Ore Geology Reviews 88 (2017) 481–490

Contents lists available at ScienceDirect

Ore Geology Reviews

journal homepage: www.elsevier.com/locate/oregeo

Yanshanian (Late Mesozoic) ore deposits in China – An introduction to the Special Issue

Xu Deru[a,*], Chi Guoxiang[b], Zhang Yanhua[c], Zhang Zhaochong[d], Sun Weidong[a]

[a] Key Laboratory of Mineral and Metallogeny, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China
[b] Department of Geology, University of Regina, Regina S4S 0A2, Canada
[c] CSIRO Mineral Resources, PO Box 1130, Bentley, WA 6102, Australia
[d] State Key Laboratory of Geological Process and Mineral Resources, China University of Geosciences, Beijing 100083, China

ARTICLE INFO

Article history:
Received 20 April 2017
Received in revised form 24 April 2017
Accepted 25 April 2017
Available online 27 April 2017

Keywords:
Yanshanian (Late Mesozoic) orogeny
Tectonothermal events
Metallogenic belt or province
Magmatic-hydrothermal mineral system
China

ABSTRACT

The Late Jurassic-Cretaceous Yanshanian Orogeny (or "Yenshan Movement"), one of the most important tectonothermal events, is first recognized in China, especially eastern China. This Late Mesozoic orogeny, which was initiated most likely by a Mesozoic tectonic switch, strongly reworked or destructed the older continental lithospheres or cratonic keels that are manifested by alternating compressive and extensional deformation, voluminous igneous rocks, and a variety of characteristic magmatic-hydrothermal mineral systems. Despite its first discovery and definition in Yenshan-Yinshan area of North China craton, the Yanshanian Orogeny probably is of global tectonic, magmatic and metallogenic significance. However, there have been hot debates on the precise starting time, accurate duration or time-interval, detailed processes and evolution linked to deep lithospheres, tectonic nature, and geodynamic mechanism(s) of the Yanshanian Orogeny, which inevitably have hindered the understanding of the genesis, mineralizing processes and geodynamic mechanism of the Late Mesozoic magmatic-hydrothermal mineral systems.

This Special Issue captures some of the latest research results on the Yanshanian ore deposits that are involved into a few main Mesozoic metallogenic belts or provinces, from northeast to southwest China, including: (1) the Jiaodong Peninsula metallogenic province in the North China Craton, (2) the Middle-Lower Yangtze River Valley metallogenic belt in the central eastern China, (3) the Jiangnan and (4) the Nanling metallogenic belts in the South China Block, (5) the southeastern China Coast metallogenic belt, and (6) the Sanjiang metallogenic belt in southwest China. Through a multidisciplinary study, this Special Issue re-investigated and re-evaluated the relationship between the Late Mesozoic magmatic-hydrothermal mineral systems and the Yanshanian tectonothermal events in the studied metallogenic belts or provinces. A few important contributions to the topic in this Special Issue (Yanshanian metallogeny) are summarized as followings: (1) A new ore-deposit type, i.e. the "intracontinental reactivation" type, has been suggested to interpret the genesis of those Au-(polymetallic) deposits that are hosted within older metamorphic rocks and related to the Late Mesozoic basin-and-range extensional settings; (2) Late Mesozoic re-activation of the preexisting structures by the Yanshanian tectono-thermal event(s) might be an important mechanism controlling the Yanshanian large-scale mineralization; (3) A-type granites formed by partial melting of the Mesoproterozoic crust, but with inputs from mantle-derived melt are also favorable for Sn mineralization, in addition to S-type and I-type granites as previously recognized; (4) Calculated oxygen fugacities (fO_2) of granitic magmas based on chemical compositions of primary biotite have been confirmed to be effective proxy for distinguishing Cu-Au-Mo-W-Sn-Pb-Zn mineralized granites from barren granites; (5) A significant epoch of W–Sn magmatic-hydrothermal ore system at ca. 145–135 Ma has been identified in the southeastern China Coast metallogenic belt; and (6) In addition to traditional structural geology, mineralogy, petrology, geochemistry and geochronology, new analytical techniques (e.g. Cu isotopes) and data treatment method (e.g., Bi-dimensional empirical mode decomposition) can be used to provide more constraints for deep exploration.

* Corresponding author.
E-mail address: xuderu@gig.ac.cn (X. Deru).

http://dx.doi.org/10.1016/j.oregeorev.2017.04.022
0169-1368/

The term "Yenshan Movement" was first proposed by Wong (1926, 1927, 1929) (Wong Wenhao, one of the founders of the Chinese geology discipline) to represent the tectonic event responsible for the formation of a pre-Cretaceous unconformity in the Yenshan–Yinshan area of North China. This gradually evolved into the present terms of "Yanshanian Orogeny" and "Yanshanian Period" (note "Yanshan" is an updated version of spelling of "Yenshan"), which are widely used to describe the Late Jurassic to Cretaceous tectono-thermal events in eastern China, as well as those in other parts of China for the same period of time. The Yanshanian Orogeny has attracted much attention from numerous researchers for nearly a century. First, unlike most other orogenies, the Yanshanian Orogeny involves intracontinental tectonics, magmatism, structural deformation and sedimentation, with the causative geodynamic processes at depth somewhat enigmatic. Second, a large number of mineral deposits, especially those related to various magmatic-hydrothermal systems, are associated with the Yanshanian Orogeny, including many world-class deposits. According to Dong et al. (2007), nearly 80% of the medium- to large-scale metallic mineral deposits in China were formed in the Yanshanian Period.

Despite a long history of study, the precise starting time, accurate duration or time-interval of the Yanshanian Orogeny, its detailed linkages to deep lithospheric processes, and relationship to global tectonics, remain the subject of intensive scientific debate. Likewise, the nature of the Yanshanian mineral systems, especially their relationships with the tectonic settings and deep geodynamic processes, continue to be challenging topics. In recent years, significant progress has been made in understanding the tectonic framework and evolution of eastern China, due in large part to advances in analytical technologies and their increased use in China. On the other hand, detailed studies of various mineral deposits in return have contributed to a better understanding of the tectonic nature of the Yanshanian Orogeny. This Special Issue captures some of the latest research results on the Yanshanian ore deposits. In this introduction, we present a brief review of the Yanshanian Orogeny and related metallogeny, highlight the main findings as a result of the papers in this Special Issue, and provide some perspectives for future studies.

1. Brief history and current understanding of the Yanshanian Orogeny

Although "Yenshan Movement" was initially proposed based on local studies in North China, it soon became an encompassing term that is associated with voluminous Late Mesozoic intracontinental volcanic rocks and plutons and strong crustal deformation in eastern China (see Pirajno, 2013 for an overview). The significance of this tectonic event, however, goes beyond eastern China. In one of his pioneering papers, Wong (1927) suggested that "the Yenshan movement is really a general and characteristic feature of the Pacific basin, a Pan-Pacific revolution of the first importance to the tectonic study of this part of the world". The intracontinental nature of the Yanshanian Orogeny caught the interest of another Chinese geologist, Chen Guoda (who later became an Academician of the Chinese Academy of Sciences), who related the Yanshanian large-scale tectono-magmatic and metallogenic events to "platform reactivation", based on a theory he called Reactivated Tectonics (Chen, 1956, 1959, 1987). He further emphasized that such reactivated tectonics occurred not only in eastern China (especially southern China), but also in Asia, Europe, North and South Americas, and Antarctica (Chen, 1959). With the introduction of the plate tectonics (Guo et al., 1985) and subsequent mantle plume tectonics (Li, 1998) since the 1980s, various terms such as "Destruction of North China Craton" or "Reworking of South China Continent" (Zhu et al., 2012) have also been coined by Chinese geoscientists to describe the Late Mesozoic tectonic, magmatic and metallogenic events in the eastern China.

Two aspects of the Yanshanian Orogeny have been controversial: timing and geodynamic setting (Dong et al., 2007 and references therein). In relation to these, there is also ambiguity regarding whether the Yanshanian Orogeny is different between the North China and South China cratons (Wang et al., 2014). Wong (1929) initially divided the Yanshanian Orogeny into an early Phase A and a late Phase B, and suggested that they are comparable to the Jurassice (Late Jurassic) and Laramide (Late Cretaceous to Eocene) revolutions in western North America, respectively. Phase A characterized by broad folding or warping and an unconformity between the Upper Jurassic and the Lower Cretaceous sequences, whereas Phase B marked by an unconformity between the Lower and the Upper Cretaceous sequences and characterized by tight folding, overturning and overthrusting. Wong (1929) also distinguished an intermediary Phase between Phases A and Phase B, shown by intense magmatism starting with andesitic lava, followed by trachytic and rhyolitic lava, and probably ending with granitoid intrusions. Various schemes of phase divisions of the Yanshanian Orogeny were proposed by other Chinese geologists (Ren et al., 1999; Cui et al., 2002). Lately, Dong et al. (2007) "re-defined" the Yanshanian Orogeny as having a starting time at 165 ± 5 Ma (Late Jurassic) and being initiated by multidirectional plate convergences of the East Asian continents that resulted in extensive intracontinental orogeny, a tectonic switch and lithospheric attenuation in East China. These authors also divided the Yanshanian Orogeny into three episodes, namely, a predominant episode occurring at 165 (±5) to 136 Ma characterized by intensive intracontinental compressive deformation including folding and overthrusting, an intermediate episode from ca. 135 Ma to ca. 100 Ma characterized by extensional structures in relation to lithospheric collapse and thinning as well as destruction of cratons, and a last episode from ca. 100 Ma to ca. 83 Ma with NW-SE compressive deformation inducing inversion of the previous extensional basins and sinistral strike-slip movement of the regional NNE-trending fault systems.

