The Great Mineral Fields of Africa

Introduction

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The mineral wealth and potential of the African continent has been recognised for centuries and various minerals have been exploited from different parts of the continent for many millennia. Gold, copper and iron mining and metallurgy are believed to have first developed in Egypt, in the third and second millennia BCE and somewhat later in other parts of the continent. Ancient gold workings abound in many parts of Africa, with some of these having become successful gold mines during the period of colonisation. Over the past half century, many of these mines, as well as some previously unknown deposits, have become major gold producers following various prospecting endeavours using more modern exploration techniques. Besides gold, copper and iron, a number of other minerals were exploited in pre-historic times from various parts of the continent. Notable amongst these were lead, zinc and tin. New deposits and occurrences, as well as extensions to existing deposits are still being discovered to this day as exploration continues unabated. The continent is one of the world's last frontiers of untapped minerals and many exploration and mining opportunities still exist.

The type and distribution of various mineral provinces, deposits and occurrences, is directly related to the geological and tectonic framework of the continent. While most of the major gold and all of the primary diamond (in kimberlite), platinum, chrome and vanadium deposits, are associated with Archaean age cratonic nuclei (with the exception of the gold deposits hosted in the Birimian of West Africa), many base metal deposits are hosted in lithologies of the younger Proterozoic metamorphic mobile belts. Extensive deposits of coal, oil, gas and heavy mineral sands, are hosted in large Phanerozoic basins and in Holocene sediments.

Reviews of some of the great mineral fields and examples of some deposits within them are presented in this volume, however in-depth accounts of the geology and the huge number of mineral deposits of the continent is beyond the scope of this publication. In order to place the deposits in their regional geological context, a brief review of the geological framework of Africa and its mineral fields is presented, with the simplified geological framework and the position of some major deposits and mineral fields being shown on the accompanying maps (Figures 1a, 1b and 2).

Geological Framework of Africa

Geological mapping of Africa was initiated in the 19th Century. Large areas of the continent were mapped in the 20th Century during the colonial era, with the establishment of national geological surveys across much of the continent. The task of mapping is however far from over, with large areas of Africa only mapped on a reconnaissance scale. The Commission for the Geological Map of the World (CGMW), an affiliate of the International Union of Geological Sciences (IUGS), has been responsible for coordinating several continent-scale maps including the 1:5 million scale International Geological Map of Africa (3rd edition 1985-1990), the International Metallogenic Map of Africa (2002) and the Tectonic Map of Africa (2010). Further regional and continental wide maps, at a variety of scales, have been produced by other organisations.

The simplified maps produced in this chapter (Figures 1a, 1b and 2) have been adapted to facilitate the description of some of the major mineral deposits and metallogenic provinces in Africa and have been compiled from various sources (see reference list at the end of the paper). The major geological entities of the African continent are briefly described below.

1. Archaean Nuclei, Cratons, Shields and Platforms

Continental crust is generally divided into old stable regions called **cratons**, which are characterised by thick lithosphere, and generally younger tectonised regions referred to as **mobile** belts, characterised by intense regional deformation and metamorphism, as well as a thinner lithosphere. Where the crystalline igneous and metamorphic rocks of the cratons are exposed, they are called **shields** or **shield areas**. In most places the cratons are covered by younger sedimentary basins, referred to as **platform sediments**. The cratons have grown in size throughout geological history, starting with Archaean nuclei consisting of greenstone belts, and tonalite-trondhjemite-granodioritic plutons and their deformed gneissic equivalents. Larger stable cratons formed through the accretion of belts of Proterozoic to Palaeozoic age rocks onto the Archaean cratonic nuclei, followed by stabilisation.

Figure 1a. Simplified Geological Framework of Africa.

Cratons, Shields, Mobile Belts, Massifs and Basins: AdI – Adrar des Iforas Massif; AS – Adrar Souttouf Massif; CKB – Choma-Kalomo Block; EAR – East African Rift; GB – Gariep Belt; IB – Irumide Belt; KAB – Karagwe-Ankorian Belt; KB – Kibara Belt; KI – Kayes Inlier; KKI – Kédougou-Kéniéba Inlier; LB – Lindian Belt; LBB – Liki-Bembe Basin; LiB – Limpopo Belt; MB – Mozambique Belt; MaB – Magondi Belt; MMB – Mbuji-Mayi Basin; MuB – Mauritanide Belt; NECB – North East Congo Block; RB – Ruwenzori Belt; RoB – Rokelide Belt; RT – Richtersveld Terrane; SIB – Southern Irumide Belt; SOB – Sembe-Ouessou Basin; UB – Uganda Block; UbB – Ubendian Belt; UsB – Usagaran Belt; WCB – West Congo Block; WNB – West Nile Belt.

Countries: CAR - Central African Republic; ROC - Republic of Congo (Brazzaville). The boundaries of the three great African cratons are defined by mapped or inferred sutures which separate them from adjoining regions. In places these boundaries occur within Pan African mobile belts.

Figure 1b. The Major Mineral Deposits of Africa. Location of significant mines, mineral deposits and mineral exploration projects. In parts, smaller deposits are shown in order to emphasise the Great Mineral Fields or important areas of mineralisation. Only selected commodities have been included. Major geological components of the three great African cratons and their surroundings are depicted in the background.

Collisions between, and suturing of, these larger cratons resulted in even larger composite cratons.

The continental African plate as we see it today consists of three major cratons, namely the West African, Greater Congo and Kalahari Cratons, which grew through Palaeoproterozoic and Mesoproterozoic orogenesis, and which had stabilised by the late Neoproterozoic. These three large Neoproterozoic cratons collided and accreted during the 550 ± 100 Ma “Pan-African” and “Brasiliano” tectonothermal events

which resulted in the amalgamation of the supercontinent of Gondwanaland. The present-day continental African plate is not entirely rigid and stable as there has been relative movement between its component cratons and the surrounding mobile belts, which have been re-activated along shear zones and other structures during Phanerozoic plate movements.

Africa acquired its current shape only after the Jurassic to Cretaceous break-up of the Gondwanaland supercontinent and the

formation of the Atlantic and Indian Oceans, and the Miocene opening of the Red Sea which resulted in the rifting away of the Arabian plate. The African plate is currently undergoing rifting along the East African Rift System, and its future shape will change should the Horn of Africa rift away completely.

During the Neoproterozoic another large craton, called the “West Nile” or “East Saharan” Craton, existed in what is now northeast Africa. This craton behaved in a rigid manner during Pan-African collisions with the West African Craton to form the Trans-Saharan Mobile Belt, and with the Greater Congo Craton to form the Oubanguide Belt. However, at different times during these collisional events, the thick lithospheric root under this “East Saharan Craton” became delaminated and was replaced by fertile asthenospheric mantle (Karmakar and Schenk, 2015). The region then lost its rigid “cratonic” character, and was intruded by large volumes of late Pan-African granites, Mesozoic to Cenozoic ring complexes, as well as large igneous provinces (LIPs) such as in the Nigerian ring complexes, the Tibesti uplift of northwestern Chad and southwestern Libya, the Cameroon volcanic line, the El Haruj el Aswad and other LIPs of central Libya, the Jebel Marra LIP in western Sudan and ring complexes of Jebel Uweinat and Jebel Arkenu, in southeastern Libya (Abdelsalam *et al.*, 2002). The East Saharan region is now referred to as the “East Saharan Metacraton” (Abdelsalam *et al.*, 2002), or the East Saharan Ghost Craton (Karmakar and Schenk, 2015).

The oldest rocks of the African continent are the Archaean nuclei of the cratons (Figure 1a). These nuclei (>2.5 Ga) are comprised of a variety of granitoids with associated greenstone belts. They represent the cores around which the African cratons were accreted and are of great significance from a metallogenic point of view. Several generally well defined Archaean nuclei are present on the African continent, including the Kaapvaal and Zimbabwe nuclei of the Kalahari Craton; the Tanzanian, Bomu (northeast Democratic Republic of Congo (DRC)), North Uganda, Kasai, and Ntem nuclei of the Greater Congo Craton, and the Kénéma-Man and Reguibat nuclei of the West African Craton.

The Archaean nuclei host a variety of world class mineral deposits (of various ages), of which gold, platinum, diamonds, iron ore and manganese are some of the most important (Figures 1b and 2).

2. Metamorphic Mobile Belts

The Archaean cratonic nuclei are surrounded by younger metamorphic mobile or orogenic belts. These mobile belts vary in age, from the Paleoproterozoic to Neoproterozoic. They represent the metamorphosed roots of older orogenic fold belts that have been subjected to reactivation at various stages through geological time. They vary considerably in size, geology, degree and nature of tectonism and metamorphism and in their contained mineral deposits. Mobile belts may represent collision zones between cratonic blocks, accompanied by major tectonic uplift, metamorphism and erosion. In many instances, the cratonic rocks have been subjected to reworking and metamorphism within the mobile belts. In other instances, the mobile belts comprise accreted terrains and collisional zones, or they may represent aulacogens, or failed rifts. The older mobile belts were those along which Archaean nuclei were originally sutured (or joined together along fault zones) and became stabilised with time through the acquisition of thicker lithospheric roots, becoming “cratonised,” and in this way the cratons have grown. All of the Proterozoic mobile belts older than the “Pan-African” mobile belts were already part of

the enlarged cratons during the formation of Gondwanaland. The three large African cratons that were involved in the Pan-African orogenic events, were themselves consolidated during earlier Palaeoproterozoic and Mesoproterozoic orogenies.

