SEG Compilation 15

Mineral Deposits of Africa (1907–2023): Foundation for Future Exploration

Preface

Compiled from Economic Geology *and SEG Publications*
SEG Compilation 15
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Preface

The African continent extends over an area of approximately 30 million km² and represents 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 mined since the earliest days of civilization. This exploration accelerated in the 19th and 20th centuries with demand from an exploding world population that needed the resources to underpin society's expectations and fueled by the industry's ability to mine deeper and more effectively than ever before. Discovery of the Witwatersrand gold fields 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 (2024) with a very considerable number of exploration and mining companies active throughout the continent.

This 2024 compilation is a comprehensive update of a previous compilation from the Society of Economic Geologists, *Mineral Deposits of Africa: A Compilation (1907–2016)*, which was released in 2016 and available on DVD. Eight years on, the rate of exploration and new discoveries on the continent has accelerated recognition that this vast and challenging landscape and geology undoubtedly has extensive mineral resources yet to be discovered. This is reflected in the proliferation of relevant papers recently published through the multiple outlets offered by the Society and, hence, the requirement for this update. Equally importantly, making this documentation available in this digital format ensures that the content can be easily accessed and that it will be more widely utilized than perhaps has been the case in the past.

The Society has facilitated this new digital format, with its Africa focus, in advance of the SEG 2024 conference in Windhoek, Namibia, September 27–30, 2024, anticipating that it will be of interest to many participants of the conference and well beyond as explorers and miners are reminded of the resource potential of the continent.

Many of the known deposits and new discoveries have received extensive coverage in the issues of *Economic Geology* commencing soon after its first date of publication in 1905, and 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 contributions published in the Society's Reviews volumes, Special Publications, Monographs, Anniversary Volumes, and quarterly publication (*SEG Newsletter/SEG Discovery*), until the end of 2023. Discussions relating to papers published in *Economic Geology* have also been included where the debate is deemed to have been substantive. A small number of book reviews are also referenced where the contents of the books, published elsewhere, have some relevance to mineral deposits in Africa.

Following a first section that considers publications relating to mineral deposits throughout Africa and within major geographic regions, deposits are grouped according to what are largely accepted categories reflecting specific deposit types such as Archean gold, Witwatersrand gold, sediment-hosted copper, and Bushveld Ni-Cu-platinum group element (PGE) deposits without necessarily assigning common metallogenic controls. Taking the same approach of avoiding groupings based on genetic controls, given that quite commonly there is ongoing debate over such issues, more general groupings such as "Other Copper and Copper-Zinc" and "Lead and Zinc" have been utilized. The key premise in this approach is that readers can consider which commodity they wish to evaluate and then use this resource to identify where in Africa occurrences have been identified and described.

A list of categories and brief comments on what is covered in these is compiled in Table 1.

As a general guide, the locations of major deposit groups are illustrated in Figure 1, but this is far from comprehensive.

This task would have been even more demanding if it was not for the very considerable support provided by my colleague Janet Davis and by SEG staff in Littleton, Colorado. My sincere thanks to them and to former SEG Regional Vice President for Africa, Mike Venter, current Regional Vice President for Africa, John Paul Hunt, and Ester Shalimba, of the University of Namibia, for their informed reviews and input to this compilation.

It would be inexcusable not to draw attention to a significant review of the major mineral occurrences of Africa that was published outside the outlets offered by the SEG but merits consideration in parallel with this compilation. The 2016 special issue of *Episodes*, titled "The Great Mineral Fields of Africa," was edited by Viljoen and Wilson (2016) and provides 16 excellent reviews of important mineral types and occurrences across the continent. Permission to use the base map and mineral occurrences in figure 1b of the introduction to this special issue was generously authorized by the publish-

