

## Pulsed granitic crust formation revealed by comprehensive SHRIMP zircon dating of the SW Japan granitoids

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The origin of continental crust is a fundamental question in Earth's evolution. Granitoids, its volcanic equivalents, and metamorphic and sedimentary rocks with granitic compositions, are the main components of the upper continental crust. It is therefore important to understand the geodynamic settings in which juvenile granitic magma is generated from mantle-derived sources. Convergent plate margins, such as the Mesozoic circum-Pacific orogenic belts, are regarded as one of the plausible candidates for the post-Archean continental crust formation, as they are associated with abundant calc-alkaline I-type batholiths. However, the fundamental tectonic processes that triggered these voluminous granitic crust formations in the Mesozoic have remained largely unresolved due to the lack of precise temporal constraints on the granitic magmatism. We are currently undertaking a comprehensive geochronological study of the granitic batholith exposed in the Southwest Japan Arc, which is typical of the Mesozoic circum-Pacific orogenic belts utilizing high-precision zircon U/Pb geochronology.

In order to precisely determine the space-time distribution of the granitic magmatism that occurred in the SW Japan Arc during the Mesozoic, we have used the zircon U/Pb method to date a comprehensive suite of granitic rocks from the Chugoku Region in the SW Japan. Contrary to the results previously obtained using conventional geochronological methods, which suggested that the magmatism occurred gradually from ~100 to ~50 Ma, with the plutons forming over long time intervals, the newly obtained zircon ages reveal three clear pulses of granitic crust formation at 85, 60 and 35 Ma separated by 25 million year intervals. The 85 Ma magmatism was the most voluminous and was distributed in a broad zone that extends ~120 km across-strike, whereas the magmatism at 60 and 35 Ma were focused on the northern margin of the SW Japan Arc. Furthermore, the granitic magmatism at 85 Ma involved sediment-incorporated, ilmenite series granitic rocks, while the magmatism at 60 and 35 Ma involved more juvenile, mantle-derived, magnetite series rocks. Thus, not only did the granitic magmatism in SW Japan occur in pulses, there was also a spatial and compositional transition in the magmatism through time. This can be best explained by enhanced subduction zone magmatism during the Mesozoic, rather than the previously proposed model in which it was suggested that the granitic crust was formed by the subduction of a mid-ocean ridge on the Pacific Plate during the Middle Cretaceous.

## Petrology and zircon geochronology of the Hikami Granitic Rocks in south Kitakami Mountains, Japan

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The Hikami Granites, pre-Cretaceous older granitic complex of the South Kitakami Terrane, has long been controversial on their age of intrusion. Since unconformable relationship between the granites and the Silurian formation was shown by Murata et al. (1974). However CHIME age determination for the granites (Adachi et al., 1994), indicates Silurian to Permian age. We examined the zircon U-Pb ages of 13 samples from the Hikami Granitic Rocks, and solidification age of around 450 Ma were obtained.

Bulk rock chemical compositions of the Hikami granites were compared with Paleozoic granitic rocks in Japan. Petrochemical similarity between Hikami Granitic Rocks and the granitic rocks in the Kurosegawa Belt is consistent with the correlation between the South Kitakami and Kurosegawa Belts.

Keywords: Hikami Granites, zircon, U-Pb age, Petrochemistry

## Sr-Nd-Pb-Hf isotopic variations of Cretaceous to Paleogene granitic rocks from northeast Japan

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The Japanese Islands represent a segment of a 500 Ma old subduction related orogen developed along the western Pacific convergent margin, and most tectonic units are composed of late Paleozoic to Cenozoic accretionary complexes and their high P/T metamorphic equivalents (e.g., Maruyama, 1997; Isozaki et al., 2010). Maruyama (1997) described the formation of the Japanese Islands has been taken as the standard model for an accretionary orogeny. He also stated that the most important cause of the orogeny is the subduction of an oceanic ridge, by which the continental mass increases through the transfer of granitic melt from the subducting oceanic crust to the orogenic belt. On the other hand, Jahn (2010) described that the subduction-accretion complexes consisting of granitic and sedimentary rocks in southwest Japan are composed mainly of recycled old continental crust. Kagami et al. (1999) described that the Honshu Arc can be divided into three groups based on their Sr-Nd isotope characteristics: the Kitakami, North (Abukuma belt), and South (Ashio/Mino belts) Zones, in order of increasing Sr isotopic enrichment, with Nd isotopic depletion from NE to SW. We present Sr-Nd-Pb-Hf isotopic ratios for granitic rocks in northeast Japan.

Sr-Nd-Pb-Hf isotopic study are made for granitic rocks from the Kitakami belts (Kitakami Mountains), the Abukuma belts (Shirakami Mountains, Obonai area, Taihei Mountain, Sekiryō Mountains, and Abukuma Mountains), and the Ashio/Mino belts (Okutone area, Tadami area, Okutadami area, Taisyaku Mountains, and Ashio Mountains). Newly isotopic data from these granitic rocks show increasing enrichment of crustal component in order of the Kitakami, Abukuma, and Ashio/Mino belts. Multi-isotope plots of these rocks indicate that the trend in variation could result from the mixing of depleted and enriched components. The depleted component is likely to originate from the magmatic flux related to the Lower Cretaceous ridge subduction. On the other hand, the mixing model of subducted sediments and depleted mantle cannot explain the variation of Nd-Hf isotopic compositions of granitic rocks. The enriched component requires existence of a reservoir with low Hf initial isotope ratio, which is considered to be zircon-rich sediment derived from old continental protolith (Chauvel et al., 2008). In addition, the granitic rocks in Kitakami zone shows rather different trend from the granitic rocks in other districts. It can be explained by the hypothesis that the granitic rocks in the Kitakami zone were derived from the mixing of mantle component with enriched end member of lower Hf initial isotope ratio. This model is consistent with the fact that the Kitakami zone is characterized by the occurrence of adakitic rocks related to Lower Cretaceous ridge subduction.

Keywords: Northeast Japan, granite, Sr-Nd-Pb-Hf isotope, petrochemistry

## Garnet-bearing acidic igneous bodies in Mt. Kenashi-yama area, Fujikawaguchiko-machi, Yamanashi, Japan

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**Introduction** The garnet-bearing quartz porphyrite body in Mt. Kenashi-yama area Fujikawaguchiko-machi, Yamanashi, Prefecture was described by Katada (1956). On the other hand, there are many reports on garnet-bearing boulders in this area (Togawa et al., 1996; Togawa et al., 1997; Matsubara et al., 2008; Tamura et al., 2010).

On the detailed field works, we recognized three groups of garnet-bearing acidic igneous bodies in this area.

**Geology** The studied area is in the northern end of Izu-Bonin Arc, and is located east side of Misaka group, middle to late Miocene.

**Lithology** Three garnet-bearing acidic igneous bodies are recognized, which are named A, B and C groups.

[A group (lava flow(?))] This group exists in 1,100m to 1,200m above sea level, and is located from WSW to ENE over 2km long. The rock consists of quartz (10%-20%, md : maximum diameter = 5mm), feldspar (10%-25%, md = 4mm), garnet (1%, md = 3mm) and groundmass(60%-65%). The rock of A group shows high dense appearance.

[B group (volcanic ash(?))] This group exists at 1,200m, and this group may be exist along above the A group. This group can be assumed as garnet-bearing volcanic ash, because this group contains volcanic glasses (at under microscope) and rock fragments (If B group is not volcanic ash, this group may be the weathered zoon of A group). The B group consists of quartz (10%, md = 5mm), garnet (1%, md = 3mm) and clay matter 80%.