In the Kalahari Craton, the Kaapvaal and Zimbabwe cratonic nuclei were amalgamated along the Limpopo-Magondi orogenic belts during the Palaeoproterozoic. Mesoproterozoic belts, including the Natal-Namaqua, Rehoboth, Ngamiland and Choma-Kalomo Belts, surround this Archaean-Palaeoproterozoic core. In the Greater Congo Craton, Palaeoproterozoic belts such as the West Nile, Ruwenzori, Ubendian and Usagaran Belts, the West Central African Belt of Gabon, and the southern Angolan shield, together with the Mesoproterozoic Kibaran, Karagwe-Ankole, Irumide and southern Irumide Belts, led to the suturing of the older Archaean nuclei of the Kasai, Tanzania, North Uganda, Bomu and Ntem shields. In the West African Craton, the Archaean nuclei of Kénéma-Man and Reguibat, were accreted to the Palaeoproterozoic island arc and andean arc terrains of the Birimian volcano-sedimentary belts.

Sedimentation and basin development has taken place within some mobile belts. The sediments, which have undergone varying degrees of metamorphism, are frequently host to base metal deposits. They include the large Neoproterozoic copper-cobalt deposits of Zambia and the DRC, as well as the copper, lead and zinc deposits of the Bushmanland sequence of the Mesoproterozoic Namaqua Mobile Belt of South Africa and the Neoproterozoic Damara, Gariep and Kaoko Belts of Namibia. Granitoid intrusions into the mobile belts have given rise to important tin, tungsten, tantalum and rare earth element deposits such as those of the Damara Belt of Namibia, the Namaqua Belt of South Africa and Namibia, the Kibaran Belt of the eastern DRC, the Karagwe-Ankole Belt of Burundi, Rwanda and southwest Uganda, and the Nubian shield of Ethiopia, Somalia, Eritrea, Sudan and Egypt (Figure 1a).

3. Sedimentary Basins

Sedimentary basins, which also vary considerably in age, from Archaean to Holocene, occur throughout the continent and overlie parts of the cratons and mobile belts. They are hosts to important mineral deposits in various parts of Africa.

A remarkable succession of these basins, varying in age from 3.0 billion years to 1.8 billion years, have been preserved on the Kaapvaal Craton of South Africa and provide many clues regarding the development of the atmosphere and biosphere. They are of particular importance in that they contain some of the continent’s great mineral deposits including gold, iron and manganese (Figure 2). The size of the basins varies with age, with the oldest generally being the smallest and the youngest the largest. Some of the younger, larger basins extend onto the adjoining metamorphic mobile belts. In such instances they have been affected to varying degrees by metamorphism or tectonism related to varying phases of reactivation of the mobile belt(s).

In South Africa, the Main Karoo Basin is the largest Phanerozoic sedimentary basin, ranging in age from late Carboniferous to early Jurassic. Similar aged rift basins are found throughout South, Central and East Africa, and extend into most other parts of Gondwanaland. These basins host the *Glossopteris* flora which has given rise to many of the most important coalfields of Africa. In North Africa, large Palaeozoic to Cenozoic basins cover the Pan-African and older basement. Together with Cretaceous aged rift basins formed during

Figure 2. The Major Mineral Deposits and Mineral Fields of the Kalahari Craton, Southern Africa. Significant mines, mineral deposits and mineral exploration projects of the Kalahari craton and surrounding areas. The mineral deposits shown provide an overview of the substantial mineral legacy of the Kalahari Craton. Only major mineral commodities have been included.

the opening of the Atlantic Ocean, they are hosts to the major accumulations of oil and gas in Africa (Figure 1b). Recent coastal sediments host significant alluvial diamond fields and important heavy mineral sand deposits (Figures 1b and 2).

4. Igneous Intrusions

A feature of the continent is the large variety and age span

(Archaean to Holocene) of predominantly mafic, magmatic intrusions into cratons, mobile belts and sedimentary basins. These intrusions may take the form of pipes, volcanic complexes, dykes, sills, laccoliths, lopoliths, significant layered intrusions (Bushveld, Great Dyke) and large igneous provinces. They vary in composition from ultramafic to mafic and felsic, with carbonatite and kimberlite intrusions also present. These intrusions host some of the most important mineral deposits of the continent. Rare earth elements, phosphate and copper

are associated with alkaline intrusives, while all the important primary diamond deposits occur on the cratons and are related to kimberlite pipes and dykes. A variety of intrusions of various ages and types are also an integral part of the mobile belts and, in places, host important mineral deposits. Ring complexes of alkaline granite and syenite are commonly found in Africa, especially in those regions that experienced Pan-African orogenesis. They host deposits of tin, tantalum, niobium, tungsten, rare earth elements, beryllium and fluorite.

Mineral Deposits and Mineral Fields

The mineral deposits and mineral fields of the continent are briefly discussed according to their commodities, geological setting and tectonic framework, as outlined above and shown in Figures 1a, 1b and 2.

1. Gold

The mining of gold has always been associated with Africa, with gold artefacts and jewellery having been found in localities as far afield as Egypt, Nubia (Sudan), West Africa and South Africa (Mapungubwe on the banks of the Limpopo River). Ancient gold workings abound in many parts of the continent including South Africa, Zimbabwe, West, North and Northeast Africa amongst others. In Ghana, ancient workings were a prelude to the founding of the great Ashanti Empire and the establishment of the famous Gold Coast, the forerunner of modern day Ghana.

Most of the large goldfields of the continent occur in the ancient cratons, commonly in greenstone belts and more rarely, associated with granitoids. Gold mineralisation, which can occur in a variety of host rocks, is frequently associated with major structures, or important terrain boundaries, or zones of competency contrast. The deposits are generally classified as orogenic gold deposits. In West Africa most of the gold deposits, which are not unlike those of the Archaean greenstone belts, are associated with major structures in the younger Palaeoproterozoic volcano-sedimentary belts of the West African shield.

The Nubian shield, the Damara Belt gold province of central Namibia and the Hoggar region of the Trans-Saharan Mobile Belt, are important younger Neoproterozoic gold provinces which are currently attracting attention from exploration and mining companies.

Goldfields of the Archaean Cratonic Nuclei

The Archaean greenstone belts of the Kaapvaal Craton of South Africa are perhaps the best studied and host small- to medium-sized gold mines. Most of the gold has been won from the Barberton Greenstone belt, which is well known for the clues it has yielded regarding early life and earth processes. It is also the type area for komatiites, mafic and ultramafic volcanics and intrusives, which are associated with a number of important types of mineralisation in Africa and elsewhere. Several distinct styles of gold mineralisation have been identified in the Barberton Greenstone belt, including lode gold deposits associated with a variety of structural settings. More competent and reactive rock types and lithologies, with competency contrast, are particularly favourable hosts and carbonated shear zones within ultramafic rocks are often associated with antimony mineralisation and constitute a particular style of mineralisation in the Barberton and Murchison Greenstone belts. The Consolidated

Murchison mine was the largest producer of antimony in the world for several decades. Sulphidised banded iron formations also host gold mineralisation, as do iron-rich shales and greywackes which are also associated with arsenical mineralisation.

One of the earliest sedimentary basins deposited entirely within the confines of the Kaapvaal Craton is the Witwatersrand Basin which formed some 2.8 billion years ago. It is the world's largest known gold deposit and was the world's largest gold producer for 100 years, having produced a third of all the gold ever mined (see Tucker *et al.*, this volume). The closest analogy to the Witwatersrand deposits outside of South Africa, are the gold-bearing conglomerates of the Tarkwa Belt in Ghana, hosted by sediments of the West African Shield (see Smith *et al.*, this volume).

Over 4,000 ancient gold workings are known from the Zimbabwe Craton and numerous small- to medium-scale gold mines have produced, and in some cases are still producing, gold. Nearly all of these mines were established on ancient workings. Models of gold mineralisation are similar to those for the Kaapvaal Craton, with a number of large mines such as the Gaika being associated with antimony mineralisation in carbonated ultramafic rocks. All the large gold mines are associated with major structures, with mineralisation occurring in banded ironstones and other more competent rock types including mafic and felsic volcanics. The older multi-million ounce gold deposits in Zimbabwe include the Globe and Phoenix, Cam and Motor and Sherwood Star Mines, while a new generation of restarted old mines and new mines are operating at present, an example being the Blanket Mine (Foster *et al.*, 1986).

The Congo Kasai Craton covers a large area in central Africa but it is largely covered by younger sediments of the Congo Basin. A number of small gold deposits occur in an Archaean granite greenstone window in the southwestern DRC and northeast Angola and in the northwestern portion of the craton in the Republic of Congo and Cameroon (Figure 1a). Virtually all the deposits have a resource of less than one million ounces of contained gold.

Gold has been extracted from the northeastern portion of the Congo Craton since colonial times, with mines such as Kilomoto having produced significant amounts of the metal. Recent work has established a mineral resource of over 20 million ounces of gold at the old Kibali Mine, where mineralisation occurs in a number of high grade shoots along a major shear zone.

Following a spate of exploration programmes, commencing in the 1980s, greenstone belts of the Tanzanian Craton, which had previously been known to host a few small gold mines based on ancient workings and developed during colonial times, now contains several world class gold mines such as the Geita and Bulyanhulu. A number of mineralisation models similar to those developed and postulated for gold deposits in the other Archaean cratons and useful for gold exploration programmes, have been established (Henckel *et al.*, this volume). Gold mineralisation is associated with several greenstone belts in the Kénéma-Man Craton of Liberia and Sierra Leone. The mineralisation occurs in structurally controlled quartz-pyrite-arsenopyrite lodes and is frequently hosted in banded iron formation and amphibolites. The 1.7 million ounces of gold at the New Liberty gold mine in western Liberia are hosted in quartz lodes within an ultramafic body. A major shear zone in the central portion of eastern Liberia is considered to be the boundary between the Archaean and Palaeoproterozoic and this has become an important exploration target.

