

A New Interpretation of Geodynamic Context and Typology of Moroccan Anti-Atlas Silver Deposits

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Abstract

The argentiferous deposits in the Anti-Atlas chain in Morocco are encased in the meta-sedimentary, volcanic-sedimentary and volcanic terrains of the Neoproterozoic, structured and schistosed during the Pan-African orogenesis. These deposits are associated with terminal Neoproterozoic rhyolites and granitoids. The deposits of Zgounder, Imiter and Bou Madine have similarities; Structurally are controlled and associated with faults; The source of the mineralization is generally magmatic or crustal. Precipitation of the mineralization would result from the mixing of mineralized fluids with meteoric waters or brine pools. The silver deposits in the Anti-Atlas are characterized by a number of criteria, which confirm their orogenic character. These deposits are associated with orogenic accretion events in relation to Pan-African orogenesis during the Neoproterozoic. Mineralization is syn- to post-peak metamorphism, controlled and associated faults, with veins that can have significant vertical extensions. The pressure gradients, and temperature metamorphism, indicating an orogenic environment, with metamorphic facies greenschist in general. These deposits can all be linked to an argentiferous mega-event during the Upper Neoproterozoic and thus define an argentiferous metallogenic province.

Keywords: Silver, orogenic, mineralization, Anti-Atlas, Morocco

Introduction

The Anti-Atlas is a large metallic province encircled in Precambrian terrains, which flush out in the form of buttonholes. Most of these buttonholes contain mineralizations that are in development or in development, including the silver mineralization of Imiter, Zgounder,

Polymetallic from Bou Madine and Bou Azzer. These deposits have been the subject of numerous studies for several decades. This paper constitutes the first synthesis on the contingency between argentiferous mineralization and the geodynamic context in the Moroccan Anti-Atlas. The present objective is to identify, the orogenic characteristics in the argentiferous deposits in the Anti-Atlas in the south of Morocco, the relations between these argentiferous deposits and the geodynamic context. Three main deposits are studied in this work, each with a different buttonhole, the Bou-Madine polymetallic deposit (Ougnat buttonhole). The Imiter Ag-Hg deposit (Imiter "J.Saghro" buttonhole) and the Zgounder Ag-Hg deposit (Siroua Massif); With a small glimpse of the Bou Azzer deposit. Mineralization is considered in its macroscopic aspect, as it can be observed in the field and microscopic as it is observed under the microscope. In identifying the mineralized structure, there are two major obstacles : the age of much of the mineralization, multistage mineralization; - the absence of a rigorous nomenclature, respected by the various researchers. A summary that fits well with the concern of this article has been drawn, with slight adaptations. It is now necessary to interpret the relationship between the mineralization of a number of argentiferous sites and their geodynamic environment. Such an interpretation necessarily involves the more or less complex chain of processes that gave rise to mineralization. This sequence can spread out over time, or even require one or more mineralizing phases. It is therefore impossible to observe the succession and / or the combination of the elementary processes which lead to an argentiferous mineralization. There will thus always remain a part of hypothesis linked more particularly to certain processes for which, however, a certain consensus is gradually.

Silver is a precious metal, which exists in nature in the native state, of sulphides and sulphosalt. In the Anti-Atlas silver is presented in the form of silver parageneses, Ag-Hg amalgam, silver sulphide and sulfosalts, (argentite or acanthite (Ag_2S), silveropyrite (AgFe_2S_3), schapbachite (AgBiS_2), aguilarite (Ag_4SeS) and canfieldite (Ag_8SnS_6), polybasite (Ag, Cu) $16\text{Sb}_2\text{S}_{11}$, etc.), They are often associated with base metal sulphides and sulfosalts such as arsenopyrite, pyrite, galena, sphalerite and chalcopyrite. Among the elementary processes, there are many geologic or geomorphological processes which are perfectly defined: alteration, dissolution, and transport with precipitation.

Classifications of deposits in general:

A popular classification proposed by Lindgren (1933) distinguishes the deposits formed in the different levels of the crust. The term "epithermal", "mesothermal", and "catathedral" are still used today to describe shallow deposits, intermediate depths, and deposits formed at depth. At the end of

the 20th century, the development of the theory of plate tectonics spread a whole series of classifications related to the tectonic context, Arndt & Ganino (2010). Deposits in ocean basins were distinguished from those in convergent zones or those in intracratonic contexts. This category of classification is still used, particularly when discussing the global distribution of deposits. However, these types of classifications have now largely been replaced by other types of classifications where the basic criterion is the process responsible for mineralization (Table 3). Arndt & Ganino (2010).

Characteristics of orogenic deposits

Several studies have been made on orogenic deposits, especially orogenic gold. They show a number of common characteristics for this type of deposit Kerrich et al (2000).

Geological, geodynamic and metallogenic context of Anti-Atlas

The Anti-Atlas (Figure 1) represents the northern end of the COA, extending over 700 km in a WSW-ENE direction. The anti-atlasic chain is subdivided into three domains: 1) the western part extending from the Atlantic to the foot of the Jbel Siroua. 2). The central part which includes the Jbel Siroua and the region of Bou Azzer, El Graara. 3) The eastern part includes the Jbels Saghro and Ougnat. The Major Anti-Atlas WNW-ESE accident limiting the Western Anti-Atlas of the Central and Eastern Anti-Atlas (Choubert, 1947 ; *in* Tuduri, 2005).

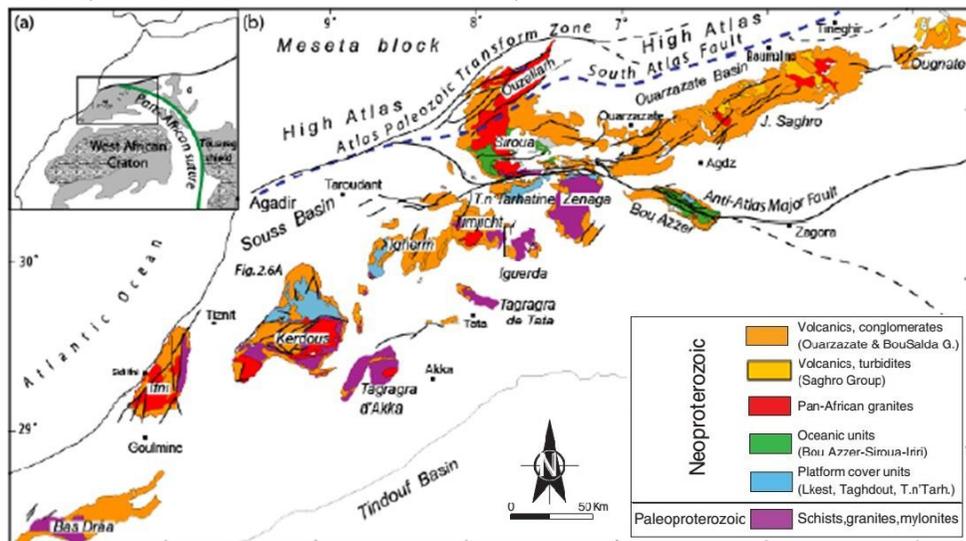


Figure 1. The schematic map of the Precambrian boutonnières of the Anti-Atlas and the localization sketch at the top left (Wafik et al, 2015).

