ALGOMA FE DEPOSITS
(MODEL 28b; Cannon, 1986)

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SUMMARY OF RELEVANT GEOLOGIC, GEOENVIRONMENTAL, AND GEOPHYSICAL INFORMATION

Deposit geology

Algoma type iron-formation is interbedded with submarine mafic to felsic volcanic rocks and volcaniclastic graywacke and shale; most deposits are in Archean greenstone belts, but some are in younger rocks of similar character. Most Algoma type iron-formation formed in island arc and related suites and was subsequently strongly deformed in orogenic belts. Most ore is oxide facies rock that consists of interlayered magnetite or hematite and metachert; less commonly iron-carbonate facies rocks are mined. No deposits of this type are currently being mined in the United States.

Examples

Archean examples: Vermillion Iron-Formation, Minn.; Sherman Mine, Temagami, Ontario; Helen Mine, Wawa, Ontario; Early Proterozoic example: Wadi Sawawin, Saudi Arabia.

Spatially and (or) genetically related deposit types

Some Algoma type iron-formation grades laterally into polymetallic sulfide facies.

Potential environmental considerations

(1) Processing ore to concentrate iron minerals produces large volumes of fine-grained tailings that must be permanently stored. Potential concerns related to voluminous tailings include: (a) silica-rich dust, (b) fibrous silicate minerals in air and water, (c) particulate and colloidal iron compounds in discharge water, (d) mixing tailings impoundment water with ground water, (e) long-term stability of tailings impoundments, and (f) mineral dust in stack emissions from kilns.

Ore that contains amphibole minerals is of particular concern because it has the potential to generate fine-grained acicular cleavage fragments that meet some legal definitions of asbestos; natural amphibole asbestos poses similar concerns. Crocidolite, the fibrous variety of riebeckite, and amosite, the fibrous variety of grunerite-cummingtonite amphibole, are known carcinogens of both the lungs and the digestive tract and can be harmful even with less than occupational exposure. Both minerals are present in some iron-formation but are far from ubiquitous. The non-asbestiform variety of grunerite-cummingtonite amphibole is common in iron-formation, including much that is mined and processed. Fine acicular particles, legally classed as asbestos, produced by fine-grinding are potentially harmful. However, epidemiological studies of miners and mill workers at a taconite mine in Minnesota, where ore contains abundant cummingtonite-grunerite, found no evidence of excess cancer (Ross, 1984). Nevertheless, any iron-formation containing amphibole probably requires special consideration with regard to mine design, milling, and waste disposal practices to minimize discharge of amphibole particles into the environment. All of these hazards are successfully mitigated at numerous large mining and processing operations.
(2) Waste rock and tailings may contain sulfide minerals associated with deposits in which iron-formation and sulfide-mineral-bearing facies are in close spatial association. These situations have some potential for acid generation, but this potential hazard is not universal.
(3) Deposits are mined from open pits, which result in a relatively large, and partly permanent surface disturbance.
(4) Ore from carbonate facies deposits may be sintered to produce iron-oxide concentrates. Stack emissions produced when carbonate ore is processed may include sulfur or other trace components.

Exploration geophysics

Gravity and magnetic methods can be used to delineate greenstone belts within granite-greenstone terranes at provincial to regional scales. Magnetic low and gravity high anomalies are usually associated with relatively nonmagnetic, dense greenstone terranes, whereas magnetic high and gravity low anomalies are usually associated with magnetic, low-density granitic terranes (Innes, 1960; Bhattacharya and Morely, 1965; McGrath and Hall, 1969; Tanner, 1969; and Condie, 1981). Gravity and magnetic methods can also be used for deposit-scale iron-formation studies. Most iron-formation is associated with positive, high-amplitude gravity anomalies because it contains elevated abundances of high-density iron minerals, including magnetite and hematite. The magnetic signature of iron-formation is usually one to two orders of magnitude greater than that of its host rock (Bath, 1962; Sims, 1972). Remote sensing imaging spectroscopy can also be used in regional exploration (Hook, 1990) because iron ore minerals and their alteration products have distinct spectral signatures (Clark and others, 1993).

The magnetic character of iron-formation is dependent on magnetic mineral content, alteration, structural attitude, and remanent magnetization. Iron-formation with low magnetite content, or deposits in which magnetite has been oxidized to non-magnetic hematite, produce low-amplitude anomalies of tens to hundreds of nanoTeslas. Flat-lying deposits with normal magnetic polarization typically produce positive anomalies of about several thousand nanoTesla. Steeply dipping or folded iron-formation dominated by remanent magnetic polarization can produce anomalies with extremely high positive amplitudes of as much as tens of thousands of nanoTesla.

