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Geological Evolution of Sukari Gold Mines Area- Eastern Desert, Egypt

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Abstract

Many common mineralized localities in the Eastern Desert of Egypt (E.D.E) are now announced as mineralized occurrences or as ore deposits for various ore minerals.The Sukari gold mines area is now worldwide famous explored and exploited site for gold as major product .In addition, other economic minerals such as; Ag, Cu, Pb, Sn, Mo, and others are important minerals association to be considered. Different basement rocks hosting mineralization in Sukari gold mines area were studied ,such as; metavolcanics and related volcanoclastics, metasediments, granite porphyry, mafic and ultramafic rocks they have been exposed showing rugged topography characterizing the study area where those within the granites are the most important. These rocks have been subjected to a number of tectonic and structural events, Also stockwork quartz veins and veinlets and quartz ridges cutting across the basement rocks. Besides, alteration processes are commonly observed in the Basement rocks of the study area.The Sukari gold mines area is now considered as one of the most important gold productive mines on the world scale. This study provides an update geological, structural and petrographical tries to assist in understanding the mode(s) of formation of the mineral potentiality of the Sukari gold mines study area and surroundings. Based on the field works and lab data results, it is recommended that in the Sukari gold mines area, the gold amounts increase with depth and westward.

INTRODUCTION

Generally, gold occurrences and mineralized sites of Egypt are mostly occur within the basement complex of the Eastern Desert, relatively concentrated in the region between south of the Qena-Qusseir road (North) to the Sudan border (South). In most of these occurrences and sites, gold occurs in the form of structurally controlled hydrothermal quartz veins and veinlets surrounded by wall rock alteration envelopes hosted in igneous and metamorphic rocks of the Nubian Shield. The gold mineralization with sulfides occur hosted in rocks of variable composition ranging from acidic to mafic or even ultramafic rock varieties .Schist – mudstone-greywacke series in addition to quartz veins and veinlets are main targets of gold mineralization.

On bases of tectonic settings and structural patterns, the areal distribution of gold mineralization and occurrences in the Eastern Desert were divided into five major groups (Moharram *et al*. 1970). In the central zone of the third group, The Sukari gold mines

area lies delineated by latitudes 25^{0} 00' 20'' and 24º 51' 45"N and longitudes 34º 40' 40" and 34^{0} 46' 30" E (Fig. 1,3).

covering an area of 160 km^2 about 23 km east of Wadi Umm Khariga and 30 km to the southwest of the Red Sea coastal town of Marsa Alam. It is located in the southern part of the Central Eastern Desert of Egypt (CEDE) just to the north of the major low-angle thrust that marks the boundary between the Central

Eastern Desert (CED) and the South Eastern Desert SED (Fig.1). It is bounded to the north, south, and west with very important mineralized sites; Igla, Abu Dabbab, Umm Kabou, Abu Rashiad, Zabara, and kurduman, and Hangaliya, Atud, and Barramiya respectively (Fig. 2).

The Sukari area has a significant mining history undertaken through all stages of history, from Pre-dynastic (Ca 3,200 BC) through Ptolemaic, Roman, Arab and British Colonial to the present day. The ancient gold mining activities were confined to the gold-bearing quartz veins without any attention to the associated alteration zones. On the other hand, most of the gold mineralized sites that have been explored and exploited within the Egyptian deserts were defined and classified as vein type deposits, epigenetically formed. Disseminated ore types and modes of formation are rare or even absent publications.

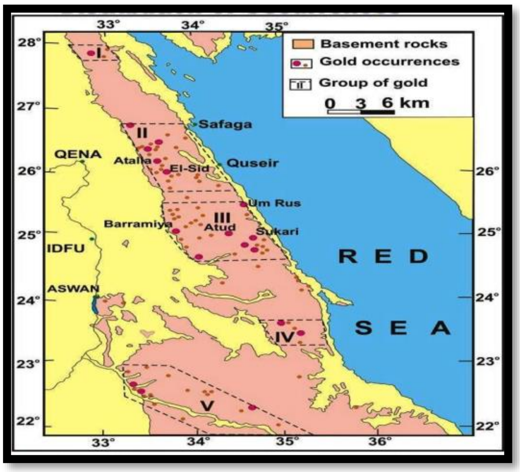


Figure 1 Shows the Precambrian rock of the E.D.E and Sinai as well as the distribution of gold in gold deposits and occurrences within the tectonic groups (after El-Ramly and others 1970).

