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Geodynamics and metallogeny of the eastern Tethyan metallogenic domain

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ABSTRACT

The Tethyside orogen, a direct consequence of the separation of the Gondwanaland and the accretion of Eurasia, is a huge composite orogenic system that was generated during Paleozoic–Mesozoic Tethyan accretionary and Cenozoic continent–continent collisional orogenesis within the Tethyan domain. The Tethyside orogenic system consists of a group of diverse Tethyan blocks, including the Istanbul, Sakarya, Anatolide–Taurides, Central Iran, Afghanistan, Songpan–Ganzi, Eastern Qiangtang, Western Qiangtang, Lhasa, Indochina, Sibumasu, and Western Burma blocks, which were separated from Gondwana, drifted northwards, and accreted to the Eurasian continent by opening and closing of two successive Tethyan oceanic basins (Paleo-Tethyan and Neo-Tethyan), and subsequent continental collision.

The Tethyan domain represents a metallogenic amalgamation across diverse geodynamic settings, and is the best endowed of all large orogenic systems, such as those associated with the Cordilleran and Variscan orogenies. The ore deposits within the Tethyan domain include porphyry Cu–Mo–Au, granite-related Sn–W, podiform chromite, sediment-hosted Pb–Zn deposits, volcanogenic massive sulfide (VMS) Cu–Pb–Zn deposits, epithermal and orogenic Au polymetallic deposits, as well as skarn Fe polymetallic deposits. At least two metallogenic supergroups have been identified within the eastern Tethyan metallogenic domain (ETMD): (1) metallogenesis related to the accretionary orogen, including the Zhongdian, Bangonghu, and Pontides porphyry Cu belts, the Pontides, Sanandaj–Sirjan, and Sanjiang VMS belts, the Lasbela–Khuzdar sedimentary exhalative-type (SEDEX) Pb–Zn deposits, and podiform chromite deposits along the Tethyan ophiolite zone; and (2) metallogenesis related to continental collision, including the Gangdese, Yulong, Arasbaran–Kerman and Chagai porphyry Cu belts, the Taurus, Sanandaj–Sirjan, and Sanjiang Mississippi Valley-type (MVT) Pb–Zn belts, the Southeast Asia and Tengchong–Lianghe Sn–W belts or districts, the Himalayan epithermal Sb–Au–Pb–Zn belt, the Piranshahr–Saqez–Sardasht and Ailaoshan orogenic Au belts, and the northwest Iran and northeastern Gangdese skarn Fe polymetallic belts. Mineral deposits that are generated with tectonic evolution of the Tethys form in specific settings, such as accretionary wedges, magmatic arcs, backarcs, and passive continental margins within accretionary orogens, and the foreland basins, foreland thrust zones, collisional sutures, collisional magmatic zones, and collisional deformation zones within collisional orogens.

Synthesizing the architecture and tectonic evolution of collisional orogens within the ETMD and comparisons with other collisional orogenic systems have led to the identification of four basic types of collision: orthogonal and asymmetric (e.g., the Tibetan collision), orthogonal and symmetric (Pyrenees), oblique and symmetric (Alpine), and oblique and asymmetric (Zagros). The tectonic evolution of collisional orogens typically includes three major processes: (1) syn-collisional continental convergence, (2) late-collisional tectonic transform, and (3) post-collisional crustal extension, each forming distinct types of ore deposits in specific settings. The resulting synthesis leads us to propose a new conceptual framework for the collision-related metallogenic systems, which may aid in deciphering relationships among ore types in other comparable collisional orogens. Three significant processes, such as breaking-off of subducted Tethyan slab, large-scale strike-slip faulting, shearing and thrusting, and delamination (or broken-off) of lithosphere, developed in syn-, late- and post-collisional periods, repsectively, were proposed to act as major driving forces, resulting in the formation of the collision-related metallogenic systems. Widespread appearance of juvenile crust and intense inteaction between mantle and crust within the Himalayan–Zagros orogens indicate that collisional orogens have great potential for the discovery of large or giant mineral deposits.

