The Neoproterozoic Mwashya–Kansuki sedimentary rock succession in the central African Copperbelt, its Cu–Co mineralisation, and regional correlations

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Abstract

Rocks of the Neoproterozoic Mwashya Subgroup (former Upper Mwashya) form the uppermost sedimentary unit of the Roan Group. Based on new field and drill hole observations, the Mwashya is subdivided into three formations: (1) Kamoya, characterized by dolomitic silty shales/siltstones/sandstones and containing a regional marker (the "Conglomerate de Mwashya" bed or complex); (2) Kafubu, formed by finely bedded black carbonaceous shales; and (3) Kanzadi, marked by feldspathic sandstones. Rocks of the Mwashya Subgroup are overlain by the Sturtian age Grand Conglomérat diamictite (equivalent to the Varianto/Brazil and Chuos/Namibia diamictites), and conformably overlie rocks of the Kansuki Formation (former Lower Mwashya), a carbonate unit containing volcaniclastic beds. New geochemical data confirm the continental rift context of this magmatism, which is contemporaneous with rift-related volcanism of the Askevold Formation (Nosib Group, Namibia). A gradational lithological transition between rocks of the Kansuki and the underlying Kanwangungu Formations, and similar petrological composition of these two formations, support the hypothesis that the Kansuki is the uppermost unit of the carbonate-dominated Dipeta/Kanwangungu sequence, and does not form part of the Mwashya Subgroup. Base metal deposits, mostly hosted in rocks of the Kansuki Formation, include weakly disseminated early-stage low-grade Cu–Co mineralisation, which was reworked and enriched, or initially deposited, by metamorphic fluids associated with the Lufilian orogenic event.

Keywords: Copperbelt; Mwashya; Lithostratigraphy; Cu–Co; Magmatism

1. Introduction

The Neoproterozoic Katangan sedimentary rock succession hosts the rich copper–cobalt deposits of the central African Copperbelt in both Democratic Republic of Congo (Congo hereafter) and Zambia, which represent the most economically important Pan-African belt of the continent. The central African Copperbelt forms a northward convex structure, straddling the Congo–Zambia border and called "Lufilian Arc". It was formed during the Lufillian orogeny (ca. 620–570 Ma), stretching over a 700-km-long and 50-km-wide region from the Mwinilunga district in northwestern Zambia (Brock, 1961; Steven, 2000), east-northeastwards through Kolwezi and Likasi (Congo), and southeastwards to Bwana Mkubwa (Zambia) and Lonshi (Fig. 1). The Katangan sedimentary rock succession totals 5–10 km in thickness and is divided into three major lithostratigraphical units (François, 1974, 1995). From bottom to top, these units are the Roan (code R), Nguba (code Ng, formerly Lower Kundelungu) and Kundelungu (code Ku, formerly Upper Kundelungu) Groups (Table 1).

The uppermost sedimentary sequence of the Roan Group is called the "Mwashya Subgroup" or "R 4" in Congo (formerly "Système Schisto-Dolomitique" of Van den Brande, 1935; "Série de Mwashya" of Oosterbosch, 1962; "Faisceau de Mwashya" of François, 1974). It has been documented in several areas that

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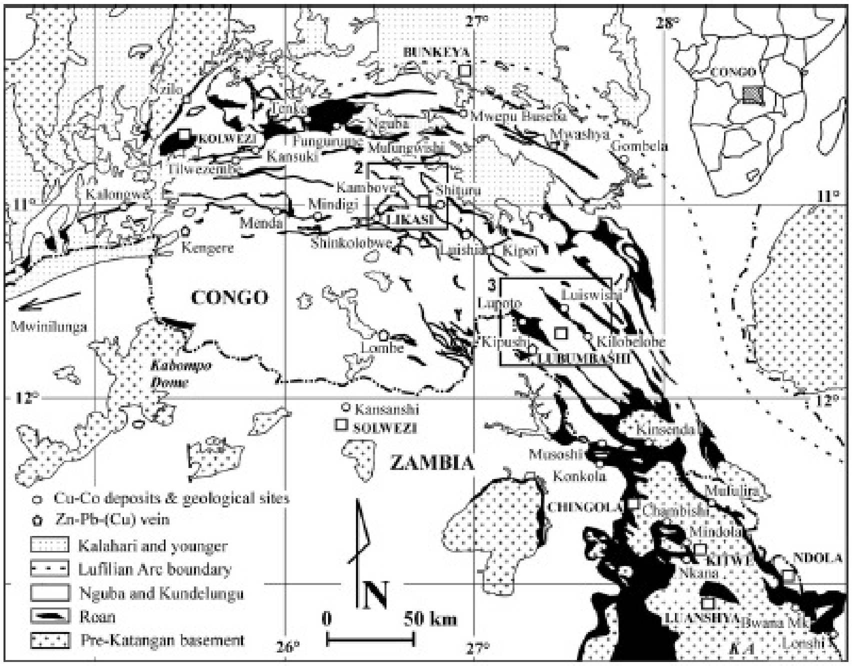

Fig. 1. Location of the main ore deposits and geological sites in the central African Copperbelt (modified from Mendelsohn, 1961; François, 1974; Cailteux et al., 1994). Areas labeled "2" and "3" are the sites of Figs. 2 and 3, respectively.

include Mwashya, Mulungwishi, Shituru, and Kambove (Fig. 1; Van den Brande, 1932, 1935; Francotte, 1959; Lefebvre, 1973, 1974, 1976, 1979; Cailteux, 1983, 1994). It is commonly divided into a predominantly dolomitic Lower Mwashya (R 4.1) and a predominantly pelitic Upper Mwashya (R 4.2) Formations, but there is no well-documented regional lithostratigraphic description of the transition and boundary between these two formations (François, 1974). In Zambia, only a dominantly argillaceous unit, called "Mwashia", is identified as Mwashya Subgroup (Mendelsohn, 1961; Cailteux et al., 1994) and is noted in stratigraphic position above the "Upper Roan" dolomite (or Bancroft Dolomite, Carbonate Unit of Binda, 1994, Kanwangungu Formation of Tshiauka et al., 1995; Table 1).

Previous authors linked the Upper Mwashya Formation and the Grand Conglomérat to form the "Système du Grand Conglomérat et du Mwashya" (e.g., Cahen and Mortelmans, 1948; Cahen, 1954; Lepersonne and Trottereau, 1974; Table 2). This interpretation was based on the hypothesis that both lithological units represent glacial to periglacial deposits, and a conglomerate near the base of the Upper Mwashya Formation (called "Conglomérat de Mwashya"; Van den Brande, 1932) was inferred to be a glacial deposit. In this alternative model, the Lower Mwashya Formation has been incorporated in pre-Mwashya units to create the "Faisceau de Mofya" of Lepersonne and Trottereau (1974), also called the "Kansuki Group" by Cahen (1974; Table 2).

The aim of this study is: (1) to improve the lithostratigraphy of the Mwashya Subgroup, i.e., to document the transition from Lower to Upper Mwashya Formations and their relationships with underlying (Dipeta Subgroup) and overlying (Grand Conglomérat tillite/diamictite) units by examining/re-examining new and old lithostratigraphic data; and (2) to better constrain the evolution of the Katangan basin during the deposition of rocks of the Mwashya Subgroup. There is a considerable interest in the Mwashya succession because of the occurrence of mafic volcanism and Cu–Co mineralisations.

2. Geological setting

Deposition of rocks of the Roan Group corresponds to the opening of a continental rift basin (fluvial clastics and lacustrine-type sediments; Buffard, 1988), which evolved into a proto-oceanic rift stage (Kampunzu et al., 1991, 1993). Sedimentary characteristics of the youngest Roan Group and of the Nguba and Kundelungu Groups rocks, indicate a widening of the basin due to extensional tectonics. Inversion from extensional to compressional tectonics, related to a convergence between the Congo and Kalahari cratons, generated the detachment of the Katangan sedimentary rock succession from the basement, and caused a north-directed folding and thrusting that led to the formation of the Lufilian Arc (Kampunzu and Cailteux, 1999). Other detachments occurred in the Congo-type Roan Group

Table 1
Lithostratigraphy of the Katangan Supergroup in Congo and Zambia (modified from François, 1974, 1987; Cailteux et al., 1994; François, 1995; Kampunzu and Cailteux, 1999; Cailteux, 2003; and according to Batumike et al. this volume)

SUPERGROUP		GROUP	SUB-GROUP	FORMATION	LITHOLOGY
Katangan	±500 Ma	Kundelungu (formerly Upper Kundelungu) Ku	Biano - Ku 3		arkoses, conglomerates, argillaceous sandstones
			Ngule Ku 2	Sampwe	dolomitic pelites, argillaceous to sandy siltstones
				Kiubo	dolomitic sandstones, siltstones and pelites
				Mongwe	dolomitic pelites, siltstones and sandstones
			Gombela Ku 1	Lubudi	pink oolitic limestone and sandy carbonate beds
				Kanianga	carbonate siltstones and shales
				Lusele	pink to grey micritic dolomite
	(± 620 Ma)			Kyandamu	Petit Conglomérat (glacial diamictite)
		Nguba (formerly Lower Kundelungu) Ng	Bunkeya Ng 2	Monwezi	dolomitic sandstones, siltstones and pelites
				Katete	dolomitic sandstones, siltstones and shales in northern areas; alternating shale and dolomite beds ("Série Récurrente") in southern areas
			Muombe Ng 1	Kipushi	dolomite with dolomitic shale beds in southern areas
				Kakontwe	carbonates Zn-Cu-Pb
				Kaponda	carbonate shales and siltstones; "Dolomie Tigrée" at the base
	CONGO ±750 Ma			Mwale	Grand Conglomérat (glacial diamictite)

SUPERGROUP	GROUP	SUB-GROUP	FORMATION	LITHOLOGY (CONGO)	LITHOLOGY (ZAMBIA)	FORMATION	SUB-GROUP
Katangan	Roan R	Mwashya (formerly Upper Mwashya) R 4	Kanwashi	sandstones or alternating siltstones and shales	dolomitic shales, grey to black carbonaceous shales, quartzites		Mwashia
			Kafubu	carbonaceous shales			
			Kamoya	dolomitic shales, siltstones, sandstones, including conglomeratic beds and cherts in variable position			
		Dipeta R 3	Kansuki R 3.4	(formerly Lower Mwashya): dolomites including volcaniclastic beds; Cu-Co	dolomites to arenitic dolomites interbedded with dolomitic shales; intrusive gabbros (formerly Carbonate Unit or Upper Roan)	Bancroft Kanwangungu RL 1 & RU 2	Kirilabombwe
			Mofya - R 3.3	dolomites, arenitic dolomites, dolomitic siltstones			
			R 3.2	argillaceous-dolomitic siltstones with interbedded sandstone or white dolomite; intrusive gabbros			
			R.G.S. - R 3.1	argillaceous-dolomitic siltstones ("Roches Gréso-Schisteuses")	shales with grit (Antelope Clastics)	Kibalongo - RL 3	
		Mines R 2	Kambove R 2.3	stromatolitic, laminated, shaly or talcose dolomites, locally sandstone at the base; interbedded siltstones in the upper part Cu-Co	dolomite, argillite beds at top	Chingola - RL 4	Kitwe
			Dolomitic shales R 2.2	R 2.2.2 & 3: dolomitic shales containing carbonaceous [illegible]	arkoses, sandy to dolomitic argillites	Pelito-arkosic RL 5	
				R 2.2.1: arenitic dolomite at the top and dolomitic shale at the base; pseudomorphs after evaporite nodules and concretions Cu-Co	arenites, argillaceous dolomites, argillites, dolomites, evaporites Cu-Co	Ore Shale RL 6	
			Kamoto R 2.1	stromatolitic dolomite (R.S.C.), silicified/arenitic dolomites (R.S.F./D.Strat.), grey argillaceous dolomitic siltstone at the base (Grey R.A.T.); pseudomorphs after evaporites at the contact with R.A.T. Cu-Co			
		R.A.T. R 1		red argillaceous dolomitic siltstones, sandstones and pelites ("Roches Argilo-Talqueuses")	conglomerates, coarse arkoses and argillaceous siltstones	Mutonda	Mindola RL 7
				base of the R.A.T. sequence - unknown	quartzites	Kafufya	
	< 880 Ma			basal pebble and cobble conglomerate	pebble and cobble conglomerate	Chimfunsi	
± 2050 Ma	KIBARAN & PRE-KIBARAN						

R, Ng, and Ku are the codes for the Roan, Nguba, and Kundelungu Groups, respectively.

