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Footwall-hosted Cu-PGE (Au, Ag), Sudbury Canada: Towards a new exploration vector

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ABSTRACT

Potential mineralogic and geochemical vectors for Cu-PGE in Sudbury are being developed as deposit models, exploration techniques and genetic models evolve in Canada's premier mining camp. Trace element analyses of the Contact, Offset and Footwall sulfide ores indicates distinctive signatures for the Cu-PGE-Au mineralization. This study presents data on halogen-bearing phases identifying a major Cl sink (scapolite) adding caution for the use of halogen anomalies currently employed as an geochemical exploration tool in Sudbury. Indicator mineral methods combined with till and bedrock geochemistry are demonstrated to be useful exploration methods for detecting the coveted precious metal-rich base metal deposits in the world-class Ni-Cu Sudbury camp. Till sampling will be most effective in the north and west parts of the Sudbury Structure, up-ice of the main Sudbury deposits where bedrock outcrop is less and till cover is more continuous and thicker.

INTRODUCTION

As part of the Geological Survey of Canada's Targetted Geoscience Initiative (TGI-3), method development studies of indicator mineral vectors for base metal deposits were initiated in the Thompson, Sudbury and Bathurst mining camps. In the last few years, new discoveries of Cu-Ni-platinum group element (PGE) deposits in Sudbury has resulted in a marked shift in exploration focus in Canada's world-class mining camp. Traditional exploration methods in the Sudbury basin have recently been challenged in the quest for new Footwall-hosted vein-style Cu-PGE (ie. Nickel Rim South, Levack Footwall) and Low-sulfide high PGE resources (ie. PM deposit) and as a result effective new techniques are in demand. In order to determine indicator and trace element signatures indicative of Cu-PGE deposits and establish practical methods for indicator mineral recovery from glacial sediments that can be applied in exploration in the region, a detailed till survey was completed around the Broken Hammer Cu-PGE deposit in 2006.

SUDBURY NI-CU-PGE ORE DEPOSITS

Sudbury Ni-Cu Contact-type deposits are interpreted to be of magmatic origin, having formed during differentiation of the SIC followed by sulphide segregation and subsequent collection in topographic lows or "embayments" at the base of the SIC. The origin of the Cu-Ni-PGE systems is controversial with both magmatic and hydrothermal processes having been supported in the literature. More recently, a magmatic-hydrothermal origin was postulated whereby initial magmatic differentiation of the sulphide liquid resulted in the formation of a residual sulphide liquid enriched in Cu, Pt, Pd and Au. This was then remobilized into structural pathways or permeable zones of brecciated country rock or Sudbury breccia in the footwall of the SIC. Later hydrothermal mobilization resulted in redistribution of base and precious metals, modification of the ore composition and the formation of Cl-rich alteration haloes. Fluid inclusion, stable isotope evidence suggests ore metal transport and redistribution involved mixing between regional groundwaters, a metal-rich ore fluid with a magmatic component to form a metal-enriched brine that partitioned, causing Au precipitation and phase separation of Cu, Au, Ag and Bi into a CH_4-bearing fluid that further dispersed Cu, Pt, Au, Ag and Bi (Farrow, 1994; Hanley et al., 2005; 2006).

Chlorine as a geochemical vector

Evidence of fluid mobility has long been recognized in Sudbury breccia host rocks to Cu-Ni-PGE ores (Speers, 1957). Alteration haloes enriched in alkali- and halogen-rich minerals and fluid inclusions are recognized around both 'sharp-walled' vein-style footwall mineralization and 'low-sulphide' mineralization, however, the use of anomalous Cl concentrations is problematic. Silicate minerals acting as sinks for Cl in Sudbury have multiple

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fluid sources involving regional groundwater and magmatic Cl in the exsolved fluid phase (Hanley et al., 2006) and hence confuse the vectoring ability. Scapolite is a major Cl-bearing phase in the Sudbury Structure with the highest Cl content of the halogen-bearing minerals (Figure 1). It occurs in sulfide ores, main mass of the Sudbury Igneous Complex (SIC) in the Creighton embayment and in footwall Huronian rocks. Fluid inclusion and stable isotope evidence suggests that Cl-rich scapolite grew as a result of groundwater fluid migration at high (520°C) temperatures (Hanley et al., 2006).

