Copper Mineralization in Adoudounian Cover of the Bou Azzer-El Graara (Anti Atlas, Morocco): Tectono-Stratigraphic Controls

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Abstract. Copper mineralization in sedimentary cover is well known in association with Pb and/or Zn in Sedex, Kupferschiefer, Mississippi Valley-Type, or Red bed deposits. In spite of great economic potential, the syngenetic versus epigenetic origin of widespread Cu occurrences in the Adoudounian sedimentary cover, in the Moroccan Anti Atlas, remains debated. Significant investigations that would provide critical information for mining exploration are lacking. Whatever their origin, these mineralizations do not correspond to classical sediment-hosted deposits, the ore being exclusively Cu concentrations in dolostone units. This study, based on field and microscopic observations, is focused on Cu mineralization hosted in the Adoudounian cover of the Bou Azzer-El Graara inlier. Two morphologic types of ore bodies exist. The first consists of stratabound lenses and the second type is vein networks along Variscan faults. Both types of mineralization have a stockwork texture and clearly postdate sedimentary fabrics, such as beddings and slumps; this suggests a common epigenetic origin for the both ore types. The proposed interpretation involves the upflow of Variscan fluid-driven interaction between a basement and its sedimentary cover.

Keywords: Copper mineralization, sedimentary cover, Anti Atlas, field relationships, morphology, texture.

1 Introduction

More than 200 copper occurrences in the Moroccan Anti-Atlas are hosted within the Neoproterozoic to Cambrian cover, often called Adoudounian cover (Pouit 1966; Bouchta et al. 1977). The growing interest of mining companies for potential copper resources induces the need for a better understanding of these mineralizations. Ore bodies are localized at different stratigraphic levels within the cover and present different characteristics. Their origin remains in most cases poorly understood; a syngenetic model explaining all of the Cu mineralizations by a single event has never been considered. In counterpart, several different genetic interpretations of some unusual copper occurrences have been proposed: (i) Leblanc (1986) suggested that the Alous mineralization formed during the cooling of an ignimbrite; (ii) Concerning the Cu-occurrences in the dolostones units in the Adoudounian cover of "Tizert", "Talat N'Ouamane", "Tizirt," and "Amadouz," whereas Pouit (1966), Bouchta et al. (1977), and Skacel (1993) considered that they were generated through a synsedimentary process, given the strong paleo-topographic control on ore deposition. Moreover, the Cu mineralizations hosted in the Neoproterozoic to Cambrian cover of the Anti-Atlas can be differentiated, according to morphology, as veins, disseminations, or stratabound bodies. So far, no relationship has been found among these different morphological types of orebodies (Pouit 1966; Skacel 1993). As a result, the syngenetic or epigenetic nature of such mineralization remains undetermined (Pouit 1966). The Bou Azzer-El Graara inlier contains numerous copper occurrences in Adoudounian cover, in particular the Jbel Laassel deposit is currently being mined, highlighting the economic interest for these mineralizations. This study is based on field and microscopic observations. The different morphologies of major copper ores in the Bou Azzer-El Graara Adoudounian cover are described and their potential tectono-stratigraphic controls are detailed. Then, new arguments are presented in order to link these different copper occurrences with one hydrothermal event.

2 Geological Setting

The Bou Azzer-El Graara inlier is one of a series of Proterozoic windows, oriented NW-SE, which expose Panafrican formations in the central part of the Anti-Atlas (Choubert 1947). These formations are unconformably overlain by a thick Neoproterozoic to Cambrian volcano-sedimentary cover (Soulaimani et al. 2014) (Fig. 1). This cover can be divided into three formations, from bottom to top: (1) The Tiddiline Formation (~750 to 650 Ma) attributed to the "Saghro Group" (Thomas et al 2004); it is mainly unconformable on the Panafrican substratum; (2) The Ouarzazate Group (~610 to 550 Ma), which rests in angular unconformity on the Tidiline Formation; (3) The terminal Neoproterozoic to Cambrian formation, often called "Adoudounian," consists of clastic and carbonate strata (Soulaimani et al. 2013).

