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Metallogenesis and the minerogenetic series in the Gangdese polymetallic copper belt

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ABSTRACT

The Gangdese is a newly explored porphyry Cu ore belt in China. In fact, except for the porphyry Cu deposits there are a lot of other deposits, forming a polymetallic copper belt in the southern Gangdese (SG, i.e., southern Lhasa terrane) and Gangdese back–arc fault uplift belt (GBAFUB, also called Lungar–Nyainqêntanglha arc). The Gangdese polymetallic copper belt contains porphyry Cu(–Mo–Au), Cu–Au and Mo(–Cu), skarn Cu(–Mo–Au–W), Pb–Zn(–Ag), Fe(–Cu) and Mo–W, breccia-type and hydrothermal vein-type Pb–Zn(–Ag) deposits. The porphyry Cu–Au mineralization occurred at the Xiongcun area of SG during the Middle Jurassic (175–160 Ma) and was associated with island arc magmatism related to the northward subduction of the Neo–Tethyan oceanic slab. The Cretaceous (ca. 112 Ma) skarn Fe(–Cu) mineralization appeared at the Nixiong area of GBAFUB and was generated in a back arc extensional setting related to the Neo–Tethyan oceanic subduction beneath the Lhasa terrane. The Paleocene–Eocene (65–51 Ma) porphyry Mo(–Cu), skarn Mo–W, and skarn Pb–Zn(–Ag) deposits are located in the eastern part of GBAFUB and related to granitoids originating from the partial melting of the old crust with contributions from the mantle. In contrast, the Paleocene–Eocene (60–45 Ma) porphyry Cu, skarn-, breccia-, and hydrothermal-vein-type Pb–Zn(–Ag), and skarn Fe–Cu deposits at the Namling area were associated with granitoids derived from the partial melting of the mantle with some input of the old crust. The Oligocene (30–23 Ma) porphyry–skarn Cu–Mo–W–Au mineralization occurred at the Zedong area adjacent to north of the Indus–Yarlung–Zangbo suture zone in a post collisional setting. The intensified Miocene (21–13 Ma) porphyry–skarn Cu(–Mo–Au), and skarn–hydrothermal-vein-type Pb–Zn(–Ag) deposits formed in the SG, whereas the porphyry Mo(–Cu) and skarn–hydrothermal-vein-type Pb–Zn(–Ag) deposits formed in the GBAFUB. The porphyry Mo(–Cu) mineralization have more substantial contributions from the old crust, in addition to the mantle, than those with porphyry Cu(–Mo–Au) mineralization. The source region of the high Sr/Y intrusions associated with post collisional porphyry Cu(–Mo–Au) mineralization is probably the arc magmas that were generated at the subduction stage and have remained stalled at the boundary between the crust and mantle since the Neo–Tethyan Ocean closed. The early subduction of the Neo–Tethyan oceanic lithosphere played a crucial role in the generation of ore deposits formed in collisional and post collisional settings. Six minerogenic series (or groups) can be recognized in the Gangdese polymetallic copper belt: (1) Jurassic porphyry Cu–Au minerogenic series related to island arc magmatism, (2) Cretaceous skarn Fe(–Cu) minerogenic series in back arc extensional setting, (3) Paleocene–Eocene granitoids-related polymetallic minerogenic series in collisional setting, (4) Oligocene porphyry–skarn Cu–W–Mo–Au minerogenic series in post collisional setting, (5) Miocene Cu–Mo–Au–Pb–Zn–Ag minerogenic series related to granitoids with substantial contributions from the mantle in post collisional setting, and (6) Miocene Mo–Cu–Pb–Zn minerogenic series related to granitoids with significant contributions from the old crust in post collisional setting. During mineralization, some deposits underwent superimposed mineralization, such as the Jiru porphyry Cu deposit where the Eocene and

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Miocene porphyry-type Cu mineralization occurred. The minerogenic series can be applied to ore prospecting. For example, when either Pb–Zn(–Ag) veins or porphyry–skarn Mo(–W–Cu) orebodies are known in an area, one of them could provide a useful exploration vector for the other.

1. Introduction

Metallogenesis related to accretionary orogenesis has undergone numerous studies mainly based on the circum-Pacific region (Sillitoe, 1997; Hedenquist et al., 2000; Cooke et al., 2005). However, the metallogenesis of collisional orogenesis characterized by the closure of the oceanic basin and subsequent collision and post collision of continental blocks is less clearly understood. Sawkins (1984) previously divided collision-related deposits into six major types: (1) ophiolite-hosted metal deposits, (2) Mississippi Valley-type (MVT) Zn–Pb deposits, (3) carbonate-hosted (i.e., Irish-type) Pb–Zn deposits, (4) sandstone-hosted (i.e., Laisvall-type) Pb(–Zn) deposits, (5) Sn–W deposits related to S-type granites, and (6) U deposits related to collisional granites (cf. Seltmann and Faragher, 1994). Recently, numerous collision-related deposits have been found. In the Qinling collisional orogenic belt, porphyry Mo, orogenic Au, and hydrothermal Pb–Zn deposits appear to be related to Mesozoic collisional orogenesis (Chen and Fu, 1992; Chen et al., 2000, 2007). In the Tibetan Orogen, Hou and Cook (2009) divided collision-related deposits into eight principle types: (1) porphyry Cu–Mo, (2) orogenic Au, (3) granite-related Sn–W–U, (4) alkali complex-related REE, (5) sediment-hosted Zn–Pb(–Cu–Ag), (6) vein-type Sb–Au, (7) skarn polymetallic, and (8) hotspring-type Cs–Au deposits. Most orogenic belts underwent early subduction and subsequent collision and therefore contain both subduction-related and collision-related deposits, with some deposits showing superimposed mineralization (Deng et al., 2010, 2014a,b).

