

LOW-TI IRON OXIDE CU-U-AU-REE DEPOSITS (MODELS 25i and 29b; Cox, 1986a,b)

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SUMMARY OF RELEVANT GEOLOGIC, GEOENVIRONMENTAL, AND GEOPHYSICAL INFORMATION

Deposit geology

These deposits consist of low-titanium iron ore that contains variable amounts of copper, uranium, gold, and rare earth elements. In the past, these deposits have been separated into two discrete subgroups. Cox (1986a,b), for instance, refers to the subgroup consisting primarily of iron oxide minerals with minor apatite as volcanic-hosted magnetite deposits (Model 25i), whereas the subgroup that contains significant amounts of copper-sulfide minerals and uranium are termed Olympic Dam-type deposits (Model 29b). However, Hitzman and others (1992) have shown that both subgroups share common genetic traits and can be merged as a distinct deposit type; the geoenvironmental model presented here pertains to the merged deposit type.

Specific characteristics of this deposit type vary among deposits, but all deposits are characterized by magnetite and (or) hematite concentrations with distinctly low titanium contents (generally <2 weight percent TiO_2); in addition, most contain some copper sulfide minerals. Most deposits display evidence, including fluid-inclusions, replacement textures, coherently zoned alteration patterns, and alteration-associated veins, of a hydrothermal origin. However, the genesis of some deposits is ambiguous, and a variety of alternative origins, including magmatic emplacement involving immiscible iron-rich melts, syngenetic exhalations, and metamorphic dehydration, have been proposed.

The deposits range from conformable to crosscutting and may be found as parts of ore systems that extend more than 3 to 5 km in the vertical dimension. Data show that deeper parts of some of these ore deposits formed from hot (400 to >600° C), magmatic ($\delta^{18}\text{O} \sim +8\text{‰}$) fluids; at more shallow levels, these deposits formed from cooler (200-400° C), mixed magmatic-meteoritic fluids ($\delta^{18}\text{O} \sim +1\text{‰}$) (Gow and others, 1994). Magnetite deposition and sodium-rich alteration zones predominate in the deeper (hotter) parts of these systems, whereas hematite, copper-sulfide minerals, and potassium-rich alteration are more prevalent in their shallower parts (fig. 1). Deposits are in rocks of widely variable ages, but are most abundant in Proterozoic (1.8-1.1 Ga) rocks.

Examples

Examples include the giant Olympic Dam uranium-copper-gold-silver-bearing deposit (Australia), the giant Bayan Obo rare earth element-niobium deposit (China), numerous iron deposits in the Kiruna district (Sweden), and iron

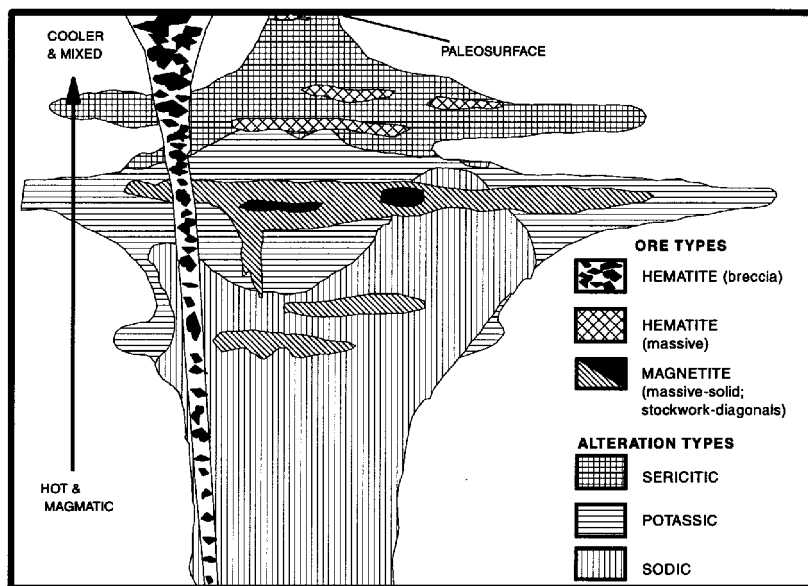


Figure 1. Generalized cross section of an idealized low-titanium iron oxide copper-uranium-gold-rare earth element deposit. Modified from Hitzman and others (1992).

deposits in Proterozoic rocks of the St. Francois Mountains (southeast Mo.) and in New York and New Jersey and in the Grenville province of New York and New Jersey. Examples in Missouri include Pea Ridge, Pilot Knob, Iron Mountain and Kratz Spring; those in New York include the Benson mines, Clifton, and Jayville; New Jersey deposits include Edison, Mt. Hope, Hibernia, Scrub Oaks, and the Hurd mine.

