Epithermal precious- and base-metal mineralization in the Eocene arc of Torud-Chah Shirin mountain range: Gandy and Abolhassani districts, Semnan, northern Iran

GHOLAM HOSSEIN SHAMANIAN
Department of Geology, University of Agricultural Sciences and Natural Resources of Gorgan, Gorgan, Iran, Shamanian@yahoo.com
JEFFREY W. HEDENQUIST
Department of Geology and Geological Engineering, Colorado School of Mines, Golden, CO 80491, USA
KEIKO H. HATTORI
Department of Earth Science, University of Ottawa, Ottawa, Ontario K1N 6N5, Canada
JAMSHID HASSANZADEH
Department of Geology, University of Tehran, Tehran, Iran

Keywords: epithermal, gold deposit, intermediate sulfidation, fluid inclusions, sulfur isotopes, northern Iran, Torud, Semnan, Tethyan orogeny.

Abstract
Subduction of Tethyan oceanic crust during the Tertiary produced the most voluminous igneous rocks in Iran. They form two belts: the NW-trending Urumieh-Dokhtar zone in central Iran and the Alborz magmatic belt in northern Iran. Recent studies suggest that a single continental arc may have been rifted to form the two belts. The belts host many precious and base metal prospects. This paper documents two of these prospects; the Gandy and Abolhassani prospects hosted by Eocene igneous rocks in the Alborz belt. The country rocks show a typical arc geochemical signature with high LILE/HFSE ratios.

The mineralization in the Gandy area form veins and breccias and is divided into three stages; precious metal mineralization (Stage I), base-metal mineralization (Stage 2) and the formation of quartz and calcite (Stage 3). Native gold is common in Fe oxides, a weathering product of pyrite, in Stage I, and coexists with galena and chalcopyrite in Stage 2. The Abolhassani veins show three stages. The first two stages formed quartz, calcite, galena, sphalerite, pyrite and chalcopyrite, and are followed by the formation of quartz and calcite.

The average of homogenization temperatures and salinities of fluid inclusion assemblages from Gandy range from 234 to 285 ˚C, and 4.2 to 5.4 wt% NaCl equivalent. These temperatures are in a good agreement with isotopic temperatures from two sulfides pairs (236 and 245 ˚C). The Abolhassani area shows higher average temperatures (234–340 ˚C) and salinities (6.7 - 18.7 wt% NaCl equivalent) of fluid inclusion assemblages. The lower temperature hydrothermal fluid component in the two areas is comparable, but the Abolhassani district contained a higher salinity component. The base metal-rich mineralization at Abolhassani may thus have been caused by the periodic injection of this high salinity fluid.

Mineralization occurred at least 430 m and 600 m below the paleowater table at Gandy and Abolhassani, respectively. Based on the low grades of Au and high salinity of fluids at Abolhassani, it is unlikely to find precious-metal rich zones at greater depth. By contrast, Gandy has potential at depth for extensions of the high-grade gold veins. Results of this study may aid in exploration of the numerous untested epithermal and related prospects along the 1800-km long volcanic belts in northern Iran.

1. Introduction

The Torud-Chah Shirin mountain range of Semnan Province is in the eastern part of the Alborz magmatic belt that crosses northern Iran, ~ 1800 km in length, from the border with Afghanistan in the east to the border with the Caucasus in the northwest (Fig. 1). The Alborz belt merges in the northwest with another Tertiary calc-alkaline magmatic belt, the Urumieh-Dokhtar (UD) zone, which runs parallel to the NW-trending Zagros orogen. Kazmin et al (1986) and Alavi (1991) attributed these two belts, Zagros and Alborz-UD, to two subduction zones. Recently, Hassanzadeh et al. (2002) suggested that the two belts were once a single arc, but separated by intra-arc extension that started in the late Eocene.

A regional geochemical survey in early 1990s by the Geological Survey of Iran covered 42,000 km^2 in north-central Iran, including the Torud-Chah Shirin range. This project found a number of precious-metal anomalies (Geological Survey of Iran, 1995). The present paper describes the epithermal occurrences of this

