Descriptive and Grade-Tonnage Models and Database for Iron Oxide Cu-Au Deposits

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DESCRIPTIVE AND GRADE-TONNAGE MODELS AND DATABASE FOR IRON OXIDE Cu-Au DEPOSITS

By Dennis P. Cox and Donald A. Singer

APPROXIMATE SYNONYMS Ironstone Cu-Au. The acronym is IOCG. (Replaces Olympic Dam Cu-Au-U, Cox, 1986b)

DESCRIPTION Iron oxide Cu-Au deposits are veins and breccia-hosted bodies of hematite and/or magnetite with disseminated Cu +Au ± Ag ± Pd ± Pt ± Ni ± U ± LREE minerals formed in sedimentary or volcano-sedimentary basins intruded by igneous rocks. Deposits are associated with broad redox boundaries and feature sodic alteration of source rocks and potassic alteration of host rocks.

GENERAL REFERENCES Williams and others, 2005; Barton, 2001; Haynes, 2000; Hitzman, 2000; Warren, 1999.

GEOLOGICAL ENVIRONMENT

Rock Types A type or I type, magnetite-series intrusions are commonly associated with IOCG deposits (Hitzman, 2000). As pointed out by Barton and Johnson (2000, p. 47) there is a wide variation in composition of the associated igneous rocks. Of the 31 copper-gold deposits in the accompanying database, 10 deposits are associated with gabbro, diorite or mafic dikes, 2 with felsic porphyry or dacite dikes, one deposit, each for monzonite, tonalite and granodiorite, and 7 deposits with granite. One prospect (visited by Cox in western Mongolia) was associated with syenite. Nine deposits have no record of an associated intrusion.

IOCG deposits are also associated with redbeds and evaporites. These rocks are older than, but close in age to, the intrusive rocks. They are commonly altered to albite-rich assemblages. Of 36 iron and copper-gold deposits in the accompanying database, 21 have associated albite alteration, and six have evidence of an evaporite in the sedimentary section.

Host rocks are faulted and deformed volcanic and sedimentary rocks with bedding-parallel permeability, and volcanic, sedimentary, and tectonic breccias. Less commonly faults and breccias in intrusive rocks can host ore. The size and degree of permeability of fault and breccia structures in the host rocks directly controls the tonnage of the contained deposit.

Age Range Lower Proterozoic deposits are known in the Carajas region of Brazil and in Mauritania (2.5-2.3 Ga), Australia (1.9-1.5 Ga), and the Khetri Copper Belt of India (1.7-1.5 Ga). See figure 1. Mesozoic deposits occur in the Coast Range of northern Chile (119-90 Ma). Miocene deposits are known in the Andes of Argentina (Dow and Hitzman, 2002). Deposits older than Late Archean are unlikely because an oxygen-rich earth atmosphere is required.

Depositional Environment and Tectonic Setting Hitzman (2000) described two permissive environments for IOCG deposits:

1. Continental margin subduction complexes with local extensional features; Resulting rifts contain oxidized rocks including subaerial volcanic deposits, conglomerates, redbeds and evaporites. Sediments deposited in these environments are sources for oxidizing, hematite-stable, NaCl-rich fluids capable of leaching and transporting copper. Magmatic belts coextensive with these rifts provide heat sources for driving hydrothermal circulation. This environment is represented by the La Candelaria and Punta del Cobre district in Chile.
2. Compression, folding and magmatism of intracratonic basins; Granitic rocks intrude rift-related assemblages, similar to those described above, that have been folded and metamorphosed. Brines released from the rift sediments are mobilized to leach metals from source rocks and deposit them in faults and breccias. The Cloncurry district in Queensland, Australia, provides examples of this environment.

Associated Deposit Types Redbed, Revett, and reduced facies sedimentary copper deposits indicate permissive areas for IOCG. Chilean manto Fe-Cu-Ag deposits (Maksev and Zentilli, 2002), albite-scapolite iron ores (Sokolov and Grigor'ev, 1977) and volcanic-hosted magnetite deposits (Cox, 1986 a) are formed in the same environment.

