, is one of the most important indicators to evaluate fluid flow in porous media. Since permeability can be measured by laboratory experiments and well logging, permeability in a large-scale reservoir must be predicted by other information. In this study, we focus on seismic velocity as information to predict permeability because it is the most trusted parameter in subsurface exploration. In order to predict permeability from seismic velocity, the relationship between permeability and seismic velocity must be revealed.

These two parameters are not directly connected to each other. Pore geometry of rock mass could be a bridge between them because it is mainly governing fluid flow and seismic velocity. However, the geometry is very complicated. For a general discussion, we adopted granular rock models including a lot of spherical grains whose size distribution is assumed to be Gaussian. The permeability and seismic velocity are numerically computed from these rock models. The permeability is calculated by lattice Boltzmann method, which is one of the computational fluid dynamic methods and well-suited for simulation under complicated fluid-solid boundary condition. The homogenization by finite element method is adopted for the calculation of seismic velocity.

It is demonstrated that the sorting parameter is governing the seismic velocity and permeability in this model. Sorting parameter is one of the most important parameters in the discussion of grain size distribution. This is an indicator which shows the standard deviation of grain-size. The result of this research shows the relationship between permeability and seismic velocity granular rock models by the bridge of grain sorting.

Keywords: granular model, permeability, seismic velocity, sorting