METALLOGENY OF THE CRATONIZED TERRANES ADJACENT TO GREEN STONE BELTS, EXAMPLES; ALAIKALIB, MAZROUB, SODARI AND UM BADIR.

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Abstract

Comparative studies, especially those built on general geology, and geochemistry carried out on North Kordofan, strictly on Mazroub, Sodari, and Um Badir, strongly indicate similar genetic relations between gossans, massive sulphides, and associated quartz veins. The gossans and VHMS, despite slight differences between them, however they show formation from the same magma. As this kind of mineralizations proved episodic emplacement, probably they are not formed in the same time. Silicification is one of the phases that implicated in the emplacement of both mineralizations they came later in the evolutionary path. In a former study, the manganese rich mineralizations emplaced in the green schist (Hamot at the Arabian Nubian Shield) and those in the adjacent cratonized terrane of tranitionally gneisses (Alaikalib and Abu samr), were treated separately, as actually they are found from the same magma. The study proves that the mineralizations found at cratonized terranes are derived from the same magma chamber as those emplaced later in the late Pan African orogeny. This would indicate that the magma chamber that formed these mineralization is much larger than have been thought. So the same processes that form the sulphides and associated quartz veins keep repetition in time from the lower Proterozoic to the upper Proterozoic. Probably, also since the Achaean wherever found.

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1. INTRODUCTION

The report contains partially the summary of other two reports written on the area, Mohmed Ali, et al. (2010, 2010) about the structure and metallogeny of the Mazroub gossans. The other discusses the relation of quartz veins in Tinna with the gossans of the Mazroub area. In this issue, there is an essay to extend the work in the area westward where much quartz veins found at the proximity of Sodari and Um Badir were added to the area. Besides two discoveries added much for the verification and unraveling the nature of mineralization in the area. Al Firga quartz veins NW to Sodari and Abu Zaema massive sulphides. These discoveries added much to the economic value of the area, where gold and silver are the primary targets. Al Firga quartz veins contain 4 g/t Au whereas, Abu Zaema contain 4000 g/t Ag. From genetic point of view these mineralizations indicate very intimate relation that quartz veins considered one of the hydrothermal phases that succeeded the syngenetic emplacement of the gossans and massive sulphides (VMS). The dilemma of contrasted metamorphic conditions that these mineralizations have been subjected to cratonization has been discussed and reached to conclusions.

1.1. LOCATION AND ACCESSIBILITY

The location of ore bodies a side from Mazroub and Tinna in other report as follows (Fig.C):

Table 1.

Firga 5-40	**N14 46 02.8 E29 18 51.0**	**Quartz vein**
Firga 6-50	**N14 45 12.7 E29 18 23.3**	**Quartz vein**
Sulphide	**N14 31 40.6 E28 28 18.6**	**Abu Zaema**

The Firga quartz veins are located 42 km NE of Sodari town. All the area is characterized by artisanal mining. The sulphides samples were collected from Abu Zaema 55km west of Sodari. The area is accessible from Kosti highway via El Obied to Mazroub and Sodari westward about 100 km approximately. Until El Obied is asphaltic road and sideway from Obied to Sodari and the assigned locations.

1.2. OBJECTIVES OF THE STUDY

The main objective is to verify the mineralization conditions of very familiar ore types; gossans, and associated quartz veins. Some of the studies carried out in the area proposed that these quartz veins were part of a huge hydrothermal pool very rich in gold and associated basemetals.

The most dominant were Ag that associated with lead-galena, Cu represented by mainly chalcopyrite, and probably sphalerite and cobalt are existed. It was indicated in former studies the relation between the metamorphic facies and the associated mineralization (Mohmed Ali et al.2010).

