Mineral Resources and Exploration in Africa

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Abstract

Africa is a continent enriched in mineralization of all types of mineral deposits as a result of its geological legacy. It is well endowed with reserves of platinum, diamond, chromite, cobalt, phosphate, manganese, gold and bauxite. Although Africa has limited mineral exploration activities, it hosts about 30% of the planet's mineral resources. It is expected that Africa has more than half of the total earth resources that need funds to be explored using the recent technology.

In recent years, Africa produced tens of metal and mineral products. Mines in Africa produced much of the world's platinum, diamond and chromite. African mines also produced a large share of the world's vermiculite, zirconium, titanium and gold. Africa has high potential explorations for precious metals, base metals, and diamonds. Metallic deposits are concentrated in Central and Southern Africa because of predominance of Precambrian igneous and metamorphic rocks, while non-metallic deposits are concentrated in North Africa.

Mining and mineral products are vital sources for development of economics of many African countries such as South Africa, Ghana, Guinea, Mauritania, Zimbabwe, Tanzania, Zambia and the Democratic Republic of Congo. Fuels and minerals accounted for about 58% of total African exports. Recent mining exploration activities are distributed mainly among South Africa, Namibia, Botswana, Tanzania, and Gabon. They mainly produce platinum, gold, diamond, tantalum and base metals. Major discoveries are several potentially diamondiferous kimberlites in Mauritania, Liberia, Namibia and Zimbabwe. South Africa is geologically a unique country in terms of variety and reserves of mineral resources. It is alone contributed by more than 50% of Africa's output for several minerals and metals (platinum, palladium, titanium, zirconium, chromite, manganese, vanadium and vermiculite).

Introduction

The mineral industry has been played an important part in the development of civilizations throughout the world history, underpinning the lithic, iron and bronze ages, industrial revolution and the recent electronic and information ages. The accelerating growth of the world's population, combined with human seeking to higher level of life standard throughout the world, is greatly increasing demands for mineral products of all types. The world may face a global mineral crisis if new mineral discoveries are not found because the Earth's finite supply of minerals is being used by a population that is growing much faster than any time in history. Most minerals are used in the high-income countries accounting for only 16% of the world population, with relatively small consumption in the other countries (Kesler, 1994). Africa and adjacent islands were home to 1,051 million people in mid 2011 (PRB, 2011), which represents 15% of the world population. It also encompasses a land area of 30.3 million km^2 (21% of the world's landmass).

Mining companies saw moderate growth in 2010, and the forecast for 2011 is strong as global demand for base and precious metals continues to climb. Prices for these commodities are expected to rise with the demand increase (PWC, 2011). The price of many metals rose in early 2008 owing to increasing consumption fueled by economic growth in China and India followed by price decreases owing to the economic downturn associated with the world financial market in the second half of 2008.

Africa is a continent enriched in mineralization of all types of mineral deposits. It has the highest potential for precious metals, base metals, and diamonds (Fig. 1). It produces tens of metal and mineral products and is a major producer of several of the strategic minerals and metals including gold, platinum, diamond, uranium, tantalum, manganese, chromium, nickel, bauxite and cobalt (Fig. 2).

Although Africa is still under primary exploration, it hosts about 30% of the planet's mineral reserves, including more than 80% of the global platinum, chromium, and tantalum; and more than 40% of gold, diamond, cobalt, manganese and phosphate, making it a truly strategic producer of these valuable metals. Metallic deposits are concentrated in Central and Southern Africa. Exports of fuels and mining products accounted for about 58% of total African exports (USGS, 2002).

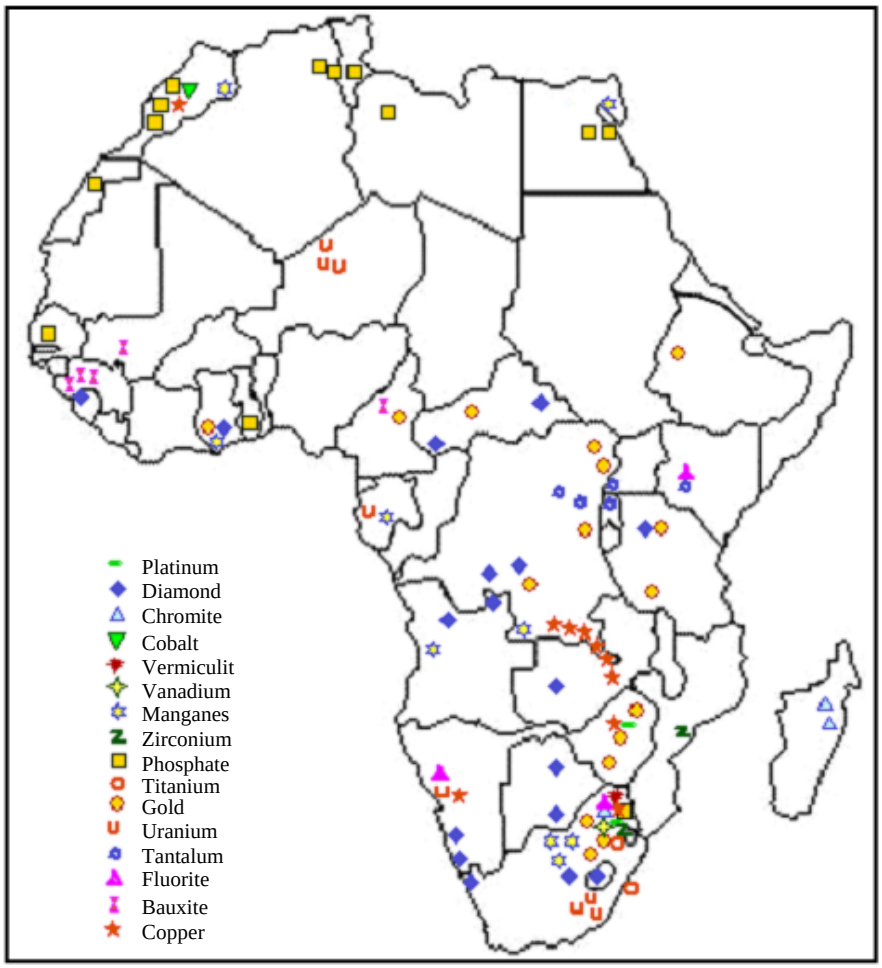

Figure 1. Geographic distribution of strategic minerals in Africa.

