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Exploration and Mapping of Metalliferous Black Shales in the Saghro Temporary Subsidence Zones (Anti-Atlas, Morocco)

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Abstract

The Saghro massif constitutes a vast metallogenic province with numerous deposits and shows of base metals (lead, zinc, copper) and precious metals (gold and silver), besides various useful substances (talc, pyrophyllite, barite, fluorite). Silver/lead occurrences are concentrated along the Cryogenian Imiter series and moderately at Boumalne and Sidi Flah. Copper occupies the plutonic intrusions and intrusive rocks of the East-Central Saghro while barite deposits are widespread throughout the Cambrian cover of the East Saghro in contact with the Ediacaran basement. To justify this distribution, the new contributions of the cartography and the organic geochemistry of the black shales of Jbel Saghro have clearly shown the particularity of the Imiter black shales in terms of the richness in organic matter (TOC = 0.18%), the blackish color and the friability. The Boumalne and Sidi Flah groups present some similarities with the Imiter group, such as the sub-equatorial structuring, the friable pelites and the richness in organic matter (Boumalne TOC = 0.11% and SidiFlah TOC = 0.16%), which is a quite good show that requires to reinforce the exploration works. For Western Saghro in the Iknioun and Qalaa't M'Gouna groups, the variations in the thickness of the volcanic cover show an irregular paleotopography with hard, greenish, organic-poor pelitic sediments (TOC = 0.01 to 0.04%). We can conclude that the formation of Imiter-type silver concentrations requires the combination of the sedimentological, the volcanic and structural factors. For Imiter-type silver these factors are: a fine pelitic and argillic casing deposited in a confined environment, a basic volcanism source of metals and other intermediate to acid generated by the hydrothermalism and heat, a convenable paleotopography and a network of fracturations to trap the mineralizations.

Keywords

Saghro, Metallic Shales, Silver, TOC, Exploration, Cryogenic, Polymetallic, Imiter

1. Introduction

The source of silver mineralization in the syn-to-late metamorphic deposits of the Saghro has always been a subject of debate (Braoudi, Tuduri, Chauvet, Essaraj, Ennaciri, Levresse, ...). Baroudi proposed that the silver concentration and associated metals are related to a tectonic-metamorphic event from a syngenetic stock contained in the black shales of the cryogenic sedimentary basins [1]. While Levresse showed that the silver mineralization of Imiter is a neutral epithermal type [2], emplaced in connection with acid magmatism accompanied by hydrothermal events during the Neoproterozoic distensive tectonics whereas Essaraj exposed that the main stage of silver ore is related to the circulation of sedimentary brines of the deep basins (Na-K-(Mg) [3]. However, all previous researches have never answered the following questions: in these basins, what is the potential rate of primary Silver? How rich are black shales in Silver?

This project aims to respond to the previous questions using mapping and geochemical tools to recognize the metal and silver-rich pelites in the Saghro cryogenic sedimentary basins. In the present study, we tried to establish the new technique of organic geochemistry to manipulate the organic content in the cryogenic pelites of Saghro, and to generate a well detailed geological map of the basement and the potential mineralized zones.

2. Geological Setting

2.1. Saghro Geological Setting

The Jbel Saghro massif covers an area of nearly 4000 km^2, it is bounded to the north by the Dades and Todgha valleys, to the east by the Ougnat and Tafilalt, to the south by the Jbel Bani and to the west by the Draa Valley. This massif is elongated in an ENE-WSW direction and it is constituted of precambrian formations outcropping in the heart of buttonholes [4] [5]. The landscaping of the Jbel Saghro is composed of several formations from Neoproterozoic to quaternary [6] (**Figure 1**). The oldest formations of Cryogenian age outcrop in four sectors defined as buttonholes surrounded by thick Ediacaran and/or Adoudounian formations (Staratigrafic table **Figure 2**). From west to east, the four sectors are respectively named: Sidi Flah-BouSkour, Kelâa M'Gouna, Boumalne and Imiter.

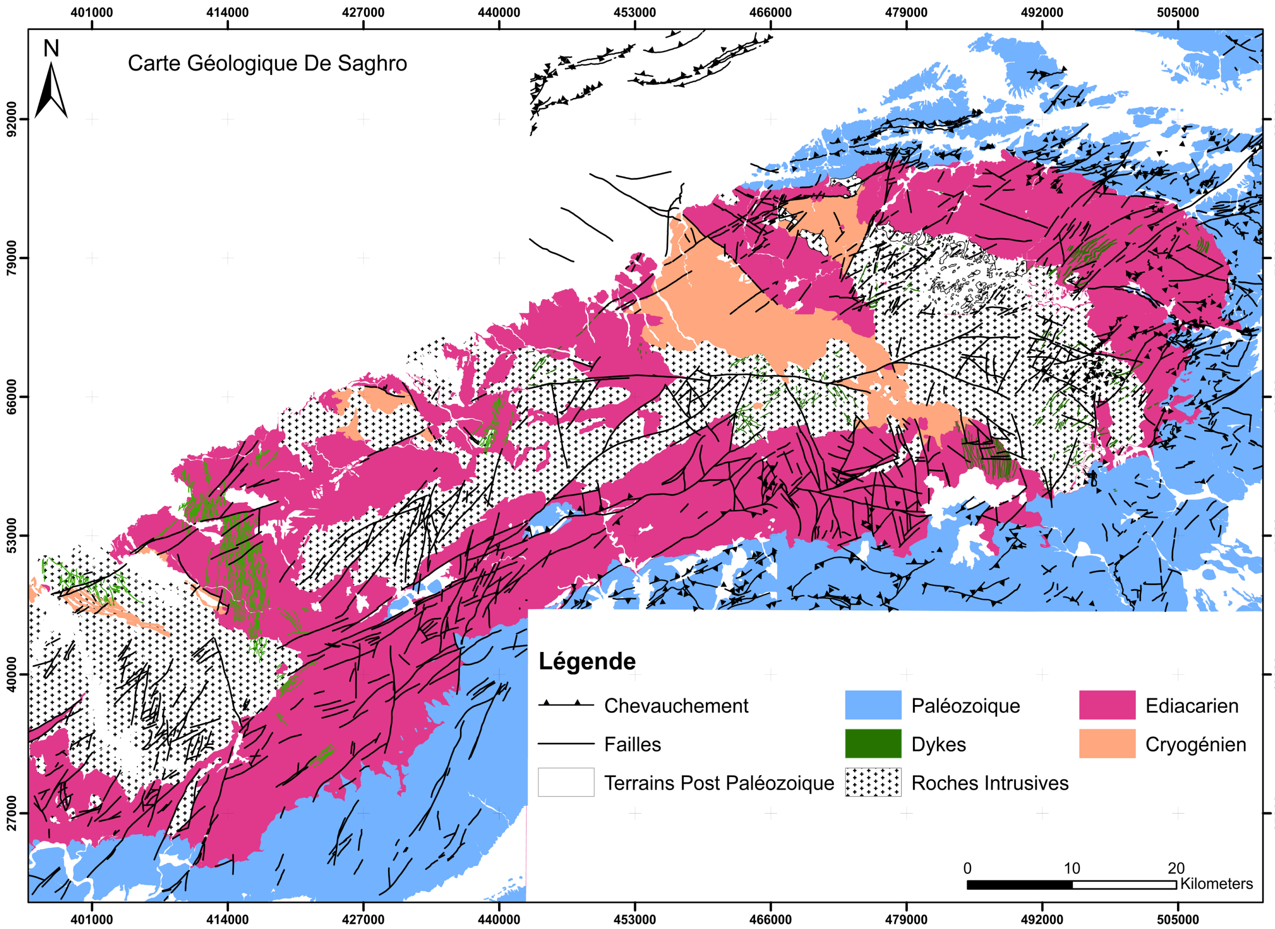

Figure 1. Simplified geological map of Jbel Saghro digitized from the 1/50.000 sheets of Saghro.

2.2. Geological Setting of the Imiter Ag-Hg Deposit

The Imiter buttonhole is located on the northern flank of the Jbel Saghro formed by a metasedimentary basement of Cryogenian age covered by the Ediacaran volcano-sedimentary series (**Figure 3**). The Imiter silver deposit is distributed along the Imiter fault system over nearly a 7 Km surface. This fault zone affects Cryogenian formations as well as Ediacaran lavas, volcaniclastites and the Cambrian cover [4] (**Figure 4**).

