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Metallogenic characteristics of some localities of gold mineralization along shear zones of Elgaab, Dum el Tor and Sodri - Um Bader, (Sudan)

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Research Article

Keywords:

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ABSTRACT

Study area is located in the eastern sector of Saharan Meta - Craton that includes the western part of Bayuda Terrane and extend southwest to Sodri - Um Badir shear zones. The sector is dominated by metasediments, metavolcanic - sedimentary series represented by chlorite - schist, quartzite, calc - silicate, and marble. Low - grade metamorphic arc - related volcano - sedimentary sequence occurs as thin narrow bands and subjected to tectono - thermal events of Pan - African orogeny during the Late - Proterozoic era (900 - 550 Ma). All these rock sequences have been intruded by syn to Late Orogenic Granitoids and post - orogenic ring - shaped complex and felsic dykes. The intrusions are thought to be the source of hydrothermal fluids that caused the precipitation of gold. Similar characteristics of geological features and tectonic settings support the possibility of the extension of gold mineralization between shear zones. The comparison between the three gold mineralizations reveals variations in minerals assemblages, pathfinders and gold grade. The result of this study defines a new metallogenic province in the west of the River Nile, which occupies a very large area covered by Phanerozoic sediments. Numerous mineral deposits of economic potentiality have been targeted along the shear zones and related fractures and faults. Among those potential deposits, five of them have been chosen as targets for future gold exploration and evaluation.

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1. Introduction

The study area is located in the eastern sector of Saharan meta craton, which is bounded by Uweinat - Salima tectonic belt in northwest Rahib ophiolite Belt in the southwest, and the southwestern boundary is the NE trending Wadi Hawar uplift. Central Africa Fault Zone with deep NE - SW - striking faults extended through the southern side and the western margin of Bayuda desert is bounded eastern side of the study area (Figure 1). The area is relatively flat and cover by thick Phanerozoic sediments. Field observations, geological mapping, and geochemical investigations suggest that

study area, dominated by low - grade meta - volcano - sedimentary sequences, has similar litho - tectonic features with North Kurdofan considered by Rahman and Elmahi, (2006) as a possible west continuation of the Upper Proterozoic Pan African Arabian Nubian Shield. The general NE - SW striking of the low - grade Pan - African rocks sequences was parallel to the dominant strike directions all over the Arabian Nubian shield. Gold mineralizations in Elgaab, Hamadi gold mine (Dum el Tor) and Gammama area of Sodri - Um Bader shear zones reveal similar characteristics geological, structural features and tectonic settings.

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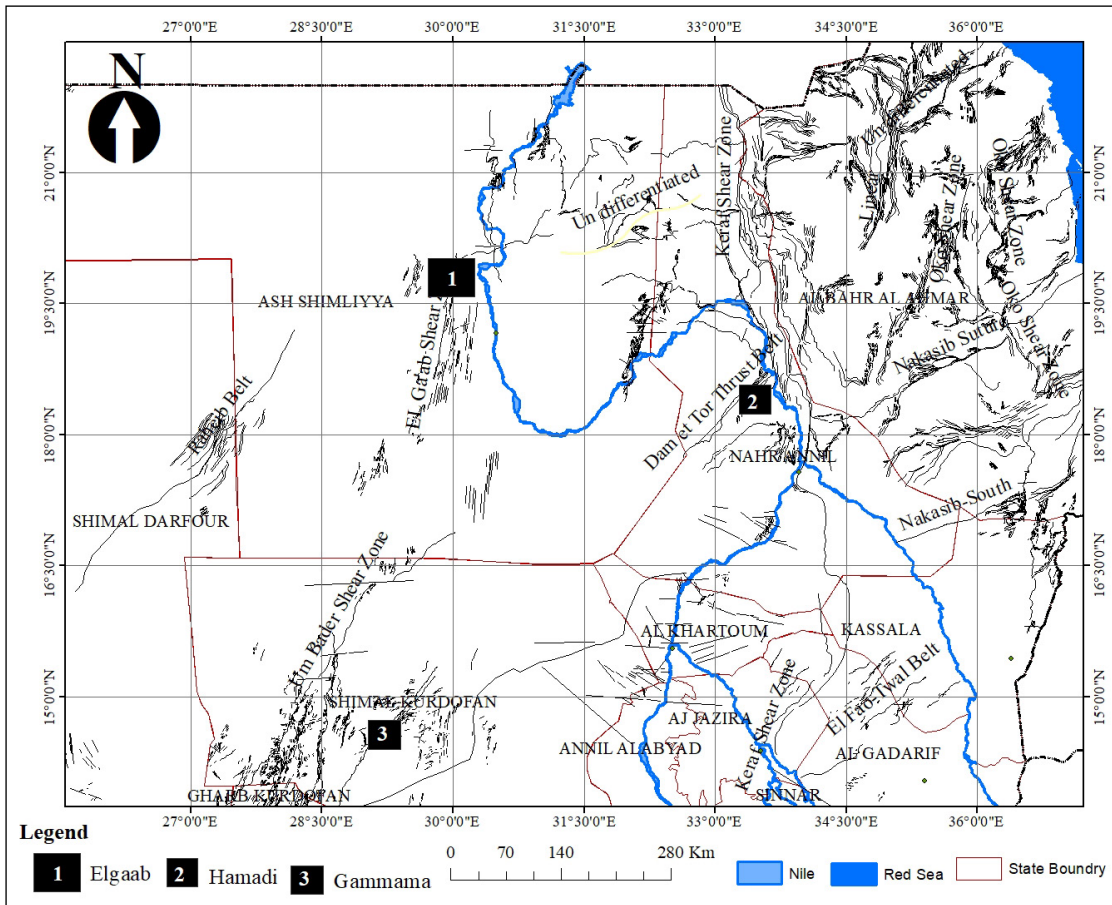


Figure 1- Location map of areas of study.

These characteristics support the possibility of the continuation of gold mineralization between the shear zones.

1.1. Applied Method

A total of 246 samples (25 chips of quartz and rocks, 31 soil, and 190 trenches samples) have been collected and analyzed using X - Ray fluorescence (XRF) method and Atomic Absorption Spectrometry (AAS) XRF analytical method: 10 g of powder sample mix by wax as binder press by pressing machine to make pallets, then read by XRF instrument, calibrated by panalytical stander for all elements (from Be to U). The determined elements depend on the wave length of the elements. AAS, used for analysis of basic elements Co, Ni, Zn, Fe etc.

