Carbonate-hosted, Nonsulphide Zn (hypogene)  
Mineral Deposit Profile E18  
by S. Paradis¹ and G.J. Simandl²

IDENTIFICATION
SYNONYMS
Zinc-oxides, willemite-dominant deposits

COMMODITIES (BYPRODUCTS)
Zn, Pb (Mn, Fe, Cu, V, Cd, Ag)

EXAMPLES
(British Columbia - Canada/International): Structurally-controlled replacement deposits: Abenab West (Namibia), Berg Aukas (Namibia), Kabwe (Zambia), Star Zinc (Zambia), Vazante (Brazil), Ariense (Brazil), Beltana (Australia), Aronna (Australia), Reliance (Australia). Stratiform deposits: Abu Samar (Sudan), Desert View (US), Franklin/Sterling Hill (US).

GEOLOGICAL CHARACTERISTICS
CAPSULE DESCRIPTION
Zinc oxide minerals, such as willemite, franklinite or zincite, occur as massive to disseminated zones hosted primarily by carbonate rocks. The two subtypes of hypogene carbonate-hosted nonsulphide Zn-Pb deposits are:

1) structurally-controlled replacement deposits in the form of podiform bodies, veins, and irregular pipes consisting mainly of willemite (±sphalerite, ±hematite, ±franklinite and ±zincite) and spatially associated with fractures and fault zones; and

2) stratiform deposits forming lenses of franklinite-willemite-zincite (±gahnite) located in highly metamorphosed terrains.

TECTONIC SETTING(S)
The structurally-controlled replacement deposits are located in intracratonic or continental margin environments in fault-controlled sedimentary basins within orogenic belts.

The stratiform deposits are located in sedimentary or volcano-sedimentary basins within orogenic belts.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING
Hostrocks to the structurally-controlled hypogene nonsulphide Zn-Pb deposits are carbonates deposited in platform successions. Shallowing-upward basins or proximity to major unconformities separating a reduced, carbonate-rich succession (below) from an oxidized sequence of terrestrial sedimentary rocks (above) are frequent settings (e.g., Beltana and Vazante deposits; Groves et al., 2003; Monteiro et al., 2006).

In case of stratiform deposits, metamorphic overprint obliterated all textural/structural indicators of depositional environment.

AGE OF MINERALIZATION
Ages of hypogene nonsulphide Zn deposits are poorly constrained between the Proterozoic to Paleozoic time.

HOST / ASSOCIATED ROCK TYPES
Structurally-controlled deposits are commonly hosted by dolostone, limestone, dolomitized limestone, argillaceous carbonate, marble and slate.

Stratiform deposits are typically hosted by metasedimentary rocks, such as calcitic and dolomitic marble, interlayered with metavolcanic and igneous intrusive rocks (Hague et al., 1956; Hitzman et al., 2003).

DEPOSIT FORM
Structurally-controlled deposits are highly irregular, consisting of podiform bodies, veins within fault and shear zones, joint and fissure-fills, and open-space fills in breccia pipe-like karst structures. Individual podiform ore bodies range from a few tens to a few hundreds of metres in the two dimensions parallel with bedding. Perpendicular to bedding, dimensions are usually a few tens of metres.

Stratiform nonsulphide deposits consist of a series of stratabound discontinuous tabular lenses that considerably

¹ Geological Survey of Canada, Sidney, BC  
² British Columbia Geological Survey, Victoria, BC  
This publication is also available, free of charge, as colour digital files in Adobe Acrobat® PDF format from the BC Ministry of Energy and Mines website at http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalog/Fieldwork.
varied in thickness and length from few tens of metres to few hundreds of metres.

TEXTURE / STRUCTURE

Mineralization in the structurally-controlled deposits is heterogeneous, resulting from various depositional mechanisms such as massive replacement of various hematitic and/or zincian dolomite wallrock facies, dissemination, internal sedimentation, fracture and vein fill, and brecciation. The massive ore is commonly granular and fine grained, and appears as finely porous to compact cryptocrystalline masses. The internal sediments consist of fine laminations of zinc oxide minerals in open cavities. Colloform or crustiform bands, rosettes and spherulites of willemite are deposited as vein and vug fill and in the matrix of breccias (Figures 1, 2).