2.3. Structural and Tectonic Setting of Imiter Buttonhole

In the Imiter buttonhole, tectonics is marked by two phases: a ductile and a breaking phase

- Fold tectonics (formation of folds)

These tectonics are represented by the anticlinal folds characterized by the E-W trending axis, and schistose structures parallel to the stratification with strong dip towards the North. In the Boumalne and Imiter buttonholes, the expression of the Panafrican tectonics is dominated by the ductile deformation of the Neoproterozoic silico-clastic metasediments, and the generation of kilometeric scale large synschistose folds and their corollable folds (B1) [8].

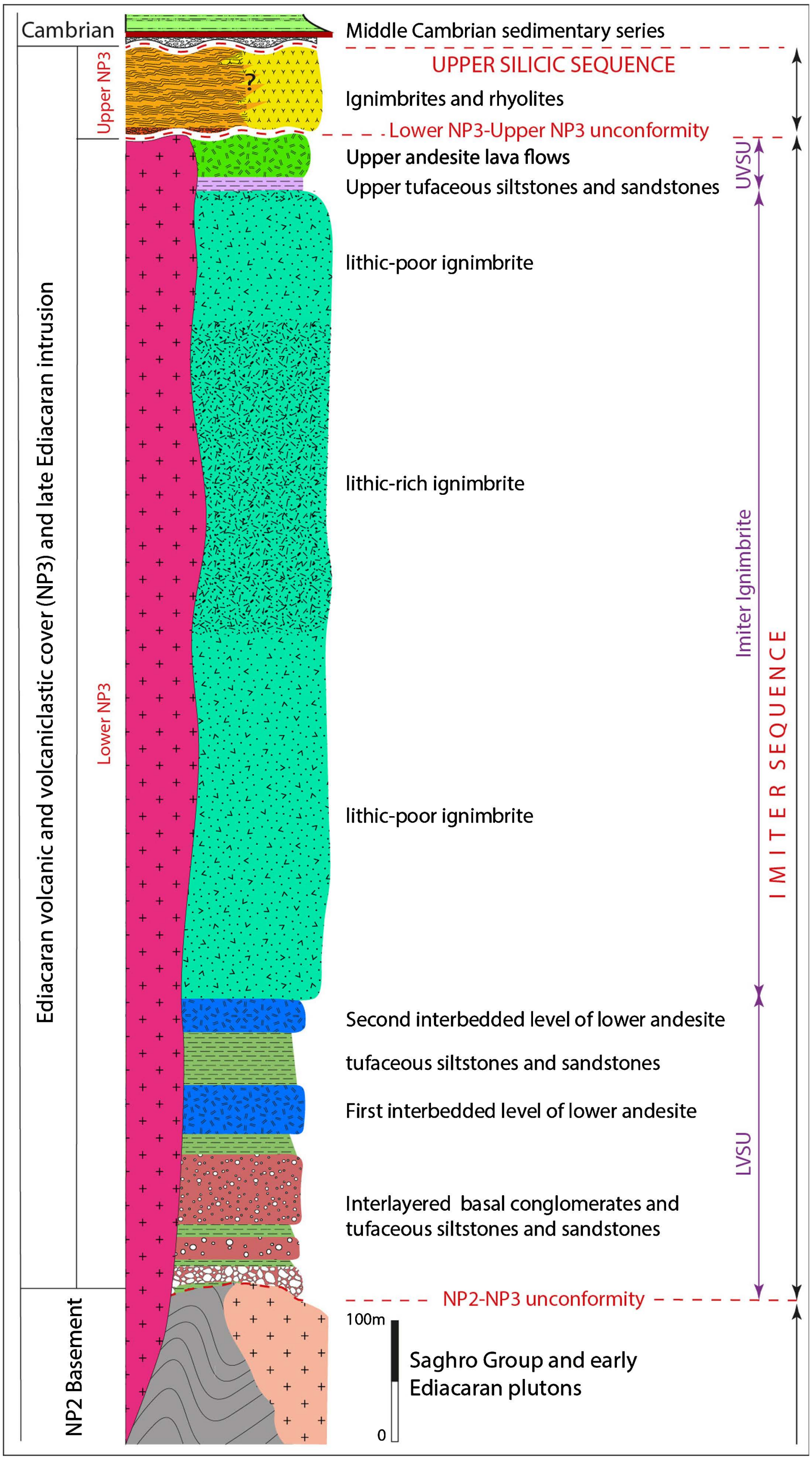

Figure 2. Generalized lithostratigraphic column for the Eastern Anti-Atlas [7].

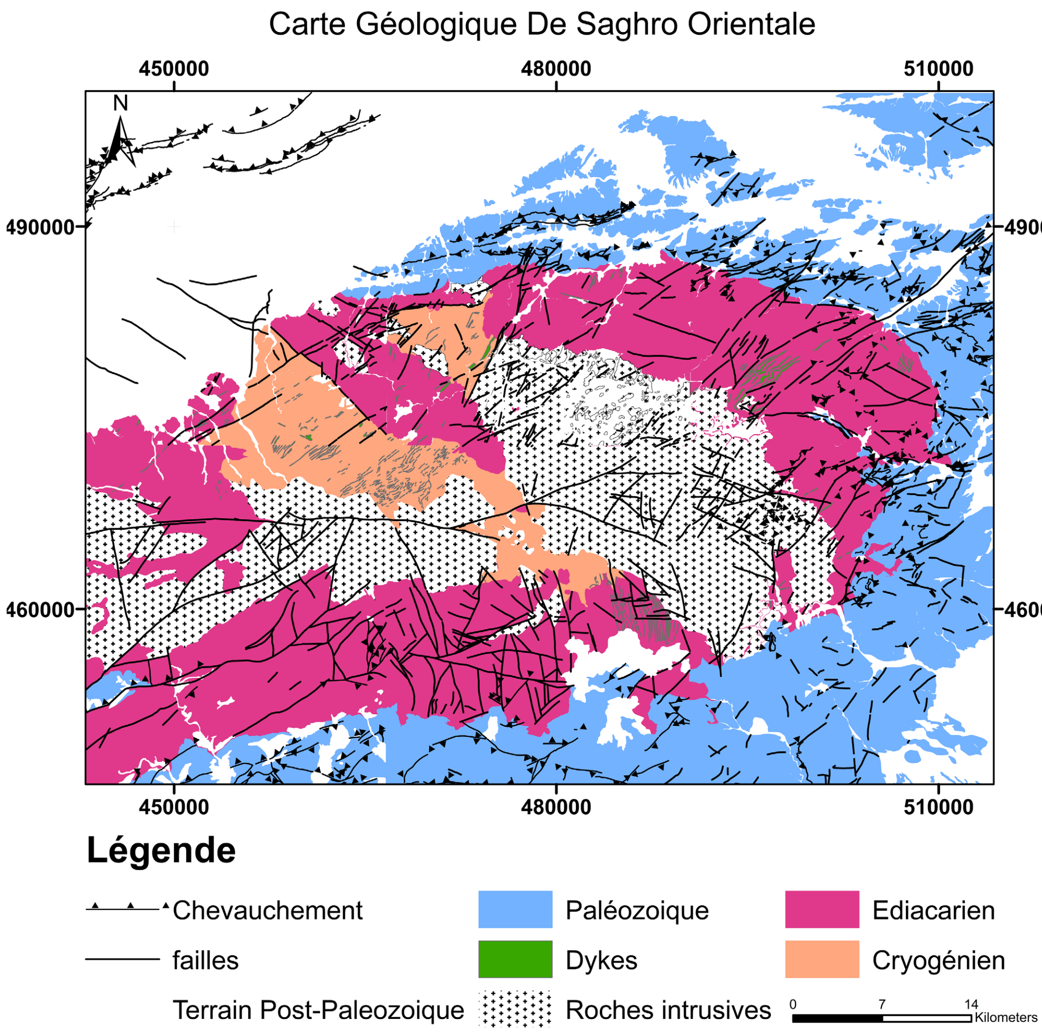

Figure 3. Situation of the Imiter buttonhole on the northern flank of the Saghro massif 1/50.000 sheet.

The deformation is older than the Imiter conglomerates (NP3Wb) that unconformably overlie the folded and weakly metamorphosed Neoproterozoic metasediments. This deformation corresponds with the non-coaxial N60-70 trending Boumalne synclinorium and the Imiter anticlinorium. These lasts bend slightly at their periclinal termination and they are parallel to the ENE-WSW trending faults [9].

