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Neoproterozoic mineralization in a hydrothermal cassiterite-sulfide deposit at Jiumao, northern Guangxi, South China: Mineral-scale constraints on metal origins and ore-forming processes

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ABSTRACT

Most tin deposits worldwide are inferred to have formed from fluids derived from evolved (granitic) magma systems. Neoproterozoic silicate- and sulfide-stage Sn deposits at Jiumao of South China, in contrast, have been thought to be derived from metasedimentary and mafic-ultramafic host rocks. The Sn deposit may thus have formed by components and processes distinct from those that commonly contribute to Sn deposits, although spatially associated greisen-hosted Sn deposits also occur. To characterize in detail the formation of the Jiumao ore deposits, which contain ~28,000 t of Sn, we present new field and petrographic observations, major- and trace-element compositions for silicate and ore minerals, and U-Pb age data of cassiterites and zircons for the deposits and granites. Our research shows that (1) the granite-greisen system formed at ~830 Ma, which is the earliest Sn mineralization event in South China; (2) the silicate- and sulfide-stage ores in the country rocks formed at an fO_2 of ~NNO with temperatures of < 570 to > 350 °C and < 350 to > 170 °C, respectively; (3) all vein-type Sn ores at Jiumao were formed by Sn-F-B-rich fluids that were derived from the Yuanbaoshan granite magma system rather than ultramafic rocks; (4) the Fe-rich character of the ores hosted by the metasedimentary rocks and the Mg-rich character of the ores hosted by the ultramafic rocks largely controlled the reactions and efficacy of cassiterite precipitation and thus ore grade. We highlight that differences in mineral assemblages largely relate to differences of the protolith compositions and fluid-rock reactions (e.g., B- and tourmaline deposition in the ores hosted by the metasedimentary rocks, but not in the ores hosted by the ultramafic rocks). Cassiterite and titanite trace-element compositions reflect fluid composition, protolith composition, and intensive parameters of crystallization.

1. Introduction

The South China Block hosts a multitude of Sn ore systems that have formed during multiple episodes mostly during the Mesozoic (at ~146–165 Ma; Hua and Mao, 1999; Mao et al., 1999a; Chen et al., 2013) and during the Caledonian (at ~410–460 Ma; Fu et al., 2004; Wang et al., 2010a; Zhang et al., 2011b; Yang et al., 2013). Sn deposits are moreover hosted by Neoproterozoic (~740–830 Ma) granites and/or by their Proterozoic metasedimentary or mafic-ultramafic rocks (e.g. at Jiumao, Chen, 1995, Chen et al., 2000; at Baotan, Mao et al., 1988, Mao, 1995). The mineralization of the mafic-ultramafic rocks is generally most economic. To optimize exploration strategy and exploitation, it is thus imperative to know if the high economic value of the Sn deposits in the mafic-ultramafic rocks relates to primary metal occurrence or fluid-controlled influx and precipitation mechanisms. Economic concentrations of Sn in mafic or ultramafic rocks are rare worldwide, but they have been reported from deposits at Cleveland and Bischoff, Australia (Collins, 1981; Solomon, 1981), Magnum Bonum, Australia (Brown et al., 1984), Kidd Creek, Canada (Relvas et al., 2006), Gejiu, China (Cheng et al., 2012), and along the mid-Atlantic ridge (Evrard et al., 2015). At these locations, Sn deposits are interpreted to have formed in deep-seafloor hydrothermal surrounding or granitic fluid systems.

For the Jiumao Sn deposit, previous studies have suggested (1) that the Neoproterozoic granite intrusions of the area discharged ore-bearing fluids that mineralized the host rocks (Mao et al., 1988; Chen

