*American Mineralogist, Volume 108, pages 338–353, 2023*

# 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 $\delta^{11}B$ values (–14.8 to –10.4‰) suggests a single magmatic boron source in the ore-forming fluids. The similar rare earth element patterns and $\varepsilon_{Nd(t)}$ 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 $^{87}Sr/^{86}Sr$ 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