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RESEARCH ARTICLE

RECONNAISSANCE STUDY ON GOLD MINERALIZATION AT ABU KHALAG AREA, BAYUDA DESERT, SUDAN

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ABSTRACT

Detailed documentation for the mineralized quartz veins and the wall-rock alteration zones at the Abu Khalag region reveals that the mineralizationoccurs along narrow discontinuous shear zones, and mostly hosted by green-schist assemblages. Shearing processes and retrograde metamorphism are one of the causes of remobilizing the auriferous quartz veins and re-deposit them at the appropriate physiochemical traps. The spatial array of Abu Khalag auriferous reefs, the zonal nature of the associated wall-rock alteration, and the structural/lithological evidences suggest that the mineralization is related to developed fluid flux during deformation/metamorphism. Gold nuggets morphology is sub to euhedral, and uneven grains, tabular and plated textures are common. Their color in all the placers is dull yellow to reddish brown and greenish yellow, reflecting (Fe, Cu) existence. Their surface is mainly medium to moderately coarse-grained. The euhedral nuggets reflect *insitu* formation at high temperatures with possible role of bacteria. No dendritic patterns for gold were observed. Abu Khalaggold-bearing quartz veins are associated with disseminated pyrite, arsenopyrite, chalcopyrite, pyrrhotite, galena, and iron ores. The deposition of gold was contemporaneous to retrogressive metamorphism and the rejuvenation along the shear zones during D_2. The auriferous quartz reefs are variable in colour, size, and are preferably hosted in the metasediments, especiallyamphibolites and calc-silicate rather than quartzites and gneisses, suggesting that gold mineralization is also lithologically controlled. The primary occurrence of gold grains is free-lodes in silicates and/or inside the disseminated sulphides in the quartz reefs. The Au-quartz veins showing two main groups/ phases. Phase one is concordant with schistosity of the bedrocks, showing sacaroidal textures, banded structures, and usually occur as discontinuous isolated patches (pinch and swell). The size of these veins ranging from few centimetres (stringer, veinlet) to more than half a metre. The Au-grade in this group ranging between 0.05 and 1.9 ppm. The second phase of quartz veins is massive formed by ductile dextral shearing, and is in the tension gashes. The concentrations of gold in this type ranging (0.05-0.4) ppm, and have average 1 metre thickness. The geochemical, lithological, structural, and mineralogical features with the style of wall rock alterations of the Au-bearing quartz veins suggest that they belong to mesothermal (orogenic) gold type.Gold also found as placer deposits, which covered vast parts of the study area. Associated gangue minerals with gold in the stream sediments are quartz, calcite, sericite, siderite, ankerite, dolomite, K-feldspars, zircon, rutile, tourmaline, epidote, and graphite. Gold nuggets shapes and sizes reflect that quartz reefs are not the only mineralized source in the study area. The gold background value in the fine-fractions of stream sediments is 0.21 ppb, the threshold is 2.91 ppb, and the anomalous value is 3.0 ppb. Cu and Zn are the main pathfinder elements for gold based on stream sediments geochemistry.

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INTRODUCTION

Techniques and methods

Stream Sediments Sampling

The studied area is shaped by two types of valleys, dominantly running E-W such as Abu Handal, Um Gudum, and Abu Geddad valleys, which follow the ancient fractures. Some valleys are trending N-S, such as Singeir Vale (Fig. 1). The stream sediment samples were collected from streams in Abu Khalag area were taken from first and second order tributaries to avoid contamination coming from distal streams (Fig. 1).

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The variety of heavy minerals in the alluvial dispersion terrain depends on the nature of the country rocks in the drainage basin, nature of the mineral deposits present, climatic and weathering processes that have altered the source rocks, beside the transportation/depositional history of the stream system. The samples were panned in the field by removing the large quantities of lighter fractions composed of quartz and other lighter minerals. The stream samples were separated first by manual magnet to avoid the paramagnetic minerals (e.g. magnetite and pyrrhotite), which can carry residual magnetism after removal of the field. Electromagnetic separation has been performed, using (*Frantz Iso-dynamic* system) to isolated diamagnetic minerals and moderately magnetic (e.g. ilmenite, chromite, almandine, and hematite etc.). The residue of the black sand is nonmagnetic fraction to weakly magnetic (e.g. tourmaline, monazite), were separated using *bromoform* heavy liquid with density *2.87 g/cm³*. The samples were then cleaned by alcohol and acetone to remove the toxicity of the *bromoform*, and were dried to avoid bacterial activities. Gold grains and associated heavy minerals were studied under (*leicaMZ57* binocular microscope) to identify the morphology, association, and physical properties. 1-2 kg were taken from each stream sample before panning, and have been quartered, sieved to -63 µm mesh, and analysed using XRF analysis technique for major and trace elements. For gold grade in the fine fraction of the stream samples (-63 µm), *aqua regia* method was used followed by analysis of atomic absorption spectrometry (AAS).

Chip Samples

Chip samples were taken from 9 quartz veins around the study area. *Aqua regia* digestion followed by (AAS) to determine gold and other base elements concentrations. Two of the samples were double-analysed using cyanide leaching technique for quality control purposes. The data have been processed using special computer software, and statistical methods applied to determine the geochemical parameters, which have been plotted using STATISTICA (*Stat Soft, Inc.,* 1995) program. Maps and Landsat images were processed with the help of Corel draw 12, GIS arc view and ENVI 4 remote sensing programs.

volcanosediments and dominant low-grade-juvenile ophiolitic island-arc and turbidites assemblages. These assemblages are related to collisional orogeny between the (ESGC) in the west and the ANS in the east (Karmakar and Schenk, 2015). Relatively younger syn to-post tectonic granitic intrusions [650–570 Ma] (Evuk*et al.,* 2014; Küster *et al.,* 2008; Shang *et al.,* 2012), and the subsequent felsic ring dykes (Fig. 3a&b) were injected at the fissures and major fault systems of the pre-existing geological units.

Sudan has been an important gold producer for possibly 3000 years ago, since the era of the ancient Pharos civilization. The small population, vast areas, and often inhospitable climate have prevented investors to start large-scale gold extraction. All explorations before 1980 followed the traditional prospecting methods of outcropping quartz veins, and all small mines developed were small vein-type underground mines. During the past two decades, the gold mining industry has seen considerably progressed, with modern technology and the hiking in prices of gold and demand worldwide. This led to discover and detect new mineralization sites, which were not detected by the traditional methods. Sudan generally consists of typical Precambrian continental cratonic granitic gneisses terrains, with occasional long narrow greenschist belts (shear and suture-related). In Sudan, as in other Nubian-Arabian Shield parts, virtually most of the gold and associated sulphide

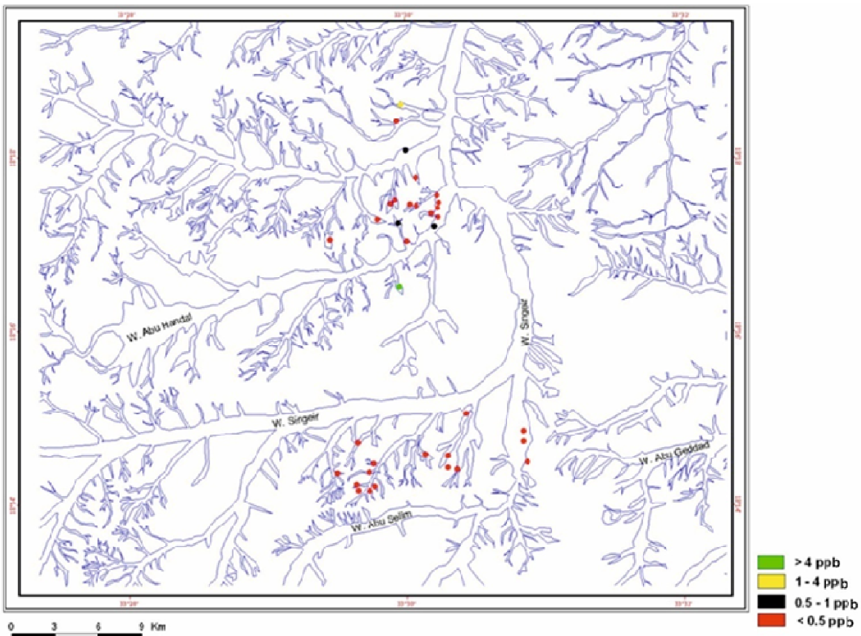


Figure 1. Location of stream sediments samples collected from the study area

Introductionand Geological settings

Abu Khalag area is a part of Arabian-Nubian Shield, it is located ~ 400 Km north of Khartoum-Sudan (Fig. 2), and situated east of the central Bayuda Desert. It situated in the eastern margin of East Sahara Ghost Craton (ESGC) (Abdelsalam*et al.,* 2003), and consists of Archaean - Paleoproterozoic crust (Rahaba-Absol Series) (Evuk*et al.,* 2014) overprinted by Neoproterozoic units (Abu Harik-Kurmut Series) (Karmakar, and Schenk, 2015). Abu Khalag occupy the margin between Paleoproterozoic medium to high-grade gneisses (which covers the western and central Bayuda Desert area) and the crust of the Arabian-African Shield (ANS) lying further east of the Bayuda Desert that composed of Neoproterozoic interfolded supra-crustal meta-

deposits are related to the greenschist belts. The source of gold in the greenschist facies are probably the metamorphosed basic and ultrabasic rocks (Peck and Huminicki, 2016), which characterize compressed and deformed slices of an old oceanic crust, frequently referred as ophiolites. These assemblages of ophiolitic origin contain mineralized horizons (Gabb, 1997):

1. The lower mantle rocks of dunite-harzburgite composition, it contains chromite and possibly platinum. Generally, this horizon observed in Sudan at Hamissana, Sol Hamed, Ingassana, and in the northeast of the Nuba Mountains.
2. The lower contact of the basalt-andesite volcanics with underlying mantle rocks as peridotites, harzburgite, and gabbro, which contain copper-nickel platinum sulphides

of Kambalda type. This horizon is not well-represented in huge units in Sudan, but tiny remnants are found in the Onib, Wadi Amur, and Ingassana Hills.