Table 1. Deposit Categories

Deposit type	Notes	No. of publications
Regional considerations	Papers reviewing resources in countries, regions, and the wider continent	19
Gold deposits—Archean	Predominantly orogenic gold deposits	23
Gold deposits—Paleoproterozoic	Orogenic deposits mostly in West Africa; also northeast Congo craton	32
Gold deposits—Neoproterozoic	One example from Hoggar (NW Africa); remainder Arabian-Nubian Shield	11
Other gold and silver	Guelb Moghrein iron oxide copper-gold (Mauritania); Imiter silver (Morocco); gold and silver occurrences in Morocco and Mali	7
Gold—Witwatersrand	Publications variously arguing for placer origins and/or the role of hydrothermal fluids since the first paper in 1909; more recently, possible importance of reduced meteoric water mobilizing gold from Archean hinterland	64
Sediment-hosted copper	Central African Copperbelt; Kalahari Copperbelt in Namibia and Botswana; also in Zimbabwe, Republic of Congo, Angola, Gabon, Morocco, and Algeria	63
Other Cu and Cu-Zn deposits	Okiep magmatic Cu; Messina breccia pipes and Palabora carbonatite in South Africa; IOCG in Tunisia, porphyry Cu in Sudan, Prieska and Swartberg massive sulfides in Bushmanland Province of South Africa, and Bisha Cu-Zn-Au deposit in Eritrea	17
Lead and zinc deposits	Range of massive sulfide, Mississippi Valley-type, and vein-type occurrences across the continent	17
Ni-Cu-PGE deposits—Bushveld	All related specifically to the Bushveld Igneous Complex in South Africa; also including chromite	75
Other Ni-Cu-PGE deposits	Orthomgamatic deposits in Bushveld-related Uitkomst Complex and the Great Dyke of Zimbabwe; also in other mafic-ultramafic intrusions, including lherzolite massif in Morocco	22
Chromite	Podiform deposits in Zimbabawe and ophiolite-related occurrences in Egypt and Morocco; the many occurrences in the Bushveld Igneous Complex are addressed in the Bushveld compilation	9
Tin, tungsten, and molybdenum	Granite-related deposits in the Bushveld Igneous Complex, Jos Plateau of Nigeria, Egypt, Variscan granites in Morocco, and those of Namaqualand, South Africa; also scheelite in skarns and tourmalinite bodies in Namibia	16
Iron deposits	Important occurrences include the Transvaal Supergroup (Kuruman) in South Africa, Nimba and Goe (Liberia), Sierra Leone, Mauritania; others throughout Central Africa, Morocco, Egypt, and Ethiopia	29
Manganese deposits	Kalahari manganese field (South Africa), Nsuta (Ghana); also Namibia (Damaran), Nigeria, Morocco, and Egypt	19
Phosphate and potash	Sedimentary phosphate deposits in Morocco and Egypt and in the Volta, Gabon, and Congo sedimentary basins; carbonatite-phosphate deposits of Uganda and across the continent; potash evaporites of northern Ethiopia	12
Uranium	In the Witwatersrand gold fields and sediment-hosted deposits in the Karoo basin (South Africa) and the late Proterozoic Copperbelt sequences; also Oklo “reactors” of Gabon; alaskite-hosted Rossing in Namibia	11
Diamonds	Kimberlite-hosted and fluvial deposits in Southern Africa; also Tanzania and Liberia; microdiamonds in granulites in Morocco	18
Other mineral deposits	Wide range, including Co-Ni laterite, rare and critical minerals, barite, vanadium, fluorite, asbestos, graphite, and major sedimentary titanium-zircon Namakwa sands of South Africa	30
Total		494

ers and Susan Frost-Killian and her co-authors (Frost-Killian et al., 2016).

Regional Considerations

Unraveling and systematically cataloging the metallogenic evolution of the continent would be challenging in the extreme given its long and complex geologic 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 those of 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 in 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

Gold deposits—Archean

Gold mineralization, mostly considered to be orogenic type, has been discovered 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,

