Epithermal deposits in South China: Geology, geochemistry, geochronology and tectonic setting

Jun Zhong ^{a, b}, Franco Pirajno^c, Yan-Jing Chen^{b*}

^a *Beijing Research Institute of Uranium Geology, Beijing 100029, China*

^b *Key Laboratory of Orogen and Crust Evolution, Peking University, Beijing 100871, China*

^c *Centre for Exploration Targeting, University of Western Australia, 35, Stirling Highway,
Crawley WA6009, Australia*

*Corresponding author: Yan-Jing Chen, Department of Geology, Peking University,
Beijing 100871, China. E-mail: gigyjchen@126.com; yjchen@pku.edu.cn; Mobile
phone: 137 0121 0355; Fax: +86 10 6275 1150

Abstract

South China Block (SCB) is the broad area including the Yangtze Craton in the northwest and Huanan Orogen in the southeast. It is an important epithermal metallogenic province in China, containing at least 1 high-sulfidation (HS) and 42 low-sulfidation (LS) Au-Ag±Cu±Pb-Zn±Sb epithermal deposits. Porphyry-type mineralization was recognized in four of the LS deposits, and thus they were regarded as LS–P type. These 43 deposits are mainly located in: (1) the Lower Yangtze River Belt and (2) the Northeastern Jiangnan Orogenic Belt in the Yangtze Craton, (3) the Wuyi-Yunkai Orogenic Belt and (4) the Southeast Coastal Volcanic Belt in the Huanan Orogen. They are mostly located in Mesozoic volcanic basins, especially where the regional faults and their subsidiaries occurred. The host rocks include Jurassic–Cretaceous volcanic-sedimentary rocks, coeval or slightly older subvolcanic, granitoids and breccias, and metamorphic basement rocks. The alteration of the HS epithermal deposit (Zijinshan Cu-Au) zoned from silicic (vuggy quartz), through alunite, to dickite and phyllic alteration zones, from the ore veins outwards. The alteration of the LS deposits is zoned from adularia-chalcedony-bladed calcite (or quartz pseudomorphs after bladed calcite) in ore veins to distal illite-sericite-chlorite-kaolinite assemblages. For those LS–P systems, besides the dominated LS alteration assemblages, phyllic and potassium silicate alteration related to porphyry mineralization were identified. Acid leaching textures and vein, stockwork and breccia structures are common in HS deposit, while the LS epithermal

deposits are characterized by open-space filling, crustifications, colloform banding and comb structures. The ore-forming fluids are low-temperature, low-salinity meteoric water-dominated in most epithermal deposits in SCB, with variable input of magmatic water. The ore components were derived from both the deep magma and host rocks, and transported upwards or laterally and precipitated in the fracture systems by fluid boiling, mixing and cooling. Most of the epithermal deposits are formed at depth of < 1.5 km and < 300 °C, with few exceptions containing porphyry-type mineralization, such as the Zhilingtou, Yinshan and Longtoushan deposits. Deep drilling is suggested in these deposits as more epithermal and/or porphyry mineralization could be expected. The mineral systems were formed in Early Yanshanian (180–130 Ma) and Late Yanshanian (120–90 Ma) periods. The Early Yanshanian epithermal ore systems are mainly located in a series of E–W-trending metallogenic belts to the west of the Lishui–Haifeng Fault, which were formed in a syn- or post-collision tectonic setting by the collision between the SCB and its surrounding plates. The Late Yanshanian epithermal deposits are mainly located in Southeast Coastal Volcanic Belt, genetically related to the westward subduction of the paleo-Pacific plate.

Keywords: South China; epithermal deposit; geological and geochemical characteristics; tectonic setting

1. Introduction

The term “epithermal” was first coined by [Lindgren \(1922\)](#) to classify those deposits formed in an ore-forming environment of low temperature and shallow depth. They usually develop at low temperatures (100–320 °C, typically 170–280 °C) and shallow crustal levels (typically < 1 km below the water table) ([White, 2003](#); [Pirajno, 2009](#)). Most of these deposits are mined for Au and Ag, but As, Sb, Hg, Tl, Te, Pb, Zn and Cu are additional commodities. Since 1970s, over a dozen schemes have been proposed on the basis of alteration and gangue mineral assemblages, metal contents, sulfides contents, and sulfide mineral assemblages, as summarized by [Hedenquist et al. \(2000\)](#) and [Simmons et al. \(2005\)](#). In general, they are typically classified into two subgroups, i.e., high sulfidation (HS, or alunite-kaolinite) and low sulfidation (LS, or adularia-sericite) ([Hedenquist, 1987](#); [Heald et al. 1987](#); [Pirajno and Bagas, 2002](#); [Pirajno, 2009](#)), although an intermediate-sulfidation (IS) type was suggested by [Hedenquist et al. \(2000\)](#) and [Einaudi et al. \(2003\)](#). The ore-forming fluids of the high sulfidation deposits are dominated by acidic fluids, resulting in typical alteration minerals including alunite, dickite, kaolinite, pyrophyllite and Au-Cu-(Ag)-dominated mineralization ([Hedenquist and Lowenstern, 1994](#); [Chen et al., 2007b](#)). Native gold dominates, whereas electrum is minor and commonly occurs with copper-arsenic and copper-antimony minerals, such as enargite and its dimorph luzonite, famatinite, covellite, tetrahedrite, and tennantite ([White et al., 1995](#); [Simmons et al., 2005](#)). Hydrothermal solutions in the LS deposits are mainly near-neutral convecting

83 meteoric water, with no input of magmatic water, resulting with the formation of
84 gangue minerals including adularia, illite, sericite, chalcedony, calcite (commonly
85 bladed) and Ag-Au-Pb-Zn-dominated mineralization ([Hedenquist and Lowenstern,](#)
86 [1994; Chen et al., 2007b](#)). Microscopic to submicroscopic gold and silver grains
87 typically occur as electrum, rare tellurides, acanthite, sulfosalts and silver selenide
88 minerals ([Simmons et al., 2005](#)). The base metal minerals include sphalerite, galena,
89 chalcopyrite, pyrite, pyrrhotite, etc.

90 Epithermal deposits are an important source of Au, Ag, Cu, Pb, Zn. About more
91 than 6,000 tonnes of gold resources from epithermal systems have been proven,
92 world-wide accounting for 12% of total Au in primary deposits ([Kerrich et al., 2000;](#)
93 [Chen et al., 2003, 2012](#)). They mostly occur in island or continent arc and back-arc
94 extension settings, and therefore are mainly located in three global metallogenic
95 provinces: the circum-Pacific orogenic belts, the Tethysides or Mediterranean
96 orogenic belt, and the Central Asia orogenic belt ([Kerrich et al., 2000; Chen et al.,](#)
97 [2012](#)). The west part of the circum-Pacific orogenic belt can be further divided into
98 two belts, one extends from Japanese archipelago, through Taiwan, Phillipine, Papua
99 New Guinea, to Solomon Islands; the other from the north margin of Okhotsk,
100 through Northeast China to South China. Epithermal deposits in the former belt are
101 formed in less than 20 Ma and caused by subduction of the Pacific plate in Cenozoic
102 time ([White et al., 1995](#)), while those in the latter were formed between 180 and 90
103 Ma ([Table 2; Fig. 1, 2; Qi et al., 2004, 2005; Mao et al., 2007](#)), and most researchers

attributed them to the subduction of the paleo-Pacific plate in Mesozoic (Zhou and Li, 2001; Pirajno and Bagas, 2002; Zhou et al., 2002; Li and Li, 2007; Zaw et al., 2007; Mao et al., 2007, 2013).

To date at least 43 epithermal deposits (Table 1, Fig. 1) have been discovered and reported in the SCB, with a total resource of ~ 650 t Au, 9400 t Ag, 2.1 Mt Pb, 2.1 Mt Zn, 3.6 Mt Cu and 0.05 Mt Sb metals. These epithermal deposits were formed in Yanshanian period and are predominantly LS, followed by LS–P and HS types in terms of mineralization types. Most of these deposits have been studied in geology, geochemistry and geochronology and reported in Chinese literature (e.g., Chen and Xu, 1997; Xu et al., 1988, 1994; Lu et al., 1997; Tao et al., 1998; Mao et al., 2007, 2008; Zhang et al., 1992, 2001, 2003a, 2003b), but only a few deposits have been introduced in English, including Yinshan Cu-Au-Ag-Pb-Zn (Li et al., 2007; Mao et al., 2011; Wang et al., 2012, 2013a), Zhilingtou Au-Ag-Pb-Zn (Pirajno et al., 1997; Pirajno and Bagas, 2002; Zeng et al., 2013; Wang et al., 2016), and Zijinshan Cu-Au deposits (So et al., 1998).

In this contribution, we summarized the principal geological and geochemical characteristics of the epithermal deposits in South China, and then discuss their genesis and geodynamic settings.

2. Tectonic framework and evolution

The SCB is the area north to the Xiang-Guang Fault, northwest to the

Longmenshan Fault, southwest to the Ailaoshan–Red River suture zone, and facing the Pacific Ocean in the southeast (Fig. 1). It is divided into the Yangtze Craton and Huanan Orogen (also called as Cathaysia Block or South China Fold Belt) sutured by the Jiang–Shao Fault (Jiangshan–Shaoxing Fault or Xiang–Gan–Zhe Suture).

The Yangtze Craton is mainly covered by the coal-bearing Phanerozoic sedimentary sequence, with the basement rocks exposed along the margins. The basement rocks in the southeast margin of the Yangtze Craton consist of Mesoproterozoic volcano-sedimentary rocks and constituting the Jiangnan Orogenic Belt (JOB), or a Mesoproterozoic accretionary arc (Fig. 1), yielding isotope ages generally in the span of 1.8–0.85 Ga (e.g., Guo et al., 1980; Hu and Xu, 2008; Pirajno, 2013). The Huanan Orogen is divided into the Southeast Coastal Volcanic Belt (SCVB) in the east and the Wuyi-Yunkai Orogenic Belt (WYOB) in the west, separated by the Lishui–Haifeng Fault (Lishui–Zhenghe–Dapu–Haifeng Fault). The SCVB is characterized by Yanshanian granitic volcanic and intrusive rocks, with a lack of Paleozoic rocks; by contrast, the WYOB is marked by widespread pre-Devonian, Late Paleozoic to Triassic rocks, in places associated with Yanshanian granitic volcanic and intrusive rocks. The locally recognized Precambrian (Mesoproterozoic to Neoproterozoic in general) rocks within the pre-Devonian basement, such as the Badu Complex in Zhejiang and the Baoban Complex in Hainan (Pirajno, 2013 and references therein), can be interpreted either as fragments of the previously called Cathaysia Land (Grabau, 1924; Shu, 2012) or as accretionary continental terranes amalgamated onto the

Yangtze Craton (Hu and Xu, 2008).

The SCB underwent multiple tectonic-magmatic-metallogenic events since the Proterozoic period (Pirajno, 2009, 2013; Shu, 2012; Wang et al., 2013b). Many researchers (e.g., Pirajno and Bagas, 2002; Charvet et al., 2010; Shu, 2006, 2012; Wang et al., 2013b) suggested that the Huanan Orogen (Cathaysia Land) firstly collided with the Yangtze Craton in the early Neoproterozoic (1.0–0.8 Ga), then separated from the latter due to Rodinia breakup in Neoproterozoic (0.8–0.68 Ga), and ultimately re-docked with the Yangtze Craton during the period of Late Ordovician–Silurian (Caledonian Orogeny). The amalgamated SCB collided with the North China Craton and Indochina Block in the Triassic, and subsequently overrode the paleo-Pacific plate since the Middle Jurassic, resulting in the emplacement of abundant igneous rocks and associated mineral systems. However, this model disagrees with the fact that the Precambrian rocks are very limited in the Huanan Orogen, and thus another group of geologists (e.g., Guo et al., 1980; Hsü et al., 1988, 1990; Hu and Xu, 2008) proposed that the Huanan Orogen evolved from a geosyncline or an archipelago with Sinian (Late Neoproterozoic) to Triassic volcano-sedimentary sequence with thickness of up to 20 km (Guo et al., 1980; Xiao and He, 2005; Hu and Xu, 2008), instead of a hypothetical Cathaysia Old Land (Grabau, 1924; Shu, 2012) formed in Early Precambrian.

The eastern SCB is characterized by Yanshanian (Jurassic to Cretaceous) magmatic rocks and mineral deposits (Pirajno and Bagas, 2002; Zhou et al., 2006; Chen et al.,

2007a; Mao et al., 2013), but the tectonic setting is a long-time controversial issue.

The Early Yanshanian (mainly Jurassic) tectonic setting has been debated between several models including (Zhong et al., 2016a): (1) a back-arc basin-and-range province related to the westward subduction of the Pacific plate (Gilder et al., 1996); (2) a syn- to post-collisional setting related to the continental collisions of the SCB with the North China Block and Indochina Block since the ending Triassic, and with the hypothesized Dongnanya Continent since the end of the Early Jurassic (Hsü et al., 1988, 1990; Chen et al., 2007a); (3) post-orogenic delamination of the lower crust (Wang et al., 2006a, 2006b); and (4) a wide magmatic arc resulting from the westward flat subduction of the paleo-Pacific plate (Zhou et al., 2006; Mao et al., 2013; Zhou and Li, 2000; Li and Li, 2007; Wang et al., 2013b). Hitherto, the westward subduction model of the paleo-Pacific plate is the most popular one to understand Early Yanshanian tectonics in the eastern SCB. Subsequently, the subduction zone of the paleo-Pacific plate is interpreted to have migrated eastward to the ocean since Cretaceous (or Late Cretaceous), resulting in an extensional setting along the margin of the overriding Eurasia continental plate (Shu, 2012; Zhong et al., 2014, 2016a), accommodating the development of rift basins filled with molasses and shoshonitic volcanic rocks, alkaline granites such as granitic intrusions at Kuiqi in Fujian and Qingtian in Zhejiang, and the mafic dykes (Zhou et al., 2006; Hu et al., 1994, 1998; Zhang et al., 2004).

3. Spatial distribution

At least 43 epithermal deposits were recognized in the SCB (Fig. 1; Table 1). They are all located in the eastern SCB, including the Lower Yangtze River Belt (LYRB), the Northeastern Jiangnan Orogenic Belt (NJOB), the Wuyi-Yunkai Orogenic Belt (WYOB) and the Southeast Coastal Volcanic Belt (SCVB). Their principal geological characteristics and geological contexts are briefly listed in Table 1 and are introduced as follows.

3.1 The Lower Yangtze River Metallogenic Belt

The epithermal deposits are not common in the Yangtze Craton (YC), but where present they are concentrated in the northeastern segment (Fig. 1), mainly located in the Lower Yangtze River Metallogenic Belt (LYRB, Nos. 1–3) and the Northeastern Jiangnan Orogenic Belt (NJOB, No. 4). The LYRB is bounded by the Xiang–Guang and Tan–Lu faults to the north and by the Yangxin–Changzhou Fault to the south (Zhou et al., 2004, 2011, 2015), covering the eastern Hubei, northern Jiangxi and southeastern Anhui provinces. It is well known for the clustering of a great number of skarn, porphyry-skarn, porphyry and vein type Fe, Cu, Au and Mo, as well as epithermal Au mineralization systems. These mineralization systems are controlled by the E–W- and NNE-trending faults and Yanshanian magmatism (Chang et al., 1991; Zhai et al., 1992; Chen et al., 2007a; Xie et al., 2011; Pirajno, 2013). Three low-sulfidation epithermal deposits were recognized in the LYRB, and are hosted in

Early Cretaceous volcanic rocks in a series of volcanic basins, including the Lishui (Nos. 1 and 2) and Luzong (No. 3) basins ([Fig. 1](#)).

The basement rocks of the LYRB are composed of a Neoarchean to Paleoproterozoic metamorphic complex and a thick flysch sequence intercalated with pelagic volcanic rocks, together with Neoproterozoic granitic rocks ([Mao et al., 2004](#)).

The basement rocks are overlain by a thick Sinian–Triassic sedimentary sequence composed of clastic rocks, siliceous rocks and carbonates, in turn overlain by the Jurassic coal-bearing strata, Early Cretaceous calc-alkaline volcanic rocks and evaporite-bearing red beds ([Mao et al., 2004](#); [Xie et al., 2006, 2011](#)).

The NNW-, NW-, NNE- and some E–W-trending faults are observed in the LYRB, controlling the distributions of the Yanshanian magmatic activities and associated mineralization. The identified Mesozoic intermediate-felsic rocks in the LYRB include: (1) high-K calc-alkaline I-type granitoids (diorite, quartz diorite and granodiorite) related to Cu-Au-Mo mineralization systems; (2) shoshonitic rocks associated with magnetite-apatite deposits, mainly represented by syenodiorite, granitic porphyry and related volcanic rocks such as trachyandesite; and (3) A-type granitoids, consisting of quartz diorite, syenite, adamellite, alkaline granite and related volcanic rocks ([Mao et al., 2004](#); [Xie et al., 2011](#)). Epithermal deposits in the LYRB include the Guanshan (No. 1), Jinjushan (No. 2) in the Lishui basin and Tiantoushan (No. 3) in the Luzong basin. They are all small in size and hosted within shoshonitic rocks ([Table 1](#); [Fig. 1](#)).

3.2 The Northeastern Jiangnan Orogenic Belt

The Jiangnan Orogenic Belt is bounded by the Pingjiang–Duchang–Jixi–Hangzhou Fault in the northwest and Jiang–Shao Fault in the southeast (Chen et al., 2007a; Pirajno, 2013). Hitherto, only one epithermal deposit, the Yinshan LS–P polymetallic deposit, was recognized in the northeastern Jiangnan Orogenic Belt (NJOB).

The basement rocks in the NJOB comprise Mesoproterozoic migmatite, gneiss, schist and granulite, with isotopic ages ranging from 1.5 to 1.2 Ga (Wang et al., 2010). They are unconformably overlain by the thick Sinian–Triassic sequences composed of clastic rocks, siliceous rocks and carbonates, the locally developed Jurassic coal-bearing strata, and the Late Jurassic–Cretaceous volcanic rocks and Cretaceous red molasses (Chen et al., 2007a; Wang et al., 2010, 2015).

A set of NW-, NNE-, NE- and some E–W-trending faults can be observed in the NJOB (Table 1), of which the Jiang–Shao Fault (the Neoproterozoic suture between the Yangtze Craton and Huanan Orogen) and the Northeast Jiangxi Fault (the suture between Jiuling and Huaiyu terranes) are the most remarkable (Shu, 2012; Liu et al., 2012). The multistage reactivations of these two faults controlled the regional tectono-magmatic-metallogenic events in the NJOB, with the Yanshanian event being most intensive and extensive (Yang et al., 2002; Wang et al., 2010; Shu, 2012).

The Neoproterozoic mafic-ultramafic rocks along the Jiang–Shao and Northeast Jiangxi faults, including peridotite, orthopyroxenite, gabbro, diabase, were interpreted as being part of the Neoproterozoic ophiolitic mélange (Shu et al., 2008; Shu, 2012;

and references therein). The Mesozoic intermediate-felsic rocks are similar to those in the LYRB, dominated by the high-K calc-alkaline I-type granitoids (granodiorite, diorite and quartz diorite) associated with porphyry or epithermal Cu-Au-Mo mineral systems, exemplified by quartz and dacite porphyries in the Yinshan deposit (Wang et al., 2012).

The Yinshan deposit is located in the Dele volcanic basin in northeastern Jiangxi Province. It was formed simultaneously with a series of other volcanic basins nearby, such as the Dongxiang and Shixi basins in the northern segment of Wuyi Shan, which also host several epithermal mineralization systems (the next section). These volcanic basins were also classified into the Gan–Hang or Shi–Hang Volcanic Belt in many Chinese literatures (Gilder et al., 1996; Zhang et al., 2009; Jiang et al., 2011).

3.3 The Wuyi-Yunkai Orogenic Belt

The Wuyi-Yunkai Orogenic Belt (WYOB) is a NE-trending mountainous area bounded by the Jiang–Shao Fault to the west and Lishui–Haifeng Fault to the east, including the Wuyi Shan in the north, the Nanling Mountains (Southern Range) in the center and the Yunkai–Dayao Mountains (close to China-Viet Nam border) in the south.

The WYOB contains 8 epithermal deposits, including one LS–P (No. 43), one HS Cu-Au (No. 38), six LS-type Pb-Zn-dominated (No. 7) or Au-Ag-dominated (Nos. 5, 6, 8, 39 and 40) ones. These deposits are mainly located at the northern and/or

southeastern margin of the WYOB and cluster in three regions, from north to south: (1) Nos. 5 to 8 in the northern Wuyi Shan where a series of Mesozoic volcanic basins occur and are also assigned to the Gan–Hang or Shi–Hang volcanic belt in many Chinese literatures as forementioned ([Gilder et al., 1996](#); [Jiang et al., 2011](#)); (2) Nos. 38 to 40 in volcano-sedimentary basins in the southern Wuyi Shan or eastern Nanling Mountains; and (3) No. 43 in the Dayao Shan.

The Paleoproterozoic Badu Group and Mayuan Group (ca. 1.9–1.8 Ga; [Yu et al., 2009](#)) and Neoproterozoic Tianjingping Formation locally outcrop in the southwestern Zhejiang and northwestern Fujian provinces and are regarded as the oldest tectonostratigraphic unit in the WYOB. They are mainly composed of mica schists, gneisses, amphibolites, quartzite, marble and migmatites ([Mei, 1998](#); [Hu et al., 1991a](#)). The Proterozoic basement was overlain by a 10-km thick Sinian–Early Paleozoic turbidite sequence ([Mao et al., 2007](#); [Hu and Xu, 2008](#)), which were tightly folded and heterogeneously metamorphosed during the Caledonian (Ordovician–Silurian) Orogeny, and intruded by Caledonian igneous rocks ([Charvet et al., 2010](#); [Shu et al., 2008](#); [Faure et al., 2009](#); [Shu, 2012](#)). The pre-Devonian tectonostratigraphic units are unconformably covered by the Late Paleozoic to Triassic sedimentary sequence of littoral, neritic and alternating marine–lacustrine facies. The Late Paleozoic–Triassic sequences were folded into a series of anticlinoria and synclinoria during the Indosinian orogeny, such as the NEE-trending Dayao Shan anticlinorium ([Huang et al., 2003](#); [Sheng, 2005](#); [Deng, 2012](#)) and the NE-trending Xuanhe anticlinorium in

southwestern Fujian Province (Zhong et al., 2014), but were not obviously metamorphosed. The post-Triassic basins are mainly filled with Jurassic–Cretaceous clastic rocks, intercalated with volcanic rocks and red beds (Mao et al., 2007; Hua et al., 2005; Huang et al., 2003; Sheng, 2005; Deng, 2012).

Granitoids in the WYOB show relatively high $\epsilon_{\text{Nd}}(t)$ values (−2 to −8) and young T_{DM} ages (< 1.5 Ga) compared to the other areas of the SCB (Gilder et al., 1996; Chen and Jahn, 1998; Shu, 2006, 2012). The volcanic rocks in the WYOB were mainly formed in both the Early and Late Yanshanian periods. The Early Yanshanian volcanic rocks are mainly bimodal basalts and rhyolites with similar thickness, and most conspicuous in southern Hunan, southern Jiangxi, western Fujian, and Guangdong provinces (Zhou et al., 2006; Chen et al., 2008a), while the Late Yanshanian volcanic rocks are predominantly rhyolites and dacites of high-K calc-alkaline S-type or I-type affinities (e.g., Zhou et al., 2006; Lu et al., 1997; Tao et al., 1998), mainly located in volcanic basins in the northern (e.g. Dongxiang and Shixi basins) and southeastern Wuyi Shan (e.g. Shanghang basin), and related to the large scale porphyry-epithermal mineralization systems (e.g. the Zijinshan porphyry-epithermal mineralization system, Zhong et al., 2014, 2016a).

3.4 Southeast Coastal Volcanic Belt

The Southeast Coastal Volcanic Belt (SCVB) refers to the area southeast to the Lishui-Haifeng Fault, where it is characterized by the widespread Yanshanian

volcanic rocks (Fig. 1). In the SCVB, Late Paleozoic–Triassic lithologic units are limited, and the pre-Devonian can be only observed along the Lishui-Haifeng Fault, such as the Mamianshan Group in Youxi County, the Fujian Province (Wang et al., 2003), or the Badu and Chencai Groups in Zhejiang Province (Fig. 1). Overall, the shortage of the pre-Jurassic rocks characterizes the SCVB. However, drilling in the SCVB revealed a “double-decker structure”, consisting of the underlying metamorphic basement and overlying volcanic rocks (Lu et al., 1997; Tao et al., 1998). The volcanic rocks are dominated by rhyolites and dacites of calc-alkaline or high-K calc-alkaline I- and S-type affinities, showing the characteristics of igneous rocks formed in continent arc (Lu et al., 1997; Zhou et al., 2006; Chen et al., 2008a) or post-collision tectonic settings (Chen, 2002; Chen et al., 2007a). The widespread NE- and NW-trending faults in the SCVB controlled the distribution of the volcano-sedimentary basins and igneous rocks.

