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"*


* BRGM, 5 Avenue Claude Fautreux, B.P. 6009, 45060 Orleans Cedex 2, France
1 Centre for Geological and Mining Research, B.P. 333, Garoua, Cameroon
2 University of Yaounde, Department of Earth Sciences, B.P. 425, Yaounde, Cameroon
3 University of Bangui, P.O. Box 908, Bangui, Central African Republic
4 University of Kigali, Kigali, Rwanda
5 University of N'Djamena, Department of Geology, 0207, N'Djamena, Chad
6 B.C.C., 101, Avenue de l'Épinette, KINSHASA/GOMBE, B.P. 1299 KIN J. Kinshasa, Congo
7 Groupe FORREST/EGH, Lieu du Chouet, Av. Foutar, No. 9, B-190 Water, Belgium

Abstract

This paper is prepared within the framework 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 50th 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 focuses 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 framework of IGCP Project 470, "The Neo-proterozoic Pan-African belt of Central Africa" and the associated BRGM scientific project "Africa 1999-2004",
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,” prepared by Amret in 1991. 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 (GNG), 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, re-referenced 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 dispersed data on geology, geochemistry, mineral resources and tectonics updated by recent publications (e.g. Latra et al., 1994; Bouchot and Fetsche, 1996; Kunii and Moutaye, 1997; Toteu et al., 2001).

For convenience of use, the accompanying map has been published at a 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, geochemistry, and the economic potential of the deposits are the most 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 Archean–Neoproterozoic 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; Fybusse et al., 1996; Tchemeni 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 (Cacen-Yachette 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) 2950–2600 Ma intrusive rocks, including TTG charnockites and associated greenstones (Cacen-Yachette et al., 1988; Toteu et al., 1994), and (iv) 2800–2500 Ma late magmatic rocks (ultramafites, K-rich granitoids, syn-granitites).

- The northern Archean DRC–CAF craton (“Haast-Zaaf”, or “West-Nilian”, Lepersonne, 1974; Mestraud, 1982; Thibault, 1983 and 2000, unpublished; Cacen-Yachette et al., 1988) contains various granite–gneiss complexes (paragneisses and granite or gabbro orthogneisses crosscut by late pegmatites) assumed to be pre-2.91 Ga (e.g. amphibole–pyroxene–bearing gneiss of Bomu Complex, CAF–DRC at 3085 ± 54 Ma, Laveau and Ledent, 1975): BIF-bearing Mesoproterozoic greenstone belts overlying the granite–gneiss complex have also been differentiated on the map, but without distinguishing between “Lower” (Mesoproterozoic–Neoproterozoic) and “Upper Kibalian” greenstone belts. The “Lower Kibalian” (DRC) comprises meta- to sub-metamorphic rocks (paragneisses, amphibolites, amphibole–garnet ± muscovite ± biotite ± sillimanite ± cordierite bearing gneiss and scarce BIF). The “Upper Kibalian” (Lepersonne, 1974) of DRC constitutes narrow troughs that contain folded terrains (quartzite, BIF, greywackes, volcano-sedimentary rocks, and basal mafic volcanic rocks) crosscut by pre-2400 and 2450 Ma granitoids (Thibault, 1983); late tonalite apparently emplaced at ca. 2750 Ma; Archean tonalite sheets of greenstone belts (2700 ± 1 Ma and 2930 ± 88 Ma, d, Koltin, 1992a) involved in the PanAfrican nappe (CAF) in northwestern Uganda (West Nile area).

The metamorphic age of the northern Archean DRC–CAF craton has been estimated at ca. 2000 Ma (Rb–Sr WR and U–Pb zircon ages) from charnockitic granitoids and interpreted as the age of a first granulite–facies metamorphism (Watian), while a second amphibolite–facies metamorphism (Arunian) was previously dated at ca. 2550 Ma by the same methods in adjoining migmatic gneisses and granites. This area was recently reassessed by Schenk et al. (2002a,b): monazite dating on the oldest Watian granitoids 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 14–18 °E (De Carvalho, 1981–1982; De Carvalho et al., 2000). Archean rocks comprise a granite (granite to tonalite) gneiss migmatic 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.
chamockite complex, gabro, norite, anorthosite, enderbitie, mafic rocks, chamockite, scarce granulite). The “Kasa–Lomani–Luame” Neoarchean–Mesoproterozoic craton (DRC–AGO) is located at 5–11°S and 19–21°E, and the poorly exposed “Cuango Shield” (AGO) is located at 9°10′S and 18°19′E (De Carvalho et al., 2006). Both areas comprise a younger granite gneiss migmatic complex and an earlier gabro–norite–charnockite complex, dated respectively at 2680 ± 5 Ma on a migmatic U–Pb isochron (Cahen et al., 1984) and 2822 ± 66 Ma on a gabro Rb–Sr isochron (Dehal et al., 1976).

2.2. Metallogeny

2.2.1. Archean

The Central Archean blocks are productive for Fe and Au (Table 2). Some of the gold occurrences...
Table 1

<table>
<thead>
<tr>
<th>Commodity (expressed as)</th>
<th>Class A (Very large deposit)</th>
<th>Class B (Large deposit)</th>
<th>Class C (Medium deposit)</th>
<th>Class D (Small deposit)</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au</td>
<td>250</td>
<td>50</td>
<td>10</td>
<td>1000</td>
<td>t (1000 kg)</td>
</tr>
<tr>
<td>Co</td>
<td>100,000</td>
<td>10,000</td>
<td>2000</td>
<td>5000</td>
<td>t (1000 kg)</td>
</tr>
<tr>
<td>Cu</td>
<td>10,000,000,000</td>
<td>1,000,000,000</td>
<td>200,000,000</td>
<td>5,000,000,000</td>
<td>t (1000 kg)</td>
</tr>
<tr>
<td>Fe</td>
<td>1,000,000,000</td>
<td>500,000,000</td>
<td>50,000,000</td>
<td>5000,000,000</td>
<td>t (1000 kg)</td>
</tr>
<tr>
<td>Ga</td>
<td>1000</td>
<td>250</td>
<td>10</td>
<td>1000</td>
<td>lbm</td>
</tr>
<tr>
<td>Ge</td>
<td>10,000</td>
<td>1,000,000</td>
<td>100,000</td>
<td>1000</td>
<td>oz (0.2 g)</td>
</tr>
<tr>
<td>Sn</td>
<td>1000,000,000</td>
<td>1,000,000,000</td>
<td>1,000,000,000</td>
<td>1,000,000,000</td>
<td>t (1000 kg)</td>
</tr>
<tr>
<td>Zn</td>
<td>1000,000,000</td>
<td>100,000,000</td>
<td>10,000,000</td>
<td>1,000,000,000</td>
<td>t (1000 kg)</td>
</tr>
<tr>
<td>Pt</td>
<td>250</td>
<td>50</td>
<td>10</td>
<td>1000</td>
<td>t (1000 kg)</td>
</tr>
<tr>
<td>Pd</td>
<td>200,000,000</td>
<td>100,000,000</td>
<td>10,000,000</td>
<td>1000</td>
<td>t (1000 kg)</td>
</tr>
<tr>
<td>Nb</td>
<td>20,000,000</td>
<td>20,000,000</td>
<td>2000</td>
<td>2000</td>
<td>t (1000 kg)</td>
</tr>
<tr>
<td>Ta</td>
<td>20,000,000</td>
<td>20,000,000</td>
<td>2000</td>
<td>2000</td>
<td>t (1000 kg)</td>
</tr>
<tr>
<td>Ti</td>
<td>20,000,000</td>
<td>20,000,000</td>
<td>2000</td>
<td>2000</td>
<td>t (1000 kg)</td>
</tr>
<tr>
<td>Th</td>
<td>20,000,000</td>
<td>20,000,000</td>
<td>2000</td>
<td>2000</td>
<td>t (1000 kg)</td>
</tr>
<tr>
<td>U</td>
<td>20,000,000</td>
<td>20,000,000</td>
<td>2000</td>
<td>2000</td>
<td>t (1000 kg)</td>
</tr>
<tr>
<td>W</td>
<td>20,000,000</td>
<td>20,000,000</td>
<td>2000</td>
<td>2000</td>
<td>t (1000 kg)</td>
</tr>
<tr>
<td>Zn</td>
<td>20,000,000</td>
<td>20,000,000</td>
<td>2000</td>
<td>2000</td>
<td>t (1000 kg)</td>
</tr>
</tbody>
</table>

