GEOLOGICA BELGICA (2007) 10/3-4: 148-151.

# THE STRATIFORM COPPER MINERALIZATION OF THE LUFUKWE ANTICLINE, LUFILIAN FORELAND, DEMOCRATIC REPUBLIC CONGO

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(5 figures)

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## Introduction

The Lufilian foreland is a triangular-shaped area located in the SE of the Democratic Republic of Congo (DRC) and to the north of the Lufilian arc (Fig. 1). The Lufilian arc contains the "Copperbelt", which extends from the DRC into Zambia and is one of the largest metallogenic districts of the world. The arc is characterized by Cu-Co mineralization and the Lufilian foreland is characterized by Cu-Ag mineralization. The host rocks of these mineralizations are the sediments of the Neoproterozoic Katanga Supergroup. While the Cu-Co deposits of the Lufilian arc have been the subject of different recent studies (e.g. Cailteux et al., 2005; Dewaele et al., 2006a), only a limited number of studies exist on the Cu-Ag deposits in the Lufilian foreland (e.g. Dewaele et al, 2006b). The geodynamic context and genesis of the foreland deposits is still enigmatic. The aim of this research is to study the processes controlling the stratiform copper mineralization at Lufukwe anticline and to propose a metallogenic model.

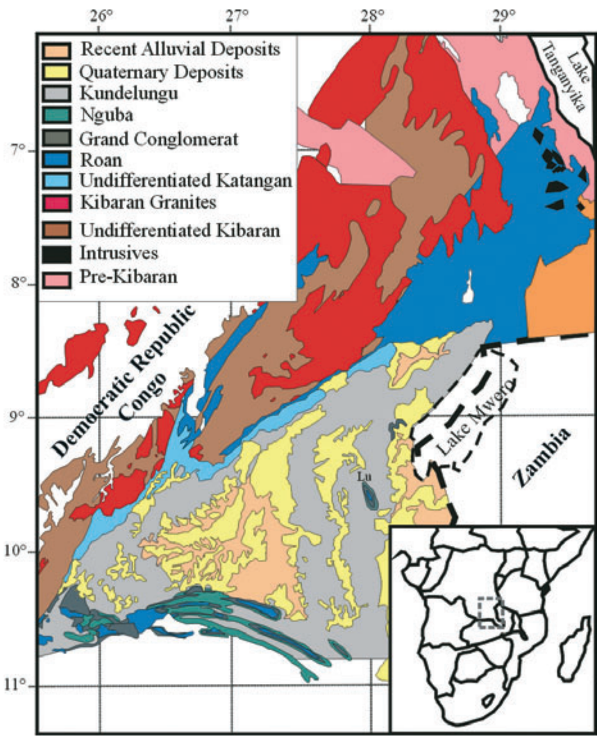


**Figure 1:** Simplified geological map for the Lufilian foreland and the northern part of the Lufilian arc, showing the location, trend and general geology of the Lufukwe anticline (Lu), (modified after Lepersonne, 1974).

## Geology and Mineralization

The Neoproterozoic Katanga Supergroup, which hosts the Cu-Ag mineralization in the foreland, is ~5 to 10 km thick and is commonly subdivided into three groups: Roan, Nguba and Kundelungu, based on the regional occurrence of two diamictites. The lower is called "Grand Conglomérat" at the base of the Nguba Group and the upper is called "Petit Conglomérat" at the base of the Kundelungu Goup (Cailteux et al., 2005). These Neoproterozoic rocks have been deformed during the Lufilian Orogeny, with its maximum peak at ~560-550 Ma (Porada & Berhorst, 2000). The Lufukwe anticline is a NNW elongated double plunged anticline situated ~200 km NE of Lubumbashi. The fold is composed mainly of Roan sediments in the core, overlain by the sediments of the Nguba Group and the lower two Subgroups of the Kundelungu Group (i.e. Kalule and Kiubo Subgroups). The sub-horizontal sediments of the Plateaux Subgroup (uppermost Kundelungu) unconformably and transgressively overly the folded sediments and dominate the northeastern, western and southwestern parts of the anticline. It is believed that these sub-horizontal sediments were deposited during the Early Paleozoic (mostly Cambrian) period rather than during the Neoproterozoic i.e. younger than 540 Ma (Kampunzu & Cailteux, 1999). The northern part of the anticline is characterized by disseminated copper-silver mineralization hosted in the Monwezi sandstone of the Nguba Goup and mainly concentrated in its lower 10 to 15 m. All surface bearings are oxidized. The main copper bearing minerals at surface are malachite and chrysocolla.