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1. Introduction

A significant advance in economic geology over the past 25 years has been the identification and establishment of the role of global tectonics in the formation and distribution of mineral deposits on Earth. Recent research has identified that the cyclical assembly and breakup of continents or supercontinents control the formation and development of various types of ore deposits (Barley and Groves, 1992; Goldfarb et al., 2005; Groves et al., 2005; Kerrich and Wyman, 1990; Kerrich et al., 2000, 2005). The breakup of supercontinents is related to mantle plumes, whereas supercontinental assembly is related to continental accretion and/or continent–continent collision (e.g., Murphy and Nance, 1992), where the former forms accretionary orogens, such as the North American Cordillera (e.g., Dickinson, 2004) and the Central Asian Orogenic Belt (CAOB; e.g., Xiao et al., 2004; Yakubchuk et al., 2005; Windley et al., 2007), and the latter forms collisional orogens, such as the Himalayan–Alpine orogen within the Tethyan domain (Sengor and Natal'in, 1996; Yin and Harrison, 2000).

The metallogeny of accretionary orogens has been well studied since the 1980s, and numerous mineral deposit models have been established for many of the major classes of deposits within these orogens, such as the formation of orogenic Au deposits in accretionary wedges (e.g., Goldfarb et al., 2005), porphyry Cu and epithermal Au deposits in magmatic arcs (e.g., Hedenquist and Lowenstern, 1994; Hedenquist et al., 1998; Richards, 2003; Sillitoe, 2000; Simmons et al., 2005), volcanogenic massive sulfide (VMS) deposits in backarc systems (e.g., Franklin et al., 1981, 2005; Lydon, 1984, 1988), and sedimentary exhalative (SEDEX) Pb–Zn deposits within passive continental margins (e.g., Leach et al., 2005, 2010). These researches have significantly improved our understanding of the metallogenic impact of accretionary orogens.

Mountain belts created by continent–continent collision, such as the Himalayan–Tibetan orogen in Asia (e.g., Yin and Harrison, 2000), the Variscan orogen in western and central Europe (e.g., Seltmann and Faragher, 1994), and the Ural orogen in Russia (e.g., Herrington et al., 2005), extend for thousands of kilometers along strike and form some of the most important geological features on the surface of the Earth. However, the metallogenic processes that operate during collisional orogenic systems are controversial. A commonly held view is that collisional orogens have limited potential for the discovery of large or giant mineral deposits, primarily as these orogens are associated with minimal formation of juvenile crust (e.g., Groves and Bierlein, 2007; Kerrich et al., 2005). Research on the Caledonian, Variscan, and Ural collisional orogens also indicates that the mineral deposits in these orogens generally formed during the early accretionary stage of orogenesis, only a few deposits, such as granite-related Sn–W and sediment-hosted Pb–Zn–Cu deposits, are generated during collision (Cuney et al., 1990; Duane and De Wit, 1988; Herrington et al., 2005; Koroteev et al., 1997; Seltmann and Faragher, 1994). An alternative view suggests that continent systems are highly prospective, and are associated with a wide variety of collision-related ore deposits (e.g., Hou and Cook, 2009). This is exemplified by the Tibetan–Himalayan and Zagros orogens, both of which were created by continent–continent collision after the closure of the Neo-Tethyan Ocean and are both well-endowed with numerous giant or superlarge mineral deposits (e.g., Hou and Cook, 2009; Hou et al., 2011; Richards et al., 2012). Extensive research into the Variscan and Himalayan–Zagros orogens has greatly improved our understanding of the geodynamic and ore-forming processes that operate in collisional systems (e.g., Hou and Cook, 2009; Seltmann and Faragher, 1994). However, the metallogenic processes that operate in collisional orogenic systems are still poorly understood, especially when compared with accretionary orogens.

