

# Compositional variations of white mica in the LCT Bermellar pegmatite (Central Iberian Zone, Spain)

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## INTRODUCTION

Granitic pegmatites are an important source of the so-called Critical Raw Materials (CRMs) by the European Commission due to their increasing demand and strategic importance. Specifically, LCT-type (Lithium-Cesium-Tantalum) pegmatites play an important role in the global supply of Li, as well as Ta and Cs. In addition, they are also enriched in Be-, Nb- and Sn-bearing minerals. The Central Iberian Zone in the Iberian Variscan Massif is well-known for the occurrence of a wide variety of LCT-type pegmatite deposits (Roda-Robles et al., 2016). The La Fregeneda-Almendra pegmatite field is one of the most relevant ones, where lithium was mined until 2010. Historical mineral occurrences have been reported in the nearby Cerralbo-Bermellar area, south of Gneissic Tormes Dome, including the presence of Sn-, Ta-, and Be-bearing minerals related to the Bermellar pegmatite, although it has not been studied in detail. The Bermellar pegmatite is structurally situated in the Cerralbo shear branch of the regional Juzbado-Penalva do Castelo sinistral shear zone. It belongs to the Pegmatoid Laminar Complex, which is constituted by abundant aplo-pegmatite dykes that are hosted by a mica schists band in the Schist-Metagreywacke Complex (SGC), trending an E-W orientation. These pegmatites are disposed subparallel to the main N110°E/70°S schistosity. The Bermellar pegmatite is associated with S1 type granites (Roda-Robles et al., 2018) and emplaced during the second phase of variscan deformation.

Recent research revealed the existence of Li-bearing minerals in the Bermellar pegmatite, including tourmaline, mica and phosphates. The present work focuses on providing a detailed description and compositional variations of the white mica from the different zones of the Bermellar pegmatite dyke in order to get key insights into the magmatic-hydrothermal evolution of the pegmatite, by a combination of petrographic studies of thin sections, Scanning Electron Microscopy-Energy Dispersive Spectrometry (SEM-EDS), Back Scattered Electron (BSE) and Electron Microprobe Analysis (EMPA).

## RESULTS

Mineralization occurs in pegmatite dykes of 1-2 m in thickness and up to 40 m in length. Textural and mineralogical variations of the studied samples define an internal zoning of the Bermellar pegmatite, which consists on border, wall, outer and inner intermediate zones, and the core. The main mineral association is made of quartz, albite, K-feldspar, and white mica. Accessory minerals include montebrasite, beryl, apatite, wardite, crandallite-group minerals, tourmaline-group minerals, zircon, rutile, cassiterite, columbite-group minerals, tapiolite, and microlite. Strong albitization and local greisenization have been identified in the intermediate zones.

White mica occurs in the border, wall, and outer and inner intermediate zones of the pegmatite. Textural characterization allowed the differentiation of three types of white mica: (i) mica-I occurs throughout all the zones, ranging from 100 to 1000  $\mu\text{m}$  in size, and up to centimetre-sized crystals in the inner zones. It exhibits well-developed cleavage parallel to elongation, and sometimes forms banded domains with plagioclase and quartz and can locally overgrow them; (ii) mica-II occurs as patches and rims that surround mica-I cores in the inner intermediate zone; and lastly, (iii) mica-III, which occurs mainly in the intermediate zone as fine-grained crystals ranging from 20 to 100  $\mu\text{m}$ . These crystals sometimes develop fan-shaped aggregates along borders and fill fractures of plagioclase, tourmaline, and beryl. It locally forms aggregates with quartz in the greisenized intermediate zones.

In the inner intermediate zones, coarse white mica-I crystals exhibit compositional zoning visible in BSE images, consisting on dark grey cores surrounded by light grey rims and patches. X-ray elemental mapping showed chemical variations according to this zoning. Overall, the light patches and rims display higher concentrations of Cs, F, Fe, Mn, Rb, and Si, while darker cores show Na and Al enriched compositions. This was further endorsed by EMPA results, which revealed two main white mica groups: Li-poor and Li-rich micas, plotting in the muscovite and lepidolite-zinnwaldite fields, respectively, according to Tischendorf et al. (1997) classification. Li-poor micas are the most abundant ones, and are enriched in  $\text{Al}_2\text{O}_3$  (avg. 36.5 wt.%), with avg. 45.4 wt.%  $\text{SiO}_2$ , and low contents of F (avg. 0.3 wt.%), FeO (avg. 0.7 wt.%), and  $\text{Li}_2\text{O}$  (avg. 0.1 wt.% calculated according to Tischendorf et al., 1997). In contrast, the Li-rich micas display lower  $\text{Al}_2\text{O}_3$  contents (avg. 22.1 wt.%), and higher  $\text{SiO}_2$  (avg. 52.7 wt.%), F (avg. 4.2 wt.%), FeO (avg. 3.3 wt.%),  $\text{Cs}_2\text{O}$  (avg. 0.2 wt.%), and  $\text{Li}_2\text{O}$  (avg. 5.5 wt.%).

## DISCUSSION AND CONCLUSIONS

Textural and compositional variations of white mica are key to understand the internal evolution of the Bermellar pegmatite as its chemistry acts as a sensitive recorder of the compositional changes of melt and fluids, and can be directly linked to stages of rare metal mineralization. Three generations of white mica have been identified that correspond to three different evolutionary stages of the dykes: (1) primary magmatic mica-I, which displays muscovite composition; (2) late magmatic to hydrothermal mica-II, which displays compositions of lepidolite and zinnwaldite; and (3) hydrothermal mica-III, displaying muscovite composition. According to the paragenetic sequence, the Bermellar pegmatite micas exhibit an evolutionary trend from magmatic muscovite to lepidolite and zinnwaldite during the late magmatic to hydrothermal stage. These general compositional variations are controlled by the  $\text{Si}_2\text{LiAl}_3$  vector, which may be considered the principal substitution mechanism and the dominant method of lithium incorporation. Additionally, a supplementary substitution vector can be described for Li-poor micas:  $\text{Al}_4\text{Si}_3\text{□}_1$  (□ representing vacancies).

Therefore, the chemical composition of white mica in the Bermellar pegmatite indicates an increase in fractionation processes when moving toward the inner zones of the pegmatite. This increase is evident in the Li and F rich phases, which occur after volatile supersaturation. Li-rich mica formation is strongly linked to evolved pegmatite fluids enriched in volatile elements, such as fluorine, boron and phosphorous. According to Ballouard et al. (2024), F could have controlled the stability of Li minerals, and lower fluid pressure might have reduced  $\text{H}_2\text{O}$  solubility in the melt, favouring lepidolite crystallization. Finally, the evolution of the residual melt would have led to the supersaturation of muscovite from late residual aqueous fluid, promoting the development of fine-grained, hydrothermal epitaxial muscovite (mica-III) onto previously formed minerals during the hydrothermal stage, coeval with the local greisenization process.

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