Iron oxide hosted copper-gold-bismuth deposits in the Tennant Creek Inlier west of the Cloncurry District (Skirrow, 2000) are similar to IOCG deposits. They have smaller tonnages (the median tonnage of 10 deposits is 3.5 million tons) and higher gold grades than IOCG deposits. Bismuth is an important byproduct and gold is locally found as a selenide. Na-Ca alteration, prominent in IOCG deposits, is lacking in the Tennant Creek District. Because of these differences, Tennant Creek deposits are not included in the IOCG model.

DEPOSIT DESCRIPTION

Mineralogy Principal minerals are magnetite, hematite, and siderite with biotite, calc-silicate minerals and minor apatite. Iron oxides have Fe:Ti ratio greater than iron oxides in most igneous rocks (Williams and others, 2005). Fe oxide Cu-Au deposits contain chalcopyrite, bornite, and gold and, less commonly, chalcocite. Pyrite or pyrrhotite are present in most deposits. Less common minerals include bastnaesite, uraninite, monazite, allanite, Pt group minerals, molybdenite, sphalerite, galena, bismuthinite, scheelite, arsenopyrite, cobaltite, and Ni-Co arsenides. Gangue minerals are quartz, biotite, calc-silicate minerals, scapolite (marialite variety, $3NaAlSi_3O_8 \cdot NaCl$), albite, fluorite, fluorapatite, calcite, barite and tourmaline. Quartz vein stockworks, common to porphyry copper deposits, are not present in IOCG deposits (Sillitoe, 2003).

Texture/Structure Ore minerals form veins and disseminations in lenticular, elongate iron oxide bodies. Open space filling in faults, tension gashes, and breccias are common (Michael Evans, Phelps Dodge Corp., written commun., 2002). Mineralized replacement features may follow bedding and other sedimentary structures. Iron oxide and copper sulfide minerals fill spaces in the matrix of breccia pipes and irregular breccia bodies of sedimentary, volcanic, or tectonic origin.

Alteration Extensive albite-oligoclase-chlorite-actinolite alteration with Na-scapolite is present in sedimentary, volcanic, and plutonic rocks near the deposits. The albite zone is depleted in K, Fe, U, REE, S, and most base metals. Albite-oligoclase alteration is also referred to as Na-Ca alteration (Carten, 1986).

Host rocks exhibit potassic (biotite-K-feldspar) alteration and may contain chlorite, pyroxene, amphibole, epidote, garnet, Na-scapolite, and anhydrite. This alteration cuts or overprints albite-oligoclase alteration.

Calcite-dolomite-pyrite veins and disseminations occur outboard of the iron oxide bodies and cut ore-related alteration (G. McKelvey, Phelps Dodge Corp., oral commun., 2002).

Ore and alteration mineral facies are asymmetric (Sillitoe, 2003) reflecting formation on a redox boundary with bornite, chalcocite, magnetite and biotite on the oxidized side and chalcopyrite and distal pyrite and calcite on the reduced side. At Olympic Dam and Prominent Hill in Australia, mineral zonation is vertical with chalcocite at the top grading downward to bornite, chalcopyrite, and pyrite at depth.

Ore Controls Pre-ore permeability of host rocks and faults and shear zones combined with redox fronts are the major ore controls of ore deposition. The largest deposits are hosted by breccias of tectonic sedimentary, volcanic or phreatomagmatic origin. Major shear zones are also important loci of IOCG deposition. Small deposits form as fault-controlled veins.

Geochemical Signature The elements Cu + Au ± Bi ± U ± Ni ± Co ± PGE ± REE are present in K-rich rocks. All of these elements can form chlorides or chloride complexes in the presence of NaCl fluids. In rocks with albite alteration, the above elements have abundances close to the limit of detection.

