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Crystallization process of zircon and fergusonite during hydrothermal alteration in Nechalacho REE deposit, Thor Lake, Canada

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The core samples of two drill holes, which penetrate sub-horizontal mineralized horizons at Nechalacho REE deposit in the Proterozoic Thor Lake syenite, Canada, were studied in order to clarify magmatic and hydrothermal processes that enriched HFSE (e.g. Zr, Nb, Y and REE). Zircon is the most common REE minerals in Nechalacho REE deposit. The zircon is divided into five types as follows: Type-1 zircon occurs as single grain in phlogopite and the chondrite-normalized REE pattern is characterized by a steeply-rising slope from the LREE to the HREE with a positive Ce-anomaly and negative Eu-anomaly. This chemical characteristic is similar to that of igneous zircon. Type-2 zircon consists of HREE-rich magmatic porous core and LREE-Nb-F-rich hydrothermal rim. This type zircon is mostly included in phlogopite and fluorite, and occasionally in microcline. Type-3 zircon is characterized by euhedral to anhedral crystal, occurring in a complex intergrowth with REE fluorocarbonates. Type-3 zircons have high contents of REE, Nb and fluorine. Type-4 zircon consists of porous-core and -rim zones, but their chemical compositions are similar to each other. This type zircon is a subhedral crystal rimmed by fergusonite. Type-5 zircon is characterized by smaller, porous and subhedral to anhedral crystals. The interstices between small zircons are filled by fergusonite. Type-4 and -5 zircons show low REE and Nb contents. Occurrences of these five types of zircon are different according to the depth and degree of the alteration by hydrothermal solutions rich in F- and CO_3 of the two drill holes, which permit a model for evolution of the zircon crystallization in Nechalacho REE deposit as follows: (1) type-1 (single magmatic zircon) is formed in miaskitic syenite. (2) LREE-Nb-F-rich hydrothermal zircon formed around HREE-rich magmatic zircon (type-2 zircon); (3) type-3 zircon crystallized thorough F and CO_3-rich hydrothermal alteration of type-2 zircon which formed the complex intergrowth with REE fluorocarbonates; (4) the CO_3-rich hydrothermal fluid corroded type-3, forming Nb-REE-poor zircons (type-3). Niobium and REE was no longer stable in the zircon structure and crystallized as fergusonite around the REE-Nb-leached zircon (type-4); (5) type-5 zircons are formed from more CO_3-rich hydrothermal alteration of type-3 zircon. Therefore, type-4 and -5 zircons are often included in ankerite. Type 3-5 zircons at Nechalacho REE deposit were formed by leaching and/or dissolution of type-2 zircon in the presence of F- and/or CO_3-rich hydrothermal fluid. The above mineral association indicates that three hydrothermal stages were present and related to HFSE enrichment in the Nechalacho REE deposit: (1) F-rich hydrothermal stage caused the crystallization of REE-Nb-rich zircon (type-2 rim and type-3), with abundant formation of phlogophite and fluorite, (2) F-CO_3-rich hydrothermal stage led to the replacement of a part of REE-Nb-F-rich zircon by REE fluorocarbonate and (3) hydrothermal stage rich in CO_3 resulted in crystallization of REE-Nb-F-poor zircon and fergusonite, with ankerite. Increases of HFSE contents, REE-Nb-F-poor zircon (type-4 and -5) and fergusonite contents during progress of hydrothermal alteration show that REE and Nb in hydrothermal fluid in the Nechalacho REE deposit were finally concentrated into fergusonite by way of zircon.