In summary (Table 1), the Precambrian terrains of the Anti Atlas are formed by two distinct groups: 1) An ancient substratum of Paleoproterozoic age, structured during the Eburnian orogenesis (Tuduri, 2005). 2) Neoproterozoic lands linked to the pan-African cycle (Gasquet et al, 2008).

Age		Groups	Lithology
Paleozoic	Adoudounien	Taroudant Group	Dolomie, conglomerate
Neoprotérozoïc	Ediacarian (NP2-NP3)	Ouarzazate Group (NP3) (580-550 Ma)	Rhyolite, granite, conglomerate
		Bou Salda Group (NP2-3) (610-580 Ma)	Sediment no classified, Volcanism and plutonism of potassium and calcium-alkaline.
		Saghro Groupe (630-610 Ma)	Turbidites, tholeitic potassic and <i>calco</i> -alkaline magmatism,.
	Cryogenian	Bou Azzer-Iriri Group (760-700Ma)	Bou Azzer Ophiolite. Iriri Tonalite, gneiss, rhyolite, andésite
	Tonian (NP2)	Lkest-Taghdout Group (1000-880Ma)	Conglomerate, limestones, Quartzite and dolerite
Paleo proterozoic	Eburnean (PI)	Zenaga-Kerdous Group (2.2 Ga-2 Ga)	Schists, granites, mylonites, paragneiss, dolerite veins...

Table. 1. Summary of the generalized lithostratigraphic column for the pan-African orogen of the Anti-Atlas after Thomas et al. (2004), modified by Gasquet et al. (2005) & Liégeois et al. (2006).

The main events are the development of a neoproterozoic "Rifted margin" divergence margin, oblique subduction, the formation of the "insular" intraoceanic arc, continental arc collision and the eventual development of an active continental arc The north margin of the COA.

The result of Hefferan et al (2014), by the combination of numerous works (Thomas et al., 2002, 2004 ; Gasquet et al., 2008 ; Abati et al., 2010 ; El Hadi et al., 2010 ; Walsh et al., 2012 et autres), Is the identification of the distinct orogenic events of the Pan-African cycle (**Figure.2**) :

a). Rifting of Rodinia which consequently the development of the passive margin of the COA and the sea floor 885-760 Ma. The evidences of the operation of this rifting are manifested by diabase dykes which cross the base Eburnéen in the buttonhole of Zenaga. Oceanization corresponds to the ophiolites of Siroua and Bou Azzer-El Graara. The deposits of the passive margin are recorded in the group of Lkest-Taghdout (Thomas et al, 2004. ; Alvaro et al 2014 ; *in* Hefferan et al, 2014).

b) The subduction to the north of the oceanic lithosphere under the island arc of Iriri and formation of the oasolite of Tasriwine in the buttonhole of Siroua and the ophiolite Bou Azzer / the insular arc of Tazigzaout-Tichibanine in the buttonhole of Bou Azzer -El Graara 760-700 Ma.

This subduction is proved by several data including the dating of Metagabbro de Tazigzaout by Lemos et al., (2006), 752 + 1 / -3 Ma and the

dating of the Granite d'Oumlil in the Bou Azzer- El Graara 697 ± 8 Ma by El Hadi et al. (2010).

c) Subduction to the north of 675 Ma. In the Saghro buttonhole, dated synorogenic intrusions confirm this subduction; The Tonalite d'Igoudrane (Schiavo et al, 2007) and granodiorite of Tiboulkhirine (Massironie et al, 2007 in Hefferan et al, 2014). La collision de l'arc insulaire d'Iriri Siroua, l'arc insulaire de Tazigzaout-Tichibanine et le complexe ophiolitique de Bou Azzer 680-640 Ma avec le COA. The consequence of this collision is the development of a metamorphism of green schist type to amphibolite or even probably schist blue (Hefferan et al. 2014).

d) Beginning of the subduction which plunges southward under the COA with development of the potassic magmatism of continental arc. Magmatism was then followed by the development of the clastic basin (620-570 Ma) and collision 615-555 Ma.

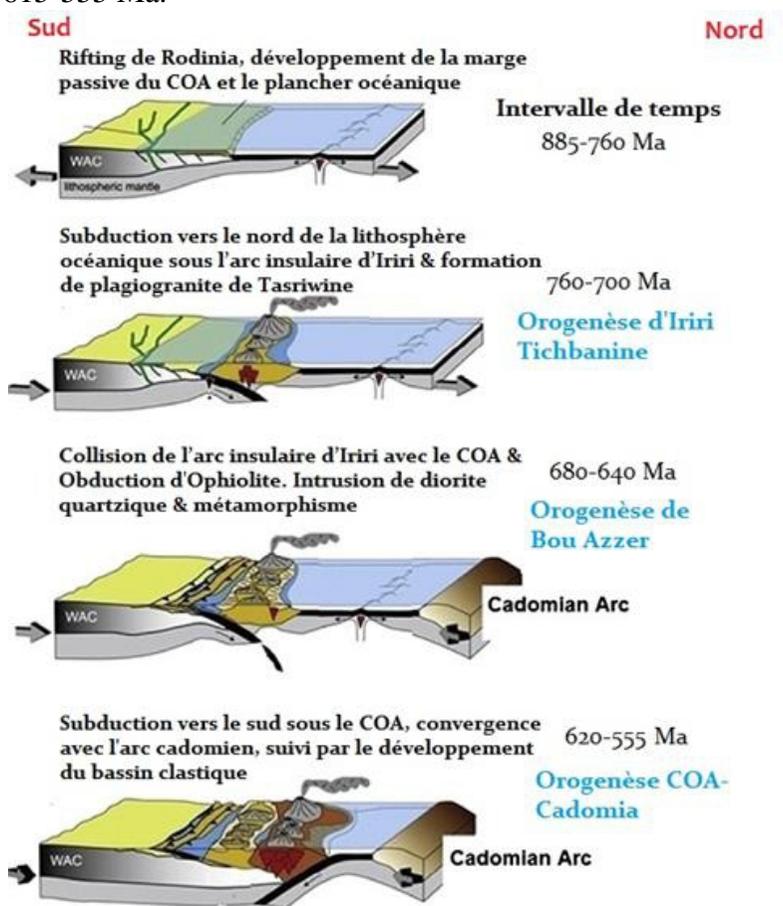


Figure.2. Schematic model showing the Proterozoic tectonic evolution of the Anti-Atlas. Developed by Saquaque et al. (1989), Hefferan et al. (1992, 2000), Thomas et al. (2002, 2004), Gasquet et al. (2005, 2008), Abati et al. (2010), El Hadi et al. (2010) and Walsh et al. (2012), modified by Hefferan et al, (2014).

