An overview of the geology and major ore deposits of Central Africa: Explanatory note for the 1:4,000,000 map "Geology and major ore deposits of Central Africa"

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Abstract

This paper is prepared within the frameworks of IGCP Project 470 and the associated BRGM scientific project "Africa 1999–2004" to accompany the 1:4,000,000 scale map "Geology and major ore deposits of Central Africa, presented at the 20th Colloquium of African Geology in Orleans in June 2004. It incorporates geological and metallogenic data from eight countries in Central Africa (Angola, Cameroon, Chad, Central African Republic, Congo Brazzaville, Democratic Republic of Congo (DRC), Equatorial Guinea and Zambia). The map is a harmonised and geo-referenced preliminary map, based on a GIS at 1:2,000,000 scale, and focusses on the spatial and temporal distribution of selected major deposits.

Keywords: Central Africa; Geology; Mineral resources; Map; GIS

1. Introduction

Central Africa is well-endowed with mineral resources, and it is host to some world-class mineral and energy deposits. Many geological maps at scales of 1:100,000 to 1:1,000,000 are available for the region. Moreover, geoscientific studies carried out over a long period of time have resulted in more than 5000 bibliographic references, but no recent reassessments of the data have been undertaken. Finally, no particular attention has been focussed previously on the geology and mineral potential across state boundaries.

Within the frameworks of IGCP Project 470, "The Neoproterozoic Pan-African belt of Central Africa" and the associated BRGM scientific project "Africa 1999–2004",

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we have undertaken a preliminary overview of the geology and mineral resources of the region to accompany the 1:4,000,000 scale map, "Geology and major ore deposits of Central Africa", published by BRGM in 2004. The overview covers the following countries, from the North to the South: Cameroon (CMR), Chad (TCD), Central African Republic (CAF), Congo Brazzaville (COG), Democratic Republic of Congo (DRC), Equatorial Guinea (GNQ), Angola (AGO), Gabon (GAB), and Zambia (ZMB). The map is based on a BRGM GIS and associated databases that incorporates map data initially compiled, reassessed, georeferenced and harmonised at a scale of 1:2,000,000. It also incorporates geological, structural and mineral information and focusses particularly on the spatial and temporal distribution of the main deposits.

The aim of the present study is to synthesise the available information to facilitate and improve regional knowledge of potential resources useful for sustainable development. It combines the hitherto often-dispersed data on geology, geochronology, mineral resources and tectonics updated by recent publications (e.g. Ledru et al., 1994; Bouchot and Feybesse, 1996; Kusnir and Moutaye, 1997; Toteu et al., 2001).

For convenience of use, the accompanying map has been published at the scale of 1:4,000,000. It was presented at the 20th Colloquium of African Geology in Orleans in June 2004 and published here as PDF format, (Fig. 1) with legend (Fig. 2).

An Access/Oracle database of 7200 ore deposits and mineral occurrences (precious and base metals, industrial minerals, coal and hydrocarbons) has been established, including information on the status of individual deposits and mines, geology, metallogeny and the economic potential of the deposits. The more important deposits of base metals, including Fe–Mn and Ti, precious metals, rare metals (Ta, Sn, Nb) and REE and U are shown on the map and are subdivided into size categories as defined in Table 1. However, deposits and occurrences of aluminium, potash, oil, gas, coal and gemstones are not localised on the map.

2. Archean craton (pre 2.5 Ga)

2.1. Geology

The Archean nuclei, well represented on the map, are composed of gneissic and anatectic complexes, and partly preserved greenstone belts and the associated magmatism. These cratons are deformed on their margins by Proterozoic orogeneses. In Central Africa, four main Mesoarchean–Neoarchean blocks have been mapped:

- The "West Central Africa" craton (Ntem in Cameroon, Equatorial Guinea, Gabon Massif and Congo), is tectonically overlain by Paleoproterozoic rocks (Nyong, CMR, Toteu et al., 2001; Feybesse et al., 1996; Tchameni et al., 2000; Shang et al., 2004). It contains: (i) Trondhjemite–Tonalite–Granite (TTG) and banded gneiss with Rb–Sr ages of 3186 ± 75–3120 Ma (Caen-Vachette et al., 1988); (ii) pre-3 Ga meta-sedimentary rocks and greenstone belts, including Banded Iron Formation (BIF) and mafic-ultramafic rocks, that were deformed up to medium-pressure granulite facies metamorphism; (iii) 2950–2800 Ma intrusive rocks, including TTG charnockites and associated greenstones (Caen-Vachette et al., 1988; Toteu et al., 1994; and (iv) 2800–2500 Ma late magmatic rocks (ultramafites, K-rich granitoids, syenogranites).

The northern Archean DRC–CAF craton ("Haut-Zaïre", or "West-Nilian", Lepersonne, 1974; Mestraud, 1982; Thibault, 1983 and 2000, unpublished; Caen-Vachette et al., 1988) contains: various granite–gneiss complexes (paragneiss and granitic or gabbroic orthogneisses cross cut by late pegmatites) assumed to be pre-2.91 Ga (e.g. amphibole–pyroxene-bearing gneiss of Bomu Complex, CAF–DRC at 3086 ± 94 Ma, Lavreau and Ledent, 1976): BIF-bearing Mesoarchean greenstone belts overlying the granite–gneiss complex have also been differentiated on the map, but without distinguishing between "Lower" (Mesoarchean–Neoarchean) and "Upper Kibalian" greenstone belts. The "Lower Kibalian" (DRC), comprises mesozonal to catazonal rocks (paragneiss, amphibolites, amphibole–garnet ± muscovite ± biotite ± sillimanite ± cordierite bearing gneisses and scarce BIF). The "Upper Kibalian" (Lepersonne, 1974) of DRC constitutes narrow troughs that contain folded terranes (quartzite, BIF, greywackes, volcano-sedimentary rocks, and basal mafic volcanic rocks) cross cut by pre-2800 and 2450 Ma granitoids (Thibault, 1983); late tonalite apparently emplaced at ca. 2750 Ma; Archean tectonic slices of greenstone belts (2706 ± 71 Ma and 2930 ± 88 Ma, cf. Rolin, 1995a) involved in the pan African nappes (CAF) in northwestern Uganda (West Nile area).

The metamorphic age of the northern Archean DRC–CAF craton had been estimated at ca. 2900 Ma (Rb–Sr WR and U–Pb zircon ages) from charnockitic granulites and interpreted as the age of a first granulite-facies metamorphism (Watian), while a second amphibolite–facies migmatitic reworking (Aruan) was previously dated at ca. 2550 Ma by the same methods in adjoining migmatitic gneisses and granites. This area was recently reassessed by Schenk et al. (2002a,b): monazite dating on the oldest Watian granulites revealed ages of ca. 2400 Ma (2442 ± 21 Ma, 2414 ± 20 Ma) for the first metamorphism, followed by a second late-stage Pan-African granulite-facies reworking (>800 °C at 7 kbar) occurring at ca. 570 Ma (570 ± 26 Ma).

- The "Central Shield" of western Angola is located at 9–17 °S and 14.4–18°E (De Carvalho, 1980–1982; De Carvalho et al., 2000). Archean rocks comprise a granite (granite to tonalite)–gneiss–migmatite complex with a Rb–Sr age of 2520 ± 66 Ma (De Carvalho et al., 2000), intruding a possible pre-2800 Ma gabbro–norite–

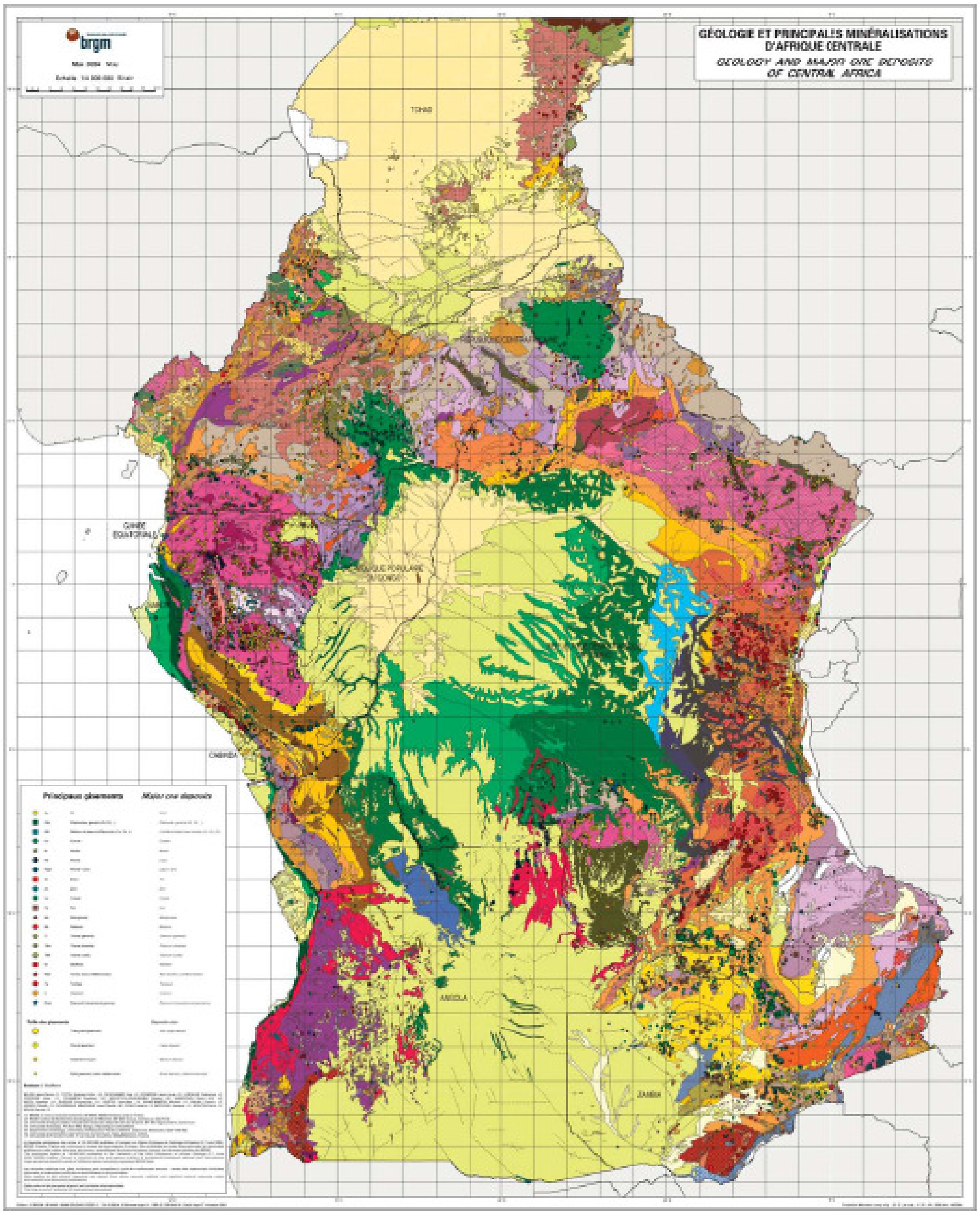

Fig. 1. Geology and major deposits of Central Africa.