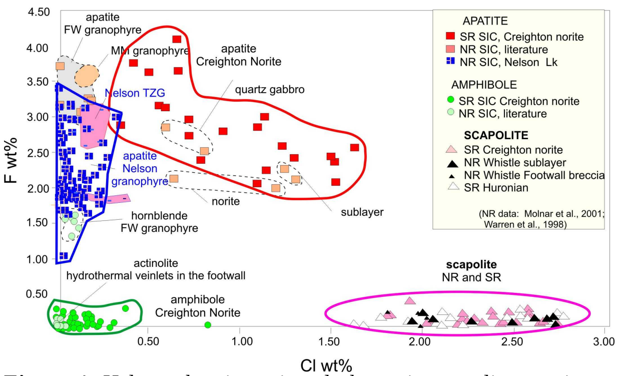

Figure 1: Halogen-bearing mineral phases in scapolite, apatite and amphibole, Sudbury. Scapolite is the largest sink for Cl in Sudbury.

SULFIDE ORE GEOCHEMISTRY

Over 400 representative sulfide samples from the Sudbury deposits were analyzed for trace and precious elements to determine distinctive trace element signatures of the various deposit types and identify potential trace element geochemical vectors for Cu-PGE. By volume, Contact Ni-Cu deposits comprise the bulk of the mined deposits in Sudbury during the last century. Pyrrhotite-rich NiCu deposits at the lower contact of the SIC hosted in footwall breccia or the sublayer that were studied include the Creighton, Crean Hill, Murray, Strathcona, Kirkwood, Levack contact, Victor 42N orebody, Craig, Hardy, East Rim Ni, Lindsley 4B, Little Stobie, Whistle, Coleman, Blezard, Clarabelle and Victoria mines. Offset deposit sulfide samples were collected from the Copper Cliff, Worthington, Whistle, Foy and Trill offsets, listed in order of decreasing tonnage. The trend within individual offset dykes with increasing distance from the SIC is towards increasing PGE, Cu and Au (Farrow and Lightfoot, 2002).

Footwall-hosted Cu-PGE deposits are a relatively new resource in the Sudbury camp with the exception of the earlier discovery of the Strathcona Deep Copper zone (Coats and Snajdr, 1984). Cu-Ni-PGE systems are composed of sharp-walled (vein) and low-sulphide end members. Cu-Ni-PGE deposits analyzed at the GSC, in this study (n > 130) include Creighton 403, Creighton Deeps, Barnett, McCreedy East 153 zone, Victor deep and the recently discovered (2003-2005) Levack Footwall, McCreedy West PM zone, Segway and Broken Hammer Cu-PGE deposits, advanced prospects and occurrences. Sharp-walled deposits are more common. Presently the only Low sulfide PGE deposit mined is McCreedy West PM. Major and junior companies are discovering numerous Low-sulphide PGE exploration targets in the Sudbury region.

Trace element geochemistry of the sulfide ores indicate anomalous Sn, Pb, Zn, Cd, In, Bi,Te in the footwall deposits relative to contact and offset mineralization. Lead is characteristically low in contact and offset deposits (~20, 40 ppm Pb) however in footwall-hosted deposits the Pb content of the sulfide ores average 250-475 ppm. Zinc an important discriminator for footwall-type deposits (>1000 ppm Zn), is characteristically low in other deposit types (< 40-80 ppm Zn). Sn concentration is a useful vector in footwall systems in the North Range ie. Wisner West (average 16 ppm Sn), Broken Hammer (~7 ppm Sn) PM zone- (6 ppm Sn), relative to all North Range contact sulfides averaging ~ 1.8 ppm and offset deposits (~3 ppm). Indium content is anomalous in footwall deposits (avg. 4-8 ppm In) relative to contact (0.1 ppm) and offset deposits (0.5 ppm). The content of Bi, Te and Se is significantly greater in footwall style deposits reflecting the trace and rare mineral assemblages with bismuthides, tellerides and selenides coupling with base and precious metals in the copper-rich ores.