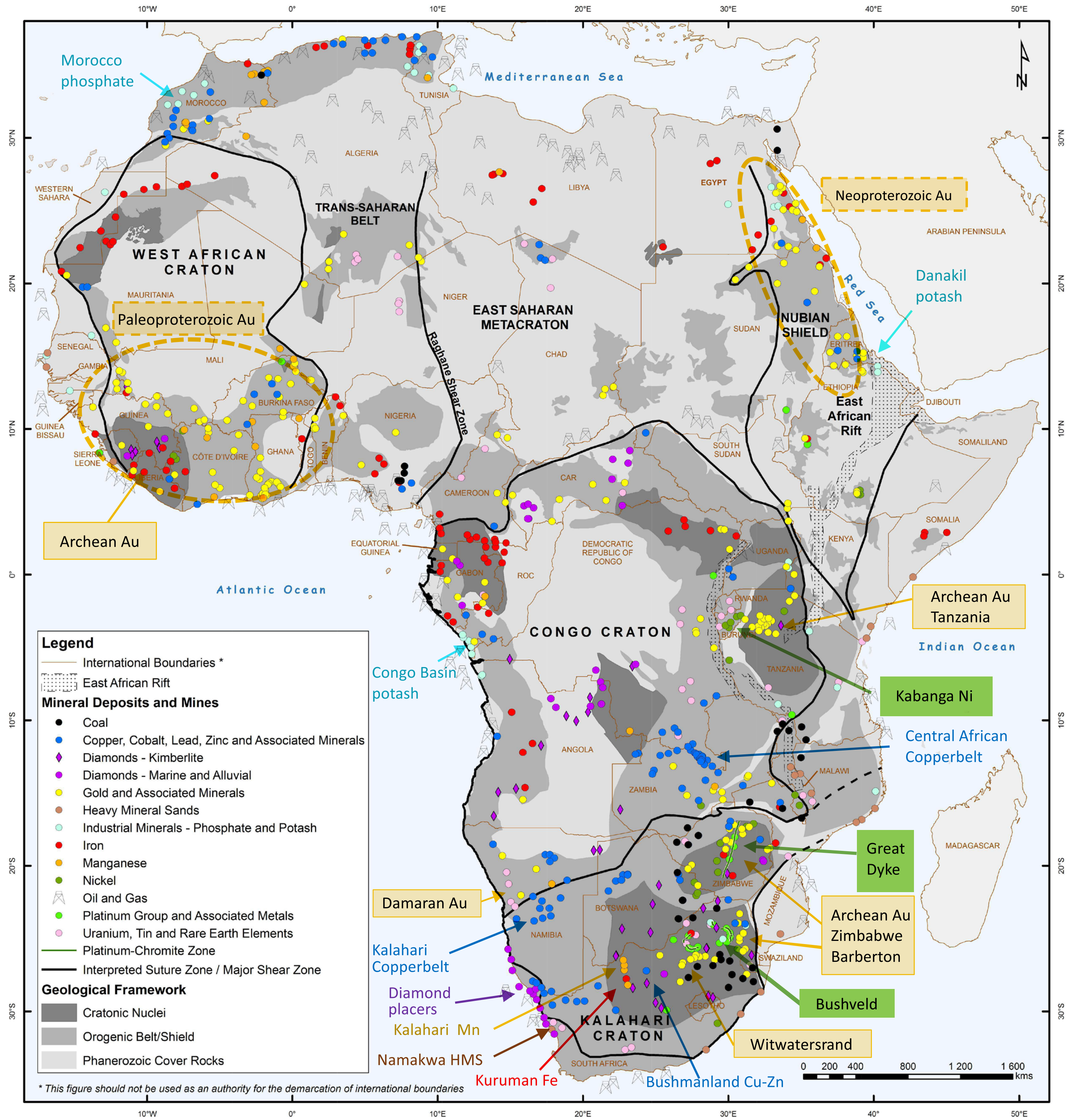

Fig. 1. Significant mineral occurrences in Africa referenced in this summary. Superimposed on a map detailing major mineral deposits of Africa published by Frost-Killian et al. (2016), used by permission of authors and publisher. Copyright Frost-Killian et al.

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). Isotopic 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 hydrothermal vent systems in the possible preconcentration 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 the Kibali mine and satellite occurrences in considerable detail by Allibone et al. (2020). Those of the Tanzania craton of East Africa were briefly referenced by Mackay (1944), with a comprehensive review of the Geita mine published by Dirks et al. (2020).

Gold deposits—Paleoproterozoic

The ca. 2.1 Ga Paleoproterozoic ("Birimian") accretionary terranes of West Africa, extending 1,600 km from eastern Senegal to Ghana, have been the focus of a resurgence of exploration leading to multiple major discoveries over the past 40 years (Goldfarb and André-Mayer, 2017; Goldfarb et al., 2017; Le Mignot et al., 2017; Thébaud et al., 2020). Broad age correlations between these mineralizing events and gold mineralization in French Guiana were demonstrated by Marcoux and Milési (1993) and more recently considered in terms of evolution of the Columbia supercontinent by Goldfarb et al. (2017).

The westernmost terranes exposed in the Kédougou-Kéniéba inlier, straddling the Senegal-Mali border, host significant operating mines (Olson et al., 1992; McFarlane et al., 2011; Lawrence et al., 2013a, b; Masurel et al., 2017a; Lambert-Smith et al., 2020; Allibone et al., 2020).

The Baoulé Mossi domain encompasses multiple orogenic belts accreted around the Archean Kénéma-Man craton, which underlies much of Guinea, Sierra Leone, and Liberia. The enormous gold endowment of the region is reflected in the multiple detailed descriptions of deposits, mostly operating mines, in Mali, Guinea, Côte d'Ivoire, Burkina Faso (Huot et al., 1987; McFarlane et al., 2011; Lawrence et al., 2013a, b, 2017; Allibone et al., 2020), and especially Ghana—including the giant ~70 Moz Obuasi mine (Mumin et al., 1996; Oberthür et al., 1996; Allibone et al., 2002a; Fougerouse et al., 2017; Oliver et al., 2020), Bogoso (Allibone et al., 2002b), Chirano (Allibone et al., 2004), Damang (White et al., 2015), and Ahafo (Masurel et al., 2021).

