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RESEARCH ARTICLE

STUDY OF POLYMETALLIC MINERALIZATIONS ASSOCIATED WITH ARCHEAN METABASITESOF AMSAGA (RGUEÏBAT RISE, MAURITANIA)

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Abstract

The Amsaga Zone is of a major importance, due to its position in the extreme south west of the Archean part of the Rgueibat shield, particularly to its location close to the Akjoujt Copper mine. Some dating migmatites indicate that granulite metamorphism affecting most Amsaga units took place between 3 and 2.7 Ga.

The field observations and microscopic study of samples analyzed of metabasite have helped to understand the relationships between lithological units and mineralization control structures such as faults and shear zones. This context reflects a tectonic control of implementation of the mineralization by movements in faults and in ductile shear zones.

The implementation of the copper mineralization could be either syngenetic, related metamorphism or hydrothermal fluid circulation, or it is late in relation hydrothermalism associated with panafrican and hercynian orogenies of Mogrein Guelb deposit, Akjoujt south of Amsaga.

Introduction:-

The Archean metabasites (especially greenstone) are major sources of gold and base metals, with important productions in several countries. They represent almost 20% of the world gold production, and contain some very large deposits (Robert and Poulsen, 1997).The majority of gold deposits in the Archean greenstone belt can be classified as mesothermal (Hagemann and Cassidy, 2000). The quartz veins are most often gold mineralized only hosted in low to medium metamorphic gradient fields, within the supracrustal distorted rock. The mineralization has no spatial or temporal relationship with the intrusive magmatic activity. There is no consensus on the source of hydrothermal fluids responsible for the mineralization. Various processes have been suggested by different authors, metamorphic devolatilization, fluid release by felsic intrusions, mantle sources (Bohlke and Kistler, 1986; Colvine and al. 1989; Cameron and al. 1989 ; Hodgson, 1993).

The complex of Amsaga constitutes the southwestern Archean part of Reguibat rise (Barrère, 1967). It is bounded to the south by allochthonous Mauritanides belt, to the east by the Taoudeni basin, to the north by the dunes of Akchar and to the west by the coastal basin (Figure 1). Potrel et al (1998) demonstrated the existence of a component of Archean crust (magmatic protolith), an age of about 3200-2870 Ma. This part of the rise also shows metamorphic rocks (mainly migmatic gneiss and metabasites) with granulite facies intersected by major granite and basic rocks (Figure 2).

The Amsaga zone was first explored by the Mauritanian Mining Industry Corporation (SNIM) that showed from geochemical prospecting campaigns(rock and soil), carried out in 2005, encouraging results for gold and base metals (Sirocco, 2012). The results of geochemistry have demonstrated abnormalities in Cu-Au (Sirocco, 2012). They are called anomalies: A, B, C, D, E, F, G and H (Sirocco, 2012). The dug trenches in anomalies H have confirmed the presence of gold, Cu and Zn mineralization, discovered previously by hammer prospecting and soil geochemistry. The company Sand Metals continued the work of SNIM in December 2011, by a geochemical soil prospecting and trenching, which are parallel to the work of SNIM to verify the reliability of previous work. This work was confirmed generally the same results of SNIM (Sirocco, 2012). Since then, the exploration work stopped and the area has never been the subject of a detailed geological study of polymetallic mineralization and conditions of formation.

The aim of this work in the Amsaga zone is to study the distribution of some base metals mineralization indices (especially copper) associated with Archean metabasite of Amsaga to determine their geochemical characteristics, origin and their implementation conditions.

Geological Setting:-

Mauritania has four main structural domains that are, from oldest to newest (Figure 1).

1. The Reguibat Rise, which extends almost 1500 km long and 400 km wide, is the northern portion of the West African Craton. It was divided into two major units (Bessoles, 1977, Vachette et al, 1973; figure 1), i) A western Archean rise (notably the massifs of Amiga, the Tijirit, the Tiris, the Tasiast, the Ouassat the Ghallaman and the Sfariat) including gneisses dated at 3.5 Ga (Potrel et al, 1996) that recorded tectonic-magmatic phases of 3.3; 3.0 and 2.7 Ga (Potrel et al, 1998). ii) A Paleo-Proterozoic ridge in the center and east (the massifs of Yeti and Eglab) essentially composed of granitoids emplaced around 2.2 Ga and 2.1 Ga, which are associated to some relics of Archean oceanic crust (2.7 Ga) (Boher et al, 1990).
2. The Mauritanide belt : in the west, it girdles the West African Craton and is composed of sedimentary and magmatic formations, metamorphosed, strongly folded and tectonised and show thrust structures verging (Sougy, 1969) at successive orogenic events: Pan African (late-Precambrian to Cambrian), Caledonian (Cambro-Ordovician) and Hercynian (Carboniferous) (Le Page, 1988).
3. Taoudeni basin includes sedimentary formations (detrital and carbonate) of the Proterozoic and Paleozoic (Rocci, 1990).These sedimentary formations occupy all the central and eastern part of the Mauritanian territory.
4. The sedimentary coastal basin of Mesozoic and Cenozoic age, occupying the western part of the country.