Table 2
Former lithostratigraphic subdivisions of the Katangan in Congo, according to the interpretation of Cahen (1954, 1974), Cahen and Mortelmans (1948), François (1974, 1995), Lepersonne and Trottereau (1974)

François, 1974, 1987, 1995				Cahen and Mortelmans, 1948; Cahen, 1954, 1974; Lepersonne and Trottereau, 1974	
Kundulengu (Formerly Upper Kundulengu)		Tillite		**Kundulengu**	
Nguba (Formerly Lower Kundulengu)		Tillite		Grand Conglomérat & Mwashya "Conglomérat de Mwashya" =tillite ?	
Roan	**Mwashya**	Upper			
		Lower		Kansuki	**Roan**
	Dipeta				
	Mines				
	R.A.T.				

lithofacies, particularly at top of the R.A.T. ("Roches Argilo-Talqueuses") and within the Dipeta Subgroups where evaporite-bearing beds have been observed (Cailteux, 1983, 1994 and references therein). Detachments were also documented at top of the Zambian-type Upper Roan/Kanwangungu (Dipeta equivalent) lithofacies (e.g., at Musoshi and Kinsenda; Tshiauka et al., 1995). In Congo and at Mufulira, the displacement of the Katangan tectonic sheets generated evaporite-facilitated mega-breccias with blocs derived from the Roan, Nguba, and Kundelungu Groups (Cailteux et al., 1994; Cailteux and Kampunzu, 1995; Jackson et al., 2003). In the central part of the Lufilian Arc, the nappes and thrust sheets rest on rocks of the Kundelungu Group (Cailteux and Kampunzu, 1995; Kampunzu and Cailteux, 1999 and references therein). In this area, rocks of the Mwashya

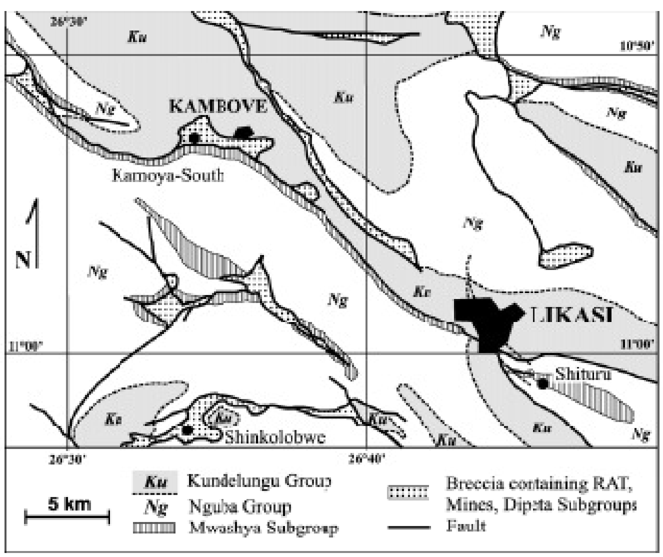

Fig. 2. Geological map of the Kambove–Likasi area (modified from Gécamines map); rocks of the Mwashya Subgroup occur along the southern side of the NW–SE tectonic lineament in the Kambove area, and in the core of the Kambove anticline in the Shituru area.

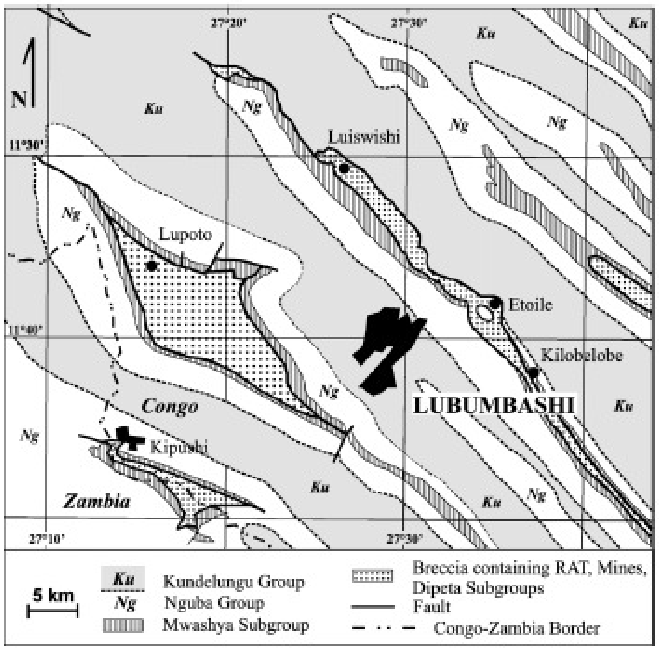

Fig. 3. Geological map of the Lubumbashi area (modified from Gécamines map); rocks of the Mwashya Subgroup occur along the southern side of the NW–SE tectonic lineament in the Luiswishi area, and form the northern and southern margins of the Kasonta anticline in the Lupoto area.

Subgroup generally outcrop along the southern side of NW–SE oriented tectonic lineaments (e.g., in the Kambove and Luiswishi areas; Figs. 2 and 3), or form the core of anticlines (e.g., in the Shituru, Lupoto, and Kipushi areas; Figs. 2 and 3). Rocks of the Mwashya Subgroup always overlie the megabreccia, and are themselves overlain by the Grand Conglomérat tillite/diamictite which forms the base of the Nguba Group. Deposition of this tillite/diamictite is constrained by zircon U–Pb SHRIMP maximum/minimum ages of 765/735±5 Ma (Key et al., 2001), and therefore corresponds to the global Sturtian glacial event. The unit is the equivalent of tillites in the Chuos Formation, west of the Otavi Mountain Land in Namibia, which have minimum ages of 746±2 Ma (Hoffman et al., 1996) and 741±6 Ma in the Gariep belt (Frimmel et al., 1996). It is also the equivalent of the 740±22 Ma tillite of the Jequitai Formation at the base of the Bambui Group in Brazil (Dardenne, 1978; Babinsky and Kaufman, 2003).

The Roan Group succession is characterized by alternating clastic and dolomitic sequences. In Zambia, it includes: (1) mostly arenaceous formations in the lower part (Mindola, Kitwe, and Antelope clastic units, previously forming the "Lower Roan"); (2) dolomites and dolomitic shales in the upper part (Carbonate Unit or Kanwangungu Formation); and (3) the Mwashya ("Mwashia") shales at the top. A similar succession typifies the Congo-type lithostratigraphy, but with a more dolomitic character: (1) dolomitic–argillaceous siltstones, sandstones, pelites (R.A.T. Subgroup) and arenaceous or siliceous dolomites, dolomitic shales and siltstones (Mines Subgroup) in the lower part; (2) dolomites interbedded with argillaceous and dolomitic siltstones (Dipeta Subgroup and Lower Mwashya Formation); and (3) the dolomitic shales, shales, and sandstones of the Upper Mwashya Formation at the top. Detailed observations on both sides of the Congo–Zambia border led to confident correlations between the two successions (Cailteux et al., 1994, 1995).

Rocks of the Lower and Upper Mwashya Formations show a lithofacies assemblage similar to those in formations of the Mines Subgroup in Congo (Oosterbosch, 1962; Cailteux, 1978, 1994; Lefebvre, 1979). Conditions of deposition alternated between intertidal and reefal (e.g., laminitic and massive stromatolitic or arenitic dolomites, occurrence of oolites, intraformational conglomerates, and pseudomorphs after evaporites), to more marine (dolomitic shales, siltstones, and feldspathic sandstones). The Lower Mwashya Formation contains mafic volcaniclastic rocks that were identified in the Shituru, Mulungwishi (Lefebvre, 1973, 1976), Kambove (Cailteux, 1983), and Luiswishi (Cailteux et al., 2003) areas (Fig. 4). These volcanic rocks are considered the extrusive equivalents to the gabbroic bodies emplaced within rocks of the Dipeta Subgroup (Congo) and "Upper Roan" (Zambia) Formations (Mendelsohn, 1961; Lefebvre, 1975, 1985).

Re-interpretation of the Katangan lithostratigraphy and orogenic event (Wendorff, 2000, 2003, 2004, 2005) suggests that

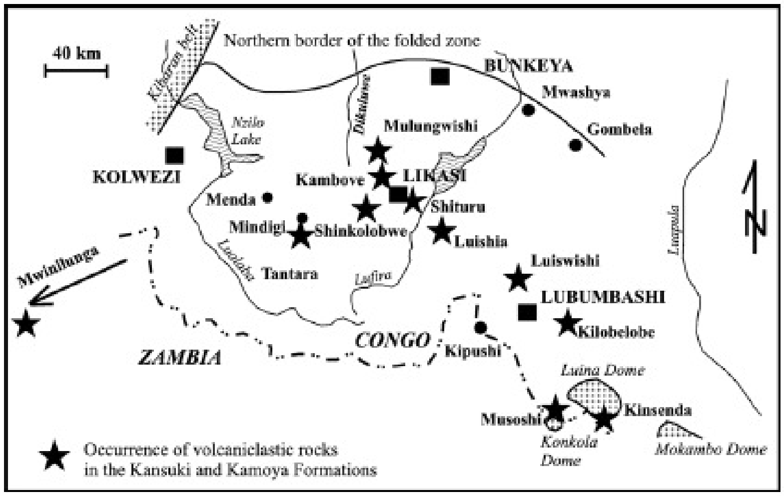

Fig. 4. Location map of the volcaniclastic rocks occurrences known in the Kansuki and Kamoya Formations.

the megabreccias were not generated by detachments and related thrusting of the Katangan rocks, but are olistostrome/debris-flow syntectonic conglomerates. Wendorff concludes that rocks of the R.A.T., Mines, and Dipeta Subgroups (renamed "Fungurume Group") were deposited in a foreland basin at the end of the Lufilian orogeny and are partly coeval with

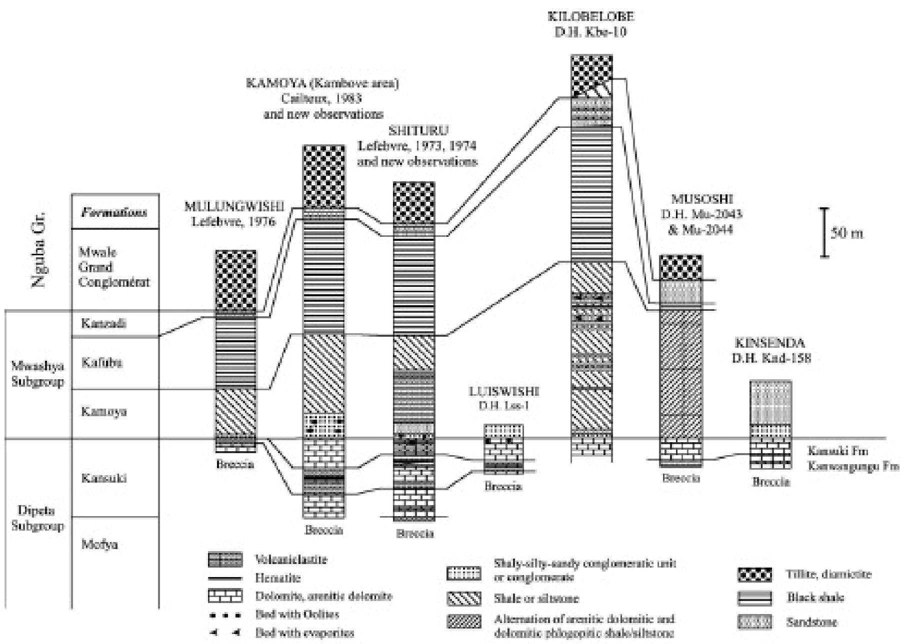

Fig. 5. Lithostratigraphy of the Mwashya Subgroup and Kansuki Formation in several areas of the Lufilian Arc.

rocks of the Sampwe Formation and Biano (formerly Plateaux) Subgroup (Table 1). Although the genesis of the Katangan megabreccias is not an objective of this paper, it is worth noting that much of the data collected in previous structural, lithologic, petrographic, geochemical, and geochronological studies (e.g., Demesmaeker et al., 1963; Cailteux et al., 1994; Cailteux and Kampunzu, 1995; Tshiauka et al., 1995; Kampunzu and Cailteux, 1999; Cailteux et al., 2005a; Kampunzu et al., 2005; Batumike et al., 2007-this volume) argue strongly against Wendorff's interpretation.

3. Definition of the Mwashya Subgroup

The Lower Mwashya Formation is marked by vertical and lateral variations of lithological facies that evolved in carbonate environment. It is 320- to 390-m-thick in the Mwashya–Gombela area in the northeast (Van den Brande, 1932, 1935) and only 80- to 120-m-thick in the Kambove–Mindigi–Menda area in the southwest (Francotte, 1959; Cailteux, 1983, 1994; Fig. 5).

