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Carlin-type gold mineralization of Albour region (Western High-Atlas, Morocco)

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Abstract

The region of Albour is located in the ancient massif western High Atlas at about 75 Km south east of the city of Marrakech and 10 Km NE of the former mine in Mo-W-Cu Azegour. The sector includes two main rock units: a Paleozoic basement composed of schists, dolomitic bars, volcanic rocks and a Cretaceous cover that overcomes it in the south. The basement is crossed by a swarm of dikes oriented N 45 related to the placement of Azegour granite. The mineralized vein is set up along a dislocation subvertical and dextre according direction N145°. It is characterized by low base metal contents such as Pb, Zn and Cu and a significant enrichment of As, Sb, Hg, and Te. Gold is expressed in the native state in the form of nanometric crystals in association with hematite and goethite. The study confirms a triple control gold mineralization: (i) a tectonic control responsible for its placement in a fault in direction N145°; (ii) a lithological control represented by lower Cambrian carbonate formations (iii) a rhelogical control marked by the reduced power of the structure in the shales compared to the dolomites. The mapping, structural studies, petrographic, mineralogical and geochemical allowed classifying mineralization of Albour in the Carlin-type gold deposits. At the regional scale, this gold mineralization would be linked to the permian hydrothermal event contemporary with the establishment of Azegour granite.

1. Introduction

The mining district of Amazmiz, located 60 km southwest of the city of Marrakech, is known for its mining potential, as evidenced by numerous deposits and indices of basic metals and precious metals such as those of Amensif, Tighardine, Erdouz, Assif El Mal, Tiqlit, Tlat Do Imjad and the Skarn deposit which is linked to setting up of the Azegour granite at permian age. The old massif of the High Atlas, characterized by a Precambrian and Paleozoic basement was structured by the Hercynian orogeny. It has been a result of a lots of researches [1-13].

The Albour sector, the subject of this study, occupies a middle position between the Tighardine deposits in the East, Amensif in the South and Azegour in the West. It has been the target of numerous mining exploration campaigns, led by the Managem group, which have identified gold showings. The main objective of this work is to identify the paragenetic and textural characteristics of Albour mineralization in order to place it in its geodynamic context.

2. Geological Setting

The sector is formed by Albour land of Lower Paleozoic age corresponding to Cambrian shales, calcschists, dolomites and andesites [14]. The unit is intruded by rhyolitic dykes and of Permian age microgranite. The exploration area covers a large corridor of dextral shear, defined by two strike-slip faults, firstly the accident Imi n'Tanout in north and the Tizi-n'test fault south (Figure 1). These large shears zones are well known throughout Morocco Hercynian chain [5, 15, 16, 17, 10].