3. The upper contact of the basaltic-andesite volcanics connect with overlying chemical sediments such as cherts and banded iron formation, as observed in Nuba Mountains and possibly at HofratEn- Nahas (South West of Darfur region), or found it covering acid volcanic rocks, as in Ariab area (open cast gold mines). This horizon contains widespread gold and base metals such as copper, lead, and zinc mineralization. Where the rocks have been metamorphosed, the gold is often remobilized into typical gold-bearing quartz veins (Bayuda Desert) (Hu *et al.,* 2016), hosted in greenschist facies and turbidite rocks.

et al. (1999) did detail geochemical prospecting in the eastern parts of Bayuda Desert. The Sudanese-French Project (2000) executed low-density stream sediments survey; they suggest certain parameters for soil and stream sediments geochemistry at Bayuda Desert. They also identified several geochemical anomaly values, which are indicative for gold mineralization. Mohammed (2005) carried detailed geological, geochemical prospecting and exploration in the eastern parts of the Bayuda Desert (south of the study area). He studied quartz veins, soil, and stream sediments and their relationships to gold.Most of the previous studies report the regional geology and structure of the Bayuda Desert. However, some of recent studies described in brief the gold mineralization. Abu Khalag area received only little investigations. Consequently, this recent

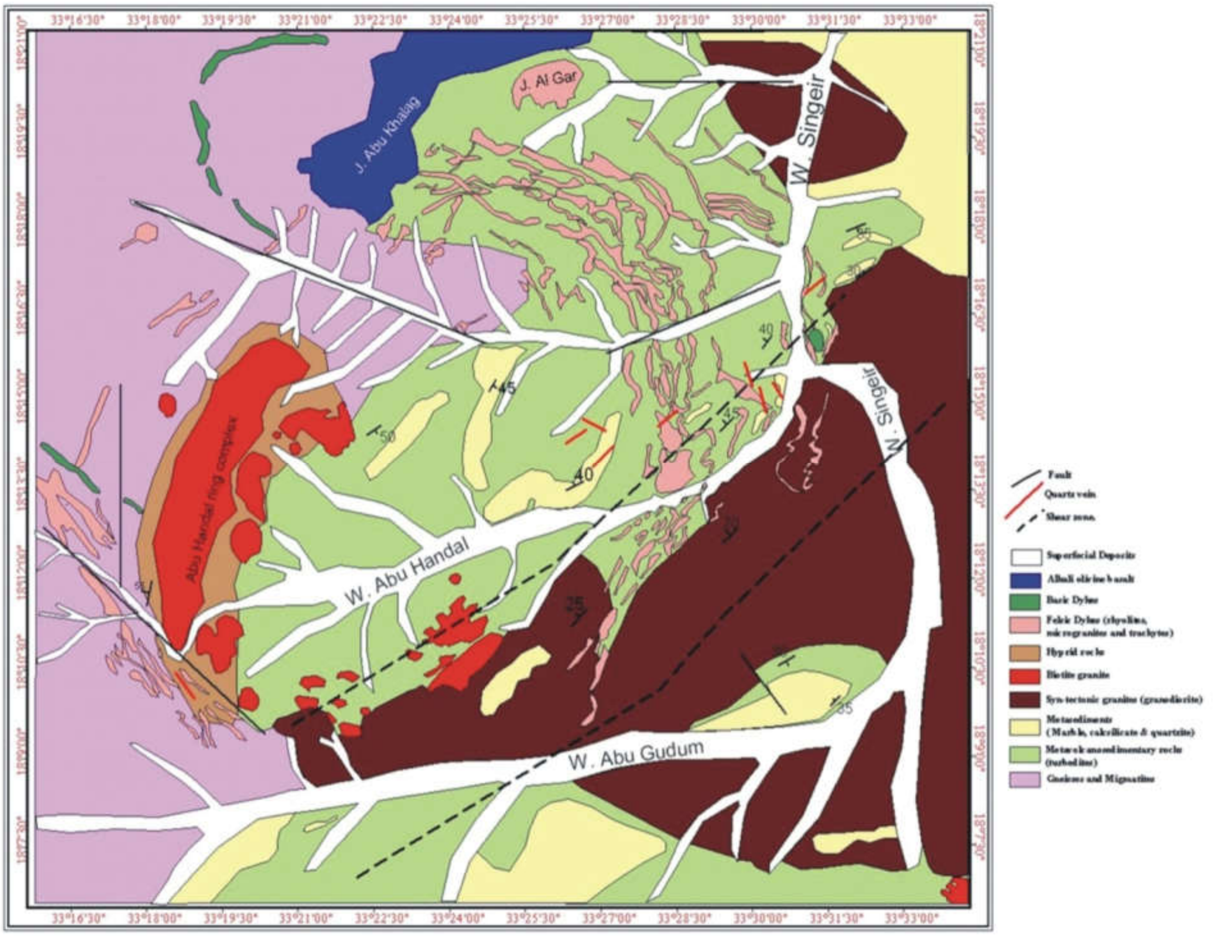


Figure 2. Simplified geological map of Abu Khalag area **10Km**

This horizon is already being recognized in several places in Sudan (Onib area, near Gabeit, Ariab, Wadi Amur area, near Derudeb, the eastern part of the Ingassana Hills, Nuba Mountains, Kapoeta in equatorial (recently South Sudan), HofratEn-Nahas in Darfur, Wadi Halfa, and in Wadi Gabgaba in the North Sudan (Fig. 4). These areas are well-known to be gold-rich zones and there are considerable evidences of associated sulphides mineralization. Numerical previous works have been done around the study area, Barth and Meinhold (1979) described locations for some potential deposits in Bayuda Desert, as part of the Sudanese-German Project in Bayuda Desert. Ibrahim *et al.* (1999) carried out a regional geological and geochemical prospecting for gold in Bayuda Desert; their work was particularly concentrated in the geology and tectonic environment of the auriferous quartz veins. Khalil

work is the first most detailed and reliable study obtained in Abu Khalag gold mineralization, which represents valuable guidance for any exploration work in the future. This work is the first study ever concerning the nature of gold mineralization in Abu Khalag area. In addition to the low density geochemical survey, this study encounters detailed litho-geochemical mapping and few chemical analyses (Altigani*et al.,* 2016a), documentation and description of the mineralized quartz reefs and their alteration zones had been done for the first time in the study area. The structural/chemical characteristics that controlling gold mineralization are presented in this study. However, more advanced work is required in the future. This study opens the door for upcoming exploration and mining activities for gold mining in that potential and greatly promising area.

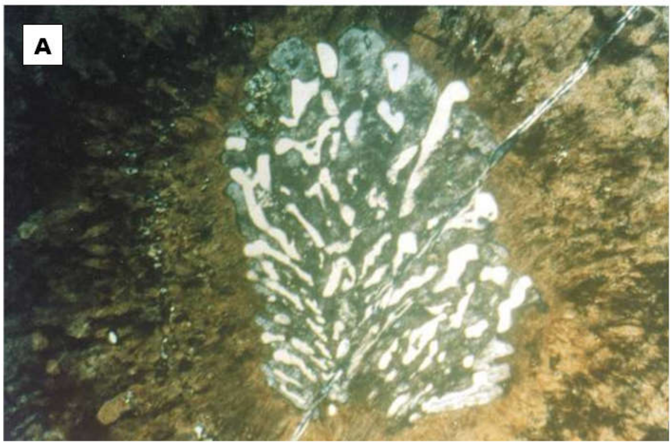
Mineralization, Structures, and Metamorphism

The auriferous quartz veins formed syn-to late tectonic with the country rocks, they show ductile deformation (inter-folial folding, boudinage, etc.). Field observations and structural studies suggest three main deformation events accompany the regional tectonism in Bayuda Desert; these three main phases might distinguish separate events and/or represent one prolonged tectonic event.