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).

Gold deposits—Neoproterozoic

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). The region's largest gold mine, the granitoid-hosted Sukari, is described in a recent paper by Zoheir et al. (2023), and the investigation of the ore-forming processes responsible for the ~0.7 Moz gold occurrence in the Gabgaba district of northern Sudan (Bertier et al., 2023) serves to highlight the wider exploration potential of the Arabian-Nubian Shield.

The description of the late Proterozoic gold mineralization of the Navachab mine in Namibia, formed during the collision of the Congo and Kalahari cratons (Wulff et al., 2010), provides important insights to what has since become a major regional exploration play with multiple discoveries over the past decade.

Other gold and silver

Other occurrences of gold and silver mineralization include the gold-copper mineralization of Guelb Moghrein in Mauritania, an unusual iron oxide copper-gold (IOCG) deposit hosted by metacarbonate rocks, with early mineralization ca. 2.5 Ga and a later shear-related event ca. 1.7 Ga (Kirschbaum and Hitzman, 2016).

At Africa's biggest silver mine, Imiter, in Morocco, the mineralization is hosted by Pan-African fault zones reactivated during Triassic-age extensional tectonism (Essaraj et al., 2016). Ophiolitic ultramafic rocks have been suggested as important source rocks for both gold and silver elsewhere in Morocco and Mali (Buisson and Leblanc, 1985, 1987; Leblanc and Lbouabi, 1988).

Gold—Witwatersrand

The characteristics and genesis of the gold deposits of the Witwatersrand were the subject of a considerable early exchange of views in 1909 (Becker, 1909; Denny, 1909; Gregory, 1909; Hellmann, 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; Minter et al., 1970; Utter, 1979; 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., 1968; 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), James and Minter (1999), and Nwaila et al. (2021). 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), Pretorius (1991), Robb and Meyer (1991), Minter et al. (1992), Frimmel et al. (1993), Phillips and Powell (1993), Frimmel et al. (1994), Phillips and Dong (1994), Zhou (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), and Large et al. (2013).

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, 1990; Reimer, 1990; Robb and Meyer, 1990; Loen, 1992; de Wit et al., 1993; Poujol et al., 1996). Frimmel (2014) and Frimmel and Nwaila (2020) propose that aqueous transport of gold leached from the hinterland surface by reduced Mesoarchean meteoric waters led to physical and chemical capture of gold by microbial mats.

Sediment-Hosted Copper

Central African Copperbelt

The Central African Copperbelt has played an extremely important role in the socioeconomic development of Sub-Saharan Africa since the early days of industrial-scale mining 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, 2018). Multiple descriptions of specific deposits include Broughton et al. (2002—Kansanshi), Steven and Armstrong (2003—Kalumbila), Haest et al. (2007—Dikulushi), Broughton and Rogers (2010—discovery of Kamoa), Schuh et al. (2012—Tenke-Fungureme), 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; Garlick, 1989; Sweeney and Binda, 1989; El Desouky et al., 2008; Heijien et al., 2008; Hitzman et al., 2010, 2012; Sillitoe et al., 2010). Re-Os and U-Pb dating of vein-hosted mineralization at Kansanshi was presented by Torrealday et al. (2000).

Other sediment-hosted copper

Sediment-hosted copper mineralization also occurs in the late Proterozoic rocks of the Kalahari Copperbelt, extending ~800 km from central Namibia into Botswana. There is evidence of a prolonged history of depositional and mineralizing events, to some extent comparable with those of the Central African Copperbelt, and with some publications stressing the role of synsedimentary processes (e.g., Oamites mine in Namibia; Lee and Glenister, 1976) and others highlighting post-diagenetic structural and hydrothermal activity (Maiden and Borg, 2011; Hall et al., 2018, 2021).

Significant Cu-Zn sulfide deposits have been described from the Matchless belt of volcano-sedimentary rocks within the Kalahari Copperbelt, and for which an affiliation with basic mafic volcanic rocks (amphibolites) has been suggested by some authors (Goldberg, 1976; Breitkopf and Maiden, 1988; Klemd et al., 1989; Häussinger et al., 1993).

Caia (1976) drew attention to sedimentological controls of stratiform copper (±lead) mineralization in Early Cretaceous sandstones of Angola and Gabon and also commented on deposits in Morocco and Algeria. More recently, sediment-hosted copper mineralization of Neoproterozoic age has been described from the Moroccan Anti-Atlas—the Bleïda deposit (Leblanc and Billaud, 1978, 1990; Leblanc and Arnold, 1994) and the Tazalaght and Agoujgal deposits (Verhaert et al., 2020).