Electrical and electromagnetic methods are generally not applied to iron-formation exploration because the ore is resistive owing to high silica (chert) content. However, electrical techniques could be used to locate conductive sulfide facies or to delineate graphitic shale horizons associated with ore deposits.

References

Geology: Goodwin (1973), Gross (1973, 1980, 1988), and Davies and Grainger (1985).
Environment: Ross (1984), Gross (1988), and Myette (1991).

GEOLOGIC FACTORS THAT INFLUENCE POTENTIAL ENVIRONMENTAL EFFECTS

Deposit size

Deposits are small (a few million tonnes) to very large (billions of tonnes); median deposit size is 170 million tonnes (Mosier and Singer, 1986).

Host rocks

Host rocks include a variety of volcanic and volcaniclastic rocks including basalt, andesite, dacite, rhyolite, graywacke, shale, and graphitic shale.

Surrounding geologic terrane

The geologic terrane surrounding Algoma iron deposits usually consists of strongly deformed and variably metamorphosed submarine volcanic sequences.

Wall-rock alteration

No wall rock alteration is associated with Algoma iron deposits. Although deposits are believed to be related genetically to submarine hydrothermal vents, nearly all known deposits are distal to vents and have no obvious related alteration.

Nature of ore

Most ore is banded rock in which iron-rich and chert bands are interlayered on a scale of one to a few centimeters. Several depositional facies are common and may be in stratigraphic superposition or as lateral equivalents. Oxide facies ore consists of both magnetite and hematite ore, and is economically the most important; iron carbonate ore is less commonly mined. Sulfide facies ore is present widely but is seldom mined. Ore grade is relatively uniform, typically about 30 to 35 weight percent iron, but may vary from 15 to 45 weight percent. Grain size varies according to degree of metamorphism as does the nature of gangue minerals. A critical factor for environmental consideration is the metamorphic development of iron-amphibole, which may generate fibrous particles during processing. Iron amphibole commonly is present in middle greenschist facies or higher metamorphic grade rocks.

Deposit trace element geochemistry

Analyses of major and trace element abundances in about 1,000 Algoma-type iron-formation samples from the Canadian shield, representing most known deposits, were summarized by Gross (1988). All determined trace element abundances are low, generally at or below average crustal abundance. One exception is gold, whose average abundance is about an order of magnitude above average crustal abundance, but still in the 0.0X to 0.00X ppm range. Except for sulfide facies iron-formation, very rarely exploited as iron ore, potential environmental effects related to trace element abundances are minimal. Sulfide facies rocks included in some mine waste, pose limited potential for acid drainage generation or release of heavy metals.

Ore and gangue mineralogy and zonation
Ore minerals are predominantly magnetite and hematite, less commonly siderite. Gangue is mostly quartz in the form of variably metamorphosed chert beds. Other gangue minerals that might be present, depending on original facies of deposition and degree of metamorphism, include greenalite, minnesotaite, stilpnomelane, iron-amphibole, iron-pyroxene, garnet, and pyrite, generally present in only trace amounts. Magnetically concentrated ore may include hematite and iron carbonate minerals as gangue.

Mineral characteristics
The most important mineral characteristic is the presence or absence of amphibole that might contribute natural asbestos fibers or asbestos-like grains produced during processing. Amphibole is a common metamorphic mineral in iron-formation and may be present in middle greenschist facies or higher metamorphic grade rocks. Original grain size is also important and varies as a function of metamorphic grade. Weakly metamorphosed iron-formation is extremely fine-grained and requires very fine grinding (as fine as 0.03 mm in some cases) to liberate iron minerals from gangue. More highly metamorphosed ore is coarser-grained and requires less grinding. The maximum grain size after grinding is generally about 0.1 mm, even for the most coarse-grained ore. Grain size fineness is correlated with increased potential for problems with dust from tailings basins, colloidal and particulate suspensions of ore and gangue minerals in released process water, and higher tailings weathering rates.

Secondary mineralogy
Because tailings are generally very-fine grained, weathering and formation of secondary minerals may proceed quickly. Iron oxide minerals alter to iron hydroxide minerals. Iron silicate minerals alter to iron hydroxide minerals and clay. Most alteration minerals are highly insoluble. Sulfide minerals, mainly pyrite, may also quickly alter and generate small amounts of acid. Much ore also contains at least trace amounts of carbonate minerals, which, when present, are probably adequate to neutralize any acid generated.