Mineralization in the stratiform tabular lenses consists of massive to disseminated equigranular, subrounded aggregates of Zn-rich minerals (Figures 3, 4, 5). The ores may have gneissic or disseminated textures, and minerals are generally coarse grained (>2-3 mm) and euhedral to subhedral (Hitzman et al., 2003).

ORE MINERALOGY (Principal and subordinate)

Structurally-controlled replacement deposits: Willemite, cerussite, coronadite, covellite, desclozite, franklinite, gahnite, galena, genthelvite, hedyphane, hemimorphite, hetaerolite, hydrozincite, mimetite, native silver, sauconite, scholzite, smithsonite, sphalerite, tarbuttite, vanadinite and zincite.

Stratiform deposits: Franklinite, willemite, zincite, adamite, anglesite, arsenopyrite, aurichalcite, azurite, chalcophanite, chalcopyrite, cuprite, gahnite, galena, hemimorphite, hetaerolite, hydrozincite, magnetite, malachite, melangerite, sauconite, smithsonite, sphalerite, tephroite and zincian fayalite (roepperite).

GANGUE MINERALOGY (Principal and subordinate)

Structurally-controlled replacement deposits: Calcite, 

manganoan calcite, dolomite, ferroan dolomite, apatite, barite, hematite, magnetite, quartz, siderite, Zn-rich chlorite. Stratiform deposits: Calcite, manganoan calcite, dolomite, ferroan dolomite, alleghanite, apatite, aragonite, barite, fluorite, garnet, goethite, graphite, hematite, leucophoenicite, jacobsite, löllingite, phlogopite, quartz, siderite, sonolite and rhodonite.

ALTERATION MINERALOGY

The structurally-controlled replacement deposits display pre to syn-mineralization alteration of the host carbonate rocks that is largely fracture-controlled and extends for about 50 m to 20 km from the major structures. Alteration consists of silicification and formation of a broad halo of net-veined breccia filled by dolomite, ankerite, siderite, hematite, jasper, and chlorite. Post-mineralization alteration locally consists of hematite, Zn-chlorite, and dolomite assemblage, and/or calcite replacing earlier dolomite and zinc minerals. No alteration mineralogy is reported for stratiform deposits.
Figure 3. Typical granular willemite-franklinite-calcite ore from Sterling Hill (U.S.A.). Specimen measures 13 by 9.5 by 6.5 cm. Willemite is brownish red, franklinite and calcite are black and white, respectively. Photo used with permission of Dr. Earl R. Verbeek, Resident Geologist, Sterling Hill Mining Museum, Ogdensburg, New Jersey, U.S.A.

Figure 4. "Classic" granular ore from Franklin deposit (U.S.A.) showing pronounced gneissic foliation with green willemite, black franklinite, and minor red zincite. The colour of much willemite at Franklin is some shade of green; at Sterling Hill, it is usually brown, tan or brownish red. Specimen measures 10 by 10 by 7 cm. Photo used with permission of Dr. Earl R. Verbeek, Resident Geologist, Sterling Hill Mining Museum, Ogdensburg, New Jersey, U.S.A.

In the case of stratiform deposits, any original pre-metamorphic alteration mineralogy was probably destroyed by metamorphic overprint. The exception may be Desert View deposit (United States), which could have a preserved manganese halo (Leavens and Patton, 2008). Sphalerite present in some structurally-controlled replacement and stratiform deposits is replaced by willemite under hydrothermal conditions (i.e., at temperatures higher than 100°C; Brugger et al., 2003).