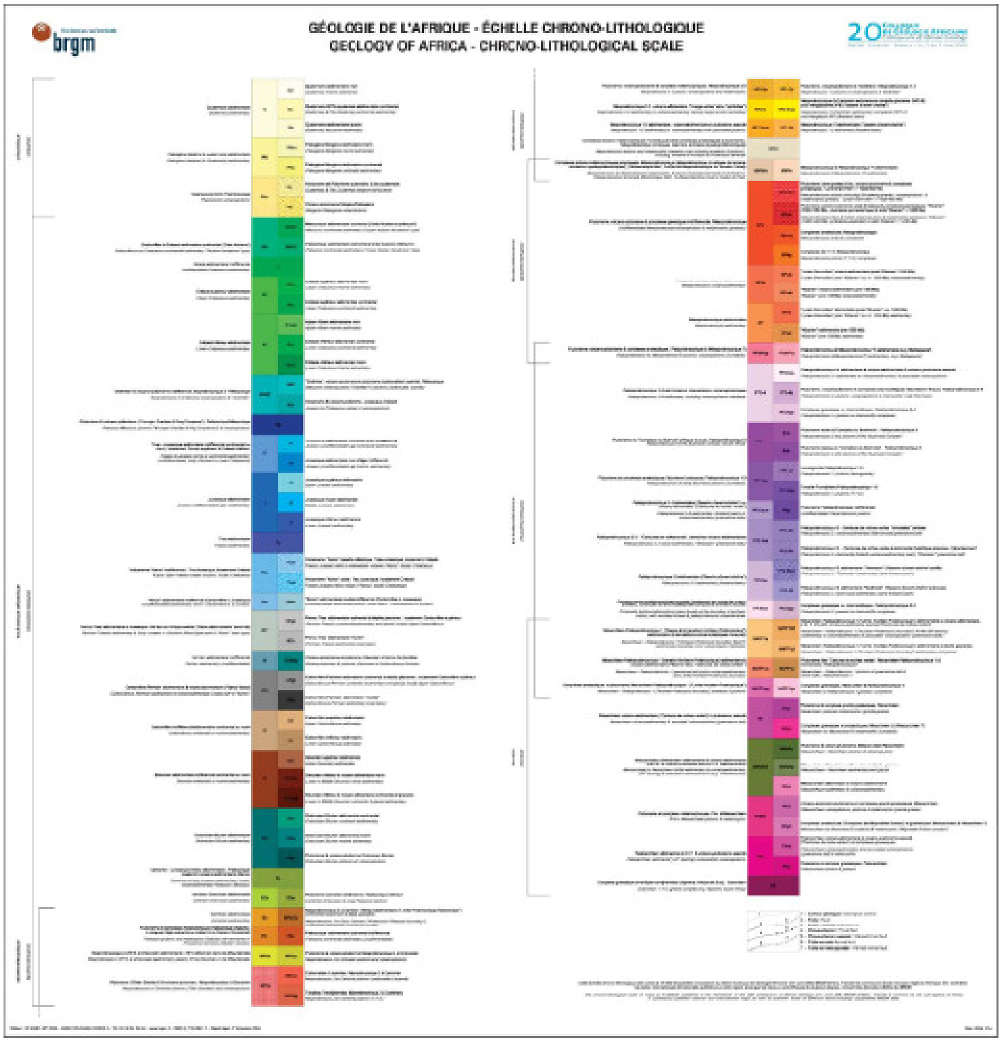

Fig. 2. Geology of Africa. Chrono-lithological scale.

charnockite complex (gabbro, norite, anorthosite, enderbite, mafic rocks, charnockite, scarce granulite).

- The "Kasai–Lomani–Luanda" Neoarchean–Mesoarchean craton (DRC–AGO) is located at 5–11°S and 19–25°E, and the poorly exposed "Cuango Shield" (AGO) is located at 9–10°S and 18–19°E (De Carvalho et al., 2000). Both areas comprise a younger granite–gneiss–migmatite complex and an earlier gabbro–norite–charnockite complex, dated respectively at 2680 ± 5 Ma on a migmatite U–Pb isochron (Cahen et al., 1984) and 2822 ± 66 Ma on a gabbro Rb–Sr isochron, Delhal et al., 1976).

2.2. Metallogeny

2.2.1. Archean

The Central Africa Archean blocks are productive for Fe and Au (Table 2). Some of the gold occurrences

Table 1
Ore deposit classification (lower limit by commodity); italic: commodity cited in the text, not represented on the 1:4,000,000 map

	Commodity (expressed as)	Class A (Very large deposit)	Class B (Large deposit)	Class C (Medium deposit)	Class D (Small deposit)	Unit
Al	*Aluminium (Bauxite ore)*	*1,000,000,000*	*100,000,000*	*10,000,000*	*1,000,000*	*t (1000 kg)*
Au	Gold (metal)	250	50	10	1	t (1000 kg)
BM	Base metal (undifferentiated)	5,000,000	500,000	50,000	5000	t (1000 kg)
Co	Cobalt (metal)	100,000	10,000	2000	200	t (1000 kg)
Coal	*Coal, lignite (substance)*	*10,000,000,000*	*1,000,000,000*	*100,000,000*	*5,000,000*	*t (1000 kg)*
Cu	Copper (metal)	10,000,000	1,000,000	100,000	10,000	t (1000 kg)
Diam	Diamond, industrial and gemstone (substance)	100,000,000	10,000,000	1,000,000	100,000	ct (0.2 g)
Fe	Iron (metal)	1,000,000,000	100,000,000	10,000,000	1,000,000	t (1000 kg)
Gas	*Gas (substance)*	*1000*	*250*	*50*	*10*	*km^3*
GemP	*Gemstones, general (substance)*	*10,000,000*	*1,000,000*	*100,000*	*10,000*	*ct (0.2 g)*
GemS	*Semiprecious stone, general (substance)*	*10*	*5*	*0.5*	*0.1*	*t (1000 kg)*
Mn	Manganese (metal)	100,000,000	10,000,000	1,000,000	100,000	t (1000 kg)
Nb	Niobium–columbium (Nb_2O_5)	250,000	50,000	10,000	2000	t (1000 kg)
Ni	Nickel (metal)	2,000,000	200,000	20,000	2000	t (1000 kg)
Pb	Lead (metal)	1,000,000	100,000	10,000	1000	t (1000 kg)
PbZn	Lead + Zinc (metal)	2,000,000	200,000	20,000	2000	t (1000 kg)
Petr	*Petroleum (substance)*	*1,000,000,000*	*100,000,000*	*10,000,000*	*1,000,000*	*m^3*
Pltd	Platinoids, group (metal)	250	50	10	1	t (1000 kg)
Ptsh	*Potash (sylvite, carnallite) (K_2O)*	*500,000,000*	*50,000,000*	*5,000,000*	*500,000*	*t (1000 kg)*
REE	Rare Earths (RE_2O_3)	250,000	25,000	2500	250	t (1000 kg)
Sn	Tin (metal)	100,000	10,000	1000	100	t (1000 kg)
Ta	Tantalum (Ta_2O_5)	25,000	5000	1000	200	t (1000 kg)
Ti	Titanium, general (TiO_2)	20,000,000	20,00,000	200,000	20,000	t (1000 kg)
TiIlm	Titanium, ilmenite (TiO_2)	20,000,000	2,000,000	200,000	20,000	t (1000 kg)
TiRt	Titanium, rutile (TiO_2)	2,000,000	200,000	20,000	2000	t (1000 kg)
Tlc	*Talc (substance)*	*20,000,000*	*2,000,000*	*200,000*	*20,000*	*t (1000 kg)*
U	Uranium (metal)	50,000	5000	500	50	t (1000 kg)
W	Wolfram (WO_3)	50,000	5000	500	50	t (1000 kg)
Zn	Zinc (metal)	2,000,000	200,000	20,000	2000	t (1000 kg)

This classification was developed for the study in order to integrate the new major industrial (A, B and C classes) and artisanal (D class) ore deposits.

(primary or secondary) are spatially associated with volcanic rocks and BIF-bearing formations (greenstone belts; e.g. Kilo-Moto, Isiro, Gorumbwa, Ituri-Uetele, DRC; Belinga, GAB, etc.). Sn-(W) magmatic-related occurrences occur along major faults (CMR–GAB, W AGO). Scarce base metal occurrences (Zn–Pb, Cu and Mn) have also been reported in Archean blocks. Near Mitzic (NW Gabon) secondary and primary diamond occurrences of unknown age (e.g. diamond-bearing dykes of kimberlitic affinity, metakimberlites?) are hosted within or along the tectonic margin (COG) of the Archean block.

3. Paleoproterozoic belts (2.5–1.6 Ga)

3.1. Geology

In Central Africa, Paleoproterozoic belts have been locally overprinted by the Pan-African event (and probably by the Kibaran in Zambia). We discuss four different belts.

1. The first Paleoproterozoic belt extends west of the Congo craton from Angola to SW Cameroon and is known as the West Central African Belt (WCAB) (Feybesse et al., 1996). The belt is characterized by post-2500 Ma sedimentation (metasediments and metavolcano-sediments) and by a 2050 ± 50 Ma high-grade metamorphism and plutonism. The crustal evolution is dominated by an Archean inheritance recorded in metasediments and metaplutonic rocks (Toteu et al., 1994; Lerouge et al., this volume). The rocks are generally well-preserved but are locally strongly deformed by the West Congolian Neoproterozoic belt.
2. The second belt, probably a northern prolongation of the WCAB is developed in central and northern Cameroon (Penaye et al., 2004). This belt is oriented NE–SW and is lithologically similar to the WCAB, but with a significant presence of Paleoproterozoic juvenile material. It was strongly reworked and dismembered during the Pan-African. It probably extends into eastern Nigeria (Penaye et al., 2004).
3. The third possible belt is located at the northern periphery of the Congo basin between Archean blocks (Ntem complex in CMR and Bomu complex in CAF) and the Pan-African thrust nappes (Yaoundé and Gbayas) to the north.

The Paleoproterozoic Ubendian event may be preserved in windows in the Neoproterozoic Copper Belt, as well as in undeformed clastic sedimentary terranes of the Bangweulu area, located to the north of the Copper Belt (geochronological and structural research carried out in the Copper Belt province by Kampunzu and Cailteux,

Table 2
Major Archean mining districts of Central Africa

Name of district, *country*, *age*, *host-rocks*	Comm.	Potential (t metal @ grade), Class of deposit	Ore deposit type and *shape*	Ore and *host-rock mineralogy*	Long; lat.	Exploitation type; *ore*
Kilo-Moto, *DRC*, *Neoarchean, albitite, albitic schist, chlorite-schist, greenstone, talcschist, amphibolite, dolerite, granitoid, mylonite, ductile tectonite, illuvium*	Au	Kilo: ca. 250 including ca. 100 (alluvial) Moto: ca. 100, A	Brittle-ductile shear-zone related mesothermal gold deposit. Granitoid-controlled ore deposits. BIF-related gold deposit (Moto). Modern placers. Mine tailings and stockpiles; *Discordant lode or vein (thickness > 5 cm), in clusters or isolated. Discordant mass or lens of massive to submassive ore. Discordant envelope of disseminated ore. Tailings, dumps, stockpiles. Present-day or recent placers*	Gold, pyrite, pyrrhotite, magnetite; *Quartz, albite, ankerite, siderite, magnetite, hematite, sericite, chlorite, epidote silicification, albitization, chloritization, sericitization*	30.03; 1.93	Underground mining. Alluvial mining. Tailings retreatment. Dredging; *Native-element ore*
Gorumbwa, *DRC*, *Neoarchean, Fe quartzite, BIF, itabirite, greenstone (s.l.), albitic schist, albitite, graphitic schist*	Au	80, B	BIF-related gold veins (epigenetic sulphidation); *Subconcordant & discordant envelope of disseminated ore*	Gold, pyrite, oxides; *Quartz, albite, carbonates, sericite*	29.57; 3.12	Open cast (open pit) & underground mining; *Native-element ore*
Isiro, *DRC*, *Neoarcean, Fe quartzite, BIF, itabirite, ankerite-, siderite-bearing carbonate rock, albitic schist, graphitic schist*	Fe	Ca. 10,000,000,000, A	Banded iron formations (BIF). Laterite-related ore deposits; *Subconcordant mass, lens or pod of submassive ore. Stratiform bed: single or multi-layered (syn-depositional with host rock). Cap, blanket, crust*	Magnetite, hematite; *Quartz, amphibole, siderite, arsenopyrite, carbonates*	27.19; 3.14	Unworked; *Primary oxide ore*
Ituri-Uele, *DRC*, *Neoarchean, Fe quartzite, BIF, itabirite, ankerite-, siderite-bearing carbonate rock, albitic schist, graphitic schist*	Fe	2,750,000,000, A	Banded iron formations (BIF). Laterite-related ore deposits; *Subconcordant mass, lens or pod of submassive ore. Stratiform bed: single or multi-layered (syn-depositional with host rock). Cap, blanket, crust*	Magnetite, hematite; *Quartz, amphibole, siderite, arsenopyrite, carbonates*	30; 2	Unworked; *Primary oxide ore*
Kasai-Lomami, DRC, Archean?, Fe quartzite, BIF itabirite	Fe	500,000,000, A	Banded iron formations; *Stratiform bed: single or multi-layered (syn-depositional with host rock)*	Magnetite, hematite; *Quartz, carbonates*	21.28; −5.47	Unworked; *Primary oxide ore*
Mékambo, *GAB*, *Archean, Fe quartzite, BIF, itabirite*	Fe	ca. 1,115,000,000, A	Banded iron formations; *Stratiform bed: single or multi-layered (syn-depositional with host rock).* *BIF-related gold veins (epigenetic sulpidation). Stockwork of veinlets*	Hematite, magnetite, goethite, gold; *Quartz, carbonates, siderite*	13.42; 1.06	Unworked; *Primary oxide ore*
Minkébé, *GAB*, *Archean, Fe quartzite, BIF, itabirite, amphibolite, gneiss*	Fe	125,000,000, B	Banded iron formations; *Stratiform bed: single or multi-layered (syn-depositional with host rock)*	Hematite, magnetite, goethite; *Quartz, carbonates, siderite*	12.84; 1.61	Unworked; *Primary oxide ore*

