Miner Deposita (2012) 47:579–588
DOI 10.1007/s00126-012-0431-6

ARTICLE

Multiple Mesozoic mineralization events in South China—an introduction to the thematic issue

Rui-Zhong Hu · Mei-Fu Zhou

Received: 8 June 2012 / Accepted: 25 June 2012 / Published online: 14 July 2012

Abstract Mesozoic mineral deposits in South China include world-class deposits of W, Sn and Sb and those that provide the major sources of Ta, Cu, Hg, As, Tl, Pb, Zn, Au and Ag for the entire country. These deposits can be classified into polymetallic hydrothermal systems closely related to felsic intrusive rocks (Sn–W –Mo granites, Cu porphyries, polymetallic and Fe skarns, and polymetallic vein deposits) and low-temperature hydrothermal systems with no direct connection to igneous activities (MVT deposits, epithermal Au and Sb deposits). Recent studies have shown that they formed in the Triassic (Indosinian), Jurassic–Cretaceous (Early Yanshanian), and Cretaceous (Late Yanshanian) stages. Indosinian deposits include major MVT (Pb–Zn–Ag) deposits and granite-related W–Sn deposits. Early Yanshanian deposits are low-temperature Sb–Au and high-temperature W–Sn and Cu porphyry types. Many Late Yanshanian deposits are low-temperature Au–As–Sb–Hg and U deposits, and also include high-temperature W–Sn polymetallic deposits. The formation of these deposits is linked with a specific tectonothermal evolution and igneous activities. This special issue brings together some of the latest information in eight papers that deal with the origins and tectonic environments of mineral deposits formed in these stages. We anticipate that this issue will stimulate more interests in these ore deposits in South China.

Keywords South China · Mesozoic · Metallogenesis

R.-Z. Hu (✉)
State Key Laboratory of Ore Deposit Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences,
Guiyang 550002, China
e-mail: huruizhong@vip.gyig.ac.cn

M.-F. Zhou
Department of Earth Sciences, The University of Hong Kong,
Hong Kong, China

Tectonic division and igneous activities

The South China Craton in the southeastern part of the Eurasian continent is made up of the Yangtze and Cathaysia Blocks (Fig. 1), which were welded together along the Jiangnan orogenic belt around 830 Ma (Zhao et al. 2011). South China is bounded by the North China Craton to the north, the Songpan–Ganzi Terrane of the Tibetan Plateau to the northwest, and the Indochina Craton to the south (Fig. 1).

The basement of the Yangtze Block consists of late Archean rocks in the north and younger, only weakly metamorphosed Mesoproterozoic to Neoproterozoic rocks in the west and east, intruded by widespread Neoproterozoic igneous bodies (Zhou et al. 2002). The sedimentary cover of the Yangtze Block consists mainly of folded Paleozoic and Early Mesozoic strata of shallow marine origin and Jurassic, Cretaceous, and Cenozoic strata of continental facies (Yan et al. 2003).

In the Cathaysia Block, the basement is composed of 1.9–1.8 Ga sedimentary rocks and Neoproterozoic to Early Paleozoic metamorphic rocks (Yu et al. 2005). Due to the Early Paleozoic (Caledonian) orogeny, Late Ordovician to Middle Devonian strata are absent but there are widespread granitic intrusions with ages ranging from 480 to 400 Ma (Yu et al. 2005).

Indosinian (Triassic) magmatism produced voluminous granitic plutons in South China, particularly in Hunan, Jiangxi, and Guangxi Provinces (Chen and Jahn 1998). The granitic rocks have a wide range of ages, from ca. 260 to 200 Ma (Wang et al. 2005, 2007; Zhou et al. 2006; Chen et al. 2011). The origin of the Indosinian magmatism is thought to be due to NW-trending flat subduction of the Pacific plate underneath South China, leading to northwestward migration of shortening and broadly zonal distribution of plutons (Cui and Li 1983; Li and Li 2007). The Indosinian deformation and magmatism were also influenced by the collision between the Indochina and South China Cratons in response to the closure of the Paleotethys Ocean (Wang et al. 2005, 2007; Zhou et al. 2006; Lepvrier et al. 2008; Chen et al. 2011).

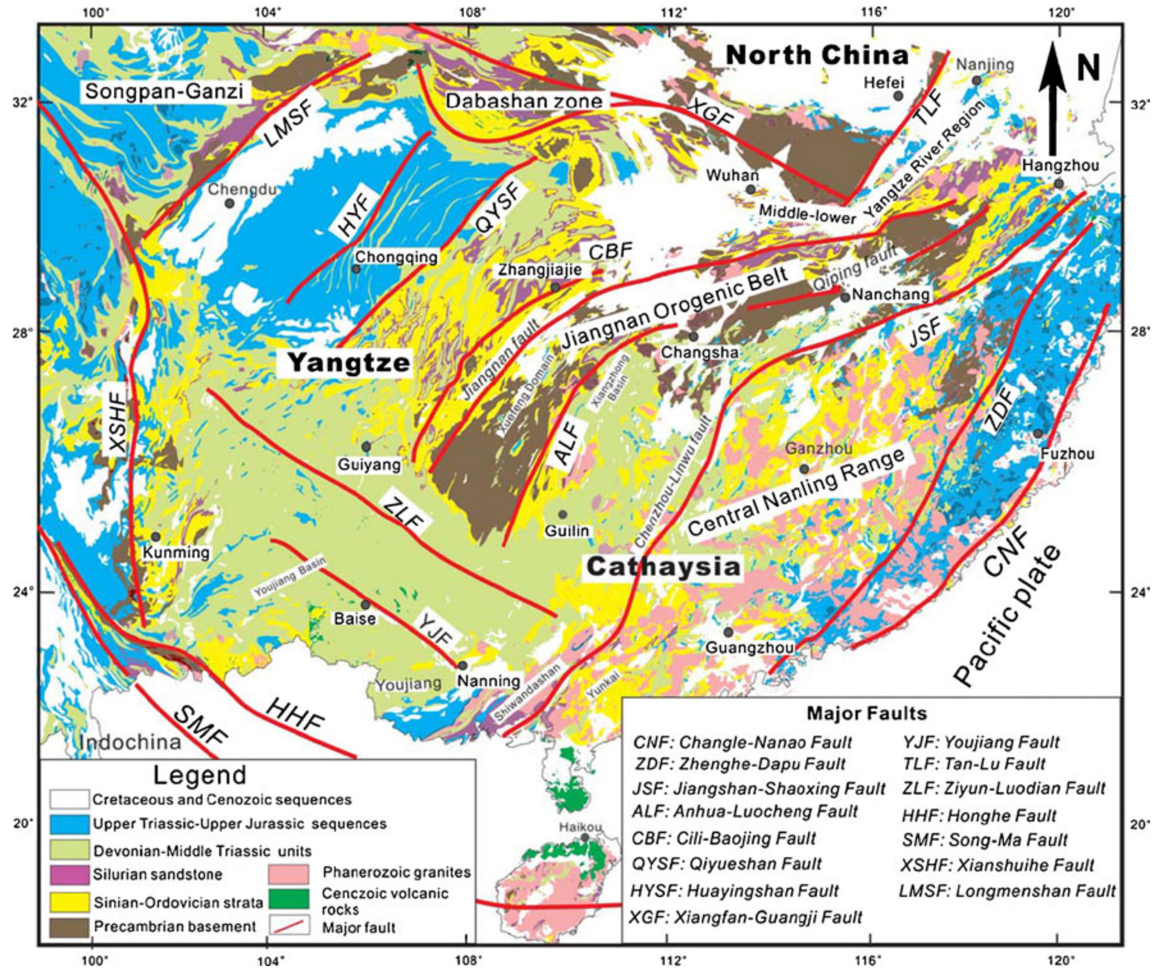

Fig. 1 Tectonic divisions of South China (adapted from Wang et al. 2012)

A profound feature of South China is the giant Yanshanian igneous province, which forms a swath >1,000 km wide across the whole Cathaysian Block and the eastern part of the Yangtze Block (Li and Li 2007). The granitic rocks in this province range in age from Jurassic to Cretaceous, notably the Early (180–125 Ma) and Late (110–85 Ma) Yanshanian periods. The formation of this igneous province was probably related to the westward subduction of the Pacific oceanic lithosphere beneath the Eurasian continent.

