Granitoid-related iron-oxide-copper-gold mineralisation, Greater Lufilian Arc, Zambia and Namibia

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The chemistry of various granitoid plutons, their ages of emplacement and metallogenetic potential are being evaluated in the Mesoproterozoic to Neoproterozoic Greater Lufilian Arc of southern Africa. Large mineral deposits of the iron-oxide-copper-gold (IOCG) family are thought to be present in the Lufilian Arc. This paper reviews the main features of the deposit type and describes evidence for such deposits in the region, including the presence of iron-oxide bodies and hydrothermal breccias.

Some Notes on Iron-Oxide-Copper-Gold Deposits

The IOCG deposits comprise a recently identified type of mineral deposit. IOCGs are known to have formed in Mesoproterozoic and Neoproterozoic rocks of Australia, Canada, Brazil, Scandinavia, China, Russia and Africa. Phanerozoic deposits occur along the Andean chain in Chile and Peru. Brazilian examples of Archaean age are also known. The relatively recent international recognition of the deposit family is expected to result in discovery of many more mineralised provinces in geological time and geographical distribution. Most IOCG deposits are located in zones of extensional tectonics and are related to intrusive rocks of the so-called 'anorogenic' type. There is, however, no direct relationship with intrusive rocks in many of the smaller deposits, nor in the 'distal' portions of larger mineralised systems.

The deposits typically contain an iron-oxide nucleus (magnetite and/or hematite). Magnetite may be altered to martite and/or hematite, and the later replacement of part or all of the iron oxides by sulphides is common. Light REE and gold are sometimes present in economic quantities; uranium content may be significant; many other metals such as silver, cobalt, manganese, nickel and PGE may occur in economic concentrations.

Zoned hydrothermal alteration characterises almost all IOCG deposits. Various alteration patterns depend on depth of ore formation and host-rock chemistry. From deeper to shallower levels, albitisation, scapolitisation, potassic alteration, sericitisation and silicification processes take place. Massive hematitisation and so-called 'red-rock' ('brown rock') alteration are widespread, over all depths and affect most types of host rocks. Regional sodic alteration marks zones of hydrothermal fluid circulation broadly surrounding the deposits. Replacement textures in host rocks are common and explosive brecciation occurs in most deposits. Many of the largest orebodies show evidence of multiple and explosive brecciation events. The geometry of the mineralised bodies varies substantially; veins are by far the most common structural style. Some orebodies occur as massive replacements that grade into stockworks, whereas others are breccia pipes, diatremes or concordant tabular bodies. Composite deposits comprising veins, breccias, stockwork zones and replacement mantos are common.

Geology of the Greater Lufilian Arc

The Lufilian Arc of southern Africa is composed of a Mesoproterozoic to Neoproterozoic rift basin that closed during the Pan-African orogeny. Rocks of the Lufilian Arc continue into parts of SE Angola, NW Botswana and the Democratic Republic of Congo (DRC). The Damara (Namibia) and Katangan (DRC and Zambia) continental to marine sedimentary rock sequences were deposited during basinal opening, with the latter hosting the world-class copper and cobalt deposits of the Copperbelt province.

Alkaline magmatism also took place during the various rifting phases that formed the Mesoproterozoic to Neoproterozoic basin. In addition, calc-alkaline and alkaline magmatism occurred after closure of the basin, during subduction-related events and later continent-continent collision. Igneous massifs such as the Lusaka, Hook, Kamanjab, Khorixas inlier and Otjiwarongo batholith are examples of granitoid bodies formed by those processes. Rocks in the massifs have a wide petrographic variability; they range from alkali to normal granites, through diorites and granodiorites, and into syenites and carbonatites. Small bodies of gabbro and hyperalkaline rocks are also present in the massifs. Some of these granitoids are high-heat producers, with elevated thorium, potassium and/or uranium content.

Iron Oxide-Copper-Gold Systems in the Greater Lufilian Arc

The IOCG systems occur in and surrounding the granitoid massifs of the Lufilian Arc. Favourable environments for development of such systems are widespread through the arc. Table 1 lists a few typical IOCG prospects and deposits in the region. Massive iron-oxide bodies seem to have formed by host-rock replacement and infill. The host rocks include true granites, syenites, carbonatites, quartz 'pods', albitised schists, volcaniclastic units and carbonates. 'Pregnant' granitoids have produced extensive hydrothermal alteration and variable abundances of iron-oxide mineralisation, particularly when intruding reactive country rocks. Large bodies of hydrothermal iron-oxide-rich rocks are found near the intrusive contacts. Many types of structural styles are known, including breccia pipes and vertical and horizontal tabular breccia bodies. Subvolcanic intrusions and apophyses of the main massifs are responsible for most mineralisation.