Thole (1976) described copper mineralization in the Shamrock mine of northern Zimbabwe, where it is one of several occurrences hosted by arkosic metasediments belonging to the Neoproterozoic Deweras and Lomagundi Groups.

Other Cu and Cu-Zn Deposits

Other copper deposits include the Okiep bornite-magnetite mineralization hosted by a 1100 Ma norite body in the granulite facies Namaqualand terrane of South Africa's Cape Province (Cawthorn and Meyer, 1993), the complex breccia-disseminated vein mineralization of the Karoo-age Messina orebodies in South Africa (Jacobsen and McCarthy, 1976; Sawkins, 1977; Sawkins and Rye, 1979, 1980; McCarthy and Jacobsen, 1980), and the copper-rich carbonatite of Palabora in South Africa (Palabora Mining Company, 1976).

The Neoproterozoic Jebel Ohier porphyry copper mineralization in the Red Sea Hills of Sudan is a rare example of a preserved porphyry system in such ancient terranes (Bierlein et al., 2020).

The Miocene-age Oued Belif occurrence in Tunisia is regarded as a low-Cu-Au IOCG deposit that was generated in response to Alpine orogenesis (Decrée et al., 2013).

Cu-Zn–rich massive sulfide mineralization (±lead) of Mesoproterozoic age has been described in the Prieska (Middleton, 1976; Schade et al., 1989; Theart et al., 1989) and Swartberg (Cawood and Rozendaal, 2020) deposits in the Bushmanland province of South Africa. Pb-Pb and zircon dating have constrained the timing of metallogenesis to younger than ca.1650 Ma (Reid et al., 1997) and probably formed ca.1200 Ma (Cornell et al., 2009).

Copper-lead-zinc mineralization in Neoproterozoic dolomites was described by Stam (1960) in the Mindouli deposit in what is now the Republic of Congo. The author suggested this and other sediment-hosted copper-lead-zinc occurrences in the region to be Mississippi Valley-type deposits, although the brief deposit descriptions would not seem to equate to current characterization of MVT mineralization.

Zinc-rich copper-gold massive sulfide mineralization has also been discovered in Neoproterozoic volcano-sedimentary host rocks in Eritrea (Barrie, 2007), and the nonsulfide 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).

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). 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).

In North Africa, massive Pb-Zn mineralization and vein-type deposits have been described from the Hercynian Meseta domain of western Morocco (Watanabe, 2002), where intrusive activity may have played a role in their genesis.

Mississippi Valley-type (MVT) Pb-Zn deposits are important in the Tethyan Atlas belt of North Africa, particularly the Touissit-Bou Beker area of northeastern Morocco (Claveau et al., 1952; Rajlich, 1983; Dupuy and Touray, 1986; Bouabdellah et al., 2012, 2015).

Further east in Tunisia, Sainfeld (1956) described sediment-hosted Pb-Zn deposits and emphasized the role of faults in controlling the mineralization. Subsequent investigations of other Tunisian deposits hosted by Triassic and Cretaceous sediments have highlighted the important contributions of salt diapirism to the mineralizing process (Rouvier et al., 1985; Rddad et al., 2019).

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).

Ni-Cu-PGE Deposits—Bushveld

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 Igneous Complex of South Africa is one of the world's greatest repositories of PGEs, nickel, and copper, as well as chromite, and was first described in detail by Wagner (1926a, b); subsequent overviews include Cousins and Vermaak (1976), Von Gruenevaldt et al. (1985), and Naldrett (1989). Specific papers have focused on mineralogical characteristics (Brynard et al., 1976; Crocket et al., 1976; Feather, 1976; Stumpfl and Tarkian, 1976; Vermaaks and Hendriks, 1976; Kinloch, 1982; McCarthy et al., 1985), and a number of publications address trace element distributions (Page et al., 1982; Cawthorn and McCarthy, 1985; Davies and Tredoux, 1985; Hiemstra, 1985; Klemm at al., 1985a; 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 titano-magnetite have been described by Hulbert and Von Gruenevaldt (1985), Engelbrecht (1985), Hatton and Von Gruenevaldt (1985), Klemm et al. (1985b), Reynolds (1985a, 1985b), 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 Schwellnus et al. (1976), Vermaak (1976b), Kruger and Marsh (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 rock types were discussed by Cawthorn et al. (1985), Barton et al. (1986), McDonald and Holwell (2011), and Yudovskaya et al. (2013), and the platiniferous UG-2 chromitite layer 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).