The Upper Mwashya Formation is dominantly formed by finely bedded shales that display more or less constant thicknesses. Thicknesses are as much as 255 m in the northern Bunkeya–Mwashya–Gombela area (Francotte, 1959), ~230 m at Kambove (Cailteux, 1983), ~220 m at Shituru, and ~200 m in the southern Menda–Shinkolobwe area (Francotte, 1959). This formation was previously subdivided into two units: (1) dolomitic silty shales at the base (R 4.2.1); and (2) carbonaceous black shales, with some sandy shale or sandstone beds, at the top (R 4.2.2) (Francotte, 1959; François, 1973; Lefebvre, 1976, 1979; Cailteux, 1983, 1994).

The transition between the Lower and Upper Mwashya Formations is marked by alternating silicified dolomites, cherts and nodular dolomitic silty shales overlying the carbonate rocks of the Lower Mwashya Formation. Two oolitic dolomitic to silicified beds were also noted in this transitional unit: one is pisolitic and the other is characterized by ~0.1 mm in diameter oolites (Francotte, 1959; François, 1974). Osagia Nucleata f. nov. oncolites were identified in the Mwashya transition, indicating shallow-water conditions (Mathy, 1978). In the northern areas (e.g., in Bunkeya, Mwashya, Gombela; Fig. 1), the transition between Lower and Upper Mwashya Formations includes the Conglomérat de Mwashya. The Lower/Upper Mwashya boundary was placed by some workers at the base of that conglomerate and thus in contact with underlying nodular dolomitic shales (Van den Brande, 1935; Cahen, 1954; Francotte, 1959). However, in the southern areas (e.g., Kambove and Shinkolobwe; Fig. 1), Francotte (1959) and François (1973) did not observe the Conglomérat de Mwashya. They therefore proposed an arbitrary lithostratigraphic subdivision, putting the contact where silicified dolomite beds and cherts become sparse and give way to what are unequivocally shales and siltstones of the Upper Mwashya Formation.

Our results suggest dividing rocks of the former "Mwashya Subgroup" in Congo into four formations. From bottom to top these include the Kansuki Formation replacing the previous Lower Mwashya unit, and the Kamoya, Kafubu, and Kanzadi Formations replacing the previous Upper Mwashya unit (Table 1).

3.1. Kansuki Formation

The Kansuki Formation contains carbonate rocks and related volcaniclastics of the former "Lower Mwashya" (Table 1; Fig. 5), and corresponds to the Kansuki Group of Cahen (1974; Table 2). Kansuki is the name of a 30-km-long alignment of hills, east of Kolwezi, where these rocks outcrop and mark the southern side of the Kakangwe–Fungurume tectonic lineament (Fig. 1).

The transition from rocks of the Dipeta Subgroup into those of the overlying Kansuki Formation is generally hidden by a tectonic break in Congo. The Dipeta Subgroup is characterized by predominantly shallow-water and evaporite-bearing white to red-brown dolomite, especially towards the top (François, 1987; Cailteux et al., 1994). In Kambove, Luiswishi, and several other areas, dolomitic rocks of the Kansuki Formation overlie the so-called "tectonic breccia" (i.e., a structural contact between rocks of the Dipeta Subgroup and Kansuki Formation). At Shituru, a normal sedimentary contact was reported with Dipeta-type, grey to red, sandy, oxidized rocks, which contain beds of pink dolomite with ferruginous oolites, that are called "Groupe de Shituru" (Lefebvre, 1974). In the Tenke–Fungurume area, Leruite (in François, 1987) documented dolomites of the "Lower Mwashya" conformably overlying havane shales or siltstones and dolomites of the "Mofya II B" (also called "Dipeta IV B" or "R 3.4.2"). However, the description of these rocks suggests volcaniclastic beds and related dolomites of the Kansuki Formation, respectively.

At Kambove, the Kansuki Formation (80-m-thick) is defined as an alternating succession of massive dolomites containing stromatolites, finely bedded intertidal-type dolomites, and irregularly bedded, talc-bearing dolomites that contain traces of microfossils (Cailteux, 1983). Conditions of deposition of these rocks were similar to those of the Kambove Formation (Cailteux, 1978; Lefebvre, 1979; Cailteux, 1983, 1994). In its upper part, the succession is characterized by numerous erosional surfaces and intraformational conglomerates, indicating increasingly shallower water conditions towards the top of the Kansuki Formation. At Shituru, this unit is as much as 80-m-thick and consists of dolomites and dolarenites ("Formation à Minerai Noir" and "Formation à Minerai Ocre"), which are hydrothermal altered (Lefebvre, 1974). At Luiswishi, it is present as a ~37-m-thick unit containing mainly massive algal to bedded arenitic silicified dolomites, and some interbedded dolomitic argillaceous siltstones and talc-bearing dolomites. One bed (~1.5-m-thick), with 0.1–0.5 mm in diameter oolites, occurs at the top of the dolomites at Luiswishi and Tilwezembe. At Kilobelobe, ~22 km southeast of Luiswishi, along the same tectonic lineament (Fig. 1), the Kansuki Formation consists of a >17.5-m-thick carbonate succession (Fig. 5). It contains a >13.4-m-thick argillaceous, talc-bearing irregularly-bedded dolomite that is marked locally by intraformational conglomerates, slumping and decimetre-thick massive dolomite beds at the base, and a 4.1-m-thick white arenitic dolomite at the top.

An abundance of volcaniclastic rocks are interbedded with the dolomite of the Kansuki Formation and define a regional "volcanic belt" (Fig. 4) observed from the Shinkolobwe, Kambove, Shituru, Mulungwishi, and Luishia areas in the west

(Lefebvre, 1973, 1974; Machairas, 1974; Lefebvre, 1976; Cailteux, 1983; Lefebvre, 1985; Cailteux, 1994), to Luiswishi, and to the Musoshi and Kinsenda areas along the Congo-Zambia border in the southeast (Tshiauka et al., 1995; this paper). The occurrence of comparable rocks in the Mwinilunga area, northwestern Zambia (Key et al., 2001), suggests an extension of this belt to this region. At Kambove, two units of stratified to massive upward fining, mafic, grey-green to green-brown debris flow tuffs were deposited within the carbonates; they are marked both by a phlogopite and a green to colourless chlorite matrix containing plagioclase (oligoclase), quartz, dolomite, tourmaline, and leucoxene–rutile (Cailteux, 1983, 1994). The plagioclase forms crystals partly or completely replaced by quartz (Fig. 6A), and shows many inclusions of Fe–Ti oxides. Rounded to sub-rounded grains of chlorite and phlogopite (~100 μm in diameter) commonly contain Fe–Ti oxide minerals, and also epidote (Fig. 6B). They may represent ghosts of Fe–Mg minerals and/or basaltic lava fragments. Locally, pyrite and chalcopyrite (containing exsolutions of bornite) have grown around Fe–Ti oxide grains. Both lower and upper tuffs, respectively 12- and 11-m-thick, are separated by a white, partly recrystallized dolomite (<3- to 4-m-thick). A

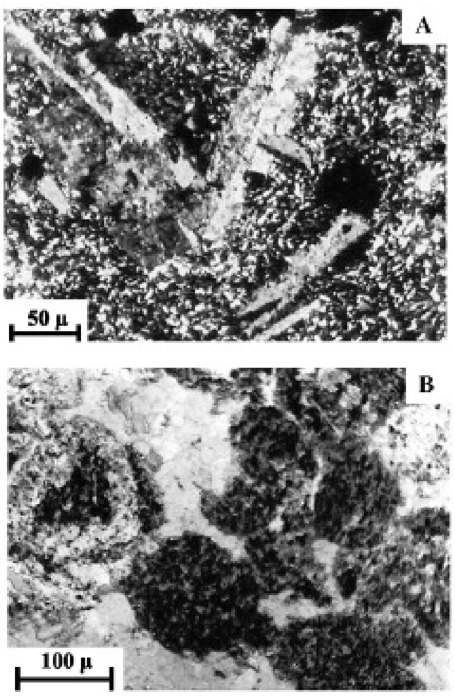

Fig. 6. Volcaniclastic rocks in the Kansuki Formation of the Kambove area; A: partly silicified plagioclase in a chloritic matrix, drill hole KW-236, sample 160; B: rounded to sub-rounded grains of phlogopite (in dark), probably ghost of Fe–Mg minerals (olivine ?) and/or basaltic flow fragments, drill hole KW-236, sample 235.

massive hematite bed (~0.8- to 2.4-m-thick in the Kamoya area) or interbedded hematite with sideritic or hematitic carbonate rocks sometimes replace the upper part of the dolomite (Cailteux, 1983, 1994). This hematite bed (≤5-m-thick) has been noted at many places along the exposed rocks of the Kansuki Formation in the folded Lufilian Arc (François, 1974). The position of the bed suggests that the iron has been remobilised from the volcaniclastic material. The base of the overlying upper tuff contains millimetre-size clasts of hematite probably originating from the underlying hematite bed, whereas the top is marked by a progressively increasing dolomitic content. At Shituru, two major volcaniclastic events also are defined by rocks at the same stratigraphic position, represented by a 3- to 6-m-thick, coarse- to fine-grained chloritic tuff and lapilli tuff ("Roches de Kipoï" RK 1 and RK 2) containing plagioclase, quartz, phlogopite and tourmaline (Lefebvre, 1973, 1974). Volcanic breccias containing 0.5-cm to decimetre-size clasts occur in the RK 2, indicating eruption of lava flows into or under water. Both tuffs are separated by dolomitic rocks (12- to 22-m-thick), which are marked locally by massive hematite at the top. Two volcaniclastic beds (respectively 2.8- and 2.9-m-thick) were identified in the same lithostratigraphic position at Luiswishi (Cailteux et al., 2003). They are separated by a 4.4-m-thick dolomite containing clasts of volcaniclastic rock and a 0.1-m-thick hematite bed overlying the dolomite.

Twelve samples of these volcaniclastic rocks were collected from drill hole cores from the Kambove (8 fresh samples), Shituru (2 fresh samples with some weathering in fractures) and Luiswishi (2 weathered samples) areas for chemical analyses. Major, trace, and rare earth element (REE) analyses of the samples were conducted using XRF spectrometry, atomic absorption spectrometry (AAS) and inductively coupled plasma mass spectometry (ICP-MS), respectively. Results (Table 3) show that the volcaniclastic rocks from these three areas have common major element characteristics. They are undersaturated in SiO_2 (36.1–47.9 wt.%), CaO- and Na_2O-poor, and MgO-rich, showing a $Mg/Mg+Fe^{2+}$ ratio of 0.5–0.8 (calculated with $Fe^{3+}/Fe^{2+}=0.2$). They also have a high LOI, ranging between 4.6 and 15.1 wt.%. Fresh samples from the Kambove area and one weathered sample from the Luiswishi area are rich in K_2O (3.6–9.2 wt.%), whereas those from the Shituru area and one from the Luiswishi area are poor in K_2O (<0.5 wt.%). These whole-rock compositions contrast with those of primary basalts (Sun and Mc Donough, 1989); they largely confirm petrographic observations and suggest mobility of the elements either during carbonate diagenesis or during later hydrothermal alteration/metamorphism. Assuming that the high LOI is largely due to the presence of carbonate and that loss of K_2O mainly results from weathering, the fresh samples from the Kambove area (with lowest LOI and highest K_2O) can be considered as the most representative. Based on a LOI-free correction, the whole-rock data may be compared with those data of gabbros emplaced into rocks of the Upper Roan Group (Zambia) and Dipeta Subgroup (Congo), and from igneous bodies interbedded in the Grand Conglomérat (Mendelsohn, 1961; Lefebvre, 1975; Kampunzu et al., 1993, 2000). Some comparable modified-alkali (e.g., alkali-rich) and SiO_2-undersaturated compositions of those

Table 3
Chemical composition of fresh samples from the volcaniclastic beds in the Kansuki Formation from Kambove (drill hole KW-236) and Shituru (drill hole S-1), and weathered samples from Luiswishi (drill hole LSS-1)