Zanaga-Zanaga III. *COG, Archean, Fe quartzite, BIF, itabirite*	Fe	160,000,000, B	Banded iron formations. Residually enriched ore deposits; *Stratiform bed: single or multi-layered (syn-depositional with host rock). Cap, blanket, crust*	Gold, Magnetite, hematite; *Quartz, carbonates*	13.60; −2.63	Mining method unkown; *Primary oxide ore*
Lobi-Lobi, *COG, Archean, Fe quartzite, BIF, itabirite, amphibolite, gneiss*	Fe	100,000,000, C	Banded iron formations; *Stratiform bed: single or multi-layered (syn-depositional with host rock)*	Hematite, magnetite, goethite	13.04; −0.49	*Primary oxide ore*
Mont M'Bilan, *COG, Archean, Fe quartzite, BIF, itabirite, amphibolite, gneiss*	Fe	70,000,000, C	Banded iron formations; *Stratiform bed: single or multi-layered (syn-depositional with host rock)*	Hematite, magnetite, goethite, oligiste, martite	10.29; 0.56	*Primary oxide ore*
Kizenga, DRC, Cenozoic on Neoarchean rocks	Mn	30,000,000, B	*Residually enriched ore deposits. Surficial orebody of secondary origin*	Mn oxides	23.07; −10.56	Unworked
Bingo, *DRC, Archean host rock. Unknown age of carbonatite?*	Nb	ca. 198,000, B	Nepheline-carbonatite hosted Nb deposits. Carbonatite-hosted apatite deposits; *Discordant envelope of disseminated ore Laterite-related ore deposits*	Pyrochlore, apatite, columbite, fluorite, titanite, magnetite. Hematite, goethite titanomagnetite, gorceixite, zircon, wad, biotite, fayalite, calcite	29.33; 0.53	Mining method unknown; *Primary oxide ore*

Potential = Production + reserves + resources.

1999 and Cailteux, 2004; and along the Great Lakes rift zone by Kampunzu, Oral Comm.). The above-mentioned belts may not be coeval in age, but they all developed between 2400 Ma and 1900 Ma, with the Ubendian belt being younger (between ca. 2100 and ca. 1700 Ma).

3.2. Metallogeny

The potential of the Central African Paleoproterozoic belts seems underestimated by comparison with their equivalents in West Africa and NE Brazil. For example, they seem to be poor in gold occurrences compared to West Africa, probably because they were not efficiently explored during the recent past (after 1975). In some geological and metallogenic aspects, they are comparable to West Africa as they display stratiform mineralisation including Mn & Fe (including BIF), Au–pyrite associated with the early stages of the orogeny, and Au–As mesothermal mineralisation associated with the final orogenic stages (Ledru et al., 1994; Bouchot and Feybesse, 1996). We discuss four areas:

1. The Ogooué-Franceville Paleoproterozoic basins are, from the mining point of view, well known for Mn (Moanda and Bangombé, Abouka, Massengo, Yeye districts, Gabon) and for U (Mounana, Bangombé, Okelobongo and Oklo. (Gauthier-Lafaye et al., 1989, 1996; Hidaka et al., 1999; Gauthier-Lafaye and Weber, 2003; Table 3). The gold district of Etéké was formed during the Paleoproterozoic in Archean metasedimentary and ultramafic rocks (Bouchot and Feybesse, 1996; Table 3). Lithological, geochronological and structural characteristics suggest comparison of this district with the Jacobina and Contendas Mirante (São Francisco craton in NE Brazil) and with the Guyana and the West Africa provinces (Ledru et al., 1994, 1997; Milesi et al., 1995, 2002, 2004; Bouchot and Feybesse, 1996). The eastern extension of the belt through COG, CAF and then DRC has been less explored, although it hosts grouped or isolated lithologically and structurally controlled occurrences of Au, Nb–Sn, Fe and Ti (ilmenite > rutile). Isolated diamond occurrences are also hosted in these formations. Their age is unknown or assumed to be Mesozoic, but the Akawatia diamond field of Ghana (Delor et al., 2004) might have a Paleoproterozoic origin for diamonds present in this belt.
2. The central–north Cameroon Paleoproterozoic Region displays Au occurrences with Paleoproterozoic and/or Neoproterozoic tectonic and/or lithological controls, and Sn occurrences with Pan-African magmatic and structural controls.
3. The WCAB involved in the West Congolian belt, hosts Sn–REE–W, U, base metals and some isolated diamond occurrences, all of uncertain ages.
4. The southeastern belt (DRC–ZMB) hosts mainly Fe–Mn deposits (Chiwefwe, Table 3) and some isolated diamond occurrences of unknown age. The Paleoproterozoic 4

Table 3
Major Paleoproterozoic mining districts of Central Africa

Name of district, *country*, *age*, *host-rocks*	Comm.	Potential[a] (t metal @ grade), Class of deposit (A,B,C)	Ore deposit type and *shape*	Ore and *host-rock* mineralogy	Long.; Lat.	Exploitation type; *ore*
Moanda, *GAB*, *Paleoproterozoic 2*, *"Francevillian" FB (pelite, sandstone) & FC (chert)*	Mn	ca. 160,000,000, A	Sedimentary manganese deposits; *Stratiform bed: single or multi-layered (syn-depositional with host rock)*	Nsutite, lithiophorite, pyrolusite (polianite), cryptomelane, rhodochrosite (dialogite)	13.18; −1.47	Open cast (open pit) mining; *Oxide/hydroxide ore within the oxidized zone*
Mounana, *GAB*, *Paleoproterozoic 2*, *"Francevillian" sandstone*	U	ca. 25,000, B	Uraniferous sandstones and residually enriched ore deposits; *Concordant to subconcordant envelope of disseminated ore, surficial orebody of secondary origin*	Pitchblende (uraninite), francevillite, uranium oxide, uraninite, montroseite, kamlanite, coffinite; *barite, calcite*	13.16; −1.38	Open cast (open pit) and underground mining. Closure in 1999; *Primary oxide ore*
Oklo, *GAB*, *Paleoproterozoic 2*, *"Francevillian"-FA, sandstone; 2 Ga natural fission reactor* (Gauthier-Lafaye et al., 1996; Hidaka et al., 1999. Gauthier-Lafaye and Weber, 2003)	U (Mn)	ca. 30,000, B	Uraniferous sandstones; *Concordant to subconcordant envelope of disseminated ore, stratiform bed: single or multi-layered (syn-depositional with host rock)*	Uraninite, coffinite, francevillite, wolsendorfite; *pyrite, galena, chalcopyrite*	13.16; −1.40	Open cast (open pit) and, underground mining; *Primary oxide ore*
Etéké, *GAB*, *Paleoproterozoic mineralization hosted by Archean unit (Ultramafic rocks, amphibolite, leptynite, leucocratic gneiss, micaschist) Primary deposit:* Dondo Mobi, Dango, Massima, Ovala, Etéké *Flats:* Migoto, Ikoye, Ovala, Pounga	Au	ca. 42, C	Brittle-ductile shear-zone related mesothermal gold deposit; *Discordant lode or vein (thickness > 50 cm), in clusters or isolated and stockworks* Alluvial-eluvial placers	Gold, pyrite, diamond, columbo-tantalite, cassiterite; *Quartz, sericite, chlorite, carbonates*	11.47; −1.50	Alluvial and open cast (open pit) mining; *Native-element ore and secondary native-element ore: "oxidized ore"*
Kribi (Les Mamelles), *CMR*, *Paleoproterozoic*	Fe	330,000,000, B	Banded iron formations (BIF). Laterite-related ore deposits; *Subconcordant mass, lens or pod of submassive ore. Stratiform bed: single or multi-layered (syn-depositional with host rock). Cap, blanket, crust*	Magnetite, hematite; *Quartz, amphibole (grunerite), carbonates, siderite-garnet*	9.97; 2.60	Unworked; *Primary oxide ore*
Chiwefwe, *ZMB*, *Paleoproterozoic*, *Bangweulu-Muva Group: metasediment, micaschist, amphibole-chlorite-schist, quartzite, conglomerate, shale and granitoid*	Fe, (Mn, Barite)	Fe: 125,000,000, B	Fe and Mn sedimentary and laterite-related ore deposits; *Concordant to subconcordant massive to submassive ore and cap*	Manganite, psilomelane, pyrolusite (polianite); *Barite*	28.91; −11.24	Open cast (open pit) mining; *Ore in which the element forms a distinct mineral phase*

Samba, *ZMB*, *Paleoproterozoic 3*, *pre-Katangan basement at 1.96 Ga* (Rainaud et al., 1999), *granodiorite, monzonite, gneiss, schist*	Cu	Cu: 250,000, C	Porphyry copper deposits; *Stockwork (or network) of stringers or veinlets*	Bornite, chalcocite, chalcopyrite, pyrite, chrysocolla, malachite *Biotite, sericite, calcite, chlorite*	27.83; −12.72	Not worked
Mkushi Copper-Kashime, *ZMB*, *Paleoproterozoic 3 at 2.049 Ga* (Rainaud et al., 1999), *pre-Katangan basement, Aplite*	Cu, (Au)	Cu: 100,000, C Au	Aplite-related copper mineralisation; *Discordant primary orebody*	Bornite, chalcocite, chalcopyrite, pyrite, chrysocolla, malachite	29.43; −13.33	Not worked

[a] Potential = Production + reserves + resources.

pre-Katangan basement of ZMB (1960 Ma, Rainaud et al., 1999), contains porphyry copper deposits (Samba, ZMB), and aplite-related Cu–(Au) deposits (Mkushi Copper-Kashime, ZMB).

4. Mesoproterozoic to early Neoproterozoic 1 belts (1.6–0.9 Ga): Kibarides, Irumides

4.1. Geology

Mesoproterozoic to the early Neoproterozoic formations have been identified mainly in the eastern part of the map area. They comprise four belts:

1. The NNE–SSW "Kibaran belt", located in eastern DRC, is marked by an inner domain and a foreland that is well developed beyond the map in Tanzania, Rwanda, and Burundi, ±Uganda (Tack et al., 2001). Mafic-ultramafic rocks emplaced between the inner and foreland domains delineate a westward curvature north of DRC. The foreland domain is composed of volcano-sedimentary formations that include detrital sedimentary rocks (conglomerate, sandstones and pelite), and interbedded basic to dacitic volcanics and sills. The belt may be correlated with rock suites in NW Tanzania (Ar/Ar ages of 1379 ± 10 and 1355 ± 10 Ma) and SW Burundi: 1360 ± 20 Ma and 1340 ± 09 Ma (Deblond et al., 2001). Kampunzu (2003, Oral Comm.) suggests that this domain is composed of two superposed clastic–carbonate sedimentary formations: (i) a lower meta-sedimentary formation (gneiss, micaschist, metasedimentary clastic–carbonate rocks), whose geodynamic setting is not well constrained, crosscut by synkinematic granitoids (ca. 1380–1370 Ma), and (ii) an upper meta-sedimentary formation overlying the 1380 Ma granites, but crosscut by Sn–granites (ca. 1000–950 Ma); this upper formation is commonly fault-bounded and could represent intracontinental arc deposits. The lower formation (partly ex-Ruzizian) is affected by a first deformation (D1) associated with the 1370–1380 Ma synkinematic granites. The upper formation (partly ex-Burundian) includes heavy mineral-bearing quartzites (showing detrital zircons with ages of 1250 Ma, Kampunzu, 2003, Oral Comm.). This lower formation grades westward to a turbiditic basin, mainly affected by the second Kibaran deformation phase (D2 at ca. 1100 Ma, Kampunzu, 2003, Oral Comm.). Rare mafic bodies (lavas or sills) are probably interbedded in all of these sedimentary deposits according to Kampunzu (2003, Oral Comm.).
2. From geochemical, geochronological and metallogenic considerations (Kampunzu, 2003, Oral Comm.), the Choma-Kalomo block (ZMB) is included in the Kibaran domain. This block is composed of orthogneisses, granitoids and gneiss complexes dated between 1343 ± 6 Ma and 1285 ± 64 Ma (U/Pb conventional method, Hanson

et al., 1988). They are crosscut by granitoids at 1198 ± 6 Ma (Hanson et al., 1988) and late Sn–granitoids at ca. 980 Ma (Kampunzu, 2003, Oral Comm.).