The gold potential of the Reguibat Archaean nucleus in northwestern Africa is considered to be limited, since it consists mainly

of granitoid gneisses and amphibolite-grade supracrustals. An exception is the 9.6 million ounce Tasiast deposit, hosted by banded iron formations in a narrow greenstone belt on the very southern edge of the Reguibat Shield (see Robertson and Peters, this volume).

Goldfields of the Proterozoic Shields

Birimian of the West African Craton

The West African Craton comprises the Kénéma-Man and Reguibat Archaean cratonic nuclei, separated by and flanked to the east by a vast area of Palaeoproterozoic rocks of the Birimian Supergroup, consisting of faulted and folded volcano-sedimentary basins and volcanic belts, with a variety of intrusive granitoids. In places, notably in Ghana, the Birimian volcano-sedimentary rocks are overlain by a younger succession of dominantly arenaceous sediments with associated conglomerate layers, known as the Tarkwaian Group. Important gold deposits are hosted in the conglomerate bands as well as being structurally controlled.

Some seventeen gold mines, most of which have come into production in the past 20 years, occur in the Palaeoproterozoic Birimian terrain of West Africa that has become one of the world's premier gold provinces. Various gold deposit types and models have been recognised including orogenic intrusion-related, skarn-hosted, porphyry-hosted, and iron oxide-copper gold (IOCG) deposits. Although major controls of mineralisation are broadly similar, gold distribution patterns are highly variable at a local scale (see Robertson and Peters, this volume and Smith *et al.*, this volume).

Ubendian Belt, Tanzania- Lupa and Mpanda Goldfields

The Palaeoproterozoic Ubendian Mobile Belt of southwestern Tanzania, with a complex history of multiple collision, accretion and strike-slip reactivation events, has two goldfields, the Lupa and Mpanda, which were formed during two different tectonic events. The Lupa gold mineralisation is in the form of auriferous quartz-sulphide veins, emplaced between 1.95 Ga and 1.87 Ga, during transpressional orogenesis (Lawley *et al.*, 2013a, b). The Mpanda goldfield consists of quartz-galena veins emplaced during the Mesoproterozoic Kibaran orogeny (Nanyaro, 1989).

Limpopo Belt, Zimbabwe and South Africa

The Limpopo Mobile Belt, consisting of upper amphibolite to granulite facies gneisses, is found between the Archaean Zimbabwe and Kaapvaal nuclei of the Kalahari Craton. It has a polyphase structural and metamorphic history, which records events at approximately 2.6 Ga, and at approximately 2.0 Ga. The North Marginal Zone of the Limpopo Belt hosts the high grade Renco gold mine in Zimbabwe (with production of 1.19 Moz of gold from 7.2 Mt ore at an average grade of 6 g/t Au), whilst the South Marginal Zone of the Limpopo Belt in South Africa, hosts the small Doornhoek gold mine. These deposits, which were formed during prograde metamorphic events, demonstrate unequivocally, the possibility of forming economic gold deposits under granulite facies conditions. They open up possibilities for gold exploration in vast areas of Africa within high-grade gneisses, which have traditionally been neglected by exploration companies in the past.

Goldfields of the Pan-African Mobile Belts

The Nubian Shield

The Nubian Shield and coeval rocks in the western part of the Arabian Peninsula form the composite Arabian-Nubian Shield (ANS), which flanks the Red Sea and comprises predominantly juvenile Neoproterozoic rocks. In northeast Africa, the Nubian Shield stretches from the Sinai Peninsula and Egypt in the north, through Eritrea and Ethiopia to Sudan, South Sudan, Somaliland and Kenya in the south (Figures 1a and 1b).

It evolved as an accretionary orogen over a period of approximately 300 million years, from about 850 to 550 Ma. Rock types present include metavolcanic and metasedimentary rocks, gabbros, gneisses, granitoids, and ophiolites, amongst others. The most important types of gold deposits include: gold associated with volcanogenic massive sulphides (VMS) and oxide gold in the weathered zones above the VMS deposits; and gold-bearing quartz-vein systems, or orogenic gold (Johnson, 2016; Groves, 2015). To a lesser extent, other types of gold occurrences include alluvial gold and gold mineralisation associated with altered ultramafic rocks (listwaenite), banded-iron formation, and tin±tungsten±molybdenum-bearing granites.

In 2014 there were more than 30 exploration and/or mining projects targeting gold, gold-copper, or gold and other base metals in the Nubian shield (Brooke Patrick Publications, 2014). VMS-hosted gold projects include, amongst others, the Bisha gold-silver-copper-zinc mine (*circa* 0.72 Moz contained gold) in Eritrea (Gribble *et al.*, 2013), and the Hassai Mine and VMS-hosted gold project in Sudan. Orogenic gold projects include, amongst others: the Sukari gold mine (measured and indicated mineral resource of approximately 13 Moz contained gold (Centamin, 2015)) and the Hamash Gold Mine in Egypt; the Lega Dembi Mine, Sakaro Mine and Tulu Kapi Project in Ethiopia; the Koka (Zara) Project and the Asmara Project in Eritrea; and the Galat Sufar South Project in Sudan.

Other mineralisation associated with the Nubian Shield includes base metals, banded iron formation, tin-tungsten, tungsten-molybdenum, tin-niobium-tantalum, platinum, chrome and mica.

The Damara Mobile Belt, Namibia

The Damara Mobile Belt of Namibia is a Pan-African belt formed by the collision of the Kalahari and Greater Congo Cratons. It consists of strongly deformed platform to basinal sedimentary and volcanic sequences, which have been intruded by syn- and late-tectonic granites, and post-orogenic alkaline ring complexes. The deformed rocks, which belong to the Neoproterozoic Damara Supergroup, are host to a variety of mineral deposits, some of which were formed by fluids mobilised during regional deformation (lead, zinc, copper), while others are related to intrusive granitoids and pegmatites (e.g., uranium, tin, tungsten, and tantalum-niobium). There are two large gold deposits in the Damara Belt, the Navachab Mine, which commenced operations in 1988, and the Otjikoto Mine, which opened in 2014.

The Navachab gold deposit, the largest gold mine in Namibia, lies in the southern Central Zone of the Damara Belt and has an estimated ore reserve of 1.2 Moz of gold, at an average grade of 1.6 to 2.0 g/t Au (Steven and Badenhorst, 2002). The gold is hosted in structurally-controlled quartz veins with sulphides, and near-massive

sulphide lenses, emplaced into an amphibolite grade metamorphosed shelf-type carbonate succession consisting of biotite schists, calc-silicate rocks, and dolomitic marbles. The ore minerals include sulphides such as pyrrhotite, chalcopyrite, sphalerite, arsenopyrite, bismuth, bismuthinite and bismuth tellurides, together with gold. Because the calc-silicate host rocks contain assemblages with garnets, clinopyroxenes, and potassic (K)-feldspar, the mineralisation was regarded as a 'skarn' deposit, possibly related to regional granitic intrusions. Recent petrological work indicates that these assemblages are the result of high-temperature, low pressure amphibolite grade metamorphism (Wulff *et al.*, 2010).

The mineralisation at Navachab and the surrounding prospects is found in the near-vertical north-western limb of a doubly plunging anticlinal dome, the Karibib Dome. The Navachab district potentially hosts more than 5 million ounces of gold. There is no isotopic evidence for the involvement of granitic sources for the fluids, although regional granites related to late-Damara extension at 530 - 500 Ma, may have played a role in imparting the very high geothermal gradients (80°C/km) in the mineralised region (Wulff *et al.*, 2010).

The size and style of mineralisation at the Otjikoto gold mine appears to be similar to that at Navachab, but there are no detailed published studies as yet. There is a declared Probable Mineral Reserve of 26.3 Mt of ore at an average grade of 1.41 g/t Au, containing 1.2 Moz of gold (B2Gold, 2016).

Gold in the Hoggar, Tuareg Shield (Trans-Saharan Mobile Belt)

The Hoggar region of southern Algeria is the central part of the Tuareg Shield, which is the northernmost exposed portion of the Trans-Saharan Mobile Belt. This large region consists of a number of different Pan-African island arc terranes, with slivers of older Archaean and Palaeoproterozoic continental fragments juxtaposed along major north-south trending shear zones. This mobile belt was the product of collision and terrane accretion during the Neoproterozoic, when the West African and the East Saharan Cratons collided. Within the Hoggar region, the Amesmessa and Tirek gold deposits are the only two currently and past producing gold mines respectively, within this large Pan-African mobile belt. Numerous smaller deposits have been identified between these two deposits, and the region appears to have potential for more deposits of a similar type (Figures 1a and 1b).

The Amesmessa gold deposit is situated about 450 km southwest of Tamanrasset, in the Hoggar region of southern Algeria, close to the Mali border. It lies along a major north-south ductile shear zone, which is two to three kilometres wide and 50 kilometres long, forming a terrane boundary that separates the Archaean, In Ouzzal terrane, from a Palaeoproterozoic terrane to the east of it. The mineralisation is hosted by quartz veins containing pyrite, galena and rare sphalerite, together with gold. The veins are mainly shear hosted, and rarely occupy tension gashes. There are dozens of vein clusters found over a north-south strike length of 12 kilometres. The Amesmessa mine has a total mineral resource, in 16 veins, hosting 1.4 Moz of gold, to a depth of 400 m (ENOR, 2012).