[C group (dike)] This group exists in 1,300m to 1,400m, and is located from WSW to ENE, over 3km long. The rock is little fragile, and consist of quartz (3%-20%, md = 4mm), feldspar (3%-20%, md = 3mm), garnet (0.1%, md = 3mm), hornblende (1%, maximum length = 9mm) and groundmass (65%-85%).

**Chemical analysis** Representative samples of each groups are analyzed by X-ray fluorescent analysis on 10 major elements. The SiO<sub>2</sub> contents of three groups are 72wt%-76wt%. It mean that these rocks are classified into rhyolite according to alkali-SiO<sub>2</sub> diagram (Le Bas, et al., 1986). There are slightly high in Na<sub>2</sub>O, and slightly low P<sub>2</sub>O<sub>5</sub> than Tanzawa Hosokawadani rhyolite (Yamashita, 1997).

**Discussion and Consideration** It can be assumed that three groups of garnet bearing acidic igneous bodies are recognized in Mt. Kenashi-yama area. They are located along WSW-ENE direction 2-3km long. A, B and C groups are possibly lava flow, volcanic ash and intrusive rock, respectively. All of them may be classified into garnet-bearing rhyolite.

Keywords: garnet, quartz, feldspar, rhyolite, Mt. Kenashi-yama, Fujikawaguchiko-machi

## Two types of websterite from the Ust'-Belaya ophiolite, Far East Russia: Origins and implications

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The Ust'-Belaya ophiolite is located in the Koryak Mountains, Far East Russia. We report two types of websterite in the mantle section of the ophiolite.

The lithology of the mantle peridotites from the ophiolite is variable from very fertile lherzolite to moderately depleted harzburgite. The mineral chemistry of the very fertile lherzolite shows similar signature to those of the subcontinental peridotite. The two types of websterite (type1 and type2) occur in them as dikes/veins. Type1 is composed of brownish colored cpx, opx and Al-spinel. On the other hand, type2 is composed of green colored cpx, opx and Cr-spinel.

Type2 websterite is similar to those reported from many other ophiolites. Websterites, which are characterized by extremely aluminous spinel similar to the type1 websterite, are never found in ophiolitic peridotites but are described in passive margin peridotites (e.g. Zabargad Island in Red Sea and Iberia Abyssal plain peridotites). These websterites are generally interpreted as high-pressure cumulates and the host peridotites are considered as fragments of subcontinental mantle.

The mantle section of the Ust'-Belaya ophiolite represents, at least partly, fragments of subcontinental mantle. The two types of websterite might be related to two different magmatisms in two different tectonic settings; type1 is formed former subcontinental to oceanic environment and then type2 is formed later oceanic to arc environment.

Keywords: Ust'-Belaya ophiolite, websterite, subcontinental mantle

## Field geological considerations on the formation mechanism of platy joints in lava flows

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Columnar jointing and platy jointing are characteristic types of jointing in volcanic rocks. The origin of columnar joints has been discussed for centuries, and at the present day it is considered that they are the result of cooling and contraction of lava (Aydin and DeGraff, 1988). However, platy joints have far less attracted researchers than columnar joints and their formation mechanism is still controversial. Platy joints can develop in thick (>100 m) and voluminous lava flows which have glassy margins such as "flood andesite" in Kyushu, Japan (Nagao et al., 1995) and ridge-forming lava flows at Mount Rainier (Lescinsky and Sisson, 1998), probably reflecting stress distribution or physical property within solidifying lava. Previous studies attributed formation of platy joints (sheeting joints) to late stage shear of lava flow and/or microlite orientation (Lescinsky and Fink, 2000), deflation of flow (Spörl and Rowland, 2006) or both flowage and shrinkage of lava (Bonnichsen and Kauffman, 1987). Although absolute evidence for the origin of platy jointing has not been found, restraining of internal lava by solidified flow margin would be an important factor in any case and density (volume ratio of crystals to glass) difference between flow margin and interior would be also important when we consider thermal contraction. It is also a problem when platy joints form, especially in the case that columnar and platy joints intersect without terminating each other. Occasionally platy joints are filled with tridymite and/or mica mineral with or without andesitic to dacitic melt, which might be segregated from the crystallizing lava body, suggesting that platy joints start to form at early stage of cooling of lava.

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Keywords: platy joints, flood andesite, internal flowage, thermal contraction, segregation vein

## Oxidation states of Fe within constituent minerals in spinel-lherzolite xenolith from Tariat Depression, Mongolia: Signif

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The Tariat depression is one of the most famous areas of deep-seated megacrystic xenoliths and mantle-derived xenoliths in the Baikal-Mongolia rift. Spinel-garnet-bearing websterite, garnet lherzolite and spinel lherzolite have been found in this area (Osanai et al. 2010). In this study, oxidation state of Fe in olivine (Ol), orthopyroxene, clinopyroxene and spinel in fresh spinel-lherzolite xenolith, and olivine in host basalt in Tariat depression were investigated using Mossbauer spectroscopy, X-ray FeL $\alpha$ /FeL $\beta$ -intensity ratio analysis (EPMA method) and transmission electron microscopy (TEM).

Olivine, clinopyroxene, orthopyroxene and spinel have homogeneous chemical compositions. Olivine is forsterite with average composition of Fo<sub>90</sub>Fa<sub>10</sub>, Clinopyroxene is Na-bearing diopside [(Na<sub>0.17</sub>Ca<sub>0.71</sub>Mg<sub>0.81</sub>Fe<sub>0.09</sub>Al<sub>0.20</sub>)<sub>2</sub>O<sub>0</sub>(Si<sub>1.89</sub>Al<sub>0.11</sub>)<sub>2</sub>O<sub>6</sub>], and have symplektite consisting of diopside and glass on the rim with the width of ~50  $\mu$ m. The chemical composition of the glass is similar to that of feldspar with compositions of An. Orthopyroxene is [(Mg<sub>0.85</sub>Fe<sub>0.09</sub>Al<sub>0.04</sub>Ca<sub>0.02</sub>)(Si<sub>0.94</sub>Al<sub>0.06</sub>)O<sub>3</sub>]. Spinel is [(Mg<sub>0.81</sub>Fe<sub>2+0.22</sub>)<sub>1.03</sub>(Al<sub>1.80</sub>Cr<sub>0.17</sub>)<sub>1.97</sub>O<sub>4</sub>].

The Fe<sup>2+</sup>: Fe<sup>3+</sup> ratios of forsterite, orthopyroxene, clinopyroxene and spinel determined by Mossbauer analysis are 97(1):3(1); 85(8):15(1); 74(4):26(3); 66(8):34(5), respectively. Fe<sup>3+</sup> in olivine is not attributed to any precipitates nor minute inclusions, which was confirmed by TEM observation, and, thus, exists in olivine structure. Fe of olivine phenocrysts from host basalt lava is only Fe<sup>2+</sup> which was proved by EPMA method.

Fe<sup>3+</sup>-bearing forsterite in spinel-lherzolite xenolith is considered to have been stable under mantle condition.

Keywords: olivine, oxidation state of Fe, spinel-lherzolite xenolith, Mossbauer methods, Mongolia



## Al/Si disordered anorthite in anorthite megacryst from Miyake-jima: effect of non-stoichiometry on Al/Si distribution

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The crystal chemistry of anorthite with the low content of albite (An<sub>92.0</sub>Ab<sub>3.4</sub>), part of a rapid cooled, anorthite megacryst occurring in 1940 ejecta from Miyake-jima volcano, Japan, has been investigated using single-crystal X-ray diffractometer and electron microprobe analyzer with wavelength dispersive X-ray spectroscopy (EMPA-WDS). The structure was refined in space group P-1 and cell parameters,  $a = 8.182(6) \text{ \AA}$ ,  $b = 12.883(4) \text{ \AA}$ ,  $c = 7.092(4) \text{ \AA}$ ,  $\alpha = 93.19(4)^\circ$ ,  $\beta = 115.91(4)^\circ$ ,  $\gamma = 91.18(4)^\circ$ . The final weighted R-factor is 3.77 % for 1549 reflections. Averaged T-O distances are 1.681  $\text{\AA}$  for T1(0), 1.674  $\text{\AA}$  for T1(m), 1.677  $\text{\AA}$  for T2(0) and 1.680  $\text{\AA}$  for T2(m), indicating each Al occupancy of 0.501, 0.453, 0.472, and 0.496, respectively. These results suggest that the Al/Si-distribution in the tetrahedral framework is highly disordered (QOD = 0.06), which results in having the c-axis in half along that determined in Al/Si ordered anorthites ( $c \sim 14 \text{ \AA}$ ).

