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An integrated metallotect and petrographic model for gold mineralization in the Eastern Desert of Egypt; a new prospecting vision

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ABSTRACT

Gold occurrences in the Eastern Desert of Egypt are classified as vein type deposits. The veins are almost bound to shear zones cut through pre-existing ophiolite slaps intercalated with island arc volcanics metamorphosed in greenschist - amphibolite facies and intruded by post tectonic granites. Field observations on gold bearing rocks, supported with petrographic investigations of native gold and associating sulfides make possible to construct a metallotect model for the gold mineralization in the Eastern Desert. The formation of gold depends on four main factors, these are: 1) the accretion of the pre-existing mafic and ultramafic rocks (ophiolites and volcanic arc assemblages), thrusted and metamorphosed in greenschist facies, 2) the north west Najd shear zones cut through the thrusted rock assemblages , 3) plutonism and the formation of leucogranite intruded the pre-existing rocks which provided the system with geothermal vent and acted as heat source scavenger of metals together with Au and Ag, from its original protore, 4) shearing and veining stage resulted in the formation of the epithermal quartz veins and sulfidation of the base metals together with gold formation. Ore microscopic examinations of the free mill gold and refract gold associating sulfides of the wallrock and quartz veins and veinlets revealed a remarkable relationship between gold mineralization and alteration processes of the host rocks. A lateral diffusion model is proposed to illustrate the conjunction of shearing and metamorphism considered to generate chemical potential gradients that drove ore – forming constituents from contiguous rocks into the brittle dilatants shear zones.

Introduction

Despite the diversities among the composition of the country rocks hosting gold veins in the Eastern Desert of Egypt; gold deposits show a close spatial relationship with the granodiorite – diorite complexes cut through pre-existing basic and ultrabasic rocks as well as metamorphic piles enclosing them [1] Many workers discussed the relationship between gold mineralization and tectonic setting. Garson and Shalaby [2] considered the tectonic of gold bearing quartz veins similar to Circum-Pacific porphyry. However, El Gaby et al. [3] considered that the subduction related calc-alkaline magmatic activity was responsible for the Au, Au-Cu, and Cu mineralization in the Eastern Desert. Hassan and El Mezayen [4] grouped the gold occurrences into ophiolitic, island arc, and cordilleran host. Osman [5,6] discussed the gold metallotect occurrences in the Eastern Desert with indication to the role of shearing and alteration processes. Botros [7] offered threefold classification of gold deposits in Egypt: stratabound, nonstratabound hosted in igneous and metamorphic rocks and placer gold deposits. This classification does not reflect the actual presentation of the gold deposits, since the quartz veins and veinlets cut through the all types of the preexisting rocks. The geologic conditions of the hydrothermal vein type deposit and banded iron formation are not equal. Moreover, there is no any gold occurrence in the banded iron formation since the ancient times. The source of gold has been discussed by many authors. Younger gabbro in Um Eliega was considered as the source of gold [8,9]. Analytical investigations of different rocks in the Arabian Nubian Massive (e.g. serpentinites, metavolcanics and metasediments) revealed gold concentrations of 20 – 50 ppb in the metavolcanics and metasediments and close to 200 ppb in the serpentinites [10]. The contact between granite and serpentinite in many areas (El Barramiya, Hangaliya, Um Russ, Sabahia, Atud, El Sukkary, El Fawakhir and

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El Sid) are considered as gold feeder during the wall rock alteration [11,12]. The extensional fracturing of the host rocks assisted the hot saline fluids to circulate and redeposited sulfides and gold [13]. The metamorphic pools in the Eastern Desert played an important role on the localization of gold deposits. El Sukkary gold deposit is situated in granite which intruding listvenite, talc-carbonate and acid volcanics metamorphosed in greenschist facies [14]. Zoheir [15] demonstrated a shear zone with a system of discrete fault zone which developed late in the deformation system at the Betam mine area, south Eastern Desert.

1- General Geology of the Basement Rocks in the Eastern Desert.

The Precambrian basement rocks of Egypt constitute the northern part of the so called the Arabian Nubian Shield. The Shield is formed in Neoproterozoic by a series of complex accretion tectonic acted on the pre-existing pre-Pan African basement called Nile Craton [16,17]. The first stage of the tectonic movement was the accretion of several terranes or island arcs [18], consisting mainly of complex intercalations of mafic to acid volcanic. Between these different terranes, ophiolite sequences (partly composed of mafic to ultramafic units as well as serpentinitic xenoliths from the upper mantle) occur as prominent suture zones [19]. An example of a complete ophiolite sequence can be observed in the region of El Fawakhier [3], Abu Marawat [20] and Wadi Ghadier [21]. Age dating investigations indicated that the island arc rocks and ophiolitic sequences formed between 780 and 800 Ma [22]. These rocks are overlain by calc–alkaline volcanic suit (Dokhan Volcanics) and covered in some areas by a molasse–type sediments (Hammamat Group) indicating an extentional stage and formation of intra–arc basins. Fold structures in the Hammamat Group and Dokhan volcanics indicate a late compressional phase, [19,23]. During the last stage of the evolution of the Arabian – Nubian Shield, post-orogenic granite, dated between 620 and 570 Ma has been intruded [24]. Pohl [25] confirmed that the post orogenic lithophile element mineralization associated with A-type magmatism as well as gold – quartz veins are occur mainly within greenschist terranes. A series of shear zones and fold structures within the post orogenic intrusive rocks support further activity associating plutonism.The NNW – SSE Najd fault system is considered as the main structural lineament [26]. Atalla – El Fawakhier, and Kom Ombo – Hudien shear zones are related to this system. However, Fowler and Osman [27] investigated two phases of late Pan African thrusting in the central Eastern Desert. In the southern part of the Eastern Desert and northeastern Sudan; the Hamisana – Oko and Onieb – Sol Hamid shear zones with some other submajor shears related to these major structures are investigated [28]. During the final orogenic stage, crustal extension led to the formation of within plate A-type granite [29]. According to Kroner [30] and *vide* Klemm et al. [19] the Pan African Orogeny started 750 Ma and ended 640 Ma ago. It means that the Pan African orogeny duration time is about 110 million years.

The classification of the Precambrian rocks in the Eastern Desert of Egypt which explain the strato-tectonic events is of El Ramly and Akkad [31], Akkad and Nowier [32] and Ries et al. [33]. Recently, Koralay et al. [34] studied the Menderas massif and calculated the age dating of Pan African rocks (**Table 1, Fig 2**). A close similar age dating data were obtained from the similar Precambrian rock units in the Eastern Desert of Egypt (**Table 1**).

2. The Pan African orogeny and Arabian Nubian Shield.

The Pan African orogeny is a convergent plate tectonic movement [30,35]. It includes two sub stages; the earlier stage is suggested to be the accretion of the ophiolites and island arc rocks [17], whereas the later stage comprises the post accretion thrusting [27], plutonism and the formation of the subaerial volcanics. Consequent metamorphism and shearing played a considerable role in the processes of gold mineralization [36]. Gold occurrences in the Eastern Desert (ED) are situated in specific areas emphasizing the contact relationship between the preexisting ophiolites and metavolcanics from one hand and post to late tectonic granites in the other hand (**Fig.1**).

