

Mineral Chemistry of REE-rich Apatite and Monazite in the Mushgai-Khudag Deposit Carbonatite-Alkaline Complex, the South Gobi, Mongolia

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REE-rich apatites and monazite occur in Mushgai-Khudag deposit within the carbonatite-alkaline complexes in South Gobi, Mongolia. The REE mineralization occurs along the periphery of alkaline massive consisting of porphyry syenite, microsyenite, and quartz syenites. The Late Jurassic alkaline intrusive complexes are 400 to 1100 m wide and 3 km length. REE grades of apatite ores are typically in the 5 wt % range (<5 wt %). The Mushgai-Khudag deposit consists of four main mineralization zones: main zone (MZ), apatite hill zone (AHZ), Tumurtui zone (TZ), and high grade zone (HGZ). REE-Sr-Fe-F-P mineralization is related to the Upper Jurassic Ulgii alkaline complexes. REE-rich fluorapatite and monazite are mainly found in the AHZ and HGZ.

LREE minerals are primarily fluorapatite, monazite, bastnaesite, and sphene. Fluorapatite is distributed much broader area, whereas monazite and bastnaesite are locally distributed. Fluorapatites show compositional zoning with monazite at the rim of this mineral. An average formula of fluorapatite is $[(Ca_{8.7}(Ce_{0.40}La_{0.18}Nd_{0.13})Na_{0.06})_{9.57}(P_5Si_{0.76}S_{0.10})_{5.86}O_{25}]F_{2.9}$ and is charge balanced by Si via coupled substitution in the Mushgai-Khudag deposit. In the backscattered electron (BSE) image, the bright parts of apatite have high contents of REEs (11.7~18.5 wt % $Ce_2O_3 + La_2O_3 + Nd_2O_3$), whereas depleted LREE contents (approximately 10~11 wt % $Ce_2O_3 + La_2O_3 + Nd_2O_3$) is found in the relatively dark parts. The strong depletion of LREEs in the core, which is well matched by depletion in Si and Na, is indicative of the coupled replaced reactions; (1) $Si^{4+} + (Y+REE)^{3+} = P^{5+} + Ca^{2+}$ and (2) $Na^{+} + (Y+REE)^{3+} = 2Ca^{2+}$. Compared to that of the core, enrichment of Ce and La is extremely found in the rim. Enrichment of LREEs and P is accompanied with depletion in Si, Na, and S, implying operation of two different coupled substitution reactions, (3) $2P^{5+} = Si^{4+} + S^{6+}$, and (4) $2P^{5+} + LREE^{3+} = 2S^{6+} + Na^{+}$.

The sulfatian monazite is formed along the apatite rim due to intensive chemical reaction in HGZ. In individual sulfatian monazite is preferentially formed due to Si and Na leaching out from apatite and sulfatian monazite (Y+REE) are balanced for the charge through coupled substitution reaction (1) and (2). Therefore, the monazites are finally balanced by the complex substitution reactions, (5) $Ce^{3+} + P^{5+} = (Ca, Sr)^{2+} + S^{6+}$.

We suggest that the high contents of REEs within the apatite are closely associated with metasomatism. REEs are strongly mobile in the last stage of metasomatism due to sulfate-rich fluid which can easily transport REEs. Further, it could be highly dependent on the pressure and temperature. Therefore, we note that the Mushgai-Khudag deposit, which has high REE contents within apatite, is closely associated with metasomatism, including a sulfate-rich fluid in the last stage of mineralization.