Keywords: Anorthite, Al/Si order-disorder, Anorthite megacryst, Structural heterogeneity



## Formation temperature of perlite and its texture by heating experiments of obsidians from Hokkaido

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The obsidians from Hokkaido were heated in electric furnaces to transform the perlite in a form like pumice in vitreosity, because remained water in obsidians becomes the gas and makes air bubbles by heating.

We examined foaming temperature of the obsidians from 13 samples in 7 Hokkaido sources, and the relations with its foaming temperature and the water content of the obsidians. In addition, we changed a heating temperature and a condition of the heating time and examined the difference in foaming form of the perlite.

Finally, we considered a relations with foaming process of the obsidians and the internal structure of the perlite through the microscopy of the perlite.

Keywords: obsidian, heating experiment, perlite, vesiculation, glass

## Estimation of intracrystalline distribution coefficient of Mg-Fe ions in olivine using Cs-corrected STEM

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Intracrystalline distribution coefficient of Mg-Fe ions between the two types of the octahedral sites (M1, M2-site) of olivine,  $(\text{Mg,Fe})_2\text{SiO}_4$ , have been estimated using X-ray or neutron diffraction studies. Recently, the high angle annular dark field (HAADF) method using scanning transmission electron microscopy with the correction of spherical aberration (Cs-corrected STEM) visualizes the element column sites in crystalline samples. In the present study, the intracrystalline distribution coefficient of Mg-Fe ions in olivine were tried to estimate using HAADF-STEM. And furthermore, Crystal Structure Analysis of same sample was carried out using a four-circle X-ray diffractometer. We used the synthetic forsterite and the natural olivine from San Carlos, Sri Lanka and Miyake-jima. HAADF-STEM images parallel to a-axis show the Mg / Fe atom columns and the columns which alternately formed of Si and O atoms. Intracrystalline distribution coefficients estimated from the brightness in M1/M2-sites for synthetic forsterite, the olivines from San Carlos and SriLanka are good agreement with those estimated from X-ray method. On the other hand, that obtained from Miyake-jima is different with that obtained from X-ray method.

Keywords: STEM, olivine, intracrystalline distribution coefficient

## A Novel Approach for the Classification of Mineral Ore Particles by A Statistical Raman Spectroscopic Method

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### [Introduction]

Mineral ores extracted by mining go through a milling process before ore dressing. An important factor in both milling and ore dressing operations is the determination of the particle size distribution of the materials being processed, commonly referred to as particle size analysis. An elemental analysis technique such as X-Ray fluorescence and destructive wet chemical analysis can determine the quantity of mineral species present in the ore, however, these chemical analysis methods do not allow the study of the composition of individual particles of different size and shape. The statistical Raman spectroscopic method is a novel approach which can resolve this problem. Using this method the Raman spectra of several hundred particles is determined after size and shape classification of each individual particle by automated particle image analysis. Raman spectroscopy can be used to acquire the spectra of any inorganic compounds such as metal oxides and nitrides which are Raman active. Many mineral resources are mined as inorganic compounds. Therefore, Raman spectroscopy can be used for the identification of the chemical composition of mineral ores. Using the statistical Raman spectroscopic method described herein, it is possible to calculate the particle size distribution and proportion by mass or volume of each chemical component or mineral species based on Raman spectroscopic information. This study will report and discuss the capability of the statistical Raman spectroscopic method using iron ore as a model material.

### [Material and Method]

Iron ore samples were purchased from a vendor. These samples had been through the ore dressing process. Statistical Raman analysis was carried out using a Morphologi G3SE-ID instrument (Malvern Instruments, UK) equipped with a dry powder sample dispersion unit (SDU) and Raman module. The laser wavelength of Raman excitation was 785nm the laser power was less than 5mW and the irradiation time was 5 sec. The particle image measurements were made in diascopic mode with a total magnification 250x. Iron ore dry powder samples were dispersed using the SDU using a short duration pulse of compressed air. Measurements were made automatically using Standard Operating Procedures (SOPs) which define the software and hardware settings used. Measurement sample was dispersed on to glass plate as sample carrier which was minimized environmental exposure by the enclosed sample chamber unit. Particle identification by Raman analysis used the spectrum correlation coefficient approach.

### [Results and Discussion]

A Total of 66,436 particles of iron ore were measured by image analysis. The circle equivalent diameter particle size distribution by volume (VCED) exhibited a monomodal distribution with size distribution percentiles as follows: 8.62 $\mu$ m (d10), 21.83 $\mu$ m (d50), 51.29 $\mu$ m (d90). A subset of 700 particles were selected and the Raman spectra were measured. Particles over 20 micron in size were selected randomly from the image analysis data and Raman spectra were acquired. The spectra enabled identification of 4 components (Fig.1). The relative proportion of each component by volume or number of particles is shown in Table 1. Component (A) comprised approximately 90% of the sample. This component exhibited a Raman spectrum typical of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> [1]. It is assumed that components (B) and (C) are polymorphs based on the ratio of the intensities at 221cm<sup>-1</sup> and 245cm<sup>-1</sup>. Component (D) exhibited a spectrum typical of  $\alpha$ -FeOOH and composed less than 3% of the sample. This result does show that the statistical Raman analysis approach can detect components present at quite low concentrations.

### [Summary]

This report illustrated the application and capability of statistical Raman analysis for the characterization of mineral ores using a new approach based on combining chemical and particle size / shape information.

SCG61-11

Room:311

Time:May 2 11:45-12:00

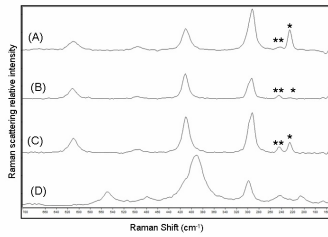


Fig 1. Raman Spectrums of iron ore.  
 (\* : 221cm<sup>-1</sup>, \*\* : 245cm<sup>-1</sup>)

Table 1.  
 Ratio of each component based on Raman spectrum

Component	Number (%)	Volume(%)
A	87.6	90.2
B	2.5	2.1
C	7.2	6.3
D	2.7	1.4

## Assessment of Nakhile porphyry Cu mineralization potential using geological, geochemical and statistical studies: a case

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The Nakhile Cu mineralization is located in 145 km northwest of Zahedan in Sistan and Baluchestan province of Iran. This area is geologically located in boundary part of Lut block and flysch zone of east Iran. Geology of the study area consists of Cretaceous to Eocene andesitic lavas and tuffs that were intruded by a dioritic to quartz-dioritic stock. The intrusive rocks are mainly altered and mineralized. Based on the petrography and XRD studies, main mineral in all types of the igneous rocks is plagioclase and the main texture is porphyry. Other minerals are clinopyroxene, amphibole, biotite, quartz, and secondary minerals that vary in the igneous rocks. A large part of the intrusive rocks is rich in pyrite. The pyrite occurs as veins, veinlets and disseminated in the stock. Cu mineralization occurs as vein and can be divided into hypogene and supergene mineralization. Hypogene mineralization is characterized by chalcopyrite and pyrite while supergene mineralization is characterized by malachite, azurite, jarosite, goethite, hematite and limonite. The propylitic alteration is dominant feature of the intrusive rocks as a wide outer zone. Potassic, phyllic and argillic alterations are also important in the area. The potassic alteration is probably important in the center part of the stock in depth. phyllic and argillic alterations are mainly formed by supergene processes.

