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Using in-situ apatite Sr isotopic compositions to constrain the origin and evolution of hydrothermal ore fluids: A case study from Southwest China

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Apatite is ubiquitous accessory mineral in a variety of rocks and hydrothermal ores. Sr isotopic compositions of igneous apatite have been considered to retain geochemical compositions of the host magma and have been widely used to investigate magmatic evolution and igneous petrogenesis. However, few attempts of apatite Sr isotopes have been used to constrain ore-forming processes of hydrothermal systems. We here report in situ LA-MC-ICPMS Sr isotopes of apatite from different stages of the Yinachang Fe-Cu-REE deposit, Southwest China. The ∼1660 Ma Yinachang deposit is hosted in late Paleoproterozoic meta-volcanic to sedimentary rocks of the Dongchuan Group. Formation of the deposit was coeval to emplacement of doleritic intrusions in the region likely within a continental rift setting. The deposit has a paragenetic sequence consisting of Na-alteration (stage I), magnetite mineralization (stage II), Cu-sulfide and REE mineralization (stage III), and final barren calcite vein (stage IV).

The stages II and III assemblages contain abundant apatite that is associated with magnetite and Cu-sulfides, respectively, providing an ideal opportunity to investigate temporal evolution of ore-forming fluids using in situ Sr isotopes. Apatite of stage II (Apt II) is associated with fluorite, magnetite, and siderite, and occur as euhedral-subhedral grains; whereas apatite from stage III (Apt III) occur either as inclusions enclosed by chalcopyrite or as isolated euhedral grains in the groundmass of ankerite and Cu-sulfides. Apt II has initial 87Sr/86Sr ratios (87Sr/86Sri) varying from 0.70377 to 0.71074, broadly compatible with those synchronous doleritic intrusions in the region (0.70592 to 0.70692), indicating that ore-forming fluids responsible for stage II magnetite mineralization were dominantly magmatic in origin or equilibrated with igneous rocks. In contrast, Apt III has much higher 87Sr/86Sr from 0.71021 to 0.72114. Some grains (metasomatized Apt III) have undergone extensive metasomatism indicated by numerous monazite inclusions with much higher 87Sr/86Sr up to 0.73721. Such high 87Sr/86Sr ratios were confirmed by bulk rock Rb-Sr isotopic compositions of metasomatized Apt III-rich ores with initial 87Sr/86Sr ratios from 0.71906 to 0.74632 in the same range of in-situ LA-MC-ICPMS analysis. The elevated 87Sr/86Sr values of metasomatized Apt III and bulk ores indicate that post stage III ore-forming fluids were much more evolved and were dominated by radiogenic Sr likely derived from the ore-hosting strata.

The increased 87Sr/86Sr ratios from Apt II to Apt III imply that the early stage ore-forming fluids were magmatic in origin and were subsequently interacted with the host rocks. This study thus unambiguously shows that in situ Sr isotopic compositions of apatite are good indicators for the sources and evolution of hydrothermal mineralizing systems.