

Apatite Rare Earth Elements Chemistry and Fluid Inclusion Study in Hydrothermal Veins of the Lemitar Mountains Carbonatite, New Mexico

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The Lemitar Mountains carbonatite (Fig. 1A) is a 515 Ma rare earth element (REE) mineral deposit in New Mexico comprising over one hundred carbonatite dikes intruded into Proterozoic igneous rocks [1, 2]. The carbonatite displays grades of up to 1.1 % total REE and showcases variable degrees of hydrothermal autometasomatism and overprinting of the surrounding host rocks through fenitization and veining [1-3]. In this study, we employ a combination of petrography, optical cold-cathode cathodoluminescence and scanning electron microscopy to delineate the mineral paragenesis of the carbonatites and the associated crosscutting hydrothermal veins (Fig. 1). The determination of trace element concentrations in apatite was achieved using LA-ICP-MS. Fluid inclusions were studied in thick sections using optical microscopy, microthermometry and a confocal Raman spectroscopy to assess their salinity, homogenization temperature, and chemical composition.

Magmatic minerals in carbonatite dikes are calcite, dolomite, phlogopite, magnetite, apatite, baddeleyite, and pyrochlore. Our study identifies three hydrothermal vein types (Fig. 1A, B): type I veins (albite-quartz) represent the earliest hydrothermal veins; type II veins (quartz-chlorite $\pm$ calcite) crosscut type I veins and are associated with REE-bearing minerals including parisite, zircon, and monazite; and type III veins composed of calcite, quartz, fluorite and barite $\pm$ hematite ($\pm$ parisite). Alteration linked to type I veins includes silicification and sodic fenitization. Alteration associated to types II veins include silicification, chloritization, potassic fenitization, and hematization. Type III veins are characterized by silicification and/or Ca-F metasomatism.

Three different generations of apatite were distinguished based on textures and REE chemistry. Apatite 1 is present as rounded xenocrysts in the carbonatite matrix and exhibits a dull yellow fluorescence. Apatite 2 is commonly found in association with hydrothermally altered carbonatites, presenting as euhedral crystals with dull to bright yellow fluorescence. Apatite 3 occurs in the fenitized host rocks adjacent to the carbonatite dikes and is characterized by 100-500 μ m long euhedral crystals with a distinct yellow to blue fluorescence. Apatite 1 contains, on average, $\sim$ 0.2 wt% REE, apatite 2 contains up to 3.2 wt% REE, and apatite 3 contains $\sim$ 0.4 wt% REE. The chondrite-normalized REE profiles of the three apatite generations exhibit distinct variations in light vs. heavy REE (Fig. 1C), with apatite 2 enriched in light REE and apatite 3 displaying a flat REE profile with a heavy REE enrichment.

Fluid inclusions (FI) hosted in apatite are complex, multi-phase, solid dominated inclusions. Quartz-hosted inclusions from type I veins are characterized by liquid (L) inclusions with up to 80 vol% vapor (V). Calcite and quartz-hosted FI in type II and calcite-, fluorite-, and quartz-hosted FI in type III veins are liquid dominated with up to 15 vol% V and some of them containing a halite daughter crystal coexisting with vapor dominated inclusions. Microthermometry in inclusions from type III veins indicate homogenization temperatures of $\sim$ 180 °C with salinities ranging from $\sim$ 2–15 wt% NaCl eq. The presence of H₂ and CH₄ gaseous species and SO₄²⁻, CO₃²⁻ as well as dissolved CO₂ species were measured in type I veins in quartz-hosted FI. Type III veins containing fluorite hosted inclusions from the fenitized country rock are observed with H₂ and CH₄ gas, and fluorite hosted inclusions crosscutting the carbonatites is observed with SO₄²⁻.

In summary, three distinct vein generations are identified, with types II and III containing REE minerals.

Apatite 1 exhibits a clear magmatic REE signature, whereas apatite 2 and 3 display an enrichment in light and heavy REE, respectively. Fluid inclusions indicate decreasing temperature from type I to type III vein with reducing gases (i.e. H₂ and CH₄) present in the fenitized zone and an oxidizing sulfate-bearing fluid in the carbonatite, potentially serving as an important ligand for REE transport in this system.

References:

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