The Tirek gold-silver deposit is situated 64 km north of Amesmessa, and is similar in its geology. It was mined between 2001 and 2007, with 57,000 ounces of gold produced by a carbon in leach (CIL) process. It has an estimated mineral resource of 0.59 Mt of ore at an average grade of 25 g/t Au, or 0.48 Moz contained gold (ENOR, 2012).

2. Diamonds

The association of diamondiferous kimberlites with "rigid cratonic nuclei of respectable antiquity" in Africa, was recognised by Kennedy (1964). This association was subsequently formalised by Clifford (1966) and became known as "Clifford's Rule", which states that diamond bearing kimberlites are to be found only on the stable cratonic nuclei, where the minimum age of the last thermal event is 2,500 Ma, or Archaean. The deep "cold roots" of the cratons have temperatures low enough and pressures high enough for diamonds to form in what is termed the diamond window. Diamond bearing Kimberlites occur in all the Archaean nuclei of Africa, with some of the largest pipes and dykes emplaced into the Kaapvaal and Zimbabwe cratons. They range in age from Archaean to Eocene (see de Wit *et al.*, this volume).

A variety of sediments containing diamonds, all derived from the diamond-bearing kimberlites of the Archaean cratons, occur throughout Africa. Uplift and erosion of the high interior plateau of southern Africa in particular, has resulted in a more than one kilometre lowering of the old land surface formed on the cratons and adjoining areas, particularly in the valleys of the Orange and Vaal rivers of South Africa. Diamonds liberated from the kimberlites were washed down the rivers and concentrated in gravels, dating from about 18 million years ago. These now form old terraces at various elevations, flanking the rivers. Alluvial diamonds were finally concentrated by wave action along the palaeo-beaches of the southwest African coastline and were also concentrated on the offshore African continental shelf (marine diamonds). Alluvial diamonds are also associated with the river systems of the Angola, Congo and Kénéma-Man Cratons (see de Wit *et al.*, this volume).

3. Platinum Group and Associated Metals

Africa hosts by far the world's greatest resources and reserves of the Platinum Group Elements (PGEs) (platinum, palladium, rhodium, ruthenium, osmium, and iridium) as well as chrome, and vanadium. These metals and minerals have been concentrated in layers in mafic rocks of the Bushveld Complex of South Africa (see Viljoen, this volume) and the Great Dyke of Zimbabwe. The Bushveld Complex was emplaced as a series of sills or sheets, intruded mainly into sedimentary formations of the Transvaal Supergroup in the north central portion of the Kaapvaal Craton. The first manifestation of this igneous activity commenced about 2.05 Ga, with the outpouring of huge amounts of felsic volcanics below which the mafic rocks were emplaced as sheets. Magmatic segregation within the various intrusive sheets gave rise to extensive layers containing concentrations of the PGEs, together with copper and nickel sulphides, as well as chromite, in chromitite layers within the mafic to ultramafic rocks. Vanadium-bearing titaniferous magnetite and phosphate (apatite)-bearing layers, occur at the top of the sequence of layered mafic rocks.

Towards the waning phase of plume activity, sheets of granitic magma were emplaced above the uppermost mafic rocks. The younger, more evolved of these I-type granites contain significant concentrations of tin, fluorite, and rare earth elements. Significant andalusite deposits have formed and are exploited, within the metamorphic aureole of the Bushveld Complex. Phalaborwa, a pipe-like alkaline intrusion, was emplaced into Archaean granitic rocks of the northeast Kaapvaal Craton at about the same time as the Bushveld Complex. The Palabora Mine is a significant producer of phosphate,

copper, vermiculite, titanomagnetite and a number of other commodities including gold, silver, platinum group elements, rare earth elements, uranium and thorium. The composition and age of emplacement of the Phalaborwa Complex suggests that it may have a genetic link to the Bushveld Complex.

The Great Dyke of Zimbabwe is a large, layered ultramafic to mafic igneous complex, consisting of four amalgamated boat-shaped, funnel-like intrusions. It averages 8 km in width, is 550 km long and bisects the craton in a north-northeasterly direction. The 2.54 Ga Great Dyke contains the world's second largest resources and reserves of the PGEs after the Bushveld Complex. The mineralisation which is also associated with significant copper and nickel sulphides, occurs in a pyroxenite layer several metres thick that is present in the upper portion of the funnel shaped intrusions, in each of a number of discrete compartments along the strike of the dyke. The dyke also hosts significant amounts of high grade chromite occurring in a number of seams, or layers of chromitite, lying several hundred metres below the PGE horizon. These seams have a greater strike extent than the PGE-bearing horizons and have been fairly extensively mined, mainly from underground operations. Important high grade chromite deposits also occur in close proximity to the Great Dyke, notably at Shurugwe. In this instance, the chromite occurs in an older greenstone belt, and is of the podiform type.

4. Iron Ore

Iron ore has been mined for centuries on the African continent and used both for the manufacture of iron-age tools and as a pigment for paint used in art and self decoration. Deposits of variable size occur throughout the African continent, many situated at the sites of ancient workings. With the increase in demand for iron ore in the last decade, extensive exploration programmes have been undertaken, with resources and reserves having been estimated for several world class deposits. Major expansions of traditional iron ore deposits and the development of some new mines also took place following the unprecedented demand for iron. The bulk of the iron deposits occur in the older rock sequences of the Archaean greenstone belts and particularly the overlying Paleoproterozoic volcano-sedimentary sequences and basins of the cratons.

Banded iron formation-hosted high-grade (>60 wt% iron [Fe]) hematite ore deposits in Paleoproterozoic sedimentary basins made up the bulk of the world's iron ore production of 3.1 billion tonnes in 2014 (USGS, 2015) and of its reserves. These deposits currently produce virtually all of South Africa's annual supply of 68 Mt of high-grade hematite ore. South Africa was the seventh largest producer of iron ore in the world at the time of writing (USGS, 2015) and the size and variety of its BIF-hosted high-grade iron ore deposits are of global significance and high economic value. Studies of South Africa's deposits have also led to a better understanding of the geological setting and genesis of these ores that can be applied to other iron ore deposits in the world (see Smith and Beukes, this volume).

Banded iron formations in Archaean greenstone sequences, particularly in areas of structural disturbance where supergene enrichment has taken place, have given rise to a number of iron ore deposits in the Kaapvaal and Zimbabwe cratons and in the cratonic nuclei of the Greater Congo Craton. The Bomvu Ridge (Ngwenya) iron ore deposit (on the south eastern flank of the Barberton Greenstone belt in Swaziland), was mined in prehistoric times, some 40,000 years ago, for pigment and from the early 1960s, for some

30 years, by modern opencast methods, then again more recently from 2011 to 2014 (reprocessing of the existing mine dumps). Similar enriched banded iron formations in the greenstone belts of the central Zimbabwe Craton have been mined and a successful steel plant, now called the Zimbabwe Iron and Steel Company (ZISCO), was established in the 1960s. The deposits near Kwe Kwe and at Mt Buchwa are the most important.

Deposits of the Archaean iron belt of Cameroon, Republic of Congo, and Gabon are grouped into those north and south of the Francavillian basins, i.e. the northern Archaean Ntem Block (e.g. Nkout, Mbalam-Nabeba, Avima, Badondo and Belinga Projects) and the southern Archaean Chaillu Block (e.g. Mayoko-Moussondji, Mayoko and Zanaga) respectively. The iron deposits are associated with Archaean itabirites, interstratified with volcano-sedimentary greenstone belt successions. The more important deposits are those which have undergone supergene enrichment, with the primary deposits generally being of lower grade. Mineralisation is predominantly hematite, with accessory goethite and magnetite.

Projects in the Ntem Block, at various stages of exploration and development, have identified extensive resources (multi-billion tonne) in primary and supergene enriched banded iron formation, with typical grades of between 30% to 35% Fe and >60% Fe respectively. The BIF mineralisation can outcrop for several tens of kilometres. The best known deposit from a historical perspective is the Belinga deposit in Gabon with an estimated mineral resource of over one billion tonnes at >60% Fe (historic estimate) (Martini *et al.*, 2002). The Mbalam/Mbarga-Nabeba deposit, which straddles the Cameroon-Republic of Congo border, has combined Ore Reserves of 517 Mt at 62.2% Fe (Sundance Resources, 2015). Other deposits include: Belinga Sud, Mebaga, Kango North, Batoala, Boka Boka, Minkebe, and N'gama in Gabon; Ntem, Nkout, Binga, Djadom, Mamelles, Lele, and Bikoula in Cameroon; and Avima (690 Mt at 58% Fe) (Core Mining, 2012), Badondo, and Youkou in the Republic of Congo (Figure 1b).

The main iron ore projects within the Chaillu Block, characterised by significant primary BIF resources with components of higher grade oxidised mineralisation, include the Zanaga, Mayoko, and the Mayoko-Moussondji Projects. In this region, BIF mineralisation outcrops for several tens of kilometres (de Waele *et al.*, 2015).

In West Africa, the iron deposits of the Man Craton occur mainly within the greenstone belts of the Archaean basement, overlying Palaeoproterozoic volcano-sedimentary successions, and late Neoproterozoic mineralisation, related to the Rokelide Orogen, in Liberia, Guinea, Côte d'Ivoire and Sierra Leone (de Waele *et al.*, 2013). Significant enriched iron ore deposits have been mined and are being investigated in banded iron formation in the eastern part of the Kénéma-Man Craton in Liberia. The Nimba Mountains, which traverse Liberia and Guinea, host a number of significant iron ore deposits including Tokadeh in Liberia, which has attracted the largest mining investment since the civil war. The Tokadeh mine, together with the Gangra and Yuelliton deposits, form part of the Western Range Project with a mineable resource estimate of 320 Mt at 50% Fe and an additional 2,000 Mt resource at 40% Fe (Kukielski, 2010). Other deposits in Liberia include the Bomi Hills, Mano River, Bea Mountain, Mofe Creek, Mt Ginka, and Bong in Liberia (Figure 1b).