Location	Kambove–Ouest								Shituru		Luiswishi	
	Lower bed (D.H. KW-236)			Upper bed (D.H. KW-236)					Volcaniclastic breccia		Lower bed	Upper bed
Sample no.	LB/1	LB/2	LB/3	UB/4	UB/5	UB/6	UB/7	UB/8	S-1/1	S-1/2	LSS-1/1	LSS-1/2
m	105.0–110.5	110.5–114.5	114.5–119.3	122.7–126.4	126.4–127.4	127.4–130.9	130.9–135.0	135.0–137.5	104.3–106.6	127.8–125.5	55.1–59.8	65.6–69.3
Major elements (wt.%)												
SiO_2	40.16	41.88	43.04	43.82	39.99	42.93	42.10	36.10	44.66	36.52	47.86	42.89
TiO_2	1.38	1.45	1.57	2.48	2.29	2.39	2.37	2.25	3.17	2.51	1.01	2.02
Al_2O_3	12.69	12.58	13.71	12.89	12.07	12.31	12.29	11.72	12.92	12.33	8.7	12.37
Fe_2O_3	11.90	12.68	15.98	13.30	14.08	13.56	14.11	14.35	10.59	29.26	9.39	13.33
FeO												
MnO	0.13	0.16	0.08	0.05	0.09	0.07	0.07	0.12	0.03	0.12	0.18	0.20
MgO	11.02	14.79	11.48	13.43	11.39	12.41	12.41	10.51	18.62	10.77	19.16	5.50
CaO	2.29	2.13	0.42	1.23	2.80	2.74	2.68	3.38	0.45	0.49	1.97	2.92
Na_2O	0.09	0.14	0.03	0.88	0.98	1.25	0.99	0.62	0.01	0.31	0.08	0.03
K_2O	5.98	4.63	5.29	5.42	4.30	5.55	6.26	3.66	0.08	0.18	0.22	9.20
P_2O_5	0.16	0.15	0.16	0.27	0.26	0.31	0.29	0.27	0.16	0.27	0.25	0.24
Cr_2O_3	0.02	0.02	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	<0.01	0.01
SrO	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.01
BaO	0.04	0.03	0.03	0.05	0.02	0.05	0.08	0.06	0.03	0.02	0.01	0.05
LOI	12.95	7.58	6.74	4.58	9.88	4.65	4.72	15.10	8.26	6.14	9.98	8.69
Trace elements (ppm)												
Cu	401	171	527	171	1106	213	125	162	1696	1548	–	–
Co	391	266	211	86	152	109	135	141	189	209	–	–
Ni	167	163	248	155	140	188	367	345	141	183	–	–
Zn	279	469	513	153	176	134	134	154	91	72	–	–
Rare Earth elements (ppm)												
Ce	16.8	28.6	27.5	53.0	41.0	48.2	44.6	37.4	71.9	22.3	59.3	53.5
Dy	2.6	3.1	3.3	5.5	4.3	5.2	5.0	4.3	5.4	3.2	4.2	4.7
Er	1.4	1.8	1.8	3.1	2.4	2.8	2.7	2.4	3.1	2.1	2.6	2.6
Eu	0.8	1.3	1.3	2.0	1.7	2.0	1.8	1.6	1.9	1.0	1.0	1.7
Gd	2.6	3.7	3.7	6.5	5.1	6.0	5.6	5.0	6.5	2.6	4.6	5.5
Ho	0.5	0.6	0.6	1.1	0.8	1.0	0.9	0.9	1.1	0.7	0.9	0.9
La	8.8	16.4	15.2	25.1	19.8	23.0	21.2	17.8	38.0	13.3	32.5	29.5
Lu	0.2	0.2	0.2	0.4	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.3
Nd	10.0	16.5	16.0	29.2	22.8	26.4	24.7	21.0	35.3	10.4	24.0	25.4
Pr	2.3	4.0	3.7	6.7	5.2	6.1	5.6	4.8	8.9	2.7	6.5	6.5
Sm	2.4	3.6	3.5	6.4	5.0	5.8	5.4	4.6	7.1	2.2	4.2	5.3
Tb	0.4	0.6	0.6	1.0	0.8	0.9	0.9	0.7	1.0	0.5	0.7	0.8
Th	4.0	3.0	4.0	5.0	6.0	5.0	5.0	6.0	3.0	2.0	8.0	4.0
Tm	0.2	0.2	0.2	0.4	0.3	0.4	0.3	0.3	0.4	0.3	0.4	0.3
U	2.5	3.5	2.9	1.7	2.0	1.6	2.4	2.0	2.5	1.6	1.9	1.3
Y	13.6	16.0	17.6	27.9	21.9	26.3	25.6	22.2	27.0	18.6	23.4	24.0
Yb	1.3	1.4	1.6	2.5	2.0	2.3	2.1	2.0	2.5	1.9	2.3	2.1

Major element XRF and Rare Earth element ICP-MS analyses by ALS Chemex, Canada; trace element AAS analyses by the STL Laboratory, Lubumbashi (Congo).

mafic rocks are attributed to interactions with hydrothermal/metamorphic fluids (Kampunzu et al., 1993). Samples from the Kambove, Shituru, and Luiswishi cores also have consistent REE compositions (Fig. 7). The chondrite-normalized REE patterns display a light REE enrichment and are quite similar to those of mafic igneous rock occurring in the Lufilian Arc, which are interpreted to have been emplaced in a continental rift setting (Kampunzu et al., 1993; Tembo et al., 1999; Kampunzu et al., 2000). Trace element concentrations are slightly higher than the normal Clarke values for some base metals in mafic rocks (e.g., Cu = 23–1696 ppm, Co = 107–391 ppm, Ni = 140–367 ppm, Zn = 72–513 ppm). Except for samples that include supergene oxides in veins (DH S-1), most of the base metal concentrations are typical of the unmineralised, high background sedimentary rocks of the Roan group.

3.2. Kamoya Formation

The Kamoya Formation includes the lower part of the previous "Upper Mwashya" and transition rocks disputed between

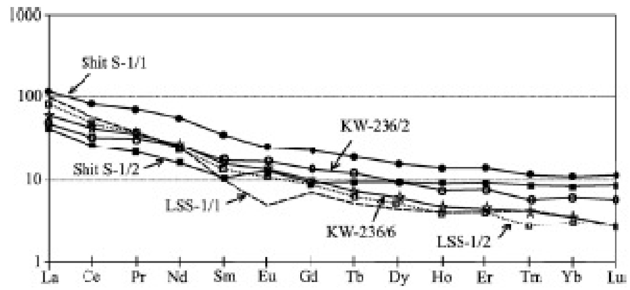

Fig. 7. Chondrite-normalized REE abundances in the volcaniclastic rocks of the Kansuki Formation at Shituru (drill hole S-1, samples 1 and 2), Kambove (drill hole KW-236, samples 2 and 6) and Luiswishi (drill hole LSS-1, samples 1 and 2) (see Table 3).

"Lower" and "Upper Mwashya" (Table 1). It is characterized by irregularly bedded dolomitic shales or siltstones that alternate with chert and conglomeratic beds in the basal part of the formation. These rocks commonly contain an important quartz, feldspar, muscovite, and biotite grain fraction in the 0.01- to 0.10-mm-size range. Geochemical data from the Mulungwishi area (Lefebvre, 1976) show relatively high concentrations of MgO and CaO, and a decreasing carbonate content (from 22% to 3% dolomite) with increasing SiO_2 (from 48% to 59%) towards the top of the formation.

The good exposure of the entire Kamoya Formation, particularly of the basal member overlying the Kansuki dolomite in the Kamoya-South open pit (Kambove area; Fig. 2), led to the name of this formation. Previous observations on drill cores (Cailteux, 1983) and new detailed field observations along the access ramp to this open pit show a succession totalling ~100 m in thickness. The basal unit (~27-m-thick; Table 4; Fig. 5) is marked by alternating siltstones which include several discontinuous, dark grey to black, massive chert beds (Fig. 8A) and matrix-supported, unsorted conglomerate beds with mm to dm in diameter, sub-angular to rounded chert clasts (Fig. 8B, C, D). The matrix of the conglomerates is a ferruginous and/or silicified siltstone containing quartz, tourmaline, chlorite, muscovite, and biotite grains. Clasts include intraformational chert fragments (Fig. 8A) and well-rounded cherty rocks. The cherty clasts show an alternation of opaline layers marked by black impurities (carbon?) and microcrystalline layers containing pyrite and quartz grains, with lesser tourmaline, titanite, zircon, and euhedral apatite. The clasts are marked by fractures filled by quartz, apatite, and pyrite. The main conglomeratic unit includes two oolitic beds that were considered a part of the Kansuki Formation in the previous lithostratigraphy (François, 1974). One is a chert containing silicified oolites, pisolites, chert clasts (Fig. 8E), and rare clastic quartz, chlorite, and titanite grains. Oolites or pisolites show zonation of crypto-crystalline chert containing black impurities (carbon?) and, sometimes in their centre quartz grains surrounded by finer chert. The second oolitic bed shows similar features, but only with mm-size oolites. Clasts of chert containing oolites also occur in the conglomeratic unit. Some interbedded dolomitic shales contain millimetre- to centimetre-size pseudomorphs after anhydrite nodules and pseudomorphs after gypsum crystals, indicating shallow water conditions. Near the bottom of the unit, the shales are characterized by a chloritic matrix, suggesting a correlation with the Shituru RK 4 volcano-sedimentary shales. The top of the unit is characterized by an increasing clastic fraction.

Table 4
Detailled lithology of the 26.6 to 26.9-m-thickness conglomeratic complex unit at the base of the Kamoya Formation in the Kambove area (drill holes KW-234, -236, -240 in Cailteux, 1983, and new observations along the access ramp of the open pit)

Lithology	
Chert (0.1 m)	Whitish bedded chert
Siltstone with clasts (1.4 m)	Siltstone containing beds with well-rounded cm grey-black to red chert clasts
Chert (0.1 m)	Grey-black to red ferruginous chert
Siltstone with clasts (1.3 m)	Siltstone containing locally well rounded to elongated cm to dm clasts of chert, oriented to the bedding (Fig. 8D)
Chert (0.1–0.2 m)	Grey-black to red ferruginous chert
Siltstone with clasts (0.15 m)	Siltstone containing some mm clasts of chert and intraclasts of siltstone; carbonaceous to the top
Chert (0.2–0.3 m)	Grey-black chert
Siltstone with clasts (2.7 m)	Siltstone containing well-rounded mm clasts of chert to the bottom
Conglomerate alternating with two oolitic beds (5.2 m)	Siltstone containing mm clasts of black opaline chert and cm to dm clasts of dark grey chert/silicified dolomite (Fig. 8B, C); presence of two oolitic cherty beds: one with silicified oolites and pisolites (Fig. 8E), the second with silicified oolites
Shale/siltstone with clasts (1.2 m)	Shale/siltstone containing well-rounded cm clasts of chert and 1–2-cm-thick discontinuous beds of chert; pseudomorphs after anhydrite nodules and after gypsum crystals
Chert (0.10–0.15 m)	Grey-black chert
Siltstone with clasts (1.2 m)	Siltstone containing well-rounded cm clasts of black to red chert; occurrence of 2–5-cm-thick partly broken beds of chert, and derived clasts in the siltstone (Fig. 8A); clasts of hematite
Chert (0.05–0.10 m)	Grey-black to red ferruginous chert
Shale/siltstone (8.4 m)	Grey to brown dolomitic shale or siltstone

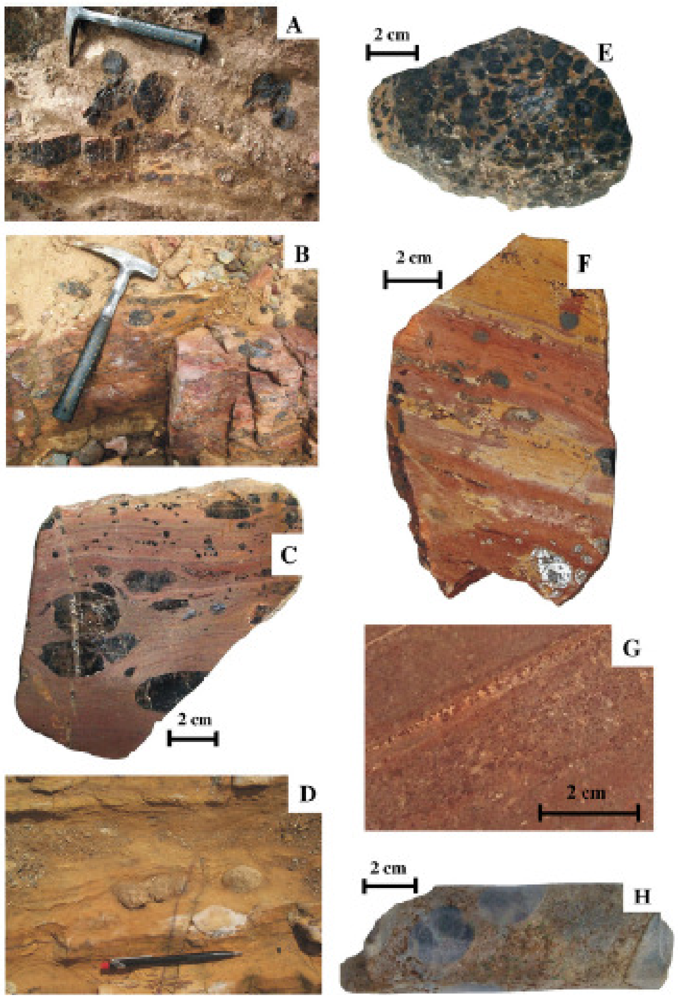

Fig. 8. Kamoya Formation, conglomeratic complex unit. (1) along the access ramp to the Kamoya open pit: (A) silty shales including a discontinuous dark grey to black massive chert bed and containing centimetre-size rounded clasts of chert; (B) matrix-supported (silty shale) bedded conglomerate containing millimetre- to decimetre-size rounded clasts of chert; (C) matrix-supported (silty shale) bedded conglomerate containing millimetre- to decimetre-size rounded clasts of chert and sub-angular millimetre-size dark-grey to black opaline clasts of chert; (D) matrix-supported (silty shale) bedded conglomerate containing well-rounded centimetre- to decimetre-size clasts of chert oriented parallel to the bedding; (E) bed containing cherty pisolites. (2) Luiswishi drill hole LSS-1: (F) matrix-supported (silty shale) bedded conglomerate containing millimetre- to decimetre-size rounded clasts of chert (sample at 6.9 m); (G) Alternating sandstones and microconglomerate layers at the base of the Kamoya Formation (sample at 21.1 m). (3) Kinsenda drill hole KND-158: (H) matrix-supported (coarse sandstone) conglomerate containing well-rounded centimetre-size clasts of white chert.