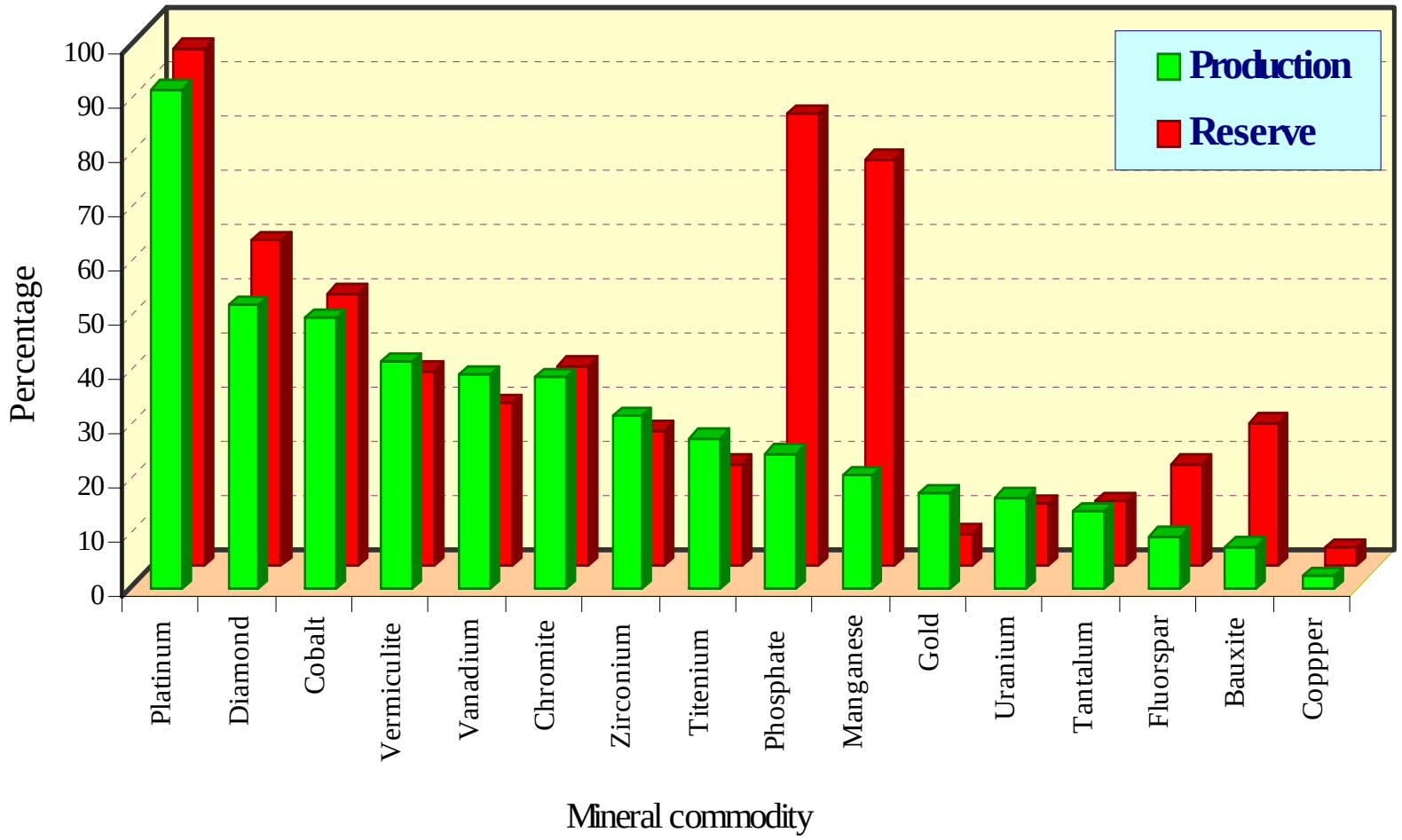

Figure 2. Productions and reserves of mineral commodities in Africa 2010.
Sources: USGS and British Geological Survey.

Mining accounts for a substantial proportion of several African countries GDP's. Unfortunately, several African civil wars are funded by (and often caused by) some of these mineral resources, in particular diamonds. Conflicts continued to destabilize development and constrained new investment in mineral exploration and development in some regions in Africa such as Angola, Democratic Republic of Congo, Sudan, Somalia, and to a lesser extent Burundi, Rwanda, Guinea, Liberia, Algeria, Ethiopia, Eritrea, Sierra Leone and the Comoros.

South Africa, Ghana, Zimbabwe, Tanzania, Zambia and the Democratic Republic of Congo dominate the African Mining industry, whilst countries such as Angola, Sierra Leone, Namibia, Zambia and Botswana rely heavily on the mining industry as a major foreign currency earner (MBendi, 2011). Africa depends on commodity exports for surviving, since many African countries are dependent on just one or more of these commodities. The recent exploration activates in Africa have been mainly focused on gold, diamond and base metals.

Although Africa has tremendous mineral wealth, it has entered the 21st Century as the continent with the most daunting development challenges. According to the UNDP Human Development Report (2010), most of the low human development countries in the world (81%), 34 out of 42 countries are from Africa.

Geology of Africa

Africa is generally a continent of plains and plateaus with intervening escarpments. It is dominated by three large masses or cratons: Kalahari, Congo, and North-West African cratons that are composed of Precambrian basement crystalline rocks consisting of schist, gneiss and greenschist. They are separated from each other by a number of mobile belts that were active in Late Precambrian and Early Paleozoic times. The Precambrian rocks are known to be the source of 80% of the world's industrial minerals and metals.

The Kalahari craton occupies much of Southern Africa and contains some of the oldest known rocks in the world (3.7Ga). It embraces some of the largest and best-developed mafic complexes in the world. The most important complex is the vast Bushveld Igneous Complex (BIC) layered intrusion. This in turn hosts some of the most fabulous ore accumulations on the planet, particularly platinum, chromite, vanadium, copper, zinc, iron, asbestos, talc, mercury, gemstones, titanium and tin ores.

The Congo craton occupies a large part of Central Southern Africa. It contains granitic basement and greenstone belts hosting mainly gold. The North-west African craton occupies the whole of Western Africa from the Gulf of Guinea in the south to the Anti-Atlas Mountains of Morocco in the north. Some granitic rocks of this craton host substantial gold mineralization as in Ghana.

The Precambrian rocks of the cratons are overlain by nonconformably Late Proterozoic to Paleozoic sedimentary rocks and depositional basins containing sandstones, shales, mudstones, conglomerates, limestones and illites. They are also important host rocks for known and potential mineralizations such as Witwatersrand gold deposits in South Africa, Tarkwaian conglomerate reefs of gold deposits in Ghana, gold alluvials in Southern Ethiopia and Northern Democratic Republic of Congo, diamond deposits in Namibia, copper deposits of the Copperbelt in Zambia and Democratic Republic of Congo, bauxite and laterite deposits in Guinea, phosphate deposits in North Africa, and rutile and other heavy minerals in Madagascar, Mozambique and Sierra Leone.

The most important geologic feature in Africa is the Great African Rift system that runs from Beira, on the coast of Mozambique in the south to Turkey in the north, a distance of 6,500 km and 45-80 km wide. It is the longest rift on the Earth's surface. East African Rift-associated volcanics including kimberlites (source of diamond) and carbonatites (rare-earth metals, phosphates and sometimes copper, gold and nickel), which occur around the East African Rift System are geologically important for their mineral content. Many African known and undeveloped non-metallic mineral deposits, such as kaolin, bentonite, and fluorite have been found along the rift zone. The rift also contains salt lakes that contain common salt, soda-ash and potash. Other major features are the Atlas Mountains located in the extreme northwest and the Paleozoic Cape fold belt in the extreme south.

Mining History in Africa

Africa is the birthplace of mining activity. The oldest mine ever discovered was located in Africa, on a Swaziland iron site and was operated as long ago as 45,000 years. Nine thousand years before the Christian era copper metallurgy was developed in Mesopotamia, and around 1,500 BC (UN, 2002). Both red haematite and black iron oxide were used as cosmetics. Gold was traditionally used in making masks and other ornaments, especially at the time of the great empires of Mali, Ghana and Ancient Egypt. Modern mineral story began with the diamond rush in Southern Africa, at the turn of the twentieth century. From that time up to the 1930s, mining activity in Africa, with the exception of Ghana (gold) and Sierra Leone (diamond), was concentrated mainly in Southern Africa. Mining activity before the 1930s was focused on diamond and gold. In 1950s, extraction of copper in Zambia and Democratic Republic of Congo reached very high levels followed by increasing production of iron in Liberia, bauxite in Guinea and uranium in Namibia and Niger. Later, mineral demand has been increased not only for such basic metals as gold, diamond, copper, aluminum and iron, but also for rare metals such as platinum, chromium, titanium and tantalum, which are required for modern industries such as electronics, communications, computers, cars, aeronautics and nuclear power.