Other Ni-Cu-PGE Deposits

Nickel-copper-PGE mineralization occurs in the Uitkomst Complex, which is believed to be cogenetic with the Bushveld Complex (Maier et al., 2004; Trubač et al., 2018).

Platinum group mineralization in that other major repository in Southern Africa, the ca. 2.5 Ga Great Dyke of Zimbabwe, is described by Wilson and Tredoux (1990) and Oberthür (2011).

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; Fiorentini et al., 2012).

Nickel-PGE mineralization occurs in a linear series of mafic-ultramafic intrusions in the Kibaran orogenic belt, extending for 300 km from northwestern Tanzania southward through Burundi, where Ni laterites have been identified, and in the Kibaran-hosted Kapalagulu intrusion of western Tanzania (Maier et al., 2007; Prendergast et al., 2021). The Kabanga deposit (Maier et al., 2011) is one of the largest undeveloped magmatic sulfide deposits in the world. Relatively recently, Ni-Cu sulfide mineralization has been identified in the Ntaka Hill ultramafic complex within the Neoproterozoic Mozambique orogenic belt in southern Tanzania (Tirschmann et al., 2010; Barnes et al., 2019).

The lenticular sulfide bodies of the Munali nickel deposit in the Pan-African Zambezi belt of southern Zambia are hosted by a mafic-ultramafic suite of rocks that are believed to have been emplaced as a residual liquid, with the mineralization subsequently overprinted by hydrothermal activity (Blanks et al., 2022).

Elsewhere in Southern Africa, nickel-copper-PGE mineralization occurs in the Mount Ayliff Complex within the Karoo igneous province (Maier et al., 2002).

The Ben Bousera lherzolite massif of northern Morocco hosts several small Cr-Ni orebodies (Gervilla and Leblanc, 1990). Partitioning of platinum group and chalcophile elements between arsenide and sulfide phases in the Ben Bousera mineralization was investigated by Piña et al. (2013).

Chromite

The chromite occurrences within the Bushveld Complex are referenced in the Bushveld compilation.

Sampson (1932) reviewed magmatic chromite deposits throughout Southern Africa. Subsequently Stowe (1994) provided a wider review that also included the Archean-age podiform deposits of Shurugwi and Mashava in Zimbabwe, and further details of Zimbabwean deposits were published by Rollinson (1997) and Prendergast (2008).

In North Africa, occurrences have been described in Egypt by Amin (1948) and Shukri (1948) and in Ethiopia by Bonavia et al. (1993). (Lherzolite-hosted deposits of northern Morocco were referenced in the section covering "Other Magmatic Nickel, Copper, and PGE Deposits" publications; Gervilla and Leblanc, 1990.)

Tin, Tungsten, and Molybdenum

Some of the oldest-known tin mineralization in Africa is associated with the Bushveld Complex (Leube and Stumpfl, 1963a, b; von Gruenevaldt and Strydom, 1985; Pollard et al., 1991). The granite-related tin deposits of the Jos Plateau in Nigeria were first described by Falconer (1912) and subsequently by Wright (1970), Kayode (1971), Olade (1980), and Imeokparia (1982). Tungsten mineralization in the Pan-African Damaran orogen in central Namibia occurs as scheelite-fluorite replacement skarns (Steven and Moore, 1994) and as structurally controlled scheelite-bearing tourmalinite bodies (Steven and Moore, 1995). Tungsten-molybdenum deposits in high-grade metamorphic rocks of South Africa's Namaqualand Metamorphic Complex appear to be genetically related to the 1.1 Ga Concordia granite but modified by the later high-grade metamorphism (Raith and Prochaska, 1995).

Tin-tungsten-fluorite veins in Egypt's Eastern Desert have been described by Amin (1947), and 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 Deposits

The extensive and economically important stratiform iron ore deposits of the Paleoproterozoic Kuruman iron formation in South Africa's Northern Cape province have been the subject of publications addressing the general characteristics (Schweigart, 1965; Beukes, 1973) and genesis (Button, 1976; Klein and Beukes, 1989). LaBerge (1973) considered iron formations on a worldwide basis, including South Africa, and suggested the possible role of biogenic processes.

Hematite-rich iron formations interbedded with quartzites were discovered in the Proterozoic Muro schist belt of Central Nigeria (Anike et al., 1993). In Central Africa, multiple iron ore occurrences have been described from what are now recognized as Archean-age greenstone belts of northeastern Democratic Republic of the Congo (Woodtli, 1961).