3. The Mesoproterozoic Irumide belt (ZMB), oriented NE–SW, is composed of gneisses, high-grade granulites, charnockitic complexes and granitoids. Some pre-Irumide granitoids (ca. 1650 Ma) and relicts of Neoarchean or Paleoproterozoic rocks have been identified (Cox et al., 2002; De Waele and Mapani, 2002). The garnet–cordierite–spinel–quartz–orthopyroxene granulitic assemblage in the inner part of the orogen was dated by Schenk et al. (2002a) at 1046 ± 3 Ma (U/Pb on monazite), consistent with the 1020 ± 6 Ga obtained on some late intrusive porphyritic granites (De Waele et al., 2003). The metamorphic grade decreases to greenschist facies to the NW of the belt.
4. We have tentatively assigned a Mesoproterozoic–Neoproterozoic 1 age to several sedimentary formations (Liki-Bembien, Ituri Group), which crop out near the frontiers of CAF, COG and DRC. These detrital rocks (conglomerate, sandstone, quartzite, pelite and argillite) change laterally to possible turbidites and calcareous sediments (limestone, calcschist). They locally display a contact metamorphism (Cu–Fe–skarn, Ca–hornfels). These rocks are assumed to be pre-950 ± 5 Ma (Thibault, 1983) or ca. 1350 Ma (Poidevin, 1996), and they are overlain by Neoproterozoic sedimentary formations (Thibault, 1983).

Isolated Mesoproterozoic–Neoproterozoic 1 outcrops, suggesting a possible intracratonic magmatism, occur in AGO, DRC and CAF. They include:

- The Kunene anorthosite–gabbro complex from Angola (De Carvalho, 1980–1982; De Carvalho et al., 1987; De Carvalho and Alves, 1990) to Namibia (1370 ± 4 Ma on zircons, Mayer et al., 2000).
- The Noqui peralkaline granite in AGO and DRC (999 ± 7 Ma, Tack et al., 2001), spatially associated with Sn occurrences. It is considered as the marker of a rifting stage in the West Congolian Belt. Similar granitoids have also been recorded along the Shanga fault west of the Paleozoic (?) to Mesozoic Carnot basin (e.g. Yobé granite at 1160 ± 61 Ma, Vicat et al., 2001).
- Dolerite dyke swarm, crosscutting Paleoproterozoic formations at the frontiers of CMR, COG and CAF. It has an estimated age of 1200 ± 1 Ma (Poidevin, 1996).

The full extent of all these Mesoproterozoic formations has been probably underestimated, as indicated by the presence of 1100–950 Ma detrital zircons in the Neoproterozoic formations in Cameroon (Toteu et al., 2004b).

4.2. Metallogeny

Different mineralized provinces have been recognized in the Mesoproterozoic to early Neoproterozoic 1 belts ("Kibaran", Irumides, etc.) of Central Africa. The best-known is the Sn, Ta (W, Nb, Be, Li, Mo, As, Au, gemstones) province of eastern DRC-Rwanda and Burundi. It contrasts with the Irumide belt of Zambia, associated with late Kibaran peraluminous magmatism between 1000 and 925 Ma, which is poorer in these commodities. Mineralization (Table 4) is represented by veins and flat-veins in zoned pegmatites. One example is the "giant" Manono pegmatite (DRC) that was been mined between 1919 and 1980 essentially within the regoliths, some of which were reactivated during the "tantalum crisis" of 2000 (artisanal mining). Ore mineralogy comprises cassiterite, columbo–tantalite, spodumene–lepidolite (Kaburiri, Lubilolewa, Niabesi–Tshonba, and Manono), beryl, tourmaline, loellingite, arsenopyrite, pyrite, autunite, wad and unspecified iron oxides. Gangue minerals include microcline, albite, apatite, muscovite, fluorite, zircon, rutile, quartz, orthoclase and beryl. The mining potential of this area is also underestimated as indicated by:

- Alluvial and primary gold (e.g. Mobale, Twangiza, DRC, Table 5).
- The presence of an underestimated Kibaran world-class PGE–Ni–Co-bearing arcuate belt with an age of ca. 1350–1370 Ma, that outcrops along the inner and outer parts of the Kibaran belt in northeastern DRC (alluvial PGE of Lubero district, close to Uganda border) and in West Tanzania (outside the area of the present map).
- The Kunene anorthositic complex, one of the most extensive in the world, was emplaced in the Mesoproterozoic (1370 Ma) and contains scarce deposits of ilmenite and hematite–ilmenite (Ti–Fe) in Namibia and Angola (Chiange, AGO, Table 5).
- Stratiform base metal deposits (Zn, Pb, Cu), analogues to those of southern Africa, have not yet been recorded in Mesoproterozoic terranes of Central Africa, but scarce base metal occurrences (Cu, Pb, Zn) have been reported locally (e.g. Irumides of Zambia or in DRC) and should be reassessed.
- Mesoproterozoic diamond-bearing kimberlites, analogues of those recently dated in West Africa (Delor et al., 2004) have not yet been recognised, although some occurrences (of unknown ages) are hosted in Mesoproterozoic rocks (e.g. the Choma-Kalomo block in Zambia and the northern part of outcrop of Mesoproterozoic rocks in the DRC) or close to assumed Mesoproterozoic granitoids emplaced along the Shanga fault west of the Carnot Mesozoic basin.
- In the Irumide belt, kyanite and copper occurrences have been identified: the Mkushi Copper district, the kyanite occurences hosted by high-grade metamorphic rocks (e.g. Leopards Hills and Mpande Hills). Numerous gem-bearing pegmatites host aquamarine-beryl deposits (Chipata, Luangwa Bridge, Lundazi, ZMB), emerald (Kagem), amethyst (Mumbwa and Kariba), tourmaline, garnet, mica, etc.

Table 4
Major peraluminous magmatism-related Mesoproterozoic mining districts of Central Africa

Name of district, *country*, *age*, *host-rocks*	Comm.	Potential[a] (t metal @ grade), *Class of deposit*	Ore deposit type and *shape*	Ore and *host-rock mineralogy*	Long.; Lat.	Exploitation type, *ore*
Kivu-Goma, *DRC*, *Meso- Neoproterozoic 1, alluvium, granitoid, pegmatite*	Sn, (Ta, Nb, W, Au, Mo, As)	Sn: ca. 270,000, A	Granitic and peri-granitic veins and stockworks (greisen). Zoned granitic pegmatites. Alluvial-eluvial placers	Cassiterite, columbo-tantalite, gold	28; −2	Alluvial mining; *Primary oxide ore*
Manono-Kitotolo, *DRC*, *Meso-Neoproterozoic 1, pegmatite 0.946 Ga on lepidolite and 0.877 Ga on muscovite), granitoid (ca. 0.947 Ga), dolerite, diabase, micaschist, alluvium*	Sn, Li, Ta (Nb, W, Bi, Mo, As)	Sn: ca. 520,000, A; Li: ca. 455,000, C	Zoned granitic pegmatites. Granitic and peri-granitic veins and stockworks (greisen). Laterite-related ore deposits. Alluvial-eluvial placers	Cassiterite, columbo-tantalite, spodumene, beryl, tourmaline, loellingite, arsenopyrite, pyrite, autunite, wad, iron oxydes; *Microcline, albite, apatite, muscovite, fluorite, zircon, rutile, quartz, orthoclase, beryl*	27.20; −7.61	Alluvial mining; *Primary oxide ore*
Machinga, *ZMB*, *Meso-Neoproterozoic* 1; *pegmatite, granitoid*	Sn	10,000, B	Zoned granitic pegmatites; *Discordant envelope of disseminated ore*	Cassiterite	26.95; −17.33	Mining method unknown; *Primary oxide ore*
Chitende, *ZMB*, *Meso-Neoproterozoic* 1; *pegmatite, granitoid*	Sn	10,000, B	Zoned granitic pegmatites; *Discordant envelope of disseminated ore*	Cassiterite	26.34; −17.40	Mining method unknown; *Primary oxide ore*
Kobo-Kobo *DRC*, *late-Kibaran*, *Meso-Neoproterozoic* 1, *pegmatite, schist, alluvium*	Be	ca. 800, C	Zoned granitic pegmatites; *Discordant envelope of disseminated ore*; Alluvial-eluvial placers	Beryl, columbite, loellingite, uraninite, triphylite, amblygonite, cassiterite, bismuth; *Tourmaline, microcline, muscovite, quartz, albite, zircon*	28.00; −3.0	

[a] Potential = Production + reserves + resources.

Table 5
Other major Mesoproterozoic mining districts of Central Africa

Name of district, *country*, *age*, *host-rocks*	Comm.	Potential (t metal @ grade), *Class of deposit*	Ore deposit type and *shape*	Ore and *host-rock mineralogy*	Long.; Lat.	Exploitation type, *ore*
Twangiza, *DRC*, *Meso-Neoproterozoic Possible Neoproterozoic structural control. Diorite, black schist/shale, ampelite, micaschist, quartzite, sandstone* (Villeneuve, 1983)	Au	ca. 220 @ 2.12 g/t, B	Alluvial–eluvial placers. Fold related gold–quartz-carbonate veins; *Discordant envelope of disseminated ore. Discordant lode or vein (thickness > 50 cm), in clusters or isolated. Present-day or recent placers*	Gold, pyrite, arsenopyrite; *Quartz, ankerite, arsenopyrite, calcite, albitization*	28.65; −2.58	Alluvial and primary mining; *Native-element ore*
Mobale *DRC*, *Mesoproterozoic–Neoproterozoic. Kibaran leucogranite. Possible Neoproterozoic structural control* (Caron et al., 1986)	Au	ca. 100, A	Fault-related syn- to late-orogenic ore deposits. Mesothermal As-sulphide-rich intra- and peri-intrusive quartz veins; *Discordant lode or vein and subconcordant vein*	Gold, pyrite, pyrrhotite, arsenopyrite, sphalerite, chalcopyrite, bismuthinite, molybdenite, cassiterite; *Quartz, carbonates*	28.19; −3.33	Open cast (open pit) mining; *Native-element ore*
Namoya, *DRC, leucogranite "S" of Kibaran belt*	Au	ca. [illegible], B		Pyrite, pyrrhotite, arsenopyrite, chalcocite, sphalerite, bismuthinite; *Quartz, chlorite, sericite*	27.54; −4.32	
Simani-Kalomo, *ZMB*, *Mesoproterozoic, granitoids, orthogneiss*	Amethyst	Amt: 10, B	Fault-related syn- to late-orogenic ore deposits. Discordant lode or vein	Amethyst, opal, quartz	26.9; −17.57	Mining method unknown Ore in which the element forms a distinct mineral phase
Chianga, *AGO, Mesoproterozoic, Kunene Anorthosite Complex*	Ti (Fe)	ca. 200000, C	Anorthosite-hosted ilmenite deposits; *Concordant to subconcordant envelope of disseminated ore.* Alluvial-eluvial placers	Ilmenite, titanomagnetite, magnetite	13.97; −15.79	Mining method unknown; *Ore in which the element forms a distinct mineral phase*

Potential = Production + reserves + resources.

- The Choma-Kalomo block contains scarce gemstones and copper occurrences (e.g. Simani-Kalomo amethyst deposit).
- Cu–pyrite skarnoids within the pre-950 Ma Liki-Bembien formation of northern Congo (Thibault, 1983).

5. Neoproterozoic-Cambrian (1 Ga–500 Ma): Pan-African belts

5.1. Geology

Pan-African belts in Central Africa are characterized by the juxtaposition of recycled and juvenile domains. Four major belts are recognized north, west, east, and south of the Congo craton.