The samples that were collected from the least altered and altered rocks in the study area were analyzed by ICP were processed by convenient software such as EXCEL and SPSS to obtain statistic parameters of: skewness, maximum, minimum and standard deviation. Then, the histograms for the amount of Cu, Au and related elements were drawn and their correlation coefficients were calculated. There are remarkable positive correlations between Cu, Au and Ag indicating their similar origin. The highest content of Cu is 7000 ppm in the study samples. The Cu anomalies are mainly observed in central and eastern parts of the area. The highest content of Au is 6000 ppb. The Au anomalies are mainly observed in western parts of the area. The higher contents of Pb, Zn and Ag are observed more away from the intrusive rocks.

The outcrops in the area are mainly similar as propylitic alteration zone of porphyry Cu deposits that is characterized by secondary hydrothermal epidote and chlorite and pyrite. The Cu porphyry mineralization and other alteration zones specially potassic probably occur in depth in the area.

## A leucogranite stock rich in high field strength elements, Kanamaru-Oguni area on the Niigata-Yamagata border, NE Japan

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A small stock of leucocratic Grt-two mica granite enriched in high field strength elements (HFSEs) has recently been found in the Kanamaru-Oguni district of the Asahi-Iide mountains in the Ashio Belt of the NE Japan arc. The granite has a high-K peraluminous composition, and is categorized as an A-type within-plate granitoid, according to several geochemical discriminants based on HFSEs. However, total Zr+Nb+Ce+Y contents are lower (166-192 ppm) and Rb/Ba ratios are higher (19-48) than those typical of A-type granitoids ( $Zr+Nb+Ce+Y > 350$ ,  $Rb/Ba < 10$ ). This suggests that this stock is in fact a highly fractionated granite, rather than an A-type intrusive. The stock solidified at shallow depth (about 3 - 6 km) from a silicic granitic magma, under moderately water-rich conditions. Geochemical modeling shows that the petrogenesis of the granite can be explained by partial melting of crustal rocks, leaving abundant plagioclase as a residual phase, with subsequent active fractional crystallization of plagioclase + alkali-feldspar. Many other small stocks composed of Grt-two mica granite occur in the Asahi and Iide mountains. The granitic activity ranges from Late Cretaceous (ca 90 Ma) to Paleogene in age. Although most of these stocks were derived from melting of various crustal rocks, some are highly differentiated, and have HFSE concentrations similar to the Kanamaru-Oguni stock studied here.

HFSE-rich granitoids also occur sporadically within the other Japanese geological units, but they are restricted in the southwestern Japan. The granitoids in the Inner and Outer Zones of SW Japan differ in composition. The HFSE-rich granitoids in the Inner Zone originated from middle to lower crustal materials, and were then strongly differentiated before emplacement. This is similar genesis to the granite in the Kanamaru-Oguni district. In contrast, the solitary HFSE-rich granitoid in the Outer Zone crops out at Cape Ashizuri. This occurrence is the only classic A-type intrusion in Japan, and is considered to have formed by a low degree of partial melting of the upper mantle or mafic lower crust. Although the HFSE-rich granitoids within the SW Japan arc may be similar geochemically to within-plate or ocean-ridge granites, they are in fact volcanic arc granites produced within the subduction zone by specific activities.

Keywords: Granite, HFS elements, Niigata-Yamagata, NE Japan

## Rare earth element compositions of the Kitahata body in the Fukae granite, northern part of Kyushu

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Cretaceous granitic rocks are widely distributed in northern part of Kyushu (Karakida, 1985), and Fukae granite is located in Kitahata district, Karatsu city, Saga Prefecture. The Fukae granite in this area (hereinafter, Kitahata body) consists of granite, aplite and felsic inclusion. The felsic inclusion is an oval figure about 50 cm in diameter, and is gradually changing from the surrounding granite. Main constituent minerals of the Kitahata body are quartz, k-feldspar, plagioclase and biotite, with apatite, zircon, opaque minerals as accessories. K-Ar biotite age of the body is 95.8 $\pm$ 2.4 Ma (Kitahata village history compilation committee, 2008). Rare earth element compositions are analyzed about ten samples, for comparison with estimated result of Kawano (2013).

In chondrite normalized REE patterns, values of LREE of the Kitahata body are the highest, and, aplite and felsic inclusion are lower than them. Normalized La/Lu ratios of the Kitahata body are also higher than those of the aplite and the felsic inclusion. Although the negative abnormalities of Eu are not observed in the Kitahata body and the felsic inclusion, it is clearly observed in the aplite. That is, Eu/Eu\* ratio of the aplite is low and the Kitahata body and the felsic inclusion show a similar value. SiO<sub>2</sub> contents increase from the Kitahata body to the felsic inclusion and the aplite. The values of LREE and La/Lu ratio of the felsic inclusion and the aplite which are rich in SiO<sub>2</sub> are lower than those of the Kitahata body, and it is suggested that they have the different origin from the Kitahata body. Although aluminum saturation index of the Kitahata body is larger than 1.0, it of the felsic inclusion is less than 0.9 and shows the character of meta-aluminous. The origin of the felsic inclusion not be considered to be a sedimentary rock, but it may originate in different felsic magma.

Keywords: Kyushu, Fukae granite, Kitahata, rare earth element



## Petrographic and geochemical studies of granitoids from the Inbi intrusives, Inner Zone of Southwest Japan

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We report a data set of whole rock compositions of seven granitoids from the early Paleogene Inbi intrusives and a granitoid from the mid Paleogene Namariyama intrusives, Inner Zone of Southwest Japan. The Inner Zone where voluminous granitic plutons occur is subdivided from the north to the south into three areas in terms of mineralogical and petrological characteristics of granitoids: the San-in Belt, the San-yo Belt, and the Ryoke Belt. The examined Paleogene intrusives, which belong to the San-in Belt, show volcano-plutonic association on the eastern side of younger Daisen volcano at the southern part of Tottori Prefecture and the northern part of Okayama Prefecture [e.g. 1-5].

Seven early Paleogene granitoids were collected from three plutons of the Inbi intrusives: Tottori granite, Ningyo Toge granite, and Sangenya granite [4]. Minerals in polished thin sections were first described under microscope. All of the granitoids from the Inbi intrusives contain quartz, feldspars, biotite and iron oxide. Most of them except for Tottori granite contain amphibole. Spinel is found as accessory mineral in some thin sections.

Each mixture of lithium tetraborate and powdered rock was put into a platinum crucible, and then ignited in a furnace at 1000 degree-C and cooled for preparing a glass bead. And then, major and trace elements were measured using XRF analyzer. To prepare sample solutions for measuring trace elements including REEs, the powdered rocks were first digested in a PTFE beaker with HF/HClO<sub>4</sub> mixture on a hotplate at 120-140 degree-C, and then residue probably including heavy minerals such as zircon was dissolved in sealed high-pressure container with HF/HCl mixture at 180 degree-C. The first step decomposed fraction and residual one were well-mixed, and then this mixture was split into two aliquots: one was separated from other elements using a quartz column filled with cation exchange resin for measuring REEs, and the other aliquot was for analysis of trace elements except for REEs. These solutions were analyzed using ICP-MS.