2.1. Early orogenic stage

The rocks of this stage are developed due to the thermal event toke place in the Late- Proterozoic age [28]. The action of this stage resulting in two main rock units; the ophiolites and the volcanic arcs assemblage which constitute the mélanged greenschist belts in the Eastern Desert.

2.1.1. Ophiolite assemblage:

Ophiolites occur as allochtonous masses in different structural levels showing successive thrust sheets. Three levels are recognized, 1) ophiolite of the lower Atalla thrust sheet cropping out at W. Atalla and El Sid overlying the Um Baanib gneiss. 2) ophiolite of the lower and tectonic mélange zones at Hafafit, and 3) ophiolite sheets occur as tectonically mixed dismembered fragments of various disseminations in the ophiolitic mélange [37].

From mineralogical point of view; peridotite constitutes the lower part, it occurs as previously serpentinised harzburgite and dunite enclosing some chromite pods. The serpentinites are commonly foliated and frequently transformed into talc-carbonates along shear faults (El Barramia). Listvenitized wall rock was enriched with gold admixed with copper and nickel sulfides [38]. The ophiolitic gabbros are of tholeiitic composition and range from isotropic gabbro at the base to hornblende gabbro at the top. Olivine is not recorded in the ophiolitic gabbro so that cumulate dunite could not develop. The gabbro grade upward to pillowed basalts of tholeiitic composition.

2.1.2. Island Arc assemblage:

It comprises bimodal volcanics (subduction related calc-alkaline andesite and dacite and related volcanoclastics tuffugene sediments. The bimodal volcanics include (a) mantle derived tholeiitic basalts and (b) the subduction related calc-alkaline basaltic andesite and dacite and their equivalent granites of the island arc granitoid (early orogenic granite).

Age dating studies revealed that the early orogenic granite is synchronous with the ophiolites (788 Ma, [33]) suggesting that the formation of ophiolites and the emplacement of granites (e.g. Um Baanib granite) was coeval and developed during the super continent Rodinia break-up [22,39]. It is here suggested that these island arc assemblage was firstly emplaced together with the ophiolites and then they were obducted in the earlier stage of the Pan-African orogeny. The obducted island arc and ophiolite assemblages show very considerable thickness in the central Eastern Desert.

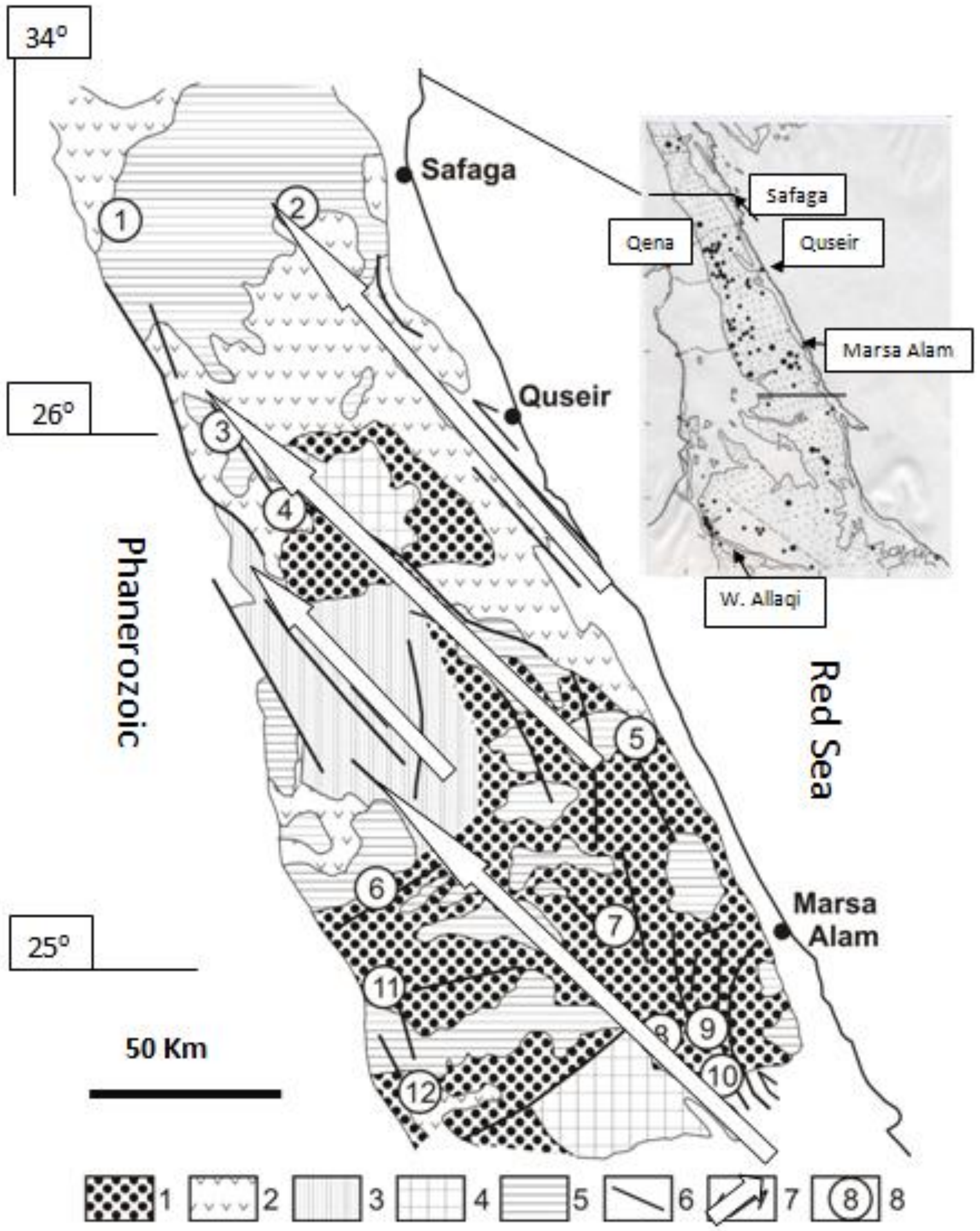


Fig. 1. Metallotect map of the Eastern Desert showing different rock assemblages and related gold occurrences, (compiled from [4,5]).

Basement rocks: 1-Ophiolite assemblage, 2- Volcanic arc assemblage, 3- Back arc sediments, 4- Syn to late tectonic granite, 5- Post tectonic granite, 6- Structure Lineaments, 7- Najd Shear and fault zones, 8- Gold occurrence (1- Fateri, 2- Abu Marawat, 3- Atalla, 4- El Fawakhier – El Sid, 5- Umm Rus, 6- Talat Gadalla, 7- Atud, 8- Hangaliya, 9- Umm Ud, 10- El Sukkary, 11- Barramiya, 12- Hamash).

