Multiple generations of tourmaline from Yushishanxi leucogranite in South Qilian of western China record a complex formation history from B-rich melt to hydrothermal fluid

TAO LIU1 AND SHAO-YONG JIANG1,2,*

1State Key Laboratory of Geological Processes and Mineral Resources, Collaborative Innovation Center for Exploration of Strategic Mineral Resources, School of Earth Resource, China University of Geosciences, Wuhan 430074, P.R. China
2Key Laboratory of Geological Survey and Evaluation of Ministry of Education, China University of Geosciences, Wuhan 430074, P.R. China

ABSTRACT

One tourmaline-bearing leucogranite dike occurs in the Yushishanxi Nb-Ta mining area in the Yushishan district of the South Qilian orogenic belt in western China. Abundant tourmalines have been identified in the leucogranite, including disseminated, crosscutting quartz-tourmaline veins and tourmaline veinlets. Detailed petrological, geochemical, and boron isotopic studies indicate that these tourmalines have distinctive core-rim zoning signatures and significant chemical variations, which can be divided into four paragenetic generations. Generation-I tourmalines in the leucogranite have a magmatic origin and were followed by hydrothermal Generation-II, Generation-III, and Generation-IV. Tourmalines from all four generations belong to the alkali group and the schorl-dravite solid-solution series. The most notable features are the variations in Mg, Fe, and Ca contents. The variable Mg/(Mg+Fe) ratios in generations I to IV may be attributed to the multiple influx and/or interaction of initially magma-derived hydrothermal fluid with surrounding rocks, magma-derived Fe-rich hydrothermal fluid, and external metamorphic fluid. In situ B-isotope analyses of tourmaline yield a total range of δ11B values from –11.7 to –6.0‰. The earliest Generation-I tourmalines have δ11B values of –11.1 to –9.6‰, whereas Generation-II and Generation-III tourmalines record a higher δ11B value of –9.5 to –6.0‰ and –9.3 to –6.9‰, respectively. Such an increase is mainly controlled by boron-isotope fractionation between melt-fluid and tourmaline-fluid, Rayleigh fractionation, and also, to some extent, by a hydrothermal recharge from the same magma source. Generation-IV tourmalines have the lightest B-isotope values (down to –11.7‰). This shift back to lighter B-isotopes in the Generation-IV cannot be explained by closed-system crystallization and isotope fractionation of known phases. Alternatively, a lighter source of boron via fluid circulation from the surrounding metamorphic rocks can explain this light boron isotope composition. Therefore, we propose that an isotopically light fluid may have derived from B release during mica breakdown within the surrounding metamorphic rocks.

Keywords: Tourmaline, geochemistry, boron isotope, magmatic-hydrothermal evolution, multiple generations, South Qilian

INTRODUCTION

Tourmaline is the most common borosilicate mineral in igneous and metamorphic rocks and ore deposits because of its wide P-T stability range and resistance to later alteration (e.g., Hawthorne and Dirlam 2011; Marschall and Jiang 2011; Trumbull et al. 2020). Tourmaline can crystallize as an early magmatic mineral (Bénard et al. 1985; London and Manning 1995; London et al. 1996; London 1999) or as a late mineral in a transitional stage from late solidus (magmatic) to early subsolidus (hydrothermal) conditions (Sinclair and Richardson 1992; London and Manning 1995; Buriánek and Novák 2007; Yang et al. 2015). The tourmaline crystal structure can generally accommodate a wide variety of cations with different sizes and valence, typically producing a complex topography and variable compositions. Owing to its negligible intra-crystalline diffusion (von Goerne et al. 1999; von Hinsberg et al. 2011), tourmaline compositions can preserve chemical fingerprints of the composition of the melt or fluid from which it crystallized (Trumbull and Chaussidon 1999; Trumbull et al. 2008; Henry and Dutrow 2012). As a result, multistage crystallization and chemical zoning in tourmalines with corresponding compositional variations can provide valuable information regarding the physico-chemical variations of the coexisting fluids and their evolution history, as well as petrogenesis and ore genesis during the growth of tourmaline (e.g., Mlynarczyk and Williams-Jones 2006; Duchoslav et al. 2017; Yu et al. 2017; Codeço et al. 2017, 2019). In granite-related hydrothermal systems, the presence of tourmaline indicates the involvement of boron and other volatiles in magmatic differentiation, magmatic degassing, fluid exsolution, wall-rock alteration, and metal transport and deposition (e.g., London et al. 1996; Smith and Yardley 1996; Jiang and Palmer 1998; Jiang et al. 2002, 2008). Boron-isotopes of tourmaline can have a wide range, and the 11B/10B ratios of different reservoirs are markedly different, making them an excellent tracer for the source of boron, origin, and evolution of fluids, P-T conditions, and water/rock interactions (e.g., Palmer et al. 1992; Palmer and Swihart 1996; Marschall et al. 2006, 2008; Trumbull et al. 2008, 2013; Yang and Jiang 2012; Yang et al. 2015; Siegel et al. 2016; Zhao et al. 2019; Trumbull et al. 2020).