Iron ore deposits are evident in West Africa, several of which are the focus of considerable economic interest today. These include the Archean banded iron formations of the Sula Mountains in Sierra Leone (Fowler-Lunn, 1933; Marmo, 1956) and in Liberia (Bomi Hills, Fitzhugh, 1953; Nimba and Goe Ranges, Berge, 1971; Berge and Jack, 1977). Numerous magnetite bodies of the Falémé district in the Paleoproterozoic Kédougou-Kéniéba inlier in eastern Senegal appear to be skarn related (Schwartz and Melcher, 2004).

Iron ore deposits have been described from the Paleoproterozoic Ijil Group of the Reguibat Shield, Mauritania, by Gross and Strangway (1961), with subsequent discussions considering the role of supergene processes in generating higher-grade hematitic material (Baldwin and Gross, 1967a, b; Dorr, 1967; Percival, 1967). Occurrences were later described from the older, probably Mesoarchean, Tiris Group in Mauritania (Bronner and Chauvel, 1979).

Elsewhere, iron occurrences of various origins have been described from across North Africa (Morocco, Algeria, Tunisia; Geijer, 1927), Morocco (Heim, 1934; Geijer, 1935), and Egypt (Nassim, 1950; Nakhla, 1961; El Hinnawi, 1965; Sims and James, 1984).

Manganese Deposits

The important Paleoproterozoic manganese deposits of the Kalahari manganese field in the Cape Province of South Africa supply 85% of the world's manganese production. The genesis of the mineralization was discussed by Du Toit (1933), followed by comprehensive coverage by Frankel (1958), de Villiers (1983; with a focus on mineralogical aspects), Gutzmer and Beukes (1995, 1996), Tsikos and Moore (1997), Evans et al. (2001), Gutzmer et al. (2002), and Tsikos et al. (2003). The late Proterozoic Otjosondu manganese-silicate horizons of the Damara orogen in Namibia have been overprinted by high-grade metamorphism, but Bühn et al. (1992) demonstrated a paleoenvironment ranging from near-shore clastic to deep-water pelagic regimes.

Elsewhere in Africa, the important Nsuta deposits of Ghana are described by Sorem and Cameron (1960), and late Proterozoic manganiferous sediments occur in northern Nigeria (Wright and McCurry, 1970). The Carboniferous Mn-Fe ores of Um Bogma in the southern Sinai region of Egypt are also of sedimentary origin (Mart and Sass, 1972; ElAgami et al., 2000).

Iron-manganese mineralization, locally enriched in barium, has been reported in the northern Afar rift in Ethiopia and has been attributed to submarine hydrothermal activity ca. 200,000 years ago (Bonatti et al., 1972).

Supergene processes often contributed significantly to the genesis of deposits or led to upgrading of ores. These include karst-hosted ferromanganese wads developed as saprolitic residue overlying Permian coal measures in South Africa (Pack et al., 2000) and the karst-filling manganese-lead-barium Imini deposits of Cretaceous age in Morocco (Force et al., 1986; Gutzmer et al., 2006).

Phosphate and Potash

The important sedimentary phosphate deposits in Morocco were described by Lawson (1931) and are also found in Egypt (Omara, 1965; Atfeh, 1966). In West and Central Africa, deposits have been reported in the late Precambrian sequences of the Volta basin, extending from Burkina Faso through to Benin (Trompette et al., 1980), and in lower Cretaceous sequences in the Gabon and Congo basins (de Ruiter, 1979). Deposits of Neogene age have been described by Fuller (1979) from the continental shelf of Southern Africa.

Carbonatite-hosted phosphate deposits have been identified in Uganda (Davies, 1947; Reedman, 1984), and Pufahl and Groat (2017) published a major review of sedimentary and igneous phosphate deposits that references many occurrences in Africa.

The potash-bearing evaporites of the Danakil depression in northern Ethiopia are a significant resource and are considered by Holwerda and Hutchinson (1968), Mohr (1968), and Hutchinson and Holwerda (1968).

Uranium

Uranium minerals are an important component of the Witwatersrand conglomerates, and uranium was reviewed in this context by Nash et al. (1981). Sandstone-hosted uranium mineralization occurs in the Karoo basin of South Africa (Turner, 1985), with Stapleton (1978) and Turner proposing an important role for organic matter.

The lower Proterozoic uranium deposits of the Franceville basin in Gabon, often referred to as "natural nuclear fission reactors," are described in detail by Gauthier-Lafaye and Weber (1989) and Gauthier-Lafaye et al. (1989).