Table 1. The tectonic evolution of Precambrian rocks in the Eastern Desert and the corresponding orogenic stages are grouped into seven main rock units arranged from younger to older as follows:

Tectonic Action	Orogenic Stage [18]	[31]	[32,40]	[33]	Age dating of Pan African magmatism in the Menderas Massif after [34]
1- Within plate magmatism	Post	Alkali Granites	Alkali Granite (G3)	Alkali Granites	Main granitoid intrusion 550 Ma
2- Plutonism	Advance	Younger granites	Younger granites (G2)	Younger granites (615 – 570 Ma)	
3- Mollase Formation		Hammamat Group	Hammamat Group	Hammamat Group	
4- Volcanogenic Island Arcs	Late	Dokhan volcanics	Dokhan volcanics	Calc-alkaline volcanic including Dokhan volcanic (639 -602 Ma)	
5- Cratonization		Syn-late tectonic granite, granodiorite and diorite	Older granites (G1)	Syntectonic to Latetectonic granodiorite, tonalite, quartz diorite. (987 – 700 Ma)	Intrusion granitoid 585 - 520 Ma
6- Accretion & Thrusting	Early	Metagabbro-diorite complex	Rubshi Group	Eastern Desert ophiolite melange	Granulite facies metamorphism 590 – 585 Ma
		Serpentinites			
		Geosynclinal metavolcanic Shazdli Group	Abu Zieran Group		
		Geosynclinal metasediments			
7- Conversion			Abu Fannani Schist	Meatiq Group	
		Gneisses and migmatites	Meatiq Group		Formattion of Parageneiss 600 – 590 Ma

2.2. Late orogenic stage

The rocks of this stage are characterized by the subareal volcanics (Dokhan volcanic) and its plutonic equivalents (Gattarian granite, G2 of [40]). The volcanics are composed of intermediate to acid subaerial lava flows, tuffs, agglomerates and subvolcanic felsite. However the orogenic plutones are mostly circular bodies survived along shear and thrust planes and are porphyritic in nature. Age dating of this granite (west Um Baanib pluton) reveals 644 Ma (about 144 Ma after the formation of ophiolites). It is noticed that during that time numerous granitic plutons intruded the Eastern Desert. The Dokhan volcanics are highly acidic unmetamorphosed and show two series, the older is andesitic – dacitic and K-poor whereas the younger series is rhyolitic – rhyodacitic tuffs.

Intrusions of gabbros onto the overthrusted ophiolites and island arc rocks are widespread in the Eastern Desert. Gabbros are grouped into older and younger gabbros. The older intrusive metagabbros and the younger one are commonly layered olivine type. The intrusive gabbro which is synonymous to the epidiorite-diorite association occupies a large area in CED extending from south Gabal Sibai to the environs of Gabal Atud, they occur also as small intrusions in the NED and Sinai. They are exclusively older than the calcalkaline granite [31]. There are two distinctive types of the metagabbros; intrusive metagabbros and the ophiolitic metagabbros. The intrusive type containes large proportions of quartz diorite. Moreover, they are tholeiitic to cala-lkaline, it is considered by Takla et al. [9] as a surge of subduction related high alumina basalt magma. The younger gabbroic rocks comprise spinel, clinopyroxenite, troctolite, olivine gabbros, norite and metadiorite. The peridotites are characterized by the presence of Mg-spinel [3]. Ortho- and clinopyroxine are fequently Cu-Ni-Co bearing sulfides. Fresh olivine is commonly marked by variations in Fe-content indicating crystallization from differentiating magma under decreasing temperature. It is assumed by El Gaby et al. [3] that the original basic magma was obviously an olivine tholeiitic containing appreciable amount of potash due to contamination during their ascent through the continental wedge. Takla et al. [9], considered the younger gabbro as a gold feeder in some mineralized areas.

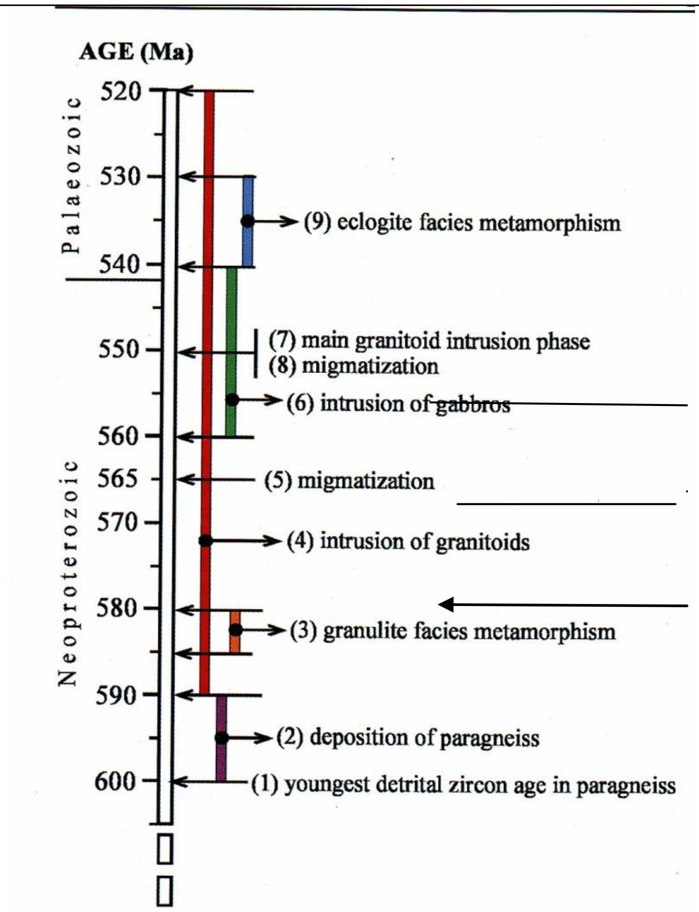
<table>
<tr><td>Age dating of Pan African magmatism in the Menderas Massif after [34]</td><td colspan="2">Compared rocks from the Eastern Desert, Egypt</td></tr>
<tr><td rowspan="8">
</td><td>Rock unite equivalent</td><td>[40]</td></tr>
<tr><td>Highly diffrenciated Albitized Granite</td><td>G3</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Post-tectonic leucogranite
Young Granite (A-Type)</td><td>G2</td></tr>
<tr><td>Young intruded gabbro and
Subareal Dokhan Volcanics</td><td></td></tr>
<tr><td>Syn-toctonic Arc granitoids
Old granite (I-Typt)</td><td>G1</td></tr>
<tr><td>Metavolcanics
Metasediments</td><td></td></tr>
<tr><td>Meatiq Group</td><td></td></tr>
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Fig. 2. Comparison between rocks of Menderas and Eastern Desert

2.3. Advanced stage

The deriving mechanism of subduction after the collision result in thrusting and shortening of crust with widespread crustal anatexis and formation of intermountain molasses sediments “Hammamat Group”. The late organic molasse facies are largely coarse terrigenous clastics with abundant conglomerates, few shales and calcareous free. These sediments are generally of non-marine fluvial environment. They accumulated in intermountain basins and troughs. It is assumed that the calalkaline granites, the Dokhan volcanics and the Hammamt clastics are coeval [39].

2.4. Post Pan African

This stage is divided into three substages:

Substage (a): In the late stage of the evolution of post orogenic granite dated between 650 – 570 Ma was intruded.

Substage (b): during this substage a within plate rifting and mega shear zones were developed such as the prominent shear zone of Najd fault system and Hamisana - Oko shear zone in north Sudan.