Relationship between granitoids and iron oxides

Evidence of close temporal and spatial relationships between the iron-oxide bodies and granitic rocks is abundant. Some localities show coarse magnetite-bearing intermediate intrusive rocks with minor copper mineralisation. This is seen in outcrops near Otjiwarongo, Namibia, in some rocks of the Hook Granite Massif, and the Kasempa and Kafue Flats regions of Zambia. In places, magnetite occurs as thin veins in the intrusions. Coarse magnetite is often spatially associated with sulphides. Magnetite 'clusters', d"1 cm in diameter, occuring in granitoids and subvolcanic rocks may result in a black and white 'dalmatian rock' texture.

Iron-oxide bodies

Iron-oxide bodies in the Lufilian Arc occur as cement in hydrothermal breccias, filling for numerous fracture zones and/or replacement three-dimensional structures in various types of rocks. In Namibia massive hematite and magnetite bodies occur in several locations. Iron-oxide bodies in the Lufilian Arc generally display sodic and sodic-calcic alteration assemblages. Parts of these alteration zones contain sulphide mineralisation, including pyrite, bornite and chalcopyrite. In western Zambia, large iron-oxide bodies protrude as needles >100 m above the broad plateau. Such geomorphic features are not observed in Namibia, probably due to less rainfall and different climatic history. Progressive iron-oxide alteration overprints textures of granitic rocks, sedimentary rocks and hydrothermal breccias, in some places to a point where the original rock is unidentifiable.

Breccias

Multiphase hydrothermal breccias with strong potassium-iron alteration (biotite-sericite-magnetite-hematite) and pyrite development surround the iron-oxide bodies. In places, these breccias have a matrix of hematite and/or magnetite, with evidence of explosive hydrothermal activity. Initial sodium-feldspathisation (albitisation) is overprinted by biotitisation. Round-clast breccias, which are cemented by iron-oxides are a common feature in some IOCG systems of the Lufilian Arc (See Table 1). Rounding is probably due to extremely alkaline or acid hydrothermal solutions etching angular rock fragments. Round fragments in hydrothermal breccias have been misidentified in the past as 'Grand' and 'Petit Conglomerat', as tectonic breccias and as sedimentary breccias. Angular hydrothermal breccias and stockworks at the Kombat deposit, Namibia, are generally thought to be collapse breccias.

Structural controls

Regional structural control is dominated by major E-W-trending fault systems. These are long-lived crustal fractures that developed during the onset of rifting, and likely have been reactivated as strike-slip and normal faults. Such E-W structures are evident in the published geological maps of the region. More local structural control includes intrusive–host-rock contacts, more reactive stratigraphic units, favourable zones along crustal-scale fractures (i.e. the Mwembezhi and Mkushi-Serenje dislocations, Zambia), and local fractures in brittle rocks. Albitisation and silicification enhance brittle fracturing, further defining prospective zones for IOCG mineralisation.

Planar features

Hydrothermal iron-oxide bodies may display layering and/or bedding. In some locations, discrete, massive iron-oxide bodies are interlayered with planar, fine-grained sedimentary rock units. Their outcrops may be tens of kilometers long. These planar features resemble banded iron formations, and are sometimes misidentified as such, but they are produced by selective replacement by thick, extensive, stratabound iron-oxide bodies. These concordant replacement bodies have a close spatial, and perhaps genetic, asscociation with hydrothermal magnetite-bearing intrusive bodies. The bodies display relict round-pebble hydrothermal brecciation (i.e. the Kasumbalesa tabular body of Zambia/DRC). Dyke-like magnetite and/or hematite veins occur as feeders to the tabular, conformable iron-oxide bodies. Tabular, non-conformable iron-oxide bodies of hydrothermal origin occur in the Congolese deposits at Luiswishi, Shituru and Kamoya. They are controlled by a regional thrust fault and its satellite structures.

IOCG-like prospects in Zambia and Namibia

The Greater Lufilian Arc of Zambia and Namibia is a prospective zone for the discovery of additional economic IOCG mineralisation. Some of the known IOCG deposits and prospects in the region are marked by an abundance of: uranium, light REE minerals, phosphates, cobalt, barium-bearing minerals, silver, PGE, titanium-bearing minerals and vanadium, as well as copper and/or gold. Some deposits do not contain any anomalous copper. Table 1 describes some features of operating deposits and prospects that are akin to IOCG systems.

There is IOCG of uncertain extent below the Witvlei sedimentary-hosted copper deposit, Namibia. Both deposits formed around 1100 Ma. The Okatjepuiko prospect, located just below the Witvlei deposit, may have been the source for the copper mineralisation in the latter. Similar relationships may characterise other mineralised areas in the Greater Lufilian Arc, and unrecognised IOCG mineralisation near Katangan sedimentary-hosted copper-cobalt may be the original source of copper, cobalt and other anomalous metals.

