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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 $Fe^{2+}Mg_{-1}$, indicating a reduced environment. Values of $\delta^{11}B$ 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 $Fe^{2+}Mg_{-1}$ and $Fe^{3+}Al_{-1}$ substitution mechanisms are dominant, demonstrating more oxidized fluids. The $\delta^{11}B$ 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 $\delta^{11}B$ 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 Al^{3+} by Fe^{3+} and has the lightest $\delta^{11}B$ values ranging from –11.4 to –10.0‰. They are interpreted to result from skarn formation under oxidized conditions. In contrast, $^{X}\square Al(NaMg)_{-1}$ 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 $Fe^{3+}Al_{-1}$, 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