Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of African Earth Sciences 42 (2005) 82–94
Journal of African Earth Sciences
www.elsevier.com/locate/jafrearsci

Lithostratigraphic position and petrographic characteristics of R.A.T. ("Roches Argilo-Talqueuses") Subgroup, Neoproterozoic Katangan Belt (Congo)

J.L.H. Cailteux [a,*], A.B.H. Kampunzu [b,✠], M.J. Batumike [c]

[a] Département Recherche et Développement, E.G.M.F., Groupe G. Forrest International, Lubumbashi, D.R. Congo
[b] Department of Geology, University of Botswana, Private Bag 0022, Gaborone, Botswana
[c] Département de Géologie, Université de Lubumbashi (UNILU), B.P. 1825, Lubumbashi, Congo

Received 1 October 2003; accepted 1 May 2004
Available online 17 October 2005

Abstract

The Neoproterozoic Katangan R.A.T. ("Roches Argilo-Talqueuses") Subgroup is a sedimentary sequence composed of red massive to irregularly bedded terrigenous-dolomitic rocks occurring at the base of the Katangan succession in Congo. Red R.A.T. is rarely exposed in a continuous section because it was affected by a major layer-parallel décollement during the Lufilian thrusting. However, in a number of thrust sheets, Red R.A.T. is in conformable sedimentary contact with Grey R.A.T which forms the base of the Mines Subgroup. Apart from the colour difference reflecting distinct depositional redox conditions, lithological, petrographical and geochemical features of Red and Grey R.A.T. are similar. A continuous sedimentary transition between these two lithological units is shown by the occurrence of variegated to yellowish R.A.T. The D. Strat. "Dolomies Stratifiées" formation of the Mines Subgroup conformably overlies the Grey R.A.T. In addition, a transitional gradation between Grey R.A.T. and D. Strat. occurs in most Cu–Co mines in Katanga and is marked by interbedding of Grey R.A.T.-type and D. Strat.-type layers or by a progressive petrographic and lithologic transition from R.A.T. to D. Strat. Thus, there is an unquestionable sedimentary transition between Grey R.A.T. and D. Strat. and between Grey R.A.T. and Red R.A.T.

The R.A.T. Subgroup stratigraphically underlies the Mines Subgroup and therefore R.A.T. cannot be comprised of syn-orogenic sediments deposited upon the Kundelungu (formerly "Upper Kundelungu") Group as suggested by Wendorff (2000). As a consequence, the Grey R.A.T. Cu–Co mineralisation definitely is part of the Mines Subgroup Lower Orebody, and does not represent a distinct generation of stratiform Cu–Co sulphide mineralisation younger than the Roan orebodies.

Keywords: Lithostratigraphy; Petrography; R.A.T.—Mines Subgroup; Sedimentary rocks; Copperbelt; Congo

1. Introduction

The Neoproterozoic Katangan R.A.T. ("Roches Argilo-Talqueuses") Subgroup is a sedimentary sequence of red massive to irregularly bedded silty dolomitic rocks at the base of the Katangan succession in the Democratic Republic of Congo, simply called Congo in this paper (Table 1). Thrusting and nappe tectonics linked to the Lufilian orogeny (Kampunzu and Cailteux, 1999) led to the décollement of the R.A.T. Subgroup from its pre-Katangan basement (François, 1973; Cailteux, 1994). Despite this tectonic complexity, the relations between R.A.T. Subgroup and the other Katangan lithostratigraphic units, especially those hosting the ore deposits, were thoroughly documented

* Corresponding author. Address: Parc des Collines, Av. Pasteur, no. 9, B-1300 Wavre, Belgium.
E-mail address: jyc.egmf@forrestrdc.com (J.L.H. Cailteux).
✠ Deceased.

1464-343X/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jafrearsci.2005.08.011

Table 1
Lithostratigraphy of the Katangan succession in Congo and Zambia (modified from Cailteux et al., 1994; François, 1974, 1995; Cailteux, 1994, 2003)

	Group	Sub-group	Lithologies
±500 Ma	Kundelungu (prev. Upper Kundelungu) Ku	Plateaux Ku 3	Arkoses, conglomerates, sandstones, shales
		Kiubo Ku 2	Sandstones, carbonated siltstones or shales, limestones
		Kalule Ku 1	Ku 1.3: Carbonated siltstones and shales; grey to pink oolitic limestone at base ("Calcaire Rose Oolitique")
			Ku 1.2: Carbonated siltstones and shales; pink to grey dolomite at base ("Calcaire Rose")
±620 Ma			Ku 1.1 "Petit Conglomérat": glacial diamictite
	Nguba (prev. Lower Kundelungu) Ng	Monwezi Ng 2	Dolomitic sandstones, siltstones or shales
		Likasi Ng 1	Ng 1.3: Carbonated siltstones and shales
			Ng 1.2: Dolomites, limestones, dolomitic shales and siltstones
±750 Ma			Ng 1.1 "Grand Conglomérat": glacial diamictite

Congo Group	Sub-group	Formation	Lithologies	Lithologies	Formation	Sub-group	Zambia Group
Roan	Mwashya R 4	Upper R 4.2	Shales, carbonaceous shales or sandsones	Black shales		Mwashia	Mwashia
		Lower R 4.1	Dolomites, jasper beds, pyroclastics and hematite; local stratiform Cu–Co mineralisation				
	Dipeta R 3	R 3.4 R 3.3 R 3.2	Dolomites interbedded with argillaceous to dolomitic siltstones and feldspathic sandstones; intrusive basic bodies	Dolomites interbedded with dolomitic shales; gabbroic bodies	Kanwangungu	Bancroft RU 1-RU 2	Upper Roan
		R.G.S. R 3.1	Dolomitic siltstones	Shales with grit	Kibalongo	Kitwe RL 3- RL 6	Lower Roan
	Mines R 2	Kambove R 2.3	Laminitic, stromatolitic, talcose dolomites and dolomitic siltstones; local stratiform Cu–Co mineralisation	Dolomites or argillaceous dolomites; local stratiform Cu mineralisation	Chingola		
		Dolomitic Shale R 2.2	Dolomitic shales, carbonaceous shales, dolomites and occasional sandstones or arkoses Dolomitic shales, sandy dolomite at top; stratiform Cu–Co (Upper Orebody)	Arenites, argillites and dolomitic argillites; occasional dolomites at the base; main stratiform	Pelito-arkosic		
		Kamoto R 2.1	R-2.1.3 "Roches Silicueuses Cellulaires: stromatolitic dolomite with interbedded siltstones; Cu–Co at top and base R-2.1.2: bedded dolomites with siltstones; silty dolomite in the lower part; stratiform Cu–Co (Lower Orebody) R-2.1.1 "R.A.T grises": dolomitic siltstone; Cu–Co at top	Cu–Co mineralisation in the lower part (Ore Shale)	Ore Shale		
	R.A.T. R 1	R 1.3	Pink-lilac, hematitic, chloritic–dolomitic massive siltstones	Conglomerates, coarse arkoses and argillaceous siltstones; occasional Cu–Co mineralisation	Mutonda	Mindola (Footwall) RL 7	
		R 1.2	Pink to purple-grey, hematitic, chloritic siltstones; sandstones in the lower part; stromatolitic dolomite at top				
		R 1.1	Purple-red, hematitic, slightly dolomitic bedded siltstones				
	Base of the R.A.T. sequence unknown			Quartzites	Kafufya		
<900 Ma	Basal conglomerate			Pebble and coble conglomerate	Chimfunsi		

because of the stratigraphic control of the orebodies. The formal Katangan lithostratigraphic column is shown in Table 1 (François, 1973; Cailteux, 1994).