The Early (180–125 Ma) Yanshanian igneous rocks include 180–170 Ma bimodal volcanic rocks in southern Hunan, southern Jiangxi, and southwestern Fujian Provinces, aluminous A-type granites in southern Jiangxi Province, and granodiorites in southeastern Hunan and northeastern Jiangxi Provinces (Li et al. 2007b). A group of dominantly 165–150-Ma granitic rocks is widespread in the central Nanling Range and neighboring regions. These are biotite and two-mica granites associated with minor amounts of granodiorite, A-type granite, and potassic syenite (Li et al. 2007b; Wang et al. 2011) which formed in an extensional environment related either to intraplate rifting (Gilder et al. 1991; Li 2000; Wang et al. 2011) or flat-slab subduction and slab-foundering (Li and Li 2007). A third group of 145–125 Ma granitic rocks is widespread in the region around the middle and lower reaches of the Yangtze River. These consist of diorite, quartz diorite, monzodiorite, and granodiorite similar to I-type granitoids (Zhou et al. 2008).

The Late Yanshanian (110–85 Ma) granitic rocks consist mainly of biotite granites in the western Nanling Range (Cheng and Mao 2010) and felsic volcanic rocks in the coastal region of the Cathaysia Block (Zhou et al. 2006).

Distribution of Mesozoic mineral deposits in South China

South China is well known for its large-scale mineralization during the Mesozoic, making the region one of the most important polymetallic metallogenic provinces in the world. Of particular importance are world-class deposits of W, Sn, and Sb (Hua et al. 2005; Peng et al. 2003, 2006; Mao et al. 2011) and some of the largest Ta, Cu, Hg, As, and Tl deposits in China (Xiong 1991; Pan et al. 1999; Lu et al. 2005; Hu et al. 2007). The known resources of Pb, Zn, Au, and Ag are also among the most important in the entire country. These deposits can be classified into polymetallic hydrothermal systems closely related to felsic intrusive rocks (tin–tungsten–molybdenum granites, copper porphyries, polymetallic and iron skarns, and polymetallic vein deposits) and low-temperature hydrothermal systems with no direct connection to igneous activities (MVT deposits, epithermal gold and antimony deposits). This deposit spectrum formed in the Triassic (Indosinian), Jurassic–Cretaceous (Early Yanshanian), and Cretaceous (Late Yanshanian). Indosinian deposits include major MVT (Pb–Zn–Ag) deposits and granite-related W–Sn deposits. The Early Yanshanian deposits are low-temperature Sb–Au and high-temperature W–Sn and Cu porphyry types. Many Late Yanshanian low-temperature Au–As–Sb–Hg and U deposits, and high-temperature W–Sn polymetallic deposits are also present. The formation of these deposits is linked with a specific tectonothermal evolution with three stages of igneous activities (Figs. 2, 3, 4, and 5).

Major granite-related deposits in South China occur in all three stages, including porphyry, skarn, and vein type deposits of W, Sn, Mo, Ta, Li, Be, Cu, Fe, Pb, Zn, Au, and Ag, which are distributed in the Nanling Range and neighboring areas, middle–lower Yangtze River region, and southeastern coastal region (Figs. 2, 3, 4, and 5). In general, these deposits are coeval with the emplacement of the host granites, and the ore-forming fluids have a major magmatic component, although meteoric water is invariably involved. Tungsten, Sn, Ta, Li, and Be deposits are generally associated with S-type or A-type granites, whereas Cu and Fe deposits are related to I-type granites (Ye et al. 1998; Hua et al. 2005; Wang et al. 2011). The polymetallic deposits of Pb–Zn–Au–Ag occur in both settings.

In contrast, numerous low-temperature, hydrothermal Hg, Sb, As, Tl, and Cd deposits, Carlin-type gold deposits, and MVT-type Pb–Zn deposits occur predominantly continent-inward in the southwestern part of the South China Craton over an area of about 0.5 million km^2 (Zhou et al. 2001; Hu et al. 2002; Peng et al. 2003; Su et al. 2009; Zhang et al. 2009). In this region, Proterozoic low-grade, metamorphic clastic rocks and thick Paleozoic and Mesozoic carbonate sequences allowed basin-wide fluid circulation where meteoric and basinal fluids leached the basement and overlying strata with magmatic input either lacking or doubtful (Zhou et al. 2001; Hu et al. 2002; Peng et al. 2003; Zhang et al. 2009; Gu et al. 2012).

The three stages of mineralization were closely related to the Indosinian and Yanshanian orogenic events. However, the tectonic regime responsible for the felsic magmatism is still a matter of debate, although it is generally accepted that in South China underwent both compressional and extensional deformation in the Mesozoic–Cenozoic as illustrated in Fig. 2. Different models, including various forms of subduction of the paleo-Pacific plate beneath the Eurasian plate, have been proposed in the last few decades (Li and Li 2007; Li et al. 2007b).

Indosinian mineral deposits

Chuan–Dian–Qian Pb–Zn deposits

More than 400 Pb–Zn–(Ag) ore deposits are known in the western Yangtze Block, including the world-class Huize deposit of Yunnan Province, and four large deposits, namely the Tianbaoshan and Daliangzi deposits of Sichuan Province and the Maoping and Maozu deposits of Yunnan Province (Fig. 3).

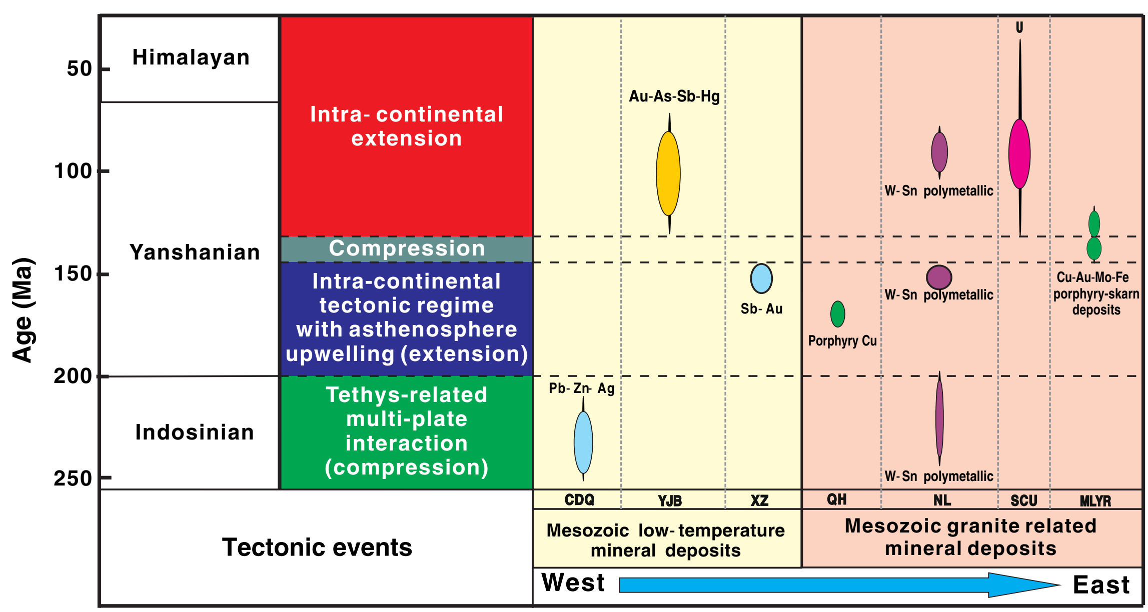

Fig. 2 Mesozoic tectonic regimes and metallogenic epochs of South China. *CDQ* Sichuan–Yunnan–Guizhou, *YJB* Youjiang basin, *XZ* Xiangzhong basin, *QH* Qing-Han Belt, *NL* Nanling, *SCU* South China uranium deposits, *MLYR* Middle–Lower Yangtze River region