WEATHERING

Nonsulphides in both deposit types can be altered by supergene processes to minerals observed in supergene nonsulphide zinc deposits. Supergene mineral assemblages form a near-surface direct-replacement cap above many structurally-controlled replacement deposits. For example, an assemblage of hemimorphite, hydrozincite, and minrecordite form a cap above the willemite bodies of the Vazante deposit (Brazil). On the periphery of the Beltuna deposit (Australia), hemimorphite and smithsonite formed by weathering of willemite. An assemblage of hemimorphite, cerussite, smithsonite, quartz, desclozite, pyromorphite, goethite, hematite, and iron-aluminum-manganese oxides replaces sulphides and willemite-bearing assemblages within the Kabwe (Zambia) and Berg Aukas (Namibia) deposits (Schneider et al., 2008).

In the case of stratiform deposits, at least some goethite and hematite form by surface alteration of franklinite. Ferric oxide and hydroxide minerals are abundant within the Franklin and Sterling Hill deposits. Furthermore, under these conditions, hemimorphite, cerussite and hydrozincite commonly replace zincite.
ORE CONTROLS

For structurally-controlled deposits, the main controls are favourable sedimentary successions with proper redox states and potential structural zones for fluid ore mixing, i.e., regional basement structural features, such as growth faults, normal and reverse faults, and shear zones.

Favorable sedimentary hosts are important for the localization of stratiform zinc oxides deposits. Faults may also have played a role in the localization of stratiform deposits but metamorphism and deformation have obliterated all evidences.

GENETIC MODEL

Structurally-controlled deposits formed where reduced, moderate to high temperature (100–330°C), Zn-rich, sulphur-poor fluid encountered a cooler, less saline, oxidized, sulphur-poor fluid of seawater, groundwater, or basinal origin (Hitzman et al., 2003). The fundamental difference between the two deposit subtypes may be the site of fluid mixing (Hitzman et al., 2003). The structurally-controlled deposits formed where fluids from a reduced sedimentary succession moved upwards along structures and encountered fluids that originated in oxidizing environment.

There is no consensus regarding the origin of the stratiform nonsulphide zinc deposits (e.g., Franklin and Sterling Hill metamorphosed orebodies) because the nature of the primary mineralization is difficult to decipher. The stratiform deposits may have formed where Zn-rich hydrothermal fluids discharged into an oxidized, sulphur-poor body of water (i.e., exhalative Zn carbonate-silicate oxide accumulations). Such mixing and accumulations of manganoferous sulphides and iron oxides may occur at the sediment/water interface or within sediments immediately beneath such body of water. There is also a possibility that the current ore assemblages may be the post-metamorphic equivalent of hemimorphite and hydrous Mn and Fe-oxides derived assemblages may be the post-metamorphic equivalent of water. There is also a possibility that the current ore within sediments immediately beneath such body of water may occur at the sediment/water interface or silicate oxide accumulations). Such mixing and stratiform nonsulphide zinc deposits (i.e., Franklin and Sterling Hill metamorphosed orebodies). Structural controls formed where fluids from a reduced sedimentary succession moved upwards along structures and encountered fluids that originated in oxidizing environment.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE

Colorimetric field test for secondary zinc minerals (“Zinc Zap”) and hand-held x-ray fluorescence spectrometry are useful in exploration for nonsulphide Pb-Zn deposits in general (Paradis and Simandl, 2011; Simandl et al., 2011). Positive Zn anomalies in residual soils and stream sediments and elevated concentrations of Pb, Mn, Fe, Cu, V, U, La, Cd, and As are also expected. Analysis of heavy mineral concentrates (identification of Zn-Pb nonsulphides) in stream and overburden may be effective in areas lacking deep weathering. Short wave ultraviolet light may help to detect an increase in the Mn content of calcite in proximity to deposit with these mangaano calcite fluorescing orange-red to red; however, calcite may also appear white, cream, yellow-orange, green or pink. If fluorescence of calcite is due to divalent Mn the colour of fluorescence will be orange-red to red. The other colours mentioned are due to different activators (quite diverse in calcite). Willemite may fluoresce green, yellow-orange or yellow under short wave ultraviolet light. Under long wave ultraviolet radiation, zincite may fluoresce yellow. Primary metamorphic zincite at Franklin and Sterling Hill does not fluoresce. Secondary zincite in veins or disseminated hydrothermal grains fluoresces in some specimens, but such zincite is uncommon and volumetrically insignificant. Willemite, ferroan dolomite, and supergene minerals such as hydrozincite and smithsonite, give distinct spectral responses in the short-wave near infrared portion of the spectrum (Hitzman et al., 2003; McConachy et al., 2009). Hyperspectral imaging holds promise as a useful tool for accurate mapping of structures, lithologies, and alteration.