2. GENERAL GEOLOGY

The geology of the Arabian Nubian Shield (ANS, Fig.B) as a huge green stone belt is formed as a result of accretion of oceanic terranes of island arcs collided together and decorated with ophiolitic sutures that obviously draw the boundaries between terranes. These terranes were resulted from geological processes of Wilson cycles in repetitive manner in the Pan African times and orogenies. They were not formed in the same time rather than in episodic pattern one terrane after the other without obvious oceans openings. When discussing the enigma associated with these processes, the main concern would be the mineralizations associated with these geological processes. Precisely, the Volcanogenic Massive sulphides (VMS) mineralizations as products of these terranes evolution. They are in turn, as they are syngenetic in nature that associated with vulcanicities and lava flows resulted from plate tectonic processes, having emplacement modes associated with the number of phases of these volcanic activities and magmatism. In general as mentioned in the literature, these calcalkaline composition magmas are similar all along the whole ANS. The sulphides associated with respect to their petrologic character are also similar with slight modification in time and space and associated structural setting. The main subject is that they are similar in composition and the host rock in general but are not formed at the same time and also evoluted as well as the rocks host them does. Applying this concept on the microcontinent, Pre Pan-African, and NeoProterozoic terranes surrounding these terranes were once oceanic arc terranes subjected to the same plate tectonic processes, magmatism, deformation, sedimentation, and metamorphism that later led to their uplifting and cratonization to the amphibolite facies. The mineralizations associated, especially the VMS were also subjected to the same process of cratonization and to the same degree of metamorphism. With the continuation of this process with time, the final result is that the Pan African terranes are metamorphosed to the green schist facies and emplaced later in time as the surrounding terranes are in the amphibolite gneiss facies. The metamorphism exerted on these mineralizations and the associated host rock played diversified role in adding or reducing these ores accumulations. In most cases the mineralizations associated with these gneisses that located close to these Pan African terranes were usually used to treated separately from those located in the adjacent green stone belts without noticing that they were produced by the same magma

but emplaced episodically in time and space since the early to the upper Proterozoic. This would greatly lead to grave misunderstanding to the genesis of both mineralizations as to the general geological setting of the area. As great negligence in the evaluation of the real evolution path of both terranes will result also in great misleading conclusions about the relation between mineralizations and their host rocks formation and evolution.

The process that converts oceanic lithosphere into continental crust as cratonization is the main mechanism that explains the whole process. In the area of continental crust of NE-Africa and Arabia originated as oceanic lithosphere that through a period of 600 m.a. (1100-500 m.a.) progressively converted into continent by processes of intraoceanic arc formation and evolution (Gass, 1977).

In northeast Africa and Arabia, the regional structural trend is N-S. Over 60% of the out crop consists of granitic plutons emplaced into eruptive rocks and volcano-derived sediments of similar composition.

Throughout the region of NE Africa, Sudan, Egypt, the dominant host rocks to the abundant granitic plutons are volcanic products of calcalkaline affinity and immature volcanoclastic sediments that suffered green schist facies metamorphism (Greenwood et al. 1976). Eruptive rocks form about 40% of this volcanosedimentary host and they are flows welded tuffs and lava flows, breccias, and agglomerate ranging in composition from basalt through basaltic andesites to dacites and rhyodacites. They are geochemically similar to low K-tholiites of immature island arcs. Certainly even the oldest host rocks, which have been metamorphosed to amphibolite facies, are geochemically and mineralogically identifiable as being of calcalkaline affinity (Nassef, 1971). Among the younger volcanic products, dacitic and rhyodacitic pyrocalstic rocks are particularly common (Bakor, 1993). Sediments range from polymictic conglomerate through coarse arenites to fine silts and shales. Rapid lateral and vertical facies variation is characteristic. Features such as slumping, grading, sole markings, and cut and fill structures indicate that many types of sediment are proximal turbidites derived from near by sources. The dominance of greywackes of andesitic and rhyodacitic compositions and the absence of continental derived sediments led Greenwood et al.(1976) to conclude that the sedimentary types and processes were most closely comparable to those of the present day intraoceanic island arcs environments as described by Mitchel and Reading (1971).

It seems evident that the development of island arc systems and their progressive cratonization by plutonism, volcanism, and attendant sedimentation, progressed through three phases of magmatism over the 1100-500 m.a. mainly of syn-post magmatism of calcalkaline

