Mineral Deposits of Africa
1907–2016

Robert (Bob) P. Foster, Editor

Preface

The African continent extends over an area of approximately 30 million km^2, representing about 20% of the Earth's total land area. From the precious and base metal deposits of Morocco to the huge metal repositories of the Bushveld Igneous Complex and Witwatersrand of South Africa, the continent is remarkably endowed with mineral wealth and has been explored and exploited since the earliest days of civilization. This exploitation accelerated in the 19th and 20th centuries with demand from an exploding world population that needed the resources to underpin society's expectations and was fueled by the industry's ability to mine deeper and more effectively than ever before. Discovery of the Witwatersrand goldfields in the 1880s and the recognition of the importance of the Central African Copperbelt in the early part of the 20th century reinforced the view that Africa was a treasure house of mineral wealth and was underexplored—a view that still prevails today (2016) with a very considerable number of exploration and mining companies active throughout the continent.

Many of the existing deposits and also new discoveries have received extensive coverage in the issues of *Economic Geology* from its first date of publication in the early 20th century. The journal remains the leading medium for the systematic and rigorous reporting of mineral deposits, consideration of the multiple metallogenic factors that underpin our understanding of and search for these deposits, and the controversies that often surround their genesis.

In addition to papers in *Economic Geology*, this compilation draws on papers and other contributions published in the Society's Special Publications, Reviews Volumes, Economic Geology Monographs, Anniversary Volumes, and Newsletters until the end of 2015. This task would have been even more demanding if it wasn't for the very considerable support provided by my colleague Janet Davis and by Publications Editor Alice Bouley, assisted by contractor Andrea Crawford. My sincere thanks to them and to SEG Regional VP for Africa, Mike Venter, for his guidance.

Regional Considerations

Unravelling and systematically cataloguing the metallogenic evolution of the continent would be challenging in the extreme, given its long and complex geological history but tectonic cycles and metallogenic belts were summarized by de Kun (1963), and Bannerjee and Ghosh (1972) correlated Precambrian “ore provinces” between east Africa, India, and West Australia, with a particular emphasis on gold and copper. Derry (1961) considered Archean-Proterozoic boundaries on a global scale and highlighted the Witwatersrand gold-uranium mineralization and the iron ore deposits of west Africa, specifically Mauritania and Liberia.

The long history of mining and mineral-deposit research in southern Africa is reflected in overviews by Pretorius and Maske (1976) and Pretorius (1976) and a wide-ranging review of the region’s metallogeny by Anhaeusser (1976). Crockett and Mason (1968) considered the evolution of mineral deposits in the region—in particular, diamonds and nickel deposits, in terms of mantle-disturbance events. Summaries of the mineral deposits of individual countries have been published for Madagascar (Chantraine and Radelli (1970), Nigeria (Orajaka, 1973; Asaah, 2011), Botswana (Baldock et al., 1976), Sierra Leone (Morel, 1979), the Democratic Republic of the Congo (Goossens, 2009), and Mauritania (Taylor et al., 2012).

Gold Deposits

Gold mineralization, mostly considered to be orogenic-type, has been discovered and exploited in Archean cratons in southern, eastern, and western Africa. The Kaapvaal Craton of South Africa (Viljoen et al., 1969; De Ronde et al., 1992; Boer et al., 1995) and the Zimbabwe Craton (Foster, 1989); Harley and Charlesworth, 1989; Blenkinsop and Friel, 1996; Kisters et al., 1998; Buchholz et al., 2007) host multiple deposits, with the association of Archean-age mineralization and banded iron formation rocks discussed by Fripp (1976) and Saager et al. (1987). Isotope and trace-element studies suggesting a role for metamorphism in the genesis of these deposits were presented by Saager and Köppel (1976), and de Wit et al (1982) considered the role of sea-floor alteration in the possible pre-concentration of gold.

The Archean orogenic gold deposits of the Kilo Moto area of the Congo Craton (Democratic Republic of the Congo) were described by Woodtli (1961a, b) and those of the Tanzania Craton of east Africa were mentioned briefly by Mackay (1944).

