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Field and ASTER imagery data for the setting of gold mineralization in Western Allaqi–Heiani belt, Egypt: A case study from the Haimur deposit

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ABSTRACT

Although associated with carbonatized/listvenitized ophiolites and thrust structures, the morphology and internal structures of the auriferous quartz veins in the Haimur deposit suggest mineralization concurrent with NE–SW dextral brittle–ductile shear zones. The latter are attributed to intense transpression regime and are associated with (N)NE-trending tight to isoclinals folds that deform the early accretionary structures.

Image processing techniques applicable to the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) data are used for mapping structures and hydrothermal alteration associated with the Haimur deposit. The automated lineament extraction by LINE module on high resolution ASTER imagery provides efficient data for potential dilation loci. Emphasis is placed on reliability of mineral indices extracted from the ASTER band ratios for identification of possibly mineralized alteration zones associated with NE-trending shear zones.

Field and remote sensing data, together with the structural fabrics along the lode-associated shear zones clearly constrain on the genetic relationship between the Haimur gold deposit and post-accretionary transpression/shearing. We conclude that hydrothermal alteration zones that are confined to tightly enfolded ophiolites and transpressive shear zones along the Western Allaqi–Heiani belt are most potential targets for new exploration plans.

1. Introduction

Understanding the structural control on vein-type gold deposits common in most orogenic belts the world over is considered complimentary for any exploration program. Robert and Poulsen (1994) demonstrated that the distribution of gold deposits in the greenstone belts is controlled by kilometer-scale, oblique or strike parallel shear zones that may represent reactivation of crustal fractures in a collision context. These shear zones served as conduits for shallow granitoids, felsic porphyries, calc-alkaline lamprophyres and mineralizing fluids. However, the first-order shear zones are not commonly economically mineralized. The economic mineralizations are found mostly in brittle–ductile shear zones of local scale, corresponding to second- or third-order structures of metric width and few kilometers length (e.g., Groves et al., 1987; Sibson et al., 1988; Eisenlohr et al., 1989; Robert, 1990; Robert et al., 1990; Robert and Poulsen, 1994; Groves et al., 2001; Goldfarb et al., 2005; Morey et al., 2007).

Orogenic lode-gold deposits are formed typically during the late stages of the deformational–metamorphic–magmatic history of evolving orogens, synchronously with at least one main penetrative deformation stage (e.g., Oberthür et al., 1994; Kerrich and Cassidy, 1994; Goldfarb et al., 2001; Groves et al., 2003). In the Arabian–Nubian Shield, the spatial and temporal relationships between auriferous quartz veins and structures led many authors to suggest a genetic relationship between gold mineralization and major Neoproterozoic tectonics (e.g., Sabet and Bordonosov, 1984; Harraz and Ashmawy, 1994; Loizenbauer and Neumayr, 1996; Zoheir, 2008a,b, 2011). El Kazzaz (1996) and Klemm et al. (2001) suggested a temporal and spatial relationship between gold mineralization and shear zones that crosscut the ophiolitic sequences, island arc assemblages and late-orogenic granitoids.

The Wadi Allaqi extends in the extreme south of the Eastern Desert of Egypt from the Hamisana Shear Zone (HSZ) in the east to the Lake Nasser in the west. Evidence of the historical mining activity in the Wadi Allaqi district is manifested by mined quartz veins and numerous stone tools used in crushing the gold ore. The area contains more than 12 gold occurrences most of which are hosted in Precambrian metavolcanic and metasedimentary rocks or in placers

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apparently derived from these rocks (Gabra, 1986). Kusky and Ramadan (2002) assumed that gold-quartz veins in the Wadi Allaqi region are mostly confined to imbricate thrust slices of ultramafic rocks, or to shear zones truncating these rocks. El-Shimi (1996) emphasized the association of gold-bearing quartz veins and granitoids intruding the metamorphosed ophiolitic-island arc rocks within the Allaqi–Heiani belt. The auriferous shear zones in the area truncate large synclines commonly associated with huge ophiolitic blocks and highly sheared metavolcanic rocks (e.g., Sadek, 1995; El-Shimi, 1996; Ahmed et al., 2001). In the central Wadi Allaqi region, Ramadan et al. (2005) suggested that the auriferous alteration shear zones developed coeval with tight overturned NW-anticlines. Zoheir (2008b) suggested that formation of Au-quartz veins in Betam deposit was syn-kinematic with the development of D3-related brittle–ductile shear zones. D3 is characterized by abundant kilometer-scale, transpressive NW- and NNW-oriented strike slip faults, post-dating the peak metamorphism in the region.

The Haimur mine area represents an old gold mining center some 200 km south of Aswan. Mining activities were sporadic since the Pharaonic era until the 20th century, but most Au-deposits have been completely abandoned in 1954 (e.g., Kochine and Basyuni, 1968; Gabra, 1986). The mined ore bodies were mainly sulfide-bearing quartz and quartz-carbonate veins associated with listvenite exposures, where pervasive cleavage and meso- to micro-folds are developed.

Unlike most gold-bearing quartz veins within the Allaqi–Heiani belt that are related to discrete NW- or NNW-trending shear zones (Kusky and Ramadan, 2002; Abdelsalam et al., 2003; Zoheir, 2008a,b), the mineralized quartz veins in Haimur deposit are confined to NE-trending shear zones. This observation would roughly suggest gold mineralization related to a different deformation phase in the evolution of the Western Allaqi–Heiani belt. In this study, field and ASTER imagery data are integrated to decipher the controls of the Haimur gold deposit relative to the evolution of the Allaqi–Heiani belt. The results of this work should aid more practicable exploration plans in this region and its surroundings.