More than 2/3 epithermal deposits in South China are located in the SCVB (Table 1, Fig. 1), including 29 LS (Nos. 9–11, 13–14, 16–37, and 41–42) and 2 LS–P (No. 12, 15) deposits. However, most of these deposits are small in size, with only three large (Nos. 11, 15, 18) and six medium-sized (Nos. 11, 13, 21, 25, 37, 41) ones.

4. Mineralization ages

The mineralization ages of epithermal deposits in the SCB are not well constrained in previous studies (Table 2, Fig. 2). These ages were obtained from dating ore

mineral, gangue mineral and ore-related igneous rocks, using a variety of methods, such as Rb–Sr, Ar–Ar isochrons, Ar–Ar apparent plateau, whole rock K–Ar and zircon U–Pb analyses ([Table 2](#)).

Epithermal deposits in the LYRB are hosted by Early Cretaceous volcanic rocks and cryptoexplosive breccias. Sericite ^{40}Ar – ^{39}Ar ages (120.8–116.0 Ma) in the Guanshan deposit and whole rock K–Ar ages (140–135 Ma) of host rocks in the Tiantoushan deposit indicate that the epithermal mineralization in the LYRB are related to the Early Cretaceous magmatism ([Liang et al., 2010a](#); [Qiu et al., 1998](#)).

The Yinshan deposit in the NJOB is the oldest epithermal mineralization system reported in the South China, with ore-related sericite ^{40}Ar – ^{39}Ar ages ranging from 178.2 to 175.3 Ma ([Li et al., 2007](#)), which are coeval or slightly later than the LA-ICP-MS zircon U–Pb ages of the intimately associated quartz porphyry, dacite porphyry and rhyolite ([Li et al., 2007](#); [Wang et al., 2012](#)).

Epithermal deposits in northern Wuyi Shan of the WYOB are considered to have formed after Late Jurassic as they are hosted in the Late Jurassic volcanic rocks of the Ehuling, Huacaojian, Huyan and Zhoujiayuan Formations ([Table 1](#)), yet specific age data are not available. Those in the southeastern Wuyi Shan were mostly formed in Early Cretaceous, indicated by the alunite ^{40}Ar – ^{39}Ar ages (~ 103 Ma) for Zijinshan, adularia ^{40}Ar – ^{39}Ar ages (94–91 Ma) for Yueyang and whole-rock K–Ar age (134.8 Ma) of altered basalt for Songxi deposit. The Longtoushan Au deposit in the Dayao Shan was formed at ~100 Ma, as revealed by the zircon SHRIMP U–Pb age of the

host volcanic rocks ([Chen et al., 2008b](#)).

Widespread volcanic rocks in the SCVB mainly erupted during the Late Jurassic to Early Cretaceous period ([Table 1](#)). Most of the epithermal deposits in the SCVB were formed in Early Cretaceous ([Table 2, Fig. 2](#)), except the Babaoshan Au and Zhilingtou Au-Ag deposits in southwestern Zhejiang Province, yielding Late Jurassic mineralization ages of 140 Ma ([Ying et al., 1997](#)) and 164–148 Ma ([Zhou and Qian, 1996](#)), respectively.

It can be concluded that the epithermal deposits in SCB were all formed in the Yanshanian period and mostly related to simultaneous thermal events. The ages of epithermal deposits in the SCB can be divided into two groups, namely Early Yanshanian (180–130 Ma) and Late Yanshanian (120–90 Ma) periods ([Fig. 2](#)). The Early Yanshanian epithermal mineral systems are rare and located to the west of the Lishui–Haifeng Fault, while the Late Yanshanian epithermal deposits are more common and mostly crop out in the SCVB to the east of the Lishui–Haifeng Fault ([Fig. 1](#)).

5. Characteristics of selected epithermal deposits

The principal geological characteristics of epithermal deposits in the SCB are listed in [Table 1](#). In this section, seven representative deposits in different metallogenic belts, with distinct metal inventories and ore types, are briefly introduced, followed by an overview of the general geological and geochemical characteristics of all the

epithermal deposits in the SCB.

5.1 Guanshan Cu-Au-Pb deposit in Jiangsu Province

The Guanshan Cu-Au-Pb deposit in Jiangsu Province is located in the Lishui volcanic basin in the LYRB, 16 km to the Lishui County. It is a small Cu-Au deposit discovered in 1957, with Cu and Au reserves of no more than 0.1 Mt (grading at ~ 1%) and 5 t (~ 0.6 g/t) ([Liang et al., 2008](#)), respectively.

The basement of the Lishui volcanic basin is composed of the Silurian (Gaojiabian Formation) to Jurassic (Xihengshan Formation) marine carbonates, which were unconformably covered by volcanic rocks of the Early Cretaceous Longwangshan, Yunheshan, Dawangshan and Jianshan Formations. Trachyandesitic rocks of the Early Cretaceous Dawangshan and Guanshan Formations are the major host rocks of the Guanshan deposit ([Fig. 3](#)). Minor amounts of tuffaceous breccias locally crop out in the southeast of the district.

The ore veins with steep dip angles (50–80°) were controlled by near-parallel fractures ([Fig. 3](#)). Ore minerals include chalcopyrite, galena, sphalerite, with minor bornite, chalcocite and pyrite. Surficial ores were oxidized to gossan, composed mainly of limonite, malachite and covellite. Major gangue minerals are barite, quartz, calcite and siderite. Two-stage alteration assemblages are recognized, including an early-stage sericite, quartz and a late-stage epidote, kaolinite, carbonate, barite. The alteration is zoned from barite, quartz, kaolinite to sericite from the ore veins outward

(Liang et al., 2008, 2010a, 2010b).

According to Liang et al. (2008), the total homogenization temperatures of the ore-forming fluids are between 133 and 304 °C (peaking at 160–220 °C), with salinities between 0.5 and 7.4 wt% NaCl eqv., and densities of 0.87–0.93 g/cm³. These authors also inferred that fluid immiscibility was the most important ore-precipitation mechanism as fluid boiling assemblages were widely observed in ore samples (Liang et al., 2008).

The $\delta^{18}\text{O}_{\text{water}}$ values increase from 0.8–4.7‰ on the surface to 6.0–10.8‰ in drill core at depth, with δD values of –81.0 to –90.0‰ (Table 3; Liang et al., 2010b; Xia, 1995). The downward increase trend of the $\delta^{18}\text{O}_{\text{water}}$ values implies that magmatic fluids were introduced into the ore system at depth. The $\delta^{13}\text{C}$ values of calcite from –1.2 to 2.9‰ (averaging at 1.3‰) are identical to those of the marine carbonates (–3 to 2‰, Hoefs, 2004), suggesting that the carbon in calcite might be derived from carbonates of the Silurian to Jurassic basement of the Lishui basin (Liang et al., 2010b). The $\delta^{34}\text{S}$ values of chalcopyrite, pyrite and galena in the Guanshan deposits are concentrated in two clusters: –0.9 – +2.0‰ and +5.6 – +9.9‰ (Table 4), suggesting a possible mixing of deep magma and basement rocks (Xia et al., 1995; Liang et al., 2010b). Moreover, the $\delta^{34}\text{S}$ values of chalcopyrite and pyrite (7.6‰ in average) in ores are higher than those of galena (1.8‰), signifying that the sulfur isotopic equilibrium might be reached in the ore-forming process (Liang et al., 2010b).

The orebodies occur in fractures of the host volcanic rocks of the Dawangshan Formation, suggesting that the mineralization events must postdate the formation of the Early Cretaceous volcanic rocks (zircon U–Pb age: 127 ± 3 to 134.8 ± 1.8 Ma, Zhou et al., 2011). This is supported by two sericite ^{40}Ar – ^{39}Ar ages of 120.8 ± 1.0 Ma and 116.0 ± 1.3 Ma for altered trachyandesitic porphyry close to the orebodies (Liang et al., 2010a).

The Guanshan deposit was regarded as a typical HS epithermal system, based on the presence of barite, kaolinite and base metal sulfides by Liang et al. (2008, 2010a, 2010b). However, barite, kaolinite and base metal sulfides are not diagnostic minerals in HS systems and can be also observed in LS ones (Hedenquist et al., 2000; Simmons et al., 2005). Typical diagnostic minerals of the HS system, such as alunite, vuggy quartz, enargite, digenite, are absent in the deposit, and the ore-forming fluids were of low temperature and mainly derived from meteoric water. These geological and geochemical features differed from those in the typical HS deposit, but are more consistent with the LS epithermal systems. Hence, we suggest that the Guanshan deposit might be a LS, rather than HS epithermal system.

5.2 Yinshan Ag-Pb-Zn-Cu-Au deposit in Jiangxi Province

The Yinshan Ag-Pb-Zn-Cu-Au deposit is the only epithermal system identified in the NJOB. It is located at the northeast margin of the Dexing-Lehua (simplified as Dele) volcanic basin, and is thought to belong to the same metallogenic system with

the Dexing porphyry Cu deposit and Jinshan shear zone-hosted Au deposit in the basin (Mao et al., 2011). By 2007, the total proven reserves in the Yinshan deposit were 0.86 Mt Cu (grading at ca. 0.53%), 114 t Au (0.62 g/t), 2600 t Ag (196 g/t), 0.38 Mt Pb (1.75%) and 0.42 Mt Zn (1.91%) (Mao et al., 2011).

The oldest and most important host rocks of the deposit are the low-grade metamorphic rocks of the Mesoproterozoic Shuangqiaoshan Group, which were folded into a NE-plunging Yinshan anticline. These metamorphic rocks were further intruded by Jurassic dacite, andesite and quartz porphyries, and unconformably covered by dacitic and rhyolitic volcanic rocks of the Middle Jurassic Ehuling Formation (Fig. 4a). On the basis of stratigraphic and crosscutting relationships, the intermediate-felsic magmatic rocks in the Yinshan deposit are divided into three stages, from early to late: (1) rhyolitic lavas and quartz porphyry stocks in the Jiulong and Beishan areas; (2) dacite and dacite porphyries, mainly distributed in Xishan and surrounding areas; and (3) a small amount of andesite porphyry, confined to the Xishan volcanic edifice in the west of the ore district (Fig. 4; Hua, 1987; Li et al., 2007; Mao et al., 2011). These magmatic rocks, together with local outcrops of cryptoexplosive breccias, are controlled by the E–W-, (N)NE-, (N)NW-trending faults and their subordinate structures.

An early-stage Cu-Au and late-stage Ag-Pb-Zn mineralization were recognized in the Yinshan deposit, according to the mineral assemblage, ore fabrics and crosscutting relationships (Zhang et al. 2003c; Li et al., 2007). The steep Cu-Au orebodies,

comprising disseminated ores, occur at depth and/or close to the central dacite and quartz porphyries, cryptoexplosive breccias and phyllic rocks in the Jiuqu, Jiulong and Xishan areas (Fig. 4a, b), while the Ag-Pb-Zn ore veins occur in relatively outer and shallower parts in Beishan, Jiulong and Yinshan areas (Fig. 4a). The ore minerals include pyrite, chalcopyrite, tennantite, enargite, tetrahedrite, galena, sphalerite, native silver and argentite, while the major gangue minerals are quartz, sericite, chlorite, calcite and siderite. The Cu-Au mineralization is closely related to sericitization and silicification, while Ag-Pb-Zn to chloritization, carbonization and weak sericitization.

The ore-forming fluids in the Yinshan mineral system are rich in Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , SO_4^{2-} and F^- . Three types of fluid inclusions were recognized: vapor-rich, liquid-rich aqueous and daughter mineral-bearing inclusions. Homogenization temperatures related to Cu-Au mineralization range from 200–520 °C, with corresponding salinities of 4.3–58.8 wt% NaCl eqv.; while those of the Ag-Pb-Zn mineralization are 130–310 °C and 2.4–11.8 wt% NaCl eqv., respectively (Lin and He, 1990; Zhang et al., 2003c, 2007; Wang et al., 2013a).

Zhang et al. (2003c) summarized the published δD and $\delta^{18}\text{O}_{\text{water}}$ values of the ore-forming fluids in the Yinshan deposit (Table 3). The δD and $\delta^{18}\text{O}_{\text{water}}$ values of the Cu-Au and Ag-Pb-Zn mineralization are $-66 - -46.5\text{‰}$, $3.8 - 11.3\text{‰}$ and $-78.9 - -42.7\text{‰}$, $0.2 - 10.4\text{‰}$, respectively. The authors inferred a mixing process between magmatic and meteoric water, as shown in the δD vs. $\delta^{18}\text{O}$ plot (Fig.11). Most (99%) of the $\delta^{34}\text{S}$ values of sulfides concentrate between -2.5 and $+4.1\text{‰}$ (0.9‰ in average),

with few exceptions ranging from -10 to -12.2% , suggesting that the sulfur mainly came from ore-hosting igneous rocks, although minor sulfur in wallrocks was also introduced (Wu, 1998; Liu, 2005). The $^{206}\text{Pb}/^{204}\text{Pb}$, $^{207}\text{Pb}/^{204}\text{Pb}$, $^{208}\text{Pb}/^{204}\text{Pb}$ values of sulfides are $17.880\text{--}18.168$, $15.389\text{--}15.722$, $37.633\text{--}38.568$, respectively (Jiang, 1992; Liu, 2005), close to both the metamorphic rocks of the Shuangqiaoshan Group ($17.890\text{--}18.319$, $15.528\text{--}15.540$, $38.170\text{--}38.445$) and dacite porphyries ($17.957\text{--}18.168$, $15.467\text{--}15.551$, $37.883\text{--}38.097$), implying that they were both the possible lead sources of the ore system.

One sericite sample in altered dacite porphyry and two in quartz porphyry related to Cu-Au mineralization yielded $^{40}\text{Ar}\text{--}^{39}\text{Ar}$ age of 178.2 ± 1.4 , 175.4 ± 1.2 and 175.3 ± 1.1 Ma (Li et al., 2007), nearly coeval or slightly later than the SHRIMP or LA-ICP-MS U-Pb ages of the dacite porphyry (181 ± 3 to 170 ± 1 Ma, Li et al., 2007; Wang et al., 2012) or quartz porphyry (176 ± 1 to 172 ± 1 Ma, Wang et al., 2012), suggesting that the Cu-Au mineralization shares intimate spatial and temporal relationships with these porphyries. The Ag-Pb-Zn mineralization, postdating the Cu-Au mineralization, possibly formed in the Late Jurassic as they were spatially related to and partly hosted in the Jurassic volcanic rocks of the Ehuling Formation.

In summary, the Cu-Au orebodies in the Yinshan polymetallic deposit are spatially, temporally and genetically associated with dacite and quartz porphyries, resembling those of the porphyry Cu-Au deposits. This is further supported by the occurrence of the halite-bearing inclusions and high temperature, high salinity of the ore-forming

fluids, although the potassium silicate alteration was not recorded. The Ag-Pb-Zn mineralization, however, is interpreted to be formed in a LS epithermal environment, indicated by the low temperature ore-forming fluids, mineralogy and ore geology characteristics. Therefore, we consider the Yinshan deposit to be a porphyry–epithermal mineralization system.

5.3 Zijinshan Cu-Au-Mo-Ag orefield in Fujian Province

The coexistence of LS and HS epithermal and porphyry deposits in a same mineral system is uncommon because of their different formation depths (Heald et al., 1987; Hedenquist et al., 1998, 2000; Simmons et al., 2005). The Zijinshan Cu-Au-Mo-Ag orefield is a perfect example hosting all the endmembers of the epithermal-porphyry system (Zhang et al., 1992, 2001, 2003b; Zhong et al., 2011, 2014, 2016a), including Zijinshan HS Cu-Au, Yueyang LS Ag-Au-Cu, Luoboling porphyry Cu-Mo and several transitions and combinations thereof (Fig. 5). By the end of 2011, the proven reserves in the Zijinshan orefield were 399.8 t Au, 4.14 Mt Cu, 6339 t Ag, and 0.11 Mt Mo (Zhang, 2013), making it the largest Cu-Au ore district in the Fujian Province.

The Zijinshan orefield is located to the northeast of the Shanghang Cretaceous volcano-sedimentary basin in southwest Fujian Province. The main lithostratigraphic units herein are the Neoproterozoic metamorphic rocks of the Louziba Group, the Late Paleozoic clastic rocks, and the Early Cretaceous volcanic rocks of the Shimaoshan Group (Zhong et al., 2014). The pre-Jurassic rocks were folded into a

NE-trending anticline which was intruded by the Yanshanian granitoids along its axis (Fig. 5). These granitoids host most of the orebodies in the orefield and include: (1) Middle–Late Jurassic (165–157 Ma) Zijinshan granite batholiths; (2) Late Jurassic (150 Ma) Caixi monzogranite; (3) Early Cretaceous (108 Ma) Sifang granodiorite and Luoboling granodiorite porphyry (105 Ma); and (4) small-sized Early Cretaceous granite/dacitic porphyries (e.g., Luoboling granodiorite porphyry) and cryptoexplosive breccias (Zhang et al., 2001; Zhao, 2007; Jiang et al., 2013; Zhong et al., 2014). All the deposits in the orefield were formed in the Early Cretaceous and associated with simultaneous magmatic activities (Zhang et al., 1992, 2001, 2003a, 2003b; Zhong et al., 2014). In the following sections, we will briefly introduce the geological and geochemical characteristics of the Zijinshan HS Cu-Au and Yueyang LS Ag-Au-Cu deposits.

5.3.1 Zijinshan Cu-Au deposit

The giant Zijinshan Cu-Au deposit is the first HS epithermal deposit recognized in mainland China (So et al., 1998; Zhang et al., 1992). It contains proven reserves of ~ 400 t Au (average grade at 0.5 g/t) and 2.32 Mt Cu (averaging at 0.36%) (Zhang, 2013). It is located in the center of the Zijinshan orefield, where a dacitic volcanic dome was identified (Fig. 5; Zhang et al., 1992; So et al., 1998). The dacitic porphyry occurs as a pipelike intrusion in the central part of the ore district and is surrounded by cryptoexplosive breccias, which also crop out as NW-trending veins in the

northwest part of the deposit (Fig. 6). Copper and gold mineralization at Zijinshan mainly occurs as veins or lens in the cryptoexplosive breccias and NW-trending fractures in host granites (Fig. 6).

Pervasive hydrothermal alteration is recognized in the Zijinshan deposit. From the ore veins outward, the alteration is zoned from silicic (vuggy quartz), through alunite, dickite, to phyllic alteration (Fig. 6a, b). Gold orebodies are confined to the vuggy quartz zone (Q) above the present water table near 650-m level (Fig. 6b), where native gold grains are typically associated with quartz, goethite and limonite (Fig. 7a, f). This possibly indicated that the gold ores formed partially by secondary enrichment as the result of later circulation of meteoric waters through permeable breccia ores (So et al., 1998). Copper orebodies occur mainly in the alunite alteration zone (Q-Alu) beneath the 650-m level (Fig. 6b), with major ore minerals of digenite, covellite, enargite, pyrite and some tin-bearing sulfides (Fig. 7g, h; Liu et al., 2016). Gangue minerals are alunite, quartz, pyrophyllite, dickite (Fig. 7d, e). The Cu ores are featured by veins, stockworks and breccias (Fig. 7b, c). Deep drilling revealed a thick copper orebody at –400-m level, indicating more possible reserves at depth. The alunite alteration zone gives way to phyllic alteration zone (Q-Ms) in outer and deeper sections, which mainly include sericite, quartz, pyrite and minor dickite, alunite. The forementioned mineral assemblages and ore fabrics show that the Zijinshan Cu-Au deposit is a typical HS epithermal system.

According to So et al. (1998), Zhang et al. (1992) and Chen (1999), three types of

fluid inclusions were identified in the Zijinshan deposit, namely: liquid-rich aqueous, vapor-rich aqueous and CO₂-H₂O type inclusions. The homogenization temperatures and salinities of fluid inclusions in the Q, Q-Alu and Q-Ms alteration zones are 100–180, 250–320, 300–380 °C and 0.1–1.9, 1.1–21.6 and 3.9–15.2 wt% NaCl eqv., respectively. Analyses of fluid inclusions suggest that the ore-forming fluids are rich in K⁺, SO₄²⁻, HCO₃⁻, but depleted in Cl⁻ (Zhang et al., 1992). So et al. (1998) further suggested that mixing between the magmatic and meteoric water is the possible reason for the precipitation of high sulfidation-state Cu minerals and gold. Recently, we have calculated the formation depths of the CO₂-H₂O type inclusions in the Zijinshan deposit to be 1.0–2.1 km (Table 3, Zhong et al., 2016b), which is greater than other epithermal systems worldwide. The high temperature of ore-forming fluids and greater depths of the deposit suggest that it might be linked to a porphyry mineralization system.

Quartz grains separated from ores yielded δD and $\delta^{18}O_{\text{water}}$ values of –55 to –78‰ and –4.9 to +10.3‰ (Table 3; Zhang et al., 1992; Wei and Tao, 1998; Zhou et al., 1998; Chen, 1999), respectively. The evolutionary trend of the ore-forming fluids in the δD vs. $\delta^{18}O_{\text{water}}$ plot indicate a mixing process between magmatic and meteoric waters, which is in agreement with the forementioned conclusions drawn from fluid inclusion study by So et al. (1998). The $\delta^{34}S$ values of sulfides range from –8.4 to +5.1‰ (Table 4), and one alunite sample yielded $\delta^{34}S$ value of +26.9‰. The calculated average $\delta^{34}S$ value of sulfides is –0.7‰, suggesting a magmatic origin for

sulfur (Zhang et al., 1992; Chen, 1999). The $^{206}\text{Pb}/^{204}\text{Pb}$, $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{208}\text{Pb}/^{204}\text{Pb}$ ratios of ores are 18.408–18.600, 15.604–15.874 and 38.437–39.203 (Table 4; Zhang et al., 1992; Chen, 1999), respectively. These values are close to both the Jurassic and Cretaceous magmatic rocks (Jiang et al., 2013), suggesting that they are both the probable lead sources. Zhang et al. (1992) and Chen (1999) reported the Pb-isotope model ages for most of the sulfides ranging from 184 to 128 Ma, which supports the conclusion of lead source from the Yanshanian magmatic rocks.

Various methods were used for ore-forming age determination and the results are partly listed in Table 2. Chen (1996) and Zhou and Chen (1996) reported a Rb–Sr isochron age of 100 ± 3 Ma for fluid inclusions in quartz grains in the gold ores. Zhang et al. (1992) analyzed the alunite in copper ores, yielding a K–Ar age of 103.8 Ma. We have recently dated five alunite samples using laser ^{40}Ar – ^{39}Ar method and gotten their ages all around 103 Ma (Table 2). These ages are nearly identical or slightly later than the zircon U–Pb ages of the dacitic and granodiorite porphyries (~ 105 Ma, Hu et al., 2011; Huang et al., 2011), signifying that the Cu and Au mineralization are related to coeval Cretaceous magmatism.

On the basis of the abovementioned ore and gangue mineral assemblages, wall rock alteration, physico-chemical conditions of ore-forming fluids and isotopic signatures, it is concluded that the Zijinshan Cu–Au deposit is a typical HS epithermal system, which is closely associated with coeval dacitic magmatism in Early Cretaceous.

5.3.2 Yueyang Ag-Au-Cu deposit

The Yueyang Ag-Au-Cu deposit, nearly 3 km southwest to the Zijinshan Cu-Au deposit, is located at the northeast margin of the Yueyang Mesozoic volcanic basin (Fig. 5). The proven reserves in the deposit are 1330 t Ag, 8.2 t Au and 0.04 Mt Cu (Zhang, 2013).

The main sequences in the mining area are the Early Cretaceous volcanic rocks of the Shimaoshan Group and Quaternary sediments (Fig. 8a). The upper part volcanic rocks of the Shimaoshan Group, with sporadic U mineralization, are composed of rhyolite, rhyolitic volcanic breccia, tuff, and tuffaceous sandstone, while the lower part are mainly hornblende and biotite trachyandesite, with minor andesite, dacite, sandstone and conglomerate. Core drilling revealed underlying Neoproterozoic low-grade metamorphic rocks of the Louziba Group and the Jurassic Zijinshan granites (Fig. 8b), which are the major host rocks of the concealed Ag-Au-Cu orebodies. The orebodies, stratiform or lens in shape, are controlled by a series of NW-trending (290–320°) listric normal faults or fractures, with shallow dip angles (< 20°) (Fig. 8b). Major ore minerals include chalcopyrite, pyrite, sphalerite, galena, native silver, argentite, native gold (Fig. 9g, h, i), and the main gangue minerals are quartz, chalcedony, illite, adularia, sericite, calcite and chlorite (Fig. 9f, h, i). Hydrothermal alteration is intensive in the district, including silicic, sericite, adularia, carbonate, chlorite and argillic alteration. The ores are mostly in veins or stockworks with distinctively banded crustiform-colloform and open-space filling (e.g., dursy

quartz) textures (Fig. 9a–e). On the basis of mineral assemblages and crosscutting relationships, an early Cu mineralization stage and a late Ag and Au mineralization stage are recognized, which are intimately associated with sericitic, and silicic, adularia alteration, respectively.