The post-Panafrican sedimentary series of the Anti-Atlas (Figure 4) begins with deposits of the terminal Neoproterozoic, followed by the Palaeozoic sediments from the Cambrian to the Upper Carboniferous. The complete sequence is about 8-9 km thick in the western Anti-Atlas, whereas it is about 4-5 km in the eastern Anti-Atlas, south of the Saghro and Ougnat. In general, in the Anti-Atlas the sedimentary series were deposited in shallow marine environments (Michard et al, 2008).

Metallogenic Context of the Anti-Atlas

The Moroccan Anti-Atlas is a vast metallic province (Figure 3) which contains numerous deposits and indices with base or precious metals known for more than a millennium (Tuduri, 2005,). One can conclude from the substances exploited and / or enclosed in most of these deposits, that the Anti-Atlas is a metallic argentiferous province.

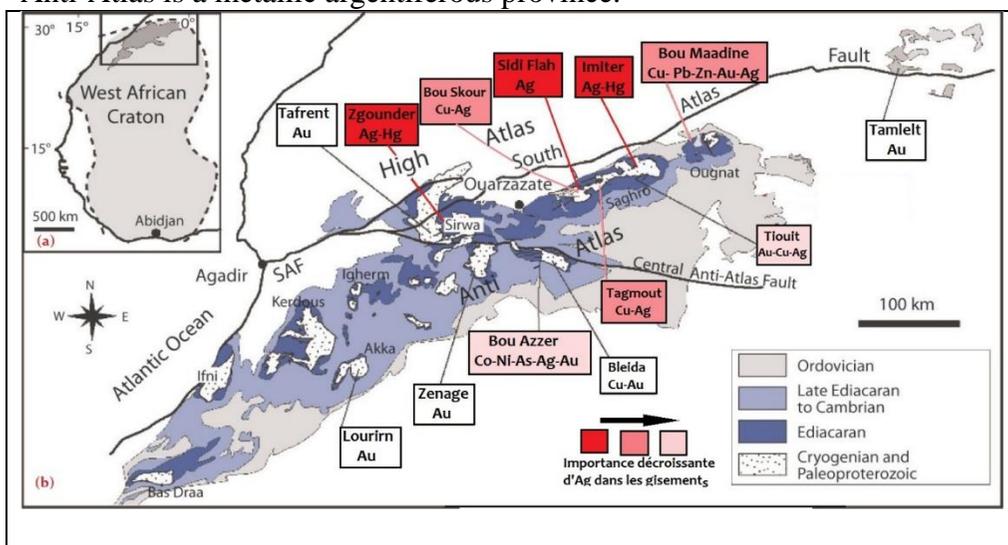


Figure. 3.(a) The Anti-Atlas orogenic belt at the northern limit of the COA. (B) a schematic geological map of the anti-atlas chain and the location of the main mineral deposits, (Gasquet, 2005). Completed.

The silver deposits in the Anti-Atlas

The polymetallic deposit of Bou-Madine (Massif de l'Ougnat, Anti-Atlas oriental)

The Bou Madine deposit is located in the Precambrian boutonniere of the Ougnat at the eastern end of the Anti-Atlas range, about 200 km as the crow flies north of Ouarzazate (Figure 4, 5). The Precambrian buttonhole of the Jbel Ougnat (Figure 8) located in the Eastern Anti-Atlas is composed of two large lithostructural units which are:

- 1- The pleated metasedimentary base (Fig. 5 & 6), schistosed, of "middle" Neoproterozoic age (Saghro Group) composed of pelites and turbiditic grauwackes intersected by granitoid, Levresse, (2001). They develop a contact metamorphism with biotite, cordierite, andalusite and garnet in the metasedimentary series (Levresse, 2001).
- 2- The volcanoclastic coverage of the terminal Neoproterozoic ("NP3") rests unconformably on the metasedimentary base directly or through gaps with elements of the base (Paile, 1983 ; Fretton,1988 ; Aït Saadi, 1992, *in* Levresse, 2001).

Three stages of mineralization controlled by structural evolution are distinguished by Abia & Soulaïmani, (2011), these stages have been divided into sub-stages or episodes, based on textures (**Figure.7**). The main characteristics of Bou Madine silver deposit are summarized in the table 2:

Minéralisation host	The volcanoclastic coverage of the terminal Neoproterozoic; Formation (FTT) with ignimbrites, andesitic casting and rhyolitic intrusions
Age of igneous rocks associated with mineralization	Rhyolitic intrusion of (FTT) 553 ± 16 Ma (Levresse, 2001)
Morphology and textures of ore	Filling of veins; massive, banded et brecciated ore
Mineralization stages (Abia et al, 2003 & Abia & Soulaïmani, 2011).	<p>Stage I : Fe-As- (Sn) stage :</p> <ul style="list-style-type: none"> • Episode (1a): massive or banded pyrite 1 (pyrrhotite and cassiterite). • Episode 1b : arsenopyrite (arsenopyrite 1) <p>Stage II : (Zn-Pb-Fe-Cu-Sn) :</p> <ul style="list-style-type: none"> • Episode (2a) with sphalerite and accessory chalcopyrite, pyrite and stannite, and • Episode (2b) galena. <p>Stage III : (As-Fe-Pb-Zn-Cu-Ag-Sb-Bi) with arsenopyrite, pyrite, traces of galena, sphalerite, chalcopyrite, gray copper, argentopyrite (AgFe₂S₃), schapbachite (AgBiS₂), aguilarite (Ag₄SeS) & canfieldite (Ag₈SnS₆)</p>
Conditions of ore formation	Temperature between 360°C et 150 °C. fS entre 10 ⁻¹⁸⁻⁸ bar et 10 ⁻⁹⁻⁷ bar. The minimum fluid trapping temperature between 150 ° C and 200 ° C for estimated trapping pressures of 400 bar. the fluid's pH for temperatures of 150°C to 300°C, respectively between 6.5 et 7.
Source of mineralization	Crustal (Abia et al (1999). Magmatic (Levresse, 2001) Mixing with meteoric waters or brines from the Adoudounian Basin (Levresse et al., 2004).
Age of Mineralization	Contemporary with rhyolitic intrusions of (FTT)

	553 ± 16 Ma (Levresse, 2001)
Genetic model	<ul style="list-style-type: none"> - A copper porphyry, With an ESE-WNW extension regime at the origin of the normal faults of direction N70 ° E to N30 ° related to rhyolitic intrusion age 553 ± 16 Ma, (Levresse, 2001). - A neutral epithermal type (low-sulfidation or even sericite-adular), controlled by the NW-SE and NE-SW during the late panafrican phase. Sub-contemporary to the placement of rhyolitic domes dated by Levresse (2001) à 553 ± 16 Ma (Abia & Soulaimani, 2011).
Orogenic characteristic identified	<ul style="list-style-type: none"> - The Bou Madine deposit is associated with neoproterozoic orogenic accretion events. - Mineralization is syn-to post-peak of metamorphism, controlled and associated with faults, with veins that may have significant vertical extensions. - Presence of metamorphic Green schist facies. Pressure, temperature and metamorphism gradients indicate orogenic environment. - The ore is associated to acid alteration (quartz-sericite-pyrite) during the stage (a1).

