Mantle control for a giant Neoproterozoic epithermal silver deposit: Imiter (Morocco)

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Abstract. The giant epithermal Ag-Hg deposit of Imiter (Morocco) is investigated to test a possible transfer of chalcophile elements from the mantle to superficial crustal levels during Pan-African times. The accretion of the Anti-Atlas belt at the West African continent is characterized by a four stage succession of events, that is, extension, subduction, moderate collision and extension. The strongest metallogenic activity which is dominated by base- and precious metal deposit formation, occurs during the late extensional stage at the Precambrian-Cambrian transition. In the Imiter Ag-Hg deposit, the origin of metals and ligands, deduced from S, fluid inclusions, He, and Re/Os data obtained on sulphide phases and gangue minerals, had a dominantly mantle source.

Keywords. Epithermal deposit, mantle source, Neoproterozoic, Anti-Atlas, Morocco

1 The Imiter Ag-Hg deposit (Morocco)

The Imiter deposit is located on the northern side of the Saghro massif, which constitutes, with the other Proterozoic inliers (Ifni, Kerdous, Akka, Bou Azzer, Sirwa and Ougnat) the Anti-Atlas orogenic belt of Morocco (Fig. 1) bordering over more than 700 km from the Atlantic ocean to Algeria the northern side of the western African Craton WAC (Ennih and Liegeois 2001; Fekkak et al. 2001). Magmatic activity extends from the Palæoproterozoic to the Neoproterozoic and corresponds to two successive periods of crustal accretion during the Eburnean (Birimian) and Pan-African orogenies. The widespread early Palaeozoic cover makes the geology of Anti-Atlas a reference for the Precambrian/Cambrian boundary. The Imiter Ag-Hg deposit is precisely dated at 550 Ma (zircon ion-probe U-Pb dating from associated rhyolites; Levresse 2004) coeval with regional extensional tectonic activity characterizing the P/K transition. Imiter is a world-class silver deposit with currently identified resources of 10 000 metric tones (t) metal. It was formerly interpreted through a black-shale remobilization model (Leistel et Qadrouci 1991) but is now considered as a case of Neoproterozoic epithermal mineralization (Levresse 2001 ; Cheilletz et al. 2002). The Imiter Ag-Hg deposit is hosted by black shales and volcanics of Middle and Late Neoproterozoic age, respectively, and unconformably overlain by a Palaeozoic sedimentary succession. The silver mineralization is genetically related to felsic volcanic rocks (domes and dykes) dated at 550±3Ma (Levresse, 2001). This epithermal event postdates a discrete base metal episode associated with granodiorite intrusions dated at

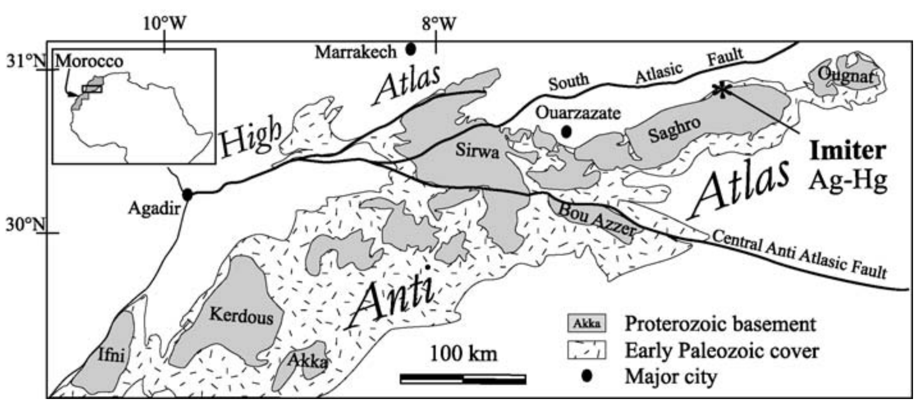

Figure 1: Major geological units of the Anti-Atlas belt in southern Morocco and position of the Imiter deposit

572±5Ma (ion-probe U–Pb dating on zircon; Levresse 2001). Wall-rock alteration associated with the epithermal silver event was minimized by the neutrality of the hydrothermal fluids. The silver mineralization is structurally controlled by the Imiter fault zone which experienced two successive tectonic regimes (Levresse 2001).