Our current studies (Zhong et al., 2016c) indicate that the fluid inclusions in the Yueyang deposit are dominated by the two-phase NaCl-H₂O inclusions, with very few halite-bearing and NaCl-H₂O-CO₂ inclusions, locally identified in the Cu mineralization-stage samples. The homogenization temperatures and salinities of the inclusions for Ag-Au and Cu mineralization are 120–260, 220–380 °C and 0.9–5.0, 4.6–31.7 wt% NaCl eqv., respectively. Using the boiling-point curves for H₂O-NaCl system (Haas, 1971), we have estimated the Cu and Ag-Au mineralization depths to be 527 m and 448 m on average. We also suggest that fluid boiling is the major mechanism causing the precipitation of ore minerals as the fluid boiling assemblages were commonly observed in ore samples.

The δD and $\delta^{18}O_{\text{water}}$ values of ore-forming fluids decreased from $-64 - -62\text{‰}$ and $2.3 - 2.7\text{‰}$ in the Cu mineralization stage to $-81 - -63\text{‰}$ and $-3.8 - 0.2\text{‰}$ in the Ag-Au mineralization stage (Zhong et al., 2016c), indicating a meteoric water-dominated source for Ag-Au mineralization, with little input of magmatic components in the Cu mineralization stage. Lin (2006) reported the $\delta^{34}S$ values of sulfides ranging from $-6.5 - +4.8\text{‰}$ (averaging at nearly zero), indicating a magmatic origin for sulfur, which is further supported by the low Co/Ni ratios (< 1) of the pyrite grains (Lin,

2006).

Zhang et al. (2003a) and Liu and Hua (2005) dated two Ag-Au mineralization-related adularia samples, yielding ^{40}Ar – ^{39}Ar ages of 94.7 ± 2.3 Ma and 91.5 ± 0.4 Ma, which are nearly 10 Ma years younger than the Re–Os age of molybdenite in Luoboling porphyry Cu–Mo deposit (~ 105 Ma, Zhong et al., 2014) and the forementioned alunite ^{40}Ar – ^{39}Ar ages in the Zijinshan Cu–Au deposit (~ 103 Ma).

As mentioned above, the mineral assemblages and ore fabrics show that the Yueyang Ag–Au–Cu deposit is a typical LS epithermal system. It was formed by fluid boiling of low temperature, low salinity meteoric water, with little input of magmatic components. A two-stage mineralization scenario in the Zijinshan orefield can be presumed as the LS system was formed nearly 10 Ma later than the porphyry and HS epithermal systems.

5.4 Songxi Ag–Sb deposit in Guangdong Province

The Songxi (or Baoshan) Ag–Sb deposit is a large deposit located at the north margin of the Zhaigang Mesozoic volcanic basin in northeastern Guangdong Province, with total proven reserves of 1199.8 t Ag (grading at ca. 302.7 g/t) and 0.05 Mt Sb (1.65%) (Xiao, 2001).

The main lithologic sequences in the deposit include the Early Jurassic clastic rocks of the Jinji Formation, the Middle Jurassic clastic, pyroclastic rocks and tuffaceous

siltstone of the Zhangping Formation, and the Late Jurassic pyroclastic rocks of the Gaojiping Formation (Fig. 10a). These sequences were folded into a SE-plunging anticline and were further cut by the NE-, NW- and E–W-trending faults. Two-stage magmatic events are recognized, namely: andesitic basalts in the Jinji Formation and quartz porphyries at depth or around the ore system (Xiao, 2001; Chen et al., 2008c).

The ore veins in the black carbonaceous shale, siltstone and volcanic tuff of the Early Jurassic Jinji Group are controlled by the NE-trending faults and subsidiary structures. They all dip to SE and have a funnel shape in cross-section profiles (e.g., Fig. 10b), which made Xiao (2001) and Chen et al. (2008c) infer that the fluid source was probably located at depth to the southeast. Major ore minerals include stibnite, pyrite, arsenopyrite, freibergite, sphalerite, miargyrite, pyrargyrite, dyscrasite, native silver, galena, chalcopyrite and pyrrhotite. Gangue minerals are quartz, calcite, chlorite, dolomite and sericite. The mineralization is characterized by veins and stockworks with comb and geodal structures. Hydrothermal alteration is intensive and evolved from the orebodies outwards, from silicification, through carbonization, sericitization, to propylitization (Xiao, 2001; Chen et al., 2008c; Guo and Peng, 2009).

Yao et al. (1996) and Xiao (2001) reported homogenization temperatures of 80–300 °C, salinities of 2.2–19.4 wt% NaCl eqv., and densities of 0.7–1.0 g/cm³ for the ore-forming fluids. The calculated pressures range from 15.9 to 19.1 MPa, corresponding to a formation depth of 600 to 700 m (Yao et al., 1996). From the

isothermal diagram in the cross-section profile drawn by [Xiao \(2001\)](#), it can be inferred that the fluid ascended from deep levels in southeast to shallow levels in northwest of the ore district. Fluid inclusion composition analyses indicated that the ore-forming fluid is rich in Na^+ , Ca^{2+} , K^+ and HCO_3^- , SO_4^{2-} , Cl^- , and F^- ([Xiao, 2001](#)).

The δD and $\delta^{18}\text{O}$ values of the fluid are -43.6 to -78.0‰ and -6.8 to $+7.0\text{‰}$, which plot between the magmatic and meteoric water boxes, indicating a mixing trend between these two end-members ([Yao et al., 1996](#); [Xiao et al., 1997](#); [Xiao, 2001](#); [Chen et al., 2008c](#)). Several quartz and calcite samples yielded $\delta^{13}\text{C}$ values of -6.8 to -0.5‰ , close to but lower than those of the deep-seated source, which indicate that the carbon might have originated from deep-seated magmas, with some minor assimilation of organic carbon from the host rocks ([Xiao, 2001](#)). The $\delta^{34}\text{S}$ values of sulfides range from -11.3 to $+14.3\text{‰}$, but are especially concentrated between -4.2 and $+4.0\text{‰}$ (about zero in average), indicating a magmatic-dominated origin, with some introduction of sulfur from the host rocks ([Chen et al., 2008c](#)). The $^{206}\text{Pb}/^{204}\text{Pb}$, $^{207}\text{Pb}/^{204}\text{Pb}$, $^{208}\text{Pb}/^{204}\text{Pb}$ values of ores are 18.136 – 18.983 , 15.649 – 15.848 , 38.461 – 39.299 , respectively. These data plot between the orogen and upper crust lines ([Fig. 15](#)), indicating a possible mantle-crust mixing source for the lead ([Yao et al., 1996](#); [Xiao, 2001](#); [Guo and Peng, 2009](#)).

[Cai \(1996\)](#) obtained a K–Ar age of 134.8 Ma for a basalt sample with propylitic alteration in the Early Jurassic Jinji Formation, which is much later than the actual age of the Jinji Formation. [Cai \(1996\)](#) suggested that the propylitic alteration resulted

from the hydrothermal event synchronous to Ag-Sb mineralization in the ore district. Thus the K–Ar age can approximately represent the possible ages of hydrothermal alteration and mineralization. This suggestion is further supported by the Pb-isotopic model age (140 Ma) of sulfides and zircon U–Pb age (137 ± 5 Ma) of the granite porphyry in the district (Chen et al., 2008c).

The ore genesis of the Songsi Ag-Sb deposit was debated from a hydrothermally overprinted VMS (Zheng, 1996; Meng and Wang, 1998) to an epithermal origin (Yao et al., 1996; Xiao, 2001; Chen et al., 2008c). Although the orebodies are hosted in marine volcanic-sedimentary rocks, it was closely related to the quartz porphyry at depth, according to the isotopic and geochronologic analyses (Chen et al. 2008c). Moreover, the orebody morphologies, mineral assemblages, ore fabrics, and physico-chemical conditions are all consistent with those of the LS epithermal systems (c.f. Simmons et al., 2005; Hedenquist et al., 2000). Therefore, we consider it to be a LS epithermal, rather than a VMS deposit.

5.5 Longtoushan Au deposit in Guangxi Province

The Longtoushan Au deposit, located in the Dayao Shan uplift in southwestern WYOB, is the only epithermal deposit recognized in the hinterland of the Huanan Orogen (Fig. 1). It was discovered by the No. 6 Geological Team of Guangxi Province in 1982, and contains more than 5 t Au with grade ranging from 1.5 to 37.3 g/t (Xie and Sun, 1993).

The main lithostratigraphic units outcropped in the ore district include the Cambrian low-grade metamorphic rocks of the Huangdongkou Formation, and the unconformably overlying Early Devonian clastic rocks of the Lianhuashan Formation (Fig. 11a). The Longtoushan volcanic edifice is located in the center of the ore district and intrudes into the above lithologic sequences. The volcanic vent is filled by granitic porphyry, rhyolitic porphyry and cryptoexplosive breccias. Several quartz porphyry and felsophyre dikes occur in the periphery of the volcanic vent and are controlled by NW-, S–N-trending transtensional shear and NE-, NW-trending transpressional shear faults or fractures (Xie and Sun, 1993).

The gold orebodies are controlled by the abovementioned faults, and mainly developed in the contact zones between the subvolcanic rocks and wallrocks (Fig. 11). Both primary and oxidized ores are recognized in the Longtoushan deposit. Primary ores occur in veins, stockworks, breccias or as disseminations. The oxidized ores are located near the surface and mainly include gold, limonite and quartz, with ore grades largely increased. The primary ores can be divided into two types: (1) disseminations or veins in volcanic rocks, especially in breccias; and (2) veins or stockworks in the clastic rocks of the Lianhuashan Formation. The main ore minerals of the primary ores include native gold, pyrite, galena, chalcopyrite, arsenopyrite, stibnite, while the major gangue minerals are tourmaline, quartz, sericite, K-feldspar, kaolinite, chlorite and calcite. Gold mineralization in primary ores is closely related to tourmalinization and silicification, which evolves outward into sericite and argillic alteration (Xie and

Sun, 1993; Zhu, 2002). Besides the gold mineralization, Huang et al. (1999) reported typical porphyry-type Cu mineralization associated with the potassium silicate and phyllic alteration in the central sectors of the granitic porphyry at depth (~70 m above sea level).

Xie and Sun (1993) and Zhu (2002) reported homogenization temperatures of the fluid inclusions to be 159–320 °C and 177–286 °C, respectively, indicating that the deposit was formed in an epithermal environment. Cations in the fluids are dominated by K^+ , Na^+ , Ca^{2+} and Mg^{2+} , anions by SO_4^{2-} , Cl^- and F^- , and molecules are predominant of H_2O , CO_2 , CO , CH_4 , H_2 , and N_2 (Zhu, 2002). Fluid boiling was the most important mechanism causing ore precipitation (Huang et al., 1999).

The δD and $\delta^{18}O_{water}$ values of the ore-forming fluid are $-60.8 - -79.5\text{‰}$ and $-2.2 - -7.4\text{‰}$, pointing to a meteoric water source for the ore-forming fluids (Zhu, 2002). Sulfides in the ores yielded $\delta^{34}S$ values between -9.8‰ and $+2.5\text{‰}$, averaging at 0.9‰ , signifying a magmatic source of sulfur. The $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$ values of ores range from 18.159 to 19.019, 15.652 to 16.169, and 38.611 to 40.242, respectively. It was suggested that the lead is mainly sourced from the Mesozoic volcanic rocks, and minor from the metamorphic rocks (Xie and Sun, 1993; Huang et al., 1999; Zhu, 2002).

Zircon SHRIMP U–Pb ages of granitic porphyry and rhyolitic porphyry yielded 100.3 ± 1.4 Ma and 103.3 ± 2.4 Ma ages (Chen et al, 2008b), suggesting that the gold mineralization at Longtoushan occurred in Early Cretaceous.

On the basis of the ore geology, fluid geochemistry and stable isotopic studies, we consider the Longtoushan Au deposit to be a LS epithermal system formed in Early Cretaceous. The intimate relationship between gold mineralization and tourmaline clearly show that the ore-forming fluid is of high F content, which is different from other epithermal systems in coastal areas. The coexistence of shallow epithermal gold mineralization and deep porphyry Cu mineralization suggests that the Longtoushan deposit is a promising porphyry-epithermal target, similar to the Zhilintou polymetallic deposit.

5.6 Zhilintou Au-Ag-Pb-Zn deposit in Zhejiang Province

The Zhilintou (or Yinkengshan) deposit in Zhejiang Province is located at the northeastern Chencai-Suichang Uplift to the south of the Jiang–Shao Fault and west of the Lishui-Haifeng Fault (Fig. 1; Pirajno et al., 1997; Ji and Shao, 1998; Zhu et al., 2009). It was a large polymetallic system with total proven reserves of more than 20 t Au (averaging at 8.4–46.2 g/t), 1000 t Ag (165–685 g/t), 0.1 Mt Pb (0.9–6%) and 0.1 Mt Zn (0.9–6%) (Zhu et al., 2009). Recently, concealed Mo orebodies have been found beneath the Au-Ag-Pb-Zn orebodies between + 65 m to –510 m ASL (above sea level), with inferred Mo reserves of about 63, 000 t at average grade of 0.07% (Fig. 12; Zeng et al., 2013; Wang et al., 2016; Zhong et al., 2016a).

Paleoproterozoic high-grade metamorphic rocks of the Badu Group and overlying Late Jurassic volcanic rocks of the Dashuang Formation are the main

lithostratigraphic units in the deposit (Fig. 12a). The Badu Group, mainly consisting of biotite monzogneiss, biotite plagiogneiss and granulite, is regarded as the oldest tectonostratigraphic unit in the Hunan Orogen (Yu et al., 2009) and of relatively high background gold values (11.5 ppb average) (Zhu et al., 2009). The Dashuang Formation includes rhyolitic crystal tuff, ignimbrite, rhyolite and volcanic breccias. Both the metamorphic rocks and volcanic rocks were intruded by a series of Yanshanian subvolcanic rocks, including felsophyre, granitic porphyry, quartz diorite porphyry and andesite porphyry (Fig. 12a, Zhou and Qian, 1996; Zhu et al., 2009).

The Au-Ag ore veins, controlled by the E–W- and NWW-trending faults, are hosted in the metamorphic rocks of the Badu Group (Fig. 12a, b). They are located between 100 and 650 m ASL and cut by the N–S-trending F_1 and F_{42} faults, as well as the granitic porphyry and felsophyre (Fig. 12a). The Pb-Zn-(Ag) orebodies occur in a steeply dipping pipe (close to the andesitic porphyry) or veins in the pyroclastic rocks, felsophyre and cryptoexplosive rocks, cutting the Au-Ag orebodies (Zhou and Qian, 1996; Zhu et al., 2009). The newly discovered Mo orebodies at depth are mainly veins or stockworks in both the granitic porphyry and metamorphic rocks of the Badu Group (Fig. 12b).

The early mineralized Au-Ag veins consist of open-space fillings of cockade-textured quartz alternating with layers of fine-grained quartz, sulfides and clay minerals. Euhedral adularia crystals were observed and intergrown with euhedral quartz crystals and interstitial sericite (Pirajno et al., 1997). The late Pb-Zn

mineralization occurs as veins or stockworks, consisting of sphalerite, galena, pyrite, quartz, chalcedony, sericite, calcite and chlorite. The Mo ores mainly include veins or stockworks of molybdenite, pyrite, quartz, sericite, K-feldspar, chlorite (Wang et al., 2016).

From the central parts of the Au-Ag orebodies outwards, the alteration is zoned from silicification, through sericitization, to chloritization-sericitization (Zhu et al., 2009). The Pb-Zn mineralization is associated with sericitic, chloritic and siliceous alteration, but no zonation was reported. The forementioned mineral assemblages and ore fabrics indicated that the Zhilingtou Au-Ag-Pb-Zn deposit is a typical LS epithermal mineralization system, probably linked to a buried porphyry Mo system at depth.

According to Zhu et al. (2009), three types of fluid inclusions were identified, namely: liquid-rich aqueous, minor halite-bearing aqueous and CO₂-H₂O inclusions. Most of the fluid inclusions in the Au-Ag stage yield homogenization temperatures of 119–300 °C, with few up to 350–400 °C, and corresponding salinities range from 10.1 to 16.0 wt% NaCl eqv.. Fluid inclusions in the Pb-Zn mineralization stage are predominantly liquid-rich aqueous, with homogenization temperatures of 119–380 °C and salinities of 4.1–7.9 wt% NaCl eqv.. Ore-forming fluids are rich in K⁺, Na⁺, Ca²⁺, Mg²⁺ (cations), Cl⁻, HCO₃⁻, and SO₄²⁻ (anions), and volatile components such as CO₂ and CH₄.

The δD, δ¹⁸O and δ¹³C values of the ore-forming fluids in Zhilingtou are -73‰ to

824 -61‰ , -8‰ to $+3.1\text{‰}$ and -5.6‰ to -5.4‰ (Luo et al., 1985; Zheng and Liu, 1986;
825 Xu et al., 1988), respectively. On the δD vs. $\delta^{18}\text{O}$ diagram (Fig. 13), the data plot
826 between the magmatic and meteoric water boxes and show a mixing trend between
827 them. Zhu et al. (2009) also reported sulfur isotopic data of the sulfides, metamorphic
828 and volcanic rocks. The relationship of $\delta^{34}\text{S}_{\text{py}} > \delta^{34}\text{S}_{\text{sp}} > \delta^{34}\text{S}_{\text{gl}}$ show that a sulfur
829 isotopic equilibrium was basically reached. The $\delta^{34}\text{S}$ values of sulfides are between
830 those of the metamorphic rocks and volcanic or subvolcanic rocks, implying that both
831 of them are probable sulfur sources. The $^{206}\text{Pb}/^{204}\text{Pb}$, $^{207}\text{Pb}/^{204}\text{Pb}$, $^{208}\text{Pb}/^{204}\text{Pb}$ ratios
832 of sulfides in the Au-Ag and Pb-Zn ores are 17.115–18.114, 15.457–15.795,
833 38.355–39.095 and 17.917–18.258, 15.421–15.974, 38.535–39.462 (Zhou and Qiu,
834 1997), respectively. The Pb-isotopic data plotted on the $^{208}\text{Pb}/^{206}\text{Pb}$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$
835 diagram (Fig. 15) are in good linear relationship between the metamorphic and
836 volcanic rocks, signifying that they both are the possible lead sources (Zhou and Qiu,
837 1997; Chen and Xu, 1997; Zhu et al., 2009).

838 The geochronologic dating results of both the ores and relevant granitic rocks are
839 listed in Table 2. The Rb–Sr isochron ages of ores in the Zhilingtou deposit varied from
840 164 to 107.6 Ma (Table 2). Zhou and Qian (1996) reported zircon TIMS U–Pb age of
841 148 ± 0.5 Ma for the granite porphyry that cut the Au-Ag orebodies, and a zircon
842 TIMS U–Pb age of 104.8 ± 0.8 Ma for the felsophyre dike cutting the
843 Pb-Zn-associated granite porphyry. Based on field observations and zircon TIMS
844 U–Pb ages, Zhou and Qian (1996) suggested that the Au-Ag mineralization occurred

between 164 and 148 Ma, and the Pb-Zn mineralization occurred during 148–104.8 Ma. Recently, [Zeng et al. \(2013\)](#) gave more reliable geochronological data for the Mo mineralization, including the molybdenite Re–Os isochron age of 110.1 ± 1.8 Ma and related zircon SIMS U–Pb age of 113.6 ± 1.0 Ma.

[Pirajno et al. \(1997\)](#) inferred an intimate relationship between the LS epithermal Au-Ag, Pb-Zn and porphyry Mo mineralization. The Pb-Zn mineralization, postdating the Au-Ag mineralization, might be genetically related to the porphyry Mo mineralization, while the earlier Au-Ag mineralization might be nearly coeval to the Yinshan polymetallic deposit in the NJOB nearby. In other words, the Zhilingtou deposit, located on the overlapping area between the NJOB and SCVB, may be linked to both the Jurassic mineralization in NJOB and Cretaceous mineralization in SCVB.

6. Ore geology and geochemistry: a summary

6.1 Host rocks

The epithermal deposits in the SCB are hosted by variable lithologies in different geological time, including: (1) Jurassic–Cretaceous volcanic-sedimentary rocks; (2) Jurassic–Cretaceous cryptoexplosive breccias and granitoids; and (3) Proterozoic metamorphic basement rocks.

In the SCB, Jurassic–Cretaceous volcanic-sedimentary rocks include trachyandesite, rhyolite, andesite, dacite, ignimbrite, tuff, pyroclastic rocks, minor sandstone, siltstone and shales ([Table 1](#)). The intermediate–felsic volcanic rocks (rhyolite, andesite, dacite)

and their subvolcanic counterparts are intimately associated with epithermal systems (Table 1), while the sedimentary rocks are only observed in a few deposits (e.g., No. 3 Tiantoushan, No. 8 Huxu, No. 28 Taihuashan, No. 37 Qianshan, No. 40 Songxi and No. 42 Qinggang).

Another important type of host rocks are the Jurassic–Cretaceous cryptoexplosive breccias, which are recognized in both the LS and HS epithermal deposits, such as Guanshan (No. 1), Xiaban (No. 33), Qianshan (No. 37), Longtoushan (No. 43), and Zijinshan (No. 38). The formation of cryptoexplosive breccias not only provides enough space for ore minerals, but also stimulates fluid boiling, which is an important mechanism for the precipitation of ore minerals. Besides the breccias, some of the epithermal orebodies are also hosted in older granitoids, which are intensively fractured and conducive for the transportation and precipitation of ore metals, as best exemplified by the Zijinshan Cu-Au and Yueyang Ag-Au-Cu deposits (section 5.3).

The basement rocks are rarely exposed in the SCB, but are usually identified at depth beneath the volcanic rocks by drilling, especially in the SCVB. These metamorphic rocks include the Paleoproterozoic Badu Group (Zhilingtou, Babaoshan), Mesoproterozoic Shuangqiaoshan (Yinshan) and Mamianshan Group (Xingxi, Qingyunshan, Xiqian), and the Neoproterozoic Zhoutan Group (Huxingshan) and Daoxian Formation (Nanyang) (Table 1). In these deposits, the ore veins are hosted in both the basement metamorphic rocks and the overlying volcanic rocks, except for the Au-Ag orebodies at Zhilingtou.

Most of the epithermal deposits in the SCB can be found in nearly synchronous subaerial volcanic-subvolcanic rocks, suggesting an intimate spatial-temporal and genetic relationship between them. Some of the epithermal orebodies are also hosted in a variety of igneous, sedimentary or metamorphic rocks of different ages (Table 1). The permeability of the wall rocks seems to be most important for the location of orebodies, because high-grade ores are commonly found in the intensively fractured wallrocks as well as cryptoexplosive breccias.

6.2 Structures and orebody occurrence

Tight folds in pre-Jurassic rocks and faults are commonly observed during multistage tectonic events in South China. The regional faults and their subsidiary structures, generally NE-, NW- and E–W-, S–N-trending, control the locations of the volcanic-subvolcanic rocks and the epithermal orebodies (Table 1). The orebodies commonly occur as veins, lens or tabular shape, with few as stratiform in interlayer fractures, such as those in the Huxingshan (No. 7), Dalingkou (No. 11), Xialong (No. 16) deposits. The intersections of faults are favorable for the movement of hydrothermal fluids, particularly for promoting high-grade orebodies, as exemplified by the combinations of the E–W- and NE- or NW-trending faults in LYRB, and the NE- and NW-trending faults in the SCVB. Some of the epithermal orebodies are controlled by the radiating fault systems of the related volcanic edifices, such as those in the Guanshan Cu-Au (No. 1), Dalingkou Ag-Pb-Zn (No. 11), Zhilingtou Pb-Zn (No.

15) and Longtoushan Au (No. 43) deposits. The ore-controlling breccias in the
epithermal deposits in SCB are either veins (e.g., Zijinshan Cu-Au deposit) or pipes
(e.g., Longtoushan Au deposit).