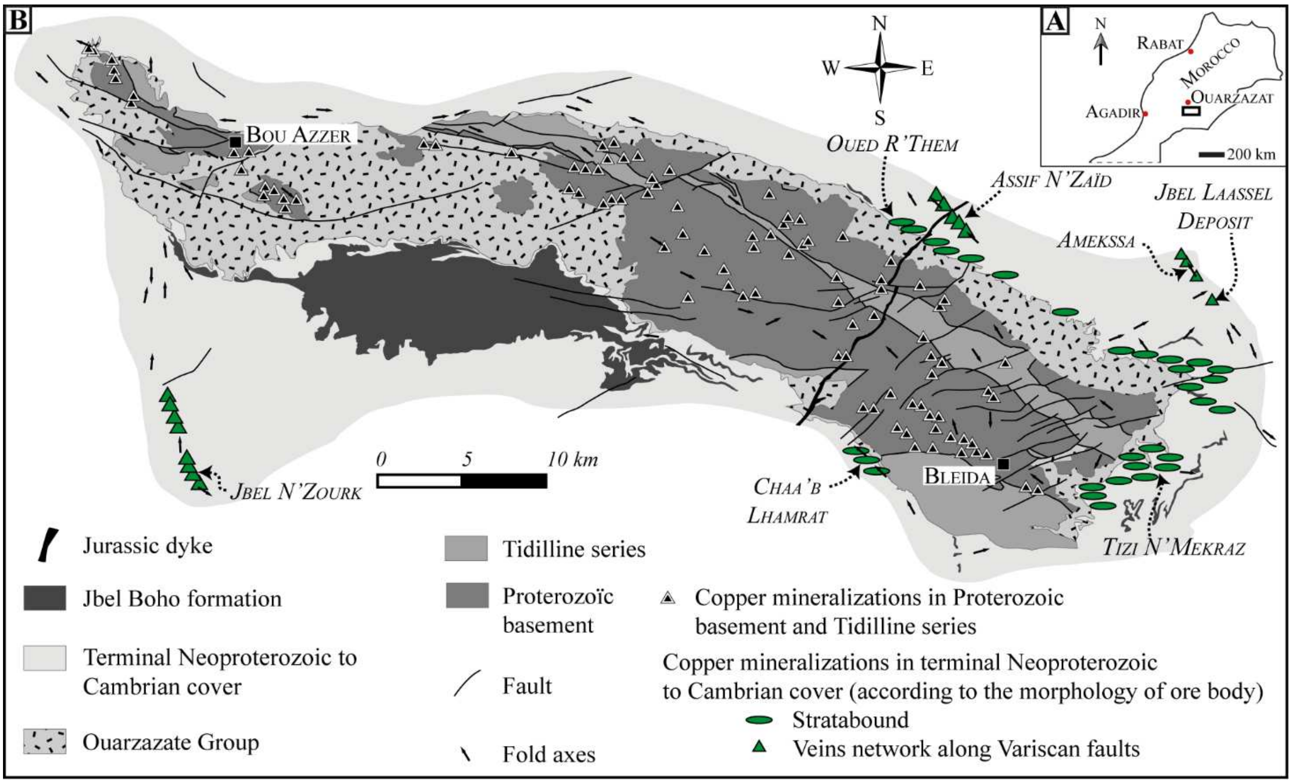

Figure 1. A. Simplified map of Morocco showing the location of the Bou Azzer El Graara area; **B.** Geological and structural map of the Bou Azzer-El Graara area with occurrences of copper mineralization. Modified from Leblanc (1975).

This last formation is associated with a major marine transgression toward the southeast and can be subdivided into two groups: the Taroudannt Group, with Lower Dolostones and Lower Sandstones units, and the Tata Group, with Upper Dolostones and Upper Sandstones units (Choubert 1952; Boudda et al. 1979) (Fig. 2).

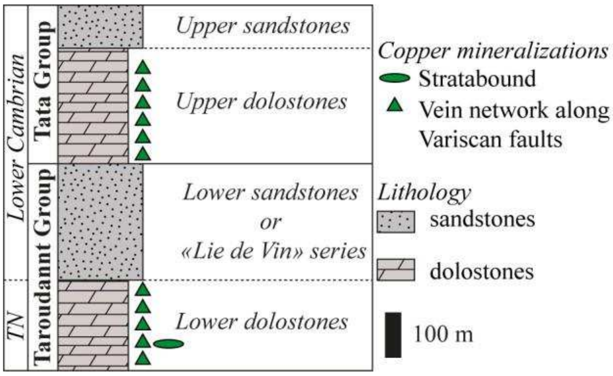

Figure 2. Simplified lithostratigraphic column of the Adoudounian cover in the Bou Azzer-El Graara inlier, showing vein-type and stratabound copper mineralizations. Abbreviation: TN, terminal Neoproterozoic.

