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Temporal–spatial distribution and tectonic setting of porphyry copper deposits in Iran: Constraints from zircon U–Pb and molybdenite Re–Os geochronology

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ABSTRACT

Porphyry copper deposits (PCDs) in Iran are dominantly distributed in Arasbaran (NW Iran), the middle segment of the Urumieh–Dokhtar Magmatic Arc (UDMA), and Kerman (central SE Iran), with minor occurrences in eastern Iran and the Makran arc. This paper provides a temporal–spatial and geodynamic framework of the Iranian porphyry Cu (Mo–Au) systems, based on geochronologic data obtained from zircon U–Pb and molybdenite Re–Os dating of host porphyritic rocks and molybdenites in 15 major PCDs. The dating results define a long metallogenic duration (39–6 Ma), and suggest a long history of tectonic evolution from the accretionary orogeny related to early Cenozoic closure of the Neo-Tethys Ocean to subsequent collisional orogeny for the Iranian porphyry copper systems.

The oldest porphyry mineralization occurred in the eastern part of Iran after the closure of a branch of the Neo-Tethyan (Sistan) Ocean between the Lut and Afghan blocks in the late Eocene (39–37 Ma). This was followed by mineralization in the Kerman porphyry copper belt over a time interval of about 20 m.y., where two metallogenic epochs have been recognized, including late Oligocene (29–27 Ma) and Miocene (18–6 Ma). The Bondar-e-Hanza deposit formed in the late Oligocene, while and the remaining dated deposits belong to Miocene epoch. According to the deposits' characteristics and their ages, the Miocene epoch can be divided into early, middle, and late stages. The Darreh Zar, Bakh Khoshk, Chah Firouzeh and Sar Kuh deposits formed during the early–middle Miocene. The largest porphyry deposits occur in the middle stage during the middle Miocene (14–11 Ma) and include the Sar Cheshmeh, Meiduk, Dar Alu and Now Chun deposits. These deposits were formed during crustal thickening, uplift, and rapid exhumation of the belt. The final stage of porphyry mineralization occurred during the late Miocene (9–6 Ma), and formed the Iju, Kerver, Kuh Panj and Abdar deposits.

There were two porphyry mineralization stages in the Arasbaran porphyry copper belt in NW Iran, including an older late Oligocene (29–27 Ma) and a younger early Miocene (22–20 Ma) events. The Haft Cheshmeh deposit belongs to the older stage, and the world-class Sungun and Masjed Daghi deposits formed during the early Miocene.

In the middle segment of the UDMA (Saveh–Yazd porphyry copper belt), PCDs formed during middle Miocene time (17–15 Ma). The geochronological results reveal that the porphyry mineralization moved from the northwest to southeast of UDMA over the time.

Our dating results, combined with the possible late Eocene–Oligocene timing for collision between the Arabian and Iranian plates, support a model for Iranian PCD formation by partial melting of previously subduction-modified lithosphere in a post-subduction and post-collisional tectonic setting.

1. Introduction

Porphyry copper systems are mainly developed at convergent plate margins, including continental margin and island-arc settings (Sillitoe, 2010, and references therein), where subduction of oceanic crust is related to arc-type magmatism that generates most of the hydrous, oxidized upper crustal granitoids genetically related to ores. In these magmatic arcs, deformation can be very complex, and porphyry copper deposits can form in a variety of tectonic settings (Richards, 2009). Porphyry copper deposits in the Andes are classic deposits that are generated in the continental arcs in response to flattening of the subducting oceanic slab and associated crustal thickening and block uplift (Bissig et al., 2003; Kay et al., 1999; Perelló et al., 2003; Richards et al., 2001;

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Skewes and Stern, 1995). Recently, it was proposed that some PCDs develop after the end of subduction in a post-collisional tectonic setting (Hou et al., 2009; Richards, 2009; Shafiei et al., 2009; Sillitoe, 2010). The source of post-collisional porphyries is more complex and several sources and processes have been proposed including metasomatised lithospheric mantle and underplated mafic rocks and/or subduction modified lower crust (Hou et al., 2009; Richards, 2009, in press; Shafiei et al., 2009). Post-collisional magmatism occurs in response to several phenomena including delamination, slab break-off, back-arc extension, and thermal relaxation (Davies and von Blankenburg, 1995; Kay and Kay, 1993; Richards, in press).