The geodynamic mechanisms initiating the Yanshanian Orogeny and associated tectonic, magmatic and metallogenic processes have also been a subject of controversy. First of all, it has been debated whether the tectonics in eastern China switched from a Paleo-Tethys ocean-related regime in Early Mesozoic (pre-Yanshanian) to an intracontinental regime in Late Mesozoic (Yanshanian) (Hsü et al., 1990; Xu et al., 2007; Wang et al., 2013a). Second, even if most of Chinese geoscientists now believe that the Late Mesozoic tectonics in eastern China were caused largely by the subduction of the paleo-Pacific plate beneath the eastern Asian margin and associated geodynamics (e.g., slab foundering or roll-back or back-arc extension), there have been different schools of thought with respect to the timing, mode and dynamics of the subduction (Zhou et al., 2006; Li and Li, 2007; Sun et al., 2007; Jiang and Li, 2014). Nevertheless, it is generally agreed that during the Mesozoic, the eastern part of China was subjected to an intense tectonic activity, i.e. from the ca. 230–210 Ma collisional orogeny, through the ca. 180–160 Ma subduction of the paleo-Pacific plate beneath the Eurasian continental margin, to the ca. 150–80 Ma (peaking at ca. 130–110 Ma) lithospheric thinning and delamination (Zhai et al., 2004; Zhou et al., 2006; Li and Li, 2007; Mao et al., 2011a). This tectonic change not only reworked or destructed the older continental lithospheres or cratonic keels, but also initiated development of voluminous igneous rocks (Zhou and Li, 2000; Mao et al., 2014), and a variety of compressive and extensional structures manifested by fold and thrust zones, strike-slip fault zones, metamorphic core complexes (MCCs), block faulting, and basin-and-range-style tectonic provinces (Faure et al., 1996; Lin et al., 2008; Li et al., 2004; Zhang et al., 2007; Shu et al., 2009; Wang et al., 2011; Wang and Shu, 2012; Zhang et al., 2012; Charles et al., 2013; Li et al., 2013; Wang et al., 2013b; Li et al., 2014, 2016; Wang et al., 2014; Pirajno and Zhou, 2015; Shi et al., 2015).

2. Overview of the Yanshanian metallogeny

As mentioned earlier, the Yanshanian Orogeny is associated with the formation of a high number of mineral deposits including many world-class ones (Chen et al., 1998; Zhai et al., 2001; Hua et al., 2003; Mao et al., 2005, 2011a,b, 2013). The Yanshanian metallogeny is closely related to the unique tectonic setting of east China in the Late Mesozoic, and is characterized by large-scale tectono-thermal events with extensive reactivation and destruction of the older continental lithospheres or cratonic keels, in relation to the prolonged interaction between the Central-Asian, Circum-Pacific and Tethys-Himalayan geodynamic systems (Chen et al., 2012; Dong et al., 2007). A variety of mineral deposits including porphyry-, porphyry-epithermal-, porphyry-skarn-, skarn-, granite-, volcanic rock-, MVT-, Carlin- and hydrothermal vein-type W, Sn, Bi, Mo, U, Sb, Cu, Pb, Zn, Au, Hg, As and Tl ore deposits were formed during the Yanshanian period (Mao et al., 2011a,b, 2013; Pirajno, 2013; Goldfarb et al., 2014; Xu et al., 2016a, 2017a; Hu et al., 2017). These deposits can be grouped into different metallogenic belts or provinces (Fig. 1), briefly described below. The authors believe that more Yanshanian ore deposits will be discovered in other metallogenic provinces in China, due to increasing geological studies as well as the application of new analytical techniques.

(1) *The Northeast China metallogenic province* (Mao et al., 2011a) is located north of the Xilamulunhe (or Solonker suture) and comprises the Great Xing'an belt in the west and the Changbai belt in east, both overprinting the pre-existing Xingmeng (or Altaid) orogenic belt. The major mineral systems are porphyry Mo-Cu, granite-related polymetallic Sn, vein-type Pb-Zn-Ag, epithermal Au and Cu-Ni deposits related to mafic and/or ultramafic rocks. Three major periods of mineralization occurred at 235–210 Ma, 190–137 Ma and 130–115 Ma (Mao et al., 2011a; Zeng et al., 2013), with the latter two belonging to the Yanshanian period. The 190–137 Ma mineralization is characterized by porphyry Mo-Cu and vein type Cu deposits, and somewhat later, granite-related skarn and vein type polymetallic Sn, skarn Fe-Mo-Pb-Zn, epithermal Au, and vein type Pb-Zn-Ag deposits, whereas the youngest period (130–115 Ma) is associated with late alkaline magmatism which produced porphyry Mo, syenite-related REE-bearing deposits as well as Pb-Zn-Ag deposits.

(2) *The EW-trending Yan-Liao metallogenic belt* at the northern margin of the North China Craton (Mao et al., 2011a) contains porphyry and/or skarn Mo, lode gold and lode Ag-Pb-Zn deposits that have similar metal associations to that in the East Qinling-Dabie orogenic belt. The ages of the Mo deposits in the belt reflect three pulses of magmatism at 240–225, 190–170, 148–137 Ma (Mao et al., 2005; Zeng et al., 2013). The lode gold deposits are hosted by granite intrusions, Archean basement, Proterozoic metamorphic rocks and Phanerozoic sedimentary rocks, of which the Archean basement is the most important (Pirajno et al., 2009). Geochronological data for the gold deposits indicate three pulses of mineralization, at 205 Ma, 190–175 Ma, and 126–120 Ma (Mao et al., 2011a). Vein type Pb-Zn-Ag deposits occur around the porphyry and/or skarn Mo deposits, and lode gold deposits are situated further outward, showing a zonation from Mo through Pb–Zn–Ag to Au.

(3) *The Jiaodong Peninsula metallogenic province* in the southeastern corner of the North China Craton, located in Jiaodong Peninsula, Shandong Province (Fig. 1), contains the greatest Au resources in China, with the proven reserves of more than 3600 t (Yang et al., 2014). There are also two Fe-skarn ore districts in western Shandong Province and along the border area between southwestern Hebei and southeastern Shanxi provinces in the interior of the North China Craton. Both the Au and Fe mineralization occurred between 125 and 115 Ma (Mao et al., 2011a). More than 150 known Au deposits in this region are structurally controlled by the NE- to NNE trending faults and have an intimate association with the Yanshanian (ca. 165–110 Ma) granitoids. They are generally interpreted as the result of de-cratonization of the North China Craton marked by lithospheric thinning, asthenospheric upwelling, and extensive granitic and mafic magmatism due to the Late Mesozoic tectonic inversion (i.e. the Yanshanian Orogeny) peaking at ca. 125 Ma (Zhu et al., 2011; Zhai and Santosh, 2013). As a result, these Early Cretaceous gold deposits were named intracratonic extension-related or "decratonic" gold deposits (Zhu et al., 2011, 2012; Zhai and Santosh, 2013; Zhu et al., 2015), rather than "orogenic" deposits (Kerrich et al., 2000).

(4) *The EW-trending East Qinling-Dabie orogenic belt* (Mao et al., 2011a), positioned between the North China and Yangtze Cratons, is probably the most important repository of molybdenum resources in the world. The belt also hosts numerous lode Au and Ag-Pb-Zn deposits. Three epochs of granitoid magmatism and Mo mineralization have been identified at ca. 233–221 Ma, ca. 148–138 Ma and ca. 131–112 Ma, respectively (Chen et al., 2007; Mao et al., 2011a,b). Among these, porphyry and/or skarn Mo or Mo-W deposits related to I-type and transitional I- and S-type granites are dated at 148–138 Ma. In contrast, porphyry Mo deposits related to S-type and some transitional S- and I-type granite-related have ages ranging from 131 to 112 Ma. Several dozen lode gold deposits, hosted by the Precambrian basement rocks appear to have formed during the Yanshanian (ca. 172–99 Ma; Mao et al., 2002). The lode Ag-Pb-Zn vein deposits are commonly peripheral to the porphyry and/or skarn Mo (W) deposits, displaying a zoning from the porphyry and/or skarn Mo in the center to Ag-Pb-Zn veins in the periphery (Mao et al., 2011b).

(5) *The "V-shaped" Middle–Lower Yangtze Valley metallogenic belt (MLYB)* in central China (Fig. 1), one of the most important Cu-Au-Mo-Fe-polymetallic belts in eastern China, is situated along the northern margin of the Yangtze Craton, bounded by the Xiangfan-Guangji and Tan-Lu faults to the northwest and by the Yangxin-Changzhou Fault to the southeast (Pirajno and Zhou, 2015; Zhou et al., 2015). In this belt, two major mineral systems in more than 200 deposits and occurrences have been identified: porphyry-skarn-stratabound Cu-Au-Mo-Fe deposits with an age range of ca. 149–105 Ma and apatite-magnetite (or magnetite porphyry) deposits with ages of 135–123 Ma (Mao et al., 2011a; Pirajno and Zhou, 2015; Zhou et al., 2015). The former mostly occurs in the Edongnan, Jiurui, Anqing-Guichi, Tongling and Ningzheng uplifted areas at the intersections of NE- and EW-trending faults, and has genetic link to high-potassium calc-alkaline granitoids (pyroxene monzodiorite, diorite and granodiorite), whereas the latter is strictly confined to the Ningwu, Lucong and Fanchang rift basins, and is typically associated with subvolcanic rocks of shoshonite affinity.