6.3 Wallrock alteration and ore fabrics

The epithermal deposits of HS, LS, LS-P subtypes have different wallrock
alteration assemblages and ore fabrics. The Zijinshan HS-type Cu-Au deposit contains
an alteration assemblage of alunite, vuggy quartz, dickite, kaolinite, sericite,
pyrophyllite, characterized by intensive acid leaching textures, veins, stockworks and
breccia structures. From the ore veins outwards, alteration zoning is from silicic
(vuggy quartz), through alunite, to dickite and phyllic alteration zones in the Zijinshan
deposit. Typical LS-type deposits, exemplified by the Yinfengjian (No. 6), Zhilingtou
(No. 15) and Yueyang (No. 39), are characterized by the adularia, illite, chalcedony,
calcite and sericite. Alteration is zoned from the adularia-chalcedony-bladed calcite
(or quartz pseudomorphs after bladed calcite) in ore veins to distal
illite-sericite-chlorite assemblages. Rhodonite and tourmaline were recognized in the
Zhilingtou (No. 15) and the Longtoushan (No. 43) deposits, respectively, implying
that the ore-forming fluids were enriched in Mn and B. Open-space filling,
crustifications, colloform banding and comb structures are common in the LS-type
epithermal deposits, due to low pressure and low temperature environments. The
LS-P deposits (Yinshan, Jinjiyan, Zhilingtou, Longtoushan) contain epithermal

Au-Ag-Pb-Zn orebodies and concealed porphyry-type Cu or Mo orebodies, associated with sericite, adularia, illite and phyllic or potassium silicate alteration.

6.4 Fluid inclusions

To discriminate the genesis of hydrothermal mineral systems, [Chen et al. \(2007b\)](#) suggested a compositional classification of fluid inclusions (FIs), i.e., aqueous FIs (W-type), daughter mineral-bearing FIs (S-type), carbonic-aqueous FIs (C-type). The W-type was further divided into liquid-rich (WL) and vapor-rich (WV) subtypes according to liquid and vapor phase ratio. These authors also set up a diagnostic linkage of the S-type FIs to magmatic hydrothermal deposits, the C-type FIs to metamorphic hydrothermal (orogenic-type) deposits, and the W-type FIs to epizonogenic hydrothermal deposits including epithermal and Carlin-type Au, MVT Pb-Zn, Sedex Pb-Zn, VMS Cu-Zn, as well as many sedimentary-hosted low-temperature hydrothermal mineral systems, such as Hg-Sb, U, fluorite and barite ([Chen, 2010a](#); [Chen et al., 2014b, 2016](#)). The types, homogenization temperatures, salinities and estimated trapping pressures of FIs available for the epithermal deposits in SCB are listed in [Table 3](#).

Fluid inclusions of most epithermal deposits in the SCB are dominated by the WL- and WV-subtype inclusions with low homogenization temperatures, low salinities and high densities ([Table 3](#)), which are characteristics of meteoric water ([Chen et al., 2007b](#)). Minor S-type inclusions were recognized in the Yinshan and Zhilingtou

deposits, consistent with the presence of the porphyry type mineralization. The C-type inclusions were only observed in the alunite alteration zone of the Zijinshan HS epithermal deposit (Zhong et al., 2016b).

Hydrothermal ore deposits are formed as a consequence of the breakdown of metal complexes transported by fluids in the Earth's crust (Seward and Barnes, 1997; Pirajno, 2009). Boiling, fluid mixing, cooling and fluid-rock interaction can all play important roles in the deposition of sulfides from ore fluids (Simmons et al., 2005; Hedenquist and Henley, 1985; Seward and Barnes, 1997; Canet et al., 2011). Fluid boiling is very important for ore precipitation in most epithermal deposits in the SCB. This is supported by the occurrence of adularia, bladed calcite or quartz pseudomorphs of blade calcite, co-existence of WL- and WV-subtype inclusions with similar homogenization temperatures and contrasting salinities. The Yinshan deposit, however, is believed to have formed from either fluid mixing (Zhang et al., 2003c) or simple fluid cooling process (Wang et al., 2013a).

The mineralization depth calculated for most LS epithermal deposits in SCB are less than 1.5 km, consistent with the ore formation depth of epithermal deposits worldwide (Hedenquist et al., 2000; White, 2003; Simmons et al., 2005; Pirajno, 2009). The mineralization depths for the Zijinshan and Zhilingtou deposits are up to ~ 2.0 km, probably showing the continuity between epithermal and porphyry mineralization at deeper levels.

6.5 Hydrogen, oxygen and carbon isotopes

The $\delta^{18}\text{O}$ and δD signatures are powerful tracers of ore-fluid sources (Hoefs, 2004). The data for the epithermal systems in the SCB are summarized in Table 3 and illustrated in Fig. 13. For most LS deposits, fluid inclusions data plot between the meteoric water line and the magmatic water box, but closer to the former, pointing to a predominant meteoric water source, with little input of magmatic components. Another explanation that could be surmised from stable isotopic data is water-rock interaction between deeply circulated meteoric water and wallrocks—the “ ^{18}O -shift” (Craig, 1963; Taylor, 1974). In any case, both explanations are consistent with the ore-forming fluids being sourced mainly from the meteoric water. For the Zijinshan HS and Zhilingtou and Yinshan LS–P deposits, a mixing trend between magmatic fluids and meteoric water is suggested (Fig. 13).

The $\delta^{13}\text{C}$ values of calcite samples have been provided for Guanshan (Liang et al., 2010b), Zhilingtou (Xu et al., 1988) and Songxi (Xiao, 2001). Carbon from calcite in the Guanshan deposit is likely derived from the basement carbonates (Liang et al., 2010b), while the carbon in the Zhilingtou and Songxi deposits would have originated from the mixing of meteoric and magmatic water, with little input from the wallrocks (Xu et al., 1988; Xiao, 2001).

6.6 Sulfur and lead isotopes

The $\delta^{34}\text{S}$ ranges and their averages for some epithermal deposits in SCB are listed

in Table 3 and illustrated in Fig. 14. Most of the epithermal deposits have narrow $\delta^{34}\text{S}$ ranges (-10‰ to $+5\text{‰}$) (Table 4; Fig. 14), each with a peak around $0\text{--}5\text{‰}$ in the $\delta^{34}\text{S}$ histograms (not shown). The average $\delta^{34}\text{S}$ values also fall in the range between -5‰ and 5‰ (Fig. 14). The narrow $\delta^{34}\text{S}$ ranges and the near-zero $\delta^{34}\text{S}$ averages of sulfides from the epithermal deposits in SCB are similar to those of the granitic rocks (Hoefs, 2004) and porphyry-skarn mineralization systems in SCB (Zhong et al., 2016a). Hence the $\delta^{34}\text{S}$ isotope compositions confirm that, sulfur for most epithermal deposits in the SCB is mainly magmatic in origin.

The Songxi Ag-Sb deposit, however, is an exception. It yields a broad range of $\delta^{34}\text{S}$ values and a high $\delta^{34}\text{S}$ average of 10.6‰ (Table 4, Fig. 14), which is generally attributed to a contribution of sulfur from the wallrocks (Xiao, 2001; Chen et al., 2008c). Although the sulfur for other epithermal deposits is dominantly of magmatic origin, the introduction of sulfur from wallrocks, especially the basement rocks, was also suggested in SCB, as for example the Guanshan (Liang et al., 2010b), Bamao (Liu et al., 1990) and Zhilingtou (Zhu et al., 2009) deposits.

Available lead isotope compositions are listed in Table 4. In the plumbotectonic model (Fig. 15), most of the data plot in good linear relationship between the volcanic rocks and basement metamorphic rocks, indicating that the lead might be sourced from both endmembers.

In general, both the sulfur and lead isotopes show that the ore components in epithermal deposits in SCB are mainly derived from the coeval magmatic rocks, with

1007 varying degrees of contribution from basement metamorphic wallrocks.

1008 **6.7 Ore genesis**

1009 On the basis of the abovementioned geological and geochemical characteristics of
1010 epithermal deposits in the SCB, the following conclusions can be drawn: (1) most of
1011 the epithermal deposits are spatially, temporally and genetically related to coeval or
1012 slightly earlier Yanshanian volcanic-subvolcanic rocks; (2) some of the epithermal
1013 orebodies are also hosted in the metamorphic basement rocks, sedimentary or
1014 magmatic rocks of different age; (3) the epithermal orebodies are mainly controlled
1015 by faults, fractures, and/or breccia veins; (4) the ore-forming fluids of the epithermal
1016 deposits in the SCB are dominantly meteoric water, with variable inputs of magmatic
1017 water; (5) fluid boiling is the most favorable mechanism for ore precipitation for both
1018 the LS and HS systems, followed by fluid mixing and cooling; (6) based on sulfur and
1019 lead isotopes systematics, the ore components are mainly derived from the coeval
1020 volcanic-subvolcanic rocks and metamorphic basement rocks.

1021 Although each epithermal deposit has unique geological and geochemical features,
1022 a general ore genesis model can be suggested in this contribution. For the LS
1023 epithermal deposits, the ore-forming fluids are generally near-neutral pH meteoric
1024 water, with variable input of magmatic components. The hydrothermal fluids are
1025 driven by heat energy related to magmas at depth with subsequent circulation and
1026 scavenging of ore materials from the host volcanic and metamorphic rocks. The

ore-forming fluids carrying metals such as Au, Ag, Cu, Pb and Zn would be further transported upwards or along interlayer fractures in the reactivated faults, fractures and/or breccia pipes or veins, and the ore components would be subsequently precipitated via fluid boiling, cooling and/or fluid-rock interactions. The occurrence of adularia-illite-bladed calcite-chalcedony alteration mineral assemblages is diagnostic of these LS mineral systems. In the HS systems (Zijinshan Cu-Au deposit), significant amounts of acidic magmatic vapors, carrying ore components, ascended upward through volcanic vents, breccias pipes, veins and/or associated fractures, and subsequently mixed with meteoric water in shallower parts of the system, resulting in the formation of widespread acid-leaching alteration zones, represented by vuggy quartz and alunite-pyrophyllite-dicknite-kaolinite alteration assemblages. Ore components in the wallrocks (e.g., Jurassic Zijinshan granite batholiths in the Zijinshan deposit) were also scavaged by the acidic ore-forming fluids, as indicated by sulfur and lead isotope systematics. Gold, enargite, hypogene covellite were further precipitated by fluid boiling.

In general, the epithermal deposits in the SCB show similar geological and geochemical features to other epithermal mineral systems worldwide ([Hedenquist and Lowenstern, 1994](#); [Hedenquist et al., 2000](#); [Simmons et al., 2005](#)). These epithermal mineral systems are usually located in the upper parts of an epithermal-porphyry system, where the porphyry orebodies can be expected to occur at depth, best exemplified by the Zhilingtou, Jinjiyan and Longtoushan deposits.

7 Exploration implication

Epithermal orebodies in the SCB are variable in size, shape, grade, and commonly concealed (e.g., Zhilingtou Au-Ag, Yueyang Ag-Au-Cu). These features make them difficult to find and explore (Simmons et al., 2005). In this contribution, we have summarized several geological characteristics as prior considerations for epithermal deposit exploration.

At a regional scale, (1) the epithermal deposits in the SCB, except the Longtoushan Au deposit, are all hosted in the Mesozoic volcanic basins in the eastern part of the SCB (Fig. 1). They are mostly located in the SCVB, followed by the LYRB, and marginal area of tectonic uplifts (e.g., Nos. 5 to 8 in northern Wuyi Shan and Nos. 38 to 40 in southeastern Wuyi Shan); (2) the location of epithermal deposits in the SCB are controlled by the regional faults or their subsidiaries, such as those along the Lishui–Haifeng and Jiang–Shao Faults (Fig. 1). The regional faults and their subsidiaries controlled the location of volcanic basins, and consequently, the epithermal deposits.

At deposit scale, (1) all epithermal orebodies are of Jurassic or Cretaceous age, mostly hosted in coeval or older volcanic-subvolcanic rocks. Absence of pre-Jurassic epithermal deposit in the SCB probably resulted from poor preservation potential of the shallow epithermal orebodies (mostly < 1.5 km); (2) the intersections between second- or third-order faults, radiating fractures related to volcanic edifices and breccia pipes are the most favorable locations for mineralization; (3) intensive and

pervasive alteration zones are important indicators for orebodies, especially vuggy quartz in HS and quartz veins in LS deposits that are more resistant to erosion; (4) in some epithermal deposits, the ore veins can be traced downwards into the underlying (e.g., Zhilingtou) or proximal (e.g., Yinshan) metamorphic basement rocks; (5) the epithermal deposits with higher temperatures ($> 300\text{ }^{\circ}\text{C}$) and depths ($> 1.5\text{ km}$) are usually linked to porphyry systems at depth, such as the Zhilingtou (Zeng et al., 2013; Wang et al., 2016), Jinjiyan (Du et al., 1998a, 1998b) and Longtoushan (Huang et al., 1999) deposits.

We believe that more epithermal deposits can be found in the Mesozoic volcanic basins in eastern SCB, especially where adjacent to the regional faults and their subsidiaries. As to the potential area indicated by geophysical and geochemical data, large-scale structural and alteration mapping are the most effective way to discover orebodies.

8 Tectonic settings

The Yanshanian tectonic setting of the eastern SCB is a long-time controversial issue, which has been debated between four views (section 2) drawn out mainly from geochemistry of igneous rocks. As we know, the mineral systems are a powerful indicator of tectonic settings, but unfortunately, have been not commonly employed in previous studies.

Zhong et al. (2016a) have summarized the Mo deposits in SCB and suggested that

the Early Yanshanian Mo deposits in SCB were formed in syn- to post-collisional tectonism following the closure of eastern Paleo-Tethys, whilst the Late Yanshanian Mo deposits were generated by the westward subduction of the paleo-Pacific plate. This conclusion is fully consistent with the geological and geochemical characteristics of the epithermal deposits in SCB, which is briefly introduced as below.

The epithermal deposits in the SCB are formed in the Early Yanshanian (180–130 Ma) and Late Yanshanian (130–90 Ma) periods (Fig. 2; Table 2). The Early Yanshanian epithermal deposits are located in nearly E–W-trending metallogenic belts to the west of the Lishui–Haifeng Fault, including the Tiantoushan deposit (No. 3) in the Lower Yangtze Metallogenic Belt, the Yinshan (No. 4), Zhilingtou (No. 15) and Babaoshan (No. 19) deposits in the northeastern Jiangxi–western Zhejiang metallogenic belt, and the Songxi deposit (No. 40) in the eastern Nanling metallogenic belt. The Late Yanshanian epithermal deposits, however, are located mainly in the SCVB and intimately related to coeval volcanic-subvolcanic rocks adjacent to or to the east of the Lishui–Haifeng Fault (Fig. 1).

The E–W-trending distribution of the Early Yanshanian epithermal deposits, as well as the absence of an eastward younging trend, indicates that at least the WYOB to the west of the Lishui–Haifeng Fault can not be attributed to the subduction of the paleo-Pacific plate. Geochemical data on the epithermal deposits associated with volcanic-subvolcanic rocks also do not support a subduction model of the paleo-Pacific plate, but agree with a syn- to post-collision tectonic model. For

instance, the Yinshan volcanic-intrusive complex is thought to have derived from partial melting of the relict Neoproterozoic island arcs in an intracontinental extensional tectonic setting (Wang et al., 2012; Liu et al., 2012).. The absence of widespread Jurassic volcanic rocks (Lu et al., 1997; Tao et al., 1998; Zhou et al., 2006; Shen and Ling, 2002; Wang et al., 1994), the geochemical features of the Jurassic granitoids (Chen and Jahn, 1998; Zhou et al., 2006) and mafic-ultramafic rocks (Chen et al., 2005, 2008a), and the distribution of E–W-trending W-Sn-Bi-Mo metallogenic belts (Mao et al., 2013; Hua et al., 2010) also support a syn- to post-collision tectonic setting. It was suggested that the SCB collided with the North China Craton in Late Triassic (Chen and Fu, 1992; Chen, 2010b; Chen and Santosh, 2014; Li et al., 2015), and with the Indochina Block and the hypothesized Dongnanya Continent in the period of Triassic to Early Jurassic (Hsü et al., 1988, 1990; Chen et al., 2007a).

The widespread Late Yanshanian epithermal deposits are mostly located in the SCVB along a NE-trending belt parallel to the present coast line (Fig. 1). Besides, the Late Yanshanian epithermal mineralization associated with volcanic-intrusive rocks, which are predominately calc-alkaline I-type granitoids, exhibit continental arc magmatic rock signatures (Lu et al., 1997; Tao et al., 1998; Zhou et al., 2006). These confirm that these igneous rocks and epithermal systems are linked to the westward subduction of the paleo-Pacific plate (Pirajno and Bagas, 2002; Chen et al., 2007a; Mao et al., 2013; Zhong et al., 2014, 2016a).

In summary, the Early Yanshanian epithermal deposits are formed in a syn- to

post-collision tectonic setting resulted from the collisions of the SCB with the North China Craton, the Indochina Block and the hypothesized Dongnanya Continent. On the other hand, those formed in Late Yanshanian period are linked to the westward subduction of the paleo-Pacific plate.

9. Conclusions

1. At least 43 HS and LS epithermal deposits have been recognized in the South China Block, located in the Lower Yangtze River Belt, the northeastern Jiangnan Orogenic Belt, the Wuyi-Yunkai Orogenic Belt and the Southeast Coastal Volcanic Belt.

2. These epithermal deposits were located in volcanic basins adjacent to regional-scale crustal faults or their subsidiaries. The orebodies consist of veins, lens and/or pod-like in shape, and are hosted in fractures, breccia veins or pipes in the Jurassic–Cretaceous volcanic-sedimentary rocks, granitoids and breccias, and metamorphic basement rocks.

3. The alteration of HS epithermal deposits from the ore veins outwards is zoned from silicic (vuggy quartz), through alunite, to dickite and phyllic. The alteration of the LS deposits is zoned from adularia-chalcedony-bladed calcite (or quartz pseudomorphs after bladed calcite) in the ore veins to distal illite-sericite-chlorite-kaolinite assemblages. Acid leaching textures and vein, stockwork and breccia structures are common in HS deposits, whereas the LS

epithermal deposits are characterized by open-space filling, crustifications, colloform banding and comb structures.

4. The ore-forming fluids of the epithermal deposits are low temperature, low salinity, and dominated by meteoric water, with small inputs of magmatic fluids. The ore components in epithermal deposits are mainly derived from the coeval magmatic rocks, with varying degrees of contribution from basement metamorphic wallrocks. The ore-forming fluids were transported upwards or laterally and precipitated ore minerals in the fault or fracture systems by fluid boiling, mixing or cooling processes.

5. The ore-forming depths for most epithermal deposits are generally less than 1.5 km. A few exceptions with mineralization depths greater than 1.5 km and temperatures higher than 300 °C are commonly related to a porphyry mineral system. Deep drilling is suggested in order to target epithermal and/or porphyry mineralization at depth.

6. Epithermal deposits in SCB were mostly located in eastern SCB and formed in the Early (180–130 Ma) and Late (120–90 Ma) Yanshanian period. The Early Yanshanian epithermal systems are located in a series of E–W-trending metallogenic belts to the west of the Lishui–Haifeng Fault, which were formed in a syn- or post-collision tectonic setting by the collision between the SCB and its surrounding plates. The Late Yanshanian epithermal deposits are mainly located adjacent to or to the east of the Lishui–Haifeng Fault, linked to the westward subduction of the paleo-Pacific plate.

Acknowledgements This work was financially granted by the National Science Foundation of China (No. 41502083) and the Ministry of Science and Technology of China (Project No. 2009BAB43B04). Prof. M. Santosh and an anonymous reviewer are thanked for their constructive review and suggestions.

References

- Cai, J.H., 1996. Ore genesis of the Baoshan Ag-Sb Deposit in Meixian, Guangdong Province. *Guangdong Nonferrous Metals* (1), 6–10 (in Chinese).
- Canet, C., Franco, S.I., Prol-Ledesma, R.M., González-Partida, E., Villanueva-Estrada, R.E., 2011. A model of boiling for fluid inclusion studies: Application to the Bolanos Ag-Au-Pb-Zn epithermal deposit, Western Mexico. *Journal of Geochemical Exploration* 110, 118–125.
- Chang, Y.F., Liu, X.P., Wu, C.Y., 1991. The copper-iron belt of the Lower-Middle reaches of the Yangtze River. Geological Publishing House, Beijing. 379 pp. (in Chinese).
- Charvet, J., Shu, L.S., Faure, M., Choulet, F., Wang, B., Lu, H.F., Breton, N.L., 2010. Structural development of the Lower Paleozoic belt of South China: genesis of an intracontinental orogen. *Journal of Asian Earth Sciences* 39, 309–330.
- Chen, H.S., 1996. The research on the mineralization chronology and isotopic

1192 exploration assessment for Zijinshan copper-gold deposit. *Geotectonica et*
1193 *Metallogenia* 20 (4), 348–360 (in Chinese with English abstract).

1194 Chen, J.H., 1999. The metallogenic mode of Zijinshan copper (gold) deposit. *Gold* 20
1195 (7), 6–11 (in Chinese with English abstract).

1196 Chen, Y.J., 2002. Several important problems in study of regional metallogenesis in
1197 China: their relationship to continental collision. *Earth Science Frontiers* 9 (4),
1198 319–328 (in Chinese with English abstract).

1199 Chen, Q.F., 2007. The geology characteristics of Qiucun gold deposit in Fujian
1200 Province. *Jiangxi Nonferrous Metals* 21 (04), 8–11 (in Chinese with English
1201 abstract).

1202 Chen, Y.J., 2010a. On epizonogenism and genetic classification of hydrothermal
1203 deposits. *Earth Science Frontiers* 17, 27–34 (in Chinese with English abstract).

1204 Chen, Y.J., 2010b. Indosinian tectonic setting, magmatism and metallogenesis in
1205 Qinling Orogen, central China. *Geology in China* 37, 854–865 (in Chinese with
1206 English abstract).

1207 Chen, Y.J., Fu, S.G., 1992. *Gold Mineralization in West Henan*. Seismological Press,
1208 Beijing, 1–234 (in Chinese with English abstract).

1209 Chen, H.S., Xu, B.T., 1997. Mineralization chronology and isotopic geochemistry for
1210 gold-silver deposits in Zhejiang. *Geology of Zhejiang* 13 (02), 37–46 (in Chinese
1211 with English abstract).

1212 Chen, J.F., Jahn, B.M., 1998. Crustal evolution of southeastern China: Nd and Sr

-
- 1213 isotopic evidence. *Tectonophysics* 285, 101–133.
- 1214 Chen, R.K., Zheng, B.L., 1998. Discussion on the metallogenic pattern of Qinxì silver
1215 deposit in Zhouning County, Fujian Province. *Geology of Fujian* (04), 203–209
1216 (in Chinese with English abstract).
- 1217 Chen, L.Z., Wu, Z.S., 2006. Geological characteristics and ore-searching directions of
1218 Qingyunshan copper-gold deposit, Dehua County, Fujian Province.
1219 *Contributions to Geology and Mineral Resources Research* 21 (supp.), 30–33 (in
1220 Chinese with English abstract).
- 1221 Chen, Y.J., Santosh, M., 2014. Triassic tectonics and mineral systems in the Qinling
1222 Orogen, central China. *Geological Journal*, 49, 338–358.
- 1223 Chen, Y.J., Bao, J.X., Zhang, Z.J., Chen, H.Y., Liu, Y.L., 2003. Laumontitization as an
1224 exploration indicator of epithermal gold deposits: a case study of the Axi and
1225 other epithermal systems in West Tianshan, China. *Chinese Journal of*
1226 *Geochemistry* 22 (4), 289–301.
- 1227 Chen, W.F., Chen, P.R., Xu, X.S., Zhang, M., 2005. Geochemistry of the Cretaceous
1228 basaltic rocks in South China and its constraint on the subduction of the Pacific
1229 plate. *Science in China (Earth Sciences)* 35 (11), 1007–1018 (in Chinese).
- 1230 Chen, Y.J., Chen, H.Y., Zaw, K., Pirajno, F., Zhang, Z.J., 2007a. Geodynamic settings
1231 and tectonic model of skarn gold deposits in China: an overview. *Ore Geology*
1232 *Reviews* 31, 139–169.
- 1233 Chen, Y.J., Ni, P., Fan, H.R., Pirajno, F., Lai, Y., Su, W.C., Zhang, H., 2007b.