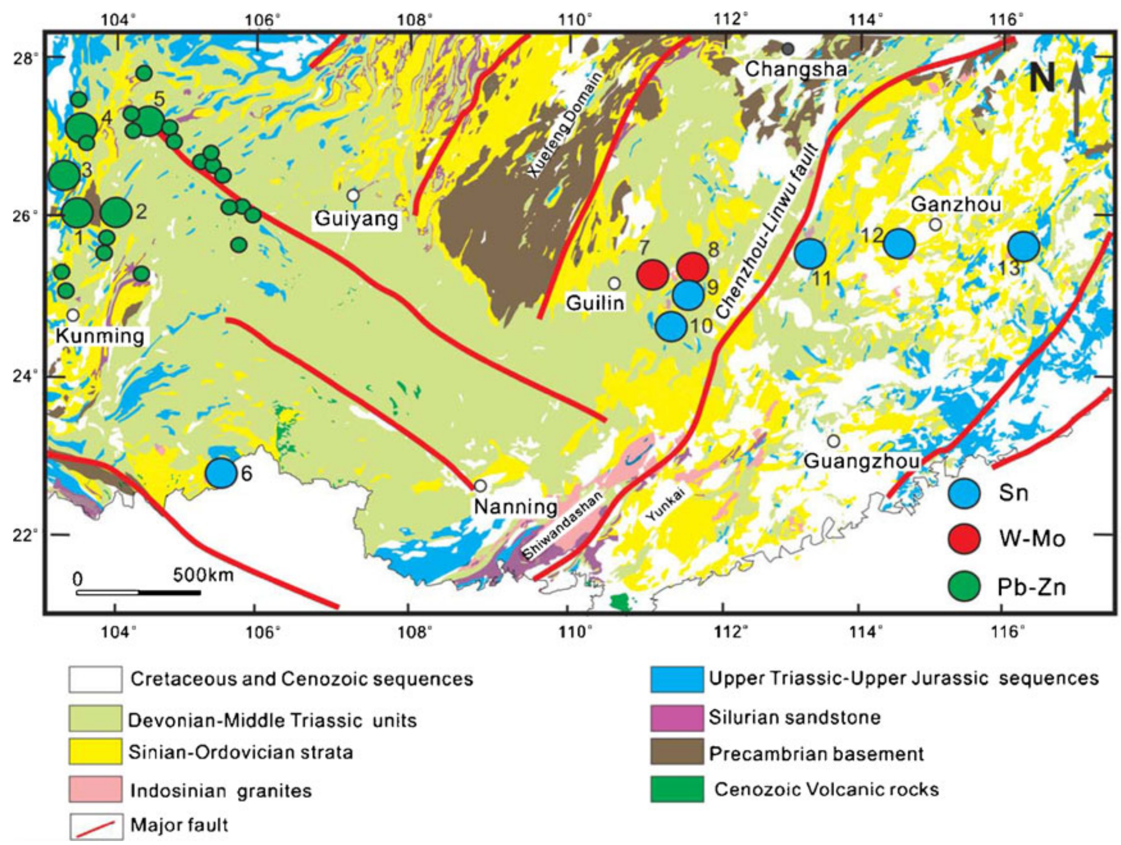

Fig. 3 Distribution of Triassic (Indosinian) MVT-style Pb–Zn–Ag deposits and granite-related Sn and W–Mo deposits. Deposits: *1* Maozu, *2* Huize, *3* Daliangzi, *4* Tianbaoshan, *5* Maoping, *6* Xinzai, *7* Gaoling, *8* Yuntoujie, *9* Liguifu, *10* Limu, *11* Hehuaping, *12* Xianetang, *13* Hongshan

These deposits form the important Chuan (Sichuan)–Dian (Yunnan)–Qian (Guizhou) (CDQ) Pb–Zn metallogenic province with total Pb+Zn metal resources of 20 Mt and have been the major source of base metals in China over the past several decades (Zhang et al. 2009).

The Pb–Zn deposits are hosted in Neoproterozoic to Permian carbonate strata and likely formed at 245–225 Ma (Li et al. 2004a, b), coincident with the collision between the Indochina and South China Cratons. Their ore-forming processes were similar to those of MVT-type deposits elsewhere, involving extraction of ore-forming elements from country rocks by broad-scale convective circulation of basin-related fluids and subsequent precipitation of these elements in favorable structural and lithological units (Zhou et al. 2001; Zhang et al. 2009).

Indosinian Sn and W–Mo deposits

These deposits were related to late Indosinian granitic magmatism in the Nanling Range. Several large Sn and W–Mo deposits were recently dated at 200–230 Ma using molybdenite Re–Os and muscovite $^{40}Ar/^{39}Ar$ dating methods (Cai et al. 2006; Wei et al. 2007; Yang et al. 2009; Feng et al. 2011). They are mainly of quartz vein-type, and include the Xinzai tin deposit in eastern Yunnan Province, the Gaoling and Yuntoujie W–Mo deposits in eastern Guanxi Province, the Limu and Liguifu Sn polymetallic deposits in eastern Guanxi Province, the Hehuaping Sn polymetallic deposit in southern Hunan Province, the Xianetang Sn polymetallic deposit in southern Jiangxi Province, and the Hongshan Sn polymetallic deposits in western Fujian Province (Fig. 3). The mineralization is associated with the 200–235 Ma intrusionsof S-type granites under a compressional setting produced by northward flat slab subduction underneath South China and collision of the South China Block with the Indochina and North China Blocks (Wang et al. 2005, 2007; Lepvrier et al. 2008; Chen et al. 2011).

Early Yanshanian mineral deposits

W–Sn deposits

The broad-scale Yanshanian granitic magmatism in South China resulted from amalgamation of the Indochina, South China, and North China Blocks. Numerous W–Sn polymetallic deposits formed in the period of 160–150 Ma in the central

Nanling Range (Mao et al. 2004, 2011; Peng et al. 2006; Hu et al. 2012b). These deposits are typically enriched in Mo, Bi, Pb, Zn, Cu, and Ag. Several giant deposits in this region include the Shizhuyuan W–Sn–Mo–Bi–F, Furong Sn, Yaogangxian W, and Xianghualing Sn–W deposits (Fig. 4). The Furong Sn polymetallic deposit was discovered in the late 1990s and is expected to become a world-class tin producer (Li et al. 2007). Despite extensive mining since the 1930s, the central Nanling region is still rich in W and Sn, with metal resources of 1.7 Mt W and 1.2 Mt Sn.