OTHER EXPLORATION GUIDES

Deposits may produce a gravity signature. Electrical methods will not be successful due to the absence or small amounts of sulphides. Deposits that contain magnetite and franklinite can produce a magnetic response; a larger response should be observed with stratiform nonsulphide deposits.

ASSOCIATED DEPOSIT TYPES

Carbonate-hosted, nonsulphide Zn-Pb (supergene, B09), Mississippi Valley-type (MVT, E12), and Irish-type (E13) are the most commonly associated deposits. Other potentially associated deposits are stratiform Zn sulphide and Fe (oxide or sulphide), Broken Hill-type (S01), magnetite (i.e., iron oxide deposits), sedimentary manganese (F01), and carbonate-hosted Cu±Pb±Zn (E02) deposits.

COMMENTS

These deposits are unusual in that they produce zinc, occasionally lead, and little else. The chemistry of the fluids responsible for the hypogene structurally-controlled nonsulphide deposits is similar to solutions produced in many continental sedimentary basins. Therefore these deposits could be found in the same districts as MVT, Irish-type and potentially sedimentary exhalative (SEDEX) deposits. British Columbia has prospective strata for these deposits in the miogeoclinal carbonate platform rocks of the Ancestral North America continental margin and in the pericratonic rocks of the Kootenay terrane.
exploration efforts. Discovery of outcropping hypogene Zn-Pb nonsulphide deposits depends on recognition and knowledge of the physical properties of common nonsulphide zinc minerals. The selection of grassroots exploration areas should target sedimentary rock sequences that have known nonsulphide (supergene and hypogene) zinc prospects, stratiform manganese deposits, Mississippi Valley-type deposits or Broken Hill-type deposits.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE

Most of the known deposits (except Vazante with 28.5 Mt at 18.3% Zn, and Franklin with 21.8 Mt at 19.5% Zn) fall in the range of <1 to 10 Mt and grade 5 to 38% Zn and 0 to 11% Pb. They may contain low concentrations of Mn, Fe, Cu, V, Cd, Ag, and Ba.

ECONOMIC LIMITATIONS

Some deposits (e.g., Beltana and Aroona) are amenable to open pit mining operations; however, most hypogene nonsulphide deposits are exploited by underground mining.

IMPORTANCE

Nonsulphide deposits were the main source of zinc prior to the 1930s. Following the development of differential flotation and breakthroughs in smelting technology, the mining industry turned its attention almost entirely to sulphide ores. Today, most zinc is derived from sulphide ore. The nonsulphide deposits provided roughly 7% of the world’s zinc production in 2009. Hypogene nonsulphide deposits are relatively rare compared to supergene nonsulphide deposits, and they currently represent less than 2% of the zinc production.

ACKNOWLEDGMENTS

This manuscript benefited from reviews by Maria Boni (Università di Napoli, Italy), Donald Sangster (Geological Consultant, Ottawa) and David Lefebure (currently with Lefebure GeoLogic Ltd., Salt Spring Island, BC, Canada; former chief geologist of the British Columbia Geological Survey, Victoria, Canada). The project started under the umbrella of the Cordilleran Targeted Geoscience Initiative-3 Program of the Geological Survey of Canada, and was done in collaboration with the British Columbia Geological Survey.

SELECTED BIBLIOGRAPHY