0.5 g of powder sample adds to mixture of acid hydrofluoric, per chloric and nitric (10 ml, 5ml and 2ml respectively). Dry in hot plate after add 10 ml of HCl 50% then transfer the solution into 50 ml volumetric flask then read it by AAS after calibrated by series of

stander solutions. The artisanal gold mining mega-pits and trenches in Elgaab area have helped substantial investigations of the subsurface geology, besides the description of the shapes, features and geometry of the ore body, lithological horizon bearing mineralization since there are no boreholes and geophysical survey conducted in the area. The main aim of the study is to define spreading of the gold mineralization along shear zones beneath thick cover of Phanerozoic sediments. As a result of the study, based on the geological, geochemical and structural features, possible new metallogenic province is defined in the west part of River Nile. In the process, geological, geochemical and structural studies were carried out in the three shear zones.

2. Geological Setting

2.1. Lithology

Metasediments, metavolcano - sedimentary series represented by chlorite - schist, quartzite, calc

- silicate, and marble are dominantly outcropped in the study area. Low - grade metamorphic arc - related volcano - sedimentary sequence occurs as thin narrow bands and subjected to tectono - thermal events of Pan-African orogeny during Late - Proterozoic era (900 - 550 Ma), resulted in low - grade green - schist to lower amphibolite facies, with local high - grade gneiss inlier. All these rock sequences have been intruded by syn to late orogenic granitoids mainly diorite and post - orogenic ring - shaped complex and felsic dykes. The basement rocks of Northern Kurdofan consist of high - grade and low - grade metamorphic assemblage exposed in the foreland of the Arabian - Nubian Shield in the western Nile. Those assemblages are intruded by syn - orogenic granite and post - orogenic granite and dykes. Shear zone related fractures were intruded

by intermediate to acidic composition dykes such as quartz porphyry, dacite and trachyte (Figure 2).

2.2. Geotectonic and Local Structures

The continuation of Delgo - Atmur suture in the eastern Nile, were represented by NNE striking Elgaab shear zone, which possible reaches Sodri – Um Badir shear zones in North Kurdofan. Dum el Tor Shear zone which represents the western branch of the Red Sea - Oko shear zone of Nakasib Suture into East Bayuda Desert, and possibly continues westwards. The rifting between East Sahara / Halfa and Bayuda / Kurmut terranes had began before 750 Ma and might have started as early as 830 Ma (Kuster and Liegeois, 2001). Then followed by sea floor spreading and ocean

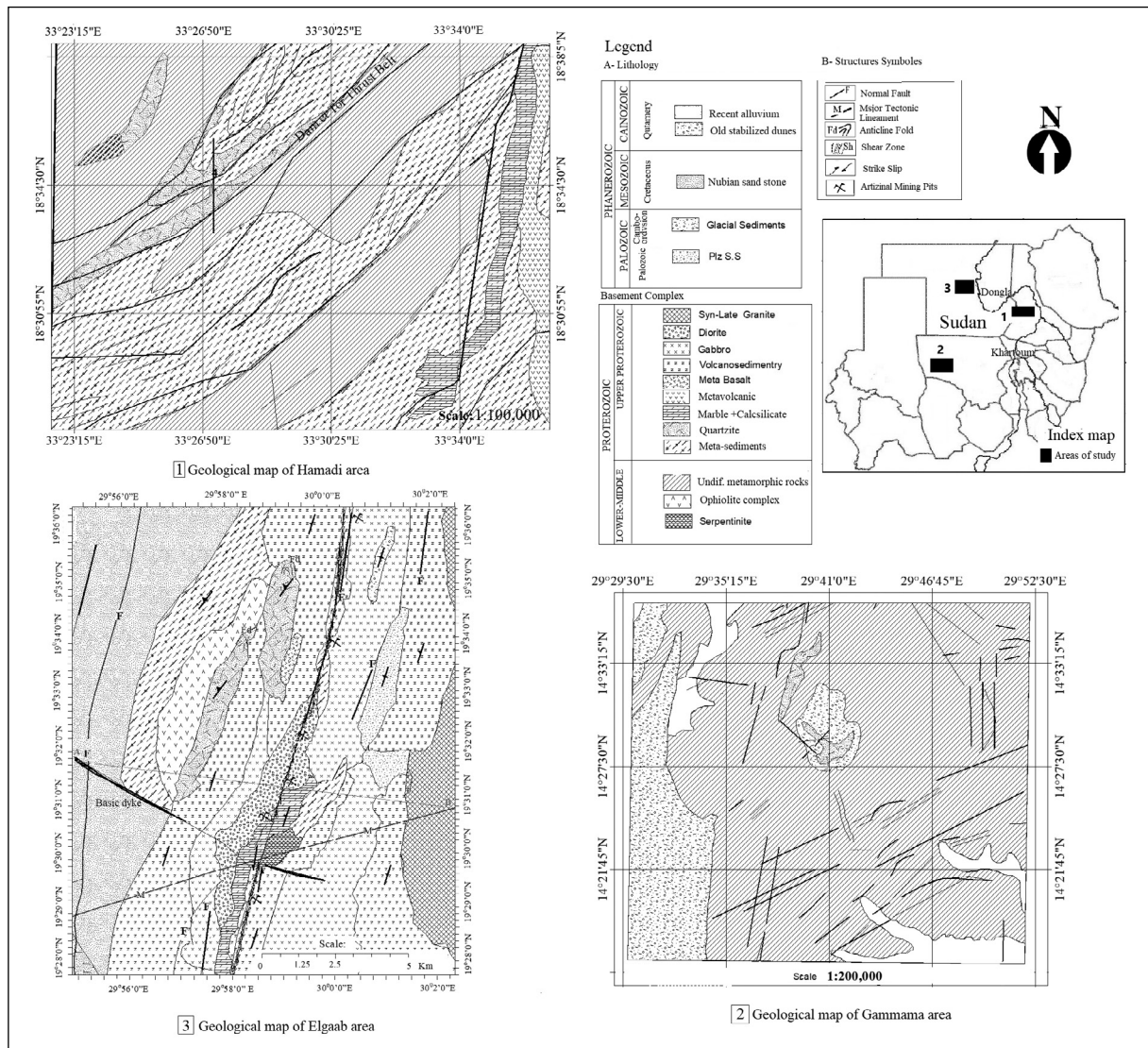


Figure 2- Geological map of the areas of study.

basin formation. Suturing of the terranes was initiated at around 720 Ma, and it was probably completed by 700 Ma (Stern et al., 1994). The Basin closure driven by N - S shortening and collision between Halfa and Bayuda / Kurmut terranes started at southeastern part of the Halfa terrane probably around 750 Ma (Abdelsalam et al., 1995).