THE BROKEN HAMMER FOOTWALL-HOSTED VEIN-STYLE CU-PGE DEPOSIT

Quaternary geology

The Sudbury region was most recently glaciated during the Late Wisconsinan (25,000 to 10,000 years ago), during which time ice of the Labrador Sector covered the Sudbury region and generally flowed south-southwest (Boissoneau, 1968). In the Wisner Township area, till was deposited by ice flowing southward (185-175°). The local till generally has a silty sand to sand matrix and is loose, thus making it an ideal sample medium for indicator mineral sampling. The Wisner Township area is dominated by bedrock outcrop and thin (<2 m) discontinuous till veneer over bedrock (Bajc, 1997). The deposit itself was overlain by 1 to 3 m of till prior to being exposed in exploration trenches. Deglaciation occurred about 10,000 years ago, exposing all glacial sediments to weathering and soil forming processes since that time.

The Sudbury region has been affected by atmospheric contamination related smelting of ore and the anthropogenic effects on till mineralogy and geochemistry are a concern. However, Bajc and Hall (2000) demonstrated that airborne contamination in soils in the North Range is limited to the upper organic horizon (humus) and has not affected the B- or C-horizon parts of the soil profile developed on till.

Historically, till sampling has not been carried out in support of mineral exploration in Sudbury however, the North Range and west end of the Sudbury structure, have thicker and more continuous till cover of till than the South Range. North Range targets utilizing till surveys have the added advantages of being up-ice (north) of the main Sudbury deposits, thus background metal concentrations in till will be lower.

Local deposit geology

The Broken Hammer resource is situated on the North Range of the Sudbury Structure in Wisner township, 1.5 km north of the SIC contact with the footwall Levack Gneiss Complex. The Broken Hammer Zone is a shallow surface zone of vein and vein stockwork-hosted copper-PGE mineralization hosted within Sudbury breccia developed in NeoArchean quartz monzonite, Levack Gneiss Complex. The total Inferred Mineral Resource is estimated at 251,000 tonnes at a grade of 3.80 g TPM/t (1.56 g/t Pd, 1.62 g/t Pt, and 0.61 g/t Au), 1.00% copper, and 0.10% nickel. (Wallbridge Press Release, November 29, 2005). The surface expression is a zone ~ 25 m x 250 m plunging SW that extends 100 m deep. The main 2-120 cm wide chalcopyrite Big Boy vein is dominantly chalcopyrite-magnetite-millerite with numerous trace and rare precious metal minerals as tellurides, bismuthides, selenides and stannides (Table 1).

The well exposed regolith of the Cu-PGE vein contains abundant sperrylite, Se-galena, cassiterite, kotulskite, merenskyite, electrum, arsenopyrite and native silver (Figure 2). Trace elements in the mineral assemblages in the weathered sulfide include Pd-Pt-Sn-Pb-Au-Ag-As-Bi-Te which are reflected in the sulfide ore lithogeochemistry.

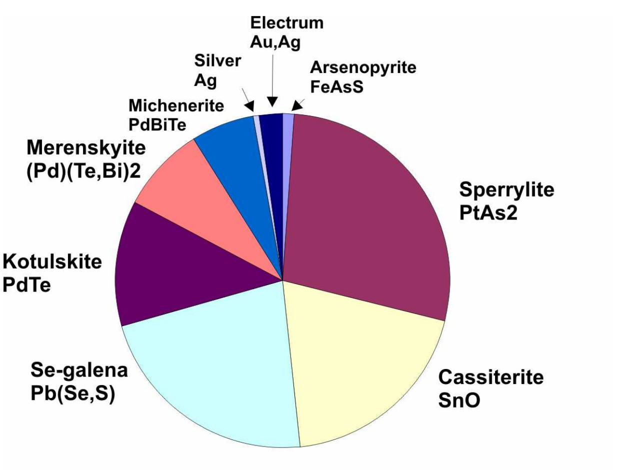

Figure 2: Relative abundance of Pt-Pd-As-Sn minerals in 1 kg sample of regolith from Broken Hammer chalcopyrite vein. N=180 mineral grains.

Till Survey Results

Indicator minerals

To date, data for only two indicator minerals are available for till samples collected around the Broken Hammer deposit. Native gold and sperrylite ($PtAs_2$) grains were panned from the till preconcentrates prior to heavy liquid separation and indicator mineral picking. Silt-sized (10 to 50 µm) sperrylite grains in till are the most direct indicator of the Broken Hammer Cu-PGE mineralization. Concentrations are highest in till overlying and just down-ice (south) of the main chalcopyrite vein and vary from 1 to an impressive 714 grains per 10 kg. Sperrylite is present in till up to 150 m down-ice of mineralization.

