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Autor: Moritz, Robert / Ghazban, Fereydoun

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SHORT COMMUNICATION

Geological and fluid inclusion studies in the Muteh gold district, Sanandaj-Sirjan zone, Isfahan Province, Iran*

by *Robert Moritz*[1] and *Fereydoun Ghazban*[2]

Abstract

Metamorphic rocks of the Sanandaj-Sirjan zone host the Muteh gold mining district. The gold occurrences are in northwest-striking and northeast-dipping normal faults crosscutting the regional ductile pattern of the host rocks. This faulting is possibly related to a Tertiary extensional uplift event. The hydrothermal alteration assemblage quartz-muscovite-pyrite-carbonate-albite overprints the metamorphic assemblage. Gold is associated with pyrite. Fluid inclusion data suggest that gold deposition is related to mixing between a regional CO_2-bearing saline fluid and a dilute fluid, possibly of meteoric origin.

Keywords: ore deposit, gold, fluid/rock interaction, tectonic pattern, Zagros range, Iran.

Introduction

Their is still little knowledge about the characteristics, setting and genesis of gold deposits in the Zagros range and the neighbouring tectonic zones of Sanandaj-Sirjan and Urumieh-Dokhtar (Fig. 1). In an earlier contribution, MORITZ et al. (1993) discussed some aspects of the sedimentary rock-hosted disseminated gold deposit at Zarshuran in northwestern Iran (Fig. 1), probably a Carlin-type deposit of Oligo-Miocene age. The present paper focuses on the Muteh mining district hosted by metamorphic rocks, a major gold producer of Iran in the Isfahan province, about 270 km southwest of Teheran (FARHANGI, 1991). THIELE et al. (1968) invoked a genetic relationship between the gold deposit and granitic intrusions of assumed Precambrian age, whereas PAIDAR-SARAVI (1989) suggested that the gold deposit is of metamorphogenic origin. However, evidences presented by these authors to support these models are scarce or unclear. In this contribution, we present new field, petrographic and microthermometric fluid inclusion data which allow to constrain the genesis of this important gold mining district. One particular aim of our study is to contrast regional fluids with respect to fluids spatially associated with the gold-bearing ore zones.

Regional geological setting

The Muteh gold district occurs in a northeast-elongated, 50 km long metamorphic rock complex, northwest of the town of Isfahan. These metamorphic rocks belong to the northwest-trending Sanandaj-Sirjan tectonic zone which lies between the Tertiary Urumieh-Dokhtar Magmatic Belt and the Zagros Simply Folded Belt (Fig. 1). An apparent Precambrian age has been considered by THIELE (1966) and THIELE et al. (1968) for the metamorphic rocks of the study area. However, there are no conclusively proved Precambrian rocks exposed in the Sanandaj-Sirjan zone, and detailled investigations have shown that a large part of the metamorphic rocks are rather Paleozoic to Mesozoic, partly fossiliferous sequences (ALAVI, 1994). The metamorphic rocks are predominantly composed of gneisses,

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[1] Département de Minéralogie, Université de Genève, rue des Maraîches 13, CH-1211 Genève 4, Switzerland.
[2] Department of Geology, University of Teheran, Iran.

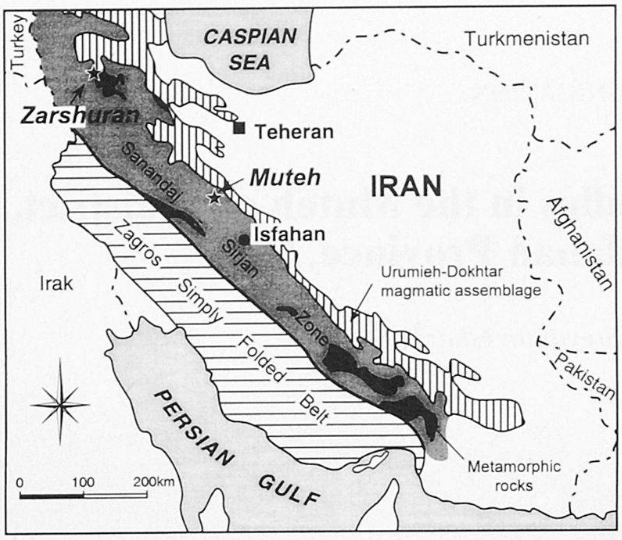

Fig. 1 Location of gold deposits and tectonic zones of western Iran after STÖCKLIN (1968).