Investment and Exploration Level in Africa

Mining industry is essential to the development and economic growth of many African countries. It is also essential as a valuable source for foreign exchange earnings. Some countries depend mainly on mineral exports such as Mauritania (54.1% from the total exports), Zambia (50%), Guinea (45.4%), Niger (32.5%) and Democratic Republic of Congo (DR Congo, 25%) (Fig. 3). Primary mineral exports in the main mineral producers in Africa such as South Africa and Zimbabwe and Ghana constitute less than 25% from the total exports (Fig. 3). In South Africa, one of the largest mineral producers not only in Africa but also in the world, of total exports of all goods that were valued at $30.8 billion, primary mineral sector contributed only by $5.32 billions (17.3%) in 2000. South Africa alone exports more than 60% of the total African mineral exports. Mineral exports of South Africa within Africa accounted for less than 1% of the South African mineral export trade (USGS, 1999). Mineral imports are not high in Africa due to lack of mineral industries. Few countries such as South Africa, Egypt and Morocco have considerable mineral imports (Fig. 4). Although South Africa was self-sufficient in the vast majority of its mineral needs, some mineral commodities were imported by a total value of $710 millions from total mineral exports of $5.32 billions (13.4%) in 2000 (Mineral Trade Statistics, 2000). The

most significant mineral imports include alumina, coking coal, rough and cut diamonds, certain ferroalloys, magnesite, magnesia, precious metals, and sulfur (USGS, 1999).

Most types of mineral deposits have been found in Africa, some are unique in concentrations and reserves such as diamond of Botswana, platinum, gold, chromite, vermiculite, manganese and fluorspar of South Africa, copper-cobalt deposits of Zambia and Democratic Republic of Congo, tantalum of Democratic Republic of Congo, and uranium of Niger. Exploration investment is the only way in which depleting reserves can be replaced and new discoveries made to cover the increasing of mineral demand.

Mineral exploration in Africa was extremely low compared with all other major mineral-producing regions of the world during the 1980s, and inadequate during 1990s. The mining industry worldwide spends about 10% of the value of its production annually on exploration. By contrast, Africa only spent about 1% in 1980s (Keatley, 1992).

The worldwide non-ferrous exploration budget has been increased gradually from $2 billion in 2003 to $10.68 billion in 2010. Although Africa holds more than 30% of the global reserves of minerals and metals, the mineral exploration budget in 2010 was about $1.4 billion (13% of 2010's global budgets). DR Congo, South Africa, Zambia, and Burkina Faso are accounted together for almost half the region's total. The bulk of global exploration spending is carried out by Canada and Australia-based companies; however, resource-hungry China is also becoming an increasingly important investor in mineral exploration worldwide (MEG, 2011).

Gold continued to be the most important commodity explored for and developed globally in 2010. It attracted 51% of the total exploration budget, followed by base metals (copper, nickel and zinc) (33%), diamond (3%) and platinum group metals (2%) (MEG, 2011).

Strategic Metals And Minerals in Africa

Africa has high potential for precious metals, base metals, and diamonds because of the common Precambrian igneous and metamorphic rocks. It produces more than 60 mineral and metal products. It is a major producer of several of what so-called strategic minerals and metals including platinum, diamond, chromite, vermiculite, vanadium, manganese, zircon, phosphate, titanium, gold, uranium, coltan (tantalum), fluorspar, bauxite, copper. It leads the world in production and reserves of platinum, diamond, chromite cobalt, manganese, phosphate and gold (Fig. 2).

Platinum group elements (PGE)

Platinum may be counted as one of the precious metals since it is more costly than gold. It is one of a group of metals called platinum group elements (PGE) consisting of iridium, osmium, palladium, platinum, rhodium, and ruthenium. The main uses for platinum are in jewelry, electrical and dental industries.

South Africa dominated the world's platinum production with 88% of global output in 2009 (141,000 kg) provided by Bushveld Igneous Complex. Russia followed with 11.6% of world production. Zimbabwe provided 4% from the Great Dyke (Brown et al., 2010; USGS, 2011)

In South Africa, platinum production declined in 2009 by 6.5% compared to 2005 due to safety stoppages, strike action, smelter power outages and geological issues, and closure of a number of uneconomic shafts and pits (Matthey, 2010).

In Zimbabwe, Platinum production was increased by 32% in 2009 compared with 2005, to become the third biggest miner of platinum after South Africa and Russia, due to its increasing supply of the mineral to the international market by 32.2% to 7,230 kg. This increase was due to the continuation of expansion programs at the operating mines on the Great Dyke (Matthey, 2010).

World known resources of PGE in mineral concentrations that can be mined economically are estimated to total more than 66 million kilograms. The largest known reserves occur in the Bushveld Complex in South Africa that counts 95.5% of world PGE reserves.

PGE exploration has not been restricted to South Africa and Zimbabwe, but some limited investigations have been carried out in Botswana, Namibia, Tanzania and Uganda. Minor production comes from Ethiopia, Sierra Leone, and Democratic Republic of Congo.

Most platinum is produced as a by-product in the refining of other metals, mostly nickel. South Africa is the only place in the world, where primary PGE ores are mined. The chief mineral of platinum is the native metal.

Platinum prices advanced strongly on May 2008, rising from a low of $400 per troy ounce in 2001 to the maximum $2,200 and closing the year at $800 per troy ounce with world financial crisis (Fig. 3). Platinum prices have increased gradually to reach 1,800 per troy ounce in mid 2011 (InfoMine, 2011). South Africa produced PGE (platinum and palladium) worth an estimated $12 billion mined in 2009.

Diamond

Diamond is produced as primary (kimberlites) and secondary (placers, alluvial and marine) ore. Approximately 5,000 kimberlites, mantle-derived ultrabasic narrow dikes of igneous rocks, at very high temperature (900-1,300 ºC) and pressure (140-200 km depth), are currently known in the world, but only about 100 contain economic diamonds with concentrations of less than about one part in five million (De Beers, 2002). Diamond that does not meet gem-quality standards for color, clarity, size, or shape is used principally as an abrasive, and is termed "industrial diamond" (USGS, 2011).

Natural diamond resources have been discovered in more than 35 countries. They account for about 1.2% of all industrial diamond used, while synthetic diamond accounts for the remainder (USGS, 2011).

To date, Africa has produced over 75%, in value, of the world's diamonds with more than 1.9 billion carats worth an estimated $US 158 billion mined. Global rough diamond production rose 39% by value in 2010 to $12 billion, according to Kimberley Process statistics. In terms of volume, rough diamond production rose nearly 7% to 133.12 million carats. The average price per carat produced rose 30% to $90.13 (DiamondsNet, 2011).

Mining activities are concentrated in South Central Africa, with diamonds being produced primarily from kimberlite mines (South Africa, Angola, DR Congo, Ghana, Tanzania, Lesotho and Botswana), followed by alluvial dredging operations (Angola, Central African Republic, Namibia and South Africa) and offshore marine diamond activities (South Africa and Namibia). Most of West Africa's diamond production in the area originates from fluviatile placers and only on a minor scale from eluvial deposits or from altered kimberlite pipes (MBendi, 2011).

