Compilation of West African mineral deposits: Spatial distribution and mineral endowment

Vanessa Markwitz^{a,*}, Kim A.A. Hein^{b,1}, John Miller^c

^a School of Earth and Environment, The University of Western Australia, M004, Crawley, WA 6009, Australia

^b School of Geosciences, University of the Witwatersrand Johannesburg, PBag 3, WITS 2050, South Africa

^c Centre for Exploration Targeting, School of Earth and Environment, The University of Western Australia, Crawley, WA 6009, Australia

Article history:

Received 15 December 2014

Received in revised form 22 April 2015 Accepted 19 May 2015

Available online xxx

Keywords:

West African geology and metallogeny West African Mineral Deposit Database Metal endowment

Frequency distribution of West African mineral deposits

* Corresponding author. Tel.: +61 8 6488 1894.

E-mail addresses: vanessa.markwitz@research.uwa.edu.au (V. Markwitz), kim.ncube-hein@wits.ac.za (K.A.A. Hein), john.miller@uwa.edu.au (J. Miller).

¹ Tel.: +27 11 717 6623.

The West African Craton is highly endowed in minerals, and their spatial and temporal distribution varies from single to multi-phase mineralization events. They are broadly related to three major tectono-metallogenic elements and formed during distinct mineral epochs: (1) In both Archean Shields (Kénéma-Man and Reguibat) and Paleoproterozoic domains (Baoulé-Mossi, Eglab). These are characterized by giant iron ore deposits that formed between ca. 2.5–2.3 Ga, nearly all gold, porphyry copper, lead–zinc and sedimentary manganese ore that developed between 2.2 and 2.1 Ga, and primary diamonds that formed between two intervals at ca. 2.2–2.0 Ga and in the Mesozoic. (2) Across Pan-African and Variscan belts. These are distinguished by major Precambrian IOCG's, copper–gold that formed at ca.

2.1 Ga and approximately 680 Ma, and Neoproterozoic sedimentary iron ore and phosphate deposits. (3) Within intracratonic and coastal basins. These include the development of Cenozoic lateritic bauxites over Mesozoic dolerites, Tertiary/Quaternary mineral sands deposits, oolitic iron ore and sedimentary phosphate deposits. Geological, spatial and temporal correlations using the multi-commodity West African Mineral Deposit Database highlight that gold and non-gold commodities formed in multiple phases. This commenced in the Liberian Orogeny (2.9–2.8 Ga) with the enrichment of iron ore, nickel sulphides, diamonds and gold in the earth's crust. The pre-Eburnean or Tangaeen–EoEburnean–Eburnean I Event yielded gold, and the major Eburnean Orogeny yielded gold, iron ore, manganese, diamonds, magmatic nickel sulphides, copper–gold, lead–zinc, and REE minerals. Throughout the Pan-African event sedimentary manganese deposits, lead–zinc, REE minerals, sedimentary phosphates, and again gold were formed. Primary diamonds and magmatic nickel sulphides are related to the break-up of Gondwana, followed by an intense lateritic weathering period that formed bauxite deposits along the craton margin.

1. Introduction

Over the last two decades West Africa has become a focus for mineral exploration and exploitation with world-class resources of gold, iron ore, diamonds, bauxite, phosphate, uranium and other commodities. The majority of these deposits are situated in the vast West African craton, and are hosted within basement rocks, along the margins of the craton, or are situated in intracratonic and coastal basins (Fig. 1). Exploration activities are mostly limited to gold in greenstone and volcano-sedimentary belts, iron ore related to Archean BIF (Banded Iron Formation), and IOCGs (Iron Oxide Copper Gold) and VMS (Volcanogenic Massive Sulphide) deposits.

The geology of the craton is generally composed of Archean to Paleoproterozoic crystalline and volcanoclastic basement rocks that are unconformably overlain by Paleoproterozoic volcanosedimentary sequences and these in turn intruded by TTG granitoids and granites.

Over the last 30 years, the number of gold discoveries has exceeded all other commodity types by volume with economic gold deposits discovered, delineated and developed in Mali, Mauritania, Senegal, Burkina Faso, Ghana and Cote d'Ivoire.

The focus of this paper is to provide a geological overview of the West African Craton, including the tectonic evolution and mineral endowment of the craton based on the updated West African

Mineral Deposit Database (WAMDD). This unique database was produced between 2010 and 2013 by compiling available geological and resource data for the West African Craton and included 441 mineral deposits. We also used the data compilation to produce a time–space diagram for the economically significant West African mineral deposits to illustrate the temporal and spatial distribution of mineral deposits, and to provide key formation controls for the main exploited commodities.

2. Geological overview of the West African Craton

The West African craton is one of the largest cratons on the African continent with a lithosphere that is between 150 and 200 km thick (Roussel and Lesquer, 1991) (Fig. 1). It is composed of Archean and Paleoproterozoic rocks that crop out over an area of approximately 4.5 million km². The craton consists of two Archean domains; the Reguibat Shield (first described by Menchikoff, 1949) in the north and Kénéma-Man domain in the south. In both shields the western portion consists of Archean rocks that are separated from Paleoproterozoic rocks in the east by major shear zones. The western boundaries of both Archean Shields are defined by major regional thrust systems of Pan-African and Variscan age in the Mauritanian belt, and Pan-African age in the Rokelides (Schlüter and Trauth, 2008). The Shields are separated by the intracratonic Neoproterozoic to Paleozoic Taoudeni basin and surrounded by Pan-African (660–550 Ma) and Variscan (~330 Ma) orogenic belts. They are flanked by coastal basins related to Mesozoic to Cenozoic Atlantic rifting.

The two shields, Kénéma-Man and Reguibat, have similar ages of crustal formation and tectonic overprint, and were affected by at least three major tectono-thermal events: (1) the 3.5–2.9 Ga Leonean Orogeny (Morel, 1979); (2) the 2.9–2.8 Ga Liberian Orogeny (Bering et al., 1998; Goujou et al., 1999; Thiéblemont et al., 2001; Egal et al., 2002) and (3) the 2.15–1.8 Ga Eburnean

Orogeny (Caen-Vachette, 1986; Kusnir, 1999; Feybesse et al., 2006). The Eburnean Orogeny is associated with significant gold mineralization in Paleoproterozoic greenstone belts. These belts host metamorphosed volcanic, volcano-sedimentary and sedimentary rocks of the Birimian Supergroup, as described from studies in Ghana and Burkina Faso by Attoh (1982), Eisenlohr (1989), Feybesse et al. (1990), Hein et al. (2004), Tshibubudze et al. (2009), Baratoux et al. (2011) and craton-wide studies by Milési et al. (1989), Abouchami et al. (1990) and Boher et al. (1992). Basins such as the Taoudeni, Volta, Bové, and Tindouf formed during the Neoproterozoic to Paleozoic (Fig. 1). During the Pan-African Orogeny at approximately 650–500 Ma, the Rokelide, Dahomeyan, and Pharusian orogenic belts were formed (e.g., Thorman, 1976; Cluver and Williams, 1979; Black, 1980; Villeneuve and Cornee, 1994; Attoh et al., 1997; Villeneuve, 2005). The southern part of the craton experienced two major glaciation recorded in the late Precambrian and late Ordovician, observed from the Tindouf, Taoudeni and Volta basins (Deynoux et al., 1985 and references therein; Ghienne, 2003). Extensional tectonics associated with the fragmentation of the Gondwana continent affected large parts of the craton. Swarms of dolerite dykes and sills intruded the southern part of the West African Craton during continental breakup and emplacement of the Central Atlantic Magmatic Complex (CAMP), and some dykes are overlain by the Taoudeni basin (pre-CAMP) (Marzoli et al., 1999; Bertrand et al., 2014). The emplacement of kimberlites took place probably during the Neoproterozoic (Chirico et al., 2010, 2014), but can also be of an Early Cretaceous age (Rombouts, 1987), and produced major diamond resources. Long periods of erosion were associated with the

formation of vast bauxite resources during the Cretaceous and Cenozoic and formation of the Iullemeden Basin on the south-eastern margin of the craton (Moody and Sutcliffe, 1991). During prolonged laterization, phosphate deposits developed at low latitude locations on continental shelf and shallow marine locations.

2.1. Precambrian shields

The Reguibat Shield is bounded in the north by the Tindouf basin and the Pan-African age Anti-Atlas, in the east by the Taoudeni basin, and in the west by the Variscan Mauritanian Fold Belt. It can be divided into two age specific domains, namely the western Archean domain, and the eastern Paleoproterozoic Yetti and Eglab sub-domains (Sougy, 1961), with the latter often referred to as the Eglab Shield. The boundary between the Archean and Paleoproterozoic domains is characterized by a series of regional thrusts (Fig. 1). The Yetti sub-domain comprises strongly folded volcano-sedimentary sequences that are intruded by granites, and the Eglab sub-domain by large undeformed and metamorphosed granitoids and felsic volcanic rocks of the Eglab Series (Peucat et al., 2005; and references therein). They were accreted, developed as a passive margin, and later deformed by the Eburnean Orogeny during eastward subduction of the craton (Tokarski, 1991). Archean and Paleoproterozoic rocks were unconformably overlain by postEburnean sedimentary cover of the Guelb el Hadid sequence, and Mesoproterozoic to Paleozoic sedimentary rocks (Bessoles, 1977; Black, 1980; Clauer et al., 1982).

In contrast, the Archean Kénéma-Man domain stretches across Sierra Leone, Liberia and Guinea, and is a typical granite–greenstone terrain. It consists of ~3.44 Ga layered TTG (tonalite–trondhjemite–granodiorite) gneiss and supracrustal rocks containing greenstone sequences that are interpreted as parts of an ancient continental nucleus similar to the Archean domain of the Reguibat Shield. The margins of the greenstone sequences were intruded by 2.73–2.78 Ga granites, and ultramafic to mafic igneous intrusions (Barth et al., 2002). These rocks were deformed and reworked during the Leonean (3.5–2.9 Ga) and Liberian (2.9–2.8 Ga) orogenies and mafic igneous suites consisting of volcanic greenstone sequences, BIF and mafic igneous suites were deposited (Beckinsale et al., 1980; see Table 1 and Fig. 2). Subsequent to the Leonean Orogeny, the Archean rocks of the Kénéma-Man domain were cratonized except in the eastern part which was intruded by Eburnean age granitoids.

2.2. Paleoproterozoic Baoulé-Mossi domain (including Kédougou-Kéniéba Inlier)

The Paleoproterozoic terrane in the southern part of West African Craton is strongly mineralized in various economically important commodities and therefore described in more detail. The terrane consists of the Baoulé-Mossi domain (Bessoles, 1977), the Kédougou-Kéniéba, Kayes and Ansongo inliers comprising relicts of Archean rocks in a granite–greenstone terrane. These domains are composed of Paleoproterozoic volcano-sedimentary sequences that underwent reworking during the Eburnean Orogeny (Hirdes et al., 1996; Peucat et al., 2005). Basement rocks contain linear volcano-sedimentary and volcano-plutonic greenstone belts. Above a mapable unconformity

Tarkwa-type sedimentary sequences were deposited between 2133 and 2097 Ma (Taylor et al., 1988, 1992; Abouchami et al., 1990; Leube et al., 1990; Liégeois et al., 1991; Boher et al., 1992; Hirdes et al., 1992; Pigois et al., 2003) in an intracontinental rift setting (Hastings, 1982). Large volumes of Eburnean granitoids were intruded between

2.18 and 2.07 Ga across the Baoulé-Mossi domain. Birimian supracrustal rocks and granitoids were affected by the Eburnean Orogeny resulting in thrusting and isoclinal folding, and greenschist to amphibolite facies metamorphism (Leube et al., 1990; Taylor et al., 1992; Hirdes and Davis, 1998). Several Eburnean tectonic phases that shaped the greenstone belts are well described by authors such as Bonhomme (1962), Ledru et al. (1989, 1991), Leube et al. (1990), Milési et al. (1992) and Feybesse et al. (2006), and are correlated to significant mineralization processes across the West African Craton (Table 1).

The diverse structural architecture of Birimian greenstone belts is recognized in the Baoulé-Mossi domain. Greenstone belts are linear in form and metamorphosed to lower greenschist to amphibolite facies depending on the distance from granitoid intrusions.

Numerous studies of the Eburnean granitoids indicate they were emplaced at 2178–2176 Ma (U–Pb) in the Ghanaian Ashanti Belt (Hirdes et al., 1992), 2090–2070 Ma in eastern Guinea (Egal et al., 2002), 2076 ± 16 Ma in the Mauritanian Eglab Shield (Peucat et al., 2005), 2160–2080 Ma in the Kédougou-Kéniéba Inlier in Senegal and Mali (Dioh et al., 2006), and 2181–2117 Ma in northeast Burkina Faso (Tapsoba et al., 2013). The Eburnean granitoids are typical ovoid in form or composite batholiths that constitute ca. 70% of the Birimian terrane, ranging in composition from TTGs to leucogranites (Hirdes et al., 1992). Some of the granitoids crosscut the volcanic belts, whereas others intrude the Paleoproterozoic basins or older gneissic complexes. After 2.0 Ga primary diamond deposits occur in kimberlitic pipes and dykes, located mainly in the Archean Kénéma-Man domain, underlain by granitoids and gneisses (Chirico et al., 2014).

The Kédougou-Kéniéba Inlier (Fig. 1) crops out over 16,000 km²

in Senegal and Mali, and is interpreted as the product of accretion of north-easterly trending Birimian age volcanic terrains that were intruded by calc-alkaline granites. Birimian supracrustal rock sequences are unconformably overlain by Neoproterozoic and Cambrian continental to glacial sedimentary rocks in the east and three major tectonic events have been defined similar to those in the Baoulé-Mossi terrane (Leube et al., 1990; Ledru et al., 1991; Milési et al., 1992).

2.3. Pan-African to Variscan belts

The West African Craton is bounded by Pan-African and Variscan age belts (Fig. 1). The belts are largely overlain by Paleozoic to Cenozoic sediments of intracratonic and coastal basins. During Pan-African (660–650 Ma), Caledonian (~490–390 Ma), and Variscan-aged (~330 Ma) orogenic cycles the Pan-African and Variscan belts were thrust onto Archean/Paleoproterozoic rocks of the West African Craton (Thorman, 1976; Cluver and Williams, 1979; Villeneuve, 1984). The Mauritanian belt (Sougy, 1962) is the only fold-thrust belt that was affected by all three orogenic cycles, whereas all other belts display only Pan-African structures, including the Bassaride fold belt (Villeneuve, 1984),

the Rokelide belt (550–500 Ma; Allen, 1968), the Dahomeyan (610–570 Ma; Attoh et al., 1997), the Pharusian belts (~600 Ma; Caby, 1970) and the Anti-Atlas (Ennih and Liégeois, 2001).

2.4. Intracratonic and coastal basins

The intracratonic and coastal basins of West Africa formed after long periods of erosion (Fig. 1). Sedimentary sequences range in age from Neoproterozoic to Paleozoic and are subdivided according to distinctive stratigraphy and geographical locations. This includes the intracratonic Taoudeni basin, and surrounding Bové, Volta, and Tindouf basins (Lecorche et al., 1991). Sediments are generally undeformed and unmetamorphosed. However, basin margins were locally deformed during Pan-African and Variscan orogenies.

The intracratonic Taoudeni basin covers the central part of West African Craton (over 2 million km²) and separates the Man (including Baoulé-Mossi domain) from the Reguibat Shield. The Taoudeni basin comprises Neoproterozoic to Devonian-Carboniferous sedimentary rocks to Recent cover sediments (Deynoux et al., 1985; Shields et al., 2007a,b; Rooney et al., 2010 and references therein; Huneau et al., 2011). The onset of sedimentation occurred between 1100 and 1000 Ma. Sedimentary sequences are in general flat lying and not metamorphosed. They comprise continental to shallow marine sedimentary rocks. The Taoudeni basin can be subdivided into several sub-basins or troughs with different structural development and sedimentation (Villeneuve and Corneé, 1994). Sedimentary sequences of the Taoudeni basin vary in thickness but do not exceed 4 km (in average less than 3 km) The sequences were

weakly affected by the Pan-African/Variscan orogenies resulting in the development of low angular unconformities and reactivated basement faults (Deynoux, 1982). Permian/Jurassic doleritic dykes and Proterozoic/Cretaceous kimberlitic pipes intruded both basement and sedimentary sequences of the Taoudeni basin (Kusnir, 1999).

The Bové basin, located in Guinea and Guinea Bissau, is an extension of the Taoudeni basin and contains Neoproterozoic to Cretaceous continental sediments which continue westwards beneath the younger Senegal–Mauritania basin. A major basin controlling, NW-trending Pan-African fault transects the basin and controls the synformal basin architecture (Ritz and Bellion, 1988).

The Volta basin is located between the Baoulé-Mossi domain and Pan-African Dahomeyan belt. It covers an area of approximately 400,000 km² extending from Ghana, Togo, and Burkina Faso to Niger. It is positioned near the south-eastern margin of the craton and contains Mesozoic Neoproterozoic and Paleozoic epi-continental, marine, and molasse sedimentary rocks that unconformably overlies the Birimian basement. They represent the evolution from a cratonic basin or passive margin that was inverted at approximately 570 Ma during the PanAfrican-Dahomeyan orogen to become a foreland basin (Affaton et al., 1991; Porter et al., 2004; Nédélec et al., 2007).

At the northern margin of the Reguibat Shield lies the Tindouf basin (Gevin, 1960) stretching east–west for 800 km from the Western Sahara and Mauritania to Algeria. The basin contains largely undeformed Paleozoic to Mesozoic sedimentary sequences that were deposited in a passive margin setting (Cavaroc et al., 1976; Guerrak, 1989; Villeneuve, 2005). Burkhard et al. (2006) proposed that the Anti-Atlas could be the deformed northern part of the Tindouf Basin.

The Senegal–Mauritanian coastal basin (SMCB) is considered as one of the largest Atlantic coastal sedimentary basins in West Africa and covers an area of ca. 340,000 km². It extends from north-western Mauritania to southwest Guinea-Bissau. The basin contains Mesozoic to Cenozoic sedimentary sequences that are related to the formation of the Mesozoic Atlantic rifted passive margin (Pitman and Talwani, 1972) with a thin Oligocene to Recent sub-horizontal sandy cover sequence. However, the presence of the volcanic rocks in the Dakar region indicates that magmatic activity, with concomitant extensional north–south trending fault–fracture formation, occurred during the break-up of Gondwana in the Jurassic (Dewey et al., 1973).