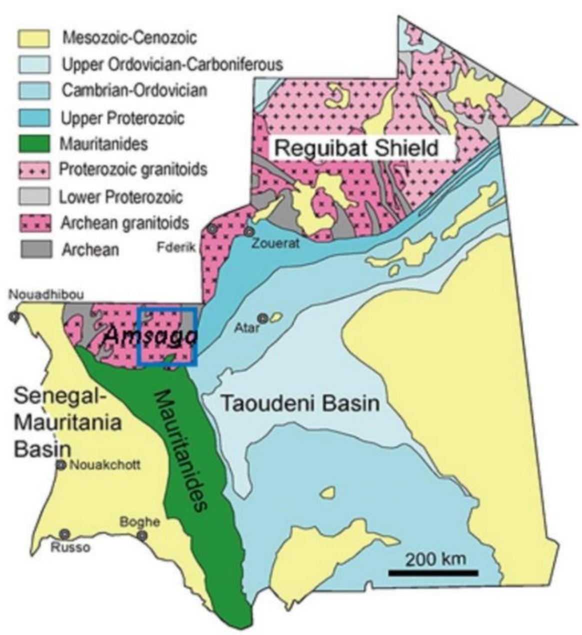

Figure 1: Structural Domains of Mauritania (Bessoles 1977, as amended).

The complex of Amsaga consists of a rocky procession intensely deformed with a multitude of minor folds and ductile shears (Portel, 1994, Schofield et al, 2007). It includes: (i) metamorphic rocks (the granulite metamorphism occurred between 3 and 2.7 Ga (Potrel et al, 1996) (ii) intrusive plutonic rocks (the Touijenjert granite gives a U-Pb age of 2726 ± 7 Ma according to Potrel (1994), the Iguilid gabbros a Sm-Nd age of 2706 ± 54 Ma; Potrel et al 1998; Pitfield et al, 2004; Figure 2).

The Metamorphic rocks are composed of:-

1. Migmatitic Gneiss: a large part of the southern half of the Amsaga zone is covered by rocky lenticular structure. The biotite quartzo-feldspar gneiss represent the dominant lithology, with in the background the amphibolite lenses, measuring a few centimeters to over 100m in length. The amphibolite dykes are schistose.
2. Amphibolites and amphibole schist prevalent, especially in the southern half of Amsaga.
3. Gneiss and hypersthene quartz-feldspar gneiss: The main facies exposed in the northern half of Amsaga are massive quartz-feldspar gneiss and charnockitic of hypersthene gneiss.
4. Quartzite mylonite: The major shear zones located in Amsaga are characterized by the presence of quartzite mylonite (Key et al, 2008) whose thickness varies from a few centimeters to over ten meters
5. The metabasite of Amsaga. They are especially prevalent in the southern half of Amsaga (Figure 2). They usually occur in dykes and intrusive in all metamorphic rocks (above-mentioned). Metabasic rocks consist of gabbros and Iguilid Guelb El Azib, amphibolite (leucocratic plagioclase, quartz, melanocratic), andesitic basalt, anorthosite and mafic schist to sericite with local intrusions of dolerite dykes. The regional direction to amphibolite is between N0 and N25°. Some amphibolite showed directions surrounding N45° due to local tectonics. They consist generally of hornblende and varying amounts of plagioclase, sometimes with minor amounts of clinopyroxene, quartz and opaque minerals, including magnetite and rarely pyrite. Secondary minerals are biotite, carbonates, chlorite and epidote. All of Amsaga metabasite are Archean; metagabbros of Iguilid and metagabbros of Guelb El Azib were dated respectively at 2.74 and 2.70 Ga (Portel, 1994).

The plutonic rocks including (Figure 2):-

1. Touijenjert granite: vast massif widely distributed in the east-central part of the area of Atar.
2. Ioulgend granite: it is a pegmatite outcropping in small escarpment located in the south of Touijenjert granite.
3. Aoutitilt porphyritic granites which are exposed along the western edge of Amsaga as a series of small hills and elongated and rounded reliefs (Pitfield et al, 2004).
4. Anorthosites: they are massive with medium to coarse grained and varying amounts of hornblende and feldspar.
5. Pegmatite: Several generations of quartz-feldspar pegmatite, of a thickness greater than 1m.