## Remote Sensing

Visual image interpretation of ASTER (Abrams, 2000) false color composites indicates the presence of: (1) ten NE to ENE orientated strike slip faults that cut and displace the folded Katanga rocks and the sub-horizontal sediments of the Plateaux Subgroup (uppermost Kundelungu). Therefore, the NE to ENE faults are postdating deposition of the entire Katanga Supergroup, (2) two WNW orientated strike slip faults that cut the folded rocks but do not cut the sediments of the Plateaux Subgroup i.e. predate the NE to ENE faults, (3) fractures oriented in several directions that are likely related to the folding or the later faulting, (4) tight folding in the northern part of the anticline, which caused intense fracturing in this part. Copper mineralization is observed only along the NE to ENE strike-slip faults and the copper grades observed in boreholes decrease away from these faults.

## Petrography and paragenesis

A total of 45 fresh core samples from the Monwezi sandstone were examined by transmitted and reflected light microscopy. The sandstone is mainly composed of quartz and feldspar (Fig. 2A). Some clays and calcites are common in the upper and middle parts of the sandstone and some lithic fragments are common in the lower parts. Few amount of pyrobitumen is present as tiny particles and isolated nodules. The sandstone underwent intense compaction followed by silica cementation (authigenic quartz overgrowths; Fig. 2A). After compaction and cementation, the feldspars underwent severe alteration (Fig. 2A) followed by an intense dissolution (Fig. 3), which resulted in a well-developed secondary porosity.

Copper mineralization, with no associated gangue mineral phase, is mainly concentrated in cavities, in microcracks that postdate the authigenic quartz and partially replace the detrital grains. Copper minerals often occur in typical rectangular feldspar forms (Fig. 2B & C) and their size is always dependant on the overall size of the host rock. Therefore, the copper mineralization postdates compaction, cementation and feldspar dissolution (Fig. 3). The copper minerals are primary chalcopyrite, which was the first to develop, followed and replaced by bornite and chalcocite (Fig. 2B), and supergene digenite, covellite and native copper replacing the primary minerals (Fig. 2B & C). Other late secondary minerals are cuprite, malachite, chrysocolla, azurite and hematite (Fig. 3). Non-copper sulfides predating the mineralization are pyrite and arsenopyrite (Fig. 3).

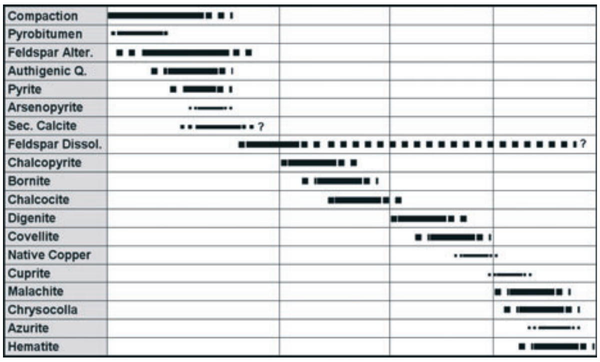


**Figure 3:** Paragenetic sequence of the mineralization at Lufukwe.

Point counting and grain size measurements performed on 20 samples indicate that the horizons with the highest copper content are those with a grain size larger than 170 µm, with more than 35% altered feldspars and with little or no fine-grained matrix. The Monwezi sandstone shows an upward fining and an increase in matrix content (clay and calcite).