(5) *The Jiangnan Au-Cu-Pb-Zn-Sb-Ag-W metallogenic belt* (Fig. 1) is located in the southeastern margin of the Yangtze Block, corresponding to the Jiangnan Orogen that is interpreted as the Neoproterozoic collisional product of the Yangtze Block with the Cathaysia Block of South China. This NNE-SSW-trending belt comprises several jurisdictions (administrative provinces) including, from northeast to southwest, Zhejiang, Anhui, Jiangxi, Hunan, Guangxi, Guizhou and possibly Guangdong. The Jiangnan Orogen is

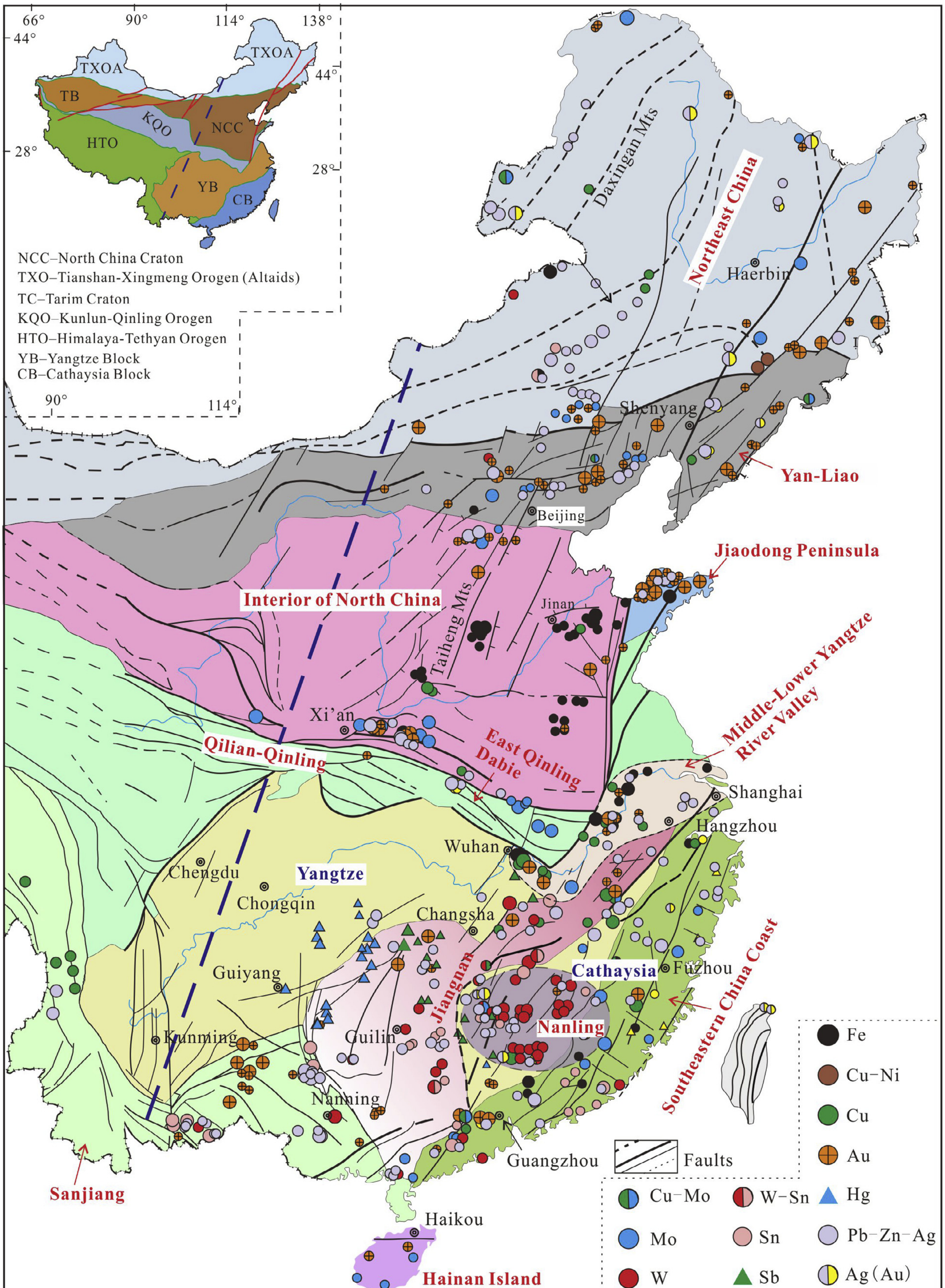

Fig. 1. Important metallogenic belts or provinces covering the predominant Yanshanian (Late Mesozoic) ore deposits in China. From northeast to southwest China: the Northeast China metallogenic province, the Yan-Liao metallogenic belt, the Jiaodong Peninsula metallogenic province, the East Qinling–Dabie metallogenic belt, the Middle-Lower Yangtze River Valley metallogenic belt, the Jiangnan metallogenic belt, the Nanling metallogenic belt, the southeastern China Coast metallogenic belt, the Sanjiang metallogenic belt, and the Hainan Island metallogenic belt.

characterized by widespread outcropping of Neoproterozoic low-grade metamorphosed volcaniclastic and sedimentary rocks with typical turbidite sequences, and by abundant felsic and mafic intrusions with ages ranging from Neoproterozoic to Cretaceous. Another characteristic feature in this belt is the elegant development of Basin-and-Range style structures, delineated by a series of NE- to NNE-trending uplifts, extensional basins, and metamorphic core complexes (MCCs) bounded by strike-slip faults (Fu et al., 1999; Wang and Shu, 2012), similar to those in North America (Eaton, 1982; Henry and Perkins, 2001). A variety of ore deposits of Neoproterozoic to Late Mesozoic ages are developed in the Jiangnan belt (Xu et al., 2017b, this issue), including hydrothermal Au, Au-Sb, Au-Sb-W and Cu-Co-(Au) deposits mostly hosted within Neoproterozoic volcaniclastic sedimentary rocks, porphyry- and skarn-type Cu-Au-Pb-Zn deposits and W-(Cu) deposits, associated with Mesozoic granitoids, and Cu–Ni sulfide deposits related to mafic/ultramafic rocks. The Jiangnan belt has become an important Au-Cu-Pb-Zn-Sb-Ag-W polymetallic belt in South China.

(7) *The E-W-trending Nanling W-Sn-Bi-Mo-Be-Cu-Pb-Zn metallogenic belt* (Fig. 1), one of the most important polymetallic belts in the world, occurs in the interior of the Cathaysia Block, South China, with its eastern, southern, western and northern boundaries roughly corresponding to southern Jiangxi, northern Guangdong, northern Guangxi and southern Hunan, respectively (present coordinates: 107°–116° E and 24°–27° N). This intraplate belt contains abundant mineral resources of nonferrous, rare and scarce, REE and U metals, and has a genetic link with voluminous Late Mesozoic granitoids. Representative world-class mineral systems include, the Shizhuyuan W-Sn-Bi-Mo-Be deposit, Furongtian Sn-polymetallic deposit, Huangshaping and Baoshan Cu-Pb-Zn deposit, Yaogangxian W-Ag deposit and Xianghualing Sn-polymetallic deposit in Hunan Province, the Dabaoshan Fe-Cu-Mo deposit, Fankou Pb-Zn deposit and Tiantangling Sn-Rb polymetallic deposit in Guangdong Province, and the Xihuashan, Piaotang, Maoping and Tangping W-Sn polymetallic deposits, Huameiao W-Bi, Huangshakeng W-Cu, Yanbei and Taixiba Sn, Dajishan and Kuimeishan W deposits, and the Zudong REE deposit in Jiangxi Province. These deposits have mineralization ages ranging from ca. 225 Ma to 91 Ma, with a peak at ca. 156 Ma, and are genetically ascribed to porphyry-, granite-, skarn-, skarn-greisen-, greisen-, hydrothermal vein-, and sedimentary-reworked (Xu et al., 2016b). Despite a multistage emplacement of granitoids from Indosinian to Yanshanian (ca. 280–102 Ma), the Nanling belt is dominated by the Yanshanian granitoids of ca. 160 Ma (Xu et al., 2016b). Most of the Late Mesozoic granitoids are highly fractionated and have geochemical affinities of I-, S- and A-type granites (Zhou et al., 2006; Li et al., 2007; Jiang et al., 2009; Xu et al., 2016b).

(8) *The NE-trending southeastern China Coast Au-Ag-Sn-W-Sb-Cu-Pb-Zn-U metallogenic belt* (Fig. 1), an important component of the South China metallogenic province (Mao et al., 2011a,b, 2013), is essentially confined to the "Coastal Volcanic Belt" and its adjacent areas (Pirajno and Bagas, 2002) that extends for nearly 1200 km along most of the southeastern China coast from northern Zhejiang, through Fujian to southwest Guandong. This belt comprises Cretaceous (ca. 130–80 Ma) felsic-intermediate volcanic and subvolcanic rocks and coeval granitoids, and has a broad range of mineral systems including both low- and high-sulfidation epithermal Au-Ag-(Cu-Pb-Zn) deposits, porphyry Sn-W deposits, porphyry-epithermal Cu-Mo-Au-Ag deposits, and skarn-, manto- and hydrothermal vein-type Sn-Pb-Zn-Sb-Ag, Sn-Cu-Pb-Zn, Sn-W-Cu and W deposits (Pirajno and Bagas, 2002; Mao et al., 2011a, 2013; Goldfarb et al., 2014). Most of the volcanic and subvolcanic rocks and granitoids have geochemical affinities of calc-alkaline I-type granites, partly with A-type granite affinities, and petrogenetically have been generally considered to be produced via mixing between depleted asthenospheric melts and subduction-related enriched mantle melts under back-arc extensional setting, initiated by the NW–WNW-ward subduction of the paleo-Pacific plate beneath the eastern Asian continent (Zhou et al., 2006; Li and Li, 2007).