Africa is the world's largest producer of diamonds, producing as much as 52.4% of global production in 2009 (Brown et al., 2010), and reserving 60% of the global diamond. DR Congo was the world's second top-producing country by volume for 21.3 million carats

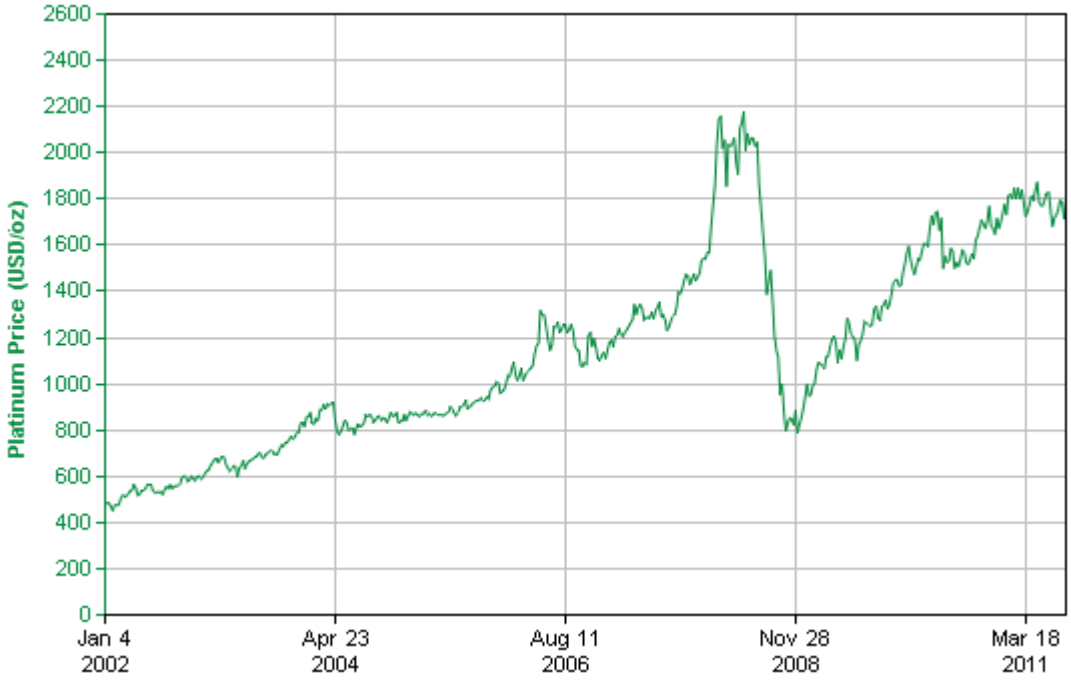

Figure 3. Platinum prices (US$/ounce) from Jan 2004 to August 2011. Source: InfoMine.com.

(17.5% of the world production and 33.5% of the African production) after Russia that produced 34.8 million carats (28.7%) in 2009. The other top diamond producers in Africa included Botswana (27.9% of the African production), Angola (21.7%), South Africa (9.6%), Namibia (1.9), Zimbabwe (1.5%) and Guinea (1.1%). Other African countries produced minor amounts of diamond, including Sierra Leone, Ghana, Tanzania, Central African Republic, Cote d'Ivoire, Congo Brazzaville, Lesotho, Liberia, Togo and Cameroon. The discovery of potential diamondiferous kimberlites in Mauritania by Rex Diamonds and Ashton is rated as exciting discoveries and could yield potential (MBendi, 2011). Most of West Africa's diamond production is originated from placer deposits that formed from erosion of diamondiferous kimberlites.

The total rough exports by all Kimberley Process member states jumped 51% to $37.6 billion, while rough imports also rose 51% to $37.78 billion. The European Union was the world's top rough exporter in 2010 with rough diamonds valued at $14.3 billion leaving the region; Israel came in second place with $3.74 billion in rough exports; Dubai was third place with $3.54 billion followed by Botswana at $2.88 billion; Russia at $2.78 billion and Canada at $2.41 billion. Europe was also the top rough importer in 2010 with $13.59 billion worth of goods followed by India at $11.23 billion, Israel with $4.43 billion, Dubai with $2.06 billion and China with $2.02 billion (DiamondsNet, 2011).

Cobalt

Cobalt is a strategic metal used in many diverse industries. The largest use is in superalloys. About 50% of the world's cobalt was extracted as by-product of nickel mining. Morocco is currently the only producer of primary cobalt.

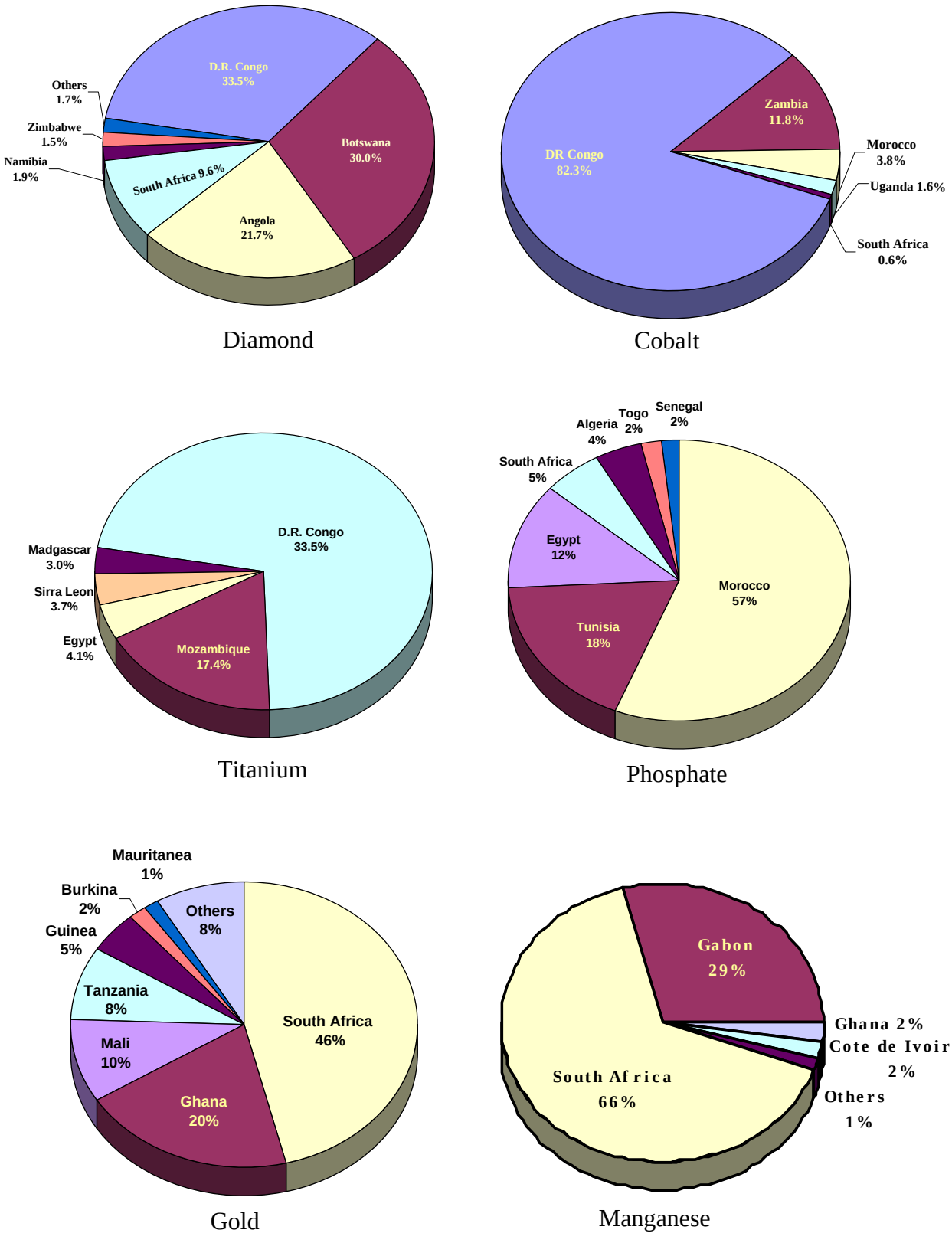

Figure 4. African Mineral production of diamond, cobalt, titanium, phosphate, gold and manganese in 2009.

