Tourmaline composition and boron isotope signature as a tracer of magmatic-hydrothermal processes

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Abstract

This study presents a petrogeochemical and boron isotope study on tourmaline from the barren Damai, and the contemporaneous but ore-bearing Dewulu and Meiwu intrusions, to better understand the origins, sources, and fluid evolution of magmatic-hydrothermal ore systems and provide ore formation implications for gold, copper, and iron deposits in the Xiahe-Hezuo polymetallic district in the West Qinling, China. Tourmaline from all three intrusions shows similar compositions and encompasses Na-Fe schorl and Na-Mg dravite. Tourmaline at Dewulu is primarily found in tuffaceous breccias and a quartz diorite porphyry. In the tuffaceous breccia body, tourmaline occurs as fine-grained anhedral masses that fill voids and cement fragments of breccia and sickle quartz. Tourmalines in breccia are texturally similar to those formed in typical breccia pipes, which are attributed to explosion or collapse induced by a transition from magmatic to hydrothermal Si- and B-rich fluids. They display element substitutions controlled by Fe2+Mg−1, indicating a reduced environment. Values of δ11B are –6.6 to –4.0‰, representing the primary magmatic-hydrothermal fluids. Tourmaline from the Dewulu quartz diorite porphyry is coarse-grained, euhedral, and found in quartz-sulfide veins. The tourmaline displays oscillatory zoning textures but lacks correlative variations of major elements. The Fe2+Mg−1 and Fe3+Al−1 substitution mechanisms are dominant, demonstrating more oxidized fluids. The δ11B values in the cores, ranging from –7.1 to –5.6‰, suggest that the tourmalines in the quartz veins were inherited from magmatic-hydrothermal fluids that precipitated the fine-grained tourmaline in the tuffaceous breccia body. A large δ11B isotopic fractionation that decreases from cores (–5.6‰) to rims (–10.7‰) indicates significant fractionation during degassing occurred, increasing oxygen fugacity of the residual liquid. The Meiwu locality hosts fine-grained euhedral tourmalines coexisting with magnetite. Their composition is controlled by substitution between Al3+ by Fe3+ and has the lightest δ11B values ranging from –11.4 to –10.0‰. They are interpreted to result from skarn formation under oxidized conditions. In contrast, □Al(NaMg)−1 is the dominant substitution mechanism for Damai tourmalines and attributed to (geochemically) reduced fluids with a low salinity. We conclude that tourmalines with low Fe values, substitution mechanisms dominated by Fe3+Al−1, and large shifts of B isotopic composition are potentially an ore-forming indicator in the Xiahe-Hezuo polymetallic district.

Keywords: Tourmaline origin, textural occurrence, boron isotope signature, magmatic-hydrothermal processes, ore-forming tracer; Isotopes, Minerals, and Petrology: Honoring John Valley

Introduction

Magmatic-hydrothermal systems host a wide range of ore deposits in diverse tectonic settings, including porphyry, skarn, and epithermal deposits (Sillitoe 2010; Hong et al. 2017; Maner et al. 2019). Tourmaline is a common gangue mineral in many of these deposits worldwide owing to its stability over a wide range of temperature and pressure conditions (Jiang et al. 2008; Marschall and Jiang 2011; Slack and Trumbull 2011). Tourmaline may preserve textural, compositional, and isotopic features during growth and hence reveal considerable details about the environment in which it crystallized (Mlynarczyk and Williams-Jones 2006; Pal et al. 2010). Consequently, documenting the magmatic and hydrothermal records in tourmaline is an important step for furthering our understanding of the origin and evolution of ore fluids, the mineralizing processes, and thereby providing a potentially valuable tool for mineral exploration (Garda et al. 2009; Hong et al. 2017).

The Xiahe-Hezuo polymetallic district located in the Triassic West Qinling Orogen in central China has been the focus of significant (ore deposit) exploration and research in recent years (Jin et al. 2017; Qiu and Deng 2017; Sui et al. 2018; Qiu et al. 2020;