There are three main types of W–Sn mineralization in this region, i.e., greisen-, skarn-, and quartz vein-type (Peng et al. 2006; Hu et al. 2012a, b; Wei et al. 2012). All three types commonly occur together in most deposits, but they can also

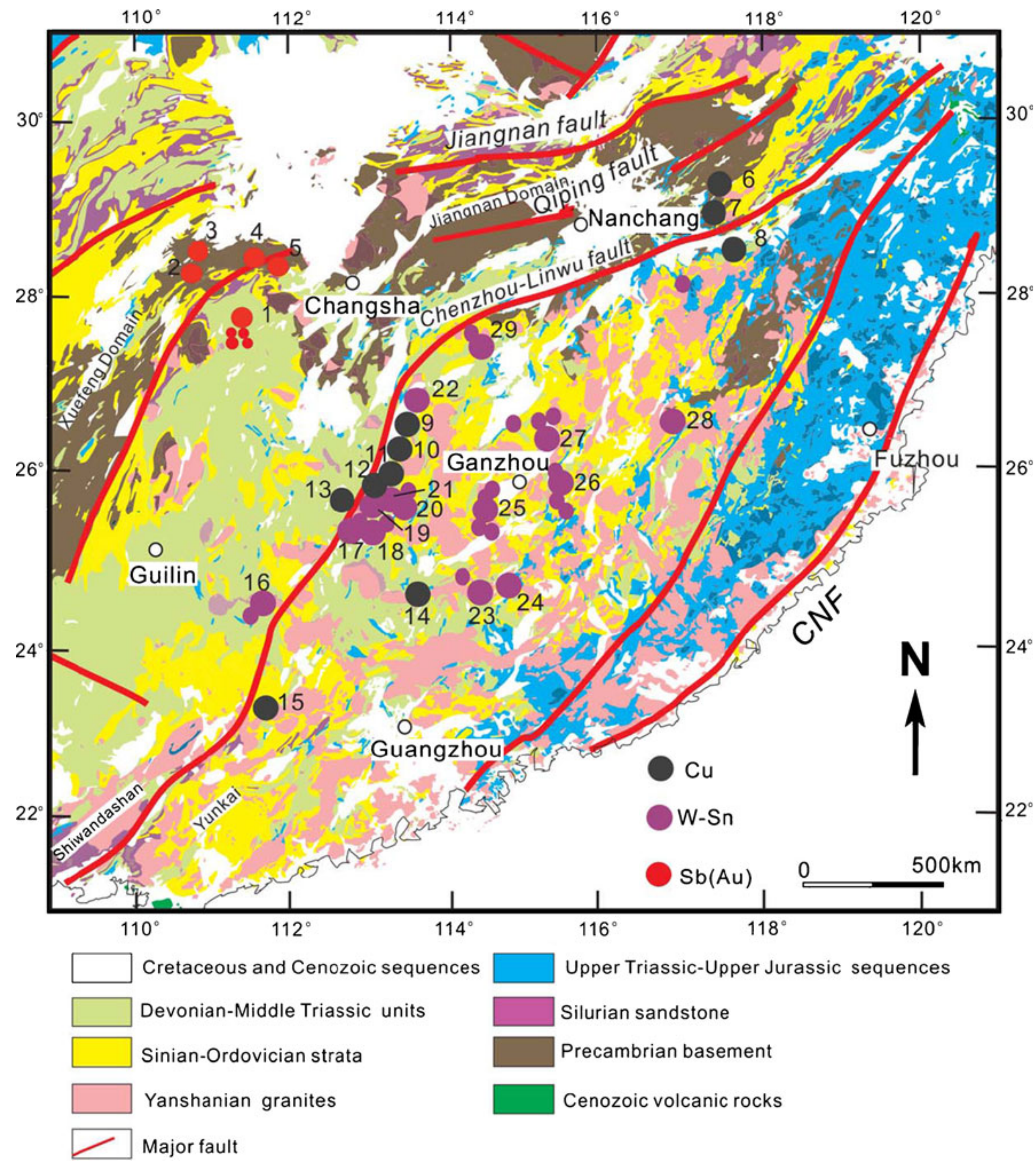

Fig. 4 Distribution of Jurassic (Early Yanshanian) low-temperature Sb–Au and granite-related W–Sn and Cu porphyry deposits. Note that porphyry copper deposits occur in the broadly NE trending Qing–Han belt over 2,000 km, parallel to the regional Chenzhou–Linwu fault. Deposits: *1* Xikuangshan, *2* Zhazixi, *3* Woxi, *4* Fuzhuxi, *5* Banxi, *6* Dexing, *7* Yinshan, *8* Yongping, *9* Qibaoshan, *10* Shuikoushan, *11* Baoshan, *12* Huangshaping, *13* Tongshanling, *14* Dabaoshan, *15* Yuanzhuding, *16* Sanhu, *17* Xianghualing, *18* Furong, *19* Xintianling, *20* Shizhuyuan, *21* Yaogangxian, *22* Xitian, *23* Dajishan, *24* Guimeishan, *25* Xihuashan, *26* Pangushan, *27* Huameiao, *28* Xingluokeng, *29* Hukeng

occur separately. All these deposits are spatially, temporally, and genetically related to widespread Mesozoic granitic intrusions with zircon U–Pb ages of 150–160 Ma, believed to have been produced by crustal anatexis (Hu et al. 2012a, b; Wei et al. 2012). Tungsten and tin deposits usually occur close to the contact and apical zones of the intrusions and their Devonian to Permian sedimentary wall rocks. The magmatic–hydrothermal fluids have variable meteoric components.

Porphyry copper deposits

Major porphyry copper deposits occur in the broad NE trending Qing-Han belt over 2,000 km, which runs parallel to the regional Chenzhou–Linwu fault. Mineralization is associated with 180–170 Ma porphyry systems including the giant Dexing Cu porphyry cluster in the northeast (Lu et al. 2005; Li and Sasaki 2007) and the Dabaoshan deposit in the south (Wang et al. 2011) (Fig. 4). There are several skarn Cu–Pb–Zn deposits at Huangshaping, Baoshan, Tongshanling, Shuikoushan, and Qibaoshan in the southern part of the belt, and a subvolcanic intrusion-related Cu–Au deposit at Yinshan in the northeastern part (Li et al. 2007a). The copper porphyry systems are related to I-type magnetite-series multiple felsic intrusions. There is an offset of about 20 Myr between the 180–170 Ma Qing-Han Cu porphyry belt and 160–150 Ma tin granites in broadly the same region. This age gap needs further refinement in order to understand the metallogenic evolution of South China. It is remarkable that a similar situation exists at the active South American continental margin where the 25–10-Ma Central Andean tin belt in southernmost Peru and Bolivia is about 10–20 Ma younger than the major Cu porphyry systems in northern Chile and southern Peru (Lehmann et al. 1990).

Sb–Au deposits

There are more than 170 Sb deposits within the Xuefeng Range and Xiangzhong Basin (Fig. 4). In the Xuefeng Range, Sb mineralization most commonly occurs in Proterozoic, Sinian, and Cambrian clastic rocks, and has associations of Sb–(Au–W). Examples are the Woxi Sb–Au–W, Zhazixi Sb–W, Fuzhuxi Sb–Au, and Banxi Sb deposits.

Antimony deposits in the Xiangzhong Basin are hosted in Sinian–Permian and Cretaceous strata, with those having the greatest economic significance occurring primarily in Devonian and Carboniferous strata. The giant Xikuangshan stibnite deposit lies in the central part of the Xiangzhong Basin and formed at about 155 Ma (Hu et al. 1996; Peng et al. 2003), hosted by carbonate rocks and minor clastic rocks.