-
- 1234 Diagnostic fluid inclusions of different types hydrothermal gold deposits. *Acta*
1235 *Petrologica Sinica* 23 (09), 2085–2108 (in Chinese with English abstract).
- 1236 Chen, C.H., Lee, C.Y., Shinjo, R., 2008a. Was there Jurassic Paleo-Pacific subduction
1237 in South China?: Constraints from $^{40}\text{Ar}/^{39}\text{Ar}$ dating, elemental and Sr-Nd-Pb
1238 isotopic geochemistry of the Mesozoic Basalts. *Lithos* 106, 83–92.
- 1239 Chen, F.W., Li, H.Q., Mei, Y.P., 2008b. Zircon SHRIMP U–Pb chronology of
1240 diagenetic mineralization of the Longtoushan porphyry gold orefield, Gui County,
1241 Guangxi. *Acta Geologica Sinica* 82 (7), 921–926 (in Chinese with English
1242 abstract).
- 1243 Chen, G.W., Xiao, Z.Y., Xia, B., 2008c. Geochemical characteristics and
1244 mineralization model of Songxi silver (antimony) deposit, Guangdong Province.
1245 *Contributions to Geology and Mineral Resources Research* 23 (02), 100–105 (in
1246 Chinese with English abstract).
- 1247 Chen, Y.J., Pirajno, F., Wu, G., Qi, J.P., Xiong, X.L., 2012. Epithermal deposits in
1248 North Xinjiang, NW China. *International Journal of Earth Sciences* 101,
1249 889–917.
- 1250 Chen, D., Hu, S.L., Zhang, Z.Y., Zhang, L.Y., Sun, Q.Z., 2014a. On ore-control
1251 factors and prospecting orientation of Jinjushan Au-polymetallic deposit in
1252 Lishui of Jiangsu. *Journal of Geology* 38, 110–116 (in Chinese with English
1253 abstract).
- 1254 Chen, Y.J., Santosh, M., Somerville, I.D., Chen, H.Y., 2014b. Indosinian tectonics and

1255 mineral systems in China: an introduction. *Geological Journal* 49, 331–337.

1256 Chen, Y.J., Zhang, C., Wang, P., Pirajno, F., Li, N., 2016. The Mo deposits of
1257 Northeast China: a powerful indicator of tectonic settings and associated
1258 evolutionary trends. *Ore Geology Reviews*, 10.1016/j.oregeorev.2016.04.017.

1259 Cheng, Q.K., 2003. Geological character and prospecting sign of gold deposit in
1260 Yinfengjian, Jiangxi Province. *Mineral Resources and Geology* 17, 429–433 (in
1261 Chinese with English abstract).

1262 Craig, H., 1963. The isotopic geochemistry of water and carbon in geothermal areas:
1263 Nuclear geology of geothermal areas: Spoleto, Pisa, Consiglio Nazionale della
1264 Ricerche, Laboratorio de Geologia Nucleare, p. 17–53.

1265 Cui, H.F., Zhang, W.X., Zhang, Y.J., 2008. Study on the geological characteristics of
1266 the Dasiji silver-lead-zinc deposit in Taizhou County, Zhejiang Province. *Journal*
1267 *of Changchun Institute of Technology (Natural Science Edition)* 9 (4), 51–54 (in
1268 Chinese with English abstract).

1269 Deng, J., 2012. Mineralization regularity of the copper-gold polymetallic deposits in
1270 Dayaoshan, Guanxi, China. *Geology and Resources* 21 (3), 302–306 (in Chinese
1271 with English abstract).

1272 Dong, P., Wang, W.B., Liu, K.J., 1993. The geochemical conditions and the origin of
1273 ore-forming materials of Bamao silver deposit, Zhejiang. *Volcanology Mineral*
1274 *Resources* 14 (1), 49–59 (in Chinese with English abstract).

1275 Du, Y.S., Jiang, Y.H., Ye, G.S., 1998a. Genetic mineralogic features of the electrum

1276 and pyrite in the Jinjiyan gold deposit, Zhejiang Province and their geologic
1277 significance. *Geoscience* 12 (2), 214–221(in Chinese with English abstract).

1278 Du, Y.S., Jiang, Y.H., Ye, G.S., 1998b. Study on features and metallogenic mechanism
1279 of Jinjiyan gold deposit, West Zhejiang Province. *Earth Science – Journal of*
1280 *China University of Geosciences* 23 (03), 46–50 (in Chinese with English
1281 abstract).

1282 Einaudi, M.T., Hedenquist, J.W., Inan, E.E., 2003. Sulfidation state of fluids in active
1283 and extinct hydrothermal systems: transitions from porphyry and epithermal
1284 environments. *Special Publication Society of Economic Geologists* 10, 285–314.

1285 Fang, F., 2005. On discussion of geologic characteristics and genesis of Xiangluping
1286 electrum deposit in Northern Fujian. *Geology of Fujian* (01), 12–18 (in Chinese
1287 with English abstract).

1288 Fang, R.J., 2006a. Discussion on geologic characteristics and genesis of Maluntou
1289 gold deposit in Zhenghe County, Fujian Province. *Geology of Fujian* (04),
1290 180–184 (in Chinese with English abstract).

1291 Fang, J.G., 2006b. Geological characteristics of the Xiaban gold deposit and its ore
1292 prediction. *Mineral Resources and Geology* 20 (02), 133–137 (in Chinese with
1293 English abstract).

1294 Fang, R.J., 2007. Ore-control characteristics of geological structures of the Xingxi
1295 gold deposit in Zhenghe County, Fujian Province and its ore-finding prospects.
1296 *Geology of Fujian* (01), 20–26 (in Chinese with English abstract).

1297 Faure, M., Shu, L.S., Wang, B., Charvet, J., Choulet, F., Monié, P., 2009.
1298 Intracontinental subduction: a possible mechanism for the Early Paleozoic
1299 Orogen of SE China. *Rerra Nova*. Doi:10.1111/j.1365-3121.2009.00888.
1300 Gilder, S.A., Gill, J., Coe, R.S., Zhao, X.X., Lou, Z.W., Wang, G.X., 1996. Isotopic
1301 and Paleomagnetic Constraints on the Mesozoic Tectonic Evolution of South
1302 China. *Journal of Geophysical Research–Solid Earth* 107 (B7), 16137–16154.
1303 Grabau, A.W., 1924. Migration of geosynclines. *The National Geological Survey of*
1304 China, p. 208–237.
1305 Guo, R., Peng, E.S., 2008. Mineralization characteristics and ore-forming mechanism
1306 of the Jianbidong Pb-Zn deposit in Fengshun County, Eastern Guangdong.
1307 *Mineral Resources and Geology* 22 (06), 506–509 (in Chinese with English
1308 abstract).
1309 Guo, R., Peng, E.S., 2009. Regional geological background, ore-forming characters
1310 and metallogeny of Songxi silver deposit, East Guangdong. *Geotectonica et*
1311 *Metallogenia* 33 (04), 567–572 (in Chinese with English abstract).
1312 Guo, L.Z., Shi, Y.S., Ma, R.S., 1980. Tectonic framework and crustal evolution of
1313 South China. *Contributions to 26th International Geological Congress*, vol. 1.
1314 Geological Publishing House, Beijing, pp. 109–116 (in Chinese).
1315 Haas, J.L., 1971. Effect of salinity on maximum thermal gradient of a hydrothermal
1316 system at hydrostatic pressure. *Economic Geology* 66, 940–946.
1317 Heald, P., Hayba, D.O., Foley, N.K., 1987. Comparative anatomy of volcanic-hosted

1318 epithermal deposits: acid-sulfate and adularia-sericite types. *Economic Geology*
1319 82, 1–26.

1320 Hedenquist, J.W., 1987. Mineralization associated with volcanic-related hydrothermal
1321 systems in the Circum-Pacific basin: Transactions of the Fourth Circum Pacific
1322 Conference on Energy and Mineral Resources Conferences, Singapore,
1323 American Association of Petroleum Geologists, p 513 – 524.

1324 Hedenquist, J.W., Henley, R.W., 1985. The importance of CO₂ on freezing-point
1325 measurements of fluid inclusions - evidence from active geothermal systems and
1326 implications for epithermal ore deposition. *Economic Geology* 80, 1379–1406.

1327 Hedenquist, J.W., Lowenstern, J.B., 1994. The role of magmas in the formation of
1328 hydrothermal ore deposits. *Nature* 370, 519–527.

1329 Hedenquist, J.W., Arribas, A., Reynolds, T.J., 1998. Evolution of an intrusion-centered
1330 hydrothermal system: Far Southeast-Lepanto porphyry and epithermal Cu-Au
1331 deposits, Philippines. *Economic Geology* 93 (4), 373–404.

1332 Hedenquist, J.W., Arribas, A.R., Gonzalez-Urien, E., 2000. Chapter 7 Exploration for
1333 epithermal gold deposit. *SEG Reviews* 13, 245–277.

1334 Hoefs, J., 2004. Stable isotope geochemistry (5th edition). Berlin: Springer-Verlag.
1335 1–244.

1336 Hsü, K.J., Sun, S., Li, J.L., Chen, H.H., Pen, H.P., Sengor, A.M.C., 1988. Mesozoic
1337 overthrust tectonics in South China. *Geology* 16 (5), 418–421.

1338 Hsü, K.J., Li, J.L., Chen, H.H., Wang, Q.C., Sun, S., Sengor, A.M.C., 1990. Tectonics

1339 of South China - key to understanding West Pacific geology. *Tectonophysics* 183
1340 (1–4), 9–39.

1341 Hu, S.X., Xu, J.F., 2008. The metallogeny of South China closely relationships to its
1342 geotectology. *Geology in China* 35 (6), 1045–1053 (in Chinese with English
1343 abstract).

1344 Hu, J.X., Xu, J.K., Kang, H.N., Tong, C.X., Chen, C.H., Ye, G.G., 1991a. Geological
1345 features of the Lower Proterozoic Badu Group of southwestern Zhejiang and its
1346 implications. *Regional Geology of China* 3, 234–240 (in Chinese with English
1347 abstract).

1348 Hu, Y.H., Xu, B.T., Li, C.J., Jiang, X.L., 1991b. Genetic characteristics and
1349 minerogenetic model of the epithermal gold-silver deposits in Mesozoic volcanic
1350 rocks in Zhejiang. *Mineral Resources and Geology* 05 (03), 176–182 (in Chinese
1351 with English abstract).

1352 Hu, S.X., Zhao, Y.Y., Hu, Z.H., Guo, J.C., Xu, B., 1994. Evolution and development
1353 of tectonics and magmatism at the active continental margin of the East China
1354 during Mesozoic and Cenozoic. *Acta Petrologica Sinica* 10 (04), 370–381 (in
1355 Chinese with English abstract).

1356 Hu, S.X., Wang, H.N., Wang, D.Z., Zhang, J.R., 1998. Geology and geochemistry of
1357 gold deposits in east China. Science Press, Beijing, 1–343 (in Chinese).

1358 Hu, C.J., Huang, W.T., Bao, Z.W., Liang, H.Y., Wang, C.L., 2011. Isotopic age,
1359 geochemistry and metallogenic significance of the dacite in the Zijinshan

1360 orefield, Southwest Fujian. *Acta Mineralogica Sinica* 31 (supp.), 588–589 (in
1361 Chinese)

1362 Hua, R.M., 1987. A discussion on the mechanism of lead, zinc and copper
1363 metallogenesis in Yinshan, Jiangxi Province. *Mineral Deposits* 6 (02), 90–96 (in
1364 Chinese with English abstract).

1365 Hua, R.M., Chen, P.R., Zhang, W.L., Yao, J.M., Lin, J.F., Zhang, Z.S., Gu, S.Y., 2005.
1366 Metallogenises and their geodynamic settings related to Mesozoic granitoids in
1367 the Nanling Range. *Geological Journal of China Universities* 11, 291–304 (in
1368 Chinese with English abstract).

1369 Hua, R.M., Li, G.L., Zhang, W.L., Hu, D.Q., Chen, P.R., Chen, W.F., Wang, X.D.,
1370 2010. A tentative discussion on differences between large-scale tungsten and tin
1371 mineralizations in South China. *Mineral Deposits* 29 (1), 9–15 (in Chinese with
1372 English abstract).

1373 Huang, T.M., 2008. Geologic characteristics and genesis of the Qianshan lead-zinc
1374 deposit in Anxi County of Fujian Province. *Geology of Fujian* 27, 186–194 (in
1375 Chinese with English abstract).

1376 Huang, B.Z., Zheng, R.L., You, Y.C., Xu, Z.L., Li, Q., Tian, D.H., Wang, Y.B., Gao,
1377 J.X., 1983. On geological characteristics and mineralization mechanisms of
1378 Wubu Pb-Zn deposit, Zhejiang. *Bulletin of Nanjing Insititute of Geology and*
1379 *Mineral Resources*. 04 (02), 85–104 (in Chinese with English abstract).

1380 Huang, M.Z., Chen, W.S., Li, W.Z., Xu, F.S., Li, X.Y., 1999. Longtoushan gold

1381 deposit of subvolcanic-cryptoexplosion breccia type, Guangxi. *Acta Geoscience*
1382 *Sinica* 20 (1), 39–46 (in Chinese with English abstract).

1383 Huang, H.M., He, Z.J., Cui, B., 2003. Metallogenic series of granite in Dayaoshan of
1384 Guangxi. *Geological Prospecting* 39, 12–16 (in Chinese with English abstract).

1385 Huang, W.T., Hu, C.J., Li, J., Liang, H.Y., Wu, J., Wang, C.L., Bao, Z.W., Chen, Y.J.,
1386 Wang, X.Z., 2011. LA-ICP-MS zircon age and geological characteristics of the
1387 mineralized Luoboling porphyry in the Zijinshan orefield, Fujian. *Acta*
1388 *Mineralogica Sinica* 31 (supp.), 588–589 (in Chinese).

1389 Ji, G.Q., Shao, J., 1998. Origin of Zhilington Au-Ag deposit in Zhejiang Province.
1390 *Journal of Precious Metallic Geology* 07 (04), 11–18 (in Chinese with English
1391 abstract).

1392 Jiang, X.X., 1992. On the origin of Yinshan polymetallic deposit, Jiangxi. *Journal of*
1393 *Guilin College of Geology* 12 (1), 41–49 (in Chinese with English abstract).

1394 Jiang, S.Y., 2003. Research on the ore-forming conditions of Taihuashan Au (Ag)
1395 deposit at Youxi County. *Contributions to Geology and Mineral Resources*
1396 *Research* 18 (supp.), 52–55 (in Chinese with English abstract).

1397 Jiang, Y.H., Zhao, P., Zhou, Q., Liao, S.Y., Jin, G. D., 2011. Petrogenesis and tectonic
1398 implications of Early Cretaceous S- and A-type granites in the northwest of the
1399 Gan-Hang rift, SE China. *Lithos* 121, 55–73.

1400 Jiang, S.H., Liang, Q.L., Bagas, L., Wang, S.H., Nie, F.J., Liu, Y.F., 2013.
1401 Geodynamic setting of the Zijinshan porphyry-epithermal Cu–Au–Mo–Ag ore

1402 system, SW Fujian Province, China: constraints from the geochronology and
1403 geochemistry of the igneous rocks. *Ore Geology Reviews* 53, 287–305.

1404 Kerrich, R., Goldfarb, R.J., Groves, D.I., Garwin, S., Jia, Y.F., 2000. The
1405 characteristics, origin and geodynamic settings of supergiant gold metallogenic
1406 provinces. *Science in China (Ser D)* 43 (Suppl): 1–68.

1407 Li, N.S., 2007. Geologic characteristics and origin of the Niulukeng lead-zinc deposit
1408 in Minqing City. *Geology of Fujian* 26 (1), 27–33 (in Chinese with English
1409 abstract).

1410 Li, Y.J., 2008. Metallogenic mechanism and ore forecasting of Huaixi copper-gold
1411 deposit, Pingyang County, Zhejiang Province. (Master Dissertation) China
1412 University of Geosciences (Wuhan), 1–72 (in Chinese with English abstract).

1413 Li, X.Z., 2012. Geological features of the Tiantoushan gold (copper) ore deposit.
1414 *Geology of Anhui* 22, 256–260 (in Chinese with English abstract).

1415 Li, Z.X., Li, X.H., 2007. Formation of the 1300-km-wide intracontinental orogen and
1416 postorogenic magmatic province in Mesozoic South China: A flat-slab
1417 subduction model. *Geology* 35 (2), 179–182.

1418 Li, H.Z., Zhang, Y.J., 2008. Study on geological characteristics of the Dalingkou
1419 silver-polymetallic deposit in Tiantai County, Zhejiang Province. *Resources*
1420 *Environment Engineering* 22 (5), 488–490 (in Chinese with English abstract).

1421 Li, X.F., Watanabe, Y., Mao, J.W., Liu, S.X., Yi, X.K., 2007. Sensitive high-resolution
1422 ion microprobe U–Pb Zircon and ^{40}Ar – ^{39}Ar muscovite ages of the Yinshan

1423 deposit in the northeast Jiangxi province, South China. *Resource Geology* 57 (3),
1424 325–337.

1425 Li, Y.J., Wei, J.H., Yao, C.L., Yan, Y.F., Tan, J., Peng, L.N., Xiao, G.L., Ye, Z.F., 2010.
1426 Genetic relationship of the Huaixi Copper-Gold deposit and the Caomen alkaline
1427 granite, Southeastern Zhejiang Province, China: constraint from geochronologies.
1428 *Journal of China University of Geoscience* 35 (04), 585–596 (in Chinese with
1429 English abstract).

1430 Li, N., Chen, Y.J., Santosh, M., Pirajno, F., 2015. Compositional polarity of Triassic
1431 granitoids in the Qinling Orogen, China: Implication for termination of the
1432 northernmost paleo-Tethys. *Gondwana Research* 27, 244–257.

1433 Liang, L.H., 2008. Discussion on the geologic characteristics and genesis of the
1434 Siyang lead-zinc deposit in Putian City, Fujian Province. *Geology of Fujian* (03),
1435 259–266 (in Chinese with English abstract).

1436 Liang, Y.H., Sun, X.M., Zhai, W., Ma, C., Wu, Z.Q., Ding, C.G., Wang, T.X., Li, A.J.,
1437 Liang, J.L., 2008. Geochemistry of ore-forming fluids and genesis of Guanshan
1438 Cu-Pb-Au polymetallic deposit in Jiangsu Province. *Mineral Deposits* 27 (05),
1439 605–612 (in Chinese with English abstract).

1440 Liang, Y.H., Sun, X.M., Zhai, W., Ma, C., Wu, Z.Q., Ding, C.G., Wang, T.X., 2010a.
1441 $^{40}\text{Ar}/^{39}\text{Ar}$ dating of the Guanshan high sulphidation type Cu-Pb-Au deposit in
1442 Jiangsu Province and its geological significance. *Geology Journal of China*
1443 *Universities* 16 (02), 143–148 (in Chinese with English abstract).

-
- 1444 Liang, Y.H., Sun, X.M., Zhai, W., Ma, C., Wu, Z.Q., Ding, C.G., Wang, T.X., 2010b.
1445 Stable isotopic geochemistry and genesis of the Guanshan high-sulphidation type
1446 Cu-Pb-Au deposit in Jiangsu Province. *Geological Exploration* 46 (4), 698–704
1447 (in Chinese with English abstract).
- 1448 Lin, M.L., 2003. Geological characteristics of Taihuashan Au deposit in the middle of
1449 Fujian Province and research on its genesis. *Contributions to Geology and*
1450 *Mineral Resources Research* 18 (Sup.), 64–67 (in Chinese with English abstract).
- 1451 Lin, Q.S., 2006. On the characteristics and genesis of the Yueyang silver polymetallic
1452 deposit in Wuping County, Fujian Province. *Geology of Fujian* (02), 82–88 (in
1453 Chinese with English abstract).
- 1454 Lin, D.S., He, G.C., 1990. A study on the mineral inclusions of the Yinshan Cu-Pb-Zn
1455 polymetallic deposit at Dexing, Jiangxi Province. *Mineral Resources and*
1456 *Geology* 4 (17), 50–58, 68 (in Chinese with English abstract).
- 1457 Lin, M.L., Huang, Q.Y., Wong, G.C., 2005. Geological characteristics and genesis of
1458 Xiqian Au-Cu deposit, Fujian Province and ore searching direction in the mining
1459 district. *Contributions to Geology and Mineral Resources Research* 20 (supp),
1460 58–60, 90 (in Chinese with English abstract).
- 1461 Lindgren, W., 1922. A suggestion for the terminology of certain mineral deposits.
1462 *Economic Geology* 17, 292–294.
- 1463 Liu, P., 1990. Some ore textures from Babaoshan gold-silver deposit, Zhejiang. *Earth*
1464 *Science – Journal of China University of Geoscience* 15 (4), 407–412 (in

1465 Chinese with English abstract).

1466 Liu, Z.Y., 2005. Geological setting and metallogenesis of Lehua-Dexing metallogenic
1467 belt in Northeastern Jiangxi Province. (PhD dissertation) Northeastern University,
1468 86–105 (in Chinese with English abstract).

1469 Liu, J.W., 2009. Discussion on the geological characteristics and genesis of the
1470 Qinggang Pb-Zn deposit in Wuhua County, Guangdong Province. Xinjiang
1471 Nonferrous Metals (02), 4–6 (in Chinese).

1472 Liu, S.J., 2012. The geological characteristics and prospecting potential of the
1473 Huxingshan Pb-Zn-Au deposit. Geology Resources and Mines 13, 120–121 (in
1474 Chinese with English abstract).

1475 Liu, J., Peng, F., 1991. The minerogenetic condition and geological characters of the
1476 Jinjushan gold deposit of Lishui, Jiangsu Province. Journal of Kunming Institute
1477 of Technology 16 (3), 1–8 (in Chinese with English abstract).

1478 Liu, Z.P., Wu, J.Z., 1995. Genesis of the Xiaxidi silver deposit in Fuqing, Fujian
1479 Province. Geology of Fujian (02), 75–84 (in Chinese with English abstract).

1480 Liu, X.D., Hua, R.M., 2005. $^{40}\text{Ar}/^{39}\text{Ar}$ dating of adularia from the Bitian
1481 gold-silver-copper deposit, Fujian Province. Geological Review 51 (2), 151–155
1482 (in Chinese with English abstract).

1483 Liu, K.J., Dong, P., Wu, J.L., 1990. Geological characteristics and genesis of Bamao
1484 silver deposit, Zhejiang. Bulletin of Nanjing Institute of Geology and Mineral
1485 Resources 11 (01), 38–53 (in Chinese with English abstract).

1486 Liu, X., Fan, H.R., Santosh, M., Hu, F.F., Yang, K.F., Li, Q.L., Yang, Y.H., Liu, Y.S.,
1487 2012. Remelting of Neoproterozoic relict volcanic arcs in the Middle Jurassic:
1488 Implication for the formation of the Dexing porphyry copper deposit,
1489 Southeastern China. *Lithos* 150, 85–100.

1490 Liu, W.Y., Cook, N.J., Ciobanu, C.L., Liu, Y., Qiu, X.P., Chen, Y.C., 2016. Mineralogy
1491 of tin-sulfides in the Zijinshan porphyry-epithermal system, Fujian Province,
1492 China. *Ore Geology Reviews* 72, 682–698.

1493 Lu, Z.G., Tao, K.Y., Xie, J.Y., Xie, D.K., Wang, W.B., Chen, H.N., 1997. Geology and
1494 mineralization in Southeast China. Geological Publishing House, Beijing, 1–431
1495 (in Chinese).

1496 Luo, Z.K., Hu, G.M., Guan, K., 1985. A discussion on geological features and genesis
1497 of the Yinkenshan gold-silver deposit, Zhejiang Province. *Mineral Deposits* 04
1498 (04), 47–55 (in Chinese with English abstract).

1499 Mao, J.W., Stein, H., Du, A.D., Zhou, T.F., Mei, Y.N., Li, Y.F., Zang, W.S., Li, J.W.,
1500 2004. Molybdenite Re–Os precise dating for molybdenite from Cu-Au-Mo
1501 deposits in the Middle-Lower reaches of Yangtze River Belt and its implications
1502 for mineralization. *Acta Geologica Sinica* 78 (1), 121–131 (in Chinese with
1503 English abstract).

1504 Mao, J.W., Li, X.F., White, N.C., Zhao, C.S., Zhang, Z.H., Wang, Y.T., Hu, H.B.,
1505 2007. Types, characteristics, and geodynamic settings of Mesozoic epithermal
1506 gold deposits in eastern China. *Resource Geology* 57 (4), 435–454.

1507 Mao, J.W., Xie, G.Q., Guo, C.L., Yuan, S.D., Cheng, Y.B., Chen, Y.C., 2008.
1508 Spatial-temporal distribution of Mesozoic ore deposits in South China and their
1509 metallogenic settings. *Geological Journal of China Universities* 14 (4), 510–526
1510 (in Chinese with English abstract).