The Iranian plateau is located in the middle part of the Alpine–Himalayan orogenic and metallogenic belt, and hosts more than fifty porphyry copper (Mo, Au) deposits (PCDs) such as the world-class Sar Cheshmeh and Sungun deposits. Porphyry copper deposits in Iran temporally developed during the final closure stage of the Neo-Tethys Ocean, whereas porphyry deposits related to the Paleo-Tethys Ocean and the initial stages of the Neo-Tethys ocean(s) evolution are unknown. Generally, porphyry copper mineralization is associated with Oligo-Miocene intrusive bodies along the Urumieh–Dokhtar magmatic arc (UDMA), but some PCDs have recently been discovered in the eastern part of the country (Aghazadeh et al., 2012; McInnes et al., 2003; Richards et al., 2012; Shafiei et al., 2009).

Previous studies on the Iranian PCDs have mainly focused on the geochemistry of the associated porphyry intrusions (Aliani et al., 2009; Hezarkhani, 2006; Shafiei et al., 2009) and physico-chemical conditions of the ore-bearing fluids and hydrothermal alterations (Boomeri et al., 2009, 2010; Hezarkhani and Williams-Jones, 1998). However, high quality age dating on the host rocks and mineralization of the Iranian PCDs are limited, and previously published ages are dispersed, although some dating results were reported from the Kerman porphyry copper belt (Hassanzadeh, 1993; McInnes et al., 2003; Mirnejad et al., 2013). The lack of age data limits our understanding of the metallogenesis and the geodynamic setting of the Iranian PCDs, as well as the resource potential in Iran.

This paper reports new zircon U–Pb and molybdenite Re–Os dating results of porphyry stocks and post-mineralization intrusions and associated mineralization from the various porphyry copper belts in Iran. Some of the major characteristics of PCDs in Iran are presented in Table 1. Based on the ages obtained from this study, combined with previously published data, we define the main metallogenic epochs and temporal–spatial distribution of Iranian PCDs. These new data, together with an analysis of the tectono-magmatic evolution in the main porphyry copper belts of Iran, lead to a conceptual framework for the geodynamic setting of porphyry copper systems in Iran.

2. Geological background of porphyry copper belts in Iran

2.1. Regional geology

Iran is located in the central part of the Alpine–Himalayan orogenic and metallogenic belt (Fig. 1), that formed by complex collisional processes involving continental blocks that were separated from the northern Gondwana margin, and which were successively accreted to the southern margin of Eurasia since the Mesozoic (Berberian and King, 1981; Stampfli, 2000; Stocklin, 1974). Two main Paleo- and Neo-Tethys oceans opened and then closed; the first one separated the Iranian plate from Eurasia during late Paleozoic–early Mesozoic time and disappeared in the late Triassic, whereas the second one opened in the Permian and was located between the Iranian and Arabian plates during late Mesozoic to early Cenozoic, and closed at times variably estimated to be from the Late Cretaceous to Miocene (Agard et al., 2011; Aghazadeh et al., 2011; Allen and Armstrong, 2008; Dargahi et al., 2010; Horton et al., 2008; McQuarrie et al., 2003; Sengör and Natal'in, 1996; Stampfli, 2000; Stocklin, 1974; Yilmaz, 1993). Suture boundaries of these oceans have been identified in the northern and southeastern parts of the country (Fig. 1) and subduction of these oceans generated several magmatic arcs in the north (Caucasus) and south (Mesozoic Sanandaj–Sirjan and Cenozoic Urumieh–Dokhtar magmatic arcs). Neo-Tethys Ocean subduction-related magmatic rocks are dominantly found in the Sanandaj–Sirjan zone (Azizi and Jahangiri, 2008); however, syn- and post-collision magmatism are widespread throughout the country especially in the Urumieh–Dokhtar Magmatic Arc (UDMA), Alborz Magmatic Belt (AMB), and east Iran (Agard et al., 2011; Verdel et al., 2011).

