Sedimentology of the Shangoluwe breccias and timing of the Cu mineralisation (Katanga Supergroup, D. R. of Congo)

Pascal Mambwe a, b, c, *, Louis Kipata a, Mumba Chabu a, Philippe Muchez c, Toto Lubala a, Michel Jébrak d, Damien Delvaux e

a Department of Geology, University of Lubumbashi, B.P.1825, Lubumbashi, Democratic Republic of the Congo
b Department of Geology Exploration, Tenke Fungurume Mining S.A, Route de l’Aéroport, Bâtiment TFM, Commune annexe, Lubumbashi, Democratic Republic of the Congo
c KU Leuven, Geodynamics and Geoﬂuids Research Group, Department of Earth and Environmental Sciences, Celestijnenlaan 200E, B-3001, Leuven, Belgium
d Department of Earth Science and Atmosphere, University of Montreal, H3C3P8, Canada
e Department of Geology and Mineralogy, Royal Museum of Central Africa (RMCA), Leuvensesteenweg 13, 3080, Tervuren, Belgium

**A R T I C L E  I N F O**

Article history:
Received 7 July 2016
Received in revised form 18 April 2017
Accepted 19 April 2017
Available online 20 April 2017

Keywords:
Sedimentary breccias
Luflian arc
Katanga Supergroup
Copper mineralisation
Shangoluwe

**A B S T R A C T**

The origin of breccias in the Neoproterozoic Katanga Supergroup in D.R of Congo is still a matter of debate. At the Shangoluwe Cu deposit located in the Kambove mining district (central part of the Luflian arc), the sedimentary breccias bearing Cu mineralisation have been investigated for lithological and sedimentological study, quantitative analysis of the breccias fragments and fault kinematic analysis in order to understand the origin of the breccias, their lithostratigraphic position and the timing of mineralisation. At Shangoluwe, three sedimentary breccias sequentially deposited within the Kundelungu rocks can be identiﬁed on the basis of the nature of the matrix and fragments; from bottom to the top, the Ferruginous Breccias, the Dolomitic Breccias and the Siliceous Breccias. These breccias were deposited as lenses. The presence of debris and grain ﬂows, a ﬁnely laminated matrix, pseudo-stratiﬁcation, normal and reverse graded-bedding, and the presence of interbedded siltstone, sandy shale, dolomitic shale, shale and dolomite, are considered as evidence of a sedimentary origin of the breccias. The log normal distribution of the fragments indicates that gravity ﬂow was the main deposition mechanism.

The Ferruginous and Dolomitic Breccias are regarded as contemporaneous with the Kundelungu Group. They were deposited as lenses interbedded in the Kanianga and Mongwe formations, both affected by the Luflian orogeny (D1 – Kolwezian and D2 – Monwezian phases). The Siliceous Breccias are post-orogenic as shown by the presence of an erosional and angular unconformity respectively on the Dolomitic Breccias and the Kundelungu formations. Therefore, the Siliceous Breccias are attributed to the Lower Palaeozoic Biano Subgroup and the lithostratigraphy of the Biano Subgroup is proposed for revision accordingly. Copper mineralisation post-dates the deposition of the breccias, the dissolution of dolomite fragments and in-situ fragmentation. This mineralisation occurred during late- to post-orogenic extension of the Luflian orogeny, and was remobilised during the Cenozoic.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

The Katanga Supergroup is formed of sedimentary and meta-sedimentary rocks that crop out within the Katanga Copperbelt that extends from the SE Democratic Republic of the Congo to the northwestern and western part of Zambia. The Katanga Supergroup hosts world-class Cu-Co stratabound deposits (François, 1973, 1974; Cailteux, 1994; Cailteux and Misi, 2007; El Desouky et al., 2009; Hitzman et al., 2010; Muchez et al., 2015). The Katanga Copperbelt shows two contrasting structural domains, the folded Katangan or Luflian arc and the tabular Katangan or Katangan foreland to the north of the belt (Fig. 1). The folded Katangan contains most of the important Cu-Co deposits hosted in the Roan group and Cu-Pb-Zn mineralisation in the Nguba Group (François, 1973; Chabu, 1995; Kamona et al., 1999; Kampunzu et al., 2009; Hitzman et al., 2010;
Fig. 1. Geological and tectonic framework of the Luflian arc, Kundelungu foreland and Kibaran belt and surrounding regions with structural subdivision of the Luflian arc (after Kampunzu and Cailteux, 1999).
Within the tabular Katangan, the mineralisation includes some vein-type Cu-Ag hosted in the Kundelungu Group and stratiform Cu hosted in both Nguba and Kundelungu groups (El Desouky et al., 2007, 2008a, b; Haest et al., 2007).

Several types of breccias and conglomerates were described in both the Congolese side of the Katangan belt (Congo Copperbelt) and Zambian side (Zambia Copperbelt) but their origin remains a matter of debate (François, 1973, 2006; Binda and Mulgrew, 1974; Grujenschi, 1978; Okitaudji, 1992; Binda and Porada, 1995; Cailteux and Kampunzu, 1995; Jackson et al., 2003; Wendorff, 2000a, b; 2005a, b, 2011). In the Congo Copperbelt, Cu-Pb-Zn mineralised breccias at Kipushi were interpreted as evaporitic collapse breccias (De Magnée and François, 1988; Chabu and Boulegue, 1992). The megabreccia with fragments of the Roan, Nguba and Kundelungu groups are interpreted as part of thick tectonic sheets which formed during the main phase of the Luflian orogeny (Okitaudji, 1992; Cailteux and Kampunzu, 1995; Jackson et al., 2003). The Mines Subgroup megabreccia consists of hundreds of meters to kilometer long fragments and they contain the main Cu-Co mineralisation (Cailteux, 1994, François, 2006; Schuh et al., 2012). Grujenschi (1978) interpreted these megabreccias as wildflyschs in the Katanga sedimentary basin and Wendorff (2000a, b, 2003, 2005a, 2011) considered the megabreccias as olistostrome deposits in the Fungurume foreland basin and therefore also as younger than the Kundelungu Group.