The earlier and predominant regime led to the development of normal faults trending N80°E; the second sinistral strike-slip regime led to reactivation of the normal faults, inducing an anastomosed geometry. The epithermal silver event is divided into two successive stages characterized by two different gangue minerals, quartz and dolomite, in extensional veins, hydraulic breccias and quartz-dolomite laminations. Impressive decakilogram Ag-Hg° plates occur in the extensive fault zones and brecciated areas. Mercury content in Ag-amalgam increases from the quartz- to dolomite stage and ranges from 10 to 30% and from 20 to 40% respectively. Mineralogical textures in both stages are complex (association, replacement). Sulphides are the earliest phases. These are, in decreasing abundance, pyrite–arsenopyrite, sphalerite, galena and chalcopyrite. Sulphides occur mostly as aggregates or as xenomorphic. They are strongly corroded by native silver, sulphides and sulphosalts. Silver sulphosalts everywhere precipitated in association with or as replacement of sulphides. Imiterite is most common as needles in dolomitic geodes, associated with cinnabar and argentite. Oxydation is scarce and locally limited to the upper levels of the deposit.

2 A mantle source for metals and ligands

The origin of the metals and ligands (sulphides) was deduced from S, fluid inclusions, He, and Re/Os data obtained on sulphide phases and gangue minerals. Sulphur isotope analyses show the existence of two distinct isotopic reservoirs, one in pyrite from the surrounding black shale country rocks ($\delta^{34}S_{CDT}$=-38‰) and the other in pyrites associated with a synchronous rhyolitic dome ($\delta^{34}S_{CDT}$=-7 to -2‰). The $\delta^{34}S_{CDT}$ values of the silver mineralization event range from -28 to -2‰ and are interpreted as resulting from preferential degassing of SO2 in ascending fluids, as well as mixing between the magmatic isotopic reservoir and a country rock reservoir. Helium isotope analyses of sulphides and gangue minerals yield similar results, with 3He/4He ratios ranging from 0.76 to 2.64Ra. These data and the absence of 20Ne in the analyzed fluid inclusions suggest a mantle origin for the fluids associated with the epithermal silver event. Osmium isotopic ratios have been measured for the first time in Ag° and Ag–sulphosalts. These data and those obtained on other sulphide phases directly associated with the Ag mineralization show measured 187Os/188Os ratios of 0.142-0.197 indicating a dominantly mantle source for the associated Os. Combined with helium isotopes, these data clearly indicate that the main source of the elements (ligands and metals) is from the mantle. The source of the fluids in the Imiter Ag deposit model, unlike in classic epithermal models (Sillitoe 1993; Hedenquist et al. 2000), is hypogene. The low salinity of the fluids (Tmi = 5.9 to 0.0°C) pleads in favor of silver transport as a bisulphur complex (AgHS). The low salinity of the fluids, as well as their gas content (CO_2=50-100%, H_2S=23-36%, N_2=24-48%, of the gas phase), is characteristic of precious metal deposits of the epithermal type (Hedenquist et al. 2000).

3 Geodynamic evolution of the Anti-Atlas during Pan-African times

Regional and local isotopic analysis in conjunction with detailed tectonic and magmatic studies, permit development of a coherent genetic model to Imiter Ag deposit in the Anti Atlas geodynamic evolution. Seven major magmatic episodes are now clearly identified in the Anti-Atlas (Saquaque et al. 1992; Ennih and Liégeois 2001; Hefferan et al. 2002; Thomas et al. 2002) corresponding to major changes in geochemical characteristics and tectonic environments. These magmatic events can be grouped into four major geodynamic-stages (Fig. 2):

1. Ocean opening restricted to Bou Azzer (Fekkak et al. 2001) and probably to the Sirwa massif (Thomas et al. 2002). The age of this phase is not well constrained. However it seems to be, at Bou Azzer, coeval or older than 788±8 Ma which corresponds to the age of thermal metamorphism linked to the emplacement of a gabbroic dyke assumed to belong to the ophiolitic pile (Leblanc and Lancelot 1980). In the Sirwa inlier it appears to be coeval or older than 743±14 Ma, the age recently obtained by Thomas et al. (2002) for a tonalite protolith of an orthogneiss of the ophiolitic sequence from the Bleida Group (Thomas et al. 2002). It is more certainly contemporaneous with plagiogranite emplacement dated at 762±Ma (Samson et al. 2003).
2. Subduction contemporaneous with calc-alkaline magmatism not precisely dated (Saquaque et al. 1992), the dip direction of the subduction, toward North or South, is still matter of debate.
3. a. Obduction (Bou Azzer) related to the so-called B1 tectonic event, low-grade metamorphism, partially molten gneisses and to calc-alkaline intrusives. In fact, the age of B1, recognized in the whole AA, is only constrained in the Central AA at 690-660 Ma. These ages were indirectly obtained either on the associated calc-alkaline metaluminous magmatism supposed to be synchronous with B1, dated at 661±23 Ma (U-Pb, Mifdal and Peucat, 1985), or on metamorphic rocks at the contact of the intrusions at 685±15 Ma and far from intrusions at 663±13 Ma (U-Pb, Thomas et al. 2002). No date was obtained

for B1 in the western and eastern AA and it is uncertain if B1 has the same age in the whole AA.

b. A minor and sporadic collision phase characterized by the emplacement of granodiorites, at 615±12 Ma (Ducrot and Lancelot, 1977), coeval with the "B2" tectonic event. This phase corresponds to the definitive ocean closure.

c. An extensive (595-570 Ma) magmatic episode characterized by intermediate to felsic (mainly high-K calc-alkaline) intrusions; this episode is related to base-metal ore deposits (Cu-Pb-Zn; Levresse, 2004) and constitutes a transition towards the main late Neoproterozoic distensive tectonic event.

