

Fractionation between LREE and HREE in granitic rocks in southern Myanmar: Implications for HREE-rich granite

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As crustal abundances of heavy rare earth elements (HREE) except yttrium (Y) are generally smaller than those of light rare earth elements (LREE), HREE are more expensive than LREE in the market. At the present day, minable HREE-rich deposits are confined almost exclusively to ion-adsorption type deposits (e.g., Longnan in China), underlain by highly-differentiated (> 74 -75 % SiO₂) calcalkaline granites which are enriched in HREE and depleted in LREE. In this study, we collected granitic rocks of 67 -76 % SiO₂ in southern Myanmar to discuss characteristics of HREE-rich granites based on whole-rock geochemistry and the occurrence of REE-bearing minerals.

Alkaline rocks, formed by magma with a low degree of partial melting, are significantly enriched in LREE and are weakly enriched in HREE because LREE are more incompatible than HREE in magma because of their larger ionic radii. Fractionation of REE-bearing minerals by magmatic differentiation has an important role for the formation of HREE-rich granite rather than the degree of partial melting. In our study, Late Cretaceous to Eocene granitic rocks in southern Myanmar were analyzed and geochemical results indicated that differentiated granites over the approximate boundary of 74 % SiO₂ tend to be enriched in HREE. This boundary is more distinctly decided by the occurrence of REE-bearing than by the whole-rock chemical composition. Granitic rocks less than 74 % SiO₂ contain either or both of titanite and allanite, whereas granites over 74 % SiO₂ rarely contain these minerals. In this study, results of the EPMA analysis indicated that some titanite crystals are rich in HREE. Because titanite is the dominant HREE-bearing mineral as much as zircon in granites, undersaturation of titanite may lead to HREE-rich melt eventually. In the strongly-differentiated granites over 74 % SiO₂, titanite was rarely found and a variety of HREE-bearing minerals such as synchysite-(Y) were observed.

This study result suggests that the HREE-rich granites, as represented by parent rocks underlying ion-adsorption type deposits, were potentially formed by magmatic differentiation under the condition of titanite-undersaturation. Whole-rock chemical compositions of granitic rocks and the occurrence of specific REE-bearing minerals may be indicative of exploration for HREE deposits.

Keywords: HREE, LREE, Granite, Titanite, Allanite, Deposit

Heavy rare earth potential of apatite resources

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Phosphorous is one of the three major nutrients (N, K, P) required by plants and 80-90% of the phosphate mined in the world is used to produce chemical fertilizers. Securing stable supply of phosphate fertilizers is essential to a sustainable food production considering a continuing rapid growth of world population (Van Kauwenbergh et al., 2013). The world resources of phosphate rocks are more than 300 billion tons (U.S. Geological Survey, 2015). "Phosphate rock" is the term generally used in industry to describe mineral assemblages with a high concentration of phosphate minerals, commonly francolite ($\text{Ca}_5(\text{PO}_4, \text{CO}_3)_3(\text{OH}, \text{F}, \text{Cl})$) - apatite ($\text{Ca}_5(\text{PO}_4)_3(\text{OH}, \text{F}, \text{Cl})$) series. There are two main types of phosphate deposits: sedimentary and igneous. The former deposits sometimes are called phosphorite and contain varieties of francolite (CO_2 -rich fluorapatite), the latter mainly consist of fluorapatite (F-rich apatite) (Ihlen et al. 2014).

Apatites contain a variety of REEs in concentrations from several thousands of ppm to several wt.%. They are generally enriched in LREEs (e.g., Roeder et al., 1987), however, some apatites are rich in HREEs: apatites in sedimentary phosphate rocks (Emsbo et al. 2015) and deep sea mud (e.g., Kon et al. 2014), and igneous phosphate rocks (e.g., Hoshino et al., 2015). In addition, both Th and U contents in apatite are very low in contrast to common REE minerals such as monazite and xenotime, and this may be a big advantage over the other types of REE deposits (e.g., alkaline REE deposits). In view of the future of HREE supply (considering both feasibility and sustainability), one of the most promising sources of HREEs is apatite ores that are mined for fertilizer production, because apatite ores are sufficient in reserves and contain enough amounts of the whole REEs that can cover the world demand.

Keywords: apatite, HREE resources

The Origin of the Nangarhar Talc Deposits in the Spin-Ghar Block, Afghanistan

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Talc deposits in the E-W trending Spin-ghar block, southeastern part of Afghanistan, were formed in Paleoproterozoic carbonate rocks. There are two types of talc mineralization in the study area, one in the western part (Dar, Kherwas and Janinaw deposits) and other in the eastern part (Mamond Dara deposits) of the block, hosted by magnesite and dolomite marbles, respectively. The objective of this study is to describe the talc mineralization on the basis of field observations, microscopic observation, XRD, XRF, ICP-MS and SEM-EDS analyses.