Chemical analyses for whole rock compositions of seven Inbi granitoids yielded the following results. Molecular Al<sub>2</sub>O<sub>3</sub>/(CaO+Na<sub>2</sub>O+K<sub>2</sub>O) values are given as I-type with a range from 0.96 to 1.10. Relationship of Na<sub>2</sub>O+K<sub>2</sub>O vs. total FeO vs. MgO shows calc-alkaline series on AFM diagram. SiO<sub>2</sub> content ranges from 65.7 wt% to 73.4 wt%, and relationship between Si and other major elements gives clear differentiation trend on Harker variation diagrams. Five samples of the granitoids are categorized as high-K series. Many granitoids in this area suffer weathering. The resulting in weathering yields a decrease of CaO (from 2.5 wt% to 1.7 wt%) and Na<sub>2</sub>O (from 4.1 wt% to 3.6 wt%) for Ningyo Toge granites. Whereas Sangenya and Ningyo Toge granites contain about 200 to 360 ppm Sr, Tottori granite contains only 90 ppm Sr. The values of Ti normalized by the mean MORB composition [6] against seven granitoids yield a trend of depletion in Ti. Those of REEs normalized by the MORB composition are given as enriched LREE pattern, negative Eu anomaly, and relatively flat MREE and HREE patterns. All of these normalized patterns have characteristics as volcanic arc granites [e.g. 7].

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Keywords: granitoid, San-in Belt, XRF, ICP-MS, trace element, REE

## Petrology of ultramafic rocks in the Gosaisho series, northeastern Japan: Is the Gosaisho series the SSZ ophiolite?

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The Abukuma plateau, which extends ~180km in N-S and ~50km in E-W directions, is located along the Pacific coast of northeastern Japan. This plateau is composed mainly of Cretaceous granitic rocks and regional metamorphic rocks. In the Gosaisho-Takanuki district that is located in the central part of the plateau, the Gosaisho metamorphic rock series in the east overthrust onto the Takanuki metamorphic rock series in the west (e.g. Umemura, 1979). The Gosaisho series is mostly composed of mafic and siliceous rocks, and the Takanuki series is mainly composed of pelitic-psammitic rocks. In the Gosaisho series, many small ultramafic bodies are present in the areas adjacent to the Takanuki series. Metamorphic rocks in the Abukuma Plateau have been well studied since the late 19th century, excepting these ultramafic rocks.

The ultramafic rocks in the Gosaisho-Takanuki district are affected by contact metamorphism of the Cretaceous granitic rocks in various degrees, but their protoliths are judged as mantle peridotites and ultramafic cumulates based on their bulk rock chemistry. The ultramafic cumulates are sometimes accompanied by metagabbros. In an ultramafic body called Mount Ohtsube, mantle peridotites are distributed at the foot of the mountain and cumulates occupy its top part. It is likely that the ultramafic bodies in this area are the fragments of the lower part of an ophiolite. We also note that cordierites and associated gabbroic rocks are present in this area. They are always contained in granitic bodies, and it is likely that intrusion of cordierites coincided with the Cretaceous felsic magmatism.

The bulk rock chemistry of the peridotite is poor in Ca and Al contents (CaO <0.6 wt. %, Al<sub>2</sub>O<sub>3</sub> <1.6 wt. %). This suggests that they are highly depleted mantle peridotite. On the one hand, Cr# of spinel in the peridotite, which supposedly correspond to the degree of mantle depletion, show a wide range (14 - 87) from place to place. The spinel is poor in Ti content (TiO<sub>2</sub> <0.2 wt. %). These characteristic features of spinel suggest that the mantle section was of arc origin (Arai et al., 2011). This is consistent with the bulk rock chemistry of the associated metagabbro which is rich in Ca and Al, and poor in Ti contents (CaO = 11.6 - 17.0 wt. %, Al<sub>2</sub>O<sub>3</sub> = 13.8 - 18.5 wt. %, TiO<sub>2</sub> = 0.06 - 1.06 wt. %). It is also noteworthy that some ultramafic cumulates are very rich in Fe (up to Fo = 73).

In the Gosaisho series, siliceous rock contain early Jurassic radiolarian fossils (Hiroi et al., 1987). In addition, some low-grade metamorphic rocks show original pillow structure (Nohara and Hiroi, 1989). Hiroi et al. (1998) argued that the Gosaisho Series represents the mid-ocean ridge origin oceanic crust which overthrust onto the terrigenous Takanuki Series. However, in some places, there are calc-alkaline intrusions which have experienced regional metamorphism with the country rocks (Umemura, 1970). This is consistent with our idea that the ultramafic rocks are of arc origin. Therefore, it is suggested that the Gosaisho Series is the arc-related, supra-subduction zone ophiolite which thrust onto the Takanuki Series in the Jurassic period. However, it is also possible that the early Paleozoic Hayachine-Miyamori ophiolite (e.g. Machida and Ishiwatari, 2013). Comprehensive study of mafic and ultramafic rocks in the Gosaisho series is needed to solve this problem.

Keywords: supra-subduction zone ophiolite, ultramafic rock, Abukuma metamorphic rocks

## Experimental petrology of Goseong volcanoes, Korea

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Genozoic volcanoes with composition of alkali basalts are widely distributed in Southwest Japan, Korea, and East China. On the basis of geochemical studies, several models to explain magma origin of the alkali basalts were proposed (e.g., upwelling of hot asthenosphere, melting of stagnant slab, and so on). However, little is known about differentiation processes for the alkali basalts based on petrological studies. We therefore performed a series of experimental determinations of melting relation in alkali basalts on Goseong volcanic field, Goseong-do, Korea. Goseong volcanic field consists of seven volcanic plugs, and some of them are accompanied by lava flows. We have carried out petrological studies on alkali basalts from all the seven plugs. The alkali basalts have phenocrysts of olivine and augite and microphenocryst of spinel. Whole rock compositions show that the alkali basalts are relatively primitive ( $\text{FeO/MgO} < 0$  and  $\text{MgO} > 11$  wt %), and mineral chemistry supports this (Forsterite content in olivine  $> 87$ ). The most primitive rock was selected for melting experiments at 1110-1220 °C and 1 bar under the oxygen fugacity along the fayalite-magnetite-quartz buffer. The experimental results show that mineral assemblage (olivine, spinel, and plagioclase) is different from natural one (olivine, spinel, and augite), indicating that crystallization pressures were probably higher than the melting pressure (1 bar). Thus, we will conduct melting experiments at high pressures in future work.

## Metamorphic evolution of garnet-sillimanite gneiss from Ambatofotsy region, Antananarivo domain, east-central Madagascar

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Madagascar is situated within the central part of the Neoproterozoic East African Orogen (EAAO: Jacobs and Thomas, 2004) that marks the join between East and West Gondwana. Therefore, Madagascar is one of the most significant areas to understand the process of Orogen formation. In this study we report the newly found inclusion of kyanite + staurolite + muscovite + rutile in garnet and the mode of occurrence and discuss the metamorphic evolution of the garnet-sillimanite on the basis of estimated results by using various geothermobarometers and phase equilibrium by constructing pseudosection.

The Antananarivo domain is mainly composed of the felsic metamorphic rocks with subordinate amounts of the metasedimentary rocks (Tucker et al., 2012). There exposed magnetite-orthopyroxene-quartz gneiss (metamorphosed banded iron formation), garnet-orthopyroxene rock and garnet-hornblende-biotite gneiss around the garnet-sillimanite gneiss in the eastern part of the domain. The garnet-sillimanite gneiss is mainly composed of garnet, sillimanite, k-feldspar, plagioclase, and quartz with subordinate amounts of biotite, muscovite, monazite, zircon, rutile and graphite. Sillimanite is present in the matrix and as inclusion in garnet. Kyanite is only present as inclusion in garnet. Garnet ( $X_{Mg}=0.17-0.18$ ) also contains spinel and abundant quartz and monazite inclusions. Spinel shows Mg poor ( $X_{Mg}=0.21-0.22$ ) and Zn rich (ZnO = 18.4-19.0 wt.%) compositions. We newly found kyanite + staurolite + muscovite + rutile in the garnet. This staurolite shows Mg poor ( $X_{Mg}=0.12$ ) and Zn rich (ZnO=3.1 wt.%) composition. Garnet is replaced rim of grain by radial aggregate of biotite ( $X_{Mg}=0.58$ ) + sillimanite.