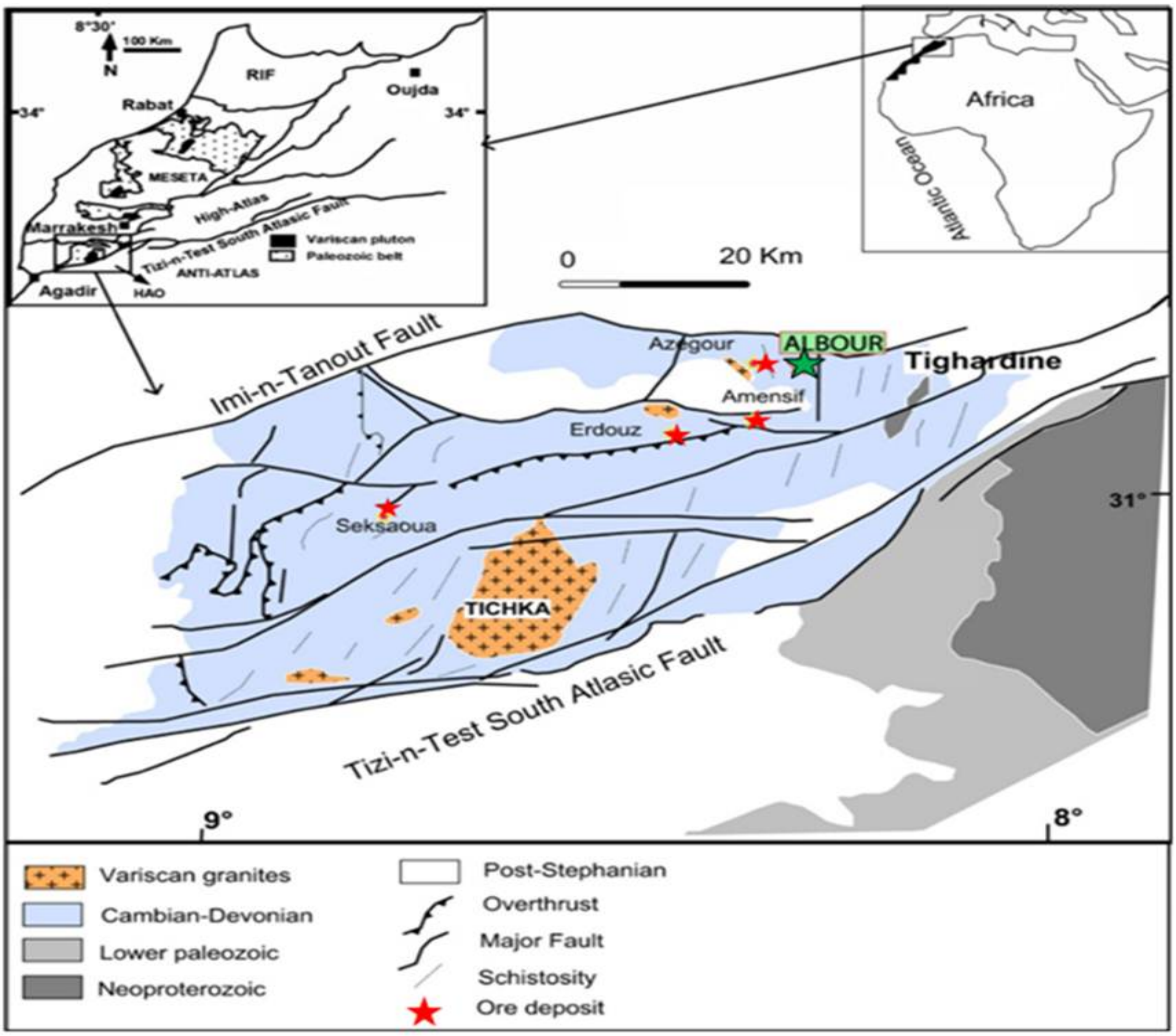

Figure 1: Structural map of the High Atlas (Koning 1957 In [18]).

Geological surveys conducted on the ground show the presence of lithological facies attributed to the Lower Cambrian and consist mainly of:

- Massive dolomitic bars NS to N15° with a dip of 65° to 80° to east. They are the enclosing rock of the mineralization. locally these bars are replaced by a solid marble gray to white (Figure 2);
- Schists and gray-green to green calcschists, affected by a schistosity of fracturation and crenulation NS with dips 45° to 75° west;
- Interbedded andesitic flows in carbonate formations and shales of Lower Cambrian;
- Rhyolitic dykes roses, microgranites and Lamprophyres, with a major direction NS, intrude to all facies above. The mineralized structure is represented by a quartz vein N145° sub-vertical.