with subsidiary marbles, amphibolites, quartzites and phyllites. Foliation in the metamorphic rocks is predominantly flat lying. Large quartz veins formed during regional metamorphism are abundant and are concordant with the foliation of the host metamorphic rocks. According to THIELE (1966), the metamorphic rocks of the study area have reached amphibolite facies conditions, and THIELE et al. (1968) mention that the northeastern part of the metamorphic rock complex has been affected by retrograde metamorphism. These observations are confirmed by the present study, since metamorphic rocks of the southwestern part of the complex contain a staurolite-biotite-garnet assemblage characteristic of amphibolite facies conditions, while the northeastern part is characterized by a typical greenschist facies assemblage which includes muscovite, biotite, plagioclase, K-feldspar and chlorite. Preliminary application of the phengite geobarometer of MASSONE and SCHREYER (1987) indicates relatively low pressure conditions (Si: 3.16 to 3.20) for the later assemblage. Abundant granitic intrusions have intruded the northeastern part of the metamorphic complex. A Precambrian to Infracambrian age has been invoked for these intrusions by THIELE et al. (1968), while OTRODI (1986; VALIZADEH, pers. communication, 1995) suggests a post Lower Jurassic age. Radiometric dating needs still to be carried out on these intrusions.

The metamorphic rocks are directly overlain by non- to slightly metamorphosed sedimentary rocks (THIELE et al., 1968), including: (1) a sequence of shales, slates, sandstones and subsidiary mafic volcanic rocks attributed to the Precambrian Kahar Formation; (2) a thick sequence of dolomites of the Infracambrian Soltanieh Formation which is considered as a northeastern correlative of the evaporitic Hormuz Formation (STÖCKLIN, 1968; HUSSEINI and HUSSEINI, 1990; TALBOT and ALAVI, 1996); (3) Permian dolomites; and (4) Eocene-Miocene conglomerates, sandstones and sandy shales. As recognized by THIELE et al. (1968) and confirmed by our study, the sedimentary rock sequences rest unconformably over the metamorphic rocks. The metamorphic rocks show an intense subhorizontal mylonitic foliation and are brecciated at the immediate contact with the overlying sedimentary rock sequences. The Infracambrian evaporite-dolomite sequence is a major décollement and has played a critical role in controlling the style of deformation of the Zagros range and the Sanandaj-Sirjan zone (ALAVI, 1994).

The geometry of the Sanandaj-Sirjan zone is dominated by northwest-oriented thrusts with a vergence to the southwest (ALAVI, 1994). TILLMAN et al. (1981) have recognized an event of extensional tectonics with northwest-oriented normal faulting which occurred during Tertiary uplift of the study area. ALAVI (1994) also reports the local occurrence of steeply dipping normal faults, and mentions the possible existence of extensional, low-angle normal faulting in the Sanandaj-Sirjan zone.

Gold occurrences

There are nine reported gold occurrences in the Muteh district. They are all in the northeastern part of the metamorphic complex, where the rocks display a greenschist facies assemblage and are cut by abundant granitic intrusions. One of the occurrences, the Chah Khatoon open pit, was producing ore until the beginning of 1995. The mining activity is presently restricted to a second occurrence, the Senjedeh open pit. On a regional scale, the gold occurrences appear to be controlled by northwest-striking lineaments. On a local scale, the orebodies are emplaced along northeast-dipping normal faults affecting the gneisses within these lineaments (Chah Khatoon and Senjedeh). The northeast-dipping normal faults are late brittle structures crosscutting the regional ductile pattern of the host rocks. Some of the other ore occurrences also seem to be controlled by lithological contacts, such as between gneiss and granite.