The Kalia deposit (Archaean BIF) in Guinea has an oxide mineral resource of 124.2 Mt at 53.5% Fe. In Guinea, the Simandou range consists of a sequence of deformed itabirites, phyllites and quartzites within Proterozoic basement rocks. At Pic de Fon and Oueleba

(Simandou), the itabirites have been enriched to form hematite and hematite-goethite mineralisation. The Simandou deposit is considered the largest undeveloped iron ore resource in the world with a probable ore reserve of 1,844 Mt at an average grade of 65.5% Fe and an estimated mineral resource of 835 Mt at an average grade of 65.0% Fe (RioTinto, 2014, 2015). There has been some debate as to whether the iron ore deposits are Archaean or Palaeoproterozoic in age (Billa *et al.*, 1999).

The Archaean Tonkolili deposit with an estimated 12.8 billion tonnes of iron rich duricrust, saprolite along with magnetite mineralisation (African Minerals, 2010) and the Neoproterozoic Marampa iron ore deposit of Sierra Leone, are important resources due for development when the present mining cycle improves.

In the Tiris Region of northern Mauritania, both hematite and magnetite deposits are mined from Archaean and Palaeoproterozoic successions of the Reguibat Shield. The main hematite deposits currently being mined are TO14 (Kédia) and M'Haoudat, which account for 60% of the total iron ore produced by the Société Nationale Industrielle et Minière de Mauritanie (SNIM). The Guelb El Rhein deposit is the only magnetite deposit currently being mined and it contains several hundred million tons of proven reserves, at an average grade of ~37% Fe (SNIM, 2013) (Figure 1b).

Some of the world's biggest iron ore deposits occur in distinctive Palaeoproterozoic sedimentary basins which were deposited on a stable, cratonic granite-greenstone basement. The Transvaal Basin of the Kaapvaal Craton is an example of such a basin and it hosts the huge Sishen and Thabazimbi deposits of South Africa. The iron ore occurs at the top of a thick sequence of dolomites, with chert rich and chert poor formations and with well-developed stromatolite structures in places (Smith and Beukes, this volume).

In southwestern Gabon, the Tchibanga deposit is a Neoproterozoic banded iron formation. Mineralisation is associated with fine-grained hematite and goethite. Significant high grade mineralisation in the form of canga (a surface enriched secondary iron ore type of mineralisation), grading at an average of 45.2% Fe, has been delineated over a surface area of 1.95 km² (Iron Ridge Resources, 2015).

Younger important iron deposits are known from Algeria and include deposits of the North African Palaeozoic Ironstone Belt which extends from Libya to western Sahara and which contains a number of identified sedimentary iron ore deposits of Ordovician to Devonian age, e.g. Gara Djebilet (1.7 billion tonnes at a grade of 57% Fe) (Taib, 2009) and Mechri Abdelaziz. Iron deposits, which are currently being exploited, are also known from younger Mesozoic sedimentary successions in Algeria, for example Ouenza (120 to 150 Mt of 53% Fe to 60% Fe) and Bou Khrada (Porter, 2005).

5. Manganese

Africa hosts just over 80 percent of the world's known land-based resources of manganese metal and produced some 41.1 percent of the 18 million tonnes of manganese metal contained in ores that were mined during 2014 (Beukes *et al.*, this volume). The deposits are mainly of sedimentary and supergene origin comprising four major types, namely banded iron formation (BIF)-hosted, black shale-hosted, oolitic and supergene/karst-hosted types. The BIF-hosted Kalahari Manganese Field (KMF) is by far the largest of these deposits with some 4,200 million tonnes of manganese metal that represents about 77 percent of the world's known land-based resource. Large, black

shale-hosted deposits are represented by those of the Francevillian succession in Gabon, the Nsouta in the Birimian succession of West Africa and the Kisenge district of the DRC. They typically consist of supergene manganese oxide ores capping 2.2-2.0 Ga manganese carbonate-bearing black shale protomorphs. Significant karst-hosted deposits are represented by the ~2.0 Ga Postmasburg Manganese Field in South Africa and the Cretaceous Imini district in Morocco. The ~1.9 Ga Tolwe manganese deposit in South Africa is the only oolitic deposit from which some minor production has come in the past (Beukes *et al.*, this volume).

6. Nickel

The nickel deposits of Africa occur mainly in the cratonic nuclei, although the intrusive mafic-ultramafic rocks of this recently defined east African nickel belt are considered to be part of a young Mesoproterozoic age, Kibaran, igneous event (Evans *et al.*, this volume). Nickel mineralisation is almost invariably associated with copper and Platinum Group Elements (PGEs), in varying concentrations. Secondary nickel deposits in the form of concentrations in laterite, also occur in certain tropical areas of Africa. Nickel mining in Africa takes place principally in Botswana, South Africa and Zimbabwe, with much of the South African and Zimbabwean production being a by-product of the platinum-group element mining in the Bushveld Complex and Great Dyke. Several large nickel deposits have been discovered elsewhere in Africa but, until recently, their development has been hindered by political risk and limitations in energy and transport infrastructure.

Nickel in Archaean Cratonic Nuclei

The greenstone belts of the Zimbabwe Craton are hosts to nine important nickel ore bodies (with the Trojan, Empress and Shangani mines being the largest), most of which have similarities to the Kambalda type nickel deposits of the Yilgarn Craton of Western Australia. Massive, as well as disseminated nickel copper sulphide ore bodies, often associated with PGEs, occur in a range of mafic and ultramafic rock types generally with komatiitic affinities. In some instances mineralisation is associated with the basal portions of komatiitic flows or komatiitic intrusions of the lowermost Sebakwaian group, while in other instances mineralisation is hosted in gabbroic intrusions. The genetically comparable Selebi-Phikwe nickel copper deposit in Botswana occurs in the Limpopo metamorphic mobile belt which separates the Kaapvaal and Zimbabwe Cratons. It is likely that the Selebi-Phikwe orebody occurs in metamorphosed mafic rocks of the craton.

The world class Nkomati nickel deposit is situated in a linear zone of differentiated mafic rocks that lies well within the floor rocks of the eastern lobe of the Bushveld Complex. Magmatic segregation has taken place within this intrusion and nickel copper sulphides have been concentrated, both as massive ore bodies at and in the immediate footwall, as well as in large disseminated ore bodies in mafic rocks where they are associated with abundant chromite. Circular pipe like bodies of mafic material intrusive into the lower portion of the western limb of the Bushveld Complex to the west of the Pilanesberg, also contain both massive and disseminated nickel copper sulphide mineralisation.

In northern Tanzania, the Dutwa nickel laterite deposit occurs in the Archaean Kilimafedha greenstone belt of the Lake Victoria

Goldfields. The greenstones are intruded by several large ultramafic bodies of possible Palaeoproterozoic age. In a number of instances surficial nickel laterites have formed on top of these bodies. The Dutwa deposit has an estimated mineral resource of approximately 106 Mt @ 0.93% Ni (Blackdown Resources, 2013).

Mobile Belts

Nickel deposits of the recently explored East African nickel belt occur in mafic to ultramafic intrusive rocks straddling the western boundary of the Archaean Tanzanian Craton and two Paleoproterozoic mobile belts to the west. Younger Paleoproterozoic to Mesoproterozoic metasedimentary rocks overlie the mobile belts and were intruded by the nickel-bearing ultramafic rocks between 1350 to 1400 Ma. Sulphide deposits including Kabanga, occur in small ultramafic intrusives in the northern sector of the belt, while the southern sector hosts sulphide and laterite mineralisation such as that of the Kapalagulu layered intrusion and smaller intrusions. The central sector contains only lateritic deposits. The main Kabanga ore body has a resource of 21 Mt grading 1.0% Ni, while some of the smaller deposits such as Luhuma and Rujungu, have yielded grades in massive sulphide of 1.1% Ni over 8.4 m and 0.7% Ni over 7 m respectively (Evans *et al.*, this volume).

The Ntaka nickel sulphide deposit in southern Tanzania is hosted in an ultramafic intrusion of unknown age, emplaced into metamorphosed volcanic and sedimentary sequences of the late Proterozoic Mozambique Belt. The deposit has estimated measured and indicated mineral resources of 12.8 Mt, at grades of 1.21% Ni and 0.25% Cu; and inferred mineral resources of 45.0 Mt, at grades of 0.3% Ni and 0.07% Cu.

7. Copper, Cobalt, Lead, Zinc and Associated Minerals

These base metals and associated minerals are mainly associated with Proterozoic mobile belts, although some important deposits also occur in cratonic areas.

Palaeoproterozoic sedimentary basins

Zinc-lead-(fluorite) in the Transvaal Supergroup, South Africa

The Neoarchaean to Palaeoproterozoic Transvaal sedimentary basin (Supergroup) overlies the Archaean Kaapvaal cratonic nucleus of the Kalahari Craton. In the Ghaap Plateau of the Griqualand West sub-basin, zinc-lead-(fluorite) has been mined in the past at the Pering and Bushy Park deposits. They constitute the oldest known Mississippi Valley-type (MVT) carbonate-hosted lead-zinc province in the world. The Pering deposit was the largest in the district, with an initial resource of 18 Mt @ 3.6% Zn and 0.6% Pb (Gutzmer, 2006).