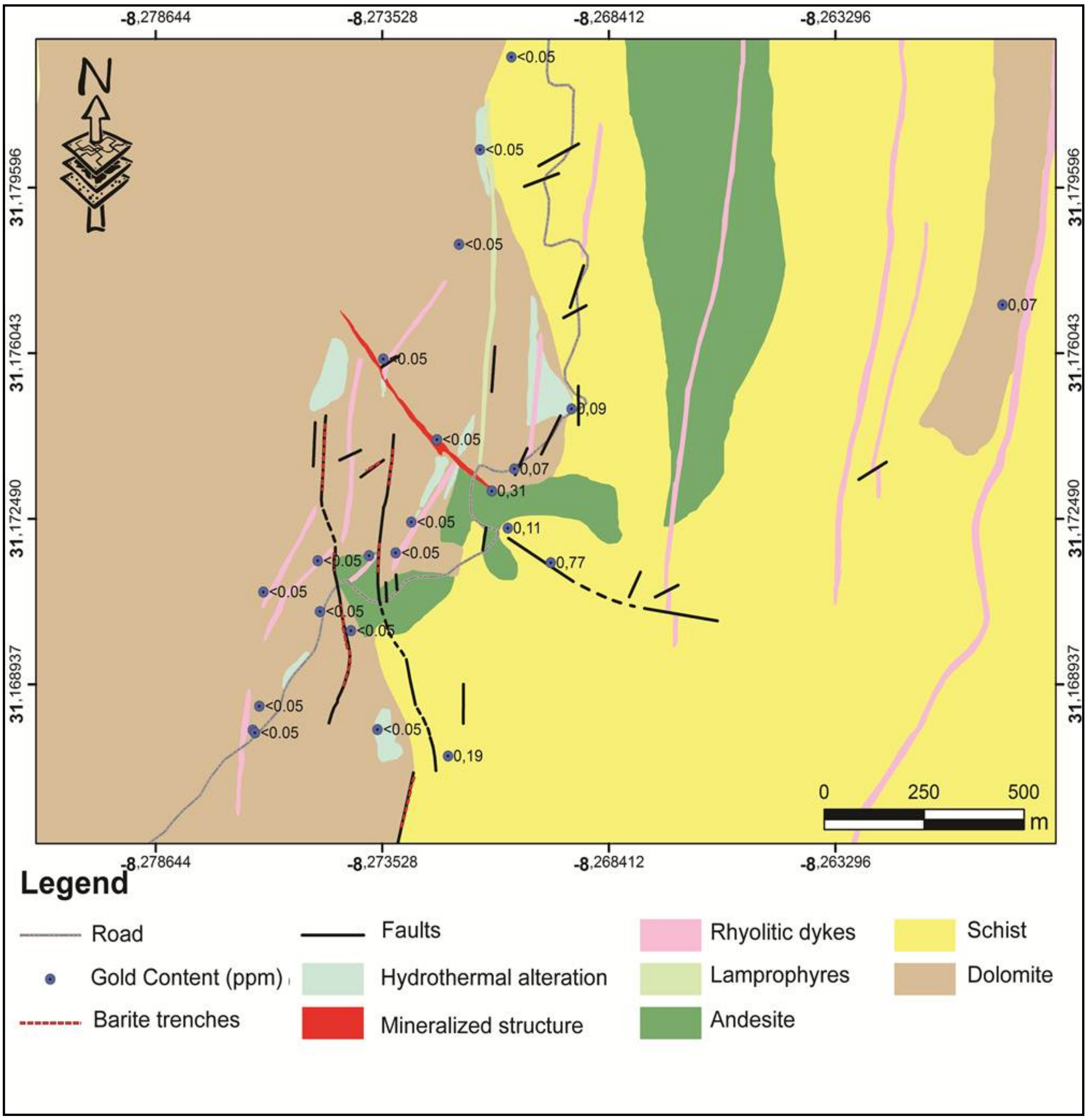

Figure 2: Geological map of Albour sector.

3. Material and Methods

The mineralization of the sector was targeted by a mineralogical study and determination of the paragenetic sequence by the examination under a metallographic microscope of about forty polished and thirty thin sections. This mineralization hosted in the dolomites, is in the form of a quartz vein direction N145 and hectometric extension. The power of this structure is irregular and vary according to lithology of surrounding rocks; in dolomites it may reach up to 10 m, whereas it's infra-metric in shale. Method of electronic scanning microscope was also use to identify the nanometrics grains of gold at the Reminex's Research Center and Laboratory of Managem group (Marrakech).

For geochemical studies around thirty samples were collected both inside and outside the main structure oxidized (Figure 3). All samples were analyzed by ICP-AES in the Reminex's research center of the Managem group (Marrakech) for determining content of gold and other metals.

Figure 3: Photographs showing (1): Subvertical mineralized vein; (2): Gossan with Pyrrhotite; (3) & (4): Brecciated aspect of mineralization.

4. Results and Discussion

4.1. Mineralogy

Mineralized veins are very compact and brecciated in silicified oxidized zones with hematite, goethite (PL I. 4). Elsewhere in the dolomites, it becomes friable with earthy texture color yellow orange to dark red (Figure 3, (1 and 2)). In fracture, we observed primarily oxides, hydroxides of iron and sporadically some fines ranges of millimeteric chalcopyrite (Figure 3, (3)). No other sulfide has been discerned macroscopically.

Metallographic examination shows the abundance of hematite and goethite. Sulfides are represented by arsenopyrite, pyrrhotite, pyrite and chalcopyrite. The gold, silver and löllingite were identified only by SEM analysis.

Hematite / Goethite: this association forms with silica the main cement of the breccia (Figure 3, (3 and 4)) and comes from an intense alteration of sulfides of the primary paragenesis. When polishing is good, beautiful shades of anisotropy can be observed in hematite (PL II. 4), whereas in the case of goethite, they are orbiteered by internal orange-brown reflections. These iron ores come in many forms and types of textures:

- Large irregular patches of very large size visible to the naked eye (Figure 4, (4));
- Fine needles scattered in the matrix or in the cavities (Figure 4, (1 and 2));
- Botryoidal texture with always hematite in the center and goethite in the periphery;
- A fortress texture where can still see the forms cubic and rhomic of pyrite and arsenopyrite;
- Pseudomorphosis of pyrite and arsenopyrite crystals.