GEOLOGIC FRAMEWORK

The geology of Sukari area is composed of basement rocks. The rock sequence comprises part of the neoproterozoic (900-650ma) Arabian-Nubian Shield (ANS). It is one of a number of areas of African Continental Crust that accreted during the Pan-African Orogeny. At a district scale, the host sequence at Sukari, comprises a NNE striking mélange of predominantly calc-alkaline igneous rocks and metasediments representing an accreted island arc (IA) or arcs (Akaad, et al, 1993).

Generally, the study area is possibly a part of the extensive ophiolite mélange of the region which overlies tectonically the Migif-Hafafit gneisses domain that exposed few kilometers to the southwest. The study area is dominated essentially by a variety of low grade regionally metamorphosed volcanic and volcanoclastic rocks spreading along Wadi Um Khariga and Wadi Sukari to the west of the study area. All are intruded by older and younger granitoid masses which are parts of larger plutons extending beyond the study area and the surrounding areas (Hangaliya, Nugrus, Igla and Ghadir). A few dykes of variable length, thickness, composition, and age intersecting the rocks of the study area are distinguishable. Quartz veins and veinlets (stockwork) and quartz ridges are commonly easily recognizable.

Many works were carried out describing the rocks of the E. D. E including the Sukari area, trying to find out a reasonable mode$_{(s)}$ of formation for the gold and the sulfide mineralization of the region. Helmy et al.(2004), stated that the dismembered ophiolitic succession is represented by serpentinites at the base, followed upward by a metagabbro-diorite complex and sheeted dykes. The serpentinites and related talc-tremolite-carbonate rocks are exposed in the western and south eastern parts of the study area. They form of lenses and dyke-like bodies enclosed in the metavolcanics exhibiting shearing and deformation at the contacts denoting a tectonic nature. Serpentinites occur at the northwestern parts along the major N-S thrust fault forming elongate thrust slabs trending E-W or NW-SE(Fig. 4).They in concordant with the regional structure of the surrounding schist or foliated metavolcanic rocks. Due to strong alteration, serpentinites cannot be typified in the field studies at Sukari mines area. The serpentinites are brecciated and fragmented whereby the massive green fragments are surrounded by a carbonate sheath that may indicate and mark a suture zone. All the rock units of the study area, have been intruded by a granitic pluton which elongates in a NNE direction, dips to the east about 65^{o}-70^{o}.The granitic pluton covers an area of about 6km² forms Gabal El-Sukari showing sharp intrusive contacts against the surrounding country rocks, suggesting asyn-to late tectonic setting (Helmy et al. 2004).

Mostly, gold mines of the Sukari area occur within the porphyry felsic elongated outcrops (Sukari granitoid porphyry) characterized with rugged topography elevated to about 350m above the Sea Level. The Sukari hill has been divided by the Sukari Gold mines Company into four zones; Amun, Ra, Gazella, and Pharaoh (Fig.5). The Sukari granitoid porphyry mountain is drained with clear drainage patterns pass to the east and west of the outcrop. On the other hand, the main porphyry felsic rocks are surrounded with low hills of erupted volcanic and volcanoclastic rocks vary in composition and age. The granitoid rocks are older and younger calc-alkaline porphyry rocks represent most important mineralized host units in the Sukari mineralized mines area. They range in composition from tonalite into quartz diorite intruded the foliated metabasalts and the associated erupted volcanoclastic rocks showing intrusive and stratigraphic contacts. Younger phases of granitic rocks were intruded and influenced the older granitic phase causing strong alterations due to hydrothermal solutions possibly coming from the south playing the main role in enriching the mineralization potentiality of the Sukari area.