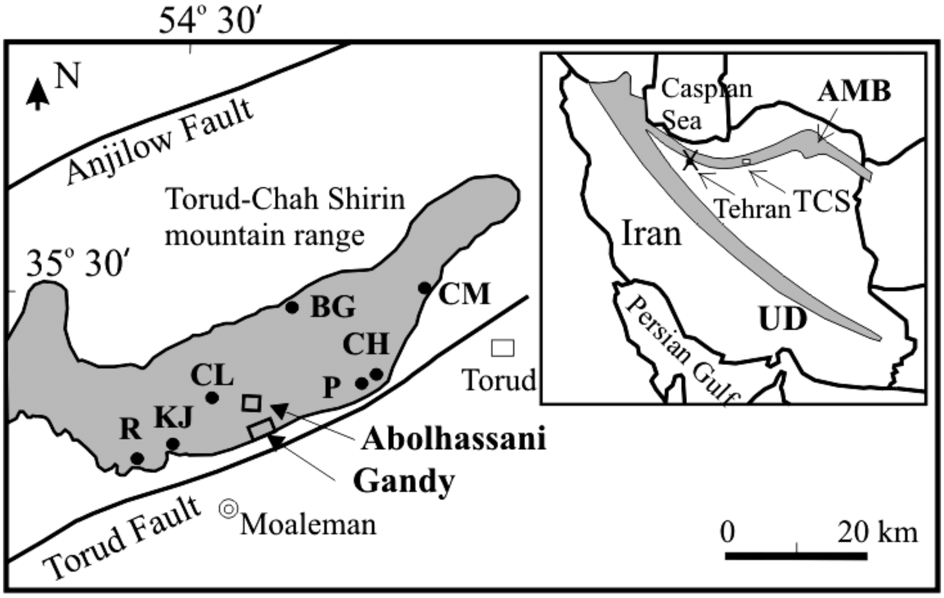

Figure 1. Location of two main Tertiary volcanic belts (shaded) in Iran: the NW-trending Urumieh-Dokhtar (UD) zone and the Alborz magmatic belt (AMB).
The Torud-Chah Shirin mountain range (TCS) contains several major epithermal systems including Gandy, Abolhassani, Baghu (BG), Chalu (CL), Cheshmeh Hafez (CH), Chahmessi (CM), Pousideh (P), Khanjar (KJ), and Reshm (R).

region, and focuses on two such prospects, Gandy and Abolhassani districts, in the Moaleman area, 400 km east of Tehran. The Gandy and Abolhassani areas, located at 35° 20' N and 54° 38' E, show high precious and base metal anomalies, respectively. Their characteristics reveal relative erosional level in the region.

2. Regional Setting

Paleogene arc-related rocks represent the most voluminous igneous rocks in Iran. They form two belts (excluding the east Iranian Eocene zone): the NW-trending UD zone of central Iran and the Alborz magmatic belt of northern Iran (Fig. 1). Similar age and lithologic sequence of the two belts suggest that the two likely formed as a single continental arc that was subsequently rifted apart (Hassanzadeh et al., 2002). Eocene magmatism produced calc-alkaline felsic to intermediate rocks in the arc, whereas Oligocene magmatism is characterized by mafic-alkaline compositions (Hassanzadeh, et al., 2002).

The Torud-Chah Shirin mountain range consists mainly of Paleogene igneous rocks. Peak magmatic activity was middle Eocene to possibly upper Eocene in age, and has been divided into three stages from oldest to youngest (Hushmandzadeh et al., 1978): 1) explosive volcanic activity represented by rhyolitic to rhyodacitic ash tuffs, and locally andesitic lava flows, with subordinate marls, tuffaceous marlstones and sandstones; 2) lava flows and pyroclastic rocks of andesite, trachyandesite, and basaltic andesite composition; and 3) subordinate dacitic-rhyodacitic rocks and hypabyssal intrusions. The structural patterns are controlled by two NE-trending strike slip faults, Anjilow in the north and Torud in the south (Fig. 1).

The Torud-Chah Shirin mountain range hosts many mineral showings and abandoned mines, particularly epithermal base-metal veins, such as those in the areas of Gandy (Au-Ag-Pb-Zn), Abolhassani (Pb-Zn-Ag-Au), Cheshmeh Hafez (Pb-Zn), Chalu (Cu), Chahmessi (Cu), and Pousideh (Cu) (Fig. 1). Other types of deposits include placer gold and an underground mine of turquoise at Baghu, skarn deposits, and Pb-Zn deposits in carbonates.

3. Local Geology

Outcrops around the Gandy districts consist mainly of felsic pyroclastic rocks, intermediate lava flows and volcanic breccias, and silicic epizonal intrusions. The local stratigraphy comprises, from oldest to youngest: 1. A sequence of thin bedded volcaniclastic rocks, siltstones and sandstones, with subordinate marlstones and tuffaceous sandstones in the lower part; 2. Lapilli tuffs, volcanic breccias and intermediate lava flows; 3. Rhyolite to rhyodacite domes.

The Abolhassani district is located ~3 km northeast of the Gandy district, and at ~1500 m elevation is 200 m higher than Gandy. The outcrops are composed of andesitic volcanic rocks, which were intruded by dacitic to rhyodacitic subvolcanic rocks. The volcanic rocks from the two areas show a typical arc geochemical signature with elevated contents of LILE and low contents of Nb, Ta, Zr, Hf and Ti.