Structural evolution:-

The various metamorphic and intrusive rocks of Amsaga complex are highly deformed with a multitude of minor folds and ductile shear. These ductile structures can be divided into three categories (Portel, 1994):

1. Initial series with ductile events also including structures associated with early migmatization. The regional direction of these early structures is NNE-SSW.
2. A second series of ductile structures oriented NE-SW associated with the compressive formation of the “flower structure” situated on the western flank of Choum-Rag El Abiod Terrane. The sheared rocks show intense planar textures in which all structures (including veins) are substantially parallel to a new foliation. The initial folds are closed and folded, and the new structures generated include a transposed and ductile gneissosity, overlaps dipping west and subvertical faults. Generally, the mylonitic quartz occupies overlaps and fault planes. The planar structures, with dips moderately to very strong to the NE, are dominant in the southern half of the 'flower structure'. These structures tend to converge toward the north in the southern part. During this event, the different lithological units are deformed by anastomosing shear. The porphyritic granites have been deformed into augen gneiss. The development of these ductile shears predetermined the establishment of Touijenjert granite. This latter truncates the major shear zones oriented NE (Portel, 1994).
3. A third period of ductile shear took place during the implementation of granite Touijenjert, or at a later stage, this is because the porphyritic phase of this granite which is locally deformed into augen gneiss. A number of minor ductile shears is also present in the non-porphyritic granite phase (Portel, 1994). A new major ductile shear zone was identified during the geological mapping (Pitfield et al., Volume 1, 2004) established by the British Geological Survey in the western part of the Amsaga. This area is divided into two terranes with distinct tectonic-magmatic evolution (Key et al., 2008).

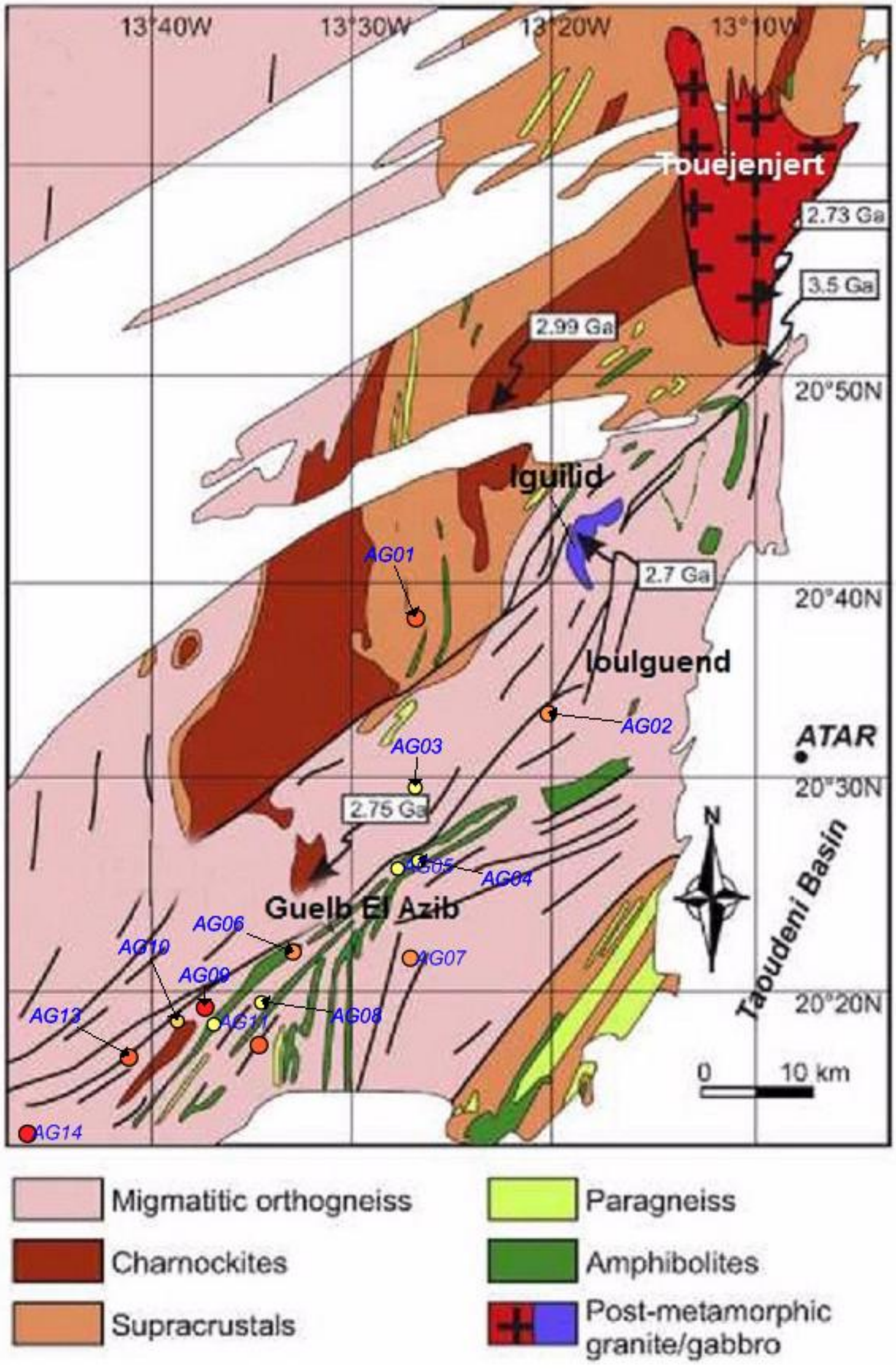

Figure 2: Geological Map of Amsaga (and samples location) amended by Berger et al. (2013).