Wendorff (2000) claimed that Red and Grey R.A.T. (Table 1) are syn-orogenic sedimentary rocks younger than the Roan Group and deposited in the Katangan foreland basin after the deposition of the Nguba Group. The major arguments put forward to justify this interpretation are: (1) speculative existence of a tectonic break between R.A.T. and dolomites of the Mines Subgroup; (2) occurrence of R.A.T. breccias at the base of thrust stacks; (3) geochemical data supposedly indicating a very high maturity of R.A.T. rocks achieved during a syn-orogenic recycling of Katangan sedimentary rocks to generate R.A.T. rocks. In this interpretation, several facts were distorted and the author ignored critical field observations against this interpretation. The objective of this paper is to present field evidence showing that the R.A.T. Subgroup cannot be younger than the Mines Subgroup, being stratigraphically located under the Mines Subgroup. In a companion paper, Kampunzu et al. (2005) show that geochemical data also do not support the interpretation of Wendorff (2000).

2. Geological background

The Neoproterozoic Katangan sedimentary basin stretches on both sides of the Congo–Zambia border and defines a north-directed thin-skinned thrust-and-fold orogenic system resulting from the convergence between the Congo and Kalahari cratons (Fig. 1). The Katangan supracrustal succession is subdivided into three lithostratigraphic units (François, 1974, 1995; Cailteux, 1994, 2003; Cailteux et al., 1994): Roan (code R), Nguba (code Ng; formerly Lower Kundelungu) and Kundelungu (code Ku; formerly Upper Kundelungu) Groups (Table 1). The unconformity between the Roan Group and the Mesoproterozoic pre-Katangan basement is exposed in the Nzilo area, near Kolwezi (Fig. 1).

The Roan Group sedimentary rocks were deposited in a rift basin, that evolved from a continental rift basin filled by a siliciclastic and carbonate sequence (starting with a basal conglomerate), to a proto-oceanic rift basin filled dominantly with dolomitic shales (Buffard, 1988; Kampunzu et al., 1991, 1993; Cailteux et al., 1994). The widening of the basin during late Roan and Nguba deposition corresponds to a major phase of extensional tectonics and normal faulting marking the transition to

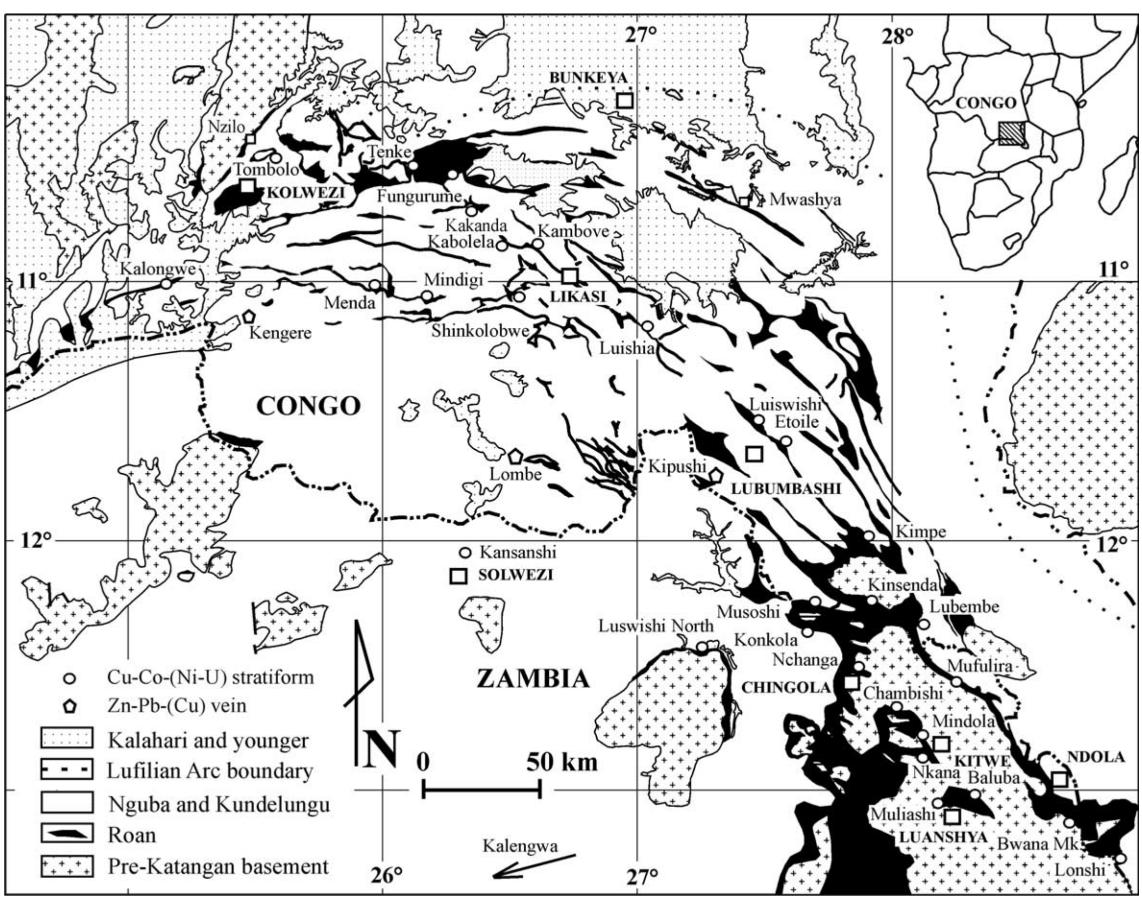

Fig. 1. Location of the main ore deposits in the Central Africa Copperbelt (modified from François, 1974; Cailteux, 1994).

a Red Sea type proto-oceanic stage (Kampunzu et al., 1993, 2000).

This basin closed during the Lufilian Orogeny leading to the development of predominantly north-verging folds, thrusts and nappes. In Congo, except for the Nzilo basal conglomerate, all exposed Roan sedimentary rocks (R.A.T., Mines, Dipeta) are part of allochthonous tectonic sheets, but detailed investigations of exposed sections (mainly in quarries and underground mines) and borehole cores allow the reconstruction of the Katangan lithostratigraphic puzzle within these thrust sheets. However, the base of the R.A.T. Subgroup has never been observed in Congo and the contact between the Dipeta and Mwashya Formations is incompletely documented.

3. Description and lithostratigraphy of Red R.A.T.

The R.A.T. Subgroup, also called "lilac R.A.T." or "Red R.A.T.", is made of hematitiferous reddish sedimentary rocks, which are sometimes confused with Red Beds (Katekesha, 1975; Brown and Chartrand, 1986). R.A.T. is an unfortunate name for these rocks because fresh R.A.T. rocks with primary mineralogy preserved are devoid of talc and consist mainly of diagenetic chlorite–dolomite and variable amounts of silica minerals (detrital and diagenetic quartz, chert). These three components represent >85% in R.A.T. (Oosterbosch, 1962; Katekesha, 1975; Cailteux, 1983). Talc is a secondary mineral reported only in the oxidised zone.