Table 2 : Main characteristic of Bou Madine silver deposit.

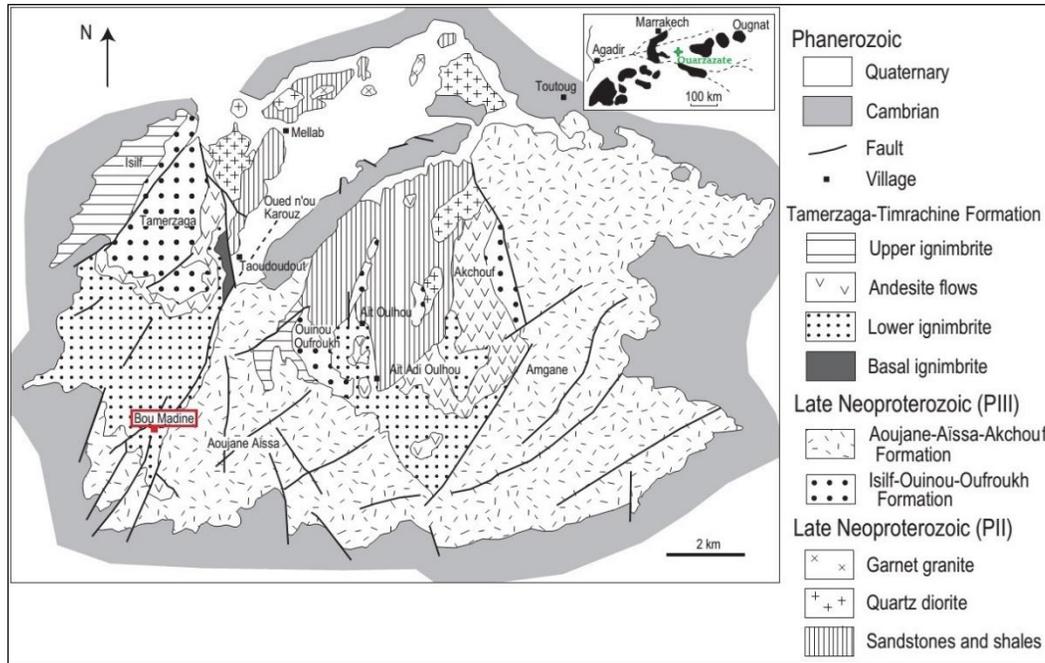
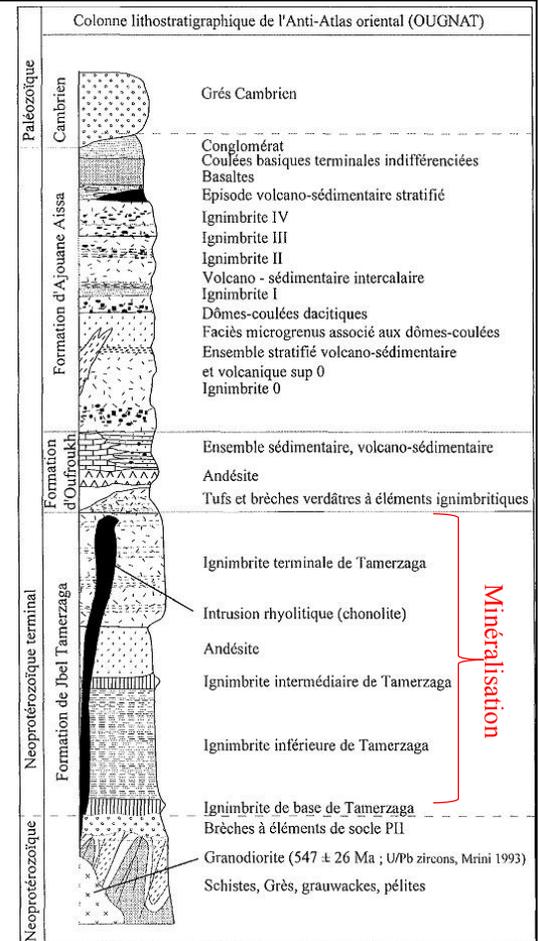


Figure.4. Simplified geological map of the Ougnate boutonhole, with location of Bou Madine deposit. (Abia et al, 2003) completed

Figure. 5. Lithostratigraphic column of Bou Madine (Paile, 1983 ; *in* Levresse, 2001), completed



Imiter Silver deposit (Saghro Massif, oriental Anti-Atlas)

Imiter district is located in the north of Imiter boutonhole (at GPS coordinates : N 31°21'4.47", W5°43'39.27"). The Imiter silver deposit is distributed along the Imiter fault (Figure 6), oriented N70 ° E to N90° E. hosted by the meta-sedimentary lands of the middle Neoproterozoic "Saghro Group" accompanied by a penetrative schistosity (Ouguir et al., 1994; Maacha et al., 2015; Lebdev et al. 2016) and at the base of volcano-sedimentary and volcanic formations of the Upper Neoproterozoic "Ouarzazate group" (Maacha et al, 2015). These terranes were structured during the Pan-African orogeny by a folding of the E-W axis to ENE-WSW. The whole is covered in major discordance by the sedimentary formations carbonate, and pelitic and sandy of the middle Cambrian (Maacha et al, 2015). Three types of orientation bodies EW to N70°E (Gaouzi et al, 2011 ; Maacha et al, 2015; Lebdev et al., 2016;) . The main ore characteristic are summarized in table 3.