4. a. A high-K calc-alkaline to alkaline magmatism ends the late (570-545Ma) Neoproterozoic time. It is linked to precious metal (Au-Ag) deposits. Preliminary Sr-Nd isotopic data for the 595-570 Ma plutonic event and 570-545 Ma volcanic episode from Saghro-Imiter indicate the same low $^{87}Sr/^{86}Sr$ (0.702 to 0.706) and $^{143}Nd/^{144}Nd$ (0.5116 to 0.5119) initial ratios, attesting to mixing between mantle and lower crust sources. This relatively primitive Sr signature is also attested by a low $^{187}Os/^{188}Os$ ratio obtained on pyrites from the rhyolitic domes, dykes and silver mineralization. The calculated Nd model ages on 595-570Ma old granites and 570-545 Ma old felsic volcanics rocks fall in a rather restricted range from 1561 to 1161 Ma suggesting an unique source of middle Proterozoic age for these two episodes of felsic magmatism. A similar middle Proterozoic source is also invoked for the felsic volcanism of the Sirwa window (Thomas et al. 2002).

b. Alkaline volcanism at 531±5Ma, which post-dates the late Neoproterozoic magmatism and heralds the starts of the Palæozoic times.

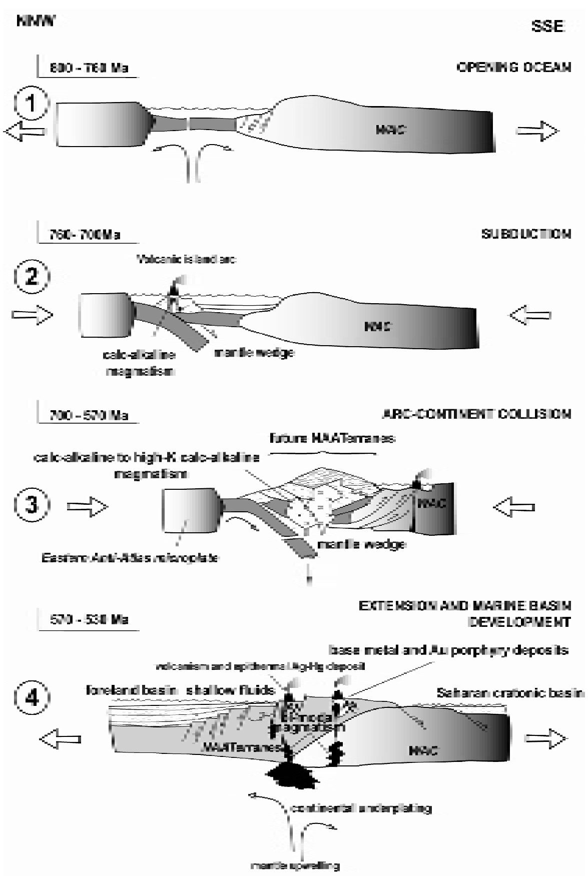

Figure 2: Geodynamical restoration of the Pan-African Anti-Atlas belt at the northern limit of the WAC

4 Conclusion: Imiter as a Precambrian analogue to modern epithermal deposits

An active margin is developed during the stage 3 of the evolution described above. The 570-530 Ma stage 4 characterizes the transition to a passive continental margin coupled with extensional tectonics and the development of marine basins to the north and the Saharan cratonic basin to the south. During this period, magmatism and metallogenic activity have a long common history (e.g. felsic volcanism and the Ag-Hg giant deposit of Imiter: Cheilletz, 2002; Levresse et al. 2004). They have mantel-like and *pro parte* infracrustal signatures. Thus, large volumes of juvenile materials, precious metals and chalcophile elements are added to the continental crust. The post-collisional features, related extensive high-K calc-alkaline magmatism, and marine basin development, together indicate high heat flow contribution due to continental underplating and/or mantle upwelling. This geodynamic control is particularly fruitful for the development of superficial hydrothermal mineralization as epithermal or base metal porphyry deposits (Cheilletz et al. 2002). Moreover, huge metal transfers suggest the existence of verticals drains able to mobilize the deepest parts of the lithosphere. This model which involves a large part of the lower crust and the mantle, is in opposition with the re-mobilization model previously elaborated to explain the origin of giant precious metal deposits, such as Imiter, from local superficial convective cells (Leistel and Qadrouci, 1991).

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