Copper-Silver, Lead-Zinc in the Magondi Belt, Zimbabwe

The Palaeoproterozoic Magondi Supergroup (*circa* 2.1-2.0 Ga) was deposited on the western flanks of the Archaean Zimbabwe Craton. It was deformed and metamorphosed at 2.0-1.97 Ga during

the Magondi Orogeny (Master *et al.*, 2010). The Deweras and Lomagundi Groups contain several stratabound sediment-hosted Cu-Ag deposits, including Mangula and Norah, which constitute the Magondi Copperbelt (Master, 1991). Other deposits in this belt include the Alaska, Shackleton, Shamrocke, Avondale and Angwa, mines. The Piriwiri Group hosts sedimentary exhalative massive sulphide Cu-Zn-Pb-Ag deposits, which have been mined at Sanyati. All these deposits are structurally complex, having undergone polyphase deformation and greenschist to amphibolite-grade metamorphism. Most of the mines, which were historically active between 1957 and 2001, are now defunct.

Copper-cobalt deposit in the Ruwenzori Belt

The Buganda Group of Uganda occurs within the Palaeoproterozoic Ruwenzori Belt, on the northern margin of the Archaean Tanzanian craton. The Buganda Group is a volcano sedimentary succession, metamorphosed at amphibolite grade, and dated at 2.16-2.06 Ga (Master *et al.*, 2013). It hosts the Kilembe Cu-Co deposit which occurs on the flanks of the Ruwenzori Mountains. Kilembe is regarded as a structurally complex, Besshi-type massive sulphide deposit, consisting of massive chalcopyrite, pyrrhotite and cobaltiferous pyrite layers, intercalated with metasedimentary and metavolcanic rocks (Master *et al.*, 2013). Although the Kilembe mine operated from 1956 to 1978, in the last two decades, the cobaltiferous pyrite stockpiles were treated using a bioleach process, to produce cobalt.

Mesoproterozoic provinces (1600-1000 Ma)

Namaqua Province

In southern Africa, the Mesoproterozoic Namaqua metamorphic complex contains various granitoid rocks dated at between 1200 Ma and 1000 Ma, which have intruded older Palaeoproterozoic to Mesoproterozoic gneisses and metasediments. Within the Namaqua belt, the most important mineral deposits occur in Bushmanland, in the Northern Cape Province of South Africa. They include the large Aggeneys and Gamsberg zinc-lead-copper-silver massive sulphide orebodies of central Bushmanland. The deposits occur in a sequence of dominantly metasedimentary rocks with some volcanics. Aggeneys is a lead, zinc, copper and silver ore body, while Gamsberg is dominantly a zinc ore body with minor amounts of lead. A number of similar, smaller deposits occur in the area and all are thought to be of sedimentary exhalative genesis. The Prieska and Areachap copper-zinc deposits, which lie further east, close to the boundary with the Kaapvaal Craton, are considered to be of volcano sedimentary origin.

Granitic intrusions and high grade metamorphism in Bushmanland, have resulted in the formation of numerous corundum-sillimanite ore bodies. Muscovite, spodumene, as well as tungsten and tin, have been mined from two pegmatite belts in the province, while low grade uranium mineralisation is common in granites, pegmatites and younger sediments. The Steenkampskraal monazite deposit is one of the largest and highest grades of its kind in the world.

A younger event in the metallogenic evolution of this subprovince was the emplacement into characteristic “steep structures”, at about 1100 Ma, of copper bearing noritoid bodies of the O’okiep district. While ancient copper mining took place in Namaqualand, it was also

the site of the earliest modern mining in South Africa in the mid-Nineteenth Century, and mining continued until the late Twentieth Century.

Mozambique Belt in northern Mozambique

The Mozambique Belt in northern Mozambique consists predominantly of various high-grade gneissic terranes aged between *circa* 1100 and 970 Ma, with some older components. They constitute a mega-nappe which was thrust over the *circa* 1140–1120 Ma Nampula Block, along the Lurio shear zone, during Pan-African Himalayan-style continent-continent collision (Grantham *et al.*, 2008). This thrusting was accompanied by Pan-African granite magmatism and the emplacement of the extensive pegmatite field north east of Vila de Mocuba. The pegmatites, which occur in the basement orthogneisses and in metasedimentary and metavolcanic paragneisses, have yielded a large variety of gemstones as well as large amounts of tantalite and microlite. The pegmatites also contain rare earth elements as well as uranium. The Tete metagabbro–anorthosite mass contains significant bodies of vanadium-bearing titanomagnetite which could be economically exploited. Coarse-grained anorthosite with attractive labradorite crystals from the Tete Complex has been quarried recently for dimension stone.

Late Mesoproterozoic to Neoproterozoic sedimentary basins

Rehoboth Subprovince and Kalahari Copperbelt

The Rehoboth Subprovince is situated on the northeastern flank of the Kalahari craton, in central Namibia. It contains magmatic arc rocks dated at *circa* 1.2 Ga, which contain subeconomic porphyry-type Cu deposits, such as Damas. Overlying the arc rocks is the Tsumis Group of the Sinclair Supergroup which extends northeast for hundreds of kilometres into Botswana, where it is known as the Ghanzi Group (Lehmann *et al.*, 2015). The Tsumis and Ghanzi Groups are hosts to stratabound sediment-hosted copper-silver deposits that constitute the Kalahari Copperbelt. The belt is 1,000 km long and up to 250 km wide, and was deformed during the Neoproterozoic Damara orogeny. The Kalahari Copperbelt in Namibia, includes the Klein Aub, Oamites and Witvlei deposits, while in Botswana it includes the new Boseto mine, and several advanced stage exploration projects (Lehmann *et al.*, 2015) (Figure 2).

Central African Copperbelt

The Central African Copperbelt of Zambia and the Democratic Republic of Congo (formerly Zaire), is one of the greatest mineralised regions in the world containing some of the largest and richest copper, cobalt and uranium deposits. These deposits are hosted mainly by metasedimentary rocks of the Neoproterozoic Katanga Supergroup, which is thus the most economically important stratigraphic entity in Central Africa. In addition to the copper-cobalt and uranium deposits, there are also major deposits of lead-zinc-copper ($\pm$ gallium (Ga) and germanium (Ge)), nickel and iron hosted by Katangan rocks.

The Katanga Supergroup is a Neoproterozoic metasedimentary sequence which consists of the Roan, Nguba, Kundelungu, Fungurume and Biano Groups. The lowermost Roan Group, which contains most of the stratiform Cu-Co mineralisation, was deposited

after *circa* 880 Ma (Armstrong *et al.*, 2005), and is subdivided into the mainly siliciclastic Lower Roan Subgroup, and the mainly dolomitic and evaporitic Upper Roan Subgroup.

The Katanga Supergroup contains the world's greatest concentration of copper found in sediment-hosted stratabound copper deposits of approximately 185 million metric tons, which constitutes half of the total world copper resource hosted in sedimentary rocks (Zientek *et al.*, 2014). It also contains the largest resource of cobalt. These deposits, known as the Central African Copperbelt, occur in a 600 km-long arcuate trend, called the Lufilian Arc, which extends from the southeastern part of the Democratic Republic of the Congo (DRC), to Zambia. The part of the trend within the DRC is referred to as the Katangan or Shaban Copperbelt (with around 85 Mt mined and proven resources, dominated by the Kamoa, Kolwezi and Tenke-Fungurume deposits); the part in Zambia is called the Zambian Copperbelt (with 25 proven deposits, having a total of about 100 Mt Cu). The recently discovered Kamoa deposit, on the extreme western edge of the Lufilian arc, west of Kolwezi in the Katanga province of the DRC, is one of the world's largest copper deposits, containing 800 Mt @ 2.5% Cu, or 20 Mt Cu (Schmandt *et al.*, 2013). Another major Cu-Co deposit in the Katangan Copperbelt is Tenke-Fungurume, with an estimated resource of 547 Mt ore @3.5% Cu and 0.27% Co (Shuh *et al.*, 2012; Hitzman *et al.*, 2012). The classic deposits of the Zambian Copperbelt are Nchanga-Chingola, Konkola, Mufulira, Chambishi, Nkana, Chibuluma, Baluba, Luanshya and Bwana Mkubwa. Many of these mines are now worked out and others are nearly exhausted. The Konkola Deep and Konkola North deposits represent the future of copper mining in the Zambian Copperbelt.

The Katanga Supergroup was deformed and metamorphosed during the Pan-African Zambezi and Lufilian orogenies, at between 600 and 480 Ma. Metamorphism in the Zambian Copperbelt was mainly of greenschist facies. In the Domes area to the west of the Copperbelt, amphibolite facies assemblages are recognised. This region hosts the important giant Lumwana Cu-(U), Trident Ni-(Cu, Co) and Kansanshi (Cu, Au) deposits, which constitute what has been dubbed the "Western Copperbelt" of Zambia.

Mineralisation

The sediment-hosted, stratabound copper deposits of the Central African Copperbelt in Zambia and Katanga consist of fine-grained, Cu, Cu-Fe, and Cu-Co minerals, that form stratabound to stratiform disseminations in siliciclastic or dolomitic metasedimentary rocks of the Katanga Supergroup. Chalcocite and bornite, carrollite and chalcopyrite typically make up the primary ore zones. The ore minerals occur as cements, replacements, and as veinlets. Some important deposits, such as Kansanshi, are not stratiform, but vein type. The ores have been oxidized under tropical conditions, and the secondary ore minerals consist of malachite, chrysocolla and heterogenite. In addition to Cu-Co deposits, the Central African Copperbelt also hosts major Zn-Pb-Cu-Ga-Ge polymetallic deposits, of which the most important are the Kipushi deposit in the DRC and the Kabwe deposit in Zambia. In the Kafubu area of the Zambian Copperbelt, basement schists host the world's second largest emerald district after Colombia (Zwaan *et al.*, 2005).