1. The belt north of the Congo craton is oriented NE–SW to ENE–WSW. It is characterized by the presence of NE–SW shear zones (e.g. Adamawa and Sanaga faults) and by the southward thrusting of its southern limit onto the Congo craton (Yaounde-Gbayas meso- to catazonal nappes extending from Cameroon to Uganda through CAF (Poidevin, 1983; Ball et al., 1984; Pin and Poidevin, 1987; Nzenti et al., 1988; Ngako et al., 1991; Rolin, 1992, 1995a,b; Toteu et al., 2001, 2004a). The belt comprises polycyclic (Adamawa-Yade in CMR, CAF and TCD) and monocyclic domains (e.g. Yaounde and Poli in CMR and Gbayas in CAF, Lere in TCD). All of the rocks in these belts are metasedimentary and volcano-sedimentary (various kyanite schists and gneisses, migmatites, amphibolites and quartzites) and metaplutonic rocks (gabbro, garnet–pyroxene-bearing diorite and granitoid). They were metamorphosed under amphibolite to granulite facies between 640 and 600 Ma (Pin and Poidevin, 1987; Nzenti et al., 1988; Toteu et al., 1987, 2001; Penaye et al., 1993). The plutonic rocks in the belt generally were emplaced prior to, during and after the Pan-African deformation. Most of the intrusive rocks mapped in the southern section, however, were involved in the south-verging nappe tectonics, and their emplacement either predated or was coeval with that deformation. Geochemically, all are high-K calc-alkaline in composition.
2. The NNW–SSE West Congolian belt and its "foreland" sedimentary deposits (Maurin, 1993; Tack et al., 2001) were built during a three-phased evolution: (i) a 1000–910 Ma rifting stage (also suggested by the study of mafic dykes; Mpemba Boni and Vellutini, 1992) followed by (ii) the deposition of passive margin platform deposits (pre-Pan-African), and (iii) Pan-African deformation that began at ca. 600 Ma (Maurin, 1993) and ended at 566 Ma (Tack et al., 2001). The major structures in the belt verge to the east (Maurin, 1993; Tack et al., 2001). NNE-SSW sinistral shear zones have also been mapped in Cameroon.
3. The "Copper Belt", developed in Zambia and DRC between the Congo and Kalahari cratons, is part of the "Katangan Belt" (e.g. "Dome region" and "External Fold and Thrust Belt"; Unrug, 1988; Kampunzu et al., 2000). The Copper Belt belongs to the Lufilian Arc, an arcuate thrust and fold belt developed in northern Zambia and southeastern DRC (Kampunzu and Cailteux, 1999) during the Neoproterozoic transcontinental Damara–Lufilian–Zambezi Orogeny. This orogenic system separates the Mesoproterozoic terranes of DRC–RWA–BDI ("Kibaran") from those of Zambia and Mozambique ("Irumides" and "Choma-Kalomo block", SE of the map). Overlying pre-Katangan basement composed of Paleoproterozoic calc-alkalic volcanic arc formations and schists (Rainaud et al., 1999); the Katangan sedimentary succession comprises three successive supergroups (Cailteux et al., 1994; Cailteux, 2004):

(1) the Roan Supergroup composed of (i) the Basal conglomerate; (ii) the "Lower Roan" sequence including, the Mindola siliciclastic unit (ZMB–DRC) and the "Roches Argilo Talqueuses" Group (argillaceous dolomitic siltstones and sandstones, DRC) at the base; at the top of the Lower Roan sequence is the Cu–Co-bearing Mines Group (dolomitic shales and dolostones, DRC) and Cu–Co-bearing Kitwe unit (arenites, argillites and dolostone, ZMB–DRC); (iii) the Dipeta Group (DRC) and Bancroft unit (formerly "Upper Roan", ZMB); and (iv) the Mwashya Group (ZMB–DRC).
(2) the Nguba Supergroup, formerly the "Lower Kundelungu Supergroup" composed of glaciogenic deposits—("Grand Conglomérat" and diamictites), dolostones, limestones, dolomitic and sandy shales and siltstones.
(3) the Kundelungu Supergoup, formerly the "Upper Kundelungu Supergroup" composed of syn-orogenic dolomitic and sandy shales, limestone, sandstones and late-orogenic molasse deposited in an oxidising environment.

The Katangan Belt tectonics (Unrug, 1988; Kampunzu and Cailteux, 1999; Kampunzu et al., 2000) is marked by a (D1) fold and thrust deformation with a northward transport direction, followed by (D2) sinistral strike-slip faults and clockwise rotation of the eastern block. The regional metamorphism increases from the north to the south: prehnite–pumpellyite facies metamorphism has affected the northern external zone ("Katangan aulacogen" and outer part of "External Fold and Thrust belt"); a syn-deformation D1 greenschist facies metamorphism (708 ± 7 Ma, Cosi et al., 1992) is documented within the "Dome region" and the "External Fold and Thrust belt" tectonic units; a Syn-D1 amphibolites facies is also present in the "Dome region", while whiteschists and eclogites (Chewore "ophiolites", 1393 ± 22 Ma, Oliver et al., 1998; Johnson and Oliver, 2000) have been described south of the Dome region in areas adjacent to the Neoproterozoic Zambezi Belt (Cosi et al., 1992; Massone et al., 1994; Kampunzu et al., 2000).

4. We may also mention here the presence of N–S trending Neoproterozoic grabens extending for about 160 km along strike (e.g. the Itombwe trough, Villeneuve, 1983). These grabens contain a lower group of black schists, siltstones and tillites, and an upper group of conglomerates, sandstones and schists. They occur in the east of the map area (eastern DRC), parallel to the western Great Lakes Rift.

5.2. Metallogeny

The Neoproterozoic belts (Tables 6 and 7) are host to various deposits: (i) base metal (e.g. Cu–Co mineralisation of the "Copper Belt" in Zambia and DRC and stratiform base metal mineralisation in west COG); (ii) Co–mafic–ultramafic laterite-derived deposits in southeast Cameroon; (iii) granitoid and fault-related rare metals (Sn W REE occurrences in Cameroon and Chad); (iv) gold in the Lom region (CMR); (v) rutile at Akonolinga (CMR); and (vi) industrial minerals (e.g. talc of the Nyanga Syncline, Gabon).

- The "giant" Copper Belt (Table 6) is one of the major mineral provinces in the world (Laznicka, 1999) for Co–Cu, and it also hosts Pb, Zn, Ni, Ge, Ga, U, Au, Ag and PGE mineralisations. The belt contains "Kupferschiefer" (or "Cu shale") types or residually enriched stratabound ore deposits. Locally, these deposits are partly fault-controlled. The morphology of the lode ore is stratiform (or stratabound), cut by discordant lodes and/or overprinted by tabular-shaped vein bodies of secondary origin. In DRC, the highly mineralised segment of this orogen in the Katanga region comprises numerous fields (e.g. Kabolela, Kakanda, Kalukundi, Kambove-Kamoya, Kamatanda, Kasonta, Kinsenda, Kolwezi (Dikuluwe-Mashamba, Kamoto, Musonoï, Mutoshi, +Tailings), Luishia, Luiswishi-Lukuni, Musoshi, Ruashi-Etoile, Shituru, Tenke-Fungurume. In Zambia, the province comprises the following major districts: Konkola district (Konkola Deep, Konkola North Mining Area, Bancroft, Kirila Bomwe), Nama, Nchanga District (Nchanga, Chingola), Nkana District (Nkana Division, slag, Rokana), Luanshya District (Luanshya Division and Mine and Baluba Division and Mines), Chambishi District (Chambishi, Chambishi South-East, Fitula), Mufulira District (Mufulira, Mokambo), Lumwana project (Chimiwungo—Malundwe deposits), Chibuluma (Mine), Kalumbila, Muliashi and Muliashi North, Kansanshi and Sanje. Mesothermal uranium mineralisation (Shinkolobwe Kasompi, Musonoï, DRC, and Table 6) is also present in the Copper Belt. It occurs in discordant lode or vein deposits preferentially controlled by faulting (shear-zones or reverse faults).
- Base metal deposits (Table 7). (i) Base metal mineralisation is a significant feature of the Neoproterozoic "schisto-calcaire" of COG (e.g. districts of Yanga-Koubenza-Palanda, M'Passa, Hapilo, etc.). The deposits comprise stratiform and discordant carbonate-hosted stratabound and vein Pb–Zn deposits of Mississippi Valley type (MVT). (ii) Also noteworthy are the dolomite-hosted replacement pipe-like breccia deposits of the Kipushi type (e.g. Kipushi, DRC). These are considered to be syn- to late-orogenic fault-controlled ore deposits, which have been residually enriched. Their morphologies are varied—they occur as columns, chimneys with locally brecciated primary ore, and locally as blankets of residual ore.
- Significant amounts of Ge have been reported form Kipushi primary ores and slags. However, Ge in slags (e.g. the lowest part of the Lubumbashi "Big Hill) is not recovered by present operations, which are focussed on Co–Cu production.
- Carbonatite, skarn-, granitoid- and fault-related ore deposits. A variety of minerals are associated with calc-alkaline or peralkaline magmatism (Table 8). The mineralisation occurred at different stages of the Neoproterozoic-Cambrian orogenic evolution:
  - Carbonatite-hosted apatite and Nb ore deposit (Mabounié, GAB).
  - Sn–W–REE ± Ta–Zr in zoned granitic pegmatites, granitoid-controlled ore deposits, fault-related ore deposits and rare ore deposits related to alkaline to peralkaline intrusive complexes (Goutchoumi, CMR; Bishasha, Mumba, Numbi, DRC).
  - Au occurrences in fault-related and granitoid-controlled ore deposits (Central Cameroon field) and rare breccia-hosted iron-oxide-rich deposits of probable iron ox–copper–gold type at Mumbwa, ZMB.
  - U as uraniferous peri- or intra-granitic veins (Goblé-Kitongo, CMR).
  - Pb–(Zn) skarns (Bukanda, Excelsior Zink, ZMB).

  Mabounié (GAB) is a world-class residually enriched carbonatite-hosted apatite and Nb ore deposit of Neoproterozoic 3 (K/Ar age of 660 ± 13 Ma; Laval et al., 1988), (Table 8).

  Peralkaline and carbonatite-related deposits in NE DRC (northern extension of Itombwe trough, western margin of the rift) occur in a N–S peralkaline province characterised by carbonatites (10 identified) and peralkaline complexes (e.g. Lueshe, Bingo, Montabio). Radiometric ages are not well constrained and range between Neoproterozoic (Lueshe at 822 ± 120 Ma by Rb/Sr method) and Cambrian (Lueshe 516 ± 26 Ma by K/Ar method; Woolley, 2001). The carbonatites (dolomite–carbonatite, calcite–carbonatite, calciocarbonatite) and syenite of Lueshe (DRC) were emplaced into Mesoproterozoic schists and quartzite. Weathered pyrochlore-bearing carbonatites present a major potential for Nb, Ta and REE. Peralkaline intrusive complexes occur also in Zambia (Numbi).