Paleoproterozoic rocks in west Africa host a considerable number of orogenic gold deposits and these have been the focus of a resurgence of exploration in the past 40 years. The ca. 2.1 Ga Birimian accretionary terranes of the Baoule Mossi domain host major deposits in Burkina Faso and Ghana (Huot et al., 1987; Mumin et al., 1996; Oberthür et al., 1996; Yao et al., 2001; Allibone et al., 2002a, b, 2004; White et al., 2015), and the Birimian rocks of the Kédougou-Kéniéba Inlier, bridging the Senegal-Mali border, also host significant occurrences (Olson et al., 1992; McFarlane et al., 2011; Lawrence et al., 2013a, b). Broad age correlations between these mineralizing events and gold mineralization in French Guiana were demonstrated by Marcoux and Milési (1993).

Gold mineralization in the Lupa Goldfield of southwest Tanzania was described by Gallagher (1939) and subsequently demonstrated to be linked to the Ubendian orogenic cycle and dated at approximately 1.9 Ga (Lawley et al., 2013a, b).

The Neoproterozoic Pan-African terranes of the Arabian Shield in northeast Africa and Saudi Arabia are physically challenging exploration environments but host many orogenic gold deposits (El Boushi, 1972; Almond et al., 1984; Dostal and Dupuy, 1987; El-Bouseily et al., 1987; LeAnderson et al., 1995; Doebrich et al., 2004; Zoheir et al., 2008; Trench and Groves, 2015). Broadly equivalent age mineralization is also present in the Damara orogen of Namibia (Wulff et al., 2010).

The characteristics and genesis of the gold deposits of the Witwatersrand were the subject of a considerable early exchange of views in 1909 (Gregory, 1909; Hellmann, 1909; Becker, 1909; Denny, 1909), and continued with the extensive contribution of Graton (1930) and then Du Toit (1940), with subsequent papers focusing on the presence of uraninite (Miholić, 1954; Davidson, 1957; Pegg, 1959; Fuller, 1960). Additional publications address mineralogy (Saager and Mihalik, 1967; Saager, 1968; Maclean and Fleet, 1989) geochemical studies of host rocks, gold, and other minerals (Hargraves, 1963; Von Rahden, 1965; Saager and Esselaar, 1969; Utter, 1979; Minter et al., 1970; Oberthür and Saager, 1986; Phillips, 1987; Agangi et al., 2013), the role of carbonaceous matter (Parnell, 1996; England et al., 2001), and sulfur-, lead-, and oxygen-isotope characteristics (Hoefs et al., 1969; Köppel and Saager, 1974; Vennemann et al., 1996).

Papers with a focus on fundamental sedimentological studies include Minter (1976), Smith and Minter (1980), Minter et al. (1988), Els (1991), and James and Minter (1999). Wider considerations of the roles of sedimentation and hydrothermal activity in the genesis of the mineralization include Pretorius (1981), Phillips et al. (1989), Phillips and Myers (1989), Reimer and Mossman (1990), Wahl (1991), Robb and Meyer (1991), Pretorius (1991), Minter et al. (1992), Frimmel et al. (1993), Phillips and Powell (1993), Zhou (1994), Frimmel et al. (1994), Phillips and Dong (1994), Blenkinsop and Erikson (1995), Zhou et al. (1995), Minter (1999), Gartz and Frimmel (1999), Phillips and Law (2000), Frimmel and Minter (2002), Frimmel et al. (2005), Law and Phillips (2005), Large et al. (2013), and Frimmel (2014). Broader factors linked to age of mineralization and possible provenances of metals and minerals have also been considered in attempts to constrain genetic models (Barton et al., 1989; Robb and Meyer, 1990; Reimer, 1990; Barton et al., 1990; Loen, 1992; de Wit et al., 1993; Poujol et al., 1996).

Copper Deposits

Sediment-hosted copper: Central African Copperbelt

The Central African Copperbelt has played an extremely important role in the socio-economic development of sub-Saharan Africa since the early days of industrial-scale exploitation in the late 19th century. Early observations were provided by Ball and Shaler (1914) and Robert (1931), followed by Oosterbosch and Schuiling (1951) and Gillson (1963), with Garlick (1964) noting an association between copper mineralization and algal reef structures, and Maynard (1991) suggesting a role for diagenesis. Comprehensive overviews were provided by Gustafson and Williams (1981), Hitzman et al. (2005), and Selley et al. (2005). Specific deposits were described by Broughton et al. (2002 – Kansanshi), Steven and Armstrong (2003 – Kalumbila), Haest et al. (2007 – Dikulushi), Broughton and Rogers (2010 – discovery of Kamoa), and Schmandt et al. (2013 – Kamoa). The sources of copper, cobalt, and other metals and the genesis of the mineralization have been the subject of numerous contributions relating to specific deposits and wider regional-scale considerations (Unrug, 1988; Sweeney and Binda, 1989; Garlick, 1989; El Desouky et al., 2008; Heijien et al., 2008; Hitzman et al., 2010; Sillitoe et al., 2010; Hitzman et al., 2012; Schuh et al., 2012). Re-Os and U-Pb dating of vein-hosted mineralization at Kansanshi was presented by Torrealday et al. (2000).