3. Regional metallogeny of the West African Craton

The West African Craton is host to a diversity of mineral commodities. Many are clustered in highly endowed metallogenic provinces that have been affected by discrete orogenic events (Fig. 2). The most metal endowed regions are the Paleoproterozoic Baoulé-Mossi domain, Archean Kénéma-Man domain and Kédougou-Kéniéba Inlier in the southern part of the craton. They are known to host world-class gold deposits, important diamond and iron ore concentrations, and nickel, manganese, uranium, lead–zinc, bauxite, antimony, and columbite–tantalite mineralization (Fig. 1 and Table 1). The majority of orogenic gold deposits formed during the Eburnean Orogeny, but there are a number in Ghana, Burkina Faso and Mali that formed before the Eburnean Orogeny (Tangaeen event) during a period of arc–backarc formation (Tshibubudze et al., 2009; Hein, 2010; de Kock et al., 2012; Fig. 2).

In the northern part of the West African Craton, mineral deposits are scattered throughout Paleoproterozoic rocks of the Reguibat Shield, with the potential for primary sources of diamonds close to the Junction Zone that separates the Yetti from the Eglab subdomain (Kahoui et al., 2008), and gold (Conchita Florence deposit) and copper in the Yetti sub-domain (Fig. 1). Mineralization is associated with NW–SE trending regional shear zones; the Reguibat Shield has been subjected to four deformation periods, including intense thrusting during the Pan-African and Variscan orogenies. Archean rocks of the Reguibat shield host world-class iron ore and a number of gold deposits. Furthermore, phosphate deposits are developed along the northern margin of the Taoudeni basin.

Additionally, layered mafic intrusions were formed during the Pan-African Orogeny, carrying significant chromite, zinc and platinum ore into Neoproterozoic rocks. Younger Pan-African orogens host important deposits of copper–gold, mineral sands, iron ore, bauxite, lead–zinc, chromite, nickel–cobalt, diamonds and gold. The distribution of these mineral deposits is broadly spaced.

Sedimentary copper mineralization was developed in ferruginous sandstones in the Paleozoic. During the break-up of Gondwana, kimberlite dykes intruded the Archean basement of the Man shield and produced significant primary diamond deposits in Guinea, Liberia and Sierra Leone (Rombouts, 1987). Large magmatic complexes that intruded during the Cretaceous period along the craton margin may be related to the break-up, and are associated with platinum mineralization in layered intrusions in the Freetown Inlier (Sierra Leone and Liberia) and nickel–copper mineralization in the Mount Kakoulima complex (southern Guinea, Kindia region, 50 km northeast of Conakry). An erosional event that extended into the Tertiary was associated with tropical weathering and formation of iron, manganese and bauxite lateritic duricrusts, as well as oolitic ironstones, and zinc and copper gossans. Undeformed and flat-lying Tertiary phosphates also formed at this time. Large

diamond placer deposits formed over Archean rocks of the Kénéma-Man craton, especially in Sierra Leone (Table 1).

3.1. West African Mineral Deposit Database (WAMDD)

The multi-commodity WAMDD (provided as an appendix) was compiled from published scientific journals and books, published databases (SIGAfrique by Milési et al., 2004; ACP mining databank website, 2014), company reports and company websites. Critical insights obtained from this database have been integrated into this review of the mineral deposits in West Africa.

The WAMDD has a total of 442 mineral deposits covering 18 commodities in 11 countries (Fig. 1 and Table 2). The database contains 77 mineral deposits in Guinea, 69 in Ghana, 62 in Burkina Faso, 43 in Cote d'Ivoire, 35 in Mali, 28 in Liberia, 27 in Mauritania, 24 each in Senegal and Sierra Leone, 19 in Niger, and 13 in Togo. Descriptions of the deposits include deposit name, general geologic and geographic location, commodity, status of exploration, deposit type, metallogeny, current owner/operator, host rocks, metamorphic grade, geometric and kinematic controls, alteration, geochronological age and method, resource and reserve, and past production. The data quality and accuracy varies from poor to very good in relation to geological and geographical data. In general, descriptions of gold deposits are well documented, but data quality varies for iron ore, chromium, bauxite, manganese, and diamond deposits.

The main commodities in West Africa are (1) gold as orogenic, intrusion-related, skarn-hosted, porphyry-hosted, paleoplacer, and within IOCG deposits; (2) iron ore as sedimentary-BIF, skarn-hosted, oolitic ironstones, lateritic duricrusts, and intrusion-related deposits; (3) lateritic bauxite; (4) diamonds as kimberlites pipes or placers; (5) base metals and REE as intrusion-related, laterite, unconformity-related, orogenic and sedimentary; (6) sedimentary phosphate, and (7) sedimentary manganese deposits.

The following commodity descriptions are based on the WAMDD.

3.1.1. Gold/copper–gold

Native gold in association with silver, copper, lead and zinc is the most commercially exploited commodity in West Africa. Gold as free grains is also mined across the West African Craton from artisanal mines in bedrock and also recent alluvial deposits. In the WAMDD, one hundred and ninety eight (198) gold deposits are included (Table 2). Mesothermal gold mineralization in the Birimian Supergroup occurs as two main types, namely quartz vein-hosted and disseminated sulphide type (Leube et al., 1990; Lesquer et al., 1991; Béziat et al., 2008), and most developed between 2.2 and 1.8 Ga. Of these, orogenic gold deposits formed between 2.2 and

2.0 Ga, intrusion-related (and skarn) between 2.2 and 2.1 Ga, and paleoplacer types between 2.06 and 1.8 Ga. There are also examples of atypical major supergene gold deposits such as Yatela, which has been correlated with glacial formation on the West African craton during the Miocene–Eocene epochs (Matsheka and Hein, 2011; Fig. 1). Furthermore, gold mineralization is also known from the Archean of Sierra Leone and Liberia dating to 2.9 Ga (Foster and Piper, 1993). The youngest in situ recognized gold phase occurs in the Pan-African Dahomeyan belt of Togo.

3.1.1.1. Orogenic, skarn-hosted and intrusion-related gold deposits. Orogenic gold in West Africa is hosted in a range of rock types including mafic-hosted (both intrusive and extrusive units), granitoid-hosted, sediment-hosted, carbonate-hosted, and BIF-hosted (Fig. 3). Orogenic gold in shear zones, commonly in quartz veins, is the dominant style of mineralization in West Africa. Intrusion-related deposits and skarn deposits are rarer and, with some exceptions, are also controversial with respect to an agreed genetic model. Generally gold mineralization is associated with greenschist metamorphosed terrains, and less commonly in lower amphibolite facies rocks. Most deposits are found in the Baoulé-Mossi domain and the Kédougou-Kéniéba Inlier and are spatially associated with shear zones. The shear zones commonly occur at the contact between Birimian metasedimentary and metavolcanic rocks (Kesse, 1985), with gold deposits expressing a significant degree of structural control (Béziat et al., 2008). Some gold mineralization is related to the pre-Eburnean metallogenesis (Tangaeen event) at approximately 2.19–2.15 Ga (Allibone et al., 2002; Tshibubudze et al., 2009; Hein, 2010; de Kock et al., 2012) which is observed in Ghana (e.g., Wassa), Burkina Faso (e.g., Kiaka, Essakane) and Mali (e.g., Morila). In the West African Craton the peak of mineralization was during the Eburnean Orogeny at approximately 2.15–2.10 Ga and produced very large (>10 Moz) gold deposits associated with regional northeast–southwest trending shear zones. Gold occurs as free grains associated with quartz and/or is hosted in sulphides (mainly pyrite and arsenopyrite) (Milési et al., 1989). Extensive hydrothermal alteration is observed throughout gold-rich areas, with carbonate–pyrite–chlorite–sericite alteration in meta-sedimentary rocks, actinolite–chlorite–quartz $\pm$ chalcopyrite $\pm$ albite $\pm$ (leucoxene) in mafic volcanics, and quartz–chlorite–sericite–epidote in felsic intrusives.

3.1.1.1.1. Kénéma-Man Domain Kénéma-Man domain. In the Archean Kénéma-Man domain of the West African Craton, most greenstone belts (and associated gold deposits) are poorly preserved due to deep erosion (Olade, 1980; Fig. 3). Bessoles (1977) attributed gold mineralization to deformation in the Liberian Orogeny (WAMDD; Fig. 2). The gold deposits are hosted in greenschist facies rocks of greenstone belts in Sierra Leone and Liberia, while high grade basement gneisses are barren (Fig. 3). However, gold mineralization is focussed along lithological contacts between greenstone belts and gneisses or granites, as can be observed in the Bea Mountain range of Liberia (Weaju deposit), and within Archean BIF's. Gold rarely occurs in first-order crustal scale shear zones, but is focussed in second and higher order shears (Foster and Piper, 1993).

In the largest greenstone belt of Sierra Leone, the Sula Kangari belt, orogenic gold mineralization is hosted in structurally controlled quartz–pyrite–arsenopyrite veins within banded iron formations and amphibolites (Foster and Piper, 1993). In the Baomahun deposit, gold is spatially associated with faults that were

generated during the northwest formation of thrusts. Similar styles of mineralization within identical host rocks occur in the Nimini greenstone belt, approximately 50 km east of Baomahun in the Komahun district (Fig. 1). At Komahun auriferous quartz veins containing sulphide–carbonate–

phlogopite/biotite are located at the contact of BIF with chlorite–garnet bearing amphibolitic schist. However, the contact is folded and overprinted by gold bearing northeast-trending shears and brecciated veins.

3.1.1.1.2. Baoulé-Mossi domain. Orogenic gold deposits occur extensively throughout the Baoulé-Mossi domain. These areas contain widespread Birimian metavolcanic and metasedimentary sequences and were intruded by granitoids. However, there are major variations in the relative volumes between volcanic rocks (broadly corresponding to greenstone belts in Fig. 3), sedimentary rocks and granitoids. In Burkina Faso, granitic intrusions are voluminous, representing between 70% and 80% of the entire Birimian outcrop (Béziat et al., 2008). In contrast, the Siguiri Basin is dominated by sediments with minor volcanic units and granitoids. This variation in rock types is reflected in major variations in the deposit host rock types ranging from sedimentary rocks, mafic dykes, volcanic rocks to granitoids. The granitoids intrude either greenstone belts or adjacent Paleoproterozoic basins throughout the Baoulé-Mossi domain and generally range in composition from diorite–granodiorite to granodiorite–granite.

Ghana. The largest known gold endowment in the West African Craton is in Ghana. The major gold camp in Ghana occurs along the contact between the Ashanti volcanic belt and turbidites of the Kumasi basin, termed the Ashanti Belt (Fig. 3). In the Ashanti belt, the shear zone hosted Obuasi deposit is by far the largest (~50 Moz) and extends over a strike length of 8 km. Obuasi's mineralization has been dated at 2.092 ± 10 Ma (Oberthür et al., 1998), similar to the 8 Moz Prestea deposit at 2.098 ± 10 Ma (Allibone et al., 2002). Most gold occurs as massive, laminated and brecciated quartz veins in turbidites, but gold is also associated with disseminated gold-bearing arsenopyrite in graphitic shear zones. In addition, disseminated gold-bearing sulphide bodies occur at Bogoso and in the Salman deposit. These orebodies host auriferous arsenopyrite and pyrite in metasedimentary rocks, and exhibit some relationship to shear zones and quartz veins (Milési et al., 1992; Mumin et al., 1994; Allibone et al., 2002).

A second zone of extensive gold mineralization in Ghana lies at the contact between the Sefwi greenstone belt and the Kumasi basin. One of the largest deposits in the belt, the ~30 Moz Bibiani gold mine, contains complex quartz vein systems with disseminated sulphide zones adjacent to brittle-ductile graphitic shears that formed during the Eburnean Orogeny (Allibone et al., 2002).

Disseminated and stockwork gold mineralization within granitoids has been documented, for example, at the Akrokerri, Ayankyerim, and Dokrupe granitoids in Ghana (Yao and Robb, 2000). At Anyankyerim, auriferous S-type granitoids are characterized by quartz veins and stockworks, and pervasive alteration zones that are dominated by pyrite and arsenopyrite. The largest of these intrusion-hosted deposits is the Subika in the Sefwi Belt. Notably, the gold mineralization along the Sefwi Belt extends into eastern Côte d'Ivoire.

Burkina Faso. Orogenic gold in Burkina Faso is associated with metavolcanic-sedimentary sequences of the north–northeast trending greenstone belts (e.g., Essakane, Kiaka, Taparko, Kalsaka, Fété Kolé) as well as at the contact between greenstones and granites (Goulago-Goren belt, Nyieme-Boromo belt). One of the

largest deposits is the ~4 Moz Essakane deposit in the OudalanGorouol greenstone belt in north-eastern Burkina Faso. Essakane has been described as syn-deformational and formed during the Eburnean Orogeny (Foster and Piper, 1993; Feybesse et al., 2006; Béziat et al., 2008; Tshibubudze and Hein, 2013). Gold occurs within quartz–carbonate stockwork veins in greenschist facies volcano-sedimentary sequences that were altered to sericite,

carbonate and silica with accessory albite, arsenopyrite and pyrite (Tshibubudze et al., 2009). Similar alteration patterns have been reported at the 4.3 Moz Kiaka orogenic gold deposit, and observed in metasedimentary rocks of the Tenkodogo greenstone belt (140 km southeast of Ouagadougou). The host rocks exhibit a broad alteration system, where gold is associated with pyrrhotite, pyrite and arsenopyrite (Volta Resources, 2011; WAMMD). Furthermore,

gold can be accompanied by considerable amounts of silver, as reported from the Taparko deposit (Au contains 10–14% Ag; Bourges et al., 1998; Reipas and Coutoure, 2008), which is located 200 km northeast of Ouagadougou in the southern Bouroum greenstone belt. At Taparko, gold mineralization in quartz–tourmaline veins is hosted in northwest and north-trending shear zones at the contact of metasedimentary rocks units and mafic volcanics (Vanin et al., 2004). Gold mineralization in association with pyrite–chalcopyrite–sphalerite–pyrrhotite–galena occurs as a field of sub-vertical quartz veins in 5–20 m wide brittle-ductile shear zone array (Bourges et al., 1998). Béziat et al. (2008) and Hein (2010) related formation of the Taparko deposit to synto late-stage deformation in the Eburnean Orogeny.

Mali. In southern Mali there is a range of deposit styles; these are both proximal and distal to large regional shear zones. For example, the 7.5 Moz Morila deposit (Randgold Resources, 2009) is hosted in highly deformed garnet-bearing sediments and is interpreted as an intrusion-related metamorphic deposit, enriched by surrounding gold-bearing metasedimentary rocks and greywackes. As summarized by McFarlane et al. (2011), the maximum age of the deposit is constrained at 2098–2091 Ma from local quartz–diorite, granodiorite, and leucogranite intrusions, with an absolute age for the mineralization at 2074 ± 14 Ma (U–Pb titanite). Gold occurs within polymineralic veins containing native bismuth, maldonite, aurostibite, rare tellurobismuthite, and löllingite. This is overprinted by disseminated arsenopyrite porphyroblasts that contains polygonal gold inclusions. In contrast to Morila, the ~5 Moz Syama gold deposit is associated with the regionally extensive Syama Shear Zone. The deposit is hosted within a tightly folded sequence of basalt, andesite, interbedded argillite and greywacke, black shale and andesitic–lamprophyric intrusions (Olson et al., 1992). The host stratigraphy is imbricated and over-turned with basalt the preferred host rock, but all units are mineralized. Whilst units with ductile fabrics are mineralized, the highest gold grades are linked to breccias and veinlet stock works. The veinlets comprising ankerite–quartz–albite are linked to high grade ore with 3–15% pyrite. Pyrite occurs as two phases, a very fine-grained disseminated phase, with a second coarser-grained euhedral phase (Olson et al., 1992). The Syama deposit lacks a large volume of quartz veining (in marked contrast to vein-hosted gold deposits such as Obuasi in Ghana).

Southern Mali also contains sheeted vein arrays developed around and within intrusions. Gold mineralization in the Kalana Gold Mine is predominantly hosted by metasediments adjacent to a diorite intrusion with a 1.5 Moz pit-contained mineable resource (Avnel Gold Mining Ltd, 2014). Low angle and flat dipping laminated quartz veins associated with pyrite and arsenopyrite occur within and also adjacent to the diorite. Sheeted vein hosted gold deposits also occur within Guinea, including the mafic extrusive hosted Kiniéro deposit and also the 7.8 Moz Siguiri deposit which is solely hosted within sediments of the Siguiri Basin. The Siguiri deposit is unusual due to the extensive amount of lateritization (compared to other deposits in West Africa) resulting in a large amount of oxides.

Cote d'Ivoire. An example of a skarn-type association is the Ity mine located in Cote d'Ivoire, which is hosted in a Paleoproterozoic inlier the Archean Kénéma-Man domain. The inlier is composed of Birimian metasedimentary that unconformably overlies the Archean basement. This deposit is hosted in Birimian meta-carbonates, adjacent to the Toulépleu-Ity tonalite (approximately 2.10 Ga (Pb–Pb); Kouamelan et al., 1997). Gold mineralization accumulated as secondary fracture fillings in a tectonic breccia zone with a resource grade of 3.45 g/t and a measured/indicated resource of 0.296 Moz (La Mancha, 2012).

3.1.1.1.3. Kédougou-Kéniéba Inlier (KKI). The Kédougou-Kéniéba Inlier is positioned between south-western Mali and eastern Senegal, and has a distinct style of gold mineralization due to the presence of an extensive sequence of carbonates, with some skarn-related gold mineralization.

In Senegal the Sabodala deposit is located on one of the splay faults off the NE–SW trending Main Transcurrent Shear Zone. The ore is hosted in the Paleoproterozoic Mako-Saboussire Supergroup comprising deformed and metamorphosed tholeiitic and alkaline lavas interbedded with volcanoclastic sediments and intruded by 'belt-type' granitoids (Marcoux and Milesi, 1993; Bourges et al., 1998). Sedimentary-hosted gold is associated with sulphides in quartz–tourmaline veins and as stratabound mineralization in tourmalinized sandstones.