The obduction of Atmur-Delgo ophiolite took place ~702 Ma (Harms et al., 1994), and the peak metamorphism were accepted to occur coeval. Collision between Bayuda / Kurmut and Halfa terranes was associated with progressive deformation, granitoid intrusions and metamorphism that continued until 650 Ma. These granitoid intrusions are accepted as the source of hydrothermal fluids that precipitate gold. Data from Jebel Rahib ophiolite within Rahib belt indicates that an ocean was present at ~740 Ma until its closure at ~707 Ma (Harms et al., 1994). Multi - phase deformation has affected the basement rocks in

the study area. A pair of anticline - syncline overturn fold system with NE - SW trending axial plane is recognized in the mapped area. The NNE normal faults also deformed the rocks in the study area. Other set of E - W striking fault represent by second order drainage pattern, cutting lithological units and displaced the NE - SW trending lineament (Figure 3). The study area is traversed by NE striking major shear zone and extends several hundred kilometers parallel to Dam El Tor shear zone, suggested earlier as western continuation of Sodri - Um Badir shear zone of Northern Kurdofan (Rahman and Elmahi, 2006). The central part of the shear zone in the area characterized by the present of quartz veins, which are formed in the highly sheared acidic, intermediate and basic meta - volcanic and meta - sediment in Hamadi gold mine area.

More than five phases of deformation have affected the Hamadi gold mine in the East Bayuda area. The first phase is a bedding - parallel schistosity.

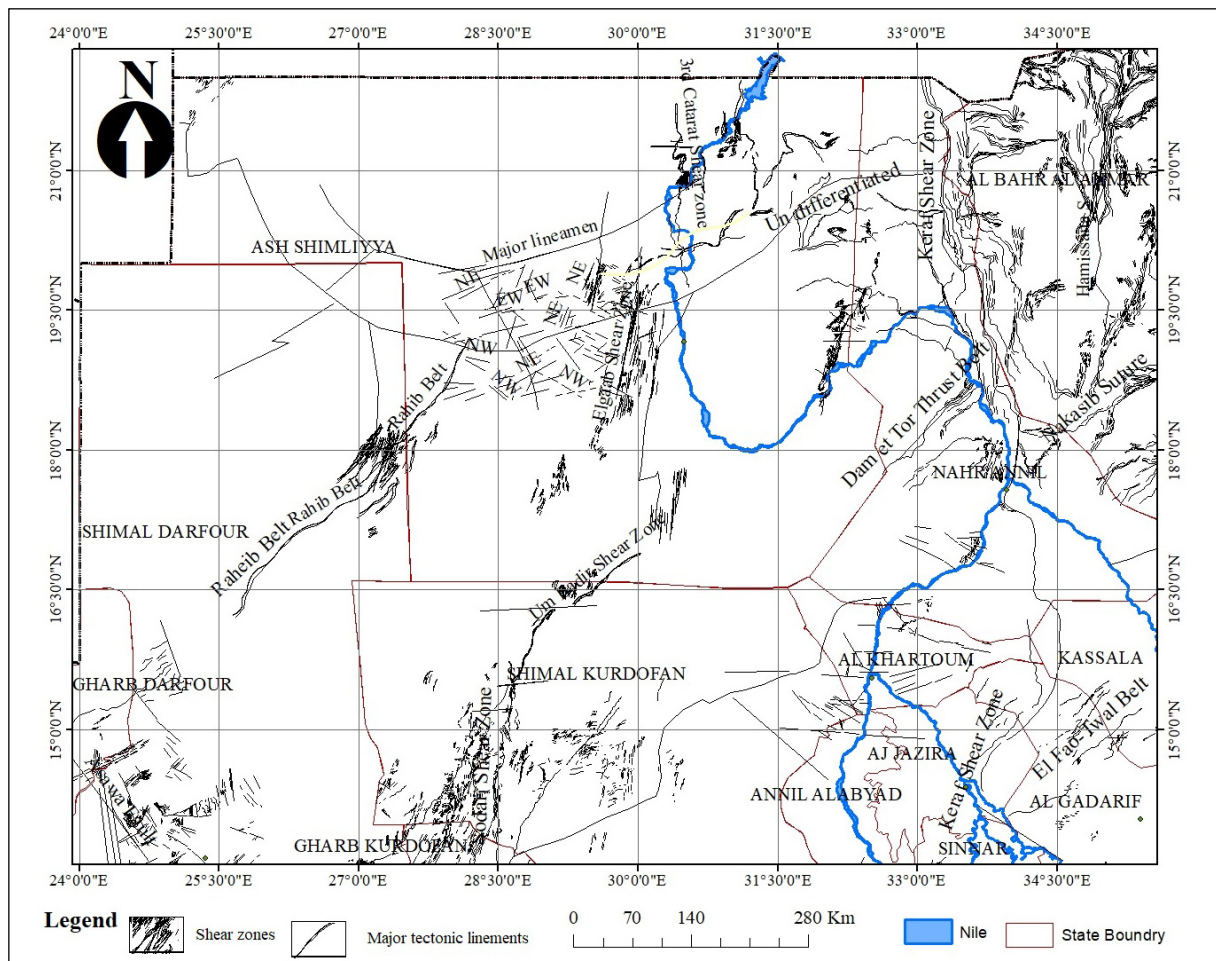


Figure 3- The tectonic map of north and central Sudan modify after tectonic and structural map of Sudan and Rose - Geo (2018) tectonic map of Sudan.

The second phase is related with folding. Dextral shearing is the dominant one and caused the formation of Z - shaped chevron fold from centimeters to hundred meters in size (Figure 4c). As a result of the shearing movement quartz boundinage (pinch - and - swell) structure has formed during the third phase of deformation (Figure 4b). Similarly in Elgaab gold mineralization zone exposed subsurface structures in artisanal gold mining mega pits, shows that at least five phases of deformation have affected the area and represented by: D1; stress pressure (convergent), D2 folding, followed by D3; faults along fold axial-plane, then followed by D4; shears fabrics. D5 corresponds to tension gashes. The complex fabrics are good path ways for fertile hydrothermal fluids to precipitate gold along shear zones (Figure 4).