1. D_1phase is isoclinal recumbent folds with axis (20º, 30º, 40º), and plunging with(10º-15º) to SW. The collision direction of arc assemblages (Arabian Shield) with cratonic Nubian shield has been described as the earliest phase of deformation (D_1). The verging shows that the effective stresses, which made isoclinal recumbent folds, must have been played from E to W (direction of collision forces). This stage of folding is indicated by (M and W-shaped) micro folds. D_1 isoclinal recumbent fold has been refolded by D_2 open anticlinal fold, forming mushroom pattern, dome and basin, and double plunging features are observed. Also, refolding made transposition for the bedding and foliation with the fold axis. Structures belonging to the D_1 generation are only recorded in the members if the high-grade sequence.
2. D_2 is an open anticline fold with axial plane E-W direction. D_2 is characterized by refolding of older isoclinal recumbent fold (D_1) forming the observed mushroom interference patterns; this form ductile shearing trends 40º, 340º (the direction of old quartz veins). D_2 considered as the main phase for first gold deposition. An en-echelon structure formed due to the dextral movement, which shifted the old direction of quartz veins by 25º towards North. The shearing related to D_2 superimposed on the earlier foliations, developing crenulation cleavage pattern. The plunging is followed by domal uplifting, due to the emplacement of ring complexes, which caused cauldron structures and consequently formation of ring dykes. D_2refolding is associated with thrusting and sliding events, these horizontal planes defines the contact between the low and high-grade metasediments, it also considered to be the main cause for cigar-shaped pebbles at the axial fold planes. The main intrusions of syn-tectonic granites were inserted in the cores of D_2 anticlinal folds and at the main fracture planes.
3. D_3isplunging stage, which formed by refolding and emplacement of granitic intrusions (domal uplifting), which changed the direction of the open anticlinal fold axial plane to SW by 10º to 20º. This process uplifted the oldest unit (gneisses) and located it at the same level with younger gold-bearing volcano-sedimentary units.

Associated with the above-mentioned deformation phases, secondary events or stages are commonly existing, such as ductile strike-slip movements, shearing, torsion, boudinage and sausage structures, and brittle dip-slip shearing.

There are two dominant general trends of foliations in the study area (Fig. 5), the first (older) trends E-W, and is parallel to asymmetrical recumbent fold axis (D_1). The dip amount of this foliation is 0º to 60º. This older phase associated with D_1 folding, and discordantly situated across the later shearing that trends N-S. Tectonic joints trend N-S, they may relate to the major Keraf shearing (Abdelsalam*et al.,* 1998; Evuk*et al.,* 2014). The low-grade meta-volcanics (arc-volcanic assemblage) are not affected by the D_1, they are believed to exist post to $D_1$and just after collision. Schandelmeier*et al.* (1994) have concluded that the Keraf Zone (Fig. 5) is a geo-suture formed due to the collision of the Nile Craton (ghost craton) and Nubian Shield; they also reported that the Keraf structural style is relatively younger and overprint the E-W trending structures in the high-grade gneisses located in the west of the Nile. However, we found basic volcanic xenoliths included in the gneisses of Abu Harik (Altigani*et al.,* 2016a), which previously thought a part of the Nile Craton. This finding suggests the boundary between juvenile crust and the craton is located more far due west of Sudan (Altigani*et al.,* 2016a). It also shows that these cratonic gneisses are in fact shearedgranitoids. The general trend of the structures, which controlling the main old deposits ofgold in the Red Sea region (eastern Sudan, western Saudi) is NE-SW (Stern*et al.,* 1989) (Fig. 6). The rocks of Abu Khalag area are generally metamorphosed under greenschist facie, which characterized by sericite-schist, carbonates, calc-silicates, and turbidites (Altigani*et al.,* 2016a). The mineral assemblage in these rocks consists mainly of muscovite, k-feldspar, chlorite, quartz, garnet, graphite, and disseminated sulphides. These rocks are the main gold host in the study area. Graphite (organic material) is noticeably associated with rich-zones ofgold in the metasediments.



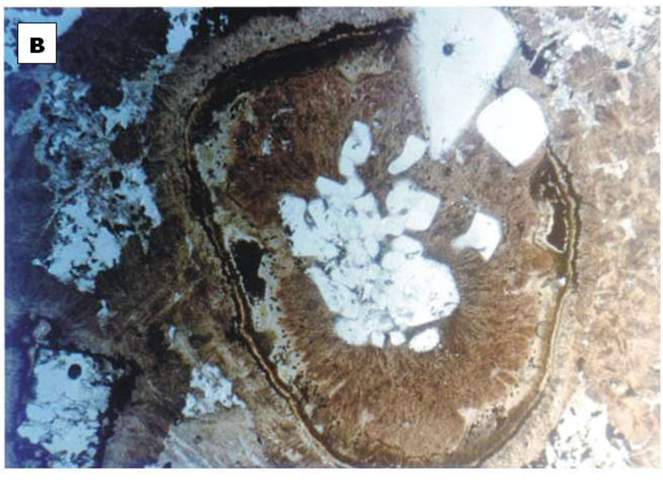


Figure 3. A and B: photomicrographs show different micro-textures (graphic, spherulitic) in the felsic dykes from the study area. These textures indicate devitrification and slow-cooling of these dykes, suggesting shallow emplacement

These graphitic materials may have host the mineralized fluids or formed and redistributed by later hydrothermal activities (Peters *et al*., 2007).High-grade mineral assemblages in upper amphibolite facies (~890 Ma; Karmakar, and Schenk, 2015) are frequently found at the study area, characterized by biotite and snow-ball garnet porphyroblasts. The principal minerals assemblage in this phase is staurolite, kyanite, tremolite, wollastonite, hornblende, biotite, and garnet.

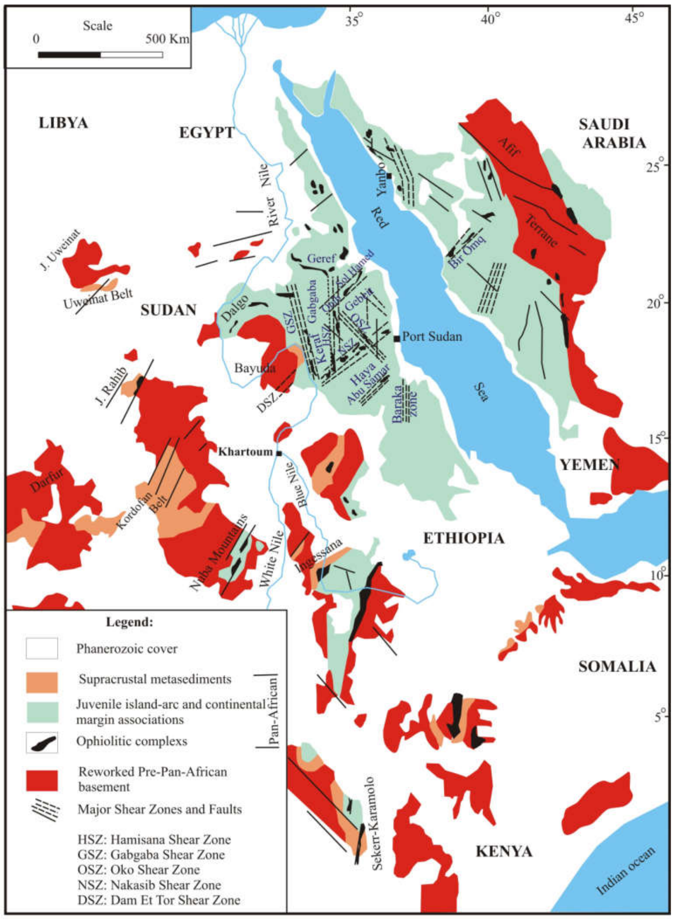


Figure 4. Distribution of basement units in Sudan and adjacent areas of Nubian-Arabian Shield (modified after Abdel Rahman, 1993)

The metamorphic re-crystallization (thermal metamorphism) at the study area (~670 Ma; Karmakar and Schenk, 2015), which occur at low temperatures produces hydrous minerals such as chlorite, and micas. With increasing of temperature, a series of dehydration and de-carbonation reactions occur (Fyfe*et al.,* 1978; Miyashiro, 1978; Chi and Xue, 2011). Devolatilization due to the metamorphism, which affected the volcano-sedimentary successions, is proofed as the source of mineralized hydrothermal solutions through the orogenic gold types (Groves *et al.,* 1998 and2015; Hu *et al.,* 2016). The average metapelites lose 5wt% of their volatiles is (2.6 % H_2O + 2.4% CO_2) during the prograde metamorphism; these devolatilization took place deep in the crust, and solutions trapped where it was produced. These solutions would occupy 12% of the rock volume at 500º C and 5Kbar (beginning of the hydrothermal solution stage) (Barnes, 1979). The aqueous fluids will precipitate quartz as it moves towards earth surface after pressure relief. These fluids focused into zones of high structural permeability and lower P_f penetration in shape of quartz veins. Foliated and fractured rocks, fault zones, fold hinges, and thrust zones are particularly the favourable places for gold deposition (Barnes, 1979). This can explain the spatial association of the auriferous quartz veins with schistose metamorphic rocks, and the open fractures in the study area, rather than other massive or non-foliated rocks. Devolatilization reactions are shown in following examples (Barnes, 1979):

Pyrophyllite = kyanite + quartz + H_2O
Muscovite + quartz = sillimanite + K-feldspar + H_2O
Calcite + quartz = wollastonite + CO_2
Dolomite = calcite + periclase + CO_2