In the western part of the block, talc is parallel to sub parallel to magnesite rock and cross cut by intrusive igneous rocks of diabase. Metamorphic rocks of quartz chlorite schist are parallel to sub parallel to talc ore body and magnesite. Massive layers of tremolite about one meter thick were observed at Kherwas. Intrusive rocks have not been identified and a thin layer of talcose quartz has been marked within talc veins at Janinaw. A thick layer of talc contains needle like macroscopic tremolite crystals in the matrix of talc at Janinaw. In the Mamond Dara area at the most eastern part of the block, parallel alternating layers of talc and dolomite marbles occur with quartz chlorite schist mostly altered to chlorite. Massive gneiss occurs at the contact of these talc, dolomite marbles and quartz chlorite schist. Mineral assemblages in the western part are (a) talc + tremolite + calcite, and (b) talc ± cordierite, while those in the eastern deposits are (c) talc + dolomite + calcite ± quartz ± apatite and (d) talc + dolomite + calcite. Talc was formed by alteration of tremolite and magnesite in Dar and Kherwas deposits, while in Janinaw and Mamond Dara, talc was formed by alteration of dolomite and tremolite and by alteration of dolomite, respectively. Total REE contents of talc bodies, magnesite and dolomite marbles range from 0.9, 5.3 and 13.0 ppm, respectively. The SiO₂ contents of carbonates and talc bodies range from 1.6 to 33.3 wt% and from 52.9 to 65.1wt %, respectively, while MgO contents of carbonate and talc bodies range from 18.4 to 48.1 wt% and from 29.4 to 34.0 wt%, respectively. The CaO contents in talc bodies and magnesite are less than 1 wt%, while those of dolomite marbles ranges from 18.0 to 26.0 wt%. The concentration of Al, Ta, Hf, Zr, Th and REE in talc ore and carbonates rocks is very low and inconsistent with a felsic igneous rock protolith, whereas the low concentrations of Cr, Ni, and Co are inconsistent with a mafic igneous protolith. On the basis of this low concentration of trace elements and REE, the Mg-rich carbonate rock is likely the protoliths of talc ore. Magnesium has been derived from pre-existing Mg-rich carbonate host rocks, i.e., magnesite and dolomite marbles.

Keywords: Nangarhar, Spin-Ghar, Talc, Magnesite, Tremolite, Dolomite marble

Evolution of the hydrothermal fluid at the Takatori deposit, Japan - Replacement texture at the rim of wolframite

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The Takatori deposit is a vein type tungsten deposit in Japan. The tungsten-bearing mineral is wolframite ((Fe, Mn)WO₄), which has a complete solid solution of iron and manganese. Although previous papers pointed out that the replacement texture at the rim of wolframite was formed by a later fluid, the nature of the later fluid was not clear. The purpose of this study is to reveal the characteristics of the later hydrothermal fluid at the Takatori deposit.

Samples were obtained from the No.7 vein at -4 Level (60m above sea level) and -7 Level (30m below sea level). They are called the middle and lower samples, respectively in this study.

SEM-EDS mapping images of the rim of wolframites showed replace textures. Since the replacement texture can be distinguished by the Mn/Fe ratio in wolframites, the Mn/Fe ratio was measured by EPMA. In the middle samples, the ratio in the center of wolframites was between 40 and 50 mole%, but the ratio increased up to 70 mole% at the rim of some crystals with pyrite.

These replacement textures were assumed to form by replacement of iron in the wolframite with manganese in the later fluid that came into the hydrothermal system after the wolframite formation. The later fluid flowed around wolframite crystals and made replacement texture in the middle samples.

In the lower samples, SEM-EDS mapping images and the change of Mn/Fe ratio showed oscillatory and complicated textures with pyrite and other sulfide minerals. These are also recognized as replacement textures that were formed by the later fluid since the trend of the change of Mn/Fe ratio is the same as that in the middle samples. The textures were formed by the later fluid which flowed through cracks in wolframite.

Based on the relationship between pH and oxygen fugacity in phase diagrams, the temperature of the later fluid that made replacement textures was lower than that of the fluid, which had precipitated wolframites. The replacement of iron with manganese was occurred because ferberite (FeWO₄) was unstable and hubnerite (MnWO₄) with pyrite was stable.

Keywords: Takatori deposit, wolframite, replacement texture, hydrothermal deposit

Fluid inclusion study of core samples collected from the Iheya North Knoll in the Okinawa Trough

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From July 9 to 26 in 2014, the dive expedition (Exp. 907, CK14-04) was performed at the Iheya North Knoll in the middle Okinawa Trough to confirm hydrothermal seafloor mineralization. The core samples used in this study were obtained from Hole C9015B and C9016B of the research target area. Microscopic observation and fluid inclusion microthermometry were mainly focused to reveal the ore formation condition. The objective of this study is to clarify geochemical characteristics and the point of similarity between Kuroko deposits and seafloor hydrothermal deposits.

The characteristics of the ores collected from Iheya North Knoll are as follows: C9015B samples are pyrite rich but chalcopyrite is minor, therefore, the characteristic of sulfide assemblage is not similar to yellow ore of Kuroko deposits. C9016B samples are divided into two groups. a) At the upper portion, from 29.6 to 32.7 mbsf, only framboidal pyrite could be observed. b) At the lower portion, from 38.1 to 42.1, pyrite is minor, while galena and sphalerite is abundant like Kuroko of Kuroko deposits.

Homogenization temperatures of fluid inclusions in quartz of C9015B range from 266.7 to 338.4°C and the salinity ranges from 0.00 to 6.30 wt. % NaCl eq. Homogenization temperatures of fluid inclusions in anhydrite of C9016B range 271.1 to 348.5°C and the salinity range from 3.2 to 6.1 wt. % NaCl eq. Both the data of fluid inclusion microthermometry of C9015B and C9016B samples are well plotted on the boiling curve of seawater. The fact that low salinity fluid can be observed may support the occurrence of boiling during the formation of the ore in Iheya North Knoll, Okinawa Trough.