In the northern facies (e.g., in the Mwashya and Bunkeya areas; Van den Brande, 1932, 1935), the succession is defines by 190- to 220-m-thick, greenish-grey shales and siltstones. These clastic units include a conglomeratic bed (Conglomérat de Mwashya) and ferruginous cherty and oolitic beds near their base. The Conglomérat de Mwashya is an approximately 1.5-m-thick matrix-supported conglomerate, consisting of 10–20 vol. % unsorted and well rounded clasts (0.1–5.0 cm in diameter) with a greenish-grey argillaceous matrix (Van den Brande, 1932). The clasts consist mainly of dolomite, partly or completely silicified oolitic carbonate, and rare pinkish chert, reddish-brown quartzite, and granite. The matrix also contains many ~0.01 mm in diameter and sub-angular grains of quartz, feldspar, micas, and chert.

An approximately 3-m-thick conglomerate, called "Poudingue polygénique", comparable to the Conglomérat de Mwashya, has been documented at Mulungwishi (Lefebvre, 1976; Fig. 5). It overlies the Kansuki Formation that includes from top to bottom: a 0.1-m-thick massive dolomite, a volcaniclastic bed, and arenitic dolomites. The Poudingue polygénique is a matrix-supported conglomerate containing well-rounded 0.5 to 50 mm in diameter, unsorted clasts. Most of the clasts are grey and massive dolomite or arenitic dolomite. Clasts of black chert (containing carbonate and iron oxides), argillaceous siltites, volcanoclastite, microcline, quartz, and feldspar have also been documented. This conglomerate is overlain by a 49.0-m-thick, greenish-grey, dolomitic and silty shale unit that contains common chert beds.

Descriptions made at Shituru (Lefebvre, 1973, 1974; Fig. 5) suggest that the Kamoya Formation includes a 1- to 3-m-thick siltstone bed containing silicified clasts with black oolites, overlain by a 2- to 4-m-thick volcanic breccia, at the base. These basal units are overlain by chloritic/tuffaceous sandstones (~11-m-thick), chloritic sandy pelites (RK 3 "tuff and lapilli tuff", 54 m), greenish-grey dolomitic silites or silty shales containing chert beds, and (RK 4) chloritic shales or pelites containing conglomeratic beds (36-m-thick). In this ~105-m-thick succession, the RK 3-, and RK 4 rocks may originate from reworking and deposition in the sedimentary basin of volcanic material originally extruded during the RK 1 and RK 2.

In the Luiswishi area, dolomite of the Kansuki Formation is overlain by a >12.6-m-thick succession of alternating sandstones and siltstones, which includes two matrix-supported conglomeratic beds that are similar to those in the Kamoya Formation (Figs. 5 and 8F). These conglomerates include an argillaceous matrix of quartz and chlorite grains (~0.01 mm in diameter), with ~10 vol.% unsorted and well-rounded clasts (~0.1 to 3.0 cm in diameter) of silicified arenitic dolomite. Some beds contain intraclasts of shale or siltstone. In this area, the base of the Kamoya Formation consists of sandstones including reddish micro-conglomerate beds that show a silicified matrix containing chert and silicified dolomite clasts (≤1 mm in diameter; Fig. 8G).

The Kamoya Formation at Kilobelobe is a 182-m-thick succession of massive to bedded siltstones or fine-grained sandstones that contain mainly quartz and feldspar grains (0.01–0.1 mm in diameter) and <5 vol.% carbonate (Fig. 5). The siltstones are marked by millimetre- to decimetre-thick, dark grey, argillaceous layers/beds that increase in frequency and thickness upwards. The succession also includes decimetre- to metre-thick evaporitic siltstones (pseudomorphs after gypsum, ≤5 mm in diameter), ≤8-dm-thick volcaniclastic beds, and centimetre-thick chert layers. A 3.6-m-thick basal unit includes millimetre- to centimetre-size clasts of arenitic carbonate from the underlying Kansuki Formation, quartzite, and chert within a white silty to sandy or a weathered dark brown matrix. This bed is interpreted to be the equivalent to the Conglomérat de Mwashya. It is overlain by a 5.8-m-thick grey feldspathic sandstone (0.1 to ≥1 mm grain size).

3.3. Kafubu Formation

The Kafubu Formation (~90-m-thick at Shituru, ~110-m-thick at Kambove, ~80-m-thick at Mulungwishi; Fig. 5), named after the Kafubu River that crosses these rocks in the Lubumbashi area (Dumont et al., 1997), is mostly finely bedded, grey to dark grey or black, pyrite-bearing shale sequence (Francotte, 1959; François, 1973; Lefebvre, 1976, 1979; Cailteux, 1983). The rocks contain fine-grained detrital quartz, feldspar, muscovite, and biotite, and are characterized by a high carbon content and low carbonate abundance. Values of 5.57 wt.% C, <1.25 vol.% carbonate, and 49–65 wt.% SiO_2 characterize these rocks at Shituru (Ngoie et al., 2003). This formation represents a typical and homogeneous regional lithostratigraphic marker, extending from Menda in the south-west part of the Lufilian Arc (François, 1973), north to Mufulira, Chambishi–Nkana, and Luanshya in the southeastern part of the Zambian Copperbelt (Mendelsohn, 1961).

Abundant pyrite occurs locally, particularly at Shituru where it forms significant stratiform concentrations (4.5 to 6.0 vol.%; Ngoie et al., 2003). Pyrite occurs as fine, disseminated, framboidal or euhedral grains, as pseudomorphs after small nodules of anhydrite, and as centimetre-thick, lenticular, layer-parallel impregnations. Some pyrite in fractures and faults suggests remobilisation during compressional tectonics.

The Kafubu Formation at Kilobelobe (Fig. 5) is a 140-m-thick, banded, dark-grey to black, carbonaceous, pyritic shale, marked locally by alternating millimetre-thick shale and sandy–silty carbonate layers, erosional surfaces, and gravity intraformational conglomerates. Massive to irregularly bedded, silty, grey to black pelite occurs as centimetre- to decimetre-thick beds along the transition with rocks of the overlying Kanzadi Formation.

3.4. Kanzadi Formation

Documented at Kanzadi (Nguba area) by Lefebvre (1979), the Kanzadi Formation is characterized by millimetre/centimetre- to metre-thick beds of pink to green feldspathic sandstone, arkose or conglomeratic arkose, alternating with shale or siltite. These sandstones/arkoses, indicating tidal flat or fluvial (e.g., deltaic-type) regressive deposition (Lefebvre, 1979), were recorded in the Mwashya–Gombela, Tantara (Shinkolobwe), and Lubumbashi areas (Van den Brande, 1935; Rorive, 1952; Cahen, 1954; Lefebvre, 1979; Buffard and Muhagaze, 1981; Buffard, 1988). In the Lubumbashi area (e.g., at Kilobelobe; Figs. 1 and 5), the formation (≤25–37 m in total thickness and several kilometres in length at Kilobelobe) consists of discontinuous and alternating coarse-grained (≤1 mm), quartzitic-feldspathic, massive, and fine-grained, quartzitic, bedded sandstones. The bedded sandstones display spectacular cross-bedding and ripple marks (Buffard and Muhagaze, 1981). At Kilobelobe, the formation includes siltstone beds, and locally is marked by a ≤1.5-m-thick massive or irregularly bedded argillaceous siltstone at the base.

In the central area, the sandy character of this formation is strongly diminished and only varve-type rhythmic alternations of millimetre- to centimetre-thick pale grey sandy–silty layers occur with black shale (e.g., at Mulungwishi; Lefebvre, 1976).

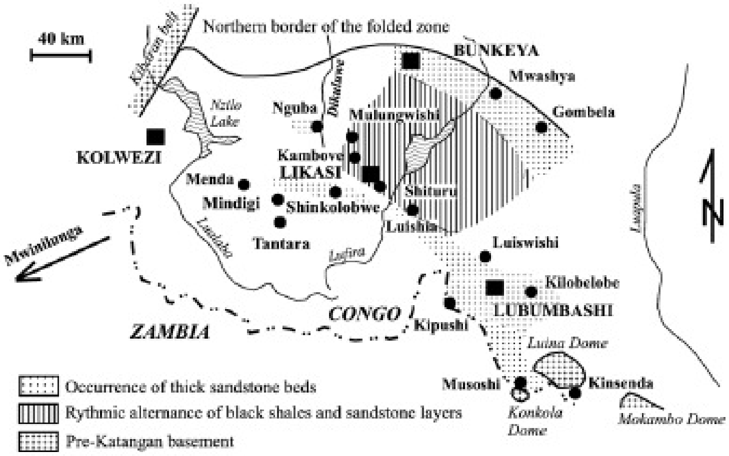

Fig. 9. Occurrences of the Kanzadi sandstones and rhythmic alternating layers of black shales/sandstones in the Lufilian Arc (modified from Buffard, 1988).

The carbonate content is very low (~0.40 vol.% at Shituru; Ngoie et al., 2003). Geographical distribution of the sandstones indicates that they are mostly developed along the northern and southern borders of the Lufilian Arc, whereas the rhythmic deposition of black shale and sandstone mainly occurred in the central part (Fig. 9).

The transition between rocks of the Mwashya Subgroup and Grand Conglomérat shows alternating siltites or shales and tillitic beds in the Shituru, Mwepu–Buseba, and Kambove areas (Robert, 1928; Van den Brande, 1935; Lefebvre, 1973, 1979; Cailteux, 1983, 1994). Shales and siltites of the Mwashya Subgroup at this contact are marked by load deformations, slumping, erosional channels, gravity intraformational breccias, and fracturing. In the north-western part of the Tenke–Kolwezi area (e.g., at Kalumbwe, Chabara, Mamfwe, and Kabulungu), the Grand Conglomérat shows a discordant contact at different lithostratigraphic positions with the Mwashya succession (François, 1973; Cailteux, 1991). Locally, rocks of the Mwashya Subgroup are absent, and the tillite/diamictite directly overlies dolomites of the Kansuki Formation. At Kilobelobe (Fig. 5), this transition consists locally of ≤20-m-thick, massive to irregularly bedded, silty pelite or argillaceous siltstone marked by load deformations. This pelite or siltstone unit decreases in thickness and disappears a few hundreds metres further to the northwest. In these conditions, the Grand Conglomérat thus directly overlies the sandstones of the Kanzadi Formation and contains many millimetre- to centimetre-size clasts of these sandstones. The Grand Conglomérat in the Kilobelobe area also contains clasts of black shale of the Kafubu Formation.

