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METALLOGENESIS OF THE DIKULUSHI Cu-Ag ORE DEPOSIT IN THE LUFILIAN FORELAND (DEMOCRATIC REPUBLIC OF THE CONGO)

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(3 figures)

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Introduction

The Dikulushi Cu-Ag deposit is located west of Lake Mweru in the northeastern part of the Lufilian foreland, at ~ 300 km NE of Lubumbashi (Fig. 1). The Lufilian foreland is situated north of the Lufilian belt. The Lufilian belt contains part of the largest copper province known on earth (the "Central African Copperbelt") consisting of pre- to syn-orogenic stratiform Cu-Co deposits and syn- to post-orogenic Zn-Cu-Ni-Pb-Ge-U deposits. Combined production and reserves total approximately 190Mt of Cu (Hitzman et al., 2005) of which 102Mt are contained in the Congelese part of the Lufilian belt. Different base metal occurrences have been identified in the Lufilian foreland, but their geodynamic context and metallogenesis remains enigmatic.

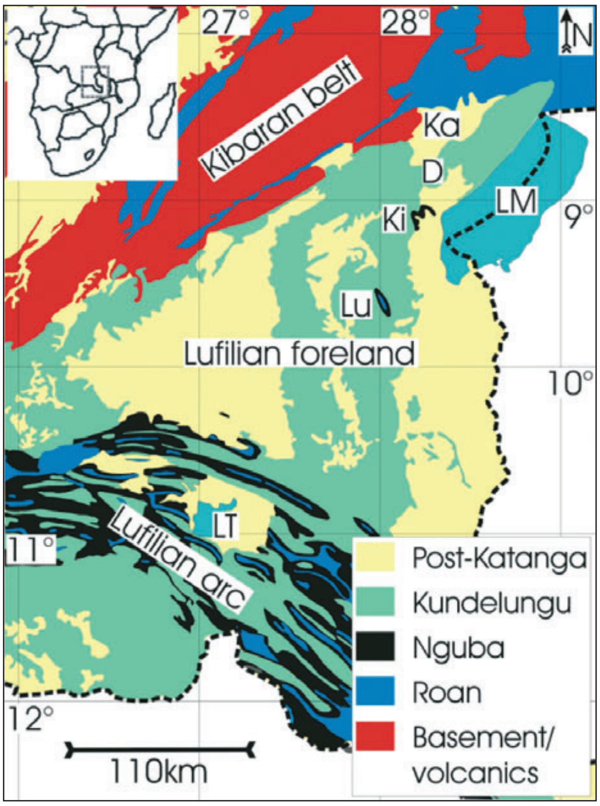

Figure 1: Geological map of the southern part of Katanga (Ka: Kabangu anticline; D: Dikulushi anticline; Ki: Kiaka anticline; Lu: Lufukwe anticline; LM: Lake Mweru; LT: Lake Tshangalele) (modified after Lepersonne, 1974).

The Cu-Ag deposit at Dikulushi has been mined since 2002, with total production and reserves estimated at 1.94Mt at an average grade of 8.5% Cu and 226g/t Ag (Tassel, 2003). Exploitation currently reached a depth of 150m, with a mine diameter of 480m. This resulted in an excellent 3D exposure of the mineralization, which allows us to investigate the relation between deformation and mineralization in space and time.

Geologic setting

The Dikulushi mine is located in the Neoproterozoic Lufilian foreland, which forms a triangular area that is bordered by the Mesoproterozoic Kibaran belt in the west and by the Paleoproterozoic Bangweulu block in the east. The Lufilian foreland consists of rocks belonging to the Katanga Supergroup. The ~ 7km thick Katanga Supergroup can be subdivided in the Roan, Nguba and Kundelungu Groups, based on the regional occurrence of two diamictites (Cailteux et al., 2005).

The Kundelungu rocks were deformed during the Lufilian orogeny, which is characterized by a NE-transport direction. The deformation caused a NW-oriented folding in the Lufilian foreland. The NW-oriented anticlinal domes were unconformably overlain by a subtabular mollasse that contains arkoses, sandstones, sandy shales and conglomerate beds (François, 1974). This mollasse was deposited during the Lufilian orogeny, which is confirmed by ^{40}Ar/^{39}Ar age data on detrital muscovites that point to a maximum sedimentation age of 573±5 Ma (Master et al., 2005). After the Lufilian orogeny, the stress conditions changed to extension causing the formation of the NE-oriented Mweru-Tschangalele riftzone.

