Magmatic-hydrothermal iron oxide-Cu-Au-Ag-U deposits

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Magmatic-associated hydrothermal vein, breccia and replacement deposits, characterized by abundant Fe-oxide and enrichment in Fe-Cu-Au ± U, rare earth elements, Co, Bi, Ag, W, and other metals comprise the distinct, yet highly variable, IOCG class of mineral deposits. They are attractive targets for exploration and development due to their polymetallic nature and enormous size and grade potential. The type example, Olympic Dam in Australia, is quoted by WMC as containing 3.81 billion tonnes @ 1.1% Cu, 0.5 g/t Au and 400 g/t U_3O_8. Other important examples include Kiruna in Sweden (>2 billion tonnes grading 60% Fe), Bayan Obo in China (~50 million tonnes grading 6% REE oxides and 1.5 billion tonnes grading 35% Fe), Candellaria in Chile (470 million tonnes grading 0.95% Cu, 0.22 g/t Au and 3.1 g/t Ag), Salobo in Brazil (~450 million tonnes grading 1.15% Cu and 0.5 g/t Au), Sossego in Brazil (219 million tones grading 2.19% Cu, 1.14 g/t Au), and many others.

Iron-oxide copper-gold (IOCG) deposits formed along extensional and collisional cratonic margins, both modern and ancient, both incipient and mature, which promoted partial melting of deep continental crust to uppermost mantle rocks and production of magmas of a wide range of compositions. They are most abundant in Proterozoic terrains, although Phanerozoic and Archean examples are present. IOCG deposits occur in felsic to intermediate volcano-plutonic terrains, but in some cases there is a spatial, if not direct genetic relationship to mafic and ultramafic magmas, as is the case with Olympic Dam and carbonatite-associated Fe-phosphate-REE deposits (e.g., Bayan Obo). They are often associated with the root zones of volcanic centers, and some IOCG deposits have many similarities to Fe-rich porphyry copper systems. Also, there is a continuum of IOCG deposits types and forms ranging from deeper-seated replacement and breccia styles to iron-oxide rich epithermal type deposits. They formed along and at the intersections of major crustal lineaments, and often display strong structural control over their morphology and ore textures. The wide range of geotectonic settings and associated magma compositions generate an equally complex range of deposit sub-types. Different investigators have placed a range of deposit sub-types within the IOCG class including:

1. Felsic to intermediate breccia hosted deposits (Olympic Dam).
2. Stratabound replacement and breccia ironstone hosted deposits.
3. Hydrothermal iron-apatite deposits.
4. Graphitic-sediment hosted ISCG (iron-sulphide copper-gold).
5. Iron-phosphate-REE carbonatite associated deposits.
6. Iron oxide-fluorite breccia pipes.
7. Iron oxide-rich epithermal veins and breccia.

IOCG deposits display close time-space relationships with distinct alteration styles. The ores are associated with widespread alkali-Fe metasomatism, including multiphase sodic to sodic-calcic and potassic alteration, sometimes associated with alkali-rich intrusions. Enrichment in one or more of PO_4, CO_2, and F is common. Other common hydrothermal alterations may include proximal apatite, Fe-rich amphiobole and biotite, carbonate, fluorite and tourmaline veins, breccia, disseminations, and replacement. Distal alterations include sericite, silicification, quartz veining, and phyllic and prophyllitic styles. Iron is usually magnetite and/or hematite, but can include and is occasionally dominated by Fe-silicates, Fe-carbonates and/or Fe-sulphides. Generally, magnetite forms at deeper levels, as a higher temperature and/or more reduced form of Fe-oxide. In contrast, hematite occurs at shallower depths or in peripheral halos surrounding core regions in lower temperature and more oxidizing environments. However, considerable overlap and superposition occur amongst the various alteration assemblages due to the episodic and dynamic nature of IOCG systems. The source of hydrothermal fluid is orthomagmatic ± circulation of ground water driven by heat of the intrusion. Metals are derived from source intrusions, but can also be leached from host rocks.

Despite their attractive economic potential, IOCG deposits have only recently emerged as a deposit type of choice for exploration in Canada. Vast and largely unexplored, yet highly prospective terrains abound, including Central Mineral Belt, Grenville Province, Southern Province, Mid-Continent Rift, Trans-Hudson Orogen Wernecke Mountains, and the Great Bear Magmatic Zone (GBMZ). Several of these districts host past-producing mines that are now classified as IOCG-type deposits. The GBMZ remains Canada's premier emerging IOCG district, with delineation of the Sue-Dianne Fe-oxide Cu-Ag-Au

diatreme breccia and recent discovery of the NICO Co-Au-Bi ironstone replacement type deposit. However, the GBMZ also hosts ~10 past-producing mines that exploited high-grade U-Ag-Cu deposits that are best described as quartz-carbonate-hematite rich IOCG associated epithermal vein systems.

Metal associations in IOCG deposits are highly variable and controlled largely by composition and chemistry of source intrusions, but also are affected by circulation of groundwater and magmatic fluids with resultant fluid-host rock exchange reactions. Uranium is enriched in many deposits but economic concentrations are restricted to only a few. The most important U-bearing IOCG is the Olympic Dam deposit, which at 400 g/t U_3O_8 (roughly one pound per tonne) is the world's largest individual uranium concentration. In Canada, the former mines of the Great Bear Magmatic Zone comprise an extensive IOCG-province with proven uranium potential. Uranium occurs primarily as pitchblende, and is not uncommon as small veins peripheral or distal to the centers of hydrothermal alteration and mineralization. More significant concentrations are associated with structurally higher-level hematite-rich breccias, and quartz-hematite and quartz-carbonate-hematite veins and breccias. Due to their unique metal association, IOCG deposits can be targeted during exploration using magnetic, gravity and multiparameter radiometric geophysical surveys. Other geophysical techniques such as IP, resistivity, and EM are sometimes useful, but may be difficult to interpret due to the interference of magnetite and hematite, and the widespread distribution of barren disseminated and vein sulphides. Various geochemical exploration techniques can also be used under appropriate climatic and overburden conditions, to delineate anomalous metals in the secondary environment. However, regional and targeted geological, alteration, and structural mapping remains the most effective exploration tool in areas with reasonable outcrop exposure.