Table 6
Major Neoproterozoic mining districts of the Central African Copperbelt (Cu, Co, Ni, U, and Ag)

Name of district, *country*, *age host-rocks*	Comm.	Potential (t metal), *Class of deposit*	Ore deposit type and *shape*	Ore and *host-rock mineralogy*	Long.; Lat.	Exploitation type; *ore*
Katanga Province and Zambian Copperbelt *DRC-ZMB*, *Neoproterozoic*, *"Série des Mines"*. *Sandy-, shaly-dolomites, black shale, sandstone. Locally ± fault control*	Cu–Co–(Zn, Pb, Ge, Ga, U, Au, ±Ni, ±PGE)	Cu: ca. 144,000,000 TCu @ 2.9%, A; Co: ca. 6,000,000 TCo @ 0.12%, A (Cailteux, 2004); Ag: ca. 500 in Chambishi District & ca. 560 in Mufulira District, ca. 575 in Luanshya Mine, C; Au: 65 at Kansanshi; >10 in Chambishi District, B/C; Ni: ~43,000 in Kalumbila, C	Kupferschiefer (or Cu shale) deposits; *Stratiform lode*; Residually enriched ore deposits; *Tabular-shaped orebody of secondary origin*; Locally ± fault control; *discordant lode or vein*	Chalcopyrite, chalcocite, bornite, carrolite, sphaerocobaltite, stainierite, malachite, digenite, asbolane, linnaeite, pyrite, molybdenite, uraninite, autunite, brannerite, torbernite, pentlandite, siegenite, violarite, pyrite, pyrrhotite magnetite, hematite, gold, silver; *Quartz, chlorite, mica, dolomite, talc, tourmaline, apatite, mica, dolomite, talc*	26.64; −10.75	Underground and open cast mining; Industrial wastes (slags, tailings); *Ore of secondary minerals from the oxidized and cementation zone & Primary oxide ore*
Kamoto and Musonoi, *DRC*, *Neoproterozoic Katanga Basin, Shaba "Copper Belt", Kolwezi District, "Série des Mines" Sandy-, shaly-dolomites, black shale, siltstones. Fault control*	Cu–Co U,	Cu: ca. 11,700,000; KTO s.s. @ 4.35% 16,450,000 KTO + KOV, A; Co: ca. 1,040,000 KTO s.s. @ 0.5%, A; Musonoi U: ca. 3000, C	Kupferschiefer (or Cu shale) deposits. Shear-zone related mesothermal uranium deposits; *Stratiform & discordant lode or vein*; Residually enriched ore deposits; *Tabular-shaped orebody of secondary origin*	Kamoto: uraninite, pyrite, chalcopyrite, carrolite, chalcocite, bornite, hematite, asbolane, heterogenite (stainierite), sphaerocobaltite, linnaeite, malachite, digenite; + at Musonoi: torbernite, cuprosklodowskite, guilleminite, vandenbrandeite, oosterboschite, cornetite, uranophane soddyite; *Quartz, chlorite, mica, dolomite, talc*	Kamoto: 25.42; −10.75 Musonoi: 25.50; −10.67	Underground and open cast mining; *Primary sulphide ore; ore of secondary minerals from the oxidized and cementation zone*
Shinkolobwe, Kasompi *DRC*, *Neoproterozoic Katanga Basin, Shaba "Copper Belt", Likasi District, "Série des Mines". Schist, talcschist, sandy dolomite, mica bearing-sandstone, mudstone, argillite, supergene clay. Fault control*	U	Shinkolobwe: U: ca. 30,000, B; Co: 95,000 @ 0.75%; Cu: 42,000 @ 0.33% A; Kasompi: U: ca. 3000, C	Shear-zone related mesothermal uranium deposits (hydrothermal remobilization during tectonic events), from *stratiform Co–Ni–Cu-sulfide-bearing ore deposits. Discordant lode or vein*	Shinkolobwe: Pitchblende, uraninite, torbernite, kasolite, sklodowskite, gummite, vuarite, cattierite, siegenite, monazite *Quartz, tourmaline, apatite, chlorite, globertite, mica, dolomite, molybdenite, pyrite, chalcopyrite, Ni–Co oxide, Ni–Co sulphide, talc* Kasompi: ibid. + cuprosklodowskite, vandenbrandeite	Shinkolobwe: 26.53; −11.07; Kasompi: 25.91; −10.97	Shinkolobwe U: underground and open cast mining; *Primary oxide ore*

Potential = Production + reserves + resources.

Table 7
Other major Neoproterozoic mining districts of Central Africa

Name of district, *country, age, host-rocks*	Comm.	Potential (t metal), *Class of deposit*	Ore deposit type and *shape*	Ore and *host-rock* mineralogy	Long.; Lat.	Exploitation type; *ore*
Yanga-Koubenza-Pianda, *COG, Neoproterozoic "Schisto-calcaire": limestone, bioherm-limestone, oolithic–limestone, dolomite, marl, marble sandstone, siltstone, argillite, mudstone, coal-bearing rocks, dolerite. Very low grade metamorphism*	Pb, Zn	Pb: ca. 1,250,000, A; Zn: ca. 375,000, B	Carbonate-hosted stratabound and vein Pb–Zn deposits of Mississippi Valley type, MVT, and/or dolomite-hosted replacement pipe-like breccia deposits analogue to Kipushi type). Fault-related ore deposits. *Stratiform bed and discordant lode or vein*	Galena, sphalerite, pyrite	13.85; −4.37	Unworked. *Primary sulphide ore*
M'Passa, *COG, Neoproterozoic "Schisto-calcaire": limestone, bioherm-limestone, oolithic–limestone, dolomite, marl, marble sandstone, siltstone, argillite, mudstone, coal-bearing rocks. Very low grade metamorphism*	PbZn (total), (Cu, Ag, V, Ge)	ca. 200,000, B	Carbonate-hosted stratabound and vein Pb–Zn deposits of Mississippi Valley type, MVT, and/or dolomite-hosted replacement pipe-like breccia deposits analogue to Kipushi type). Fault-related ore deposits. *Stratiform bed and discordant lode or vein*	Sphalerite, galena, chalcocite	14.16; −4.37	Underground mining. *Primary sulphide ore*
Hapilo, *COG, Neoproterozoic; dolerite, diabase*	Pb	Pb: ca. 125,000, B; Zn: ca. 115,000, C	Fault-related ore deposits/ *Discordant lode or vein*	Galena, sphalerite, pyrite	13.78; −4.36	Unworked. *Primary sulphide ore*
Kipushi, *DRC, Southern Katanga, Damara-Katangian sequence, dolomite Katangan, mainly?*	Zn, Pb, Cu, Ag Ge, (Cd)	Zn: ca. 9,450,000, A; Pb: ca. 840,000, B; Cu: ca. 4,400,000, B; Ag: ca. 2200, C; Ge (tailings): ca. 3000, A	Dolomite-hosted replacement pipe-like breccia deposits; fault-related syn- to late-orogenic ore deposits. Residually enriched ore deposits. Mine tailings. *Column, chimney with possibly brecciated ore. Cap, blanket, crust. Tailings*	Pyrite, arsenopyrite, sphalerite, galena, reniérite, germanite, gallite, chalcopyrite, molybdenite, bornite, cerussite smithsonite, malachite, calamine, cuprite, goethite, hematite, chalcocite, copper, silver, tennantite, linnaeite, cobaltite, briartite, carrollite. *Siderite, baryte dolomite*	27.25; −11.8	*Primary sulphide ore, Ore of secondary minerals from the oxidized and cementation zone*
Dikulushi, *DRC, Neoproterozoic, Mudstone, argillite, clay, sandstone*	Ag–Cu	Ag: ca. 500 @ 289 g/t C; Cu: ca. 325,000, B	Dolomite-hosted replacement pipe-like breccia deposits (Kipushi); Brittle-fault related ore deposits. *Stratabound envelope of disseminated ore. Discordant mass (cylinder, stock, cone, etc.) with filling commonly brecciated*	Chalcocite, malachite, azurite, chrysocolla, bornite	28.22; −8.89	*Open cast (open pit) mining. Ore in which the element forms a distinct mineral phase*
Kabwe, *ZMB, Damara-Katangian sequence Kabwe Dolomite Formation, ore deposit estimated at 680 ± 15 Ma (Pb-Pb)*	Pb-Zn (Ge, Se, Ni)	Pb: ca. 2,500,000, A; Zn: ca. 3,651,000, A	Dolomite-hosted replacement pipe-like breccia deposits. *Column, chimney with possibly brecciated ore. Concordant to subconcordant mass, lens or pod of massive to submassive ore*	Sphalerite, galena, pyrite, chalcopyrite, briartite, reniérite, willemite, cerussite, smithsonite, goethite, hematite *Quartz, carbonates*	28.45; −14.45	Open cast (open pit) and underground mining. *Primary sulphide ore*

Potential = Production + reserves + resources.

Table 8
Major magmatic-related Neoproterozoic mining fields of Central Africa

Name of district, *country, age, host-rocks*	Comm.	Potential (t metal), *Class of deposit*	Ore deposit type and *shape*	Ore and *host-rock* mineralogy	Long.; Lat.	Exploitation type; *ore*
Mabounié, *GAB, Neoproterozoic 2, Carbonatite, alterite*	Nb, (apatite)	Nb: ca. 780,000 @ 1.9%, A. (Phos: ca. 35,000,000, C)	Carbonatite-hosted apatite deposits. Laterite-related ore deposits. *Discordant envelope of disseminated ore*	Pyrochlore, crandallite, florencite (Ce, La, Nd), baddeleyite, apatite, magnetite, ilmenite, xenotime	10.59; −0.75	Nb: Unworked. *Primary oxide ore*
Lueshe, *DRC, Neoproterozoic 2–Cambrian (?) hosted by Mesoproterozoic formations, Dolomite–carbonatite, calcite–carbonatite, Calciocarbonatite, syenite, schists and quartzite*	Nb, (Phos, Ta, Th)	Nb: ca. 400,000 @ 1.34%, A	Nepheline-carbonatite hosted Nb deposits. Residually enriched ore deposits. Laterite-related ore deposits. *Discordant envelope of disseminated ore. Cap, blanket, crust*	Pyrochlore. Apatite. *Cancrinite, Aegirine, Albite, K-Feldspar, Pyrrhotite, Pyrite, Amphibole, Albitization, Metasomatism*	29.13; −1.02	Open cast (open pit) mining. *Primary oxide ore*
Goutchoumi, *CMR, Neoproterozoic, fault, granitoid, migmatite*	W	ca. 4500, C	Fault-related syn- to late-orogenic ore deposits. Granitic and peri-granitic veins and *stockworks (greisen). Discordant lode or vein*	Wolframite, uranium oxide, galena, sphalerite). *Quartz*	13.43; 9.58	Mining method unknown. *Primary oxide ore*
Bishasha, Mumba, Numbi *DRC, Meso-Neoproterozoic 2: Itombwe Trough (schist, micaschist, quartzite, meta-quartzite), Mesoproterozoic granitoids (aplite, pegmatite, monzogranite, adamellite), and Nepheline-bearing-syenite of Numbi (NP2)*	Sn–W	Sn: ca. 1000, C; W: ca. 500, C	Zoned granitic pegmatites and granitoid-controlled ore deposits. Fault-related syn- to late-orogenic ore deposits. Ore deposits related to alkaline to peralkaline intrusive complexes (Numbi). *Subconcordant vein, bedded vein, discordant lode or vein*	Cassiterite, stannite, wolframite, columbo-tantalite, spodumene, lepidolite, chrysoberyl, topaz, pyrite, arsenopyrite, galena, sphalerite, gold, bismuthinite, molybdenite. + Titanite & Fluorite (Numbi). *Quartz, tourmaline, orthoclase, microcline, muscovite, kaolinite albite, beryl, amblygonite, andalusite, apatite*	28.88; −1.65	Alluvial mining. *Primary oxide ore*
Central Cameroon (BO: Betaré Oya, Col: Colomine, K: Kambélé), *CMR, Neoproterozoic, Granite-related, Fault Controlled, Mylonite, ductile tectonite, granitoid*	Au, diamond (alluvium)	BO: ca. 20, C; Col: ca. 12, C; K: ca 15, C	Fault-related syn- to late-orogenic ore deposit, placers. *Discordant lode or vein. Alluvium*	Gold, diamond. *Quartz, carbonates, tourmaline*	BO: 14.08; 5.60, Col: 14.38; 4.98, K: 14.40; 4.45	BO: Alluvial mining. *Native-element ore*
Mumbwa, *ZMB, Neoproterozoic; Porphyroid granite, syenite, arenite, mudstone*	Au–Cu	Cu: ca. 500,000, C; Au: ca. 10, C	Breccia-hosted iron-oxide-rich deposits 5 (probable iron ox–copper–gold type). *Discordant envelope of disseminated ore*	Gold, iron and copper oxides, pyrite. *Quartz, silicification*		Unworked. *Ore in which the element forms a distinct mineral phase*
Goblé-Kitongo, *CMR, Neoproterozoic. granite and pegmatite; Cenozoic laterite*	U	ca. 2200, C	Uraniferous peri- or intra-granitic (leucogranite) veins. *Discordant lode or vein*	Uranium oxide (unspecified)	13.17; 8.50	Unworked. *Primary oxide ore*
Bulanda (BK); Excelsior Zinc (EZ), *ZMB*	Pb, Zn	BK: Pb: >25,000, B; EZ: id.	Pb–Zn skarns. *Discordant lens of submassive ore and disseminated ore*	Sphalerite, galena	BK: 29.08; −9.97, EZ: 28.03; −15.33	Mining method unknown

Potential = Production + reserves + resources.