Topography, physiography
Algoma-type iron-formation deposits are found in a variety of physiographic settings. They are characteristic deposits of Archean shields; many are in areas of low relief. They may also be present in high relief areas, particularly where older shields have been incorporated in younger orogenic belts. The principal topographic and physiographic concern associated with Algoma-type iron-formation deposits relates to large volumes of tailings that are characteristically produced. In areas of high relief, it may be difficult to site tailings impoundments with adequate volume. In settings where rapid surface water runoff can produce flash flood hazards, impoundments must be protected from failure.

Hydrology
Hydrologic communication between ground water, waste piles, and tailings is a predictable consequence of mining. A detailed study of a taconite tailings basin in Minnesota and its surroundings (Myette, 1991) suggests that associated environmental problems are minimal. Abundances of components dissolved in water of a tailings test well are well below maximum abundances permitted by state standards for drinking water, except those of fluoride, which are near the maximum permitted abundance. Particulate abundances in discharge water are also low, except during occasional periods of very high precipitation or snow melt.

Mining and milling methods
With few exceptions, Algoma-type iron-formation is mined in open pits, and ore is processed to high-grade concentrates and pelletized at mine sites. Open pit mining tends to produce relatively large volumes of waste rock that must be disposed of near mines. Mine waste generally includes a variety of volcanic and volcaniclastic rocks with which iron-formation is interlayered. Ore concentration generates large volumes of tailings, mostly composed of silica and lesser iron silicate and iron carbonate minerals. Where iron carbonate is the ore mineral, mine sites may also include roasting or sintering plants; stack emissions, particularly if the ore contains sulfide minerals, may contain elevated metal abundances that may accumulate in downwind areas. Stack emissions of mineral dust might also be a concern; scrubbing or filtering might be required to eliminate dust problems.

ENVIRONMENTAL SIGNATURES

Drainage signatures

Pre-mining drainage signatures for Algoma-type iron-formation deposits are unknown. In virtually all weathering regimes, primary iron minerals break down to iron hydroxide minerals and clay that are highly insoluble. With intense weathering, silica is lost, but not in concentrations that produce a detectable geochemical signature. Some asbestos-like particles may be released into surface water; however, the U.S. Environmental Protection Agency has concluded that ingestion of asbestos fibers poses no significant cancer risk (U.S. Environmental Protection Agency, 1991).

Metal mobility from solid mine wastes

Except in special cases, in which sulfide-mineral-rich rocks might be included in waste rock, metal mobility is probably negligible. Carbonate minerals in mine waste may mitigate acid generated by oxidation of sulfide minerals in sulfide-mineral rich waste. Iron weathers to largely insoluble compounds and the abundances of other metals in iron-formation are at or below average crustal abundances.

Soil, sediment signatures prior to mining

Pre-mining soil and sediment signatures for Algoma-type iron-formation deposits are unknown but stream sediments probably contain high iron abundances. In areas of intense weathering, iron-rich laterite, some of which is itself iron ore, may develop on iron-formation. In glaciated areas, most iron formation is virtually unweathered and has no associated characteristic soil signature.

Potential environmental concerns associated with mineral processing

Most Algoma-type iron-formation ore is ground to 0.1 mm or finer, concentrated by magnetic or specific gravity techniques, and formed into pellets, which are then fire hardened in rotary kilns, at or near mine sites. The large volume of tailings generated are stored in nearby impoundments. The principal environmental concern involves continued physical isolation of tailings, particularly fine-grained silica and fibrous silicate minerals. Redistribution by wind can be mitigated by wetting and vegetating abandoned tailings areas. Redistribution in surface water can be minimized at active mines by reuse of tailings water so that outflow is restricted to periods of very high precipitation. The long term, post-mining stability of tailings impoundments must be assured in their design.

Combustion products from rotary kilns are generally vented through stacks and may carry fine ore particles that should be removed by scrubbing or filtering before combustion products are released to the atmosphere. On-site sintering mills used to process carbonate facies ore may require assurance of acceptable stack emissions.

Smelter signatures

No smelting is involved in production of Algoma-type iron ore.

Climate effects on environmental signatures

Principal climatic concerns relate to the continued integrity of tailings impoundments in climates with high annual or seasonal precipitation and with airborne redistribution of tailings in dry climates. Even in humid climates, milling operations generally reuse nearly all process water to minimize water outflow through tailings basins. In climates susceptible to extreme precipitation, however, measures are required to assure that flooding does not compromise the containment of tailings either during or after mining.

Geoenvironmental geophysics

Electrical methods can be used to identify conductive ground water plumes produced by high abundances of dissolved solids, colloids, and acid. The self potential method can detect leaks in tailings impoundment dikes. Remote sensing methods can be used to quantify areas of permanent surface disturbance related to mining and ore processing. Remote sensing methods may also be used to identify areas of stressed vegetation related to sulfur and fugitive-metal stack emissions and contaminated surface water.

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