Spatially and (or) genetically related deposit types

None.

Potential environmental considerations

- (1) Mining copper sulfide-mineral-rich examples may generate acid drainage.
- (2) Some deposits are extremely large and development may involve ground disturbance throughout large areas.
- (3) Uranium-rich deposits may produce radon or create problems associated with elevated radiation levels.
- (4) Elevated fluorine abundances in drainage water may cause health problems, including brittle bones and tooth discoloration.

Exploration geophysics

Magnetite-rich systems can be readily recognized by aeromagnetic or ground magnetic surveys although surrounding country rocks that contain significant amounts of magnetite may complicate interpretation (for example, Kiruna area). Magnetite-dominated deposits in Missouri, for example, are associated with high-amplitude positive magnetic anomalies (Kisvarsanyi, 1981). Hematite-rich systems may have little magnetic expression. However, because both magnetite and hematite enriched rocks are much more dense than host rocks, they may be detectable by gravity surveys. Large deposits may be located on major lineaments that can be detected on satellite imagery. The unexposed Olympic Dam deposit, for example, was partly discovered because of its association with coincident positive gravity and magnetic anomalies and location on a major photolineament (Hoover and Cordell, 1992). Deposits that have high sulfide mineral content can be detected by electrical methods. Alteration zones associated with many deposits have been recrystallized during metamorphism so that they are not readily identifiable by geophysical methods.

References

Leonard and Buddington (1964), Buddington (1966), Hauck (1990), Oreskes and Einaudi (1990), Hitzman and others (1992), Gow and others (1994).

GEOLOGIC FACTORS THAT INFLUENCE POTENTIAL ENVIRONMENTAL EFFECTS

Deposit size

Deposits range from small to very large, but many representatives are small (less than 1 million tons). Most economic iron deposits range between 3.5 and 450 million tons, with a median value of 40 million tons. The giant Olympic Dam deposit exceeds 200 million tons. Kiruna is one of the World's eight largest iron ore producers.

Host rocks

Host rocks vary widely and may include virtually any rock type; however, most host rocks are felsic volcanic or plutonic rocks.

Surrounding geologic terrane

Most deposits are in moderate to high grade metamorphosed felsic volcanic or plutonic rocks. Typically, these rocks are associated with either a continental volcanic arc (Andean volcanic setting) or anorogenic felsic magmatism that accompanied post-tectonic extensional collapse of orogens. For example, Kiruna ore is typically associated with alkalic rhyolite, trachyte, and (or) trachyandesite. Most deposits in New York are associated with granitic gneiss principally composed of quartz and either albite or microcline. Deposits in New Jersey are associated with a series of predominantly monzonite or quartz monzonite intrusions. Most deposits in Missouri are associated with granite porphyry or iron-rich trachyte. Most of these rocks have very limited acid-buffering capacity. However, other host rock types, including carbonate rocks, that have high buffering capacity may be present.

Wall-rock alteration

Wall-rock alteration is commonly intense. Spatial alteration zonation includes, from bottom up, sodic, potassic, and

sericitic zones (fig. 1). Specific alteration assemblages depend on host rock type but commonly consist of:

Sodic alteration- magnetite + albite ± actinolite ± apatite ± chlorite.

Potassic alteration- magnetite ± hematite + apatite + potassium feldspar ± sericite ± albite ± chlorite ± biotite ± epidote ± carbonate ± barite.

Sericitic alteration- hematite + sericite ± carbonate ± barite ± fluorite.

In addition, wall rock is commonly anomalously enriched in Ba, P, F, Cl, Mn, B, K, and Na.