1511 Mao, J.W., Zhang, J.D., Pirajno, F., Ishiyama, D., Su, H.M., Guo, C.L., Chen, Y.C.,
1512 2011. Porphyry Cu-Au-Mo-epithermal Ag-Pb-Zn-distal hydrothermal Au deposit
1513 in the Dexing area, Jiangxi province, East China—A linked ore system. *Ore*
1514 *Geology Reviews* 43. 203–216.

1515 Mao, J.W., Cheng, Y.B., Chen, M.H., Pirajno, F., 2013. Major types and time-space
1516 distribution of Mesozoic ore deposits in South China and their geodynamic
1517 settings. *Mineralium Deposita* 48, 267–294.

1518 Mei, Y.W., 1998. The Wuyishan Orogen and its ore-forming process. *Jiangxi Geology*
1519 12, 109–115 (in Chinese with English abstract).

1520 Meng, X.L., Wang, L.M. 1998. The geological characteristics and genesis of Songxi
1521 silver (antimony) deposit in Guangdong. *Journal of East China Geological*
1522 *Institute* 21 (1), 52–62 (in Chinese with English abstract).

1523 Peng, T.P., 2011. The geologic characteristics and the ore-finding perspective of the
1524 Shenyanjian silver polymetallic deposit in Anxi County, Fujian Province.
1525 *Geology of Fujian* (3), 200–204 (in Chinese with English abstract).

1526 Peng, Z.D., Bu, A., 2003. An initial analyse on geological character of Jianbidong
1527 lead-zinc-copper ore field of Fengshun County in Guangdong Province and the

1528 ore controlling conditions. *Mineral Resources and Geology* 17 (02), 140–144 (in
1529 Chinese with English abstract).

1530 Pirajno, F., 2009. *Hydrothermal Processes and Mineral System*. Springer, Berlin, 1250
1531 pp.

1532 Pirajno, F., 2013. *The Geology and Tectonic Settings of China's Mineral Deposits*.
1533 Springer, Berlin, 679 pp.

1534 Pirajno, F., Bagas, L., 2002. Gold and silver metallogeny of the South China Fold Belt:
1535 a consequence of multiple mineralizing events? *Ore Geology Reviews* 20 (3–4),
1536 109–126.

1537 Pirajno, F., Bagas, L., Hickman, A.H., Team, G.R., 1997. Gold mineralization of the
1538 Chencai–Suichang Uplift and tectonic evolution of Zhejiang Province, southeast
1539 China. *Ore Geology Reviews* 12, 35–55.

1540 Qi, J.P., Chen, Y.J., Li, Q.Z., 2004. The epithermal deposits in the northern margin of
1541 North China Craton: spatial-temporal distribution and Tectonic setting. *Journal of*
1542 *Mineralogy and Petrology* 24 (3), 82–92 (in Chinese with English abstract).

1543 Qi, J.P., Chen, Y.J., Pirajno, F., 2005. Geological characteristics and tectonic setting of
1544 the epithermal deposits in the Northeast China. *Journal of Mineralogy and*
1545 *Petrology* 25 (2), 47–59 (in Chinese with English abstract).

1546 Qiu, J.S., Wang, Y.H., Wang, D.Z., Xu, Z.W., 1998. Ore-controlling factors and
1547 metallogenetic regularity of Mesozoic volcanic-subvolcanic activities related Au
1548 (Cu) deposit in middle-South segment of the Tanlu Fault. *Mineral Deposits* 17

1549 (supp.), 119–122 (in Chinese with English abstract).

1550 Ren, J.S., 1999. Tectonic map of China and adjacent regions. Geological Publishing
1551 House, Beijing.

1552 Seward, T., Barnes, H., 1997. Metal transport by hydrothermal ore fluids. In: Barnes,
1553 H. (Ed.), *Geochemistry of Hydrothermal Ore Deposits*, third ed. Wiley, New
1554 York, pp. 435–486.

1555 She, R.Q., 2007. Discussion on the genesis and characteristics of polymictic breccia
1556 strata in the Qianshan lead-zinc ore district of Anxi County, Fujian Province.
1557 *Geology of Fujian* (03), 151–161 (in Chinese with English abstract).

1558 Shen, Z.X., 2005. Geologic characteristics and long-term perspectives analysis of the
1559 Lingtouping lead-zinc-gold-silver polymetallic ores in Fujian Province. *Geology*
1560 *of Fujian* (3), 147–158 (in Chinese with English abstract).

1561 Shen, W.Z., Ling, H.F., 2002. Isotopic study and crust evolution of the basement
1562 metamorphic rocks, granites and volcanic rocks in Southeast China. In: Wang
1563 DZ, Zhou XM. *Petrogenesis and crust evolution of the Late Mesozoic granitic*
1564 *volcanic-intrusive complexes in Southeast China*. Science Press, Beijing,
1565 230–272 (in Chinese).

1566 Sheng, Z.H., 2005. Gold metallogenic pattern in Dayaoshan ore belt. *Contributions to*
1567 *Geology and Mineral Resources Research* 20 (sup.), 6–64 (in Chinese with
1568 English abstract).

1569 Shu, L.S., 2006. Pre-Devonian tectonic evolution of South China: from Cathaysian

1570 Block to caledonian period Folded Orogenic Belt. Geological Journal of China
1571 Universities 12 (4), 418–431 (in Chinese with English abstract).

1572 Shu, L.S., 2012. An analysis of principal features of tectonic evolution in South China
1573 Block. Geological Bulletin of China 31 (7), 1035–1053 (in Chinese with English
1574 abstract).

1575 Shu, L.S., Faure, M., Wang, B., Zhou, X.M., Song, B., 2008. Late Palaeozoic-Early
1576 Mesozoic Geological Features of South China: Response to the Indosinian
1577 Collision Events in Southeast Asia. *Comptes Rendus Geoscience* 340, 151–165.

1578 Simmons, S.F., White, N.C., John, D.A., 2005. Geological Characteristics of
1579 epithermal Precious and Base Metal Deposits. *Economic Geology* 100th
1580 Anniversary Volume, 185–522.

1581 So, C.S., Zhang, D.Q., Yun, S.T., Li, D.X., 1998. Alteration-Mineralization Zoning
1582 and fluid Inclusions of the High Sulfidation epithermal Cu-Au Mineralization at
1583 Zijinshan, Fujian Province, China. *Economic Geology* 93 (7), 961–980.

1584 Su, Y.Q., 1996. Geological feature and genesis of Jinping Au-Ag deposit in Fujian.
1585 *Gold Geology* 2 (1), 38–45 (in Chinese with English abstract).

1586 Tao, K.Y., Gao, T.J., Lu, Z.G., 1998. Basement tectonics of volcanic rock and
1587 volcanic-intrusion related to mineralization of coastal area of southeast China.
1588 Geological Publishing House, Beijing, 1–371 (in Chinese with English abstract).

1589 Taylor, H.P., 1974. The application of oxygen and hydrogen isotope studies to
1590 problems of hydrothermal alteration and ore deposition. *Economic Geology* 69,

1591 843–883.

1592 Wang, H.Q., 2008. The geological characteristics and implications of the Pb-Zn
1593 mineralization in Nanyang area of Zhenghe County, Fujian Province. *Geology of*
1594 *Anhui* 18 (04), 273–276 (in Chinese with English abstract).

1595 Wang, D.Z., Liu, C.S., Shen, W.Z., Chen, F.R., 1994. S-type volcanic complexes in
1596 South China and metallogenesis. *Journal of Nanjing University (Natural*
1597 *Sciences Edition)* 30 (2), 322–333 (in Chinese with English abstract).

1598 Wang, K.Y., Lu, Z.X., Zhang, X.G., 1998. The geological and mineralization feature
1599 of Huxu gold deposit and study on its origin. *Gold* 19 (5), 7–12 (in Chinese with
1600 English abstract).

1601 Wang, H.N., Ling, H.F., Zhou, L.Y., Yang, F.G., Wang, Y.X., 2003. Sm-Nd isotope
1602 dating and geological implications for the Mesoproterozoic Mamianshan Group
1603 in Fujian Province. *Geological Journal of China Universities* 9, 566–572 (in
1604 Chinese with English abstract).

1605 Wang, Q., Wyman, D.A., Xu, J.F., Zhao, Z.H., Jian, P., Xiong, X.L., Bao, Z.W., Li,
1606 C.F., Bai, Z.H., 2006a. Petrogenesis of Cretaceous adakitic and shoshonitic
1607 igneous rocks in the Luzong area, Anhui Province (eastern China): implication
1608 for geodynamics and Cu-Au mineralization. *Lithos* 89, 424–446.

1609 Wang, Q., Xu, J.F., Jian, P., Bao, Z.W., Zhao, Z.H., Li, C.F., Xiong, X.L., Ma, J.L.,
1610 2006b. Petrogenesis of adakitic porphyries in an extensional tectonic setting,
1611 Dexing, South China: implications for the genesis of porphyry copper

1612 mineralization. *Journal of Petrology* 47, 119–144.

1613 Wang, C.M., Wu, G.G., Zhang, D., Luo, P., Di, Y.J., Yu, X.Q., 2010. Regional
1614 metallogenic characteristics and mineralizing pedigree in northeastern Jiangxi.
1615 *Global Geology* 29 (4), 588–600 (in Chinese with English abstract).

1616 Wang, G.G., Ni, P., Zhao, K.D., Wang, X.L., Liu, J.Q., Jiang, S.Y., Chen, H., 2012.
1617 Petrogenesis of the Middle Jurassic Yinshan volcanic-intrusive complex, SE
1618 China: Implications for tectonic evolution and Cu-Au mineralization. *Lithos* 150,
1619 135–154.

1620 Wang, G.G., Ni, P., Wang, R.C., Zhao, K.D., Chen, H., Ding, J.Y., Zhao, C., Cai, Y.T.,
1621 2013a. Geological, fluid inclusion and isotopic studies of the Yinshan
1622 Cu-Au-Pb-Zn-Ag deposit, South China: Implications for ore genesis and
1623 exploration. *Journal of Asian Earth Sciences* 74, 343–360.

1624 Wang, Y.J., Fan, W.M., Zhang, G.W., Zhang, Y.H., 2013b. Phanerozoic Tectonics of
1625 the South China Block: Key Observations and Controversies. *Gondwana*
1626 *Research* 23, 1273–1305.

1627 Wang, G.G., Ni, P., Yao, J., Wang, X.L., Zhao, K.D., Zhu, R.Z., Xu, Y.F., Pan, J.Y., Li,
1628 L., Zhang, Y.H., 2015. The link between subduction-modified lithosphere and the
1629 giant Dexing porphyry copper deposit, South China: constraints from high-Mg
1630 adakitic rocks. *Ore Geology Reviews* 67, 109–126.

1631 Wang, G.G., Ni, P., Zhao, C., Chen, H., Cai, Y.T., Li, L., Zhu, A.D., 2016. A combined
1632 fluid inclusion and isotopic geochemistry study of the Zhilingtou Mo deposit,

1633 South China: implications for ore geology and metallogenic setting. *Ore Geology*
1634 *Reviews*. doi:10.1016/j.oregeorev.2015.11.023.

1635 Wei, J.X., Tao, G.Y., 1998. Ore-forming fluid and metallogenic model of the Zijinshan
1636 Cu-Au deposit. *Mineral Deposits* 17 (supp.), 1095–1098 (in Chinese with
1637 English abstract).

1638 White, N.C., 2003. epithermal gold deposits. Society of Economic Geologists Beijing
1639 Gold Workshop, 25–26 Oct, p 118 (confidential document distributed in China
1640 University of Geosciences).

1641 White, N.C., Leake, M.J., Mccaughey, S.N., Parris, B.W., 1995. epithermal Gold
1642 Deposits of the Southwest Pacific. *Journal of Geochemical Exploration* 54 (2),
1643 87–136.

1644 Wu, Z.J., 1991. A discussion on the geochemical characteristics of elements and
1645 genesis of Shatan Au-Ag deposit. *Geology of Jiangxi* 5 (2), 109–117 (in Chinese
1646 with English abstract).

1647 Wu, Z.J., 1998. Stable isotope geochemical characteristics of Yinshan polymetallic
1648 deposit, Jiangxi Province. *Bulletin of Mineralogy, Petrology and Geochemistry*
1649 17 (1), 28–30 (in Chinese with English abstract).

1650 Wu, Q.Z., Wang, S., Jiang, H.S., Zhao, M.F., 1993. The physicochemical conditions
1651 of the Tiantoushan gold deposit, Anhui Province. *Science Technology of Gold*
1652 *Geology* 1, 1–8 (in Chinese).

1653 Xia, J.S., 1995. Location and prospecting model of endogenetic metallic deposits in

-
- 1654 Lishui volcanic basin, Jiangsu. *Geology of Jiangsu* 19 (1), 5–11 (in Chinese with
1655 English abstract).
- 1656 Xiang, H.L., He, M.Z., 2000. Geological features and ore-hunting indicators of
1657 Qiucun gold deposit in Dehua County, Fujian Province. *Geology of Fujian* (02),
1658 66–71 (in Chinese with English abstract).
- 1659 Xiao, Z.Y., 2001. *Geology, geochemistry and metallogenic model of the Songxi*
1660 *Ag-Sb deposit in Northeast Guangdong. (Ph.D. dissertation) Hefei University of*
1661 *Technology (Hefei), 1–160 (in Chinese with English abstract).*
- 1662 Xiao, W.J., He, H.Q., 2005. Early Mesozoic thrust tectonics of the NW Zhejiang
1663 region (Southeast China). *Geological Society of America Bulletin* 117, 945–961.
- 1664 Xiao, H.L., Fu, D.X., Qi, J.Z., 1997. Geological and geochemical characteristics of
1665 Songxi Ag-Sb deposit in Guangdong. *Volcanology Mineral Resources* 18 (4),
1666 298–307 (in Chinese with English abstract).
- 1667 Xie, L.S., Sun, B.D., 1993. Geological characteristics of Longtoushan
1668 volcanic-subvolcanic gold deposit, Guigang City, Guangxi. *Geology of Guangxi*
1669 06 (04), 27–42 (in Chinese with English abstract).
- 1670 Xie, G.Q., Mao, J.W., Li, R.L., Zhang, Z.S., Zhao, W.C., Qu, W.J., Zhao, C.S., Wei,
1671 S.K., 2006. Metallogenic epoch and geodynamic framework of Cu-Au-Mo-(W)
1672 deposits in Southeastern Hubei Province: constraints from Re–Os molybdenite
1673 ages. *Mineral Deposits* 25 (1), 43–54 (in Chinese with English abstract).
- 1674 Xie, G.Q., Mao, J.W., Zhao, H.J., 2011. Zircon U–Pb geochronological and Hf

1675 isotopic constraints on petrogenesis of Late Mesozoic intrusions in the southeast
1676 Hubei Province, Middle-Lower Yangtze River belt (MLYRB), East China. *Lithos*
1677 125, 693–710.

1678 Xu, B.T., 1994. Geologic characteristics, metallogenic age and genesis of the Haoshi
1679 Ag deposit, Zhejiang Province. *Bulletin of Mineralogy, Petrology and*
1680 *Geochemistry* (01), 12–13 (in Chinese with English abstract).

1681 Xu, B.T., Xia, A.N., Zheng, S.H., Chen, C.Y., 1988. Characteristics and sources of
1682 ore-forming fluids in the Zhilintou gold-silver deposit studied by stable isotope
1683 method. *Mineral Deposits* 07 (04), 27–32 (in Chinese with English abstract).

1684 Xu, B.T., Li, C.J., Chen, H.S., 1994. Mineralization chronology and isotopic
1685 geochemistry of the Haoshi silver deposit in Zhejiang Province. *Mineral*
1686 *Deposits* 13 (03), 271–281 (in Chinese with English abstract).

1687 Yang, M.G., Wang, F.N., Zeng, Y., 2002. The ore-forming environment and its process
1688 in northeast Jiangxi. *Resource Survey and Environment* 23, 122–129 (in Chinese
1689 with English abstract).

1690 Yao, D.X., Li, Z.L., Ye, Y.F., Zhang, S.J., 1996. Geology and genesis of the Baoshan
1691 silver (antimony) deposit in Eastern Guangdong. *Mineral Deposits* 15 (02),
1692 123–132 (in Chinese with English abstract).

1693 Ye, N., 1993. The geological characteristics of Shatan Au-Ag deposit. *Geology of*
1694 *Jiangxi* 7, 175–183 (in Chinese with English abstract).

1695 Ying, J.L., Zhao, P.Y., Guo, H., 1997. Study on the determination of ore-formation age

1696 of primary gold ore. *Uranium Geology* 13 (04), 232–240 (in Chinese with
1697 English abstract).

1698 Yu, J.B., 2001. Geologic features of Huxingshan gold deposit, Dongxiang. *Geology of*
1699 *Jiangxi* 15 (4), 267–270 (in Chinese with English abstract).

1700 Yu, J.H., Wang, L.J., O'Reilly, S.Y., Griffin, W.L., Zhang, M., Li, C.S., Shu, L.S., 2009.
1701 A paleoproterozoic orogeny recorded in a long-lived cratonic remnant
1702 (Wuyishan terrane), eastern Cathaysia Block, China. *Precambrian Research* 174,
1703 347–363.

1704 Zartman, R.E., Doe, B.R., 1981. Plubotectonics-the model. *Tectonophysics* 75,
1705 135–162.

1706 Zaw, K., Peters, S.G., Cromie, P., Burrett, C., Hou, Z.Q., 2007. Nature, Diversity of
1707 Deposit Types and Metallogenic Relations of South China. *Ore Geology*
1708 *Reviews* 31 (1–4), 3–47.

1709 Zeng, Q.D., Wang, Y.B., Zhang, S., Liu, J.M., Qin, K.Z., Yang, J.H., Sun, W.D., Qu,
1710 W.J., 2013. U–Pb and Re–Os geochronology of the Tongcun molybdenum
1711 deposit and Zhilingtou gold-silver deposit in Zhejiang Province, Southeast China,
1712 and its geological implications. *Resource Geology* 63, 99–109.

1713 Zhai, Y.S., Yao, S.Z., Lin, X.D., Zhou, X.R., Wan, T.F., Jin, F.Q., Zhou, Y.G., 1992.
1714 Metallogenic regularities of iron-copper (gold) deposits in Middle-Lower
1715 Yangtze River Valley. Geological Publishing House, Beijing. 235 pp. (in Chinese
1716 with English abstract).

-
- 1717 Zhang, J.Z., 2013. Geology, exploration model and practice of Zijinshan ore
1718 concentrated area. *Mineral Deposits* 32, 757–766 (in Chinese with English
1719 abstract).
- 1720 Zhang, Y.J., Wei, X.L., 1999. Geologic characteristics and genesis of the Yinfengjian
1721 gold orefield, Jiangxi Province. *Geological Exploration of Non-ferrous Metals* 8
1722 (6), 700–703 (in Chinese with English abstract).
- 1723 Zhang, D.Q., Li, D.X., Zhao, Y.M., Chen, J.H., Li, Z.L., Zhang, K.Y., 1992. Alteration
1724 and mineralization zoning of the Zijinshan copper-gold deposit. Geological
1725 Publishing House, Beijing. 77 pp. (in Chinese).
- 1726 Zhang, D.Q., Li, D.X., Feng, C.Y., Dong, Y.J., 2001. The temporal and spatial
1727 framework of the Mesozoic magmatic system in Zijinshan area and its geological
1728 significance. *Acta Geoscientia Sinica* 22 (05), 403–408 (in Chinese with English
1729 abstract).
- 1730 Zhang, D.Q., Feng, C.Y., Li, D.X., She, H.Q., Dong, Y.J., 2003a. ^{40}Ar – ^{39}Ar dating of
1731 adularia from Bitian sericite-adularia type epithermal Ag-Au deposit in Fujian
1732 Province and its geological significance. *Mineral Deposits* 22 (4), 360–364 (in
1733 Chinese with English abstract).
- 1734 Zhang, D.Q., She, H.Q., Li, D.X., Feng, C.Y., 2003b. The porphyry-epithermal
1735 metallogenic system in the Zijinshan region, Fujian Province. *Acta Geologica*
1736 *Sinica* 77 (02), 253–261 (in Chinese with English abstract).
- 1737 Zhang, W.H., Zhang, D.H., Liu, M., 2003c. Study on ore-forming fluids and the

1738 ore-forming mechanisms of the Yinshan Cu-Pb-Zn-Au-Ag deposits, Jiangxi
1739 Province. *Acta Petrologica Sinica* 19 (02), 242–250 (in Chinese with English
1740 abstract).

1741 Zhang, Y.Q., Zhao, Y., Dong, S.H., Yang, N., 2004. Tectonic evolution stages of the
1742 Early Cretaceous rift basins in Eastern China and adjacent areas and their
1743 geodynamic background. *Earth Science Frontiers* 11 (03), 123–133 (in Chinese
1744 with English abstract).

1745 Zhang, D.H., Xu, G.J., Zhang, W.H., Golding, S.D., 2007. High salinity fluid
1746 inclusions in the Yinshan polymetallic deposit from the Le–De metallogenic belt
1747 in Jiangxi Province, China: Their origin and implications for ore genesis. *Ore
1748 Geology Reviews* 31, 247–260.

1749 Zhang, M., Wu, J.H., Zhu, X.Y., 2009. Geochemical characteristics of trachyte in
1750 Shixi and Sanbaishan basin, and its geological significance. *Journal of East
1751 China Institute of Technology* 32 (1), 52–60 (in Chinese with English abstract).

1752 Zhao, X.L., 2007. The geochronology, petrography and geochemical characteristics of
1753 Mesozoic granitoids from Shanghang area in SW Fujian and their implications.
1754 (Master dissertation) Chinese Academy of Geological Sciences (Beijing), 1–57
1755 (in Chinese with English abstract).

1756 Zheng, Q.N., 1996. Main geological characteristics of a submarine basic volcanic
1757 effusive silver-antimony deposit. *Mineral Deposits* 15 (03), 238–248 (in Chinese
1758 with English abstract).

-
- 1759 Zheng, R.L., Xie, C.Z., 1984. A preliminary study of the distribution of silver in the
1760 Wubu Pb-Zn deposit, Zhejiang Province. *Mineral Deposits* 03 (01), 19–26 (in
1761 Chinese with English abstract).
- 1762 Zheng, M.H., Liu, J.M., 1986. Material sources of the Zhilingtou gold-silver ore
1763 deposit in Zhejiang Province. *Mineral Deposits* 05 (01), 39–52 (in Chinese with
1764 English abstract).
- 1765 Zhong, J., Chen, Y.J., Chen, J., Li, J., Qi, J.P., Dai, M.C., 2011. fluid inclusion study
1766 of the Luoboling porphyry Cu-Mo deposit in the Zijinshan ore field, Fujian
1767 Province. *Acta Petrologica Sinica* 27 (05), 1410–1424 (in Chinese with English
1768 abstract).
- 1769 Zhong, J., Chen, Y.J., Pirajno, F., Chen, J., Li, J., Qi, J.P., Li, N., 2014. Geology,
1770 geochronology, fluid inclusion and H-O isotope geochemistry of the Luoboling
1771 porphyry Cu-Mo deposit, Zijinshan orefield, Fujian Province, China. *Ore*
1772 *Geology Reviews* 57, 61–77.
- 1773 Zhong, J., Chen, Y.J., Pirajno, F., 2016a. Geology, geochemistry and tectonic settings
1774 of the molybdenum deposits in South China: A review. *Ore Geology Reviews*
1775 <http://dx.doi.org/10.1016/j.oregeorev.2016.04.012>.
- 1776 Zhong, J., Chen, Y.J., Chen, J., Qi, J.P., Dai, M.C., 2016b. Geology and fluid inclusion
1777 geochemistry of the Zijinshan high-sulfidation epithermal Cu-Au deposit, Fujian
1778 Province, SE China: Implication for deep exploration targeting. *Journal of*
1779 *Geochemical Exploration*. under review.

1780 Zhong, J., Chen, Y.J., Qi, J.P., Chen, J., Dai, M.C., Li, J., 2016c. Geology, fluid
1781 inclusion and stable isotope study of the Yueyang low-sulfidation Ag-Au-Cu
1782 deposit, Zijinshan orefield, Fujian Province, China. *Ore Geology Reviews*, under
1783 review.

1784 Zhou, H.N., 2005. Geologic characteristics and genesis of the Qinxi lead-zinc-silver
1785 deposit in Zhouning County. *Geology of Fujian* (01), 19–24 (in Chinese with
1786 English abstract).

1787 Zhou, J.F., Qian, J.M., 1996. The metallogenic epoch of Zhilintou gold-silver
1788 deposit. *Geology of Zhejiang* 12 (01), 60–67 (in Chinese with English abstract).