3. Mineralization

As it is known from the previous geological works in Sudan, many of the vein - type gold deposits are formed along major lineaments, such as the Oko shear zone of Nakasib suture in the Red Sea hills, Dum El Tor shear zone in Bayuda Desert and across Sodari - Umm Badr shear zones in North Kordofan (Schandelmeier and Richter, 1991; Abdel Rahman and Mahi, 2006). Vein - type gold mineralization is also formed along the N - S trending Gabgaba lineament

(Keraf shear zone) (Vail, 1985; Kröner et al., 1987; Abdelsalam and Dawoud, 1991; Stern, 1994).

The occurrences of gold - bearing quartz veins along shear zones are controlled by tectonic lineaments with their sub - vertical tension faults (fractures). The gold - bearing quartz veins are mainly developed as fracture filling injected along the foliation planes of greenschist during Pan - African Orogenic event in Late - Proterozoic era. The quartz veins were deformed by the first and second deformation phases (foliation planes). The kink band structures indicate that the veins were subjected to possible several subsequent shearing events, resulted in pinch - and - swell structure. The process and the genesis of gold mineralization may have taken place after the intrusion of granitoid particularly diorite and granodiorite, which are accepted as the source of energy that triggered the initiation of the hydrothermal activity during orogenic events. Heat source during the shearing events is responsible for re-mobilized and re-concentration of gold and associated elements across the study area, which similar processes recognized across the Arabian - Nubian Shield.

Quartz veins are usually thin and stringers are wide - spread. Many types of quartz veins are recognized and recorded; the massive smokey, grey,

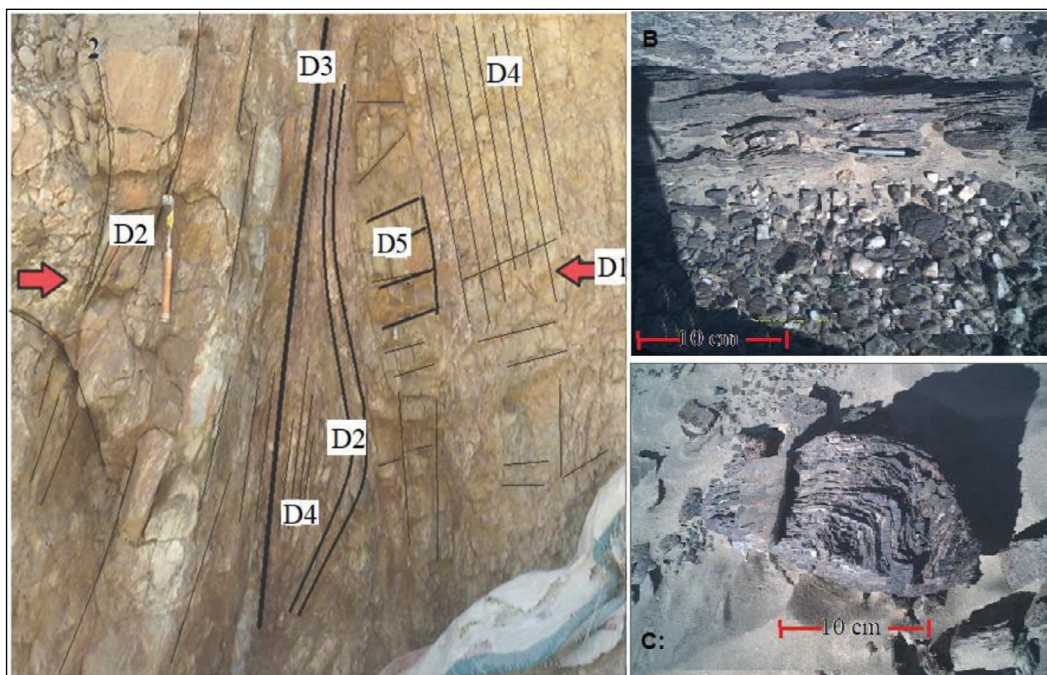


Figure 4- a) Vertical section across artisanal gold mining mega - pits illustrates the subsurface structural features, Elgaab area, b) pinch and swelling - Hamadi, c) z - shape chevron fold - Hamadi.

brecciated recrystallized, white to pinkish, and vuggy which are the richest by gold contents. The wall rock alteration is limited and confined to the area adjacent to the quartz veins, generally from 0.7 m to 2.00 m wide. Sericitization, kaolinitization, iron oxides, and iron carbonate are dominant, with rare graphite and chlorite. The gold and associated elements in Elgaab gold mineralization are arsenic, chromite and nickel, with arsenic the main pathfinders. The minerals associated to gold mineralization, based on ore microscopic investigation, are pyrite, magnetite, covellite, and chalcopyrite (Figure 5).

Hamadi gold mineralization associated with ankerite, iron oxides and tourmaline as the pathfinder (Figure 6). In Sodri - Um Badir shear zone gold mineralization in hand spacemen display dark colours, rich in sphalerite, malachite, galena, pyrite and other sulphides mineral. Nuggets of visible gold are often seen around oxidized pyrite or insides the cavities.

Gammama gold mineralization associated with copper, lead and zinc (Figure 7), with no clear pathfinder element. The mineral associated to

gold mineralization based on the ore microscopy investigation, are chalcopyrite, pyrite, marcasite, hematite, and magnetite. Adularia, ankerite are indicator minerals (keys elements) and tourmaline could be a pathfinder in prospecting for gold in the study area. Electron Microscope EDS graph shows that the gold is also associated with Pd, Palladium is a precious white metal has price higher than gold (Figure 8).