Ongoing investigations at the Kombat copper deposit in the Otavi Mountains of Namibia also show geological features that are characteristic of the IOCG deposit type. Brecciation and stockworks of hydrothermal origin host most of the ore-grade rocks at the deposit. Primary copper mineralisation always occurs near or surrounding large bodies of iron- and/or manganese-oxides. No direct relationship with granitoid rocks has been established, but mineralisation could be related to the Otjiwarongo Batholith, buried below carbonate rocks and calcrete.

Some prospects in northern Namibia also have gold-rich and copper-rich surface anomalies, are associated with subvolcanic intrusive bodies, and contain abundant magnetite- and hematite-filled fractures that carry gossans after copper and iron sulphides. Host rocks may be granitoids, brittle quartzites or albitised metamorphic rocks.

In parts of Namibia, Neoproterozoic syenitic and carbonatitic magmas are associated with hydrothermal brecciation, diatremes, massive iron-oxide bodies, and iron-oxide-filled veins. Parts of the iron-oxide bodies are characterised by significant vugs and gossans after sulphide mineralisation. In some places, fresh bornite is observed on the surface.

Zambian deposits such as Dunrobin (Au), Nampundwe (pyrite+Cu±Au), Kalengwa (Cu+Ag±Au), and Kasumbalesa (Cu±Au), also display some characteristics of IOCG deposits. A relation to intrusive rocks at these four deposits is not evident. They are all fracture-controlled and display evidence of hydrothermal activity. Intrusive rocks that acted as heat engines for the hydrothermal systems are thought to be near and under cover. The origin of the Kansanshi deposit and the Lewis-Marie group of small deposits is uncertain, but these may not be IOCG deposits. Many small IOCG prospects have been explored in ther region surrounding the Hook Granite in Zambia during the past ten years. None have been large or high-grade enough to warrant large-scale mining. Occurrences such as Hippo, Luiri Hills, Shimyoka, Silver King, Sable Antelope, Kalengwa, Lou Lou and Kantonga, are a few examples of IOCG deposits near Mumbwa and west of Lusaka (i.e. several cubic kilometers of rocks near Shimyoka with 0.2% Cu). The Kasempa-Kalengwa area in western Zambia is another location that merits further exploration for IOCG. It has hundreds of gold, copper and iron-oxide occurrences related to small intrusions.

Presently, at least four small mineral exploration companies are actively investing in ground geophysics, soil and rock sampling, and diamond drilling of gold and copper prospects in the NW Kamanjab inlier (Namibia), near the Hook Granite, and in the Eastern Province of Zambia, with excellent results. The Congolese part of the Lufilian Arc is also under active exploration for IOCG targets by junior corporations and intermediate mining companies.

Peculiarities of Zambian and Namibian IOCG systems

The IOCG prospects and deposits of western Zambia and northern Namibia seem to differ in many features from the classic IOCG deposit type model. The country rocks have not been subjected to high temperatures and strong metamorphic deformation. In general, they tend to be undeformed. Most original hydrothermal textures are pristine. High temperature gradients due to emplacement of nearby plutons seem to be the only cause of the major alteration assemblages.

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Table 1. Details of selected IOCG deposits and prospects in the Lufilian Arc, Africa