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

(primary or secondary) are spatially associated with volcanic rocks and BIF-bearing formations (greenstone belts; e.g. Kilo-Moto, Irao, Gorumbwa, Ituri-Uele, DRC; Belinga, GAB, etc.). Sn-W magmatic-related occurrences occur along major faults (CMR--GAB, W AGO). Scarcity of metal occurrences (Zn-Pb, Cu and Mn) have also been reported in Archean blocks. Near Mitizé (NW Gabon) secondary and primary diamond occurrences of unknown age (e.g. diamond-bearing dykes of kimberlite 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 overwritten 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) (Fayolle 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 metaprotrozoic rocks (Toteu et al., 1994; Iraouge et al., this volume). The rocks are generally well-preserved and 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 Bonou complex in CAF) and the Pan-African thrust nappes (Yaoundé and Ghayas) to the north.

The Paleoproterozoic Ubendian event may be preserved in windows in the Neoproterozoic Copper Belt, as well as in undeformed clastic sedimentary terrains of the Bangweulu area, located to the north of the Copper Belt (geochronological and structural research carried out in the Copper Belt province by Kampani and Calleux,
<table>
<thead>
<tr>
<th>Name of dinner, country, anc. language</th>
<th>Comm.</th>
<th>Potential (1 metal &amp; grade)</th>
<th>Ore deposit type and shape</th>
<th>Ore and base rock mineralogy</th>
<th>Long. lat.</th>
<th>Exploration type, note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kira-Mine, BRC</td>
<td>Au</td>
<td>Moly in 250 lb forming co. 100 (cambian)</td>
<td>Massive ore, gold deposit, pyrite, chalcopyrite, pyrrhotite</td>
<td>Magnetite, hematite, pyrite; base iron formation</td>
<td>30.01.195</td>
<td>Underground mining, Regional mining, Underground mining, Underground mining, Underground mining</td>
</tr>
<tr>
<td>No. 34, Shikoku, Japan</td>
<td>Au</td>
<td>moly in 250 lb forming co. 100 (cambian)</td>
<td>Massive ore, gold deposit, pyrite, chalcopyrite, pyrrhotite</td>
<td>Magnetite, hematite, pyrite; base iron formation</td>
<td>30.01.195</td>
<td>Underground mining, Regional mining, Underground mining, Underground mining, Underground mining</td>
</tr>
<tr>
<td>Inos, DRC</td>
<td>Fe</td>
<td>100 million, 150 m, pyrite, chalcopyrite, pyrrhotite</td>
<td>Massive ore, gold deposit, pyrite, chalcopyrite, pyrrhotite</td>
<td>Magnetite, hematite, pyrite; base iron formation</td>
<td>30.01.195</td>
<td>Underground mining, Regional mining, Underground mining, Underground mining, Underground mining</td>
</tr>
<tr>
<td>Inos, DRC</td>
<td>Fe</td>
<td>150 million, 150 m, pyrite, chalcopyrite, pyrrhotite</td>
<td>Massive ore, gold deposit, pyrite, chalcopyrite, pyrrhotite</td>
<td>Magnetite, hematite, pyrite; base iron formation</td>
<td>30.01.195</td>
<td>Underground mining, Regional mining, Underground mining, Underground mining, Underground mining</td>
</tr>
<tr>
<td>Kajiki-Kamome, DRC, Aomori</td>
<td>Fk</td>
<td>500 million, 150 m, pyrite, chalcopyrite, pyrrhotite</td>
<td>Massive ore, gold deposit, pyrite, chalcopyrite, pyrrhotite</td>
<td>Magnetite, hematite, pyrite; base iron formation</td>
<td>30.01.195</td>
<td>Underground mining, Regional mining, Underground mining, Underground mining, Underground mining</td>
</tr>
<tr>
<td>Mitaishi, Gifu, Aomori</td>
<td>Fe</td>
<td>150 million, 150 m, pyrite, chalcopyrite, pyrrhotite</td>
<td>Massive ore, gold deposit, pyrite, chalcopyrite, pyrrhotite</td>
<td>Magnetite, hematite, pyrite; base iron formation</td>
<td>30.01.195</td>
<td>Underground mining, Regional mining, Underground mining, Underground mining, Underground mining</td>
</tr>
<tr>
<td>Mitaishi, Gifu, Aomori</td>
<td>Fe</td>
<td>150 million, 150 m, pyrite, chalcopyrite, pyrrhotite</td>
<td>Massive ore, gold deposit, pyrite, chalcopyrite, pyrrhotite</td>
<td>Magnetite, hematite, pyrite; base iron formation</td>
<td>30.01.195</td>
<td>Underground mining, Regional mining, Underground mining, Underground mining, Underground mining</td>
</tr>
<tr>
<td>Location</td>
<td>Geology</td>
<td>Reserves</td>
<td>Method</td>
<td>Notes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------------------------------------------------------------</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Zamuza-Zamuza III, COS</td>
<td>Fe: 160,000,000; B: 8.60—2.83</td>
<td></td>
<td></td>
<td>Mining method unknown; Primary oxides are unknown.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Archon, Fe: quartz, BIF, shilstone, quartzite</td>
<td>8.60—2.83</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lobu-Lobu, COS, Archaen, Fe: quartz, BIF, shilstone, amphibolite, marl</td>
<td>Fe: 100,000,000, C: 3.04—0.49</td>
<td></td>
<td></td>
<td>Primary oxides are unknown.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most M: Bzla, COS, Archaen, Fe: quartz, BIF, shilstone, amphibolite, marl</td>
<td>Fe: 70,000,000, C: 3.29—0.56</td>
<td></td>
<td></td>
<td>Primary oxides are unknown.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kionga, DRC, Cenozoic, Nyanzian rocks</td>
<td>Mt: 30,000,000, B: 3.33—0.53</td>
<td></td>
<td></td>
<td>Unworked</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bingo, DRC, Archaen but rock:</td>
<td>Nt: ca. 190,000, B: 2.07—10.56</td>
<td></td>
<td></td>
<td>Primary oxides are unknown.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Potential = Production + reserves + resources.

3. The PAAR is involved in the West Congolian belt, which is a major structural complex associated with the collision of the Proto-Atlantic and the Protocratophylane. The PAAR is characterized by a series of tectonic and magmatic events, including the emplacement of mafic and ultramafic intrusions, the formation of subduction complexes, and the development of orogenic belts. The PAAR is associated with the development of the Atlantic Ocean and the formation of the African continent.

4. The PAAR is also associated with the formation of the East African Rift System, which is a major tectonic feature in the region. The PAAR is characterized by a series of extensional events, including the formation of rift-related magmatic belts, the development of basaltic volcanism, and the formation of grabens. The PAAR is associated with the development of the Red Sea and the Gulf of Aden.