The reference lithostratigraphic section of the Red R.A.T. Subgroup was selected on the basis of the investigation of underground sections and a large number of exploration boreholes drilled in the footwall of the Musonoi copper deposit (Kolwezi mining district), and described by R. Oosterbosch in internal Gecamines mining reports before being synthesized and formalized by François (1973, 1974). The Katangan experts used this as the reference lithostratigraphic section because the succession does not contain any breccia intercalation and displays a 235 m thick continuous Red R.A.T. sedimentary succession (François, 1973, 1974). From top to bottom it includes:

(1) R 1.3 (150 m): pink-lilac, massive, silty (25 vol.% quartz), chlorite- (30–50 vol.%) and dolomite-rich (20–40% dolomite) rocks containing up to 5% hematite. More sandy and irregularly bedded lithologies mark the lower part of the succession where a marker unit called "grès ocellés" occurs. This marker unit includes interbedded sandstones/siltstones with shaly layers in the lower part (Fig. 2a).
(2) R 1.2 (45 m): pink to purple-grey, irregularly bedded chlorite-rich (45–55%) siltstones (30–40% quartz) with minor dolomite (10%) and hematite (5%); a pink silicified dolomite with local stromatolites occurs at the top (Fig. 2b).
(3) R 1.1 (40 m): chlorite-rich (up to 50%) or sandy (up to 40% quartz) purple-red to pale orange irregularly bedded siltstones (Fig. 2c) containing in addition hematite (10%) and minor dolomite (5%).

A critical observation from this continuous succession of Red R.A.T. is that the amount of dolomite increases upwards (from 5% in R 1.1 up to ~40% in R 1.3) whereas hematite modal content decreases (from 10% in R 1.1 down to 5% in R 1.3).

Although, Red R.A.T. is rarely exposed in a continuous section similar to the one exposed at Musonoi, the reconstruction of Red R.A.T. lithostratigraphy from all Katangan thrust sheets and nappes led to a consistent distribution of the three R.A.T. formations identified above. Several variations of facies have been observed

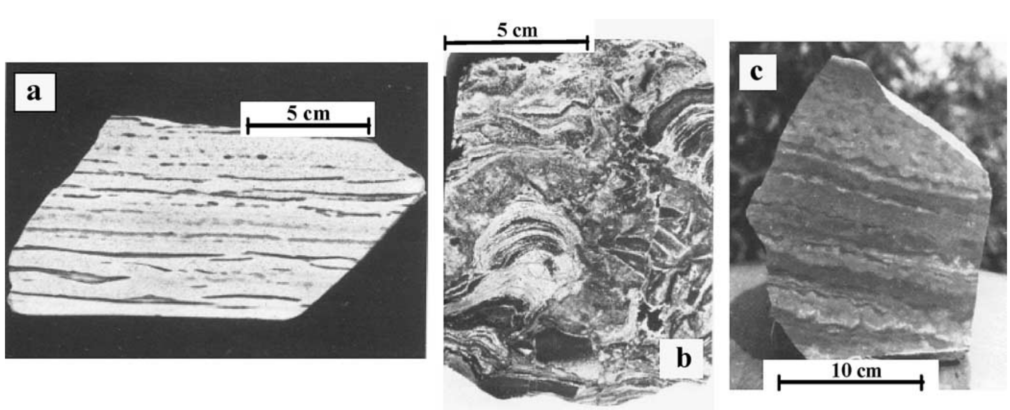

Fig. 2. (a) "Grès ocellés" at the base of R 1.3.1 Formation (Red R.A.T. 3) showing interbedded sandstones and siltstones with shaly layers (dark), sample from Kamoto mine (François, 1973); (b) siliceous pink dolomite with stromatolites, top of R 1.2 Formation (Red R.A.T. 2), sample from borehole Kadi-6 at 303 m, Kolwezi area (François, 1973); (c) R 1.1 Formation (Red R.A.T. 1) showing irregularly bedded siltstones with minor dolomite, sample from Kamoto mine (François, 1973).

(Oosterbosch, 1962; François, 1973), e.g. pebbly sandstones occur in R 1 at Tombolo (north of Kolwezi) whereas dolomite beds were documented in R 1.3 at Kalongwe (south of Kolwezi). Regionally, a siliciclastic R.A.T. lithofacies occurs to the north whereas a chlorite–dolomite rich R.A.T. lithofacies marks the southern regions of the Lufilian Arc in Congo.

Rocks forming the R 1.3 Formation at Kamoto (Kolwezi mining district) and Kambove contain 25–40 vol.% detrital minerals consisting mainly of quartz. Accessory detrital minerals (<1 vol.%) include green chlorite, red greenish chlorite (pseudomorph after biotite), micas, tourmaline, ilmenite, zircon and illite (Oosterbosch, 1962; Katekesha, 1975; Cailteux, 1983). No sorting of detrital minerals was observed in these rocks. Albite (5–6 vol.%) was reported in R.A.T. from Fungurume (Oosterbosch, 1950, 1962) but it is not yet known if it is diagenetic/metamorphic or detrital. However, detrital microcline represents an important rock component (>5 vol.%) at Fungurume (Oosterbosch, 1950, 1962) and is the only feldspar (<1 vol.%) at Kamoto (Katekesha, 1975). These observations contradict the assertion of Wendorff (2000) that "feldspars are absent in R.A.T. rocks".

Diagenetic minerals include dolomite, Mg-chlorite II pseudomorph after detrital minerals (Mg-chlorite I and biotite), chalcedony and quartz overgrowing detrital quartz, tourmaline overgrowing detrital tourmaline, monazite, apatite, dahlite, hematite and detrital ilmenite converted into leucoxene-rutile (Cailteux and Dimanche, 1973; Katekesha, 1975; Lefebvre, 1976; Cailteux, 1978, 1983). Katekesha (1975) suggested that diagenetic chlorite in R.A.T. originated from diagenetic transformation of detrital illite. Metamorphic minerals include mainly phengitic muscovite.

4. Grey R.A.T.–Red R.A.T. linkage

Grey R.A.T. ("R.A.T. grises") is a 1–8 m thick dolomitic or chloritic siltstone or silty dolomite (5–55 vol.% dolomite, 5–35% quartz, 30–55% diagenetic chlorite) occurring at the base of the Mines Subgroup. Red R.A.T. contains quartz (detrital and diagenetic overgrowths), chert, diagenetic Mg-chlorite and dolomite as the main rock-forming minerals ($\geqslant$90 vol.%). Accessory detrital and diagenetic minerals include tourmaline, green chlorite, micas, monazite, apatite, dahlite, leucoxene-rutile and sulphides. Metamorphic minerals include mainly phengitic muscovite and phlogopite in the southern part of the Congolese Copperbelt. Therefore, the main rock-forming and accessory minerals (detrital, diagenetic and metamorphic) are identical in Red and Grey R.A.T. The individual mineral compositions are also similar (e.g. Audeoud, 1982; Okitaudji, 1989). The only difference between these rocks is their colour and the relative proportion of detrital and diagenetic minerals. Red R.A.T. always contains a substantial amount of detrital minerals whereas the amount of these minerals is highly variable in Grey R.A.T., with some samples devoid of detrital fraction (e.g. Grey R.A.T. exposed at Etoile: Lefebvre and Cailteux, 1975).

Except for its grey colour and the occurrence of sulphides, both indicating the deposition of the Grey R.A.T. sedimentary rocks in a reduced environment, other lithological characteristics such as the grain size, the mineral and whole rock compositions of Grey R.A.T. and Red R.A.T.-1.3 are similar at Shinkolobwe, Kamoto, Fungurume, Kakanda, Kabolela and Kambove (Oosterbosch, 1950, 1962; Katekesha, 1975; Lefebvre, 1976; Cailteux, 1978, 1983; Moine et al., 1986). This led Katangan geologists to consider Grey R.A.T. as the topmost part of the R.A.T. succession deposited in an anoxic environment (Oosterbosch, 1950, 1962; Bartholomé et al., 1972; Cailteux, 1978, 1983, 1994).