Deposit Tonnage and Grade Ore tonnages vary widely with more than 3.8 billion tons at Olympic Dam, Australia (Williams and others, 2005), and 470 million tons at La Candelaria, Chile. Tonnages of iron-only deposits range from 700 million to 2 billion tons or more.

Within the 33 IOCG deposits in the accompanying file, two distinct tonnage-grade populations can be recognized (Table 1): 12 consist of deposits hosted in faults or veins (labeled as fault-/vein-hosted type in the database) and 21 consist of deposits hosted in breccias or fault-zones (labeled as fault-zone-/breccia-hosted). The difference in tonnage (median 3.5 Mmt vs. 120 Mmt for fault zone-/breccia-hosted) reflects the type and extent of permeability in the host rock and the amount of open space available for mineral deposition. The differences in grade (2.3 percent Cu versus 1.1 percent for fault-zone-/breccia-hosted) may reflect the economies of scale, such that large tonnage deposits with lower grade ores can be mined more cheaply by bulk mining methods.

Of the twelve fault-vein-hosted deposits, six are in Queensland, Australia and have no recognized associated intrusion, and six are in northern Chile and are associated with diorite intrusions.

GENETIC OVERVIEW

Although some authors have shown evidence for a magmatic origin of the ore fluids responsible for mineralization (Pollard, 2000; Kendrick and others, 2007), the present authors believe that the accompanying database shows that the primary role of magmas was the production of heat and that their contribution of metals to the ore fluid was minor. Evidence for this conclusion are the wide variation in composition of associated igneous rocks, and the presence of albite alteration (in 21 deposits) and Na-scapolite (17 deposits) suggesting a widespread reaction with NaCl brines. Brine influx of such a magnitude is more likely to have originated from sedimentary sources than from igneous intrusions. In our database we have attempted to identify the sedimentary, and/or volcanic rocks surrounding the deposit as the source of the brine and ore-metals. We were successful in 19 of the 36 cases studied.

Mafic to granitic magmas with low volatile content activate oxidized NaCl brines from evaporites and other sedimentary sources. These brines, heated by the intrusions, leach K, Fe, Cu, Au and other metals from the surrounding rocks and form metal chloride complexes at near magmatic temperatures (Barton, 2001). The oxidized brines migrate from the source rocks into surrounding country rocks. Ore deposition occurs where the brines mix with reduced fluids in permeable breccias and in fault zones. Skarn-like mineral assemblages in the ore zone are produced in response to heat from the associated magmas. Potassic alteration results from reaction of KCl in the brine with mafic silicates in the host rock. Reduced fluids deposit pyrite and calcite outboard of the ore zone. The highly variable metal composition of the ores depends in large part on the composition of different source rocks leached by the NaCl brine.

Iron-only deposits (albite-scapolite iron deposits) may reflect ore deposition in environments where reduced sulfur is unavailable. Haynes (2002) pointed out that districts with large iron-only deposits (Sokolovskaya, Kachar) generally do not contain significant IOCG deposits. Conversely, in districts with large IOCG deposits (i.e. Punta del Cobre district, Chile) iron-only deposits (Marcona, Peru and El Romeral, Chile) are smaller.

Iron oxide Cu-Au deposits are similar to sediment-hosted copper deposits in the alteration mineralogy of source rocks and host rocks. Hayes (1990) described albite-chlorite alteration of redbed source rocks, and distal pyrite-calcite outboard of copper deposits in the Revett Quartzite of Montana and Idaho.

EXAMPLES

La Candelaria, Chile (Marschik and Fontboté, 2001)

Starra, Australia (Rotherham and others, 1998)

Ernest Henry, Australia (Mark and others, 2000)

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TABLE

Table 1. Percentile distribution of ore tonnage and copper and gold grades in two subtypes of IOCG deposits.

