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The Sarcheshmeh porphyry copper deposit, Kerman, Iran: A mineralogical analysis of the igneous rocks and alteration zones including halogen element systematics related to Cu mineralization processes

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ABSTRACT

The giant Sarcheshmeh porphyry Copper deposit is located 65 km southwest of Kerman City, southeastern Iran. Numerous Miocene porphyry stocks and dykes intruded thick sequences of Upper Cretaceous sedimentary and Eocene volcanic rocks. Hypogene and supergene porphyry Cu mineralization occurs within the granodioritic porphyry and host rock sequence, which was extensively altered to a dominantly potassic, phyllic, and argillic assemblage with interstitial to distal propylitic types.

Biotite-bearing assemblages occur as both primary phenocrysts and secondary replacements showing variable size, colour, and shape. Fluorine contents (0.22 to 1.33 wt.%) and X_{Mg} (0.54 to 0.71) in biotites from the potassic and phyllic zones are higher than those of non-mineralized granitoids (F = 0.09 to 0.56 wt.%, X_{Mg} = 0.43 to 0.54), whereas their Cl contents (Cl = 0.05 to 0.24 wt.%) are lower than those of the non-mineralized granitoids (Cl = .0.11 to 0.45). The biotites from the phyllic zone have higher log (fH_2O/fHF) and log ($fH_2O/fHCl$) values than those of the potassic zone, as well as the granitoid and andesitic dykes. The log ($fHF/fHCl$) values determined for the granitoid, potassic and phyllic zones are similar, though more negative than those of the andesitic dykes. The log ($fHF/fHCl$) values have a similar range for biotite from the granitoid, and potassic and phyllic zones. The halogen fugacity ratios established for fluids associated with the Sarcheshmeh deposit from their F and Cl contents in biotite show that the granitoid, potassic zone and phyllic zone are increasingly affected by meteoric waters. The fluids that circulated in the phyllic zone are predominantly of meteoric origin, possibly overprinting original phyllic zone halogen contents.

The Cl intercept values of biotite in the granitoid, and phyllic and potassic are similar to other ore-forming systems and tend to be more Cl-rich than Cl-intercept values of biotites in common igneous rocks. Calculated F/Cl intercept values for biotite in the granitoid and potassic zone are also consistent with many other porphyry copper forming systems.

1. Introduction

The giant Sarcheshmeh deposit is located 65 km southwest of Kerman city, southeastern Iran (lat. 29°56′30″ N., long. 55°52′30″ E (Fig. 1). The deposit is known as a typical porphyry Cu deposit with respect to alteration types, mineralization style, ore grade and size, tectonic setting, and igneous rock features (Waterman and Hamilton, 1975; Shahabpour, 1982; Hezarkhani, 2006). The deposit is ellipsoidal in shape, about 2 km long, 1 km wide, and 1 km deep and early on was noted to contain 450 million tonnes of sulfide ore, with an average grade of 1.13% Cu and 0.03% Mo (Waterman and Hamilton, 1975). More recent ore reserve calculations show that it contains 1200 million tonnes of sulfide ores, with an average grade of 0.7% Cu and 0.03% Mo (Shafiei and Shahabpour, 2008), that includes a greater proportion of deeper hypogene ore.

In general, porphyry Cu deposits are formed by hydrothermal fluids that are derived from crystallizing intermediate to acidic magmas emplaced into the upper crust associated with magmatic arcs (Sillitoe, 1972, 2010; Burnham, 1997). In the later stages of crystallization, these magmas exsolve a broad spectrum of volatiles that are important to ore formation; Cl-enriched magmatic fluids are essential to formation of porphyry Cu deposits (Burnham and Ohmoto, 1980; Webster, 2004). The chemical composition of biotite, a common phase in mineralized granitoids and porphyry Cu to porphyry Mo deposits, is sensitive to chemical and physical factors associated with early magmatic to subsequent hydrothermal activity, including the concentration of water, halogens, ore metals, oxidation states and sulfidation equilibria, volatile phase exsolution melt-fluid-