4. Mineralization and Alteration

Mineralization in the Gandy area occurs as veins and breccias and is divided into three main stages. Stage I is economically important with high precious metal contents. Stage II consists of four substages and contains the majority of base-metal mineralization. Native gold is commonly found within alteration products of pyrite and secondary iron oxides, such as goethite, in stage I, and coexists with galena and chalcopyrite in stage II. Sphalerite crystals and aggregates display subtle color zoning with white to light yellow core changing to yellow rims. The FeS and CdS contents range from 0.8 to 1.6 and 0.2 to 0.6 mol%, respectively. The final stage is dominated by quartz and calcite.

Mineralization of the Abolhassani veins is divided into three main stages. The first two stages contain similar mineral assemblages, including quartz, calcite, galena, sphalerite, pyrite and chalcopyrite. The final stage is dominated by quartz and calcite. No gold particles were found in Abolhassani samples. Sphalerite crystals do not display any color zoning, and their FeS content ranges from 1 to 3 mol%.

In the Gandy district, the main supergene minerals are goethite, Fe-O-OH, malachite, covellite, cerussite, and smithsonite, which replace 20 to 50% of the primary sulfide minerals. The main supergene minerals in the Abolhassani district are similar to those in the Gandy area, but the supergene effects are only incipient in this district. The minimum, average and maximum assays from 14 channel samples of Gandy veins are: 0.1, 14.5, 68.3 g/t Au, 1.0, 30.6, 161.2 g/t Ag, 0.002, 3.1, 13.1 wt% Pb, 0.004, 0.84, 3.8 wt% Zn and 0.002, 1, 6.3 wt% Cu. For comparison, the values from 19 channel samples of Abolhassani veins are: 0.1, 0.85, 6 g/t Au, 1.5, 29.5, 115.2 g/t Ag, 0.001, 6.4, 16.5 wt% Pb, 0.001, 1.2, 5.2 wt% Zn, and 0.01, 0.83, 7.7 wt% Cu.

Hydrothermal alteration of variable intensity is exposed in scattered outcrops and covers about 4 km^2 in Gandy and 1 km^2 in Abolhassani. Intense alteration halos up to 2-m width are developed adjacent to the veins, with quartz, illite and calcite.

5. Fluid inclusion and sulfur isotope data

Fluid inclusion and sulfur isotope compositions were analyzed from sulfide-sulfate assemblages of stage II of Gandy and stages I and II of Abolhassani. In both districts data on fluid inclusion assemblages were obtained principally from subhedral crystals of sphalerite. The average of homogenization temperatures (Th) and salinities of fluid inclusion assemblages from Gandy range from 234 to 285 ˚C, and 4.2 to 5.4 wt% NaCl equivalent, with a peak of values at about 250 ˚C. The homogenization temperatures are in a good agreement with isotopic temperatures from two sphalerite and galena pairs (236 and 245 ˚C). The average temperature and salinity of fluid inclusion assemblages from Abolhassani district range from 234 to 340 ˚C, and 6.7 to 18.7 wt% NaCl equivalent, showing a clear trend of dilution. Pairs of sphalerite-galena do not give reasonable isotopic temperatures at Abolhassani.

Comparison of Th versus freezing (TmI) values for the two deposits indicates the presence of a moderately saline fluid (5-6 wt% NaCl) of similar temperature (250 ˚C) in both deposits, as well as a high salinity fluid at Abolhassani. The base metal-rich mineralization at Abolhassani may thus have been caused by the periodic introduction of this high salinity fluid. Similar evidence for the presence of lower and higher salinity fluids in the same deposit has also been noted previously for silver- and base-metal mineralization in the Fresnillo district (Simmons et al., 1988; Simmons 1991) and in other intermediate-sulfidation epithermal deposits of Mexico (Albinson et al., 2001). The Abolhassani district shows higher average Ag/Au (34.7) and Pb + Zn contents (up to 7.6 wt%) than Gandy (Ag/Au 2.1 and 3.9), consistent with the higher maximum salinity at Abolhassani (18.7 wt% NaCl equivalent) compared with Gandy (5.4 wt%).

6. Discussion

Precious and base-metal mineralization within hydrothermal breccias of Gandy may have deposited under boiling conditions, whereas base-metal mineralization in stage II most likely occurred due to dilution. The mixing trend of fluids suggests that based-metal sulfides in the Abolhassani veins were likely deposited during periodic injection and dilution of brines. The minimum depth of formation was at least 430 m and 600 m below the paleowater table for Gandy and Abolhassani, respectively. Such depths are characteristic of silver and base metal-rich epithermal systems of the intermediate-sulfidation category (Hedenquist et al., 2000; Albinson et al., 2001). In both districts it is possible that significant mineralization existed at shallower depths and has now been eroded. The present surface at Abolhassani probably represents a deeper level than Gandy, consistent with the higher Ag/Au ratios and higher base-metal contents at Abolhassani, both of which typically increase with increasing depth in epithermal deposits (Buchanan, 1981). In addition, the average temperatures in the two districts, as well as the sulfidation state as indicated by FeS compositions of sphalerite, are typical of the Ag-Au and base-metal style of intermediate-sulfidation epithermal mineralization noted elsewhere, e.g., in Mexico and Nevada (Albinson et al., 2001; John, 2001).