(9) *The Sanjiang (meaning "three rivers", i.e., Jinshajiang, Lancangjiang and Nujiang rivers) metallogenic belt* (Fig. 1) is the easterly extension of the Tethyan-Himalayan tectonics and contains a number of important porphyry-, porphyry-skarn-, skarn-, porphyry-epithermal-, VHMS-, shear zone-, hydrothermal vein-, granite-related greisen-, SEDEX-, MVT- and sandstone hosted Cu, Mo, Au, Pb, Zn, Ag, Sn and rare metals ore deposits (Hou et al., 2007, 2011; Zaw et al., 2007; Deng et al., 2014). Although most of these ore deposits are of Himalayan ages, some of them may be related to the Yanshanian tectono-thermal event(s). For example, Cheng et al. (2013) and Xu et al. (2015) have interpreted some granitic magmatic-hydrothermal Sn-Cu polymetallic mineral systems (e.g., Dulong and Gejiu in Yunnan Province, and Dachang in Guangxi Province) which have mineralization ages of ca. 90–81 Ma as the result of lithospheric thinning, basaltic underplating and associated crustal melting under the Middle-Late Cretaceous back-arc extensional or intra-arc rifting setting initiated by the subduction of the Paleo-Pacific Plate beneath the Eurasian continent. Nevertheless, more work is needed to address the interrelationship between the Tethys-Himalayas tectonic and the Pacific tectonic regimes in this region, in the context of the Late Mesozoic tectonism and magmatism.

(10) *The Hainan Island metallogenic belt* (Fig. 1) is situated in the southwestern part of the Cathaysia Block of South China and contains several orogenic type, granite-related and epithermal Au deposits, porphyry- and hydrothermal vein-type Mo-polymetallic deposits, skarn-type Fe ore deposits, and porphyry-epithermal Cu-Pb-Zn-Ag deposits (Xu et al., 2016a, 2017a). These deposits mainly formed in the Indosinian (Triassic) and Yanshanian (Jurassic to Cretaceous) epochs. Among these, the orogenic gold mineralization, which produces more than 95% of gold metal in Hainan Island, took place during the Early Mesozoic (ca. 228–224 Ma), whereas the granite-related mineralization is related to Late Cretaceous (ca. 100 Ma) adakite-like granitoids (Xu et al., 2017a). The Mo-polymetallic deposits are hosted predominantly within the Cretaceous high-K calc-alkaline, I-type series granitoids. Three Mo mineralizing events at ca. 112 Ma, ca. 106–95 Ma and ca. 89–72 Ma have also been identified and interpreted as a response to episodic rollback of the subducted slab of the paleo-Pacific plate under the South China continental margin (Xu et al., 2016a).

3. Highlight of papers in this Special Issue

This Special Issue brings together some of the latest information on Yanshanian metallogeny obtained from multidisciplinary studies. The nineteen papers in this issue deal with Yanshanian ore deposits formed in different epochs and under different tectonic settings during the Late Mesozoic geodynamic evolution of China, including detailed case studies of some specific deposits from different metallogenic belts or regions, as well as review papers on specific types of mineralization or on mineralization-controlling factors. The metallogenic belts or regions in which one ore more Yanshanian deposits are examined in this Special Issue include (from northeast to southwest, Fig. 1) Jiaodong Peninsula, Middle-Lower Yangtze River Valley, Jiangnan, Nanling, Southeastern China Coast, and Sanjiang. The more important findings in these papers are briefly summarized as follows.

Two papers addressed *the Jiaodong Peninsula metallogenic province* (Fig. 1). Yang et al. (2017a) carried out analyses on fluid inclusions, stable isotopes and sensitive high-resolution $^{40}Ar/^{39}Ar$ dating on hydrothermal sericite of the Wang'ershan gold deposit. Their work shows that the Wang'ershan deposit formed at ca. 120 Ma and has ore-forming fluids from a metamorphic-dominant mixed source likely related to the dehydration and decarbonization of a subducting paleo-Pacific plate. Moreover, the reaction between auriferous ore fluids, ferruginous host rocks, and fluid-immiscibility processes caused by fluid-pressure cycling during seismic movement along fault zones that host lode-gold orebodies, are interpreted as the two main precipitation mechanisms of gold deposition. As a result, Yang et al. (2017a) suggested that gold mineralization in the Jiaojia goldfield of the Jiaodong province was a large-scale unified event, with consistent timing, origin, process and mechanism. Likewise in another paper, Guo et al. (2017) launched a systematic comparison between ore fluids for both the Jiaojia- and Linglong-type Au mineralization (Qiu et al., 2002), by virtue of fluid inclusion and H-O-S-Pb isotope data. Their comparative analysis shows that both the Jiaojia- and Linglong-type deposits share similar sources and nature of the ore fluids and formed in the same metallogenic event and by similar Au depositional mechanism. They further suggested that both Jiaojia- and Linglong-type ores, with different mineralization styles, can exist in an individual deposit.

Two papers are related to *the Middle–Lower Yangtze Valley metallogenic belt* (Fig. 1). Based on detailed field work and mineralogical investigation (especially SEM/EDS and XRD analyses for the colloform pyrite), Zhang et al. (2017a) carried out *in situ* analyses on major- and trace elements, and sulfur isotope of pyrite of various origins from the Xinqiao large-scale Cu-S-Fe deposit in the Tongling area, by using EMPA (Electron Microprobe Analyzer), LA-ICP-MS (Laser Ablation Inductive Coupled Plasma, Mass Spectrometry) and SHRIMP (Sensitive High Resolution Ion Microprobe) methods. Their study indicates that the Xinqiao stratiform mineralization may be associated with the ca. 140 Ma Jitou quartz diorite stock, as is the case for the skarn-type mineralization hosted within the contact between the Jitou stock and the Lower Permian limestone. Thus, the authors suggest that the Xinqiao deposit is of magmatic-hydrothermal origin and related to Yanshanian magmatism. The second paper (Zhang et al., 2017b) investigated the petrogenesis and W-Mo enriched indicators of the ca. 145 Ma Gaojiabang "satellite" granodiorite porphyry in the northern part of the lower Yangtze continental terrene (southern Anhui Province), through an integrated analysis of the geology, mineralogy and whole-rock geochemistry. The results show that the Gaojiabang granodiorite porphyry is a highly evolved I-type granite sourced from the transition zone between lower crust and upper mantle through strong fractional crystallization. They concluded that the favorable indicators for W-Mo mineralization are that the "satellite" granodiorite porphyry has a small volume (<0.5 km^3), contains >5 vol.% hornblende, has a low $\sum$REE concentration (145–160 ppm) and weak negative Eu anomaly (0.85–0.94), with a high differentiation-index and water content, and low oxygen fugacity. Finally, Zhang et al. (2017b) suggested that these criteria can be used to identify potential W-Mo mineralized intrusions in southern Anhui Province.

Five papers discuss aspect of and mineral systems in *the Jiangnan metallogenic belt* (Fig. 1). Xu et al. (2017b) first conducted a comprehensive review on ore geology, geochemistry and geochronology of the gold (Au) (-polymetallic) deposits in this belt. Combined with their new S-Pb isotopic and geochronological (Ar-Ar, Re-Os and zircon U-Pb) data on several deposits, they recognized three Au mineralizing epochs: ca. 423–397 Ma mineralization associated with the early Paleozoic tectonothermal event(s), ca. 176–170 Ma (Jurassic) mineralization likely induced by the subduction of the paleo-Pacific plate beneath the South China continent, and ca. 144–130 Ma (early Cretaceous) mineralization (the most important one in the region) related to the Late Mesozoic extensional regime in South China. Based on the geological, geochronological, C-H-O-S-Pb-He-Ar isotopic and fluid inclusion data as well as the analysis on the tectonic and magmatic events, a new ore-deposit type, i.e. "*intracontinental reactivation type*", which is characterized by synchronous development of Au–polymetallic mineralization, reactivation of structures initially developed in Neoproterozoic metamorphic rocks, and widespread emplacement of the Late Mesozoic granites, has been suggested to explain the genesis of Au (-polymetallic) deposits in the Jiangnan belt. This new ore deposit-type has been further taken up by Deng et al. (2017), who suggested that the large Wangu Au deposit in northeastern Hunan Province, an important constituent of the Jiangnan metallogenic belt, is an example of the "intracontinental reactivation" type, as the geological and geochemical characteristics and timing of mineralization do not comply with typical orogenic, epithermal, intrusion-related or Carlin-type Au deposits. In the same region, Wang et al. (2017a) also present a case study of ore genesis of the Jingchong Co-Cu polymetallic deposit hosted within a NE-trending strike-slip fault zone, through investigations on ore geology, mineral chemistry (chlorite, pyrite) and S-Pb-He-Ar isotopes of sulfides. The results suggest that the Jingchong deposit formed from a hydrothermal system associated with the Late Jurassic to Early Cretaceous Lianyunshan granitoids, which were derived from crustal anataxis of the Archean to Paleoproterozoic Lianyunshan Group in a back-arc extensional setting in the Late Mesozoic. It is suggested that exploration for this type of Co (-polymetallic) deposits in northeastern Hunan Province should focus on the junction areas where re-activated faults and granitoid intrusions developed in the vicinity of the Lianyunshan Group (Wang et al., 2017a). Effectively, these two papers (Deng et al., 2017; Wang et al., 2017a) indicate that Late Mesozoic re-activation of pre-ore structures (faults) by the Yanshanian tectono-thermal event(s) is important for the Yanshanian mineralization. Two other papers by Jiao et al. (2017a,b) also emphasize the re-activation of pre-existing structures that lead to the enrichment or refinement of Au, as shown by the relationship between Au mineralization and development of ductile-shear zones in the Hetai goldfield in Guangdong Province. Through an integrated analysis on structures, zircon U-Pb ages, mineralogy and C-H-O-S-Pb-He-Ar isotopes, Jiao et al. (2017a,b) suggest that the Hetai goldfield was subjected to two ductile shearing events: an early sinistral ductile shearing at ca. 240 Ma, and a late dextral ductile-brittle shearing at ca. 204 Ma (Indosinian), followed by brittle reactivation and associated gold mineralization at ca. 175–152 Ma (Yanshanian). This inference is further supported not only by the ore-forming temperatures estimated from geothermometers of minerals arsenopyrite, chlorite and sphalerite intergrown with native gold, which are considerably lower than that for the ductile deformation, but also by the C-H-O-S-Pb-He-Ar multi-isotopic data which indicate that the ore fluids and metals may have undergone two stages of evolution, i.e. from the Indosinian metamorphic water-dominated fluids mixed with minor magmatic waters, to the Yanshanian magmatic water-dominated fluids mixed with mantle-derived fluids and meteoric waters. Jiao et al. (2017a,b) thus proposed that the Au mineralization in the Hetai goldfield predominantly occurred during the Yanshanian period, and only minor gold mineralization and associated sulfidation took place during the earlier Indosinian ductile deformation.