Hydrothermal alteration associated with the gold occurrences is characterized by intense bleaching of the host rocks. It consists of silicified

Tab. 1 Summary of microthermometric fluid inclusion data.

FI type	Occurrence	Tm CO_2	Th CO_2	Tm Clat	Tm Ice	Th total
I	Regional quartz veins	–58.1; –56.9 (–57.0) n = 6	8.3; 23.6 (18.5) n = 8	–0.9; 7.5 (3.1) n = 17	–12.9; –6.7 n = 4	148; 257 (208) n = 14
II	Regional quartz veins	–58.5; –57.2 (–57.3) n = 12	–23.8; 12.0 (–5.7) n = 12	8.7; 9.4 n = 2		
III	Late gold quartz veins and regional quartz veins near gold occurrences			6.4; 8.7 (7.6) n = 27		181; 302 (221) n = 28
IV	Late gold quartz veins and regional quartz veins				–26.9; –21.0 (–23.5) n = 22	84; 191 (122) n = 33

All values in °C; first and second values = minimum and maximum values, respectively; in brackets = mode; n = number of measurements; Th CO_2 and Th total are to the liquid.

zones with microcrystalline to crystalline quartz, fine grained muscovite, pyrite, dolomite-ankerite and albite. Subsidiary alteration minerals are chlorite and rutile. Some irregular, microscopic veining is also recognized with quartz, dolomite-ankerite and pyrite as the dominant minerals, and subsidiary albite and muscovite. Some of the quartz-carbonate veins show open-space growth texture with euhedral and comb-shaped minerals. Breccias occur in places with fragments of silicified host rock cemented by carbonate. Straight, northeast-dipping 1 to 2 cm thick quartz-carbonate-coarse pyrite veins occur within the silicified ore zone and in the vicinity of the main orebodies. Gold is typically associated with pyrite. PAIDAR-SARAVI (1989) also reports the presence of minor chalcopyrite, galenobismutite, bismuth, galena, sphalerite, and pyrrhotite.

The alteration and veining associated with the gold orebodies overprint the metamorphic mineral assemblage and ductile fabric of the host rocks. Mass balance calculations of the alteration process are hindered by the fact that the metamorphic rocks remote from the orebodies show some variability in primary mineralogy, and the difficulty to distinguish with certainty if the precursor of the altered host rocks was a paragneiss, a foliated granite or a rock intermediate in composition between an amphibolite and a paragneiss.

Fluid inclusion types and microthermometry

A microthermometric fluid inclusion study has been undertaken (1) on barren, regional quartz veins concordant with the foliation of the host gneisses, and (2) on quartz veins and silicified host rocks from gold orebodies of the Muteh district. Four fluid inclusion types have been recognized (Tab. 1): *Type I* are liquid-rich, two phase inclusions at room temperature. Salinities based on clathrate melting temperature range between 4.9 and 16.6 wt% NaCl equivalent, with a mode at 12 wt%. Total homogenization temperatures fall between 148 and 257 °C with a mode at 208 °C (Fig. 2). *Type II* are vapour-rich, one to two phase inclusions. Clathrate dissociation temperatures indicate salinities of 1.2 and 2.6 wt% NaCl equivalent. CO_2 melting temperatures are below –56.6 °C in both type I and type II inclusions, and indicate the presence of other dissolved gases. Type I and type II inclusions occur in the regional quartz veins that are unrelated to the gold occurrences. Both types occur as secondaries in separate trails or together in clusters. *Type III* are liquid-rich, two phase inclusions at room temperature. Total homogenization tem-