The layering (S0) of the cryogenic metasediments is still preserved and clearly visible. On the Imiter sheet, a main phase of ductile deformation (B1) and a mostly oblique axial plane schistosity (S1), sometimes associated with discrete lineation, were recognized at the outcrop scale. The schistosity is more penetrative in the pelitic levels of the long flanks of the secondary folds, it shows a trending 50˚ - 70˚ dip towards N330-340, subparallel to the stratification. While on the short flanks, the schistosity is subvertical and N90-110 oriented. In Boumalne and Imiter sheets, there is no evidence of the second metamorphic foliation or the existence of small B2 driving folds highlighted in some models. However, the dispersion of fold axes and foliation paths, evident especially in the

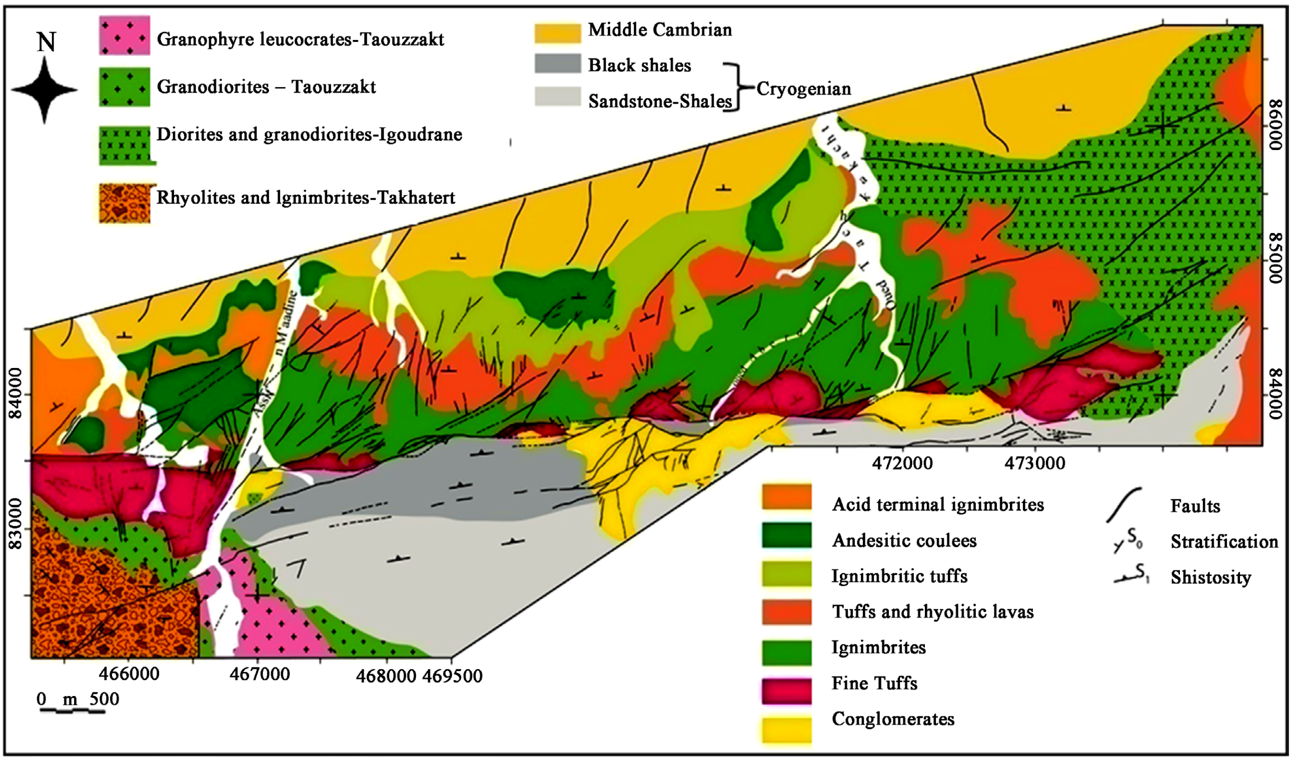

Figure 4. Geological map of the Imiter mining area showing the Neoproterozoic basement formations digitized from the Imiter 1/50.000 sheet.

Imiter buttonhole [4]. It suggests the existence of a second phase of regional deformation (B2). Finally, the weak ductile-fragile deformation of local magnitude affecting the Neoproterozoic (NP3) dykes is observed [10]. They are more likely related to basement bulging and tectonics of Hercynian and post-Hercynian periods.

The Cryogenian series of Imiter are deformed according to two folding phases.

- Synschist phases

It is represented by first diverted folds or second diverted folds towards the South-East. Their axis shows NNE to NE [4]. Trending directions and more or less accentuated plunges towards the NE. These folds present a well-developed slatey cleavage-type axial plane schistosity in the pelitic levels, which are refracted in the sandstone levels [11] [12].

- Post-schistose phase

It generates folds with a large curvature radius and it is located to south of the buttonhole. The axis of the folds is N110 trending to 130˚E with a 40˚ oriented dip towards the west with a subvertical axial plane. Other post-schist folds are observed in the vicinity of the Imiter fault. They vary in direction from N 90˚ NNW with dips varying from vertical to horizontal. These folds are related to the operation of the Imiter fault

- Breaking tectonics

The breaking tectonics is materialized in the Imiter buttonhole by various faults systems:

E - W trending system

This fault system constitutes the Major Accident of Imiter. It separates the northern block dominated by collapsed Ediacaran terrains from the southern block dominated by Cryogenian terrains, which is the main metallotect of the mineralization [4] [13] [14].

ENE-WSW trending system:

These subequatorial ENE-WSW trending faults intersect the E-W trending faults. These two trending faults define the extensive pull-apart basins [15] corresponding to the high silver potential mining zones.

NE-SW trending system:

NE-SW trending system is the most important system in the Imiter buttonhole. It is a linear system that cuts all the Saghro formations, including the Paleozoic's. These faults are very complex and polyphase, they occur before, during and after the Pan-African orogeny, as follows.

Normal faults set

They led to the opening of the middle Neoproterozoic basin filled by Neoproterozoic sediments and magmatic tholeitic

Dextral faults set

They occurred during orogenic compression, and the produced the B1 fold attributed to the first Pan-African phase [16]

Distensive and sinister faults set:

They were generated during late Ediacaran age throughout the terminal volcanic activity. They are characterized by a hydrothermal circulation and by the alteration of the surrounding rocks. This phenomenon is observed near the NE trending faults.

Normal faults set

Generally represented by a weak decrochement component during the Paleozoic.

According to measurements made at the surface, the fault families are distributed along three main directions [N070-90˚E], [N020-50˚E] and [N90-120˚E] (**Figure 5**).

2.4. Geological Setting of the Boumalne Buttonhole

The Boumalne massif is formed by a Precambrian basement surmounted by an unconformable Paleozoic cover.

- The Cryogenian metasedimentary formations in the Boumalne buttonhole are organized according to 3 units
- The lower sandstone-pelitic sediments or Izemgane Formation

This sandstone-pelitic formation contains detrital, volcanic and volcaniclastic elements, corresponding mainly to grauwackes. This latter is organized most often as massive decimetric benches, and sometimes as a pluri-metric benshes. These benshes alternate with decimetricpelitic levels, that are of a phyllite character and finer grain size. The grauwackes and pelites are organized in positive turbidite sequences.