Substage (c): during this final stage a crustal extinction took place resulted in the formation of A-type granite and felsite dykes called as post tectonic felsite dykes. The rocks belong to this substage are characterized by Na-rich granites. The Alkaline granites are very widespread in the Eastern Desert. It was developed after cratonozation either due to metasomatic processes or it was derived from low K-magma. Some worldwide gold deposits show close relationship with albitized granites in shear zones (Western Australia, [41] and central western Spain, [42]).

3. Relationship between tectonic setting and gold deposits

3.1. Gold related to metamorphosed ophiolites

The greenschist assemblage in the ED suffered westward (WNW) compression during its accretion onto old craton to the west. This westward compression is responsible for the creation of the Najd shear system and its complementary dextral Qena- Safaga Shear. Second order shears were investigated in the ED, El Gaby et al. [3]. It appears that the sinistral NNW-SSE Atalla trend and the dextral N-S trend Hamisana shear are more prominent in the SED [43]. The metamorphism of the ophiolites and associating volcanic preceded by the emplacing of the late tectonic granites are considered as the main factors initiate the gold mineralization in the Eastern Desert of Egypt. During the orogenic activity; zones of high strain (mostly shear zones) are active in between domains or blocks of less deformed crustal segments (gneiss domes). Such zones of high strain may also act as conduits for the remobilization and interaction between metals and other sulfide fluid phases. In particular fluid activity has a potential of redistributing and concentrating elements. It is noticed that the CED comprises the highly condensed old gold working (Fig. 1). Also, it reveals wide spectrum of quartz veins intruding through calc-alkaline granites and the preexisting ophiolites. Commonly, gold is considered to be related to post tectonic granite intrusions and latter shear fracturing affected the ophiolites and the calc-alkaline granites. Generally, gold deposits in the CED are clustered along these shear zones and fault systems [3].

Field investigations revealed that the gold related to metamorphosed ophiolites can be classified into the following classes:

3.1.1. Gold related to the intrusion of granite into pre-existing island arc metavolcanics and ophiolite assemblages (EL Sukkari gold mine)

3.1.2. Gold related to sheared ophiolites intruded by calc-alkaline post tectonic granite in contact with serpentionite (El Sid -Atalla area)

3.1.3. Gold related to the ophiolitic serpentinites intruded by granites (El Barramia gold mine)

3.1.4. Gold related to the copper-bearing calcalkaline porphyritic granite intruding the metavolcanics and ophiolite assemblage (Hamash gold mine)

3.1.5. Gold related to gabbro and metagabbro assemblages intruded by granite (Atud gold mine)

3.2. Gold related to metavolcanics

It comprises bimodal volcanics such as subduction related calc-alkaline andesite and dacite as well as volcaniclastics (tuffogene sediments). The bimodal volcanics include (a) mantle derived tholeiitic basalts and (b) the subduction related alkaline basalts andesite and dacite and their equivalent granites of the island arc granitoid. It is suggested that these island arc assemblage was firstly emplaced together with the ophiolites and then they were obducted in the earlier stage of the Pan-African orogeny. The obducted island arc and ophiolite assemblages show very considerable thickness in the central Eastern Desert and hence a numerous gold occurrences. It is noticed that no gold has been recorded in the quartz gneisses or in the high grade schist or molasse sediments. Moreover the gold working is scattered along the suture contact between the island arcs of the north and south of Wadi Allaqi. Gold mineralization in W. Allaqi is expressed in swarm of gold-bearing quartz veins scattered along 15 gold occurrences, which form the southern gold deposit in the Eastern Desert. Regionally, the mineralization shows close spatial association with island arc and occasionally with ophiolitic melange domains. Temporally and spatially, the gold mineralization do not show association with any phase of magmatic activity including the felsic intrusion but it can be emplaced post dating the late-collision granitiods and subsequently to the emplacement of post-collision granitoids [44].

From metamorphic point of view, the gold mineralization reflects major positive relation with the greenschist facies domains and subordinate one to amphibolite facies domains. This attributed to the favourable P-T conditions at greenschist facies to yield brittle – ductile shear zones needed for circulation and deposition of Au-bearing fluids during the first generation folding.

Within island arc terrains, gold mineralization shows no affinity for any particular lithology since mineralization enclosed within a diversity of rock varieties including meta-basalts, basaltic andesite, meta-andesite, metagabbro, meta-diorite, meta-pyroclastics and siltstones. The distribution of gold mineralization within the arc regions shows the following characteristics [13]:

3.2.1. Strong association with competent rocks (metavolcanics and their plutonic equivalent) rather than with the less competent ones (volcaniclastic sediments).

3.2.2. It is confined to the high strain zones within the competent domains which in turn linked with penetrative foliation, hinge zones of F1 folds and brittle –ductile shear zones of D1 type.

3.2.3. It is associated with the lithological contact within the D1 high strain zones.

3.2.4. It is associated with the highly Fe-rich basic and intermediate rocks rather than the acidic ones which not hosting any mineralization.

It is believed that, gold mineralization has been derived from metamorphic fluids created by the dehydration and decarbonatization of ophioltic mélange assemblage located between the accreted island arc belts [45,46]. The fluids were initiated during the collision stage and related regional metamorphism, partial melting of such rock assemblage at amphibolite facies. The resulted auriferous fluids tend to migrate from high pressure source zone to low pressure host zone (island arc regions at P-T of green schist metamorphic facies) and deposited in structural traps of dilatant sites along the brittle-ductile shear zones in the hinge zones of first generation structure. Gold related to metavolcanics are found in Abu Swayel, Um Garayat, Shashoba, Um Teyor and Abu Fas. All these areas are confined to Allaqi suture in the southern part of the Eastern Desert [6].

4. Sheared granite and gold mineralization in the Eastern Desert

Resurvey of the central and southern Eastern Desert by Smith et al. [47] and Kontny et al. [36] revealed five steeply dipping, NW-SE to E-W- trending shear zones with a strike length of 100-150 km and a width 10 - 15 km. They form an en-echelon left-stepping pattern and effectively partition the ED into domains of variable strain. Internally, deformation is complex with coeval strike-slip shearing, thrusting and folding. In the central Eastern Desert, thrusting is associated with flower-like structures that taper and root into parallelism with a major N-S trending shear zone. Strike –slip duplexes are contemporaneous with the NW-SE trending Najd Shear system of Saudi Arabia [28,48,49].

Three of these structures are present at Hafafit, Wadi Gerf, Atalla – El Fawakhir and Wadi Allaqi shear belt. It is suggested that the compression generated by oblique plate convergence was resolved into bulk sinestral shear and partitioned into a series of ductile brittle shear zones with an overall NW directed movement from transpressional flower-like roots in the south to strike-slip dominated horizontal movements in the CED and NED segments. Positive flower structures were recorded in many areas in the central Eastern Desert [14,47]. Widespread extensional reactivation and crustal thickening during the waning stage of the Pan African orogeny is identified by copper – gold mineralization. El Gaby et al. [3] identified three mega shear zones, the Qena – Safaga trending NE-SW, Kom Ombo trending NW-SE almost parallel to Najd System, and the Hamisana Shear trending NNE-SSW, which separate the Allaqi ophiolites from Onib-Sol Hamid one [50]. It is suggested that during the orogenic stage zones of high strain, mostly shear zones were active in between domains or blocks of less deformed crustal segments. Such zones of high strain may also act as conduits for the movement of metals and the fluid phases. In particular fluid activity has a potential of redistributing and concentrating elements. Four main lineament trends are recognized [16]. Structural studies on the El Sid – Fawakhir gold deposit [51] and on El Sukkary gold deposit [14] revealed that the main direction of quartz is NS whereas gold mineralization is found along NNW and SSE microfractures. Moreover, Hangaliya gold prospect is situated in the Nugrus shear zone, the quartz veins in this area are parallel to the main foliation [50]. These results are concordant with the idea that the emplacement of quartz veining is due to major shear event (Najd Shear System), whereas, gold mineralization is post dating and toke place alongside brittle-ductile stretched deformation. In addition, the intersection between the fractures and joint system as well as the contacts between granite and basic and ultrabasic country rocks are considered as the most favourable sites for gold mineralization [6].