Deposit/ Prospect	Tons x10^6	Cu Wt %	Au g/t	Mineralisation Styles	Associated Metals	Associated Rocks
Okatjepuiko, Witvlei, Nm	Undim.	X n.a. Undim.	X n.a. Undim.	Ht bxs in subvolcanic porphyritic intermediate rks. FeOx bodies replacing bxs + fracs. Bn rk altn	Cu,Au	Subvolcanic porphyritic intrusions, gabs + felsic intrusions, subrounded ht bxs
Kombat Mine, Nm	~12	~2.94	X n.a.	Large FeOx bodies serve as nucleus for copper sulphs hosted in ht bxs + stwks. Grades of silver and lead: ~20gAg/t,~2%Pb.	Ag,Pb,Mn,Zn,Ba,As,P,Ni,Co	Otjiwarongo Batholith may be source
Otjikoto Au Deposit, Nm	n.a.	n.a.	n.a.	FeOx nucleation? Coarse free Au, tourmalinisation, sheeted vein systems controlled by E-W structures	PGEs,Cu,B	Otjiwarongo Batholith may be source; hosted by albitised metapelites, siliciclastics + carb; qtz pods
Mesopotamie Farm Area, Nm	n.a.	X n.a.	X n.a.	Massive FeOx bodies along E-W structures + sulphidation around them. Ht bxs.	Au,Cu,LREE	Graphic alkali granites intrude other gtds; qtz pods
Dunrobin Au Mine, Zm	~0.002	n.a.	9.3*	Structurally-controlled; FeOx nucleates sulphidation+Au. Diss + replacements in country rks. Qtz+py veins. Replacement FeOx bodies. Racoon-style FeOx-pyrite banding.	Ag,Bi,Mn,Pb,Sb,As	hosted by folded Katangan carb + gtds
Nampundwe Pyrite Mine, Zm	23 (Cu) 10 (Fe)	0.79	X n.a.	Selective mag replacement in folded sedimentary rocks. Specularite-matrix in polymictic multiphase ht bxs associated to gtds.	16% pyrite. 57% Fe	Small bodies of gab +felsic intrusives, mag-bear diorite; lamprophyre dykes; qtz pods
Kasempa Prospect Area, Zm	n.a.	X n.a.	X n.a.	Selective mag replacement in folded sedimentary rocks. Massive FeOx w/ sulphs. stwks, round-pebble ht bxs, sheeted mag veins. Various large size prospects.	LREE,Co,Au?	Small bodies of alkaline gabs intrude Katangan lss, masive FeOx hills; lamprophyre dykes
Kalengwa Mine, Zm	0.6 init 1.9 fin	16 init 9.44 fin	n.a.	Tabular replacement in sediments, ht bxs, supergene enrichment to chalcocite body; polymictic ht bxs; Cu sulph dissemination	50gAg/t,LREE, U**	gabic rocks, hosted by Katangan siliciclastics. Syenites + granites
Quartzite-Hosted Deposits	n.a.	X n.a. **	n.a. **	Sulph-bear ht bx veins cemented by mag, hydroth. Bx bodies. All frac controlled.	LREE,Fe,U,Zn **	Brittle quartzites + carb, small subvolcanic porphyritic bodies, + qtz pods
Deposits in Alkaline Rocks + Carbonatites	n.a.	X n.a.	X n.a.	Diatremes, stwks, bx bodies, round-pebble ht bxs, braided veins, masive FeOx bodies, controlled by regional structures.	Fe,LREE,Zr,La, Nb,Zn**	Lamprophyre + carbonatite dykes, syenites, alkaline granites
Tevrede deposit, Kamanjab, Nm	n.a.	X n.a.	n.a.	Ht polymictic bxs cemented by mag and/or hematite; braided vein systems, stwks, frac-controlled mnzn. Massive FeOx bodies	LREE**	alkaline granites, granites
Shimyoka Area, Kafue Flats, Zm	Cubic kms	0.2 **	X n.a.	FeOx bodies w/ diss cp+py, ht bxs, shear zones, stwks. Mnzn related to intrusive bodies.	LREE,P,F,U,Co	Syenites, Katangan carb, qtz pods, gabs, red-altered gtds
Kantonga, Zm	n.a.	X n.a.	X n.a.	Tabular replacement of mag & hem in sedimentary units; large bodies of mag and hem filled polymictic ht bxs; stwks; various Cu sulphs disseminated in FeOx.	Cu,Au,Mn,LREE, phosphates	Syenites and granites that intrude Katangan carbs, syenites and granodiorites; lamprophyre dykes
Sable Antelope, Zm	n.a.	X n.a.	n.a.	Sulph-bear FeOx-filled ht bxs, diatremes, bn-rk altn, network of fissure veins, FeOx bodies	Ag,Ba,Zn,LREE **	Hosted by Katangan massive white or pink dol ls, in flank of anticline; lamprophyre dykes
Hippo Mine, Zm	0.016	9.4 ***	2.1	Sulph-bear frac-controlled FeOx, bx + stwk	Fe,F,As,Pb,Zn	Hosted by Katangan silststone. Very little outcrop, all covered.

Notes: *Dunrobin mine produced over 40,000 oz of gold by 1935. It produced 13,817 oz of gold from 1936 to 1961. ** not well studied. *** Hippo mine produced 2280 tons of ore at an average grade of 27.4% Cu. altn = alteration; bear = bearing; bn = brown; bx = breccia; bxs = breccias; carb = carbonate; cp = chalcopyrite; diss = disseminated, dissemination; dol = dolomite, dolostone; FeOx = iron-oxide; fin = final; frac = fracture; gab = gabbro; gtd = granitoid; ht = hydrothermal; init = initial; LREE = light rare earth elements; mag = magnetite; n.a. = not available; Nm = Namibia; po = pyrrhotite; py = pyrite; qtz = quartz; rk = rock; stwk = stockwork ;sulph = sulphide; undim. = undimensioned; X n.a. = metal is present but data is not available; Zm = Zambia.