The vast majority of cobalt resources in Africa occur in sedimentary copper deposits of Democratic Republic of Congo and Zambia where more than 50% of the global reserves (USGS, 2011). World production was decreased by about 5% in 2009 compared with the previous year due to the dramatic decrease of the Canadian production by about 50%, from 8,600 tons in 2008 to 4,100 tons in 2009.

In 2009, Africa produced 58.8% of world production of cobalt, an increase by 8.8% as compared with 2008 production. Most of the increase was from DR Congo that increased cobalt production by 14.5%, from 31,000t in 2008 to 35,500 in 2009. Zambia is the largest second producer of cobalt in Africa (11.7%) after DR Congo, followed by Morocco (2.2%), Uganda (0.9%) and South Africa (0.3%) (Fig. 4), (Brown et al., 2010 and USGS, 2011). The production of cobalt from Zambia was decreased from 6,900t in 2008 to 5,000t in 2099.

Cobalt is mainly associated with copper in the Katanga Province that hosts the Central African Copperbelt occupying the southern part of the Lufilian arc that extends for 800 km into Democratic Republic of Congo and Angola with 100 km width. The Copperbelt is one of the world's greatest metallogenic provinces containing 36% of the world's cobalt reserves with 0.4% cobalt content (Misra, 2000). It is estimated to contain more than 8 million tons of cobalt (Annels and Simmonds, 1984). By-product cobalt has been produced from Democratic Republic of Congo since 1925 from the copper ores of Katanga (Lamey, 1966). It began with 126 tons. Carrollite, cobalt-bearing sulfide occurs as an accessory phase of economic significance (up to 0.5% cobalt) in the ore shale of Katanga rocks (Misra, 2000).

Demand of cobalt for jet aircraft and smaller power stations has been strong and is expected to trend upwards. The rechargeable battery industry has been rapidly increasing the amounts of cobalt it uses in recent years. Global cobalt prices have been in continuous decline (about 10% per year) since 2008. The recent price is $17/lb, while it was $50/lb in 2008 (InfoMine, 2011).

Vermiculite

Vermiculite is the commercial name used to describe micaceous mineral that expands when heated. It provides good thermal insulation in lightweight plaster and concrete. South Africa has the largest output of vermiculite in the globe.

Approximately 94.5% of Palabora's mined vermiculite from South Africa was exported, which accounts for an estimated 36.4% of the world's average annual total vermiculite production of about 200,000 ton (Palabora Mining Co., 2010). Minor productions were recorded from Egypt (3.9%) and Zimbabwe (1.6%).

World vermiculite reserves are estimated to be 50 Mt (enough for the next 100 years at current usage rates). South Africa is the largest second holder of vermiculite after United States of America (64%), holding 36% (14Mt) of the world known reserves. Palabora mine, South Africa is the major source of vermiculite.

Prices for vermiculite concentrate ranged from $210 to $460/ton (Moeller, 2010), largely dependent on grade sizing.

Vanadium

Vanadium's primary use is as a hardening agent in steel, in which it is critical in imparting toughness and wear resistance. Most of vanadium deposits are obtained as a by-product of the treatment of titaniferous magnetite, phosphate rock, and uraniferous

sandstone and siltstone, in which it constitutes less than 2% of the host rock. Significant amounts are also present in bauxite and carboniferous materials, such as crude oil, coal, oil shale, and tar sands.

In Africa, vanadium was produced from titaniferous magnetite mined from the Bushveld Complex. South Africa is the only producer of vanadium in Africa. It produced 14,500 tons (32% of the world vanadium production), and hosts 3.5 million tons (25.6% of the global reserves). South Africa is the second top vanadium producer in the world, after China (39%) and followed by Russia (27.1%) (USGS, 2011).

In 2011, the ferro vanadium (FeV) price as published in InfoMine, averaged $30/kg of contained vanadium, compared with $80/kg reported in the first half of 2008.

Chromite

Chromite is the primary commercial source of chromium (Cr) that has a wide range of uses in metals, chemicals, and refractories. Chromium is a critical alloying ingredient for the production of stainless and hardened steel. Chromite deposits form as a direct result of igneous differentiation. During the crystallization of magma, usually mafic or ultramafic, heavy, metal-rich liquids settle and accumulate at the base of magma chamber leading to layered intrusions. Good examples of layered intrusions that host economic concentrations of chromite occur in the mafic igneous rocks are the Bushveld Igneous Complex (BIC), South Africa; the Great Dike, Zimbabwe and Stillwater, Montana, USA.

The largest chromite-ore-producing countries are India, Kazakhstan, South Africa, and Turkey. Their production accounted for about 80% of world production (USGS, 2002). South Africa alone accounted for 43.5% of the world total.

In 2009, world chromite known reserves exceed 350 million tons. South Africa contains the world's the second largest known deposits of chromite (37% of global reserves) after Kazakhstan (51.4%) (USGS, 2011). The chromite reserves are found in the Bushveld Igneous Complex. Almost 99% of African chromium resources are geographically concentrated in southern Africa; South Africa, 90% and Zimbabwe, 9%.

South Africa is the leading manufacturer of chromite globally and a major supplier of ferrochrome. It produced 6.9 Mt in 2009 (37% of the world production and 96.4% of the African production). Zimbabwe produced chromite from the Great Dike, 60,000 tones (2.7% of the African production) in 2009. Minor production was recorded from Madagascar (0.8%) and Sudan (0.2%).

Chromite is generally produced as a by-product of PGE mining. In 2010, the average price of ferro chrome ranged from $1.5/kg in 2005 to the highest price $6.2/kg in March 2008. It increased from $1.5/kg in April 2009 to $2.7/kg in mid 2011 (InfoMine, 2011).

Zirconium

Zirconium metal is used in corrosive environments, nuclear fuel cladding, and various specialty alloys. Zirconium oxide exhibits high light reflectivity and good thermal stability and is primarily used as colors for pottery and other ceramic products.

The primary source of zirconium is the mineral zircon ($ZrSiO_4$) principally found in heavy-mineral sands, which is also the primary source of all hafnium. Zirconium and hafnium are contained in zircon at a ratio of about 50 to 1. Zircon is normally produced as a byproduct of the mining and processing of heavy-mineral sands.

In 2009, excluding U.S. production, world production of zirconium mineral concentrates in 2009 was about 1.16 Mt, a 9% decrease compared with revised 2008

(USGS, 2011). The leading producers of zircon were Australia (36%) and South Africa (30%). Africa shared in the global production by about 4.2Mt (32%), from South Africa (30%) and Mozambique (2%).

South Africa produces zirconium as a zircon byproduct from Richard's Bay and Namakwa Sands. Palabora Mining Co. Ltd. produces 70% of the world's baddeleyite (zirconium sulfate) used in specialized applications in the refractory, ceramics, tanning industries, and in kidney dialysis machines. Potential of zircon also exists in Kenya, Tanzania, Namibia, Sierra Leone, Senegal and Gambia. Mining operations from Sierra Leone ceased in 1995 due to political instability. Sierra Leone used to be one of the world's largest zircon producers (MBendi, 2002).

World reserves of zircon are estimated to be 56 Mt of ZrO_2 in 2009. South Africa is the second largest global reserves of Zirconium (25%) after Australia (41%). Recently, the zirconium industry continued to be active in the exploration and development of mineral deposits on a global basis, particularly in Australia, Kenya, Mozambique, South Africa, and the United States (USGS, 2002).

Several new mines were bought online in Mozambique and South Africa since 2007, ensuring adequate global supply for several years.

The average price of zircon was $880 to $900 per metric ton, up from $725 to $800 per ton at yearend 2008. In 2009, the average unit value of imported unwrought zirconium including sponge and powder from France was $51.50 per kilogram, a 27% increase from that in 2008 (USGS, 2011).