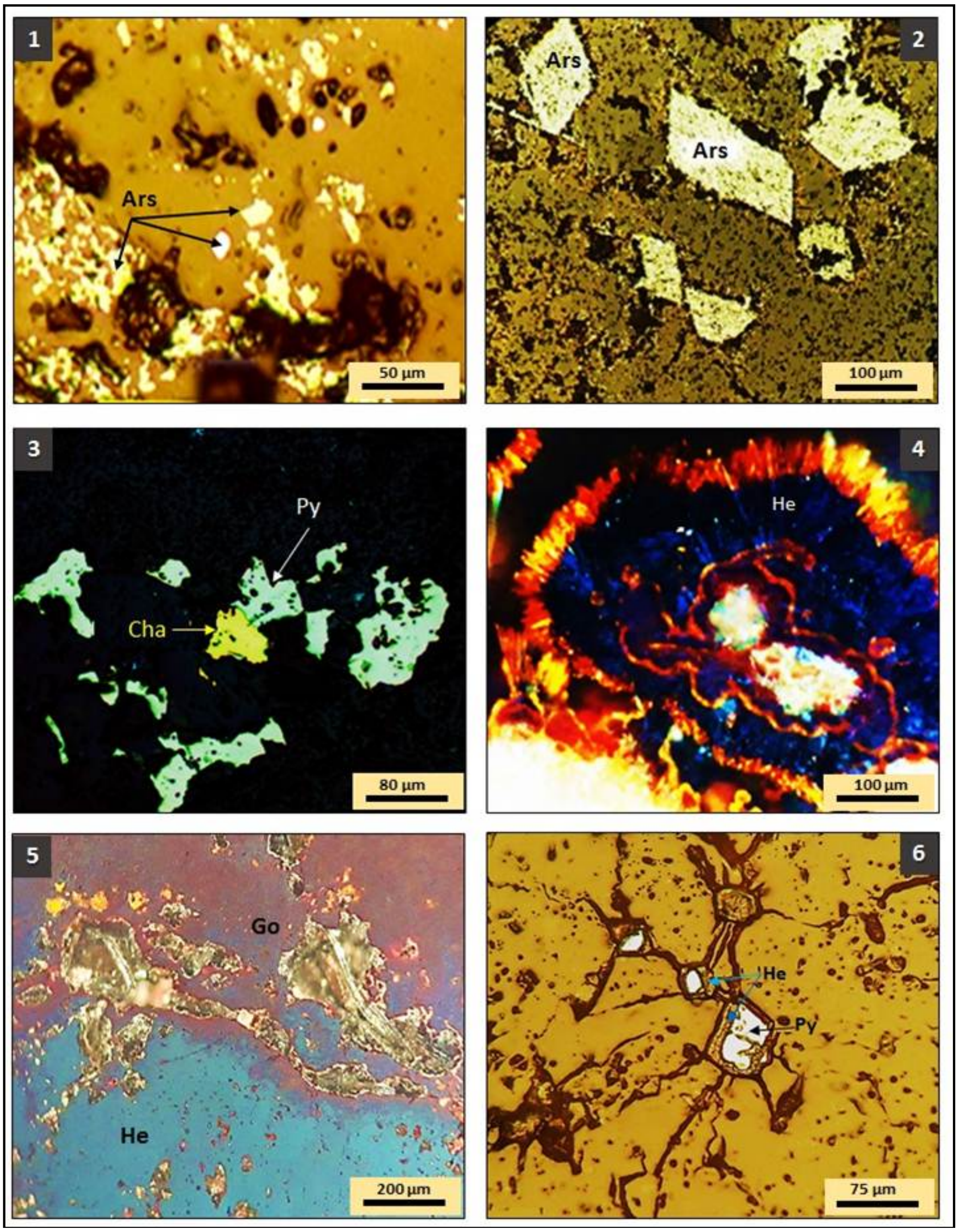

Figure 4: Photomicrographs in reflect light of Albour ores: (1) caried texture of arsenopyrite. (2) Automorphic Arsenopyrites (3) Chalcopyrite associated with pyrrhotite. (4) Botryoidal texture of acicular hematite. (5) Hematite-goethite association. (6) Pyrite pseudomorphosed by hematite.