1789 Zhou, S., Chen, H.S., 1996. Geochronology and geological significance of the
1790 Zijinshan copper-gold deposit. *Bulletin of Mineralogy, Petrology and*
1791 *Geochemistry* 15 (04), 216–219 (in Chinese with English abstract).

1792 Zhou, L.Y., Qiu, Y.S., 1997. Metallogenic system of gold deposits in Mesozoic
1793 continental margin volcanic rocks, Zhejiang. *Geology of Zhejiang* 13 (02), 11–21
1794 (in Chinese with English abstract).

1795 Zhou, Z.Q., Luo, Y.S., 1997. The summary of geological characteristics and
1796 propeeting methods for Xialong silver-gold deposit in Yongjia County. *Geology*
1797 *of Zhejiang* 13 (02), 22–30 (in Chinese with English abstract).

1798 Zhou, X.M., Li, W.X., 2000. Origin of Late Mesozoic igneous rocks in Southeastern
1799 China: implications for lithosphere subduction and underplating of mafic
1800 magmas. *Tectonophysics* 326 (3–4), 269–287.

-
- 1801 Zhou, S., Qiu, R.Z., Chen, H.S., 1998. Characteristics of hydrogen and oxygen
1802 isotopic composition of the Zijinshan copper-gold deposit and the relation to the
1803 ore-forming process. *Geology of Fujian* (2), 94–100 (in Chinese with English
1804 abstract).
- 1805 Zhou, T.H., Goldfarb, R.J., Phillips, G.N., 2002. Tectonics and distribution of gold
1806 deposits in China—an overview. *Mineralium Deposita* 37 (3–4), 249–282.
- 1807 Zhou, T.F., Yuan, F., Hou, M.J., Du, J.G., Fan, Y., Zhu, G., Yue, S.C., 2004. Genesis
1808 and geodynamic background of Yanshanian granitoids in the eastern Jiangnan
1809 Uplift in the adjacent area of Anhui and Jiangxi Provinces, China. *Journal of*
1810 *Mineralogy and Petrology* 24 (3), 65–71 (in Chinese with English abstract).
- 1811 Zhou, X.W., Li, S.R., Lu, L., Lin, W.B., 2005. Research on the composition
1812 typomorphism of pyrite from Longkeng gold-silver mineralization district in
1813 Wuyi, Zhejiang Province, China. *Bulletin of Mineralogy, Petrology and*
1814 *Geochemistry* 24 (4), 317–326 (in Chinese with English abstract).
- 1815 Zhou, X.M., Sun, T., Shen, W.Z., Shu, L.S., Niu, Y.L., 2006. Petrogenesis of
1816 Mesozoic granitoids and volcanic rocks in South China: a response to tectonic
1817 evolution. *episodes* 29, 26–33.
- 1818 Zhou, T.F., Fan, Y., Yuan, F., Zhang, L.J., Ma, L., Qian, B., Xie, J., 2011. Petrogenesis
1819 and metallogeny study of the volcanic basins in the Middle and Lower Yangtze
1820 Metallogenic Belt. *Acta Geologica Sinica* 85 (05), 712–730 (in Chinese with
1821 English abstract).

1822 Zhou, T.F., Wang, S.W., Fan, Y., Yuan, F., Zhang, D.Y., White, N.C., 2015. A review
1823 of the intracontinental porphyry deposits in the Middle-Lower Yangtze River
1824 Valley metallogenic belt, Eastern China. *Ore Geology Reviews* 65, 433–456.

1825 Zhu, G.T., 2002. Study on geological character and genesis of Longtoushan gold
1826 deposit of Guangxi. *Mineral Resources and Geology* 16 (05), 266–272 (in
1827 Chinese with English abstract).

1828 Zhu, X.D., Ye, Y.J., Wen, F.C., 1994. Ore-forming geological conditional and
1829 exploration priority of the silver ores in the volcanic terrain of Eastern Fujian.
1830 *Geology of Fujian* (02), 83–98 (in Chinese with English abstract).

1831 Zhu, X.D., Liu, Z.P. Wu, J.Z., 1995. Metallogenic regularity of silver deposits hosted
1832 in volcanic terrain of the Eastern Fujian. *Geological Exploration of Non-ferrous*
1833 *Metals* 04 (03), 129–136 (in Chinese with English abstract).

1834 Zhu, A.Q., Zhang, Y.S., Lu, Z.D., Zhang, C.L., 2009. Study on the metallogenic series
1835 and belt of the Zhejiang Province. Geological Publishing House, Beijing. 433 pp.
1836 (in Chinese).

1837 Zijin Mining Group Co., 2008. Reserve verification report in the east section of the
1838 Yueyang Ag-Au-Cu deposit (from August, 2002 to December, 2007).
1839 Unpublished report. (in Chinese).

1840 Zijin Mining Group Co., 2011. The design proposal for porphyry Cu-Au orebodies at
1841 depth of the Zijinshan high-sulfidation Cu-Au deposit. Unpublished report. (in
1842 Chinese).

1843

1844

1845 **Figure Captions**

1846 Fig. 1 Simplified geological map showing the distribution of epithermal deposits in
1847 South China (modified from [Ren et al., 1999](#) and [Wang et al., 2013b](#)).

1848

1849 Fig. 2 Isotopic ages of epithermal deposits and associated magmatic rocks in South
1850 China.

1851

1852 Fig. 3 Geological map the Guanshan Cu-Au-Pb deposit (modified after [Liang et al.,](#)
1853 [2008](#)).

1854

1855 Fig. 4 Geological map (a) and cross-section (b) of the Yinshan Ag-Pb-Zn-Cu-Au
1856 deposit (modified after [Zhang et al., 2007](#) and [Mao et al., 2011](#)).

1857

Fig. 5 Geological map of the Zijinshan orefield (after [Zhong et al., 2014](#)).

Fig. 6 Geological map (a) and geological profile of exploration line No. 7 (b) of the Zijinshan Cu-Au deposit (modified after [Zijin Mining Group Co., 2011](#)).

Fig. 7 Microphotographs showing the mineral assemblage and ore fabrics of the Zijinshan Cu-Au deposit. (a) Oxidized and leached ore showing vuggy quartz. (b) Covellite-digenite veins cutting pyrite veins. (c) Breccia-type copper ores, showing altered granite fragments and matrix of fine-grained pyrite, covellite, digenite, quartz and dickite. (d) Dickite replacing sericite along microfractures (crossed polars). (e) Fine-grained dickite surrounding euhedral alunite (backscatter electron image). (f) Native gold grain in the vuggy quartz zone. (g) Covellite replacing digenite (backscatter electron image). (h) Enargite coexisting with dickite in the alunite alteration zone, suggesting that the Cu-Au mineralization postdate the sulfate alteration.

Fig. 8 Geological map (a) and profile of exploration line No. 65 (b) of the Yueyang Ag-Au-Cu deposit (modified after [Zijin Mining Group Co., 2008](#)).

Fig. 9 Microphotographs showing the mineral assemblage and ore fabrics of the Yueyang Ag-Au-Cu deposit. (a) Ag-bearing polymetallic ore veins (~ 3 cm in width), showing comb quartz, miarolitic and drusy structures. (b) Native silver and argentite-bearing quartz vein in the coarse-grained granite. (c) Ag-associated intensively silic alteration, cut by late-stage white quartz stockworks. (d) Chalcopyrite-quartz vein, , the euhedral and coarse quartz (and amethyst) vein enclosed by a margin of chalcopyrite and pyrite. (e) Late-stage quartz-chalcedony-amethyst vein in volcanic rock, showing colloform structures. (f) Quartz vein with comb texture. (g) Native silver, chalcopyrite, argentite, galena and pyrite coexist in a quartz vein. (h) Adularia grains intergrown with quartz, sphalerite and galena in the Ag-bearing veins (back-scatter electron image). (i) Native silver and calcite grains filling the cavities between euhedral quartz grains (backscatter electron image).

1891 Fig. 10 Geological map (a) and profile of prospecting line No. 4 (b) of the Songxi
1892 Ag-Sb deposit (modified after [Chen et al., 2008c](#)).

1893

1894 Fig. 11 Geological map (a) and cross-section profile (b) of the Longtoushan Au deposit
1895 (modified after [Zhu, 2002](#)).

1896

1897 Fig. 12 Geological map (a) and cross-section profile (b) of the Zhilingtou Au-Ag-Pb-Zn
1898 deposit (modified from [Zhu et al., 2009](#)). Note that the Au-Ag and Mo orebodies are
1899 projected onto the surface.

1900

1901 Fig. 13 δD – $\delta^{18}O$ diagram (after [Taylor, 1974](#)) for selected epithermal deposits in South
1902 China.

1903

1904 Fig. 14 $\delta^{34}S$ values of sulfides for selected epithermal deposits in South China (sample
1905 numbers in bracket).

1906

Fig. 15 Pb isotopic compositions of selected epithermal deposits in South China (base maps are from [Zartman and Doe, 1981](#)). Pb isotopes of volcanic rocks in South China are from [Lu et al. \(1997\)](#), [Liu \(2005\)](#) and [Xu et al. \(1994\)](#), while those of the metamorphic rocks are from [Lu et al. \(1997\)](#).

Table captions

Table 1 List of epithermal deposits in South China.

Table 2 Isotopic ages for epithermal deposits and associated igneous rocks in South China.

Table 3 Fluid inclusion types, microthermometric results and δD , $\delta^{18}O$ and $\delta^{13}C$ ratios for selected epithermal deposits in South China.

Table 4 $\delta^{34}S$ values and Pb isotopic compositions of selected epithermal deposits in South China.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Late Jurassic
Gaojiping Fm.

Middle Jurassic
Zhangping Fm.

Early Jurassic
Jinji Fm.

Andesitic basalt

Fault and its number

Orebody

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15

Table 1

Table 1 List of epithermal deposits in the South China Block

No	Deposit/ County/ Province	Ore type	Resources (t, Mt) @ grade (g/t, %)	Intrusion and age	Host rocks and age	Local fault trends	Occurrence and size of orebody	Major alteration and stage	Ore mineral	Gangue mineral	Data source
1	Guanshan/ Lishui/ Jiangsu	LS?	Au: <5 t @ ~0.6 g/t; Cu: <0.1 Mt @ ~1%; Pb: byproduct	Early Cretaceous trachyandesite porphyry	Early Cretaceous Dawangshan Fm. (hornblende) trachyandesite, cryptoexplosive breccia	NE, E-W	Veins in radium faults of the Guanshan volcanic edifice; biggest: 185 ×1350×(2–5) m	$phy+Cu+Pb+Au\rightarrow$ $kao+carb+brt$	Cpy, Gl, Sph, Bn, Cc, Py, Au	Br, Qtz, Cal, Ser	Liang et al., 2008, 2010a, 2010b
2	Jinjushan/ Lishui/ Jiangsu	LS	Au: <5 t @ 3–495 g/t	Early Cretaceous trachyandesite porphyry	Early Cretaceous Dawangshan Fm. trachyandesite tuff, pyroclastic rocks and breccias	NW, E-W	Veins, lens in caldera-related faults; biggest: 300×100×(55–75) m	phy $\rightarrow qtz+PMS+Au\rightarrow brt\rightarrow q$ $tz+carb$	Au, Cpy, Cc, Tth, Gl, Sph	Ser, Qtz, Br, Cal, Chl	Liu and Peng, 1991; Chen et al., 2014a
3	Tiantoushan / Zongyang/ Anhui	LS	Au: <5 t @ 3.6–14.9 g/t; Cu: <0.1 Mt @ 0.5–1.5%	andesite porphyry	Late Jurassic Zhuanqiao Fm. pyroclastic rocks, trachyandesite tuff, Middle Jurassic Luoling Fm. sandstone	N-S, NE	veins in faults; biggest: 400 × 380 × (0.9–1.9) m	phy $\rightarrow qtz+Au+Cu\rightarrow brt+chl$ $+zo\rightarrow carb+kao$	Py, Cpy, Au, Ag, El	Qtz, Br, Sid, Zo	Wu et al., 1993; Li, 2012
4	Yinshan/ Dexing/ Jiangxi	LS-P	Ag: 2600 t @ 196 g/t; Pb: 0.38 Mt @ 1.75%; Zn: 0.42 Mt @ 1.91%; Cu: 0.86 Mt @ 0.53%; Au: 114 t @ 0.62 g/t	Late Jurassic dacite and quartz porphyry	Mesoproterozoic Shuangqiaoshan Gp. phyllite, Late Jurassic Ehuling Fm. pyroclastic rocks, rhyolite	NNE, NE, NNW	Ag-Pb-Zn veins in fault zones; Cu-Au orebodies in porphyry and contact zone	$phy+Cu+Au\rightarrow Pb+Zn+c$ $hl+carb+srt$	Py, Cpy, Gl, Sph, Apy, Ag, Arn, Cav, Au	Cal, Qtz, Chl, Ser, Sid	Li et al., 2007; Mao et al., 2011; Hua, 1987; Zhang et al., 2003c

5	Shatan/ Qianshan/ Jiangxi	LS	Au: ~ 5 t @ 2.0–10.4 g/t; Ag: < 200 t @ 151–236 g/t	Subvolcanic rocks	Late Jurassic Ehuling Fm. tuff	NW, E–W, NE	Veins, lens, stratiform in faults	$phy \rightarrow qtz + adl + Au + Ag \rightarrow$ $kao + ill$	Au, El, Ku, Arn, Pyr, Py, Po, Gl, Sph	Qtz, Adl, Ill, Ser, Kao, Cal	Wu, 1991; Ye, 1993
6	Yinfengjian/ Dongxiang/ Jiangxi	LS	Au: > 5 t @ 9.0 g/t	Diorite and dacite porphyry	Late Jurassic Huacaojian and Huyan Fm. tuff and rhyolite	E–W, NNW, NNE, S–N	Veins in fault zone	$qtz \rightarrow qtz + adl + ser + Au \rightarrow$ $qtz + chl + kao$	Au, El, Cpy, Gl, Sph, Cc	Qtz, Ser, Adl, Chl, Cal	Zhang and Wei, 1999; Cheng, 2003
7	Huxingshan/ Dongxiang/ Jiangxi	LS	Au: < 5 t @ 1.5–100 g/t; Pb: < 0.1 Mt @ 1.6–8.8% Zn: < 0.1 Mt @ 1.4–18.6% U: byproduct	Subvolcanic rocks	Neoproterozoic Zhoutan Gp. quartz-mica schist, phyllite	NE, NNE, NW	veins, lens, bed-shaped in interlayer fracture zones	$chl + ser \rightarrow qtz + carb + Au +$ $Pb + Zn \rightarrow kao + hem$	Au, Ag, Cv, Py, Cpy, Gl, Sph	Qtz, Kao, Chl, Fl, Ser, Cal	Yu, 2001; Liu, 2012
8	Huxu/ Dongxiang/ Jiangxi	LS	Au: < 5 t @ 3.7–8.1 g/t	quartz diorite porphyry	Late Jurassic Zhoujiayuan Fm. volcanic-sedimentary rocks	NEE, NNE, NE, NW	Veins controlled by faults	$qtz + Au \rightarrow qtz + PMS + Au$ $\rightarrow qtz + carb$	Au, Ag, Gl, Sph, Py, Cpy, Bn	Qtz, Cal, Ser, Chl, clay	Wang et al., 1998
9	Haoshi/ Shengxian/ Zhejiang	LS	Ag: > 200 t @ ?	Late Jurassic dacite	Late Jurassic Xitoushan and Jiuliping Fm. pyroclastic rocks	S–N, E–W, NWW	Veins in fault zone	$chl + ser \rightarrow qtz + fl + Ag + PM$ $S \rightarrow carb + kao$	Ag, Arn, Pol, Tth, Py, Sph, Gl, Cpy	Qtz, Ser, Cln, Chl, Cal, Fl, Brt, Rds	Xu, 1994; Xu et al., 1994

10	Bamao/ Xinchang/ Zhejiang	LS	Ag: > 200 t @ n×10–n×100 g/t	Subvolcanic rocks	Early Cretaceous Chaochuan Fm. breccias, tuff and andesite	S–N, NW	Veins in fault zone	$phy \rightarrow qtz + di + PMS + Ag$ $\rightarrow qtz + brt + Ag \rightarrow qtz + car$ $b + fl$	Arn, Pol, Tth, Ag, Py, Sph, Gl	Qtz, Di, Brt, Ser, Cal, Fl, Chl, Rds	Liu et al., 1990; Dong et al., 1993; Zhu et al., 2009
11	Dalingkou/ Tiantai/ Zhejiang	LS	Ag: > 200 t @ 16–1186 g/t; Pb: ? @ 0.7–2.0%; Zn: ? @ 1.5–3.5%	Early Cretaceous subvolcanic rocks	Late Jurassic Xitoushan Fm. pyroclastic rocks, Early Cretaceous Chaochuan Fm. volcanic-sedimentary rocks	S–N	Veins, lens, stratiform in caldera-related faults; biggest: 500 × 450 × 9.1 m	$qtz + arg \rightarrow qtz + PMS \rightarrow brt$ $\rightarrow qtz + fl \rightarrow Ag + qtz$	Gl, Sph, Py, Pol, Pyr, Apy, Arn, Tth, Cpy	Qtz, Ser, Chl, Brt, Cal, Fl, Ep	Li and Zhang, 2008; Zhu et al., 2009
12	Jinjiyan/ Jinhua/ Zhejiang	LS–P	Au: < 5 t @ ? Ag: byproduct; Mo: unknown	(quartz) felsophyre	Mesozoic crystal tuff, perlite, breccia	NE	Mo veins in the contact zone; Au–Ag veins in the breccias and fault zones	$phy + Mo \rightarrow Au$ $(Ag) + PMS + qtz \rightarrow qtz + ka$ o	El, Ku, Py, Mo	Qtz, Fl, Ser, Kao	Zhou and Qiu, 1997; Du et al., 1998a, 1998b
13	Jintiansi/ Longyou/ Zhejiang	LS	Au: > 5 t @ ?; Ag: > 200 t @ <200 g/t	Mesozoic felsophyre, quartz porphyry	Mesozoic adamellite,	NE	Veins controlled by faults	$phy + chl \rightarrow qtz + Au + Ag \rightarrow$ $carb + kao$	Arn, El, Ag, Py, Cpy, Gl, Sph	Qtz, Ser, Chl, Kao, Cal	Tao et al., 1998
14	Longkeng/ Wuyi/ Zhejiang	LS	Ag: < 200 t @ ?	Subvolcanic rocks	Late Jurassic Moshishan Gp. tuff	NE	Veins controlled by faults and fractures	$phy + chl \rightarrow adl + carb + Ag$ $\rightarrow qtz$	Py, Arn, Hes, Ag, Ku	Adl, Qtz, Cal, Fl	Zhou et al., 2005; Zhu et al., 2009

15	Zhilingtou/ Suichang/ Zhejiang	LS-P	Au: > 20 t @ 8.4–46.2 g/t Ag: > 1000 t @ 165–685 g/t; Pb: > 0.1 Mt @ 0.9–6%; Zn: > 0.1 Mt @ 0.9–6%	Late Jurassic subvolcanic rocks	Paleoproterozoic Badu Gp. metamorphic rocks; Late Jurassic Dashuang Fm. volcanic rocks,	NWW, E–W, S–N, NW	Veins, lens, tabular in ductile shear zones and fracture zones; biggest: 422×186×4.7 m	<i>Au-Au:</i> $phy+chl \rightarrow qtz+adl+rdn+$ $Au+Ag \rightarrow carb+qtz;$ <i>Pb-Zn:</i> $phy+chl \rightarrow qtz+Pb+Zn \rightarrow$ $carb+qtz \pm Pb \pm Zn$	El, Ku, Arn, Dys, Cpy, Py, Sph, Gl	Qtz, Rdn, Adl Cal, Ser, Rds, Cln, Chl	Zhou and Qian, 1996; Ji and Shao, 1998; Zhu et al., 2009
16	Xialong/ Yongjia/ Zhejiang	LS	Ag: < 200 t @ 207–376 g/t; Au: < 5 t @ 1.7–2.8 g/t	Subvolcanic rocks	Late Jurassic Xitoushan and Jiuliping Fm. volcanic rocks	NNE	stratiform, lens in fault zone	$phy+chl \rightarrow qtz+Au+Ag \rightarrow f$ $l+carb$	Ag, Arn, Ku, Au, Py, Cpy, Gl, Sph	Qtz, Ser, Chl, Cal, Fl	Zhou and Luo, 1997; Zhu et al., 2009
17	Dasiji/ Huangyan/ Zhejiang	LS	Ag: < 200 t @ 88–173 g/t; Pb: < 0.1 Mt @ 1.7–2.7%; Zn: < 0.1 Mt @ 1.9–3.7%		Late Jurassic Gaowu Fm. volcanic rocks	NNW	veins, lens controlled by faults	$qtz \rightarrow phy+Ag \rightarrow qtz+PM$ $S \rightarrow carb+Pb+Zn$	Arn, Ag, Ku, Gl, Sph	Qtz, Ser, Kao	Cui et al., 2008
18	Wubu/ Huangyan/ Zhejiang	LS	Pb: > 0.5 Mt @ 1.2–1.5%; Zn: > 0.5 Mt @ 1.9–2.2% Ag: byproduct	Quartz felsophyre	Late Jurassic Xishantou, Dashuang, and Early Cretaceous Guantou Fm. volcanic rocks	NNW	veins, lens in fault zones; biggest: 2000×30×800 m	$phy+chl \rightarrow qtz+Pb+Zn \rightarrow$ $carb$	Sph, Gl, Py, Cpy, Ag, Arn	Qtz, Ser, Cal, Rds, Rdn, Chl, Kao	Huang et al., 1983; Zheng and Xie, 1984
19	Babaoshan/ Longquan/ Zhejiang	LS	Au: < 5 t @ 4.6 g/t; Ag: < 200 t @ 112.8 g/t	Subvolcanic rocks	Late Jurassic Dashuang Fm. pyroclastic rocks, Paleoproterozoic Badu Gp. biotite plagioclase gneiss	NE	veins, lens controlled by faults	$phy \rightarrow qtz+adl+Au+Ag \rightarrow$ $qtz+carb$	Ku, El, Arn, Ag, Py, Apy, Sph, Gl	Qtz, Ser, Cal, Chl, Adl, Ep	Liu, 1990; Zhu et al., 2009
20	Huaixi/ Pingyang/ Zhejiang	LS	Cu: < 0.1 Mt @ 0.5–3%; Au: < 5 t @ 1.6–2.0 g/t	Subvolcanic rocks	Early Cretaceous Chaochuan Fm. volcanic rocks	NW	veins, lends, bead-shaped in fault zones	$phy \rightarrow PMS+qtz+chl+ep$ $\rightarrow carb+qtz$	Cpy, Au, Jmt, Dom, Cc, Cv	Qtz, Cal, Ep, Chl, Fl, Ser	Li, 2008

					Late Jurassic Nanyuan Fm.							
21	Xingxi/ Zhenghe/ Fujian	LS	Au: > 5 t @ 2.5–11.3 g/t	Subvolcanic rocks	volcanic rocks, Mesoproterozoic Mamianshan Gp. metamorphic rocks	NW, NE	Veins in fault zones; biggest: 338×5.6×472 m	$phy+chl \rightarrow qtz+Au+PMS$ $\rightarrow carb+qtz$	Py, Cpy, Sph, Au, Cv	Chl, Ser, Qtz, Cal	Fang, 2007	
22	Maluntou/ Zhenghe/ Fujian	LS	Au: < 5 t @ 4.8 g/t	Subvolcanic rocks	Early Cretaceous Shimaoshan Gp. volcanic rocks	NW	veins, lens in fault zones; biggest: 420×4.0×133 m	$phy+chl \rightarrow qtz+Au \rightarrow hem$	Py, Au, El	Chl, Ser, Qtz	Fang, 2006a	
23	Nanyang/ Zhenghe/ Fujian	LS	Pb: < 0.1 Mt @ 0.5–6.4%; Zn: < 0.1 Mt @ 2.7–4.4%	Subvolcanic rocks	Sinian Daoxian Fm. metamorphic rocks, Late Jurassic Nanyuan Fm. volcanic rocks	NW	Veins in fault zones; biggest: 300×157×9.2 m	$chl+ep \rightarrow Pb+Zn+qtz \rightarrow$ $carb+clay$	Gl, Sph, Py, Cpy, Ag	Qtz, Chl, Ep, clay	Wang, 2008	
24	Jinpin/ Zhenghe/ Fujian	LS	Au: < 5 t @ 1.7–8.1 g/t; Ag: < 200 t @ 152–439 g/t	Subvolcanic rocks	Late Jurassic Nanyuan Fm. volcanic rocks	NNW, NW	Veins in fault zones; biggest: 700×140×500 m	$qtz \rightarrow Au+Ag+PMS+qtz$ $\rightarrow carb+qtz$	Au, Ag, El, Py, Gl, Sph, Cpy, Cc, Cv Arn, Cha,	Qtz, Cal, Chl, Ep	Su, 1996	
25	Xiangluping / Zhenghe/ Fujian	LS	Ag: > 200 t @ 346–4430 g/t; Au: byproduct	Subvolcanic rocks	Late Jurassic Nanyuan Fm. crystal tuff	NNE, N–S	Veins, lens in fault zones; biggest: 200×41×55 m	$phy \rightarrow qtz+Au+Ag \rightarrow carb$ $+qtz$	Ag, Au, El, Gl, Sph, Py, Cpy, Skn, Cv	Qtz, Chl, Ep, Ser, Cal	Fang, 2005	
26	Qinxi/ Zhouning/ Fujian	LS	Ag: < 200 t @ ~ 94.3 g/t	Rhyolite porphyry	Late Jurassic Nanyuan Fm. ignimbrite	NE	Veins in fault zones; biggest: 300×4×100 m	$phy+chl \rightarrow Ag+PMS+qtz$ $\rightarrow fl+carb+kao$	Gl, Sph, Py, Ag, Arn	Qtz, Prl, Ill, Kao, Ser	Chen and Zheng, 1998; Zhou, 2005	