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et al., 1994); (2) that metamorphic reactions during Neoproterozoic and Caledonian orogenies mobilized and locally concentrated Sn and other volatile elements in the metasedimentary and mafic-ultramafic country rocks (Xian, 1984, 1988; Chen, 1995, Chen et al., 2000); and (3) that the mafic-ultramafic magmatism primarily formed the Jiumao Sn deposit (Shui et al., 1988; Zhu, 1989, 1991). It remains, however, unresolved if all of the Sn mineralized zones at Jiumao have had the same Sn source or formation history. It also remains unconstrained if the Sn mineralization formed during the Neoproterozoic or subsequently. Gangue and sulfide minerals were dated from the ores hosted by the mafic-ultramafic and the metasedimentary rocks (Sibao Group), which yielded both Neoproterozoic and Caledonian ages (a biotite K-Ar age of 433 Ma and galena Pb isotopic model ages of 470 and 773 Ma, respectively; Xian, 1984,1988; Mao et al., 1988). Direct in situ dating of ore minerals (e.g. cassiterite, Nb-Ta oxides, or molybdenite) has been successfully applied to many mineral deposits by now (Gulson and Jones, 1992; Romer and Wright, 1992; Romer and Lüders, 2006; Mao et al., 1999b; Liu et al., 2007; Yuan et al., 2008, 2011, 2012a; Che et al., 2015; Harlaux et al., 2017), but it has not yet been applied to the Jiumao deposit. Here we use mineralogical and geochronological methods to study the Jiumao Sn deposit in order to (1) characterize the fluid and metal sources of the Sn deposits hosted by the granite and various wall rocks; (2) constrain the transport processes and precipitation mechanisms of Sn; and (3) quantify the tempareture-fO_2 conditions that prevailed during mineralization.

2. Geological setting

The study area is located in the southwest of the Jiangnan Orogenic Belt (Fig. 1a), in Guangxi Province, South China (Chen, 1995). The orogenic belt represents the Proterozoic subduction-collision suture of the Yangtze and Cathaysia Blocks (Guo et al., 1980; Charvet, 2013; Shu et al., 2015) and comprises metamorphic sedimentary, volcanoclastic, and ultramafic to silicic intrusive igneous rocks that are ~930–800 Ma old and extend over an area of 200 × 1000 km through central China. The Sibao Group, consisting of sandy-argillaceous detrital rocks, forms the basal sequence with deposition ages of ~870–835 Ma (Wang et al., 2006, 2010a, 2010b; Zhao et al., 2011; Wang et al., 2012). Early and middle Neoproterozoic igneous rocks form mafic-ultramafic layers and lenses in over 300 outcrops (BGMRGX, 1985; Li, 1999; Zhou et al., 2000, 2004; Lin et al., 2016). The mafic-ultramafic rocks in the Yuanbaoshan study area are inferred to have been emplaced at ~830–860 Ma (Yao et al., 2014a; Lin et al., 2016). All of the mafic-ultramafic rocks have possibly experienced significant seafloor hydrothermal alteration (Yan et al., 2003; Lin et al., 2016). The Sibao Group and mafic-ultramafic rocks have undergone greenschist facies regional metamorphism at ~860–800 Ma, and they may have also been affected by a late-Caledonian (~460–390 Ma) intracontinental orogenesis (Chen, 1995; Shu et al., 2015; Xu et al., 2016).

Silicic intrusions include granodiorite and biotite granites (Fig. 1a). The Yuanbaoshan pluton, which crops out about 1 km west of the Jiumao village and covers an area of > 300 km^2, is dominantly composed of coarse-grained biotite granite(Figs. 1b, 2a). It has an S-type affinity (A/CNK ~1.10–1.40). The intrusion was emplaced at ~833–820 Ma (Li, 1999; Wang et al., 2006; Yao et al., 2014a)

The ore at Jiumao occurs in three forms: (1) Type-I in greisen of the Yuanbaoshan pluton (2) Type-II in the Sibao Group and amphibolite host rocks (Fig. 2b, c), and (3) Type-III stannite-sulfide ore in the Sibao Group rocks (Fig. 2d). Over 80% of the remaining Sn reserves at Jiumao (near 28,000 t) are contained in the Type-II ore, while greisen ore in the granite has been nearly completely quarried. In the country rocks, 29 lodes consisting of 155 ore bodies have been identified, which are typically sub-parallel to the schistosity and lenticular (Figs. 1c, 2b). Mineralized Sibao Group metasediments and mafic-ultramafic rocks form the east limb of the Yuanbaoshan anticline, which is intruded by the Yuanbaoshan granite. Regional faults that trend approximately NNE, NWW, and NS are common in the area. The NNE- and NWW-trending faults crosscut the Yuanbaoshan pluton and Devonian strata (Fig. 1a). They are thus relatively young and unrelated to the Sn mineralization. The NS-trending faults (Fig. 1b), in contrast, only crosscut the Proterozoic granite intrusions and country rocks and they are locally Sn mineralized.