Two papers addressed the magmatic-hydrothermal mineral systems in *the Nanling metallogenic belt* (Fig. 1). Li et al. (2017) utilized published chemical compositions of biotite to calculate oxygen fugacities (fO_2) of magmas for Yanshanian (Jurassic to Cretaceous) fertile and barren granitoids in South China (mostly in Nanling). In combination with whole-rock Fe^{3+}/Fe^{2+} and zircon Ce^{4+}/Ce^{3+} ratios from the literature, they found that in areas of

Cu–(Au)–Mo mineralization, ore-bearing granites have distinctly higher oxygen fugacities than barren granites, and that granites related to Cu–(Au)–Mo mineralization have the highest oxygen fugacities, followed by those related to Cu-Pb-Zn and W, and finally by those related to W-Sn and Sn. The study results also reveal a decreasing trend of oxygen fugacities from NE to SW and from SE to NW, for the early Yanshanian and the late Yanshanian granites, respectively, linked to a switch in the direction of subduction of the Paleo-Pacific plate. It is proposed that the compositions of fresh primary biotite in granitic rocks may be used as an exploration tool. In the second paper, Wang et al. (2017b) carried out an integrated analysis on mineralogy, whole-rock geochemistry and zircon U-Pb age and Lu-Hf isotopes of the muscovite granites occurring as "satellite" intrusions, within or surrounding the early Yanshanian batholitic biotite monzogranites, from six magmatic-hydrothermal vein-type W ore deposits in the Nanling belt. The results confirm that the muscovite granites (rather than the biotite monzogranites), which contain ca. 134 Ma hydrothermal zircons and formed from highly fractionated granitic magmas, are the parental rocks of the W deposits. This new finding indicates that the muscovite granites can be used as a general guide for the exploration of magmatic-hydrothermal vein-type W deposits in Nanling and elsewhere in the world.

Five papers denoted their contributions to *the southeastern China Coast metallogenic belt* (Fig. 1). In the first paper, Qiu et al. (2017) reported on a recently discovered ca. 140 Ma granite-related Sn-Cu-Pb-Zn deposit, i.e. the Jinkeng deposit in eastern Guangdong Province, SE China. Through a systematic study of the geology, zircon U-Pb and molybdenite Re-Os geochronology, geochemistry, and Lu–Hf isotopic compositions of the mineralized granites of the Jinkeng deposit, they identified a significant period of W–Sn metallogenesis at ca. 145–135 Ma in the southeastern China Coast belt. Their results also indicate that the Sn-rich mineralized granites are highly fractionated I-type granites derived from a reduced (fO_2 below NNO) magma mainly due to partial melting of the Proterozoic basement (with minor contribution from the mantle) under an extensional regime, probably linked to the rollback of the paleo-Pacific Plate. In the second paper, Zheng et al. (2017) also reported a newly discovered, Late Cretaceous (ca. 79 Ma) A-type granite-related W–Sn deposit, i.e., the Xishan deposit in western Guangdong Province. The integrated analysis on zircon U-Pb age, whole-rock geochemistry, Sr–Nd–Pb–Hf isotopes and molybdenite Re–Os age indicates that the A-type granites, which formed by partial melting of Mesoproterozoic crust of the Cathaysia Block (with addition of mantle-derived melt), have an emplacement age of ca. 79 Ma, consistent with the timing of W-Sn mineralization. This suggests that A-type granites, in addition to I-type and S-type, can also lead to Sn mineralization, in the background of Cretaceous lithospheric extension and asthenospheric upwelling induced by subduction of the paleo-Pacific plate. Nevertheless, Tethyan tectonics may have also played a role in initiating the A-type granitic magmatism, considering the granite-related Sn-Cu polymetallic deposits with the mineralizing ages of ca. 90–81 Ma in the Sanjiang metallogenic belt (see the below). Two other papers (Li and Jiang, 2017; Xu et al., 2017c) focused their attention to the Late Mesozoic tectono-magmatic processes and associated Au-Cu-Mo mineralization of the Zijingshan orefield, one of the largest porphyry-epithermal Au-Cu-Mo ore systems in South China. Xu et al. (2017c) conducted a new analysis on petrography, whole-rock geochemistry and zircon U–Pb geochronology, geochemistry and Hf isotope of the multiphase granitic intrusions from the newly discovered Xinan Cu-Mo deposit in the Zijinshan orefield. Combined with the previously published data, the results indicate that the Mesozoic igneous rocks in the Zijinshan orefield are attributed to at least two stages of magmatism: one occurring during the Middle to Late Jurassic (ca. 169–150 Ma), whereas the other during the late Early Cretaceous to earliest Late Cretaceous (ca. 112–98 Ma). Although these Mesozoic igneous rocks may be related to the subduction of the paleo-Pacific plate and most of them likely formed from partial melting of the Paleoproterozoic metamorphosed Cathaysia Block basement, the Middle to Late Jurassic granitoids are related to a compressional stress field, whereas the late Early Cretaceous to earliest Late Cretaceous ones, with more mantle and/or juvenile mafic lower crustal input, are related to an extensional setting, due to change in subduction direction, plate rollback and slab window-opening. Xu et al. (2017c) concluded that tectonic regime transition, high oxygen fugacity (fO_2) and involvement of mantle/mafic lower crustal materials during the late Early Cretaceous to earliest Late Cretaceous might have been instrumental in generating the Zijinshan porphyry-related Au-Cu-Mo mineralization. In combination with the previously published Re–Os isotopes, zircon U–Pb ages and trace elements, and Sr–Nd–Pb isotopes, Li and Jiang (2017) presented new Pb–S and Re–Os isotopic and zircon trace elements data of the mineralization-related granitoids from both the Zijinshan epithermal Cu–Au and Luoboling porphyry Cu–Mo deposits, in order to provide insights into the relationship between the porphyry Cu–Mo and the epithermal Cu–Au ore systems. The results suggest that the Luoboling and Zijinshan ore deposits may have been formed from two separate magmatic-hydrothermal systems, with a dominant enriched mantle origin for the former and a mixed source of the enriched mantle-derived magmas with the lower crust-derived felsic magmas for the latter. High oxygen fugacity and water contents control the capacity of the magmatic system to carry Cu, Mo and Au, and to produce economic mineralization, as also discussed in Li et al. (2017). Moreover, the fact that Cu and Au show vertical zoning and different fertility due to Au transportation at low oxygen fugacity and its precipitation during the decreasing temperature and pressure and changing pH conditions suggests that there is a large Cu–Mo potential in the deeper part of the Zijinshan epithermal deposit, where further deep drilling and exploration are encouraged. In the last paper, Yang et al. (2017b) carried out a detailed study on geological feature, magnetite composition, fluid inclusions, and stable isotopes of the Makeng Fe-ore deposit hosted within middle Carboniferous to Lower Permian limestones in Fujian Province. Their results indicate that the Makeng deposit is a typical skarn type, with the ore fluids mainly from magmatic water, and that fluid boiling induced massive deposition of magnetite, whereas fluid mixing caused precipitation of Pb, Zn ± Fe in the late stage of mineralization.

Finally, three papers focused on *the Sanjiang metallogenic belt* (Fig. 1). Du et al. (2017) carried out new analysis of C-O isotopes of calcite to address the ore fluid source and ore-forming processes of the Yangla Cu deposit, which is associated with the Triassic (ca. 230 Ma) granites in the Sanjiang metallogenic belt. Combined with ore geology, they suggested that both CO_2 degassing and water-rock interaction were responsible for precipitation of hydrothermal calcite intimately related to the Yangla skarn Cu mineralization. A new analytical technique on Cu isotopes was applied to the Hongshan-Hongniu skarn Cu deposit and related Triassic (ca. 216 Ma) quartz monzonite porphyry to investigate their genetic relationship (Wang et al., 2017c). The δ^{65}Cu values of the chalcopyrite, intrusion and host rocks demonstrate that the porphyry rather than the host rocks gave a predominant contribution to the Cu mineralization. Therefore, this provides a potential scope for deep exploration. Chen et al. (2017) applied the Bi-dimensional empirical mode decomposition (BEMD) method, an information extraction technique based on geophysical data (e.g., gravity), to the

Gejiu Sn-Cu polymetallic ore field and its adjacent Bozhushan Ag-Pb-Zn ore field at a scale of 1:200,000. The BEMD yielded three two-dimensional intrinsic mode function (i.e. $BIMF_1$, $BIMF_2$, $BIMF_3$) images and one residue (Res(m, n)) image that depict four layers of geological architectures at different wavelengths within the study area. The interpretation on these extracted information from gravity data thus suggests that the Gejiu orefield and related granites are located at the transitional zone between the uplift and depression, whereas the Bozhushan orefield and related granites are situated within the depression zone, which implies that the diversity of the Late Yanshanian granites and the related polymetallic deposits in the study area may be controlled by the complexity of the crust-mantle interaction at depth (Chen et al., 2017).