Late Yanshanian mineral deposits

Au–As–Sb–Hg–Tl–Cd deposits

Gold, Hg, Sb, As, Tl, and Cd deposits in the Youjiang Basin and adjacent areas include Carlin-type Au and vein-type Hg, Sb, As, Tl, and Cd deposits (Fig. 5). They are hosted in Neoproterozoic to Triassic carbonate and clastic rocks, with most of the Au deposits occurring in Triassic strata, the Hg deposits in Cambrian strata and the Sb deposits in Devonian strata. These deposits probably formed during the period of 135–80 Ma, based on limited dating results, although ages of about 200 Ma are also possible (Hu et al. 2007; Su et al. 2009; Gu et al. 2012).

Carlin-type gold deposits in this region were discovered in the 1980s. These low-temperature, hydrothermal deposits were formed by large-scale migration of meteoric and/or basin-related fluids, and the ore-forming elements were derived from the basement and surrounding strata (Hu et al. 2002; Su et al. 2009).

The formation of the Carlin-type Au and vein-type Hg, Sb, As, Tl, and Cd deposits at 135–80 Ma was contemporaneous with the emplacement of mantle-derived, mafic dikes, which were related to mantle upwelling and lithospheric extension, and probably triggered hydrothermal fluid circulation and leaching of ore-forming elements from the basement and country rocks to form the deposits (Hu et al. 2007).

Sn polymetallic deposits

Several world-class Sn polymetallic deposits in the western Nanling Range include the Gejiu Sn–Cu deposit in Yunnan Province, the Dachang Sn–Sb deposit in Guanxi Province, and the Dulong Sn–Zn deposit in Yunnan Province (Fig. 5). There are three main types of Sn mineralization, i.e., skarn-, stratiform-, and quartz vein-types which are commonly found together in the same deposits. Although there are different opinions regarding the genesis of the deposits, they were likely formed from magmatic–hydrothermal events at 100–80 Ma. For example, the Gejiu Sn deposit has a molybdenite Re–Os isochron age of 83±2 Ma and model age of 83±1 to 84±1 Ma, in good agreement with a zircon LA–ICP–MS U–Pb age of 85.0±0.9 Ma for the granite (Yang et al. 2008).

U deposits

Vein-type uranium deposits in South China have been the major source of this metal for the country in the past several decades. The major deposits formed at around 120–80 Ma when South China experienced major extension and mantle upwelling, and are hosted in granitic, volcanic, and

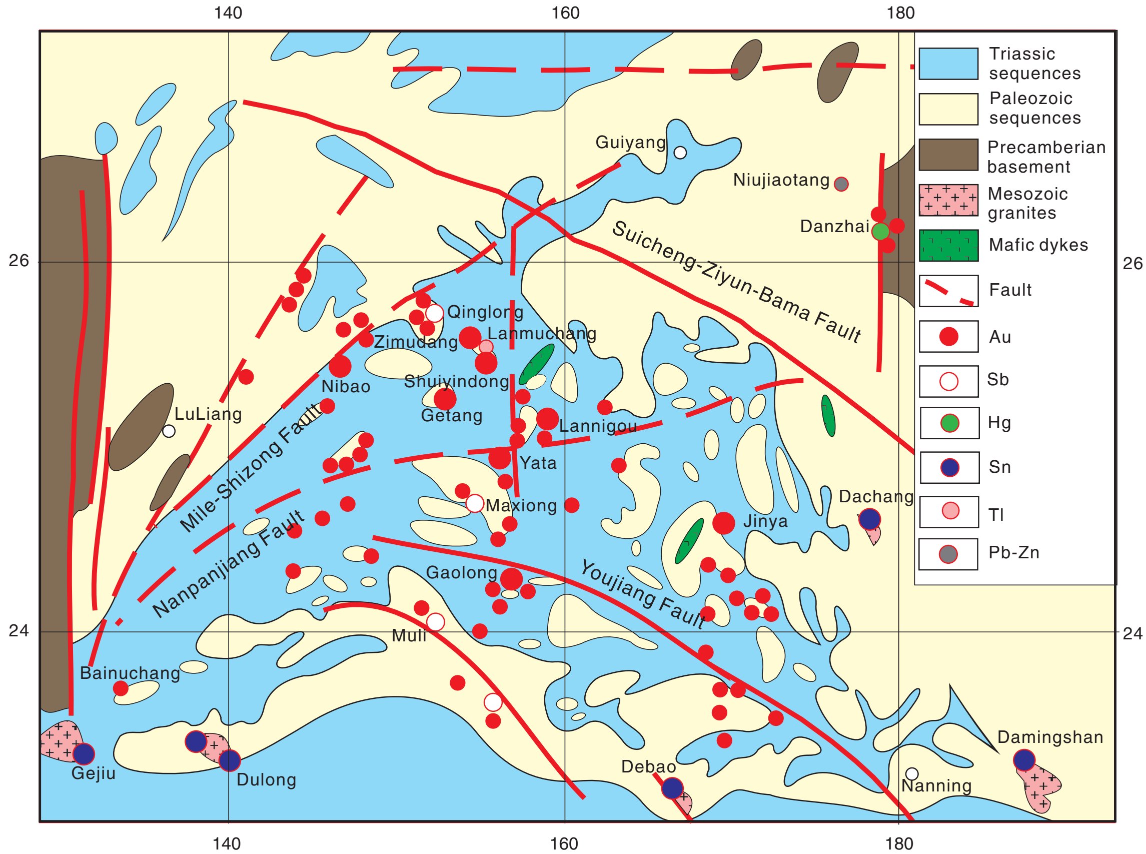

Fig. 5 Distribution of Cretaceous (Late Yanshanian) low-temperature Au–As–Sb–Hg and granite-related Sn polymetallic deposits in the Youjiang Basin and adjacent areas. Note that the basin is confined between the Mile–Shizong and Ziyun–Luodian faults

carbonaceous and siliceous, pelitic sedimentary rocks (Hu et al. 2008). The uranium deposits are spread over the whole Cathaysian Block and also occur in the Jiangnan orogenic belt. They are associated with Cretaceous–Tertiary extensional basins and mantle-derived igneous rocks which induced hydrothermal fluid circulation and leaching of U from the uranium-rich crustal rocks including granites (Hu et al. 2008). The formation of vein-type uranium deposits elsewhere in the world also has been linked to the emplacement of mafic dikes or crustal extension such as those in Hercynian granites of the La Crouzille district of the Massif Central, France (Ruzicka 1993).

Cu–Au–Mo–Fe deposits in the Middle–Lower Yangtze River region

The Middle–Lower Yangtze River region on the northern margin of the Yangtze Block is one of the most important metallogenic belts in South China. It extends from Wuhan (Hubei Province) in the west to Zhenjiang (Jiangsu Province) in the east. It comprises several ore clusters, dominated by Mesozoic (100–150 Ma) granite-related Cu–Fe–Au–Mo mineralization, but there are also magnetite–apatite deposits (Zhai et al. 1996; Pan and Dong 1999; Mao et al. 2006, 2009). The former are related to high-K calc-alkaline, I-type granitoids, including diorite, quartz diorite, and granodiorite. The latter belong to the shoshonite series consisting of pyroxene diorite porphyry, diorite porphyry, syenitic granite porphyry, and their corresponding eruptive rocks. The genesis of the porphyry–skarn and stratabound Cu–Au–Mo–Fe deposits has been debated for a long time. These ore systems are thought to be skarns since most orebodies are hosted in both calc- and magnesian-silicate rocks formed by metasomatism of carbonate rocks and hornfels (Pan and Dong 1999; Zhao et al. 1999; Zhou et al. 2008; Mao et al. 2009). The magnetite–apatite deposits in the Cretaceous basins are considered to have formed in continental subvolcanic hydrothermal systems or to be porphyry-type iron deposits (Zhang 1986), similar to the Kiruna type (Yu and Mao 2002).