3.5. Mwashya Subgroup in Zambia-type lithology

In the southeastern part of the Copperbelt, what is called "Mwashia" (150- to 650-m-thick) in the Zambia-type lithology, is the equivalent to the former "Upper Mwashya" formations in Congo (Cailteux et al., 1994). It is represented by dominantly fine-grained and finely bedded argillaceous carbonaceous shales (Mendelsohn, 1961). In the Chambishi–Nkana area (Mendelsohn, 1961), rocks of the Mwashya Subgroup consist of lower grey argillites (150- to 300-m-thick), which include thin carbonate beds, and upper carbonates (~240-m-thick) with interbedded thin shales. Conglomeratic beds occur in a more arenaceous facies, in the lower part of the argillites. The base of the argillites is marked by a conglomerate that consists a greenish-grey, dolomitic to argillaceous, and arenaceous matrix containing sub-angular to sub-rounded clasts (1 to 10 cm in diameter) of dolomitic sandstone. These beds look like similar to the conglomerate beds in the Kamoya Formation in Congo. In the Mufulira region, the Mwashya Subgroup is formed by shale, black carbonaceous shale, grey glassy quartzites, and minor dolomite and grit beds (Mendelsohn, 1961). In the Butondo stream area, rocks of the subgroup include from bottom to top: (1) ~30-m-thick quartzite; (2) ~45-m-thick carbonaceous shale; and (3) ~35-m-thick dolomite. Load deformation and slump of rocks of the Mwashya Subgroup have been reported at the transition with the Grand Conglomérat (Binda and Van Eden, 1972). The base of the Mwashya succession in Konkola is marked by a (carbonated-altered-? and argillaceous) completely disaggregated matrix-supported conglomeratic bed with well-rounded silicified clasts containing silicified black oolites; this bed might be correlative with to the Conglomérat de Mwashya (Cailteux, 1994).

At Musoshi, along the Congo–Zambia border (Fig. 1), rocks of the Mwashya Subgroup observed in drill holes Mu-2044 and Mu-2043 overlie those of the Kanwangungu and Kibalongo Formations; the transition is a breccia zone with deformed/fractured fragments from all three units (Fig. 5; Table 1). The equivalent of the Kansuki Formation (29-m-thick) is a massive to bedded, grey to white, arenitic dolomite, which includes some dolomitic shaly beds or layers containing pseudomorph after anhydrite nodules at the top of the sequence. A 7-m-thick volcaniclastic bed occurs at the base of the sequence, at the contact with the breccia. The equivalent of the Kamoya Formation (131 m in total thickness) is present as an alternating succession of millimetre- to centimetre-thick white to grey coarse dolomitic sandstone (0.01 to 1 mm grain size) and grey-green shaly to silty phlogopitic layers. No chert, oolites, or conglomeratic beds have been observed. The overlying Kafubu Formation is represented by a 7-m-thick, finely bedded, grey to black, carbonaceous, silty, phlogopite-bearing, dolomitic shale. At the top of the succession, the Kanzadi Formation shows 24-m-thick, massive to bedded, white to grey, feldspathic, carbonate-poor sandstones (0.1 to 0.5 mm grain size). The sandstones are marked by micro-conglomeratic beds (0.1 to >1 mm grain size) at their base and by millimetre- to decimetre-thick beds of grey-green micaceous shales in their centre. The Grand Conglomérat concordantly overlies the sandstones of the Kanzadi Formation.

At Kinsenda (Fig. 1; drill hole Knd-158; Fig. 5), the Kamoya Formation (>58-m-thick) consists of fine- to coarse-grained sandstones, including silty shale beds. It is marked at its base by a coarse sandy matrix-supported conglomerate unit (~14-m-thick), containing well-rounded (1 to 5 cm in diameter) clasts of quartz and chert (Fig. 8H). The underlying Kansuki Formation includes from top to bottom a 16-m-thick, grey to brown, bedded to massive, arenitic dolomite, a ~2-m-thick gabbroic bed, and a ~12.5-m-thick Kanwangungu-type massive to bedded, grey to white or pinkish brown, arenitic carbonate showing typical stylolitic surfaces. The contact between the base of the Kanwangungu Formation and top of the Kibalongo Formation (Table 1) is a tectonic detachment marked by a 1.5-m-thick breccia containing mostly Kanwangungu-type fragments.

In northwestern Zambia, in the Kabompo area (southwestern part of the Lufilian Arc), the Mwashya Subgroup was identified only as a carbonaceous pyritic black shale (Steven, 2000). There is also a sequence of altered mafic volcanic rocks, the Lwavu volcanics, overlying "Upper Roan" arkosic quartzites (Key et al., 2001) which could be related to volcaniclastic rocks of the Kansuki Formation.

3.6. Mwashya Subgroup in northern areas of the Lufilian Arc

Sedimentary rocks units, similar to those described above for formations of the Mwashya Subgroup, have been observed in areas north of the Lufilian Arc (e.g., in the Lukoka valley and Lufukwe anticline; Cahen, 1954). The lithologies, from bottom to top, include black carbonate and silicified carbonates (cherts), thick carbonaceous shales (suspected to be Kafubu Fm equivalent), and coarse arkoses to quartzitic and quartzo-feldspathic sandstones (suspected to be Kanzadi Fm equivalent). Further to the north (west of Kalemie), conglomeratic feldspathic sandstones were documented (Cahen, 1954) that resemble the rocks near the base of the Mwashya Subgroup.

4. Base metal occurrences

They are a number copper–cobalt occurrences or small deposits hosted in rocks of the Kansuki and Kamoya Formations (e.g., Shituru, Tilwezembe, Mutanda ya Mukonkota, and Kipoï). Shituru, ~1 km south of Likasi (Fig. 1), is the most important of the deposits. It is Cu-rich, but poor in Co, originally containing ~445,000 tonnes Cu (mined ores between 1919 and 1954 and remaining indicated resources). There are two main orebodies hosted in dolomite of the Kansuki Formation, which is located along the southern flank of a north-verging syncline with axial plane dipping ~55° SSW (Lefebvre, 1974). The mined materials were oxidized secondary ores (10.5 wt.% Cu average grade; François, 1974), whereas deeper undeveloped primary sulphide ores grade ~0.3 to 2.1 wt.% Cu and 0.05 to 0.1 wt.% Co (Lefebvre, 1974). The Fe–Cu–Co sulphides include an early stage of fine-grained, disseminated, stratiform, locally framboidal pyrite, chalcopyrite and bornite, with a second stage of bornite, and carrollite or linnaeite (Lefebvre, 1974). The ores are mainly hosted in massive to bedded, partly silicified or recrystallized dolomite and in interbedded dolomitic shale. Host rock lithologies and sulphide distribution/parageneses are similar to those of the lower and upper orebodies in the Mines Subgroup (Lefebvre, 1974; Cailteux et al., 2005b). Minor Cu–Co sulphides also occur in volcaniclastic beds closely overlying these dolomites (Lefebvre, 1974). Common supergene replacement of chalcopyrite and bornite by digenite and chalcocite occurs in the transition zone to the secondary oxide ores.

Tilwezembe and Mutanda ya Mukonkota, respectively 30 and 45 km ESE of Kolwezi along the same tectonic lineament as Shituru (Fig. 1), are two recently explored and mined Cu–Co deposits hosted in rocks of the Kansuki Formation. The ores form irregular, supergene bodies hosted in weathered rocks of the Kansuki Formation, of the underlying breccias marking the tectonic lineament, and in fractures in rocks of the overlying Kamoya Formation. Grades of the oxide ores are as high as 9 wt.% Cu and 4 wt.% Co at Tilwezembe (François, 1973). Hypogene sulphide (mainly carrollite) mineralisation (as much as 0.7 wt.% Cu and 0.6 wt.% Co at Tilwezembe) occurs as 1 to > 5 mm in diameter disseminated grains in recrystallized carbonate rocks of the Kansuki Formation.

5. Discussion

5.1. Lithostratigraphy

Recent observations made at several sites in Congo have resulted in a better understanding of the Mwashya succession. This has resulted in a proposed new lithostratigraphic subdivision for these rocks.

The Kansuki Formation in Congo is mainly a carbonate unit characterized by reefal to intertidal deposition. It is marked locally by agitated conditions (some oolites in dolomite; e.g., in Tilwezembe and Luiswishi areas) and by shallow water conditions near the top of the formation (e.g., erosional surfaces, intraformational conglomerates, and pseudomorphs after anhydrite). Interpretation that includes the Kansuki Formation within the Mwashya Subgroup (Oosterbosch, 1962; François, 1974) is subject to debate by the fact that this formation could be considered as part of the predominant shallow-water dolomite occurring at the top of the Dipeta Subgroup/Kanwangungu Formation–Upper Roan Group succession. This hypothesis is strongly supported by a gradational lithological transition between the Kanwangungu and Kansuki Formations at Kinsenda, and by similar petrological features that include arenitic dolomites.

In contrast, the overlying Kamoya, Kafubu and Kanzadi Formations, which make up the remainder of the Mwashya Subgroup, show an argillaceous–detrital succession representing a major change in conditions of deposition. Slumps in siltstone/silty shale, chert, and silicified dolomite beds, oolites in chert, matrix-supported conglomerate (e.g., the Conglomérat de Mwashya) formed by clasts originating from the same lithologies (e.g., siltstone, chert, and oolitic chert), and pseudomorphs after evaporite (e.g., at Kilobelobe), suggest shallow water and locally agitated conditions at the base of the Kamoya Formation. Some of the clasts (e.g., granite in the northern areas; Vanden Brande, 1932) may have been sourced from rocks of the Kibaran or pre-Kibaran basement (Table 1). The conglomeratic beds, in fact, are part of a detrital sedimentary rock complex, as already suggested by Van den Brande (1935). Its regional occurrence signifies a major depositional event, which may be related to widening of the sedimentary basin and/or a climate change (e.g., from arid to wet). Rocks of the overlying Kafubu and Kanzadi Formations suggest a cold climate, sea level lowering, and contractions of the sedimentary basin, marked by episodic climatic changes, before the onset of the Sturtian glacial event leading to the deposition of the Grand Conglomérat (Cahen, 1947, 1954; Buffard, 1988). Distribution of proximal massive sandstone beds north and south of the sedimentary basin (Fig. 9) support this model.

The Grand Conglomérat is thicker (as much as 1000 m) in the north than in the south (500 m to 200 m). Load deformation, slumping, and intraformational breccias observed at top of the Kanzadi Formation suggest an incomplete lithification during deposition of the Grand Conglomérat. The partial or complete lack of rocks of the Mwashya Subgroup in the north-western (Kolwezi) and north-eastern (Lubumbashi) areas, as well as the presence of many clasts typical of rocks of the Kansuki (e.g., dolomite, volcaniclastics), Kamoya (e.g., oolites, chert), Kafubu, and Kanzadi Formations in the Grand Conglomérat (François, 1973, 1987; Cailteux, 1991; this study), indicate an extensive erosion of the sedimentary rocks of the Mwashya Subgroup and a discordant deposition of the Grand Conglomérat. Although the Grand Conglomérat seems to have been deposited concordantly on rocks of the Mwashya Subgroup in the southern areas (e.g., at Kambove, Shituru, and Kinsenda), most observations suggest a transgressive deposition of the glacial diamictite from the continental topography to the north.

The major tectonic and evaporite-facilitated detachment, which is observed between the Kansuki Formation and the underlying Dipeta Subgroup/Kanwangungu Formation from the Kolwezi area up to the Musoshi area (Cailteux and Kampunzu, 1995; Tshiauka et al., 1995; Kampunzu and Cailteux, 1999), also took place between the Kanwangungu and Kibalongo Formations at Kinsenda. The breccia marking this detachment includes fragments from rock units both below and above the detachment, and strongly supports a tectonic origin rather than a sedimentary genesis as proposed by Wendorff (2000, 2004).

5.2. Cu–Co mineralisation

The origin of the Cu–Co mineralisation hosted in rocks of the Kansuki Formation has been attributed to hydrothermal events related to deposition of volcaniclastic rocks (e.g., at Shituru; Lefebvre, 1974). However, (1) the Cu–Co mineralisation is mostly hosted in Mines-type carbonate lithologies and not in the volcaniclastic rocks (Lefebvre, 1974); (2) there are few deposits hosted in rocks of the Kansuki Formation despite the voluminous exposure of volcaniclastic rocks (Fig. 4); and (3) the volcaniclastic rocks of the Kansuki Formation lack strong Cu–Co anomalies (Table 3). It is noteworthy that rocks of the Kansuki Formation overlie breccias occurring along the tectonic lineaments. These breccias are the same as those that include the mineralised Mines Subgroup blocs. These blocs have been shown to host reworked primary syngenetic to diagenetic Cu–Co minerals (by metamorphic fluids during the Lufilian orogeny; e.g., Cailteux and Kampunzu, 1995; Cailteux, 1997; Lerouge et al., 2004; Cailteux et al., 2005b). We, therefore, propose that the Kansuki Cu–Co ores originate from: (1) local, low grade, syngenetic to early-diagenetic, disseminated mineralisation, with metals derived from continental and/or igneous sources; (2) later reworking and enrichment of this low grade mineralisation (e.g., at Shituru), or new younger metal deposition (e.g., at Tilwezembe), by syn-tectonic metamorphic fluids probably derived from rocks of the Roan Group (e.g., from the Mines Subgroup).

