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The role of the granite emplacement and structural setting on the genesis of gold mineralization in Egypt

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ABSTRACT

The Eastern Desert of Egypt is well known as a gold-mining district since ancient times. Gold mineralization is closely associated with the granitic rocks in such way that the mineralization is either hosted by or occurs immediately adjacent to the granite intrusions. Granitic rocks accompanying gold mineralization in the Eastern Desert can be grouped into three categories i.e. syn-late tectonic calc-alkaline granites, calc-alkaline to mildly alkaline granites of the transitional stage and post-tectonic alkaline granites.

Tectonically, gold mineralization is linked with the tectonothermal stages that were operative during the evolution of the Arabian–Nubian Shield (ANS). During the primitive stages of the island-arc formation, pre-orogenic gold mineralization (auriferous exhalites) was formed by hot brines accompanying submarine volcanic activity. No role for the granite is observed in this stage. Syn-orogenic gold mineralization (i.e. gold hosted in altered ophiolitic serpentinites along thrust faults and in sutures, quartz veins hosted in the metavolcano-sedimentary assemblage and/or the I-type granitic rocks surrounding them) connected with the collision and accretion stage is characterized by emplacement of calc-alkaline (I-type) older granite batholiths. Shear fractures reflected in brittle–ductile shear zones and amphibolite-green schist facies regional metamorphism were broadly contemporaneous with this intense compressional tectonic regime. Available fluid inclusion microthermometry and isotopic studies reveal that both metamorphic and magmatic fluids related to the syn-late tectonic calc-alkaline granites were operative. A further indication for the role of the granites is indicated by the presence of some concentrations of Antimony, Bismuth, Molybdenum, Tungsten, Rubidium, Beryllium, Tin, Yttrium, Ytterbium, Tantalum and Niobium in some auriferous quartz veins in the Egyptian gold mines.

In the cratonal development of the (ANS), the land underwent a transitional stage between the major subduction-related calc-alkaline magmatic activity and the subsequent post-tectonic plutonism represented by the alkaline granites. This transitional stage is dominated by the eruption of Dokhan volcanics and deposition of molass-type Hammamat sediments. At ~590–530 Ma, the Arabian–Nubian Shield was deformed by post-accretionary structures, in the form of N-trending shortening zones such as the Hamisana shear zone and NW-trending strike-slip faults such as the Najd fault system. The regional NNW–SSE directed extension opened spaces that were progressively sealed with different magmatic phases including among them a considerable proportion of rocks referred to as "younger granites" in the Egyptian literature. Late-orogenic gold mineralization connected with the transitional stage is represented principally by the gold-bearing quartz veins traversing Hammamat molasse sediments, quartz veins traversing syn-extensional younger granites and generally quartz veins in ductile to brittle shears related to the Najd fault system and within Hamisana shear zone and its splays.

By the end of Pan African orogeny until the Tertiary, the basement was intermittently intruded by a number of sub-alkaline to per alkaline granite bodies that host Mo, Sn, W, Nb–Ta and U mineralization in the Eastern Desert of Egypt. Anorogenic gold mineralization connected with post-orogenic granites is represented by small amounts of the element in disseminations, stockworks and quartz veins of Sn–W–Ta–U mineralization.

The present review shows that gold mineralization in Egypt is an expression of two major cycles with distinct magmatic and tectonic characteristics, and the two cycles were separated by a transitional stage. The emplacement of granites in the compressional cycle played an important role in metamorphosing the country rocks by producing the heat energy required for the regional metamorphism and the providing of the magmatic fluids. The H_2O–CO_2 fluids enriched in volatiles were released at the greenschist–amphibolite facies transition at 450°–500 °C and mixed with the I-type calc-alkaline granite related fluids and both moved down a temperature gradient away from the amphibolite-green schist transition at depth to a lower temperature regime in the upper levels where it is deposited in brittle–ductile shear zones. With the extensional cycle, the syn-extensional granite intrusions acted as heat engine in such way that the heat of the granite drove the convective cells to circulate through the auriferous host-granite contacts, leaching gold and other elements and depositing it in structurally

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favorable sites. In addition, the contrasts in competency between the granites with brittle deformational characteristics and the surrounding country rocks with a ductile response to stress, led to a generation of extensive fracture pattern within the more competent unit.

1. Introduction

Ancient Egypt has a long, deep and consistent relationship with gold. The latter was one of the earliest metals to be discovered, and the country became one of the first of many civilizations to boast a wealth of this valuable material. Naqada is a town on the west bank of the Nile in the Egyptian governorate of Qina and it was known in Ancient Egypt as “Nubt” and in classical antiquity as “Ombos”. Its name derives from ancient Egyptian “nub”, meaning gold. The earliest geological map, known as the Turin Papyrus, reveals the bekhen stone quarries and the gold mines in the Wadi Hammamat near Naqada. This map was drawn during the reign of Ramses IV (Harrell and Brown, 1992).

Ancient Egyptians were clever in prospecting and extracting metal ores from open pits and underground mines in spite of the primitive technology available to them. The historical mining was focused entirely on the near-surface high grade quartz veins and the associated alluvial gold. Although, it was mined since the Dynastic times, no data are available as to the total tonnage of ore mined out or the gold that was extracted from it. Total gold production of ancient Egypt was 18 tons (Klemm et al., 2001). Recently, during the 19th century (1902–1958), the total extracted gold amounts to about 7 tons, as reported by Kochin and Bassyuni (1968). In the last few years, the Egyptian government has issued some companies the rights to exploit gold from the Egyptian mines.