The mineralization in this region is genetically linked to the Jurassic and Cretaceous subduction of the Pacific plate. Mao et al. (2006) proposed a two-stage tectonic–metallogenic model in which ore deposits are related to the subduction of the paleo-Pacific plate and subsequent lithospheric extension. Xu et al. (2002) and Wang et al. (2007) recognized the adakite affinity of the granitic rocks related to the porphyry–skarn Cu–Au–Mo–Fe ore spectrum and proposed that these intrusions are derived by partial melting of thickened or delaminated lower crust. Hou et al. (2007) suggested a thick delaminated lower crust model to explain the magmatism (150–100 Ma) and associated mineralization, whereas the 140–125 Ma Early Yanshanian magmatism and associated mineralization was attributed to ridge subduction in the Cretaceous (Ling et al. 2009).

The thematic issue of Mesozoic mineral deposits in South China

Recent studies of mineral deposits in South China have advanced our understanding of their occurrence and mode of formation. This special issue brings together some of the latest information on this topic in eight papers dealing with mineral deposits formed in three distinct stages.

Wei et al. use infrared microscopy to examine fluid inclusions in wolframite from the Xihuashan W deposit and conclude that the wolframite did not co-precipitate with quartz (Wei et al. 2012). They suggest that it was deposited prior to quartz during boiling of the ore-forming fluid. Mixing between a dominantly magmatic fluid and a minor meteoric fluid triggerred wolframite precipitation in the Xihuashan deposit. Quantitative modeling of isotopic compositions of wolframite and quartz shows that mass fractions of the meteoric water in the mixed fluid were between 0.1 and 0.4 during the silicate-oxide stage. Differences in fluid inclusions from wolframite and quartz demonstrate that conventional microthermometric data from gangue minerals cannot be used for simple extrapolation of the depositional conditions of associated ore minerals.

Qi et al. recognize two episodes of Late Jurassic W–Sn polymetallic mineralization in Northern Guangdong (Qi et al. 2012). An early episode of tungsten mineralization is represented by the Yaoling, Hongling, and Meiziwo deposits, during the Late Jurassic (158–159 Ma), and a younger episode represented by the Jubankeng tungsten deposit during the Early Cretaceous (~138 Ma). W–Sn mineralization in the Nanling region occurred in several intervals at 90–100, 134–140, 144–162, and 210–235 Ma. The most important large-scale W–Sn mineralization event occurred during the Late Jurassic (150–160 Ma).

Hu et al. present He and Ar isotopic analyses of fluid inclusions in pyrite and arsenopyrite from Yaogangxian, the largest W deposit in South China (Hu et al. 2012a). The deposit and hosting intrusion likely formed at ~155 Ma. Their results suggest that the ore-forming fluids were mixtures of crustal and mantle fluids. The existence of mantle noble gases in the fluids, exsolved from the W-bearing granitic magma, provides new insights into the origin of the W deposits and associated granites. The hosting granites were previously considered as S-type, but actually formed by crustal melting induced by heat and volatiles released from the mantle.

Xie et al. report zircon U–Pb and phlogopite ^{40}Ar–^{39}Ar dating results from the Chengchao and Jinshandian skarn Fe deposits in the western part of the middle–lower Yangtze River metallogenic province (Xie et al. 2011). These results confirm that the intrusions and associated Fe mineralization formed contemporaneously at ca. 135 Ma. Xie et al. relate 141–137-Ma skarn Cu–Fe deposits to 140–136-Ma diorites and quartz diorites and 133–132-Ma skarn Fe deposits with 133–127-Ma quartz diorites and granites. The two episodes of magmatic activities and associated skarn mineralization were probably associated with thinning of the lithosphere induced by asthenospheric upwelling.

Su et al. study the Carlin-type Shuiyindong gold deposit in Guizhou, formed in the Late Yanshanian (Su et al. 2011). They report four different types of gold-bearing arsenian pyrite in the paragenetic sequence of hydrothermal mineralization. They propose that the zoned arsenian pyrite likely formed in two distinct stages. The early stage involved a fluid with relatively high activity of As relative to Au, followed by a late stage of Au- and As-poor fluids that formed As-poor pyrite overgrowths on gold-bearing pyrite cores.

Gu et al. study gold deposits that are closely associated with paleo-oil reservoirs in sedimentary rocks of the Youjiang Basin (Gu et al. 2012). They show the co-existence of mobilized organic matter (bitumen) with ore-stage minerals and identify abundant hydrocarbons in the ore fluids. They propose that gold originated, migrated, and precipitated along with the hydrocarbons in an immiscible, gold- and hydrocarbon-bearing basinal fluid. Exhumation of the basin during the Yanshanian resulted in destruction of the hydrocarbon reservoirs leaving only bitumen residues.

Ye et al. investigate the Niujiaotang Cd deposit that they consider to be of MVT type (Ye et al. 2011). Sphalerite in the deposit contains more than 5,000 tons Cd metal with Ga and Ge as by-products. Cadmium mostly occurs as an isomorphous impurity in sphalerite. Independent Cd minerals, greenockite and otavite, are considered to be secondary. Both Cd and Zn are thought to be derived from the associated early Cambrian strata. In the Niujiaotang ore district, Zn and Cd in the Cambrian strata were mobilized by the brines that rose along the Zaolou fault system, producing stratiform Cd-rich Zn orebodies within the host rocks.

Cheng et al. report an Ar–Ar age of 82.7±0.7 for vein-type Sn mineralization in the Gejiu ore district (Cheng et al. 2012). They use this age to indicate a co-genetic relationship of the ores and the Late Cretaceous granitic pluton. Initially, magmatic–hydrothermal fluids were mixed with meteoric water en route to interpret hydrogen and oxygen isotope data. Sulfur isotopes support ore fluid exsolution from the tin granite. Circulation of hydrothermal fluids and ore precipitation were structurally controlled and localized along interbedded limestone and dolomite in the thick Triassic carbonate strata.

Acknowledgments We thank all the authors for their contributions to this special issue and Wang Yue-Jun, Tao Yan, Gao Jian-Feng, Huang Zhi-Long, Li Xiao-Feng, Su Wen-Chao, Qi You-Qiang, and Zhao Xin-Fu for help with preparation. We are grateful for the financial support from the National Basic Research Program of China (973 Program) (2007CB411400). Thanks are also due to reviewers and particularly the handling editors for their constructive comments on the manuscripts. Bernd Lehmann is gratefully acknowledged for his patience and great support that made this special issue possible.

References

Cai MH, Chen KX, Qu WJ, Liu GQ, Fu JM, Yin JP (2006) Geological characteristics and Re–Os dating of molybdenites in Hehuaping tin–polymetallic deposit, southern Hunan province. Mineral Deposits 25:263–268 (in Chinese with English abstract)

Chen JF, Jahn BM (1998) Crustal evolution of southeastern China: Nd and Sr isotopic evidence. Tectonophysics 284:101–133

Chen CH, Hsieh PS, Lee CY, Zhou HW (2011) Two episodes of the Indosinian thermal event on the South China Block: constraints from LA–ICPMS U–Pb zircon and electron microprobe monazite ages of the Darongshan S-type granite suite. Gondwana Res 19:1008–1023

Cheng YB, Mao JW (2010) Age and geochemistry of granites in Gejiu area, Yunnan province, SW China: constraints on their petrogenesis and tectonic setting. Lithos 120:258–276

Cheng YB, Mao JW, Yang ZX (2012) Geology and vein tin mineralization in the Dadoushan deposit, Gejiu district, SW China. Mineralium Deposita. doi:10.1007/s00126-012-0409-4