5. The PAAR is also associated with the development of the circum-African tectonic system, which is a major tectonic feature in the region. The PAAR is characterized by a series of extensional events, including the formation of rift-related magmatic belts, the development of basaltic volcanism, and the formation of grabens. The PAAR is associated with the development of the Red Sea and the Gulf of Aden.
<table>
<thead>
<tr>
<th>Name of deposit, country</th>
<th>Commd.</th>
<th>Potential (Gt, gsm)</th>
<th>One deposit type and share</th>
<th>Ore and host-rock mineralogy</th>
<th>Long, Lat</th>
<th>Explanation type, av.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maceda, Galicia, Spain</td>
<td>Mn</td>
<td>ca. 180,000,000, b</td>
<td>Sedimentary manganese deposits; Stratified bed; single or multi-layered epigenetic within host rock</td>
<td>Native, pyrolusite, pyrophanite, (pyrolusite), pyrrhotite, (pyromorphite)</td>
<td>15 R, 4-47</td>
<td>Open cut and open pit mining; Oxidized ore within the spilitized core</td>
</tr>
<tr>
<td>Morena, Guadalajara, Mexico</td>
<td>U</td>
<td>ca. 25,000, B</td>
<td>Umnisoli manganese and reddish manganese deposits; Concentrate is manganese overgrowth of disseminated ore, rounded borders of secondary minerals</td>
<td>Pyrolusite (manganese), hematite, pyrite, ironstone, limestone, coal, shale, argillite</td>
<td>15 R, 4-38</td>
<td>Open cut and open pit underground mining; Gereal in 1990; Primary oxide ore</td>
</tr>
<tr>
<td>Olok, Galicia, Spain</td>
<td>U (Fe)</td>
<td>ca. 30,000, B</td>
<td>Umnisoli manganese; Concentrate is secondary growth of disseminated ore, stratified bed; single or multi-layered (epigenetic within host rock)</td>
<td>Umnisoli, coffinite, framboidal, vesuvalite, pyrite, galena, chalcopyrite</td>
<td>15 R, 4-40</td>
<td>Open cut and open pit underground mining; Primary oxide ore</td>
</tr>
</tbody>
</table>
| Eritrea, Ethiopia | Au    | ca. 42, C | Intrusive-dacite porphyry related manganese-pyrite deposits; Exposed line of ore (dike-like) | Gold, pyrite, bismuth, gold-bismuth, cassiterite, (quartz), arsenic, silver, calamine | 11 R, 4-120 | Agricultural and open cut (exploitation) mining; Natural weathered and secondary native-element ore |}
| Kifalai, Kibara, Tanzania | Fe | 350,000,000, B | Banded iron formation (BIF) | Magnetite, hematite, quartz, apatite, (pyrite), ironstone, calamine, iron-ore snow | 9 R, 2-06 | Unworked; Primary oxide ore |
| Chifubwe, Zambia, Angola | Fe | 125,000,000, B | Fossilized sedimentary carbonaceous ironstone; Concentrate is sulfide-matrix to carbonaceous and sap | Magnetite, pyrite, bismuth, cobalt, arsenic, copper | 18 R, 6-124 | Open cut (open pit) mining; Ore is sulfide element forms a distinct mineral phase |
pre-Katangan basement of ZMB (1960 Ma, Raina et al., 1999), contains porphyry copper deposits (Samba, ZMB), and aplite-related Ca-(Au) deposits (Mukhi Copper-Kashme, ZMB).

4. Mesoproterozoic to early Neoproterozoic belts (16–0.9 Ga): Kibaran & Isimudite

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-SW “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 define a westward-vergent fold belt of DRC. The foreland domain is composed of metavolcanic-sedimentary formations that include detrital sedimentary rocks (conglomerates, sandstones and pelites), and interbedded basaltic andesite lavas. The belt may be correlated with rock suites in NW Tanzania (Nd/Nd ages of 1379 ± 10 and 1554 ± 10 Ma) and SW Burundi (130 ± 20 Ma and 1340 ± 20 Ma (Debold et al., 2001)). Kampunzu (2003, Oral Comm.) suggests that this domain is composed of two superposed elastic-carbonate sedimentary formations: (i) a lower meta-sedimentary formation (gneiss, metachert, meta-sedimentary elastic-carbonate rocks), whose geodynamic setting is not well constrained, crossed by synkinematic granitoids (ca. 1380–170 Ma), and (ii) an upper meta-sedimentary formation overlying the 1380 Ma granites, but crosscut by Sn-granites (ca. 1060–1250 Ma). This upper formation is commonly fault-bounded and could represent intracontinental arc deposits. The lower formation (partly ex-Ruzizi) is affected by a first deformation (D1) associated with the 1750–1880 Ma synkinematic granitoids. The upper formation (partly ex-Burundi) includes heavy mineral-bearing quartites (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. 1160 Ma, Kampunzu, 2003, Oral Comm.). Rare mafic bodies (lava or silicic) are probably interbedded in all of these sedimentary deposits according to Kampunzu (2003, Oral Comm.).

2. From geochemical, geochronological and magmatic considerations (Kampunzu, 2003, Oral Comm.), the Chona-Kolongo block (ZMB) is included in the Kibaran domain. This block is composed of orthogneiss, granitoids and gneiss complexes dated between 1343 ± 6 Ma and 1285 ± 6 Ma (U/Pb conventional method, Hanson
et al., 1988). They are crossected by granitoids at 1198 ± 6 Ma (Hanson et al., 1988) and late Sn–granitoids at ca. 940 Ma (Kampunzu, 2003, Oral Comm.).

3. The Mesoproterozoic Irumide belt (ZMB), oriented NE-SW, is composed of gneisses, high-grade granulites, charnockites, complexes and granitoids. Some pre-Irumide granitoids (ca. 1650 Ma) and relics of Neoarchean or Paleoproterozoic rocks have been identified (Cox et al., 2002; De Waele and Mapula, 2002). The gneiss-orthogneiss-orthopyroxene-granulite assemblage in the inner part of the orogen was dated by Schenk et al. (2002a) at 1046 ±1 Ma (U/Pb on monazite), consistent with the 1076 ±6 Ga obtained on some late intrusive porphyry granites (D De Waele et al., 2003). The metamorphic grade decreases to gneissic facies to the NW of the belt.

4. We have tentatively assigned a Mesoproterozoic–Neooproterozoic I age to several sedimentary formations (Likile-Benbeni, Iari Group), which crop out near the frontiers of CAR, COG and DRC. These detrital rocks (conglomerate, sandstone, quartzite, pelite and argillite) change laterally to possible turbidites and calareous sediments (limestone, calccrete). They locally display a contact metamorphism (Ca–Fe–skarn, Ca–hornfels). These rocks are assumed to be pre-950 ±5 Ma (Thibault, 1983) or ca. 1350 Ma (Poldervaart, 1956), and they are overlain by Neooproterozoic sedimentary formations (Thibault, 1983).

Isolated Mesoproterozoic–Neooproterozoic I outcrops, suggesting a possible tectonic magmatism, occur in AGO, DRC and CAR. They include:

- The Kanene 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 Nkou peralitite 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 silting stage in the West Congolian Belt. Similar granitoids have also been recorded along the Shanga fault west of the Paleozoic (?) to Mesoarchean orogen basin (e.g. Yobe granite at 1160 ±61 Ma, Vkat et al., 2001).
- Dolerite dyke swarm, crosscutting Paleoproterozoic formations at the frontiers of CMR, COG and CAR. It has an estimated age of 1200 ±1 Ma (Poldervaart, 1996).