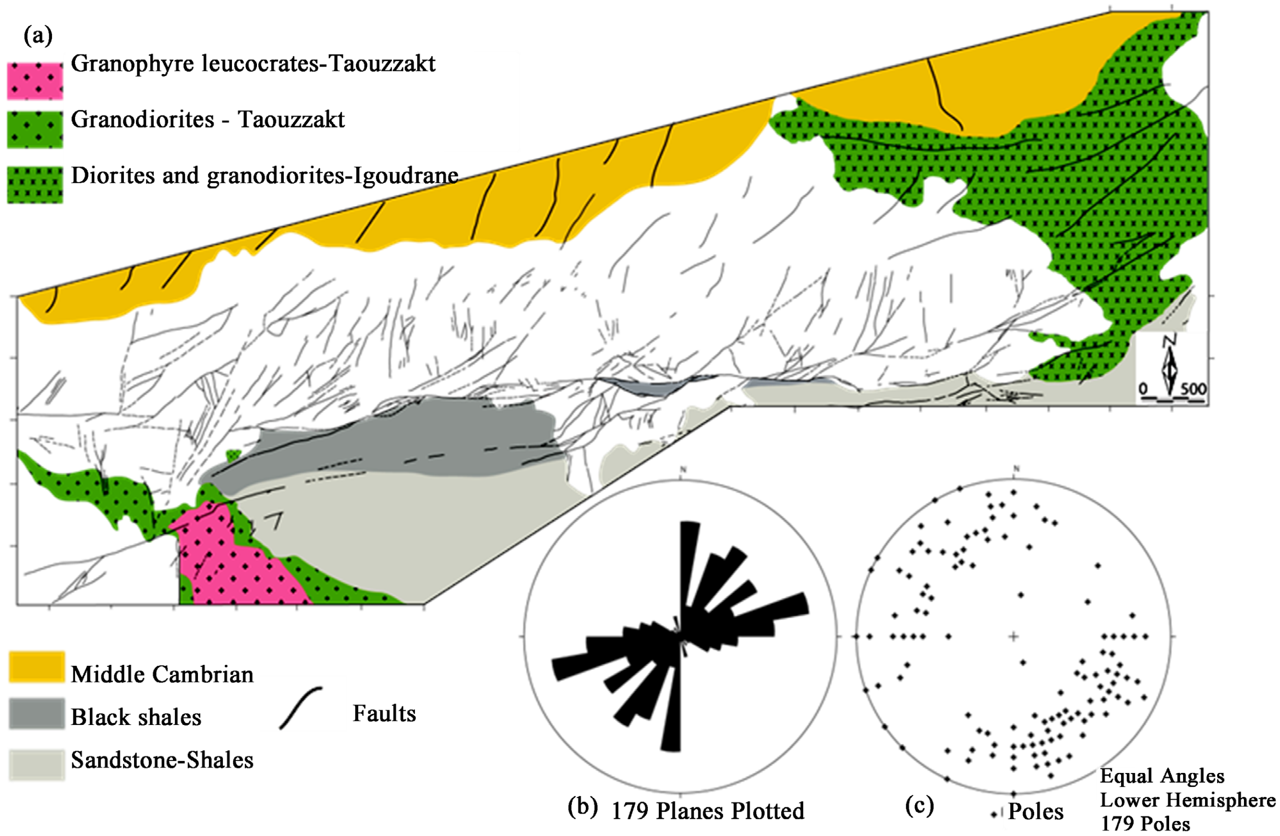

Figure 5. Structural map of the Imiter mining discrete, (b) Directional rosette, (c) Stereogram of dips.

- The dominant pelitic sediments, or median pelitic formation

It is constituted by very schistose beige to black pelites. Towards the top, a frequent intercalation of black iron and manganese oxides-rich levels are found. This formation contains some veins layers and flows of basalts.

- The upper sandstone-pelitic sediments, or Tiboulkhirine Formation:

The formation is elongated according to ENE-WSW orientation and includes massive beds of grauwackes, alternating with more frankly schistose pelitic and siltitic levels, organized in positive sequences of turbidites [4]. However, it differs from previous unit by the fact that no frankly volcanic levels have been recognized [17]

This series of sedimentary and volcano-sedimentary origin is folded and slightly affected by a very weak regional greenschist metamorphism; the benches are ENE-WSW trending with an average dip of 45˚, variable from 30˚ to 70˚ towards the northern-west. Sedimentological studies interpreted these silico-clastic formations as submarine cone type deposits transported by important turbidity currents [18] [19] [20].

Numerous metalliferous shows have been the subject of mining exploration in the Iknioun area, they are hosted in intrusions and their host rocks and are of unequal importance. These showings are represented by Ba, Pb, Zn and Cu vein deposits, linked to an acid vein network (quartz) and carbonate veins. These types of veins resemble the vein procession described in Ougnat [21]. Other mineralizations are disseminated in the Iknioun granodiorite near Douar Mi-Kbi and in the quartz monzonite near Douar Agoulzi n-Ikkine.This type of mineralization is certainly related to the strong hydrothermal fluids circulations in the area. The most important showings are Cu, Pb, Ba, and Mn [22].

2.5. Qalaa't M'Gouna Buttonhole

The Kelaat Mgouna Cryogenian group consists of five silico-clastic formations. It has been considered to be deposited in a back-arc basin related to a subduction zone, located more to the south-west at the major accident of the Anti-Atlas area. Such an arc would have been the main source of detrital material. In fact, the analysis of the modal composition of the grauwackes of this group, the study of the lithic framework of its conglomerates and the study of the detrital zircons, show that the source is continental and belongs to a passive margin formed by a metamorphic basement and an anteroproteozoic orogenic belt. The Kelaat Mgouna group would have been deposited in a passive context in an opening basin contemporary with the pre-Panafrican extension [19].

The KelaatMgouna Group corresponds to deposits verticalized during the major Pan-African phase. Its thickness is estimated at 4000 m corresponding to the stacking of five silico-clastic formations. Synsedimentary and subaqueous basaltic flows are interbedded. The silico-clastic formations are formed respectively by conglomeratic and coarse sandstone gravity deposits, medium to fine sandstones, turbidites and other facies that are generally organized in normal grading sequence [23].

2.6. The Buttonhole of Bouskour-Sidi Flah

The buttonhole of Bouskour-sidi-flah is located in the north-western part of Jbel Saghro. It is located to the east of the Ouarzazate city, between the valley of Dades and that of Draa in the south. It is constituted by the Cryogenian volcano-sedimentary formations cut by microdiorite dykes, rhyolite, trachy-andesite and by Cryogenian to Ediacaran granodiorites [20]. This causes a contact metamorphism. These formations are surrounded by the Ediacaran alkaline granite. The later magmatism is manifested by the network of reddish Ediacaran rhyolite dykes, dolerite dykes and gabbro intrusions [21] [24].

The andesitic volcanism of Bouskour represents the manifestation of a cryogenian volcanic arc [25], the magmatism is also represented in this buttonhole by a calc-alkaline plutonic series (from gabbros to granites) [26].

The mining district is constituted by intrusive and extrusive magmatic rocks (granodiorite, andesite, granite, dolerite…), associated with ignimbrites (clasts). Mineralization is hosted in volcano-sedimentary formations, crossed by rhyolite dykes and affected by several orogenic phases [19] [27] [28].

The "crow's foot" sector constitutes the main mineralized zone in the Bouskour mining district, as it contains, in addition to the main vein of regional extension, the F1 and F2 veins. The F1 vein is connected to the main vein and is slightly off-set to the sinister along the Clavel fault, while the curved F2 vein is thought to be damped on the approach to this NE-SW trending fault [29]. This sector is in fact the most transtensive zone in the region, related to the sinister play of the N160 fracture that hosted the main lode mineralization.

To better understand the metallogeny of the large Bouskour copper deposit, Azmi proposed that the emplacement of these mineralizations in a Cryogenian-calc-alkaline magmatic host (andesite and type I granodiorite), is related to a subduction geodynamic context [30].

3. Methodology

- The methodology of this work is based on an in-depth study of the study area to fully understand the litho-geochemical and structural evolution of silver mineralization.
- 1) A data synthesis that was carried out from previous academic works, exploration/mining works (BRPM, MANAGEM, MINISTER). 2) the realization of simplified geological maps of the Eastern and Western Saghro by treating the lithological and metallo-structural evolution of each unit with the different metalliferous shows and the different local mining activities. This helped establishing regional maps that indicate the distribution of base metals and precious metals. The maps are implicated to guide the mining exploration and search for potential areas. 3) The basic data are verified every time on the field by detailed geological mapping missions along the Saghro massif with a systematic sampling on 20 m grid following perpendicular sections to the schistosity planes.

4. Results

4.1. The Silver Ore Show of the Tawayya Sector

It is characterized by the outcrop of the Imider Pluton located at 3 km south of the Imiter village. At its southern limit, the pluton is unconformably overlain and reworked by conglomerates, volcanic tuffs and breccias belonging to the Ediacaran era. The mineralized structures are collected in the ignimbrites according to stockwork form, and they are silver galena-rich. These mineralized structures are limited in the thin extensions, which necessitates reinforcing the study by drilling.

4.2. The Cupro-Silver Show of Tiboulkhirin-Tagdilt Sector

The rhyolitic Pluton of Tiboulkhirineis situated at 1.5 km southeast of the Tiboulkhirine village. It is a small hill shaped pluton located on the left flank of the Assif Moungarf Mountain. The small intrusive body is completely surrounded by the Cryogenian sandstone-peliticmetasediments, it incorporates copper mineralization-rich quartz veins.

