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Geology, mineralogy, and geochemistry of fault-controlled hydrothermal Cu–Au mineralization in the Shanmen Volcanic Basin, SE China

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ABSTRACT

The Yukeng–Banling deposit is a typical fault-controlled hydrothermal Cu–Au deposit in the Shanmen Volcanic Basin (SVB), SE China. Ore bodies commonly occur as lodes, lenses and disconnected pods dipping SW with vertical zonation of ore minerals. Ore-related hydrothermal alteration is well developed on both sides of the veins, dominated by silicification, sericitization, chloritization and argillation with a banded alteration zonation. The mineralization can be divided into three stages (stages I, II and III). Native gold is present as veinlets in fractures of fine-grained pyrite from stage II.

Zircon U–Pb and Rb–Sr isochron ages indicate that the Cu–Au mineralization is coeval with the Caomen alkaline granite and Xiaokeng quartz-diorite, both emplaced at ca. 102 Ma. Microthermometric measurements of fluid inclusions in quartz and sphalerite from stage II veins indicate that the Yukeng–Banling deposit is an epithermal deposit. Six ore-related quartz grains have δD_{H2O} values of −69 to −43‰, and $\delta^{18}O_{H2O}$ values calculated using total homogenization temperatures that range from −2.0 to 0.7‰. All samples plot in an area between the magmatic field and the meteoric line, suggesting that the ore-forming fluids are derived from a mixed source of magmatic and meteoric waters. $\delta^{34}S$ values for eight pyrite separates range from −2.1 to +4.1‰ with an average of +1.7‰, and $\delta^{34}S$ values for galena and sphalerite are 2.3‰ and 2.2‰, similar to magmatic sulfur. Four alkaline granite samples have Pb isotopic ratios $(^{206}Pb/^{204}Pb)_t$ = 18.175–18.411, $(^{207}Pb/^{204}Pb)_t$ = 15.652–15.672 and $(^{208}Pb/^{204}Pb)_t$ = 38.343–38.800. Three quartz-diorite samples have ratios $(^{206}Pb/^{204}Pb)_t$, $(^{207}Pb/^{204}Pb)_t$ and $(^{208}Pb/^{204}Pb)_t$ of 18.277–18.451, 15.654–15.693 and 38.673–38.846, respectively. These age-calculated lead isotopic data for alkaline granite are similar to those for the analyzed sulfides. Co/Ni ratios for stage II pyrites range from 1.42 to 5.10, indicating that the Yukeng–Banling deposit records the past involvement of magmatic hydrothermal fluids. The isotope data, together with geological, mineralogical and geochronological evidence, favor a primary magmatic source for sulfur and metals in the ore fluids. Mixing of the Cu- and Au-rich fluids with meteoric water led to precipitation of the Cu–Au veins along NW-trending faults.

The Yukeng–Banling deposit, the contemporaneous Caomen alkaline granite and Xiaokeng quartz-diorite in the SVB formed under an extensional setting, due to high-angle subduction of the paleo-Pacific plate. The extensional setting facilitated the formation of Cu- and Au-rich magmas which was derived from enriched mantle and lower crust.

1. Introduction

Mesozoic large-scale magmatism and associated ore formation in South China mainly occurred in three episodes at 230–210, 170–150 and 100–90 Ma (Mao et al., 2008). The 100–90 Ma event coincided with epithermal Au–Ag–Cu and granite-related polymetallic W–Sn mineralization, with the former controlled by rift basins, uplifts and metamorphic core complexes (Mao et al., 2008). Previous studies have documented a close spatio-temporal relationship between some Cu–Au deposits and the Cretaceous volcanic basins, such as the Zijinshan high sulfidation epithermal Cu–Au deposit located at the northeastern margin of the Shanghang Volcanic Basin (Jiang et al., 2013). The Southeastern China Folded Belt (SCFB, also called Southeastern Coastal Magmatic Belt), separated from the Cathaysia Block by the Zhenghe–Dapu Fault (*ZDF*) to the north (Fig. 1A), is also potentially an economically important part of South China. Late Mesozoic intrusive and volcanic rocks are widespread in this region, commonly in the Cretaceous NE-trending volcanic basins. However, Cu–Au mineralization associated with these volcanic basins is rarely reported in the SCFB so far.