affinity, and episodes of granitic magmas. The primary heat source in magma genesis was along oceanic Benioff Zones (Oxburgh and Turcotte, 1970) and the generation of magma was from descending oceanic plate. It seems possible that much of the Pan African north of the equator was produced by intraoceanic island arc evolution and progressive cratonization. The examples set here; first in the case of Alaikalib of the Red Sea Hills, where the manganese ore that associated with massive sulphide that associated with amphibolite gneisses of Tolik Series (Alaikalib and Abu Samr) is having the same genesis of the manganese ore associated with the green schist rocks of Sinkat area (Hamot) as they are both located in Haya Terrane. As it is obvious from the different degree of metamorphism of the two ores as one in the amphibolite and the other is in the green schist facies, however they have the same genetic setting as they have the same chemical composition. The matter is conceivable through the concept that the hydrothermal process that formed the two mineralizations is repeatedly operating through time as episodic rejuvenations first since the lower Proterozoic when the gneisses of Alaikalib were once at the green schist facies to the upper Proterozoic where the ore of the green schist facies of Sinkat-Hamot area exis after a later phase of vulcanicity and sedimentation occurred. So in this case the relations between the two ores are simple and well understood. The other example is the gossans of the Mazroub area (the subject of this study), the massive sulphides in Sodari area (Abu Zaema), and the mineralized quartz veins at both locations (Al Firga). All these mineralizations are having the same geochemical signals and in turn the same genetic model and derivation. The Mazroub gossans are hosted in metavolcanics encapsulated and protected green schist remnants enclaved in the generally gneissic host (Fig. A). It is quite obvious as mentioned earlier that the green schist facies conditions are the most favorable for mineralization emplacement rather than amphibolite facies conditions. Equally these mineralizations were become massive and compact due to continuous hydrothermal intrusion processes. In the very close environ they were formed, these hydrothermal interventions gave protected and preserved them and gave strength to resist deformation and metamorphism in the amphibolite facies. The general shape of this host rock in the Mazroub area is a thin and slim folded metavolcanic strip that host the gossans, embedded in a dominantly gneissic terrane (Fig. A). The same thing could be mentioned for the massive sulphides of the Sodari area (Abu Zaema). They are very rich in lead that may reach to 90% concentration and in turn Ag that reached 5000 ppm (as would be discussed later). Quartz veins in Tinna village (11km west from Mazroub area to the direction of Sodari) and those exactly found at Sodari are having the same chemical signal and hence genesis. These sulphides of

Mazroub and Sodari (hosted in gneissic terrane) are comparable with those of Abu Tulu that hosted in the andesites of the green schist facies. As they are both located in two contrasting degree of metamorphism, however, their similarity is conceivable through the mode of multiple hydrothermal pulses concept.

2.1. GEOLOGY OF THE AREA

Two fundamental basement categories are exposed, high grade poly metamorphic lucocratic orthogneisses and paragneisses with minor inlier of amphibolite, calcsilicates and marbles (Schandelmeier et al. 1991). They are lower to middle Proterozoic in age (Harms et al. 1990). These gneisses are unconformably overlain by a series of low to medium grade metasediments ranging from meta siltstone which are exposed to the granites are found intruding the basement of the western part of the area. Numerous narrow elongated ridges consist generally of cataclastically deformed high grade basement of metasediments. Fractures and shear zones intruded by dykes of intermediate to acidic composition (quartz porphyry, trachytes, and latites). Alkali complexes are standing high in the area (J. Katul and Abu Asal).

2.3. GEOLOGY OF THE MINERALIZATION

In what concerning the contrasting degree of metamorphism mineralization of the Alaikalib and Abu Samr where the manganese rich ore body that emplaced in the green schist facies at Hamot-Sinkat is chemically similar to that emplaced in the amphibolite gneiss facies. This process has been explained by the mechanism of multiple hydrothermal activities in time and space since the lower Proterozoic to the upper Proterozoic (Mohmed Ali, 2009, Mohmed Ali et al. 2010).

The quartz veins associated with the Mazroub disseminated sulphides, Tinna Quartz veins proved compositionally similar (Mohmed Ali et. 2010 A and B). Those quartz veins in the Mazroub area were associated with Mazroub gossans that were emplaced in slim preserved metavolcanic portion that in turn emplaced in the gneissic rocks. Those sulphides that form the base of comparison in both facies were to some extent up normal. Their coarse grain nature may hint to their over growth under amphibolite facies conditions. It was obvious that they were intruded in the green schist facies but in some part they suffered amphibolite facies metamorphism as proposed. The quartz veins in Tinna village were obviously intruded in the green schist facies but also recrystallized in the amphibolite facies metamorphism close with their host gneisses. The same could be mentioned for those quartz veins in Sodari and Um Badir area in general. From chemical observation (will be discussed later), it was obvious that they carry the same signal. Some massive sulphides were discovered also in Sodari area (Abu Zaema). It seems encountered the same conditions as the sulphides of Mazroub. The