Structural architecture

Four different stratigraphic units can be identified in the Dikulushi mine. (1) The Kiaka unit occurs in the far western corner of the mine (blue in Fig. 2) and consists of a brecciated dolomite with a red matrix. (2) The Dikulushi unit occupies the eastern side (brown in Fig. 2) and consists of massive red sandstone layers with some thin intercalated red shale layers and conglomeratic beds. Wave ripples are observed in the massive sandstone layers. The conglomeratic beds filled channels. (3) The Plastecine shales unit borders the Kiaka unit to the east (pink in Fig. 2) and consists of a red-brown ductile deformed shale. The shale surfaces are often polished and a limited green alteration occurs in spots and bands. In the shale, fragments of mica-rich sandstone, silicified carbonate and stromatolitic chert may occur. (4) The Mixed unit is observed at the contact between the Plastecine shales unit and the Dikulushi unit (yellow in Fig. 2). It is characterised by a mixture of lithologically distinct rocks that are in faulted contact. These rocks consist of red mica-rich sandstone, grey-green shale, ductile deformed red-brown shale with green alteration spots, grey brecciated carbonate and a breccia consisting of greenish basalt fragments in a clayey matrix.

The bedding has a constant orientation (~098/48) in the mine. Only in the central faulted zone, the bedding becomes highly irregular, probably as a consequence of drag folding. The central faulted zone is limited by the Main fault corridor (MF)/Northern fault (NF) to the North and by the Southern fault (SF) to the South (Fig. 2).

Layer-parallel faulting in the mine is mostly limited to the contact zone between the Mixed unit and the Dikulushi unit and to the central faulted zone (Fig. 2). The layer-parallel faults in the western part of the mine are associated with kink folds that have a NNW-oriented fold axis. The layer-parallel faults in the central faulted zone are probably associated with drag folds. Three groups of layer-discordant faults can be discerned, based on their fault orientation. The first group of mainly subvertical NNW-oriented faults is dominantly observed in the western part of the mine and forms the contacts between the Plastecine shales unit and the Kiaka/Mixed units (Fig. 2). A reverse dip-slip movement along these faults injected the Plastecine shales unit into the surrounding units. The second group of steeply south dipping (~70°) EW-oriented faults builds up the Main fault corridor, which forms the northern contact between the Mixed unit and the Dikulushi unit (MF in Fig. 2). Several of these faults underwent a reverse oblique-slip movement and transported the Mixed unit over the Dikulushi unit. Steeply south dipping (~70°) NE-oriented layer-discordant faults form the third group and built up a NE-oriented fault corridor. This corridor is part of the central faulted zone. The Northern and Southern faults limit the corridor to the North and to the South respectively (Fig. 2). Faults from the NE-oriented fault corridor underwent a normal or reverse, oblique- to strike-slip dominated movement.

Alteration of the Dikulushi unit in the footwall and hanging wall of the NE-oriented fault corridor is mainly limited to layer parallel alteration of the more permeable sandstone beds (Fig. 2). Alteration becomes more extensive along the contact between the Dikulushi unit and the Mixed unit in the western part of the mine. Within the central faulted zone, the entire Dikulushi unit is grey-green altered. Alteration in the other units is more limited and does not follow a distinct pattern.

The main ore body at Dikulushi has an overall ENE-orientation and dips 70° to the SE. The ore body remains open to a depth of 400m. The first mineralization precipitated in a complex set of EW- and NE-oriented faults and is observed in the western part of the mine. The second, massive orthorhombic chalcocite mineralization, precipitated along several NE-oriented faults that crosscut the eastern section. At depth, this massive chalcocite mineralisation surrounds remnant blebs of bornite, which may indicate remobilization of the first mineralization phase along the NE-oriented faults. The mineralizing phases were followed by an intense secondary alteration. During secondary alteration, nearly all rocks were stained with Fe-oxides and supergene enrichment caused the formation of covellite, malachite, azurite and chrysocolla.

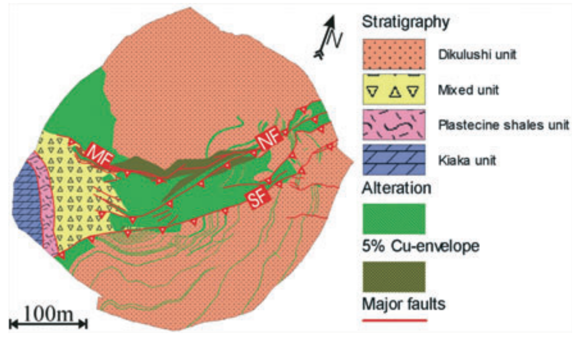

Figure 2: Geological map of the mine showing the alteration pattern and the 5% Cu-envelope (NF: Northern fault; SF: Southern fault; MF: Main fault corridor).