At Shangoluwe, the precipitation of copper minerals in the breccias was mentioned by Cailteux and Dessart (1984) and François (2006), but without any details on the relationship with the host rock, depositional setting and tectonic deformation. Copper mineralisation in the Kundelungu Group surrounding the Shangoluwe breccias has not been reported by previous studies. The Shangoluwe breccias were not considered in recent studies that focussed on descriptive models, grade-tonnage relationship, assessment of sediment-hosted copper deposits and regional stratigraphic correlations of the Neoproterozoic Katanga Supergroup in the Congo Copperbelt (Hitzman et al., 2012; Taylor et al., 2013; Zientek et al., 2014).

In this work, we investigate the structural, lithological and sedimentological aspects of the Shangoluwe breccias hosted within the Kundelungu rocks. The aims of this paper are to understand the origin of the Shangoluwe breccias and their lithostratigraphic position. The Cu mineralisation hosted in these breccias and surrounding Kundelungu rocks is discussed in terms of the timing of precipitation. The paper also discusses the relationship between the formation of the breccias and the brittle tectonic evolution within the Congo Copperbelt.

2. Geological setting

2.1. Lithostratigraphy of the Katanga Supergroup

The Neoproterozoic Katanga Supergroup consists of a ~530 m-thick sequence of sedimentary and metasedimentary rocks. It was deposited in an extensional setting during the Neoproterozoic and subsequently deformed during the Luflian orogeny as a consequence of the interaction between the Congo and the Kalahari cratons (Porada and Berhorst, 2000) during the amalgamation of the Pan-African Gondwana supercontinent (Grantham et al., 2003; De Waele et al., 2008). This supergroup is divided into three groups, based on the occurrence of two regional diamictites: Roan, Nguba and Kundelungu groups from bottom to the top (François, 1973, 2006; Cailteux et al., 1994, 2007; Batumike et al., 2007). The Roan and Nguba groups are separated by the Grand Conglomérat diamictite or Mwale Formation (Ng 1.1) at the base of the Nguba Group. The Petit Conglomérat diamictite or Kyandamu Formation (Ku 1.1) at the base of the Kundelungu Group forms the boundary between the Nguba and Kundelungu groups (Table 1).

The Roan Group is stratigraphically well-known because it contains important Cu-Co mineralisation. It is subdivided into four subgroups: RAT (R1), Mines (R2), Dipeta (R3) and Mwashya (R4) subgroups (Cailteux et al., 2005a, 2007). The Mines Subgroup consists of alternating siltstone, carbonaceous dolomitic shale and dolomite. It is subdivided into three formations: Kamoto (R 2.1), Dolomitic shale (R 2.2) and Kambove (R 2.3). Three Cu-Co orebodies are known within the Mines Subgroup; the Lower orebody hosted in the Dolomitic Shale Formation and a third orebody (not always present) at the lower part of the Kambove Formation (Kampunzu et al., 2009).

The Shangoluwe deposit is one of the Cu-(Pb-Zn) deposits hosted in the Kundelungu Group. It is located along the NW-SE regional M’sesa fault, which crosses the Kambove synform (Fig. 2). The mineralisation at Shangoluwe is stratabound and hosted in breccias and surrounding Kundelungu Group rocks. The deposit is structurally divided into three zones (North, Central and South) separated by transverse sinistral faults (François, 2006; Kipata, 2013). The deposit was discovered in 1931 by the ‘Union Minière du Haut-Katanga’. A total of 1,030,627 tons of ore with an average grade of 9.63% Cu were mined between 1933 and 1943 by open pit and underground operations (Cailteux and Dessart, 1984).

2.2. Luflian and post-Luflian geodynamics

The Luflian orogeny operated within three major tectonic phases (François, 1974, 2006; Kampunzu and Cailteux, 1999). As a result of this orogeny, the Katangan belt presents two contrasting tectonic domains, the folded Katangan belt referred to as Luflian arc due to its arcuate shape and the undeformed Katangan belt or Katangan foreland to the north of the belt. The first phase (D1) or Kolwezian phase is characterised by northward verging folds and thrust sheets. It is coeval with the main deformation phase in the Zambezi belt. The second phase (D2) or Monwezian phase generated large left-lateral strike-slip faults. The last phase (D3) or Shilatembo phase is marked by structures transverse to the trend of Luflian arc.

On the basis of a regional fault-kinematic and palaeostress investigation in the Congo Copperbelt, Kipata et al. (2013) defined eight brittle tectonic stages. These brittle events range from the onset of the brittle realm during the Luflian orogeny paroxysm (~530 Ma) to post-orogenic periods. The first five brittle stages (1–5) are related to the Luflian orogeny, from its paroxysm to the final post-orogenic extension. The stages 1 and 2 correspond to the Kolwezian phase (D1) of Kampunzu and Cailteux (1999) and the Stage 3 is correlative to the Monwezian phase (D2) of the same authors. The sixth stage corresponds to the Shilatembo phase (D3) of Kampunzu and Cailteux (1999) and is considered by Kipata et al. (2013) as related to post-Luflian (Early Mesozoic?) transpressional inversion. The two last stages (7th and 8th) are related to late Cenozoic rifting of the East African Rift System.

3. Petrography and ore mineralogy

In the Shangoluwe deposit, the breccias are dominantly constituted by fragments belonging to the Roan and Kundelungu groups. The Kanianga Formation (Ku 1.3) is recognised in the Shangoluwe North and Central, whereas the Mongwe Formation (Ku 2.1) crop out in the Shangoluwe South (François, 2006; Kipata, 2013).
3.1. Kanianga Formation (Ku 1.3)

The Kanianga Formation (Ku 1.3) is made up of alternating green laminated dolomitic shales, grey shales, grey dolomitic sandy shales, blackish grey massive dolomite and stratified dark grey dolomite (Fig. 3A and B). All of these lithologies are weathered into a brownish argillaceous rock with sericite, chlorite and black manganese oxides. On thin sections, muscovite is mainly associated with dolomite crystals, chlorite, authigenic quartz and detrital coarse quartz grains in the dolomitic sandy shales. Veins of pyrite-chalcopyrite-chalcocite-dolomite-quartz are usually observed.

The stratified grey dolomite is characterised by a parallel bedding and dissemination of fine- to coarse-grained euhedral pyrite. Under the microscope, this rock is formed by rhombohedral dolomite crystals with occasional muscovite flakes. Dominant copper sulphides include bornite, chalcopyrite and chalcolite, locally oxidised into malachite and chrysocolla, but azurite is found occasionally in pores and fractures.