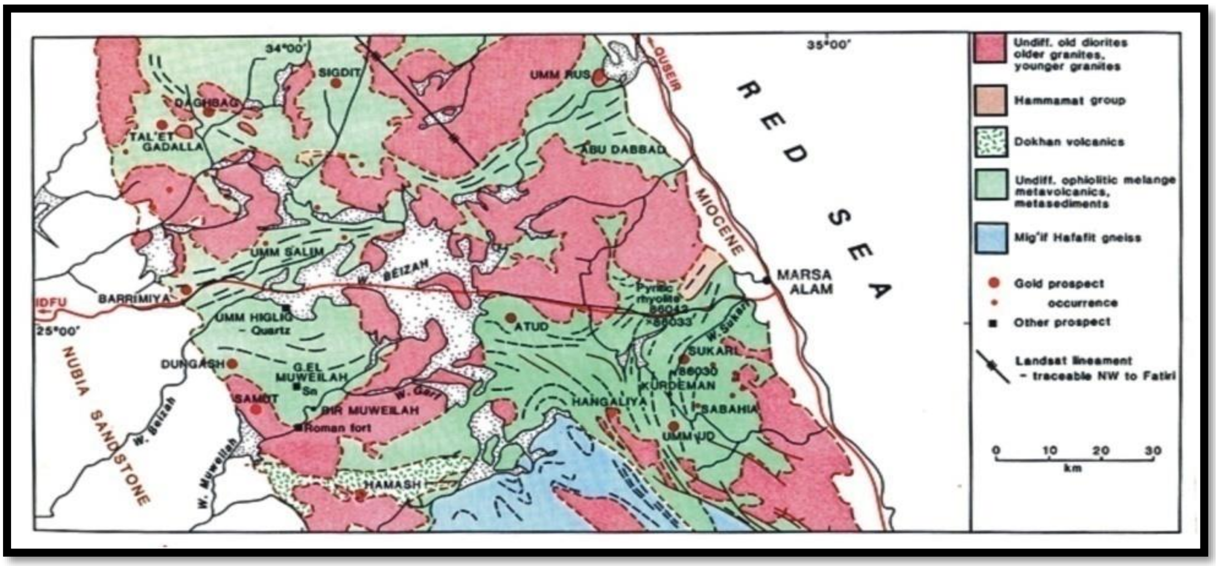


Figure 2 Location map for the Sukari study area and related gold mineralization sites, C.E.D.E. (EGPC and CONOCO, 1987).

Figure 3 Regional location of Sukari Gold Mines Area.

In some places, the foliated metabasalts seem to have been easily invaded by a large number of milky white quartz veins and lenses of varying sizes (e.g. the quartz ridge) (Fig.6).The quartz veins and veinlets at the Sukari area constitute a fissure-filling system commonly intruding the various rock types at the study area especially the granite and the metavolanics (Sharara, 1999).

On structural bases, a series of stacked brittle-extensional veins of a short length within stockwork zones host the high grad mineralization (Hellman and Schofield, 2003). The area between the Hafafit Dome and Red Sea coast, (including the El- Sukari mining region) display an arc structure with a NW trend (Helmy et al. 2004). The Sukari gold mines were formed under E-W compression event (Osman and Abdel- Khalek, 2004).The Umm Kariga area is a part of old shores of geosynclinal basin while the El-Sukari metabasalts were formed by subaerial volcanic activity involving the eruption of basaltic lava that was associated with minor pyroclastics (El-Essawy, 1967).

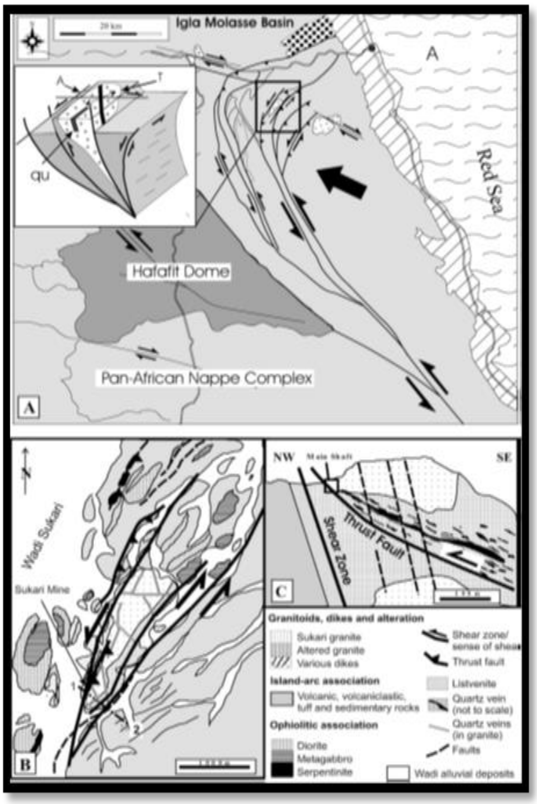


Figure 4 Gological and structural map of the Sukari gold mines, (Helmy et al. 2004).

In this study, the emplacement of mafic/ultramafic rocks coming from the south and southeast areas (Wadi Gadier and Kurdoman in particular) have been subjected to the major N-S and NW-SE thrust faults. The finally products were strong shearing and reached to change to talc carbonate graphite schist units that characterizing the main gold mineralized units occur in the study area (Fig.7). As a result of the intrusion of the granitoid rocks, relative structural features such as; deformation, curvature, bending, dislocation, and folding and associated hydrothermal solutions have been occurred. The western side of the Sukari main granitoid porphyry stock shows strong shearing and variable alteration products along the NNW-SSE thrust fault that running along Wadi Um Khariga and marking the western edge of the bulk rocks that occur at the Eastern edge of Wadi El- Sukari exposed from the south towards the north.

