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Transpressional imbricate thrust zones controlling gold mineralization in the Central Eastern Desert of Egypt

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ABSTRACT

Strongly deformed volcaniclastic metasediments and ophiolitic slices hosting the Sukari gold mineralization display evidence of a complex structural evolution involving three main ductile deformational events (D_1–D_3). D_1 produced ENE-trending folds associated with NNW-propagating thrust slices and intrusion of the Sukari granite (689 ± 3 Ma). D_2 formed a moderately to steeply dipping, NNW-trending S_2 foliation curved to NE and developed arcuate structure constituting the Kurdeman shear zone (≤595 Ma) and East Sukari imbricate thrust belt. Major NE-trending F_2 folds, NW-dipping high-angle thrusts, shallow and steeply plunging mineral lineation and shear indicators recorded both subhorizontal and subvertical transport direction during D_2. D_3 (560–540 Ma) formed NNE-trending S_3 crenulation cleavage, tight F_3 folds, Sukari Thrust and West Sukari imbricate thrust. The system of NW-trending sinistral Kurdeman shear zone (lateral ramps and tear faults) and imbricate thrusts (frontal ramps) forming the actuate structure developed during SE-directed thrusting, whereas the prevailing pattern of NNE-trending dextral Sukari shear zone and imbricate thrusts forming Sukari thrust duplex developed during NE-directed tectonic shearing. Sukari granite intruded in different pluses between 689 and 540 Ma and associated with at least four phases of quartz veins with different geometry and orientation. Structural analysis of the shear fabrics indicates that the geometry of the mineralized quartz veins and alteration patterns are controlled by the regional NNW- and NE-trending conjugate zones of transpression. Gold-bearing quartz veins are located within NNW-oriented sinistral shear zones in Kurdeman gold mine area, within steeply dipping NW- and SE dipping thrusts and NE- and NS-oriented dextral and sinistral shear zones around Sukari mine area, and along E-dipping backthrusts and NW-SE and N-S fractures in Sukari granite. The high grade of gold mineralization in Sukari is mainly controlled by SE-dipping back-thrusts branched from the major NW-dipping Sukari Thrust. The gold mineralization in Sukari gold mine and neighboring areas in the Central Eastern Desert of Egypt is mainly controlled by the conjugate shear zones of the Najd Fault System and related to E-W directed shortening associated with oblique convergence between East and West Gondwana.

1. Introduction

The Eastern Desert of Egypt represents the northwestern continuation of the Arabian Nubian Shield (ANS), which lies within the suture between East and West Gondwana (Fig. 1) at the northern end of the Neoproterozoic East African Orogen (EAO). The ANS formed during Cryogenian–Ediacaran time (790–560 Ma) and was generated in association with the breakup of Rodinia ~800–900 Ma and closure of the Mozambique Ocean (Stern et al., 2004) due to collision between East and West Gondwanaland at ~600 Ma.

The Eastern Desert of Egypt represents the northwestern continuation of the ANS which developed as crust of Middle Cryogenian–Ediacaran age (790–560 Ma) between northeast Africa and west Arabia (Fig. 1). This crust is the northern extension of the EAO and was generated in association with the ~800–900 Ma breakup of Rodinia and closing of the Mozambique Ocean (Stern et al., 2004) due to collision between East and West Gondwanaland at ~600 Ma (Meert, 2003; Fritz et al., 2013). The EAO is an extensive Neoproterozoic accretionary orogen and collisional zone within Gondwana (Stern, 1994; Johnson et al., 2011). The late Proterozoic Arabian–Nubian Shield (ANS) forms the suture between East and West Gondwana at the northern end of the East African Orogen.

The tectonic evolution of the Arabian–Nubian Shield encompasses three stages spread over 600 Ma: accumulation of arc terrains within the Hijaz Magmatic Arc, followed by accretion of the Hijaz Magmatic Arc against the Nile Craton (Fig. 1), and post-accretion reworking of the accreted arc (Camp, 1984; Abdelsalam and Stern, 1996; Fritz et al., 1996; Augland et al., 2012).