This type of deposit is quite widespread in the basement formations, along an E-W to NE-SW trending fractures and linear faults. Some deposits have been explored and sampled by scraping and drilling, while some of them have been extracted manually. In the metasedimentary basement of the Tagdilt zone, copper mineralization (**Figure 6**) is present either in fractures distributed in the Cryogenian granite, or in vein sets sometimes included in dislocation zones, or as impregnated deposits in fractured areas.

4.3. Iknioun-Outaaoui Cupro-Gold Shows

The NW sector of Iknioun belongs to the Boumalne-Dades buttonhole, and it is essentially occupied by the largest granodiorite massif known in the Saghro.

The E-W trending granodiorite of Iknioun has been intruded in the sandstone-pelite series during the final phase of the Pan-African orogeny, it is cut by a set of dykes (**Figure 7**) of very varied directions and petrographic nature (andesite, rhyolite, dolerite). This massif records an intense fracturation of N45˚ major trending. The field of constraint underwent a rotation of 90˚ with kinematic change from dexter to sinister.

The Iknioun granodiorite is cut by quartz veins of N100˚ to N170˚ major trendings bearing late disseminated gold mineralization and an early copper paragenesis expressed as chalcopyrite, covellite, grey copper and hematite (**Figure 8**).

The Cryogenian sandstone-pelitic basement is cut by a N100˚ trending vein set parallel to S0 hosting pyrite-hematite-malachite mineralization, sometimes it is accompanied by traces of ochre.

The andesitic, doleritic and acidic dykes mainly NW-SE to NNW-SSE trending, sometimes show mineralization with millimetric patches of pyrite.

Formed mainly by black shales (pelites), due to their high organic matter content. These black pelites alternate with more or less sandstone pelites and centimetric sandstone beds. This unit is found further north at the Imiter silver deposit. The importance of contact metamorphism due to dioritic and granodioritic intrusions [15], folded, tilted and verticalised by phases B1 and B2 of the Pan-African orogeny and N70 to E-W unthreading. This metamorphism is responsible for the emplacement of granitoids (e.g. Iknioun granodiorite) [31].

4.4. The Ore Shows of Bouibika

The newly re-evaluated Bouskour deposit is a large, polymetallic vein-type system in the Precambrian Sidi Flah-Bouskour inlier of the eastern Anti-Atlas orogen [32]. The "crow's foot" sector is the main mineralized zone in the Bouskour mining district, as it contains the F1 and F2 veins in addition to the regionally-extending main vein. The F1 vein is connected to the main vein and is slightly offset to the sinister along the Clavel fault, while the curved F2 vein is cushioned on approach to this NE-SW-trending fault [29]. This area is in fact the most transtensive zone in the region, linked to the sinister play of fracture N160, which hosted the main vein mineralization (**Figure 9**).

The Bouibika sector is located in the southern flank of Jbel Saghro, about 65

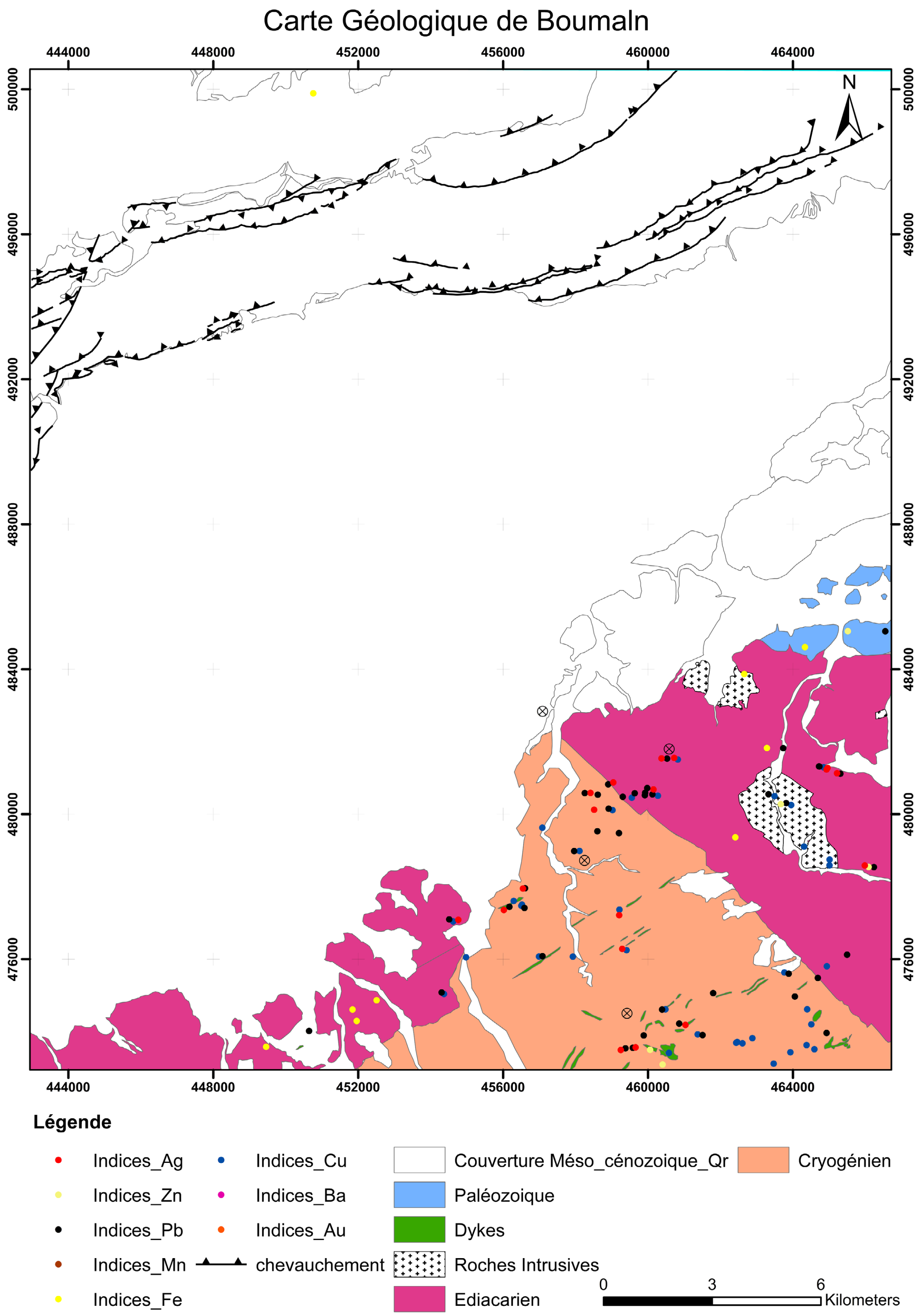

Figure 6. Geological map presenting main shows of mineralization of the Boumalne buttonhole (digitized from the Boumalne sheet 1/50.000).