Subsequent metamorphism has caused the alteration assemblage associated with many deposits to be recrystallized to feldspar, pyroxene, and amphibole.

Nature of ore

Most ore consists of either magnetite, hematite, or mixtures thereof. Less commonly, ore, including that at Olympic Dam and Bayan Obo, is rich in combinations of copper sulfide minerals, uranium, and rare earth elements. Ore may be either stratiform or discordant. Magnetite-rich deposits are more commonly concordant, whereas hematite-rich deposits are commonly discordant. Magnetite-rich ore is generally equigranular. Where copper sulfide minerals are present, chalcopyrite is dominant. At Olympic Dam, however, large amounts of chalcocite and bornite are present in addition to chalcopyrite. Pyrite, in veins and disseminated in ore, is generally present in minor amounts. Uranium is in uraninite, pitchblende, and brannerite. Anomalous abundances of the rare earth elements are present in almost all deposits. At Bayan Obo, they constitute as much as 6.1 weight percent of the ore and are principally in bastnaesite, florencite, monazite, and xenotime. Other common rare earth element-bearing phases are apatite and fluorite.

Deposit trace element geochemistry

In addition to copper, uranium, and the rare earth elements, which may be important ore constituents, deposits may also contain anomalous concentrations of Ba, P, F, Cl, Mn, B, K, and Na. Some deposits also have elevated Au, Ag, Co, Ni, Te, As, Mo, and Nb abundances.

Ore and gangue mineralogy and zonation

Minerals listed in general decreasing order of abundance (potentially acid-generating minerals underlined).

Deep: Ore- magnetite, apatite, minor chalcopyrite, and pyrite. Wall rock- albite, actinolite, and chlorite.

Shallow: Ore- hematite, magnetite, copper sulfide minerals (principally chalcopyrite, possibly bornite and chalcocite), apatite, pyrite, monazite, bastnaesite, florencite, xenotime, uraninite, brannerite, and pitchblende. Wall rock- potassium feldspar, sericite, chlorite, actinolite, barite, carbonate, epidote, and biotite.

Mineral characteristics

Sulfide minerals are present in some magnetite-rich deposits, but are more common in hematite-bearing ore. Sulfide minerals are usually a minor component of most deposits and are predominantly copper or iron sulfide minerals.

Secondary mineralogy

Secondary minerals are generally not significant. Some sulfide-mineral-rich deposits have associated porphyry copper-style supergene enrichment in which secondary chalcocite has been derived from primary chalcopyrite.

Topography, physiography

Low-titanium iron oxide deposits have neither characteristic topographic nor physiographic expressions.

Hydrology

Magnetite-rich ore appears to have low porosity and permeability. Hematite-rich ore is probably more permeable and tends to form discordant bodies. No general known association exists between deposit setting and position of the ground water table.

Mining and milling methods

These deposits have been and are being mined both by underground methods and by open pitting. Active underground examples include deposits in the St. Francois Mountains, Mo., in the Kiruna district (Sweden), and at Olympic Dam (Australia). Ore at Bayan Obo (China) is open pit mined.

Subsequent to mining, most ore at Kiruna undergoes primary crushing, is processed to produce a high grade magnetite concentrate, and then pelletized. The Olympic Dam deposit produces copper, uranium, gold, and silver

by first processing ore to produce copper flotation concentrates. An acid leach is used to extract uranium from both concentrates and gangue; the concentrates are further processed by copper smelting and electrowinning to obtain copper, gold, and silver.

ENVIRONMENTAL SIGNATURES

Drainage signatures

Information on the composition of pre- and post-mining drainage from these deposits appears to be very limited. Published environmental reports on the Olympic Dam deposit are principally concerned with water use and aquifer depletion. A report by Smith (1988) notes that water downstream from the Pea Ridge and Pilot Knob, Mo., mines has increased turbidity, that the abundance of fine-grained material in the streambed is increased, and that the benthic-invertebrate population is reduced. However, the study also notes that data are insufficient to directly link these phenomena to mining activity.

