REE-enrichment in Apatite-britholite exsolutions in carbonatite (In Ouzzal terrane, Hoggar, South Algeria)

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Ihouhaouene area in In Ouzzal terrane (Hoggar, South Algeria) is exceptional by numerous carbonatite complexes systematically associated to syenites. They constitute one of the oldest carbonatite emplaced at 2 Ga. Various types of carbonatites are distinguished by their successive placement and pegmatitic to brecciated appearance. The first-generation of carbonatites are always brecciated with elements of syenite and carbonate cement with calcite, apatite, alkali feldspar, wollastonite, clinopyroxene +/- sphene, allanite, quartz and garnet. Late carbonatite intrusions appear in small pegmatitic veins rich in apatite (3-50 mm). All carbonatites are calciocarbonatites (38-50 wt% CaO) with silica content ranging from 5 to 21 wt% SiO_2. The high silica content is interpreted as assimilation of syenite material during emplacement.

Carbonatites have high Rare Earth Element (REE) concentrations with high Ligh REE/Heavy REE fractionation (e.g. 1088 ppm La, La/Yb= 144-198) and variable concentrations in Th (26.5-197 ppm). The REE concentrations are mainly controlled by apatite phenocrysts (30-40 vol.%) with 4-9 wt% REE. In late pegmatitic carbonatite, REE-rich apatites are green-yellow phenocrysts with britholite exsolution (up to 40 vol.%, $Ca_4(REE)_6(SiO_4,PO_4)_6(OH,F,Cl)_2$). Britholites are hexagonal and occur as fine lamellar exsolutions (<10 um) in the same crystallographic axis (001) than apatites or as irregular-shaped grains (10-200 um). All britholites contain 8-16 wt% La, 21-43 wt% Ce and 7-12 wt% Nd. The apatite-britholite exsolutions correspond to a substitution of the trivalent rare-earth elements (REE^{3+}) and Si^{4+} for Ca^{2+} and P^{5+}. The REE substitution is accompanied by a change in volatile composition with F-rich apatite and Cl-rich britholite indicating that Si and Cl-rich hydrothermal fluids are present at the late stage of carbonatite evolution leading to REE-enrichment and the crystallization of REE minerals.