As a result of the petrographic observation, the metamorphic condition of the garnet-sillimanite gneiss was increased from the stability field from staurolite + quartz to garnet + kyanite (Spear and Cheney, 1989). Garnet + sillimanite + spinel + quartz was stable during the peak metamorphic condition. The estimated peak pressure and temperature condition is ca. 800 °C at 0.9 GPa by using garnet-sillimanite-plagioclase-quartz geobarometer (Spear, 1993) and garnet-sillimanite-spinel-quartz geothermobarometer (Nichols et al., 1982) with garnet activities calculated after Berman (1990). Garnet is replaced rim of grain by radial aggregate of biotite ( $X_{Mg} = 0.58$ ) with sillimanite. This reaction is hydrous reaction from garnet + k-feldspar + H<sub>2</sub>O to biotite + sillimanite + quartz with decreasing temperature (Le Breton and Thompson, 1988). This retrograde metamorphic condition is almost consistent with the estimated P-T condition from the garnet-hornblende-biotite gneiss. The estimated pressure and temperature condition is ca. 700 °C at 0.6 GPa by using garnet-hornblende geothermometer (Graham and Powell, 1984), hornblende-plagioclase geothermometer (Holland and Blundy, 1994) and garnet-hornblende-plagioclase-quartz geobarometer (Kohn and Spear, 1990). In summary we newly identified the clockwise P-T path from the garnet-sillimanite gneiss exposed in Ambatofoty region, eastern part of the Antananarivo domain.

Keywords: Gondwana supercontinent, east-central Madagascar, Antananarivo domain, Garnet-sillimanite gneiss, Clockwise P-T path

## Petrogenesis of garnet-clinopyroxene rocks from the Gondwana collisional orogeny

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Madagascar - Southern India - Sri Lanka - East Antarctica region, which is regarded as a part of the East African - Antarctic Orogenic Belt formed by complex subduction-accretion-continent tectonic events related to the amalgamation of Gondwana Supercontinent during Neoproterozoic, is characterized by the presence of major suture zones (e.g. Palghat-Cauvery Suture Zone in southern India) which correspond to paleo-plate boundaries formed by the closure of Mozambique Ocean at ca. 530-550 Ma. The dominant lithologies of the suture zones are felsic to intermediate orthogneiss, metasediments, and mafic-ultramafic suites. Particularly, the occurrence of mafic-ultramafic suites (ophiolite or layered intrusion) is a unique character of the suture zones compared to surrounding granulite blocks and cratons. Here, we report new petrological and geochemical data of metagabbroic garnet-clinopyroxene rocks from Sri Lanka and discuss its petrological implications. Mineral assemblages of the rocks are garnet + clinopyroxene + orthopyroxene + ilmenite + hornblende + plagioclase (type 1), and garnet + plagioclase + clinopyroxene + orthopyroxene + quartz + ilmenite (type 2). Type 2 rock shows a decompression texture of orthopyroxene + plagioclase symplectite formed by a reaction: garnet + quartz => orthopyroxene + plagioclase. Similar rocks and textures have been reported from the Palghat-Cauvery Suture Zone in South India (Nishimiya et al., 2008; Sajeew et al., 2009; Saitoh et al., 2011), Highland Complex in Sri Lanka (Osanai et al., 2006), and Lutzow-Holm Complex in East Antarctica (Saitoh et al., 2012). Temperature and pressure conditions inferred for the type-1 Sri Lankan metagabbro based on pseudosection analysis in NCFMASHTO system is 970-1040C and 8-10.5 kbar, which is significantly lower in pressure than the results of Osanai et al. (2006) (>18 kbar, >1000C). Recent petrological and geochemical studies of the Palghat-Cauvery suture zone in southern India suggest that similar metagabbros and related mafic-ultramafic suites occur as various blocks within ortho- and paragneisses as melange. Similar occurrences and P-T evolution of metagabbro bodies in several Gondwana fragments suggest that the Palghat-Cauvery Suture Zone might continue to the Lutzow-Holm Complex (East Antarctica) through Highland Complex (Sri Lanka).

Keywords: granulite, Gondwana, suture zone, pseudosection

## Neoproterozoic and Middle Neoproterozoic bimodal magmatism in the Gondwana orogeny, South India

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Detailed petrological investigations for bimodal association of basaltic and rhyolitic magmas, which is regarded to have formed at subduction or rift zones, provides important information to investigate magma petrogenesis and tectonic evolution in a convergent or divergent margin settings. Here, we report first preliminary petrological and geochemical data of the Neoproterozoic charnockite-mafic granulite association in the Madras Block and Middle Neoproterozoic granite-amphibolite association in the Mesoarchean Coorg Block, southern India. Irregular-shaped mafic granulite (basaltic andesite) occurs as blocks of about tens of centimeter within charnockite (dacitic) in the Madras Block, while amphibolite (basaltic trachy-andesite) blocks in the Coorg Block are surrounded by sub-alkaline granite. Although there is no obvious texture of magma mixing in the Madras samples probably due to post-magmatic high-grade metamorphism and complete recrystallization, plagioclase in the contact zone between mafic enclave and host granite from the Coorg Block shows oscillatory and dusty zonings, which might suggest bimodal magmatism in Middle Neoproterozoic divergent margin in southern India.



## Infiltration of CO<sub>2</sub>-H<sub>2</sub>O binary fluid and formation of patchy charnockite from Southern India

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Since the first discovery of patches, veins and ladders of coarse-grained orthopyroxene-bearing felsic granulite (incipient charnockite) within foliated amphibolite-facies gneiss from Kabbal in Karnataka, southern India, by Pichamuthu (1960), the origin and petrogenesis of charnockite and its implications for granulite processes in lower crust have been the focus of many petrologists. According to previous studies, charnockite formation in the SGT is considered to have resulted by the infiltration of CO<sub>2</sub>-rich anhydrous fluids along structural pathways within upper amphibolite-facies gneisses, resulting in the lowering of water activity and stabilization of orthopyroxene through breakdown of biotite (e.g. Janardhan et al., 1979; Newton et al., 1980; Hansen et al., 1987; Santosh et al., 1990; Newton, 1992; among others).

This study presents new petrological data of 'incipient' charnockite developed within garnet-biotite (Grt-Bt) gneiss from Kakkod with the western Trivandrum Granulite Block (TGB), India. In this locality, bulk rock compositions of charnockite and the host Grt-Bt gneiss are almost equivalent. The result of conventional geothermobarometry using Grt-Opx-Pl-Qtz assemblage shows the peak metamorphic condition of 860-960 °C and 6.9-8.4 kbar, which is consistent with the results of mineral equilibrium modeling. The metamorphic condition certainly corresponds to granulite-facies event, and it is higher than those reported from other incipient charnockite localities in the TGB and adjacent Nagercoil Block. Furthermore, the estimated metamorphic condition is too high for the stability of the host Grt-Bt gneiss that contains a mineral assemblage formed at amphibolite-facies condition. In addition, although pseudosecondary fluid inclusions are composed of pure CO<sub>2</sub>, secondary fluid inclusions contain CO<sub>2</sub>-H<sub>2</sub>O binary fluid. Therefore, patchy charnockite in Kakkod from the TGB is considered to have formed by infiltration of CO<sub>2</sub>-H<sub>2</sub>O binary fluid during a retrograde stage. The petrogenetic model of incipient charnockite formation proposed in this study is therefore different from reported petrogenesis from other localities.