In south-western Mali, gold mineralization is within shear zones proximal to the Senegalo-Malian Shear Zone, and is hosted by sandstones, shales and also carbonates. The sandstones and breccia sequences of the Dialé-Daléma Formation are host to the Loulo and P64 gold deposits, which comprise auriferous tourmalinized sandstones and shales. These sedimentary units can be up to 15 m thick and several kilometres long. The deposits are located adjacent to the regional northeast-trending Senegalo-Mali Shear Zone. Total mineral resources at Loulo were estimated in December 2013 at 7.7 Moz (4.6 g/t) and total reserves of 5.3 Moz (4.9 g/t) (Randgold Resources, 2013).

Another important gold deposit hosted predominantly in metacarbonates is Sadiola Hill (Boshoff et al., 1998; Matabane, 2008). Sadiola Hill is associated with a shear zone that plays off the main Senegalo–Malian Shear Zone. Gold resources were estimated in December 2012 of 3.19 Moz (at 1.7 g/t) and reserves 2.13 Moz (at

1.8 g/t; IAMGOLD, 2013). In addition, the Alamoutala skarn-hosted gold deposit is also hosted in carbonate rocks with the presence of magnetite and concentric zonation around a granodiorite. Alamoutala occurs in the same stratigraphic position as Sadiola Hill and has been referred to late orogenic contact-metasomatic skarns associated with microdiorite intrusions (Schwartz and Melcher, 2004).

3.1.1.1.4. Reguibat shield. The high-grade Archean terranes of the Reguibat Shield show little evidence of hydrothermal activity and significant gold mineralization is not yet known apart from the very large Tasiast deposit. Tasiast is located in the southwestern region of the Reguibat Shield within Archean rocks of the Aouéouat greenstone belt. In 2013, measured resources were estimated at 1.1 Moz (0.64 g/t) and proven reserves of 1.45 Moz (1.33 g/t; Kinross Gold Corporation, 2014). The Tasiast gold mine is situated within the north–south trending Tasiast-Piment structural corridor, which is structurally controlled by late, discrete faults and shears (Stuart, 2010). It is located in the apex of a shallow plunging anticline in the hangingwall of an adjacent major fault.

3.1.1.1.5. Pan-African Pharusian and Dahomeyan belts. Gold deposits exist along the border of the Ouzzal granulite Inlier and eastern part of the Pharusian belt in Algeria, and proximal to a regional north–south trending crustal-scale shear zone (Caby, 1996; Marignac et al., 1996). Gold at the Amesmesa and Tirek prospects occurs in quartz veins hosted by mylonites associated with

pyrite, galena, gold and sphalerite (Ferkous and Leblanc, 1995). The mineralization formed during the later stages of the Pan-African Orogeny at ~545 Ma (U–Pb; Semiani et al., 1995).

In the Pan-African Dahomeyan belt in Togo, gold mineralization is hosted in the structurally controlled Atacora Unit (or Togo Formation). The Atacora Unit comprises a series of gneiss, eclogite, granulite, schist, quartzite, and ultrabasic rocks. They may have their origin in an Archean foreland basement and underwent a complex metamorphic history from eclogite facies high temperatures/high pressures, subsequently to granulite, amphibolite and finally greenschist facies (Agbossoumonde et al., 2001). Orogenic gold is associated with disseminated pyrite–chalcopyrite–galena mineralization, and host rocks underwent albitization and tourmalinization (Guide pour l'investissement minier au Togo, 1995).

3.1.1.2. Paleoplacer/alluvial gold deposits. Paleoplacer gold mineralization is an important genetic gold type and contributes to the vast gold reserves in West Africa, especially in Ghana where it was first described in the Tarkwa district by Kesse (1985) (Fig. 3). Oxidized gold occurs in quartz-pebble meta-conglomerates horizons of the Birimian system in the Banket Series overlying the Kawere Series of the clastic sedimentary Tarkwaian Group within the Ashanti Belt. The Banket conglomerates host vein-quartz, quartzites and schist pebbles in a quartzite matrix, with hematite, ilmenite, magnetite and rutile as accessory minerals. Gold concentrations in the Banket Series are variable, with exploitable horizons in hematite-rich conglomerates and as free grains. Paleoplacer deposits in Ghana are the most significant gold resources after orogenic gold, including the 10.3 Moz Tarkwa and 3.4 Moz Damang deposits (Gold Fields, 2011), and the 6.6 Moz Iduapriem deposit (AngloGold Ashanti, 2012), all mined in the southern part of the Ashanti belt. In the Tarkwa deposits, gold grades are limited to two conglomerate horizons located close to the southern end of a northeast trending regional syncline. Gold in the Tarkwa reefs has been dated at $2.107\text{--}2.102 \pm 13$ Ga (Adadey et al., 2009; Perrouty et al., 2012).

Damang is a hydrothermal gold deposit that overprints paleoplacer gold within the Tarkwaian Formation (Marston et al., 1992; Pigois et al., 2003). As stated by Tunks et al. (2004), the majority of the current gold distribution is interpreted to be related to the formation of late-stage fault breccias, controlled by sub-horizontal extensional quartz vein systems. The later hydrothermal gold mineralization has been dated at 2060 ± 90 Ma (U–Pb; Pigois et al., 2003), or as suggested by White et al. (2014), ages of metamorphism, fluid flow and gold mineralization ranges from 2030 Ma to 1980 Ma.

Several small Tarkwa-type deposits also occur in Burkina Faso, for example the ~1.9 Moz Youga deposit in southeast Burkina Faso (Endeavour Mining, 2011), the 0.4 Moz Bondi deposit (Orezone Gold Corp, 2010), and the Intiedougou prospect. Gold mineralization at Bondi in the Houndé greenstone belt occurs in fault-breccias that are located within the north–northeast trending Bondi structural corridor, and associated splay faults (Buro, 2009). The Bondi structural corridor is defined by a shear zone hosted within auriferous Tarkwa-type metasedimentary rocks. Similar structural relationships apply to the Intiedougou deposit, which is also situated in the Houndé greenstone belt where Tarkwa-type rocks were deposited and deformed in narrow fault-bounded basins.

Less economically important, but wide-spread throughout the craton, are alluvial gold concentrations in modern river gravels which are derived from primary gold occurrences (for example Dunkwa deposit in Ghana). In addition, alluvial occurrences are known from the Dahomeyan mobile belt in Togo, where they originated from basic–ultrabasic rocks of the Atacora

Unit, or the pelitic sediments of the Buem Unit (Guide pour l'investissement minier au Togo, 1995). Also in the Archean of Liberia, small alluvial gold deposits have been traditionally mined, such as the River Cess and Swajuvlehn deposits. In the upper Yatela Main of the Yatela gold mine (~3.5 Moz; IAMGOLD, 2010), situated in the KédougouKéniéba Inlier in southwest Mali, detrital gold occurs in ferruginous sands, aeolian, clay and saprolite, that formed in part from the dissolution of mineralized carbonate sequences below the upper supergene/placer sequence.

3.1.1.3. Porphyry copper–gold, iron oxide copper gold (IOCG) deposits, and copper. Copper mineralization occurs as three deposit styles, namely, porphyry copper–gold in Cote d'Ivoire, Mauritania, Niger and Burkina Faso; IOCGs; and sandstone-hosted deposits in Mauritania.

Porphyry related copper–gold–molybdenite–silver deposits are characteristically low in copper grades (0.32% at Gaoua, 0.56% at Diénéméra, and 0.36% at Gongondy), along with low grade gold, silver and molybdenum. The deposits are developed around intrusive complexes, commonly as veins and hydrothermal breccias. The most significant deposits are at Gaoua, Gongondy, Goren and Diénéméra deposits. They are characterized by quartz–sulphide disseminated ore and discordant quartz veins, and in association with chlorite–sericite–epidote–carbonate–sulphide hydrothermal alteration. The porphyry copper–gold deposits are located along a north trending copper–gold corridor in the Boromo greenstone belt in southwestern Burkina Faso. Copper–gold mineralization is associated with diorites and diabases, and hosted in breccias where copper mineralization has been overprinted by a later orogenic gold event (Siebenaller et al., 2011). The fault-related Gaoua copper–gold deposit is associated with synto late-orogenic mineralization in the north-trending copper–gold porphyry corridor. At first, the orebody was formed at 2161 ± 23 Ma, and later overprinted by orogenic gold mineralization (Mignot et al., 2014). Gaoua is hosted at the contact of Paleoproterozoic diorite and andesite with typical assemblages of pyrite, chalcopyrite–covellite–galena, malachite, anhydrite, magnetite, and silver telluride in the host rocks.

The Kourki copper–molybdenite deposit in Niger is another example of this type of mineral deposit. In addition, porphyry copper–gold deposits are known from the northern part of the Pan-African Mauritanian belt in the Akjouit area, where northwest trending porphyry dykes intersect strongly metamorphosed volcano-sedimentary sequences (Martyn and Strickland, 2004; Villeneuve, 2005; Fig. 3).

Copper–gold mineralization in IOCG's is typically structurally controlled and contains significant volumes of breccias. IOCG's deposits are located close to the Proterozoic craton margin in the Pan-African Mauritania belt (Fig. 1) where they formed during the Paleoand Neoproterozoic. This belt hosts amphibolite, amphibolite–garnet schist, mica schist, abundant BIF and breccias of the Eizzene and Oumachoueima Groups (Martyn and Strickland, 2004). The Oumachoueima Group is host to significant copper–gold (bismuth) mineralization that is related to complex stockwork vein systems.

The largest IOCG deposit in Mauritania is the Guelb Moghrein deposit. This deposit belongs to one of the oldest known exploitation and metallurgical sites in Africa that have been dated to the Neolithic (Kolb et al., 2006). Total sulphide resources are estimated 30 Mt Cu at 1.01% and oxide resources of 4.2 Mt Cu (1.16%) (First Quantum, 2013). The Occidental and Oriental ore bodies, extend over 600 m in trend and are hosted in an approximately 30 m wide tabular meta-carbonaceous breccia. This ore-breccia formed at 2492 Ma (in situ U–Pb; Meyer et al., 2006), and involved a strong metasomatic overprinting (Kolb et al., 2008), with a paragenetic sequence defined by chalcopyrite, pyrrhotite, cubanite, cobaltite, arsenopyrite, magnetite, malachite and gold. The area east of Guelb Moghrein is

host to several smaller IOCG occurrences, represented by the deposits of Tabrinkout and Akjout. The mineralization at Tabrinkout is controlled by late stage fractures in an extensive Fe–Mg–Ca carbonate and quartz vein system (Strickland and Martyn, 2002; Martyn and Strickland, 2004).

The Chegga mesothermal copper occurrence in Mauritania is located on the northern margin of the Taoudeni Basin, close to the Eglab. This low grade deposit is hosted in Neoproterozoic to Carboniferous ferruginous sandstones and hosts disseminated malachite mineralization.

In greenstone belts of the central part of the Mauritanian belt, unconstrained Paleo to Neoproterozoic disseminated copper ore occurs, which is associated with malachite in hydrothermal vein systems and gossans. In addition, copper–tin mineralization is known from the hydrothermal Catherine deposit in the Eglab Shield (Fig. 1), where the mineral assemblages are composed of cassiterite, stannite, malachite and chalcopyrite within greisen.

3.1.2. Iron ore

Detailed published studies on the formation of iron ore in West Africa are limited, although the iron ore deposits are widespread along the craton margin, with varying grades from low to very high (Table 1 and Fig. 4). Iron ore mineralization occurs in (1) banded iron formations (BIF), (2) skarn deposits, (3) oolitic ironstones/lateritic crusts, and (4) within magmatic complexes mostly in Archean or reworked Birimian Supergroup sequences. They are generally limited to the Archean Kénéma-Man domain and Reguibat Shield, and scattered across the Baoulé-Mossi domain, Kédougou-Kéniéba Inlier, Eglab Shield, Pan-African Dahomeyan and Rokelide belt, and at the border of the Taoudeni, Tindouf, Volta, and Bové basins. The WAMDD contains seventy-six (76) iron ore deposits containing some detailed deposit descriptions.

As reported by Insoll (1997), Pleiner (2000), Ross (2002) Dueppen (2008), and Hein and Funyufunyu (2014), iron has been a resource for cultural and agricultural purposes for centuries in West Africa, with vein-hosted iron and lateritic duricrusts provided the raw material from a range of small deposits scattered across the WAC.

3.1.2.1. BIF hosted iron ore. High grade hematite–magnetite ores are mined in Mauritania, Guinea and Cote d'Ivoire. They are hosted in Neoarchean to Paleoproterozoic BIFs that associate with metamorphosed volcano-sedimentary formations. They overlie gneissic basement in the Kénéma Man and Reguibat Shield where they form mountain chains that extend for tens to hundreds of kilometres. BIF units in Liberia and Sierra Leone also contain mineable manganese concentrations. The average Fe₂O₃ grade ranges from 30% to 40%; the ore consist of various iron-bearing minerals including magnetite, hematite, specularite, goethite, and hydrohematite.

In general, the metamorphic grade of BIF in the WAC ranges from greenschist to granulite facies. Greenschist to amphibolite metamorphic facies is attained in the Mauritanian Idjill Group, as well as in the Kambui Group of Sierra Leone and counterparts in the Guinean Simandou Series. Amphibolite to granulite facies is attained in the Liberian Nimba Supergroup and Mauritanian Tiris Group.

In the area around Zouerate in Mauritania, high grade BIF-hosted iron ore deposits include deposits such as Tazadit, Koedia Idjill, and M'Haoudat. These deposits occur in the Paleoproterozoic Idjill Group which is thrust onto the Archean basement (Bronner and Fournon, 1992). North of M'Haoudat the lower grade Sfariat iron ore deposit (32% Fe₂O₃), which is hosted in an itabirite of

the Rich Anajim Group, has been dated at 2.11–2.06 Ga (U–Pb; Schofield et al., 2006) and formed where intense folding and thrusting resulting in imbricate stacking of iron rich layers.

In Guinea, two significant regions of high grade iron ore deposits are known from the southeast of the country namely (1) the Simandou chain that forms a north–south trending 115 km long mountain range that hosts numerous iron ore occurrences (e.g., Simandou, Zogota); and (2) the 25 km long Mount Nimba mountain range, which extends into Liberia and continues into Cote d'Ivoire. Most of the high grade Liberian iron ore deposits are mined at Bomi Hills. However, several economic relevant deposits host large tonnages of medium to low grades iron ore including the Bong deposit with 300 Mt of iron ore at 37% Fe₂O₃.

The BIF horizons in the Sula Mountains of Sierra Leone are hosted in an elongate northerly-trending greenstone belt (120 km long by 16 km wide). The BIF horizons are complexly folded and sheared; a near surface zone of iron mineralization extends for 24 km in length and 2.5 km in width.

In association with BIF-hosted iron ore deposits are lateritic ferruginous duricrusts of high to medium grade ore that crop out in the Rokelide Belt of Sierra Leone. Iron ore/manganese deposits occur in quartz–mica schists of the Marampa Group where the quartz–hematite horizons measure up to 65 m in thickness. The horizons have been isoclinally folded and thrust and host iron ore grades at approximately 28% Fe₂O₃.

3.1.2.2. Skarn hosted iron ore. Skarn-hosted iron ore deposits are restricted to the Falémé volcanic belt in the Kédougou-Kéniéba Inlier of Senegal, which hosts 9 major and 19 minor ore bodies (e.g., Farangalia, Koudékourou, Kouroudiako and Goto deposits), distributed in a 65 km long and 15 km wide belt where microdiorite is interpreted as the most likely source of iron enrichment. The deposits contain approximately 42% of iron ore related to magnetite-rich endo- and exoskarns, which were derived from dolomitic and calcitic marbles. Host rocks and ore were metamorphosed to greenschist facies during the early stages of the Eburnean Orogeny and later intruded by microdiorites at 2.07 Ga (Pb–Pb; Milési et al., 1989). Metals, which are associated with skarn hosted iron ore include magnetite, chalcopyrite, pyrrhotite, hematite, pyrite, arsenopyrite, pentlandite and cobaltite.

3.1.2.3. Oolitic hosted iron ore. Oolitic ironstone deposits flanking the basins of the West African Craton, formed during the Neoproterozoic and the Cenozoic. Host rocks occur as large lenses consisting of ferriferous sediments such as sandstones, tuffs, mudstones, argillites, and clay. They developed during cold/temperate climates at the margin of an epicontinental sea (Guerrak, 1989).

The oldest Fe-bearing oolites occur at the southern margin of the Taoudeni basin and are known as the Neoproterozoic/Cambrian Balé and Nioro deposits. Whereas Devonian oolitic ironstone lenses of the Gara deposits are located at the southern margin of the Tindouf basin. They occur in chloritic to ferruginous sandstones of the Djebilet Formation and range in thickness from 4 to 30 m. Typical mineral assemblages consist of magnetite, hematite, goethite, siderite and pyrite (Guerrak, 1988) with a cut-off grade of 57% Fe₂O₃. Another cluster of oolitic ironstone deposits are located at the eastern margin of the Baoulé-Mossi domain in Niger. This includes the Miocene aged deposit of Kollo, which contains iron ore concentrations of approximately 40% Fe₂O₃.

3.1.2.4. Laterite hosted iron ore. Ferruginous lateritic duricrusts occur throughout West Africa, but rarely form economic accumulations of iron ore mineralization. The ferruginous lateritic duricrusts developed during the Mesozoic and Cenozoic in stable, slowly eroding, tropical environments of contrasting seasons (Nahon, 1991). The lateritic crusts commonly form through in situ chemical processes; iron crusts are located on lower present-day elevations relative to bauxitic formations (Yardy, 1993; Brown et al., 1994). Laterites that formed as caps and ferruginous duricrusts host a variety of associated minerals including magnetite, goethite, hematite (martite), silica, gibbsite; minor manganese, sulphur and phosphor. Average iron oxide grades of approximately 35–45% Fe₂O₃ are common.

Lateritic formations at the Guinean Kaloum Centre deposit average 30–40 m, but can be up to 100 m thick and usually contain ferricretes or bauxitic components. Mineralization of iron ore is accompanied by nickel and cobalt, with grades of approximately 53% Fe₂O₃.