In the southeastern Zhejiang Province and northeastern Fujian Province, (i.e., eastern SCFB, Fig. 1A), many Cu–Au–Mo prospects occur in or at the margin of Cretaceous volcanic basins. Examples include the Chilu porphyry Mo deposit (Re–Os age of 105.6 Ma) located at the northeastern margin of the Xianglushan–Shangcun

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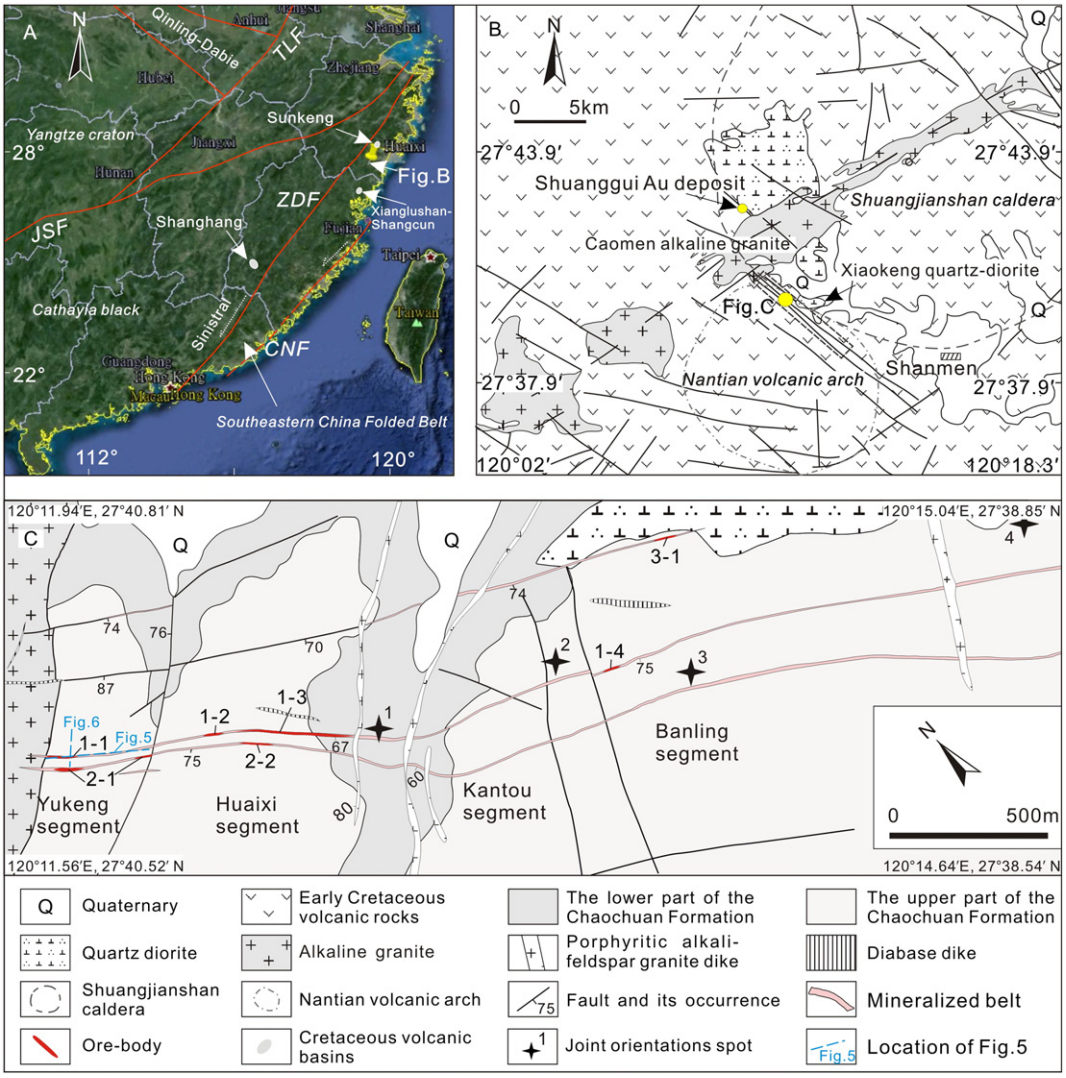