The Tethyside orogen was a direct consequence of the separation of the Gondwana supercontinent, the formation of Pangaea, and the accretion of Eurasia, and forms a huge composite orogenic system that was generated during Paleozoic–Mesozoic (Paleo-Tethyan to Neo-Tethyan) accretionary and Cenozoic continent–continent collisional orogenesis within the Tethyan domain (Fig. 1). The orogen represents one of the most significant global metallogenic provinces, and contains numerous large or giant ore deposits that formed at various stages from accretion to collision, providing a unique opportunity for the investigation of metallogenesis and continental assembly. The geodynamic evolution of the Tethyan domain has been well studied (e.g., Metcalfe, 1997, 2006, 2013; Sengor, 1979, 1987, 1991; Stampfli, 2000), including the metallogeny of local areas or specific deposits within the domain (Hou et al., 2007, 2009, 2011; Jankovic, 1977; Sillitoe, 1978; Yigit, 2006, 2009, 2012; Zhang et al., 2009, 2010). These researches have allowed the determination of genetic links between metallogenesis and geodynamic processes in an accretionary–collisional orogenic system. This paper provides an overview of the tectonic evolution and the principal ore deposit types of the eastern Tethyan domain.

2. Tectonic evolution of the Tethyan domain

The term Tethys was first introduced by Suess (1893) and refers to a wide embayment along the southern margin of the Eurasian continent that was present during the Paleozoic and Mesozoic. More recent studies indicate that this area consists of a series of ocean basins that opened and closed between the Paleozoic and Cenozoic; these basins were separated by numerous scattered continental blocks (i.e., “Tethyan blocks”) located between the East European Craton and the Kazakhstan Block in the north, and the Indian and Arabian–African cratons in the south (Figs. 2 and 3; Metcalfe, 1996, 2002; Pan et al., 1997; Zhong, 1998). These “Tethyan blocks”, scattered within Tethyan Ocean basins, include the Istanbul, Sakarya, Anatolide–Taurides (AT), Central Iran (CI), Sanandaj–Sirjan (Ss), Afghanistan, Songpan–Ganzi (SG), Eastern Qiangtang (EQ), Western Qiangtang (WQ), Lhasa, Indo-China, Sibumasu, and Western Burma (WB) blocks from west to east (e.g., Stampfli, 2000). The majority of these blocks separated from Gondwana, drifted north, and accreted to the Eurasian continent, causing the formation and disappearance of Tethyan basins (Figs. 2 and 3; Sengor, 1979; Golonka, 2004). This indicates that Gondwana dispersion and Asian accretion, including the rifting and separation of two or three continental slivers from the margin of Gondwana, their northwards translation and amalgamation to form the Eurasian continent, were a major control on the geodynamic processes that occurred during the evolution of the Tethyan domain (Golonka, 2004).

2.1. Formation of the Tethyan Ocean

The Tethyan Ocean is often depicted as a single wide triangular ocean that extended into the Pangaea supercontinent from the east, and consisted of two successive ocean basins, named the Paleo-Tethys and the Neo-Tethys (e.g., Sengor, 1979, 1987). The Paleo-Tethys Ocean basin was formed by Devonian to Permian seafloor spreading between Gondwana and an elongate continental sliver that includes the North China, South China, Indochina, and Tarim blocks (Fig. 2; Metcalfe, 1996, 2002; Pan et al., 1997; Zhong, 1998). At least four branches of the Paleo-Tethys developed in East Asia, but the main branch of the ocean is represented by the Longmucuo–Shuanghu, Changning–Menglian, Inthanon, and Bentong–Raub suture zones (Fig. 4; Wang et al., 2001a; Li et al., 2006; Metcalfe, 2013). Other ocean branches include the Song Ma and Ailaoshan between south China (SC) and Indochina blocks, and Jinshajiang between SC and EQ blocks (Fig. 4). The Paleo-Tethyan Ocean basin reached its maximum extent during the early Permian, during formation of the Pangaea supercontinent by the assembly of Gondwana and Laurasia (e.g., Stampfli, 2000). The opening of the Paleo-Tethyan Ocean basin separated paleobiogeographic realms during the Carboniferous and Permian, leading to the Carboniferous–Permian marine lithostratigraphy, biostratigraphy, and fauna of blocks near Gondwana being distinct from those drifting within the Paleo-Tethyan Ocean basin, with the former (e.g., Himalaya) containing