3.2. Mongwe Formation (Ku 2.1)

The Mongwe Formation (Ku 2.1) consists of greenish grey argillaceous dolomitic sandy shales within laminated grey shale layers. Under the microscope, the argillaceous dolomitic sandy shale is formed of fine- to coarse-grained quartz crystals, dolomite, muscovite, biotite and chlorite. The main sulphides are pyrite, chalcopyrite and bornite, but occasionally supregenic minerals such as malachite and chrysocolla occur in association with the sulphides. They are observed in pores and fractures together with authigenic quartz, hematite and goethite.

3.3. Breccias

According to Morrow (1982) and Jebrak (1997), breccias can be classified based on the nature of the matrix, lithology, structure, texture, fragment maturity, deformation and mechanism of formation. At Shangoluwe, three types of breccias were distinguished based on the nature of the matrix and lithology: Ferruginous, Dolomitic and Siliceous Breccias.

3.3.1. Ferruginous Breccias

These Ferruginous Breccias (Fig. 3D) are made up of millimetric to centimetric (up to 50 cm) fragments of massive and laminated siliceous dolomite, black dolomite (“dolomite tigrée”), stratified grey dolomite, massive grey to black sandy dolomite and massive grey siliceous dolomite. The matrix is an iron-rich sandy clay consisting of quartz, hematite and clay minerals.

On thin sections coarse-grained and authigenic quartz are associated with equal sized dolomite in a clay-rich matrix. Disseminated euhedral pyrite is found in dolomite fragments, whereas framboidal pyrite is associated with chalcopyrite and bornite, both within the matrix and fractures. Pyrite has been replaced locally by hematite. Goethite and hematite are prominent mineral phases and give the breccias a brownish red color. Azurite, chalcocite, chrysocolla, covellite and malachite are the common supregenic minerals.

Table 1

<table>
<thead>
<tr>
<th>Supergroup</th>
<th>Group</th>
<th>Subgroup</th>
<th>Formation</th>
<th>Members &amp; lithologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>±570 Ma</td>
<td>Kundelungu Ku</td>
<td>Ngule Ku 2</td>
<td>Sampe - Ku 2.3</td>
<td>Arkoses, conglomerates, argillaceous sandstones, sedimentary breccias</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ku 2.1</td>
<td>Dolomitic pelites, argillaceous to sandy siltstones</td>
</tr>
<tr>
<td></td>
<td>Gombela Ku 1</td>
<td>Kubo - Ku 2.1</td>
<td>Dolomitic sandstones, siltstones and petilites</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mongwe - Ku 2.1</td>
<td>Dolomitic pelites, siltstones, sandstones and sedimentary breccias</td>
</tr>
<tr>
<td>±635Ma</td>
<td>Nguba Ng</td>
<td>Bunkeya Ng 2</td>
<td>Monwezi - Ng 2</td>
<td>Dolomitic sandstones, siltstones and petilites</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Katene - Ng 2.1</td>
<td>Dolomitic sandstones or siltstones in northern facies; alternating shale and dolomite beds (“Série Récurrence”) in southern facies</td>
</tr>
<tr>
<td></td>
<td>Muombe Ng 1</td>
<td>Kipushi - Ng 1.4</td>
<td>Dolomite with dolomitic shale beds</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Kakontwe - Ng 1.3</td>
<td>Carbonates</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Kaponda - Ng 1.2</td>
<td>Carbonate silstones or siltstones; dolomite Tigrée at the base</td>
</tr>
<tr>
<td>±765 ± Ma</td>
<td>Roan R</td>
<td>Mwashya (formerly Upper Mwashya) R 4</td>
<td>Kanzadi - R 4.3</td>
<td>Carbonaceous shales</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Kamoya - R 4.1</td>
<td>Dolomitic shales, siltstones, sandstones, including conglomeric beds and cherts in variable position</td>
</tr>
<tr>
<td>Katangan</td>
<td>Dipeta R 3</td>
<td>Kansuki - R 3.4</td>
<td>Dolomites including volcanioclastic beds (formerly Lower Mwashya)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mofya - R 3.3</td>
<td>Dolomites, arenitic dolomites, dolomitic siltstones</td>
</tr>
<tr>
<td></td>
<td>Mines R 2</td>
<td>R 3.2</td>
<td>Argillaceous dolomitic siltstones with interbedded feldspathic sandstones or white dolomites; intrusive gabbros</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RGS - R 3.1</td>
<td>Argillaceous dolomitic siltstones (R.G.S., “Roches Grése-Schisteuses”)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Kambove - R 2.3</td>
<td>Stromatolitic, laminated, shaly or talcose dolomites; locally sandstones at base; beds of siltstones at top</td>
</tr>
<tr>
<td></td>
<td>Shales Dolomitiques – R 2.2</td>
<td>Dolomitic shales including three carbonateous horizons; occasional dolomites</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kamoto - R 2.1</td>
<td>Stromatolitic dolomite (R.S.C.), silicified/arenitic dolomites (R.S.F./D.Strat.), grey argillaceous dolomitic siltstone at the base (Grey R.A.T.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>833 ± 10 Ma</td>
<td>R.A.T. R 1</td>
<td></td>
<td>Red argillaceous dolomitic siltstones and sandstones (&quot;Roches Argilo-Talqueuses&quot;)</td>
<td></td>
</tr>
<tr>
<td>&lt;900 Ma</td>
<td>Base of the R.A.T. sequence unknown</td>
<td></td>
<td>Basal conglomerate</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 2. Location of the Shangolwe Cu deposit and the geology of the Kambove region (François, 2006).
3.3.2. Dolomitic Breccias

The Dolomitic Breccias are characterised by a massive siliceous matrix (Fig. 3E). Dolomite fragments are also millimetric to centimetric (up to 50 cm) with color varying from light-grey to dark-grey. Azurite, malachite, chrysocolla, chalcocite, covellite, sphalerite and galena are found in the matrix and in fractures. They

Fig. 3. Kundelungu rocks and Shangoluwe breccias. A: Fractured dolomitic shale (Kanianga Formation-Ku 1.3), B: Pyritic dolomite (Kanianga Formation-Ku 1.3), C: Argillaceous sandy dolomitic shale (Mongwe Formation-Ku 2.1), D: Ferruginous Breccias (Fe.Br.), E: Dolomitic Breccias (Dol.Br.), F: Siliceous Breccias (Sil.Br.).