4. Geochemical Characteristics

4.1. Distribution of Gold and Associated Elements

The assay results of gold and associated elements in Elgaab area Cu, Pb, Zn, As beside Cr and Ni, indicate that the gold content in soil samples shows higher values (0.18 - 8.391 g/t) than those returned by both quartz veins (0.053 up to 2.93) and trenches samples (0.5 to 0.8 g/t). This disparity may be attributed to the secondary gold enrichment. Arsenic display the highest values when compared to the other trace elements. Cu, Pb, Zn, Ni, and Cr show low content and irregular distribution, except for Cr which

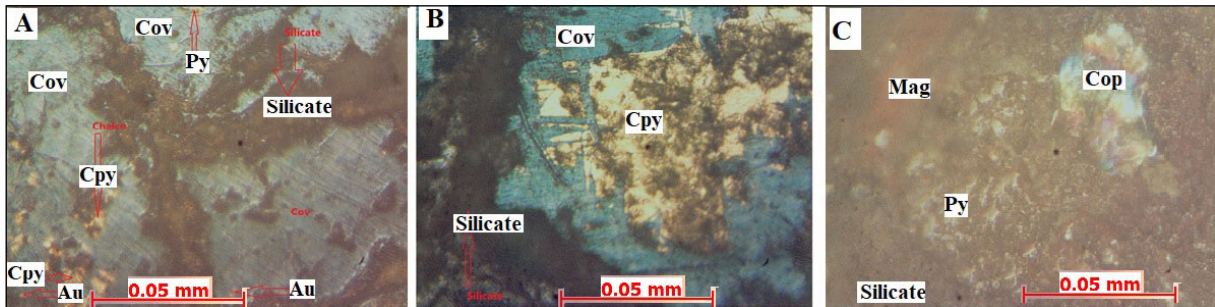


Figure 5- Light reflected microscope views of; a) pyrite (Py), primary chalcopyrite tarnished to yellow (Cpy) replaced by covellite pale blue (Cov), very fine grained golden yellowish (Gol) and silicate dark grey (20X), b) primary chalcopyrite yellow (Cpy) replaced by covellite blue (Cov), and silicate dark grey and c) pyrite (Py), multi-colored native copper (cop), pale brown magnetite (Mag) and silicate dark grey (20X) from Elgaab area.

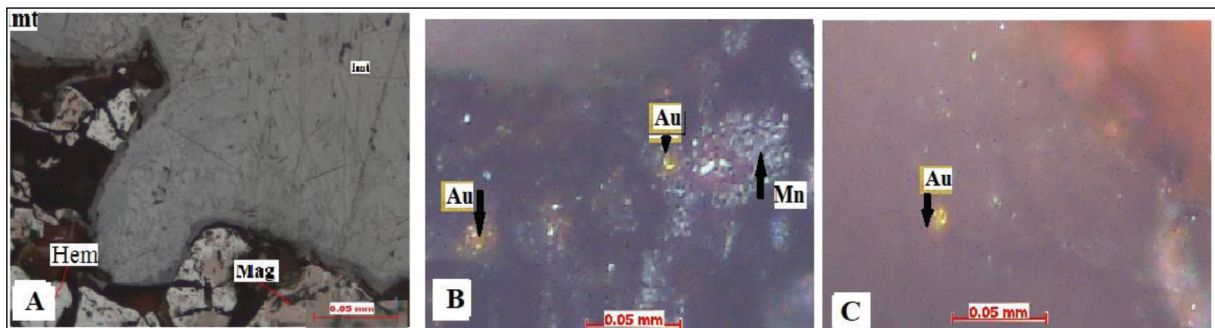


Figure 6- a), b) and c) Shows hematite, magnetite, manganese and pyrite is the most common minerals associated with gold in (Hamadi) Dom el Tor shear zone.

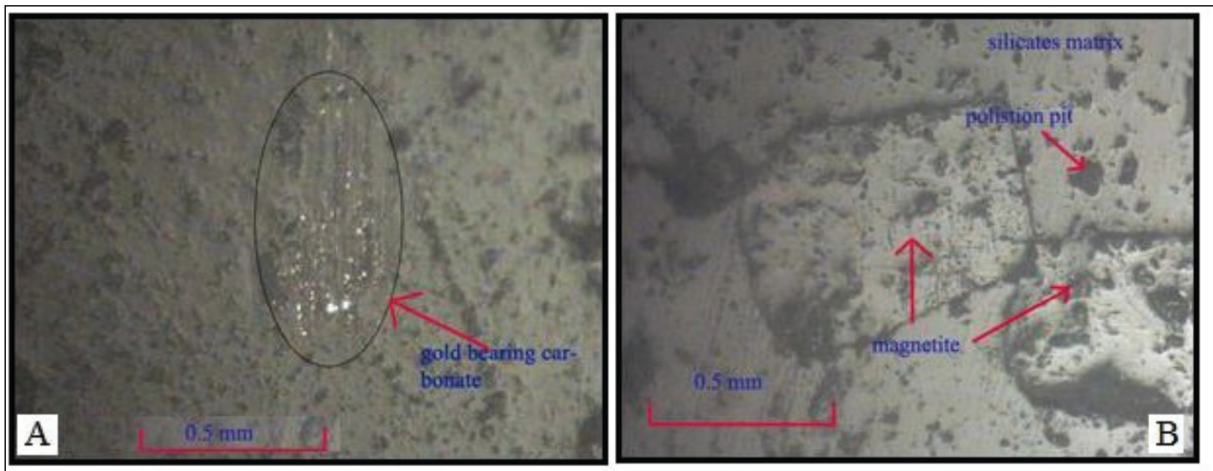


Figure 7- a) Shows gold bearing carbonate, Gammama (Sodari shear zone), b) photomicrograph shows cubic magnetite, Gammama.

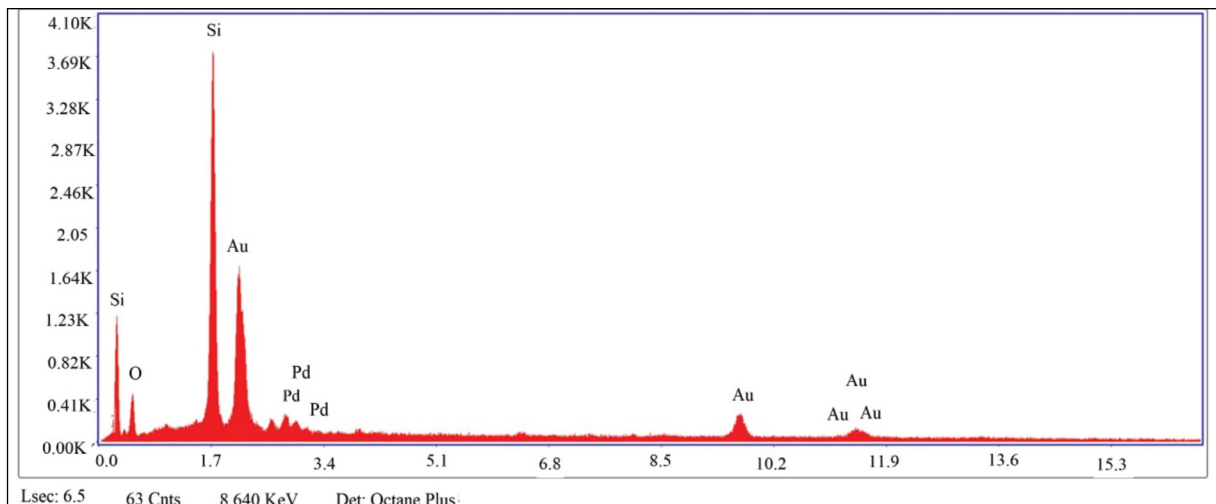


Figure 8- Electron scan microscope graph shows the gold associated with Pd.