During the late Paleozoic compressional event, the Panafrican basement structures were reactivated along the inlier's borders. This deformation resulted in box-shaped folds distributed throughout the Bou Azzer-El Graara area, marked by large open synclines of Cambrian rocks (Soulaimani and Burkhard 2008). Upright detachment folds, from meters to decameters in scale, are common in the Lower Cambrian rocks and exhibit a predominant NW-SE trend with subordinate NE-SW structures (Soulaimani and Burkhard 2008).

3 Copper Mineralization

3.1 Ore body

In the Bou Azzer-El Graara Adoudounian cover, two types of orebody morphologies can be distinguished, according to (i) the shape of the mineralized envelope at meter to kilometer scale, and (ii) the relation between this envelope and the geological features of the host rock: either stratabound or vein networks spatially associated with Variscan faults. The former ore type is exclusively located in Lower Dolostones units of the Taroudannt Group. It consists of two coarse-grained black dolostone beds separated by a micritic dolostone bed. This particular set of lithologies is localized in the lower part of Lower Dolostones (Fig. 2), and occurs continuously in the cover around the inlier, whether mineralized or not. Where present, the copper mineralization displays a stratabound geometry, with a thickness of ~1.5 to 4 m and a lateral extent of 2 m to more than 5 km (Fig. 3A), and a copper content of 0.4 to 2.5%. The most important ore bodies of this type are Tizi N'Mekraz, Oued R'Them, and Chaa'b Lhamrat (Fig. 1).

The second ore type is present in both the Taroudannt and Tata Groups, throughout the Lower and Upper Dolostones (Fig. 2). It is exclusively associated with NW-SE-oriented, vertical to sub vertical Variscan faults (Fig. 3B). On both sides of these faults, the cover presents meter to decimeter-scale folds with the same NW-SE-trending axes. These folds are concentrated in a more or less narrow band, named herein the "folding band." The ore body is uniformly in contact with these faults; its lateral extension corresponds to the width of the "folding band." On surface, the width is in the range of 2 to 200 m and the lateral extent is 1 to 5 km. Depth extension is only known for the Jbel Laassel deposit, where it is at least 120 m. Copper contents are in the range of 0.3 to 3%. The most important ore bodies in the considered inlier are the Jbel Laassel deposit, the Amekssa and Assif N'Zaïd in the Upper Dolostones and the Jbel N'Zourk in the Lower Dolostones (Fig. 1).

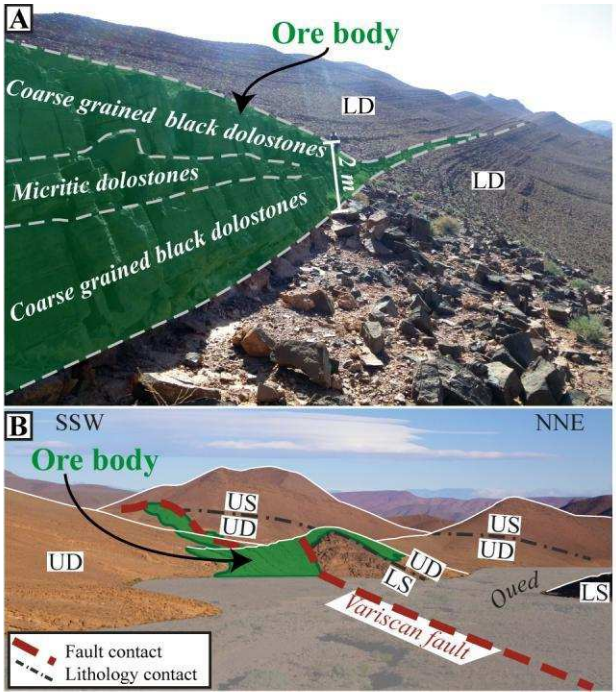

Figure 3. Photographs: A, Stratabound ore body of Oued R'Them in Lower Dolostones; B, Vein network along Variscan fault of Amekssa in Upper Dolostones. Abbreviations: LD, Lower Dolostones; LS, Lower Sandstones; UD, Upper Dolostones; US, Upper Sandstones (see Fig. 2).