## Fluid inclusion microthermometry

Microthermometric analysis in the detrital and authigenic quartz of the Monwezi sandstone was carried out on a calibrated Linkam THMSG 600 stage. Reproducibility

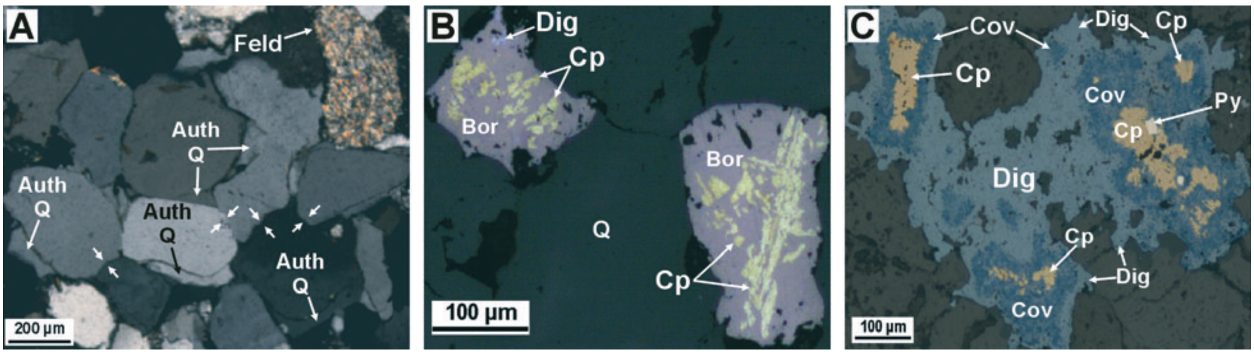


**Figure 2:** Microphotographs of the Monwezi sandstone. (A) concavo-convex contacts (see arrows), thick authigenic quartz overgrowths (Auth Q) and highly altered feldspars (Feld), (cross-polarized light). (B) bornite (Bor) in typical rectangular feldspar forms replacing chalcopyrite (Cp) and is replaced by digenite (Dig), (reflected light). (C) chalcopyrite replacing tiny pyrite (Py) and both minerals are replaced by digenite (Dig) and covellite (Cov), (reflected light).

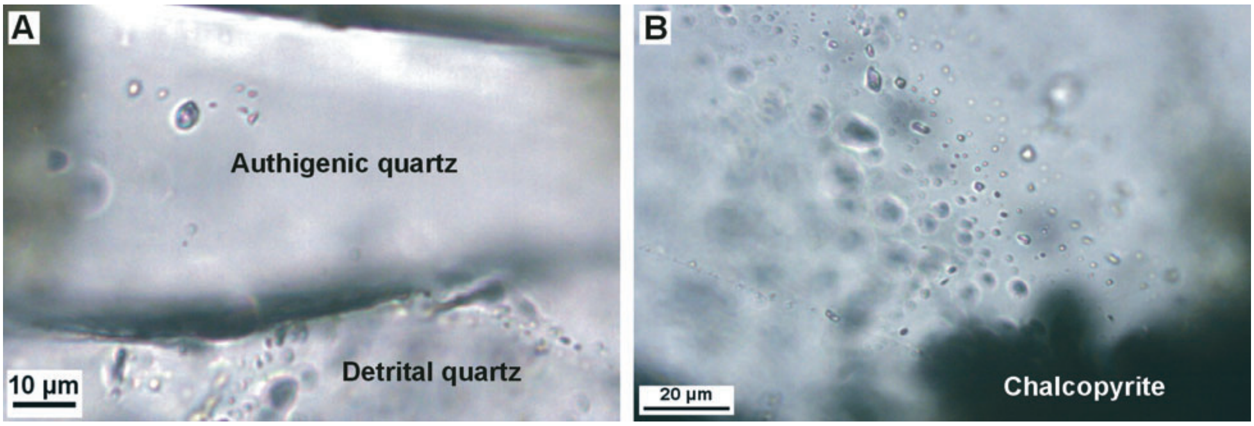


**Figure 4:** Fluid inclusions microphotographs. (A) small primary fluid inclusions in authigenic quartz. (B) secondary fluid inclusions trails radiating from chalcopyrite.

was within 0.2 °C for the first (Tfm) and final ice melting ($Tm_{ice}$) temperatures and ~3 °C for the homogenization temperature (Th). Small (~5 µm) primary two-phase (L+V) aqueous inclusions are present in the authigenic quartz (Fig. 4A). They have a Tfm lower than -40 °C, which likely indicates an $H_2O$-NaCl-$CaCl_2$ composition, a Th between 80 and 130 °C (n =14) and $Tm_{ice}$ between -24.8 and -16.4 °C (n =10). The $Tm_{ice}$ values correspond to a salinity between 18.8 and 23.4 eq. wt.% $CaCl_2$.