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

4.2. Metallogeny

Different mineralized provinces have been recognized in the Mesoproterozoic to early Neooproterozoic I belts ("Kibaran", Irumide, etc.) of Central Africa. The best-known is the Sn–Ta (W, Nb, Be, Li, Mo, As, Au, gilmet-sno) province of eastern DRC-Rwanda and Burundi. It contrasts with the Irumide belt of Zambia, associated with the Kibaran penuraluminous 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 mined between 1919 and 1980 essentially within the pegmatite, some of which were reactivated during the "tantalum crisis" of 2000 (artisanal mining). One mineralogy comprises cassiterite, columbo–tantalite, spodumene-lepidolite (Kaburri, Lubukleva, Niabesi-Tolomba, and Manon), byssolite, tourmaline, lelengite, aegyptinite, pyrite, autunite, wad and unspecified iron oxides. Gangue minerals include microcline, albite, apatite, muscovite, fluorite, zircon, rutile, quartz, orthoclase and byssolite. The mining potential of this area is also underestimated as indicated by:

- Alluvial and primary gold (e.g. Mobole, Twangiza, DRC, Table 5).
- The presence of an undated Kibaran world-class PGE–Ni–Co-bearing auruate 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 Kanene anorthosites complex, one of the most extensive in the world, emplaced in the Mesoproterozoic (1770 Ma) and contains scarce deposits of ilmenite and hematite-ilmenite (Ti–Fe) in Namibia and Angola (Chang, AGO, Table 5).
- Stratum base metal deposits (Zn, Pb, Cu), analogues to those of southern Africa, have 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, analogous of those recently dated in West Africa (Delor et al., 2004) have not yet been recognized, 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 Camot Mesoarchean basin.
- In the Irumide belt, kyanite and copper occurrences have been identified: the Mkaushi Copper district, the kyanite occurrences hosted by high-grade metamorphic rocks (e.g. Leopards Hills and Mpyane Hills). Numerous gem-bearing pegmatites host aquamarine-beryl deposits (Chipata, Luangwa Bridge, Landazi, ZMB), emerald (Kagem), anegagh (Mambwa and Kariba), tourmaline, garnet, mica, etc.
### Table 4
Major mineral deposits in the Maciu-Namibian mineral district of Central Africa

| Name of deposit, country, age, location | Comm. | Potential (metal @ grade) | On deposit type and shape | On and host-rock mineralogy | Long., Lat. | Exploration type.
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Kinshasa, DRC</td>
<td>Mt. Kasa, vanadium, pyrochlore</td>
<td>Sn, Cu, Zn, Pb, Ag, Au</td>
<td>250,000 @ 4%</td>
<td>Zoned granitic pegmatite, pegmatite</td>
<td>Copper, cobalt, nickel, pyrite</td>
<td>250, -200</td>
</tr>
<tr>
<td>Maswaan, Namibia</td>
<td>Mt. Nkombe, vanadium, niobium, niobium, tin, tantalum</td>
<td>Sn, Cu, Zn, Pb, Ag, Au</td>
<td>50,000 @ 4%</td>
<td>Zoned granitic pegmatite, pegmatite</td>
<td>Copper, cobalt, nickel, pyrite, mica, feldspar, muscovite, hornblende, biotite, tourmaline</td>
<td>200, -150</td>
</tr>
<tr>
<td>Musukwe, ZMB</td>
<td>Mt. Nkombe, vanadium, niobium, tin, tantalum</td>
<td>Sn, Cu, Zn, Pb, Ag, Au</td>
<td>50,000 @ 4%</td>
<td>Zoned granitic pegmatite, pegmatite</td>
<td>Copper, cobalt, nickel, pyrite, mica, feldspar, muscovite, hornblende, biotite, tourmaline</td>
<td>200, -150</td>
</tr>
<tr>
<td>Chilonda, ZMB</td>
<td>Mt. Nkombe, vanadium, niobium, tin, tantalum</td>
<td>Sn, Cu, Zn, Pb, Ag, Au</td>
<td>50,000 @ 4%</td>
<td>Zoned granitic pegmatite, pegmatite</td>
<td>Copper, cobalt, nickel, pyrite, mica, feldspar, muscovite, hornblende, biotite, tourmaline</td>
<td>200, -150</td>
</tr>
<tr>
<td>Käll-Käll, DRC</td>
<td>Mt. Nkombe, vanadium, niobium, tin, tantalum</td>
<td>Sn, Cu, Zn, Pb, Ag, Au</td>
<td>50,000 @ 4%</td>
<td>Zoned granitic pegmatite, pegmatite</td>
<td>Copper, cobalt, nickel, pyrite, mica, feldspar, muscovite, hornblende, biotite, tourmaline</td>
<td>200, -150</td>
</tr>
</tbody>
</table>

*Potential = Exploration + reserves + resources

### Table 5
Major mineral deposits in the Lualaba, Ituri, and Itua-Kani districts of Central Africa

| Name of deposit, country, age, location | Comm. | Potential (metal @ grade) | On deposit type and Age | On and host-rock mineralogy | Long., Lat. | Exploration type.
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Kinshasa, DRC</td>
<td>Mt. Shaba, cobalt, copper, nickel</td>
<td>Cu, Zn, Pb, Ag, Au</td>
<td>250,000 @ 4%</td>
<td>Zoned granitic pegmatite, pegmatite</td>
<td>Copper, cobalt, nickel, pyrite, mica, feldspar, muscovite, hornblende, biotite, tourmaline</td>
<td>250, -200</td>
</tr>
<tr>
<td>Lualaba, DRC</td>
<td>Mt. Nkombe, vanadium, niobium, tin, tantalum</td>
<td>Sn, Cu, Zn, Pb, Ag, Au</td>
<td>50,000 @ 4%</td>
<td>Zoned granitic pegmatite, pegmatite</td>
<td>Copper, cobalt, nickel, pyrite, mica, feldspar, muscovite, hornblende, biotite, tourmaline</td>
<td>200, -150</td>
</tr>
<tr>
<td>Ituri, DRC</td>
<td>Mt. Nkombe, vanadium, niobium, tin, tantalum</td>
<td>Sn, Cu, Zn, Pb, Ag, Au</td>
<td>50,000 @ 4%</td>
<td>Zoned granitic pegmatite, pegmatite</td>
<td>Copper, cobalt, nickel, pyrite, mica, feldspar, muscovite, hornblende, biotite, tourmaline</td>
<td>200, -150</td>
</tr>
<tr>
<td>Itua-Kani, DRC</td>
<td>Mt. Nkombe, vanadium, niobium, tin, tantalum</td>
<td>Sn, Cu, Zn, Pb, Ag, Au</td>
<td>50,000 @ 4%</td>
<td>Zoned granitic pegmatite, pegmatite</td>
<td>Copper, cobalt, nickel, pyrite, mica, feldspar, muscovite, hornblende, biotite, tourmaline</td>
<td>200, -150</td>
</tr>
</tbody>
</table>

*Potential = Exploration + reserves + resources
5. The Choma-Kalomo block contains scarce gemstones and copper occurrences (e.g. Simani-Kalomo amethyst deposit).

- Cape-type mafonites within the pre-950 Ma Luki-Bembi formation of northern Congo (Tibault, 1983).