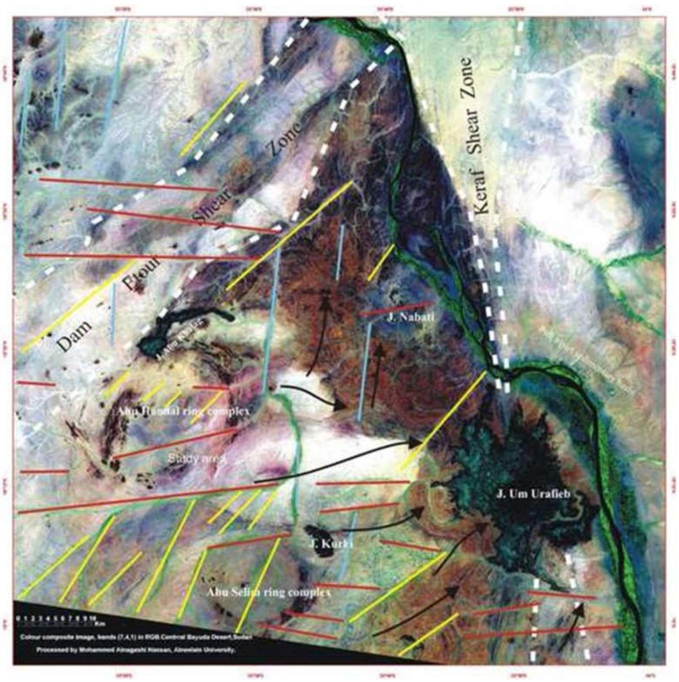


Figure 5. General trends of regional structures, and locations of ring complexes in eastern Bayuda Desert

RESULTS AND DISCUSSION

Gold Mineralization

In the Arabian-Nubian Shield, which Bayuda Desert is part of it; gold mineralization is affected by the emplacement of the post-tectonic granitoid rocks (late stage of D_2). The deposit occurs as Au-bearing quartz veins with few amounts of disseminated sulphide assemblages. Gold-bearing reefs display pinch-swell structures, showing evidences of multiple deposition stages. The P/T formation conditions of these reefs are at/or below greenschist metamorphic grade.The source of the ore-bearing fluids is related to late Precambrian (Neo-Proterozoic) subduction, and associated with calc-alkaline magmatism of island-arcs. The mineralized solutions are produced by metamorphism (Harraz, 2002), which formed under mesozonal conditions between (300 and 475) ºC at 150-300 mpa and depth exceeded 10 Km (Harraz, 2002). The thermal effects of deep magma could also play role, initiating devolatilization reactions, the circulation of meteoric water at deep levels, and/ordeep crustal assimilation, where magma reacted with Au-rich country rocks (Peters *et al.,* 2007; Zelenski*et al.,* 2016).Abu Khalag Auriferous quartz veins are structurally controlled by the older faulting systems (NNW) that exist during Neoproterozoic Pan-African tectonic events. High content of Cl in stream sediments geochemistry may suggest an existence of NaCl-rich inclusions in quartz veins

(Altigani *et al.,* 2016 b). The appearance of carbonates, kaolinized and sericitized materials confirms the metamorphic origin of gold mineralization.Abu Khalag gold mineralization is shear zone-related quartz veins type, these reefs lie within the continental collision (Island arcs collision) zones as known in many places throughout the world (Algeria, Canada, Australia, and Africa), and most of them are Archaean or Paleo-Proterozoic in age (Ferkous and Monie, 2002). The Neoproterozoic rocks in north-east Africa record as connected units resulted from the successive accretion of island arcs. These collision tectonics produced an extensive horizontal shortening along thrust zones and caused massive crustal thickening (Kröner, 1984; Abdelsalam, 2002 and 2011).The earlier generation of gold mineralization formed in an island arc setting, which related to the waning stage of tectono-volcanic activity that ended 715 Ma ago. During the Pan-African orogeny (650 Ma), induced regional deformation, metamorphism, magmatism, collision of micro-plates, and thickening are reported. Gold has been remobilized and re-concentrated either in the zone of metamorphic permeability or in the collapse breccia. Around 550 Ma ago, the final tectonic event is well-recorded along shear zones and trans-current faults with NE-NW and N-S trends (Elsamani*et al.,* 2010). This event was accomplished by crustal cooling, and formation of auriferous quartz veins along shear zones. The generation of gold was contemporaneous with the retrogressive phase of metamorphism and the rejuvenation of movements along the shear zones.

graphite are the main gangue minerals. Phase 1 quartz veins (reefs) show ductile deformation (folding, boudinage structure). Phase 2 show brittle deformations (shearing, jointing) and associated brecciating. Both quartz vein types show different colours, from pinkish, white, smoky, milky to dark grey. They have different textures such as sacaroidal, banded, and massive textures. The lengths and widths of quartz veins are varying from few centimetres (stringer, veinlet, and stock-work); to greater than 0.5 m usually discontinuous isolated patches occur.In the Abu Khalag gold is associated with the quartz veins, which are hosted in metasedimentary assemblages, especially calc-silicates. The gold in the study area found as gold-silver blend or inside the sulphide grains. Gold also found in placer deposits and residual soil, which covered vast parts of the study area. Total number of 9 chip samples were collected from the different phases of quartz veins. All the chip samples were analysed for gold using Aqua Regia and atomic absorption spectrometry(A.A.S) methods (Table 1). Based on the character of the mineralization structure patterns, and on the metamorphic grade of the host rocks, it suggested that both intrusions and vein systems formed in depths of at least 5 km with pressure of 2 Kbar (Kreuzer, 2004).Abu Khalag gold mineralization is orogenic gold deposits, which deposited from mesothermal hydrothermal fluids. These fluids could be generated from different origins and temperatures, from beinghigh temperature and magmatic or metamorphic to low temperature and sedimentary. The deposits are the result of more than one

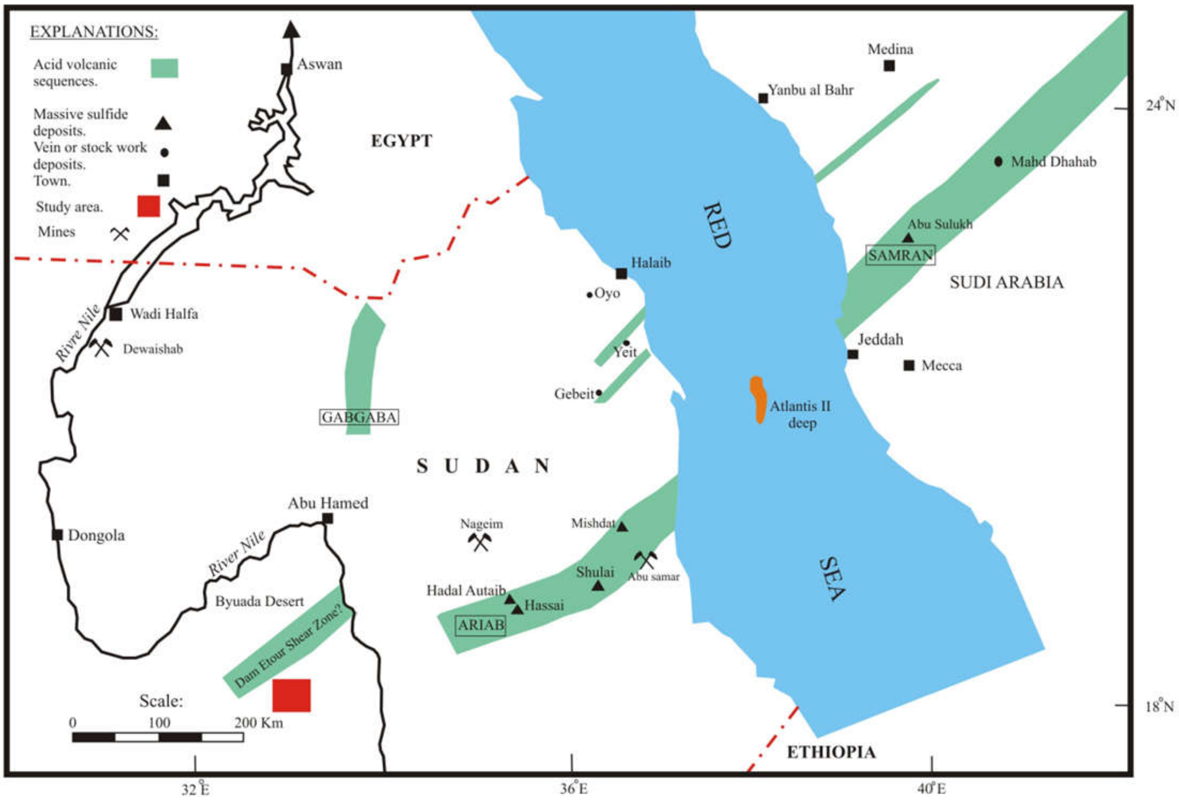


Figure 6. Sketch map showing the general trends of Au-bearing belts in Arabian-Nubian Shield (modified after: Babiker, 1977, personal communication)

Auriferous veins and related mineralization

Economically important ore minerals in Abu Khalag area include gold and associated pyrite, marcasite, arsenopyrite, and pyrrhotite. Minor ores represented by galena, sphalerite, and chalcopyrite. Quartz, carbonates (calcite, siderite, ankerite, and dolomite), feldspars, tourmaline, fluorite, barite, epidote, and

fluid episode and deposited under high intensity structures (e.g. Groves *et al.,* 2015; Peters *et al.,* 2007).

Hydrothermal Alteration

Proterozoic belts of Bayuda Desert have complex history of hydrothermal alterations, which related to the hydrothermal activity during the regional deformation, metamorphism, and granitoid emplacement. Intensive shearing and retrograde metamorphism would also cause formation of high temperature-acidic solutions, which are capable of leaching gold from source rocks under oxidizing and acidic conditions and transport it. As the hot solutions contact relatively cooler rocks at shallower depths, gold could be able to precipitate in appropriate structural and physiochemical traps. Therefore, the distribution of the Abu Khalag auriferous quartz veins, the zonal nature of associated wall-rock alteration around shear zones, structural and textural evidences suggest that gold mineralization is related to enhance fluid flux during deformation (Groves *et al.,* 2015; Harraz and Hamdy, 2015). Abu Khalag gold mineralization is a Neoproterozoic hydrothermal shear zone-related system of quartz veins. The alteration and mineralization processes in Abu Khalag area are restricted to specific setting and are presented in structurally favourable (Groves *et al.,* 2015) sites (hinges of anticlines of host rocks turbidites, hinges of Z-shaped ductile shearing).