massive sulphides emplaced syngenetically with the green schist metavolcanic rocks and subjected to high degree of metamorphism in the amphibolite facies. The host rock was protected and slightly affected by deformation and metamorphism unlike the rest of the environ of the sulphides that mostly associated by the hydrothermal alteration. As it seems there are similarities between these massive sulphides discovered at the Mazroub gossans (concealed volcanogenic massive sulphides) and those discovered at Sodari area (VMS). The difference between the gossans and surface volcanogenic massive sulphides is the existence of the iron cap and the oxidation zone in the gossans. The correlation based comparison between the chemical signals between those sulphides salts, oxides, hydroxides, oxyhydroxides of the iron cap and those metals sulphides at reduction zone indicate the same process that the comparison that based on iron cap and surface volcanogenic massive sulphides (VHMS) is valid. The chemical comparison also between quartz veins in the Sodari area (Al Firga) and those of the massive sulphides is also similar. That would lead to the same explanation of the relation between the sulphides of the Mazroub area and closely associated quartz veins. It was rationalized by the fact that quartz vein and in other words the silicification process is one of the hydrothermal alteration processes with which the sulphide mineralization was emplaced. So the separated huge quartz veins were indication of an extensive silicification process all over the region and equally considered as one of the products of the huge hydrothermal pulses that produced the gossans and the VMS.

3. MINERALIZATION

3.1. STATISTICAL DATA

As clear from table 1 gold is promising at these locations and it is highly recommended to execute extensive exploration work on the area. Au average is 3.2 g/t, 0.23 min.value, 9.17 max.value. Cu is also promising, 2652 ppm average value, 85.8 min.value, and more than 1% max.value, so it deserve more work. Zn and lead are not important at this site, however they show higher values at other locations, and drilling might give more information about their real values.

Table 2. Sodari quartz veins.

ɜa/elem	Au ppm	Cu ppm	Pb ppm	Zn ppm
QZ50A	5.02	226	11	0
QZ50B	0.32	85.8	15	0
QZ50C	0.43	604	111	18
QZEWA	9.17	10850	17	85
QZEWB	0.23	1490	23	10
QEWC	4.53	2657	20	0
Average	3.2833	2652.133	32.83	18.83
Minimum	0.23	85.8	11	0
Maximum	9.17	10850	111	85

Table 3. Sodari massive sulphides.

sa/element	Au ppm	Ag ppm	Cu ppm	Zn ppm	Pb%	Co ppm	Feppm	Mn ppm
1	0.18	3000	10863	370.2	85.2	918	2260	1260
2	0.23	3000	7875	570.5	77.3	67	3000	340
3	0	2700	8478	340.1	76.7	63	2560	41
4	0.09	2600	7218	247	75.8	957	2940	1265
5	0.53	4000	8460	204.6	73.6	1552	2680	431
6	0.47	3000	6606	173.8	66	905	5340	1014
Average	0.25	3050	8250	317.7	75.76	743.66	3130	725.1667
Minimum	0	2600	6606	173.8	66	63	2260	41
Maximum	0.53	4000	10863	570.5	85.2	1552	5340	1265

Many massive sulphides locations have been revealed. They are very promising, especially for Pb and Ag. Ag reaches 4000ppm value. Usually there are intimate relations between lead and silver that normally hosted in the lead. This relation could be used as path finder for both as they increase and decrease concomitantly. Au is the most important target but still Ag is showing Bonanza values. It deserves the name Silver Valley. Ag average grade is 3050 g/t, and alone it deserve opening a mine at this location, min. value is 6606 ppm and max. value is 4000 ppm. Au is above anomaly value and deserve more work, Average grade is 0.25 g/t, min. value is 0, max.value is 0.53 g/t. Pb is very anomalous and also a mine could be opened here to extract these minerals after proper prospecting program is executed. Pb average grade is 75.76%, min. value 66%, max.value is 85.2%, and it is the most higher value ever encountered at these kind of ore and locations and propably more could be found with the proper exploration program. Cu is highly anomalous and deserves much work. Cu average grade is 8250 ppm, min. value is 6606 ppm, max. value is 10863 ppm. Zn also is important and hint for high potentiality with detail exploration. Zn average grade is 317.7ppm, min.value is 173.8ppm, and max.value is 570.5ppm. Co is also anomalous with average grade 743.66 ppm, min.value 63 ppm, max.value 1552ppm. Tinna and Mazroub quartz veins as well as gossans detail chemistry were discussed in other reports and paper and they have been used here for sake of comparison (Mohmed Ali et al. (2008, 2010, and 2010). **3.2. CHEMICAL CORRELATIONS RESULTS**