Fig. 3. Contact between pink S-type granite (pale) with serpentines (dark), El Sid - El Fawakhier area.

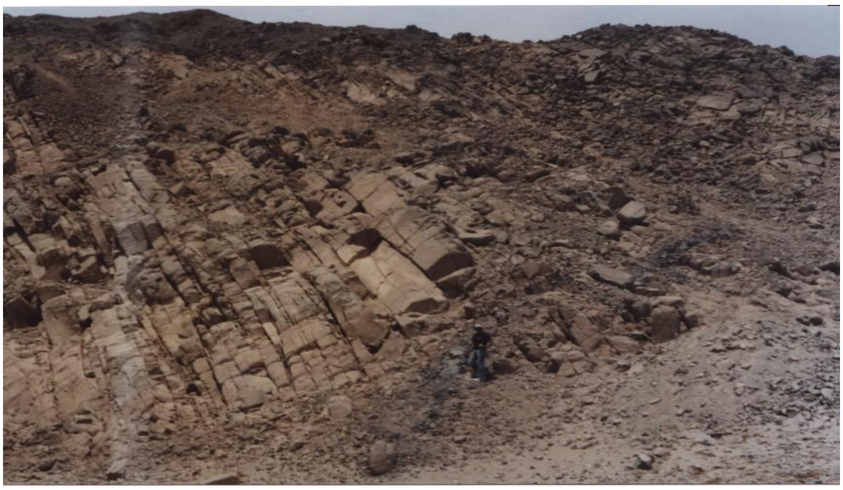

Fig. 4. Sheared granite (two sets) El Fawakhier granite.

5. Petrography of gold deposits in the Eastern Desert:

The main gold deposits of the Eastern Desert of Egypt are restricted to quartz veins occupying pre-existing fractures. In some areas, the wallrock alteration played an important role in gold mineralization [11]. The distribution of gold among sulfides, quartz and oxides in sheared granite at Hangaliya gold mine was discussed on the light of major tectonized Nugrus granite [52]. In general, the zone of alteration is varied from area to another depending on the country rocks and the type of alteration. The quartz veins are made up of massive quartz with disseminated gold and sulfide minerals (pyrite, arsenopyrite, sphalerite, galena, tellurides and chalcopyrite). In some occurrences, the ore is associated with felsites dykes either as stock works of minor quartz veinlets (Fateri area), or contained in pyrite and arsenopyrite grains (**Fig. 5**) disseminated throughout the whole contact between quartz and granitic body such as in Atalla [12], El Fawakhier and El Sid [53,54], Hamash [55], Um Munqol [56] and Um Balad [57].

In the zone of oxidation, native pure gold is almost found inside collomorphous goethite, hydrogoethite and copper oxides [58].

The mineralized veins are hosted in a variety of basement rocks including ultramafics, metavolcanics, metasediments, intrusive gabbros and associated with diorite – granodiorite plutons and their contacts with schists. They are structurally controlled, being fissure filling and may be arranged as a series of en-echelon veins to form ore zones which at Barramiya, Atud, Hangaliya, Um Rus and Sukkari range between 1.5 and 2.0 m thickness and reaches up to 3.0 m at El Sid [6]. Strikewise, the vein extends for some hundreds of meters and may continue for considerable distances along the dip, for example, 455 m at El Sid. The main vein vary in width between 0.6 and 1.5 m. Fine gold disseminations < 20 µm are recorded in the alteration zones bordering the veins in El Sukkary, Barramiya, El Fawakhier, Atalla, Hamama, Fatiri, Um Munqol, and Hangaliya. At the southern Eastern Desert, Um Geriyat, El Teyor and Shashoba at Wadi Allaqi where they proved to be of economic value.

The veins are made up of massive milky or grayish white quartz. In many cases, the quartz represents at least two generations. An older brecciated milky quartz which is usually barren and a younger grey quartz that cements the fragments of the older phase and is usually gold-bearing. Ankerite is present with quartz as quartz carbonate assemblge at the wall rock in El Barramiya, Atalla and Siega area SED [12,38,45].

Ore microscopic examinations reveal textural relationship between refractory gold and sulfides (**Fig. 21**). Pyrite is the main host mineral of refract gold with minor arsenopyrite, galena sphalerite and chalcopyrite.

The gold – bearing sulfide disseminated alongside the wallrock. Gold may present between sulfides (**Fig.5**) or at the micro fissures in sulfides (**Figs. 6, 7, 8, 9**). In some sulfides gold is locked inside sulfide (**Figs. 10, 12, 13, 14**). In some samples gold precipitated at the outer part of pyrite as epitaxial grain (**Fig. 11**). In the oxidation zone gold is found inside either Psuedomorphous or collomorphous goethite or/and hyrogoethite after pyrite (**Figs. 15, 16**). Diffused gold along the pyrite contact is common (**Fig. 17**). Galena and sphalerite may associate gold as a fissure filling inside pyrite (**Fig.18**). Free mill gold is recorded in some places in Allaqi where pure native gold found as filling of micro fractures in quartz (**Figs. 19, 20**).

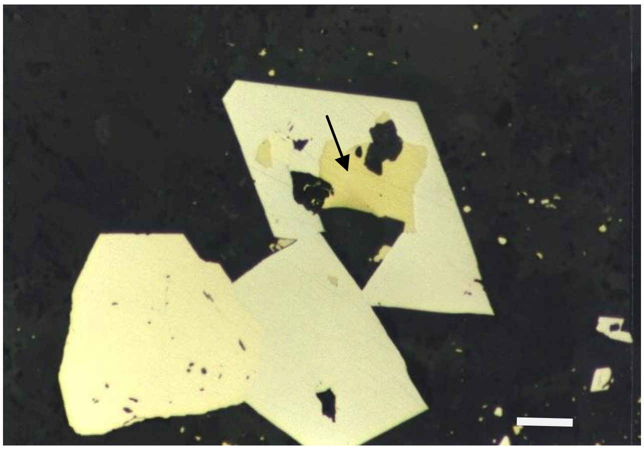

Fig.5. Gold (yellow) in arsenopyrite. Reflected light, Atalla gold mine, bare scale 20 µm.