The structural patterns have been strongly influenced the granitoid rocks and evidenced by strong shearing, mylonitization, and slickenside. The major thrust fault was extended southward to reach the Kurdoman mineralized site (Fig.8). Faults, joints, fractures, cracks, alterations, veins, veinlets and dykes and stockwork are common recognizable features in the studied granitoid rocks and the surroundings.

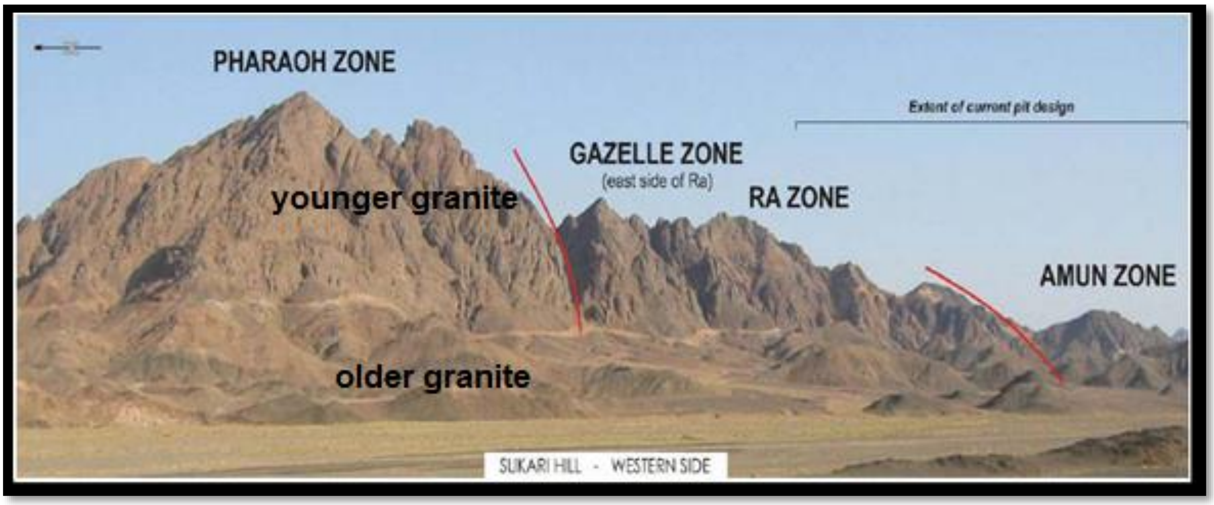


Figure 5 The topography of old sukari gold mine and View of the Sukari Hill with designated Geographical Zones (looking S-E) modified after Centamin Gold mines Company.

Figure 6 Quartz ridge areaat Sukari gold mine.

Figure 7 Strongly sheared talc carbonate graphite schist.

Figure 8 primitive Sukari Mine company's work for exploring kurdoman area.

N-S, NW-SE, NNW-SSE, and E-W fault trends are running through the granitoid porphyry rocks leaving strong evidence. In addition, joint sets with various trends, and short porphyry dykes run through the granitoid pluton. These structural patterns probably have been facilitated for the hydrothermal solutions to penetrate and influence major areas of the mineralized rocks (Fig.9), in some places along the major N-S thrust. The talc carbonate rocks are traversed by irregular hard siliceous sometimes hematized carbonate veins of varying thicknesses as well as with numerous white quartz veinlets.

A consideralble number of acidic, basic, and intermediate dykes which are the thickness, composition, and trend. These dykes show rejuvenation in some places of the Sukari study area.

Figure 9 The evidence of alteration processes at Sukari granitoid pluton (Kaolinizationand Hematization)

METHODOLOGY

Representative bedrock and soil samples have been taken from selected places at the bottom and deep walls of the open pit zone where, the strongly sheared rocks that described as "talc carbonate graphitic schist" expose. At the open pit site, shearing was measured showing N-S striking, mostly nearly vertical and dipping southeast. The rocks are soft, talcose and highly graphitized with conserved resistant andesitic fragments used in measuring the strike and dip (Fig.7). The samples were analyzed for Au and Ag and other trace elements using Ultra-Trace Lab and Genalysis Lab in Australia. Forty eight (48) thin-sections and (30) polished surface were prepared by EMRA lab. The sections were examined using the Lica Ore microscope where the petrographical study was achieved using a polarizing light and. Polished thin-sections were studied under reflected light in order to determine the mineral associations.

ALTERATION TYPES

The Sukari area rocks were subjected to hydrothermal solution events. The studied rocks show alteration products along shear zones, resulted in colors, texture and mineralogical change. Silicification, kaolinization, ferrugenation, hematization, carbonatization, sericitization, albitization, graphitization and sulphidization, are common recognizable alteration types (Fig.9). Graphitization process is commonly occurs in most gold mineralized zones in the Sukari gold mines study area. It is possibly occurred due to frictional heating of carbonaceous mineral constituents of the rocks of the study area associated with strong dynamic weakening in the rocks. The enrichment of graphitization in the rocks of the study area could be used as an indicator of transient frictional heating during seismic slip in the upper crust.