3.1.2.5. Intrusion-related iron ore. Intrusion-related iron ore is known from the Fe–V–Ti bearing veins of Tin Edia deposit located in the Oudalan province in northeast Burkina Faso. Magnetite-bearing veins crosscut layered intrusions of Paleoproterozoic ultramafic rocks (such as gabbro-norite and dunite). These veins have a length of about 400 m, ranging from 0.5 to 5 m in thickness to a maximum of 10 m, and are distributed in a subvertical and shallow dipping vein system. The deposit is located on the limb of the northeast trending Oursi syncline and mineralization consists of fault-controlled mineralized veins (Neybergh et al., 1980; Milesi et al., 1992). The primary oxidized ore consists of chalcopyrite, pyrite; vanadium-bearing magnetite, hematite, goethite, pentlandite, and ilmenite.

3.1.3. Bauxite

The landscape of West Africa was shaped during the Mesozoic (post-Gondwana) and Cenozoic (African surface) and is dominated by the presence of plateaus and plains containing bauxitic duricrusts.

Their formation is controlled by several factors:

- Climate (annual mean of 20 °C – >1200 mm/year rainfall).
- Tectonics (formed on stable shields/flat platforms with minimal erosional processes on relicts of Cretaceous–Paleogene peneplains).
- Geomorphology (the presence of well-drained flat Miocene high-elevated plateaus superimposed on Late Cretaceous to Eocene peneplains; two or more paleosurfaces across the region have been identified (c.f., Chardon et al., 2006; Bogatyrev et al., 2009); considerable uplift from Mesozoic to Eocene).
- Time (large bauxite deposits are inferred to have formed in less than 10 Ma).

Lateritic bauxites formed above various rock units throughout the southern part of the West African Craton (Fig. 4) such as: (1) Mesozoic dolerites that intruded Precambrian and Paleozoic

rocks in the early Jurassic (198–203 Ma; Schlische et al., 2003) and form part of the Central Atlantic Magmatic Province (CAMP); these crop out mainly in the Taoudeni basin of Mali and Burkina Faso and Fouta Djallon massif in Guinea. (2) Paleoproterozoic–Neoproterozoic/Paleozoic siliceous sedimentary and interglacial rocks are found in the Taoudeni basin of Burkina Faso, the Fouta Djallon massif in Guinea, the Gbonge-Mokanji bauxite belt in Sierra Leone, and Tarkwa-type rocks of southern Ghana, and Paleoproterozoic volcano-plutonic, metavolcanic and metasedimentary rocks of southern Ghana. The main ore minerals in bauxitic crusts are gibbsite, boehmite and limonite with associated gangue minerals including hematite, goethite, and magnetite. Fifty-seven (57) bauxite deposits are described in the WAMDD (Table 2).

3.1.3.1. Mesozoic dolerites. Major bauxite deposits are formed atop Mesozoic dolerites in regions such as the Boké belt in the Fouta Djallon massif in Guinea, including the Labé plateau. Bauxites of the Boké bauxite belt show profiles consisting of a thin overburden, 4–10 m of hard bauxite (high grade Al_2O_3 and Fe_2O_3), 4 m of low grade transitional bauxite intercalated with clay, and 5 m of soft bauxite (high Al_2O_3 and kaolin). Examples include the Sangarédi deposit, but also many other bauxites such as Bidikoum, Gaoual, Silidara. The world's largest and highest quality bauxite deposits are hosted in the Boke bauxite belt (part of the Fouta Djallon massif) in Guinea. The high grade Sangarédi deposit (>60% Al_2O_3) consists of three bauxitic layers that formed during two bauxitic phases in the Mid-Cretaceous and Eocene. According to Bardossy and Aleva (1990) bauxite pebbles infilled an alluvial channel and secondary bauxitic processes upgraded the deposits.

Economically relevant bauxites also developed on high plateaus. For example, in Guinea, the central Labé plateau hosts the Tougué deposit (amongst others) which rises to an elevation of 1.2 km above sea level. It is characterized by the Mid-Cretaceous and Eocene paleosurfaces. Equally two-stage bauxites at the Fria deposit in the Boke belt of the Fouta Djallon massif (close to the Atlantic Ocean) crop out at an elevation of about 300 m above sea level (Patterson et al., 1986).

Adjacent to the southern border of the Taoudeni basin several small bauxite deposits have been discovered (but none mined to date). Lahirasso and N'Dorola in Burkina Faso and Koubaya deposit in Mali are located along the River Niger; some of these laterites are alluvial, and some are duricrusts. They are derived from fiat-lying Permian sedimentary rocks and Mesozoic dolerites sills that were subjected to tropical weathering and are situated on a plateaux at the southern end of the Taoudeni Basin.

3.1.3.2. Paleoproterozoic metasedimentary rocks. Bauxite deposits also occur on Paleoproterozoic metasedimentary rocks of acidic composition with high SiO_2 content and low Fe content. Good examples are the Ghanaian bauxites at Awaso, Aya-Nyinahin, Nsisero, and Kibi.

The Opon Mansi deposit is hosted in Tarkwa-type sedimentary rocks and bauxite is found throughout the horizon containing pebble ore, conglomeritic ore, yellow-cavern ore, porous ore, soft ore and hard ore.

Bauxites at Ejuanema occur on a fiat highland (approximately 720 m above sea level) along the escarpment of the faulted and dissected Kwahu plateau, which is located in the Ashanti region 180 km northwest of Accra. It is the only deposit in the WAC associated with Neoproterozoic rocks of the Voltaian systems. However on the southern margin of the Taoudeni basin in Mali, bauxites occur in Neoproterozoic rocks at an elevation of 600–650 m.

Bauxite deposits in the Rokelide belt of Sierra Leone were discovered between 1960 and 1970s with economic important bauxite deposits in the Kasila Group as bauxitic crusts including the Port Loko and Mekanji Hill deposits.

In the Dahomeyan belt of Togo the Benin Structural Unit contains the Mt Agou bauxite deposit, which overlies the Neoproterozoic charnockitic Agou igneous complex.

3.1.4. Diamond

Diamond discoveries and exploitations have been economically and politically significant in West Africa since the mid-20th century. Diamonds were first discovered in Ghana in 1919 and 1922, then in Cote d'Ivoire between 1927 and 1930 and Liberia in the 1930s. Economically important discoveries were made in Sierra Leone from 1930 to 1960, and in Guinea from 1934 to 1960. The quality and quantity of diamonds varies considerably from small, industrial grade diamonds in Ghana to large, gemstone quality diamonds in Sierra Leone (Fig. 4). In 1967 the major diamond deposits were found in Sierra Leone in the Nimini Hills. Many diamond occurrences have been recognized proximal to producing deposits, but also scattered in regions where previously no significant deposits were found, such as the Bové and Volta Basin.

In the Reguibat Shield of the West African craton, Kahoui et al. (2008) reported that kimberlite indicator minerals occur associated with outcropping dykes of komatiitic–picritic. However, no diamond occurrences have been found to date.

Twenty diamond (20) deposits are listed in the WAMDD and described by two main deposit styles (Table 2) namely, (1) Primary Mesozoic kimberlite dykes and pipes, some associated with economic important alluvial placer deposits; and (2) diamondiferous paleoplacer types in Paleoproterozoic sedimentary rocks, and alluvial placers in Tertiary to Recent gravels that drain Paleoproterozoic supracrustal rocks. The majority of primary and secondary diamond deposits are reported from the Archean Kénéma-Man domain (e.g., Koidu Pipe and Tongo fields in eastern Sierra Leone; Banankoro in Guinea; and Mano River in Liberia), with some occurrences in the Baoulé-Mossi domain (Fig. 4).

3.1.4.1. Kimberlitic diamonds. Kimberlitic dykes, both barren and mineralized, are located in Sierra Leone, Guinea, Cote d'Ivoire and Liberia. The kimberlitic dykes trend north–northeast in Liberia, northeast in Sierra Leone, east–west in Guinea and north–south in Cote d'Ivoire (Rombouts, 1987; Pouclet et al., 2004). Diamondbearing kimberlite dykes and smaller pipes intruded Archean basement during the Cretaceous and Jurassic periods (Bardet and Vachette, 1966), and are associated with the break-up of Gondwana (Fig. 2).

Kimberlitic hosted diamonds were first identified in West Africa in the Kono district in Sierra Leone, and subsequently at Tongo and Koidu. These dyke systems, trending 070–074°f, occur between

two parallel regional scale fault systems, the Oyie-Shongbo and Yasamba faults. The Koidu and Tongo dyke systems produced large quantities of diamonds. In the Barsalogo diamond field in northeast Burkina Faso, one rare kimberlite plug, and several diamondiferous lamproite plugs and dykes were the targets of exploration drilling in the 1960s–1970s. Diamond-bearing tuffisite dykes in Ghana are dated at 2029 ± 22 Ma and were formed during the late stages of the Eburnean Orogeny (Krymsky et al., 2003; Delor et al., 2004).

3.1.4.2. Placer diamonds. Alluvial diamonds occur in Tertiary to Recent gravels that are eroded from Birimian supracrustal rocks (e.g., Anwiaso in Ghana; Aredor placer in Guinea; and Kono, Nimini Hill, Sewa River in Sierra Leone). Diamonds found in the Baoulé-Mossi domain are usually associated with gold–platinum–antimony–titanium–rare earth elements, such as in the Anwiaso and Birim deposits in Ghana, but the diamonds are entirely alluvial and account for more than 90% of the country's diamond production.

In the Birim diamond field, the diamonds occur in paleo-valleys and terraces that developed in three successive stages during the Cenozoic. Importantly although the source of primary diamonds in Ghana is not known, they have been transported only a short distance from the source (Olade, 1980; McKittrick et al., 1993; Appiah et al., 1996; Canales, 2005; Dampare et al., 2005). These authors debate that the source:

- (1) might have been deformed during tectonism and may lie beneath the thick Voltaian Basin north to northeast of the Birim Basin,
- (2) that a diamondiferous komatiite is situated proximally and has not yet been found,
- (3) that a metamorphosed kimberlite exists southeast near Akwatia, or the
- (4) source lies within turbidites of the Tarkwaian sequences.

In the Akwatia diamond field in the Birim River Basin, diamondbearing gravel beds have an average thickness of 2 m under 5–6 m of regolith. The primary sources for diamonds are proposed to be Mesoproterozoic or Cretaceous lamproites (Olade, 1980).

At the Bonsa diamond field, the diamond reserves have been estimated to 2.6 million carats. The deposits occur as paleoplacers associated with Tarkwaian sequences such as the Ntronang deposit in Ghana and the Tortiya deposit in Cote d'Ivoire.

Diamond occurrences are also known in the Kédougou-Kéniéba Inlier in gravels of the Falémé River and also in carbonate-rich rocks at Falea and Moussala where the diamonds occur, associated with Fe, Mn, Au, Ag, Ni, Co, Pt, corundum, P, Ti, REE, Nb and gemstones.

3.1.5. Base metals

Base metal deposits found in West Africa are poly-metallic including nickel, copper, zinc and cobalt. Documentation pertaining to these deposits is rare, exploration has been limited in comparison to that for gold, and the potential of these mineral resources is underdeveloped (Fig. 1). Twenty-eight (28) base metal deposits are listed in the WAMDD (see appendix), which includes the commodities of nickel–cobalt, copper, lead–zinc, tin, antimony, yttrium, and chromium (Table 2). Examples of copper mineralization have been discussed in a previous section.

3.1.5.1. Nickel–cobalt. Nickel ores have historically not been the focus of exploration in West Africa, and documentation of nickel occurrences is limited. However, twelve sizeable deposits are known from the southern part of the craton, and these are associated with Archean,

Paleoproterozoic and Mesozoic ultramafic–mafic complexes. Cenozoic laterization also resulted in the formation of nickel-bearing ferruginous crusts (see WAMDD for references).

Nickel deposits in West Africa are usually polymetallic, and host copper–cobalt and PGE minerals. Deposits in Cote d'Ivoire and Guinea are located in the Archean part of the Kénéma Man Shield and may follow the margin to the Baoulé-Mossi domain (Fig. 1). In Burkina Faso and the Rokelide belt of Guinea deposits are usually isolated.

The Cretaceous Kaloum igneous complex is mineralized in primary Ni–Co–Cu–(PGE). The complex is located at the northern tip of the Rokelide belt and contains thick sequences of peridotite and gabbro that intruded Proterozoic basement, and Paleozoic sedimentary rocks of the Bové Basin (Moreau et al., 1996).

Nickel laterite deposits crop out in the Dix-Huit Montagnes region in western Cote d'Ivoire where they form plateaus of laterite duricrust, for example on the Sipilou, Moyango or Koutabolo massifs. In Burkina Faso in the Boromo greenstone belt, the nickel–cobalt laterite that forms the Bongo deposit occurs as nickelbearing ferruginous nodules.

Lead–zinc, tin, antimony, uranium, yttrium, chromium, platinum deposits have been the focus of limited exploration from time to time across the West African Craton and along the craton margin. Lead–zinc, tin, antimony, uranium, yttrium, and chromium occurrences/deposits are hosted in volcano-plutonic and sedimentary rocks, and within the Archean Shields, Baoulé-Mossi domain, Mauritanian, Dahomeyan and Pharusian Belts, and the Bové Basin, are mostly structurally controlled.

3.1.5.2. Lead–zinc. Significant lead–zinc deposits form volcanogenic massive sulphide (VMS) deposits in Paleoproterozoic rocks in Burkina Faso (Schwartz and Melcher, 2003) and were discovered in the late 1970s. The unique Perkoa deposit in the Boromo greenstone belt hosts high grade/tonnage sphalerite, but low concentrations of galena and copper. The deposit comprises two massive lenses that are approximately 5.8 m in thickness, and are separated by altered volcano-sedimentary units. In comparison, the structural controlled Tiébélé deposit in the Bolé greenstone belt of Burkina Faso (Ilboudo, 1980; Castaing et al., 2003; Ilboudo et al., 2008), is lower in grade, but associated with gold mineralization. The mineralized zone is up to 20 m thick in a sequence of rhyolites and schists.

VMS deposits are also known in the Pan-African Pharusian belt of Mali, where the Tessalit deposit is the most significant resource for zinc, galena and copper. The VMS deposit of Tessalit occurs on the western part of the In Ouzzal Inlier and is hosted by a volcanic complex of porphyritic rhyolite in the Neoproterozoic Tilemsi Group (Leblanc and Sauvage, 1986). In the Dahomeyan Belt of Togo, a single occurrence of zinc in a gossan is known and is associated with iron oxide and manganese mineralization.

3.1.5.3. REE. Rare earth mineralization occurs in the Neoproterozoic alkaline ring complex of Bou Naga (Malavoy, 1931; Blanc, 1986; Blanc et al., 1992). Rare earth mineralization, including yttrium and thorium, occurs along the western side of a syenite and is hosted within veins and fluid infiltration zones. It formed during uplift and late-orogenic extensional leading to exhumation of Bou Naga complex in the Neoproterozoic (680 ± 10 Ma; Blanc et al., 1992).

3.1.5.4. Chromite. Disseminated chromium ore can be found at Mt Djeti/Mt Ahito in Togo within the Dahomeyan belt, where they are associated with serpentinite lenses in ultramafic schists of the Benin structural unit; these were discovered in the late 1980s. Furthermore, small podiform chromite deposits are known from Mauritania. At Amsaga, disseminated chromite mineralization is hosted in Neoarchean banded serpentinites of the Reguibat Shield. Podiform-type chromite deposits of Guidimaka are hosted in the Mauritanian belt where massive pods of chromite are associated with late Paleozoic mineralization. Economic chromite deposits in the Kénéma-Man domain are rare with the exception of Hangha in Sierra Leone, which was discovered in the 1929 by the Geological Survey of Sierra Leone. It is closely associated with emplacement of an ultramafic–mafic complex in the Kambui greenstone belt of the Kambui Supergroup. Hangha's chromite bodies are located along a 100 km long northeast trending zone that stretches from the Kambui to the central Gori belt. The mineralization occurs as narrow lenses or bands in sheared serpentine–dunite (Morel, 1979; Olade, 1980) and formed during intense alteration that produced chromium–tremolite, chromium–muscovite, and talc assemblages.

3.1.5.5. Antimony. In Burkina Faso, the antimony (stibnite) vein type deposit at Mafoulou is hosted in basalt-andesite rocks of the Goren volcano-sedimentary belt (Koala, 1980), but is now completely mined out.

3.1.5.6. Tantalum. In Ghana, tantalum is found in pegmatites at the Akim-Oda deposit. The pegmatites are associated with TTGs; columbite–tantalite minerals were accumulated as placer deposits.

In Cote d'Ivoire, cassiterite minerals occur as placer deposits in the Touvre tin deposit (Fig. 1).

3.1.5.7. Uranium. Uranium was discovered in the 1970s at Falea (KKI in Mali). This unconformity related deposit occurs at the contact between sandstones of the Falea sedimentary basin and granitoids of the Falea plateau. So far only a fraction of this plateau has been explored. The 2 km long, low grade Firawa uranium prospect in Guinea (in the Kénéma-Man domain) is associated with rare-earth mineral sands, and is probably structurally controlled. Exploration has occurred for uranium in the Mako and Diale shales in the region of Saraya, as well as for lithium, tin and molybdenum in the Paleoproterozoic granites of the Kédougou-Kéniéba Inlier.

3.1.5.8. Platinum. On the Atlantic coast of Sierra Leone, the 7 km thick 230–180 Ma Freetown layered complex (Briden et al., 1971; Beckinsale et al., 1977; Chalokwu, 2001) was emplaced into the Archean basement and Neoproterozoic Kasila Group during the formation of the middle Atlantic Ocean and breakup of Pangea. The 910 km² complex is composed of layers of gabbro, norite, troctolite and anorthosite (Umeji, 1983; Chalokwu, 2001) and hosts platinum-group mineralization in situ or as placer deposits, for example, at the York platinum mine. The Freetown layered complex extends into Liberia where it crops out as the Robertsport complex.

3.1.6. Phosphates

In West Africa, sedimentary phosphate deposits are located along the eastern and western craton margin, in the SenegalMauritania and Togolese coastal basins, and intracratonic Volta and Taoudeni Basins. The majority of deposits formed at lowlatitudes between 9°N and 20°N. A number of phosphates are also situated at approximately 6°N latitude in the Togolese coastal basin (Fig. 1). Thirty-two (32) deposits have been described in the WAMDD (Table 2). Two types are characterized: the most economically important are; (1) unmetamorphosed sedimentary flat-lying Mesozoic–Eocene deposits and, (2) highly deformed Neoproterozoic/Cambrian sedimentary phosphates. Both types have the same average grades of ca. 20–40% P₂O₅, but differ in extent and upgrading due to weathering and expansion.

