Borates of the rhodizite group as sensors to evaluate the pegmatite fractionation degree

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Minerals of the rhodizite-londonite series are rare borates occurring in few LCT granitic pegmatites of Madagascar, Russia, the USA, and the UK. Rhodizite, the potassic end-member, was first described by Rose (1834) on tourmaline crystals from the Oural mountains, stored in the Royal Museum of Berlin mineral collection. The rhombic dodecahedral shape of the crystals, as well as preliminary chemical tests, allowed this author to confirm the new species and to underline some similarities with boracite. The quantitative chemical data obtained by Damour (1882) on Russian samples did not allow the determination of alkalis and of the light elements Be and Li; however, the investigation of new rhodizite samples from Madagascar (Lacroix, 1922) led to a better characterization of the chemical composition of the species. As underlined by Simmons et al. (2001) and Pekov et al. (2010), who described in detail the history of those minerals, the first charge-balanced formula of rhodizite was determined by Pring et al. (1986), by merging all available chemical and structural data. The simplified formula given by these authors for rhodizite is $(K,Cs)Al_4Be_4(B,Be)_{12}O_{28}$, leading to the end-member formula $KAl_4Be_4(B_{11}Be)O_{28}$. Londonite, the Cs-dominant analogue of rhodizite, was described in the Antandrokomby pegmatite, Madagascar, by Simmons et al. (2001).

A few samples of "pink londonites" were recently discovered in the Ambalabe granitic pegmatite, Madagascar, and Hatert et al. (2025) showed that they correspond to a new mineral species, the lithium-dominant end-member of the rhodizite group, with the $LiAl_4Be_4(B_{11}Be)O_{28}$ end-member formula. The mineral was approved by the IMA-CNMNC under the name touretite (IMA # 2023-003), and forms white to pinkish rhombic-dodecahedral crystals reaching 1 cm in diameter, deposited on tourmalines, feldspars, and heavily corroded spodumene and danburite. The streak is white, the lustre vitreous, and touretite does not show any fluorescence under short wave (254 nm) or long wave (366 nm) ultraviolet light. The Mohs hardness is 8, cleavage is absent, the tenacity is brittle, the fracture is conchoidal, and the measured density is 3.06(1) g/cm3. Optically, touretite is colourless, isotropic, non-pleochroic, and shows an index of refraction of n = 1.6952 ± 0.0005 (measured using a light source of 589 nm wavelength).

The empirical formula of touretite, calculated on the basis of 28 oxygen atoms per formula unit from the chemical analysis determined by LA-TOF-ICP-MS, is $(Li_{0.38}Cs_{0.24}K_{0.14}Rb_{0.03}Na_{0.02}Pb_{0.01}[]_{0.18})_{\Sigma 1.00}(Al_{4.00}Si_{0.05}Fe^{2+}_{0.03}Mn_{0.02})_{\Sigma 4.10}(Be_{3.60}Li_{0.40})_{\Sigma 4.00}(B_{11.28}Be_{0.72})_{\Sigma 12.00}O_{28}$. The cubic unit-cell parameters, determined by single-crystal X-ray diffraction methods, are a = 7.31202(15) Å, V = 390.942(14) Å^3. The structure refinement was performed in space group *P-43m* from 226 unique reflections, to the final R1 value of 0.0444. The structure of touretite contains clusters of four edge-sharing AlO_6 octahedra located around the origin of the unit-cell, and linked to the BeO_4 and BO_4 tetrahedra by corner-sharing (Figure 1). The alkali cations occupy the Li/Cs site in a large cavity at the center of the unit-cell and have a coordination number of 12. The coordination polyhedron can be described as a truncated tetrahedron, that shares its small triangular faces with faces of the BeO_4 tetrahedra. The species was named to honour Jacques and Lydie Touret, for their contribution to mineralogical sciences.

During their formation, pegmatite deposits are affected by a fractional crystallization process, that induces geochemical variations reflected in the chemical composition of mineral species; this fractionation consequently provokes increases of the Mn/Fe, Ta/Nb, Hf/Zr, Rb/K, and Cs/Li ratio (Simmons et al. 2004). In the most evolved pegmatites, zircon is enriched in Hf, iron-manganese phosphates are enriched in Mn, and alkali feldspars are enriched in Rb, while oxides of the columbite group become Ta- and Mn-rich and evolve towards tantalite-(Mn).

The crystallization of lithium-rich species is certainly the most prominent sign of fractionation, with the formation of elbaite, "lepidolite", spodumene, petalite, and phosphates of the triphylite-lithiophilite and amblygonite-montebrasite series. Cs-rich species only occur in highly fractionated pegmatites, where pollucite and pezzottaite appear.

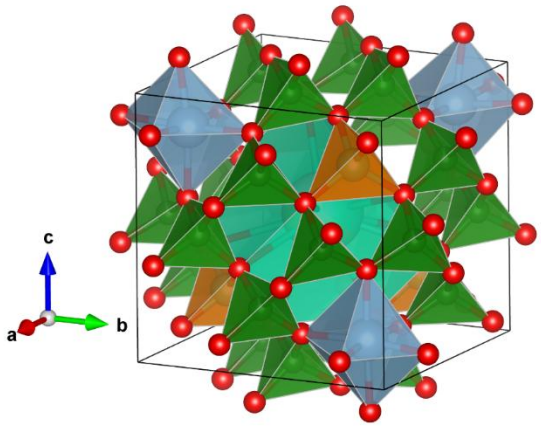

Figure 1. Clinographic view of the crystal structure of touretite. BO_4 and BeO_4 tetrahedra are shown in green and orange, respectively, and AlO_6 octahedra in blue. The large spheres represent the alkali site.

Minerals of the rhodizite group certainly occupy a special position in these genetic sequences. Due to the large cavity in their crystal structure, they are able to accommodate alkalis such as K, Cs, and Rb, as well as the smaller Li atom. Therefore, they can be used as a probe to decipher the evolution of both the Rb/K and Cs/Li ratio. Simmons et al. (2001) underlined that, in the Betafo mining district, Cs-rich londonite is observed in the most evolved pegmatites, occurring in the northwestern part of the district, while Cs-poor and K-rich rhodizite samples occur in the less evolved deposits at the eastern part of the district. The geographic position of Ambalabe, where touretite samples were found, corresponds to the eastern part of the Betafo district, where less evolved Cs-poor pegmatites occur. This feature explains why the Cs-content of touretite is relatively low.

Mineral species in close association with touretite include Li-rich tourmaline-group minerals, "lepidolite", and spodumene, thus indicating that the Ambalabe pegmatite is moderately fractionated, with Li-rich species but without Cs-rich species as pezzottaite or pollucite. As a consequence, londonite, touretite, and rhodizite, certainly constitute good indicators of highly-, moderately-, and poorly-fractionated pegmatite deposits, respectively. This rule, however, cannot be strictly applied, since minerals of the rhodizite group generally occur in miarolitic cavities where late fluid circulations may affect their geochemistry.

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