Fig. 4. Field photographs used for the quantitative analysis of the Shangoluwe breccias: BX1, BX2, BX3 (Dolomitic Breccias) and BX4 (Ferruginous Breccias).
are associated with neoformed quartz grains and occasional muscovite, goethite and dolomite. The dissolution of dolomite fragments has produced deeply weathered carbonate minerals associated with authigenic quartz.

3.3. Siliceous Breccias
The Siliceous Breccias contain deeply weathered dolomite fragments in a recrystallised siliceous matrix (Fig. 3F). Dolomitic fragments are millimetric to centimetric (up to 80 cm) in size and weathered into yellowish and brownish argillaceous rocks. Malachite and barite are present in dissolution cavities and pores of altered fragments. The breccias are massive or characterised by a finely laminated matrix containing spots of malachite. On thin sections altered dolomite is associated with muscovite and newly formed quartz. Carbonate residues fill micropores left between granular quartz grains. Disseminated chalcopyrite, bornite and pyrite occur in the recrystallised siliceous matrix and in fractures.

4. Quantitative analysis of the breccias

4.1. Methodology
The methodology for breccias analysis is based on the quantitative approach developed by Jebrak (1997), Bérubé and Jebrak (1999) and Lorilleux et al. (2003). In this study, four representative photographs were analysed after contrast enhancement, manual extraction using a Wacom tablet, and geometric fragment analysis using the Image-J public domain software. Only fresh and slightly weathered outcrops were selected for this analysis because it was not possible to recognise the fragment contour on deeply weathered outcrops. The Siliceous Breccias were not considered for the quantitative analysis because they are intensely weathered into clay or clayey rock.

Five main parameters were recorded: the particle size distribution (PSD), aspect ratio, circularity, area/perimeter ratio, and fragment solidity. The interpretation of the data is based on the style of initial fragmentation, fragmentation process and transportation.

The style of initial fragmentation is evaluated using PSD analysis. In isotropic rocks, normal PSD corresponds to the formation of semi-equal fragments that show a regular fragmentation pattern. Such pattern is characterised by a low energy fragmentation process such as desiccation, cooling, or extension with a low differential stress (Jebrak, 1997). It could also result from a late sorting of the fragments by a dynamic process, such as water transportation. A log normal to fractal distribution indicates an early focalisation of the fragmentation and results from a high energy process such as explosion or seismic process. Fragmentation processes are investigated by studying the evolution of the geometric parameter of the fragments. Transportation processes after fragmentation are described by geometric parameters related to the shape of the fragments: solidity and circularity are the expression of the shape complexity; low circularity (0.1) and low solidity (0.5) indicate a very complex shape. The area/perimeter ratio is also an expression of the complexity. The particle aspect ratio gives the shape factor, i.e. the ratio between length and width of the fragment.

4.2. Results
The results of the quantitative analysis are shown on Figs. 4 and 5 and listed in Table 2. The quantitative analysis of the Ferruginous Breccias indicates that the PSD of the fragments is weakly dispersed, reflecting a lower level of maturity. Long fragments are similar to those observed in Ferruginous Breccias, but less abundant.

The high aspect ratio suggests a later in-situ fragmentation after deposition of the sedimentary breccias, possibly during the main tectonic stages of the Luflian orogeny. The in-situ fragmentation is followed by dissolution of dolomite fragments. The low value of the area/perimeter ratio (<0.05) is recognised in the Dolomitic Breccias. It is not dependent of the aspect ratio, which suggests that there is no relationship between fragmentation and dissolution of the dolomite fragments at Shangoluwe.

The PSD of the Ferruginous and Dolomitic Breccias has a log normal distribution which suggests formation by high energy processes (Fig. 5E; Table 2) such as gravity flow which is proposed as the trigger mechanism for Shangoluwe breccias deposition. This indicates the absence of a low energy environment at Shangoluwe which is typical for breccias induced by a hydrothermal process such as fluid–assisted brecciation, or volume reduction or expansion (Jebrak, 1997).

5. Sedimentology of the breccias
The three types of breccias are characterised by their texture and internal clast organisation.

5.1. Morphology of the clasts
Quantitative macroscopic analysis and microscopic observations indicate that the shape of the dolomite fragments are very angular to sub-angular (low sphericity), but some are sub-rounded due to dissolution after deposition (Fig. 4). Their size varies between a few mm and 80 cm. These fragments are characterised by in-situ fragmentation, likely during the Luflian orogeny (cf. quantitative analysis). The dolomite fragments are poorly sorted and supergene Cu minerals such as azurite, chrysocolla, chalcocite, covellite and malachite are found in the cavities. These observations suggest that these breccias are immature, with a short distance transport of the fragments.

5.2. Turbidity current
A series of observations at the Shangoluwe North deposit on outcrops and drill cores indicate that the sedimentary breccias were deposited through turbidity currents.

5.2.1. Intercalated layers in breccias and graded-bedding
The stratified greenish grey siltstones and sandy shales intercalated in the Ferruginous Breccia are altered into brown or red argillaceous rocks. These siltstones and sandy shales (8–10 m thick) were also deposited at the contact between the Ferruginous and Dolomite Breccias (Fig. 6). They were intersected by drill holes Shan 0071, Shan 0072, Shan 0073, Shan 0074, Shan 0075, Shan 0134 and Shan 0290 (Schuling, 1940; Calleux and Dessart, 1984).

In the Dolomitic Breccias, layers of grey to brownish shale mineralised in chalocite (~1 m thick), grey dolomitic shale (~1 m thick), blackish grey massive dolomite (~1 m thick) and stratified dark grey dolomite (~0.1–2 m thick) were intersected by drill holes SG 0030, SG 0076, SG 0077 and SG 0078 (Fig. 7A). Drill hole SG 0029 intercepted the same breccia alternating with a stratified dark grey dolomite (~10 cm thick), a grey dolomitic shale (~10–20 cm thick) and a grey to pinkish shale (~30 cm thick). The petrographic composition of these layers is similar to that of the surrounding Kundelungu rocks.

A normal graded-bedding is observed in both the Ferruginous and Dolomitic Breccias. The Dolomitic Breccias starts with a basal
4 m-thick layer containing decametric clasts, followed by a layer containing medium-sized clasts (<10 cm diameter) and a top layer characterised by smaller clasts with sizes ranging from few millimeters to centimeters. In the Shangoluwe Central and South deposits a succession of normal and reverse graded-bedding is also observed in some layers (1–2 m thick).