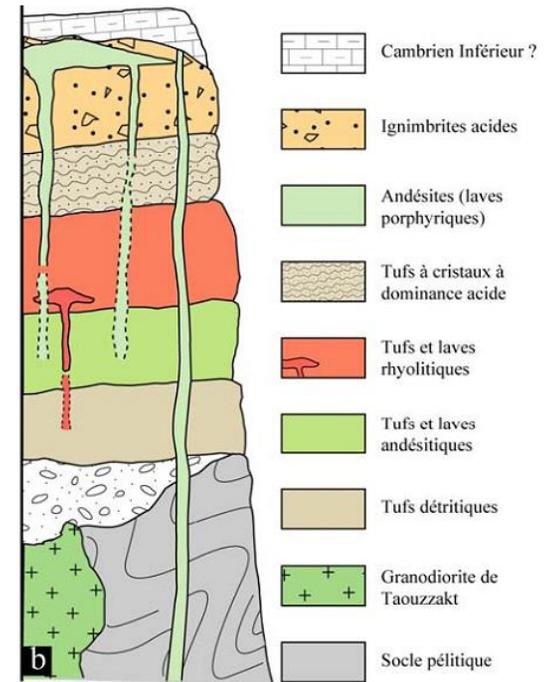
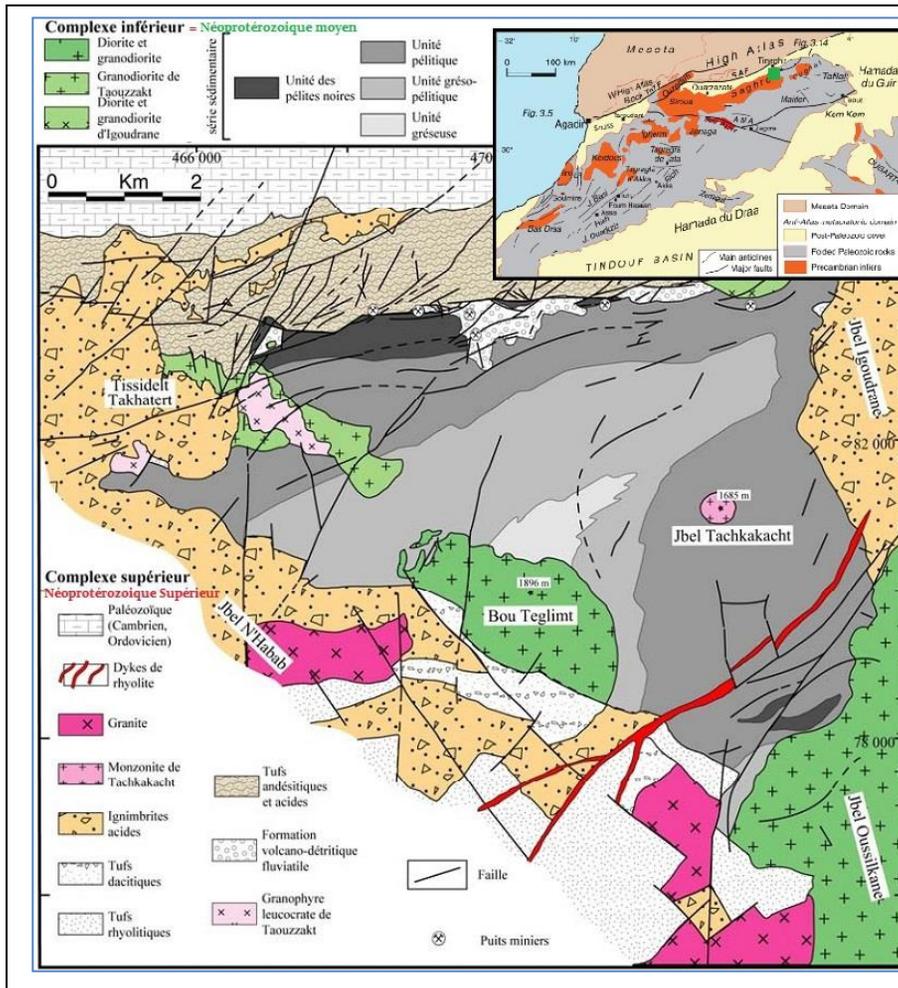


Figure. 6. Geological map of the Imiter boutonhole (internal SMI document), with its location in the Anti-Atlas, modified and completed.

Figure.7. Summary stratigraphic log of Imiter mining sector, based on SMI documents

Ore-bearing rocks	The ore is distributed along the fault bundle, encased in the mid-Neoproterozoic meta-sedimentary terrains and at the base of volcanic-sedimentary and volcanic formations of the Upper Neoproterozoic (Maacha et al.,2015; Lebdev et al. 2016)
Age of igneous rocks associated with mineralization	Taouzzakt Granodiorite 572 ± 5 Ma and Takhatert rhyolite 550 ± 3 Ma, (Levresse, 2001)
Ore morphology and textures	Clusters, veins; massive ore, ribbon, breccia, disseminated or in stockwerk...
Mineralization stages	<p>- The first syngenetic and tectono-metamorphic stage, (Fe) pyrite and milky quartz veins in black shales (associated panafrican metamorphism foliation) (Levresse, 2001).</p> <p>- The early hydrothermal sulphide stage : The silver epithermal stage (Pb, Zn, Cu, Fe, As, As-Co-Ni, Hg and Ag) (pyrite, arsenopyrite, chalcopyrite, galena, copper-gray, sphalerite silver amalgam, silver sulfosalts, and argentite) and imiterite) (Guillou et al. 1985) associated with E-W quartz veins (<i>Qtz2 phase</i>) and N130 ° E dolomite veins breccias (<i>dolomite phase</i>) with sometimes hydraulic. Spatially they are related to the granitoids and the aureole of contact metamorphism (Levresse, 2001).</p>
Ore's formation Conditions	<p>Temperature between 350°C et 180°C Pressions between 0,8 à 5 kbar, during tectono-metamorphic stage. Aqueous magmatic fluids with pH ~ 7; and salinity ~ (0,5 to 14,5 eq. NaCl). Ag is carried in the solution in the form of sulphide complexes (Ag (SH) - ²). Precipitation of metals is probably related to the mixing of deep fluids and superficial fluids (brine) (Levresse, 2001).</p>
Ore Source	The sulphides associated with argentiferic paragenesis would have a purely mantle source (90%) to be related to felsic volcanism. The S of the pyrites comes from the black shales and the late-neoproterozoic felsic volcanism, (Levresse et al., 2004).
Ore deposit Age	Neoproterozoic terminal; Contemporary to the introduction of Takhatert 572 ± 5 Ma rhyolite intrusions and Taouzzakt 550 ± 3 Ma granodiorite (Levresse, 2001).
Genetic model	<p>- Succession of tectono-metamorphic, magmatic and volcanic episodes of reconcentrations of a syngenetic metal stock closely associated with black shales. (Baroudi et al. (1999),</p> <p>- An epithermal model related to rhyolitic magmatism at the end of the terminal Neoproterozoic (Levresse, 2001). In these two cases, the authors agree that a distensive tectonic characteristic of the Precambrian-Cambrian transition would favor the formation of structural traps (Tuduri, 2005).</p>
Orogenic characteristics identified	The ore in the Imiter deposit is hosted by meta-sedimentary sequence deformed and schistosed syn at post-peak panafrican metamorphism. The ore is distributed along the fault bundle of significant vertical extensions, linked to the major accidents "fault of Imiter". The pressure, temperature and metamorphism gradients, indicating an orogenic environment.

Table 3 : Main characteristic of Imiter silver deposits

Zgounder silver ore deposit (Siroua Massif, Central Anti-Atlas)

The Zgounder silver deposit is located on the western flank of the Precambrian massif of Siroua in the Anti-Atlas, about 200 km east of Taroudant (Figure 4). GPS: N 30 ° 45'44 ", W 07 ° 44'35 "; Alt. 2000 m. The Siroua massif belongs to the pan-African orogenic domain, it is located north of the Major accident of the Anti-Atlas (**Figure.1 & 3**).