4. Summary and perspective for future studies

From the above highlights, a few important contributions to the topic of this Special Issue (Yanshanian metallogeny) can be summarized as: (1) A new ore-deposit type, i.e. the "intracontinental reactivation" type, has been suggested to interpret the genesis of those Au-(polymetallic) deposits that are hosted within older metamorphic rocks and related to the Late Mesozoic basin-and-range extensional settings; (2) Late Mesozoic re-activation of the preexisting structures by the Yanshanian tectono-thermal event (s) might be an important mechanism controlling the Yanshanian large-scale mineralization; (3) A-type granites formed by partial melting of the Mesoproterozoic crust, but with inputs from mantle-derived melt are also favorable for Sn mineralization, in addition to S-type and I-type granites as previously recognized; (4) Calculated oxygen fugacities (fO_2) of granitic magmas based on chemical compositions of primary biotite have been confirmed to be effective proxy for distinguishing Cu-Au-Mo-W-Sn-Pb-Zn mineralized granites from barren granites; (5) A significant epoch of W–Sn magmatic-hydrothermal ore system at ca. 145–135 Ma has been identified in the southeastern China Coast metallogenic belt; and (6) In addition to traditional structural geology, mineralogy, petrology, geochemistry and geochronology, new analytical techniques (e.g. Cu isotopes) and data treatment method (e.g., Bi-dimensional empirical mode decomposition) can be used to provide more constraints for deep exploration.

Although the papers in this Special Issue presented detailed studies of individual deposits from various metallogenic provinces and suggested some exploration strategies, the dynamic mechanism(s) driving the Yanshanian large-scale metallogenesis and associated magmatism and crustal deformation, and the intrinsic genetic linkage of the Yanshanian ore systems to the deep lithospheric processes, remain undetermined. The multi-stage nature of the Yanshanian Orogeny, characterized by alternating compression and extension, adds additional complexity to the geodynamic setting. Furthermore, the effects of other tectonic events (both in time and space) on the Yanshanian Orogeny, including the collisions between the North China and the South China blocks, and between the South China and the Indochina blocks, the subduction of the paleo-Pacific oceanic plate, and the evolution of the paleo-Asian tectonic domains, need to be further evaluated. This also stems from the fact that continental China (especially eastern China) is the result of the protracted tectonic histories highlighted by multistage tectono-thermal events which most likely have reworked or modified, superimposed and re-activated pre-existing structures, rocks and even mineral deposits. As a result, a comprehensive metallogenic model for Yanshanian ore deposits is still somewhat lacking. Such a model should incorporate geological, geochronological, geochemical, and geophysical information into an integrated tectonic framework, taking into account the deep processes related to plate and mantle plume tectonics, crust-mantle interaction, and large-scale metal enrichment processes.

Conflict of interest

None.

Acknowledgements

This research was financially co-supported by the DREAM project of MOST, China (No. 2016YFC0600401), the National Natural Science Foundation of China (No. 41472171, 41672077, 41302049) and Chinese Ministry of Land and Resources (200646092). We thank the authors for their contributions in preparing the papers for this Special Issue within a tight time frame. In addition, we express our sincere thanks to following reviewers for their great assistance: Karel Breiter, Huayong Chen, Yanbo Cheng, Ian Coulson, Hongrui Fan, Baoqun Hu, Zhilong Huang, Shaoyong Jiang, Vadim Kamenetsky, M.A Kusiak, Houming Li, Wenbo Li, Yanhe Li, Mingxing Ling, Jiajun Liu, Sheng-Ao Liu, Jingwen Mao, Mark Pearce, Kezhang Qin, Tsilavo Raharimahefa, Richard Smith, Xiaoming Sun, Thomas Ulrich, Changming Wang, Peter Sorjonen-Ward, Yulin Xie, Cheng Xu, Chunji Xue, Liqiang Yang, Xiaoyong Yang, Xueming Yang, Shunda Yuan, Qingdong Zeng, Rongqing Zhang, Wei Zhang, Guochun Zhao, Kuidong Zhao, Xiaobo Zhao, Taofa Zhou, Janwei Zi, and other anonymous reviewers. Finally, a particular thank is given to the Editor-in-Chief Franco Pirajno for his editorial handling of this Special Issue.

References

Charles, N., Augier, R., Gumiaux, C., Monié, P., Chen, Y., Faure, M., Zhu, R.X., 2013. Timing, duration and role of magmatism in wide rift systems: insights from the Jiaodong Peninsula (China, East Asia). Gondwana Res. 24, 412–428.

Chen, G.D., 1956. Examples of "activated region" in Chinese Plateform with special reference to the "Cathaysia" problem. Acta Geol. Sinica 36, 239–272 (in Chinese with English abstract).

Chen, G.D., 1959. The third basic tectonic element of the earth's crust, the Diwa (geodepression) region. Chin. Sci. Bull. 3, 94–95.

Chen, G.D., 1987. On the geotectonic nature of the Fen-Wei rift system. Tecionophysics 143, 217–223.

Chen, G.D., Yang, X.Y., Liang, X.Q., 2012. Some cruxes of dynamics study on activated region. Chin. J. Geol. 37 (3), 320–331 (in Chinese with English abstract).

Chen, Y.-J., Chen, H.-Y., Zaw, K., Pirajno, F., Zhang, Z.-J., 2007. Geodynamic settings and tectonic model of skarn gold deposits in China: an overview. Ore Geol. Rev. 31, 139–169.

Chen, Y.J., Guo, G.J., Li, X., 1998. Metallogenic geodynamic background of Mesozoic gold deposits in granite-greenstone terrains of North China Craton. Sci. China (Series D) 41 (2), 113–120.

Chen, Y.Q., Zhang, L.N., Zhao, B.B., 2017. Application of Bi-dimensional empirical mode decomposition (BEMD) modeling for extracting gravity anomaly indicating the ore-controlling geological architectures and granites in the Gejiu tin-copper polymetallic ore field, southwestern China. Ore Geol. Rev. 88, 832–840.

Cheng, Y., Mao, J., Spandler, C., 2013. Petrogenesis and geodynamic implications of the Gejiu igneous complex in the western Cathaysia Block, South China. Lithos 175–176, 213–229.

Cui, S.Q., Li, J.R., Wu, Z.H., Yi, M.C., Shen, S.M., Ying, H.R., Ma, Y.H., 2002. Mesozoic and Cenozoic intracontinental orogenesis of the Yanshan area, China. Geological Publishing House, Beijing. 386. p (in Chinese with English abstract).

Deng, J., Wang, Q.F., Li, G.J., Li, C.S., Wang, C.M., 2014. Tethys tectonic evolution and its bearing on the distribution of important mineral deposits in the Sanjiang region, SW China. Gondwana Res. 26 (2), 419–437.

Deng, T., Xu, D.R., Chi, G.X., Wang, Z.L., Jiao, Q.Q., Ning, J.T., Dong, G.J., Zou, F.H., 2017. Geology, geochronology, geochemistry and ore genesis of the Wangu gold deposit in northeastern Hunan Province, Jiangnan Orogen, South China. Ore Geol. Rev. 88, 619–637.

Dong, S.W., Zhang, Y.Q., Long, C.X., Yang, Z.Y., Ji, Q., Wang, T., Hu, J.M., Chen, X.H., 2007. Jurassic tectonic revolution in China and new interpretation of the Yanshan Movement. Acta Geol. Sinica 81 (11), 1449–1461 (in Chinese with English abstract).

Du, L.J., Li, B., Huang, Z.L., Zhou, J.X., Zou, G.F., Yan, Z.F., 2017. Carbon-oxygen isotopic geochemistry of the Yangla Cu skarn deposit, SW China: implications for the source and evolution of hydrothermal Fluids. Ore Geol. Rev. 88, 809–821.

Eaton, G.P., 1982. The basin and range province: origin and tectonic significance. Annu. Rev. Earth Planet. Sci. 10, 409–440.