Cui S, Li J (1983) On the Indosinian orogeny along the Chinese Western Pacific belt. Acta Geologica Sinica 57:51–61 (in Chinese with English abstract)

Feng JR, Mao JW, Pei RF, Li C (2011) A tentative discussion on Indosinian ore-forming events in Laojunshan area of southeastern Yunnan: a case study of Xinzhai tin deposit and Nanyangtian tungsten deposit. Mineral Deposits 30:57–73 (in Chinese with English abstract)

Gilder SA, Keiier GR, Luo M, Goodell PC (1991) Timing and spatial distribution of rifting in China. Tectonophysics 197:225–243

Gu XX, Zhang YM, Li BH, Dong SY, Xue CJ, Fu SH (2012) Hydrocarbon- and ore-bearing basinal fluids: a possible link between gold mineralization and hydrocarbon accumulation in the Youjiang basin, South China. Mineralium Deposita. doi:10.1007/s00126-011-0388-x

Hou ZQ, Pan XF, Yang ZM, QU XM (2007) Porphyry Cu–(Mo–Au) deposits not related to oceanic–slab subduction: examples from Chinese porphyry deposits in continental settings. Geosci J Graduate School, China Univ Geosci 21(2):332–351, in Chinese with English abstract

Hu X, Pei R, Zhou S (1996) Sm–Nd dating for antimony mineralization in the Xikuangshan deposit, Hunan, China. Resour Geol 46:277–281

Hu RZ, Su WC, Bi XW, Tu GZ, Hofstra AH (2002) Geology and geochemistry of Carlin-type gold deposits in China. Mineralium Deposita 37:378–392

Hu RZ, Peng JT, Ma DS, Su WC, Shi CH, Bi XW, Tu GZ (2007) Epoch of large-scale low-temperature mineralizations in southwestern Yangtze massif. Mineral Deposits 26:283–296 (in Chinese with English abstract)

Hu RZ, Bi XW, Zhou MF, Peng JT, Su WC, Liu S, Qi HW (2008) Uranium metallogenesis in South China and its relationship to crustal extension during the Cretaceous to Tertiary. Econ Geol 103:583–598

Hu RZ, Bi XW, Jiang GH, Chen HW, Peng JT, Qi YQ, Wu LY, Wei WF (2012a) Mantle-derived noble gases in ore-forming fluids of the granite-related Yaogangxian tungsten deposit, Southeastern China. Mineralium Deposita. doi:10.1007/s00126-011-0396-x

Hu RZ, Wei WF, BI XW, Peng JT, Qi YQ, Wu LY (2012b) Molybdenite Re–Os and muscovite $^{40}Ar/^{39}Ar$ dating of the Xihuashan tungsten deposit, central Nanling district, South China. Lithos. doi:10.1016/j.lithos.2012.05.015

Hua RM, Chen PR, Zhang WL, Yao JM, Lin JF, Zhang ZS, Gu SY, Liu XD, Qi HW (2005) Metallogenesis related to Mesozoic granitoids in the Nanling Range, South China and their geodynamic settings. Acta Geologica Sinica 79:810–820

Lehmann B, Ishihara S, Michel H, Miller J, Sanchez A, Tistl M, Winkelmann L (1990) The Bolivian tin province and regional tin distribution in the central Andes—a reassessment. Econ Geol 85:1044–1058

Lepvrier C, Van Vuong N, Maluski H, Thi PT, Van Vu T (2008) Indosinian tectonics in Vietnam. Compt Rendus Geosci 340:94–111

Li XH (2000) Cretaceous magmatism and lithospheric extension in Southeast China. J Asian Earth Sci 18:293–305

Li ZX, Li XH (2007) Formation of the 1300-km-wide intracontinental orogen and postorogenic magmatic province in Mesozoic South China: a flat-slab subduction mode. Geology 35:179–182

Li XF, Sasaki M (2007) Hydrothermal alteration and mineralization of middle Jurassic Dexing porphyry Cu–Mo deposit, southeast China. Resour Geol 57:409–426

Li WB, Huang ZL, Wang YX, Chen J, Han RS, Xu C, Guan T, Yin MD (2004a) Age of the giant Huize Pb–Zn deposits determined by Sm–Nd dating of hydrothermal calcite. Geol Rev 50:189–195 (in Chinese with English abstract)

Li WB, Huang ZL, Chen J, Han RS, Zhang ZL, Xu C, Guan T, Yin MD (2004b) Rb–Sr dating of mineral assemblage from the Huize giant Zn–Pb deposit, Yunnan province. Acta Mineralogica Sinica 24:113–116 (in Chinese with English abstract)

Li ZL, Hu RZ, Yang JS, Peng JT, Li XM, Bi XW (2007a) He, Pb and S isotopic constraints on the relationship between the A-type Qitianling granite and the Furong tin deposit, Hunan Province, China. Lithos 97:161–173

Li XF, Watanabe Y, Mao JW, Liu SX, Yi XK (2007b) Sensitive high-resolution ion microprobe U–Pb Zircon and Ar-40–Ar-39 muscovite ages of the Yinshan deposit in the northeast Jiangxi province, South China. Resour Geol 57:325–337

Li XH, Li WX, Li ZX (2007c) On the genetic classification and tectonic implications of the Early Yanshanian granitoids in the Nanling Range, South China. Chin Sci Bull 52:1873–1885

Ling MX, Wang FY, Ding X, Hu YH, Zartman RE, Xiong XL, Sun WD (2009) Cretaceous ridge subduction along the Lower Yangtze River belt, Eastern China. Econ Geol 104:303–321

Lu JJ, Hua RM, Yao CL (2005) Re–Os age for molybdenite from the Dexing porphyry Cu–Au deposit of Jiangxi Province, China. Geochimica et Cosmochimica Acta 69(suppl):A882

Mao JW, Xie GQ, Li XF (2004) Mesozoic large scale mineralization and multiple lithospheric extensions from South China. Earth Sci Front 11:45–56 (in Chinese with English abstract)

Mao JW, Wang YT, Lehmann B, Yu JJ, Du AD, Mei YX, Li YF, Zang WS, Stein HJ, Zhou TF (2006) Molybdenite Re–Os and albite $^{40}Ar/^{39}Ar$ dating of Cu–Au–Mo and magnetite porphyry systems in the Yangtze River valley and metallogenic implications. Ore Geol Rev 29:307–324

Mao JW, Shao YJ, Xie GQ, Zhang JD, Chen YC (2009) Mineral deposit model for porphyry–skarn polymetallic copper deposits in Tongling