has a medium concentration. Arsenic shows irregular but very high content that range between 197 - 17905 ppm. Zn; content range between (16 to 880 ppm). Trace elements Th, Ba, Co, Ga, Mo, Ge, W, V, Nb, Zr, Y, Sc, Rb - Sr, Hf, analysis results obtained from quartz veins samples reveal very low values. Except Ni, Cr, Pb, Zn and Cu shows relatively medium to high values. Cerium (Ce), shows very low value among all samples. Pb content range between (19 to 253 ppm) and (40 to 180 ppm) for quartz veins and soil samples from Elgaab mineralization zone, respectively single elements geochemical mapping “iso - concentrate map” is usually used as an effective tool for assign the areas of anomalous value as well as the trend of mineralization.

It is worth mentioning that, prospecting criteria or evidences for Cu, Pb and Zn, gossans - like and VMS mineralization in Elgaab and Hamadi areas are not recognized during this study. Meanwhile those criteria are recorded in North Kurdofan along Sodri - Umm Badir shear zones. The chemical analysis reveal high Au values ranging between 0.49 and 10.00 g/t, while Ag shows relatively medium values ranging between 3 and 5 ppm. Zn and Pb lead display low concentrations ranging between 8 and 129 ppm and 5 and 79 ppm, respectively. In contrast Cu shows the highest concentration values ranging between 14500 - 77200 ppm. Assay results of quartz veins samples, from Hamadi gold mine, Dom el Tor shear zone, reveal Au content vary between (0.11 to 10.25 g/t). The relative high coefficient of variation of Au

(156.75% - 252.6307%) suggests that Au is inhomogeneously, or irregular distributed in quartz veins when compare to Au content in soil. Cu has highly potential content (14500 - 772000 ppm), which is considered to be highly anomalous in Gammama - Sodri - um Badir shear zone the presence of sulphides, such as pyrite (FeS₂) chalcopyrite (CuFeS₂), and galena (PbS), could indicate shear-related massive sulphides mineralization at depth.

The histograms for Au, and associated Cu, Pb, Zn, Ni and Cr for the rocks and quartz veins samples in Elgaab area of study are displaying irregular distributions for the elements described. The histogram

of frequencies shows the whole population in the curve of frequencies is bimodal. That means the whole population is split into 2 sub - populations background and anomalous (Figure 9). The high coefficient of variation indicate irregular erratic distribution of gold in quartz veins. While in Hamadi gold mine area the histogram of Au display same population, the Au content range between 0.49 - 10.00 ppm (Figure 10).

In Sodri - Um Badir shear zone gold mineralization histogram for Au, Ag, Zn, Pb and Cu displays irregular symmetrical distribution of Au, Zn, Pb and Cu while Ag shows regular symmetrical distributions (Figure 11).

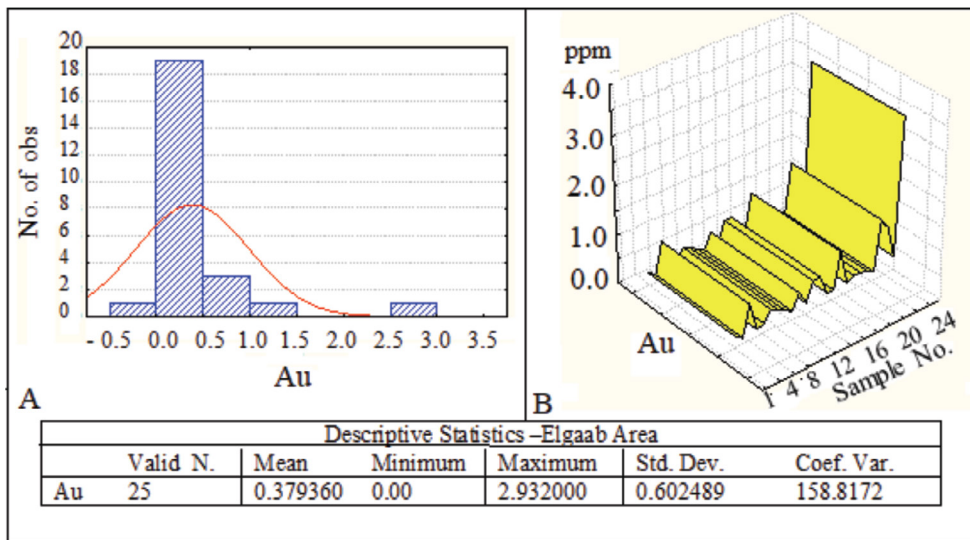


Figure 9- Hamadi area; a) histogram of Au and b) sequential graph.

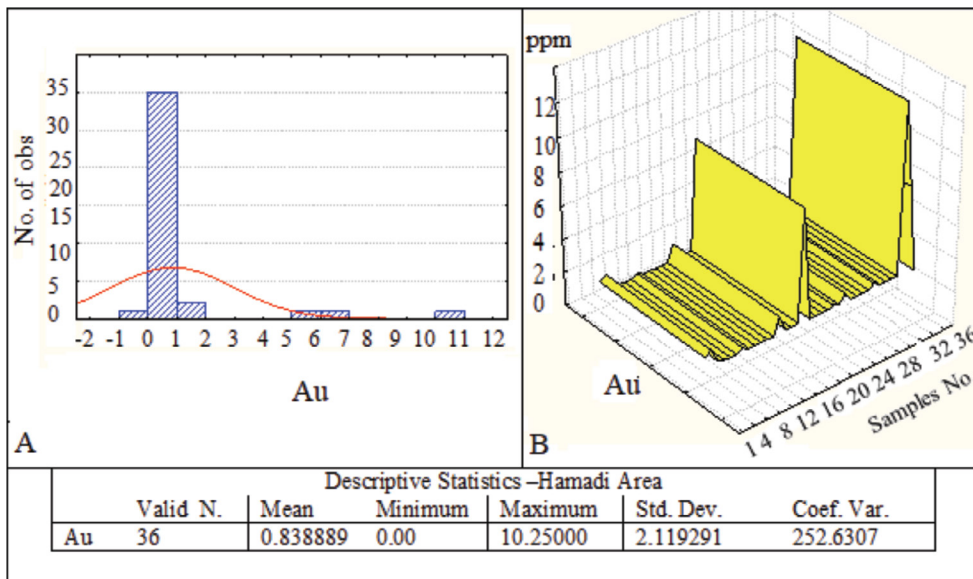


Figure 10- Hamadi area; a) histogram of Au and b) sequential graph.