Keywords: incipient charnockite, metamorphic fluid, pseudosection, geothermobarometry, Trivandrum Granulite Block, southern India



## Relationship of zeolites and host rocks

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Natural zeolites occur in various rocks, such as igneous rocks, sedimentary rocks, and metamorphic rocks, at surface and shallow zone of upper crust.

In this research, the relationship between chemical composition of the host rocks and zeolite species are discussed in terms of the basis of chemical analysis of samples from Izu Peninsula and the Chichijima of Ogasawara (Bonin) Islands.

Although origin relations between the microscopic zeolite species and host rock compositions are seen under the conditions of low water/rock ratio, like a burial diagenesis, low degree regional metamorphism, and contact metamorphism, it has reported that macroscopic crystals occur in veins and geodes, not controlled by host rock composition, as they produced under the conditions of high water/rock ratio of hydrothermal alteration, in a previous work. (Utada 1995)

### Result and discussion

The identification of the zeolites species are characterized by X-ray diffractometry and bulk rock chemical composition of host rocks are analyzed by X-ray fluorescence.

To research 10 points of Chichijima (Ogasawara islands) and 2 points of Izu Peninsula, eight kinds of zeolite ( Heulandite, Analcime, Chabazite, Mordenite, Erionite, Phillipsite, Stilbite and Yugawalite) were able to be identified.

Samples from Chichijima, Stilbite was detected on Miyanohama, Hatsuneura north side, Hatsuneura south side, Suzaki, Buta seashore, and Kin-shi beach.. Stilbite did not occur on the samples from other 4 points

As a results Si/Al ratio of the host rocks are clearly different between the points of Stilbite occurred and not occurred, Si/Al ratio of former rocks were 5.248~7.672, the latter rocks were 4.230~4.768. The boundary of Stilbite occurrence Si/Al ratio of host rock seems to be around 5. . In the Chichijima (Ogasawara islands), correlation was found between host rocks and formed zeolites.

Keywords: zeolites, host rocks, Chichijima, Ogasawara islands

## Three pyroxene andesite (pigeonite-augite-hypersthen andesite) from Hakone volcano

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Pigeonite phenocryst bearing volcanic rock is very rare in the world. Pigeonite-augite-hypersthen andesite (= three pyroxene andesite or pigeonite andesite ) from Hakone volcano is very famous according to the detailed studies on the pyroxenes using microscope by the late professor Kuno (Kuno 1935, Kuno 1936). On the bases of the detailed EPMA analyses of the pyroxene crystallization sequences as well as estimated magmatic temperatures using pyroxene geothermometer, for the pigeonite andesite, the author suggests the following working hypothesis, i.e. the pigeonite andesite was induced by magma mixing between three pyroxenes andesite magma (about 1070 degree C) originated from the primitive high temperature hydrous tholeiite magma within secondary magma reservoir opened for water, and the high temperature magma (about 1110 degree C) in the secondary magma reservoir. The key concept is that cocrystallization of three pyroxene phenocrysts under open system for water in the secondary magma reservoir.

Keywords: Hakone volcano, pyroxene geothermometer, pigeonite, magma mixing, three pyroxene andesite, magmatic temperature

## The structural water in hydrothermally synthesized monazite

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**Introduction:** The U-Th-Pb dating of accessory minerals such as zircon and monazite is widely applied for various types of rocks [1,2,3]. There has been proposed another method to obtain geochronological information from these minerals: quantifying the degree of metamictization (destruction of crystal structure by radioactive components). It is reported for zircon that the water content (up to 10 wt%) is in proportion to the degree of metamictization, thus to the concentration of radioactive nuclei and geological age[4]. Monazite on the other hand usually undergoes much less metamictization than zircon due to the higher bond strength of P and O compared to that of Si and O; this results in the lower water content in the metamictized monazite. Determination of the structural water content in monazite without radioactive damage is thus necessary to constrain the "initial" water content prior to hydration. The water content bears significance also for better understanding the crystal chemistry of monazite. In this study, we synthesized monazite single crystals at hydrothermal condition and determined the content of structural water as a function of pressure.

**Experimental method:** The hydrothermal synthesis of monazite was conducted at a temperature of 800 degC and pressures of 1.5, 10 and 15 kbar using a cold-seal pressure vessel and a piston cylinder apparatus. The CePO<sub>4</sub> reagent was encapsulated with H<sub>2</sub>O or H<sub>2</sub>O-NaCl solution and run for ca. 100 hours. The FT-IR analyses of the obtained monazite single crystals were conducted to determine the concentration of structural OH on the basis of Lambert-Beer's Law. The molar absorption coefficient was estimated by linear calibration curve against the OH stretching vibration wavenumber [5].

**Results and Discussion:**The broad absorption band was observed at 3100-3600 cm<sup>-1</sup> in the crystals synthesized in all the experimental conditions. The water content of synthesized monazite was estimated approximately to be 20-70 ppm, showing no large pressure dependence. FT-IR analyses of pleochroic absorption are on-going to determine the OH dipole orientation within the crystal structure.

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**Keywords:** hydrothermal synthesis, accessory mineral, monazite dating, metamictization, nominally anhydrous minerals, FT-IR

## Phase relation in ternary feldspar system at high temperature

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During cooling of rocks or by change of chemical composition of feldspar, feldspar transforms to other polymorphs and forms various micro-textures. Observing micro-textures of feldspar is a useful approach to give a constraint to the thermal history of the rock. It has been known that the feldspars in ultrahigh-temperature (UHT) metamorphic rocks have ternary feldspar (Tfs) composition and those have the various and complex microtextures. However, the occurrence and the formation process of micro-textures in Tfs had not been studied in detail and they could not be interpreted by the widely used phase diagram with 2nd-order C2/m-C-1 phase transition at high temperature. And furthermore, although many experimental studies were performed, with respect to the phase relation on the plagioclase feldspar and alkali feldspar systems, the detailed experiments for the phase relations in the An-Ab-Or ternary feldspar system were restricted and its phase relations still remain ambiguous. Due to the high crystallization temperature of ternary feldspar (Tfs), Tfs would preserve the information about thermal history in more detail than those recorded on alkali feldspars and plagioclase feldspars. Previous thermodynamic studies on the C2/m - C-1 phase transition (Kroll et al., 1980; Salje et al. 1985, Carpenter, 1988) were carried out using the in situ powder X-ray experiments on pure Ab compositions. Due to the spatial resolution of analytical instruments, they missed the formation of the micro-texture on C2/m - C-1 phase transition. In this study, high temperature and high pressure experiments were carried out to decide the phase relation at high temperature including the phase relation between the C2/m and the C-1 in the An-Ab-Or ternary feldspar system at 1100 - 1300C and 10 kbar. We reveal the formation process of complex micro-textures of Tfs in UHT metamorphic rock by the present phase diagram.

We employed mixture of powdered lamellae-free oligoclase and sanidine crystal as starting materials. Bulk composition of starting materials was prepared by varying ratio of oligoclase and sanidine. We focused whether micro-textures derived from the C2/m - C-1 phase transition were formed or not. Experimental products were observed using field emission scanning electron microscopy (FE-SEM, JEOL JSM-7001F) and annular dark-field scanning transmission electron microscopy (ADF-STEM, JEOL JEM-2100F) to observe micro-textures.