Petrography

The sulphides at Dikulushi precipitated during two distinct mineralizing phases (cfr Dewaele et al. 2006). The first mineralizing phase started with the precipitation of arsenopyrite, pyrite and semi-transparent sphalerite, chalcopyrite, associated with undulose quartz and very coarse-grained saddle dolomite (Fig. 3). The first mineralizing phase ended with the precipitation of tennantite, galena, sphalerite, chalcopyrite, bornite and chalcocite (Fig. 3), associated with quartz, dolomite and calcite as gangue minerals (Fig. 3). The calcite contains twins that formed due to deformation at a higher temperature (Burkhard, 1993).

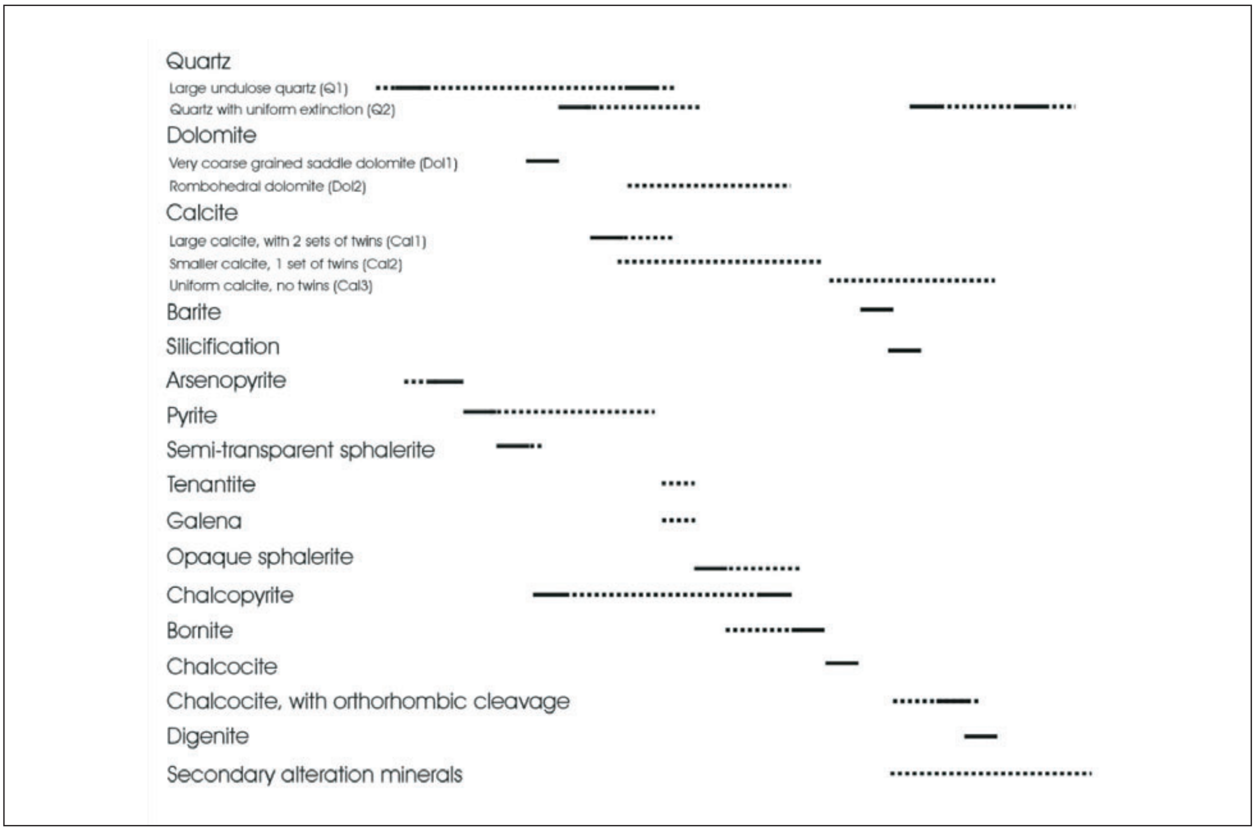

Figure 3: Paragenetic sequence for the two sulphide mineralizations and their associated gangue minerals.

The second mineralizing phase is characterised by massive orthorhombic chalcocite, associated with barite, uniform calcite and quartz as gangue minerals (Fig. 3). This chalcocite must have precipitated at temperatures below 103°C to acquire its orthorhombic shape (Ramdohr, 1969). The paragenetic sequence ends with a phase of strong secondary alteration, with the formation of Fe-oxides, malachite, azurite and chrysocolla.