3.1.6.1. Mesozoic to Eocene phosphates. The late Paleogene epoch of phosphate deposition is characterized by the widespread distribution of Mesozoic to Cenozoic sediments along the margins of West Africa craton. Rocks with high phosphorite potential include carbonate-clays in the Senegal-Mauritania and Togolese basins (Pokryshkin, 1991). However, the scale of phosphate deposition in the Eocene was small as indicated by the total resources of approximately 2500 Mt of 20–31% P₂O₅.

In the Togolese coastal basin, phosphates formed in marine

sediments from Mesozoic and Tertiary systems rest discordantly on the Precambrian Dahomean basement. Those phosphate beds probably formed during transgressional phases onto the continental margins, followed by progressive deepening of the basin and preservation of organic matter (Johnson et al., 2000). Additionally, major deposits such as Kpogamé and Hahotoé are covered by a 7–30 m thick lateritic crust. Consequently, they were only discovered in 1952 and exploited since the 1960s, but the relatively high cadmium concentrations (Cd mean = 58 mg/kg) are greater than permitted for use in Europe (e.g., Gnandi and Tobschall, 2002).

On the western margin of the West African craton Eocene phosphate deposits are of greater extent and volume than those in Togo; they are found near the Senegal River (e.g., Bofal/Loubboira, Matam) and formed in shallow marine environments. At Bofal along the Senegal River at the western part of the Mauritanides, highly siliceous (35% SiO₂) phosphate horizons of about 20% P₂O₅ (Appleton, 2002) are mined. They are overlain by approximately 8 m of clay and sandstone with a thick lateritic cover. South of Bofal in Senegal, several small Eocene phosphate deposits straddle the Senegal River where phosphate beds can be traced for approximately 100 km, including Matam, N'Diendouri and Ouali-Diala. The Matam phosphates were discovered in the early 1900s, but prospecting only began in 1966 when more deposits were found.

Close to the Atlantic Ocean, Eocene phosphate horizons were discovered 80 km northeast of Dakar on the Thiès Plateau in Senegal in 1945 and 1948. They are associated with a fracture system which was active during sedimentation and were reactivated during formation of aluminous phosphates (Flicoteaux and Hameh, 1989; Pascal and Cheikh Faye, 1989). These phosphate horizons were upgraded during long periods of weathering. The economically important phosphate mines of Taiba and Thiès. They have a thick cover of about 25 m of Quaternary aeolian sands. At Thiès 10 m thick aluminous phosphate crusts have been described with a 3 m overburden (Flicoteaux and Hameh, 1989).

3.1.6.2. Neoproterozoic/Cambrian phosphates. Neoproterozoic phosphate horizons are found on the eastern and western margin of the West African craton; they are generally thick (~30–40 m) but their lateral bedded extent is limited. Deposits in the Volta Basin are situated on its eastern tectonized margin in the Dahomeyan belt such as the <30 m thick phosphate horizons of the Bassar deposit in Togo. In Burkina Faso and Niger, Neoproterozoic–Cambrian

(660–570 Ma) phosphates are hosted in the Pendjari/Oti Supergroup of the basin. However, many Voltaian phosphate deposits are confined to a siltstone-chert unit with minor intercalated limestone and dolomite (Lucas and Prevot, 1981; Dardenne et al., 1986). Phosphorite deposits such as Kodjari, Aloub-Djouana and Tapoa, formed in shallow marine environments and are not substantially reworked (Trompette et al., 1980; Ouedraogo, 1982) apart from diagenesis and weathering. The 35–40 m thick Tapoa phosphate deposit developed in siltstones on a (probable) continental shelf. Lucas et al. (1986) suggested that the deposit was reworked and/or phosphate particles accumulated resulting in the upgrading and concentration of phosphorites, probably in a confined graben. The deposit has a high silica and low magnesium content.

In the north-west of the Taoudeni basin in Mauritania, Neoproterozoic/Cambrian phosphates cover sections of the Adrar Plateau above an erosional unconformity. The Neoproterozoic Bthaat Ergil Group comprises phosphatic basal conglomerates, shales, siltstones and sandstones that were eroded from the Pan-African belt (Dallmeyer and Lecorche, 1990). The Bthaat Ergil Group is correlated with the Pendjari Group of the Volta Basin, which dominates in tillites and molasse units. However, comparisons and correlations of lithostratigraphic successions on the opposite sides of the Taoudeni Basin is difficult due to variations in composition and thickness. Phosphates of the Bathat Ergil deposit are an example and probably, like all deposits of similar age, related to a continental shelf environment and perhaps associated with the warming of shallow marine basins (Pokryshkin, 1991).

On the western margin of the West African craton Neoproterozoic phosphates are situated in the northern Bové Basin. As an example, the phosphate horizons of the Namel deposit present as 9 m thick phosphatic pelites, 2 m thick calcareous phosphates, and 8 m thick coarse phosphates (Pascal and Sustrac, 1989).

3.1.7. Manganese

Considerable manganese mineralization is known from the southern half of the West African Craton where deposits are evenly distributed across the Baoulé-Mossi domain, Dahomeyan and Rokelide belts and, marginally, in the Volta basin (Fig. 1). Economic ore occurs as supergene enrichments of in situ Mn–Fe rich carbonaceous sedimentary rocks, where manganese oxides were deposited in terrestrial/marine environments including the Tambão and Billiata in Burkina Faso (Beauvais et al., 2008; Tshibubudze and Hein, 2013) and in the Ansongo district in eastern Mali. Most deposits are situated at the edges of greenstone belts (Leube et al., 1990) and formed as volcanogenic deposits hosted in mafic volcanics (e.g., Peters, 2013 in the Goren belt in Burkina Faso and Nsuta in Ghana). There is a strong stratigraphic control on the formation of the ore on a regional scale.

The distribution of manganese deposits throughout the West African Craton is variable. The oldest ore is associated with Archean BIF's of the Kambui Supergroup in volcano-sedimentary sequences in Cote d'Ivoire (Duékoué deposit). The majority of the manganese deposits are known from the

Paleoproterozoic where medium to high grade deposits occur in intracratonic settings comprising manganese oxides in carbonate beds, black shales and shales (e.g., Nsuta and Konongo deposit in Ghana, or Mokta deposit in Cote d'Ivoire). Thirty-two manganese (32) deposits are listed in the WAMDD (Table 2). The Mesoproterozoic is barren, while in the Neoproterozoic to Cambrian, manganese deposits in West Africa are restricted to BIF and glaciogenic-related sequences in the Dahomeyan and Rokelide belt. Large terrestrial deposits formed as mangacrete crusts during Eocene supergene weathering (e.g., Tambão and Billiata in Burkina Faso), and in the Miocene of Niger as oolitic beds (e.g., Say Diabou and Say Tamou deposits). An association between manganese and gold has been observed in volcanosedimentary Birimian Supergroup, for example, at the Konongo deposit in Ghana where ores occur as stratabound lenses both as pre- and post-tectonic mineralization (Ntiemoah-Agyakwa, 1979). Gold–manganese deposits are interpreted as either volcanogenic disseminations, orogenic gold style (Mumin et al., 1988), or seafloor metamorphic dewatering (Leube et al., 1990). The host rocks are usually layered and comprise volcano-sedimentary sequences intercalated with chemical sedimentary rocks.

Birimian supracrustal rocks are an important host to manganese deposits such as those at Tambão and Billiata in Burkina Faso and the Ansongo district in eastern Mali where ore presents as subvertical massive in situ manganese oxide ore that are overlain by supergene mangacrete crust. The surficial orebody at Tambão formed during the Eocene and the lateritic crust constitutes a thick weathered profile to 70 m depth which formed by systematic Mn-leaching and concomitant Si–Al enrichment and precipitation of goethite. The primary host rocks to the manganese deposits at Tambão include tuffaceous, volcano-sedimentary and manganese-bearing chemical sequences of the Birimian Supergroup.

In contrast, typical lateritic manganese (carbonate type) associated with iron-rich bauxite occur at Awaso in Ghana in Birimian supracrustal rocks of the Sefwi belt where brecciated bauxite and manganese developed in strongly weathered sequences. Manganese mineralization in iron-rich environments occurs also in the Neoarchean and Neoproterozoic BIFs of the Rokelide belt (e.g., Marampa manganese deposit), and the Dahomeyan belt (e.g., Lalamila deposit). At Tonkolili in Sierra Leone secondary caps of iron ore/manganese ore overlie Precambrian BIF.

3.1.8. Heavy minerals

Accumulations of heavy minerals have been described by Kesse (1985) within the Tarkwa-type conglomerates comprising accessory rutile, sericite, chlorite, chloritoid, epidote, tourmaline, zircon, garnet, pyrite and gold. However, heavy minerals also form economic mineable deposits in Sierra Leone, Mauritania and Senegal (Fig. 1) in coastal areas of the Atlantic Ocean. Twenty (20) heavy mineral deposits are included in the WAMDD (Table 2). Sierra Leone is ranked among the world's five leading producers of rutile (Yager et al., 2010) with important economic deposits such as Rotifunk. This deposit occurs in the Rokelide belt in a 6–7 m thick horizon of sandy clay of the Bullom Group, which overlies metasedimentary rocks of the Kasila Group. The heavy mineral horizon is approximately 0.5–2 km wide, 12 km long, and contains on average 0.7% rutile, 0.84% ilmenite, 0.06% zircon. They were probably eroded from charnockitic granulites and amphibolites of the Kasila Group and concentrated in drainage systems.

Furthermore, important Quaternary mineral sand deposits occur along the coastlines of Mauritania and Senegal. In Mauritania the Jreida-Lemsid mineral sand placer deposit consists mainly of ilmenite with minor zircon, hematite, vesuvianite, monazite, rutile, and corundum. The Djiféré and Lompoul

deposits in Senegal are hosted in Quaternary coastal sands of the Thiès Plateau in an extensive coastal dune system. The mineralized Lompoul dune system is between 2 and 4.5 km wide, with dunes ranging from 5 to 30 m in height, and flat lying mineralized horizons with an average thickness of 1 m. The main minerals are ilmenite, rutile, zircon, and leucoxene.

4. Mineral endowment and frequency distribution

The West African craton is highly endowed in metals. They show distinct spatial, temporal, and frequency distribution patterns. Approximately 50% of all mineral deposits in the database are situated in Paleoproterozoic domains; 13% are situated in Archean domains; 13% in cratonic/coastal basins; and 9% occur in the PanAfrican belts (WAMDD; Table 2).

4.1. Gold and copper–gold

Gold and copper–gold deposits occur widespread across the southern part of the craton, and isolated deposits are known in the Reguibat shield (Fig. 3). Gold occurs dominantly in Paleoproterozoic domains; mainly in the Baoulé-Mossi domain and Kédougou-Kéniéba Inlier. There are five times fewer gold occurrences in the Archean, and even less in the Pan-African belts (Table 2). With 198 gold deposits described in the WAMDD, gold is the most explored, known and exploited mineral in West Africa. Giant gold deposits with total resources of >10 Moz have been exploited in Ghana (including Ahafo, Bibiani, Prestea, Tarkwa and Obuasi), in the Kédougou-Kéniéba Inlier in Mali (Sadiola), and in the Archean part of the Reguibat shield in Mauritania (Tasiast).

The temporal distribution of different gold types indicates multiple phases of gold mineralization took place (Fig. 2). These distinct periods of gold formation can be defined as during:

- (1) The Liberian Orogeny in the Archean of Sierra Leone (e.g., Baomahun) and Liberia.
- (2) The Tangaean–Eburnean I Event observed in Burkina Faso and Mali (Kiaka, Essakane, Morila). This event is also inferred to have been a source for the paleoplacer deposits of the Tarkwa Group. The paleoplacer deposits in Ghana are overprinted by the Eburnean gold phase indicating an older gold event as source of the paleoplacers.
- (3) The major gold event during the Eburnean Orogeny in the Birimian (formation of orogenic, intrusion-related and skarn type deposits).
- (4) The ‘Pan-African’ Event in the Dahomeyan belt in Togo.

The gold deposits differ in the composition of their host rocks, kinematic controls and mineralogical paragenesis. In areas with limited dyke systems, such as in Cote d’Ivoire, metal endowment is

significantly less (Fig. 3). Whereas in the Kédougou-Kéniéba Inlier, parts of Ghana and Burkina Faso gold relate well to mapped dyke systems.

In contrast to the gold systems, porphyry Copper–Gold systems are located in restricted areas. These deposits occur in the BoromoGoren greenstone belt in Burkina Faso, and as isolated occurrences in Guinea, and Mauritania. This spatial restriction is interpreted to reflect the specific tectonic setting and spatial location required to form porphyry deposits as well as IOCGs. Orogenic gold deposits can form over a much larger range of tectonic settings and host rocks.

4.2. Iron ore

Several mineralization phases produced important iron ore that developed during the Liberian and Eburnean Orogenies, and also the Pan-African. The most dominant iron phase occurs as BIF-hosted iron ore in both Archean Shields (e.g., Nimba, Simandou, Guelb El Aouj, Koedia Ifjill, Tazadit) and correlates with the early phases of craton evolution during the Liberian Orogeny (Table 2; Figs. 1, 2 and 4). According to the WAMDD approximately 55% of all iron ore deposit styles are BIF and sediment-hosted. This is followed by approximately 24% of dominantly lateritic iron, located in the Dahomeyan (Lalamila, Bitjabe, Bassar) and Rokelides (Yomboyeli, Marampa) Pan-African belts. Iron enrichment in skarns (9% of all iron ore deposits; WAMDD) in the Falémé district is also an important style and formed during the Eburnean Orogeny.

4.3. Bauxite

The spatial distribution of bauxite deposits is limited to the southern part of West African Craton, stretching east–west from Ghana into Sierra Leone. Nearly 80% of bauxite deposits overlie Mesozoic dolerites. The formation of bauxites is controlled by climate, and tectonic and geomorphological processes over time. The spatial distribution suggests a correlation with the weathering of Mesozoic dolerites (Fig. 4). Two main clusters of bauxite deposits are recognized, one cluster between 12 and 10°N latitude and the other located equatorially at approximately 6°N latitude. Smaller scale bauxite deposits can be found in intracratonic basins such as the Bové basin (Boké belt: e.g., Sangarédi, Gaoual) and Taoudeni basin (Table 2). Interestingly, bauxite deposits occur nearly exclusively over Mesozoic dolerites within the boundary of the West African Craton (Fig. 4).

4.4. Diamonds

The major event that produced diamonds in the West African Craton (Fig. 2) correlates with the Mesozoic break-up of Gondwana, when kimberlitic pipes and lamproites intruded into the Archean terrane of the Archean Kénéma-Man Shield. Reactivated faults are inferred to have acted as conduits for kimberlite dykes (Haggerty, 1982). A second ‘older’ kimberlite intrusion event is observed in Ghana in Birimian rocks and northeast Burkina Faso in TTG granitoids, and probably relate to formation during the Eburnean Orogeny.

The location, size and frequency distribution of the diamond deposits are illustrated in (Fig. 4). Mesozoic dyke systems cut across the kimberlites (linked to the Atlantic rift; Fig. 2) and almost 70% of all deposits are observed within the Archean craton (Table 2; WAMDD). Kimberlite pipes are often located on the edge or crosscutting dolerite dykes. These are also the locations where giant primary diamond deposits developed such as the Koidu Pipes in northeast of Sierra Leone in the Tongo Field, and the Aredor and Diani fields in the Banankoro-Férouba district in southeast Guinea. The dykes trend NNE in Liberia, NE in Sierra Leone, E–W in Guinea and N–S in Cote d’Ivoire (Rombouts, 1987; Pouclet et al., 2004). Alluvial diamond placer deposits are widespread from Guinea to Togo and are located along major river systems draining to the Atlantic Ocean, such as the Mano and Lofa Rivers in Liberia and the Sewa River in Sierra Leone.

4.5. Base-metals

Base-metal occurrences can be correlated to various deformation events, and are scattered throughout the West African Craton, which highlights the various ages and geological settings of these deposits. Lead–zinc and copper mineralization are geologically restricted and are correlated predominantly to the Eburnean Orogeny, and to a lesser extent the Pan-African Orogeny.

The formation of magmatic nickel sulphides can be correlated to at least three phases of mineralization (Fig. 2 and Table 1), namely during the Liberian and Eburnean orogenies, and during the Atlantic rift phase. Ni–Co deposits are associated with emplacement of ultramafic intrusions in the Archean shields of the craton (Table 2), but also form plateau deposits as laterite duricrusts.

5. Conclusion

The West African Craton is a complicated structural area with multiphase tectonic events due to its intercontinental/intracontinental collision history. This manuscript has addressed the distribution of all known mineral deposits of the West African Craton using the WAMDD (provided as an appendix). The WAMDD is the first of its kind ever published as an openfile database. The data quality and documentation varies especially with non-gold deposits. However, we have used the information in the WAMDD to assess the spatial and temporal distribution of mineralization phases for a range of commodities.

Primary mineralization events are largely linked to deformation episodes and tectonic events (Table 1). We have synthesized the major mineralization stages, tectonic events and stratigraphy for the Archean/Paleoproterozoic domains, the Pan-African/Variscan belts and the intracratonic/coastal basins. This has provided a new assessment of the metallogenic development of the globally significant West African Craton.

Acknowledgements

We would like to gratefully acknowledge AMIRA International and the industry sponsors, including AusAid and the ARC Linkage Project LP110100667, for their support of the WAXI project (P934A). We are also appreciative of the contribution of the various Geological Surveys/Department of Mines in West Africa as sponsors in kind of WAXI. Finally, we wish to recognize our WAXI research colleagues from the various Institutions from around the world.