The polymetallic mineralization:-

The presence of copper mineralization was detected during the field observations. It is more or less disseminated and associated with magnetite in the shear zones. The mineralization is not related only to metabasite. It may be associated with mafic intrusions, felsic with a medium to strong alteration (silicification, argillic alteration, sericite and oxidation). The dominant mineralization is mainly malachite and azurite, sometimes associated with sulphides consisting primarily of chalcopyrite, pyrite and sphalerite. It is particularly associated with veins of quartz and iron oxides (hematite and limonite). The mineralization is concentrated in zones of fracture. Azurite and malachite may be related to all types of rock (granitoids, biotite schist, mafic schists, migmatite and amphibolites; Figure 3).

An intense alteration usually accompanies the mineralization, often on large areas. The type of alteration varies depending on the host lithology. The alteration biotite is most dominant in the metabasite, with substantial quantities of quartz and sericite close in some mineralized metabasite rocks.

There is a close relationship between these geochemical anomalies and shear zones in the N20 to N30 direction.

Figure 3: Copper mineralization associated with different rocks of Amsaga zone.

Petrographic and metallographic study:-

The samples studied in thin and polished sections correspond to typical amphibolite facies, with regional metamorphism. The rock is composed primarily of amphibole (up to 60-70%), plagioclase (about 15%), quartz (5%) and biotite between 10-15% (Figure 4). The main forms of amphibole mineral are characterized by elongated prismatic crystals, of irregular grain forms with a sub parallel orientation well remarked. The particle size varies between 0.5-2.0 mm. They are characterized by dark greenish color, strong pleochroism.

Another mafic mineral present in all samples is biotite, characterized by long prismatic crystals in close association with amphibole. The rock is sphene enriched (size varies between 0.2-0.4 mm), usually included in amphibole and biotite (Figures 4a and 4b). Some crystals are of clear zonal structure. The plagioclase is present in irregular crystals whose size is ranging between 0.2-0.5 mm. The plagioclase has a clear lamellar structure. The grains are slightly affected by the alteration. The quartz forms irregular xenoblastic grains, slightly elongated parallel to the foliation.

The epidote is present as small grains, generally in direct contact with opaque minerals. The latter are present as sporadic grains dispersed within the amphibole. The rock is rich in accessory apatite which is in the form of slightly fractured rounded grains.

The presence of sulphates, in aggregate or disseminated in the rock, has been noted in some samples. They are mainly comprised of chalcopyrite and pyrite in aggregate form and disseminated in the host rock, with irregular variable size (up to several mm), sometimes presenting inclusions of sphalerite.

In some cases, the chalcopyrite relationship with sphalerite suggests late chalcopyrite formation. It should be mentioned that chalcopyrite inclusions generally follow the recrystallization planes (Figure 4c and 4d), which suggests a polyphase implementation of the mineralization.

The typical zonal distribution of chalcopyrite inclusions is visible sometimes, concentrated in the core of the aggregate and very fine inclusions irregularly distributed in marginal portion.

The sphalerite is observed as irregular aggregates or shaped isolated grains, in some cases it is developed along the mineral cleavage planes of metabasic rocks. It is undoubtedly, the first sulfide mineral formed in metal association. Pyrite has a very limited distribution in the polished section. It is found in some isolated grains in association with chalcopyrite (Figure 4c).

The magnetite is present in some samples, sometimes associated with hematite. It is observed in aggregate, slightly broken and lined with gangue minerals along the margins.

Iron hydroxides have been also observed with minor distribution in some samples associated with chalcopyrite aggregates (Figure 4d.).

Geochemical study of mineralization

During this study, rock chip prospections with selective sampling of formations that may be mineralized were conducted in the southern part of Amsaga. This campaign aims to discover new defects, but also to confirm the old anomalies discovered by the SNIM. A total of 14 samples were collected and analyzed at the ALS-Chemex laboratory in Ireland (Figure 2). For the multi-element analysis, the ICP-MS method with Aqua Regia extraction was performed, using the fine fraction (<0.063 mm). On the other hand, 10 metabasite samples were analyzed at the National Office of Hydrocarbons and Mines (ONHYM) for platinum group elements but the obtained results were negative.