2. Materials and methods

Field work for comprehensive lithological and structural mapping is attempted to reveal the regional and mine-scale setting of the Haimur gold deposit. Ore and host rock samples and structural data were collected from the mine area and surroundings. Geometry of the mineralized quartz veins is based on analysis of fault slip data, i.e., striated surfaces (slickensides).

In this study subsets of the high-resolution, cloud-free level 1B ASTER VNIR & SWIR data (Granules ID: ASTL_1B 00303222007083127 and 00303222007083118, acquired on March 22nd, 2007), have been processed using the ENVI 4.5 (ENVI® image processing and analysis software, from ITT Visual Information Solutions).

This study includes the use of principal component analysis (PCA), Fast Fourier Transform (FFT), redundant wavelet transform (RWT) and automated lineaments extraction techniques to facilitate tracing the structural patterns and investigate the relationship between structural setting and gold mineralization in Haimur gold mine. Furthermore, the mineralized alteration zones are identified using the PCA of mineralogical indices extracted from the ASTER band ratios. The USGS spectral library (http://www.speclab.cr.usgs.gov) of rock forming minerals was used to evaluate the ASTER image spectral signatures, considering the already identified mineral composition of the different lithological units in the study area.

3. Geologic setting

The Allaqi–Heiani belt is the western part of the main Allaqi–Heiani–Gerf–Onib–Sol Hamed–Yanbu deformation zone (Abdelsalam and Stern, 1996). The latter represents an important Neoproterozoic, arc–arc suture in the Arabian–Nubian Shield (e.g., Abdelsalam et al., 2003). This suture is expressed in a ~30 km wide zone of highly deformed ophiolites, shelf metasediments, arc metavolcanic/volcaniclastic rocks and granitoids. It separates the ~750 Ma Gerf terrane from the 830–720 Ma Gabgaba terrane in the South Eastern Desert of Egypt (Fig. 1a; e.g., Stern et al., 1989; Abdelsalam and Stern, 1996; Abdelsalam et al., 2003).

Hassaan and El-Sawy (2009) mapped 16 localities of gold-bearing quartz-veins and associated alteration zones within the ophiolite nappes, island arc rocks and related rocks in the Allaqi–Heiani, Onib Sol Hamed belts. They suggested that these veins are controlled by foliation and shear planes that are overprinted by regional D2 and D3 thrust structures. Several gold-bearing quartz veins along the Allaqi–Heiani belt are confined to discrete brittle–ductile shear zones formed related to a late transpressive shearing event (e.g., El-Shimi, 1996; El Kazzaz, 1996; Kusky and Ramadan, 2002; Zoheir, 2008a,b).

The Haimur gold deposit occurs in the Western Allaqi–Heiani belt, confined to tightly-folded, variably carbonatized ophiolites embedded in calcareous and locally carbonaceous metasedimentary rocks (Fig. 1b). Field observations and detailed geological mapping indicate the presence of abundant chert, marble and magnesite bands associated with variably silicified and carbonatized serpentinite, metagabbro, and metabasalt in the mine area. Talc and graphite lamina are abundant next to the marble bands. The ophiolites, chert and marble occur either as large blocks or as small fragments embedded in metasiltstone, metagraywacke and quartz-feldspathic schist. The island arc metavolcanic rocks comprise highly sheared metaandesite, metadacite and pyroclastics, generally metamorphosed under greenschist facies conditions (e.g., El Nisr, 1997). Higher-grade metamorphism and microstructures have been reported in the gneissic and schistose metasedimentary rocks farther north of the mine area (e.g., Abd El-Naby and Frisch, 2002).

Gold-bearing quartz and quartz-carbonate veins are associated with highly tectonized, carbonatized serpentinite and listvenite, along NE-trending, anastomosing shear zones that strike N55°E and dip 50–80° to NW along thrust planes (e.g., Darwish, 2004; Emam, 2005; Emam and Zoheir, 2013). Discontinuous quartz lenses (locally 1 m-thick) can be traced for more than 25 m along strike. The mineralization zone comprises two main quartz veins and pervasively silicified and carbonatized host rocks collectively forming a ca. 20 m-wide zone.

4. Structural framework

4.1. The Western Allaqi–Heiani belt

The Western Allaqi–Heiani belt has evolved through multiphase deformation history, in which an early N–S to NNE–SSW regional shortening led to development of SSW-verging folds and NNE dipping thrusts (Abdelsalam et al., 2003). This phase is interpreted as a major terrane accretion by basin closure above a N-dipping subduction zone. Structures related to the early deformation phase were developed due to top-to-the-south nappe stacking as regional frontal and lateral ramps (e.g., Abdelsalam et al., 2003; Ren and Abdelsalam, 2006). Strain appears to have changed from an overall N–S shortening, related to emplacement of the ophiolitic nappes, to a more E–W directed compressional regime. Accordingly, the verging folds-and-thrust belt was deformed by N- and NE-trending tight and isoclinal folds, and major (N)NW-trending wrench faults/shear zones, mostly associated with measurable offsets (e.g., Abdelsalam and Stern, 1996; Abdelsalam et al., 2003). NE-fold axes, intersection lineations, and shear zones are best developed in the western part close to Lake Nasser (e.g., Abdelsalam et al., 2003).