Table 1. The statisticalparameters of Au in quartzveinfrom the study area (n=9)

Sample No.	Au (ppm)
1	0.20
2	0.70
3	0.20
4	0.12
5	0.40
6	0.07
7	0.05
8	1.28
9	1.47
Mean	0.50
Median	0.20
Max	1.47
Min	0.05
Standard deviation	0.54
Background	0.20
Threshold	0.57
Anomalous	0.60

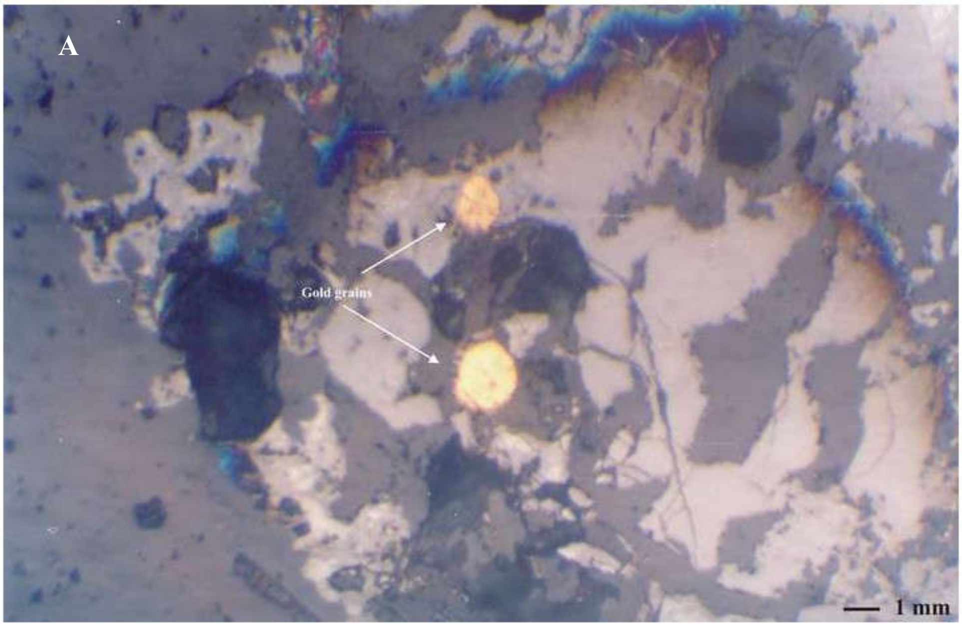


Figure 7. A: gold grain filling fracture in quartz vein phase 1.

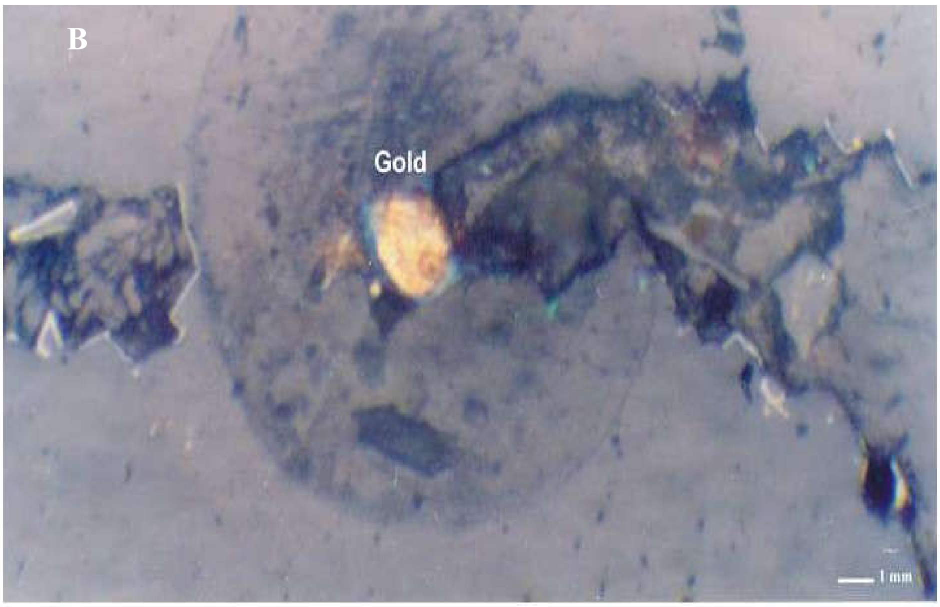


Figure 7. B: gold grains situated in highly fractured and oxidized zone in quartz vein phase 1

The hydrothermal activity at the study area is shown in many ways; one feature is quartz, quartz-calcite, and calcite veins, which form lenses and stringers in wall-rock alteration zones. Other features are the silicification, kaolinization, and sericitization processes. The presence of sulphides in wall-rock alteration zones and the replacement textures indicate the fundamental roles of hydrothermal components such as H_2O, CO_2, and Cl in the host rocks. The hydrothermal activity of deep-crustal metamorphic fluids formed during ophiolite emplacement and reaction with sea water within the orogeny environment (Groves *et al.,* 2015). Retrograde reactions (e.g. Ca-rich plagioclase → Na-rich plagioclase) cause freeing massive amount of hot silica that captures gold and other sulphides. These auriferous quartz veins usually occur adjacent to carbonate lenses within the host rocks, which indicate sub-marine environment of formation. Later tectonism and associated metamorphism lead to hydrothermal circulation and rejuvenation, and then deposition as auriferous reefs after pressure release.Gold in quartz veins found in two genetic types: sub-microscopic inclusions inside the sulphides (basically pyrite and arsenopyrite), and as free lodes in the silicates. The gold lodes size increases due to the metamorphic recrystallization (Ixer, 1990). Quartz veins in Abu Khalag can be divided into two main sub-groups or phases based on their size, colour, and mode of occurrence.

Table 2. Summery of the chemical reactions that take place in alteration zones of deposits in green schist facies rocks after (Kerrich, 1983)

A) **Outer zone**: (formation of quartz, sericite, chlorite and epidote):
1) 3 (Ca, Na) Al2 Si2O8+CO2+1/2 H2O → Ca2 (Al, Si) 3 O12 (OH) +Na Al Si3 O8+CaCO3+1/2O2Plagioclase epidote
albite calcite
2) Na Al Si3O8+K^{+1}+2H^{+1}→ K (Al Si) 3O10 (OH) 2+6SiO2+3Na^{+1}
Albite fluid sericite fluid
3) 6Ca2 (Mg, Fe) 5 SiO22 (OH) 2 +12CO2+14H2O→5 (Mg, Fe) 6 SiO4O10 (OH) 8+12(CaCO3) +28SiO2
Actinolite chlorite
calcite quartz
B) Inner zone: (quartz, sericite, carbonate, epidote, arsenopyrite and pyrite)
4) NaAlSi3O8+ (Mg, Fe5Al2Si3O10 (OH) 8+5CaCO3+5CO2+K^{+1}→KAl3Si3O10 (OH)2+ 5Ca (Mg,
Albite chlorite calcite sericite
Fe) (CO3)2 + 3SiO2 + 3H2O + Na^{+1}
Ferron-dolomite quartz
5) (Mg, Fe) 6Si4O10 (OH8) +6CaCO3+6CO2→6Ca (Mg, Fe) (CO3) +4SiO2+4H2O
Chlorite calcite fluid Ferron- dolomite quartz
6) 3(Mg, Fe) 6Si4O10 (OH) 8+15CaCO3+2K^{+1}+15CO2→2KAl$_3$Si3O10 (OH)2+
Chlorite calcite fluid sericite
15Ca (Mg, Fe) (CO) 2+3SiO2+9H2O+2H^{+1}
Quartz
7) Fe3O4+6H2S+O2→3FeS2+H2O+2H^{+1}
Magnetite fluid pyrite
8) Fe+2H2S+1/2O2 → F2S+H2O+2H^{+1}
Free iron fluid pyrite
9) Ca (Mg, Fe) (CO3)3+2H2S+1/2O2→Fe2S+CaMg (CO3)2+CO2+H2O
Ferron dolomite fluid pyrite dolomite

Phase one

This type is early mineralized phase, mostly horizontal and trending NW-NNW in direction. They inserted within the schistosity of the host rocks. This type shows boudinage structure, indicating ductile shearing. The thickness of the veins in this phase is between 3 to 30 cm, and they vary in length. These stringers are surrounded by kaolin-rich alteration zones. The distances between stringers are irregular (average 10-15cm), and the stringers are dipping 20º due SW.This type of auriferous quartz veins seems to be affected by secondary enrichment processes. Gold is re-concentrated in the foot wall alteration zones rather than in the quartz veins itself. This also indicated by the high content of iron in polished sections. The replacing of magnetite by hematite and the emplacement of gold and pyrite in the fractures of gangue minerals are other supportive factors.The alteration zones are composed of kaolin, sericite, and ankerite. This type of quartz veins is highly sheared, jointed (three sets), and brecciated. The kaolin-rich materials in the wall-rocks are rounded and ellipsoidal, indicating reworking and movement during hydrothermal alteration. The thickness of hanging wall reaches up to 15 cm, and foot wall up to 20 cm, and both alteration zones are mineralized. The colours of these quartz veins vary from grey to reddish brown depend on their iron contents. Their contents of gold are rather higher than the other type (>1ppm). They are thick at the hinges of folds indicating ductile deformation (Mehnert, 1968). This horizontal veins type seems to be inserted syn- to post to D_1 in the extensional fractures. The existence of horizontal reefs suggests that original mineralized-fluids were intensely over-pressed during veins formation; it has been noticed in other orogenic gold deposits (Chi and Xue, 2011).