ore dense district of Middle–Lower Yangtze Valley metallogenic belt. Mineral Deposits 28:109–119 (in Chinese with English abstract)
Mao JW, Pirajno F, Cook N (2011) Mesozoic metallogeny in East China and corresponding geodynamic settings—an introduction to the special issue. Ore Geol Rev 43:1–7
Pan Y, Dong P (1999) The Lower Changjiang (Yangzi/Yangtze River) metallogenic belt, east central China: intrusion- and wall rock-hosted Cu–Fe–Au, Mo, Zn, Pb, Ag deposits. Ore Geol Rev 15:177–242
Pan JY, Zhang Q, Shao SX, Zhang Z (1999) Geochemistry of halogens in the Wanshan mercury deposit and its geological implications. Acta Mineralogica Sinica 19:90–97 (in Chinese with English abstract)
Peng JT, Hu RZ, Burnard PG (2003) Samarium–neodymium isotope systematics of hydrothermal calcites from the Xikuangshan antimony deposit (Hunan, China): the potential of calcite as a geochronometer. Chem Geol 200:129–136
Peng JT, Zhou MF, Hu RZ, Shen NP, Yuan SD, Bi XW, Du AD, Qu WJ (2006) Precise molybdenite Re–Os and mica Ar–Ar dating of the Mesozoic Yaogangxian tungsten deposit, central Nanling district, south China. Mineralium Deposita 41:661–669
Qi HW, Hu RZ, Wang XF, Qu WJ, Bi XW, Peng JT (2012) Molybdenite Re–Os and muscovite $^{40}Ar/^{39}Ar$ dating of quartz vein-type W–Sn polymetallic deposits in Northern Guangdong, South China. Mireralium Deposita. doi:10.1007/s00126-012-0406-7
Ruzicka V (1993) Vein uranium deposits. Ore Geol Rev 8:247–276
Su WC, Heinrich CA, Pettke T, Zhang XC, Hu RZ, Xia B (2009) Sediment-hosted gold deposits in Guizhou, China: products of wall-rock sulfidation by deep crustal fluids. Econ Geol 104:73–93
Su WC, Zhang HT, Hu RZ, Ge X, Xia B, Chen YY, Zhu C (2011) Mineralogy and geochemistry of gold-bearing arsenian pyrite from the Shuiyindong Carlin-type gold deposit, Guizhou, China: implications for gold depositional processes. Mineralium Deposita. doi:10.1007/s00126-011-0328-9
Wang YJ, Zhang YH, Fan WM, Peng TP (2005) Structural signatures and $^{40}Ar/^{39}Ar$ geochronology of the Indosinian Xuefengshan transpressive belt, South China Interior. J Struct Geol 27:985–998
Wang YJ, Fan WM, Sun M, Liang XQ, Zhang YH, Peng TP (2007a) Geochronological, geochemical and geothermal constraints on petrogenesis of the Indosinian peraluminous granites in the South China Block: a case study in the Hunan Province. Lithos 96:475–502
Wang Q, Wyman DA, Xu JF, Zhao ZH, Jian P, Zi F (2007b) Partial melting of thickened or delaminated lower crust in the middle of eastern China: implications for Cu–Au mineralization. J Geol 115:149–161
Wang L, Hu MA, Yang Z, Qu WJ, Xia JL, Chen KX (2011) U–Pb and Re–Os geochronology and geodynamic setting of the Dabaoshan polymetallic deposit, northern Guangdong Province, South China. Ore Geol Rev 43:40–49
Wang YJ, Fan WM, Zhang GW, Zhang YH (2012) Phanerozoic tectonics of the South China Block: key observations and controversies. Gondwana Research. doi:10.1016/j.gr.2012.02.019
Wei DF, Bao ZY, Fu JM, Cai MH (2007) Diagenetic and mineralization age of the Hehuaping tin–polymetallic orefield, Hunan province. Acta Geologica Sinica 81:244–252
Wei WF, Hu RZ, Bi XW, Peng JT, Su WC, Song SQ, Shi SH (2012) Infrared microthermometric and stable isotopic study of fluid inclusions in wolframite at the Xihuashan tungsten deposit, Jiangxi province, China. Mineralium Deposita. doi:10.1007/s00126-011-0377-0
Xie GQ, Mao JW, Zhao HJ, Duan C, Yao L (2011) Zircon U–Pb and phlogopite ^{40}Ar–^{39}Ar age of the Chengchao and Jinshandian skarn Fe deposits, southeast Hubei Province, Middle–Lower Yangtze River Valley metallogenic belt, China. Mineralium Deposita. doi:10.1007/s00126-011-0367-2
Xiong XX (1991) Discussion on the geological features and genesis of realgar ore deposit, Shimen. Min Geol 12:161–167 (in Chinese with English abstract)
Xu JF, Shinjo R, Defant MJ, Wang Q, Rapp RP (2002) Origin of Mesozoic adakitic intrusive rocks in the Ningzhen area of east China: partial melting of delaminated lower continental crust. Geology 30:1111–1114
Yan DP, Zhou MF, Song HL, Wang XW, Malpas J (2003) Origin and tectonic significance of a Mesozoic multi-layer over-thrust within the Yangtze Block (South China). Tectonophysics 361:239–254
Yang ZX, Mao JW, Chen MH, Tong X, Wu JD, Cheng YB, Zhao HJ (2008) Re–Os dating of molybdenite from the Kafang skarn copper (tin) deposit in the Gejiu tin polymetallic ore district and its geological significance. Acta Petrologica Sinica 24:1937–1944 (in Chinese with English abstract)
Yang F, Li XF, Feng ZH, Bai YP (2009) $^{40}Ar/^{39}Ar$ dating of muscovite from greisenized granite and geological significance in Limu tin deposit. J Guilin Univ Technol 29:21–24 (in Chinese with English abstract)
Ye Y, Shimazaki H, Shimizu M (1998) Tectono-magmatic evolution and metallogenesis along the Northeast Jiangxi deep fault, China. Resour Geol 48:43–50
Ye L, Cook NJ, Liu TG, Ciobanu CL, Gao W, Yang YL (2011) The Niujiaotang Cd-rich zinc deposit, Duyun, Guizhou province, southwest China: ore genesis and mechanisms of cadmium concentration. Mineralium Deposita. doi:10.1007/s00126-011-0386-z
Yu JJ, Mao JW (2002) Distribution, geology and ore-forming environment of Kiruna type iron deposits. Mineral Deposits 21 (Suppl):83–86, in Chinese with English abstract
Yu JH, Zhou X, O'Reilly SY, Zhao L, Griffin WL, Wang R, Wang L, Chen X (2005) Formation history and protolith characteristics of granulite facies metamorphic rock in Central Cathaysia deduced from U–Pb and Lu–Hf isotopic studies of single zircon grains. Chin Sci Bull 50:2080–2089
Zhai YS, Xiong YY, Yao SZ, Liu XD (1996) Metallogeny of copper and iron deposits in the Eastern Yangtze Craton, east-central China. Ore Geol Rev 11:229–248
Zhang RH (1986) Sulfur isotopes and pyrite–anhydrite equilibria in a volcanic basin hydrothermal system of the Middle to Lower Yangtze River Valley. Econ Geol 81:32–45
Zhang CQ, Yu JJ, Mao JW, Rui ZY (2009) Advances in the study of Mississippi Valley-type deposits. Mineral Deposits 29:195–210 (in Chinese with English abstract)
Zhao YM, Zhang YN, Bi CS (1999) Geology of gold-bearing skarn deposits in the Middle and Lower Yangtze River Valley and adjacent regions. Ore Geol Rev 14:227–240
Zhao JH, Zhou MF, Yan DP, Zheng JP, Li JW (2011) Reappraisal of the ages of Neoproterozoic strata in South China: no connection with the Grenvillian orogeny. Geology 39:299–302
Zhou CX, Wei CX, Guo JY (2001) The source of metals in the Qilingchang Zn–Pb deposit, northeastern Yunnan, China: Pb–Sr isotope constraints. Econ Geol 96:583–598
Zhou MF, Yan DP, Kennedy AK, Li YQ, Ding J (2002) SHRIMP zircon geochronological and geochemical evidence for Neo-Proterozoic arc-related magmatism along the western margin of the Yangtze Block, South China. Earth Planet Sci Lett 196:51–67
Zhou XM, Sun T, Shen WZ, Shu LS, Niu YL (2006) Petrogenesis of Mesozoic granitoids and volcanic rocks in South China: a response to tectonic evolution. Episodes 29:26–33
Zhou TF, Fan Y, Yuan F (2008) Advances on petrogenesis and metallogeny study of the mineralization belt of the Middle and Lower Reaches of the Yangtze River area. Acta Petrologica Sinica 24:1665–1678 (in Chinese with English abstract)