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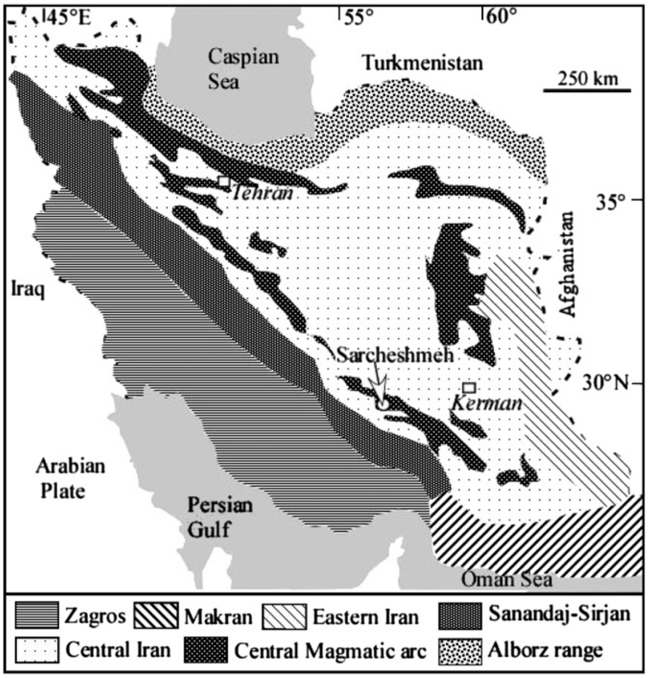

Fig. 1. Simplified regional geotectonic map showing some major geological-structural zones of Iran and location of Sarcheshmeh porphyry copper deposit (modified from Stöcklin, 1968).

vapor elemental partitioning relations and complexing at the range of temperatures and pressures of ore formation (Webster, 2004). The timing of fluid-vapor saturation affects the partitioning of F and Cl between granitoid magmas, crystallizing minerals, and exsolving magmatic hydrothermal fluids, which strongly controls metal complexing, and mass transport to the site of hydrothermal ore deposition (Webster, 1997). The temperature, salinity, and pH of F- and Cl-bearing fluids are also responsible for the alteration associated with porphyry emplacement (Munoz, 1984; Webster, 1997; Candela, 1997), including formation of biotite, K-feldspar, magnetite, and pyrite assemblages that are typically of proximal hypogene porphyry Cu formation.

Between 70 to 90 % of the F and Cl in muscovite- and fluorite-free granitoid rocks is contained in biotite, with the remainder in apatite, amphibole, and titanite (Speer, 1984). The behavior of F and Cl in biotite is key to understanding the role of halogens in both the crystallization of magmas and the derivation of the hydrothermal fluids. Substitution of F or Cl in the hydroxyl site of mica is controlled by the activity of F or Cl, the composition of the mica, and temperature (Munoz and Ludington, 1974, 1977; Munoz and Swenson, 1981; Munoz, 1984, 1992; Lentz, 1994). Both experiments and thermodynamic studies show that Mg-rich micas incorporate more F than Fe-rich micas under similar conditions. This is termed the principle of Fe–F avoidance (Ramberg, 1952; Ekstrom, 1972) and has been confirmed in natural micas (Zaw and Clark, 1978; Sisson, 1987; Zhu and Sverjensky, 1991, 1992; Boomeri et al., 1997; Yang and Lentz, 2005), including mica from a variety of ore-forming granitoid systems.

This paper describes geological and mineralogical features of the Sarcheshmeh porphyry Cu deposit, with a focus on the composition of biotite in the intrusive granitoid rocks and the alteration zones in an attempt to characterize the evolution of hydrothermal fluids responsible for deposit formation. Although several methods of investigation have been previously integrated to examine the evolution of hydrothermal fluids in the Sarcheshmeh porphyry Cu deposit, such as fluid inclusion studies (Hezarkhani, 2006), this study is the first attempt to identify links between intrusive rocks, alteration zones, and porphyry Cu mineralization through the analysis of biotite compositional systematics.