We would also like to thank Rokhaya Samba Diene from the DMG – Senegal for her discussions about phosphate deposits in Senegal, Jochen Kolb for his advice on Mauritanian geology and comments for improving this paper, and Klaus Gessner for proofreading earlier versions.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.precamres.2015.05.028>

References

- Abouchami, W., Boher, M., Michard, A., Albarede, F., 1990. A major 2.1 Ga event of mafic magmatism in West Africa: an early stage of crustal accretion. *J. Geophys. Res.* 95 (B11), 17605–17629.
2014. ACP Mining Website, http://mines.acp.int/html/accueil_en.html
- Adadey, K., Clarke, B., Théveniaut, H., Urien, P., Delor, C., Roig, J.Y., Feybesse, J.L., 2009. Geological map explanation – Map sheet 0503 B (1:100 000). In: Geological Survey Department of Ghana (GSD), CGS/BRGM/Geoman.
- Affaton, P., Rahaman, M.A., Trompette, R., Sougy, J., 1991. The Dahomeyide orogen: tectonothermal evolution and relationships with the Volta Basin. In: Dallmeyer, R.D., Lécorché, J.P. (Eds.), *The West African Orogens and Circum-Atlantic Correlatives*. Springer, New York, pp. 107–122.
- Agbossoumonde, Y., Menot, R.-P., Guillot, S., 2001. Metamorphic evolution of Neoproterozoic eclogites from south Togo (West Africa). *J. Afr. Earth Sci.* 33 (2), 227–244.
- Allen, P.M., 1968. The geology of part of an orogenic belt in western Sierra Leone, West Africa. *Geologische Rundschau* 58 (2), 588–620.
- Allibone, A., Teasdale, J., Cameron, G., Etheridge, M., Uttley, P., Soboh, A., AppiahKubi, J., Adanu, A., Arthur, R., Mamphey, J., Odoom, B., Zuta, J., Tsikata, A., Pataye, F., Famiyeh, S., 2002. Timing and structural controls on gold mineralisation at the Bogoso Gold Mine, Ghana, West Africa. *Econ. Geol.* 97, 949–969.
- AngloGold Ashanti, 2012. Operational Profile. Iduapriem, Ghana, Short report, 5 p. Appiah, H., Norman, D.I., Kuma, J.S., 1996. The diamond deposits of Ghana. *Afr. Geosci. Rev.* 3 (2), 261–272.

- Appleton, J.D., 2002. Local phosphate resources for sustainable development in subSaharan Africa. British Geological Survey, Report CR/02/121/N, 134 p.
- Attoh, K., 1982. Structure, gravity models and stratigraphy of an early Proterozoic volcanic-sedimentary belt in northeastern Ghana. *Precambrian Res.* 18 (3), 275–290.
- Attoh, K., Dallmeyer, R.D., Affaton, P., 1997. Chronology of nappe assembly in the Pan-African Dahomeyide orogen, West Africa: evidence from 40 Ar/39 Ar mineral ages. *Precambrian Res.* 82 (1–2), 153–171.
- Avnel Gold Mining Ltd., 2014. Kalana mineral resource estimate and preliminary economic assessment – Mali. In: NI 43-101 Technical Report, 31 March 2014, 189 p.
- Baratoux, L., Metelka, V., Naba, S., Jessell, M.W., Grégoire, M., Ganne, J., 2011. Juvenile Paleoproterozoic crust evolution during the Eburnean orogeny (~2.2–2.0 Ga), western Burkina Faso. *Precambrian Res.* 191 (1–2), 18–45.
- Bardet, M.G., Vachette, M., 1966. Determinations d'âges de kimberlite de l'Ouest Africain, et essai d'interprétation des datations des diverses venues diamantifères dans le monde. In: 3rd Symposium on African Geology, BrusselsTervuren.
- Bardossy, G., Aleva, G.J.J., 1990. Lateritic Bauxites/Developments in Economic Geology. Elsevier, Amsterdam 27, 624 p.
- Barth, M.G., Rudnick, R.L., Carlson, R.W., Horn, I., McDonough, W.F., 2002. Re–Os and U–Pb geochronological constraints on the eclogite–tonalite connection in the Archean Man Shield, West Africa. *Precambrian Res.* 118 (3–4), 267–283.
- Beauvais, A., Ruffet, G., Hénocque, O., Colin, F., 2008. Chemical and physical erosion rhythms of the West African Cenozoic morphogenesis: the 39 Ar–40 Ar dating of supergene K–Mn oxides. *J. Geophys. Res.* 113 (F4), F04007, 1–15.
- Beckinsale, R.D., Bowles, J.F., Pankhurst, R.J., Wells, M.K., 1977. Rubidium–strontium age studies and geochemistry of acid veins in the Freetown complex, Sierra Leone. *Mineral. Mag.* 41, 501–511.
- Beckinsale, R.D., Gale, N.H., Pankhurst, R.J., Macfarlane, A., Crow, M.J., Arthurs, J.W., Wilkinson, A.F., 1980. Discordant Rb–Sr and Pb–Pb whole rock isochron ages for the Archaean basement of Sierra Leone. *Precambrian Res.* 13 (1), 63–76.
- Bering, D., Brinckmann, J., Camara, N., Diawara, M., Gast, L., Kieita, S., 1998. Evaluation de l'Inventaire des Ressources Minérales de Guinée. C. T. R. d. G. R. F. d'Allemagne, Hannover, Germany, BGR Projet 94.2025.8, 109 p.
- Bertrand, H., Fornari, M., Marzoli, A., García-Duarte, R., Sempere, T., 2014. The Central Atlantic Magmatic Province extends into Bolivia. *Lithos* 188, 33–43.
- Bessoles, B., 1977. Géologie de l'Afrique. Le craton Ouest-Africain. Mémoires BRGM, Paris, 88, 402 p.
- Béziat, D., Dubois, M., Debat, P., Nikiéma, S., Salvia, S., Tollon, F., 2008. Gold metallogeny in the Birimian craton of Burkina Faso (West Africa). *J. Afr. Earth Sci.* 50, 215–233.
- Black, R., 1980. Precambrian of West Africa. Episodes 4, 1–8.

Blanc, A., These du Doctorat 1986. Le magmatisme du complexe alcalin mineralise en terres rares, Yttrium et Thorium du Bou-Naga (Mauritanie): environnement geologique et geochemique, radiochronologie et signification geodynamique. Universite de Nice, 247 p.

Blanc, A., Bernard-Griffiths, J., Caby, R., Caruba, C., Caruba, R., Dars, R., Fourcade, S., Peucat, J.J., 1992. U–Pb dating and isotopic signature of the alkaline ring complexes of Bou Naga (Mauritania): its bearing on late Proterozoic plate tectonics around the West African craton. *J. Afr. Earth Sci.* 14 (3), 301–311.

Bogatyrev, B.A., Zhukov, V.V., Tsekhovskiy, Y.G., 2009. Formation conditions and regularities of the distribution of large and superlarge bauxite deposits. *Lithol. Miner. Resour.* 44 (2), 135–151.

Boher, M., Michard, A., Albareda, F., Rossi, M., Milesi, J.-P., 1992. Crustal growth in West Africa at 2.1 Ga. *J. Geophys. Res.* 97 (B1), 345–369.

Bonhomme, M., Thesis 1962. Contribution a l'etude geochronologique de la plateforme de l'Ouest africain. Univ. Clermond-Ferrand, France, pp. 62.

Boshoff, F., Hanssen, E., Hill, J.V., Jones, D., Kaisin, J., Traore, S., Voet, H.W., 1998. The Sadiola Hill Mine: a lower Proterozoic gold deposit in the Kenieba window – Mali, West Africa. In: *Pathways 98, Exploration Symposium*, Vancouver, Canada,

Bourges, F., Debat, P., Tollon, F., Munoz, M., Ingles, J., 1998. The geology of the Taparko gold deposit, Birimian greenstone belt, Burkina Faso, West Africa. *Mineralium Deposita* 33, 591–605.

Briden, J.C., Henthorn, D.I., Rex, D.C., 1971. Palaeomagnetic and radiometric evidence for the age of the Freetown igneous complex, Sierra Leone. *Earth Planet. Sci. Lett.* 12, 385–391.

Bronner, G., Fournu, J.P., 1992. Audio-magnetotelluric investigation of allochthonous iron formations in the Archaean Reguibat shield (Mauritania): structural and mining implications. *J. Afr. Earth Sci.* 15 (3–4), 341–351.

Brown, E.T., Bourlès, D.L., Colin, F., Sanfo, Z., Raisbeck, G.M., Yiou, F., 1994. The development of iron crust lateritic systems in Burkina Faso, West Africa examined with in-situ-produced cosmogenic nuclides. *Earth Planet. Sci. Lett.* 124 (1–4), 19–33.

Burkhard, M., Caritg, S., Helg, U., Robert-Charrue, C., Soulaïmani, A., 2006. Tectonics of the Anti-Atlas of Morocco. *Comptes Rendus Geoscience* 338 (1–2), 11–24.

Buro, Y., 2009. Technical Report on the Mineral Resource of the Bondigui Gold Project. Prepared by Met-Chem Canada Inc., Montréal, Québec, 135 p.

Caby, R., Phd thesis 1970. La Chaîne Pharusienne dans le Nord-Ouest de l'Ahaggar (Sahara Central, Algerie); sa Place dans l'Orogenese du Precambrien Superieur en Afrique. Universite Montpellier.

Caby, R., 1996. A review of the In Ouzzal granulitic terrane (Tuareg shield, Algeria): its significance within the Pan-African Trans-Saharan belt. *J. Metamorph. Geol.* 14, 659–666.

Caen-Vachette, M., 1986. Apport de la geochronologie isotopique a la connaissance du Proterozoique inferieur de l'Afrique de l'Ouest. CIFEG publication occasionnelle 10, pp. 25–44.

Canales, D.G., M.Sc. dissertation 2005. The Akwatia diamond field, Ghana, West Africa – Source rocks. New Mexico Institute of Mining and Technology, Socorro, pp. 143.

Castaing, C., Billa, M., Milési, J.P., Thiéblemont, D., Le Mentour, J., Egal, E., Donzeau, M., Guerrot, C., Cocherie, A., Chevremont, P., Tegye, M., Itard, Y., Zida, B., Ouedraogo, I., Kote, S., Kabore, B.E., Ouedraogo, C., Ki, J.C., Zunino, J., 2003. Notice explicative de la Carte géologique et minière du Burkina Faso à 1/1 000 000, 3eme Edition. Ministère des Mines, Burkina Faso, pp. 148.

Cavaroc, V.V., Padgett, G., Stephens, D.G., Kanes, W.H., Boudda, A., Woolen, I.D., 1976. Late Paleozoic of the Tindouf Basin, North Africa. *J. Sediment. Res.* 46 (1), 77–88. Chalokwu, C.I., 2001. Petrology of the Freetown Layered Complex, Sierra Leone: Part II. Magma evolution and crystallisation conditions. *J. Afr. Earth Sci.* 32 (3), 519–540.

Chardon, D., Chevillotte, V., Beauvais, A., Grandin, G., Boulangé, B., 2006. Planation, bauxites and epeirogeny: one or two paleosurfaces on the West African margin. *Geomorphology* 82 (3–4), 273–282.

Chirico, P.G., Malpeli, K.C., Anum, S., Philips, E.C., 2010. Alluvial diamond resource potential and production capacity assessment of Ghana. In: US Geological Survey Scientific Investigations Report 2010-5045, 25 p.

Chirico, P.G., Malpeli, K.C., Van Bockstael, M., Mamandou, D., Cisse, K., Diallo, T.A., Sano, M., 2014. Alluvial diamond resource potential and production capacity assessment of Guinea (version 1.1, April 2014). In: U.S. Geological Survey Report 2012-5256, 49 p.

Clauer, N., Caby, R., Jeannette, D., Trompette, R., 1982. Geochronology of sedimentary and metasedimentary Precambrian rocks of the West African craton. *Precambrian Res.* 18, 53–71.

Cluver, S.J., Williams, H.R., 1979. The Late Precambrian and Phanerozoic geology of Sierra-Leone. *J. Geol. Soc. Lond.* 136, 605–618.

Dallmeyer, R.D., Lecorche, J.P., 1990. 40 Ar/39 Ar polyorogenic mineral age record in the northern Mauritanide orogen, West Africa. *Tectonophysics* 177 (1–3), 81–107. Dampare, S., Asiedu, D., Banoeng-Yakubo, B., Shibata, T., 2005. Heavy mineral analysis of alluvial sediments from the Akwatia area of the Birim diamondiferous field, Ghana. In: Okayama University Earth Science Report 12., pp. 7–14.

Dardenne, M.A., Trompette, R., Magalhaes, L.F., Soares, L.B., 1986. Proterozoic and Cambrian phosphorites – regional review: Brazil. In: Cook, P.J., Shergold, J.H. (Eds.), *Phosphate deposits of the world*, vol. 1, pp. 116–131, London.

Delor, C., Milesi, J.P., Lafon, J.M., Krymsky, R., 2004. The Akwatia diamond-bearing tuffsite dykes swarms (Ghana): syntectonic products of deep mantle origin emplaced during the final stages of the Eburnian orogeny (2050–2000 Ma). In: 20th Colloquium of African Geology, Orleans, France, p. 128.

de Kock, G.S., Théveniaut, H., Botha, P.M.W., Gyapong, W., 2012. Timing the structural events in the Palaeoproterozoic Bolé–Nangodi belt terrane and adjacent Maluwe basin, West African craton, in central-west Ghana. *J. Afr. Earth Sci.* 65, 1–24.

Dewey, J.F., Pitman, W.C., Ryan, W., Bonnin, J., 1973. Plate tectonics and the evolution of the Alpine system. *Geol. Soc. Am. Bull.* 84, 3137–3180.

Deynoux, M., 1982. Periglacial polygonal structures and sand wedges in the late Precambrian glacial formations of the Taoudeni basin in Adrar of Mauretania (West Africa). *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 39 (1–2), 55–70.

Deynoux, M., Affaton, P., Trompette, R., Villeneuve, M., 2006. Pan-African tectonic evolution and glacial events registered in Neoproterozoic to Cambrian cratonic and foreland basins of West Africa. *J. Afr. Earth Sci.* 46 (5), 397–426.

Deynoux, M., Sougy, J., Trompette, R., 1985. Lower Paleozoic rocks of West Africa and the western part of Central Africa. In: Holland, C.H. (Ed.), *Lower Paleozoic Rocks of Northwest and West-Central Africa*. Wiley, New York, pp. 337–495.

Dioh, E., Béziat, D., Debat, P., Grégoire, M., Ngom, P.M., 2006. Diversity of the Palaeoproterozoic granitoids of the Kédougou Inlier (eastern Sénégal): petrographical and geochemical constraints. *J. Afr. Earth Sci.* 44 (3), 351–371.

Dueppen, S.A., PhD thesis 2008. Reinventing equality: the archaeology of Kirikongo, Burkina Faso. University of Michigan, pp. 328.

Egal, E., Thieblemont, D., Lahondere, D., Guerrot, C., Costea, C.A., Iliescu, D., Delor, C., Goujou, J.C., Lafon, J.M., Tegye, M., Diaby, S., Kolie, P., 2002. Late Eburnean granitization and tectonics along the western and northwestern margin of the Archean Kénéma-Man domain (Guinea, West Africa Craton). *Precambrian Res.* 117, 57–84.

Eisenlohr, B.N., 1989. The Structural Geology of the Birimian and Tarkwaian Rocks in Ghana, BGR Report 106 448, 66 p.

Endeavour Mining Ltd., 2011. Endeavour's Growth Plan April 2011, Presentation.

Ennih, N., Liégeois, J.-P., 2001. The Moroccan Anti-Atlas: the West African craton passive margin with limited Pan-African activity: implications for the northern limit of the craton. *Precambrian Res.* 112 (3–4), 289–302.

Ferkous, K., Leblanc, M., 1995. Gold mineralisation in the West Hoggar shear zone, Algeria. *Mineralium Deposita* 30 (3), 211–224.

Feybesse, J.-L., Billa, M., Guerrot, C., Duguey, E., Lescuyer, J.L., Milési, J.P., Bouchot, V., 2006. The Palaeoproterozoic Ghanaian province. Geodynamic model and ore controls, including regional stress modelling. *Precambrian Res.* 149, 149–196.

Feybesse, J.-L., Milesi, J.-P., Ouedraogo, M.F., Prost, A., 1990. La "ceinture" Proterozoïque inférieure de Boromo–Goren (Burkina Faso): un exemple d'interférence entre deux phases transcurrentes éburnéennes. *Comptes Rendus de l'Académie des Sciences de Paris Série II, Sciences de la Terre et des Planètes* 310, 1353–1360.

First Quantum Minerals Ltd., 2013. Annual Report 2013, 118 p.

Flicoteaux, R., Hameh, P.M., 1989. The aluminous phosphate deposits of Thies, western Senegal. In: Notholt, A.J.G., Sheldon, R.P., Davidson, D.F. (Eds.), *Phosphate Deposits of the World*, vol. 2. Cambridge University Press, pp. 273–276.

Foster, R.P., Piper, D.P., 1993. Archaean lode gold deposits in Africa: crustal setting, metallogenesis and cratonization. *Ore Geol. Rev.* 8, 303–347.

Gévin, P., 1960. Etudes et reconnaissances géologiques sur l'axe cristallin Yetti-Eglab et ses bordures sédimentaires. *Bulletin du Service de la carte géologique de l'Algérie* 23, 328.

Ghienne, J.-F., 2003. Late Ordovician sedimentary environments, glacial cycles, and post-glacial transgression in the Taoudeni Basin, West Africa. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 189 (3–4), 117–145.

Gnandi, K., Tobschall, H., 2002. Heavy metals distribution of soils around mining sites of cadmium-rich marine sedimentary phosphorites of Kpogamé and Hahotoé (southern Togo). *Environ. Geol.* 41 (5), 593–600.

Gold Fields, 2011. Tarkwa Gold Mine. Technical Short Form Report, 22 p.

Goujou, J.C., Thieblemont, D., Delor, C., Cocherie, A., Lacomme, A., Lafon, J.M., Tegye, M., Theveniaut, H., Sall, H., Souare, S., Toure, J., Bah, M., Balde, A., Sane, H., 1999. Notice explicative de la Carte géologique de la Guinée à 1/200 000. d. I. G. e. d.

I. E. Ministère des Mines, Conakry, Guinée, 22 p.

Guerrak, S., 1988. Geology of the Early Devonian oolitic iron ore of the Gara Djebilet Field, Saharan Platform, Algeria. *Ore Geol. Rev.* 3 (4), 333–358.

Guerrak, S., 1989. Time and space distribution of Palaeozoic oolitic ironstones in the Tindouf Basin, Algerian Sahara. *Geol. Soc. Lond. Spec. Publ.* 46 (1), 197–212.

Gueye, M., Siegesmund, S., Wemmer, K., Pawlig, S., Drobe, M., Nolte, N., Layer, P., 2007. New evidences for an early Birimian evolution in the West African Craton: an example from the Kedougou-Kenieba inlier, southeast Senegal. *South Afr. J. Geol.* 110 (4), 511–534.