In several places, Grey and Red R.A.T. are separated by breccias assumed to be of tectonic-sedimentary origin by Wendorff (2000) and linked to tectonic processes by Cailteux and Kampunzu (1995). Important to stress is that the breccias separating R.A.T. and Mines Subgroups are not the so-called "R.A.T. breccias" of local mining geologists. Cailteux (1978, 1983, 1994) documented a lithostratigraphic and petrographic continuity between Red and Grey R.A.T. in the Kambove area. The transition zone in this area is made up of 2.5–7.0 m thick variegated pink-white to yellow-green R.A.T. located between red (0.8–3.0 m thick) and grey (3.0–8.0 m thick) R.A.T. (e.g. borehole Kya-10, Fig. 3). The progressive change of colour marking this transitional zone reflects a gradual decrease of hematite bound to diagenetic minerals (in dolomite, in quartz, and tourmaline overgrowths). Along the transition zone between Red and Grey R.A.T., hematite in overgrowths of tourmaline and quartz progressively decrease in abundance. Only traces of hematite are found in the cores of dolomite grains in the variegated yellow–green R.A.T. near the Grey R.A.T. There is no hematite in the Grey R.A.T., which instead contains pyrite. Whole rock chemical analyses and the distribution of quartz/chert, chlorite and dolomite indicate that there is no change at the transition zone between Red and Grey R.A.T. (Fig. 4). This progressive transition between Red and Grey R.A.T. is not unique to the Kambove area, since it was also described in borehole cores from Tenke, Kalukundi (ca. 20 km W of Tenke) and Shadiranzoro along the northern flank of the Dipeta Syncline, between Tenke and Fungurume (Gecamines unpublished reports).

Grey and variegated R.A.T. were deposited in a supratidal-evaporitic environment as indicated by: (1) carbonate-quartz pseudomorphs after gypsum or anhydrite in lenticular or nodular concretions (Fig. 5); (2)

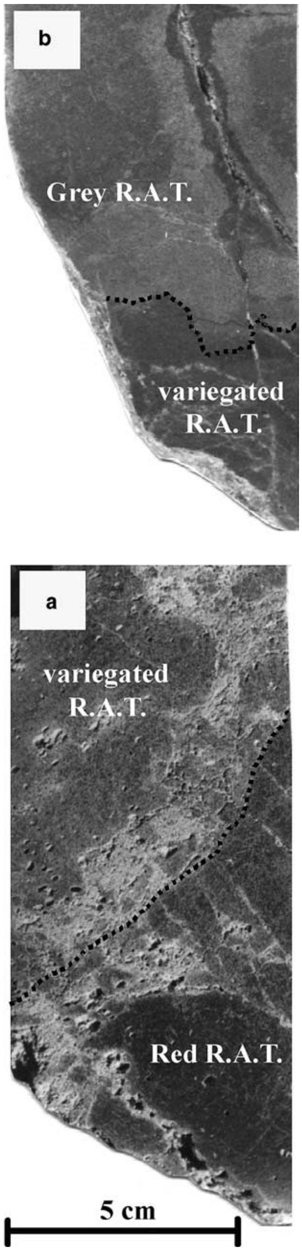

Fig. 3. Lithostratigraphic contact: (a) between Red and Variegated R.A.T. (sample 1177/1) and; (b) between Variegated and Grey R.A.T. (sample 1163/2). Both samples are from the borehole D.H. Kya-10, Kambove (Cailteux, 1978, 1983).

high Mg content (up to 13 wt%) and Li (up to 874 ppm) in the chloritic matrix; (3) high salinities in fluid inclusions inferred to be primary and related to the depositional environment because they are recorded in minerals coexisting with primary evaporitic minerals (Katekesha, 1975; Cailteux, 1978, 1983, 1994; Moine et al., 1986). The presence of evaporites at the transition between Red and Grey R.A.T. (Cailteux, 1994) explains the development of a major layer-parallel décollement along this transition during the Lufilian orogeny (Kampunzu and Cailteux, 1999). In several areas the breccia that formed along this décollement surface occulted the original lithological transition (evaporitic variegated R.A.T.) between Red and Grey R.A.T. However, in all thrust sheets Red and Grey R.A.T. occur in the same geometric position beneath the Mines Subgroup and the succession always proceeds from Red R.A.T. (R-1.3 Formation) to Grey R.A.T. and to D. Strat. (Oosterbosch, 1950; François, 1973; Katekesha, 1975). A section recently exposed in the Luiswishi open pit illustrates this succession, starting with ca. 40 m thick Red R.A.T. (R 1.3) overlain by Grey R.A.T. (Fig. 6). The transition zone in this succession is a ca 1.5 m thick breccia including centimetre to decimetre sized clasts of both Red and Grey R.A.T.

There is no doubt that Red and Grey R.A.T. are in stratigraphic continuity and should be grouped together as suggested by all Katangan experts for several decades. Wendorff (2000) does not question this conclusion, and even groups Red and Grey R.A.T. within a single lithostratigraphic unit as previously discussed by Cailteux (1994). In contrast, according to the Katangan geologists, the Grey R.A.T. is part of the Mines Subgroup rather than the R.A.T. Subgroup for three reasons: (1) Grey R.A.T. is conformable with the overlying D. Strat. Formation whereas in most cases it is separated from Red R.A.T. by a tectonic contact; (2) it is a grey unit deposited under anoxic conditions as are the overlying Mines Subgroup units; (3) it is a mappable unit at 1/5000 scale with specific lithological features and thus deserves an individual lithostratigraphic ranking. From a lithostratigraphic point of view, it could be taken for the uppermost formation of the R.A.T. Subgroup as suggested by Cailteux (1994) and Wendorff (2000), or as the lowermost unit of the Mines Subgroup (see above).

Some authors suggested that the breccia between Red and Grey R.A.T. could be a sedimentary conglomerate deposited from the erosion of the Red R.A.T sediments, before the deposition of Grey R.A.T. This interpretation was based on an inferred erosional surface at the top of Red R.A.T. and on a presumed monogenetic composition (Red R.A.T.) of breccia clasts in the Kamoto mine (Bartholomé et al., 1972; Katekesha, 1975). However, laterally the same breccia becomes polygenetic (Fig. 7), with clasts of Red and Grey R.A.T., D. Strat. and R.S.F. "Roches Siliceuses Feuilletées" (Cailteux, 1978; Cailteux and Kampunzu, 1995). This invalidates a pre-Grey R.A.T. sedimentary origin for this conglomerate.

The major issue still to be resolved here is the linkage between Red and Grey R.A.T. and the rest of the Katangan lithostratigraphic units. As there is an agreement that Red and Grey R.A.T. are in stratigraphic continuity, the discussion will focus on the relationships between Grey R.A.T. and the rest of the Katangan lithostratigraphic units; and the conclusion drawn from this discussion then applies equally to the R.A.T. Subgroup.

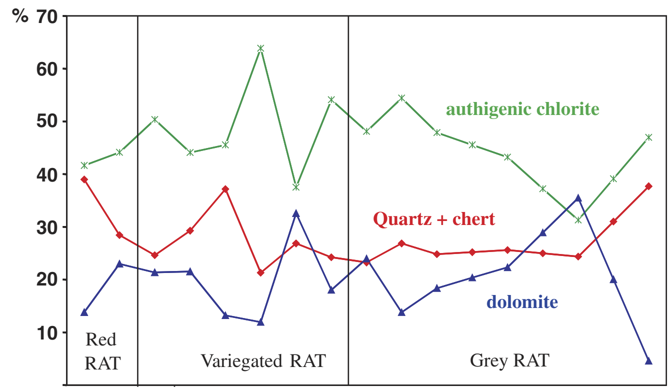

Fig. 4. Distribution of the three main rock-forming minerals in Red, Variegated and Grey R.A.T. Formations; samples from borehole D.H. Kya-10, Kambove (Cailteux, 1983).