4.2. Correlation

The proportion of quartz veins samples from Elgaab study area containing gold above the detection limit is 77.4%. Were the detection limit is 0.001 ppm, with mean value 4.416 ppm. The correlation matrix indicate that Cu versus Au show no correlation. Au versus Pb (0.05) and Zn (0.07) show very weak positive correlation. Au versus Cr (-0.02) show negative weak correlation. Au versus Ni (-0.10) show negative correlation. While Au versus As (0.90) shows very strong positive correlation, the correlation matrix display that Au versus Cu (0.45) has perfect correlation. The source of the high Cu content are possibly due to the associating chalcopyrite and malachite observed in auriferous quartz vein in the vicinity of the mineralization zone. Au versus Pb (-0.06) shows negative weak correlation, and Zn (0.49) shows positive perfect correlation, while Pb versus Cr and Ni show positive correlation. Pb versus As show weak positive correlation (Table 1).

The chemical analysis results reveals low values for Pb in both Elgaab and Sodri - Um Badir areas of study. Zn versus Au shows weak positive correlation. On other hand Zn shows no correlation with both Cu and Pb. Zn versus Ni shows weak positive correlation, and versus both Cr and As shows weak negative correlation. The chemical analysis results reveals low values for Zn in Sodri - Um Badir as compared to values obtained for Elgaab area of study. Zn and Pb were detected in hand specimens by their minerals ore sphalerite and galena, respectively. Although the chemical analysis results reveals low values, in Gammama site of Sodri - Um Badir shear zones (Table 2).

Numerous minerals deposit of economic potential have found to be occurring along shear zone and associated gashes and faults. This could be realized by detail exploration using advanced geophysics techniques and deep drilling. In this respect, the study

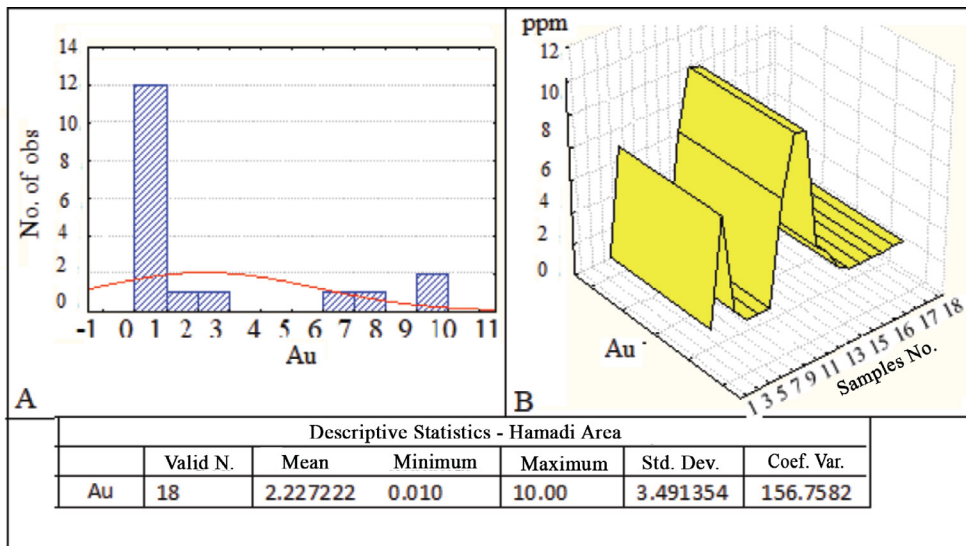


Figure 11- Gammama area; a) histogram of Au and b) sequential graph.

Table 1- Correlations matrix (Elgaab) gold and associated elements.

	Au	Cu	Pb	Zn	Ni	Cr	As
Au	1.00						
Cu	-0.00	1.00					
Pb	0.05	-0.01	1.00				
Zn	0.07	0.05	-0.08	1.00			
Ni	-0.10	0.74	0.43	0.14	1.00		
Cr	-0.02	0.05	0.58	-0.21	0.36	1.00	
As	0.90	0.05	0.11	-0.08	-0.01	-0.04	1.00

Table 2- Correlations matrix (Gammama) gold and associated elements.

	Au	Ag	Zn	Pb	Cu
Au	1.00				
Ag	-0.118319	1.00			
Zn	0.49	0.35	1.00		
Pb	-0.06	0.15	0.54	1.00	
Cu	0.45	0.03	0.326	0.33	1.00

points to five selected targets for future gold follow up exploration (Figure 12).

5. Results

The areas of study intersected by three major shear zones namely; Elgaab, Gammama in Sodri - Um Badir and Hamadi mine of Dom el Tor shear zone. All zones constitute huge flat area of sandy sheets covering both Phanerozoic sediments and underlying basement rocks. Volcano - sedimentary sequences of Neo-Proterozoic and partially Meso - Proterozoic granitic gneiss were intruded by syn to late granitoid intrusions, and later by post orogenic granite and felsic dykes. The gold - bearing quartz veins are mainly developed as fracture filling injected along the foliation planes of green-schist rocks, formed at different stages during the Pan - Africa Orogenic events (900 – 550 Ma.).

The geological, lithological, structural criteria and geochemical mapping indicate that the mineralization domains are confined to the NNE shear and related tensional gashes. Thus, Elgaab gold mineralization could be classified as epigenetic shear - related mineralization. The process and the genesis of gold mineralization emplacement may had taken place after the intrusion of batholithic granitoids particularly diorite and granodiorite, which were believed to be the source of energy that triggered the hydrothermal solutions during orogenic events. While the heat generated during the shearing events could be responsible for re-mobilization and re-concentration (enrichment) of gold and associated elements across the area of study, in similar process as documented in Arabian - Nubian Shield.