Phase two

This phase is intercalated with carbonates. They are whitish coloured, reflecting lower iron contents, and showing staining of malachite. Ductile dextral shearing affected this vein type, which is located in tension gashes formed by superimposition of two sets of shearing. The veins strike NE (0º-60º), and situated in the tension gashes of D_2. The concentration of gold in this type of quartz veins is up to 0.4 ppm (Table 1). These veins are shallow in depth, and longer than phase 1 veins, and their thickness up to 1m.

Gold Precipitation in Abu Khalag Area

Abu Khalag gold mineralization is mesothermal gold type, which occurs in depths between 5 to 10 Km. Ductile deformation and shear zones are often observed in the study area, and have clear effects in the gold deposit. These deep shear zones became paths for the thermal fluids, which responsible of gold precipitation. Field observations revealed wide spread processes of carbonation, chloritization, and sericitization have been occurred during ductile deformation and hydrothermal alterations (Table 2). The rapid drop in pressure associated with the formation of breccia-veins lowered gold solubility (Craig and Vaughan 1981). The CO_2-rich fluids move rapidly upwards and the remaining fluid became saturated with sulphides and gold. Brecciating increased at the surface area exposed to the hydrothermal fluid, enhancing the rate of the metasomatism and gold precipitation. Gold complex with sulphur-bearing species became unstable and precipitation of gold occurred when these fluids lose sulphur species by the reaction with the Fe^{+2} to form pyrite and other iron-rich sulphides (Colvine*et al.,* 1984). In addition, magnesian-basaltic oceanic crust, considered as one of causes for mobilizing iron from gold-rich pyrite in superimposing subduction-related oceanic sediments (Steadman *et al.,* 2013). The metamorphic alteration of the sulphides are playing big role released the metallic elements in to the mineralizing fluid during prograde metamorphism (Hu *et al.,* 2016).The physical traps of gold are those of permeable media such as brecciating zones. Chemical traps (in this case carbonates) include any condition that lead to chemical precipitation of gold from a fluid due to change in pH or Fe/S/O_2 fugacity in the solution. In Abu Khalag, gold was re-concentrated by two possible processes:

a)Intrusions

The area around Abu Khalag displays severalsyn-orogenic acidic ring-dykes intruded during major faulting events.

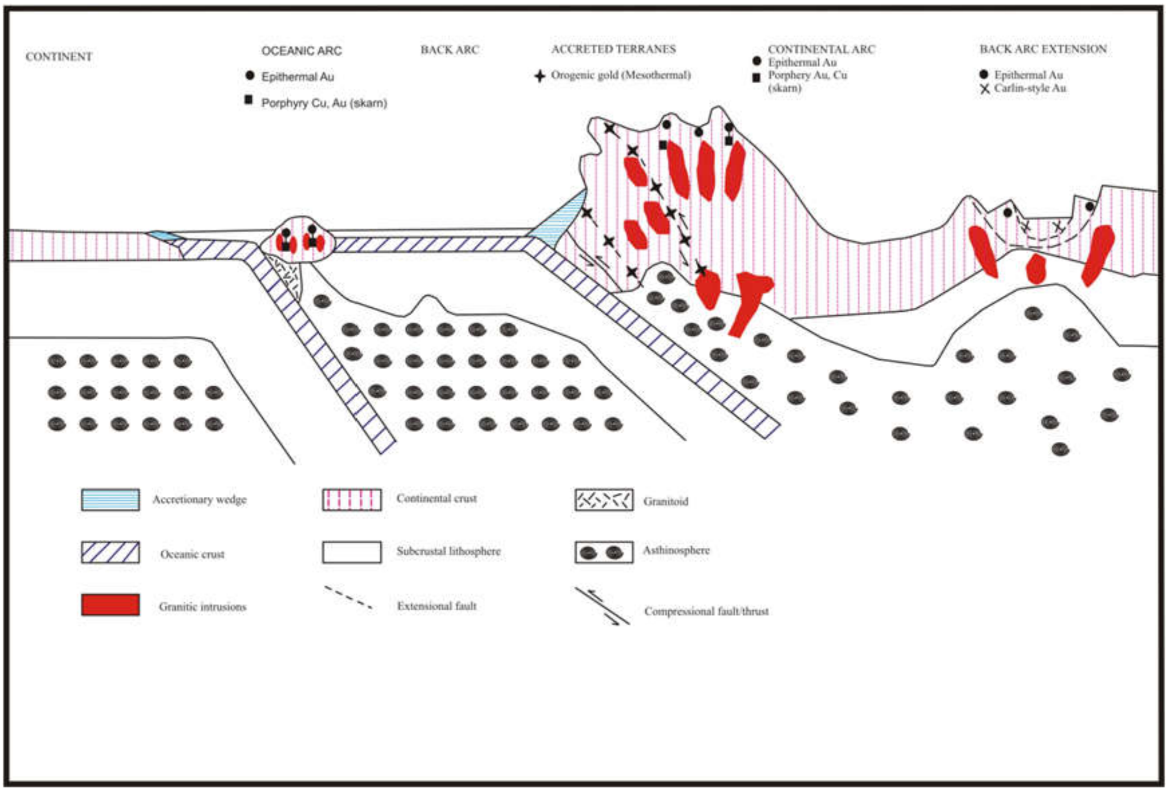


Figure 8. Geological sketch illustrates tectonic settings of gold-rich epigenetic mineral deposits. Epithermal veins, gold-rich porphyry, mesothermal gold, and skarn deposits, form in the shallow (~5 Km) parts of both continental and island arc in compressional through extensional regimes (modified after Groves*et al.*,1998)

Table 3. Selected analyses of stream sediments samples from the study area (in ppb using AAS technique)

Sample No.	1	2	3	4	5	6	7	8	9
SiO_2	34.12	40.12	41.7	42.54	39.98	41.5	27.46	40.54	41.89
Al_2O_3	11.3	12.48	13.48	13.23	12.2	13.31	10.28	13.7	13.49
Fe_2O_3	6.61	5.85	6.57	7.08	7.48	6.55	7	6.38	6.96
MgO	3.1	2.03	2.7	2.7	2.53	2.48	2.06	2.49	2.72
CaO	8.88	2.53	2.77	3.24	3.11	3.97	11.66	2.82	2.89
Na_2O	0.99	0.64	0.64	1.53	0.59	0.59	0.21	0.57	0.59
K_2O	0.76	1.06	1.23	1.16	0.78	0.94	0.36	1.04	0.96
TiO_2	1.15	1.2	1.25	1.41	1.36	1.69	0.85	1.37	1.32
Ag	2.5	b.d.l	b.d.l	b.d.l	2.5	2.5	2.7	b.d.l	2.5
As	<10	<10	<10	<10	<10	<10	134	<10	<10
Ba	229	284	303	269	238	282	217	283	273
Co	20	12	16	18	24	21	19	16	17
Cu	13	18	24	26	37	24	34	24	26
Cr	116	103	106	105	140	146	112	108	101
Ga	12	12	14	12	8	12	9	12	14
Mn	756	564	703	804	846	734	610	685	752
Ni	38	31	33	30	43	35	35	32	35
Rb	24	30	33	28	23	23	13	26	26
Sr	180	155	171	223	169	206	144	180	186
V	138	120	128	152	160	149	155	141	154
Zn	65	48	60	59	55	50	50	60	61
Zr	469	536	524	622	466	707	240	529	428
Au	1.43	0.12	0.9	0.15	0.21	0.44	0.11	0.18	0.4

Stream samples taken close to these dykes give the highest value of gold. These reflect the important role of these intrusions and ring complexes to remobilize gold (post-tectonic mineralization phase) (Hein, 2015). It also confirmed by the local artisanal workers' activities, which focus panning the residual soil surrounding these felsic dykes, where centimetres-size gold nuggets have been reported. The relationship between Au-rich reefs and intrusions has been described in many places worldwide (e.g. Voroshin*et al.,* 2014; Hein, 2015).

b) Supergene enrichment

Supergene gold within the oxidized zone on the top of the auriferous hydrothermal fluids occurs usually as physico-chemical alteration, forming sub-rounded primary gold grains (Fig. 7a&b). Iron caps (gossans!!) have been noticed in many localities at Abu Khalag and surrounded areas.