Gold: detected only by SEM micrograph, it is expressed in the native state in small free nanometric size grains in the iron oxides and hydroxides (Figure 5, (5 and 6)).
Pyrrhotite: observed in the samples taken at the Oued Akker, which is located at a height difference of more than 600 m from the trenches made by MANAGEM in the vein (Figure 3). Pyrrhotite comes in form of large irregular sections isolated or associated with chalcopyrite (Figure 4, (3), Figure 5, (2)). The identification for the first time of a gossan in Oued Aker, whose primary paragenesis is composed mainly of pyrrhotite and chalcopyrite probably, suggests the presence of a vertical zonality which can only be confirmed by sounding works.
Pyrite: this sulfide rarely occurs in the form of automorphic crystals, partially preserved (Figure 4, (6)). It is often scattered in polycrystalline areas (Figure 4, (6)) or isolated in the gangue (Figure 5, (1)). They are transformed to hematite and/or goethite and sometimes overgrown with gangue minerals.
Chalcopyrite: this disseminated ore is relatively rare and associated with pyrrhotite and pyrite (Figure 4, (3)). Its unusual very light-yellow color is probably linked to the presence one or more of trace elements.
Arsenopyrite: it is observed in all samples and is present in ranges (Figure 4, (1)) or in pseudomorphosed automorphic crystals by hematite (Figure 4, (2)). The photomicrographs SEM revealed its presence in the quartz-carbonate gangue in disseminated form as fine micrometric crystals (Figure 5, (4)). Native gold and silver and löllingite were identified only by micrograph SEM; they form microcrystals in association with iron oxides (Figure 5, (5, 6, 7 and 8)).
Hydrothermal alteration of Albour sector is mainly manifested by dolomitization, silicification and carbonates dissolution with the development of jasper, followed later by late supergene alteration to hematite-goethite. This zonation of hydrothermal alteration is typical Carlin-type gold deposits of [19]. The proximity of the Albour deposit to the Azegour granite allows us to associate it with the placement of this granite and with the hydrothermal phenomena that accompany it. The percolation of hydrothermal solutions in the Cambrian dolomites led to the release of the iron coming from their silicification and decarbonation. These initially acidic fluids, gradually become neutral [20] thus facilitating, transporting the gold in the form of complex bisulfide (H_2S) [21].

4.2. Paragenetic sequence

The examination of the textural relationships of the various ores of the deposit of Albor, made it possible to propose the genetic sequence recorded in Table 1.
Pyrrhotite has never been identified in neighboring of Albour deposits as Tighardine and Amensif. The existence of arsenopyrite fine crystals strongly reminiscent arsenopyrite stage II of Amensif deposit [22]. This pyrrhotite, probably enriched in gold, is formed following the circulation of hydrothermal fluids rich in complex compounds containing sulfur and arsenic [23]. The established paragenesis also presents some similarities with stage III-B and III-C of Carlin-type gold deposit of Shuiyindong in China [24]. The stage III-C will correspond to the secondary gold in Albour area (Gold II) who is resulting from remobilization of cryptocrystalline gold of arseniferous pyrites of the III-B stage [24]. The mineralization of Albour represents the stage of supergene alteration composed of iron oxides and hydroxides. Only borehole work will allow access to the primary paragenesis of Albour area, in particular the primary gold stage (Gold I) which is often closly associated with the deposition of areniferous pyrite in Carlin-type gold deposits.