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 southwestern thrusting of its southern limit onto the Congo craton (Yaounde-Ghayas mts. to cataclinal nappes extending from Cameroon to Uganda through CAF (Poldervaart, 1958; Bell et al., 1994; Poland and Poldervaart, 1987; Nzembi et al., 1998; Ngoko et al., 1991; Rolin, 1992, 1995a; Toteu et al., 2001, 2004a). The belt comprises polydeutic (Adamawa-Yade in CMR, CAF and CTD) and monodeutic domains (e.g. Yaounde and Polin CMR and Ghayas in CAF, Leere in CTD). All of the rocks in these belts are metasedimentary and metavolcanic formations (various kyanite schists and greisses, migmatic, amphibolites and quartzites) and metaplutonic rocks (gabbro, gneisses-porphyry-bearing diorite and granitoid). They were metamorphosed under amphibolite to granulite facies between 640 and 600 Ma (Poldervaart, 1987; Nzembi et al., 1998; Toteu et al., 1987, 2001; Banya et al., 2003). 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-vergent nappes tectonics, and their emplacement either predated or was coeval with that deformation. Geochemically, all are high-K calc-alkaline in composition.

2. The Northeast-Southwest West Congolian belt and its “foreland” sedimentary deposits (Maurin, 1995; 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 dikes; Mpenza Boni and Veluitteni, 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, 1995) and ended at 566 Ma (Tack et al., 2001). The major structures in the belt verge to the east (Maurin, 1995; Tack et al., 2001). NNE-SSW sinistrals 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 “Katanaga Belt” (e.g. “Dome region” and “External Fold and Thrust belt”, Unrug, 1988; Kampanzu et al., 2000). The Copper Belt belongs to the Luflidian Arc, an arcuate thrust and fold belt developed in northern Zambia and southeastern DRC (Kampanzu and Calugas, 1999) during the Neoproterozoic tectonothermal Dmbwe-Lufilian-Zambian Orogeny. This tectonothermal system separates the Mesoproterozoic terrains of DRC-RWA-BDI (“Kibanan”) from those of Zambia and Mozambique (“Inumide” and “Choma-Kalomo block”, see on the map). Overlying pre-Katangan basement composed of Palaeoproterozoic calc-alkaline volcanic arc formations and schists (Rainaud et al., 1999): the Katangan sedimentary succession comprises three successive supergroups (Cailleux et al., 1994; Caillet, 2004b):

(a) The Roan Supergroup composed of (i) the Basal conglomerate; (ii) the “Lower Roan” sequence including the Mirunda schist unit (2MBR-DRC) and the “Roan Group” (argillaceous dolomitic limestones and sandstones, DRC) at the base; and (iii) the Lower Roan sequence in the Cu-Co-bearing Mbaire Group (dolomitic shales and dolostones, DRC) and Cu-Co-bearing Kigi unit (ammonites, argillites and dolostone, ZMB-DRC); (iii) the Dpata Group (DRC) and Bancroft unit (formerly “Upper Roan”, ZMB); and (iv) the Mwenda Group (ZMB-DRC).

(b) The Lunga Supergroup, formerly the “Lower Kandungwan Supergroup” composed of carbonatic deposits (“Grand Congolaisat” and diamictites), dolostones, limestones, dolomitic and sandy shales and silts.

(c) The Kandungwan Supergroup, formerly the “Upper Kandungwan Supergroup” composed of syn-orogenic dolomitic and sandy shales, limestones, sandstones and late-orogenic molasse deposited in an oxidizing environment.

The Katangan Belt tectonics (Unrug, 1988; Kampanzu and Calugas, 1999; Kampanzu 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 south to the north of the prehnite-pumpellyite facies metamorphism and has affected the northern external zone (“Katanaga subcogen” and outer part of “External Fold and Thrust belt”); a syn-D1 amplitudes fades is also present in the “Dome region”, while whitecherts and eclogites (Ortho-ortholiths), 193 ± 22 Ma, Oliver et al., 1998; Johnson and Oliver, 2000) have been described south...
of the Dome region in areas adjacent to the Neoproterozoic Zambesi Belt (Costi et al., 1995; Musaue et al., 1994; Kampunzu et al., 2000).

We may also mention here the presence of N-S trending Neoproterozoic granites extending for about 160 km along strike (e.g. the Itempwe trough, Vilenaue, 1985). These granites contain a lower group of black shales, siltstones, and tuffs, and an upper group of granites, sandstones and shales. 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 latitite-derived deposits in southeast Cameroon; (iii) granitoid and fault-related rare metals (Sn, W, REE occurrences in Cameroon and Congo); (iv) gold in the Lon region (CMR); (v) rutile at Akondjinga (CMR); and (vi) industrial minerals (e.g. talc of the Nyanga Syntaxis, Gabon).

- The “garnet” Copper Belt (Table 6) is one of the major mineral provinces in the world (Lamicka, 1999) for Co-Cu, and it also hosts Pb, Zn, Ni, Ge, Ga, U, Au, Ag and PCP mineralisations. The belt contains “Kupferschiefer” (or “Cu shale”) types or residually enriched stratiform ore deposits. Locally, these deposits are partly fault-controlled. The morphology of the banded strataform (or stratiform) is cut by discordant bodies and/or overprinted by tabular-shaped oenoids bodies of secondary origin. In DRC, the highly mineralised segment of this ore zone is the Katanga region comprises numerous fields (e.g. Kabele, Kakanda, Kalikundu, Katabowe-Kanuma, Kasandula, Kasaona, Kasimba, Kolwezi, Dikulukwe-Mashamba, Kamoto, Musingo, Mutshu, Tullings, Luvungi, Lusunda-Lukus, Musoshi, Ruashi, Ebitwe, Shitum, Tenke-Fungurume. In Zambia, the province comprises the following major deposits: Konka district, Konka North Mining Area, Bancroft, Kirk Bank), Nama, Ndche District (Ndunga, Chingola), Nkana District (Nkana Division, dag: Bolosa), Luma District (Luma Divisions and Mwe and Baluba Divisions and Mwe), Chambishi District (Chambishi, Chambishi South-East, Festiva), Mufara District (Mufara, Mokamba, Lumwana project (Chinwagandi-Malundwe deposits), Chiluluma (Mine), Kakomboka, Mwahyi and Mondisi North, Kasombi and Sampa. Mesothermal iron and copper mineralisation (Shindowe Kasompi, Musofo, DRC, and Table 6) is also present in the Copper Belt. It occurs a discordant lode or vein deposits preferentially controlled by faulting (shar-zones or reverse faults).

- Base metal deposits (Table 7). (i) Base metal mineralisation is a significant feature of the Neoproterozoic “schist-o-slate” of COG (e.g. districts of Yanga-Koutoumou-Tshumakou, D’Poussu, Hikolo, etc.). The deposits comprise stratiform and discordant carbonate-hosted strata-bound and vein Pb-Zn deposits of Mississippi Valley type (MTV). (ii) Also noteworthy are the dolomite-hosted replacement pipes of breccia deposits of the Kipushi type (e.g. Kipushi, DRC). These are considered to be syn- to late-oreogenic fault-controlled ore deposits, which have been residually enriched. Their margins are variegated—till they occur as columns, chimneys in locally brecciated primary ore, and locally as blebs of residual ore.

- Significant amounts of Ge have been reported from 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 focused on Cu–Co production.

- Carbonate, carbon, granitoid and fault-related ore deposits. A variety of minerals are associated with calc-alkaline or peraluminous magmatism (Table 8). The mineralisation occurred at different stages of the Neo-proterozoic-Cambrian orogenic evolution.

- Carbonate-hosted deposits and Nb ore deposit (Maboumé, GAB).