	Fault-/vein-hosted	Fault-zone-/breccia-hosted
number	12	21 deposits
90th Tons	0.65	25 million mt
50th Tons	3.5	120 million mt
10th Tons	15	1,100 million mt
90th Cu	1.2	0.41 percent
50th Cu	2.3	1.1 percent
10th Cu	4.9	1.7 percent
90th Au	0.14	0.13 grams/ton
50th Au	1	0.48 grams/ton
10th Au	5.8	2.1 grams/ton

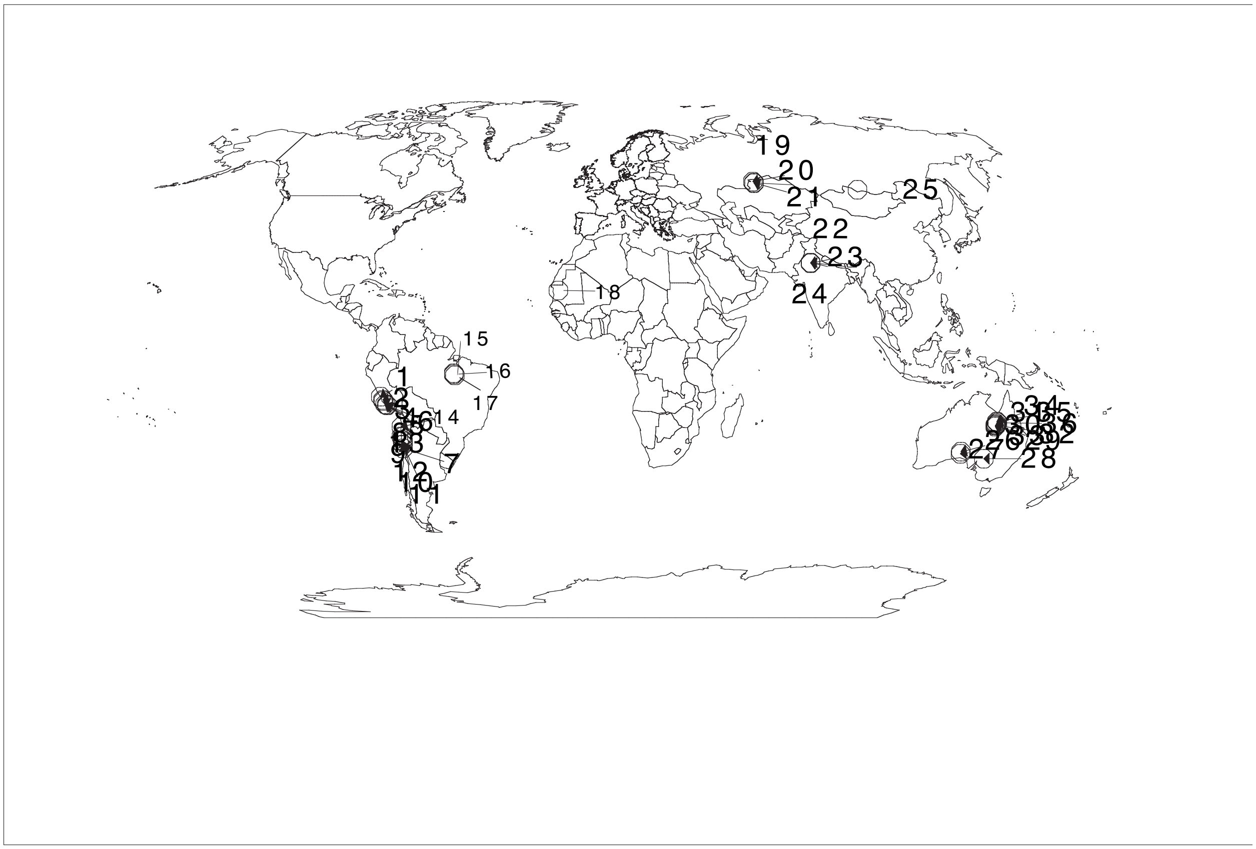

Figure 1 World distribution of 33 iron oxide Cu-Au deposits and 3 albite-scapolite iron deposits, numbers 19, 20, 21.