Titanium:

The principal mineral sources of titanium are rutile, ilmenite, leucoxene and anatase. They are usually found in localized beach placer deposits that may be called Heavy Mineral Sands (HMS). Some 94% of world demand for titanium is in the form of titanium dioxide and about 6% in titanium metal and metal alloys. The principal end uses for titanium dioxide are pigments, catalysts, ceramics, coated fabrics and textiles, floor coverings, printing ink, roofing granules and alloys.

Titanium is a rather common metal in igneous rocks but is rarely concentrated into primary ore deposits. Most of titanium minerals as well as zirconium, thorium and rare earth elements are obtained from placer deposits especially beach sands. To produce titanium, the basic ore, usually rutile (TiO_2) is converted to sponge.

World production of titanium dioxide (TiO_2) contained in titanium mineral concentrates (ilmenite and rutile) decreased by 10% (5.8Mt) compared with that of 2008 (6.4Mt) (USGS, 2011). Africa produced 1.62 Mt of ilmenite and rutile, 28% of the world production in 2009, and 19% of the global reserves.

South Africa is the major titanium producer in Africa (72% of the African production in 2009), 18.5% of global output and. It holds 10.3% of world titanium reserves. Mozambique is the second major producer in Africa (17.4%), Egypt (4.2%), Sierra Leon (3.7%) and Madagascar (3%).

Exploration and development activity is picking up in Africa, in particular along the Mozambican coast, Kenya, South Africa and Gambia.

Prices for bulk ilmenite and rutile concentrates in 2009 were higher compared with prices in 2008. They were ranged from $401 to $439 per metric ton in 2009 compared with $393 to $407 per ton in 2008 (USGS, 2011). Ferro titanium prices changed from $21/kg in 2005 to $3/kg in April 2009, and increased again to $9/kg in July 2011 (InfoMine, 2011).

Phosphate:

Phosphate rock is essentially calcium phosphate (apatite) plus various impurities such as iron oxides, clay silica, fluorine and perhaps uranium as in the Red Sea phosphate deposits, Egypt.

Phosphate rock was used primarily for production of wet-process phosphoric acid for fertilizer applications, which accounted for more than 95% of domestic consumption. The remainder was used in the manufacturing of animal feed supplements, for direct application to soil, and for elemental phosphorus production. Domestic consumption of phosphate rock decreased to 27.5 Mt compared with 31.6 Mt in 2008 (USGS, 2009).

There are two main types of phosphatic rock of economic potential in Africa:

(1) Phosphate-rich sedimentary rock (phosphorite) of marine origin. It forms 76% of world phosphate. This type dominates in Northern Africa. Guano, bird droppings, is rich in phosphate and form 1% of world phosphates. Minor amount of guano occurs in some coastal cavities of Cheringoma and Jofane limestones in Mozambique (Cilek, 1989). It just covers local agricultural needs.

(2) Igneous-origin phosphates that occur in carbonatites, pipe-like basic igneous rocks that occur in Centeral and Southern Africa such as Uganda, Tanzania and South Africa (Palabora Complex). This type forms 23% of world phosphate (Guilbert and Park, 1986). Apatite is the most valuable by-product mined from Palabora.

Africa produced about 25% of global phosphate in 2009, down from 29% in 2001. Morocco is the largest producer of phosphates in Africa. It produces about 23 Mt that is corresponding to 56.2% of the African production, and 13.7% of the world production. The other major producers in Africa are Tunisia (18.1%), Egypt (12.2%), South Africa (5.5%), Algeria (4.4%), Togo (2.1%) and Senegal (1.6). Minor productions were recorded from Tanzania and Burkina Faso.

Africa holds 83.3% of world phosphate reserves. Morocco alone holds about 77% of the global phosphate deposits (92.4% of the total African reserves). Morocco's enormous phosphate deposits are hosted in late Cretaceous, Paleocene and Eocene marine sediments. Rock sequences comprising clay, marl, limestone and chert, contain several phosphate-rich beds. Mabounie carbonatite in Gabon has considerable phosphate potential with an available annual production estimated at 2Mt/yr of high-grade (39% P_2O_5) concentration. Angola, Uganda, Tanzania, and Mozambique have great potential to develop several phosphate deposits that occur in carbonatite complexes.

Prices of phosphate rock had been averaged $50/ton for along time from 1981 to 2007 when they increased to reach $440/ton in the first half of 2008. The prices dropped to $100/ton with the global financial crisis late 2008, and slightly increased again in 2011 to $200/ton (Mundi, 2011).

Manganese

Manganese is essential to iron and steel production by virtue of its sulfur-fixing, deoxidizing, and alloying properties. Products for construction, machinery, and transportation are leading end uses of manganese. Manganese is also a key component of certain widely used aluminum alloys and, in oxide form, dry cell batteries. As ore, additional quantities of manganese are used for such non-metallurgical purposes as plant fertilizers, animal feed, and colorants for brick.

China, the leading producer of manganese, produced 12Mt of in 2009, representing 36% of the world's production. Africa's contribution to global manganese comes from South Africa that has about 75% of the world's identified manganese resources.

In 2009, Africa produced about 7Mt of manganese ore (21% of the global production), mostly from South Africa that produced around 4.6Mt, representing 14% of the world production and 66% of the African production. Gabon is the second top African manganese production (29%). Significant amounts of manganese were produced from Ghana (2.1%), Cote de Ivoire (2.1%). Minor amounts were produced from Morocco, Egypt, Namibia and Sudan.

The average price of manganese was assessed at $3.5/kg in 2011, down from $4.7/kg in 2007 (InfoMine, 2011).

Gold

Egypt has been the birthplace of gold mining industry since Pharaoh Time, before 3,000 B.C. Most of the gold goes into the manufacture of jewelry. However, because of its superior properties, gold became an essential metal in the modern industries such as computers, communications equipment, spacecraft and jet aircraft engines.

With the increase in price of gold and the worldwide economic slowdown, investment in gold has increased, with investors seeking safe haven investments.

World gold production is recorded in more than 90 countries. Several more countries also produce substantial quantities of gold. Global annual mine production in 2009 was 2460 tons (USGS, 2011).

Africa's gold mine production was about 439 tons in 2008, which was a decrease of about 9% compared with that of 2007. Production decreased significantly since 1995 because of the long-term decline in South African production that more than offset the increased output in Ghana, Guinea, Mali, and Tanzania (USGS, 2008). In 2008, Africa's share of world gold mine production was about 22%.

Africa has lost its place as one of the major gold producers, 23.4% in 2001 to be 17.6% in 2009; due to loosing South Africa its place as a No. 1 gold producer globally in 2007 (10.6%). South Africa is now the fourth largest gold producer in the world (8.1%) after China (13.1%), USA (9.1%), and Australia (9.1%). Gold production in South Africa has almost halved since 2001 (402 tons of gold).

Africa has eighteen countries known as gold producers (>1000 kg/yr), but about 90% of Africa's gold production comes from six countries: South Africa (46%), Ghana (20%), Mali (9.6%), Tanzania (8.4%), Zimbabwe (3.7%) Guinea (5.2%) and Burkina Faso.

South Africa's gold production has been declining steadily, with an annual decrease of around 3% since 1990. Gold production was down by more than 50% from 431 tons in 2000 to 198 tons in 2009. The decline of gold production in South Africa can be attributed in part to problems of electricity production and high average production costs, coupled with labor problems. All lead to lowering grades as well as several mines reaching the end of their lives. Grades remained the same at around 5.1 g/t (MBendi, 2002).

About 40% of African gold production originates from small-scale miners known in Africa as artisans (Keatley, 1992). African reserves of gold are not certain, but gold reserves in South Africa alone represented 38% of the global reserves, but now it represents about 6% (USGS, 2011).