Faure, M., Sun, Y., Shu, L., Monié, P., Charvet, J., 1996. Extensional tectonics within a subduction-type orogen: the case study of the Wugongshan dome (Jiangxi Province, southeastern China). Tectonophysics 263, 77–106.
Fu, Z.R., Li, Z.J., Zheng, D.Y., 1999. Structural pattern and tectonic evolution of NNE trending strike slip orogenic belt in the border region of Hunan and Jiangxi provinces. Earth Sci. Front. 6 (4), 263–272 (in Chinese with English Abstract).
Goldfarb, R.J., Taylor, R.D., Collins, G.S., Goryachev, N.A., Orlandini, O.F., 2014. Phanerozoic continental growth and gold metallogeny of Asia. Gondwana Res. 25, 48–102.
Guo, L.N., Goldfarb, R.J., Wang, Z.L., Li, R.H., Chen, B.H., Li, J.L., 2017. A comparison of Jiaojia- and Linglong-type gold deposit ore-forming fluids: do they differ? Ore Geol. Rev. 88, 511–533.
Guo, L.Z., Shi, Y.S., Ma, R.S., Lu, H.F., Ye, S.F., 1985. Plate movement and crustal evolution of the Jiangnan Proterozoic mobile belt, SE China. Earth Sci. J. Geol. Soc. Japan 2, 156–166.
Henry, C.D., Perkins, M.E., 2001. Sierra nevada-basin and range transition near Reno, Nevada: two-stage development at 12 and 3 Ma. Geology 29, 719–722.
Hou, Z.Q., Pan, G.T., Mo, X.X., Xu, Q., Hu, Y.Z., Li, X.Z., 2007. The Sanjiang Tethyan metallogenesis in SW China: tectonic setting, metallogenic epoch and deposit type. Ore Geol. Rev. 31, 48–87.
Hou, Z.Q., Zhang, H.R., Pan, X.F., Yang, Z.M., 2011. Porphyry Cu (-Mo-Au) deposits related to melting of thickened mafic lower crust: Examples from the eastern Tethyan metallogenic domain. Ore Geol. Rev. 39, 21–45.
Hsü, K.J., Li, J.L., Chen, H.H., Wang, Q.C., Sun, S., Sengor, A.M.C., 1990. Tectonics of South China: Key to understanding West Pacific geology. Tectonophysics 183, 9–39.
Hu, R.Z., Chen, W..Terry., Xu, D.R., Zhou, M.F., 2017. Reviews and new metallogenic models of mineral deposits in South China: an introduction. J. Asian Earth Sci. 137, 1–8.
Hua, R.M., Chen, P.R., Zhang, W.L., Liu, X.D., Lu, J.J., Lin, J.F., Yao, J.M., Qi, H.W., Zhang, Z.S., Gu, S.Y., 2003. Metallogenic systems related to Mesozoic and Cenozoic granitoids in South China. Sci. China (Series D) 46 (8), 816–829.
Jiang, X.Y., Li, X.H., 2014. In situ zircon U-Pb and Hf-O isotopic results for ca. 73 Ma granite in Hainan Island: Implications for the termination of an Andean-type active continental margin in southeast China. J. Asian Earth Sci. 82, 32–46.
Jiang, Y.H., Jiang, S.Y., Dai, B.Z., Liao, S.Y., Zhao, K.D., Ling, H.F., 2009. Middle to late Jurassic felsic and mafic magmatism in southern Hunan Province, southeast China: implications for a continental arc to rifting. Lithos 107, 185–204.
Jiao, Q.Q., Deng, T., Wang, L.X., Xu, D.R., Chi, G.X., Chen, G.W., Liu, M., Chen, Y.S., Gao, Y.W., Zou, S.H., 2017a. Geochronological and mineralogical constraints on mineralization of the Hetai goldfield in Guangdong Province, South China. Ore Geol. Rev. 88, 655–673.
Jiao, Q.Q., Wang, L.X., Deng, T., Xu, D.R., Chen, G.W., Yu, D.S., Ye, T.W., Gao, Y.W., 2017b. Origin of the ore-forming fluids and metals of the Hetai goldfield in Guangdong Province of South China: constraints from C-H-O-S-Pb-He-Ar isotopes. Ore Geol. Rev. 88, 674–689.
Kerrich, R., Goldfarb, R., Groves, D., Garwin, S., Jia, Y.F., 2000. The characteristics, origins, and geodynamic settings of supergiant gold metallogenic provinces. Sci. China (Series D) 43 (Supp.), 1–68.
Li, B., Jiang, S.Y., 2017. Genesis of the giant Zijinshan epithermal Cu-Au and 1 Luoboling porphyry Cu–Mo deposits in the Zijinshan ore district, Fujian Province, SE China: a multi-isotope and trace element investigation. Ore Geol. Rev. 88, 753–767.
Li, J.H., Ma, Z.L., Zhang, Y.Q., Dong, S.W., Li, Y., Lu, M.A., Tan, J.Q., 2014. Tectonic evolution of Cretaceous extensional basins in Zhejiang Province, eastern South China: structural and geochronological constraints. Int. Geol. Rev. 56 (13), 1602–1629.
Li, J.H., Shi, W., Zhang, Y.Q., Dong, S.W., Ma, Z.L., 2016. Thermal evolution of the Hengshan extensional dome in central South China and its tectonic implications: New insights into low-angle detachment formation. Gondwana Res. 35 (2016), 425–441.
Li, S.Z., Suo, Y.H., Santonsh, M., Dai, L.M., Liu, X., Yui, S., Zhao, S.J., Jin, C., 2013. Mesozoic to Cenozoic intracontinental deformation and dynamics of the North China Craton. Geol. J. 48, 543–560.
Li, X.Y., Chi, G.X., Zhou, Y.Z., Deng, T., Zhang, J.R., 2017. Oxygen fugacity of Yanshanian granites in South China and implications for metallogeny. Ore Geol. Rev. 88, 690–701.
Li, Z., Liu, S.F., Zhang, J.F., Wang, Q.C., 2004. Typical basin-fill sequences and basin migration in Yanshan, North China-Response to Mesozoic tectonic transition. Sci. China Ser. D Earth Sciences 47 (2), 181–192.
Li, Z.L., Hu, R.Z., Yang, J.S., Peng, J.T., Li, X.M., Bi, X.W., 2007. 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, 161–193.
Li, Z.X., 1998. Tectonic history of the major East Asian lithospheric blocks since the mid-Proterozoic -a synthesis. Mantle dynamics and plate interactions in East Asia. Geodynamics 27, 221–243.
Li, Z.X., Li, X.H., 2007. Formation of the 1300-km-wide intracontinental orogen and postorogenic magmatic province in Mesozoic South China: a flat-slab subduction model. Geology 35 (2), 179–182.
Lin, W., Wang, Q.C., Chen, K., 2008. Phanerozoic tectonics of south China block: new insights from the polyphase deformation in the Yunkai massif. Tectonics 27, TC6004.
Mao, J.R., Li, Z.L., Ye, H.M., 2014. Mesozoic tectono-magmatic activities in South China: retrospect and prospect. Sci. China (Earth Sciences) 57 (12), 2853–2877.
Mao, J.W., Cheng, Y.B., Chen, M.H., Pirajno, F., 2013. Major types and time-space distribution of Mesozoic ore deposits in South China and their geodynamic settings. Miner. Deposita 48, 267–294.
Mao, J.W., Goldfarb, R.J., Zhang, Z.W., Xu, W.Y., Qiu, Y.M., Deng, J., 2002. Gold deposits in the Xiaoqinling-Xiong'ershan region, Qinling Mountains, central China. Miner. Deposita 37, 306–325.
Mao, J.W., Pirajno, F., Cook, N., 2011a. Mesozoic metallogeny in East China and corresponding geodynamic settings—an introduction to the special issue. Ore Geol. Rev. 43, 1–7.
Mao, J.W., Pirajno, F., Xiang, J.F., Gao, J.J., Ye, H.S., Li, Y.F., Guo, B.J., 2011b. Mesozoic molybdenum deposits in the east Qinling-Dabie orogenic belt: characteristics and tectonic settings. Ore Geol. Rev. 43, 264–293.
Mao, J.W., Xie, G.Q., Zhang, Z.H., Li, X.F., Wang, Y.T., Zhang, C.Q., Li, Y.F., 2005. Mesozoic large-scale metallogenic pulses in North China and corresponding geodynamic settings. Acta Petrol. Sin. 21, 169–188 (in Chinese with English abstract).
Pirajno, F., Bagas, L., 2002. Gold and silver metallogeny of the South China Fold Belt: a consequence of multiple mineralizing events? Ore Geol. Rev. 20, 109–126.
Pirajno, F., Ernst, R.E., Borisenko, A.S., Fedoseev, G., Naumov, E.A., 2009. Intraplate magmatism in Central Asia and China and associated metallogeny. Ore Geol. Rev. 35, 114–136.
Pirajno, F., 2013. The Geology and Tectonic Settings of China's Mineral Deposits. Springer, Dordrecht, Berlin, p. 679.
Pirajno, F., Zhou, T.F., 2015. Intracontinental porphyry and porphyry-skarn mineral systems in eastern China: scrutiny of a special case "Made-in-China". Econ. Geol. 110, 603–629.
Qiu, Y.M., Groves, D., McNaughton, N., Wang, L.G., Zhou, T.H., 2002. Nature, age, and tectonic setting of granitoid-hosted, orogenic gold deposits of the Jiaodong Peninsula, eastern North China craton, China. Mineral. Depos. 37, 283–305.
Qiu, Z.W., Yan, Q.H., Li, S.S., Wang, H., Tong, L.X., Zhang, R.Q., Wei, X.P., Li, P., Wang, L.M., Bu, A., Yan, L.M., 2017. Highly fractionated Early Cretaceous I-type granites and related Sn polymetallic mineralization in the Jinkeng deposit, eastern Guangdong, SE China: constraints from geochronology, geochemistry, and Hf isotopes. Ore Geol. Rev. 88, 718–738.
Ren, J.S., Wang, Z.X., Chen, B.W., Jiang, C.F., Niu, B.G., Li, J.R., Xie, G.L., He, Z.J., Liu, Z. G., 1999. The Tectonics of China from a Global View-a Guide to the Tectonic Map of China and Adjacent Regions-view Geotectonics of China from Globe. Geological Publishing House, Beijing. 25 p. (in Chinese with English abstract).
Shi, W., Dong, S.W., Zhang, Y.Q., Huang, S.Q., 2015. The typical large-scale superposed folds in the central South China: Implications for Mesozoic intracontinental deformation of the South China Block. Tectonophysics 664, 50–66.
Shu, L., Zhou, X., Deng, P., Wang, B., Jiang, S.Y., Yu, J., Zhao, X., 2009. Mesozoic tectonic evolution of the Southeast China Block: new insights from basin analysis. J. Asian Earth Sci. 34, 376–391.
Sun, W.D., Ding, X., Hu, Y.H., Li, X.H., 2007. The golden transformation of the Cretaceous plate subduction in the west Pacific. Earth Planet. Sci. Lett. 262, 533–542.
Wang, T., Zheng, Y.D., Zhang, J.J., Zeng, L.S., Donskaya, T., Guo, L., Li, J.B., 2011. Pattern and kinematic polarity of late Mesozoic extension in continental NE Asia: perspectives from metamorphic core complexes. Tectonics 30 (TC6007), 1–27.
Wang, D.Z., Shu, L.S., 2012. Late Mesozoic basin and range tectonics and related magmatism in Southeast China. Geosci. Front. 3 (2), 109–124.
Wang, F., Wang, Q.C., Lin, W., Wu, L., Shi, W.B., Feng, H.L., Zhu, R.X., 2014. $^{40}Ar/^{39}Ar$ geochronology of the North China and Yangtze Cratons: New constraints on Mesozoic cooling and cratonic destruction under East Asia. J. Geophys. Res.: Solid Earth, Earth 119, 3700–3721.
Wang, P., Dong, G.C., Santosh, M., Liu, K.R., Li, X.F., 2017c. Copper isotopes trace the evolution of skarn ores: a case study from the Hongshan-Hongniu Cu deposit, southwest China. Ore Geol. Rev. 88, 822–831.
Wang, X., Ren, M.H., Chen, J., 2017b. The muscovite granites: parental rocks to the Nanling Range tungsten mineralization in South China. Ore Geol. Rev. 88, 702–717.
Wang, Y., Zhou, L.Y., Zhao, L.J., 2013b. Cratonic reactivation and orogeny: an example from the northern margin of the North China Craton. Gondwana Res. 24, 1203–1222.
Wang, Y.J., Fan, W.M., Zhang, G.W., Zhang, Y., 2013a. Phanerozoic tectonics of the South China Block: Key observations and controversies. Gondwana Res. 23 (4), 1273–1305.
Wang, Z.L., Xu, D.R., Chi, G.X., Shao, Y.J., Lai, J.Q., Deng, T., Guo, F., Wang, Z., Dong, G. J., Ning, J.T., Zou, S.H., 2017a. Mineralogical and isotopic constraints on the genesis of the Jingchong Co–Cu polymetallic ore deposit in northeastern Hunan Province, South China. Ore Geol. Rev. 88, 638–654.
Wong, W.H., 1926. Crust movement in eastern China. In: Proceedings of 3th Pan-Pacific Science Congress, Tokyo, 642–685.
Wong, W.H., 1927. Crustal movements and igneous activities in eastern China since Mesozoic time. Acta Geol. Sinica 6, 9–37.
Wong, W.H., 1929. The Mesozoic orogenic movement in eastern China. Bull. Geol. Soc. China 8, 33–44.
Xu, B., Jiang, S.Y., Wang, R., Ma, L., Zhao, K.D., Yan, X., 2015. Late Cretaceous granites from the giant Dulong Sn-polymetallic ore district in Yunnan Province, South China: Geochronology, geochemistry, mineral chemistry and Nd–Hf isotopic compositions. Lithos 218–219, 54–72.
Xu, C., Chen, H.Y., Huang, W.T., Qi, J.P., Duan, G., Zhang, L.J., Wu, C., Zhang, S., Zhong, W.B., 2017c. Mesozoic multiphase magmatism at the Xinan Cu–Mo ore deposit