- Sn-W-REE ± Ta-Zr in zoned granitic pegmatites, granitoid-controlled ore deposits, fault-related ore deposits and rare ore deposits related to adakite to peraluminous intrusive complexes (Goutchouni, CMR; Biahsha, Mumba, Numbi, DRC).

- Au occurrences in fault-related and granitoid-controlled ore deposits (Central Cameroon Field) and rare breccia-hosted iron-oxide-iron deposits of probable iron ox-copper-gold type at Mumba, ZMB.

- U in uraniumiferous porphyry-granitic veins (Gobhe-Kongo, CMR).

- Cu-Pb-Zn skarn (Bukanda, Excelsior Zink, ZMB).

- Maboumé (GAB) is a world-class residualy enriched carbonate,-hosted apatite, and Nb ore deposit of Neoproterozoic 3 (K/Ar age of 860 ± 13 Ma; Laval et al., 1985) (Table 8).

- Peraluminous and carbonatite-related deposits in NE DRC (northern extension of Itempwe trough, western margin of the rift) occur in a N-S peraluminous province characterised by carbonatites (10 identified) and peraluminous complexes (e.g. Lushe, Bingi, Mubalafo).

- Radiometric ages are not well constrained and range between Neoproterozoic (Lushe at 822 ± 13 Ma) by Rb/Sr methods and Cambrian Lushe 516 ± 26 Ma by K/Ar method; Woolley, 2001). The carbonatite (dolomitic-carbonatite, calcite-carbonatite, calcite-carbonatite) and syenite of Lushe (DRC) were emplaced into Neoproterozoic schists and quartzite. Weathered pyrochlore-bearing carbonatites presents a major potential for Nb, Ta and REE. Peraluminous intrusive complexes occur also in Zambia (Narira).
<table>
<thead>
<tr>
<th>Name of district, country, s.p.</th>
<th>Lithology</th>
<th>Mineralogy</th>
<th>Economic significance</th>
<th>Type of ore deposit</th>
<th>Exploration type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kamamori, Honshu</td>
<td>Sandstone: quartz, feldspar, mica, quartzite, graphite.</td>
<td>Slate, schist, gneiss, marble.</td>
<td>Underground and open-pit mining, industrial minerals, ore of secondary origin from the oxidized and carbonaceous zones.</td>
<td>Primary oxide ore</td>
<td>Underground and open-pit mining, industrial minerals, ore of secondary origin from the oxidized and carbonaceous zones.</td>
</tr>
</tbody>
</table>
• Scarcity residual Co-Ni ore deposits have been identified on laterite capping Neoproterozoic mafic-ultramafic maoric complexes (e.g. Konjo, Cameroon, Table 9).

• Rutile and Industrial Minerals (Table 9). In Cameroon, the rutile (Ti) of Akonolinga district is hosted by Neoproterozoic metasediments and intrusions of the Yaounde Group. The sources of alluvial-pluvial industrial minerals are located: the rutile near the site of the Neoproterozoic Arikpite. A district of talc is hosted by Neoproterozoic 3 sedimentary sequences of the Nanga province (limestone, dolomite and evaporite-bearing deposits) in Gabon. Some deposits of feldspar or nepheline occur in different countries (e.g. Ebondu, Cameroon).

• The gemstone fields that are associated with HP granulate zones (such as the Mozambique Belt), are very limited, except in the Iramide 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 gemstone deposits of East Africa” at 1:4,000,000, presented during the CAG20 colloquium, Deschamps, et al. (2004). They include aquamarine, amethyst, agate, chalcedony, opal, etc.

6. Paleozoic-Mesozoic basins (524–65 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 (Lepers, 1974, De Carvalho, 1983–1985). It contains Paleozoic (Carboniferous–Permian) marine sediments and continental coal-bearing and glaciogenic-sediments are present in some troughs. Mesozoic (Karoo, Jurassic–Cretaceous) sediments (lithoclast and fluvial deposits) and Late Cretaceous continental sequences (Kwanza Group, DRC) are also represented. In the northern part of Central Africa, early Cretaceous rifting (North-CMR, South TCD, Garaud and Mazin, 1992) occurs in response to both a subaerial extensional regime and a 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 Palaeozoic in the Congo Basin and in small troughs developed on the Precambrian basement. Classic and/or carbonate-bearing sequences (siltstone, sandstone, greywacke, arkose, zeolites, jasper-
generic sediments, limestones, dolomite, scorce matric and felsic volcanics and volcanioclastics rocks) were deposited in GAB, AGO (Alto-Chibango, Malungo, Terero), and DML (Bumumay, Lualu).

In the northern part of the map (TCM, CMF, CAF, Mestraad, 1982), Paleozoic glaciogenic clastic sedimentary formations include tillites, diamictites, argillite, mudstone (CAF), as well as fenestelliferous sequences (TCM), 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 Azulhal (GAB) and in Luanda and Lusos-Cassina (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 (Lepomonee, 1974; De Camvalho, 1980–1982) contains Paleozoic–Mesozoic formations (Karoo, Jurassic–Early Cretaceous). They comprise clastic-carbonate limestones and fluviatile deposits (Lusos-Cassina, Calonda, and Cuando in AGO) and Late Cretaceous continental clastic sedimentary formation (Kwango in DRC). The Cairo Super group (mainly sandstones and mudstones, e.g., TMR) was deposited from Carboniferous to Jurassic. The lower 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 basaltic flows of the Late Cretaceous continental sequences (Kwango, DRC) contain freshwater lakes, estuaries, palynomorphs and, at the base, diamond-bearing gravels.

The coastal basin (western GAB–AGO; De Camvalho, 1980–1982; Basset, 1984), comprises mainly marine clastic-carbonate formations, that overlies the Precambrian rocks and were deposited from the Cretaceous to the Plinioocene.

Mesozoic fluvial and lacustrine clastic (conglomerates, sandstones and shales) and carbonatic sediments were deposited from Early to Late Cretaceous in restricted troughs of CMR (Logbadejika, Vina North, Mbanwa, Gomba, Cross, Manyu, Amakawo, Mbugu, and Bwoko sandstones). Similar deposits also occur in TCM (Early Cretaceous in Lévi, Late Cretaceous in Lwabi) and in CAF (two distinct areas: SW Camot-Beberati and NE Moula-Guadja, Mestraad, 1982). Mesozoic to Neogene clastic sediments (conglomerates, sandstones and shales) have also been deposited in the coastal Dusula passive-margin basin.

