

Using in situ Sr isotopes of apatite to unravel the fluid evolution of an IOCG system: A case study from the Kangdian IOCG belt, SW China

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Iron oxide-copper-gold (IOCG) deposits have been attracting a lot of recent exploration interest but the source(s) of fluids and ore metals, and evolution of the ore-forming systems remain controversial. The Lanniping Fe-Cu deposit is one of the important occurrences in the recently-defined Kangdian IOCG metallogenic province, southwestern China. Orebodies are hosted in the metasedimentary rocks of the late Paleoproterozoic Dongchuan Group that are controlled by structures, and consist mainly of massive and brecciated ores. Orebodies contain dolerite fragments, suggesting the mineralization is slightly later than the emplacement of mafic intrusions. The paragenetic sequence of the deposit includes pre-ore Na-alteration dominated by albite (stage I); Fe-(REE) mineralization dominated by magnetite and hematite with subsidiary fluorapatite (stage II); Cu-(REE) mineralization with chalcopyrite, bornite, biotite, chlorite, K-feldspar and minor allanite (stage III); and final barren calcite veining (stage IV) .

Apatite is a ubiquitous accessory mineral in a variety of rocks and hydrothermal ores. Strontium isotopes of apatite are well known to retain petrogenetic information and have been widely used to investigate the origin of igneous rocks, but such attempts have rarely been made to constrain ore-forming processes of hydrothermal systems. We use Sr isotopes of apatite to reveal the evolution of the ore fluids of the Lanniping IOCG deposits. Euhedral to subhedral apatite grains are associated with magnetite and cut by later Cu-sulfides and carbonates. They commonly exhibit obvious core-rim structures in CL and BSE images. The cores of apatite, containing minor magnetite inclusions, have homogeneous blue CL colors. In contrast, their rims exhibit yellow or green CL color and are darker than cores in BSE images. The rims may contain chalcopyrite and allanite inclusions, suggesting that metasomatism of the rims occurred during ore formation by the stage III fluids. LA-MC-ICP-MS analyses reveal that the cores and the rims have distinct trace elements and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, allowing for an understanding of the fluid evolution of the mineralizing system. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of the apatite cores are broadly compatible with the doleritic intrusions, indicating that ore-forming fluids responsible for stage II magnetite mineralization were largely equilibrated with mantle-derived mafic rocks. In contrast, the rims of apatite have $^{87}\text{Sr}/^{86}\text{Sr}$ ratios between the bulk-rock Sr isotopic compositions of the country rocks and doleritic intrusions, suggesting that external brines were involved in stage III mineralization. The rims were leached of LREEs from fluorapatite but these were partially incorporated into new LREE-bearing phases. Thus the external brines changed the physical-chemical conditions of the initial magmatic fluids during stage III mineralization, which facilitated Cu-sulfide deposition and mobilized REE from fluorapatite by coupled dissolution and re-precipitation processes.