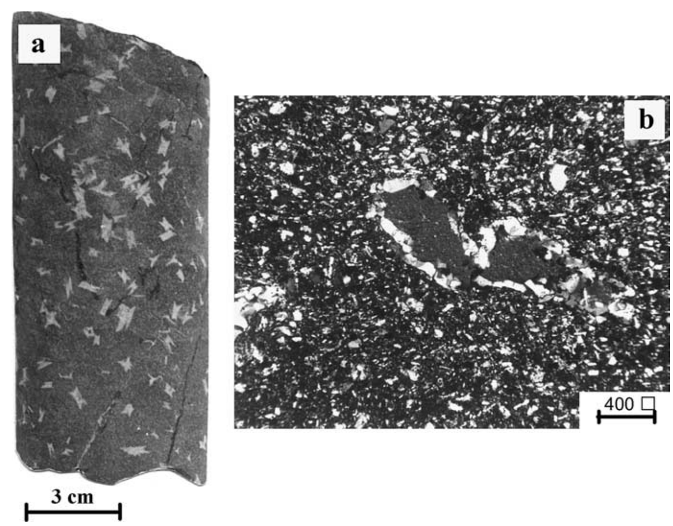

Fig. 5. Petrographic characteristics of Grey R.A.T. with: (a) dolomite-quartz pseudomorph after gypsum, sample from borehole Kw-216 (Cailteux, 1978, 1983); (b) thin section showing patches of dolomite with a quartz rim, pseudomorph after gypsum or anhydrite; borehole Kda-307, Kakanda (Cailteux, 1978, 1983).

5. Relationships between Grey R.A.T. and Mines Subgroup

Experts of Katangan lithostratigraphy (e.g. Oosterbosch, 1962; François, 1973, 1974; Cailteux, 1994; Cailteux et al., 1994) located the R.A.T. Subgroup stratigraphically beneath the Mines Subgroup on the basis of two critical observations, ignored by Wendorff (2000). These critical constraints are briefly reviewed below.

5.1. Conformable sedimentary contact between Grey R.A.T. and D. Strat. Formations

The Grey R.A.T. is always conformably overlain by silty dolomites of the D. Strat. "Dolomies Stratifiées" Formation (Mines Subgroup). Wendorff (2000), distorting published data of Cailteux (1978), claims that the contact R.A.T.–D. Strat. is brecciated and/or tectonically affected. However, what this author did not realise is that the tectonic contact commonly occurs between Grey and Red R.A.T., sometimes within the Red R.A.T. in areas where a continuous succession Red–Variegated–Grey R.A.T. was documented, or between other Mines Subgroup lithological units (e.g. D. Strat.) and Red R.A.T. where the tectonic break cuts across the Mines Subgroup succession (ramps), but there is usually no tectonic break between Grey R.A.T. and D. Strat. The contact between these two lithostratigraphic units is always a "clean" conformable sedimentary contact (Oosterbosch, 1950, 1962; Demesmaeker et al., 1963; François, 1973, 1987; Katekesha, 1975; Lefebvre and Cailteux, 1975; Lefebvre, 1976; Cailteux, 1978, 1983).

5.2. Evidence for a lithological transition between R.A.T. and D. Strat. rocks

Wendorff (2000), misquoting previously published data, claims that "feldspars are absent in the R.A.T.

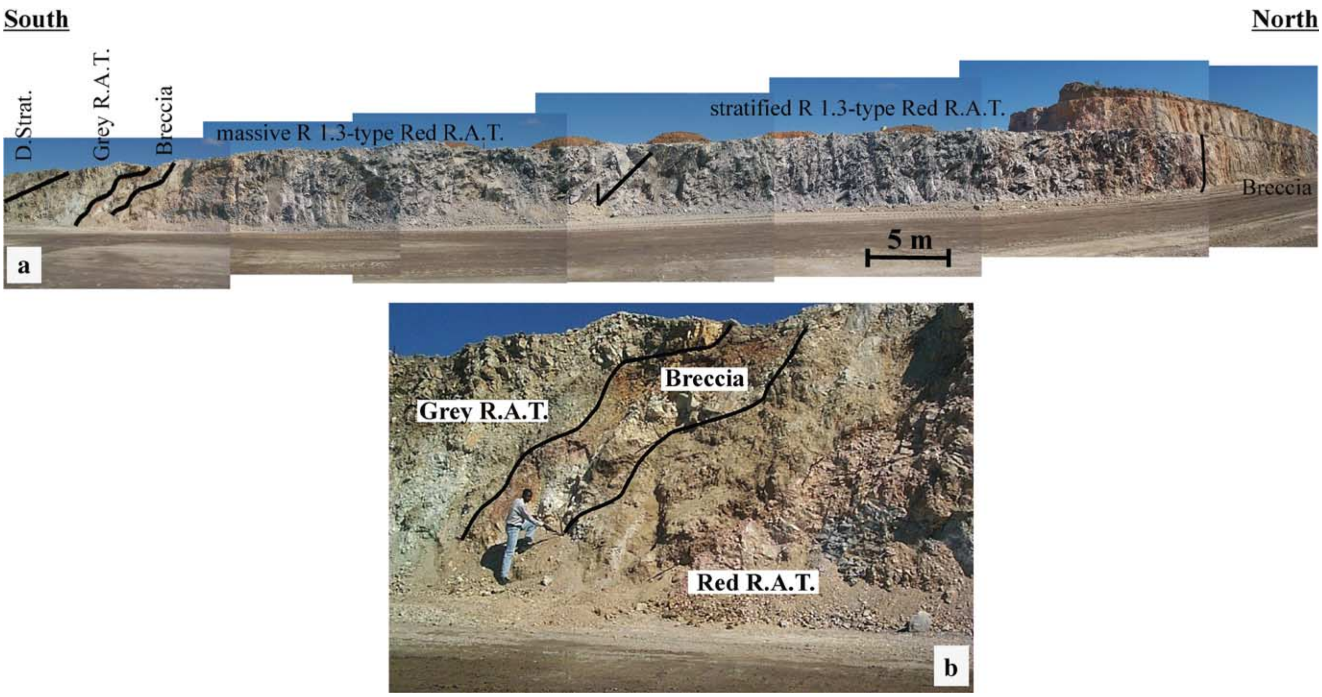

Fig. 6. (a) Panoramic view of the relationships between Red R.A.T.—Mines Subgroup Formations (Grey R.A.T.- –D. Strat.) normal lithostratigraphic succession, Luiswishi ore deposit; (b) breccia at the contact between Red and Grey R.A.T. including both Red and Grey R.A.T. fragments.