6.1.2. Magnatism
Post-Darwinian magmatism started during the Cretaceous. Subalkaline to alkaline granites and gabbro dolerite were also emplaced during the same period. Cretaceous mineralized carbonates and syenitic intrusions, scoria Mesozoic dolerite volcanics and volcanoplutonic complexes (basalt, tephrite, trachyte-phono-lite) have been emplaced in the alkaline province of central-western AGO (e.g., Citando, Tshwara, ca. 90–130 Ma; L.A.E.A., 1985; 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 metal in Coochbeach, GAB; bauxite in Doué oré, GAB; phosphate in GAB, COG and AGO). Phosphorites have been recorded in Upper Cretaceous sedimentary formations (Tshwara, COG). Uranium is also present as stratabound beds in uranium-bearing phosphorites (Calonda, AGO); Kamba Nsibi and Kanzi, DRC) in the same basin from Cretaceous to Palaeocene. Uranium deposits occur also in Zambia (e.g., Kanita; U-Th-Fe Jura deposits including autunite, meta-autunite, phosphoranylite, uranophane) important topaz and Mibemiet resources (Pasko Nshim, Maluku, Bulu-Koyou, COG), as well as bitumen-bearing deposits, are hosted by Cretaceous sediments of the coastal basins (e.g., Libongo and Udri deposits, AGO) Gypsum and anhydrite deposits are hosted by Early Cretaceous sediments (Kamba, AGO). Diamond-bearing Cretaceous palaeoplacers are also known at Quimangao and Toca (AGO) (Table 10).
- Mesozoic and Palaeozoic carbonates hosting different valuable commodities have been identified in several places (Woolley, 2001). They include Nb at Kalwe, ZMB; Fe at Fialurdo: baryte, phosphorite, REE, and Th in AGO (Tshwara deposit formed ca. 128–131 Ma), fluorite, and Nb at Benga, AGO. Details are given in Table 11. Jurassic granitoid-controlled uranium ore deposits occur in ZMB (e.g., Hook Granite Massif). The Kafula deposit is a gem-bearing pegmatite and pegmatitite deposits developed in Paleoproterozoic rocks and possible Late Kibaran rocks during the Upper Ordovician (Czech Geological Survey data; Knabe, 2005; Oral Comm.).
- Coals occur in the eastern DRC in the Lukuga Permain basin, 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 diamondiferous kimberlites (e.g., Mbuvi-Mayi in DRC, Camach, Camafo, Catoa, Camagio, Congo in AGO) and palaeoplacers, including diamonds reworked in basaltic rocks of Upper Cretaceous age at Kwango, DRC, and diamond-related Mesozoic sedimentary rocks of CAF (Casir, 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., Mbuvi-Mayi at ca. 71 Ma). All of these
<table>
<thead>
<tr>
<th>Name of district, country, age host-rock</th>
<th>Comm.</th>
<th>Potential (t metal @ grade)</th>
<th>Ore deposit type and shape</th>
<th>Ore and host-rock relationship</th>
<th>Long, Lat.</th>
<th>Exploitation type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goobech, GAB, Musozoic, Phaneritic</td>
<td>Pb</td>
<td>ca. 15,000, C</td>
<td>Red bed hosted and deposits.</td>
<td>Galena</td>
<td>9.51; -1.00</td>
<td>Primary sulphide ore</td>
</tr>
<tr>
<td>Eourekkili, GAB, Early Cretaceous,</td>
<td>Bari</td>
<td>ca. 1,600,000</td>
<td>Banded, peloidite hosted strata-bound ore deposits with veins.</td>
<td>Baryte, hematite</td>
<td>10.54; -3.04</td>
<td>Unworked, Baryte</td>
</tr>
<tr>
<td>Upper Cretaceous,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cacheiras de Birga, AGO, Early Cretaceous,</td>
<td>Cu</td>
<td>ca. 110,000, C</td>
<td>Red bed (sandstone) hosted basemetal deposits.</td>
<td>Chalcopyrite, bornite, digenite, covellite, idaite, mackinawite, arsenite</td>
<td>14.09; -11</td>
<td>Ore is with the element from a distinct mineral phase</td>
</tr>
<tr>
<td>Upper Cretaceous,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tekkaniou, COG,</td>
<td>Pb</td>
<td>ca. 100,000,000, C</td>
<td>Phosphates (or sedimentary phosphates).</td>
<td>Phosphates</td>
<td>12; -4.5</td>
<td>Mining method unknown: Phosphate (2005)</td>
</tr>
<tr>
<td>Upper Cretaceous,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gabinda, AGO, Late Cretaceous,</td>
<td>U, Pb</td>
<td>ca. 15,800, B</td>
<td>Uraniferous phosphorites.</td>
<td>Uriferous phosphorites.</td>
<td></td>
<td>Unworked</td>
</tr>
<tr>
<td>(Mauritania) to Palaeocene, phosphorites</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kandu Nait, Kanzu, D&amp;C Musozoic,</td>
<td>U, Pb</td>
<td>ca. 2200, C Kanzu U:</td>
<td>Uraniferous phosphorites.</td>
<td>Feldspar, apatite, quarts, wavelite</td>
<td></td>
<td>Unworked</td>
</tr>
<tr>
<td>Cretaceous: Phosphorite</td>
<td></td>
<td>ca. 5200, C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primeu Noire, Malaka,</td>
<td>Mg2</td>
<td>Petra 150,000,000, B</td>
<td>Salt and gypsum deposits.</td>
<td>Cerussite, bishoffite, tachyhematite, bismuth, arsinite</td>
<td>11.93; -4.88</td>
<td>Solution mining method: Primary soluble salts</td>
</tr>
<tr>
<td>Holle Konkouta, COG,</td>
<td></td>
<td>MGC: 70,000,000, B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Cretaceous,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sambe, AGO, Musozoic,</td>
<td>Gypsum</td>
<td></td>
<td>Salt and gypsum deposits.</td>
<td>Gypsum, arsinite</td>
<td>13.87; -11.17</td>
<td>Mining method unknown: Ore is with the element from a distinct mineral phase</td>
</tr>
<tr>
<td>Early Cretaceous,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gypsum &amp; arsinite-bearing sediments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Potential = Production + reserves + resources.

Ores are assumed to be the sources rocks of Cenozoic alluvial-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 Miocene sandstones of Lower and Upper Katarapt age and with the "Formation des Cirques" (Upper Queloi). In Chad this cover developed from the Upper Pliocene to the Quaternary and overlies Paleocene and Maestrichtian 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 granitoids and syenite ring-complexes; recent and active alkaline volcanism such as Mount Cameroon and Lake Nyos).
Table 11
Major carbon-bearing Mesozoic mining districts of Central Africa

<table>
<thead>
<tr>
<th>Name of district, country, age, host rock</th>
<th>Commodity, Location</th>
<th>Potential (ton metal @ grade) Class of deposit</th>
<th>Ore deposit type, and shape</th>
<th>One and host-rock mineralogy</th>
<th>Long, Lat</th>
<th>Exploitation type, ore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kalawe, ZM, Copperbelt</td>
<td>Ni, (Phos.) phones</td>
<td>Nb: ca. 1,000,000, A</td>
<td>Precipitate, apatite, magnesite, iron oxides, calcite, phlogopite</td>
<td>30.02 14.10</td>
<td>Mining method unknown. Primary oxide ore, pyrophosphate</td>
<td></td>
</tr>
<tr>
<td>Bailundo, AGG, Mosaic</td>
<td>Fe, (Barte, Phone REE, Th)</td>
<td>Fe ca. 62,000,000, C</td>
<td>Carbonate-hosted ore deposits. Alluvial to eolian placers. Precambrian urigenous of disseminated ore placers</td>
<td>Magnetite, apatite, marcasite, limonite, pyrites, muscovite, baryte, iron oxides, coronal fluorite</td>
<td>15.98 12.34</td>
<td>Unworked</td>
</tr>
<tr>
<td>Talenda, AGG, Mosaic</td>
<td>Fazrite phones</td>
<td>Fl ca. 2,300,000, b</td>
<td>Carbonate-hosted ore deposits. Dissolved envelope of disseminated ore placers</td>
<td>Fluorite, baryte, pyritic, apatite, magnesite, pyrites, calcite, dolomite, carbonates, quartz</td>
<td>13.87 14.00</td>
<td>Unworked, Fluorite</td>
</tr>
<tr>
<td>Bonga, AGG, Mosaic</td>
<td>Nb, (Phos.) phones</td>
<td>Nb: ca. 14,000, C</td>
<td>Carbonate-hosted ore deposits. Dissolved envelope of disseminated ore placers</td>
<td>Precipitate, anatase, rutile, magnetite</td>
<td>13.97 14.26</td>
<td>Unworked. Ore in which the element forms a distinct mineral phase</td>
</tr>
</tbody>
</table>

Potential = Production + reserves + resources.