The general scarcity of reactive (sulfide) minerals suggests that most of these deposits have relatively limited acid generation capacity. However, elevated concentrations of copper and slight pH reduction may result from deposits having moderate sulfide mineral abundances; sulfide-mineral-rich systems, such as Olympic Dam, are probably capable of generating very low pH water and mobilizing significant amounts of base metals. The concentrations of uranium, radium, and radon in water are a concern because these elements are known human carcinogens. Their abundances are partly correlated with their bedrock concentrations. As a result, elevated abundances of these elements may be associated with some deposits. Elevated fluorine concentrations in water, which are known to damage bone and cause tooth discoloration, may be present in water associated with some low-titanium iron deposits; however, no evidence indicates that such elevated abundances are actually present.

Metal mobility from solid mine wastes

Studies documenting the mobility of metals from solid mine waste have not been identified. Application of general, process-related studies (Ficklin and others, 1992; Plumlee and others, 1992; Plumlee and others, 1993) suggests the following:

- (1) Because deposits are in host rocks having widely different acid buffering capacity and because deposits contain significantly variable sulfide mineral abundances, acid generation and metal mobility may vary greatly.
- (2) Metal discharge from deposits hosted by high-acid-buffering-capacity rocks (carbonate rocks) is likely to be minimal, especially given the generally low sulfide mineral content of most ore. Acid and metal discharge from moderate to low-acid-buffering-capacity host rocks (feldspathic gneisses) may be substantially greater.
- (3) Most deposits contain sparse copper and iron sulfide minerals and thus have a relatively low acid generation capacity. However, ferric iron in hematite, which is commonly associated with sulfide minerals, may facilitate acid producing reactions if hematite is destabilized in the prevailing climatic regime.
- (4) Copper sulfide- and hematite-rich deposits (such as Olympic Dam) may have significant acid generation capacity. Although no data on the chemistry of water draining from the Olympic Dam deposit has been identified, metal concentrations may be similar to those characteristic of drainage water associated with porphyry copper deposits.
- (5) Water that contains high concentrations of uranium is known to be derived, in part, from uranium-enriched country rock. Therefore, deposits with elevated concentrations of uranium may generate uranium-rich water which, in turn, may present significant health hazards.
- (6) Some geologic environments generate fluorine-rich water that can damage human bones and cause tooth discoloration. Fluorine-rich water may develop in association with some deposits of this type.

Soil, sediment signatures prior to mining

The geochemical signatures of soil associated with these deposits apparently has not been documented. These deposits are characterized by elevated P, S, F, CO₂, Cu, Mo, V, Co, Na, and K abundances. Some or all of these elements may be enriched in associated soil. Titanium, chromium, and nickel abundances are depleted in most of these deposits.

Potential environmental concerns associated with mineral processing

Iron ore is generally beneficiated (gravity, magnetic, flotation, or selective flocculation) before treatment in a blast furnace. Rare earth elements and uranium are generally physically concentrated and then processed by a variety of chemical techniques. At the Olympic Dam, Australia, deposit, tailings contain elevated metal abundances, including 0.15 to 0.2 weight percent copper and 250 to 300 ppm U₃O₈, which may be a source of drainage contamination.

Smelter signatures

Copper sulfide minerals are typically smelted and may produce SO₂-rich and metal-rich emissions, which may increase acidity and foster accumulation of heavy metals in downwind areas.

Climate effects on environmental signatures

The effects of various climate regimes on the geoenvironmental signature specific to low-titanium iron oxide copper-uranium-gold-rare earth element deposits are not known. However, in most cases the intensity of environmental impact associated with sulfide-mineral-bearing mineral deposits is greater in wet climates than in dry climates. Acidity and total metal concentrations in mine drainage in arid environments are several orders of magnitude greater than in more temperate climates because of the concentrating effects of mine effluent evaporation and the resulting "storage" of metals and acidity in highly soluble metal-sulfate-salt minerals. However, minimal surface water flow in these areas inhibits generation of significant volumes of highly acidic, metal-enriched drainage. Concentrated release of these stored contaminants to local watersheds may be initiated by precipitation following a dry spell.

Geoenvironmental geophysics

Acid or metal-bearing water, fluid movement, and active sulfide mineral oxidation can all be identified using electrical methods. Associated geochemical signatures that involve rare earth elements or radioactive minerals can be detected by spectral reflectance or gamma-ray spectral methods, respectively.

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