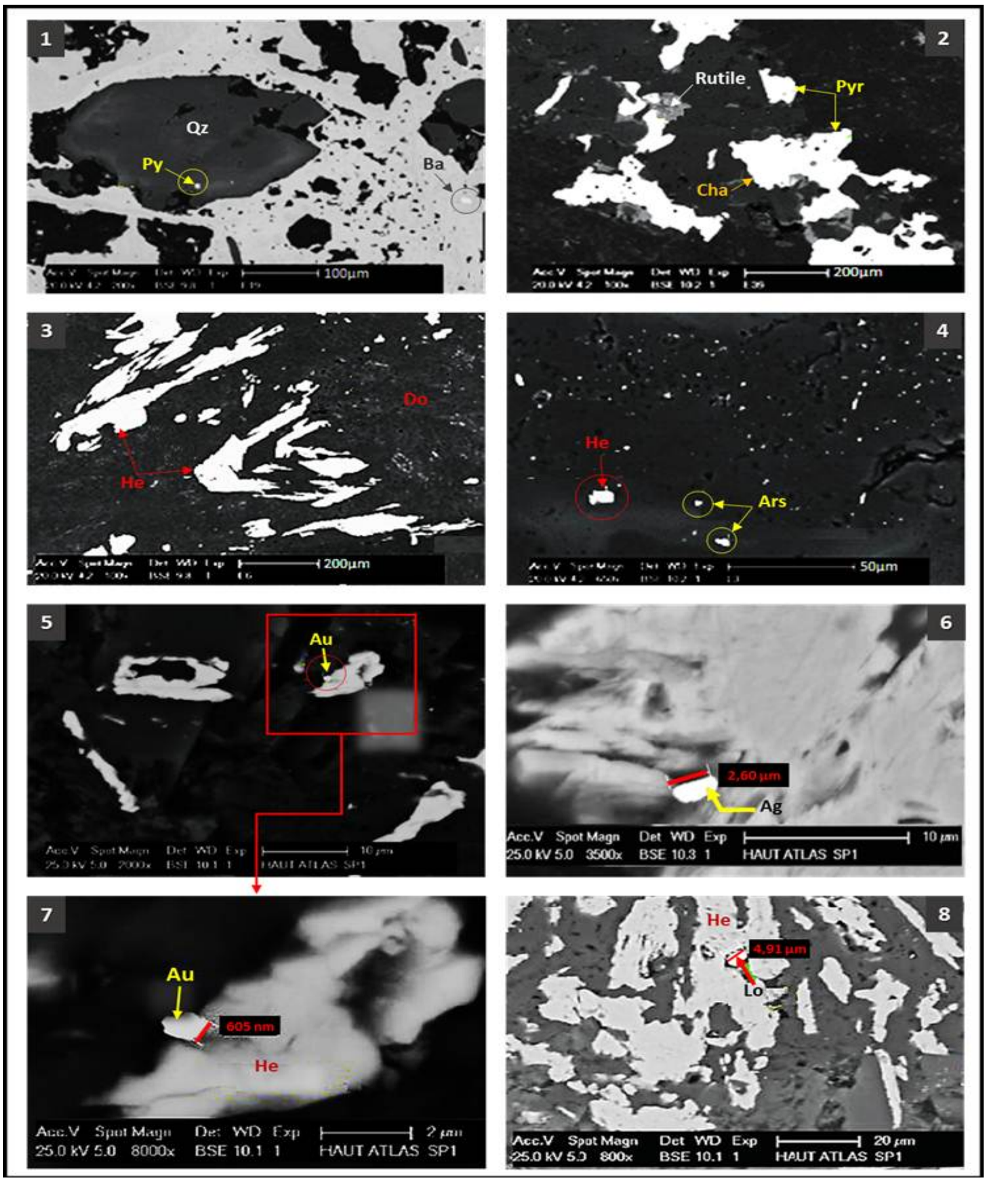

Figure 5 : SEM Photomicrographs showing: (1) Quartz with pyrite inclusion (2) Chalcopyrite associated with pyrrhotite (3) Iron oxide (4) Quartz with arsenopyrite inclusions (5) - (6) Golden grain. (7) Silver grain (8) Lollingitis.

Table 1: Sequence paragenetic of mineralization in Albour area.

Minerals	Primary paragenesis	Secondary paragenesis
Gold I	……………????..............	
Pyrrhotite		
Pyrite		
Arsenopyrite		
Chalcopyrite		
Gold II		
Hematite /Goethite		

4.3. Geochemistry

It should be noted that apart from the main structure, the Au contents (<0.05 g/t) remain low throughout the sector (Figure 6) which suggests the presence of a single mineralized structure. Significant gold concentrations have been identified in some samples upstream of the mineralized. The relative contents of Pb, Cu, Zn, As, Ba and Sb for some samples is shown in Table 2.

Table 2: Data ICP-AES of some mineralized samples.

Tranches	Tr 1	Tr 2	Tr 3	Tr 3'	Tr 4	Samples outside the mineralized structure				
Sample	*E76*	*E77*	*E78*	*E78'*	*E75*	*E24*	*E29*	*E28*	*E14*	*E19*
Au (ppm)	1,15	1,79	0,43	0,29	0,4	0,77	0,05	0,05	0,05	0,06
As (ppm)	8569	728	1109	1107	883	0,0585	0,0238	0,0191	0,0307	0,0016
Ba (ppm)	16588	15651	16338	16325	24175	0,3346	1,1775	1,348	1,2302	1,6031
Sb (ppm)	<32	72	<32	<32	<32	-	-	-	-	-
Zn (ppm)	546	326	569	571	470	0,0002	0,0097	0,0002	0,0128	0,0207
Cu (ppm)	71	54	321	325	83	0,228	0,27	0,14	0,124	0,288
Pb (ppm)	96	77	100	105	94	0,0203	0,017	0,0219	0,0139	0,0195