The vast literature on the Copperbelt, from the 1890s to the mid 1990s was documented in the comprehensive bibliography of Master (1997). Since then, a new golden era has dawned, following the ending of state monopolies in mining and research in both the DRC and

Zambia. The new exploration and mining rush by private enterprise has led to a boom in research, resulting in new insights into the formation of the Cu-Co and uranium deposits in this world-class district. The results of multidisciplinary studies in the Zambian and Congolese (Katangan) Copperbelts, have been summarized in several key papers and special volumes which have appeared in the past eleven years (Robb *et al.*, 2005; Selley *et al.*, 2005; Hitzman *et al.*, 2012). Haest and Muchez (2012) provided a review of both stratiform and vein-type mineralisation (Cu-Co, Cu-Ag and Zn-Pb-Cu-Ag) in the Central African Copperbelt, as well as in the Damara Belt of Namibia. Detailed reviews of the Central African Copperbelt, its Cu-Co deposits and exploration potential, were published by Taylor *et al.* (2013) and Zientek *et al.* (2014). The uranium mineralisation in the Katangan belt has mainly been studied mineralogically over the past century, but the processes leading to the formation of uranium deposits have received attention recently and have been reviewed by Eglinger *et al.* (2013), and by Kinnaird and Nex (this volume).

Iron-oxide-copper-gold deposits in Neoproterozoic mobile belts

There are a number of occurrences of granitic intrusion-related iron-oxide-copper-gold (IOCG) deposits in various Pan-African mobile belts in Africa. Within the Katangan metallogenic province in Zambia, the Katangan sedimentary rocks, which host Cu-Co, were intruded by granites during the Pan-African Lufilian orogeny, at around 550 Ma. Associated with the intrusive granites, there are numerous Cu-(Ag, Au, Pb, Zn) occurrences in the surrounding metasedimentary rocks, among which is the large Kitumba deposit, identified as an IOCG deposit, with an Indicated Resource (by 2013) of 87.6 Mt @ 1.17% Cu (0.5% Cu cutoff) (Robertson, 2013). Other IOCG deposits in Pan-African belts include the Guelb Moghrein Cu-Au deposit near Akjoujt in the Mauritanide belt, Mauritania (with 26.36 Mt @ 1.26% Cu, 0.87 g/t Au, First Quantum Mining, 2011), and the Hofrat-en-Nahas Cu-Au-(U) deposit in South Sudan, with reserves of 20 Mt @ 5.9% Cu (Yao and Master, 2001).

Mesozoic to Miocene lead-zinc-silver deposits of the Alpine Orogeny

The Jurassic carbonate platform of northeastern Morocco and northwestern Algeria is host to in excess of 100 Mississippi Valley-type (MVT) lead-zinc occurrences, varying from small uneconomic occurrences to major districts. In Morocco, the Touissit-Bou Beker district with estimated combined production and reserves of more than 70 Mt at an average grade of 4% Pb, 3.5% Zn, ~1% Cu and 120 g/t Ag, is considered to be one of the largest MVT districts in the world and accounts for a large portion of Morocco's total base metal production (Bouabdellah *et al.*, 2012). Deposits which have and are being mined, include Mekta, Beddiane, Touissit, and Bou Beker in Morocco and El Abed in Algeria.

Further to the east in Tunisia, Triassic to Miocene carbonate sequences host abundant zinc-lead-barite-fluorite±silver deposits, including Fedj el Adoum (Fej Lahdoum), Bou Grine, Boujabeer, Hassine, Djebba, Djerissa, and Ouled Moussa. The deposits are generally classified as MVT deposits, with mineralisation cross-cutting host rocks ranging from Triassic to Miocene and Pliocene in age. The mineralising fluids appear to have exploited thrusts, regional

northeast-southwest and northwest-southeast trending faults, salt diapirs and various unconformities (Bouhlef, 2005; Sheppard *et al.*, 1996).

8. Uranium, Tin, and Rare Earth Elements

Uranium

Africa has been a significant world producer of uranium since 1945 when it was discovered in the Democratic Republic of the Congo and mined at Shinkolobwe, which provided 30,000 tonnes of uranium ore for the Manhattan Project to produce atomic bombs. Africa currently provides some 18% of the world's uranium (Kinnaird and Nex, this volume). There are four major types of deposits that produce the majority of the uranium in Africa: the Archaean quartz-pebble-conglomerate hosted gold-uranium deposits of the Witwatersrand in South Africa; the Neoproterozoic end-orogeny sheeted leucogranites and small stocks of Namibia; the Mesozoic sandstone-hosted roll-front deposits of Niger and Malawi; and the recent, channel-hosted calcrete and alluvial deposits in Namibia.

Tin

Because of its hardening effect on copper, tin was used in bronze implements as early as 3500 BC, although the pure metal was not used until about 600 BC. Tin has been mined in Nigeria since the 9th century with the famous Benin bronzes dating from the 13th century. Significant volumes of tin production began in the 20th century and maximum output from African deposits was reached in the 1970s. African deposits range in age from Archaean in Zimbabwe and Palaeoproterozoic in South Africa, to Mesozoic and Pleistocene in Nigeria (Kinnaird and Nex, this volume). Major eras of tin mineralisation are related to continental amalgamation at the end of the Proterozoic and these are represented in Neoproterozoic Pan-African Belts in Namibia, Nigeria, Rwanda, Somaliland, and the DRC. In Mesozoic times cassiterite mineralisation was associated with granite magmatism related to the fragmentation of Gondwana. These deposits occur in Nigeria, Cameroon and Namibia. African tin deposits include disseminations in granite cupolas, lode-style mineralisation - either as endogranitic or exogranitic veins, rare metal pegmatites, other veins not directly associated with granites, as well as in eluvial and alluvial deposits (Kinnaird and Nex, this volume).

Rare Earth Elements

Rare Earth Elements (REE) are vital to a wide range of modern high technology applications and the critical strategic role of REE to the economic development of the U.S.A., European Union and Japan, has been recognised. China holds a near monopoly over the supply of REE and REE products – accounting for around 95% of the global supply in 2010. These factors triggered a rush to discover REE deposits and develop REE production outside of China.

At the beginning of 2015 there were 11 advanced REE projects on the African continent – projects on which formally defined resources had been published (Harmer and Nex, this volume). On average, the most REE-enriched magmatic rocks are carbonatites, followed by peralkaline granites and syenites. Enrichment of the REE to ore levels is the consequence of the incompatible behaviour of the REE during magmatic crystallisation and their limited solubility in

low temperature aqueous solutions, making the REE largely immobile during weathering.

Enriching processes can be conveniently grouped, on the basis of the temperature range over which they operate, into Primary Magmatic, Magmatic/Hydrothermal and Epithermal. Even the most enriched igneous rocks require the action of one or more secondary processes to produce economically significant grades of the REE (Harmer and Nex, this volume).

9. Coal, oil and gas

Coal

Africa is host to coal deposits stretching from the far north to the far south and ranging in age from the Carboniferous through to the Miocene. Coal production in the north of the continent is however currently of a very limited nature compared to that in the south where, due mainly to its low cost and relative abundance, the commodity has long been the primary source of energy (Hancox, this volume). The coalfields of Africa and the Gondwanaland coal of South Central Africa (SCA) in particular, contain significant resources of both thermal and metallurgical coal.

All of Africa's coals are associated with non-marine to marginal marine terrestrial clastic sedimentary sequences and most commonly in the SCA, these are mudstones and sandstones assigned to the Karoo Supergroup and its spatial and temporal equivalents. Whilst the coals in the rest of Africa span the Carboniferous to Miocene, most SCA coals formed during two periods of time, one in the Early Permian and the other in the Middle-Late Permian. Unlike the Carboniferous coals from the northern hemisphere, SCA Permian coals generally have high Ash contents.

Geologically, the pre-Karoo (basement) tectonic framework exerts an important control on the geometry and development of the SCA Karoo Basins, as well as on the thickness of the sedimentary fill and coal seam characteristics. Historically, coal production in Africa has been the preserve of South Africa, which is by far the largest producer, utiliser and exporter of coal in the region. This has been augmented by far smaller scale production from Botswana, Zimbabwe, Zambia, southwestern Tanzania and Nigeria. More recently, Mozambique has become a producer as well, surpassing Zimbabwe in 2012, to become the second-largest coal producer in Africa.

Of the North African coals, economically the most important are the Cretaceous bituminous and sub-bituminous coals, known from Algeria, Benin, Egypt, Libya, Mali, Mauritania, Niger, Nigeria, Senegal, and Sudan. Nigeria has the most potential, with coal resources believed to be in excess of 4 billion tonnes, including Africa's largest deposits of lignite (Ohimain, 2014 from Hancox, this volume).

Oil and Gas

Africa currently produces some 7.0% of the world's oil and a similar amount of its gas, from a range of basins that include intra-cratonic sags and epicratonic embayments. In 2013, Africa held 7.7% of the world's known oil reserves and 7.6% of the world's gas reserves. Petroleum occurs throughout the stratigraphic column, extending from geographically widespread seepages in Recent sediments, to oil in fluid inclusions in the Late Archaean sediments of the Witwatersrand Basin (Selley and van der Spuy, this volume).