5.3. Regional correlation and timing with the Damara Supergroup in northern Namibia

Deposition of rocks of the Mwashya Subgroup is constrained by zircon U–Pb SHRIMP geochronology of the Kansuki volcanic event. Results yield consistent maximum ages of: (1) 760 ± 5 Ma in the Zambian Copperbelt (Armstrong et al., 1999); (2) 765 ± 5 Ma on mafic flows in the Mwinilunga area, northwestern Zambia (Key et al., 2001); and (3) 745 ± 7.8 and 752.6 ± 8.6 Ma on meta-gabbro bodies occurring within the "Upper Roan" of both the Domes Region and north of the Kansanshi mine in Zambia, respectively (Barron et al., 2003). A minimum age of 735 ± 5 Ma may be provided by "(probably Kundelungu) pods of porphyritic and brecciated rocks" in the Mwinilunga area (Key et al., 2001).

Rift-related igneous rocks (epidote-altered flow, agglomerate, and tuff) of the Askevold Formation, at the top of the Nosib Group in the northern Damara belt, Namibia (Kamona and Günzel, 2007-this volume, and references therein), are in a similar time-stratigraphic position as the volcaniclastic rocks of the Kansuki Formation. They are constrained between 756 ± 2 and 746 ± 2 Ma (Hoffman et al., 1996) and overlain by the Sturtian Varianto/Chuos (Grand Conglomérat equivalent) diamictite. Small base metal deposits or occurrences (≤ 5 million tons ore each), including those at Neuwerk and Askevold (Cu, with very minor Pb or Zn), and at Nosib (Cu–Pb–V), are mainly hosted within the volcaniclastic rocks of the Askevold Formation, and to some extent within the Varianto/Chuos diamictite (Nosib deposit) or within the siliceous limestone unit overlying this diamictite (Neuwerk deposit). Metals and ore-fluids are suggested to be related to the Askevold volcanism (Kamona and Günzel, 2007-this volume, and references therein). The metal association in the deposits of the Askevold Formation (Cu, Pb, Zn, V) is similar to that of the other occurrences or deposits hosted in rocks of the overlying Otavi Group (e.g., Berg Aukas, Abenab, Tsumeb, and Kombat), of the Nguba Group of the Congo–Zambia Copperbelt (e.g., Kipushi and Kabwe) and of the West Congolian Group (e.g., Bamba–Kilenda; Kanda Nkula et al., 2003), suggesting a similar ore genesis. By contrast, the mineralisation hosted in rocks of the Kansuki Formation is defined by a Cu–Co association, which suggests an alternative correlation with ores of the Mines/Kitwe Subgroups.

6. Conclusions

A new lithostratigraphic subdivision of the Mwashya Subgroup is proposed, including three formations of regional extent that represent the previous Upper Mwashya Formation (Table 1; Fig. 5); from bottom to top they are:

(1) Kamoya Formation, characterized by dolomitic silty shales/siltstones/sandstones including conglomeratic beds and cherts in variable positions in its lower part
(2) Kafubu, Formation which is a series of finely bedded and slightly dolomitic shales, with a high carbon content indicating a lowering of sea level;
(3) Kanzadi Formation, with sandstones alternating with black shales or siltites, marking basin contraction and periodic climatic changes before the onset of the Grand Conglomérat Sturtian glacial event.

The previous Lower Mwashya Formation, re-named the Kansuki Formation (Table 1; Fig. 5), is a dolomitic formation, which included detrital and volcaniclastic beds that are suggested here to no longer form part of the Mwashya Subgroup. A lithostratigraphic continuity between the Kanwangungu (Bancroft/Upper Roan) and Kansuki Formations has been clearly observed at Kinsenda, with similar predominant shallow-water and evaporite-bearing character occurring in both sequences (François, 1987; Cailteux et al., 1994; Tshiauka et al., 1995). Therefore, the rocks of the Kansuki Formation represent the uppermost unit of the Dipeta Subgroup/Kanwangungu Formation sequence. In Musoshi- and Congo-type lithologies, the Dipeta Subgroup/Kanwangungu–Kansuki Formations transition is hidden by a tectonic break (Cailteux and Kampunzu, 1995). In Congo, the Kansuki Formation is thicker than in Zambia and displays more variable facies. Detailed correlations between Dipeta–Mofya–Kansuki rocks remain to be documented.

The clastic dominant Kamoya, Kafubu, and Kanzadi Formations form a new detrital succession showing lithological features distinct from those of the underlying mostly carbonate rocks of the Kansuki Formation and Dipeta Subgroup/Kanwangungu Formation. The conglomerate or conglomeratic complex at the base of the new Mwashya succession is a regional marker unit that does not display indications of glacial to periglacial origin (e.g., varves, pediments, attrition faces, or glacial striations). In agreement with Demesmaeker et al. (1963), François (1973, 1974), and Lefebvre (1976), but in contrast to the hypothesis of Cahen and Mortelmans (1968), this unit, and particularly the Conglomérat de Mwashya, cannot be included in the Grand Conglomérat tillite/diamictite formation.

The Cu–Co deposits hosted in rocks of the Kansuki Formation include a syngenetic to early diagenetic period of low-grade ore deposition. The age of the ore is predated by the emplacement of the igneous rocks at ca. 765–745 Ma (Armstrong et al., 1999; Key et al., 2001; Barron et al., 2003). Later reworking and enrichment of this first stage of mineralisation and deposition of new, younger ores by metamorphic fluids is constrained by the Lufilian orogenic event (625–530 Ma).

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References

Armstrong, R.A., Robb, L.J., Master, S., Kruger, F.J., Mumba, P.A.C.C., 1999. New U–Pb age constraints on the Katangan sequence, central African Copperbelt. Journal of African Earth Sciences 28, 6–7.

Babinsky M., Kaufman, A.J., 2003. First direct dating of a Neoproterozoic post-glaciogenic cap carbonate. In: Sial, et al. (Ed.), IV South American Symposium on Isotope Geology (IV SSAGI) Short Papers 1679-3684, vol. 1, pp. 321–323.

Barron, J.W., Broughton, D.W., Armstrong, R.A., Hitzman, M.W., 2003. Petrology, geochemistry and age of gabbroic bodies in the Solwezi area, northwestern Zambia. In: Cailteux, J. (Ed.), Proterozoic Sediment-Hosted Base Metal Deposits of Western Gondwana, Abstract Volume of the Conference and Field Guidebook, 3rd IGCP-450 Meeting and Field Workshop, Lubumbashi, D.R.Congo, pp. 75–77.

Batumike, M.J., Cailteux, J.L.H., Kampunzu, A.B., 2007. The Neoproterozoic Nguba and Kundelungu successions in the central African Copperbelt: lithostratigraphy, basin development and regional correlations. Gondwana Research 11, 410–425 (this volume).

Binda, P.L., 1994. Stratigraphy of Zambian Copperbelt orebodies. In: Kampunzu, A.B., Lubala, R.T. (Eds.), Neoproterozoic Belts of Zambia, Zaire and Namibia. Journal of African Earth Sciences, vol. 19, pp. 251–264.

Binda, P.L., Van Eden, J.G., 1972. Sedimentological evidence on the origin of the Precambrian Great Conglomerate (Kundelungu Tillite), Zambia. Palaeogeography, Palaeoclimatology, Palaeoecology 12, 151–168.

Brock, B.B., 1961. The structural setting of the Copperbelt. In: Mendelsohn (Ed.), The Geology of the Northern Rhodesian Copperbelt. MacDonald, London, pp. 81–89.

Buffard, R., 1988. Un rift intracontinental du Précambrien Supérieur : le Shaba méridional (Zaïre). Evolution sédimentaire et tectonique du Supergroupe de Roan au Groupe du Kundelungu inférieur (Supergroupe du Kundelungu). Ph.D. thesis, University of Maine (France).

Buffard, R., Muhagaze, L., 1981. Sur les modalités de dépôts des filons hématitifères du Mwashya supérieur (Précambrien supérieur) de la région de

Lubumbashi, Shaba, Zaïre. Annales de la Société Géologique de Belgique 104, 193–203.

Cahen, L., 1947. A propos de formations éoliennes périglaciaires de la Série de Mwashya. Bulletin de la Société Belge de Géologie 56, 8–15.

Cahen, L., 1954. Géologie du Congo Belge. Vaillant Carmanne, Liège.

Cahen, L., 1974. Geological background of the copper-bearing strata of southern Shaba (Zaïre). In: Bartholomé, P. (Ed.), Gisements Stratiformes et Provinces Cuprifères. Centenaire de la Société Géologique de Belgique, Liège, pp. 57–77.

Cahen, L., Mortelmans, G., 1948. Le Groupe du Katanga. Evolution des idées et essai de subdivision. Bulletin de la Société Belge de Géologie 57, 459–475.

Cailteux, J., 1978. La succession stratigraphique du C.M.N. (ou R-2.3) au centre de la sous-province cuprifère shabienne. Annales de la Société Géologique de Belgique 100 (1977), 73–85.

Cailteux, J., 1983. Le Roan shabien dans la région de Kambove (Shaba-Zaïre). Etude sédimentologique et métallogénique. Ph.D. thesis, University of Liège (Belgium).

Cailteux, J., 1991. La tectonique intra-katanguienne dans la région Nord-Ouest de l'Arc Lufilien (Shaba, Rép. du Zaïre). Annales de la Société Géologique de Belgique 113 (1990), 199–215.

Cailteux, J., 1994. Lithostratigraphy of the Neoproterozoic Shaba-type (Zaire) Roan Supergroup and metallogenesis of associated stratiform mineralization. In: Kampunzu, A.B., Lubala, R.T. (Eds.), Neoproterozoic Belts of Zambia, Zaire and Namibia. Journal of African Earth Sciences, vol. 19, pp. 279–301.

Cailteux, J., 1997. Minéralisations à U-Pb-Se-Mo-Ni dans le gisement stratiforme cupro-cobaltifère de Kambove-Ouest (Shaba, Rép. Zaïre). In: Charlet, J.-M. (Ed.), Colloque International Cornet Gisements stratiformes de cuivre et minéralisations associées, Mons (1994). Académie Royale des Sciences d'Outre-Mer, pp. 245–268.

Cailteux, J., Kampunzu, A.B., 1995. The Katangan tectonic breccias in the Shaba province (Zaire) and their genetic significance. In: Wendorff, M., Tack, L. (Eds.), Late Proterozoic Belts in Central Africa. Musée Royal de l'Afrique Centrale, Tervuren (Belgium) Annales des Sciences Géologiques, vol. 101, pp. 63–76.

Cailteux, J., Binda, P.L., Katekesha, W.M., Kampunzu, A.B., Intiomale, M.M., Kapenda, D., Kaunda, C., Ngongo, K., Tshiauka, T., Wendorff, M., 1994. Lithostratigraphical correlation of the Neoproterozoic Roan Supergroup from Shaba (Zaire) and Zambia, in the central African copper–cobalt metallogenic province. In: Kampunzu, A.B., Lubala, R.T. (Eds.), Neoproterozoic Belts of Zambia, Zaire and Namibia. Journal of African Earth Sciences, vol. 19, pp. 265–278.

Cailteux, J., Binda, P.L., Kampunzu, A.B., Katekesha, W.M., Kaunda, C., Wendorff, M., 1995. Results of lithostratigraphic correlation of the late Proterozoic Roan Supergroup between Zambia and Zaire, central African Copperbelt. In: Wendorff, M., Tack, L. (Eds.), Late Proterozoic Belts in Central Africa. Musée Royal de l'Afrique Centrale, Tervuren (Belgium) Annales des Sciences Géologiques, vol. 101, pp. 21–27.

Cailteux, J., Kampunzu, A.B., Ngoie Bwanga, F., 2003. Lithostratigraphy of the Mwashya Subgroup in Congo (central Africa Copperbelt), with special reference to the Luiswishi area. In: J. Cailteux (Org.), Proterozoic Sediment-Hosted Base Metal Deposits of Western Gondwana. Abstract Volume of the Conference and Field Guidebook, 3rd IGCP-450 Meeting and Field Workshop, Lubumbashi, D.R.Congo, 83–88.