In order to study the fertility of the Archean metabasite of Amsaga, compared to polymetallic mineralization, 10 samples of metabasite and 4 samples composed of granite, gneiss and quartzite were selected. The results of chemical analyzes in the majority of samples confirm the presence of significant anomalies for some base metals especially copper (Figure 5, Table 1). The copper levels, ranging from 0.5% to 3.3% (Figure 5, Table 1), represent an important target for copper exploration. The average grade of the Rock samples in the Amsaga zone is 75 ppm. Abnormal copper values are positively correlated to the sulfur content, which suggests the presence of sulphides (pyrite and chalcopyrite) in the samples.

The analyzed metabasite contain very elevated levels of iron that range between 5.9% and 30.3% (Table 1), suggesting the presence of copper sulfides and iron oxides.

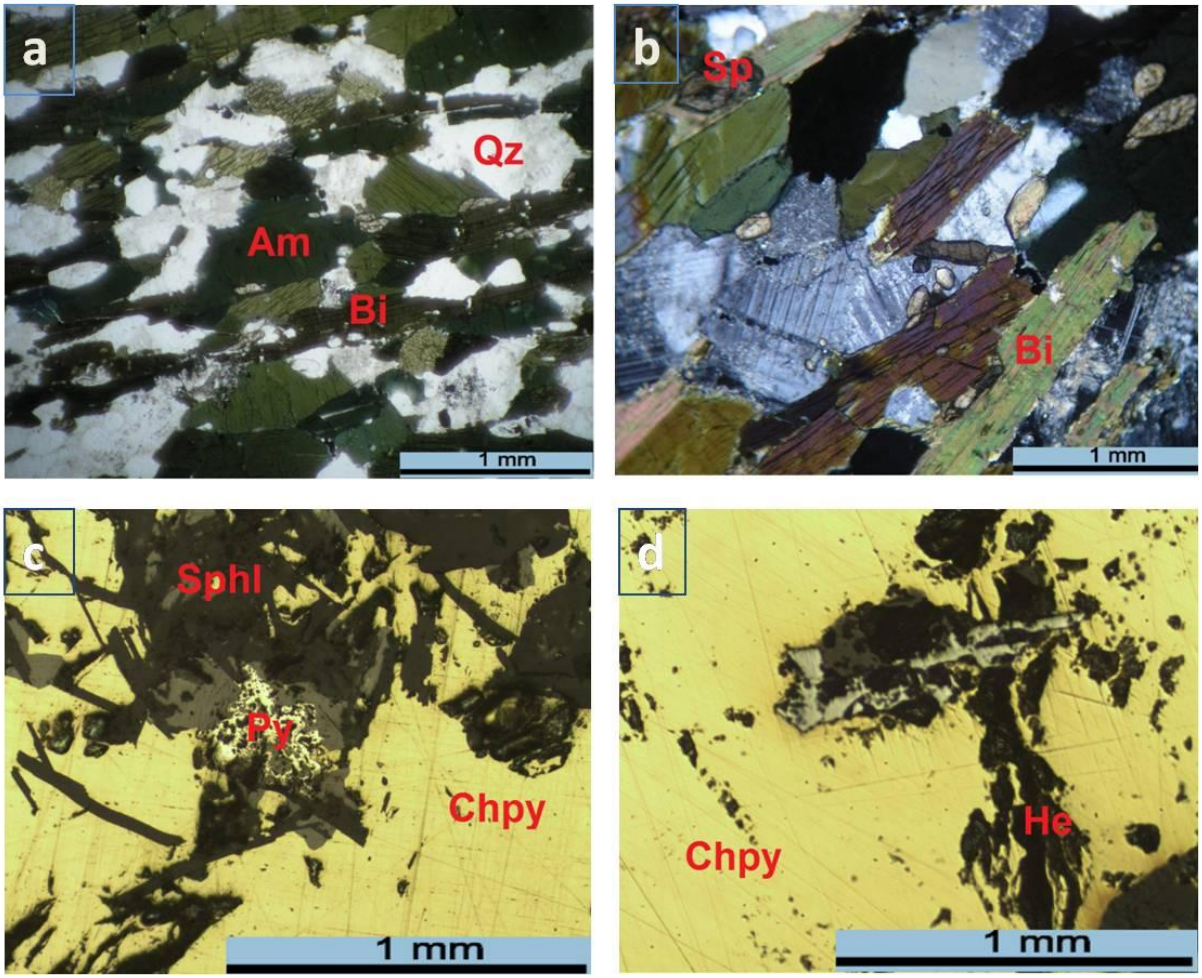

Figure 4: Representative microphotographs of Amsagametabasite facies and the associated mineralization: a: quartz-amphibolites; b: amphibolite rich sphene; c and d: Sulphide mineralization in metabasite. Am: Amphibole; plagioclase; Bi: Biotite; QZ: Quartz; Sp: Sphene; Py: Pyrite; Chpy: chalcopyrite; SphI: sphalerite; He: hematite.