(Zijinshan Orefield): Geodynamic setting and metallogenic implications. Ore Geol. Rev. 88, 768–790.
Xu, D.R., Deng, T., Chi, G.X., Wang, Z.L., Zou, F.H., Zhang, J.L., Zou, S.H., 2017b. Gold mineralization in the Jiangnan Orogenic Belt of South China: Geological, geochemical and geochronological characteristics, ore deposit-type and geodynamic setting. Ore Geol. Rev. 88, 565–618.
Xu, D.R., Fu, G.G., Xu, Y.M., Tian, X.F., Wu, C.J., Hou, M.S., Lei, Z.H., Gong, S.Q., Zhang, Y.J., Huang, G.F., 2016b. Study and Prospecting on the Sn-polymetallic Ore Deposits in Qianlishan-Qitianling Area, Southern Hunan Province of South China. Science Press, Beijing. 333 p. (in Chinese).
Xu, D.R., Wang, Z.L., Wu, C.J., Zhou, Y.Q., Shan, Q., Hou, M.Z., Fu, Y.R., Zhang, X.W., 2017a. Mesozoic gold mineralization in Hainan Province of South China: genetic types, geological characteristics and geodynamic settings. J. Asian Earth Sci. 137, 80–108.
Xu, D.R., Wu, C.J., Hu, G.C., Chen, M.L., Fu, Y.R., Wang, Z.L., Chen, H.Y., Hollings, P., 2016a. Late Mesozoic molybdenum mineralization on Hainan Island, South China: geochemistry, geochronology and geodynamic setting. Ore Geol. Rev. 72 (1), 402–433.
Xu, D.R., Xia, B., Li, P.C., Chen, G.H., Ma, C., Zhang, Y.Q., 2007. Protolith natures and U-Pb sensitive high mass-resolution ion microprobe (SHRIMP) zircon ages of the metabasites in Hainan Island, South China: Implications for geodynamic evolution since the late Precambrian. Island Arc 16, 575–597.
Yang, L.Q., Deng, J., Wang, Z.L., Zhang, L., Guo, L.N., Song, M.C., Zheng, X.L., 2014. Mesozoic gold metallogenic system of the Jiaodong gold province, eastern China. Acta Petrol. Sin. 30, 2447–2467 (in Chinese with English abstract).
Yang, L.Q., Guo, L.N., Wang, Z.L., Zhao, R.X., Song, M.C., Zheng, X.L., 2017a. Timing and mechanism of gold mineralization at theWang'ershan gold deposit, Jiaodong Peninsula, eastern China. Ore Geol. Rev. 88, 491–510.
Yang, Y.L., Ni, P., Pan, J.Y., Wang, G.G., Xu, Y.F., 2017b. Constraints on the mineralization processes of the Makeng iron deposit, eastern China: Fluid inclusion, H-O isotope and magnetite trace elementanalysis. Ore Geol. Rev. 88, 791–808.
Zaw, K., Peters, S.G., Cromie, P., Burrett, C., Hou, Z.Q., 2007. Nature, diversity of deposit types and metallogenic relations of South China. Ore Geol. Rev. 31, 3–47.
Zeng, Q.D., Liu, J.M., Qin, K.Z., Fan, H.R., Chu, S.X., Wang, Y.B., Zhou, L.L., 2013. Types, characteristics, and time-space distribution of molybdenum deposits in China. Int. Geol. Rev. 55 (11), 1311–1358.
Zhai, M.G., Meng, Q.R., Liu, J.M., Hou, Q.L., Hu, S.B., Li, Z., Zhang, H.F., Liu, W., Shao, J., Zhu, R.X., 2004. Geological features of Mesozoic tectonic regime inversion in Eastern North China and implication for geodynamics. Earth Sci. Front. (China University of Geosciences, Beijing) 11 (3), 285–297 (in Chinese with English abstract).
Zhai, M.G., Santosh, M., 2013. Metallogeny of the North China Craton: Link with secular changes in the evolving Earth. Gondwana Res. 24, 275–297.
Zhai, M.G., Yang, J.H., Liu, W.J., 2001. Large clusters of gold deposits and large-scale metallogenesis in the Jiaodong Peninsula, Eastern China. Sci. China (Series D) 44 (8), 758–768.
Zhang, H.Y., Hou, Q.L., Cao, D.Y., 2007. Study of thrust and nappe tectonics in the eastern Jiaodong Peninsula, China. Sci. China, Ser. D Earth Sci. 50 (2), 161–171.
Zhang, B.L., Zhu, G., Jiang, D.Z., Li, C.C., Chen, Y., 2012. Evolution of the Yiwulushan metamorphic core complex from distributed to localized deformation and its tectonic implications. Tectonics 31, TC4018.
Zhang, D.Y., Zhou, T.F., Yuan, F., Fan, Y., Chen, X.F., White, Noel C., Ding, N., Jiang, Q. S., 2017b. Petrogenesis and W-Mo fertility indicators of the Gaojiabang "satellite" granodiorite porphyry in southern Anhui Province, South China. Ore Geol. Rev. 88, 550–564.
Zhang, Y., Shao, Y.J., Chen, H.Y., Liu, Z.F., Li, D.F., 2017a. A hydrothermal origin for the large Xinqiao Cu-S-Fe deposit, Eastern China: evidence from sulfide geochemistry and sulfur isotopes. Ore Geol. Rev. 88, 534–549.
Zheng, W., Mao, J.W., Zhao, H.J., Ouyang, H.G., Zhao, C.S., Yu, X.F., 2017. Geochemistry, Sr–Nd–Pb–Hf isotopes systematics and geochronological constrains on petrogenesis of the Xishan A-type granite and associated W-Sn mineralization in Guangdong Province, South China. Ore Geol. Rev. 88, 739–752.
Zhou, T.F., Wang, S.W., Fan, Y., Yuan, F., Zhang, D.Y., White, Noel C., 2015. A review of the intracontinental porphyry deposits in the Middle-Lower Yangtze River Valley metallogenic belt, Eastern China. Ore Geol. Rev. 65, 433–456.
Zhou, X., Sun, T., Shen, W., Shu, L., Niu, Y., 2006. Petrogenesis of Mesozoic granitoids and volcanic rocks in South China: a response to tectonic evolution. Episodes 29, 26–33.
Zhou, X.M., Li, W.X., 2000. Origin of Late Mesozoic igneous rocks in Southeastern China: implications for lithosphere subduction and underplating of mafic magmas. Tectonophysics 326, 269–287.
Zhu, R.X., Chen, L., Wu, F.Y., Liu, J.L., 2011. Timing, scale and mechanism of the destruction of the North China Craton. Sci. China-Earth Sci. 54 (6), 789–797.
Zhu, R.X., Fan, H.R., Li, J.W., Meng, Q.R., Li, S.R., Zeng, Q.D., 2015. Decratonic gold deposits. Sci. China (Series D) 58 (9), 1523–1537.
Zhu, R.X., Yang, J.H., Wu, F.Y., 2012. Timing of destruction of the North China Craton. Lithos 149, 51–60.