- Scarce residual Co–Ni ore deposits have been identified on laterite capping Neoproterozoic mafic-ultramafic magmatic complexes (e.g. Kongo, Cameroon, Table 9).
- Rutile and Industrial Minerals (Table 9). In Cameroon, the rutile (Ti) of Akonolinga district is hosted by Neoproterozoic micaschists and gneisses of the Yaounde Group. The sources of alluvial–eluvial industrial minerals are locally the micaschist near the sole of the Neoproterozoic nappes. A district of talc is hosted by Neoproterozoic 3 sedimentary sequences of the Nyanga province (limestone, dolomite and evaporite-bearing deposits) in Gabon. Some deposits of feldspar or nepheline occur in different countries (e.g. Eboundja, Cameroon).
- The gemstone fields that are associated with HP granulite zones (such as the Mozambique Belt), are very limited, except in the Irumide Belt of Zambia, where amphibolites and granulites are developed. Some ore deposits are not reported on this map, but on the companion map "Geology and gemstones deposits of East Africa" at 1:4,000,000, presented during the CAG20 colloquium, Deschamps et al., 2004). They include aquamarine, amethyst, agata, chalcedony, opal, etc.

6. Paleozoic–Mesozoic basins (542–65 Ma)

6.1. Geology

A sedimentary basin formed on the Congo Craton and now broadly termed the Congo Basin is a prominent feature of the Central Africa region (Lepersonne, 1974; De Carvalho, 1980–1982). It contains Paleozoic (Carboniferous–Permian) marine sediments and continental coal-bearing and glaciogenic-sediments are present in some troughs. Mesozoic (Karoo, Jurassic–Cretaceous) sediments (lacustrine and fluviatile deposits) and Late Cretaceous continental sequences (Kwanga Group, DRC) are also represented.

In the northern part of Central Africa, early Cretaceous rifting (North CMR, South TCD, Guiraud and Maurin, 1992) occurs in response to both a submeridian extensional regime and dextral strike-slip movement, producing pull-apart basins along the Central Cameroon Shear zones.

6.1.1. Sedimentary formations

Sedimentary formations were deposited from the late Neoproterozoic to the Paleozoic in the Congo Basin and in small troughs developed on the Precambrian basement. Clastic and/or carbonate-bearing sequences (siltstone, sandstone, greywacke, arkose, ±conglomerate, ±glacio-

Table 9
Major Neoproterozoic mining districts of Central Africa (supergene deposits, industrial minerals)

Name of district, *country, age, host-rocks*	Comm.	Potential (t metal), *Class of deposit*	Ore deposit type and *shape*	Ore and *host-rock* mineralogy	Long.; Lat.	Exploitation type; *ore*
Kongo, *CMR, Cenozoic Co–laterite. Neoproterozoic mafic-ultramafic rocks*	Co (Ni)	ca. 160,000, A	Co- Laterite-related ore deposits. Ore deposits hosted by mafic-ultramafic magmatic complex: *Cap, blanket, crust, discordant envelope of disseminated ore*	Nickel silicate, cryptomelane, magnetite, nontronite, goethite, magnesite (giobertite). *Serpentine, antigorite, talc.*	13.85; 3.25	Unworked. *Ore of secondary minerals from the oxidised zone*
Akonolinga, *CMR, Quaternary alluvium, Neoproterozoic source, micashist, gneiss*	Rutile, (kyanite)	Rutile: ca. 2,600,000; A	Alluvial–eluvial placers reworked from Neoproterozoic Yaounde nappe; source rocks: micaschist & gneiss	Rutile, kyanite, garnet	12.23; 3.62	Unworked, ±dredging. *Primary oxide ore*
Nyanga Province, *GAB, Mourindi, N'Dende, Doussala, Porro*, etc.; *Nyanga formation, Neoproterozoic 3: limestone, dolomite*	Talc.	ca. 73,000,000, A	Sedimentary-related and evaporite-related industrial rocks and minerals. Residually enriched ore. Deposits	Talc. *Dolomite, chlorite, kaolinite quartz*	10.67; −2.50	Unworked. *Ore in which the element forms a distinct mineral phase*
Eboundja Syenite, *CMR, Quaternary alluvium, Neoproterozoic, nepheline-bearing-syenite*	Nepheline	ca. 800,000,000, A	Ore deposits related to alkaline to peralkaline intrusive complex. Industrial rocks and minerals related to plutonic rock. *Envelope of disseminated ore*	Nepheline, feldspar	9.9; 2.78	Unworked, ±Open cast (open pit) mining. *Ore in which the element forms a distinct mineral phase*

Potential = Production + reserves + resources.

genic sediments, limestones, dolomite, scarce mafic and felsic volcanics and volcaniclastic rocks) were deposited in GAB, AGO (Alto-Chiloango, Macondo, Terrero), and DRC (Bushimay, Lulua).

In the northern part of the map (TCD, CMR, CAF; Mestraud, 1982), Paleozoic glaciogenic clastic sedimentary formations include tillites, diamictites, argillite, mudstone (CAF), as well as fossiliferous sequences (TCD), from Cambrian to Upper Devonian age. During the Carboniferous–Permian periods, clastic ± carbonate-bearing formations (argillite, siltstone, sandstone, arenite, marl and limestone were deposited in Agoula (GAB) and in Luanda and Lutoa-Cassange (AGO). They developed in a passive-margin platform environment, while continental glaciogenic and coal-bearing clastic sedimentary formations were deposited in tectonic troughs in the eastern DRC (Lukuga).

The central Congo Basin (Lepersonne, 1974; De Carvalho, 1980–1982) contains Paleozoic–Mesozoic formations (Karoo, Jurassic–Early Cretaceous). They comprise clastic–carbonate lacustrine and fluviatile deposits (Lutoa-Cassange, Calonda, and Cuango in AGO) and Late Cretaceous continental clastic sedimentary formation (Kwanga in DRC). The Karoo Supergroup (mainly sandstones and mudstones, e.g. ZMB) was deposited from Carboniferous to Jurassic. The lowest part of Karoo contains glaciogenic clastic sediments; the middle part is represented by sandstones containing coal; and the upper part is represented by Jurassic mudstones and sandstones with interlayered basalts. The late Cretaceous continental sequences (Kwanga, DRC) contain freshwater fishes, ostracods, palynomorphs and, at the base, diamond-bearing gravels.

The coastal basin (western GAB–AGO; De Carvalho, 1980–1982; Bassot, 1988), comprises mainly marine clastic–carbonate formations, that overlie the Proterozoic rocks and were deposited from the Cretaceous to the Pleistocene.

Mesozoic fluviatile and lacustrine clastic (conglomerates, sandstones and shales) and carbonatic sediments were deposited from early to late Cretaceous in restricted troughs of CMR (Logbadjeck, Vina North, Mbéré, Garoua, Cross, Manyu, Amakassou, Kontcha, and Bénoué sandstones). Similar deposits also occur in TCD (early Cretaceous in Léré, late Cretaceous in Lamé) and in CAF (two distinct areas: SW Carnot-Berberati and NE Mouka-Ouadda; Mestraud, 1982). Mesozoic to Neogene clastic sediments (conglomerates, sandstones and shales) have also been deposited in the coastal Douala passive-margin basin.

6.1.2. Magmatism

Post-Pan-African magmatism started during the Cambrian. Sub-alkaline to alkaline granitoids were emplaced from the late-Cambrian to the Ordovician in CMR, CAF, TCD, AGO and ZMB. Moreover, in AGO, syenite, gabbro and dolerite were also emplaced during the same period. Cretaceous mineralized carbonatites and syenitic intrusions, scarce Mesozoic doleritic volcanics and volcano-plutonic complexes (basalt, tephrite, trachyte-phonolite) have been emplaced in the alkaline province of central-western AGO (e.g. Catanda, Tchivira, at ca. 90–130 Ma; I.A.E.A., 1986; Woolley, 2001) and in ZMB (Table 11).

6.2. Metallogeny (Table 10)

- The Mesozoic sedimentary basins host stratabound mineralisation in coastal basins of the western margin of Africa, (e.g. Cu–Pb–Zn base metals in Cocobeach, GAB; barite in Dourekiki, GAB; phosphate in GAB, COG and AGO). Phosphorites have been recorded in Upper Cretaceous sedimentary formations (Tchicanou, COG). Uranium is also present as stratiform beds in uranium-bearing phosphorites (Cabinda, AGO; Kundu Nzobé and Kanzi, DRC) in the same basin from Cretaceous to Palaeocene. Uranium deposits occur also in Zambia (e.g. Kariba; U–Phos–Fe Jurassic deposits including autunite, meta-autunite, phosphuranylite, uranophane). Important potash and MgCl resources (Pointe Noire, Makola, Holle, Kouilou, COG), as well as bitumen-bearing deposits, are hosted by Cretaceous sediments of the coastal basin (e.g. Libongos and Undi deposits, AGO). Gypsum and anhydrite deposits are hosted by Early Cretaceous sediments (Sumbe, AGO). Diamond-bearing Cretaceous paleoplacers are also known at Quimangoa and Toca (AGO) (Table 10).
- Mesozoic and Paleozoic carbonatites hosting different valuable commodities have been identified at several places (Woolley, 2001). They include Nb at Kaluwe, ZMB; Fe at Bailundo; barite, phosphorite, REE, and Th in AGO (Tchivira deposit formed at ca. 126–131 Ma); fluorite, and Nb at Bonga, AGO. Details are given in Table 11. Jurassic granitoid-controlled uranium ore deposit occurs in ZMB (e.g. Hook Granite Massif). The Kafubu emerald field in gem-bearing pegmatites and metasomatic deposits developed in Paleoproterozoic rocks and possible Late Kibaran rocks during the Upper Ordovician (Czech Geological Survey data; Kribek, 2005, Oral Comm.).
- Coals occur in the eastern DRC in the Lukuga Permian basin, a southern extension of the Itombwe Neoproterozoic trough. Five coal beds have been identified in the clastic sedimentary rocks, including some glaciogenic materials (Table 12).
- Mesozoic diamond deposits (Table 13) comprise diamond kimberlites (e.g. Mbuyi-Mayi in DRC; Camatchia, Camafuca, Catoca, Camagico, Tongo in AGO) and paleoplacers, including diamonds reworked in basal beds of Upper Cretaceous age at Kwanga, DRC, and diamond-related Mesozoic sedimentary rocks of CAF (Censier, 1989)). Available geochronological data on kimberlites are however rare or unpublished. They suggest (i) a main early Cretaceous period of pipe emplacement and (ii) a Late Cretaceous extraction (e.g. Mbuyi-Mayi at ca. 71 Ma). All of these

Table 10
Major sediment-hosted Mesozoic mining districts of Central Africa

Name of district, *country, age, host-rocks*	Comm.	Potential (t metal @ grade), Class of deposit	Ore deposit type *and shape*	Ore and *host-rock* mineralogy	Long.; Lat.	Exploitation type; *ore*
Cocobeach, *GAB, Mesozoic, Triassic*	Pb	ca. 15,000, C	Red Bed hosted lead deposits. *Stratiform bed*	Galena	9.51; −1.00	*Primary sulphide ore*
Dourekiki, GAB, *Early Cretaceous, Upper Cocobeach, Upper Aptian*	Barite	ca. 1,400,000, B	Sandstone, ±dolomite hosted stratabound ore deposits, residually enriched. *Stratiform bed, cap and blanket*	Barite, hematite	10.54; −3.04	Unworked. *Barite*
Cachoeiras de Binga, *AGO, Early Cretaceous, Upper Cuvo, calcarenite, conglomerate, sandstone, siltstone, anhydrite-bearing beds*	Cu	ca. 110,000, C	Red Bed (sandstone) hosted base metal deposits. *Stratabound bed*	Chalcopyrite, bornite, digenite, covellite, idaite, malachite, azurite	14.09; −11	*Ore in which the element forms a distinct mineral phase*
Tchicanou, COG, *Upper Cretaceous*	Phos	ca. 100,000,000, C	Phosphorites (or sedimentary phosphates); *Stratiform bed*	Phosphorites	12; −4.5	Mining method unknown: *Phosphate (P2O5)*
Cabinda, *AGO, Late Cretaceous (Maastrichtian) to Palaeocene, phosphorite*	U, Phos	U: ca. 15,000, B	Uraniferous phosphorites. *Stratiform bed*			Unworked
Kundu Nzobé, Kanzi, *DRC, Mesozoic, Cretaceous, Phosphorite*	U, Phos	Kundu Nzobé U: ca. 2200, C Kanzi U: ca. 2200, C	Uraniferous phosphorites. *Stratiform bed*	Feldspar, apatite, quartz, wavellite	Kundu Nzobé; 12.63, 5.20; Kanzi: 12.83	Unworked
Pointe Noire, Makola, Holle, Kouilou, *COG, Lower Cretaceous, dolomite, anhydrite and salt-bearing rocks, sandstone, siltstone*	Potash, MgCl	Potash: 135,000,000, B MgCl: 70,000,000, B	Salts and gypsum deposits. *Stratiform bed: single or multi-layered (syn-depositional with host rock)*	Carnallite, bischoffite, tachyhydrite, halite, anhydrite	Pointe Noire: 11.93; −4.88; Holle: 12.13; −4.57	Solution mining method. *Primary soluble salts*
Sumbe, *AGO, Mesozoic, Early Cretaceous, Gypsum & anhydrite-bearing sediments*	Gypsum, anhydrite	Gp. ca. 150,000,000, B	Salts and gypsum deposits. *Stratiform bed*	Gypsum, anhydrite	13.87; −11.17	Mining method unknown. *Ore in which the element forms a distinct mineral phase*

Potential = Production + reserves + resources.

deposits are assumed to be the sources rocks of Cenozoic alluvial–eluvial deposits (e.g. Kasai and Tshikapa, in western and eastern CAF districts Table 13).