Granite rocks constitute about 40% of the area covered by the Proterozoic shield rocks in Egypt (Hussein et al., 1982) and gold mineralization in the Eastern Desert of Egypt is closely associated with these granitic rocks in such way that the mineralization is either hosted by or occurs immediately adjacent to the granite intrusions. Understanding the timing of gold mineralization with respect to the different epochs of the granitic emplacement in the Nubian Shield of Egypt could lead to improved exploration criteria. Island-arc, orogenic and post-orogenic stages were indicated for the tectonic-magmatic evolution of the Nubian Shield in Late Proterozoic times, and the different styles of gold mineralization recognized in the Eastern Desert were inferred to have developed during these stages (Botros, 2002). During the evolution of the Nubian shield, the Neoproterozoic terrane has experienced accretional structures in the early stages of the Pan-African orogeny; whereas these structures have been obliterated by post-accretionary structures (N-trending Hamisana shear zone and NW-trending strike-slip Najd fault system) during the late orogenic-extensional stage of the cratonal development.

The present paper deals with the role of the granite emplacement and the control of the compressional-related structures and the post-accretionary structures in the genesis of gold mineralization in Egypt.

2. Overview of the evolution of the Arabian–Nubian Shield in Egypt

The Precambrian basement complex of Egypt comprises about 10% of the total area of the country. In the Eastern Desert of Egypt, these basement rocks constitute apart of the Nubian Shield that has formed a continuous part with the Arabian Shield in the Arabian Peninsula before the opening of the Red Sea.

The Arabian–Nubian Shield (ANS) in NE Africa and West Arabia evolved between ~870 and 550 Ma as one of the largest tract of juvenile continental crust of Neoproterozoic age on Earth (Sturchio et al., 1983; Stern and Hedge, 1985; Kroner et al., 1994; Bregar, 1996; Patchett and Chase, 2002; Stern, 2002; Johnson, 2014). The formation of this juvenile crust started by the island-arc stage, where oceanic arcs were generated within and around the margins of the Mozambique Ocean. Volcanic rocks of this stage in the Eastern Desert of Egypt are equivalent to Younger Metavolcanics (YMV) of Stern (1981) and Shadli metavolcanics of El Ramly (1972). Ophiolites were formed in back-arc basins during this stage (Stern, 1981; El Gaby et al., 1984; Akaad et al., 1996).

The various arc terranes formed during the previous stage collided with each other and were subsequently accreted onto the East Sahara craton, west of the present River Nile, until c. 600 Ma ago. Early collision of these ensimatic arcs with each other (e.g. the collision of the ensimatic Gerf island arc and Gabgaba terranes) led to the welding of the various arc terranes along ophiolite-bearing suture zones (e.g. the Allaqi suture that formed between ~800 and 700 Ma). The calc-alkaline magmatic plutonic activity developed in the Eastern Desert during this stage is represented by the synorogenic “older gabbroic plutonites” and the “older granites” (Akaad, 1996). The older granites are subduction-related I-type magnetite-series granites, formed in old Benioff zones by partial fusion of the mantle wedge with little or no crustal melt contribution (Hussein et al., 1982).

At ~590–530 Ma, the Arabian–Nubian Shield was deformed by post-accretionary structures, in the form of N-trending shortening zones such as the Hamisana shear zone and NW-trending strike-slip faults such as the Najd fault system. The latter is common in the central Eastern Desert of Egypt, known as the Wadi Hodein–Wadi Kharit shear system (Stern, 1994; Greiling et al., 1994) and in Arabia as the Najd Fault System (Stoesser and Camp, 1985; Stern, 1985). These post-accretionary structures formed in response to the terminal collision between East and West Gondwana, with the Arabian–Nubian Shield being squeezed between them (Burke and Sengor, 1986; Kröner et al., 1987; Berhe, 1990; Stern, 1994; Abdelsalam, 1994; Abdelsalam et al., 2003; Kusky et al., 2003; Johnson and Woldehaimanot, 2003; Abdeen and Abdelghaffar, 2007).

Late orogenic histories are usually associated with extension where the lower crust and mantle lithosphere in these orogenic bets may have still being under compression while upper crust had experienced extension (Fritz et al., 2002). The late orogenic-extension stage in the evolution of the Nubian Shield in the Eastern Desert is a continuous process characterized by the final emplacement of Pan-African cover nappes, the final exhumation of metamorphic core complexes (e.g. Meatiq, Sibai and Hafafit), the effusion of the Dokhan volcanics, the formation of intramontane molasse-type basins, and the intrusion of syn-extensional plutons along regionally NW–SE directed extension opened space (Fritz et al., 1996). The syn-extensional plutons are dominated by “younger gabbros” and some phases of the late-to post tectonic “younger granites”. Various granites of variable ages have been emplaced during late Pan-African extension (Greenberg, 1981) and these granites softened the crust by enhanced advective heat supply (Bregar et al., 2002). The geochemical signature of the syn-tensional granites varies from calc-alkaline to late orogenic A-type magmatism (Fritz et al., 1996). The latter is lumped together in Egypt as G-3 granite (Hussein et al., 1982) that hosts Mo, Sn, W, Nb–Ta and U mineralization. It is to be noted that calc-alkaline magmatism is not necessarily related to subduction. Hopper et al. (1995) explained that calc-alkaline magmatism can result from lithospheric extension in areas with a long history of previous subduction stages.

3. Granite rocks in the Eastern Desert

In Egypt, granites cover ~40,000 km^2 of the area covered by the basement rocks and gold deposits are closely associated with these