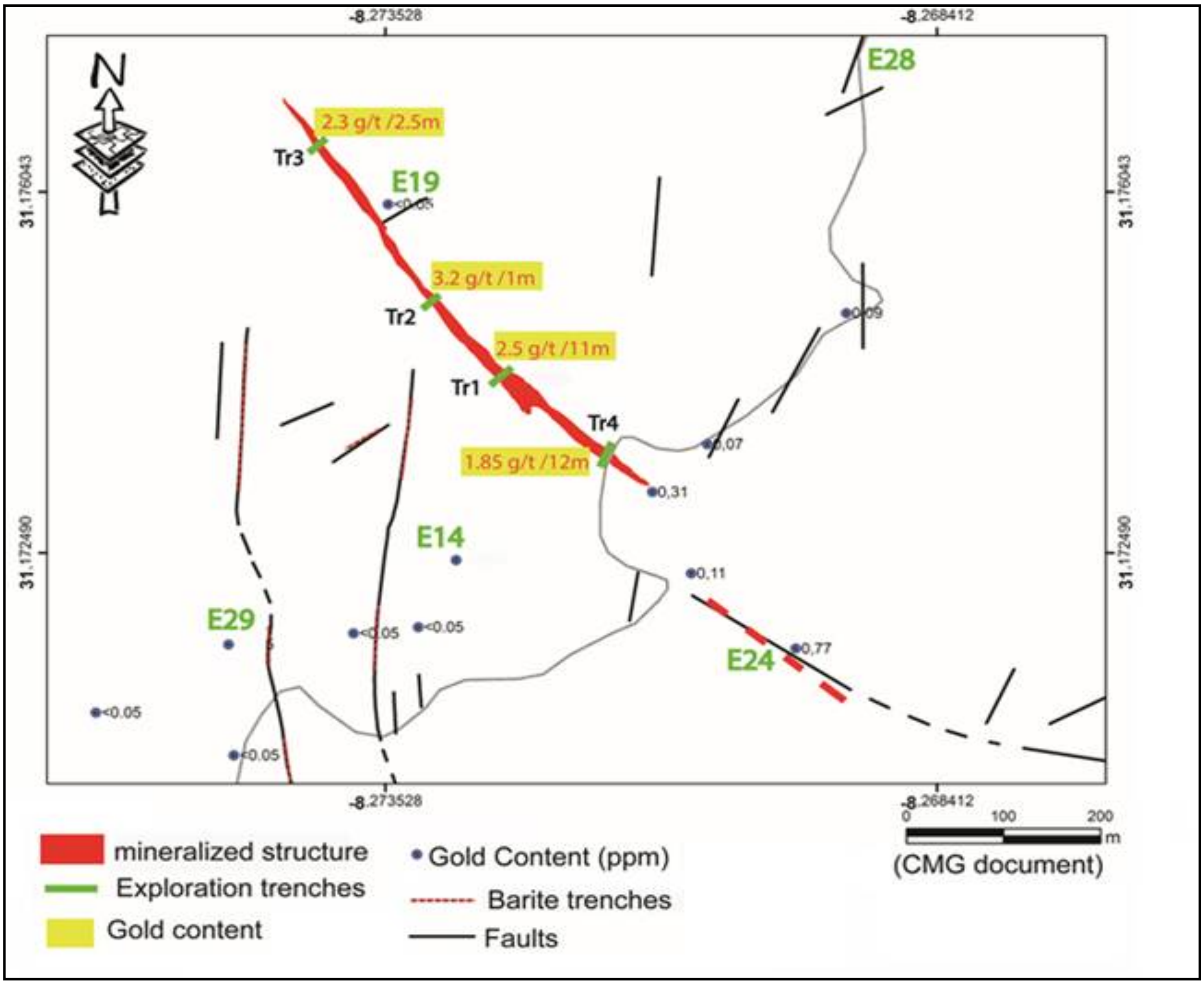

Figure 6: Gold content of samples analyzed by ICP-AES.

The presence of gold in the mineralized structures with quartz gangue, associated with jasper explains the correlation between silica and gold that's also positively correlated with arsenic. The recognition in this study of crowns of arseniferous pyrite is a very important point to underline. The low base metal content compared to that of gold and arsenic and the presence of microscopic gold in the Albour deposit are common characteristics of Carlin-type gold deposits [20, 25, 26] (Figure 7).