In the Siroua massif the terrain consists of a volcanosedimentary series, the Zgounder series assigned to the terminal Neoproterozoic by Choubert & Faure Muret (1990). It is bordered on the west by a terminal Neoproterozoic granodiorite massif, covered to the east by volcano-detritic formations, of the Neoproterozoic terminal and by phonolites and Neogene Tuffites (Marcoux & Wadjinny, 2005 ; Essarraïj & Michard, 2011).

This series of Zgounder is straightened, shows an E-W direction (Fig. 8) and a strong dip towards the south; It would correspond to the southern flank of an anticline E-W direction (Essarraïj & Michard, 2011). It occupies an area of about 9 km², formed by three series, one distinguishes from the base to the top (*in* Marcoux & Wadjinny, 2005):

- The blue series, is thick 300 and 400m, composed of sandstones, grauwackes and pelites, with levels of tuff, the whole being capped by a level of orange rhyolite;
- The brown series, also 300 to 400 m high, consisting of micaceous and sandy schists, and breccias and pelites with fragments of volcanic glasses. This formation is capped by a dolerite sill;
- The black series at the summit, about 900 in thickness, composed of an acidic volcanic complex (ignimbrites, rhyolitic breccias), which forms the roof of mineralized levels. To the south, this formation ends with sandstones and grauwackes, with intermediate levels of conglomerate (Figure 8).
- Two types of metamorphism appear in the series bearing mineralization at Zgounder, A regional epizonal and the second contact. The latter is caused either by the intrusion of the Askaoun granite, located to the west of the terminal neoproterozoic mine (575 ± 8 Ma, U-Pb zircon, Thomas et al., 2002), and by Associated rhyolitic intrusions (Figure 8), or by a dolerite sill. A Neogene volcanism "Pontian" materialized by trachytic tuffs and phonolites is observed further east, J. Siroua volcano (Essarraïj & Michard, 2011).
- The Zgounder area is affected by four fractures: east-west, north-south, "sub-vertical" and two conjugate systems, NE-SW and NW-SE. They can be interpreted as fractures associated with the E-W folding of the series (Marcoux & Wadjinny, 2005 ; Essarraïj & Michard, 2011).

In the Zgounder deposit, silver mineralization is located at the top of the brown (schisto-sandstone) formation, encased in pelitic levels, tuffaceous breccias and dolerite. The silver mineralization can be observed up to 70 m inside the shale, with a higher concentration in the first 20 to 25 m. The mineralization is closely associated with the E-W grinding zones and the N-S fracture zones (Smeykal, 1972 ; Petruk, 1975) (Figure.9). The mineralization takes the form of a lens of variable dimensions (10 to 25 m wide and 20 to 60 m long), but follow the east-west fractures with a general dip to the south. The rooting of these fractures, recognized up to 300 m, is disturbed by subhorizontal faults (Marcoux & Wadjinny, 2005).

The main characteristic of Zgounder silver mineralization are summarized in the table 4.

Figure. 8. Detailed map of the mine and its surroundings with location of the Zgounder silver deposit in the Anti-Atlas., (Demange, 1977), completed

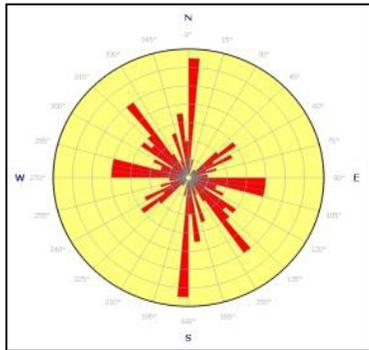
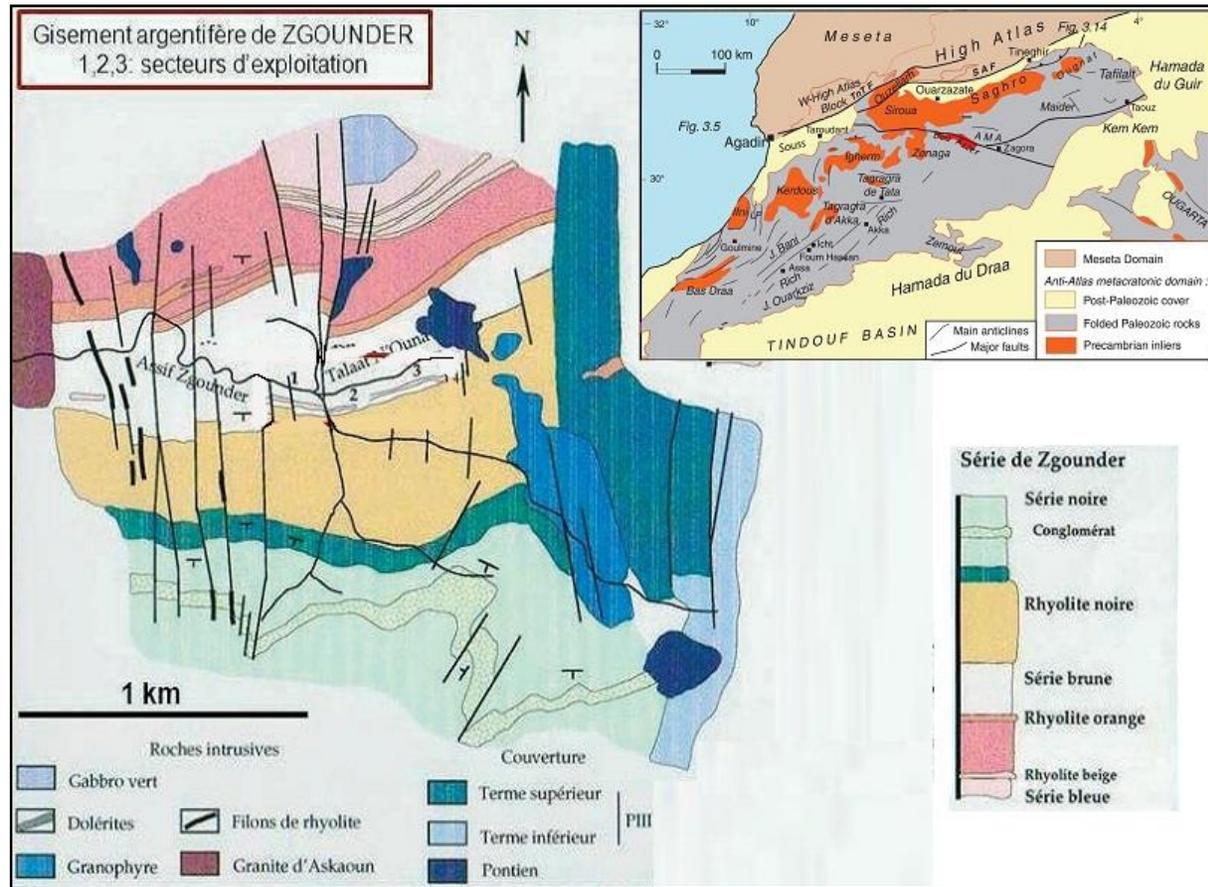


