Multistage boron metasomatism in the Alamo Complex (Central Iberian Zone, Spain): Evidence from field relations, petrography, and $^{40}$Ar/$^{39}$Ar tourmaline dating

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ABSTRACT

The Alamo Complex consists of structural-metamorphic domes surrounded by low-grade metasedimentary rocks of Upper Proterozoic to Lower Cambrian age that form part of the Schist Graywacke Complex (Central Iberian Zone, Spain). Tourmaline is ubiquitous throughout the domes, in which it occurs in tourmalinites, psammo-pelitic schists, quartzites, gneisses, migmatites, leucogranites, aplo-pegmatites, and quartz veins. Overall, tourmaline compositions can be described within the four component system schorl-dravite-foitite-magnesiofoitite, with $K_2O < 0.23\%$, low Ca contents, $Mg/(Mg+Fe) = 0.25–0.71$ and $X/(X+Na) = 0.18–0.43$, where $X =$ vacancies in the X site. Field relations and petrographic observations, combined with tourmaline $^{40}$Ar/$^{39}$Ar data, provide evidence of intense boron metasomatism affecting this region. Tourmaline $^{40}$Ar/$^{39}$Ar step-heating spectra for Cambrian-Ordovician orthogneisses are complex, yielding a pseudo-plateau age of ~370 Ma that is interpreted to reflect Variscan rejuvenation of older tourmaline. Tourmaline $^{40}$Ar/$^{39}$Ar data for mylonitized and folded tourmalinites yield disturbed spectra with pseudo-plateau ages of ~355–342 Ma that are unsuitable for precise age determination. These ages, however, are consistent with published ages (340–350 Ma) for the second Variscan deformation (D2). Tourmaline from fine-layered tourmalinite and metasedimentary rocks yield well-defined plateau ages of 317 and 315 Ma, respectively, recording an additional metasomatic event concomitant with anatexis and evolution of B-bearing granites, pegmatites, and hydrothermal fluids. The different tourmaline-forming stages reflect significant boron cycling within the continental crust of the Central Iberian Zone, driven by deformation, metamorphism, and magmatism during the Variscan orogeny. Boron-rich aqueous fluids related to Cambro-Ordovician magmatism are considered to be the primary source of boron.

Keywords: Tourmaline, petrography, chemical composition, $^{39}$Ar/$^{40}$Ar dating, Alamo Complex, Central Iberian Zone, Spain

INTRODUCTION

Although boron is one of the less abundant elements of the Earth, it is nevertheless a widespread constituent of the continental crust, being enriched in sedimentary, igneous, and metamorphic rocks. The preference of boron for aqueous fluids and its susceptibility to fractionation make boron a useful tracer for hydrologic and magmatic/hydrothermal processes (Leeman and Sisson 1996). The formation of boron-bearing fluids involves several crustal processes such as metamorphic devolatilization and magmatism. Boron is believed to largely reside in minerals such as clays, micas, and tourmaline (Leeman and Sisson 1996). The latter is by far the main sink for boron in crustal rocks with a wide physical and chemical stability and mode of occurrence (Henry and Dutrow 1996). This is due, in part, to the ability of the tourmaline structure to accommodate various elements of different sizes and valence states (Hawthorne and Henry 1999). The chemical variability, together with its refractory character and ubiquity, make tourmaline a powerful tool in petrology and a potentially important geochemical monitor.

This work builds upon previous studies of tourmaline-rich rocks in the Central Iberian Zone (Pesquera et al. 2005). It aims to contribute to an understanding of the relationships between tourmalinization and geological processes, based on field and petrographic observations in conjunction with $^{40}$Ar/$^{39}$Ar tourmaline data. In this regard, there is conflicting evidence concerning the reliability of the $^{40}$Ar/$^{39}$Ar dating method in tourmaline. Ring-silicates have been generally considered the least retentive minerals for Ar and tend to trap excess Ar (Dalrymple and Lanphere 1969; Fortier and Giletti 1989). However, Andriessen et al. (1991) found K-Ar ages to be consistent with the known age constraints, suggesting a closure temperature similar to that of hornblende (~500–550 °C). Some studies indicate that tourmaline is able to yield reasonably acceptable ages of tourmalinization and metamorphism (Fitch and Miller 1972; De Jong 1991). Further difficulties arise because (1) of the very low $K_2O$ contents, except for some tourmalines with $>2$ wt% $K_2O$ such as the “potassium-dravites” from high-P terrains (e.g., Shimizu and Ogasawara 2005) and (2) the tourmaline may develop different growth stages during metamorphism (Henry and Dutrow 1996). Despite these problems, and due to the small variations in Rb/Sr and Sm/Nd ratios in tourmaline, the $^{40}$Ar/$^{39}$Ar dating method