Other sediment-hosted copper mineralization is evident in the Pan African-age Damara orogen of Namibia and Botswana (Lee and Glenister, 1976; Maiden and Borg, 2011), and an earlier description of sediment-hosted copper-dominated mineralization in Angola and the Republic of Congo was published by Stam (1960). Thole (1976) described copper mineralization hosted by Neoproterozoic rocks in the Shamrock Mine in northern Zimbabwe.

Caia (1976) drew attention to sedimentological controls of copper mineralization in early Cretaceous sandstones of central and west Africa.

Copper-zinc deposits

Cu-Zn-rich massive sulfide mineralization of Mesoproterozoic age has been described from the Prieska deposit in the Bushmanland province of South Africa (Middleton, 1976; Theart et al., 1989; Schade et al., 1989) and is also an important component of the Noeproterozoic Matchless belt of volcano-sedimentary rocks in the Damara orogen of Namibia (Goldberg, 1976; Breitkopf and Maiden, 1988; Klemd et al., 1989; Häussinger et al., 1993).

In north Africa, copper-iron mineralization of Neoproterozoic age has been described from Bleïda in the Moroccan Anti-Atlas (Leblanc and Billaud, 1978 and 1990; Leblanc and Arnold, 1994). Zinc-rich copper-gold massive sulfide mineralization has also been discovered in Neoproterozoic volcano-sedimentary host rocks in Eritrea (Barrie, 2007), and the non-sulfide Skorpion zinc deposit in Namibia probably represents the product of supergene alteration of massive copper-zinc sulfides hosted by Neoproterozoic rocks in Namibia (Borg et al., 2003).

Other copper deposits

These include the late-Archean or early-Proterozoic Guelb Mohgrein IOCG deposit in Mauritania (Taylor et al., 2012 – see Regional section) and the Miocene-age Oued Belif IOCG occurrence in Tunisia (Decrée et al., 2013), the breccia-disseminated-vein mineralization of the Karoo-age Messina orebodies in South Africa (Jacobsen and McCarthy, 1976; Sawkins, 1977; Sawkins and Rye, 1979; McCarthy and Jacobsen, 1980; Sawkins and Rye, 1980), and the copper-rich carbonatite of Palabora in South Africa (Palabora Mining Company, 1976).

Lead and Zinc Deposits

Lead-zinc massive sulfide mineralization has been described from the Paleoproterozoic Birimian terrane of Burkina Faso (Perkoa – Schwartz and Melcher, 2003). Zinc-lead mineralization, variably enriched in copper, is hosted by the Bushmanland Group of South Africa, where Pb-Pb and zircon dating have constrained the timing of metallogenesis (Reid et al., 1997; Cornell et al., 2009). Neoproterozoic zinc-lead-copper mineralization is also described from the Rosh Pinah mine in the Damara orogen of Namibia (Page and Watson, 1976). The complex lead-zinc-copper mineralization of the Tsumeb mine, also in the Damaran of Namibia, is referenced in a description of the germanium minerals (Sclar and Geier, 1957). Massive Pb-Zn mineralizaton and vein-type deposits have also been described from the Hercynian Meseta domain of western Morocco (Watanabe, 2002).

MVT-type Pb-Zn deposits are important in the Tethyan Atlas belt of north Africa (Reynolds and Large, 2010) and have been described from the Touissit-Bou Beker area of northeastern Morocco (Claveau et al., 1952; Rajlich, 1983; Dupuy and Touray, 1986; Bouabdellah et al., 2012 and 2015) and also in Tunisia (Sainfeld, 1956). Rouvier et al. (1985) proposed a link between diapir emplacement and genesis of lead-zinc mineralization for some of the occurrences in north Africa, including the Bou Grine deposit in Tunisia. Other deposits described by Reynolds and Large (2010) as hybrid, and possibly involving input from magmatic and basinal-brine processes, include Oued Amizour in Algeria and Sidi Driss and Bou Aouane in Tunisia.

