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Sulfide mineral chemistry investigation of sediment-hosted stratiform copper deposits, Nahand-Ivand area, NW Iran

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ABSTRACT

Copper mineralization in Nahand-Ivand area, NW Iran, appears as disseminated copper sulfides along a redox boundary between gray sandstone and microconglomerate and hematitic sandstones, siltstones and shaly marl. Geochemical analyses of the Nahand-Ivand deposits show as much 35 wt.% Cu and 730 ppm Ag in the gray sandstone. Electron probe micro-analysis (EPMA) was used to determine the mineralogical composition and distribution patterns of copper and silver-bearing phases mainly in pyrite and Cu-bearing sulfides. The EPMA data were essential for evaluating the distribution and partitioning of potential economically-valuable components between co-existing minerals. Furthermore, they contribute to a better understanding of the genesis of the Nahand-Ivand copper deposits and will guide further exploration in the region.

The EPMA results from different types of pyrite reveal Cu contents as high as 0.32 wt.%, 1.10 wt.%, and 2.88 wt.% for framboidal pyrite (PyI), overgrowths on framboidal pyrite (PyII), and diagenetic pyrite (PyIII), respectively. This successive increase of copper from PyI to PyIII is attributed to a continuous supply of copper that replaces framboidal pyrite in turn by the more copper-rich digenetic pyrite. Because of hydrothermal overprinting, pyrite has been replaced by djurleite, roxbyite, and other nonstoichiometric Cu–S minerals that include covellite. The EPMA study indicates that covellite contains significant concentrations of Ag (locally >1 wt.%). In contrast. only trace amounts of silver have been detected in pyrite and other copper sulfides, indicating that covellite is the major Ag-carrier in the ore. According to textural relationships, such open space filling, impregnation, and replacement textures, and the EPMA results, later stage copper-bearing fluids were responsible for the silver enrichment in the Nahand-Ivand deposits.

1. Introduction

Sediment-hosted stratiform copper deposits are a large group of ores that include some of the richest copper deposits in the world. They can be defined as stratiform deposits disseminated to veinlet native copper and copper sulfides hosted by reducing sedimentary rocks, including organic-rich black shales (Brown, 2005; Desouky and Muchez, 2009).

The copper deposits in the Nahand-Ivand area of northwestern Iran share many of these characteristics. For example, the host rocks are gray sedimentary beds that include shallow-water marl, siltstones, and sandstone, and they are surrounded by immature, coarse-grained red-bed sediments. These deposits are the products of the long lived flow of copper-enriched fluids through red beds that may be continuing to the present day)Hitzman et al., 2005; Ingham et al., 2014). The location of Cu mineralization is controlled by the interplay between sediment permeability, the direction of fluid flow, and the proportion of reducing components, such as organic matter and sulfides, in the host rock (Subr'as et al., 2003; Gablina et al., 2006; Raphael Cabral and Beaudoin, 2007; Brems et al., 2009; Solimana and Goresy, 2012; Greenwood et al., 2013; Pingkanga et al., 2013).

Although several attempts have been made in the past decades to study the major and trace element geochemistry of sulfide minerals from sediment-hosted stratiform copper deposits, these characteristics generally remain poorly understood (Hitzman et al., 2005; Dewaele et al., 2006; Durieux and Brown, 2007; Desouky et al., 2010; Brown, 2005, 2014). The geochemistry of sulfide minerals is important, not only for understanding the geological history of the deposits, but also for the mining and exploration industry.

In this paper, we first describe the general geology of the study area, with emphasis on pyrite and copper sulfide mineral distribution patterns. We then focus on the variable origins of pyrite and Cu sulfides,

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the major ore minerals in the Nahand-Ivand area. The Cu-bearing phases are dominated by nonstoichiometric minerals and make up a compositional succession ranging from the Cu-rich sulfides or chalcocite–digenite (Cu_2S–$Cu_{1.75}S$) series, to the Cu-poor sulfides or geerite–covellite ($Cu_{1.5-1.6}S$–CuS) series. These nonstoichiometric minerals have a limited stability range and their precipitation reflects the compositional evolution of the hydrothermal fluid during ore formation (Gablina et al., 2006; Cook et al., 2011; Demir et al., 2013; Hazarika et al., 2013). The main aims of this study include an improved understanding of the hydrothermal systems and the controlling factors for the genesis of the sediment-hosted copper deposits in the Nahand-Ivand area.

2. Regional geology

The Nahand-Ivand area in northwestern Iran is located 20 km to the north of the town of Tabriz and covers a large area in the Tabriz basin. This area is situated in the western Alborz–Azerbaijan geostructural zone of Iran (Nabavi, 1976) (Fig. 1a), which is part of the Alpine–Himalayan fold belt (Karimzadeh Somarin, 2004). The local strata have been intensely folded with the development of NW-trending regional anticlines and synclines (Fig. 1b).