Secondary fluid inclusion trails were observed cutting the detrital and authigenic quartz and mainly developed near to and radiating from copper sulfide minerals (Fig. 4B). Therefore, they likely developed from micro-crack healing during mineralization (i.e. represent the mineralizing fluid; cf. Essarraj et al., 2005). The two-phase (L+V) aqueous fluid inclusions of these trails have Tfm values of ~ -20 °C, which is indicative for a $H_2O$-NaCl composition, a Th between 120 to 180 °C (n =74) and $Tm_{ice}$ between -4.9 and -1.1 °C (n =38). These $Tm_{ice}$ values correspond to a salinity between 1.9 and 7.7 eq. wt.% NaCl. The Th versus salinity plot for these secondary fluid inclusion trails indicates the presence of a general trend of increasing Th with increasing salinity (Fig. 5). This trend indicates the mixing of the mineralizing fluid

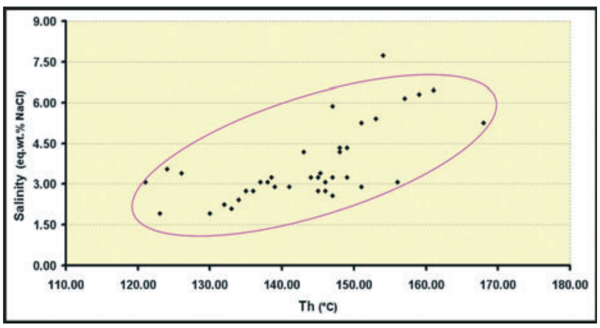


**Figure 5:** Th versus salinity plot of the secondary fluid inclusions occurring in trails.

with a colder lower salinity fluid (e.g. Valenza et al., 2000). As a result of this mixing the highest measured Th (180 °C; Fig. 5) and salinity (7.7 eq. wt.% NaCl; Fig. 5) of these secondary fluid inclusion trails are taken as the minimum temperature and salinity of the initial mineralizing fluid.

## Discussion and conclusion

The stratiform copper mineralization in the Lufukwe anticline is controlled by three main factors. The first is a structural factor represented by folding, faulting and fracturing. The presence of copper mineralization along the NE to ENE strike slip faults and the high copper grades in the boreholes close to them indicates that the mineralization is related to these faults and they likely have acted as fluid pathways. The second is a diagenetic factor represented by intense feldspar dissolution, which greatly enhanced the porosity of the host rock. The third is a lithological factor represented by the variability in composition and grain size of the Monwezi sandstone. The good porosity and permeability of the lower 10 to 15 meters of the host rock caused the preferential lateral migration of the mineralizing fluids, which likely circulated upwards along the faults. The pyrobitumen and its former hydrocarbons could have acted as catalyst for the feldspar dissolution (Blake & Walter, 1999), as a source of sulfur or as a reductant for the copper or non copper sulfides (Hitzman et al., 2005).

Since the mineralization is related to faults that postdate the entire Katanga sequence (i.e. the NE to ENE strike-slip faults), the age of 573 ± 5 Ma for the end of deposition of the Kundelungu sediments (Master et al., 2005) can be considered as the maximum age for the mineralization. A post-orogenic fluid-mixing model can be proposed, in which the mineralization is related to the mixing of a mineralizing fluid with a temperature ≥ 180 °C and a salinity ≥ 7.7 eq. wt.% NaCl, migrated upward along the NE to ENE orientated faults, with a colder lower salinity fluid, present in the Monwezi sandstone. Primary copper precipitation was possibly induced by reduction from preexisting hydrocarbons and sulfides and/or by the drop in the fluid salinity and temperature.

Based on the results of this research, areas with NE to ENE structural lineaments are expected to be good sites for future copper exploration in the Lufilian foreland, especially when these structural lineaments cut previously folded or thrust-faulted Katanga rocks.

## Acknowledgments

The research of H. El Desouky was financed by KU Leuven. Thin, polished and doubly polished sections were carefully prepared by H. Nijs. Anvil Mining Congo is thanked for the support and access to samples.

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