5.2.2. Pseudo-stratification and finely laminated matrix
Dolomite layers (~0.5 cm thick) and irregular stratification planes (~0.2 cm thick) occur in both the Ferruginous and Dolomitic Breccias. They contain supergene copper mineralisation such as malachite, azurite and chalcocite. The thickness of each layer in these breccias varies between 10 cm and 1.20 m. Most fragments are oriented parallel to these irregular stratification planes forming

![Fig. 5.](image)

Table 2
Parameters resulting from the quantitative analysis according to the approach of Jébrak (1997), Bérubé and Jébrak (1999) and Lorilleux et al. (2003).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Bx1: Dolomitic Breccias</th>
<th>Bx2: Dolomitic Breccias</th>
<th>Bx3: Dolomitic Breccias</th>
<th>Bx4: Ferruginous Breccias</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect ratio (AR)</td>
<td>1.3</td>
<td>Numerous long early fragments</td>
<td>1.3</td>
<td>Large distribution with long early fragments</td>
</tr>
<tr>
<td>Solidity</td>
<td>0.93</td>
<td>0.9</td>
<td>0.93</td>
<td>0.84</td>
</tr>
<tr>
<td>Circularity</td>
<td>0.68</td>
<td>0.68</td>
<td>0.54</td>
<td>0.58</td>
</tr>
<tr>
<td>P/A</td>
<td>0.8</td>
<td>0.8</td>
<td>1.8</td>
<td>2.6</td>
</tr>
<tr>
<td>Remarks</td>
<td>Circularity increases and AR decreases</td>
<td>AR remains stable</td>
<td>AR remains stable</td>
<td>AR remains stable</td>
</tr>
<tr>
<td>Results</td>
<td>Low maturity, high circularity, low P/A et high dispersion</td>
<td>Low maturity, high circularity, low P/A et high dispersion</td>
<td>High maturity, low circularity, high P/A, and low dispersion</td>
<td>High maturity, low circularity, high P/A, and low dispersion</td>
</tr>
</tbody>
</table>
a pseudo-stratification in Ferruginous and Dolomitic Breccias (Fig. 7B). This pseudo-stratification is often parallel to the bedding of the Kanianga and Mongwe formation rocks. The Siliceous Breccias are characterised by a recrystallised and finely laminated siliceous matrix. The dolomitic fragments are weathered into a clayey rock or soft clays (Fig. 7C).

5.3. Mud flow and continuity of sedimentation

In the Shangoluwe Central deposit, a red argillaceous layer (~3 m thick) is present at the contact between the Kundelungu sequence and the Ferruginous Breccias. It consists of small dolomite fragments (~1 mm diameter) in an argillaceous matrix. On thin sections the rock contains abundant muscovite, quartz and hematite. The argillaceous layer is interpreted as a mud flow. However, in the northern and southern part of the deposit, a unit (~2 m thick) consisting of alternating shales (2–10 cm thick) and Ferruginous Breccias is observed. The transition between shale and breccias is progressive and characterised by an apparent continuous sedimentation.

5.4. Grain and debris flow deposits

The Siliceous Breccias contains massive breccias (~8 m thick) at its base, followed successively by finely laminated breccias (~4 m thick) with clasts oriented parallel to the pseudo-stratification and by a unit consisting of clast-supported breccias (~8 m thick). At the top, the Siliceous Breccias (~5 m thick) is not cemented and the fine-grained matrix is also absent (Fig. 7D). The interaction between different clasts is occasionally observed on the surface of the clasts by the presence of shock marks. This stratigraphic succession and the sedimentological characteristics recognised in the Siliceous Breccias are typical of grain flow deposit as discussed by Lowe (1979) and Cojan and Renard (2006).

Although some layers of the Dolomitic and Ferruginous Breccias are characterised by turbidity currents (e.g. silstone and sandy shale layers), other layers are characterised by a poor correlation between clast size and bed thickness, an inverse or inverse-to-normal grading with a mud flow (e.g. northern part of the Shangoluwe). Therefore, these two breccias were most likely deposited by debris flows.

6. Structural analysis

The structural analysis was carried out on the breccias and surrounding Kundelungu rocks at Shangoluwe North, Central and South in order to constrain the relative age of the different hypogene sulphide veins.

6.1. Folding and faulting

Folding is related to the Kolwezian deformation phase D1 (Kampunzu and Cailteux, 1999) or brittle deformation stages 1–2 of Kipata et al. (2013) affecting both the breccias (Ferruginous and Dolomitic Breccias) and surrounding Kundelungu sequence. Drag folds, inclined folds, overthrust folds and southwest verging recumbent folds were identified in the Shangoluwe area (Fig. 8A–D). Four different fault and fracture sets were identified in the Shangoluwe North deposit by Kipata et al. (2013, site Kat 16). The first set (brittle stage 1 of Kipata et al. 2013) comprises thrust faults and fractures formed under NNW-SSE compression, affecting the Kanianga Formation and the Ferruginous and Dolomitic Breccias. The second set (brittle stage 3 of Kipata et al., 2013) consists of strike-slip fault planes and fractures which formed in a strike-slip context with NE-SW horizontal compression. The third set (brittle stage 5 of Kipata et al., 2013) comprises normal fault planes with a slight strike-slip component which reactivated the contact between the Ferruginous Breccias and the Kundelungu rocks during the post-orogenic E-W extension. The last set (brittle stage 6 of Kipata et al., 2013) corresponds to bedding plane reactivations with sub-horizontal slip lineations coated with black and pink Fe-oxides, corresponding to the far-field Mesozoic transpressional reactivation. The hypogene sulphides such as pyrite, chalcocite, bornite, galena and sphalerite occur in dolomite veins related to the brittle stages 5 and 6.