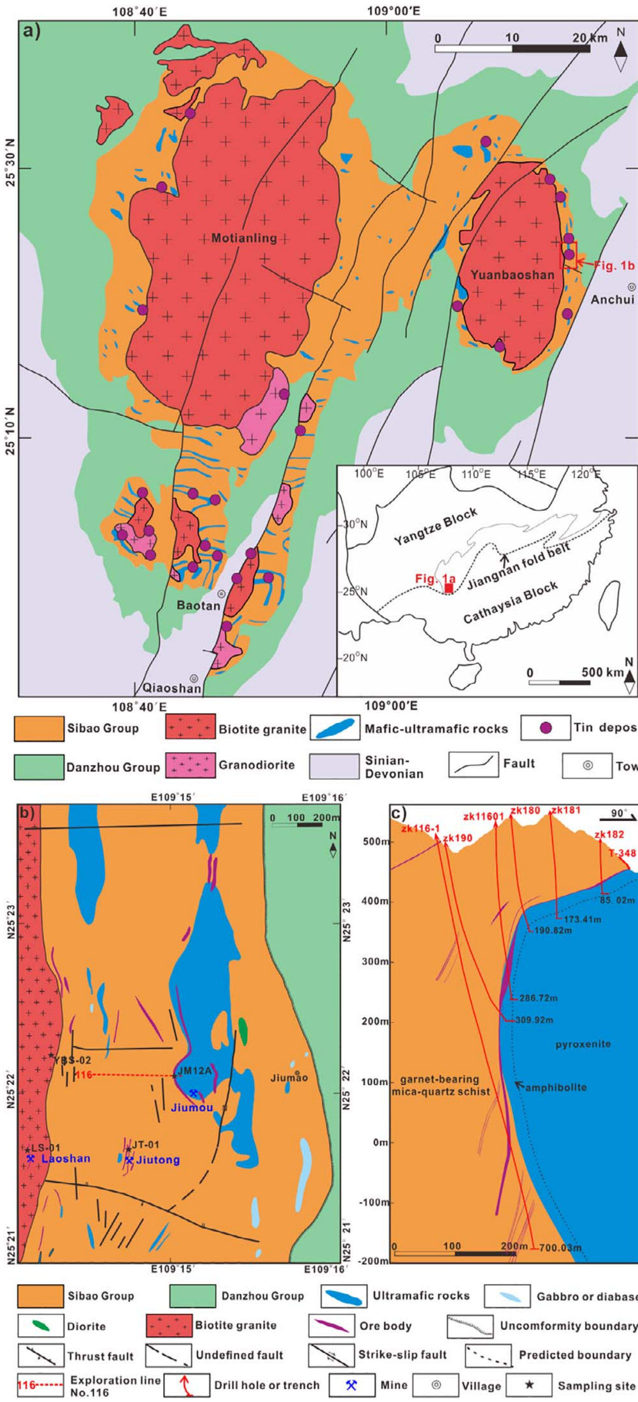

Fig. 1. (a) Regional geological map showing the location of the Yuangbaoshan granite and other Paleoproterozoic granite intrusions in northern Guangxi, South China (modified from Zhang et al. (2016)). The Jiumao ore deposit is located in the east of the Yuanbaoshan pluton (see inset). (b) Map showing the geology and distribution of the ore bodies, the exploration lines and mines of the Jiumao deposit (modified from Chen (1995)). The Jiumao ore deposit includes lodes at Jiumou, Jiutong, and Laoshan. (c) Cross section of exploration line No.116 at Jiumao that has drilled through metasedimentary rocks and mafic-ultramafic rocks of the Sibao Group which hosted abundant Sn-bearing ore veins.