27	Niulukeng/ Minqing/ Fujian	LS	Pb: < 0.1 Mt @ 0.3–5.4%; Zn: < 0.1 Mt @ 0.4–5.5%	Granite porphyry	Late Jurassic Nanyuan Fm. rhyolitic tuff	N–S, NNE	Veins, lens in fault zones; biggest: 200×135×110 m	$phy+chl \rightarrow qtz+Pb+Zn \rightarrow$ $carb+qtz$	Sph, Gl, Py, Po, Cpy	Qtz, Cal, Chl, Ser	Li, 2007
28	Taihuashan/ Youxi/ Fujian	LS	Au: 4 t @ 0.2–24.2 g/t; Ag: 111 t @ 83 g/t	Rhyolite porphyry	Late Jurassic Nanyuan Fm. volcanic rocks intercalated by silicic rock and mudstone Mesoproterozoic Mamianshan Gp.	E–W, NE, NW	Veins, lens in fault zones; biggest: 234×11×3.3 m	$\backslash phy+chl \rightarrow qtz+Au+Ag+$ $PMS \rightarrow carb+qtz$	Au, Py, Cin, Gl, Sph	Qtz, Ser, Kao, Ill, Cal	Lin, 2003; Jiang, 2003
29	Qingyunshan/ n/ Dehua/ Fujian	LS	Au: < 5 t @ 1.5–5.5 g/t	Subvolcanic rocks	metamorphic rocks, Late Jurassic Changlin and Nanyuan Fm. volcanic–sedimentary rocks Mesoproterozoic Mamianshan Gp.	NE, NW, E–W	Veins in fault zones; biggest: 350×190×1.6 m	$phy+chl \rightarrow qtz+Au \rightarrow carb$	Au, Py, Cpy, Bn, Gl, Sph, Cv	Qtz, Ser, Chl, Kao, Cal	Chen and Wu, 2006
30	Xiqian/ Dehua/ Fujian	LS	Au: < 5 t @ 3.7 g/t	Subvolcanic rocks	metamorphic rocks, Late Jurassic Changlin and Nanyuan Fm. volcanic–sedimentary rocks	NW, NE	Veins, lens in fault zones	$phy+chl \rightarrow qtz+Au \rightarrow carb$ $+qtz$	Py, Cpy, Cc, Bn, Tth, Sph, Gl	Qtz, Ser, Cal, Chl	Lin et al., 2005
31	Qiucun/ Dehua/ Fujian	LS	Au: < 5 t @ 3.1–8.2 g/t;	Late Yanshanian diorite porphyry	Late Jurassic Nanyuan and Changling Fm. volcanic rocks,	NE, E–W	Tabular, pipe, pocket controlled by fault zones; biggest: 700×184×8.2 m	$phy+chl \rightarrow Au+qtz \rightarrow car$ $b+qtz$	Py, Gl, Cpy, Sph	Qtz, Ser, Chl, Ep, Cal	Xiang and He, 2000; Chen, 2007

32	Lingtouping / Yongtai/ Fujian	LS	Pb: < 0.1 Mt @ ~ 4.3%; Zn: < 0.1 Mt @ ~ 2.7%; Au: < 5 t @ 1.3–44.4 g/t; Ag: < 200 t @ ~ 80.7 g/t	Subvolcanic rocks	Late Jurassic Nanyuan Fm. pyroclastic rocks	NW	Stratiform, controlled by fault zones	$phy+Au+Ag \rightarrow qtz+carb$ $+chl+Pb+Zn$	Au, Py, Gl, Sph	Qtz, Chl, Cal, Ser, Ep	Shen, 2005
	Xiaban/ Dehua/ Fujian		Au: < 5 t @ 1.0–26.4 g/t; Ag: < 200 t @ 4–232 g/t	Rhyolite porphyry, granite porphyry	Late Jurassic Nanyuan Fm. tuff, cryptoexplosive breccia	NW	Veins, lens in fracture zones and breccias; biggest: 50×110×5 m	$phy+Au \rightarrow carb$	Au, Ag, Py, Gl, Sph, Cpy	Qtz, Ser, Chl, Ep, Cal, Kao, Brt	
34	Xiaxidi/ Fuqing/ Fujian	LS	Ag: < 5 t @ ~ 426.8 g/t	Subvolcanic rocks	Late Jurassic Nanyuan Fm. tuff	NW	Veins in fault zones; biggest: 950×170×6.1 m	$phy+chl \rightarrow Ag+qtz \rightarrow car$ $b+qtz$	Arn, Py, Hes, Cha, El, Gl, Sph	Qtz, Ser, Cal, Prl	Liu and Wu, 1995
35	Siyang/ Putian/ Fujian	LS	Pb: < 0.1 Mt @ 0.4–1.3%; Zn: < 0.1 Mt @ 0.1–5.0%	Subvolcanic rocks	Late Jurassic Nanyuan Fm. tuff	NE, NW	Veins, lens in fault zones	$phy+Pb+Zn \rightarrow carb+qtz$	Gl, Sph, Arn, Cpy, Mo	Qtz, Ser, Cln, Chl	Liang, 2008
	Shengyanjia n/ Anxi/ Fujian		Ag: < 200 t @ 29–279 g/t; Pb: < 0.1 Mt @ 1.0–8.5%; Zn: < 0.1 Mt @ 1.0–3.3%	Subvolcanic rocks	Late Jurassic Nanyuan Fm. rhyolite and tuff	NE	Veins controlled by faults	$phy+Pb+Zn \rightarrow carb+qtz$	Arn, Gl, Sph, Py	Qtz, Ser, Chl, Ep	
37	Qianshan/ Anxi/ Fujian	LS	Pb: > 0.1 Mt @ 0.5–10.5%; Zn: > 0.1 Mt @ 0.1–2.6%	Subvolcanic rocks	Early Triassic Xikou Fm. siltstone, sandstone, hornstone and cryptoexplosive breccias	NE	Veins, lens controlled by fault zones; biggest: 300×350×21 m	$phy+chl+ep \rightarrow Pb+Zn+qt$ $z \rightarrow carb+qtz$	Gl, Sph, Py, Cpy	Cal, Qtz, Ser, Chl, Ep	She, 2007; Huang, 2008

38	Zijinshan/ Shanghang/ Fujian	HS	Cu: 2.3 Mt @ 0.36%; Au: 399.8 t @ 0.2–0.5 g/t	Dacite porphyry	Middle Jurassic medium to fine-grained granite, Yanshanian cryptoexplosive rocks	NW	Veins controlled by caldera-related fault zones and breccias	$phy \rightarrow xalu \rightarrow Au + Cu + di \rightarrow$ qtz	Au, Dig, Ern, Cv, Py	Qtz, Alu, Di, Ser, Prl	So et al., 1998; Zhang et al., 1992, 2001; Zhang, 2013 Zhang et al., 2003a; Lin, 2006; Liu and Hua, 2005; Zhang, 2013
39	Yueyang/ Shanghang/ Fujian	LS	Ag: 1330 t @ ~ 130 g/t; Au: 8.2 t @ 0.3–0.9 g/t; Cu: 0.04 Mt @ ~ 1.1%	Subvolcanic rocks	Middle Jurassic medium to fine-grained granite, Early Cretaceous Shimaoshan Gp. volcanic rocks	NW	Lens, stratiform controlled by fault zones	$phy + chl + Cu \rightarrow xqtz + adl + c$ $arb + Ag + Au \rightarrow qtz$	Ag, El, Arn, Au, Cpy, Py, Gl, Sph	Qtz, Ser, Adl, Cal, Kao	Xiao, 2001; Chen et al., 2008c; Guo and Peng, 2009 Peng and Bu, 2003; Guo and Peng, 2008
40	Songxi/ Meizhou/ Guangdong	LS	Ag: 1199.8 t @ 302.7 g/t; Sb: 0.05 Mt @ 1.65%	Subvolcanic rocks	Early Jurassic Jinji Fm. tuff, sandstone, siltstone	NE	Veins in fault zones	$phy \rightarrow Ag + PMS + qtz \rightarrow Sb$ $+ qtz \rightarrow carb$	Stb, Py, Apy, Tth, Frb, Sph, Mgy, Pyr, Dys, Blr, Gl, Cpy Gl, Sph,	Qtz, Cal, Chl, Ser	Liu, 2009
41	Jianbidong/ Fengshun/ Guangdong	LS	Pb: 0.15 Mt @ 3–28%; Zn: 0.14 Mt @ 3–28%; Cu: byproduct	subvolcanic rocks	Late Jurassic Gaojiping Fm. volcanic rocks	E–W, NW, NE	Lens, veins in fault zones	$phy + chl \rightarrow qtz + Pb + Zn \rightarrow$ $carb + fl$	Cpy, Py, Mr, Cv, Cc	Qtz, Chl, Ser, Cal	Liu, 2009
42	Qinggang/ Wuhua/ Guangdong	LS	Pb: < 0.1 Mt @ 0.4–3.4%; Zn: < 0.1 Mt @ 0.3–2.7%	subvolcanic rocks	Early Jurassic Jinji Fm. sandstone, shale, andesite and tuff	NW	Veins, lens in fault zones	$phy + chl \rightarrow qtz + Pb + Zn \rightarrow$ $carb$	Gl, Sph, Py, Cpy	Qtz, Ser, Chl, Cal	

43	Longtousha n/ Guigang/ Guangxi	LS	Au: > 5 t @ 1.5–37.3 g/t	granite porphyry	Yanshanian rhyolite, cryptoexplosive rocks	S–N, NW, E–W	Veins, lens in caldera-related faults	$tur+kfs \rightarrow tur \pm Au \rightarrow phy \pm A$ $u \rightarrow qtz + PMS + Au \rightarrow kao +$ qtz	Au, Py, Mr, Apy, Cpy, Bs, Gl, Sph	Qtz, Ser, Kao, Tur, Kfs, Chl, Cal	Xie and Sun, 1993; Zhu, 2002
----	---	----	--------------------------	---------------------	---	--------------------	--	---	--	--	---

Abbreviations:

Ore type: HS–high sulfidation; LS–low sulfidation; LS-P–low sulfidation to porphyry

Resources: Mt, million ton; t, ton.

Alteration and mineralization: *Ag*–silver mineralization; *arg*–argillic alteration; *Au*–gold mineralization; *adl*–adularization; *alu*–alunitization; *brt*–baratization; *carb*–carbonatization; *chl*–chloritization; *Cu*–copper mineralization; *di*–dickitization; *ep*–epidotization; *fl*–fluoritization; *hem*–hematitization; *ill*–illitization; *kao*–kaolinitization; *kfs*–potassic feldsparthization; *Pb*–lead mineralization; *phy*–phyllic alteration; *PMS*–polymetallic sulfidization; *qtz*–silicification; *rdn*–rhodonitization; *ser*–sericitization; *Sb*–stibium mineralization; *tur*–tourmalinization; *Zn*–zinc mineralization; *zo*–zoisitization

Ore minerals: *Ag*–native silver; *Apy*–arsenopyrite; *Arn*–argentite; *Au*–native gold; *Blr*–boulangerite; *Bs*–bismuthinite; *Bn*–bornite; *Cav*–calaverite; *Cc*–chalcocite; *Cha*–chlorargyrite; *Cin*–cinnabar; *Cpy*–chalcopyrite; *Cv*–covellite; *Dig*–digenite; *Dom*–domeykite; *Dys*–dyscrasite; *El*–electrum; *Ern*–enargite; *Frb*–freibergite; *Gl*–galena; *Hes*–hessite; *Jmt*–jamesonite; *Ku*–kustelite; *Mgy*–miargyrite; *Mo*–molybdenite; *Mr*–marcacite; *Po*–pyrrhotite; *Pol*–polybasite; *Py*–pyrite; *Pyr*–pyrargrite; *Skn*–skinnerite; *Sph*–sphalerite; *Stb*–stibnite; *Tth*–tetrahedrite

Gangue minerals: *Adl*–adularia; *Alu*–alunite; *Brt*–barite; *Cal*–calcite; *Chl*–chlorite; *Cln*–chalcedony; *Di*–dickite; *Ep*–epidote; *Fl*–fluorite; *Ill*–illite; *Kao*–kaolinite; *Kfs*–K-feldspar; *Prl*–pyrophyllite; *Qtz*–quartz; *Rdn*–rhodonite; *Rds*–rhodochrosite; *Ser*–sericite; *Sid*–siderite; *Tur*–tourmaline; *Zo*–zoisite

Table 2

Table 2 Isotopic ages for epithermal deposits and associated magmatic rocks in the South China Block

No.	Deposit/ County/Province	Sample description	Dated rocks/ minerals	Method	Age/Ma	Data sources
1	Guanshan/ Lishui/Jiangsu	altered dacite	sericite	Ar–Ar plateau	120.8 ± 1.0	Liang et al., 2010a
		altered dacite	sericite	Ar–Ar plateau	116.0 ± 1.3	Liang et al., 2010a
3	Tiantoushan/ Zongyang/Anhui	Zhuanqiao Fm. volcanic rocks	whole rock	K–Ar	140–135	Qiu et al., 1998
4	Yinshan/ Dexing/Jiangxi	Cu–Au mineralized dacite	sericite	Ar–Ar plateau	178.2 ± 1.4	Li et al., 2007
		Cu–Au mineralized dacite	sericite	Ar–Ar plateau	175.4 ± 1.2	Li et al., 2007
		Cu–Au mineralized quartz porphyry	sericite	Ar–Ar plateau	175.3 ± 1.1	Li et al., 2007
		Dacite porphyry	zircon	SHRIMP U–Pb	181 ± 3	Li et al., 2007
		Xishan rhyolite	zircon	LA-ICPMS U–Pb	176 ± 1	Wang et al., 2012
		Jiuqu quartz porphyry	Zircon	LA-ICPMS U–Pb	176 ± 1	Wang et al., 2012
		Beishan quartz porphyry	zircon	LA-ICPMS U–Pb	172 ± 1	Wang et al., 2012
		Jiuqu dacite porphyry	Zircon	LA-ICPMS U–Pb	170 ± 1	Wang et al., 2012
		Xishan andesite porphyry	zircon	LA-ICPMS U–Pb	166 ± 1	Wang et al., 2012
9	Haoshi/ Shengxian/Zhejiang	silver ore	quartz	Rb–Sr isochron	104 ± 5.6	Xu et al., 1994
		silver ore	sericite	K–Ar	95	Xu et al., 1994
10	Bamao /Xinchang/Zhejiang	Ore	whole rock	K–Ar	84.7 ± 3.3	Liu et al., 1990
		Ore	whole rock	K–Ar	75.4 ± 3.1	Liu et al., 1990
		Ore	whole rock	K–Ar	74.9 ± 3.5	Liu et al., 1990
		Ore	whole rock	K–Ar	68.6 ± 3.2	Liu et al., 1990
11	Dalingkou/ Tiantai/Zhejiang	Pb–Zn ore	whole rock	K–Ar	100.4	Hu et al., 1991b
12	Jinjiyan/ Jinhua/Zhejiang	gold ore	whole rock	K–Ar	98	Zhou and Qiu, 1997

		gold ore	whole rock	K–Ar	100	Zhou and Qiu, 1997
14	Longkeng/ Wuyi/Zhejiang	ore	adularia	K–Ar	90	Hu et al., 1991b
15	Zhilintou/ Suichang/Zhejiang	gold and silver ore	whole rock	Rb–Sr isochron	140–144	Chen and Xu, 1997
		ore from orebody No. 3 •	quartz	Rb–Sr isochron	127.1 ± 6.8	Chen and Xu, 1997
		ore from orebody No. 4	quartz	Rb–Sr isochron	159.9 ± 5.4	Chen and Xu, 1997
		Cu ore vein	quartz	Rb–Sr isochron	164	Zhou and Qian, 1996
		Cu ore vein	quartz	Rb–Sr isochron	107.6	Zhou and Qian, 1996
		post-ore felsophyre	zircon	TIMS U–Pb	104.8 ± 0.8	Zhou and Qian, 1996
		granite porphyry	zircon	TIMS U–Pb	148 ± 0.5	Zhou and Qian, 1996
		concealed granite porphyry	zircon	SIMS U–Pb	113.6 ± 1	Zeng et al., 2013
		Mo ore	molybdenite	Re–Os isochron	110.1 ± 1.8	Zeng et al., 2013
18	Wubu/ Huangyan/Zhejiang	rhyolite	whole rock	K–Ar	105	Huang et al., 1983
19	Babaoshan/ Longquan/Zhejiang	gold ore	whole rock	Rb–Sr isochron	140 ± 5	Ying et al., 1997
20	Huaixi/ Pingyang/Zhejiang	ore-bearing quartz vein	quartz	Rb–Sr isochron	101 ± 2	Li et al., 2010
34	Xiaxidi/ Fuqing/Fujian	silver ore	quartz	Rb–Sr isochron	100 ± 5	Zhu et al., 1995
		Shimaoshan Gp. pyroclastic rock	whole rock	Rb–Sr isochron	103.1 ± 6.7	Zhu et al., 1994
		Shimaoshan Gp. pyroclastic rock	whole rock	Rb–Sr isochron	105.4 ± 3	Zhu et al., 1994
38	Zijinshan/ Shanghang/Fujian	alunitization Cu ore	alunite	laser Ar–Ar	103.3 ± 1.2	unpublished data
		disseminated Cu ore	alunite	laser Ar–Ar	102.8 ± 1.3	unpublished data
		mineralized breccias	alunite	laser Ar–Ar	103.3 ± 1.2	unpublished data
		alunite stringer with disseminated mineralization	alunite	laser Ar–Ar	103.2 ± 1.5	unpublished data

		alunite vein	alunite	laser Ar-Ar	103.3 ± 1.5	unpublished data
		gold ore	quartz	Rb-Sr isochron	100 ± 3	Chen, 1996
		copper ore	alunite	K-Ar	103.8	Zhang et al., 1992
39	Yueyang/ Shanghang/Fujian	gold, silver ore vein	adularia	Ar-Ar isochron	94.7 ± 2.3	Zhang et al., 2003a
		gold-bearing quartz vein	adularia	Ar-Ar plateau	91.5 ± 0.4	Liu and Hua, 2005
40	Songxi/ Meizhou/Guangdong	altered andesitic basalt	whole rock	K-Ar	134.8	Cai, 1996
43	Longtoushan/ Guigang/Guangxi	ore-related granite porphyry	zircon	SHRIMP U-Pb	100.3 ± 1.4	Chen et al., 2008b
		ore-related rhyolite	zircon	SHRIMP U-Pb	103.3 ± 2.4	Chen et al., 2008b

Table 3

Table 3 Fluid inclusion types, microthermometric results and δD , $\delta^{18}O$ and $\delta^{13}C$ ratios for selected epithermal deposits in the South China Block

No.	Deposit	Fluid inclusion types	Th (°C)	Salinity (wt.%)	Density (g/cm ³)	Pressure (Mpa)	Depth (km)	δD (‰)	¹⁸ O _{water} (‰)	¹³ C (‰)	Data source
1	Guanshan	WL, WV	133–304	0.5–7.4	0.70–0.98			–81 to –90	+0.1 to +10.8	–1.2 to 2.9	Liang et al., 2008; 2010b; Xia, 1995
4	Yinshan	WL, WV, S	130–520	2.4–58.8		<26	<1	–42.7 to –78.9	+0.2 to +11.3		Zhang et al., 2003c, 2007; Wang et al., 2013a
9	Haoshi							–60 to –68	–1.6 to –2.4		Xu, 1994; Xu et al., 1994
10	Bamao	WL, WV	109–303	4.5–8.5	0.76–1.00	20–57.6	0.6–1.6	–109to –59.6	–7.5 to +6.6		Liu et al., 1990; Lu et al., 1997
11	Dalingkou	WL, WV	102–310	0.1–8.1		13–40	0.5–1.5	–101.0 to –70.4	–6.7 to +4.1		Lu et al., 1997; Zhu et al., 2009
15	Zhilingtou	WL, WV, S	119–400	4.1–16.0		22–64	0.7–2.0	–73 to –59	–8.0 to +3.1	–5.6 to –5.4	Xu et al., 1988; Chen and Xu, 1997
18	Wubu	WL, WV	160–360	2.9–10.9		5–14.5	0.5–1.5		–7.1 to –6.0		Lu et al., 1997; Zhu et al., 2009
38	Zijinshan	WL, WV, C	100–380	0.1–21.6	0.3–1.1	10–58.3	1.0–2.1	–78 to –55	–4.9 to +10.3		Zhang et al., 1992; Chen, 1999; Zhong et al., 2016b
39	Yueyang	WL, WV	120–260	0.9–5.0	0.4–1.1	4–5	0.4–0.5	–55.1 to –11.9	–3.42 to +1.92		Lin, 2006; Zhong et al., 2016c
40	Songxi	WL, WV	80–300	2.2–19.4	0.7–1.0	15–19	0.6– 0.7	–78.0 to –43.6	–6.8 to +7.0	–6.8 to –0.5	Yao et al., 1996; Xiao, 2001; Chen et al., 2008c
43	Longtoushan	WL, WV	177–286					–60.8 to –79.5	–2.2 to –7.4		Huang et al., 1999; Zhu, 2002

Abbreviations:

FI type: WL, liquid-rich aqueous inclusion; WV, vapor-rich aqueous inclusion; C, CO₂-H₂O inclusion; S, daughter mineral-bearing inclusion; Th–homogenization temperature; The mineralization depths for epithermal deposits in SCB were calculated under either hydrostatic or lithostatic pressure, as the pressures usually fluctuate in porphyry–epithermal environment.

Table 4

Table 4 $\delta^{34}\text{S}$ values and Pb isotopic compositions of selected epithermal deposits in the South China Block

No.	Deposit	$\delta^{34}\text{S}$ (‰)	$^{206}\text{Pb}/^{204}\text{Pb}$	$^{207}\text{Pb}/^{204}\text{Pb}$	$^{208}\text{Pb}/^{204}\text{Pb}$	Data source
1	Guanshan	−0.9–+2.0; +5.6–+9.9				Liang et al., 2008; 2010b; Xia, 1995
4	Yinshan	−2.5–+4.1; −10–−12.2	17.880–18.168	15.389–15.722	37.633–38.568	Zhang et al., 2003c; Wang et al., 2013a; Jiang, 1992
9	Haoshi	−0.3–+6.6	18.296–18.43	15.585–15.751	38.595–39.136	Xu et al., 1994
10	Bamao	−9.8–+3.8	18.336–18.506	15.540–15.777	38.540–39.132	Liu et al., 1990; Lu et al., 1997
11	Dalingkou	−6.8–+7.4	17.099–18.960	15.350–15.637	38.370–41.650	Lu et al., 1997; Zhu et al., 2009
15	Zhilingtou	+1.2–+5.9	16.886–18.624	15.431–15.799	36.512–39.385	Xu et al., 1988; Chen and Xu, 1997
18	Wubu	−4.0–+6.3	17.990–18.270	15.370–15.640	37.740–38.370	Lu et al., 1997; Zhu et al., 2009
38	Zijinshan	−8.4–+5.1	18.408–18.600	15.604–15.874	38.437–39.203	Zhang et al., 1992; Chen, 1999
39	Yueyang	−6.5–+4.8				Lin, 2006
40	Songxi	−11.3–+14.3	18.136–18.983	15.649–15.848	38.461–39.229	Yao et al., 1996; Xiao, 2001; Chen et al., 2008c
43	Longtoushan	−9.8–+2.5	18.159–19.019	15.652–16.169	38.611–40.242	Huang et al., 1999; Zhu, 2002