Cailteux, J.L.H., Kampunzu, A.B., Batumike, M.J., 2005a. Lithostratigraphic position and petrographic characteristics of R.A.T. («Roches Argilo-Talqueuses») Subgroup, Neoproterozoic Katangan belt (Congo). In: Robb, L., Cailteux, J., Sutton, S. (Eds.), Recent Advances in the Geology and Mineralization of the Central African Copperbelt. Journal of African Earth Sciences, vol. 42, pp. 82–94.

Cailteux, J.L.H., Kampunzu, A.B., Lerouge, C., Kaputo, A.K., Milesi, J.P., 2005b. Genesis of sediment-hosted stratiform copper-cobalt deposits, central African Copperbelt. In: Robb, L., Cailteux, J., Sutton, S. (Eds.), Recent Advances in the Geology and Mineralization of the Central African Copperbelt. Journal of African Earth Sciences, vol. 42, pp. 134–158.

Dardenne, M.A., 1978. Síntese sobre a estratigrafia do Grupo Bambuí no Brasil Central. In: Congresso Brasileiro de Geologia, 30, Anais, Recife, Brazil, SBG, 2, 597–610.

Demesmaeker, G., François, A., Oosterbosch, R., 1963. La tectonique des gisements cuprifères stratiformes du Katanga. In: Lombard, J., Nicolini, P. (Eds.), Gisements Stratiformes de Cuivre en Afrique, 2ème Partie: Tectonique. Association des Services Géologiques Africains (Paris), Lusaka 1962, pp. 47–115.

Dumont, P., Hanon, M., Ngoyi, L.K., 1997. La structure géologique du Plateau des Biano (Shaba, Zaïre). Musée Royal de l'Afrique Centrale, Tervuren (Belgium), Rapport Annuel 1995 and 1996, pp. 169–182.

François, A., 1973. L'extrémité Occidentale de l'Arc Cuprifère Shabien. Etude Géologique, Gécamines, Likasi (Shaba-Zaïre).

François, A., 1974. Stratigraphie, tectonique et minéralisations dans l'Arc cuprifère du Shaba (Rép. du Zaïre). In: Bartholomé, P. (Ed.), Gisements Stratiformes et Provinces Cuprifères. Centenaire de la Société Géologique de Belgique, Liège, pp. 79–101.

François, A., 1987. Synthèse géologique sur l'Arc cuprifère du Shaba (Rép. du Zaïre). Société Belge de Géologie, Centenaire 1987, pp. 15–65.

François, A., 1995. Problèmes relatifs au Katanguien du Shaba. In: Wendorff, M., Tack, L. (Eds.), Late Proterozoic Belts in Central Africa. Musée Royal de l'Afrique Centrale, Tervuren (Belgium). Annales des Sciences Géologiques, vol. 101, pp. 1–20.

Francotte, J., 1959. Excursions effectuées les 10, 11 et 12 juillet 1959 dans les terrains du faisceau de Mwashya. Bulletin de la Société Géologique du Congo Belge et Ruanda-Urundi. Université d'Elisabethville, pp. 26–30.

Frimmel, H.E., Klötzli, U.S., Siegfried, P.R., 1996. New Pb–Pb single zircon age constraints on the timing of Neoproterozoic glaciation and continental break-up in Namibia. Journal of Geology 104, 459–469.

Hoffman, P.F., Hawkins, D.P., Isachsen, C.E., Bowring, S.A., 1996. Precise U–Pb ages for early Damaran magmatism in the Summas Mountains and Welwitschia Inlier, northern Damara Belt, Namibia. Communications Geological Survey of Namibia 11, 47–52.

Jackson, M.P.A., Warin, O.N., Woad, G.M., Hudec, M.R., 2003. Neoproterozoic allochthonous salt tectonic during the Lufilian orogeny in the Katangan Copperbelt, Central Africa. Geological Society of America Bulletin 115, 314–330.

Kamona, A.F., Günzel, A., 2007. Stratigraphy and base metal mineralization in the Otavi Mountain Land, Northern Namibia. Gondwana Research 115, 374–391 (this volume).

Kampunzu, A.B., Cailteux, J., 1999. Tectonic evolution of the Lufilian Arc (Central Africa Copper Belt) during Neoproterozoic pan African orogenesis. Gondwana Research 2, 401–421.

Kampunzu, A.B., Kapenda, D., Manteka, B., 1991. Basic magmatism and geotectonic evolution of the Pan African belt in Central Africa: evidence from the Katangan and West Congolian segments. Tectonophysics 190, 363–371.

Kampunzu, A.B., Kanika, M., Kapenda, D., Tshimanga, K., 1993. Geochemistry and geotectonic setting of late Proterozoic Katangan basic rocks from Kibambale in Central Shaba (Zaire). Geologische Rundschau 82, 619–630.

Kampunzu, A.B., Tembo, F., Matheis, G., Kapenda, D., Huntsman-Mapila, P., 2000. Geochemistry and tectonic setting of mafic igneous units in the Neoproterozoic Katangan basin, Central Africa: implications for Rodinia break-up. Gondwana Research 3, 125–153.

Kampunzu, A.B., Cailteux, J.L.H., Moine, B., Loris, H.N.B.T., 2005. Geochemical characterisation, provenance, source and depositional environment of "Roches Argilo-Talqueuses" (R.A.T.) and Mines Subgroups sedimentary rocks in the Neoproterozoic Katangan Belt (Congo): lithostratigraphic implications. In: Robb, L., Cailteux, J., Sutton, S. (Eds.), Recent Advances in the Geology and Mineralization of the Central African Copperbelt. Journal of African Earth Sciences, vol. 42, pp. 119–133.

Kanda Nkula, V., Franceschi, G., Tack, L., 2003. Late Pan-African fault-related sediment-hosted mineralization in the Democratic Republic of Congo (DRC): emplacement, genetic similarities and differences. The examples of Bamba Kilenda (Bas-Congo), Dikulushi, Kapulo and Kipushi (katanga). In: Cailteux, J.L.H. (Ed.), Proterozoic sediment-hosted base metal deposits of Western Gondwana (IGCP 450). 3rd Conference, Lubumbashi, Congo, Abstract volume, pp. 150–155.

Key, R.M., Liyungu, A.K., Njamu, F.M., Somwe, V., Banda, J., Mosley, P.N., Armstrong, R.A., 2001. The western arm of the Lufilian Arc in NW Zambia and its potential for copper mineralisation. Journal of African Earth Sciences 33, 503–528.

Lefèbvre, J.-J., 1973. Présence d'une sédimentation pyroclastique dans le Mwashya inférieur du Shaba méridional (ex-Katanga). Annales de la Société Géologique de Belgique 96, 197–217.

Lefèbvre, J.-J., 1974. Minéralisations cupro-cobaltifères associées aux horizons pyroclastiques situés dans le faisceau supérieur de la Série de Roan à Shituru, Shaba, Zaïre. In: Bartholomé, P. (Ed.), Gisements Stratiformes et Provinces Cuprifères. Centenaire de la Société Géologique de Belgique, Liège, pp. 103–122.

Lefèbvre, J.-J., 1975. Les roches ignées dans le Katangien du Shaba (Zaïre). Le district du cuivre. Annales de la Société Géologique de Belgique 98, 47–73.

Lefèbvre, J.-J., 1976. Le contact entre le Kundelungu et le Roan à Mulungwishi, Shaba, Zaïre. Annales de la Société Géologique de Belgique 99, 451–466.

Lefèbvre, J.-J., 1979. Le Groupe de Mwashya, mégacyclothème terminal du Roan (Shaba, Zaïre Sud-oriental). I. Approche lithostratigraphique et étude de l'environnement sédimentaire. Annales de la Société Géologique de Belgique 101 (1978), 209–225.

Lefèbvre, J.-J., 1985. Le Groupe de Mwashya, mégacyclothème terminal du Roan (Shaba, Zaïre Sud-oriental). II. Volcanisme et dynamique du bassin sédimentaire. Musée Royal de l'Afrique Centrale, Tervuren (Belgium), Département de Géologie et Minéralogie, Rapport Annuel 1983–1984, pp. 121–151.

Lepersonne, J., Trottereau, G., 1974. Notice explicative de la carte géologique du Zaïre au 2000000. Direction de la Géologie du Département des Mines de la République du Zaïre.

Lerouge, C., Cailteux, J., Kampunzu, A.B., Milesi, J.P., Fléhoc, 2004. Preliminary sulfur isotope data of the Luiswishi ore deposit, DRC. 20th Colloquium on African Geology: Abstracts, Orléans, 2–7 June 2004. BRGM, p. 261.

Machairas, G., 1974. Découverte de roches volcano-détritiques associées à la mineralization cuprocobaltifère du Shaba (Zaïre). Comptes Rendus de l'Académie des Sciences de Paris 278, 553–556.

Mathy, P.K., 1978. Oncolites and catagraphs from the Precambrian of Zaire (lower Zaire, Shaba and Kasai). Bulletin de la Société Géologique de Belgique 101, 193–207.

Mendelsohn, F., 1961. The Geology of the Northern Rhodesian Copperbelt. MacDonald, London.

Ngoie, B.F., Cailteux, J.L.H., Kaputo, K.A., Kampunzu, A.B., 2003. The Neoproterozoic Mwashya Subgroup at Shituru (Congo): geochemistry of Upper Mwashya black shales and base metal occurrences. In: J. Cailteux (Org.), Proterozoic Sediment-Hosted Base Metal Deposits of Western Gondwana, Abstract Volume of the Conference and Field Guidebook, 3rd IGCP-450 Meeting and Field Workshop, Lubumbashi, D.R.Congo, 113–1178.

Oosterbosch, R., 1962. Les minéralisations dans le système de Roan au Katanga. In: Lombard, J., Nicolini, P. (Eds.), Gisements Stratiformes de Cuivre en Afrique, 1ère Partie, Copenhagen, 1960. Association des Services Géologiques Africains, Paris, pp. 71–136.

Robert, M., 1928. La géologie du Katanga méridional après la campagne 1926–1927 du Service Géographique et Géologique du Comité Spécial du Katanga. Annales de la Société Géologique de Belgique, Publications du Congo Belge 51, 55–67.

Rorive, R., 1952. Le site hydrogéologique des sources de la Kimilolo. Annales du Service des Mines, Comité Spécial du Katanga 17, 55–71.

Steven, N.M., 2000. A Shaba-type Cu–Co(–Ni) deposit at Luamata, West of the Kabompo Dome, northwestern Zambia. Exploration Mining Geology 9, 277–287.

Sun, S., Mc Donough, W.F., 1989. Chemical and isotopic systematics of ocean basalts: implications for mantle composition and processes. In: Saunders, A. D., Norry, M.J. (Eds.), Magmatism in the Ocean Basins. Geological Society of London, Special Publication, vol. 42, pp. 313–345.

Tembo, F., Kampunzu, A.B., Porada, H., 1999. Tholeitic magmatism associated with continental rifting in the Lufilian Fold Belt of Zambia. Journal of African Earth Sciences 28, 403–425.

Tshiauka, T., Katekesha, W.M., Cailteux, J., Intiomale, M.M., Kampunzu, A.B., Kapenda, D., Chabu, M., Ngongo, K., Mutombo, K., Nkanika, W.R., 1995. Lithostratigraphy of the Neoproterozoic Katangan sedimentary sequences in the Musoshi Copper District (SE Shaba, Zaire) and incidences on copper and cobalt economic geology in Central Africa. In: Wendorff, M., Tack, L. (Eds.), Late Proterozoic Belts in Central Africa. Musée Royal de l'Afrique Centrale, Tervuren (Belgium). Annales des Sciences Géologiques, vol. 101, pp. 29–48.

Van den Brande, P., 1932. Le conglomérat de la série de Mwashya. Annales du Service des Mines, Comité Spécial du Katanga 3, 72–78.

Van den Brande, P., 1935. Etude lithologique de roches du système Schisto-Dolomitique du Katanga méridional. Annales du Service des Mines, Comité Spécial du Katanga 6, 20–31.

Wendorff, M., 2000. Genetic aspects of the Katangan megabreccias: Neoproterozoic of Central Africa. Journal of African Earth Sciences 30, 703–715.

Wendorff, M., 2003. Stratigraphy of the Fungurume Group — evolving foreland basin succession in the Lufilian fold-thrust belt, Neoproterozoic–Lower Paleozoic, Democratic Republic of Congo. South African Journal of Geology 106, 47–64.

Wendorff, M., 2004. Evolution of Neoproterozoic–Lower Palaeozoic Lufilian Arc, Central Africa: a model based on syntectonic conglomerates. Journal of the Geological Society of London 162, 5–8.

Wendorff, M., 2005. Evolution of Neoproterozoic–Lower Palaeozoic Lufilian Arc, Central Africa: a model based on syntectonic conglomerates. Journal of the Geological Society of London 162, 5–8.