Gold and graphite are closely associated in many gold deposits around the world. In the study area, it seems that the graphite is commonly thought to have played a basic role in the gold deposition in the host rocks. Hence, graphite schist rocks that rich in graphite are potential targets for gold exploration (Figs.10&11&12).

The graphite-bearing rocks in the study area are of considerable interest, for gold exploration, and also to help in understand the processes of graphite enrichment and potentially associated gold enrichment within the mineralized surrounding areas such as; Hangaliya, Atud, Barramiya, Dungash,….etc.

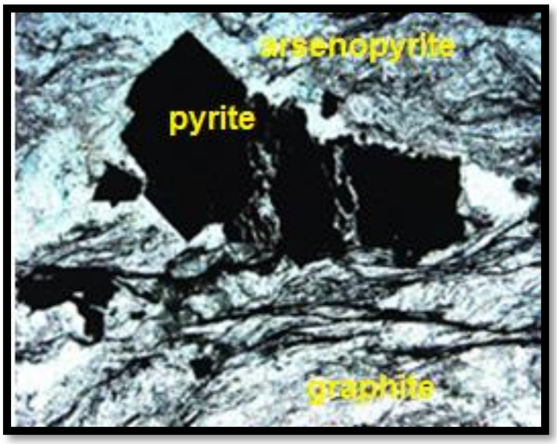


Figure 10 Microscopic view of pyrite and arsenopyrite grains in ore grade schist from Sukari gold mine. The gold occurs as micron sized grains in the pyrite and arsenopyrite. Thin black seams are rich in graphite that was introduced into the rock by hot

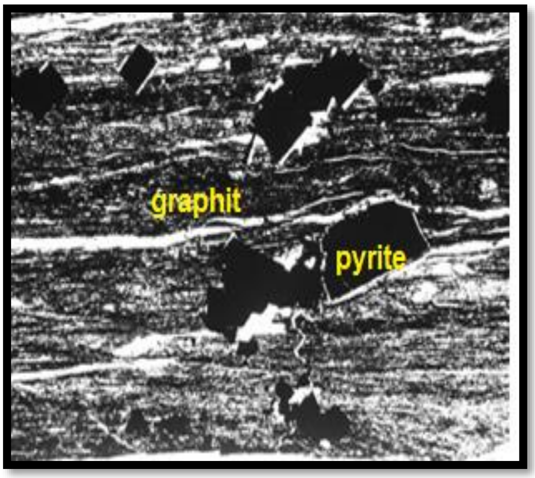


Figure 11 Microscopic view of pyrite-rich micaceous schist. Black rectangles are pyrite (FeS2), typically . Dark horizontal seams are graphite-rich muscovite foliation(X10, P.P.L).

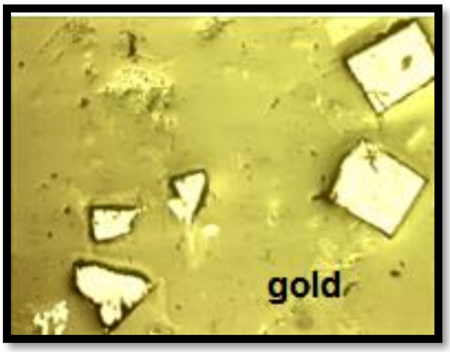


Figure 14 Microscopic view shows occurrence of gold on the margins of pyrite and chalcopyrite ×5