An unusual association of carbonate-hosted MVT-type and vein-type lead-zinc mineralization with hydrothermal gold mineralization has been described in proximity to the Bushveld Complex in South Africa (Duane et al., 1991). Vein-type lead-zinc mineralization has been described from two localities in Nigeria (Farrington, 1952; Olatunji and Ekwere, 1986)

Nickel, Copper, and PGE Deposits

These three metals are commonly associated in mineralization of undoubted magmatic origin but the genesis of some has been ascribed to hydrothermal processes and others remain in question.

The ca. 2 Ga Bushveld Complex of South Africa is one of the world's greatest repositories of platinum-group elements (PGE), nickel, and copper, as well as chromite, and was first described in detail by Wagner (1926a, b); subsequent overview contributions include Cousins and Vermaak (1976), Von Gruenevaldt et al. (1985), and Naldrett (1989). Specific papers have focused on mineralogical characteristics (Vermaaks and Hendriks, 1976; Brynard et al., 1976; Crocket et al., 1976; Feather, 1976; Stumpfl and Tarkian, 1976; Kinloch, 1982; McCarthy et al., 1985), and a number of publications address trace element distributions (Page et al., 1982; Davies and Tredoux, 1985; Hiemstra, 1985; Klemm at al., 1985a; Cawthorn and McCarthy, 1985; Lee and Tredoux, 1986; Junge et al., 2014) and sulfur-isotope studies (Holwell, 2007; Sharman et al., 2013).

The mineral and chemical characteristics of chromite and titanomagnetite have been considered by Hulbert and Von Gruenevaldt (1985), Engelbrecht (1985), Hatton and Von Gruenevaldt (1985), Klemm et al. (1985b), Reynolds (1985a, b), Von Gruenevaldt et al. (1985), and McCarthy et al. (1985),

The Merensky Reef is one of the major mineralized zones within the Bushveld Complex and its characteristics and genesis have been addressed by many papers, including Schwellnuss et al. (1976), Vermaak (1976b), Kruger and Narsh (1985), Buntin et al. (1985), Carr et al. (1994), Scoon (2002), Seabrook et al. (2005), Mitchell and Scoon (2007), Scoates and Friedman (2008), and Naldrett et al. (2011). The Platreef and associated lithologies were discussed by Cawthorn et al. (1985), Barton et al. (1986), McDonald and Holwell (2011), and Yudovskaya et al. (2013), and UG2 has been described by Gain (1985).

A number of publications have addressed wider aspects of the mineralization and potential metallogenic controls (Vermaak, 1976a; Harmer and Sharpe, 1985; Sharpe and Hulbert, 1985; Viljoen and Scoon, 1985; Nel, 1985; Mathez, 1989; Mathez and Mey, 2005; Arndt et al., 2005; Cawthorn et al., 2005; Maier and Barnes, 2010; Barnes et al., 2010). Nickel-copper-PGE mineralization is also hosted by the Uitkomst Complex, which is believed to be coeval and cogenetic with the Bushveld Complex (Maier et al., 2004).

Platinum group mineralization in that other major repository in southern Africa, the ca. 2.5Ga Great Dyke of Zimbabwe, is described by Wilson and Tredoux (1990) and Oberthür (2011). Elsewhere in southern Africa, nickel-copper-PGE mineralization is hosted by the Karoo-age Mount Ayliff Complex (Maier et al., 2002).

Other orthomagmatic nickel deposits include those hosted by Archean greenstone belts in Zimbabwe (Viljoen et al., 1976; Prendergast, 2003; Prendergast and Wilson, 2015) and eastern Botswana (Selebi Pikwe – Wakefield, 1976), and broadly similar deposits occur in the Kibaran orogenic belt in Tanzania and Burundi (Maier et al., 2007, 2011; Tirschmann et al., 2010).

Nickel mineralization ascribed a hydrothermal origin has been described from the Central African Copperbelt (Capistrant et al., 2015). Nickel-cobalt-arsenide mineralization occurs as massive and disseminated lodes and veins of Hercynian age in the Anti-Atlas of Morocco (El-Naciri et al., 1997; Ahmed et al., 2009; Oberthür et al., 2009), and an occurrence of native silver was described by Leblanc and Lbouabi (1988). Partitioning of platinum group and chalcophile elements in chrome-nickel mineralization in the Beni Bousera massif in Morocco was investigated by Piña et al. (2013).

Chromite

Chromite deposits of the Great Dyke and Bushveld Complex are discussed by Sampson (1932) and also by Stowe (1994), who provided a wider review that also included the Archean-age podiform deposits of Shurugwi and Mashava in Zimbabwe.