The above mentioned correlation is applied on recently discovered mineralizations; Sodari quartz veins (Al Firga)**,** Sodari sulphides (Abu Zaema). The comparison also includes Tinna Village (11km between the Mazroub and Sodari) quartz veins, and Mazroub gossans. Sulphides as

pure mineralizations (VMS) or in massive sulphides (gossans) were mainly analyzed and used for correlation.

Cu/Pb of Sodari quartz veins, and Cu/Zn for the same quartz veins show similarities of patterns. Generally this process proves valid based on this correlation. The correlation also includes that relation of the Cu/Pb of the Sodari sulphides also seems similar to the above mentioned (Fig. 1, 2, 3). Au/Zn of Tinna quartz veins is showing a curve with two inclinations, one positively correlated, the other is reversed and similar to Cu/Zn and Au/Zn of the Sodari sulphides (Fig. 4,5,6). Au/Zn of the Sodari, and Tinna quartz veins are having the same patterns as positive correlations and suddenly reversed trend too (Fig. 7,8,9). Cu/Au of Sodari quartz veins, Tinna quartz veins, and Sodari sulphides are similar and showing elements regrouping (Fig. 10,11,12). Cu/Zn for Sodari quartz veins, Tinna quartz veins, and Sodari sulphides are also similar and show two elements regroupings (Fig. 13,14,15). Cu/Pb of Sodari quartz veins, Mazroub gossans, and Sodari sulphides correlations proved similar and showing two minerals regroupings (Fig. 16,17,18).

4. CONCLUSIONS AND RECOMMENDATIONS

1. Based on chemical correlations, the quartz veins in the Mazroub area, Sodari, and Um Badir areas are formed through the same genetic model, structurally controlled, emplaced episodically. They were not formed in the same time and space, and still bearing to some extent variable mineral paragenesis. The ones that are highly enriched with gold needed much verification especially structural.
2. The massive sulphides of Sodari, and Mazroub, as the first is exposed volcanogenic massive suphides, and the second is bearing iron cap on surface and concealed massive sulphides below. Despite this variation they are formed through the same magma and the succeeding hydrothermal phases. Probably they are not formed at the same time as they are also emplaced episodically and structurally controlled. Secular variations are controlled by time, space, magma evolution, and structure. Despite all these variation, they were formed by the same magma chamber and the succeeding hydrothermal phases.
3. There is a genetic relations, based on chemical patterns between quartz veins and massive sulphides. It was known that hydrothermal alteration processes that emplaced episodically imply an extensive silicification phase or phases all over the area as a normal process of magma evolution. Means that they are evolutionary product of magma and hydrothermal processes of magma fractional crystallization or segregation. Most of these mineralizations are located west of the delineation marking boundary between ANS and Saharan Craton. Mostly in the Saharan

Craton where the main host rock is high grade gneisses. As mentioned before that the green schist conditions where platetectonic processes are much efficient, considered as the most favorable for mineralization emplacement. The green schist facies composition and structures were obliterated via deformation, metamorphism, and cratonization. Despite that still relicts of Pan African are found preserved and well protected in the area.

4. All these mineralizations are invariably cratonized and the effect of amphibolite facies of metamorphism on mineralizations is not known, however, could obviously be observed in minerals texture and structure.
5. Remnants of green schist facies rocks could be observed as relicts in the environ of the mineralizations but only as small halo and that is obvious in the Mazroub gossans where below bout 50cm of wall rock of the gossan, gneisses were found.
6. Since the period of early Proterozoic (first emplacement of mineralization) to late Proterozoic mineralization, the evolution of magma and the associated mineralizations doesn't changed much and could be chemically verified.
7. It is highly recommended to do a detail work on Sodari quartz veins, nonetheless, more exploration work to discover more targets.
8. The current policy of the Ministry of Minerals to advance the process of dividing the area for mining lease is very constructive that it could enhance proper economic exploitation of this wealth.
9. Gold, silver, lead, and copper values are high enough to speed prospection to mining in the area.

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