Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.35005

The Economic Geology of Carbonatite Complexes

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Carbonatite complexes contain approximately 60 % of the global REE resource and 95% of the niobium resource as primary and secondary deposits. The economically exploitable primary concentrations of the REE and niobium are > ~ 2 wt% and > ~0.5 wt%, respectively, whereas an enriched mantle contains only a few ppm of these metals. Assuming that carbonatitic magmas are the products of ~ 1 % partial melting of the mantle, they would only contain a few hundred ppm of REE and Nb. Thus, the challenge is to identify a process that would concentrate the metals by factors between 10 and 100. In principle, this could be fractional crystallisation of calcite. The problem with this hypothesis for niobium is that the ore mineral (pyrochlore) is texturally early. We propose, instead, that the principal concentrating processes are carbonatitic magma-induced metasomatism and melting of the host rocks, both of which consume large proportions of the Ca and Mg in the magma to form metasomatic rocks such as clinopyroxenite and biotitite, and igneous rocks such as ijolite and nepheline syenite. We further propose that this causes crystallisation of pyrochlore in the residual phoscoritic liquid, or in the alkaline silicate rocks due to the much lower solubility of niobium in silicate melts relative to carbonate melts. In most carbonate complexes the niobium ore is spatially separate from the REE ore and the REE show evidence of having crystallised from a hydrothermal fluid. As carbonatitic magmas dissolve high concentrations of H_2O, we propose that magma-induced metasomatism and melting saturates the magma in a hydrothermal fluid into which the REE are strongly partitioned and, from which they precipitate as bastnäsite and monazite. Weathering of carbonatites leads to supergene enrichment (due largely to carbonate mineral dissolution) that can substantially increase the niobium and REE grades. Pyrochlore is the principal niobium mineral in laterite-hosted Nb deposits and phosphates and carbonates, the secondary REE minerals. We propose a model for the secondary minerals involving leaching and hard soft acid base theory that successfully explains their chemistry and the formation of exceptionally high-grade laterite-hosted niobium and REE deposits.