Exsolution lamellae by a compositional gap between the C2/m and the C-1 which has near (010) interface, were observed in the run products synthesized at 1100 - 1200C. This result strongly suggests that the C2/m - C-1 transition is the first order phase transition. Moreover, the glass phase was observed in run products synthesized at 1250 - 1300C. From these experimental results, we propose the phase diagram on the Olg (An<sub>25</sub>Ab<sub>75</sub>) -Or pseudo-binary.

Napier Complex in northern Enderby Land, East Antarctica is one of the most famous regional ultrahigh-temperature (UHT) metamorphic terranes in the world. Although Tfs in Napier Complex has the complex microtextures (e.g., Harley 1985; Sheraton et al. 1987; Hokada, 2001), the occurrence and the formation process of micro-textures in Tfs have not been understood in detail. By the phase diagram obtained in the study, the formation process of Tfs in the felsic gneiss and the micro-texture in Tfs were revealed as following process. At first heterogeneous distribution of Olg, Tfs, and myrmekite-like textures were result of melting of the felsic gneiss and following crystallization. And then, the peak metamorphic temperature is estimated to be at least 1200 - 1250C. At the cooling process, the complex exsolution textures of Tfs are composed of (010) coarse lamellae derived from C2/m - C-1 first order phase transition and (-901) fine lamellae derived from spinodal decomposition.

Keywords: ternary feldspar, phase relation, high temperature experiment

## Quantitative Analysis of Rock Samples by ICP-Quadrupole Mass Spectrometer (QMS)

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ICP-Quadrupole Mass Spectrometers (QMS) can analyze multi-element quickly with high sensitivity. One problem is the interference by polyatomic molecules. For example, polyatomic molecules, such as ArO and ArCl, obstruct the analysis of Fe and As, respectively. In order to remove polyatomic molecules, ICP-QMSs using the collision gas was developed. For collision gas, generally inert gas such as He gas has been used. In this study, we try to analyze major and trace elements of standard rocks and volcanic rocks of Cameroon Volcanic Line by a ICP-QMS with He collision cell.

The iCAP-Q (ThermoScientific Inc) was selected for study. The plasma was operated at 1.7 kW and 27 MHz. The flux of Ar was about 16 L/min. The sampling cone can be removed easily without any tools and cleaning procedure is simple. The plasma gas, which is injected to vacuum system, is bended to 90 degree by an ion lens and reach to He Collision Cell. Neutral molecules are removed efficiently by the ion lens. Helium collision cell has a function as small QMS, removing interfering ions lighter than target element. The polyatomic molecules are also removed due to the reduction of their kinetic energy with He collision. The ions passing He collision cell go to the main QMS and their signals are detected by analog or pulse detections.

We used three standard rocks (JA-2, JB-2, and JB-3) and volcanic rocks at Borombi Mbo Volcano, Cameroon. The 50 mg of rock powder was put into 100 mL Teflon digestion vessel with 2.0 mL of 35 wt% HCl, 1.0 mL of 60 wt% HClO<sub>4</sub>, and 0.5mL of 50 wt% HF. The vessel was set in microwave heating system (Multiwave 3000, Parkin Elmer Inc.). The microwave power was increased to 500 W by 50 W/min and kept over 60 min. After heating, the digestion vessel was cooled down to 50 °C. In the cooled vessel, 2.5 mL of saturated H<sub>3</sub>BO<sub>3</sub> water and 2.5 mL of pure water were added, and the vessel was heated by microwave heating system again. The micro wave power was increased to 1400W by 280 W/min and kept for 20 min. After cooling, pure water was added to the sample solution and total volume was adjusted to 50 mL.

Yields of major elements in standard rocks, except for Si, were almost more than 70 %. In case most of trace elements, those were also more than 70%. Furthermore, there was no significant difference in the yield of most elements when we analyzed several times for a common sample. It is found that major elements, except Si, and most of trace elements of volcanic rocks can be analyzed by using a single ICP-QMS. In case of volcanic rock samples of Cameroon, type of these samples were identified to be an alkali basalt based on Nb/Y versus Zr/TiO<sub>2</sub> diagram. This result is consistent to the previous study on Cameroon Volcanic Line (A. Marizoli et al., 2000).

Keywords: ICP-QMS, microwave digestion, volcanic rock, quantitative analysis, Cameroon

## Validation of mass attenuation coefficients in quantitative electron probe microanalysis (EPMA)

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Mass attenuation coefficients (m.a.c.s) are important factors of accuracy in quantitative electron probe microanalysis (EPMA). New m.a.c.s are calculated from the latest version of two datasets[1][2] for  $Z = 1 - 92$ . The combination of two datasets solves the problems within them, such as spurious discontinuity and unnatural increase at high-energy sides of absorption edges. New m.a.c.s improve accuracy including geological applications.

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Keywords: electron probe microanalysis (EPMA), quantitative analysis, mass attenuation coefficients, matrix correction

## SEM-EDS Automated Particle Analysis of Mineral Compositions of Rocks

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Rocks consist of various kinds of minerals depending on their localities and formation processes. Mineral compositions of rocks are very important to study their sources and formation processes. X-ray fluorescence analysis (XRF) is commonly needed for mineral composition analysis. The XRF analysis provides the average composition of elements in a rock. Analysis of mineral particles in a rock is sometimes more important to find features of a rock. However, the analysis of a large number of mineral particles in a rock one by one requires a great deal of time. In recent years, the automated particle analysis combined with a scanning electron microscope (SEM) on energy dispersive X-ray spectrometer (EDS), which is called SEM-EDS automated particle analysis has rapidly been advancing. This method enables fast analysis of a large number of particles one by one directly.

In this report, analysis of the mineral compositions of two rocks -the Koujaku granite and the Hakkoda second-stage pyroclastic flow deposition (Ht2) - was carried out with SEM (JSM-IT300LA, JEOL)-EDS (JED2300, JEOL) automated particle analysis. The samples for this analysis were prepared as follows: rocks were crushed separately and each crushed rock embedded in resin was polished. More than a few thousand particles of the rocks were analyzed. In the Koujaku granite, quartz was a dominant constituent. K-feldspar and alkali feldspar were contained in a higher concentration than plagioclase. In addition, some colored minerals were contained. In the Ht2, pumice was a dominant constituent. In addition, quartz, feldspar and some colored minerals were contained. Additionally, many particles in the Ht2 consisted of multiple minerals unlike in the Koujaku granite. In the presentation, we will give more detailed descriptions of minerals and their components of the rocks.

Keywords: Mineral, Particles Analysis, SEM-EDS



## Dependence of water concentration distribution of columnar joints formation in analogue experiments

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Columnar joints of igneous rocks and ignimbrites have various morphological patterns. As their unit structure, column structure can be classified in terms of straight or curved. Columnar joint is formed by volume contraction due to cooling and tensile stress accumulated inner the volume is released as sequentially cracks according to the temperature gradient during cooling. Basic research to explain how curved columns are formed has not been conducted. In this study, we report the results of reproducing curved structure in analogue experiments by drying starch and water mixture. We put the mixture into a cylindrical container and light a lamp (60W) 1.5cm above the surface of mixture. We take images with X-ray CT of the specimen before drying perfectly and observe the spatial distribution of water concentration of the mixture on the way to form columnar joints. As a result, we recognize that water concentration distribution at a depth in mixture increases with the horizontal distance from just below the lamp. The direction of crack developing from the surface of the mixture to inner is almost perpendicular to the contour of water concentration. We confirm that the effect of heat from the lamp on the surface of the mixture differs with the distance from the lamp and it suggests inhomogeneous water concentration in mixture is caused by the difference of drying rate depending on the distance from the lamp. We also report the relationship between the direction of crack advance and the change of water concentration distribution with time.

Keywords: columnar joint, analogue experiment, crack formation, Micro-focus X-ray CT, concentration distribution