According to InfoMine (2011), the price of a gold has continued rising since 2000 ($280 per ounce) to $1,880 per ounce in Aug. 22, 2011). Thus 2011 is the best year for the price of gold for the last 160 years.

Uranium

Uranium is one of the most powerful natural energy sources known to humankind. It occurs in a variety of different geological environments. The largest economic deposits are in sedimentary rocks, but deposits are also found in hydrothermal, metamorphic, surficial and igneous settings. Over 95% of uranium is used in the production of electricity in nuclear power stations. The reminder is used for the propulsion of ships, research, desalination and military ordnance (USGS, 2011).

In 2010, there are 441 commercial nuclear power reactors operating in 30 countries, generating electricity 377 GWe of total capacity. They provide about 14% of the world's electricity as continuous, reliable base-load power, and their efficiency is increasing. 56 countries operate a total of about 250 research reactors and a further 180 nuclear reactors power some 140 ships and submarines (WNA, 2011).

Sixteen countries depend on nuclear power for at least a quarter of their electricity. France gets around three quarters of its power from nuclear energy, while Belgium, Bulgaria, Czech Republic, Hungary, Slovakia, South Korea, Sweden, Switzerland, Slovenia and Ukraine get one third or more. Japan, Germany and Finland get more than a quarter of their power from nuclear energy, while in the USA one fifth is from nuclear. South Africa has two nuclear reactors generating 5% of its electricity. South Africa's first commercial nuclear power reactor began operating in 1984 (WNA, 2011).

The world total mined production of uranium rose in 2009 for the third successive year to 50,700 tons, the highest annual output since 1981 and an increase of 15% compared to 2008. Africa is a major producer of uranium in 2009, accounting for 17 % (8,600 tons) of the global output (50,700 tons), (Brown et al., 2010).

The African production comes from just three major producers, Namibia (53.4% of the African production, 9.1% of the world production), which allowed this country to occupy first place in Africa and fourth place in the world for uranium ore extraction. This increase is mainly due to the development of the Rossing mine. Niger is currently extracting 3,241 tons (37.7% of African production, Fig. 5) and occupying the second place in Africa for the two successive years for uranium ore extraction. It was leading the African continent in uranium production before 2008. South Africa (7.3% of African production) and Malawi (1.2% of African production).

Kayelekera uranium mine in northern Malawi was opened and commenced production in April 2009, producing 104 tons (1.2% of the African production) from open pit and is expected to ramp up to 1460 tU/yr about mid 2012 (WNA, 2011).

All production in Africa comes from primary uranium deposits except South Africa where it has generally been a by-product of gold from Witwatersrand gold mines or copper mining from the Palabora copper mine.

Rossing Uranium Mine in Namibia produces more than 90% of the country production. It is one of the largest known uranium ore deposits in the world. It ranks fifth of its kind and has a geological history dating back 700 million years when the Namib Desert formed part of the sea.

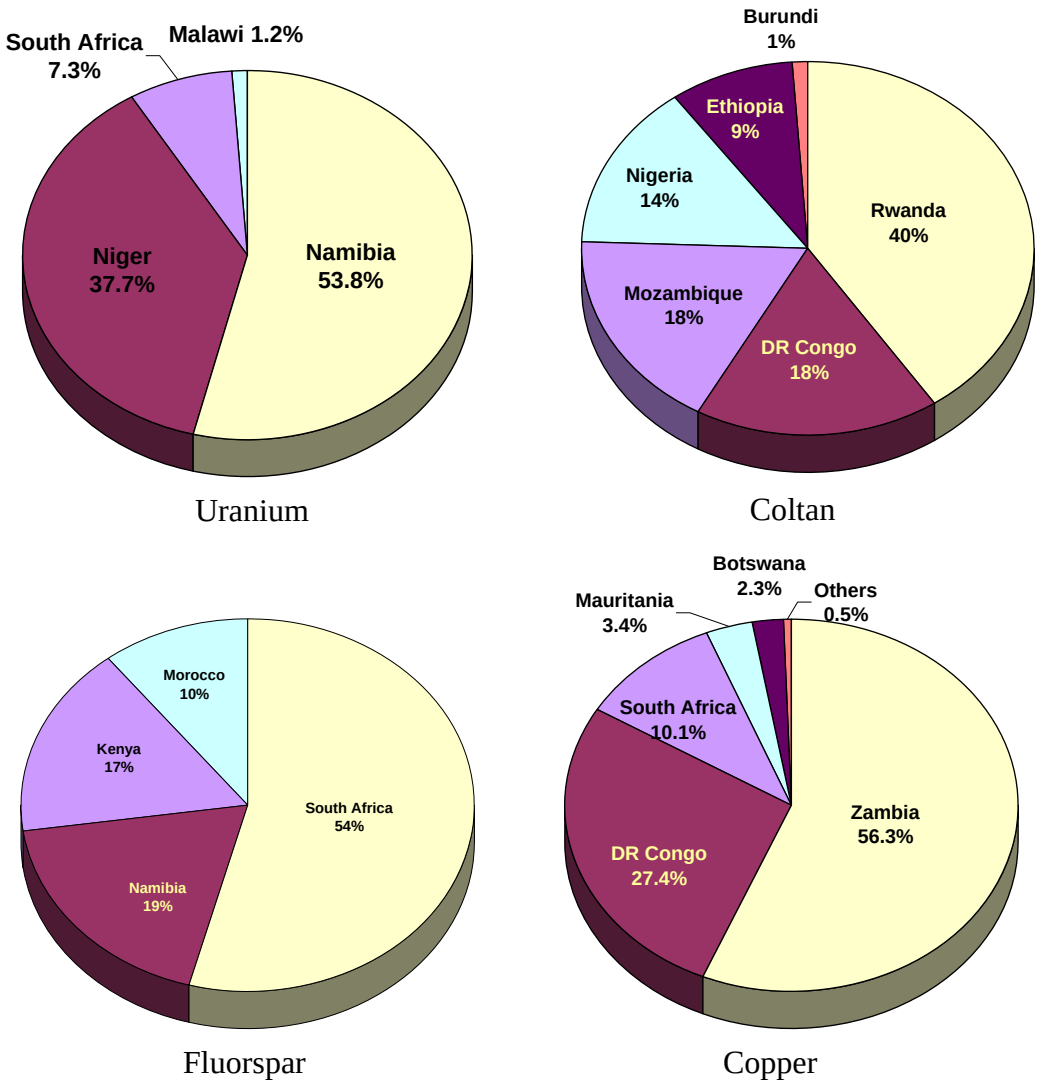

Figure 5. African Mineral production of uranium, coltan, fluorspar and copper in 2009.

Uranium prices were very low averaging $40/kg from 1988 to 2004. However, through 2005 to 2007 the spot price rose sharply, reaching a high of $300/kg in mid 2007, before falling back to $100/kg by the end of 2009 (Brown et al., 2010 and InfoMine, 2011). It averages $130/kg in the first half of 2011.

Coltan (niobium and tantalum)

The mineral coltan, short name for columbite-tantalite ore, is the principal source of niobium (columbium) and tantalum that is always found in association with niobium. African production of niobium is not significant. Niobium and tantalum do not occur naturally as free metals, but are essential components in a range of mineral species.

Tantalum is a silver-gray-blue precious metal. It has a number of properties that make it a valuable commodity including superconductivity and high melting point (2,996°C). Compacted pure metal powder forms capacitors with outstanding mass efficiency that regulates voltage in mobile and hand-held devices at high temperatures (Cellular Co., 2002). Capacitors have been a key factor in reducing the size of the mobile phone.