Figure. 9: Stereo projection of fracturation in the Zgounder district



Ore-bearing rocks	In the Zgounder deposit, argentiferous mineralization occurs at the top of the brown (schisto-sandstone) formation, encased in the volcano-sedimentary series, pelitic levels, tuffaceous breccias and dolerite.
Age of igneous rocks associated with mineralization	The intrusion of the Askaoun granite, located to the west of the terminal neoproterozoic mine (575 ± 8 Ma; U-Pb zircon, Thomas et al., 2002). End-Neoproterozoic Rhyolites
Morphology and textures of ore	Lenses of variable dimensions (10 to 25 m wide and 20 to 60 m long), Clusters, veins; Solid ore, ribbon, breccia, disseminated or in stockwerk
Mineralization stages	The early stage(E) (Fe-As-Ag) : pyrite–arsenopyrite with nanoinclusions of Ag (20 μ m) in E-W veinlets and brecciated zones. The polymetallic late stage (Cu-Pb-Zn-Ag-Hg) : chalcopyrite-galena sphalerite, native Ag, Ag-Hg amalgam (predominant argentiferous phases), acanthite, galena, pearceite, polybasite and Ag-Hg sulphide paragenesis in N-S quartz-albite-chlorite or siderite-calcite veins,: (Essarraj & Michard, 2011). Two populations of silver were pointed out Marcoux & Wadjinny, (2005) a reveal slightly later remobilisations.
Ore formation conditions	The aqueous fluids responsible for mineralization are trapped at high temperatures (450-300 ° C) at widely varying pressures (0.5-1.9 kbar) during the early stage. For the late stage, the temperature conditions are about 200 ° C., and the fluids are of the hypersaline brine type, under pressures, P <1 kbar.
Source of mineralization	The continental crust, without the perceptible participation of the mantle (Marcoux & Wadjinny, 2005).
Age of mineralization	The analysis of the isotopic composition of galena lead makes it possible to calculate a terminal Neoproterozoic age for mineralization about 510 Ma (Marcoux & Wadjinny, 2005)
Genetic model	Deposits in veinlets and brecciated zones of generally E-W direction (early high temperature stage, sulphides and sulfo-arsenides of FeAs-Co) are generally related to late-Pan-African evolution (Essarraj & Michard, 2011). hydrothermal circulations are of magmatic and / or metamorphic origin For, in corridors of compressive deformation in magmatic arc context (relative to Askaoun pluton (575 ± 8 Ma,) (Smeykal ;1972; Popov, 1989), The late stage epithermal silver and base metal, lower temperature and pressure conditions corresponds to exhumation of the Pan African (Essarraj et al., 1998 ; <i>in</i> Essarraj & Michard, 2011) or post-orogenic extension during the Upper Ediacaran-Lower Cambrian ~ 510 Ma, By mixing with very saline surface brines (Marcoux & Wadjinny, 2005)
Orogenic characteristic identified	It is encased in structured and schistosed meta-sedimentary lands during the Pan-African orogeny, with an epizonal regional metamorphism. The ore is distributed along the fault bundle of significant vertical extensions,

	the rooting of these fractures, recognized up to 300 m. The pressure gradients (0.5-1.9 kbar), temperature (450-180 ° C) and metamorphism, indicating an orogenic environment. Syn to post-peak metamorphism, during the formation phase of the pan-African orogenic belt.
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Table 4 : Main characteristic of Zgounder silver deposits

Genetic relationships between silver deposits in the Anti-Atlas

The Anti-Atlas is an silver metallic province characterized by a set of deposits that can be genetically linked. In the table below (table 5) we will make a correlation between the deposits studied.

Ore deposit	Bou Madine	Imiter	Zgounder
Ore-bearing rocks	volcanoclastic coverage of (NP3).	meta-sedimentary serie of the middle (NP2) and at the base of the volcanic-sedimentary and volcanic formations of (NP3).	volcano-sedimentary series, pelitic levels, tuffaceous breccias and dolerite, (NP3)
Age of igneous rocks associated with mineralization	Rhyolitic Intrusion of (FTT) 553 ± 16 Ma (Levesse, 2001)	Taouzzakt Granodiorite 572 ± 5 Ma & Takhatert rhyolite 550 ± 3 Ma, Levesse, (2001)	Askaoun granodiorite intrusion, (575±8 Ma) (Thomas et al., 2002). & rhyolite
Ore Morphology and textures	Fills veins; massive ore, banded and brecciated	Clusters, veins; or in stockwerk Massive ore, ribbon, breccia, disseminated...	Lenses, clusters, veins, stockwerk massive ore, breccia, disseminated or in
Ore formation conditions	The temperature between 360 ° C and 150 ° C. The pressure ~ 0.4Kbar. The pH : 6.5 - 7. fluid salinity of 1% eq. NaCl	The temperature between 350 ° C and 180 ° C. The pressures of 0.8 to 5 kbar, pH : ~ 7. fluids are aqueous with salinity of (0.5 - 14.5 eq. NaCl).	temperature 200-450 ° C. pressures largely variable 0.5-1.9 kbar hypersaline brine type
Source of mineralization	Magmatic source for (Levesse, 2001) Crustal source, (Abia et al (1999).	Purely mantle magmatic source (90%). The S of pyrites comes from black shales and felsic volcanism	Continental crust, without the perceptible participation of the mantle (Marcoux & Wadjinny, 2005).
Age of mineralization	Contemporary at the introduction of the rhyolite intrusion of (FTT) 553 ± 16 Ma (levresse, 2001)	Contemporary to the introduction of Takhatert 572 ± 5 Ma rhyolite intrusions and Taouzzakt granodiorite 550 ± 3 Ma (Levesse, 2001).	The age of the mineralization about 510 Ma (Marcoux & Wadjinny, 2005)

Table 5 : comparative table between the Bou Madine, Imiter and Zgounder silver deposits.

The relationship between the Zgounder and Imiter deposits

Zgounder and Imiter deposits have strong analogies. They are characterized by Ag-Hg mineralization exceptionally rich in silver and with high mercury silver contents. From a geological point of view, silver mineralization is associated with rhyolites and granitoids of the same age, terminal Neoproterozoic. Structurally the east-west fractures preferentially mineralized. From the point of view mineralogy, abundance of mercurial

silver and silver sulphides, geochemically (at least partial similarity of fluids) (Marcoux & Wadjinny, 2005). The Ore formation conditions are almost the same. The two deposits are considered by several authors (Essarraj et al., 1998 ; Essarraj & Michard, 2011 ; Levresse, 2001 ; 2004), as epithermal deposits related to the implementation of the terminal Neoproterozoic rhyolite magmatism. The fluids show an early stage of high temperature (near 500 ° C), suggesting a marked magmatic influence, followed by a rapid decrease, suggesting a subsurface arrival and possible mixing with superficial hypersaline waters. Zgounder and Imiter could be two expressions of the same neoproterozoic epithermal episode, which would extend into the Anti-Atlas, at least on Siroua and Saghro, beginning to define what might well be a metallogenic silver province.