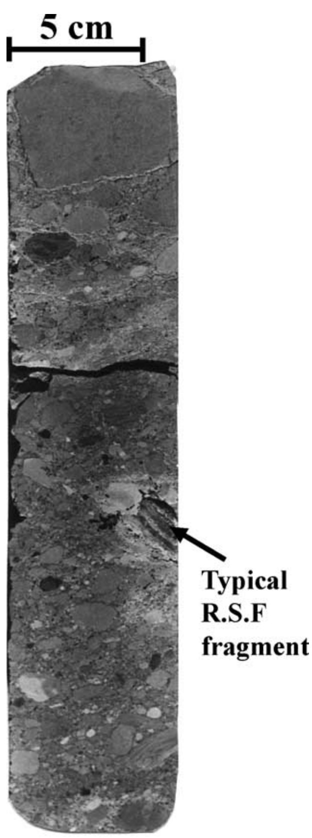

Fig. 7. Breccia between Red R.A.T. and Mines Subgroup formations containing Red R.A.T., Grey R.A.T. and Kamoto Formation (e.g. R.S.F) clasts; borehole Kda-342, Kakanda (Cailteux, 1978, 1983).

rocks and appear suddenly in the Stratified Dolomite", and raises the question "whether the composition of the R.A.T. rocks justifies the existing correlation". The above claim is not correct because: (1) in both R.A.T. and D. Strat. Formations, quartz represents the most important detrital component; (2) detrital feldspars or their relics occur in R.A.T. and Mines Subgroups (Dolomitic Shale and Kambove Formations) in the northern (e.g. Fungurume: Oosterbosch, 1962; Kolwezi: Katekesha, 1975) and southeastern (e.g. Etoile: Lefebvre and Cailteux, 1975; Kipapila: Cailteux and Lefebvre, 1975) parts of the Lufilian Arc; (3) in contrast, detrital feldspars are absent in both R.A.T. and Mines Subgroup rocks from central areas of the Lufilian Arc (e.g. Shinkolobwe, Kambove, Kakanda: Oosterbosch, 1962; Cailteux, 1978, 1983); (4) detrital feldspars are unknown in D. Strat. (Oosterbosch, 1962; Lefebvre and Cailteux, 1975; Katekesha, 1975; Cailteux, 1978, 1983). Authigenic feldspar was documented only at Etoile (Lefebvre and Cailteux, 1975); (5) Grey R.A.T. and Mines Subgroup rocks from each individual mine are characterized by the same distribution and nature of detrital minerals.

Red R.A.T., because of its distinct red colour, contrasts with Grey R.A.T. and D. Strat. Grey R.A.T. shows a transitional gradation to D. Strat. and the Kamoto Formation (Table 1). D. Strat. consists of dolomite and impure dolomite containing detrital quartz, chlorite, micas, illite, tourmaline, rutile and rare zircon (Katekesha, 1975; Lefebvre and Cailteux, 1975;

Cailteux, 1978, 1983). In the Kambove area, the base of D. Strat. is marked by a substantial amount of detrital quartz (20 vol.%) and, sometimes, by millimetre- to centimetre-sized soft clasts of Grey R.A.T. (Cailteux, 1978, 1983; Fig. 8). These clasts indicate that unconsolidated Grey R.A.T. was eroded and re-deposited in the younger D. Strat. dolomites. This requires a tectonically active sedimentary depocentre and this interpretation is supported by the occurrence of erosional surfaces in the D. Strat. dolomites (Fig. 8a). The most important conclusion from this observation is that R.A.T. was deposited before D. Strat. dolomites.

A continuous sedimentary transition between Grey R.A.T. and D. Strat. is exposed in the Luiswishi–Etoile area. In most Cu–Co deposits in Katanga, millimetre to decimetre thick Grey R.A.T.-type layers are interbedded in the Kamoto Formation, from D. Strat. up to R.S.C "Roches Siliceuses Cellulaires" (Oosterbosch, 1962; Lefebvre, 1976; Cailteux, 1978, 1983). These layers are reminiscent of varves and could mark seasonal variations in the sedimentary basin (Fig. 9).

This suggests a strong linkage between these lithostratigraphic units and this is supported by geochemical investigations (Kampunzu et al., 2005). The conclusions by Wendorff (2000) that there is an abrupt petrographic/lithological change from R.A.T. to D. Strat. and that the contact between these two formations is tectonic, reflect an incomplete understanding of the Katangan geology. There is an unquestionable continuity and sedimentary transition between Grey R.A.T. and the overlying D. Strat. At the same time, all workers agree upon the continuity between Grey and Red R.A.T. As a consequence, applying the principle of stratigraphic superposition, the R.A.T. Subgroup has to underlie the Mines Subgroup.

6. Relationships between R.A.T. and Kundelungu Group

In several places within the Katangan belt (e.g. Kamoto and Kambove-Ouest deposits), Grey or Red R.A.T. is in contact with the Kundelungu Ku 2.1 Formation (e.g. Kolwezi, Kambove: Cailteux and Kampunzu, 1995, Table 1). Wendorff (2000) assumes that Red R.A.T. is made of syn-orogenic sediments deposited upon Ku 2.1 Kundelungu rocks through an angular unconformity. But, whenever the contact R.A.T.-Kundelungu was observed, it is a tectonic contact. Shales and siltstones of the Ku 2.1 Formation, and R.A.T. formations display a tectonic fabric near that contact which does not occur within the same lithological unit a few hundred metres away (Fig. 10). Layer-parallel faults and imbricate faults affect the Kundelungu formations along that contact.

Kundelungu Group sedimentary rocks have petrographic features that are distinct from R.A.T. and Mines Subgroup rocks, i.e. they are richer in detrital feldspars and micas (Belliere, 1966; Francois and Cailteux, 1981). The Kundelungu succession is well known and mainly siliciclastic. It includes sandy and dolomitic shales lithologically and petrographically distinct from R.A.T. (Fig. 11). To the north of the Lufilian Arc, the Kundelungu rocks include coarse arenites and three pinkish carbonates forming the marker members Ku 1.2.1, Ku 1.3.1 and a 1 m thick member in the Ku 2.1; these units pinch out southwards (François, 1973, 1974). The arenites contain 60–75 vol.% detrital minerals (20–40 vol.% quartz, 5–15% feldspar, 15–35%

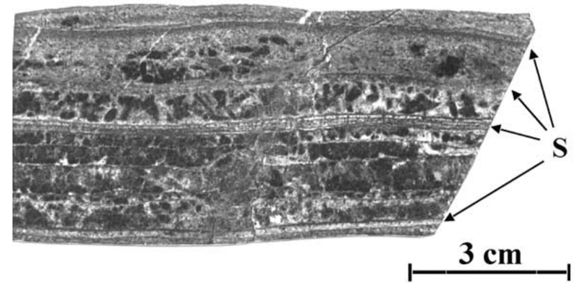

Fig. 9. Millimetre thick Grey R.A.T.-type siltstone (S) interbedded within a dolomite, D. Strat. Formation; sample from 346 m depth, borehole Kw-207, Kambove (Cailteux, 1978, 1983).

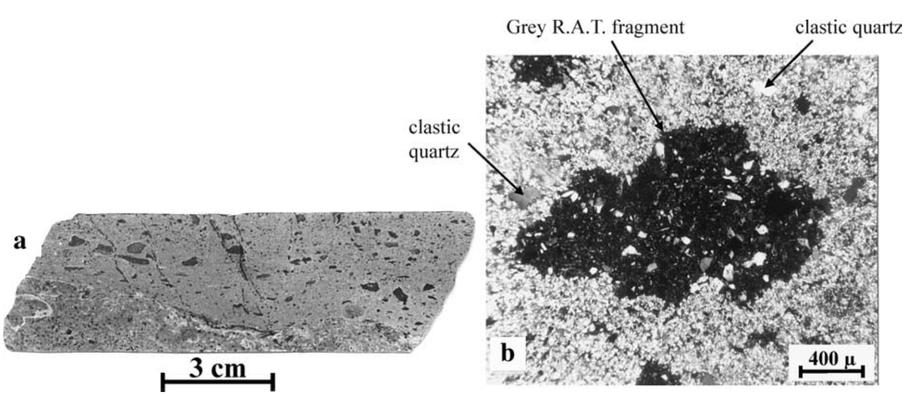

Fig. 8. (a) Millimetre- to centimetre-sized Grey R.A.T. soft clasts in an impure dolomite overlying an erosional surface, base of D. Strat.; (b) detail of a clast and of the impure dolomite matrix, sample 1595 from the borehole Kwf-1103, Kambove (Cailteux, 1978, 1983).