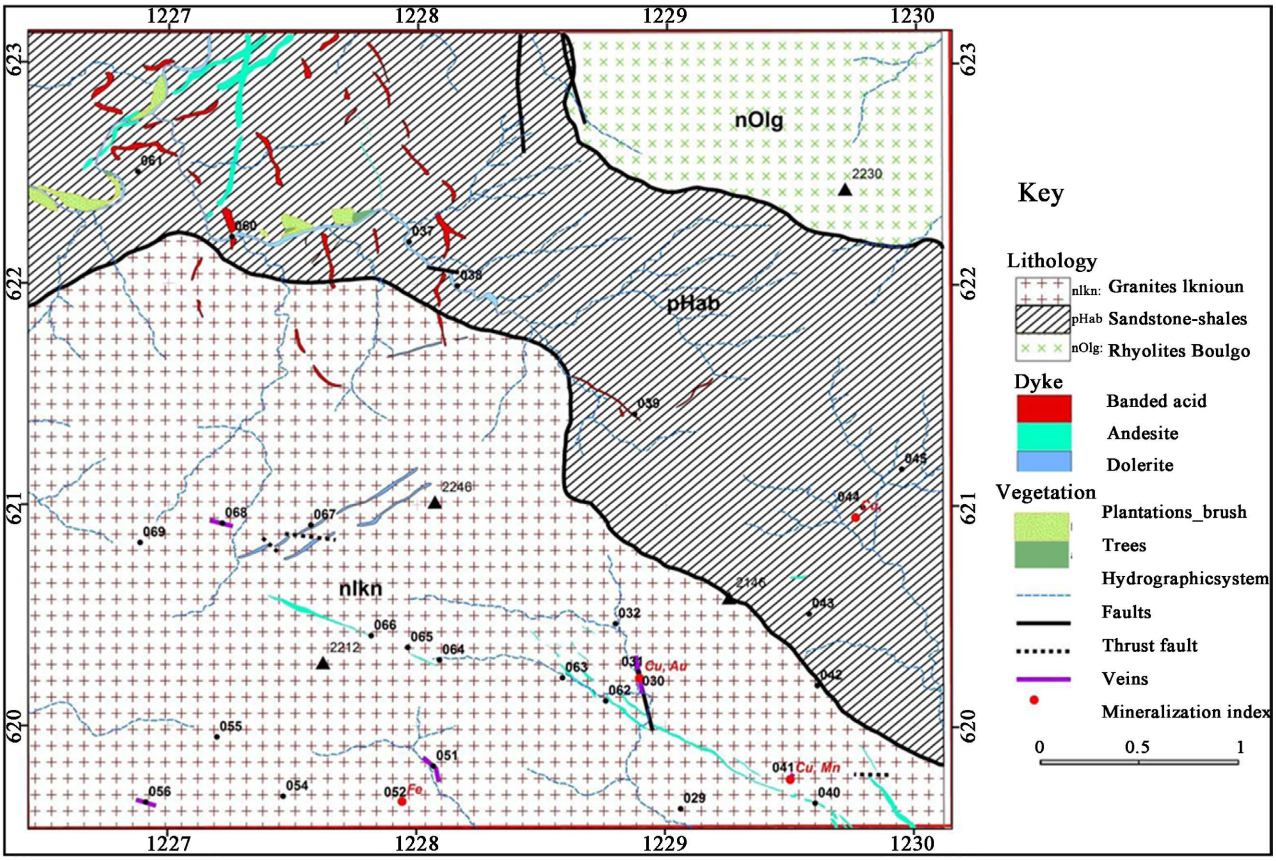

Figure 7. Geological map of the NW sector of Ikniuon (Douar Outaaoui).

km towards the east of Ouarzazate city and about 3 km towards the northwest of the Bouskour mine.

The outcropping Cryogenian basement is the main host of the silver mineralization. The discovery of new quartz, carbonate and sulphide mineralized structures are N30, N40 and N70 trending. These structures are offsetting the rhyolite dykes in a sinister set, and they contain encouraging amounts of silver, copper, lead and Zinc. The analysis results showed an interesting Silver and Copper (0.3%, 4.1% and 5.4%) values. The 1/100 geological survey shows the dominance of highly altered Cryogenian sedimentary facies intruded by basic dykes and dioritic and granodioritic magmatic rocks [33]. The whole set is affected by sub-vertical faults mainly N150 and N110 trending. Three families of N85 to N140 trending diaclases are observed.

The sampling and analysis of these areas has confirmed the existence of encouraging silver anomalies on surface, as well as a lateral continuity of silver mineralization has been found in three structures with a rate of silver.

Main results of the exploration works carried out in the Bouibika sector (sampling, trenches, drillings) have shown the following:

The rocks sampling shows the presence of significant anomalies of Silver associated to Copper and Lead (up 55% for the silver and 5% for the Copper) located in the N30, N40 and N70 trending quartz and carbonate veins. While the

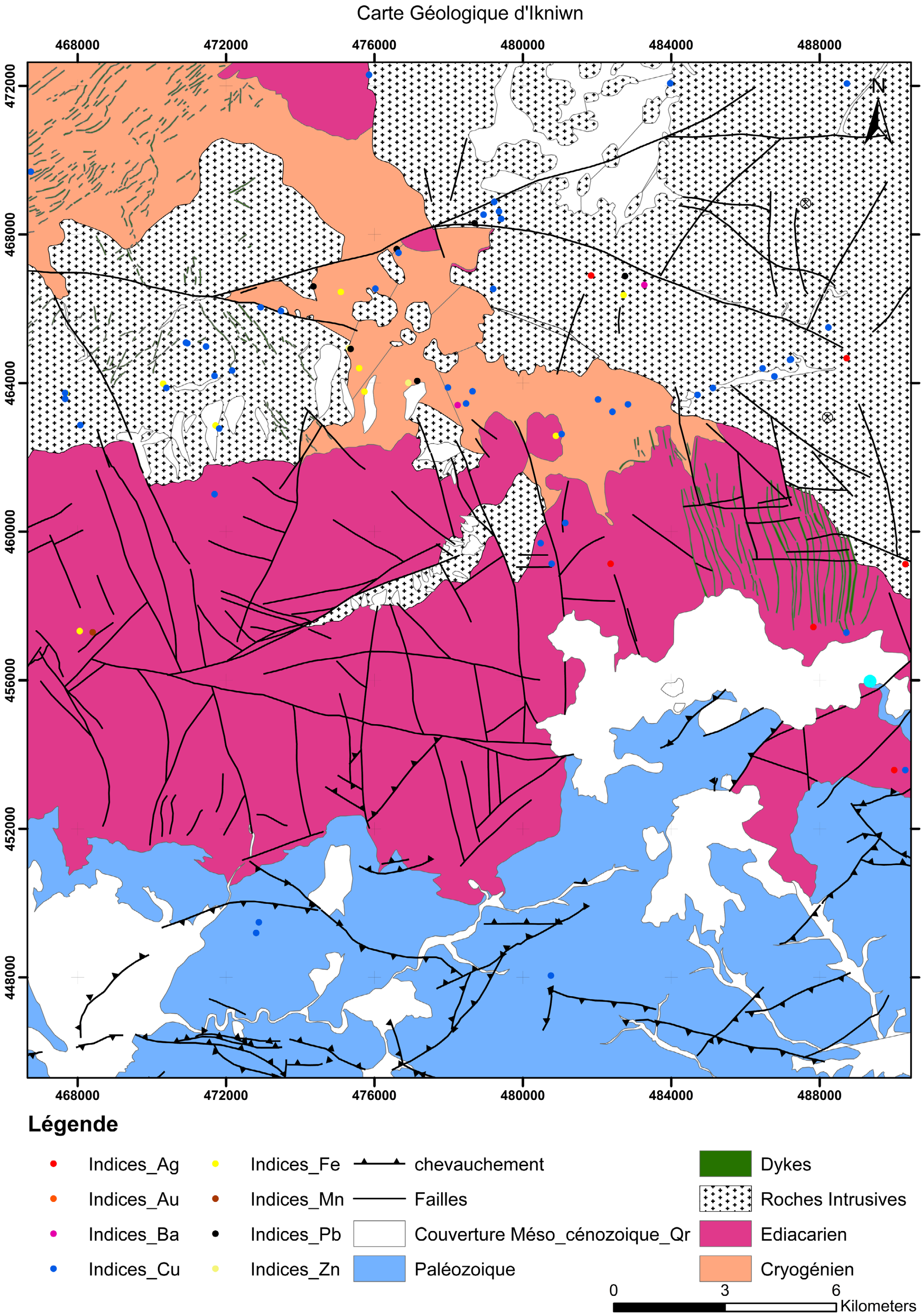

Figure 8. Geological map presenting the show ore in the Ikniwn buttonhole (digitized from the 50,000 Ikniwn sheet).

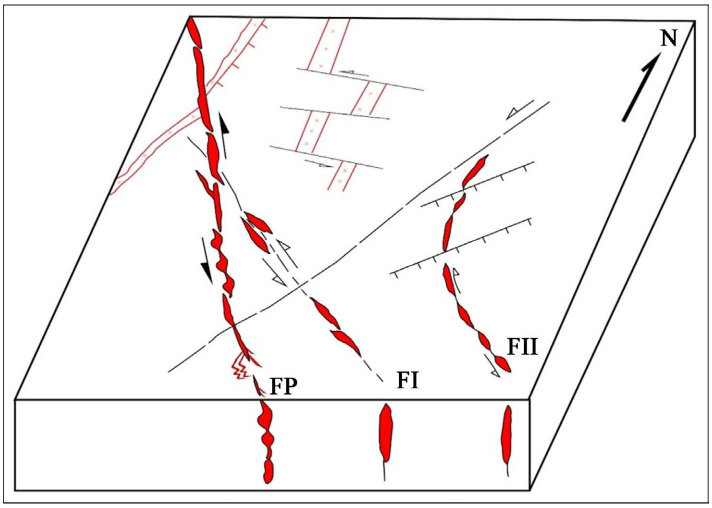

Figure 9. Interpretive block diagram of the "crow's foot" zone showing the relationship between the FP (main vein), F1 and F2 veins (Ouardi *et al.*, 2016).

trenches have shown encouraging silver. The drilling in the other hand confirms the continuity of the mineralized structures down to -100 meters in the subsurface.