The relationship between the Bou Madine and Imiter deposits

According to some authors (Abia & Soulaïmani, 2011) the Bou-Madine deposit is a neutral epithermal type. This is also the case for the deposit of Imiter according to Levresse, (2001). The similarities of these deposits are very important, in almost all respects (table 9). The mineralization precipitation occurred towards the end of the acid-to-intermediate eruptive episode of the Tamerzaga-Timrachine "FTT" formation in Bou-Madine. Sub-contemporaneous to the setting of the rhyolitic domes at Imiter dated by at 553 ± 16 Ma, in relation to the mineralization at Imiter. Precipitation of the mineralization would result from mixing with meteoric waters or brine basin Levresse (2001).

The relationship between the Zgounder and Bou Azzer deposits

Bou Azzer is 45 km as the crow flies from SW Ouarzazate (Figure 7), in the central Anti-Atlas, Bou Azzer-El Graara buttonhole, located along the major fault Of the Anti-Atlas which constitutes the northern limit of the West African Craton (Wafik et al, 2015). The deposit has been exploited for cobalt since 1933, and silver mining began in 1988. The Bou Azzer-El Graara buttonhole is part of the Pan-African orogenic belt 680- 580 Ma. The silver ore is deposited in the quartz diorite connected to an insular arc by (Boudinier et al., 1984). The age of the mineralization is not known, but there are similarities in the composition of the brine, trapping conditions and the nature of the mineral associations exist between the three deposits-Ag (Bou Azzer, Zgounder, Imiter). These conditions suggest that a major phase of brine circulation and fluid migration produced in the Anti-Atlas (Essarraj et al., 2005). Essarraj (1999), concludes that very similar brines (of the H₂O-NaCl-CaCl₂ system) of high salinity have circulated in the Zgounder and Bou Azzer deposits (24-40% by weight NaCl + CaCl₂ at Zgounder and 19 to 45% wt. NaCl + CaCl₂ at Bou Azzer), moderate temperature and pressure

conditions comparable in the two deposits (T about 200 ° C and P <100 MPa). These brines gave rise, in the first place, to different parageneses in the two deposits (Zn-Cu to Zgounder and As-Co-Ni to Bou Azzer). They then deposited the economical silver occurrence in both deposits, following an evolution marked by a drop in salinity, a slight drop in temperature, and without any significant change in the pressure conditions.

Conclusion

The main events of the pan-African orogenic cycle in the Anti-Atlas chain are: the development of a neoproterozoic "Rifted margin" divergence margin, oblique subduction, insular arc formation, continental arc collision and development of an active continental arc on the northern margin of the COA. The Bou Madine deposit for Levresse (2001) could be of copper porphyry type, but for other authors like Abia & Soulimani (2011), it is of epithermal neutral type. The mineralization genesis towards the end of the episode eruptive acid to intermediate formation of Tamerzaga-Timrachine Neoproterozoic terminal. The neutral epithermal type related to the installation of the rhyolitic magmatism at the end of the Neoproterozoic terminal Levresse, (2001, 2004) is accepted by the majority of the Authors.

In the Zgounder deposit, the precipitation of silver mineralization and the associated base metals was carried out under epithermal conditions of lower temperature and pressure (Essarraj & Michard, 2011).

From the synthesis of the work on the main silver deposits of the Anti-Atlas (Bou-Madine, Imiter, Zgounder), a number of conclusions can be drawn concerning the relations between these deposits and their relations with the Bou Azzer deposit (Co-Ni-As-Ag-Au).

The Imiter and Zgounder deposit possess strong analogies, they are characterized by Ag-Hg. They are associated with terminal Neoproterozoic rhyolites, east-west fractures are preferentially mineralized and at least partial similarities of fluids.

Between the deposits of Bou Madine and Imiter, similarities are very important, with essentially mineralization associated with synchronous rhyolite intrusions in the two deposits, dated to 553 ± 16 Ma and 550 ± 3 Ma respectively by Levresse (2001). Precipitation of the mineralization would result from mixing with meteoric or brine pools in both cases.

The relation is established between the Zgounder and Bou Azzer deposits by Essarraj (1999), this relation consists of: very similar brines of high salinity, which have circulated in both deposits. Under conditions (T around 200 ° C and P <1 KPa).

The silver deposits in the Anti-Atlas are characterized by a number of criteria, which confirm their orogenic character. These deposits are associated with orogenic accretion events in relation to Pan-African

orogenesis during the Neoproterozoic. The mineralization is syn to post-peak metamorphism, controlled and associated with faults, with veins that may have significant vertical extensions. The gradients of pressure, temperature and metamorphism, indicate an orogenic environment, with metamorphic terranes of greenschist facies. Finally, it can be noted that the silver deposits in the Anti-Atlas are of the orogenic type. They can all be linked to a silver mega-event during the Neoproterozoic and thus define an silver metallogenic province bordering west-african craton (figure 10).

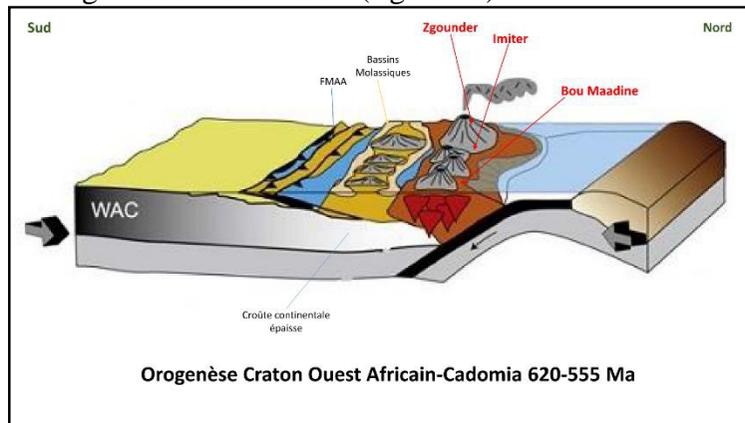


Figure.18. Schematic model of the Proterozoic tectonic evolution of the Anti-Atlas (Saguaque et al. 1989; Hefferan et al. 1992; 2000; Thomas et al. 2002; 2004; Gasquet et al. 2005; 2008; Abati et al. 2010; El Hadi et al. 2010; Walsh et al. ;2012; Hefferan et al, 2014) and Anti-Atlas argentiferous province (this study).

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