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Potential Sources of Rare Earth Elements (REEs) in Loch Borralan, Northwest Highlands, Scotland: Geochemical and Mineralogical Controls on REE Distribution in Carbonatite

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Rare earth Elements (REEs) are critical in low-carbon technologies, with a forecast of growing demand to switch to green technologies. Currently, REEs are mainly sourced from carbonatite for the light REEs (LREEs) and alkaline igneous complexes for the heavy REEs (HREEs). In this context, there has been a revived focus on the Loch Borralan Complex of Northwest Scotland for better understanding of REE enrichment processes in this complex. The complex is composed of mainly nepheline syenites, but small intrusions of carbonatite have been found and mapped in the south of the complex. Based on petrographic studies and microprobe analyses, our work has shown an enrichment in REEs in carbonatites and associated silicate rocks with whole-rock total REE oxide contents of up to 1.5 wt %. Based on textural evidence and microprobe results, this has resulted in the late magmatic crystallisation of LREE-bearing minerals, including bastnaesite, synchysite, ancylite, monazite, apatite, chevkinite, perrierite, zirconolite, titanite, REE-rich ilmenite, and allanite. Stable isotopic composition of carbon and oxygen measured in carbonate mineral separates from the different rock types in the complex suggest a primary magmatic origin. However, there is also evidence for more than one source of fluid components from the measured nitrogen and argon isotopic and elemental ratios of fluid inclusions by step crushing. Fluid inclusions and their stable isotope data show the interaction of carbonatite-derived fluids and externally derived fluids which may have exsolved or boiled, leading to fracturing of the country rock, permitting additional dilution of carbonatite-derived fluids by meteoric water. We suggest this as a means of precipitation of the REEs and other metals at Loch Borralan.