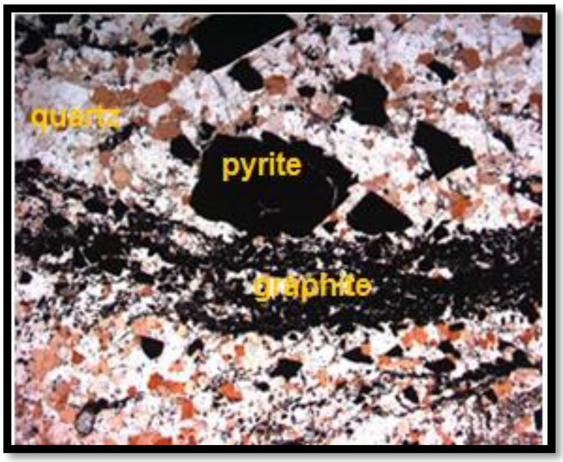


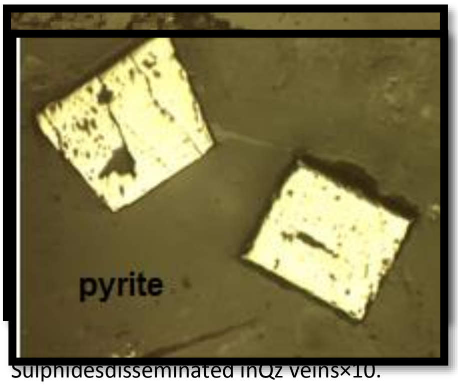
Figure 12 Microscopic view of a quartz vein (brown and white grains) in a late metamorphic shear zone. Dark horizontal seams are largely graphite aligned in the shear foliation. Large black blobs are graphite as well. This graphite was introduced via hot

MINERALIZATION

Pyrite content generally increases with depth. The estimated age of the gold mineralization at the El-Sukari gold mines area is about 530Ma using the Sm/Nd method (Harrazet al.1991).

Various episodes of hydrothermal alterations affected the El-Sukari pluton along faults and zones of intensive fracturing, producing many discontinuous alteration zones of various composition and width. These alteration zones generally trend N-E and are traversed by many conformable quartz veins and veinlets. Sharara (1999) suggested three thermal stages for gold enrichment at the El-Sukari gold mines area. At the first stage, was introduced at the temperature range between 140&370˚C. The second stage related to shear zones where, temperature ranges between 262&360˚C. The third stage characterizes with high concentration of arsenic. The gold content in the mineralized quartz vein core samples varies from 6.1 to 29.14 g/t with an average of 18.19 g/t (Khalaf and Oweiss, 1993). Sulfides occur disseminated within the quartz veins and the alteration zones where, pyrite is the most abundant sulphide mineral followed by arsenopyrite (Fig. 13).

Gold occurs either on the margins of pyrite and arsenopyrite crystals as microfracture fillings (Fig. 14).



Sulphidesdisseminated inQz veins×10.

Figure 15 Microscopic view ofeuhedraland subhedral grains of pyrite ×10.

Arsenopyrite is common in the mineralized zones of high-grade gold (Osman and Abd El-Khalek 2004).They concluded that the gold mineralization at Gabal El-Sukari occurs as structurally controlled epigenetic mineralized quartz veins genetically related to hydrothermal activities encountered average gold content of 18.19 g/t. This study shows disseminated sulfides within the quartz veins and alteration zones where pyrite is the most abundant. From detailed field and lab works, gold and sulfide mineralization seem to might be occur disseminated in both quartz veins and veinlets, in the porphyry rocks of the region and placer gold grains in wadis (many are actually electrum in which the silver content exceeds 20 wt %) may possess a wide variety of initial shapes as the grains are liberated during weathering. Because of the softness and malleability of the gold, the grains readily undergo mechanical deformation that results in rounded to flattened nuggets. Many of nomads are illegally explore and find accumulations of free gold around Sukari and Korduman.

From the results obtained, we conclude that the gold mineralizations in the Sukari gold mines area are confined to the following modes of formation owing to field investigation, petrography and geochemical data:

1. Quartz veins and veinlets.
2. Shear zones
3. The contact between acidic and basic rocks.
4. Alteration zones.
5. Graphitized schist rocks.
6. Placer deposites in wadi

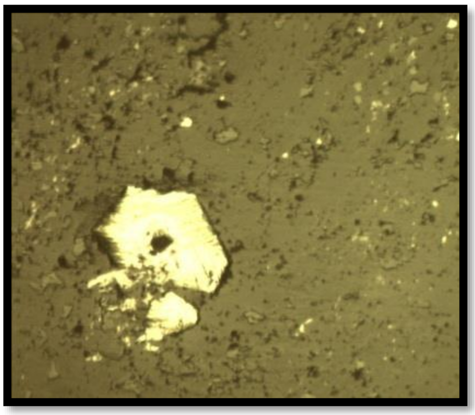
Figure 17 Microscopic view shows replacement in pyrite grain×10.

The ore microscopy studies on the selected samples involve not only to identifying ore mineral grains but also to study the ore minerals texture. The study of prepared surfaces carried out on the textures as important aspects of the study of ores and providing evidence of the nature of such processes as initial ore deposition, post deposition or metamorphism, deformation, annealing, and meteoric weathering. The recognition of textures was assisted in understanding the origin and post depositional history of gold and sulphide mineralization at the Sukari study area.

The textures of ores that formed from silicate melts (primary textures) usually show growth for the ore minerals that generally resulted in the development of euhedral to subhedral crystals, because of there is little obstruction to the growth of faces. Thus, probably primary pyrite phases those are refractory enough to retain original textures (Fig.15).