Guide pour l'investissement minier au Togo, 1995. Direction Generale des Mines et de la Geologie, Projet UN-DESA TOG99/B05, 37 p.

Haggerty, S.E., 1982. Kimberlites in Western Liberia: an overview of the geological setting in a plate tectonic framework. *J. Geophys. Res.* 87 (B13), 10811.

Hastings, D.A., 1982. On the tectonics and metallogenesis of West Africa: a model incorporating new geophysical data. *Geoexploration* 20, 295–327.

Hein, K.A.A., 2010. Succession of structural events in the Goren greenstone belt (Burkina Faso): implications for West African tectonics. *J. Afr. Earth Sci.* 56, 83–94.

Hein, K.A.A., Funyufunyu, T.A., 2014. Artisanal mining in Burkina Faso: a historical overview of iron ore extraction, processing and production in the Dem region. *Extract. Ind. Soc.* 1, 260–272.

Hein, K.A.A., Morel, V., Kagone, O., Kiemde, F., Mayes, K., 2004. Birimian lithological succession and structural evolution in the Goren segment of the Boromo-Goren Greenstone Belt, Burkina Faso. *J. Afr. Earth Sci.* 39, 1–23.

Hirdes, W., Davis, D.W., 1998. First U–Pb zircon age of extrusive volcanism in the Birimian Supergroup of Ghana/West Africa. *J. Afr. Earth Sci.* 27, 291–294.

Hirdes, W., Davis, D.W., Eisenlohr, B.N., 1992. Reassessment of Proterozoic granitoid ages in Ghana on the basis of U/Pb zircon and monazite dating. *Precambrian Res.* 56, 89–96.

Hirdes, W., Davis, D.W., Luedtke, G., Konan, G., 1996. Two generations of Birimian (Paleoproterozoic) volcanic belts in northeastern Cote d'Ivoire (West Africa): consequences for the 'Birimian controversy'. *Precambrian Res.* 80, 173–191.

Huneau, F., Dakoure, D., Celle-Jeanton, H., Vitvar, T., Ito, M., Traore, S., Compaore, N.F., Jirakova, H., Le Coustumer, P., 2011. Flow pattern and residence time of groundwater within the south-eastern Taoudeni sedimentary basin (Burkina Faso, Mali). *J. Hydrol.* 409 (1–2), 423–439.

IAMGOLD Corp., 2010. Sadiola & Yatela Gold Mines. Analyst Tour. Presentation 2010. IAMGOLD, 2013. Annual Report – A Disciplined Approach. IAMGOLD Corp, 114 p.

Ilboudo, H., Doctorate thesis 1980. Le gîte d’amas sulfure de Tiebele (Burkina Faso-Afrique de l’ouest). Facies lithologiques, structures et mineralisations. Laboratoire de Geologie, Mineralogie, Petrophysique & Tectonique, Université de Ouagadougou, 178 p.

Ilboudo, H., Lompo, M., Wenmenga, U., Naba, S., Kagambega, N., Traore, S.A., 2008. Caracteres petrographiques et structuraux des formations Paleoproterozoïques (Birimien) du gîte a sulfures de Tiebele, Burkina Faso (Afrique de l-ouest) (Petrographic and structural characters of Paleoproterozoic (Birimian) of sulphides deposits formations of Tiebele area, (Burkina Faso, West Africa)). *Journal des Sciences* 8 (3), 37–50.

Insoll, T., 1997. Iron Age Gao: an archaeological contribution. *J. Afr. Hist.* 38, 1–30.

Johnson, A.K., Rat, P., Lang, J., 2000. Le bassin sédimentaire a phosphates du Togo (Maastrichtien-Eocène): stratigraphie, environnements et evolution. *J. Afr. Earth Sci.* 30 (1), 183–200.

Kahoui, M., Mahdjoub, Y., Kaminsky, F.V., 2008. Possible primary sources of diamond in the North African diamondiferous province. In: Ennih, N., Liégeois, J.-P. (Eds.), *The Boundaries of the West African Craton*. Geological Society London, Special Publications, 297, pp. 77–109.

Kesse, G.O., 1985. *The Mineral and Rock Resources of Ghana*. Balkema, Rotterdam. Kinross Gold Corporation, 2014. Tasiast Project Mauritania. National Instrument 43-

101 Technical Report, 31 March 2014, 246 p.

Koala, K.F., Thesis 1980. L’environnement geologique de la mineralisation antimonieuse de Mafoulou (degre carre de Kaya, Haute-Volta) et les caracteres du volcanisme basique regional. Université Claude Bernard, Lyon.

Kolb, J., Sakellaris, G., Meyer, F., 2006. Controls on hydrothermal Fe oxide–Cu–Au–Co mineralization at the Guelb Moghrein deposit, Akjoujt area, Mauritania. *Mineralium Deposita* 41 (1), 68–81.

Kolb, J., Meyer, F.M., Vennemann, T., Hoffbauer, R., Gerdes, A., Sakellaris, G.A., 2008. Geological setting of the Guelb Moghrein Fe oxide–Cu–Au–Co mineralization, Akjoujt area, Mauritania. In: Ennih, N., Liégeois, J.-P. (Eds.), *The Boundaries of the West African Craton*. Geological Society London, Special Publications 297, pp. 53–75.

Kouamelan, A.N., Delor, C., Peucat, J.-J., 1997. Geochronological evidence for reworking of Archean terrains during the Early Proterozoic (2.1 Ga) in the western Cote d’Ivoire (Man Rise-West African Craton). *Precambrian Res.* 86 (3–4), 177–199.

Krymsky, R.S., Lafon, J.-M., Delor, C., Milesi, J.P., 2003. Uranium–lead technique on apatite and rutile at the Laboratory of Isotope Geology – Pará-Iso, Belém. Application to Kimberlite dating. In: 4th SSAGI, Salvador, Brazil.

Kusnir, I., 1999. Gold in Mali. *Acta Montanistica Slovaca* 4, 311–318.

- La Mancha, 2012. Reinvent, Transform, Grow. La Mancha Activity Report, 20 p. Leblanc, M., Sauvage, J.F., 1986. Un gisement polymétallique en milieu volcanosédimentaire du Protérozoïque supérieur: Tessalit (Adrar des Iforas, Mali). *J. Afr. Earth Sci.* (1983) 5 (3), 201–207.
- Lecorche, J.P., Bronner, G., Dallmeyer, R.D., Rocci, G., Roussel, J., 1991. The Mauritanide orogen and its northern extensions (Western Sahara and Zemmour) West Africa. In: Dallmeyer, R.D., Lecorche, J.P. (Eds.), *The West African Orogens and Circum-Atlantic Correlatives*. Springer, Berlin, pp. 187–227.
- Ledru, P., Pons, J., Feybesse, J.L., Dommange, A., Johan, V., Diallo, M., Vinchon, C., 1989. Tectonique transcurrente et évolution polycyclique dans le Birimien, Proterozoïque inférieur du Sénégal-Mali (Afrique de l'Ouest). *Comptes Rendus de l'Académie des Sciences, Paris, Series II* 308, 117–122.
- Ledru, P., Pons, J., Milési, J.P., Feybesse, J.L., Johan, V., 1991. Transcurrent tectonics and polycyclic evolution in lower Proterozoic of Senegal-Mali. *Precambrian Res.* 50, 337–354.
- Lesquer, A., Villeneuve, J.C., Bronner, G., 1991. Heat flow data from the western margin of the West African craton (Mauritania). *Phys. Earth Planet. Inter.* 66, 320–329.
- Leube, A., Hirdes, W., Mauer, R., Kesse, G.O., 1990. The Early Proterozoic Birimian Supergroup of Ghana and some aspects of its associated gold mineralisation. *Precambrian Res.* 46, 139–165.
- Liégeois, J.P., Claessens, W., Camara, D., Klerkx, J., 1991. Short-lived Eburnean orogeny in southern Mali. *Geology, tectonics, U–Pb and Rb–Sr geochronology*. *Precambrian Res.* 50 (1–2), 111–136.
- Lucas, J., Ilyin, A.V., Kuehn, A., 1986. Proterozoic and Cambrian phosphorite deposits: Volta Basin, West Africa. In: Cook, P.J., Shergold, J.H. (Eds.), *Phosphate Deposits of the World*, vol. 1, pp. 235–253, London.
- Lucas, J., Prevot, L., 1981. Caractères pétrographiques et microchimiques de phosphorites précambriennes du Bassin des Volta (Afrique de l'Ouest). *Consideration génétiques*. *Bulletin de la Société Géologique de France* 23 (5), 515–524.
- Malavoy, J., 1931. *Géologie de la Mauritanie du Nord*. *Comptes Rendus de l'Académie des Sciences (Paris)* 259, 184–186.
- Marcoux, E., Milesi, J.P., 1993. Lead isotope signature of Early Proterozoic ore deposits in Western Africa: comparison with gold deposits in French Guiana. *Econ. Geol.* 88, 1862–1879.
- Marignac, C., Semiani, A., Fourcade, S., Boiron, M.C., Joron, J.-L., Kienast, J.R., Peucat, J.J., 1996. Metallogenesis of the late Pan-African gold-bearing East Ouzal shear zone (Hoggar, Algeria). *J. Metamorph. Geol.* 14, 783–801.
- Marston, R.J., Woolrich, P., Kwasie, J., 1992. Closely associated stockwork and palaeoplacer gold mineralisation in the Early Proterozoic Tarkwaian System of Abosso, SW Ghana. In: *Proceedings of the 9th International Geological Conference, Regional Trends in African Geology*, Accra.
- Martyn, J., Strickland, C., 2004. Stratigraphy, structure and mineralisation of the Akjoujt area, Mauritania. *J. Afr. Earth Sci.* 38 (5), 489–503.
- Marzoli, A., Renne, P.R., Piccirillo, E.M., Ernesto, M., Bellieni, G., De Min, A., 1999. Extensive 200 million-year-old continental flood basalts of the Central Atlantic Magmatic Province. *Science* 284, 616–618.

- Matabane, M., Honours thesis 2008. The geology of the FE3 open-cast, Sadiola, Mali: stratigraphy, structure and intrusive rocks. University of the Witwatersrand, Johannesburg, 56 p.
- Matsheka, I.R., Hein, K.A.A., 2011. Character, morphology and origin of gold from the selected mines in the Yatela and Sadiola goldfield, Mali, West Africa. In: Poster Presentation to the WAXI Sponsors Meeting, Ouagadougou, Burkina Faso, 28th March to 1 April.
- McFarlane, C.R.M., Mavrogenes, J., Lentz, D., King, K., Allibone, A., Holcombe, R., 2011. Geology and intrusion-related affinity of the Morila Gold Mine, Southeast Mali. *Econ. Geol.* 106 (5), 727–750.
- McKittrick, S.A., Norman, D.I., Appiah, H., 1993. Proterozoic Ghanaian metakimberlites. In: American Geophysical Union Fall Meeting, San Francisco, December 6–10, abstract.
- Menchikoff, N., 1949. Quelques traits de l'histoire géologique du Sahara occidental.
- Livre jubilaire Charles Jacob. *Annales Hebat et Haug* 7, 303–325.
- Meyer, F.M., Kolb, J., Sakellaris, G.A., Gerdes, A., 2006. New ages from the Mauritanides Belt: recognition of Archean IOCG mineralization at Guelb Moghreïn, Mauritania. *Terra Nova* 18, 345–352.
- Mignot, E.L.E., Siebenaller, L., Beziat, D., Salvi, S., Andre-Mayer, A.-S., Reisberg, L., Velasquez, G., Zimmermann, C., Franceschi, G., 2014. The Paleoproterozoic copper-gold deposit of Gaoua, Burkina Faso: evidence for a polyphased mineralization. *Acta Geol. Sin. (Engl. Ed.)* 88 (s2), 970–972.
- Milési, J.-P., Ledru, P., Feybesse, J.-L., Dommange, A., Marcoux, E., 1992. Early Proterozoic ore deposits and tectonics of the Birimian orogenic belt, West Africa. *Precambrian Res.* 58 (1–4), 305–344.
- Milési, J.P., Feybesse, J.L., Ledru, P., Dommange, A., Ouedraogo, M.F., Marcoux, E., Prost, A., Vinchon, C., Sylvain, J.P., Johan, V., Tegye, M., Calvez, J.Y., Lagny, P., 1989. West African gold deposits in their Lower Proterozoic lithostructural setting. *Chronique de la recherche minière (France)* 497, 3–98.
- Milési, J.P., Feybesse, J.L., Pinna, P., Deschamps, Y., Kampunzu, H., Muhongo, S., Lescuyer, J.L., Le Goff, E., Delor, C., Billa, M., Ralay, F., Henry, C., 2004. Geological map of Africa 1:10,000,000. In: SIGAfric Project: 20th Conference of African Geology, BRGM, Orléans, France, June 2–7, <http://www.sigafric.net> (accessed 14.12.10).
- Moody, R.T.J., Sutcliffe, P.J.C., 1991. The Cretaceous deposits of the Iullemmeden basin of Niger, central West Africa. *Cretaceous Res.* 12, 137–157.
- Moreau, C., Ohnenstetter, D., Demaiffe, D., Robineau, B., 1996. The Los Archipelago nepheline syenite ring-structure: a magmatic marker of the evolution of the central and equatorial Atlantic. *Can. Mineral.* 34, 281–299.
- Morel, S.W., 1979. The geology and mineral resources of Sierra Leone. *Econ. Geol.* 74, 1563–1576.
- Mumin, A.A., Clarke, G.A., Flach, G.A., Badu, F., 1988. Geology and mineralogy of gold mineralization at the Bogoso concession, Western Region, Ghana. In: International Conference and Workshop on Geology and Exploration in Ghana. 75th Anniversary of the Ghana Geological Survey Department, p. 34.

Mumin, A.H., Fleet, M.E., Chrysoulis, S.L., 1994. Gold mineralisation in As-rich mesothermal gold ores of the Bogosu-Prestea mining district of the Ashanti gold belt, Ghana: remobilization of “invisible” gold. *Mineralium Deposita* 29, 445–460.

Nahon, D., 1991. *Introduction to the Petrology of Soils and Chemical Weathering*.

Wiley, New York.

Nédélec, A., Affaton, P., France-Lanord, C., Charrière, A., Alvaro, J., 2007. Sedimentology and chemostratigraphy of the Bwipe Neoproterozoic cap dolostones (Ghana, Volta Basin): a record of microbial activity in a peritidal environment. *Comptes Rendus Geoscience* 339 (3–4), 223–239.

Neybergh, H., Laduron, D., Martin, H., Verkaeren, J., 1980. The vanadiferous magnetite deposits of the Oursi region, Upper-Volta. *Econ. Geol.* 75, 1042–1052.

Ntiamoah-Agyakwa, Y., 1979. Relationship between gold and manganese mineralization in the Birimian of Ghana, West Africa. *Geol. J.* 2116, 345–352.

Oberthür, T., Vetter, U., Davis, D.W., Amanor, J.A., 1998. Age constraints on gold mineralization and Paleoproterozoic crustal evolution in the Ashanti belt of southern Ghana. *Precambrian Res.* 89, 129–143.

Olade, M., 1980. Precambrian metallogeny in West Africa. *Geologische Rundschau* 69 (2), 411–428.

Olson, S.F., Diakite, K., Ott, L., Guindo, A., Ford, C.R.B., Winer, N., Hanssen, E., Lay, N., Bradley, R., Pohl, D., 1992. Regional setting, structure, and descriptive geology of the middle Proterozoic Syama gold deposit, Mali, West Africa. *Econ. Geol.* 87, 310–331.

Orezone Gold Corp., 2010. Overview Q4 2010, Bomboré Project Report, 2 p.

Ouedraogo, Z.R., Thesis 1982. Contribution à l'étude des gisements de phosphates d'âge précambrien du Sud-Est voltaïque. *Geologie. Valorisation*. National Polytechnic Institute of Lorraine, Nancy, France, pp. 205.

Pascal, M., Cheikh Faye, M., 1989. The Matam phosphate deposits. In: Notholt, A.J.G., Sheldon, R.P., Davidson, D.F. (Eds.), *Phosphate Deposits of the World. Phosphate Rock Resources*, vol. 2. Cambridge University Press, pp. 295–300.

Pascal, M., Sustrac, G., 1989. Phosphorite deposits of Senegal. In: Notholt, A.J.G., Sheldon, R.P., Davidson, D.F. (Eds.), *Phosphate Deposits of the World. Phosphate Rock Resources*, vol. 2. Cambridge University Press, pp. 233–246.

Patterson, S.H., Kurtz, H.F., Olson, J.C., Neeley, C.L., 1986. World bauxite resources—geology and resources of aluminum. In: U.S. Geological Survey Professional Paper, Washington, 1076, 130 p.

Perrouy, S., Aillères, L., Jessell, M.W., Baratoux, L., Bourassa, Y., Crawford, B., 2012. Revised Eburnean geodynamic evolution of the gold-rich southern Ashanti Belt, Ghana, with new field and geophysical evidence of pre-Tarkwaian deformations. *Precambrian Res.* 204–205, 12–39.

Peters, L., 2013. Volcanic facies and preliminary geochemical observations of the Goren greenstone belt, Burkina Faso. In: EGU General Assembly 2013, Vienna, Austria, EGU2013-10372.

Peucat, J.J., Capdevila, R., Drareni, A., Mahdjoub, Y., 2005. The Eglab massif in the West African craton (Algeria), an original segment of the Eburnean orogenic belt: petrology, geochemistry and geochronology. *Precambrian Res.* 136, 309–352.