There is still great potential for future oil and gas discoveries in

Africa, especially offshore, as seismic, drilling and production technology constantly improve. There is also the potential for producing unconventional petroleum resources, both coal-bed methane from Karoo coals, and shale gas in parts of the Karoo Basin and in the North African source rocks of Algeria and Libya in particular.

In North Africa, post-Palaeozoic clastic sequences, ranging in age from Triassic to Cretaceous, have been deposited in a series of cratonic sag basins. Desultory petroleum exploration in North Africa throughout the early part of the last century accelerated with the discovery of the giant Hassi Messaoud oil field in Algeria, in 1953. With a reserve of 10 billion barrels, this is the largest oil field in Africa. The reservoir is the Cambro-Ordovician Hassaouana Sandstone, the source is Silurian Tannezuft shale and the seal comprises Triassic evaporates (Selley and van der Spuy, this volume).

In Libya the quest for similar fields in the Sirte Basin led to the discovery of late Cretaceous – Lower Eocene carbonate build-ups and shoals, followed by the discovery of reservoirs in Early Cretaceous sandstones in the Sarir, Messla and associated fields. Potential exists in the North African basins for tight gas production from deeply buried infra-Cambrian and Ordovician source rocks (Craig *et al.*, 2005).

The gradual break up of Pangaea from north to south led to the formation of evaporites over a series of incipient rift basins along the coast of West Africa. Petroleum has been found in salt-related Cretaceous, Palaeogene and Neogene sandstone reservoirs in Mauritania and Senegal. In Congo, Angola and Gabon, petroleum is trapped in Tertiary submarine fan sands, in Cretaceous, carbonate reservoirs and in pre-salt lacustrine carbonates and turbidite sands (Selley and van der Spuy, this volume).

The Niger Delta occurs at the southern end of a major series of rifts extending from what is now the Atlantic Ocean to the modern Mediterranean and hosts the largest petroleum province of Africa. These rifts are of Cretaceous age and at one time allowed a continuous seaway to extend across the continent. Petroleum seeps have long been known along the margins of the East African rifts and significant reserves have been discovered in Kenya and Uganda, along the eastern margin of Lake Albert.

After earlier exploration for conventional hydrocarbons, the Karoo Basins are now rather regarded as holding potential for unconventional resources. The only production in South Africa has been from the Bredasdorp Subbasin of the Outeniqua Basin, off the south coast. Gas has been produced from these basins since the early 1990s.

10. Industrial Minerals

Phosphate

Five major types of phosphate resources are mined in the world, namely marine, igneous, metamorphic, biogenic and those resulting from weathering (Van Straaten, 2002). Sedimentary and igneous phosphate rocks occur throughout Africa, while metamorphic and marine deposits occur to a lesser extent. The phosphate rock resources are unequally distributed, with the major sedimentary deposits concentrated in northern and northwestern Africa, compared with a fairly limited distribution in sub-Saharan Africa.

In eastern and southern Africa, most of the phosphate resources are associated with igneous alkaline and carbonatite complexes, the most commercially significant being the Phalaborwa Complex in

South Africa, which is the biggest resource of igneous phosphate rock currently being mined in Africa (Van Kauwenbergh, 2002). A huge resource of potentially economic phosphate rock in the form of apatite bearing gabbro-norite, occurs in a number of layers in the 1,000 m thick upper zone of the Bushveld Complex. These layers can be traced over tens of kilometres in the northern, eastern and western lobes of the Bushveld Complex (Viljoen, this volume). Apatite-magnetite mineralisation also occurs in rocks unrelated to alkaline magmatism as in Ethiopia and Mozambique, and in apatite syenites in eastern and central Zambia.

Sedimentary phosphate deposits in Africa range from late Proterozoic to Pleistocene in age. North and northwest Africa have enormous reserves of sedimentary phosphate rock within the western section of the huge Tethyan phosphate province (Notholt *et al.*, 1989), which extends into the Middle East. The northern edges of the Arabian-Nubian Shield were the site of intense phosphogenesis during Late Cretaceous to Eocene times and this area is believed to contain a large portion of the world's unexploited phosphate resources (Soudry *et al.*, 2006). Morocco, Tunisia and Egypt are all major producers. Morocco has almost 85% of the known sedimentary phosphates in Africa, with resources estimated in excess of 65 billion tonnes (Notholt *et al.*, 1989). In Morocco, phosphate was first discovered in 1908 and there are four major phosphate basins (Oulad Abdoun Basin, the central Ganntour Basin, the Meskala Basin and the Oued Eddahab Basin). Phosphate rocks of Eocene age are widely distributed in Tunisia and Algeria. Further deposits are known from Guinea Bissau, Mauritania, Senegal and Togo. In southern Africa, small sedimentary deposits are known from Angola and Tanzania.

Potash

Though potash is not presently mined in Africa the continent hosts significant deposits, particularly in the Congo Basin where three deposits are known to each host over a billion tonnes of potash ore, one seam of which is thought to be the highest grade potash deposit in the world (Pedley *et al.*, this volume). Other significant deposits are known in the Danakil depression of Eritrea and Ethiopia. Less significant deposits are hosted in the Late Triassic evaporates of Morocco as well as in Libya, Tunisia and Algeria.

The onshore portion of the Congo Basin occupies a 150 kilometre long northwest-southeast oriented coastal strip within the Republic of Congo, extending from Gabon in the north to Cabinda (Angola) in the south. Potash was first identified in oil exploration wells in neighbouring Gabon in 1948 and the Saint Paul mine was developed at Holle and operated from 1969 to 1977, mining sylvinitic ore. At peak production, approximately 450,000 tonnes of Muriate of potash were produced per year (MDPA, 1982).

The potash resources for the Mengo, Kola and Dougou deposits in the Congo are each over a billion tonnes and are open laterally. These deposits compare very favourably with sylvinitic and carnallitic deposits globally, being of excellent grade, simple mineralogy, at relatively shallow depth, with simple geometry and having very low insoluble contents. If defined, a resource for seam 3/IX (Elemental Minerals' Hangingwall Seam), would probably be the world's highest grade potash deposit at close to 60% KCl. There is the potential to expand the Congolese deposits significantly. It is probable that between 30 and 100 billion tonnes of Carnallite, grading over 18 percent KCl, are present within the onshore portion of the Congo

Basin of between 200 and 1,000 metres depth (Pedley *et al.*, this volume).

The known potash deposits of northeast Africa occur in the evaporite sediments of the Danakil Depression in the Afar region of northeastern Ethiopia and southeastern Eritrea. The deposits, which were discovered in 1906, formed by evaporation of sea water in a previous arm of the Red Sea that was isolated by uplift of the Danakil Alps. Rock-salt-dominated Quaternary evaporite beds approximately 2 km thick, are known beneath the present Asale salt lake near Dallol, in the northern part of the Danakil Depression, about 120 m below sea level (Master, 2016).

Several large playa lakes (locally referred to as 'chotts') host ephemeral carnallite crusts and intercrystalline carnallite cements in their uppermost pan-facies sediments (Warren, 2005). The chotts are within a ~1,000 kilometre-long 'belt' along the northeast extremity of the Algerian and Tunisian Sahara, and also extend into Morocco and Libya. The large Chott Djerid in Tunisia, is fed by springs and sheetfloods coming from the Atlas Mountains to the north, and its evaporites, which include halite and gypsum, formed by complete evaporation of lake waters in the dry season.

11. Heavy mineral sands

A number of heavy mineral sand deposits occur along the African coastline. They consist of concentrations of titanium minerals (rutile, ilmenite, leucoxene) and zircon, in fossil placers in young coastal sediments ranging in age from Pliocene to Recent (i.e., over the last 5 Ma).

Currently there are seven operating heavy mineral sand mines in Africa, with most production coming from South Africa (Richards Bay, Hillandale, Namakwa Sands). The other mines are located in Senegal, Sierra Leone, Mozambique and Kenya. A further thirty plus deposits are known but are considered economically marginal at present (Tyler and Minnitt, 2004; Esterhuizen, 2008; Van Gosen *et al.*, 2014).

The deposits are generally large with several having resources of more than a billion tons. The total heavy mineral content (rutile, ilmenite, leucoxene and zircon) is variable, ranging between 2 and 12 percent. Some of the smaller deposits have higher grades, containing up to 40 percent total heavy minerals, whilst most of the large deposits, with tonnages in excess of 500 Mt ore, run at a grade of more than 5 percent. The quantity of valuable minerals, i.e. zircon, rutile, ilmenite and leucoxene, together with the resource tonnages, determine the viability of a particular deposit.

Deposits are hosted mainly by young surficial unconsolidated, siliciclastic sands of marine-aeolian origin. They are generally related to extensive dune fields stretching for tens and in some cases more than a hundred kilometres parallel, or sub-parallel, to the present coastline and may occur proximal to the coast or several kilometres inland. They invariably lie close to major paleo- or present fluvial drainage systems. Most deposits vary in age from 5 Ma to the present and are commonly referred to as fossil placers. Recent dune fields also host heavy mineral sand deposits, while offshore, the continental shelf offers significant heavy mineral potential. Some high-grade deposits, like the large undeveloped Corridor Sands deposit in Mozambique, with more than a billion tons of ore, occur in older coastal dunes situated farther inland, which formed during earlier sea level transgressions.

Although African production of heavy minerals is currently second

only to Australia, the potential exists for the continent to become the leading producer of titanium feedstock and zircon in the future (Tyler and Minnitt, 2004).

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