In the Shangoluwe North and Central deposits, an important fault with profound striae and corrugations affecting the Kanianga Formation (Ku 1.3) displays a normal-sinistral slip movement. In the same formation, a reverse fault and a dip slip normal fault with profound striae and corrugations related to the brittle stage 5 was also identified (Kipata, 2013). The variety of bedding plane orientations observed in the Kundelungu rocks and the pseudo-stratification observed in the breccias can be explained by faulting and drag-folding with an axial plane oriented 74/230, which is related to brittle stage 2 (Fig. 9). In the Kundelungu Group, tectonic breccias containing angular clasts (blocks) of sandy dolomitic shales and laminated dolomitic shales were formed by transverse and strike-slip faults. In the Ferruginous and Dolomitic Breccias, the fragments are characterised by a high aspect ratio of up to 9 (cf. quantitative analysis of the breccias). Copper minerals along the faults include chalcocite, bornite, chalocite, covellite, chrysocolla, shattukite, azurite and malachite associated with minor amounts of galena and sphalerite.

In the Shangoluwe South deposit (site Kat 17 of Kipata et al., 2013), cross-cutting relationships suggest a fracturing event with subvertical fracture planes (Fig. 8G) and well-marked strike-slip striae (brittle stage 4). The contact between the Ferruginous Breccias and the Kundelungu sequence is faulted, and characterised by a sigmoidal gouge. This fault affects both the Mongwe Formation and the Dolomitic and Ferruginous Breccias (Fig. 8E and F). Azurite, chrysocolla, covellite and malachite occur in fractures (Fig. 8H).

6.2. Unconformities

Two angular unconformities were observed at Shangoluwe. The first one is an irregular erosional surface that defines the contact between the Dolomitic and Siliceous Breccias (Fig. 8I). The second separates the subhorizontal Siliceous Breccias from the underlying folded Kundelungu sequences (Fig. 8C). The base of the subhorizontal Siliceous Breccias is formed of a 15–20 cm-thick polygonal uncemented layer, indicating an erosional contact. This contact zone is characterised by a unit containing argillaceous shale and argillaceous sandy shale clasts from the Kundelungu units and dolomite clasts in an unconsolidated argillaceous sandy matrix.

7. Interpretation and discussion

7.1. Sedimentology and geodynamic context

The upper part of the Kundelungu Group (Biano Subgroup) consists of arkoses, conglomerates, argillaceous sandstones and pelites at the Biano and Kundelungu Plateaux (Alexandre-Pyre, 1967; François, 1973; Dumont et al., 1997; Batumike et al., 2006, 2007). In the Ngule area (northern part of Tenke-Fungurume), the Biano Subgroup consists of fine- to coarse-grained arkoses with intercalated argillaceous sandstones at the base, overlain by a 10 m-thick conglomerate (François, 1973). This conglomerate is made up of clasts of quartzite (60 vol %), sandstone, shale and siliceous dolomite (10 vol %) in a red to white sandy matrix (30 vol %) which
consists of coarse grained quartz. In others places (e.g. north and east of Kansenya), this succession is absent and no erosional structure is found. Only brown to grey mauve stratified sandy shale and reddish brown laminated argilaceous shale are present. Sometimes these rocks are overlain by yellow to brownish Cenozoic Kalahari sands (Alexandre, 2002; François, 1973, 2006).

Fig. 6. Shangoluwe cross section VI (Shangoluwe North deposit): Geological interpretation from Schuling (1940), Cailteux and Dessart (1984) and modified by the results of this study.

Fig. 7. Turbidity current and macroscopic characteristic of the sedimentary breccias. A: Intercalated layers of stratified and massive dolomite in the Dolomitic Breccias; B: Pseudo-stratification in the Dolomitic Breccias, C: Laminated matrix in the Siliceous Breccias, D: Uncemented breccias bearing supergene mineralisation (Siliceous Breccias).
The conglomerate observed in the upper part of the Biano Subgroup is different from the Shangoluwe breccias. Previously, François (2006) and Cailteux and Dessart (1984) interpreted the Shangoluwe breccias as tectonic breccias made up of dolomite fragments from both the Dipeta and Mine Subgroups. Wendorff (2003, 2011) described the same breccias as a syn-tectonic conglomerate within an olistostrome deposited in the Fungurume foreland, implying that these breccias are younger than the Kundelungu Group. The results from this study do not support these interpretations.

The Shangoluwe breccias are characterised by breccia fragments generally weathered into a clayey rock. The clasts are angular to subangular (Fig. 4), indicating a short distance of transportation. They are also characterised by a log normal distribution. The normal and inverse graded bedding indicate a grain and debris flow deposit, including mud flow. Pseudo-stratification, a finely laminated matrix and intercalated layers of siltstone, dolomite and sandy shale indicate deposition through turbidity currents (Fig. 7A–C). The Shangoluwe breccias have therefore a sedimentary origin, but with clasts produced locally from surrounding rocks, i.e. dominantly from the Roan Group and less from the Kundelungu Group. The breccias were sequentially deposited and consist of three different parts (Ferruginous, Dolomitic and Siliceous Breccias).

The mud flow at the base of the Ferruginous Breccias consists of small fragments of dolomite (<1 mm diameter) which has been weathered into a clayey rock. The breccias overlaying this layer have larger fragments, up to 50 cm in diameter. The continuity in sedimentation is observed in the northern and southern part of Shangoluwe. It consists of an alternation of breccias made up of small fragments (<1 cm diameter) and white to yellowish or brownish argillaceous shales (2–10 cm thick). In this context, the sedimentary Ferruginous and Dolomitic Breccias are totally different from the tectonic breccias found along the fault zones at Shangoluwe as in the Luflian arc, and described by several authors such as Okitaudji (1992), Cailteux and Kampunzu (1995), Cailteux et al. (2005a), Kipata et al. (2013), Taylor et al. (2013) and Zientek et al. (2014). These two sedimentary breccias are coeval with the Kanianga and Mongwe formations. The timing of deposition is constrained on the basis of structural and sedimentological evidences:

(i) the breccias were deposited as lenses in both the Kanianga and Mongwe formations and were affected by the same style of deformation, which is related to the Luflian orogeny (D1 - Kolwezian and D2 – Monwezian phases of Kampunzu and Cailteux, 1999, Figs. 8 and 9, Table 2) and late- to post-Luflian orogeny events (e.g. brittle stages 4, 5 and 6 of Kipata et al., 2013).

(ii) there is evidence of a continuity of sedimentation through the Ferruginous Breccias and Kanianga Formation, deposition of siltstone and sandy shale beds interlayered within the
breccia and between the Ferruginous and Dolomitic Breccia (Fig. 6; Table 3; e.g. Schuiling, 1940; Cailteux and Dessart, 1984), and the presence of dolomite, dolomitic shale and shale layers interbedded in these breccias (Figs. 6 and 7A).

