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Constraints on the ore fluids in the Chah Zard breccia-hosted epithermal Au–Ag deposit, Iran: Fluid inclusions and stable isotope studies

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ABSTRACT

The Chah Zard gold–silver deposit, in the central part of the Urumieh-Dokhtar Magmatic Arc (UDMA) of Iran, is a breccia-hosted low- to intermediate-sulfidation epithermal deposit with a resource of ~2.5 Mt averaging 1.7 g/t Au and 12.7 g/t Ag. Gold and silver mineralization occurs in breccia and veins associated with a 6.2 ± 0.2 Ma volcanic complex. Microthermometric measurements on quartz- and sphalerite-hosted, two-phase liquid-rich fluid inclusions indicate that the mineralization may have taken place between 260 and 345 °C, from a moderately saline hydrothermal fluid (8.4–13.7 wt.% NaCl equiv.). First ice-melting temperatures between −37 and −53 °C indicate that the aqueous fluids contained NaCl, $CaCl_2$ ± $MgCl_2$ ± $FeCl_2$. Coexisting liquid-rich and vapor-rich fluid inclusions in quartz and sphalerite provide evidence for boiling in ore-stage breccia and veins. Additionally, the occurrence of adularia and bladed calcite in high-grade ore zones and the presence of hydrothermal breccias and chalcedonic quartz are consistent with boiling. Calculated $\delta^{18}O$ values of water in equilibrium with quartz (+3.4 to +13.1‰) suggest that the fluid may have had a magmatic source, but was ^{18}O-depleted by mixing with meteoric water. The average calculated $\delta^{34}S_{H_2S}$ values are −0.2‰ for pyrite, +0.2‰ for chalcopyrite, −1.0‰ for sphalerite and −0.2‰ for galena. The $\delta^{34}S_{H_2S}$ values are consistent with a magmatic source for sulfur. Gold deposition at Chah Zard is inferred to have been largely caused by boiling, although fluid mixing and/or wall rock reactions may also have occurred. After rising to a depth of between 970 and 440 m, the fluid boiled, causing deposition of fine-grained quartz, and sealing of the hydrothermal conduit. Episodic boiling in response to alternating silica sealing and hydraulic brecciation was responsible for ore deposition. Gold and silver may have precipitated due to the destabilization of HS^- complexes, caused by the boiling-off of H_2S to vapor, whereas the dilution and/or cooling of hydrothermal fluids led to the precipitation of base metals.

1. Introduction

Intermediate-sulfidation (IS) style epithermal deposits have been defined by Hedenquist et al. (2000). Although such deposits have similar alteration styles and textures to low-sulfidation (LS) epithermal deposits, it has been proposed that IS deposits form at metallogenic settings different from LS deposits; while the IS has direct links with magmas, the LS has little magmatic input except from heat (e.g., Hedenquist et al., 2000; Sillitoe, 2010). This hypothesis is supported by the coexistence of IS veins and high-sulfidation (HS) epithermal deposits and porphyry deposits (e.g., Chang et al., 2011; Hedenquist et al., 1998; Izawa and Zeng, 2001). However, there has been little direct evidence to show that the fluids responsible for IS mineralization are derived from magma. In this study, we report fluid inclusion, O isotope and S isotope studies of the Chah Zard epithermal Au–Ag deposit in Iran, which reveal strong magmatic signature in the mineralizing fluids.

The Chah Zard deposit is a pipe-like breccia deposit (Kouhestani et al., 2012) that has several features similar to the LS to IS epithermal deposits as discussed by Einaudi et al. (2003), Gemmell (2004), Hedenquist et al. (2000), Sillitoe and Hedenquist (2003), and White and Hedenquist (1990). It is situated in the central part of the Urumieh-Dokhtar Magmatic Arc (UDMA) approximately 100 km southwest of the city of Yazd, central Iran (Fig. 1). Mineralization in the Chah Zard area was originally identified by Rio Tinto during a period of exploration in 2004. In 2006, Persian Gold outlined favorable drilling targets based on regional field mapping, stream sediment geochemistry, and channel sampling. By the end of 2009, two separate phases of trenching (38 trenches totaling 3545 m) and diamond drilling (38 holes, totaling 4150 m) were completed, and 4409 samples (3000 drill core and 1409 trench samples)