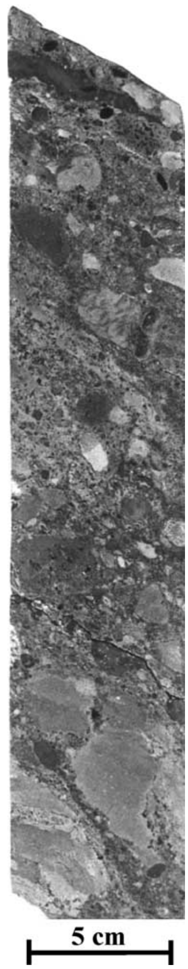

Fig. 10. Breccia ("brèche de fond") between Red R.A.T. and Kundelungu, including fragments of both formations; sample 1180 from the borehole Kya-10, Kambove (Cailteux, 1978, 1983).

muscovite), 15–25% dolomite, 5% diagenetic chlorite and 5–15% of other minerals, e.g. titanite and tourmaline (François, 1987; Batumike, unpublished data). Detrital titanite is common in Kundelungu rocks whereas it is absent in R.A.T.

7. Geochronological constraints

There are not yet direct geochronological data constraining the age of R.A.T. Subgroup rocks. However, available geochronological data on other Katangan lithological units allow placing preliminary constraints to this debate. The classical lithostratigraphic column places R.A.T. rocks in the lower part of the Katangan sedimentary succession, deposited after ~880 Ma, which is the age of detrital zircons in the lower part of the Katangan sedimentary succession (Armstrong et al., 1999), and before 760 Ma which is the age of Mwashya volcanic rocks (Armstrong et al., 1999; Key et al., 2001) located stratigraphically above the R.A.T. Subgroup (Table 1). The Grand Conglomérat, representing a tillite correlated with the 750 Ma worldwide Sturtian glacial event (Kampunzu and Cailteux, 1999) directly overlies the Mwashya Subgroup rocks. According to Wendorff's model, R.A.T. is stratigraphically part of the Kundelungu Group and rests above the Ku 2.1 Formation that is underlain by the Petit Conglomérat Tillite. The age of this second tillite is not yet constrained, but a correlation with the worldwide 620–600 Ma Marinoan glacial deposits is inferred. Therefore, according to this interpretation, the R.A.T. Subgroup is younger than 620 Ma and should be a correlative of the red siliciclastic sedimentary rocks forming the Kundelungu plateau and containing detrital micas yielding Ar–Ar ages younger than 565 Ma (S. Master, person. communic. 2001). However, in several Katangan Cu–Co deposits (e.g. Shinkolobwe, Luiswishi), Red R.A.T., Grey R.A.T. and overlying Mines Subgroup formations are cut by uraninite veins yielding ages >690 Ma at Shinkolobwe and around 625 Ma at Luiswishi (Loris et al., 1997; Kampunzu and Cailteux, 1999). R.A.T. is older than Kundelungu rocks and, therefore, cannot have been deposited upon the Kundelungu Group as suggested by Wendorff (2000).

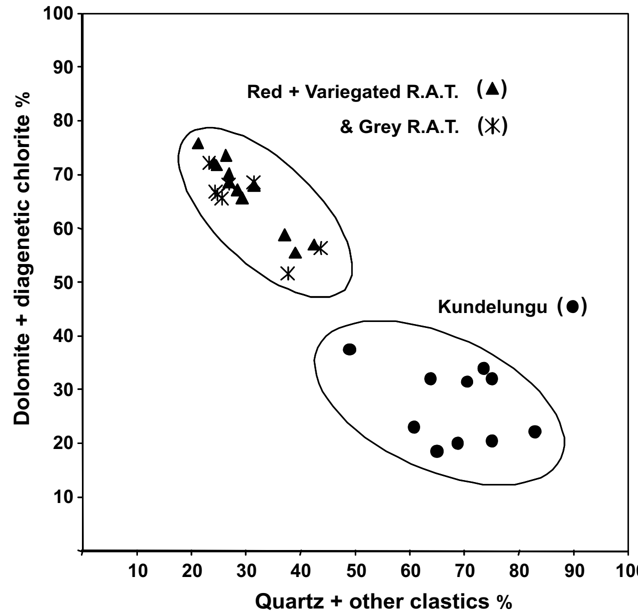

Fig. 11. Distribution of detrital and diagenetic components in R.A.T. and Kundelungu Formations; data from Cailteux (1983) and Batumike (unpublished data).

8. Implications for Cu–Co mineralisation

Two major Cu–Co stratiform orebodies hosted in the Mines Subgroup characterize the world-class ore deposits in the Congolese Copperbelt (Cailteux et al., 2005, and references therein). The Lower Orebody is hosted by rocks of the following sedimentary units: top of Grey R.A.T., D. Strat., R.S.F and base of R.S.C. The Upper Orebody occurs in the following sedimentary units: top of R.S.C, SDB ("Shale Dolomitic de Base") and BOMZ ("Black Ore Mineralized Zone"). Wendorff (2000) concluded that the olistostrome horizon includes R.A.T. sedimentary rocks and marks a prominent geochemical change from oxidising to reducing conditions responsible for the origin of syngenetic/diagenetic Cu–Co mineralisation in the Grey R.A.T. rocks. In this perspective, the Grey R.A.T. sulphide mineralisation represents a separate mineralisation event emplaced after the deposition of the Kundelungu and related to the development of the foreland basin. The data in this paper indicate that R.A.T. is not younger than Kundelungu and is not related to the development of the foreland basin; its stratigraphic position beneath D. Strat. is reconfirmed. This implies that the minor stratiform ore hosted in R.A.T. (top of the Grey R.A.T.) connects with the more important mineralisation hosted in D. Strat.–R.S.F-base of R.S.C to form the Mines Subgroup Lower Orebody, as indicated by all previous workers (Oosterbosch, 1962; Bartholomé et al., 1972; François, 1973; Katekesha, 1975; Lefebvre and Cailteux, 1975; Okitaudji, 1989; Loris, 1996). As a consequence, the prominent geochemical change from oxidising to reducing conditions in the R.A.T. rocks (from Red to Grey R.A.T.) explains not only the deposition of syngenetic/diagenetic Cu–Co mineralisation in the Grey R.A.T., but also in the whole Mines Subgroup Lower Orebody.

9. Conclusions

The main conclusions of this study can be summarized as follows:

(1) Red R.A.T. lithotype exposed in the Kolwezi area does not contain any breccia, and includes three lithostratigraphic formations displaying an increase of dolomite upwards, correlated to a decrease of hematite modal content from R 1.1 to R 1.3. A marker lithostratigraphic unit called "grès ocellés" made of interbedded sandstones/siltstones with shaly layers occurs in the R 1.3. Detrital feldspars occur in R.A.T. and Mines Subgroup rocks exposed in the northern part of the Lufilian Arc. They are absent in correlative rocks from the southern part of the Arc in Congo. Grey and Red R.A.T. have exactly the same mineral composition (for both main rock-forming and accessory minerals). The colour difference between these rocks results from their depositional environment, that was oxic during the deposition of hematite-bearing Red R.A.T. and anoxic for sulphide-bearing Grey R.A.T. and the overlying Mines Group lithologies. A gradual transition marking a progressive change of redox conditions in the Katangan basin during the deposition of R.A.T. is the existence of variegated R.A.T. preserved in a few areas where the décollement did not affect this transition zone.