The Siliceous Breccias has been deposited through an angular unconformity on both the Kanianga (Ku 1.3) and the Mongwe formations (Ku 2.1) and through an erosional unconformity on top of the Dolomitic Breccias (Fig. 8C and I; Table 3). The Siliceous Breccias is characterised by a recrystallised massive siliceous matrix, but locally laminated at the base. It is overlain by a layer with a coarse-grained matrix and followed by clast-supported breccias. The Siliceous Breccias post-dates the Luflian orogeny and is possibly younger than the sandstone, conglomerate and pellite of the Biano Subgroup. This hypothesis is supported by the following features:

(i) the upper part of the Siliceous Breccias is characterised by an un-cemented breccias and by the absence of a fine-grained matrix; indicating the termination of a depositional cycle;

(ii) the breccias has not been affected by the Luflian orogeny as observed on both Ferruginous and Dolomitic Breccias (Kipata, 2013);

(iii) there is an angular unconformity between the Siliceous Breccias and the Kundelungu sequences (Fig. 9C), while the two lower units (Ferruginous and Dolomitic Breccias) are concordant with the Kundelungu rocks (Kanianga, Ku1.3 and Mongwe, Ku 2.1 formations). There is also an erosional unconformity (Fig. 8I) on top of the Dolomitic Breccias that developed prior to deposition of the Siliceous Breccias (Fig. 8I; Table 3). These local unconformities obviously post-date the Luflian orogeny and are not related to the regional tectonic unconformity defined by El Desouky et al. (2008a) in the foreland, which corresponds to the orogenic paroxysm (Kipata et al., 2013). This regional unconformity is equivalent to the tectonic unconformity observed along the transition zone between the Luflian arc (Kiubo Formation- Ku 2.2 and Sampwe Formation - Ku 2.3) and the Katanga foreland (the Biano Plateau) in the northern part of the Tenke-Fungurume district.

7.2. Lithostratigraphic position of the Shangoluwe breccias

Wendorff (2003, 2005b) described the breccias at Mufulira and
Table 3
Stratigraphic succession defined at Shangoluwe North and Central according to the result of this study.

<table>
<thead>
<tr>
<th>Formations</th>
<th>Sedimentological characteristics</th>
<th>Deformation Cu minerals</th>
<th>Geodynamic context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siliceous Breccia</td>
<td>Laminated and massive matrix; short transport of dolomite clasts, immature rock, very to poorly sorted, angular to very angular. Clasts are oriented following the sense of flow. On subsurface the fragment still uncremented; Evidence of grain flow.</td>
<td>Post-Lufillian orogeny. Chalcocite, bornite, chalcopyrite, malachite and chrysocolla.</td>
<td>Post-orogenic</td>
</tr>
<tr>
<td>Top</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dolomitic Breccia</td>
<td>Pseudo-stratification, short transport of dolomite fragment, graded bedding, immature rock, dissolution, poorly sorted, angular to very angular. In-situ fragmentation. Interlayered layers of sandy dolomitic shale, shale, dolomite and dolomitic shale.</td>
<td>D1 &amp; D2 Lufillian phases. Chalcocite, chalcopyrite, covelline, bornite, azurite, native Cu and malachite.</td>
<td>Syn-orogenic and coeval to the deposition of Ku1.3</td>
</tr>
<tr>
<td>Bottom</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ferruginous Breccia</td>
<td>Pseudo-stratification, intercalation of sandy and argillaceous shale, dissolution, short transport of dolomite fragment. Poorly sorted, angular to very angular. In-situ fragmentation.</td>
<td>D1 &amp; D2 Lufillian phases. Chalcocite, chalcopyrite bornite, azurite malachite, covelline, native Cu and chrysocolla.</td>
<td>Syn-orogenic and coeval to the deposition of Ku1.3</td>
</tr>
<tr>
<td>Mud flow</td>
<td>Massive red argillaceous matrix within minor fragment of dolomite.</td>
<td>D1 &amp; D2 Lufillian phases. Chalcocite, chalcopyrite bornite, azurite malachite, shattukite, chrysocolla.</td>
<td>Syn-orogenic and coeval to the deposition of Ku1.3</td>
</tr>
<tr>
<td>Kanianga Formation (Ku1.3)</td>
<td>Sandy dolomitic shaley dolomitic shaley and stratified dolomite</td>
<td>D1 &amp; D2 Lufillian phases. Chalcocite, bornite, azurite malachite, shattukite, Chrysocolla.</td>
<td>Syn-orogenic</td>
</tr>
</tbody>
</table>

Mwambishi in the Zambia Copperbelt and interpreted them as synrift clastic deposits (olistostromes) in the Mwashya-Nguba basin. Previously, a tectonic origin was considered for these breccias (Cailteux et al., 1994). Wendoff (2005a) redefined the lithostratigraphy of the Katanga Supergroup as a succession of the Roan, Nguba, Kundelungu, Fungurume and Plateau groups. According to this author, the Fungurume Group is subdivided into the Kambove Formation consisting of olistostromes, the Mutoshi Formation characterised by continental red beds and marginal marine siliciclastics and the Dipeta Formation composed of mixed marginal marine clastic rocks. In the Congo Copperbelt, Wendoff (2000a,b; 2003) considered also the tectonic megabreccias (e.g. Roan Group) including the Shangoluwe breccias as having a sedimentary origin (e.g. olistostromes), but these breccias were considered as forming the Fungurume Group, younger than the Kundelungu Group. The Shangoluwe breccias was described initially as tectonic breccias consisting essentially of the clasts from the Roan Group (Cailteux and Dessart, 1984; François, 2006). However, our observations at Shangoluwe indicate that the Shangoluwe breccias are not a single sedimentary unit (Wendoff, 2011) or a tectonic breccia (Cailteux and Dessart, 1984; François, 2006), but three distinct layers can be distinguished among these breccias including Ferruginous, Dolomitic and Siliceous Breccias (Fig. 6, Table 3). These breccias contain Cu mineralisation associated with minor Zn-Pb mineralisation. The Shangoluwe breccias are interpreted as having a sedimentary origin and were deposited as lenses by gravity flow. Based on the results from this study, it is proposed to include the three breccias defined at Shangoluwe into the lithostratigraphy of the Katanga Supergroup as defined by Batumike et al. (2007). The lenses of Ferruginous and the Dolomitic Breccias are contemporaneous with the Kanianga (Ku 1.3) and Mongwe (Ku 2.1) formations while the Siliceous Breccias constitute an additional unit of the Biano Subgroup (Table 3).