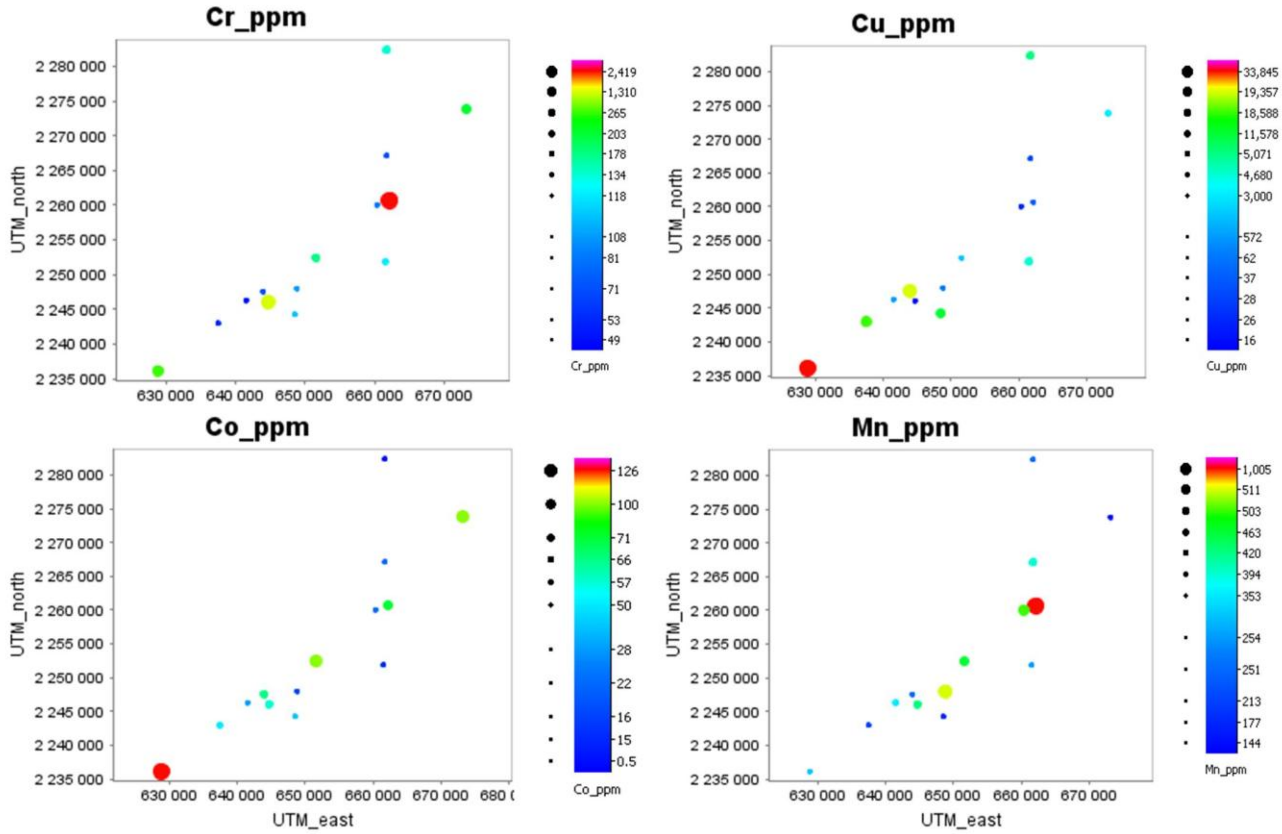

Figure 5: Maps of base metal analysis results in the Amsaga zone.

The mineralization is more concentrated in the southern part of the Amsaga zone.

The enrichment in Chrome is clearly marked in the amphibolites with varying anomalous concentrations ranged between 108 ppm and 2419 ppm. 5 of 10 samples of metabasite exhibit abnormal contents of Cr (concentration greater than 100 ppm).

Abnormal gold values were recorded in 3 samples (2 metabasite samples and 1 gneiss sample) varying between 78 and 346 ppb. These values are positively correlated with the anomalous copper values. The other base metals (Mn, Pb, Zn, Ag and Ni) have relatively anomalous values compared to regional levels (Sirocco Mining, 2012). These contents are not very high compared to copper values. There is also a partial spatial correlation between the geochemical signature copper and cobalt for 14 samples (Figure 5) among those with abnormal values (Table 1).

These geochemical data show that only a part of studied samples can present spatial correlations between copper and other base metal elements (Figure 6).This can be explained by the fact that high levels of copper are the result of copper sulphide alteration into copper carbonates, including malachite which is visible on the ground in fractures rock outcrop.