2. Geological setting

2.1. Regional geology

The Sarcheshmeh Cu porphyry is located in the SE-trending part of the Central Iran magmatic arc zone known as Sahand–Bazman magmatic arc sub-zone (Fig. 1). The Sahand–Bazman magmatic arc parallels to the Zagros Mountain chain, which is mainly composed of sedimentary rocks with continuous deposition from the Paleozoic to the Cenozoic, the Sanandaj–Sirjan belt, that is predominantly a metamorphic zone composed of sedimentary rocks intruded predominantly by Mesozoic intrusions. The Sahand–Bazman magmatic arc was formed by the subduction of NeoTethyian oceanic plate beneath Central Iran (Berberian and King, 1981; Takin, 1972; Stöcklin, 1974, 1977; Hallam, 1976; Welland and Mitchell, 1977; Desmons, 1980; Adamia et al., 1980). The Sahand–Bazman magmatic arc mainly consists of an Upper Cretaceous–Eocene basic to felsic volcanic-sedimentary complex. Oligo-Miocene granitoids intruded into thick (up to 15 km) sequences of Eocene lava, pyroclastic, and volcaniclastic rocks as batholiths, stocks, and dykes. Igneous activity in this zone commenced in the Early Eocene (50 Ma), continuing, and climaxing during the middle Eocene for the exposed volcanic rocks (Berberian and King, 1981). Magmatism continued through into the Oligo-Miocene with arc-related plutonic rocks (Alavi, 1994; Walker and Jackson, 2002; Shahabpour, 2005). Post-collisional processes also produced adakitic and alkaline rocks in this zone during the Plio-Pleistocene and Plio-Quaternary (Ghadami et al., 2008). The Miocene plutonic rocks are generally associated with extensive porphyry Cu and skarn mineralization in the Sahand–Basman zone, including Sarcheshmeh (Waterman and Hamilton, 1975; Shahabpour, 1982; Hezarkhani, 2006), Sungon (Hezarkhani and Williams-Jones, 1998), Miduk (Hassanzadeh, 1993), and many other sub-economic ore bodies (Zarasvandi et al., 2005; Shafiei and Shahabpour, 2008). The intrusive and extrusive rocks in the Sahand–Bazman zone are mainly calc-alkaline and alkaline and formed in a continental margin-situated volcanic-arc tectonic setting (Förster et al., 1972; Jung et al., 1976; Berberian et al., 1982; Shahabpour, 2005; Atapour and Aftabi, 2007).

2.2. Geology of the study area

The study area is outlined in a regional geological map (1:100,000 scale) of Rafsenjan (Dimitrijevic et al., 1971); Fig. 2 shows a simplified geological map of the Sarcheshmeh area. The oldest sequence around Sarcheshmeh are an Eocene volcanic–pyroclastic–sedimentary complex (Sarcheshmeh Complex), consisting of trachybasalt, andesite and trachyandesite, andesite-basalt, dacite, tuff, ignimbrite, and tuffaceous sandstone. Oligo-Miocene intrusive rocks intruded this volcanic–pyroclastic–sedimentary complex as batholiths, stocks, and dykes, including mineralized porphyritic stocks and dykes (Sarcheshmeh porphyries) in the Sarcheshmeh mine area. Fig. 3 shows the Sarcheshmeh porphyry, several dyke generations and the alteration zones. The Sarcheshmeh Complex and the intrusive rocks are overlain locally by Late Tertiary to Quaternary volcanic rocks ranging from trachyte to dacite in composition. The mineralized stocks and dykes are younger than the main batholith in the area (Waterman and Hamilton, 1975). K/Ar (using fresh biotite) and Rb/Sr (using biotite-whole rock pairs) ages of 12.5 ± 0.5 Ma and 12.2 ± 1.2 Ma (Middle Miocene), respectively, were reported for the mineralized granodiorite in the Sarcheshmeh deposit (Shahabpour and Kramers, 1987). Shafiei et al. (2008) proposed that the main batholith with an arc-type, normal calc-alkaline signatures formed by fractional crystallization of mantle-derived melts in a locally transtensional tectonic regime is a supra-subduction setting during Paleogene times. Shafiei et al. (2008) believe that mineralized granitoid stocks are adakite-like and formed by hydrated melting of a thickened garnet-bearing amphibolitic sub-arc crust in a compressional tectonic regime during the Neogene.