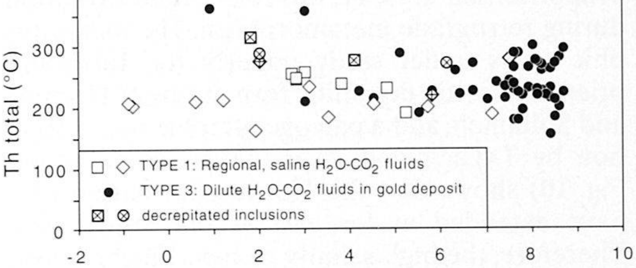

Fig. 2 Total homogenization vs clathrate melting temperatures of liquid-rich fluid inclusions.

peratures fall between 181 and 302 °C with a mode at 221 °C. Apart from total homogenization, only clathrate melting between 6.4 and 8.7 °C could be observed (Fig. 2). It indicates the presence of dissolved gases, most likely CO_2. No liquid CO_2 is visible in these inclusions. Assuming that the fluid in type III inclusions can be approximated by a H_2O–CO_2–NaCl mixture, it is concluded that the salinity ranges between 0 and 7 wt% NaCl equivalent, the density of CO_2 is less than 0.47 (g/cm^3), and the mole fraction of CO_2 is less than 0.1. Type III inclusions are only present in late stage quartz-carbonate-pyrite veins and silicified rocks at the gold occurrences, as well as in regional quartz veins in the direct vicinity of the orebodies. *Type IV* inclusions are liquid-rich, one to two phase inclusions at room temperature. Total homogenization temperatures fall between 84 and 191 °C with a mode at 122 °C. Final ice melting is between –26.9 and –21.0 °C with a mode at –23.5 °C. First ice melting temperatures are typically below –42 °C, thus indicating the presence of additional cations Na^+, such as Ca^{2+}. Type IV inclusions occur as secondaries in both late-stage veins in the orebodies and in regional quartz veins.

Discussion and conclusions

The northwest-oriented faults that control the gold orebodies in the Muteh area are parallel to the Tertiary extensional faulting event described for the study area by TILLMAN et al. (1981). Therefore, we correlate the timing of the gold mineralization event with the later Tertiary extensional tectonic event. However, such a Tertiary age based on structural arguments remains to be tested by radiometric dating.

Type I and type II inclusions record, at this stage of the study, the oldest fluid migration event in the metamorphic rocks. Both types may represent immiscibility of a saline CO_2-bearing aqueous fluid. The high salinities of type I inclusions could be due to interaction of the fluids with evaporite-rich units or, less likely, fluid evolution during retrograde metamorphism. The metamorphic rocks under study underly the Infracambrian evaporitic-dolomitic formations of Hormuz and Soltanieh, and a paleogeographic reconstruction by TALBOT and ALAVI (1996, in particular Fig. 10) shows that the Hormuz formation may have extended as far east as our study area. Therefore, the high salinity of type I inclusions is likely the result of the interaction of the regional fluids with these evaporite-rich units. The CO_2-rich nature of type I and type II inclusions may reflect the interaction of the same brines with carbonate rocks that are particularly abundant in the southwestern part of the metamorphic complex (THIELE et al., 1968). Type IV inclusions are late, low temperature brines that have circulated in the metamorphic complex after, or during the latest stages of gold ore formation at Muteh.

The low salinity of the type III fluid inclusions spatially associated with the ore deposits at Muteh is in marked contrast with respect to the regional fluid inclusion compositions. This suggests that gold deposition is related to a very distinct hydrothermal event, with circulation of a dilute fluid in the regional NW-oriented faults running through the metamorphic complex. The regional type I and the gold orebody-related type III inclusions display a range in clathrate melting temperatures with constant homogenization temperatures (Fig. 2). Thus, type III inclusions could represent the trapped diluted counterpart of the regional type I fluid.

At this stage of the study, we conclude that gold deposition is related to fluid mixing between a regional saline fluid and a dilute fluid, possibly of meteoric origin, along the northwest striking normal faults. The regional Tertiary uplift and extensional event might have provided the thermal anomaly necessary to drive the circulation of superficial meteoric fluids at depth and their mixing with deep saline fluids. Such a scenario is analogous to models proposed for the formation of base- and precious-metal deposits associated with detachment faults in the western United States by SPENCER and WELTY (1986).

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