3.2 Texture and Mineralogy

In the field, the copper mineralization of the two morphological types is essentially composed of sulphides: chalcocite and less commonly bornite, chalcopyrite, and pyrite, with associated malachite as a major mineral, subordinate chrysocolla, and rare azurite.

In both types of ore body, copper mineralization is exclusively present in quartz-dolomite veins that form a stockwork (Fig. 4). These veins cut sedimentary fabrics, like bedding and slumps. Vein abundance changes depending on the site, being lower in stratabound ore bodies than in vein network ones along Variscan faults.

At a microscopic scale, the texture of mineralization is similar for the two morphologic types, i.e., veins parallel or cut bedding but are uniformly connected to form a stockwork.

4 Discussion

From the textural point of view, the copper mineralization is present in the form of stockworks with the same ore and gangue mineralogy and the same order of magnitude copper content, whatever the morphologic type. These stockworks intersect all sedimentary fabrics. In consequence, these different types of mineralization can be considered epigenetic independent of the ore body morphology. As a whole, the reported observations suggest that all of the studied copper mineralization hosted in Adoudounian dolostones may be cogenetic, i.e., related to a single mineralizing event, at the periphery of the Bou Azzer-El Graara inlier.

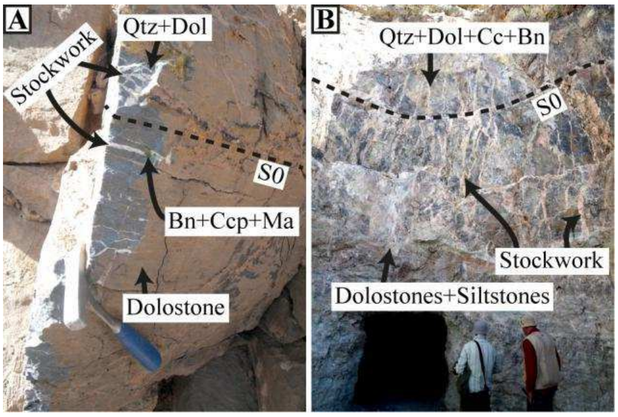

Figure 4. Photographs: A, Stockwork of the Oued R'Them stratabound mineralization in Lower Dolostones; B, Stockwork of Jbel N'Zourk mineralization along Variscan fault in Lower Dolostones. Abbreviations: Bn, bornite; Cc, chalcocite; Ccp, chalcopyrite; Dol, dolomite; Ma, malachite; Qtz, quartz.

Soulaimani and Burkhard (2008) described Variscan kink bands with a cleavage occurring in the vicinity of Panafrican structures in the basement of the Bou Azzer-El Graara inlier. These authors attributed the folds to reactivation of Panafrican structures during Variscan compression. In the Adoudounian cover, faults and folds are widely assigned to this Paleozoic compression, controlled by the movement of inherited basement structures (Leblanc 1972; Soulaimani 1997; Faïk et al. 2002; Soulaimani and Burkhard 2008). In the Bou Azzer-El Graara inlier, this deformation resulted in meter to decimeter folds, exhibiting NW-SE-trending axes with a subordinate NE-SW orientation (Soulaimani and Burkhard 2008). At Jbel Laassel, Amekssa, Assif N'Zaïd, and Jbel N'Zourk, the mineralization is spatially controlled by Variscan NW-SE faults and by NW-SE-oriented "folding bands." Under such conditions, the formation of the second morphological type of mineralization took place, at the earliest, coeval with Variscan deformation. In addition, (i) the Cu mineralizations are localized in the Lower and Upper Dolostones, (ii) Variscan deformation in the Adoudounian cover is controlled by the movement of structures inherited from the basement. It is thus possible to consider a fluid transfer process from the basement to the Adoudounian cover. The latter interpretation is consistent with the Sm/Nd age of gangue carbonates (308 ± 31 Ma) and the U/Pb age of branerite (310 ± 5 Ma), from a vein in the Bou Azzer Co-As district (Oberthür et al. 2009). The determination of the age of the stratabound Cu mineralization in the lower dolostones is more problematic, however. Currently, we can only point out that the textural and paragenetic similarities between the two morphological types strongly suggest a similar Variscan age.

To conclude, this study presents new data that contribute to a better understanding of the genesis of copper mineralization in the Adoudounian cover of the

Bou Azzer-El Graara district, and gives valuable information for mineral exploration in this region.

Acknowledgements

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