7. Cenozoic cover

7.1. Geology

In Central Africa Cenozoic formations comprise:

- Continental sedimentary cover: the central basins of Congo and Angola are mostly filled with Eocene to Upper Neogene sandstones of Lower and Upper Kalahari age and with the "Formation des Cirques" (or Upper Quelo). In Chad this cover developed from the Upper Paleogene to the Quaternary and overlies Paleocene and Maastrichtian deposits.
- Coastal and offshore basins: in Cameroon, marine sedimentary formations of Cenozoic age form part of a passive-margin basin. Marine sediments overlie Mesozoic deposits in other coastal basins (e.g. Gabon and Angola).
- Volcanism developed along the western rift in the Middle Miocene to Holocene in the Virunga Massif, DRC, and along the 1500 km NNE–SSW trending Cameroon Volcanic Line (Paleocene–Eocene granitoid and syenite ring-complexes; recent and active alkaline volcanism such as Mount Cameroon and Lake Nyos).

Table 11
Major carbonatite-related Mesozoic mining districts of Central Africa

Name of district, *country, age, host-rocks*	Comm.	Potential (t metal @ grade), Class of deposit	Ore deposit type *and shape*	Ore and *host-rock* mineralogy	Long.; Lat.	Exploitation type; *ore*
Kaluwe, *ZMB, Cretaceous, Albian, Carbonatite*	Nb, (Phos.)	Nb: ca. 1,000,000, A		Pyrochlore, apatite, magnetite, iron oxydes. *Calcite, phlogopite*	30.02; −15.18	Mining method unknown. *Primary oxide ore; phosphates*
Bailundo, *AGO, Mesozoic, Cretaceous, Carbonatite, Fe, Barite, Phos, REE, Th*	Fe, (*Barite*, Phos, REE, Th)	Fe: ca. 62,000,000, C	Carbonatite-hosted ore deposits. Alluvial–eluvial placers. *Discordant envelope of disseminated ore; placers*	Magnetite, apatite, martite, ilmenite, pyrochlore, monazite, barite, zircon, rutile, corundum, fluorite	15.96; −12.14	Unworked
Tchivira, *AGO, Mesozoic, Cretaceous, carbonatite, ijolite, nepheline-bearing-syenite, syenite, gabbro*	Fluorite	Fl: ca. 2,800,000, B	Carbonatite-hosted ore deposits. *Discordant envelope of disseminated ore; placers*	Fluorite, barite, pyrochlore, apatite, magnetite. *Nepheline, calcite, dolomite, ankerite, quartz*	13.87; −14.30	Unworked. *Fluorite*
Bonga, *AGO, Mesozoic, Cretaceous, carbonatite, nepheline-bearing-syenite, granitoid, gabbro*	Nb	Nb: ca. 14,000, C	Carbonatite-hosted ore deposits. *Discordant envelope of disseminated ore; placers*	Pyrochlore, apatite barite, magnetite	13.97; −14.26	Unworked. *Ore in which the element forms a distinct mineral phase*

Potential = Production + reserves + resources.

Table 12
Paleozoic to Mesozoic major coal basins of Central Africa

Name of district, *country, age, host-rocks*	Comm.	Potential (t metal @ grade), Class of deposit	Ore deposit type *and shape*	Ore and *host-rock* mineralogy	Long.; Lat.	Exploitation type; *ore*
Lukuga, *DRC, Palaeozoic, Permian, Upper Lukuga, Coal (bituminous coal, anthracite, graphite), tillite, diamictite, sandstone, schist*	Coal		Coal deposits type; *Stratiform lens of massive to submassive ore*	Coal	29.15; −5.86	Mining method unknown. *Coal ore*

Potential = Production + reserves + resources.

- Lateritic profiles (Paleogene to Quaternary) are developed in the tropics (e.g. CAF, central CMR and AGO), but incomplete, truncated profiles occur in Equatorial areas (GAB, south CMR).
- Quaternary alluvial–eluvial deposits (alluvium, sands, and gravels) have formed along river valleys or depressions.

All of these Cenozoic formations have been simplified on the map.

7.2. Metallogeny

The Cenozoic sedimentary covers host various mineral and energy resources. Numerous deposits are controlled by Cenozoic mechanical and chemical processes, such as lateritic, alluvial–eluvial or coastal phenomena. These processes are, in many respects, responsible for the enrichment and economic concentration of pre-Cenozoic mineralisation.

Among the major deposits, mention should be made of the following:

- Residual deposits: Bauxite—Minim Martap with a potential of 3,000,000,000 tons, Ngaoundal, and Fongo Tongo in CMR (Ntep Gweth, 2001), Kony in COG. Co–Ni laterite-related at Kongo, CMR.
- Secondary enrichment: Fe in Archean BIF in Isiro district and Ituri-Uele, DRC; Zanaga, COG; and Bélinga, GAB, etc., Mn in the Moanda deposit, Phos–Nb–REE in carbonatites at Mabounié, GAB, Nb-phosphate in GAB, and at Lueshe and Bingo in DRC, Sn–Ta in pegmatites in the Eastern DRC Kibaran province (in situ alteration of pegmatites also plays a major role for Sn and Ta beneficiation), Cu–Co in Copperbelt deposits (deep secondary enrichments by cementation processes were important in the past for the development of these deposits), Pb–Zn in MVT and pipe-related deposits such as Kipushi, DRC and M'Passa, COG.

Table 13
Cenozoic and Mesozoic selected diamond fields of Central Africa

Name of district, *country, age, host-rocks*	Comm.	Potential (carats), Class of deposit	Ore deposit type *and shape*	Ore and *host-rock* mineralogy	Long.; Lat.	Exploitation type; *ore*
Kasai Province; including Mbuyi-Mayi Mine, *DRC, Bushimaye, eastern Kasai; Mesozoic, Upper Cretaceous (ca. 71 Ma), Kimberlite, Hardened conglomerate ("Poudingue"), Sandstone*	Diam.	Mbuyi-Mayi: ca. 540,000,000, A	Diamondiferous kimberlites, paleoplacers and placers. *Envelope of disseminated ore in pipe; placers*	Diamond, *ilmenite, titanomagnetite, pyrope, diopside*	Mbuyi-Mayi 23.49; −6.08	Open cast (open pit) mining. *Ore in which the native element is free or in fissures (recoverable by grinding); Alluvial mining*
Camatchia, Camafuca, Catoca, *AGO, Early Cretaceous, Kimberlite, tuff, argillite*	Diam.	Camatchia: ca. 13,500,000, B, Camafuca: ca. 23,000,000, B, Catoca: ca. 41,000,000, B	Diamondiferous kimberlites. *Envelope of disseminated ore in pipe*	Diamond, *ilmenite, titanomagnetite, pyrope, diopside*	Camatchia, 20.48; −8.94 Camafuca: 20.52; −8.45 Catoca: 20.29; −9.38	Open cast and underground mining. *Native-element ore*
Tshikapa *DRC Cenozoic (Mesozoic) Kasai + tributaries (Lubembe, Longatshimo, Tshikapa, Luvua, Lulua, Luebo). 30,000 km². Alluvium and paleoplacers from supposed Mesozoic sources.*	Diam., Chrysoberyl	Diam. >70,000,000, B 65–80% gemstones, 0.9ct/m3 placers, 20–25% gems, 10 stones/ct Chrysoberyl, C	Diamond paleoplacers. *Alluvial–eluvial placers*	Diamond, Chrysoberyl *Ilmenite, titanomagnetite, pyrope, diopside, staurolite, tourmaline, giobertite, quartz, kyanite, epidote, corundum*	20.88; −6.54	Alluvial mining. *Native-element ore*
Western and eastern districts CAF *Cenozoic from supposed Mesozoic-(Paleozoic) sources*	Diam.	>50,000,000, B	Alluvial–eluvial placers from unknown sources (supposed Paleozoic or Mesozoic sediments)	Diamond, gold	16; 5.5	Alluvial mining

Potential = Production + reserves + resources.

- Au, diamond, rutile, Sn alluvial–eluvial or coastal placers: numerous placer-type deposits (inland placers, heavy minerals-bearing beach sand coastal deposits) are linked to secondary alluvial concentration of heavy and/or resistant minerals. Importance of placer deposits was and is still very high for artisanal and/or industrial mining of:
  - (i) Gold: Lubero area, Lugushwa, Moto district, Namoya and Twangiza areas, etc. in DRC; Bétaré-Oya and Kambélé zones, Central Cameroon Field in CMR; Roandji district in CAF; Etéké, Mitzic and N'Dangui districts, etc. in GAB.
  - (ii) Diamond: Mbuyi-Mayi, Tshikapa district, Kasaï basin, Bakwanga in DRC; Luanga-Malanje and Cassamba, in AGO; Kotto river, Sanga, Lobaye and Mambéré basins in CAF.
  - (iii) Tin (cassiterite): Mayo Darlé in CMR; Busanga, Kalounga, Punia, Kailo district, Walikale and Mumba in DRC; Mufumbi in COG; Sominki W placer in DRC.
  - (iv) Titanium minerals (ilmenite, rutile): numerous deposits in CMR, including Edea-Kribi beach-sand deposits; Dubreuil and Nanga-Eboko placers, rutile-bearing placers that are the most interesting for Ti beneficiation in the Akonolinga world-class deposit, at Yo and Dja; and the rutile–kyanite-bearing Otélé placer. Titanium minerals also occur in the Pocolo, Chitato and Chiange deposits in AGO.
- Cenozoic to Quaternary coastal and continental sediments host various industrial rocks and mineral deposits. Among the most important we can mention: clays (Yaounde and Douala region, CMR; Solwezi, ZMB); lacustrine diatomite (Lake Chad-Faya area, an A-class deposit in CMR), and trona deposits (Lake Chad, a B-class deposit in TCD), peat (COG coastal basin deposits of Cayo and N'Tombo in COG). Rift Lake sediments also host salt (Lake Kabwe, Kasenay, and DRC) and gas resources (Kivu Lake, DRC).

8. Summary and conclusion

This paper, which was prepared to accompany the 1:4,000,000 scale map "Geology and major ore deposits of Central Africa, incorporates geological and metallogenic data from eight countries in Central Africa (Angola, Cameroon, Chad, Central African Republic, Congo Brazzaville, Democratic Republic of Congo (DRC), Equatorial Guinea and Zambia). The map is a harmonised and geo-referenced preliminary map, based on a GIS at 1:2,000,000 scale, and focusses on the spatial and temporal distribution of selected major deposits.

The examination of this simplified map and the analysis of its knowledge "gaps" will allow the identification of new scientific targets such as (i) the extension of Mesoproterozoic formations and related magmatic rocks, (ii) the structural, metamorphic and geochronological relationships of "Haut-Zaïre" Archean to the Mesoproterozoic metalliferous province, and in particular the PGE belt of DRC (Lubero district)–Uganda–Burundi–Tanzania, and (iii) the age of mineralised carbonatites, pegmatites and granitoids.

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