Microthermometry

The microthermometric study focussed on minerals in both mineralizing phases (cfr Dewaele et al. 2006). Fluid inclusions in the very coarse-grained saddle dolomite and the semi-transparent sphalerite have first melting temperatures (Tfm) that vary between -52°C and -40°C. These temperatures are indicative for the presence of divalent cations (likely $CaCl_2$), in addition to NaCl (H_2O-$CaCl_2$-NaCl composition) (Goldstein and Reynolds, 1994). Final ice melting temperatures (Tm_{ice}) are between -26.3°C and -18.4°C, indicating a salinity between 20.7 and 24.4 eq.wt% $CaCl_2$. Total homogenization temperatures (Th) range between 125°C and 185°C.

Fluid inclusions in the barite, the calcite without twins and the quartz from the second mineralizing phase show Tfm values around -22.1°C. Thus the second mineralization likely precipitated from a NaCl dominated fluid with KCl as possible extra component. The Tm_{ice} values are between -16.9°C to -1.7°C, pointing to a salinity between 2.94 and 12.53 eq. wt% NaCl. The Th temperatures vary around 70°C.

Structural mineralization model

The Plastecine shales unit was injected between two NNW-oriented faults in the Kiaka unit near the contact with the Dikulushi unit. This injection occurred as a consequence of compression related to the onset of the Lufilian orogeny and brecciated the overlying units. The contact zone between the Kiaka and Dikulushi units was deformed into a mixture of lithologically distinct rocks (~the Mixed unit), derived from the Dikulushi, Kiaka and Plastecine shales units. The upward injection also deformed the overlying Dikulushi unit in a series of kink folds with associated layer-parallel faulting. Subsequently the Mixed unit was thrust along the Main EW-oriented reverse fault corridor to the North, over the Dikulushi unit. This fault corridor is limited to the East by the NE-oriented fault corridor. The first mineralization precipitated in this complex set of crosscutting EW- and NE-oriented faults, from a high temperature high salinity fluid with a H_2O-$CaCl_2$-NaCl composition. The first mineralizing phase occurred during deformation, based on the occurrence of undulose quartz, calcite with twins, etc. The sequence of sulphides from the first mineralizing phase is characterized by a transition from Fe-rich sulphides to Cu-rich sulphides.

After the first mineralizing phase, the stress conditions changed, leaving only the NE-oriented faults active. The second mineralizing phase identified at Dikulushi formed along these NE-oriented faults and consists of an orthorhombic chalcocite. This chalcocite precipitated from a medium saline NaCl fluid, with homogenization temperatures around 70°C. This mineralizing fluid possibly remobilized sulphides from the first mineralization, based on the remnant bornite blebs surrounded by orthorhombic chalcocite at depth. A barite gangue occurs associated with the orthorhombic chalcocite, which is indicative for the primarily oxidizing conditions during the second mineralizing phase.

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References

BURKHARD, M., 1993. Calcite twins, their geometry, appearance and significance as stress-strain markers and indicators of tectonic regime: a review. *Journal of Structural Geology*, 15: 351-368.

CAILTEUX, J.L.H., KAMPUNZU, A.B.H. & BATUMIKE, M.J., 2005. Lithostratigraphic position and petrographic characteristics of R.A.T. ("Roches Argilo-Talqueses") Subgroup, Neoproterozoic Katangan Belt (Congo). *Journal of African Earth Sciences*, 42: 82-94.

DEWAELE, S., MUCHEZ, P., HEIJLEN, W., BOUTWOOD, A., LEMMON, T. & TYLER, R., 2006. Reconstruction of the hydrothermal history of the Cu-Ag vein-type mineralisation at Dikulushi, Kundelungu foreland, Katanga, D.R. Congo. *Journal of Geochemical Exploration*, 89: 376-379.

GOLDSTEIN, R.H. & REYNOLDS, T.J., 1994. Systematics of fluid inclusions in diagenetic minerals. Tulsa, SEPM, *Society of Sedimentary Geology*, 199 p.

HITZMAN, M.W., KIRKHAM, R., BROUGHTON, D., THORSON, J. & SELLEY, D., 2005. The sediment-hosted stratiform copper ore system. *Economic Geology*, 100: 609-642.

LEPERSONNE, J., 1974. Carte Géologique du Zaïre au 1:2.000.000 et notice explicative (Résumé et samenvatting). *Département de Mines, Direction de Geologie, République du Zaïre*. *In* anonymous, 1975. Rapport annuels. *Royal museum for Central Africa*, Tervuren, Belgium.

MASTER, S., RAINAUD, C., ARMSTRONG, R.A., PHILLIPS, D. & ROBB, L.J., 2005. Provenance ages of the Neoproterozoic Katanga Supergroup (Central African Copperbelt), with implications for basin evolution. *Journal of African Earth Sciences*, 42: 41-60.

RAMDOHR, P., 1969. The ore minerals and their intergrowths. *Pergamon Press*, Oxford, 1207 p.

TASSEL, A., 2003. Dikulushi-setting a new benchmark. *African Mining*, 8: 24-35.