Fluid-rock interaction and fluid mixing in the large Furong tin deposit, South China: New insights from tourmaline and apatite chemistry and in situ B-Nd-Sr isotope composition

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ABSTRACT

The Furong tin deposit (South China) is genetically associated with the multiphase Qitianling batholith that consists of main-phase and minor, but more fractionated, late-phase granites. Several tourmaline and apatite generations are distinguished. Tourmaline (Tur) variants comprise pre-ore Tur-1 as disseminations and nodules in the late-phase granite, pre- to syn-ore Tur-2 as replacements in nodules and as veins crosscutting the late-phase granite and nodules, syn-ore Tur-3 in tin greisens, pre- to syn-ore Tur-4 as veins in the altered main-phase granite, and syn-ore Tur-5 from tin skarns in a distinct Ca-rich environment. Apatite (Ap) generations include accessory Ap-G in the main-phase granite, and Ap-I to Ap-III from three stages related to skarn-type mineralization (garnet-diopside stage-I, pargasite-phlogopite-cassiterite stage-II, and sulfide-rich stage-III). Textural and compositional features suggest that all tourmaline variants are hydrothermal in origin with alkali and schorl to foitite composition and minor extensions to calcic and X-site vacant tourmaline groups, whereas all apatite generations belong to fluorapatite with Ap-G crystallizing from the magma and Ap-I to Ap-III being hydrothermal in origin. The narrow range of tourmaline δ11B values (–14.8 to –10.4‰) suggests a single magmatic boron source in the ore-forming fluids. The similar rare earth element patterns and εNd(t) values (–8.2 to –5.9 for Ap-G and –8.0 to –7.3 for Ap-I) between magmatic and hydrothermal apatite indicate that the skarn-forming fluids are dominantly derived from granites. The 87Sr/86Sr ratios of Ap-I to Ap-III (0.70733–0.70795) are similar to the carbonate wall rocks, but distinctly different from the more radiogenic granites, indicating Sr exchange with carbonate rocks. Integrating previous H-O isotopic data, the tourmaline and apatite elemental and B-Sr-Nd isotope results suggest that the greisen-type ore formed by interaction of B-, Na-, Li-, Zn-, and Sn-rich magmatic fluids with the late-phase granite in a closed and reduced feldspar-destructive environment, whereas the tin skarns resulted from mixing of magmatic fluids with meteoric water and interaction with the carbonate wall rocks in an open system where oxygen fugacity changed from reduced to oxidized conditions. During fluid-rock interactions and fluid mixing, considerable Ca, Mg, V, Ni, and Sr from the host rocks were introduced into the ore system. Coupled hydrothermal minerals such as tourmaline and apatite have great potential to fingerprint the nature, source, and evolution of fluids in granite-related ore systems.

Keywords: Tourmaline and apatite chemistry, B-Sr-Nd isotopes, fluid tracer, fluid-rock interaction and fluid mixing, tin deposits

INTRODUCTION

Constraining the nature, source, and evolution of ore-forming fluids remains challenging, due to the restriction of H-O isotopes to just a few favorable mineral species and difficulty in identifying primary fluid inclusions and their paragenesis (Legros et al. 2018; Andersson et al. 2019). The chemical and isotopic records in hydrothermal minerals thus provide an alternative way to resolve this issue (Jiang et al. 1999; Su et al. 2016; Legros et al. 2018; Cedoço et al. 2021). Tourmaline and apatite have been considered as two of the best minerals for this role, due to their broad range in elemental composition and retention of chemical and isotopic signatures (Harlov 2015; Andersson et al. 2019; Dutrow and Henry 2018). Recent advances of analytical techniques, such as laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS), LA-MC-ICP-MS (MC = multi-collector), and secondary ion mass spectrometry, also permit high-precision in situ analyses of trace elements and B-Sr-Nd isotopes in tourmaline and apatite, which can provide detailed information on the fluid environment during crystal growth (Slack and Trumbull 2011; Zhao et al. 2015). However, an important precondition to use them as aids in deciphering ore genesis is the clear temporal-spatial link between tourmaline/apatite and ore minerals. Tourmaline in granite-related Sn deposits is usually paragenetically early and partly formed prior to tin ores (Trumbull et al. 2020). So far, there are still relatively few studies on syn-ore tourmaline from Sn deposits (Jiang et al. 2004; Duchoslav et al. 2017; Harlaux et al. 2020). Apatite has been widely used to constrain the petrogenesis of igneous rocks (Sha and Chappell 1999; Chu et al. 2009), discriminate mineralized from barren intrusions (Belousova et al. 2002; Cao et al. 2012), and decipher...