Tin, Tungsten, Molybdenum, Columbite

Some of the oldest known tin mineralization in Africa is associated with the Bushveld Complex (Leube and Stumpfl, 1963a, b; Pollard et al., 1991; von Gruenevaldt and Strydom, 1985). The tin deposits of the Jos Plateau in Nigeria were first described by Falconer (1912) and subsequently by Wright (1970), Olade (1980), and Imeokparia (1982), and a columbite association with the same granitic rocks was discussed by Williams et al. (1956) and MacKay (1957). Neoproterozoic scheelite-fluorite skarn mineralization occurs in Namibia (Steven and Moore, 1994), whereas tungsten mineralization in South Africa's Namaqualand may be the products of two mineralizing events (Raith and Prochaska, 1995). Molybdenum and tin-tungsten deposits related to Variscan granites in Morocco have been described by Heim (1934), Heck (1946), and Sonnet and Verkaeren (1989).

Iron and Manganese Deposits

The widely developed and economically important, dominantly stratiform, Paleoproterozoic iron ore deposits of southern Africa have been the subject of publications addressing the general characteristics (Frankel, 1958; Schweigart, 1965; Beukes, 1973) and genesis (LaBerge, 1973; Button, 1976; Klein and Beukes, 1989). Elsewhere in Africa iron occurrences of various origins have been described from north Africa (Geijer, 1927), Morocco (Heim, 1934; Geijer, 1935), Mauritania (Baldwin and Gross, 1967a, b; Percival, 1967; Bronner and Chauvel, 1979), Senegal (Schwartz and Melcher, 2004), Sierra Leone (Fowler-Lunn, 1933; Marmo, 1956), Liberia (Berge, 1974), and Nigeria (Anike et al., 1993).

The extensive Paleoproterozoic manganese deposits of southern Africa and their genesis have been discussed by Du Toit (1933), de Villiers (1983), Gutzmer and Beukes (1995 and 1996), Tsikos and Moore (1997), Evans et al. (2001), Gutzmer et al. (2002), and Tsikos et al. (2003). Manganese deposits have also been reported from Morocco (Force et al. 1986; Gutzmer et al., 2006), Ghana (Sorem and Cameron, 1960), and Nigeria (Wright and McCurry, 1970).

Phosphate Deposits

Phosphate deposits are mined extensively in north and west Africa and have been described from Morocco by Lawson (1931) and from Burkina Faso through to Benin by Trompette et al. (1980). Deposits of Neogene age have been described by Fuller (1979) from the continental shelf of southern Africa.

Uranium

Uranium minerals are an important component of the Witwatersrand conglomerates and uranium was reviewed in this context by Nash et al. (1981). Uranium mineralization also occurs in the Karoo Basin of South Africa (Turner, 1985), with Stapleton (1978) proposing an important role for organic matter. The alaskite-hosted mineralization of the Rossing deposit was described by Berning et al. (1976) and Spivey et al. (2010). An early review of uranium and related minerals in Madagascar was published by Turner (1928).

Diamonds

Specific descriptions of primary diamond deposits in South Africa have been published by Penrose (1907 – Premier), Hartog (1909 – Kimberley), and Ruotsala (1975 – Finsch), with wider perspectives provided by Dawson (1968a, b) and Gurney et al. (2005, 2010). The characteristics and development of Post-Gondwana and Recent fluvial deposits in southern Africa have been reviewed by de Witt (1999), Spaggiari et al., 1999), and Jacob et al. (1999). Du Toit (1930) provided an insight to early days of prospecting in South Africa. Further afield, the Mwadui deposit in Tanzania was described by Edwards and Howkins (1966) and a more recent discovery in Liberia was highlighted by Haggerty (2015).

Other Mineral Deposits

A wide variety of other styles of mineralization have been described from the African continent and it is not possible to incorporate all of the individual deposits, despite the fact that they may be of significance to local economies and also to future exploration strategies. Barite deposits are relatively widespread and have been described from the Archean of South Africa (Heinrich and Reimer, 1977) and the Variscan of Morocco (Valenza et al., 2000; Bouabdellah et al., 2014). Other mineralization of significance includes asbestos in southern Africa (Anhaeusser, 1976), vanadium in the Otavo Mountainland of Namibia (Boni et al., 2007), tourmaline mineralization in the Damara orogen (Steven and Moore, 1995), and skarn-hosted rare earth elements in Madagascar (Estrade et al., 2015).