7. Conclusion

The Gandy district shows three main mineralization stages, the first two being economically important with precious- and base-metal mineralization. The final stage is dominated by quartz and calcite. Mineralization of the Abolhassani veins occurred in three main stages. The first two stages contain similar mineral assemblage including quartz, calcite, galena, sphalerite, and pyrite, whereas the final stage is dominated by quartz and calcite. This district is dominated by base-metal mineralization and Au grades are relatively low in the veins.

The average homogenization temperature of fluid inclusion assemblages has a peak at about 250 ˚C and three peaks at about 250, 275, and 340 ˚C for Gandy and Abolhassani, respectively. Homogenization (Th) and ice melting point (TmI) data from fluid inclusion assemblages indicate dilution trends for both districts, with a common fluid of about 5 wt% NaCl equivalent present in both systems. In addition, a brine with a maximum salinity of about 18.7 wt % NaCl equivalent was present periodically in the hydrothermal system of Abolhassani. The minimum depth of formation was about 430 m and 600 m below the paleowater table for Gandy and Abolhassani, respectively.

The large size of the Paleogene arc in central and northern Iran and numerous geochemical anomalies in the area make it an attractive target for epithermal mineralization. This study suggests that exploration should focus on areas with evidence of relatively little post-hydrothermal erosion, <200-300 m, thus increasing the preservation potential for epithermal veins with high gold grades similar to those at Gandy.

Acknowledgments

We are sincerely grateful to the management of the Geological Survey of Iran, in particular M.T. Korehei and S. Kousari for providing the support in the field. Peter Jones of Carleton University assisted the electron probe work, Wendy Abdi and Ron Hartree of University of Ottawa assisted stable isotope analysis and XRF analyses, respectively.

References

Alavi, M., 1991, Tectonic map of the Middle East: Geological Survey of Iran.

Albinson, T., Norman, D.I., Cole, D., and Chomiak, B., 2001, Controls on formation of low-sulfidation epithermal deposits in Mexico: Constrains from fluid inclusion and stable isotope data: Society of Economic Geologists, Sp. Publ. 8: 1-32.

Buchanan, L.J., 1981, Precious metal deposits associated with volcanic environments in the Southwest. In Relations of Tectonics to Ore Deposits in the Southern Cordillera (eds. W.R.Dickson and W.D. Payne); Arizona Geol. Soc. Digest 14: 237-262.

Geological Survey of Iran, 1995, Explanatory text of geochemical map of Moaleman (6960), Report no. 9, v. 1, 33 p.

Hassanzadeh, J., Ghazi, A.V., Axen, G., and Guest, B., 2002, Oligomocene mafic-alkaline magmatism in north and northwest of Iran: Evidence for the separation of the Alborz from the Urumieh-Dokhtar magmatic arc: Geol. Soc.Amer.Abstract.

Hedenquist, J.W., Arribas R., A., and Gonzalez-Urien, E, 2000, Exploration for epithermal gold deposits: Reviews in Economic Geology, 13: 245-277.

Hushmandzadeh, A.R., Alavi Naini, M., and Haghipour, A.A., 1978, Evolution of geological phenomenon in Totud area: Geological Survey of Iran, Report no. H5, 136 p. (in Farsi).

Kazmin, V.G., Sborshikov, I.M., Ricou, L.E., Zorenshain, E.P., Boulin, S., and Knipper, A.L., 1986, Volcanic belts as markers of the Mesozoic-Cenozoic active margin of Eurasia: Tectonophysics, 123: 123-152.

John, D. A., 2001, Miocene and early Pliocene epithermal gold-silver deposits in the northern Great Basin, western USA: Characteristics, distribution, and relationship to magmatism: Econ. Geol. 96: 1827-1853.

Simmons, S.F., Gemmell, B., and Sawkins, F.J., 1988, The Santo Nino silver-lead-zinc vein, Fresnillo District, Zacatecas, Mexico: Part II. Physical and chemical nature of ore-forming solutions: Econ. Geol. 83:1619-1641.

Simmons, S.F., 1991, Hydrothermal implications of alteration and fluid inclusion studies in the Fresnillo district, Mexico: Evidence for a brine reservoir and a descending water table during the formation of hydrothermal Ag-Pb-Zn orebodies: Econ. Geol. 86: 1579-1601.