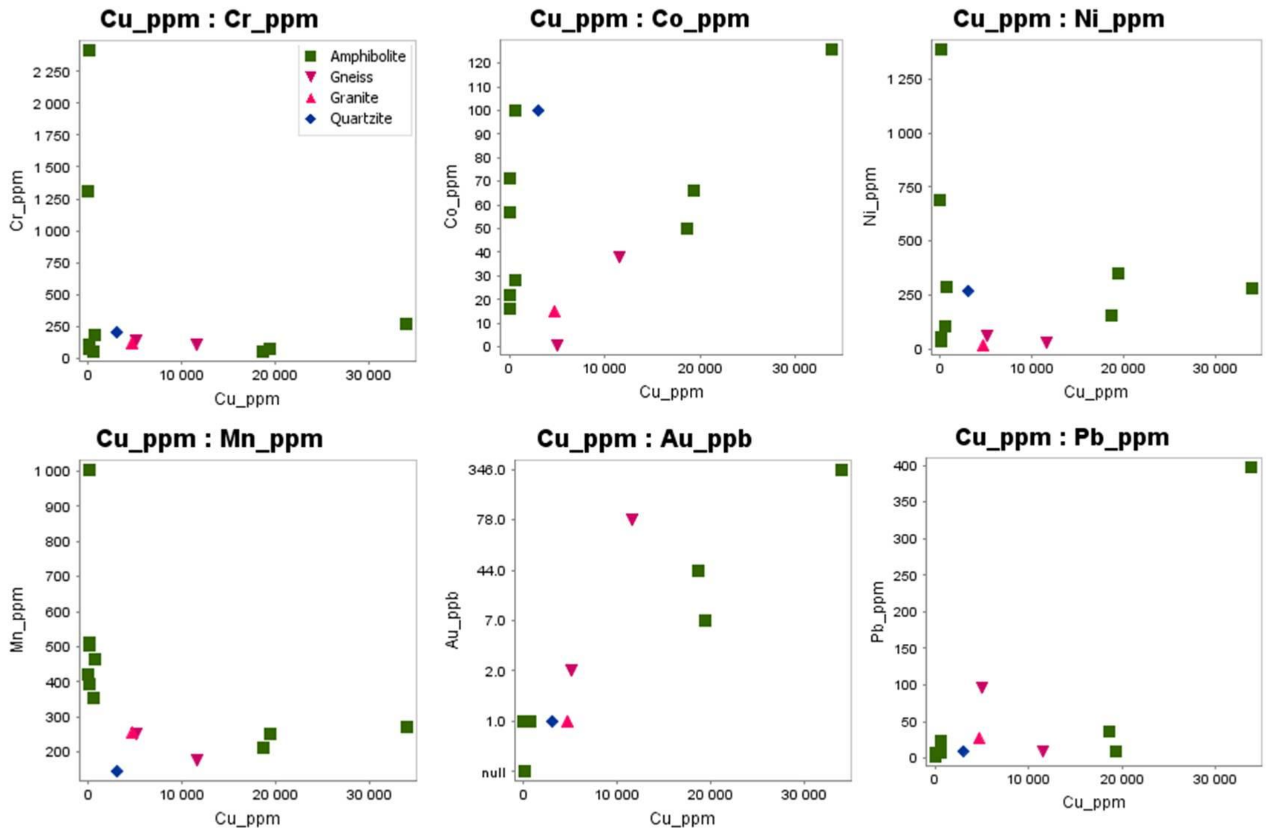

Figure 6: Correlation diagrams of base metal contents in the metabasites.