Fig. 1. (A) Tectonic map of South China, modified from Wang et al. (2005), showing the locality of the Southeastern China Folded Belt. *JSF*, *ZDF* and *CNF* denote the Jiangshan–Shaoxing, Zhenghe–Dapu and Changle–Nan'ao Faults, respectively. (B) Regional geological map of the Shanmen Volcanic Basin, modified from No. 11 G.T. (1989). This map shows that the Yukeng–Banling Cu–Au deposit lies in an area of overlap with Shuangjianshan caldera and the Nantian volcanic arch. (C) Geological sketch map of the Yukeng–Banling Cu–Au deposit showing the locality and distribution of the ore bodies and the relationship between mineralized belts, the Caomen alkaline granite, Xiaokeng quartz-diorite and NW-trending faults.

Volcanic Basin (Zhang et al., 2009), and the Shipingchuan quartz-vein Mo deposit (U–Pb age of 102.5 Ma) at the northern margin of the Sunkeng Volcanic Basin (Li et al., 2009). As one of the Cretaceous volcanic basins, the Shanmen Volcanic Basin (SVB) extends NE–SW over an area of about 600 km^2. The Huaixi Cu–Au deposit, located in the northwestern segment of Cu–Au mineralization in the SVB, was discovered in 1989 by the No. 11 Geological Team (No. 11 G.T.), Zhejiang Bureau of Geology and Mineral Resource. The No. 11 G.T. cooperated with the Entrée Gold Inc. to prospect for porphyry Cu–Au mineralization in the SVB during 2006–2009. Some researchers have studied the geology and fluid inclusions of this Cu–Au deposit, and recognized it as a typical hydrothermal-vein copper–gold polymetallic deposit (Hu et al., 1994; Tao et al., 1998). The zircon LA-ICP-MS U–Pb age of the Caomen alkaline granite and Rb–Sr isochron age of quartz from gold-bearing veins from the Huaixi Cu–Au deposit, were reported by Li et al. (2011). The previous study proposes that the Huaixi deposit has a genetic relationship with the Caomen alkaline granite (101.6 ± 0.9 Ma), and both are related to back-arc extension due to high-angle subduction of the paleo-Pacific plate. However, the mineralization and alteration zones, mineralogy, isotopic geochemistry and ore genetic model related to Cu–Au mineralization are still not clear.

This study presents new results for zircon LA-ICP-MS U–Pb ages of the Xiaokeng quartz-diorite, mineralization and alteration zonations, chemistry of pyrite, fluid inclusions, S–Pb–H–O isotopic compositions of ores and associated igneous rocks, and detailed structural analysis. These results are combined with previously published data on the Huaixi deposit and Caomen alkaline granite by No. 11 G.T. (1989, 1993), Hu and Li (1990) and Li et al. (2011) in order to further constrain the ore-genesis, tectonic setting, and ore-forming model for Cu–Au mineralization in the SVB.

2. Geological setting

The SVB is located between two major faults, the Zhenghe–Dapu (*ZDF*) and Changle–Nan'ao (*CNF*) Faults (Fig. 1A), in eastern SCFB. This area comprises mostly the early Cretaceous volcanic rocks (Fig. 1B), which formed in three volcanic eruptions during 120–102 Ma (Cui et al., 2010; Wang et al., 2010; Xing et al., 1993; Yang et al., 2008). The first two eruptions are collectively called the Moshishan Group (Yu et al., 2001). The first eruption consists of argillaceous sediments, andesites, dacites and rhyolitic volcanics, and can be divided into the Dashuang, Gaowu and Xishantou formations. Their Ar–Ar ages