Table 12
Paleozoic to Mesozoic major coal basins of Central Africa

<table>
<thead>
<tr>
<th>Name of district, country, age, host-rock</th>
<th>Commodity, Location</th>
<th>Potential (ton metal @ grade) Class of deposit</th>
<th>Ore deposit type, and shape</th>
<th>One and host-rock mineralogy</th>
<th>Long, Lat</th>
<th>Exploitation type, ore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lukuga, DRC, Palaeozoic</td>
<td>Coal, Upper Lukanga, Coal (interbedded coal, anhydrite, graphite), slate, shales.</td>
<td>Coal deposits type, Stratiform lens of coal to subbituminous coal.</td>
<td>Coal deposits type, Stratiform lens of coal to subbituminous coal.</td>
<td>Coal deposits type, Stratiform lens of coal to subbituminous coal.</td>
<td>29.58 5.16</td>
<td>Mining method unknown. Coal ore</td>
</tr>
</tbody>
</table>

Potential = Production + reserves + resources.

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

- Residual deposits: copper–nickel marcasite with a potential of 3,000,000,000 tons, Nguiguul, and Fongolo Tonga in CMR (Nep Gweth, 2001), Kony in COG. Co–Ni–Lithium-related at Konje, CMR.
- Secondary enrichment: Fe in Copperbelt DRC (Itungo, DRC; Zanga, COG; and Bilinga, Gabon). Mn in the Messulian deposit, Phos–Ni–REE in carbonates at Maloua, Gabon, Nb–phosphates in Gabon, and at Lunda and Bongol in DRC. Sr–Ti in pegmatites in the Eastern DRC–Kibara province (dia-sis alteration of pegmatites also plays a major role for Sn and Ti by 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 Kitahu, DRC and M’Paxta, COG.

* Lateitic profiles (Paleogene to Quaternary) are developed in the tropics (e.g. CAV, central CMR and AGG), but incomplete, truncated profiles occur in equatorial areas (e.g., south COG).

* Quaternary alluvial–diluvial deposits (alluvium, sands, and gravels) have formed along river valleys or depressions.

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

7.7 Metallurgy

The Cenozoic sedimentary covers host various mineral and energy resources. Numerous deposits are controlled by Cenozoic mechanical and chemical processes, such as lateitic, alluvial–diluvial or coastal phenomena. These processes are, in many respects, responsible for the enrichment and economic concentration of pre-Cenozoic mineralisation.
Table 3
Cenozoic and Mesozoic selected diamond fields of Central Africa

<table>
<thead>
<tr>
<th>Name of district, country, age, host rocks</th>
<th>Country</th>
<th>Potential (carats), Class of deposit</th>
<th>Ore deposit type and shape</th>
<th>Ore and host-rock mineralogy</th>
<th>Long, Lat.</th>
<th>Exploitation type; ore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kassai Province, including Mbay-Mayi Mine, DRC; Ubangi, eastern Kasai; Wasseio, Upper Osteocoma (ca 75 Ma), Kimberlite, Mandjel conglomerate (&quot;Poundage&quot;), Sandstone</td>
<td>Diam.</td>
<td>Mbay-Mayi ca 640,000,000, A</td>
<td>Diamondiferous kimberlites, pipe, placer and placer. Envelope of diamondiferous ore in pipe, placer</td>
<td>Diamond, lomine, titanomagnetite, pyrope, dohpide</td>
<td>Mbay-Mayi 21°46'-6.68' Open pit mining One in which the native element is free or in fines (recoverable by gravity) Alluvial mining</td>
<td></td>
</tr>
<tr>
<td>Cameroonias, Camacopia, Catac, AOG</td>
<td>Diam.</td>
<td>Cameroonias ca 17,500,000, B</td>
<td>Diamondiferous kimberlites, envelope of diamondiferous ore in pipe</td>
<td>Diamond, lomine, titanomagnetite, pyrope, dophide</td>
<td>Camacopia 26°52'; -8.45 Open use and underground mining Native element ore</td>
<td></td>
</tr>
<tr>
<td>Early Osteocoma, Kimberlite, tuff, argillite</td>
<td></td>
<td>Catac ca 41,000,000, B</td>
<td></td>
<td></td>
<td>Catac 25°29'; -9.38</td>
<td></td>
</tr>
<tr>
<td>Tshikapa DRC Cenozoic (Mesozoic)</td>
<td>Diam.</td>
<td>Chrysoberyl 70,000,000, B</td>
<td>Diamond, Chrysoberyl, lomine, titanomagnetite, pyrope, dophide, zincolite, tourmaline, gilbertite, quartz, bastite, epide, coronand</td>
<td>26°58'; -6.54 Alluvial mining Native element ore</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kassai &amp; Lobendo (Lubango, Maiungu, Tshikapa, Lieuna, Lubu, Lubu), 3000 km², kimberlite and placers fromMesozoic host</td>
<td>Diam.</td>
<td>B60-80% gneisses, 40% xenoliths, 26.2% gneiss, 10% gneiss Chrysoberyl, C</td>
<td>Diamond placer. Alluvial placer. Alluvial placer</td>
<td>Tshikapa, Chrysoberyl, lomine, titanomagnetite, pyrope, dophide, zincolite, tourmaline, gilbertite, quartz, bastite, epide, coronand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Western and eastern districts, Cahora Bassa</td>
<td>Diam.</td>
<td>&gt;50,000,000, B</td>
<td>Alluvial placer from unknown source (suggested Paleozoic or Mesozoic sediments)</td>
<td>Diamond, gold 16°; 55 Alluvial mining</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Potential = Production + reserves + resources.

- Au, diamond, rutile, Sn alluvial–eluvial or coastal placers: numerous placer-type deposits (inland placer, heavy minerals-bearing beach sand coastal deposits) are linked to secondary alluvial concentrations 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, Lulua, Moto district, Namoya and Twangiza areas, etc. in DRC; Bétaré-Oya and Kambélé zones, Central Cameroon Field in CMR; Romdji district in CAF; Béké, Mitck and N’Dangui districts, etc. in GAB.
  (ii) Diamond: Mbay-Mayi, Tshikapa district, Kassai basin, Bokwanga in DRC; Luanga-Malange and Casamance, in AOG; Kotto river, Sanga, Lobaye and Mambéré basins in CAF.
  (iii) Tin (assimilation: Mayo Darli in CMR; Buzanga, Kaboung, Putsa, Kadu district, Waleka and Mumba in DRC; Mubamba in COG; Somwika W placer in DRC.
  (iv) Titanium minerals (ilmenite, rutile); numerous deposits in CMR, including Edea-Kribi beach-sand deposits; Dubreuil and Nanga-Eboke placers, rutile-bearing placers that are the most interesting for Ti beneficiation in the Alomondingu world-class deposit at Yo and Dju; and the rutile–lynite-bearing Otélé placer. Titanium minerals also occur in the Poco, Chitato and Change deposits in AOG.

- 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, Kasamay, 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 mineralogical 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
focuses on the spatial and temporal distribution of selected mineral deposits.

The examination of this simplified map and the analysis of the 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-Zaire" Archean to the Mesoproterozoic metallogenic province, and in particular the PGE belt of DRC (Lubero district)-Uganda-Burundi-Tanzania, and (iii) the age of mineralized carbonatites, pegmatites and granitoids.

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References