Source of Gold

Various models have been proposed for the formation of mesothermal lode gold deposits (Fig.8). However, the two most important models for the sources of gold are mantle degassing and metamorphic dewatering (dehydration de-carbonation) (Fyfe*et al.,* 1978; Craig and Vaughan, 1981; Chi and Xue, 2011). Mantle degassing model suggests that gold mineralization occur during carbonitization and uplifting of the greenstone belts at the end of the crust forming cycle. After then gold bearing solutions pass upwards through the crust via ductile-brittle fracture systems, and deposit along regional extensional zones. Therefore, the source of gold was derived from upper mantle or formed along juvenile igneous rocks. The metamorphic dewatering model proposes that the ore fluids, which carry gold as reduced sulphur complexes are derived by devolatilization of the lower parts of greenstone successions during metamorphism and late-stage deformation, and granitic intrusions (Hein, 2015). In the case of Abu Khalag, and Bayuda in general, the formation of gold is probably due to the metamorphic dehydration processes. This is indicated by the structural setting, which suggests that the ore deposits are not very deeply seated. The assemblage of gangue minerals found is like that of mesothermal association such as muscovite, ankerite, biotite, albite, oligoclase, epidote, hornblende staurolite, ilmenite, and garnet.Orogenic and sulphide-rich chemical sediments may have trapped-gold liberated from favourable sources. Concentration of Au, S, and chalcophile elements was developed during the deposition of the volcano-sedimentary (turbidites) sequence, and extensional phase of basin evolution. As the basin continued to expand, a subduction zone was formed, and related immature island arc magmatism commenced (Abdel Rahman, 1993). The subduction event is also characterized by eruption of Bayuda volcanics, and emplacement of syn-volcanic plutons. Subduction- related thermal events, episodically raising geothermal gradients within the hydrated accretionary sequences, initiate and derived hydrothermal fluid for long distance (Peters *et al.,* 2007; Groves *et al.,* 2015; Zelenski*et al.,* 2016).

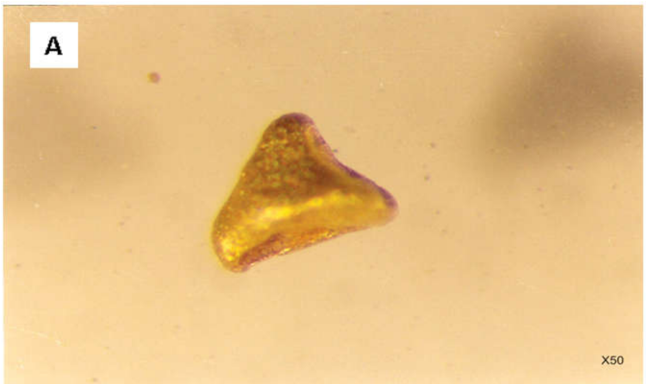
Sub-sequent strike-slip deformation, emplacement of mineralization and nappe tectonic are associated with collision of the island arcs and Bayuda terrain and resulted in closure of oceanic basins (they could be many isolated basins) (Abdel Rahman, 1993). The gold mineralization has been subjected to folding, refolding, shearing, and fragmentation (Abdel Rahman, 1993). However, the present structure of quartz veins may indicate that mineralization was introduced by hydrothermal fluids migrating along original thrust plane structures, which opened during a period of dextral kinking and faulting. The mesothermal gold deposits formed at 200º-400º C, they are structurally controlled vein systems found in metamorphic belts, principally in greenschist facies rocks (Groves *et al.,* 1987, 1988, and 1998). However, the auriferous reefs in the study area are found also associated with amphibolite facies rocks. These gold reefs are commonly located in the second or third orders of the structures, most frequently near large-scale compressional deformation. The control of the structures on gold deposits are highly variable, ranging from (i) brittle faults to ductile shear zones with low angle to high angle reverse to strike-slip motions. (ii) Foliated zones or (iii) foliated hinges in ductile turbidites sequences (Groves *et al.,* 1998). These structures and features have been observed in Abu Khalag and at adjacent sites in the Bayuda Desert.

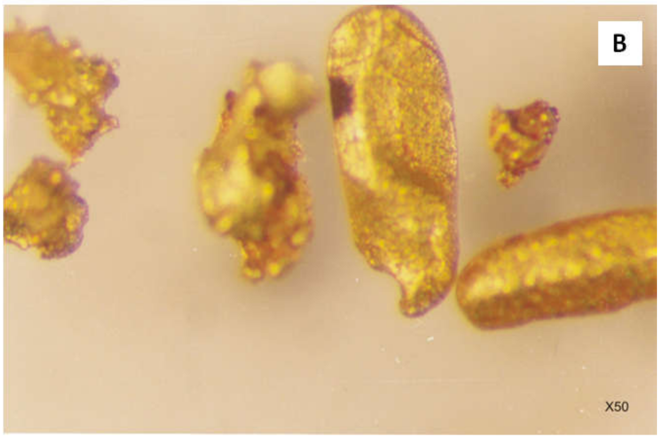
Geochemical Orientation Surveys

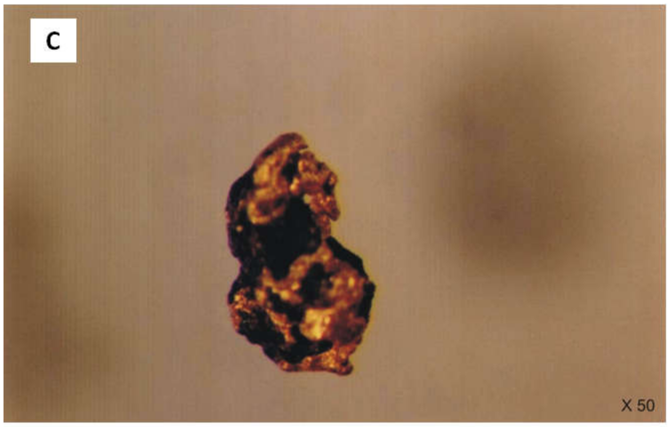
Since problems of exploration may occur in detecting primary or secondary gold dispersion haloes of mineralization, it is necessary to apply an orientation surveys, in which exploration geochemistry carried out. The objectives of orientation studies, which have been done by Sudanese-French Project (2000) in Wadi Singeir area gave results that maximum yielded sieve fraction for soil is -125 µm and for stream geochem is -63 µm, which have been followed in this study.Due to the arid environment in Abu Khalag area, in which the hydrolysis of rocks and ores is weak and the mechanical weathering is more dominant than chemical weathering, also to avoid problem of dilution of stream sediments by aeolian materials, stream sediments samples of Abu Khalag area have been treated in two different ways: (i) heavy mineral separation, to eliminate diluents effect of wind-blown sand, and (ii) Fine fraction (-63µm).

Secondary Occurrences-Placer Deposits

The study of placer deposits is difficult and requires lots of efforts to understand the formation conditions of these deposits. The effect of sedimentological, geomorphological, tectonic, and mineralogical processes is playing big role for the precipitation and formation of the heavy minerals (Dill, 2008). Nevertheless; placer gold deposits represent almost two-thirds of the world's gold reserves, and about 25% of global production (Moufti, 2014).In this work several samples have been collected in search for placer gold in Abu Khalag area. Nine out of twenty stream sediments samples produced gold nuggets. The morphology and grain shapes of gold nuggets indicating vein type deposits. The roundness and size of nuggets reflects short distance of transportation. This suggests that undiscovered primary sources (not only quartz veins) belong to another association are existing in Abu Khalag area, which requires more exploration works in the bedrocks.The erosion of gold-bearing veins and sulphide ores has, in many places, resulted in formation of placer deposits. The nature of the gold in such occurrences depends on composition, grain size, and gold grade in the source rocks. The gold in placer deposits has been dispersed along stream channels through the normal processes of erosion, transportation, and concentration based on its very high specific gravity (15-19 g/cm^3). The gold nuggets from the streams show wide varieties of sizes and shapes (**Fig. 9 a&b**), but are mostly flattened and flake-like to roughly spherical. Some gold grains display intergrowth with accessory minerals, mainly quartz. The morphology of gold grains reflects slow rate of erosion due to gentle slope, it also shows that water is not the only cause for transportation and sedimentation.







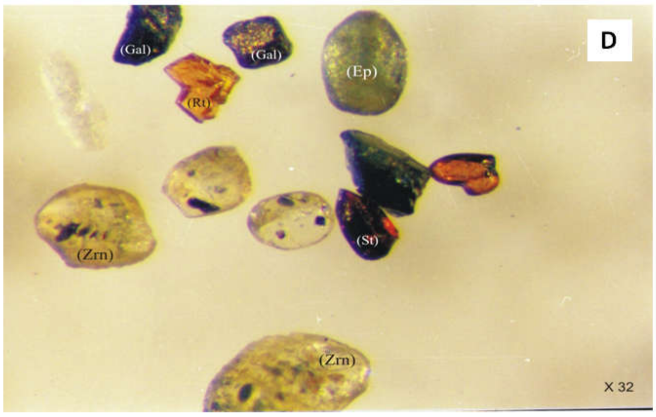


Figure 9. Photomicrographs of gold nuggets from stream sediments in the study area A: triso-octahedron, indicating nearby source. B: shows different shapes and sizes of gold nuggets. C: gold with sulphides (galena), reflecting that gold is essentially associated with sulphides then remobilized into free-lodes, and D: Gangue mineral associated with gold in stream sediments, (Gal: galena), (Rt: rutile), (Ep: epidote), (St: staurolite), and (Zrn: zircon). The zircon grains contain fluid inclusions

The grains commonly display morphologies derived from the surrounding silicate or carbonate crystals of the primary sources. Transport of gold grains results in them being abraded and leached. However, many of the gold grains inherited their original angular crystal shapes (Fig. 9 a&b). The surface leaching of gold grains results in a depletion of silver contents. The crystal faces of some nuggets, which are far from the source (quartz veins), have led to speculation that the nuggets may have grown insitu by slow precipitation and accumulation of gold in the streams. These kinds of gold grain shapes in placer deposits are very rare and found in auriferous massive sulphide deposits or gold-bearing porphyry deposits, which are close to the subduction zones. Gold nuggets have reddish and greenish yellow colour, suggest increasing in iron and copper contents.Some gold nuggets are visibly included in the sulphides (galena), indicating that gold is originally associated with sulphides in the primary source(Fig. 9c). This confirms remobilization and transportation of gold in volcanogenic sulphides by devolatilization, and deposition in physico-chemical traps.