The Central Eastern Desert (CED) is occupied by two main tectonostratigraphic units: (1) the structural unit (gneisses, migmatites, schists and amphibolites) and (2) Pan-African nappes including

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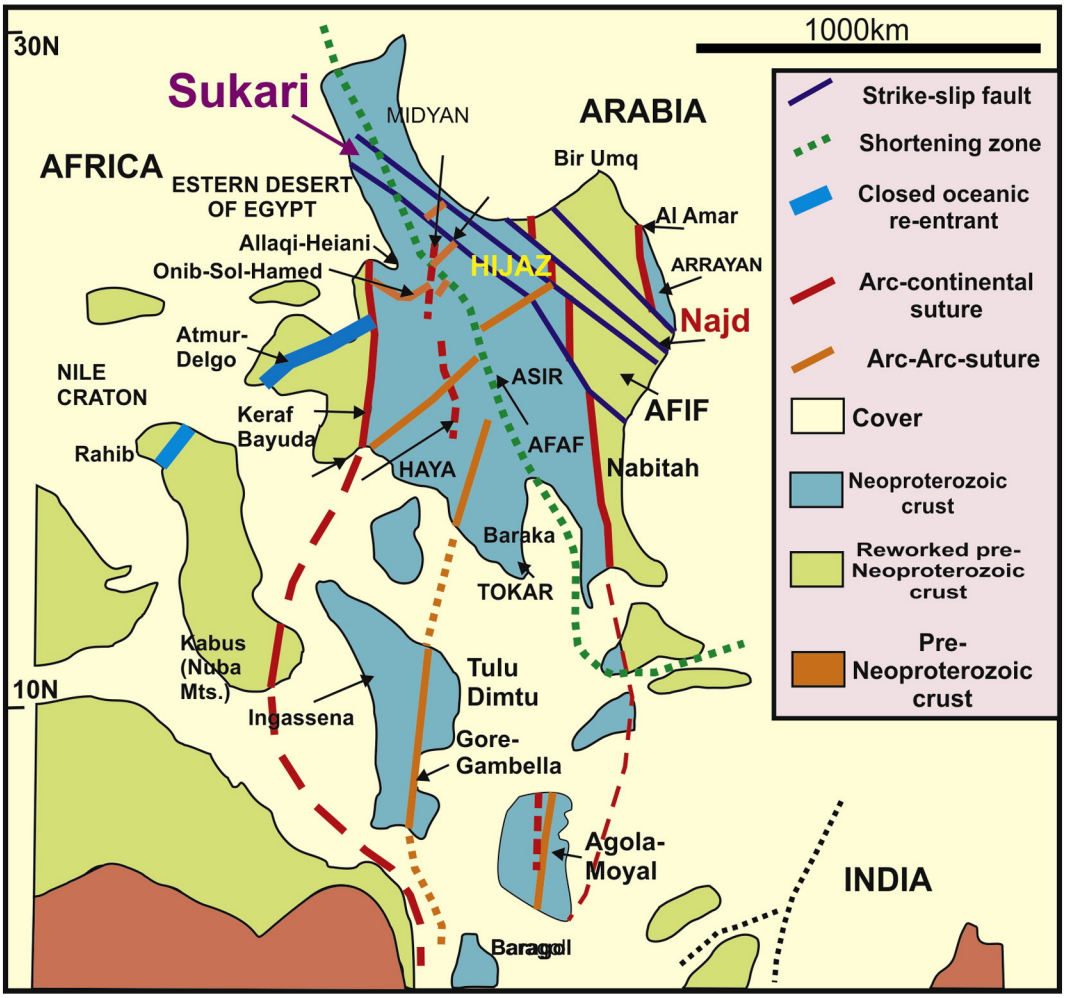

Fig. 1. Tectonic map of the Arabian–Nubian Shield (ANS) showing the location of Sukari relative to the Hijaz Magmatic Arc and the Nile Craton (after Abdelsalam and Stern, 1996).

low grade metamorphosed ophiolite slices (serpentinites, pillow lavas and metagabbros), arc metavolcanics, and arc metasediments. These two units were intruded by syn-tectonic calc-alkaline granites and metagabbro–diorite complex (606–614 Ma) and then by late to post-tectonic granites at ~590–550 Ma (Rice et al., 1993; Andresen et al., 2010).