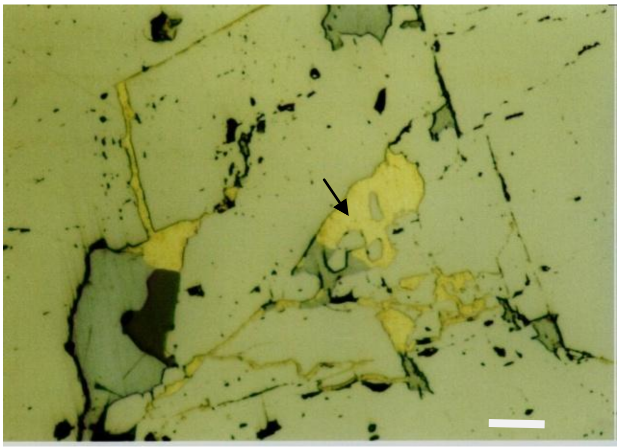

Fig.6. Gold (yellow) in micro fissures in pyrite, associating galena (gray) and sphalerite (dark gray) Reflected light, El Fawakhir gold mine, bare scale 20µm.

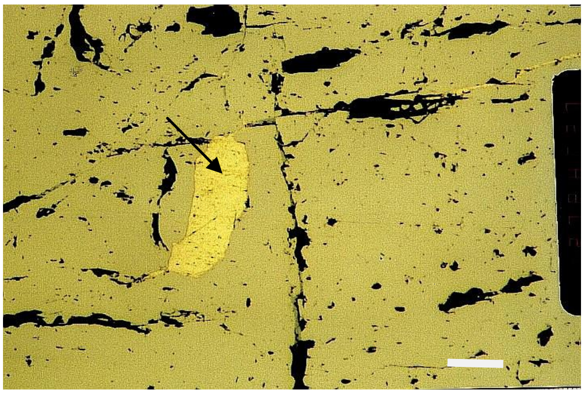

Fig.7. Pure Gold defused inside pyrite, gold hair inside very fine fractures, Hangaliya gold mine, bare scale 20 µm.

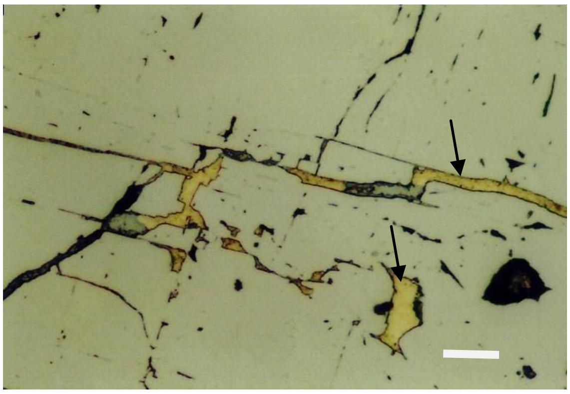

Fig. 8. Gold and galena inside fractures in pyrite (impure gold), El Sid gold, bare scale 20 µm.

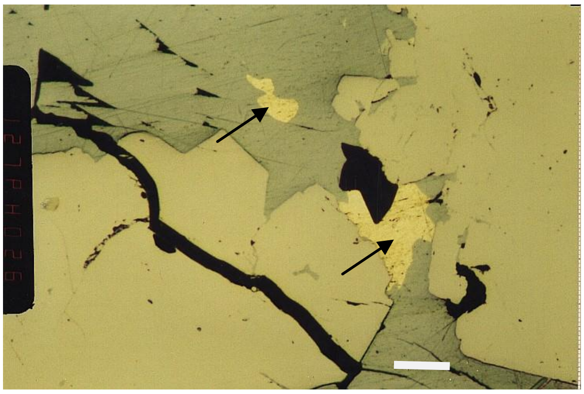

Fig.9. Gold associating galena inside pyrite, Abu Marawat gold mine, bare scale 20 µm.

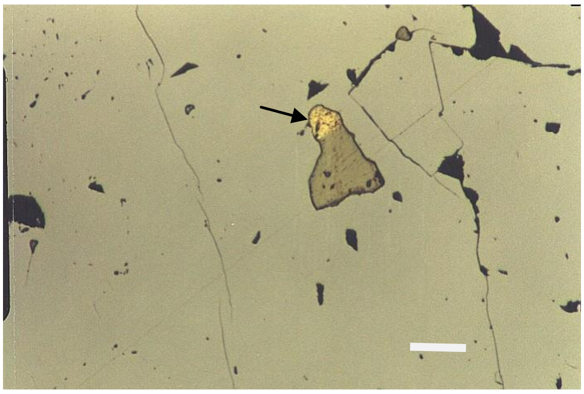

Fig 10. Composite Gold at the contact with sphalerite inside pyrite, Hammash gold mine, bare scale 20 µm.

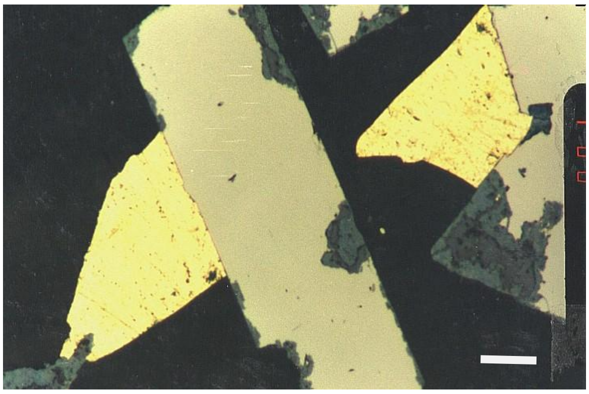

Fig. 11. Pure gold at the outer part of euhedral pyrite which reveals supergene alteration, Atud gold mine, bare scale 20 µm.

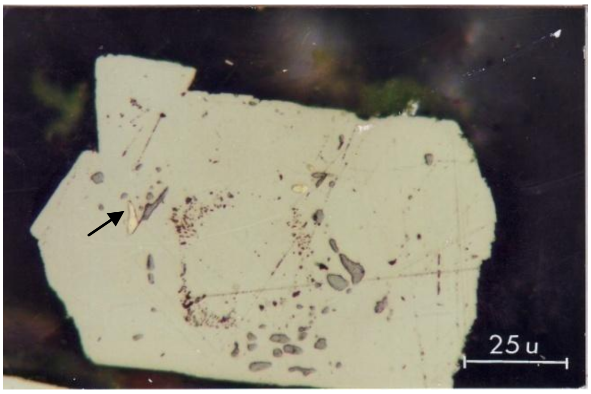

Fig. 12. Gold (yellow) associating galena (gray) inside euhedral zoned pyrite, Atalla gold mine.

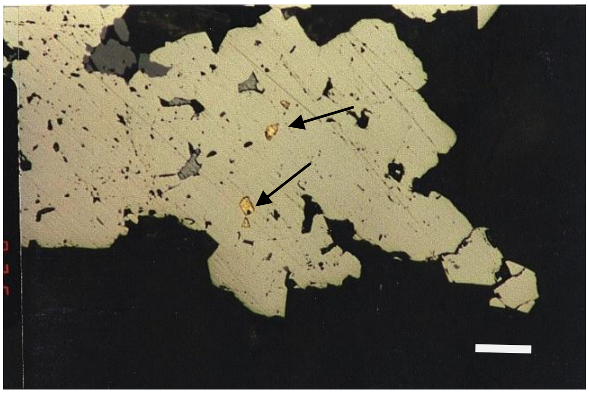

Fig 13. Very fine gold bleps inside pyrite with sphaerite micro-relicts. El Sid gold mine, bare scale 20 µm.