The assay results of Au and the associated Cu, Pb, Zn, As, Cr and Ni in Elgaab area indicate that the

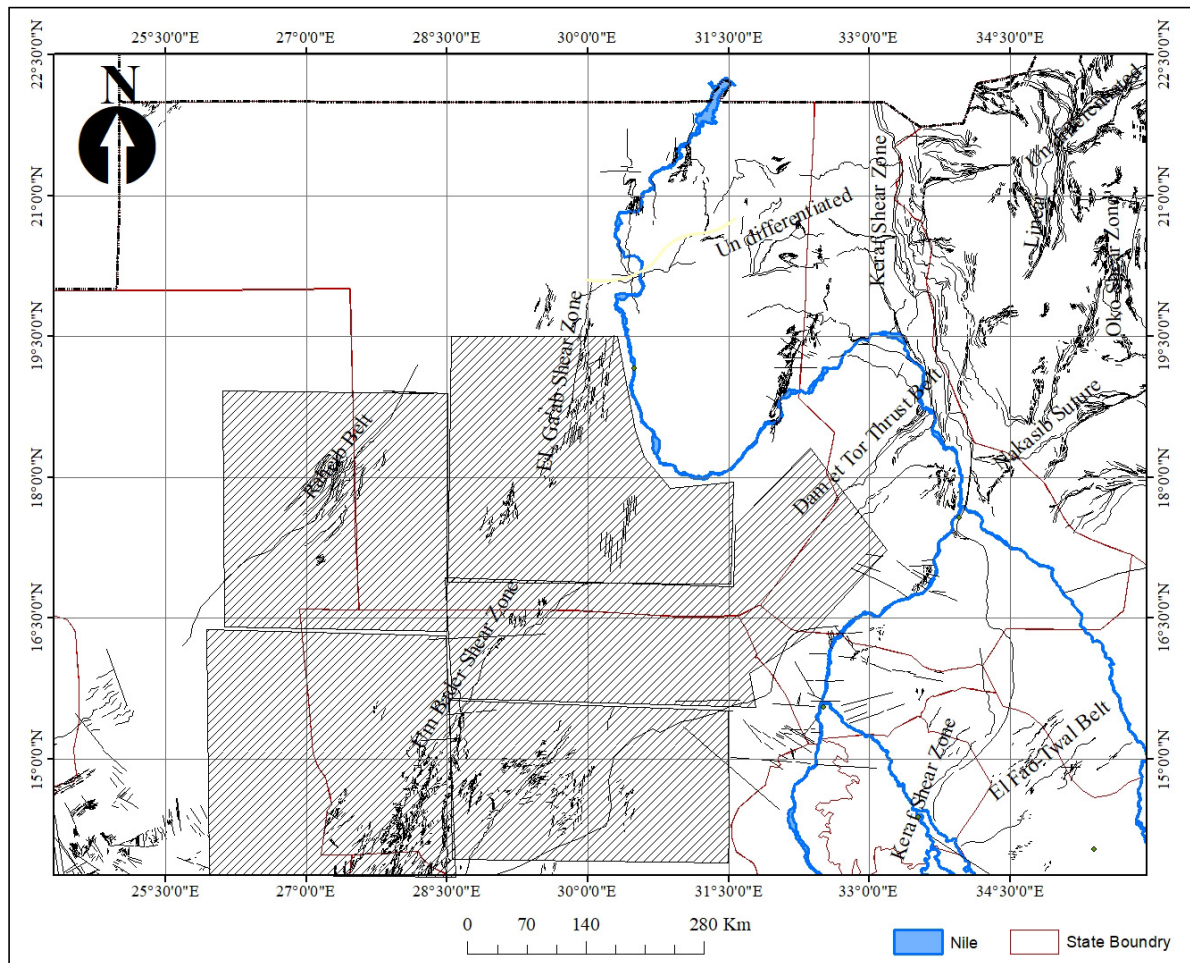


Figure 12- Location map of the selected five prospective areas for future gold exploration.

Au content in the soil samples are of higher values content (0.18 - 8.391 g/t) than those revealed by both primary lodes (0.053 up to 2.93 g/t) and trenches samples (0.5 to 0.8 g/t) respectively. The relative high coefficient of variation of Au (158.8%) suggests that Au is inhomogeneously and irregularly distributed in quartz veins. Assay results of samples from Hamadi gold mine quartz veins reveal that Au content varies between 0.11 and 10.25 g/t. The mineral associated with gold mineralization are chalcopyrite, pyrite, marcasite, hematite, and magnetite. Adularia and ankerite are indicator minerals (keys elements), whereas tourmaline could be a pathfinder. Electron Microscope - Electron dispersion spectrometry (EDS) shows that the Au is also associated with Cu and Pd. The results of analysis of quartz veins samples from Gammama in Sodri - Um Badir shear related - gold mineralization indicate that the elements associated with Au, are Ag, Zn, Pb and Cu. The Au content ranges between 0.49 and 10.00 ppm, while Cu has anomalous values as higher as 77200 ppm. The presence of sulphides, such as pyrite (FeS₂) chalcopyrite (CuFeS₂), and galena (PbS), along Sodri - Umm Badir shear zones in North Kordofan suggests the presence of shear - related massive sulphides mineralization at depth.

Comparison between Elgaab shear zone gold mineralization, Dum el Tor shear - related gold mineralization and Sodri - Um Bader shear mineralization indicates similarities in lithological characteristics of Upper Proterozoic rock assemblages. The NNE - SSW and NE - SW structural grain of Pan African Arabian- Nubian Shield were dominant, as well as the mode of occurrences of the ore bodies, and the grade of metamorphism. Regardless of those similarities there are broad variations in the metallogenic characteristics such as mineral association, pathfinder, and grade of gold content.

The results of this study define new metallogenic province in the region west of the River Nile. West of Dongla the province constitutes a huge sandy area lying between Elgaab, Dam el Tor and Sodri – Umm Badir shear zones cover the Phanerozoic sediments and basement assemblages. Nemours minerals deposit of economic potential have found to be occurring along shear zones and associated gashes and faults. This could be further realized by detailed exploration

using advanced techniques and deep drilling. In this respect, the study pointed out five potential targets for future gold exploration and evaluation, according to litho - stratigraphic similarity, geochemical and geotectonic characteristics.

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