- Pigois, J.-P., Groves, D.I., Fletcher, I.R., McNaughton, N.J., Snee, L.W., 2003. Age constraints on Tarkwaian palaeoplacer and lode-gold formation in the TarkwaDamang district, SW Ghana. *Mineralium Deposita* 38, 659–714.
- Pitman, W.C., Talwani, M., 1972. Sea floor spreading in the North Atlantic. *Geol. Soc. Am. Bull.* 83, 619–649.
- Pleiner, R., 2000. *Iron in Archaeology: The European Bloomery Smelters*. Published by Archeologicky ustav, AVCR, Prague, pp. 400.
- Pokryshkin, V.I., 1991. Global epochs of phosphate deposition in the Arabian-African region. *Int. Geol. Rev.* 33 (1), 15–24.
- Porter, S.M., Knoll, A.H., Affaton, P., 2004. Chemostratigraphy of Neoproterozoic cap carbonates from the Volta Basin, West Africa. *Precambrian Res.* 130 (1–4), 99–112.
- Poucllet, A., Allialy, M., Daouda-Yao, B., Easo, B., 2004. Découverte d'un diatrème de kimberlite diamantifère à Séguéla en Côte-d'Ivoire (Discovery of a diamondbearing kimberlite diatreme at Séguéla in Ivory Coast). *Comptes Rendus Geosciences* 336 (1), 9–17.
- Randgold Resources, 2009. Annual Report, 166 p.
- Randgold Resources, 2013. Delivering Value Again, Annual Report 2013, 231 p. Reipas, K., Coutoure, J.-F., 2008. Independent Technical Report, Taparko-Bouroum
- Gold Project, Burkina Faso. Report Prepared by SRK Consulting (Canada) Inc. for High River Gold. 31 March 2008, Project Reference Number, 120 p.
- Ritz, M., Bellion, Y., 1988. Structure of the southern Senegalo – Mauritanian basin, West Africa, from geoelectrical studies. *Tectonophysics* 148 (3–4), 235–240.
- Rombouts, L., 1987. Geology and evaluation of the Guinean diamond deposits. *Annales de la Societe geologique de Belgique* 110, 241–259.
- Rooney, A.D., Selby, D., Houzay, J.-P., Renne, P.R., 2010. Re–Os geochronology of a Mesoproterozoic sedimentary succession, Taoudeni basin, Mauritania: implications for basin-wide correlations and Re–Os organic-rich sediments systematics. *Earth Planet. Sci. Lett.* 289 (3–4), 486–496.
- Ross, D.E.G., 2002. The age of iron in West Africa. In: Heilbrunn Timeline of Art History. The Metropolitan Museum of Art, New York.
- Roussel, J., Lesquer, A., 1991. Geophysics and the crustal structure of West Africa. In: Dallmeyer, F R.D., Lecorche, J.P. (Eds.), *The West African Orogens and CircumAtlantic Correlatives*. Springer, Berlin, pp. 9–28.
- Schlishe, R.W., Withjack, M.O., Olsen, P.E., 2003. Relative timing of CAMP, rifting, continental breakup, and basin inversion; tectonic significance. In: Hames, W.E., McHone, J.G., Renne, P.R., Ruppel, C. (Eds.), *The Central Atlantic Magmatic Province. Insights from fragments of Pangea*. American Geophysical Union, Washington, pp. 33–60.
- Schlüter, T., Trauth, M., 2008. *Geological Atlas of Africa – With Notes on Stratigraphy, Tectonics, Economic Geology, Geohazards, Geosites and Geoscientific Education of Each Country*. Springer.

Schofield, D.I., Horstwood, M.S.A., Pitfield, P.E.J., Crowley, Q.G., Wilkinson, A.F., Sidaty, H.C.O., 2006. Timing and kinematics of Eburnean tectonics in the central Reguibat Shield, Mauritania. *J. Geol. Soc.* 163 (3), 549–560.

Schwartz, M.O., Melcher, F., 2003. The Perkoa zinc deposit, Burkina Faso. *Econ. Geol.* 98, 1463–1485.

Schwartz, M.O., Melcher, F., 2004. The Faleme Iron District, Senegal. *Econ. Geol.* 99, 917–939.

Semiani, A., Marignac, C., Fourcade, S., Peucat, J.J., Boiron, M.C., Joron, J.L., Kienast, J.R., 1995. Metallogenesis of the gold-bearing East-Ouzal shear-zone (Hoggar, Algeria). In: Pasava, J., Kribek, B., Zak, K. (Eds.), *Mineral Deposits.*, pp. 187–190, Rotterdam.

Shields, G.A., Deynoux, M., Culver, S.J., Brasier, M.D., Affaton, P., Vandamme, D., 2007a. Neoproterozoic glaciomarine and cap dolostone facies of the southwestern Taoudéni Basin (Walidiala Valley, Senegal/Guinea, NW Africa). *Comptes Rendus Geoscience* 339 (3–4), 186–199.

Shields, G.A., Deynoux, M., Strauss, H., Paquet, H., Nahon, D., 2007b. Barite-bearing cap dolostones of the Taoudéni Basin, northwest Africa: sedimentary and isotopic evidence for methane seepage after a Neoproterozoic glaciation. *Precambrian Res.* 153 (3–4), 209–235.

Siebenaller, L., Beziat, D., Salvi, S., 2011. WAXI Report for Volta Resources. Unpublished Report.

Sougy, J., Docteur-es-Sciences d'Etat Thesis 1961. Les formations paleozoiques du Zemmour Noir, Mauritanie septentrionale. Université Nancy, France, pp. 679.

Sougy, J., 1962. West African fold belt. *Geol. Soc. Am. Bull.* 73, 871–876.

Strickland, C.D., Martyn, J.E., 2002. The Guelb Moghrein Fe-oxide copper–gold–cobalt deposit and associated mineral occurrences, Mauritania: a geological introduction. In: Porter, T.M. (Ed.), *Hydrothermal Iron Oxide Copper–Gold and Related Deposits: A Global Perspective*. PGC Publishing, Adelaide, pp. 275–291. Stuart, H., 2010. Technical Report on the Tasiast Gold Mine, Islamic Republic of Mauritania. Prepared for Red Back Mining Inc, 102 p.

Tapsoba, B., Lo, C.-H., Wenmenga, U., Jahn, B.-M., Chung, S.-L., 2013. 40 Ar/39 Ar thermochronology of Paleoproterozoic granitoids of northeast Burkina Faso, West African Craton: implications for regional tectonics. *Precambrian Res.* 235, 208–229.

Taylor, P.N., Moorbath, S., Leube, A., Hirdes, W., 1988. Geochronology and crustal evolution of early Proterozoic granite-greenstone terrains in Ghana. In: *International Conference on the Geology of Ghana with Special Emphasis on Gold*, Geological Society of Ghana, Accra, pp. 43–45.

Taylor, P.N., Moorbath, S., Leube, A., Hirdes, W., 1992. Early Proterozoic crustal evolution in the Birimian of Ghana: constraints from geochronology and isotope geochemistry. *Precambrian Res.* 56 (1–2), 97–111.

Thiéblemont, D., Delor, C., Cocherie, A., Lafon, J.M., Goujou, J.C., Baldé, A., Bah, M., Sané, H., Mark, F.C., 2001. A 3.5 Ga granite–gneiss basement in Guinea: further evidence for early Archean accretion within the West African Craton. *Precambrian Res.* 108 (3–4), 179–194.

Thorman, C.H., 1976. Implications of klippen and a new sedimentary unit at Gibi Mountain, Liberia, West Africa, in the problem of Pan-African-Liberian age province boundary. *Geol. Soc. Am. Bull.* 87, 851–856.

- Tokarski, A.K., 1991. Tectonics of Hank sequence (upper Proterozoic) in the eastern part of Eglab massif, Reguibat shield (West African craton). *J. Afr. Earth Sci.* 12 (4), 555–560.
- Tshibubudze, A., Hein, K.A.A., 2013. Structural setting of gold deposits in the Oudalan-Gorouol volcano-sedimentary belt east of the Markoye Shear Zone, West African Craton. *J. Afr. Earth Sci.* 80, 31–47.
- Tshibubudze, A., Hein, K.A.A., Marquis, P., 2009. The Markoye Shear Zone in NE Burkina Faso. *J. Afr. Earth Sci.* 55, 245–256.
- Trompette, R., Affaton, P., Joulia, F., Marchand, J., 1980. Stratigraphic and structural controls of late Precambrian phosphate deposits of the northern Volta basin in Upper Volta, Niger, and Benin, West Africa. *Econ. Geol.* 75 (1), 62–70.
- Tunks, A.J., Selley, D., Rogers, J.R., Brabham, G., 2004. Vein mineralisation at the Damang Gold Mine, Ghana: controls on mineralisation. *J. Struct. Geol.* 26 (6–7), 1257–1273.
- Umeji, A.C., 1983. Geochemistry and mineralogy of the Freetown layered basic igneous complex of Sierra Leone. *Chem. Geol.* 39 (1–2), 17–38.
- Vanin, D., Michaud, M., Thalenhorst, H., Reipas, K., 2004, June. Taparko-Bouroum Project, Burkina Faso. High River Gold Mines Ltd, 43-101 F1 Technical Report, 185 p.
- Villeneuve, M., PhD thesis 1984. Etude géologique de la bordure SW du Craton Ouest africain. Université-Aix-Marseille III, France, 552 p.
- Villeneuve, M., 2005. Paleozoic basins in West Africa and the Mauritanide thrust belt. *J. Afr. Earth Sci.* 43 (1–3), 166–195.
- Villeneuve, M., 2008. Review of the orogenic belts on the western side of the West African craton: the Bassarides, Rokelides and Mauritanides. In: Ennih, N., Liégeois, J.-P. (Eds.), *The Boundaries of the West African Craton*, Geological Society Special Publication 297. , pp. 169–201.
- Villeneuve, M., Corneé, J.J., 1994. Structure, evolution and palaeogeography of the West African craton and bordering belts during the Neoproterozoic. *Precambrian Res.* 69, 307–326.
- Volta Resources, 2011. Annual Update 2011. Focused on Gold Production at Kiaka.
- Volta Resources Report, 12 p.
- White, A., Burgess, R., Charnley, N., Selby, D., Whitehouse, M., Robb, L., Waters, D., 2014. Constraints on the timing of late-Eburnean metamorphism, gold mineralisation and regional exhumation at Damang mine, Ghana. *Precambrian Res.* 243, 18–38.
- Yager, T.R., Bermudez-Lugo, O., Mobbs, P.M., Newman, H.R., Taib, M., Wallace, G.J., Wilburn, D.R., 2010. The mineral industries of Africa. In: *USGS 2008 Mineral Yearbook*, 25 p.
- Yao, Y., Robb, L.J., 2000. Gold mineralisation in Palaeoproterozoic granitoids at Obuasi, Ashanti region, Ghana: ore geology, geochemistry and fluid characteristics. *South Afr. J. Geol.* 103 (3–4), 255–278.
- Yardy, Y., 1993. *Petrologie des Laterites et des Sols Tropicaux*. Masson, Paris, pp. 461.

Fig. 1. A simplified map of the West African Craton that highlights the distribution of all known mineral deposits listed in the WAMDD. The limit of the craton is shown as a dashed line; map modified after Deynoux et al. (2006), Feybesse et al. (2006), Schofield et al. (2006), Gueye et al. (2007) and Villeneuve (2008).

Fig. 2. Space-time chart of distinctive West African mineral deposits. Absolute and general mineralization ages are extracted from the WAMDD. The main chart (A) emphasises the distribution of all mineral deposits in the West African Craton; and (B) presents details of the highly endowed Baoulé-Mossi domain including the Kédougou-Kéniéba Inlier during the Eburnean Orogeny.

Fig. 3. Generalized geological map of the West African Craton showing the distribution of gold types and their associated structural features.

Gold types:

○ Orogenic ⊙ Placer △ Intrusion-related ● IOCG ◊ Skarn ☆ Porphyry □ Occurrence

Archean

Paleoproterozoic

Eburnean granitoids

Birimian greenstone belts

Birimian sedimentary rocks

Pan-African / Variscan

Cover

Mesozoic dykes

Crustal-scale / regional fault

Outline of WAC

① Sefwi-Bibiani Belt

② Ashanti Belt

③ Tarkwa district

Fig. 4. Spatial distribution of iron ore, diamonds and bauxite deposit in the West African Craton, correlated with Mesozoic dolerites, and dykes (extracted from WAMDD).

Table 1

Key parameters for the formation of West African mineral deposits (extracted from WAMDD).

Main commodity	Mineralizing age	Deposit types	Location and distribution	Main structural events (ore formation)
Gold/copper-gold	Archean; 2.3–1.8	Orogenic; placer; skarn;	WAC: Area-wide across the	Liberian orogeny (intracratonic
	(Paleoproterozoic); 660–	intrusion-related; porphyry;	Baoulé-Mossi domain and KKI;	rifting in the Precambrian);
	550 Ma (Pan-African)	IOCG	Restricted marginal areas of	'Pre-Eburnean' Tangean event
			the Reguibat Shield; scattered	(arc accretion); Eburnean
			in mobile belts (Mauritanian,	orogeny (accretion of
			Dahomeyan belts;	NE-trending Birimian terrains;
			Kénéma-Man Shield	granitoid intrusions in
				intra-continental volcanic-arc
				setting); Pan-African orogeny
Iron ore	2.5–2.0 Ga (Paleoproterozoic);	BIF; ultramafic-mafic intrusion	WAC: Within and marginal of	Liberian orogeny
	Neoproterozoic/Cambrian;	related; Fe skarn; laterite	the Kénéma-Man Shield; along	(syn-depositional with host
	660–550 Ma (Pan-African);		the Archean/Paleoproterozoic	rock–cratonic sedimentation);
	Miocene		boundary of the Reguibat	Eburneanorogeny(upgrading
			Shield; restricted areas in the	due to folding and reactivation;
			Baoulé-Mossi domain, KKI and	development of skarns);
			Dahomeyan/Rokelide belts;	Pan-African orogeny
			basin margin of the Taoudeni	(re-working of Archean);
			and Volta basins	Meso-to Cenozoic weathering
				(laterization)
Bauxite	Mesozoic; Miocene	Laterite	Along the margin and within	Gondwana break-up (African
			southern part of the WAC:	surface development, intense
			Scattered in the Baoulé-Mossi	lateritic weathering)
			domain; isolated in the	
			Dahomeyan and Rokelide	
			belts; isolated at southern	
			Taoudeni basin margin; well	
			distributed in the Bové basin	
Diamond		zoic lamproites;	WAC: Mainly in the	Eburneanorogeny
		uvial	Kénéma-Man Shield; scattered	(intracratonic rift related);
			and restricted to isolated areas	Gondwana break-up
			in the Baoulé-Mossi domain;	(rift-related prior to
			scattered occurrences in Volta	continental break-up in
			and Bové basins and Rokelide	Mesozoic time); Cenozoic
			belt	intense weathering and
				erosion;
Manganese	Neoproterozoic–Paleoproterozoic;	laterite	WAC: Isolated in the	Liberian orogeny
	2.3–2.0 Ga;		Kénéma-Man Shield; scattered	(syn-depositional with host
	Neoproterozoic–Cambrian;		in the Baoulé-Mossi domain;	rock–cratonic sedimentation);
	660–550 Ma (Pan-African);		isolated in the N-Volta basin,	Eburneanorogeny
	Miocene		Dahomeyan and Rokelide belts	(intracratonic rift-related in
				greenstone belts); Pan-African
				orogeny; glaciogenic related;
				Eocene supergene weathering
Phosphate	Meso-Neoproterozoic;Ma (Pan-African);		WAC margin: Isolated clusters of phosphate accumulations in	Surrounding the Pan-African orogeny (shallow marine
			the Volta, Taoudeni, Bové	environment, continental
			adjacent WAC:	shelf); low-latitude location
				n
Base metals + REE				
Lead–zinc	Paleoproterozoic; 660–550 Ma	VMS	Within and outside the WAC in	Eburneanorogeny
	(Pan-African)		the surrounding mobile belts:	(magmatic–island arc setting);
			isolated distribution in the	Pan-African orogeny; Cenozoic
			Baoulé-Mossi domain,	weathering
			Dahomeyan/Pharusian belts	
Copper	Paleoproterozoic; 660–550 Ma	Mo–Cu porphyry;	WAC: Isolated in restricted	Eburneanorogeny
	(Pan-African); Cenozoic	granitoid-hosted;	areas of the Baoulé-Mossi	(magmatic–island arc setting);
		disseminated gossan;	domain; at the margin of the	Pan-African orogeny; Cenozoic
		fault-related	Kénéma-Man Shield; restricted	weathering
			to the northern part of the	
			Mauritania belt; isolated in the	
			Yetti domain	
Nickel	Archean; Paleoproterozoic;	Magmatic nickel sulfides;	the Kénéma-Man	Liberian and Eburnean
	ic); Cenozoic	laterites	margin; scattered and isolated	orogenies (intracratonic rifting
			in the Baoulé-Mossi domain;	in the Precambrian); accretion
			isolated occurrences in the	of Birimian terrane);
			northern tip of the Rokelide	Gondwana break-up;
			belt	Meso-Cenozoic intense
				lateritic weathering
		oterozoic; Orogenic; vein–pegmatite;	WAC: isolated occurrences in	Liberian orogeny (intracratonic
Tin	660–550 Ma (Pan-African)	orthomagmatic;	the Baoulé Mossi domain,	rifting in the Precambrian);
Yttrium		unconformity-related; alluvial	Reguibat Shield, Kénéma-Man,	Eburneanorogeny
Chromium		placer; podiform type	Mauritania and Dahomeyan	(accretional); Pan-African
Antimony			belts	orogeny

Table 2

Frequency distribution of West African mineral deposits, highlighting major deposit types for various commodities in consideration of their spatial distribution (based on the WAMDD).

	Deposit types	Frequency	Archean	Paleoproterozoic	Pan-African	Intracratonic and coastal basins
Gold/copper-gold	Orogenic	153	16	133	3	
	Alluvial/Paleo-placer	27	9	18		
	Intrusion-related (+ skarn)	5	1	4		
	Porphyry Au-Cu	10	1	6	3	
	IOCG	3			3	
		198				
Iron ore	BIF/Sedimentary	42	37	5		
	Skarn	7		7		
	Oolitic ironstone	7				7
	Laterite	18		1	10	7
	Intrusion-related	2		1	1	
		76				
Bauxite	Laterite	57		14	2	41
		57				
Diamond	Alluvial placer	11	9	2		
	Paleoplacer	3		3		
	Kimberlite	6	6			
		20				
Phosphate	Sedimentary	32				32
Manganese	Sedimentary	18		7	1	10
	BIF	12	3	7	2	
	Laterite	2		1	1	
		32				
Base metals + REE						
Lead–zinc		4		2	2	
Copper		5		3	1	1
Nickel–cobalt		12	10	2		
TantalumTinYttriumChromiumAntimony		7	1	4	2	
		28				
Heavy minerals		10		1		9
			93	221	31	109