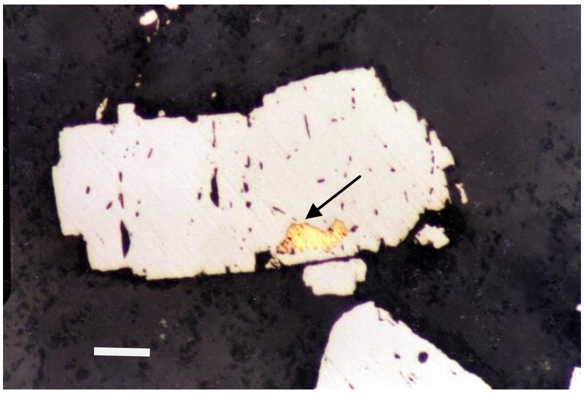

Fig.14. Native refract gold inside pyrite show micro-fractur in quartz, El Sukkary gold mine, bare scale 20 µm.

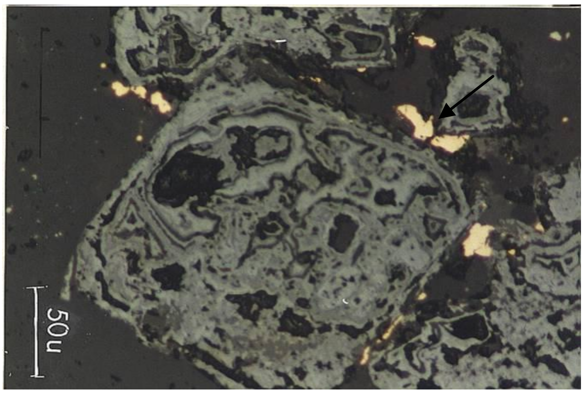

Fig. 15. Gold relicts left inside psudomorphous goethite after pyrite. Oxidation zone, Um Rus gold mine.

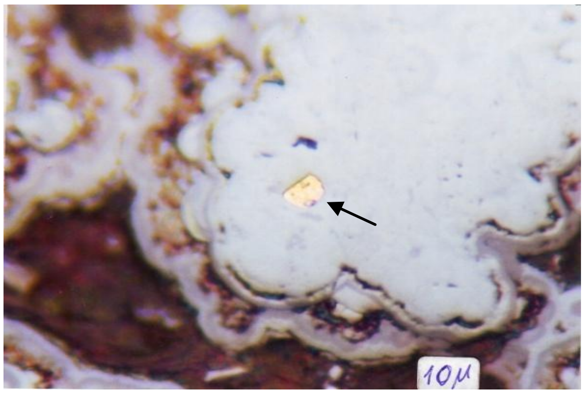

Fig. 16. Gold relicts inside collomorphous goethite after iron sulfides. Oxidation zone, Munqol area.

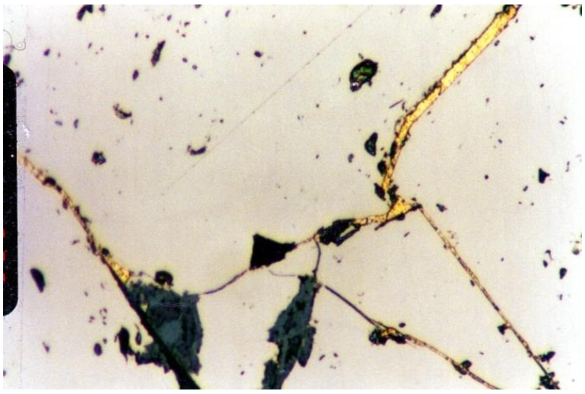

Fig. 17. Refract gold hairs (2- 5 microns thick) difussed along pyrite contacts, Umm Russ gold mine.

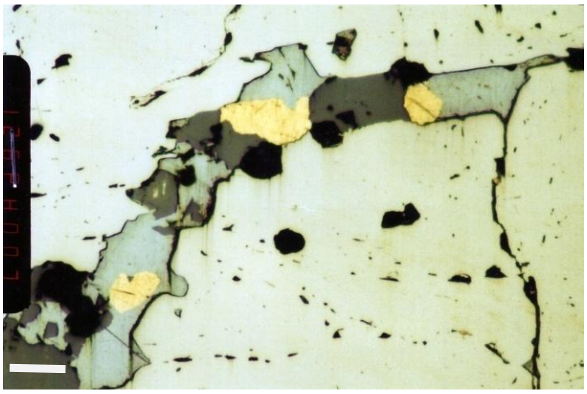

Fig. 18. Refract gold (yellow) and galena (light grey) and sphalerite (dark grey) cut through pyrite. Gold shows various reflectivities due to admixing elements. Um Ud, bare scale 20 µm.

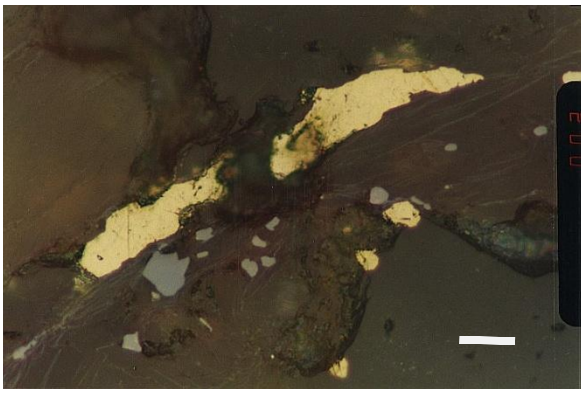

Fig. 19. Free mill gold inside sheared quartz with relicts of jarosite and anatase Um Garayat SED, bare scale 20 µm.

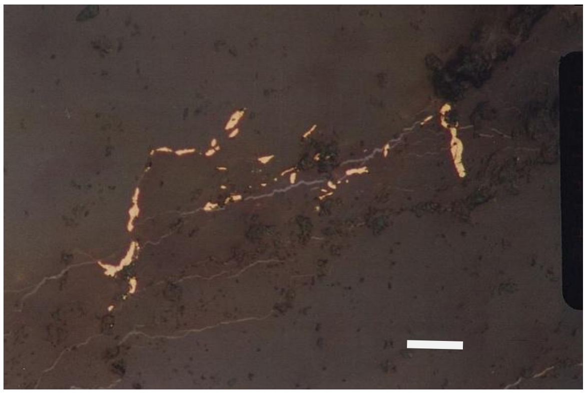

Fig. 20. Free mill native gold inside microfracure in quartz Um El Tuyor mine, SED, bare scale 20 µm.