The Tibetan Plateau is the youngest orogen and underwent amalgamation of several blocks during the evolution of the Jinsha–Honghe, Bangong–Nujiang, and Indus–Yarlung–Zangbo oceanic basins (cf. Dewey et al., 1988; Yin and Harrison, 2000; Xu et al., 2006), and therefore can be regarded as a suitable region for investigating the metallogenesis related to accretionary and collisional orogenesis. Previous studies have focused on the individual and typical ore deposits and also, to a lesser extent, on the regional metallogenesis in the Tibetan Plateau (Meng et al., 2003; Zheng et al., 2004, 2007, 2014a, 2014b; Qin et al., 2008; Yang et al., 2009; Tang et al., 2010, 2011). Hou and Cook (2009) studied the metallogenesis in the Tibetan Plateau, but emphasized only the mineralization generated in the Cenozoic corresponding to the collisional environment. Recently, many types of deposits, such as the porphyry–skarn Mo(–W) and skarn Fe(–Cu), have been recognized but were not included in the classification of collision-related deposits by Hou and Cook (2009). Furthermore, increasingly more researchers have begun to examine the relationship between subduction- and collision-related mineralization (Groves and Bierlein, 2007; Richards, 2009; Mao et al., 2014). Actually, some deposits in the Tibetan Plateau (i.e., the Xiongcun porphyry Cu–Au deposit; Lang et al., 2014) formed before the collision between the Indian and the Eurasian continents.

A minerogenetic series is used to study the ore-forming process and ore deposit association in various stages of geological history and in specific tectonic environments. When different types of ore deposits are temporally, spatially and genetically associated and are controlled by one dominant type of mineralization at a specific stage during geological history and in some specific tectonic environment, they can form a minerogenetic series (Chen, 1983, 1994; Chen et al., 2006). For example, Mao et al. (2013) applied the minerogenetic series in studying the regional metallogeny in Inner Mongolia and adjacent areas, and 11 metallogenic series have been recognized, including the Triassic–Middle Jurassic porphyry Cu metallogenic series, the Late Jurassic–Early Cretaceous epithermal type Pb–Zn–Ag–Au metallogenic series in the De'erbugan area and the Late Jurassic–Early Cretaceous granite-related Pb–Zn–Sn–Mo–Au metallogenic series in the DaHinggan Mountains and adjacent areas.

The Tibetan Plateau is composed of four continental blocks or terranes that, from north to south, are the Songpan–Ganzi, Qiangtang, Lhasa and Himalaya, respectively separated by the Jinsha, Bangong–Nujiang (BNSZ) and Indus–Yarlung–Zangbo (IYZSZ) suture zones (cf. Yin and Harrison, 2000) (Fig. 1a). In past 15 years, many prospecting and explorations have been carried out in the Lhasa Terrane and a large group of porphyry Cu–Mo–Au and skarn Pb–Zn–Ag deposits have been discovered in the Gangdese belt (Fig. 1b). The Lhasa terrane has been suggested to have undergone the southward subduction of the Bangong–Nujiang Ocean and northward subduction of the Indus–Yarlung–Zangbo Ocean since the Cretaceous period (Zhu et al., 2011). To accurately understand the metallogenesis from the oceanic subduction to the continental collision and increase understanding of the collision-related metallogenesis in the Tibetan Plateau, we focused only on the Gangdese belt where the mineralization was associated with the evolution of the Indus–Yarlung–Zangbo Ocean (i.e., part of the Neo-Tethyan Ocean) and the subsequent collision between the Indian and the Eurasian continents. In this study, we analyzed the types of major ore deposits, discussed their spatial and temporal distribution, and studied metallogenesis and the minerogenic series in the Gangdese polymetallic copper belt.

2. Regional geology

The Gangdese orogenic belt (Pan et al., 2006; Zhu et al., 2008) is generally named the Lhasa block (Dewey et al., 1988; Yin and Harrison, 2000) or Lhasa terrane (Zhu et al., 2011) and its tectonic subdivision and evolution remains the subject of much debate. The Gangdese orogenic belt is divided into the northern Gangdese, middle Gangdese, Gangdese back–arc fault uplift belt (GBAFUB), and southern Gangdese (SG), separated by the Shiquan River–Nam Tso Mélange Zone (SNMZ), Gar–Lunggar–Zhari Nam Tso–Comai Fault (GLZCF) and Shamolei–Maila–Luobadui–Milashan Fault (SMLMF), respectively (Fig. 1). The area of the SG is similar to that of the southern Lhasa terrane (Zhu et al., 2011) or as Gangdese magmatic arc (Pan et al., 2012). The GBAFUB (Zhou and Cao, 1984) was renamed the Lungar–Nyainqêntanglha (Pan et al., 2006) or Lungar–Gongbo Gyamda compound island arc belt by Pan et al. (2012). The Gangdese polymetallic copper belt discussed in this study is located within both the SG and GBAFUB, in which the tectonic and magmatic events are summarized in Fig. 2.

In the SG, the sedimentary cover is limited, including the Lower Jurassic Yeba Formation consisting mainly of clastic sedimentary rocks (e.g., slate, limestone, and sandstone) and abundant volcanic rocks comprising basalt and silicic rock, with a minor amount of andesite (Pan et al., 2004; Zhu et al., 2008), and the Upper Jurassic–Cretaceous volcano-sedimentary strata consisting mainly of