The basement rocks in the area include upper Precambrian–Lower Cambrian massive and bedded recrystallized dolomite with gypsum beds overlain by Upper Cambrian red sandstone and other Paleozoic and Mesozoic sedimentary rocks (Fig. 2a). The Tabriz basin is an intra-mountain basin (Reichenbacher et al., 2011), which is underlain by rocks of the Qom Red Bed and Upper Red Formations (Karimzadeh Somarin, 2004). The region of the present day Tabriz basin was a part of the Tethys Ocean until the Early Miocene (Stöcklin, 1977; Davoudzadeh et al., 1997; Reichenbacher et al., 2011). The regression of the Qom Sea (conglomerate of M_1^c unit) was followed by deposition of a series of continental sedimentary packages in northwestern Iran that are composed of shale, marl, siltstone, sandstone, and conglomerate with evaporates (Asadian, 1993; Karimzadeh Somarin, 2004; Rajabpour et al., 2010a, 2010b; Aghazade and Badrzade, 2010; Enayati and Yazdi, 2012). This succession is more than 2000-m-thick and considered Middle Miocene or Middle to Late Miocene in age (Davoudzadeh et al., 1997; Karimzadeh Somarin, 2004; Allen, 2004; Sen and Purabrishemi, 2010; Reichenbacher et al., 2011).

In the study area, the Upper Red Formation reaches a thickness of as much as 1200 m and covers an extensive area of about 100 km^2 to the north of Tabriz. The lower unit of the Upper Red Formation, the M_2^{mg} unit, which hosts copper deposits, includes alternating green gray sandstone and red marl with interlayers of gypsum and salt-bearing sediments (Sadati et al., 2013). Based on paleontological evidence, this unit is Middle Miocene in age (Asadian, 1993; Davoudzadeh et al., 1997; Allen, 2004; Sen and Purabrishemi, 2010; Reichenbacher et al.,

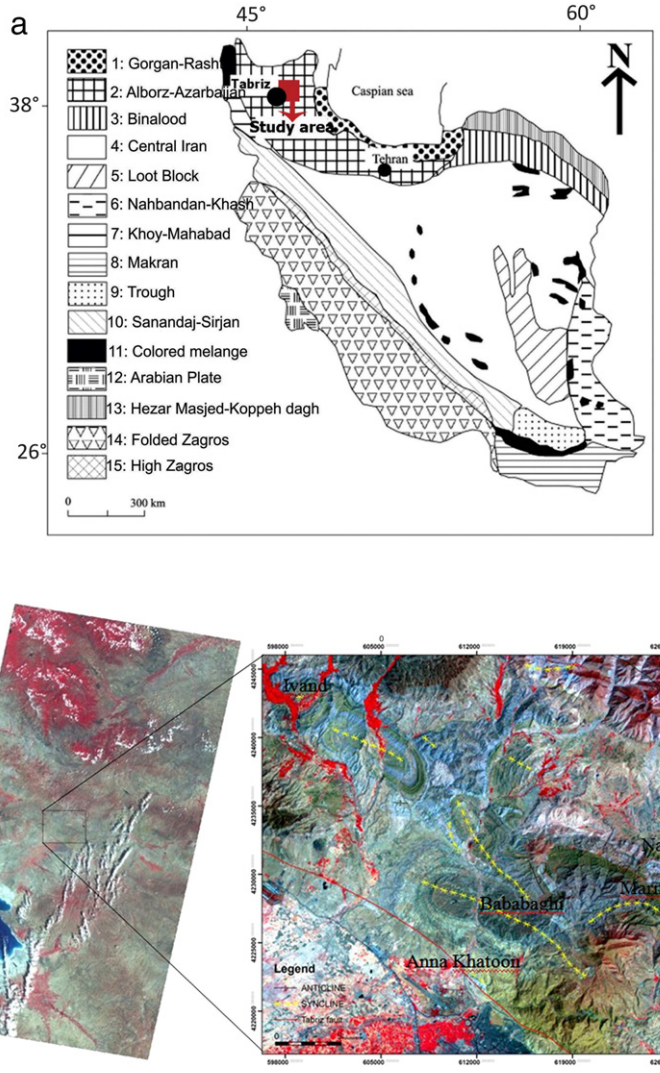

Fig. 1. (a) Major structural zones of Iran (after Nabavi, 1976) and the location of Nahand-Ivand area in the western Alborz–Azerbaijan zone. (b), Location of the Tabriz fault, and anticlines and synclines in the study area on the Landsat image (RGB: 4, 3, 2).