6. Paragenesis of gold mineralization

Microscopic investigations on the ore minerals of quartz veins and wall rocks of some important gold occurrences from central and southern Eastern Desert (Fateri, Fawakhir, El Sid, Atalla, Hangaliya, Atud, Um Ud, El Sukkary, Um Russ El Barramiya, Hamash, Um Garayat and Um Tuyor) revealed three stages of gold mineralization. During the first stage pyrite and arsenopyrite and minor pyrrhotite (**Fig. 5**) together with chalcopyrite and galena (**Figs. 10, 12**) were formed in the direct altered wallrock in contact with the quartz vein as well as in the rims of the quartz vein itself. The wall rock reveals intensive sericite and in other parts chlorite alteration [11]. Refractory gold is found inside pyrite and at the contact between pyrite and arsenopyrite. Moreover, inclusions of rutile, zircon and feldspars are found inside euhedral pyrite [12]. The second stage of mineralization is corresponding to increase of sulfur content in the system which resulted in the formation of more pyrite and absence of pyrhhotite and arsenopyrite whereas sphalerite, galena, and remarkable tellurides (**Fig. 18**) are found as free minerals or admixtures in gold and/or galena [53,54] (**Figs. 6, 8, 9**). The third stage is characterized by the presence of carbonate as dolomite

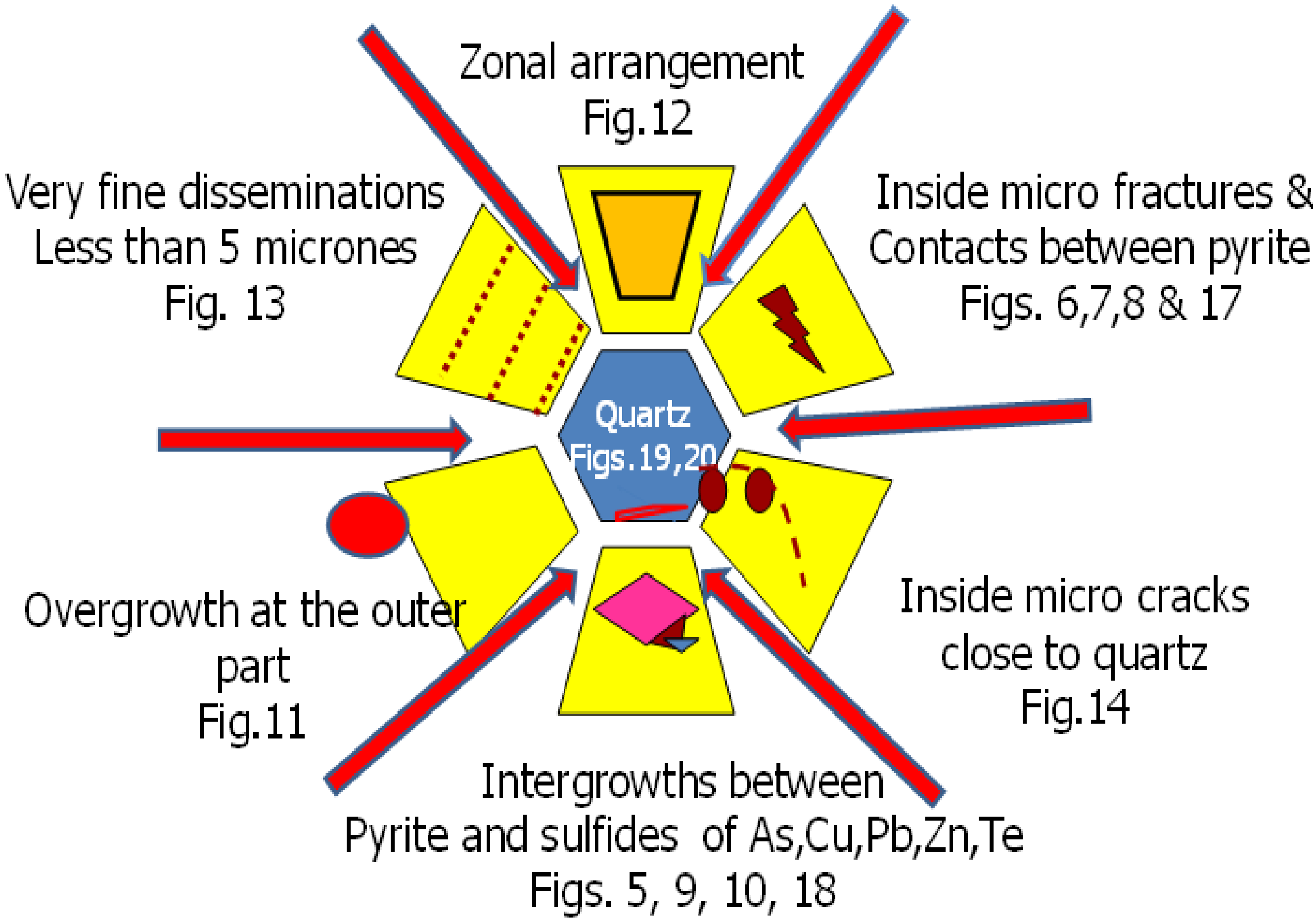

Fig. 21. Relationship between free mill gold, refractory gold and pyrite in the Eastern Desert of Egypt.

and/or ankerite under high alkaline conditions as microvienlets and at the contact between quartz and wall rock. Pyrite of this stage is barren. A lateral diffusion model (**Fig. 21**) is proposed to illustrate the conjunction of shearing and metamorphism considered to generate chemical potential gradients that drove gold and other ore – forming constituents from contiguous rocks into the brittle ductile shear zones.

Conclusions

The vein-type gold deposits in the Eastern desert of Egypt are of epithermal origin and closely related to post-orogenic granites. The gold-bearing quartz veins are hosted in a wide spectrum of rock units. Gold mineralization reveals strong relationships with the leucogranite that intruded the preexisting island arcs and ophiolite rock assemblages. Gold mineralization in the central part of the Eastern Desert are concentrated along sheared and dome terrains within the preexisting thrusted and metamorphosed ophiolites. Alteration corridors around quartz veins are vary in thickness and depth depending on degree of metamorphism and structure bottoming. It is here suggested that collision, plutonism and compressional forces and subsequent metamorphism produced the shear zones which acted as pass-ways for mineralizing solutions and played an important role in the gold mineralization.

The factors affecting the formation of gold in the ED are summarized as follows:

1. Pre-existing metamorphosed basic and ultrabasic slabs are considered as the gold feeder.
2. Late orogenic leucogranite emplaced during an extension tectonic stage that follows continental collision. The leucogranite also proceeded due to crustal heating caused by compressional tectonics.
3. Shear zones provide the system with the channels and pathways, which assist the circulation of the hydrothermal fluids.
4. Faults (Najd fault system) that intersects the preexisting shears and contacts between basic – ultrabasic rocks and the leucogranite are gold fertile areas.
5. Microfractures in the quartz veins (either visible or not). These microfracures are almost well developed at the contact with the wall rocks therefore some gold is infiltered inside these parts.
6. The variations on the metal contents in the gold deposits depend on the type of host rocks as well as the thickness of the sheared contact between them.
7. Gold was precipitated firstly in sulfides associating wall rock alteration such as arsenopyrite and arsenian – pyrite. The more fractured granite the higher gold content and sulfide disseminations are

developed, the latter gold was formed inside quartz vein as well as gold – bearing sulfides specially pyrite, galena sphalerite, and tellurides.

8. Two main types of gold are found the hypogene gold and the supergene gold. The hypogene is bound to late stage of the brittle deformation, whereas the supergene is bound to the oxidation zone in the weathering profile. The second type is found inside collomorphous and pseudomorphous iron oxides after pyrite.

9. The thickness of the pyritized zone depends on the grade of shearing, type of wall rock and grade of metamorphism.

10. The exploration target has to be focused on shear structures and along veins parallel to foliation and latest micro-tectonic fractures cut through wall – rock and quartz veins.

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