Pitchblende and secondary uranium minerals occur in the late Proterozoic sedimentary rocks in northwest Zambia that host the Central African Copperbelt deposits (Meneghel, 1981), an aspect that is covered by several of the Copperbelt publications included elsewhere in this compilation.

An early review of uranium and related minerals in Madagascar was published by Turner (1928).

The alaskite-hosted mineralization of the Rossing deposit was described by Berning et al. (1976) and Spivey et al. (2010) and further updated based on geologic mapping of the wider area, aided by hyperspectral imagery, by Gray et al. (2021).

Secondary uranium mineralization in fractured rocks overlying primary uranium mineralization in Egypt's Eastern Desert was discussed by Osmond et al. (1999).

Diamonds

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).

Microdiamonds have been identified in granulite facies rocks of northern Morocco and suggested to possibly be of economic interest (Cruz et al., 2011).

Other Mineral Deposits

A wide variety of other styles of mineralization have been described from the African continent, and it is not possible to comment on all the individual deposits, even though they may be of significance to local economies and to future exploration strategies.

Two publications describe the important Nkamouna cobalt-manganese-nickel-laterite occurrence—one of a number of such deposits in southeast Cameroon (Lambiv et al., 2009; Dzeuma and Gleeson, 2012).

Multiple publications describe occurrences of rare metals, rare earth elements (REEs), and other metals regarded as critical in a 2024 context. These include columbite in pegmatite bodies in Mozambique (Hutchinson and Claus, 1956), in carbonatite in southern Tanzania (Fawley et al., 1955), in tin-bearing granites of Nigeria (Williams et al., 1956; Mackay, 1957), the Kibaran-age Ta-Nb-bearing pegmatites of Burundi (Romer and Lehman, 1995), and skarn-hosted rare metals (REE, Zr, Nb, Th, Sn) in Madagascar (Estrade et al., 2015).

Pegmatite bodies from northeastern Tanzania contain vermiculite and gem-quality corundum, including red and magenta rubies and blue sapphires (Solesbury, 1967). The occurrence of zircon and other high field strength elements has been reported in the Tamazeght alkaline igneous system in Morocco (Salvi et al., 2000) and in the Amis Complex of peralkaline granites in Namibia (Schmitt et al., 2002). Vein-type monazite-apatite-chalcopyrite-magnetite occurrences in the high-grade metamorphic rocks of the 1100 Ma Namaqualand Metamorphic Complex in South Africa are enriched in thorium and rare earth elements (Andreoli et al., 1994).

Barite deposits are relatively widespread and range from Archean sedimentary occurrences of the Barberton Mountain Land of South Africa (Heinrich and Reimer, 1977) to the Variscan-age vein and karst deposits of Morocco (Valenza et al., 2000; Bouabdellah et al., 2014).

Vanadium occurs as vanadium-rich magnetite veins in magnetite-rich gabbros in the Oursi region of northern Burkina Faso (formerly Upper Volta, Neybergh et al., 1980) and as karst-hosted deposits in the Otavo Mountainland of Namibia (Boni et al., 2007).

Morocco's Bou Azzer nickel-cobalt-arsenide deposits are an important source of cobalt, occurring as massive and disseminated lodes and veins of Hercynian age in the Anti-Atlas region (Leblanc and Billaud, 1982; El-Naciri et al., 1997; Ahmed et al., 2009; Oberthür et al., 2009). Nickel mineralization of probable hydrothermal origin has been described from the Central African Copperbelt (Capistrant et al., 2015).

Fluorite mineralization occurs within breccia pipes and interstratified with volcaniclastic rocks related to the Bushveld Complex (Crocker, 1985) and in fault breccias and limestone-replacement bodies in Kenya's Rift Valley (Nyambok and Gaciri, 1975).

Other mineralization of interest includes major asbestos deposits in Southern Africa (Anhaeusser, 1976) and the lesser occurrences of anthophyllite-vermiculite in serpentinite host rocks in Egypt's Eastern Desert (Amin and Afia, 1954). The important flake graphite mineralization of the Molo deposit in Madagascar was generated within sedimentary rocks enriched in organic carbon by multiple thermal events during the Pan-African collision of East and West Gondwana (Scherba et al., 2018).

The massive, 1.17-billion-ton, Namakwa Sands deposit is a major resource of titanium and zircon discovered along the coastal strip of western South Africa in the early 1980s. The siliciclastic sedimentary rocks that host the heavy mineral orebodies are of Cenozoic age, the orebodies being identified as strandline dune complexes (Philander and Rozendaal, 2015). The only other titanium occurrence reported within Africa is a small sheet-like ilmenite-rich body identified within a titaniferous gabbro in the Eastern Desert of Egypt (Amin, 1954).

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