The mineralization is concentrated in WNW-ESE trending fault corridors hosted in the volcano-sedimentary formations. It is either disseminated in the host rock or linked to E-W, N-S and NW-SE trending quartz-carbonate structures. The paragenesis is polymetallic with silver, Copper, lead and Zinc.

The district is subdivided into 3 sectors: East sector (Camel's Head) where silver mineralization is related to copper while the central and north sector is associated with lead and zinc.

5. Discussion

Regarding Imiter black pelites intense organic matter that helps trapping metallic elements, we can justify its richness in Silver ore. In this study, the application of high-resolution organic geochemical analysis and detailed geochemical mapping permitted to highlight the value of the initial syngenetic Silver stock in the black pelites. The mineralography observations revealed that pyrite is the major metal mineral in the ores, which helped identifying three-stage formation histories: sedimentation, diagenesis and deformation.

In order to confirm these results, an ICP-MS analysis study showed both a solid solution and a tiny inclusion of silver naumannite in the pyrite. The mass balance calculation suggested that the silver was mainly in solid solution and minor in the form of tiny naumannite inclusions in the pyrite. The high Co and Se contents and high Co/Ni and Se/S ratios in the sedimentary pyrite indicate that the silver was probably supplied by submarine hydrothermal venting. The correlation between silver (Ag) and iron (Fe) or Se in the sedimentary pyrite indicated that Ag was enriched by Ag and Se replacing Fe and S respectively in the pyrite.

The Iknioun area occupies a median position between large precious metal mines:

- The Tiouit mine to the southwest, hosted in a potassic Ediacaran granodiorite.
- The Imiter mine to the north is hosted by Ediacaran metasedimentary formations.

The location of our sector would probably have recorded at least one of these mineralizing episodes. The samples studied indicate the presence of gold mineralization hosted in the Iknioun granodiorite, probably equivalent to that of Tiouit, and the existence of copper mineralization that extends to the metasedimentary basement.

In the Sidi Flah buttonhole, the mineralized structures are hosted in the volcano-sedimentary formations. Mineralization is either confined to quartz-carbonate veins or disseminated in the altered host rocks. Silver mineralization is associated with copper sulphides in quartz gangue structures in the eastern sector, and with Pb sulphides in carbonate gangue structures (dolomite) in the rest of the studied sectors. The high TOC content and the sub-equatorial structuration make the SidiFlah black shales the most potential for silver ore after those of Imiter, which calls for the reinforcement of the exploration trenches and drillings.

5.1. Structural Geochemistry of the Eastern Saghro

- **Case study of silver mineralization**

The mapping work combined with the systematic sampling and the first test of organic matter has shown the rate of richness in organic matter of the black shales of the study area and their friability. This friability presents convenable conditions for the fixation of metallic elements particularly the Silver. The map bellow highlights the main metallic elements found in the study area (**Figure 10**). Sidi Flah area and Boumalne expose the same trending faults found in Imiter region, they are all crossed by an E-W and NE-SW trending system, and they indicate important volcanic activities. Unlike Imiter and Boumalne, SidiFlah organic matter is sulfide-rich which makes of sidiflah a potential silver deposit that requires further exploration works.

On the other hand, the Qalaa't M'Gouna group and Ikniwn regions are also similar. They highlight a thickness variation of the volcanic cover, an irregular paleogeography and very hard black shales. Those areas are crossed by NNE-SSW and NE-SW trending faults (**Figure 11**).

- **Case study of barite mineralization**

The Saghro Massif includes an important barite deposits located at the interface between the Ediacaran basement and the sedimentary Paleozoic. This barite is concentrated mainly in the quartzite and sandstone beds of the Middle Cambrian.

At Amssaad (ImiN'Ozrou mine, Jbel Saghro), the depositionoth the barite

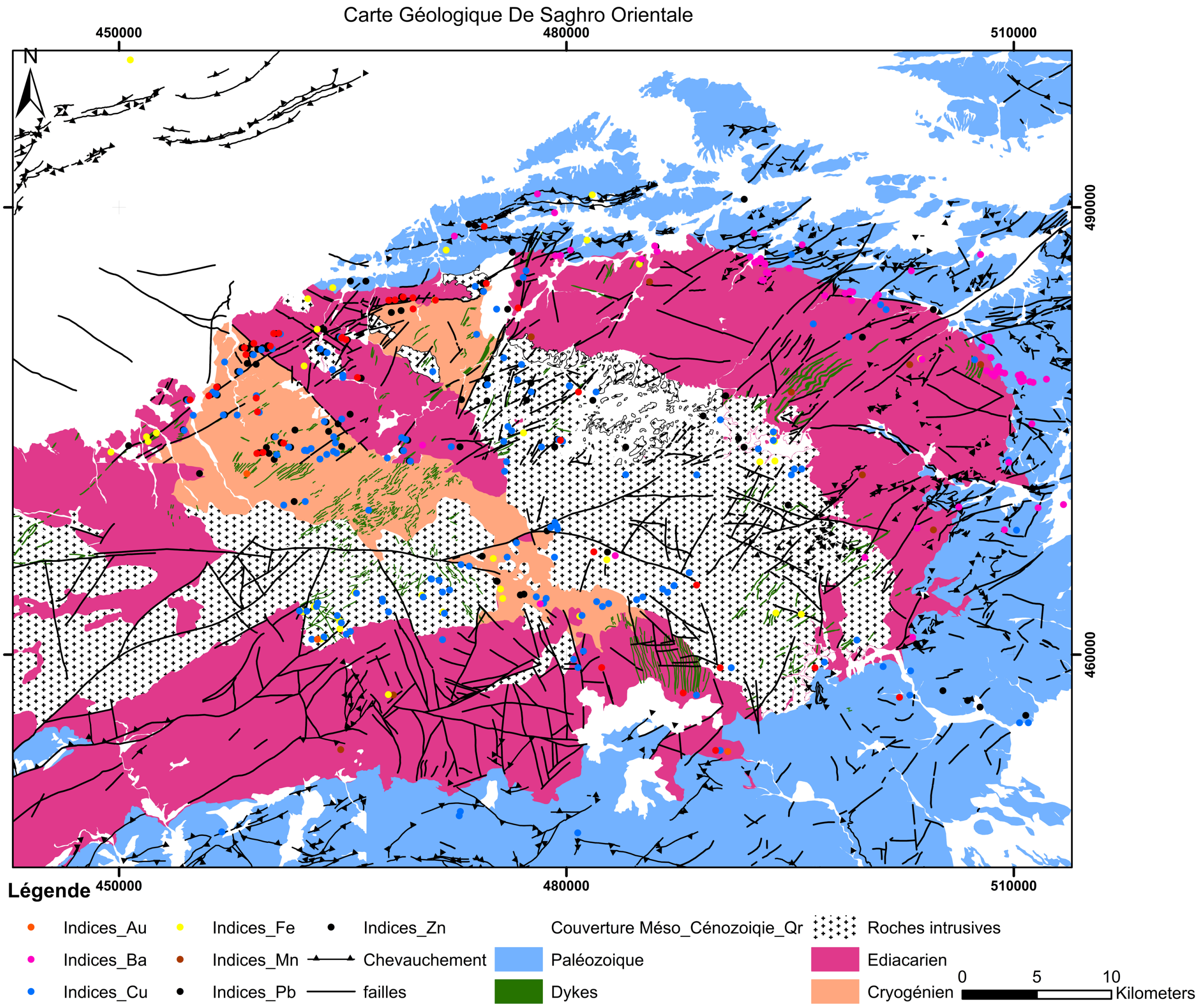

Figure 10. Geological map of the Western buttonhole digitized from the 50.000 Saghro map showing the main mineral shows found in the study area

occurred through open fractures inclined slightly eastward. While the barite of AmganeN'Ouchn occurs as a vein along a 45˚N trending subvertical dextral fault (dip = 85˚NW). The host rock is Lower Cambrian quartzite sandstone.

In the Taghazout volcano-sedimentary terrain, barite mineralization is hosted in Cambro-Ordovician shales and sandstones, and rarely in the Ediacaran andesitic flows of Jbel Merrou. However, at Mfis, there is an important barite vein mineralization associated to lead-zinc and copper sulphides, where the lead is more or less argentiferous. Towards the west, in the schistose and sandstone terrains of the Lower Cambrian of Imiter, the barite vein is transported by hydrothermal fluids and deposited in faults, fractures, joints, cavities, stratification planes and any other opening (karsts). We therefore assume that this barite precipitates by simple cooling. These veins are also well represented in the Ougnat basement and on the northern edge of the massif.