In the stream sediment samples, the common sulphides and gangue minerals associated with gold are galena, pyrite, arsenopyrite, tourmaline, zircon, rutile, apatite, epidote, and staurolite (Fig. 9d). This assemblage reflects low-grade metamorphic source rocks. It also confirms the mesothermal origin of gold mineralization (dehydration of metasedimentary rocks) in Abu Khalag. In the placer deposits environment, chemical elements mainly dissolved in water, adsorbed and incorporated in Fe-Mn oxides (Ta *et al.,* 2015), in clay minerals such as sulphides and sulphates etc. Therefore; fine-fractions of the stream sediments have high adsorption capacity for precious elements. Stream sediments as well data give unique picture of trace element distributions that reflect not only the presence of anomalies related directly to the leaching or erosion of ore bodies, but also for the geochemical characteristics of host rocks. The use of fine-fractions of stream sediments includes several advantages (i): homogeneity of the back-ground population and later confidence in the assessment of anomaly and threshold values (ii): better sampling statistics and lower costs. Significant high values of Al_2O_3in the fine-fraction of these samples are due to the intensive presence of clay minerals, which adsorbed the trace elements (especially Au) between sheeted clay crystals. Mn and Fe contents in stream sediments have high values; they form secondary oxides because of changes on Eh and pH values. These two oxides have ability to absorb and/or co-precipitate metals from various sources. Na_2O and K_2O have low values, due to leaching during the weathering.

Therefore, both elements are not considered. Most values of trace elements Ag, Cd, Cl, Hg, Sb, Tl, Sn, and W: are below detection limit. Elements such as As, Ba, Bi, Br, F, Co, Cu, Cr, Ga, Mo, Ni, Pb, Rb, Se, Sr, V, Zn, and Zr show high values because of adsorption and incorporation in Fe and Mn oxides.

The scavenging of these metals by Fe and Mn oxides takes place by one or combination of the following mechanisms: (i) Co-precipitations. (ii) Adsorption. (iii) Surface complex formation (iv) Ions exchange (v) Penetration of the crystal lattice (Levinson, 1980). The concentrations of these elements are relatively higher in the fine-grained fractions (-63 µm). The mobility of elements Au, Cu, Co, Ni, Hg, and Ag are medium under oxidation conditions, but higher under acidic condition. Those elements become immobile under neutral to alkaline conditions, which cause precipitation.The use of statistics reveals that two of the examined samples have high values of Ca, Ba, other samples have high values of As. All the samples have high values of F_2, Mn, Ba, and Sr, indicating hydrothermal alteration. The high contents of Cr, V, Ni, and Co indicate presence of basic components in the source materials. High values of Zr indicate the presence of felsic associations (zircon) in the stream sediments, which occur nearby to the meta-volcanosedimentary rocks.

Statistical Parameters of Stream Sediments

The gold and trace elements results of stream sediments samples, which collected from the study area, are presented in (Table 3). Elements such as As, Cd, Hg, Th, Br, Bi, Cl, Cs, and W show values below the detection limits, Pb, Mo U, Sn, Sc, and Ag show values below the detection limit in some samples. The rest of the elements that include, Si, Al, Fe, Co, Cu, Cr, Zn, Zr, Ti, Mn, Ni, Ba, Rb, Sr, V, Mg, Ca, Na, K, and Au represent high values in all samples. Statistically, most of the trace elements are normally distributed, because of the agreement between median and arithmetic mean. Gold shows erratic distribution in the stream sediments. This may suggest contamination of sediments by desert storms and winds. This also must be considered during the evaluation of Au grades in stream sediments of the study area and in other similar windy arid zones. The background and threshold values of gold in stream sediments were chosen after evaluation of the geochemical data, the background value decided to be 0.21 ppb (median), the threshold value for gold in stream sediments is chosen to be 2.91 ppb, and the anomalous value is 3.0 ppb, this value is greater than the threshold values for stream sediments in other parts of Bayuda Desert (Mohammed, 2005). The Au anomalous value, which defined as a deviation or departure from the norm, in sediments is calculated as 2 or 3 times the background value, or it means all values that above threshold (Levinson, 1980). The highly anomalous values of gold in sediments concentrated at the contact between the low-grade meta-volcanosedimentary rocks of Kurmut and Rahaba Series and Abu Handal ring complex (sheared granitoid). This indicates that these ring complexes have contact aureoles among the source rocks, which led to re-concentration of gold in weakness planes of fractures, foliation, and bedding planes. Mohammed (2005) concluded that the anomalous gold contents are spatially related to supracrustalmetasediments of Kurmut series and metasediments of Abu Harik series. In this study, samples from the metasediments of Rahaba series yield anomalous gold values as well.

Correlation Matrix

To know the inter-relationship between the elements and ratios, a correlation matrix of data has been generated using (STATISTICA 6.0, 1995) software program. The utility of a correlation matrix lies in the fact that it allows for a rapid determination of the behaviour of trace elements in the system. The results of correlations between elements of the stream sediments give an idea for the co-precipitant elements with Au in drainage basins, the depositional conditions, and the nature of the source. Au is moderately correlated with Cu, which is positively correlated with Co, indicating primary copper associated with high temperature chalcophile minerals such as chalcopyrite. Correlation between Au and (Cr, V) is low, suggesting that primary gold was precipitated in mesothermal environment, thus confirmed by the high positive correlation of gold with mesozonal elements, such as, Pb, Zn, Rb, and Ga. The existence of Cr and V in these sediments reflects the composite sources.High contents of Cu, Zn, and Fe indicate that gold has strong association with sulphides. This confirms the mesothermal gold deposits origin. The highly positive correlation of Au and Ni, Co, Mg, Ti, and Fe suggests presence of mafic minerals in the source of the stream sediments. It shows that the origin of gold was associated with basic/ultrabasic rocks (Peck and Huminicki, 2016). The mafic rocks are proposed to be derived from oceanic (ophiolites) assemblage. Later, gold was re-concentrated by metamorphism and devolatilization processed these mafic rocks into greenschist assemblages, including carbonates-rich quartz veins under mesozonal conditions. The mesothermal conditions are also supported by the positive correlation between Au and (Ca, Ga, Si, and Rb), which associated with K-feldspar (adularia), tourmaline, and ankerite, which are indicative for mesothermal deposits. The positive correlation of Al_2O_3 with Cu, Pb, Ni, and Zn is due to their absorption by the clay minerals.The stream sediments data has been evaluated using basic statistics, histograms and correlation matrix. The values below the detection limits are replaced by the criteria $Xi = 0.5^x$ lower limit before statistical analysis (Kelley and Kelley, 1992). The coefficient of variation value of gold is 0.5, which indicates erratic distribution of Au in stream sediments (Levinson, 1980).

Summary and Conclusion

In the Arabian-Nubian Shield, gold mineralization is widely associated with greenschist assemblages and post-tectonic granitoids. Most these deposits occur as Au-bearing quartz veins including disseminated sulphide assemblages, and display deformation, shearing structures, and show evidences of multiple mineralization stages. High content of chlorine in stream geochemistry may suggest the appearance of NaCl-rich inclusions in quartz veins. Abu Khalag gold deposits is mesothermal, shear zone-related mineralization, related to Archaean or Paleo-Proterozoic tectonism. This confirmed by geochemical, lithological, structural, and mineralogical features of quartz veins and the style of wall-rock alterations, which include sericitization, chloritization, kaolinization, and silicification. During Neoproterozoic time, the rock assemblages in northeast Africa recordedaccretion of older cratons, as well as juvenile growth of continental crust and successive collisions of island arcs (Evuk*et al.,* 2014). Abu Khalag gold mineralization formed in depths of (5-10 Km), towards the base of the seismogenic zone in the upper continental crust which, in areas of strong fluid release, acts as stressed elastic top containing overpressure hydrothermal fluids derived from metamorphic dehydration at deep levels. Au-quartz veins are hosted by faults, fractures, and hinges of the greenschist facies and to some extent in amphibolite facies. Au-grade in quartz veins range between 0.05 and 1.9 ppm. The auriferous quartz veins in Abu Khalag are divided into two main groups based on and Au grades. Field observations indicated that these veins are structurally and lithologically controlled, and it is very important to consider these litho-stratigraphic criteria during any future prospecting and exploration works.The gold background value in stream sediments is 0.21 ppb, threshold values is 2.91 ppb, and the anomalous value is 3.0 ppb. This work finds that the more important pathfinder elements for gold are Cu, Zn, and Pb in the stream sediments samples. The best mesh fraction for gold in stream sediments samples is -63 µm and for residual soil is (-125). This may help to explore new gold locations, especially in remote and difficult areas with no outcrops or exposures. Based on the results reported here, it is recommended that any exploration work in the study area and in Bayuda Desert as general should be based mainly on effective Au sampling, in care with structural, lithological, and associated pathfinder elements of gold-bearing quartz veins. Future research is required in the study area to reveal more knowledge concerning the formation of gold, and the relationships between bedrocks and mineralized reefs.

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