Hydrothermal Alteration and the Formation of an Iron-Oxide-Apatite (IOA) Type Rare Earth Element (REE) Deposit at Kwyjibo, Québec, Canada

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Kwyjibo is an unusual iron-oxide-apatite (IOA) type deposit, with a concentration of light and heavy REEs sufficient to constitute a potential economic resource of 6.92 million tons grading 2.72% TREO with an HREE proportion of 33%. Magmatic processes led to the crystallization of magnetite and fluorapatite, and hydrothermal processes led to the mobilization of REEs from the fluorapatite. The latter processes resulted in an enrichment of the REEs in andradite, allanite, and particularly in britholite. The last of these minerals (britholite) formed as a replacement of the fluorapatite through the coupled substitution of REE^{3+} for Ca^{2+} and SiO_4^{4-} for PO_4^{3-}, with the source of the REEs from the fluorapatite and the Si from hydrothermal fluid. The andradite is interpreted to have formed from the Fe^{3+} in the magnetite, Ca^{2+} and heavy REE^{3+} in the fluorapatite, and Si^{4+} from the fluid. Allanite replaced andradite with light REE^{3+} substituting for Ca^{2+}, and charge balance was achieved by the addition of hydroxide from the fluid. Hydrothermal activity terminated with the precipitation of fluorite as a result of the mobilization of Ca^{2+} and F^- into the aqueous fluid.

A reconnaissance study was conducted on fluid inclusions trapped in fluorapatite, andradite, and fluorite to gain insight into the nature and evolution of the hydrothermal system that mobilized the REEs. Two-phase (liquid + vapor), liquid-rich inclusions were the only fluid inclusions present. Primary inclusions, however, were observed in andradite, providing a record of the REE-mineralizing fluid. Secondary fluid inclusions with similar liquid/vapor volume ratios are preserved in fluorapatite and likely record the passage of this fluid. The fluid inclusions trapped in fluorite have higher liquid volume ratios consistent with the evolution of the fluid to lower temperatures. Future work will characterize the microthermometric behavior of the fluid inclusions to reconstruct the physicochemical controls of REE mineralization.