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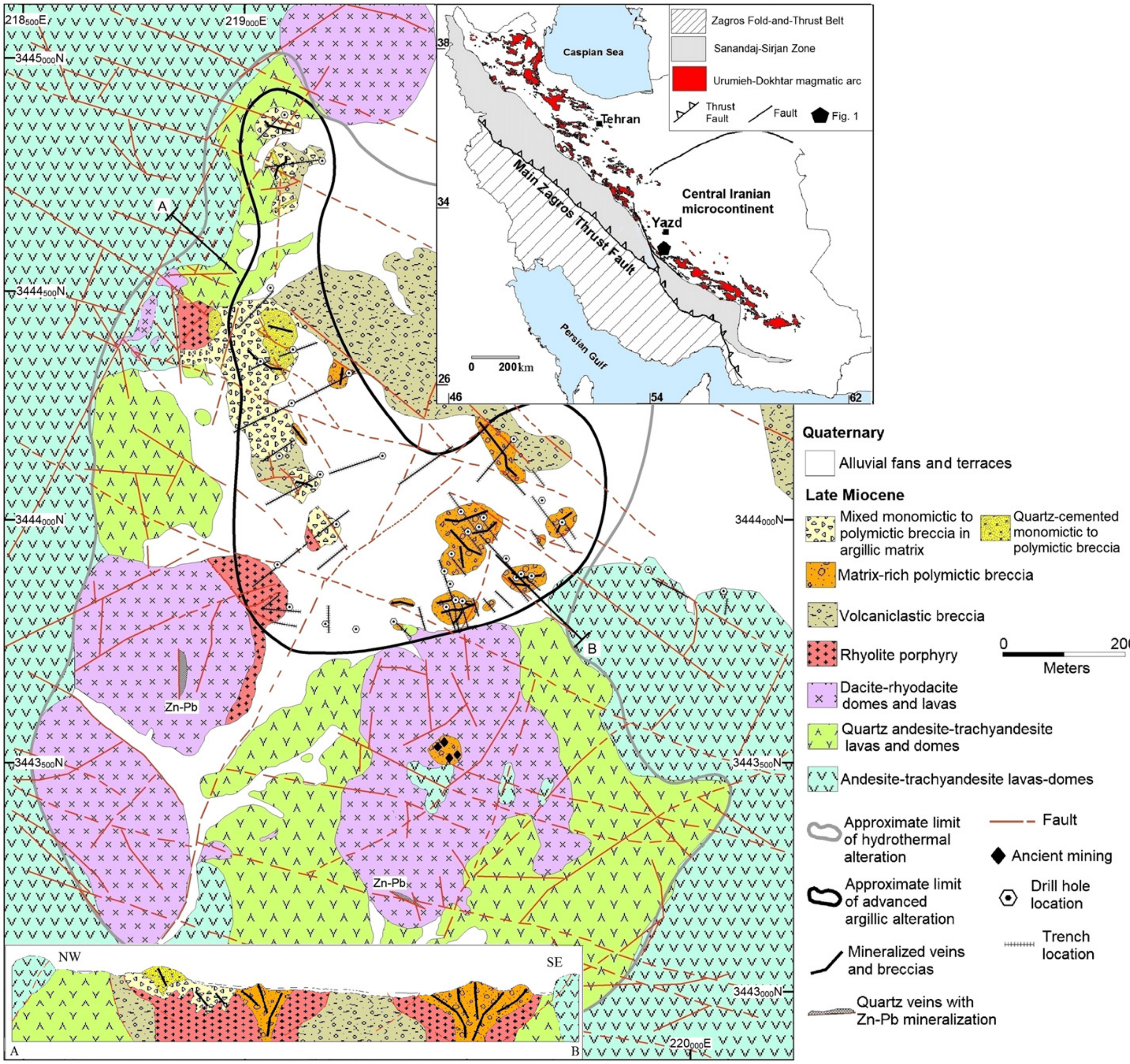

Fig. 1. Simplified geological map of the Chah Zard deposit (modified after Kouhestani et al., 2012). Note the close association of the mineralization with breccia bodies. The insets show schematic cross-section through the Chah Zard deposit, and zonal subdivisions of the Zagros orogen (modified after Alavi, 1994).

were obtained. The resource based on diamond drilling results is estimated to be ~2.5 million tonnes averaging 1.7 g/t Au and 12.7 g/t Ag, containing >3.8 tonnes of Au and >28.6 tonnes of silver, in the near-surface portion of the southern part of the area.

2. Deposit geology and mineralization

The Chah Zard deposit is spatially associated with the late Miocene Chah Zard volcanic complex (Fig. 1) emplaced at shallow crustal levels in Eocene volcanic and sedimentary sequence (Kouhestani, 2011; Kouhestani et al., 2012). This complex consists of a suite of calc-alkaline to high-K calc-alkaline andesites–trachyandesites, their differentiates (i.e., dacite–rhyodacite and rhyolite porphyry, Kouhestani, 2011) and hydrothermally altered polymictic and mixed monomictic to polymictic volcanic breccias. Host rocks are polymictic breccia units, and locally mixed monomictic to polymictic breccias (Fig. 1). The matrix-supported polymictic breccias have a fine-grained, sandy matrix, while the latter has a distinctive white clay matrix. Laser ablation-inductively coupled plasma mass spectrometry (LA-ICP-MS) U–Pb zircon dating by Kouhestani et al. (2012) gave an age of 6.2 ± 0.2 Ma for the volcanic host rocks at Chah Zard. The mineralization is developed in hydrothermal breccias, sheeted and conjugate veins, and wall rocks as disseminated sulfides, sulfosalts and electrum. Hydrothermal alteration displays a concentric zoning pattern from a central zone with a mineral assemblage of quartz, adularia, illite, illite/smectite ± pyrite ± carbonate, to enveloping chlorite, calcite ± illite ± quartz (Kouhestani et al., 2012). An extensive supergene advanced argillic blanket overprints the ore zones (Kouhestani et al., 2012).

Mineralization was introduced in five stages (Kouhestani et al., 2012). Stage-1 is characterized by zones of sericite alteration with disseminated pyrite, and pyrite–quartz–illite ± chalcopyrite-cemented breccias and veins (<5 mm width). The vein edge is typically rimmed