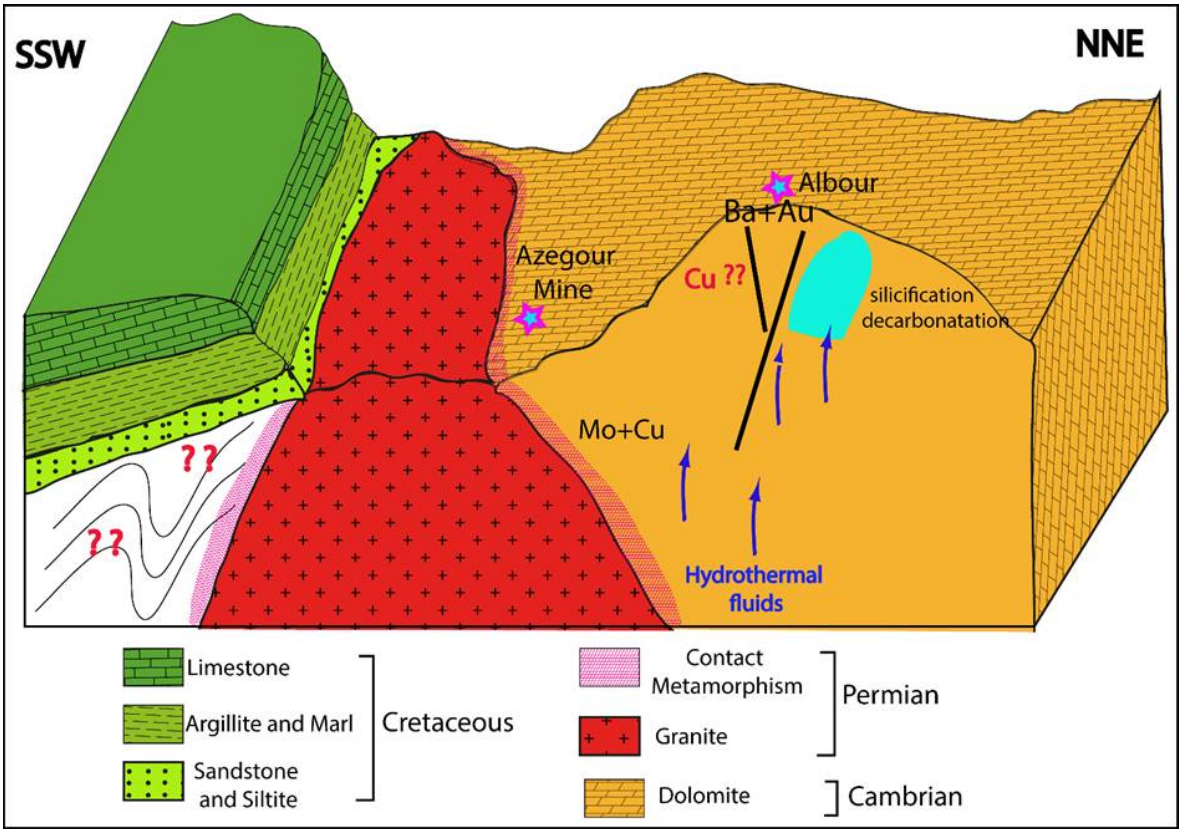

Figure 7: Genetic model of Albour gold mineralization.

The comparison of the geological characteristics of Carlin-type deposits of Nevada and Gaspésie established by Poulsen (1999) with those of the sector Albour show that the majority of the characteristics of Carlin type gold deposits exists in this region [27, 28]. Those ore deposits are characterized by gold mineralization disseminated in arseniferous pyrites enriched in As, Sb, Hg, Ba and low base metal content [29]. This mineralization has high tonnage, which makes exploitation profitable even at low content. This type of deposit accompanied by an alteration of carbonate, which are either dissolved or transformed, into silicates by a hydrothermal fluid rich in silica.

Conclusion

The geological survey and results of the geochemical analyzes made it possible to retain that mineralization of Albour is controlled by three main factors: (I) a structural control since the mineralization takes place in a fault oriented N145°, (II) a lithological control linked to the presence of the hosts carbonate formations; (III) a rheological control because the mineralized structure is more developed in the dolomites (≥ 3 m) compared to the shales (0.5 m thick).

Field observations have shown that mineralization locate along a fault N145° related to Hercynian orogenesis, this is also known in Carlin-type deposits of China and Nevada, where mineralized structures formed during an extensive deformation during the last phases of orogenesis [30].

In Albour area, gold is either native or disseminated in arseniferous pyrites as small free grains in the haematite and goethite. The hydrothermal alteration expresses by silicification and decarbonation.

The Albor gold deposit has great similarities with Carlin-type gold deposits of Nevada and China who are hosted in carbonate rocks deposited over extensive margins along the precambrian and paleozoic cratons [30]. The chemical analyzes in Albor area provided encouraging contents of gold, with enrichment in As, Sb, Ba, and low base metals content along the mineralized structure. Large concentrations of Hg, As, Sb, U and Ti are also known in Chinese Carlin-type gold deposits [27]. The genesis model and the source of metal for Carlin-type deposits and their relationship with magmatism are highly controversial [31]; those of Nevada and Indonesia are related magmatism andesitic unlike those of China [27]. Contribution of meteoric fluids was mentioned especially for Nevada deposits (Carlin, Battle Mountain and Alligator) and China (Guizhou) unlike those of Indonesia who fluids are magmatic origin. The Mesel deposit of Indonesia is associated to magmatism of subduction areas [32] as opposed to those of Nevada and China that would be related to a regional metamorphism. The sedimentary to meta-sedimentary origin was identified for Carlin-gold type deposits of china and Nevada [30, 31].

At the end of this study, the Albour sector would constitute a typical case of a Carlin- gold type deposit. Permian magmatism represented by Azegour granite is the main factor of setting up of this mineralization. Research needs to be further developed, especially after the discovery of a gossan with pyrrhotite and chalcopyrite in Oued Aker.

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