(2) A very well preserved conformable sedimentary transition marks the contact between Grey R.A.T. and the overlying D. Strat. There is an unquestionable sedimentary continuity between Red R.A.T., Grey R.A.T. and D. Strat.; therefore, R.A.T. cannot be taken for a sedimentary unit deposited upon the Kundelungu Group, as suggested by Wendorff (2000).

(3) Field relationships and available geochronological data suggest that R.A.T. rocks were deposited between 880 and 760 Ma, whereas Kundelungu rocks (above the Petit Conglomérat) are younger than 630 Ma. All Katangan sedimentary rocks older than 750 Ma were deposited in a rift basin far away from any plate convergence (Kampunzu et al., 1991, 1993, 2000) and therefore, R.A.T. cannot represent a syn-orogenic sedimentary unit originating from erosion of the emergent thrusts fronts and deposited in a foreland basin, as speculated by Wendorff (2000).

(4) The lithostratigraphic position of the Grey R.A.T. at the bottom of the Lower orebody of the Mines Subgroup invalidates the conclusion of Wendorff (2000) that the Grey R.A.T. Cu–Co ores represent a stratiform mineralisation related to the anoxic stage of the foreland basin, with the Roan (Mines) orebodies acting as source of metals in the advancing nappes.

Acknowledgements

This is a contribution to the IUGS-UNESCO-IGCP-450 project. This work benefited from the support of Forrest Group and Gecamines Mining Companies.

A.B.H. Kampunzu acknowledges the support of both the University of Lubumbashi and the University of Botswana (1996–now) for his research on the Neoproterozoic of Africa. We acknowledge S. Sutton for a constructive review of the manuscript.

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.

Audeoud, D., 1982. Les minéralisations uranifères et leur environnement à Kamoto, Kambove et Shinkolobwe (Shaba, Zaïre). Pétrographie, géochimie et inclusions fluides. Thèse de 3ème cycle, Centre de Recherches sur la Géologie de l'Uranium (Nancy, France) and University Claude-Bernard (Lyon, France), p. 211.

Bartholomé, P., Evrard, P., Katekesha, F., Lopez-Ruiz, J., Ngongo, M., 1972. Diagenetic ore-forming processes at Kamoto, Katanga, Republic of the Congo. In: Amstutz, G.C., Bernard, A.J. (Eds.), Ores in Sediments. Springer-Verlag, Heidelberg, pp. 21–41.

Brown, A.C., Chartrand, F.M., 1986. Diagenetic features at White Pine (Michigan), Redstone (N.W. Territories, Canada) and Kamoto (Zaire). In: Friedrich, G.H., Genkin, A.D., Naldrett, A.J., Ridge, J.D., Sillitoe, R.H., Vokes, F.M. (Eds.), Geology and Metallogeny of Copper Deposits, Part IV, Sediment-Hosted Deposits. 27th International Geological Congress, Moscow (1984), Special Publication 4, Society for Geology Applied to Mineral Deposits. Springer-Verlag, Heidelberg, pp. 390–397.

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). Thèse de Doctorat en Sciences, University of Maine (France), p. 316.

Cailteux, J., 1978. Particularités stratigraphiques et pétrographiques du faisceau inférieur du Groupe des Mines au centre de l'Arc cuprifère shabien. Annales de la Société Géologique de Belgique 100 (1977), 55–71.

Cailteux, J., 1983. Le Roan shabien dans la région de Kambove (Shaba-Zaïre). Etude sédimentologique et métallogénique. Thèse de Doctorat en Sciences Appliquées, University of Liège (Belgium), p. 232.

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 19, 279–301.

Cailteux, J., 2003. Proterozoic sedimentary-hosted base-metal deposits of Western Gondwana. Conference and field workshop, Lubumbashi, p. 223.

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 19, 265–278.

Cailteux, J., Dimanche, F., 1973. Examen des oxydes de fer et titane dans l'environnement du gisement de cuivre de Musoshi (Shaba, rép. du Zaïre). Bulletin de la Société Française de Minéralogie et de Cristallographie 96, 378–382.

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

Cailteux, J.L.H., Kampunzu, A.B., Lerouge, C., Kaputo, A.K., Milesi, J.P., 2005. Genesis of sediment-hosted stratiform copper-cobalt deposits, Central African Copperbelt. Journal of African Earth Sciences, (this volume), doi:10.1016/j.jafrearsci.2005.08.001.

Cailteux, J., Lefebvre, J.-J., 1975. Stratigraphie et minéralisation du gisement cuprifère de Kipapila, Shaba, Zaïre. Annales de la Société Géologique de Belgique 98, 317–330.

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, pp. 47–115.

François, A., 1973. L'extrémité occidentale de l'Arc cuprifère shabien. Etude Géologique, Gécamines, Likasi (Shaba-Zaïre), p. 120.

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, Belgique. Annales des Sciences Géologiques 101, 1–20.

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., 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., 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., 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. Journal of African Earth Sciences, (this volume), doi:10.1016/j.jafrearsci.2005.08.003.

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.

Katekesha, W.M., 1975. Conditions de formation du gisement cuprocobaltifère de Kamoto Principal (Shaba-Zaïre). Thèse de Doctorat en Sciences, University of Liège (Belgium), p. 237.

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.

Lefebvre, J.-J., 1976. Phénomènes post-diagénétiques dans l'écaille Nord-Est du gisement de Kabolela, Shaba, Zaïre. Bulletin de la Société Belge de Géologie 85, 7–29.

Lefebvre, J.-J., Cailteux, J., 1975. Volcanisme et minéralisations diagénétiques dans le gisement de l'Etoile (Shaba-Zaïre). Annales de la Société Géologique de Belgique 98, 177–195.

Loris, N.B.T.H., 1996. Etude des minéralisations uranifères du gisement cuprocobaltifère de Luiswishi (Shaba, Zaire): contextes géologiques et géochimiques. Discussion des modèles génétiques. Thèse de Doctorat en Sciences Appliquées, Polytechnic Faculty of Mons (Belgium), p. 275.

Loris, N.B.T., Charlet, J.-M., Pechman, E., Clare, C., Chabu, M., Quinif, Y., 1997. Caractéristiques minéralogiques, cristallographiques, physico-chimiques et âges des minéralisations uranifères de Luiswishi (Shaba, 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. 285–306.

Moine, B., Guilloux, L., Audeoud, D., 1986. Major element geochemistry of the host rocks in some sediment-hosted copper deposits. In: Friedrich, G.H., Genkin, A.D., Naldrett, A.J., Ridge, J.D., Sillitoe, R.H., Vokes, F.M. (Eds.), Geology and Metallogeny of Copper Deposits, Part IV, Sediment-Hosted Deposits, Special publication 4 of the Society for Geology Applied to Mineral Deposits, Moscow 1984. Springer-Verlag, Berlin, Heidelberg, pp. 443–460.

Okitaudji, L.R., 1989. Géologie sédimentaire et concentration syndiagénétique du cuivre et du cobalt dans la "Série des Mines" du

Shaba, Zaïre. Thèse de Doctorat en Sciences, Polytechnic National Institute of Lorraine (France), p. 476.

Oosterbosch, R., 1950. La Série des Mines dans le Polygone de Fungurume. Comité Spécial du Katanga, Bruxelles 14, 1–18.

Oosterbosch, R., 1962. Les minéralisations dans le systéme 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.

Wendorff, M., 2000. Revision of the stratigraphical position of the "Roches Argilo-talqueuses" (R.A.T.) in the Neoproterozoic Katangan Belt, south Congo. Journal of African Earth Sciences 30, 717–726.