7.3. Timing of copper mineralisation

Several metallogenic models have been proposed for the origin of copper and cobalt mineralisation in the Copperbelt including syngenetic (Garlick, 1961; Fleischer et al., 1976), diagenetic (Cailteux et al., 2005b; Muchez et al., 2015) and syn-orogenic (McGowan et al., 2003, 2006) models. In addition, El Desouky et al. (2008a) proposed a post-orogenic fluid–mixing model for the stratiform mineralisation in the Lufilian foreland controlled by strike-slip faults. El Desouky et al. (2009, 2010) distinguished two main hypogene Cu-Co sulphide phases in the Congo Copperbelt: an early stratiform emplacement by hydrothermal fluids and a late diagenetic to syn-orogenic hypogene Cu-Co mineralisation. The hypogene minerals are often replaced by supergene sulphides while the supergene Cu-Co oxide minerals are mainly concentrated along cracks and in fracture zones associated with faults. This clearly indicates the role of tectonic structures and alteration processes in leaching, remobilising and upgrading the primary mineralisation (Chavez, 2000; Torremans et al., 2013). Similar secondary enrichments induced by the Lufilian folding and faulting are observed in different deposits inside the Lufilian arc (Haest and Muchez, 2011; Van Langendonck et al., 2013; Kipata et al., 2013). Faults and veins contain hypogene sulphides (pyrite, chalcopyrite, bornite, galena and sphalerite) and younger supergene minerals such as azurite, chrysocolla, chalcocite, covellite and malachite.

The Shangoluwe breccias were affected by in-situ fragmentation during the Lufilian orogeny and dissolution of dolomitic fragments, which allowed fluid circulation. However, the emplacement of Cu mineralisation in veins (e.g. in the breccias and the surrounding Kundelungu rocks) and in the matrix of the sedimentary breccias (Ferruginous and Dolomitic Breccias) took place during late stages of the Lufilian orogeny or after this orogeny. The mineralisation could be associated with the brittle stage 5 (Lufilian arc parallel extension) and stage 6 (post-orogenic extension) of Kipata et al. (2013). The supergene minerals associated with the hypogene sulphides (pyrite, bornite, chalcopyrite) occur in the younger Siliceous Breccias and are related to late Cenozoic remobilisation of the mineralisation in fractures, pores and cavities created by the dissolution of dolomite fragments (De Putter et al., 2010). Although there are euhedral pyrite crystals disseminated in the dolomite clasts, an early diagenetic Cu sulphide phase has not been recognised at Shangoluwe.

8. Conclusion

The Shangoluwe breccias were defined on the basis of the
nature of the matrix and clasts. Three types of breccias were identified at Shangolowe, from bottom to top: Ferruginous, Dolomitic and Siliceous Breccias. This relationship is based on the presence of interbedded layers, erosional surfaces and angular unconformities. The study of these breccias has indicated that:

1. The Shangolowe breccias have a sedimentary origin and are constituted by dolomite clasts from rocks of the Katanga Supergroup (Roan and Kundelungu groups).
2. The quantitative analysis of the Ferruginous and Dolomitic breccias indicates a short distance of transport, deposition of breccias by gravity flow (log normal distribution of fragment) and a later in-situ fragmentation of large clasts during the Lubillian orogeny (high aspect ratio). The short distance of transport is also supported by the immaturity, low sphericity and poor sorting of the clasts.
3. The breccias were deposited by gravity flow as shown by the presence of mud flow at the base of the Ferruginous Breccias, debris flow (in the Ferruginous Breccias, Dolomitic Breccias and base of Siliceous Breccias) and grain flow at the top of Siliceous Breccias.
4. The turbidity currents are marked by the presence of a finely laminated matrix in the Siliceous Breccias, and graded bedding and pseudo-stratifications in the Ferruginous and Dolomitic Breccias with layers of sandy shale, dolomitic shale, shale and dolomite. They have the same petrographic characteristics as the Kundelungu rocks (Kanianga and Mongwe formations).
5. The stratigraphic and sedimentological observations indicate that the deposition of the Ferruginous and Dolomitic Breccias is coeval to the deposition of the Kanianga Formation (Ku 1.3) and the Mongwe Formation (Ku 2.1).
6. The structural data indicate that the Siliceous Breccias postdate the Lubillian orogeny, but the Ferruginous and Dolomitic Breccias and surrounding Kundelungu rocks were affected by the Lubillian orogeny. The Siliceous Breccias may have been deposited during the early Palaeozoic as the Biano Subgroup. The Ferruginous and Dolomitic Breccias are part of the Kanianga and Mongwe formations, and the Siliceous Breccias are attributed to the Biano Subgroup (Table 3).
7. The Cu sulphides associated with minor Pb-Zn sulphides in the Ferruginous and Dolomitic Breccias precipitated during deformation stage 5 (Lubillian arc parallel extension) and stage 6 (post-orogenic extension) of Kipata et al. (2013). The voids between clasts, karstic dissolution on dolomite fragments and fracturing allowed mineralising fluid circulation.

Acknowledgements

This results presented in this paper are part of a M.Sc. thesis by P. Mambwe at the University of Lubumbashi (DRC). Part of the thesis has been carried out at the KU Leuven (Belgium). Field assistance was provided through project RA_S1_RDC_GEO/DYN of the Belgian Cooperation to D. Delvaux. The authors would like to thank Mr. Alphonse Kaputo, Director of the Geological Department of Gécamines S.A., for allowing access to the concession. Gracé Tambwe and Eric Tshisola are thanked for their field assistance. Sebastien Lavoie, Budi Santoso, Robert North, dr. Isabelle Fay and Joseph Nzita are thanked for their encouragement and documentation, dr. Jean Liegeois and dr. Thierry De Putter are thanked for their constructive remarks on an earlier version of the manuscript. Finally, the chief editor (Read Brown Mтангanyika Mapeo), dr. Jacques Batumike, dr Jacques Caillieux and an anonymous Reviewer are gratefully acknowledged for their remarks and suggestions.

References

El Desouky, H.A., Muchez, Ph, Caillieux, J., 2009. Two Cu-Co sulphide phases and