Tantalum is used to manufacture electronic capacitors, used in consumer electronics products such as cell phones, DVD players, video game systems and computers.

About 60% of global tantalum is used for making capacitors from which 35% are used for mobile phone manufacturers. Therefore, global demand for tantalum has increased strongly since the mid-1990s.

Brazil was leading producers of tantalum and niobium mineral concentrates (64%), followed by DR Congo (5.1%) and Mozambique (5.1%), China (4.5%0 and Nigeria (4.1%) in 2009 (Fig. 5) (Brown et al., 2010). African contribution comes from other countries including Ethiopia (9% of the African production) and Burundi (1.1%).

Tantalum-bearing minerals were considered to be among the "conflict minerals" in the Congo (Kinshasa), and production, trade, processing, and use of tantalum has come under international scrutiny (Global Witness Ltd., 2009).

Bond estimated known resources of 153,000 tons of tantalum, of which 44% was in South America, 27% in Australia, 13% in Asia, 12% in Africa, and 5% in North America. Know resources were distributed among in apogranite (61%), pegmatite (25%), placer (7%) and carbonatite (7%) host rock types (USGS, 2010).

Tantalum prices have been changed slightly between $81.5/kg in 2008 and $82/kg and $87/kg in 2010 and 2011, respectively (InfoMine, 2011).

Fluorspar (Fluorite)

Fluorspar is the commercial name for the mineral fluorite (calcium fluoride, CaF2), which, when pure, consists of 51.1% calcium and 48.9% fluorine. It is found in a wide range of geological environments, mostly hydrothermal solutions sourced from igneous intrusions or deep diagenetic processes. Nearly two thirds of the world's production is for the manufacture of hydrofluoric acid, a feedstock for many different chemical processes (BGS, 2011).

World fluorspar production capacity is about 6 million tons in 2001. It was decreased about 3% in 2009 compared to 2008. This is the first decrease in annual production since 2003 and was caused by a decrease in demand due to the global financial crisis. China is leading the world in fluorspar production. It produced 53.8% of total world production in 2009, followed by Mexico (17.5%), %), Mongolia (6.3%), South Africa (5.2%), Russia (4.5%) and Spain (2.5%). Africa shared in the world in fluorspar output by about 10% in 2009. The main producers in Africa are South Africa (54.1% of the African production), Namibia (18.7%), Kenya (16.8%), and Morocco (10.4%) (Fig. 5). African producers mostly export to countries of the European Union (EU).

The world's identified resource of fluorspar is approximately 500 million tons in 2010. Africa holds about 19% of the world reserves of fluorite. South Africa is the single largest holder of these reserves 41 million tons (18%), followed by Mexico (14%), China (9%), and Mongolia (5%).

In South Africa, fluorspar occurs mostly in vast low grade deposits often with high production costs (BGS, 2011). Some fluorspar resources occur in Namibia (3 million tons) and Kenya (2 million tons) (Miller 2011). Fluorite reserves in Morocco are not certain.

After remaining relatively constant for many years, fluorspar prices rose rapidly between 2007 and 2009, averaging $300/ton (Industrial Minerals, 2010).

Bauxite

Bauxite is the major ore for producing aluminum. There are numerous bauxite deposits, mainly in the tropical and subtropical regions. Bauxite belongs to the partially consolidated laterite group formed by surface weathering. The principal aluminum hydroxide minerals found in varying proportions with bauxites are gibbsite and the polymorphs boehmite and diaspore.

Global bauxite output dropped in 2009 by 7% compared to 2008 as a result of the global recession to 199 million tones (Mt) (BGS, 2011). The major bauxite producers in the world are Australia (33%), China (15%) and Brazil (13%). The African share in the world production of bauxite has been decreased from 11% in 2001 to 8% in 2009 due to increasing of the production from China and Australia, at the time of decreasing the Guinean production from 19 Mt in 2005 to 15 MT in 2009 when Guinea became the fifth largest producer of bauxite in the world, after it was the second and third in 2001 and 2005, respectively. Guinea is the main African producer of bauxite (92%) followed by Sierra Leon (4.7%), Ghana (2.7%) and Tanzania (0.8%).

Guinea has the planet's largest known bauxite reserves (26.4%). Bauxite resources are ranked first in terms of their importance to the Guinean economy, generating almost half of the country's export revenues.

Guinean bauxite deposits, formed by the tropical weathering of underlying aluminum-rich rocks, contain 40-50% aluminum oxide (Al_2O_3). They occur across Western and Central Guinea. Minor African producers are Mozambique, Cameroon, and Cote de Ivoire. Prices of bauxite ranged between $140 and $150 per ton in 2001 and $323 to $465 per ton in 2010 (USGS, 2011).

Copper

Copper is a non-ferrous base metal and its average concentration in the earth's crust is about 50 ppm (parts per million). The average minimum exploitable grade for a copper deposit is 0.4% which equates to a concentration factor of around 80 based on average crustal abundance (BGS, 2007). Copper is one of the oldest metals ever used and has been one of the important materials in the development of civilizations.

Copper is usually found in nature in association with sulfur in the form of copper sulfide. Copper deposits are found worldwide in a variety of geological environments. Hydrothermal deposits are most significant on a global scale. Sediment-hosted deposits are the Africa's most important source of copper from the Central African Copper belt.

In 2009, copper is produced in around eight countries in Africa, two of which currently mine over a million ton of copper (84% of the African production or 6% of the world production). They are Zambia (56.3% of the African production), DR Congo (27.4%). The other African producers are South Africa (10.1%), Mauritania (3.4%), Botswana (2.3%), Zimbabwe (0.3%) and Tanzania (0.2%) (fig. 5) (Brown et al., 2010).

According to USGS (2011) current world reserves are estimated at 630 million tons, nearly one quarter of which are found in Chile. The Zambian Copper belt was estimated to contain more than 150 million tones of copper (Raybould, 1978). Copper reserves in Africa are not known except Zambia that holds 3.2% or the known global reserves. Copper belt of Katanga (Shaba) Province contains one of the greatest concentrations of high-grade copper resources in the world (3.5% copper; Lamey, 1966).

Palabora Mine is by far the South Africa's largest copper producer. It is one of the largest open-pit mines in the world. The copper ore body is hosted in a carbonatite pipe

within which grades are typically concentric with the highest values (1.0% copper) at the core (Mining Technology, 2002). Palabora Mine is also a major source for vermiculite and baddeleyite (zirconium oxide), nickel sulfate, uranium and phosphate.

Copper prices have continued their upward trend since Jan. 2009 ($4/kg) to reach a record-high of $10/kg in March 2011 (InfoMine, 2011).

Conclusions

Africa has an extremely high exploration potential for precious and base metals as well as industrial minerals especially in the Precambrian igneous and metamorphic rocks of Central and Southern Africa and Red Sea hills. The African continent remains relatively unexplored using current limited exploration budget and relatively old techniques. Excellent opportunities for gold exploration are in Egypt, Zimbabwe and in regular gold producers. Central and Southern Africa are richly diamondiferous provinces where there are numerous deep pipes and diamond bearing kimberlite pipes. Africa has an interesting potential for base metals. The Zimbabwean craton which represents a rich nickeliferrous province with a high potential for the discovery of new deposits. Copper-Cobalt mines in Zambia and Democratic Republic of Congo are in great need for upgrading. Mozambique, Nigeria and Madagascar are but a few countries that have tremendous potential for base metal and industrial mineral deposits.

Widespread of political conflicts and civil wars continued to destabilize a number of African countries and constrained new investment in mineral exploration and development in many areas. The African governments should provide stable conditions and attractive mining polices. They should also encourage the local mining companies and individuals as well as the multinational mining companies to invest in Africa. Based on mineral wealth and the other natural resources, Africa should lead the world.

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