The ultramafic rocks associated with ANS ophiolites are largely converted to serpentinite or to mixtures of serpentine, talc, tremolite, magnesite, chlorite, magnetite, and carbonate (talc-carbonate schists or listwaenite) (Stern et al., 2004; Abu-Alam and Hamdy, 2014). There is a direct relationship between carbonatization of ultramafic rocks, subsequent granite intrusions, and gold and talc mineralization. Carbonatization has resulted in gold concentrations up to a thousand times that of the original ultramafic rocks (Buisson and Leblanc, 1987; Azer, 2013).

The CED of Egypt is marked by prevalence of a NW-trending structural fabrics (Fig. 2) and the presence of structural windows (e.g. Hafafit, Sibai and Meatiq core complexes) that developed during sinistral movement along the NW-SE trending shear zone within the Najd Fault System (NFS) (Fritz et al., 1996; Abd El-Wahed, 2008, 2010). The NFS is a complex set of left-lateral strike-slip faults and ductile shear zones that strike NW-SE across the ANS (Stern, 1985). The central part of the CED is further characterized by prominent NE-, ENE- and E-W-trending tectonic fabrics developed along NE-trending, dextral strike-slip shear zones (Shalaby et al., 2005; Abd El-Wahed and Kamh, 2010; Abd El-Wahed, 2014; Abdeen et al., 2014).

The NW-trending sinistral strike-slip shear zones define the northeast and southwest borders of the core complexes (e.g. Hafafit, Sibai and Meatiq, see Fig. 2), such as the Nugrus shear zone to the east of Hafafit metamorphic core complex and to the west of the map area. This shear zone was previously interpreted as a thrust (Fig. 2) (Nugrus Thrust, Greiling et al., 1988) separating the Hafafit metamorphic core complex (footwall) and the Pan-African nappes of the Wadi Ghadir mélange. It was later interpreted as a left-lateral ductile shear zone dominated by strike-slip duplexes and linked with imbricate ramps and thrusts (Nugrus Fault, Fritz et al., 1996; Unzog and Kurz, 2000; Helmy et al., 2004; Shalaby et al., 2005). Subsequently, Fowler and Osman (2009) considered Nugrus shear zone as a post-arc collision low-angle normal ductile shear zone formed during the Neoproterozoic extensional tectonic phase. Lundmark et al. (2012) assigned an age of ≤595 Ma for left-lateral shearing of the Nugrus Shear Zone. The NW-trending thrusts east of the Hafafit core complex (Wadi Ghadir mélange) are deflected into NE-SW trends around the Sukari gold mine and thus define an example of a flower structure related to sinistral transpression along the Nugrus shear zone (Fritz et al., 1996; Shalaby et al., 2005). Some authors had previously mapped these NE-trending thrusts as SE-dipping (e.g. Fritz et al., 1996, 2002), it is clearly demonstrable that they dip towards the NW (Akaad et al., 1993; Abd El-Wahed and Kamh, 2010; Abd El-Wahed, 2014).

The Sukari gold mine is the first large-scale modern gold mine in Egypt. It is located in the Central Eastern Desert of Egypt, about 30 km southwest of the Red Sea coastal town of Marsa Alam and to the northeast of Hafafit core complex (Fig. 2). It lies within an arcuate structure which is trending NW-SE in the south and NE-SW in the north. Detailed mapping, geochemical exploration and drilling were carried out in the Sukari gold mine area by Centamin Egypt Ltd.