Table 1: Geochemical analyzes of Amsaga metabasites

sample	AG01	AG02	AG03	AG04	AG05	AG06	AG07	AG08	AG09	AG10	AG11	AG12	AG13	AG14
Pétrolog	Gneiss	Quartzit	Amphib	Amphib	Amphib	Amphib	Gneiss	Amphib	Amphib	Amphib	Amphib	Gneiss	Amphib	Amphibolite
Al_%	1,5	0,52	1,99	2	1,69	5,91	1,02	2,59	0,46	1,8	0,95	0,2	1,2	2,01
As_ppm	2,5	3	2,5	187	2,5	2,5	3	2,5	3	2,5	2,5	3	2,5	2,5
B_ppm	2,5	3	2,5	2,5	2,5	2,5	3	20	3	2,5	2,5	3	2,5	2,5
Ba_ppm	18279	59	525	220	1340	44	736	644	2013	735	162	874	415	650
Be_ppm	0,5	1	0,5	0,5	0,5	0,5	1	0,5	1	0,5	0,5	1	0,5	0,5
Bi_ppm	2,5	3	2,5	2,5	2,5	2,5	3	2,5	3	2,5	2,5	3	2,5	2,5
Ca_%	0,75	0,43	1,34	0,46	1,28	0,33	0,2	2,37	3,79	0,7	0,24	2,53	1,61	3,81
Cd_ppm	0,5	1	0,5	0,5	0,5	0,5	1	0,5	1	0,5	0,5	1	0,5	0,5
Ce_ppm	13	4	49	4	56	3	4	1	44	145	2	4	7	9
Co_ppm	0,5	100	22	71	22	100	15	16	66	28	57	38	50	126
Cr_ppm	134	203	71	2419	81	178	118	108	71	49	1310	109	53	265
Cu_ppm	5071	3000	28	37	26	662	4680	62	19357	572	16	11578	18588	33845
Fe_%	1,2	10,62	5,95	6,47	6,07	10,42	3,38	2,26	30,37	2,59	6,69	16,81	6,05	13,63
Ga_ppm	2,5	3	8	6	6	13	6	2,5	5	5	2,5	3	5	10
Ge_ppm	1	1	1	1	1	1	1	1	1	1	1	1	1	1
K_%	0,05	0,01	0,86	0,005	0,83	0,03	0,06	0,28	0,03	0,07	0,02	0,03	0,12	0,22
La_ppm	8	2	24	3	27	2	2	1	35	68	2	3	4	5
Li_ppm	3	1	7	1	5	16	14	6	1	6	1	1	5	3
Mg_%	0,22	0,16	0,72	12,36	0,79	5,36	1,12	1,22	0,27	1,29	6,2	0,07	0,4	0,95
Mn_ppn	251	144	394	1005	503	463	254	511	251	353	420	177	213	272
Mo_ppn	3	13	1	0,5	2	0,5	4	0,5	3	0,5	0,5	168	1	17
Na_%	0,01	0,01	0,2	0,005	0,17	0,005	0,03	0,18	0,01	0,05	0,02	0,03	0,005	0,07
Nb_ppm	2,5	3	2,5	6	2,5	2,5	3	2,5	3	2,5	2,5	3	2,5	2,5
Ni_ppm	60	270	34	1390	33	289	15	54	352	107	687	31	156	278
P_%	0,01	0,025	0,224	0,02	0,203	0,037	0,017	0,024	1,209	0,103	0,022	0,012	0,227	0,195
Pb_ppm	96	10	4	5	5	7	27	8	10	24	1,5	10	36	398
S_%	0,09	0,02	0,05	0,02	0,07	0,005	0,03	0,03	0,04	0,02	0,02	0,1	0,02	0,27
Sb_ppm	2,5	3	2,5	2,5	2,5	2,5	3	2,5	3	2,5	2,5	3	2,5	2,5
Sc_ppm	1	1	6	8	7	3	2	9	1	2	4	1	0,5	4
Se_ppm	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Sn_ppm	2,5	3	2,5	2,5	2,5	2,5	3	2,5	3	2,5	2,5	3	2,5	2,5
Sr_ppm	143	28	55	21	108	18	29	48	98	94	12	78	61	422
Ta_ppm	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Te_ppm	2,5	3	2,5	2,5	2,5	2,5	3	2,5	3	2,5	2,5	3	2,5	2,5
Th_ppm	6	3	2,5	2,5	2,5	7	3	2,5	3	93	2,5	3	2,5	2,5
Ti_ppm	543	118	4350	236	4633	883	99	1032	113	736	277	47	158	157
Tl_ppm	2,5	3	2,5	2,5	2,5	2,5	3	2,5	3	2,5	2,5	3	2,5	2,5
U_ppm	2,5	3	2,5	2,5	2,5	2,5	3	2,5	3	6	2,5	17	5	7
V_ppm	18	48	208	60	198	49	53	76	106	30	51	29	37	97
W_ppm	2,5	3	2,5	2,5	2,5	2,5	3	2,5	3	2,5	2,5	3	2,5	2,5
Y_ppm	7	1	22	3	25	13	1	5	38	17	2	5	13	2
Zn_ppm	52	37	71	107	70	100	34	71	26	44	24	50	45	72
Zr_ppm	12	4	11	0,5	12	4	3	2	9	3	3	5	3	7

Conclusion:-

The compilation and analysis of geochemical, petrographic and metallurgical Archean metabasites of Amsaga show that copper anomalies identified in this study have linear structures parallel to the directions of faults and shears, suggesting that the mineralization is controlled by shear, which may overlap the different facies. This indicates that the mineralization is not only associated with metabasite.

The copper mineralization of Amsaga is characterized by a paragenesis including malachite, chalcopyrite, pyrite, magnetite and sphalerite. The mineralization occurs in different forms: disseminated, aggregates in country rocks, filling geodes and veins in mafic rocks.

Field observations and microscopic study of analyzed metabasite samples allowed to conclude that the establishment of the copper mineralization could be either syngenetic, related to metamorphism and hydrothermal fluid circulation, or it is in relation to hydrothermalism associated with Pan-african and Hercynian orogenies, origin of Guelb Mogrein Akjoujt deposit in the south of Amsaga.

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