The evolution of the Neo-Tethys Ocean in Iran is associated with different kinds of mineralization and metal deposits including porphyry copper deposits (PCDs). The PCDs in Iran are centered in four belts: Arasbaran, the middle segment of the Urumieh–Dokhtar Magmatic Arc (UDMA), Kerman, and East Iran (Fig. 1). The Makran arc with its poorly understood porphyry prospects (e.g. Kharestan, Bidester, Siah Jangal) can be considered as a new porphyry copper belt. Although this belt is located in the southeastern geographic continuation of the Kerman belt, the geological and tectonic scenarios of the belts are different and subduction is ongoing in the Makran arc (McCall, 1997) whereas it ceased in late Eocene time in the Kerman belt (Dargahi et al., 2010).

2.2. Arasbaran porphyry copper belt (APCB)

The Arasbaran porphyry copper belt (APCB) is located in northwestern Iran (Fig. 1). This belt, which is 70–80 km wide and over 400 km long, is mostly composed of Cretaceous–Cenozoic volcano-sedimentary strata and Cenozoic intrusive bodies (Fig. 2).

In this area, magmatism began in the Cretaceous and continued intensively during the Cenozoic to Quaternary (Aghazadeh, 2009). The Cenozoic–Quaternary volcanism includes two main Eocene and late Miocene–Quaternary episodes (Fig. 2). The Eocene basic to intermediate sequence consists of mildly alkaline and shoshonitic affinities (Dilek et al., 2009). The late Miocene–Quaternary magmatic episode is represented by calc-alkaline to shoshonitic and ultrapotassic basic to felsic lava flows and pyroclastic rocks (Aghazadeh, 2009; Ahmadzadeh et al., 2010). The latest magmatic event is represented by alkaline rocks showing within-plate geochemical signatures (Kheirkhah et al., 2009).

Large granitoid plutons with different nature and ages were emplaced during the Oligocene–Miocene in the APCB (Aghazadeh et al., 2010, 2011; Castro et al., 2013; Jahangiri, 2007). Plutonism in the area started with middle–late Oligocene calc-alkaline association that was followed by late Oligocene–early Miocene shoshonitic intrusions (Aghazadeh et al., 2011; Castro et al., 2013). Dacitic–granodioritic and monzonitic domes and intrusive bodies were the latest plutonic activity in the area. Middle–late Oligocene rocks have a typical calc-alkaline arc affinity, whereas late Oligocene–early Miocene shoshonitic intrusions and late Miocene domes display adakitic characteristics (Aghazadeh et al., 2011; Jahangiri, 2007).

Porphyry copper mineralization in the Arsabaran belt, including the Sungun deposit, is mainly associated with Oligo-Miocene monzonitic and monzodioritic intrusive bodies (Fig. 2). There are more than 10 porphyry copper deposits and prospects in the belt (Table 1, Fig. 2) including the Sungun, Masjed Daghi, Haft Cheshmeh, Saheb Divan, Sunajeel, Niaz, Miveh Rud, Kighal and Ali Javad deposits and prospects.

2.3. Saveh–Yazd porphyry copper belt (SYPCB)

The middle segment of the Urumieh–Dokhtar magmatic arc (UDMA) lies between the cities of Saveh to Yazd and includes several porphyry copper deposits and prospects; we therefore refer to it as the Saveh–Yazd porphyry copper belt (Fig. 1). The basement rocks of the belt comprise Infracambrian to Paleozoic sedimentary rocks overlain by Mesozoic strata, which are covered or intruded by Cenozoic volcanic and intrusive rocks (Fig. 3). Cenozoic magmatic activities can be divided into two main phases: (a) intensive volcanism during the Paleogene followed by emplacement of mafic to felsic intrusive bodies during Oligocene to Miocene time (Berberian and Berberian, 1981; Haschke