The Sukari study area and the surroundings have been subjected to a number of tectonic, structural, and alteration events. Shearing, dislocation, jointing, fracturing, displacement, folding boudins, and brecciation are commonly recognized features within the study area. Initial deposition and growth of the hosted ore and gangue minerals in many localities occur in open spaces or fractures developed by dissolution or during faulting. Although the open space may no longer be evident because of subsequent infilling or deformation. The initial formation of the crystals in open space is often still evidenced by the presence of well-developed crystal faces especially in such minerals as pyrite and chalcopyrite that rarely exhibit euhedral forms (Fig.15).

All of the studied textures might be developed on a scale ranging from macroscopic to microscopic, and they were recognized in an attempt trying to



reconstruct the entire paragenetic history of the Sukari study area ore minerals. Pyrite grains are generally formed as isolated cubes and rarely as octahedral or aggregates of interfering crystals along the walls of fractures usually associated with arsenopyrite and possibly with chalcopyrite (Fig.15)

Replacement of one ore mineral by another or by a mineral formed during weathering or even consequently by hydrothermal solutions were recognized in some of the studied polished surfaces with remains of the original ore mineral (Fig.16).

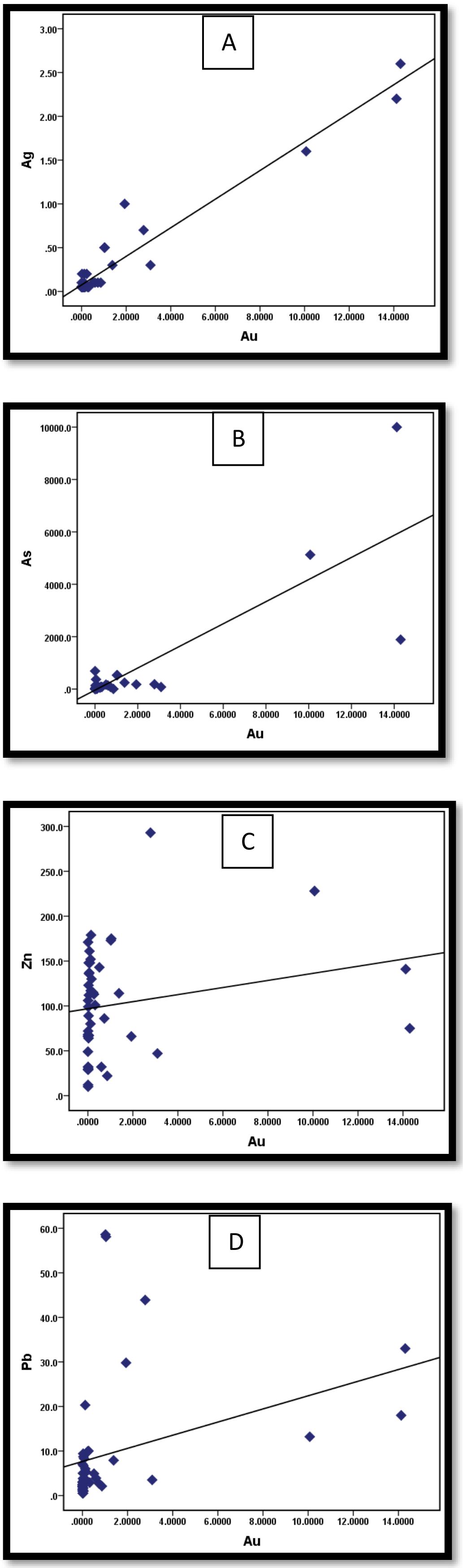
Figure 16 Microscopic view shows agrain of altered pyrite ×10.

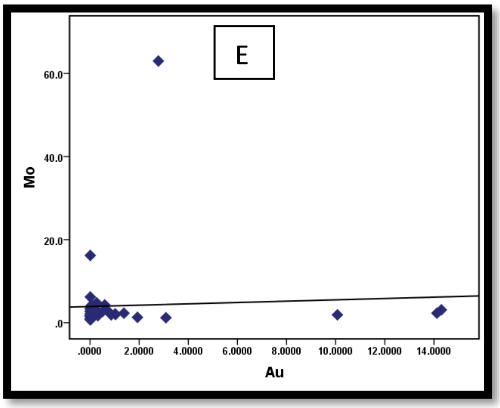
Generally, the replacement might be resulted due to actions of; dissolution and subsequent reprecipitation, oxidation, and even possible solid state diffusion. The resulting boundary between the replaced and the replacing mineral is commonly either sharp or irregular (Fig.17). Edwards (1947), Bastin (1950), and Ramdohr (1969) have described a similar wide variety of replacement geometries-rim, zonal, frontal, and so on- but they all appear to represent variations of the same process. Replacement textures depend chiefly for their development on three features of the phase being replaced:

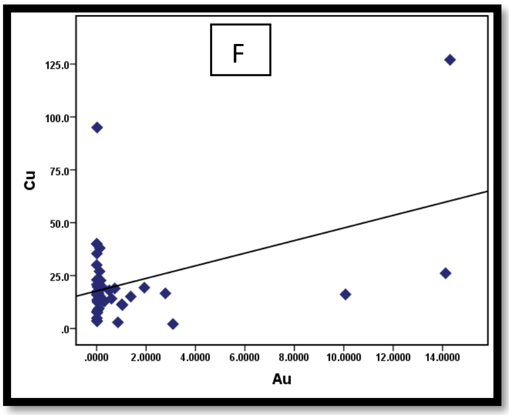
1. The surfaces available for reaction,
2. The crystal structures of the original and secondary minerals, and
3. The chemical compositions of the original mineral and the reactive fluid.

GOLD ASSOCIATIONS

The metals that associated gold at the Sukari study area and surrounding are As, Ag, Cu, Pb, Sn, Zn and Mo occasionally associated gold influenced by hydrothermal solutions at high temperatures. Hassan.et.al (1989) stated that the geochemical aureoles of Au, Cu, Mo and their morphology are controlled by the zones of tectonic disturbances and hydrothermally altered zones. These elements are possibly taken as pathfinders for gold (Fig 18).







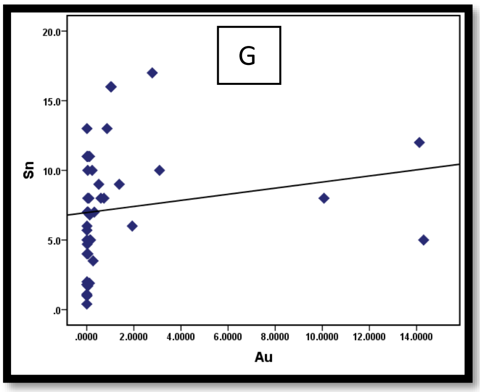


Figure 18 The diagrams A,B,C,D,E,F,G illustrate the relationship between gold and another elements

SUMMARY AND CONCLUSIONS

The geological and petrographical studies of Sukari gold mines area can be concluded as follow:

The Sukari study area and Kurdoman are surrounded by most famous mineralized sites and occurrences of economic potentialities and archeological history in the Eastern Desert of Egypt. To near southward of the Sukari gold mines study area, Ghadier, Zabara, Um Kabo, Seikate and Abu Reshaid as famous mineralized and archeological sites are located. On the other hand, Igla, Abu Dabbab, and Nuweiba mineralized sites, are located to the north, whereas, the most important relative to Sukari gold mines, Hangalia, Atud, and Barramyia old gold mines are located to the west. This study recommends major gold promising project to study the whole area from Abu Dabbab to the north to Wadi Al-Gemal area to south and to Barramya, Hamash, Atud and Hangaliya to west. This should be subjected to condensive plan to explore and evaluate the gold potentiality of the proposed area.

The gold mineralization in the Eastern Desert of Egypt occur in different rocks of variable composition ranging from acidic to mafic or even ultramafic as well as in schist (graphite schist) – mudstone-greywacke series.

The disadvantage of the plate tectonic models and classifications of gold mineralization in Egypt is that, we have contradictory on the tectonic attempts because of misuse for the huge amount of geochemical data that were used in the standard discrimination diagrams that basically used to explain the tectonic settings interpretations. For example, the term ''Pan-African'' that was introduced by Kennedy (1964) to define a widespread tectonic and thermal event which affected the African Continent during the Late Precambrian and Early Paleozoic, some 500 + 100 Ma ago. However, the term was later used by Gas (1977) to describe the whole process of cratonization of ocean arc (OA) complexes and their collision and welding to the older African craton during the time period 1200-450 Ma.

The gold mineralization in the Sukari gold mines are confined within; quartz veins and veinlets, shear zones, alteration zones,

The origin of gold mineralization and occurrences in Egypt (Eastern Desert, Western Desert, and Sinai) needs new plans of condensed geological, geochemical, and geophysical update prospecting new techniques.

The concentration of the anomalous values was related to a certain rock types (e.g the anomalous values of Au were concentrated in the quartz veins, graphite schist and altered granite).

At Sukari gold mines As, Ag, Cu, Pb, Sn, Zn and Mo occasionally associate the gold. These elements may be considered as pathfinders for gold.

The authors highlighted important point which is the increase of gold amount within deep zones of Sukari gold mines.

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