The barite generally appears in the superficial zones. It evolves towards

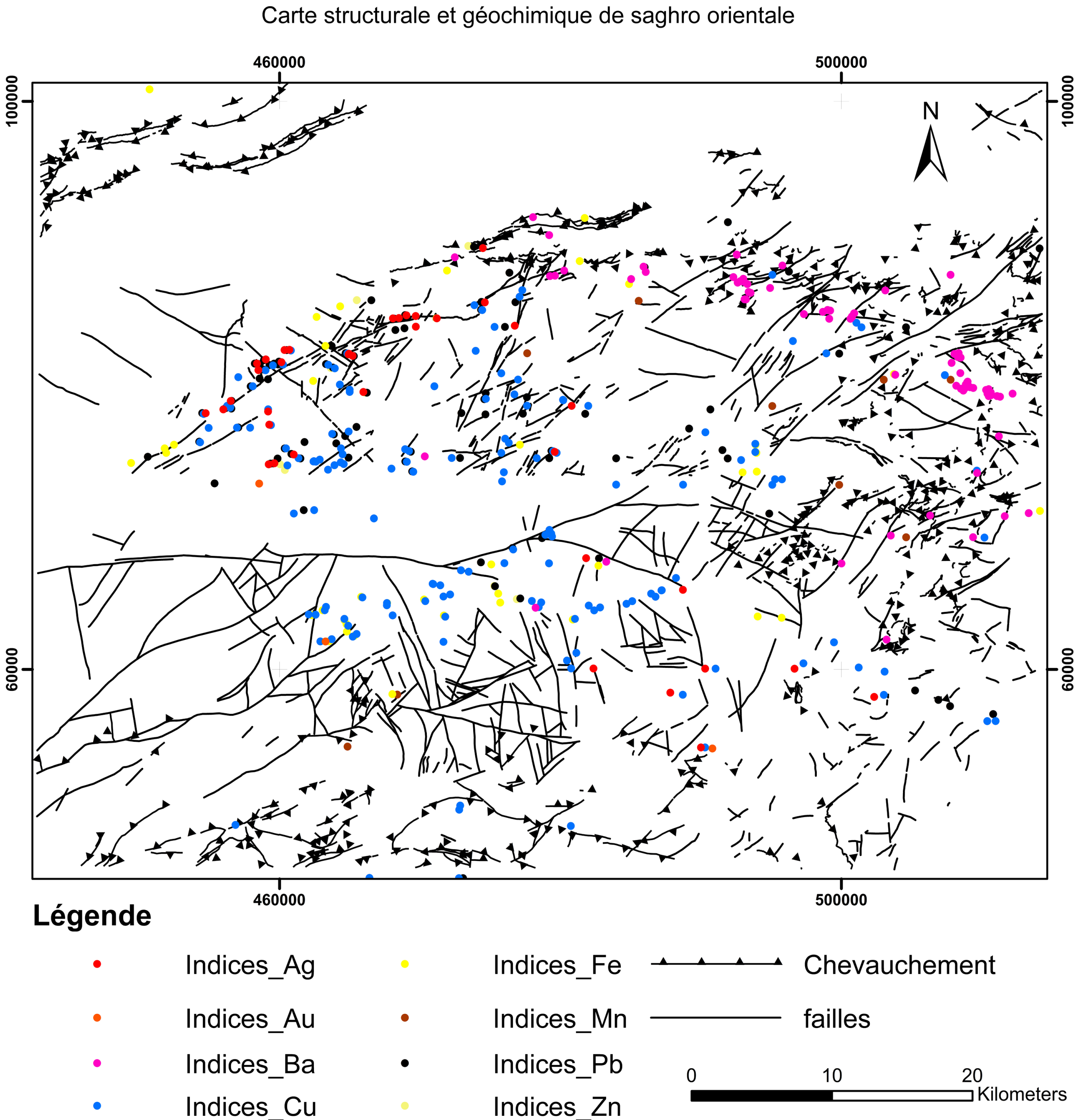

Figure 11. Structural geochemistry map of the Western Saghro buttonhole digitized from the 50.000 Saghro.

subhorizontal veinsnear the surface. It is also present in small quantities in the high zones of the vein, but it extends laterally in the sandstones to the east and southeast (Taghazout and ImiN'Ozrou). The sandstones, the shales and the green siltstones host the major part of the barite deposits with a rate close to 47% of $BaSO_4$. In the Cambro-Ordovician terrains of the eastern extremity of the Saghro (TafilaletMaider and Zagoura Plains), the surface emersion of hot barite and iron-rich hydrothermal fluids generated a barytic travertine, where barite and goethite laminae alternate up to 11 meters in thickness. This is what we call "the ferrobarytic", a rich ore with a content of up to 63% of $BaSO_4$.

5.2. Organic Geochemistry of the Eastern Saghro

Imiter black shales, Sidi Flah pelites and argillites and Boumalne group reveal almost the same characteristics in term of friability and the rate of organic matter (Table 1). The TOC of Imiter samples is equal to 0.18%, the TOC of SidiFlah Samples is equal to 0.16% while the TOC of Boumalne is equal to 0.11%.

The organic matter rate is poorly indicated in the samples of Qalaa't M'Gouna group, Ikniwen and Tiouit, it is ranging between 0.08% and 0.01% (Table 1).

6. Conclusions

The Saghro cryogenic basement is characterized by folded and metamorphosed silico-clastic meta-sediments in the low-temperature green schist facies with dioritic intrusive rocks and granodiorite type. The meta-sediments are flysch-type composed of alternating levels of sandstone, greywackes, pelites, mudstones and turbidites.

The detailed mapping of the black pelites of Saghro, shows close similarities between the Imiter, Boumalne and SidiFlah buttonholes in terms of paleogeography, thickness of the series, metamorphic and tectonic history, as well as the richness in organic matter. The results of the present study highlight also the particularity of the black shales of Imiter, the richness of this buttonhole in silver ore.

The Boumalne-Tiouit group has criteria close to those of Imiter, *i.e.* friable pelitic sedimentary facies, fairly rich in organic matter in some places (Tiboulkhirine-Tagdilt-Taghssa sector), the Imiter fault network (E-W and NE-SW) and significant volcanic activity, all of which are accepted factors for the formation of

Table 1. The results of the TOC analysis in the Saghro buttonholes.

Samples number	Sampled area	TOC %
1	Imiter	0.17
2		0.17
3		0.18
4	SidiFlah	0.16
5		0.11
6	Boulmane	0.18
7		0.11
8	Qalaa't M'Gouna	0.04
9		0.08
10	Ikniwn	0.02
11		0.08
12		0.01

an Imiter-type silver deposit.

The Iknioun cryogenic basement consists of hard pelites with mineralized quartz veins which present two major orientations which are respectively N20 to N60 and N160. They extend on some tens of meters with powers going from 30 cm to 60 cm. These veins are hosted in the quartz diorite as well as in the Oussilkane granite. The mineralized shows are represented in the field by malachite and azurite. Their mineral paragenesis is represented mainly by sulphides namely chalcopyrite, pyrite and galena which is partially to totally hematitized.

The sidi-flah buttonhole consists of Cryogenian volcano-sedimentary formations cut by microdiorite, rhyolite, trachy-andesite and granodiorite dykes, resulting in contact metamorphism. These formations are surrounded by Ediacaran alkaline granite. Later magmatism is manifested by the network of reddish rhyolite dykes of Ediacaran age and dolerite dykes and gabbro intrusion. Mineralization is concentrated in WNW-ESE troughs formed by the volcano-sedimentary formations. It is either disseminated in the host rock or linked to E-W, N-S and NW-SE-trending quartz-carbonate structures. The paragenesis is polymetallic with Ag, Cu, Pb and Zn.

The Kelaat Mgouna Cryogenic age group consists of five silico-clastic formations. It was considered as the deposit in a back-arc basin in relation to a subduction zone located more to the SW at the level of the major accident of the Anti-Atlas. Such an arc would have been the main supply source for detrital material. This massif is made up of detrital deposits, in particular hard sandstone poor in organic matter and less fractured as well as a very reduced magmatic activity in vertical dykes with schistosity, these factors made the cryogenic base of Qala't Mgoune the poorest in elements polymetallic.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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