Table 1: Mineralogy of the footwall-hosted Broken Hammer Cu-PGE (Ni) deposit, Sudbury Canada.

Mineral	Formula	Description
Major and minor minerals in the ore:		
chalcopyrite	CuFeS2	major massive replacing primary FeNi-sulphides and silicates in host rock
magnetite	Fe3O4	euhedral to rounded crystals in po-pn: minor part of primary assemblage
millerite	NiS	minor to major mineral in cpy-rich veins
Trace and rare minerals in the ore:		
Zn-bearing minerals;		
sphalerite	(Zn,Fe,Cd)S	associated with mt in cpy
Cu-bearing minerals;		
bornite	Cu5FeS4	in late cpy-bornite veins
covellite	CuS	alteration around mt in cpy
wittichenite	Cu3BiS3	
emplectite	CuBiS2	
Sn-bearing mineral;		
cassiterite	SnO2	abundant in regolith of cpy vein
Fe, Ni - bearing minerals;		
pentlandite	(Fe,Ni,Co)9S8	anhedral remnants at edge of millerite
melonite	NiTe2	rare
pyrite	FeS2	euhedral porphyroblasts in cpy; Co or Ni-rich, possibly zoned metamorphic
violarite	(Fe,Ni)3S4	alteration of pentlandite in cpy, millerite
As, Pb-bearing minerals;		
Se-galena	Pb(S,Se)	common trace mineral, 1.5 wt% Se
clausthalite	PbSe	in vein regolith
arsenopyrite	FeAsS	in vein regolith
Bi-, Te-bearing minerals;		
tetradymite	Bi2Te3S	in cpy vein, inclusions in hessite associated with Ag-cpy
kawazulite	Bi2Te2Se	
Precious metal minerals (Ag, Au);		
hessite	Ag2Te	common, associated with michenerite in cpy and bornite
naumannite	Ag2Se	in bornite
volynskyite	AgBiTe	
bohdanowiczite	AgBiSe2	5 wt% S
native silver	Ag	in vein regolith
gold	Au	also abundant in till
electrum	Au65Ag35	
Platinum Group minerals (Pd, Pt);		
merenskyite	(Pd)(Te,Bi)2	most common PGM at Broken Hammer
michenerite	PdBiTe	single and composite grains, inclusions in tnt and ep
sperrylite	PtAs2	common in surface vein and tills
moncheite	(PtTe2)	intergrown with kotulskite
kotulskite	Pd Te	with merenskyite
Pd-melonite	(Ni,Pd)Te2	
sopcheite	Ag4Pd3Te4	with UM1
crerarite	PtBiS	at silicate boundary, inclusions in actinolite
UM1	CuBi(Pd,Ni)S3	unknown mineral

Data sources: (Mealin, 2005; Watkinson et al., 2005, Pentek et al., 2006; Ames et al., 2006).

Background concentration in till north of and well south of the deposit is zero grains. The large number (100s) of sperrylite grains that were found in some till samples overlying the Broken Hammer deposit were not expected. Published regional and deposit scale studies of Canadian Ni-Cu-PGE deposits have reported a maximum of a few PGM grains (platinum group mineral) per 10 kg till sample (e.g. Tardif, 2000; Searcy, 2001; Bajc and Hall, 2000). Also unexpected was the fact that highly oxidized as well as fresh till samples contain sperrylite. These results indicate that sperrylite is more chemically robust than previously assumed and survives in highly weathered till.

Gold grain counts are highest in the highly oxidized till as well as fresh samples that contain sperrylite grains, thus at this deposit, gold grains are also a useful indicator of the Cu-PGE mineralization. Gold grain abundance varies from background concentrations of 0 to 10 grains to the most anomalous values of 456 grains per 10 kg sample. The highest values at the Broken Hammer site are significantly higher than the maximum value (n=119 grains) reported for the north and east rim region by Bajc and Hall (2000). Gold grains vary in size from 10 to 250 µm, with most grains <50 µm.

Till geochemistry

The <0.063 mm (silt+clay) fraction of till overlying and down-ice of the Broken Hammer deposit contains highly anomalous concentrations of Pt (maximum value 245 ppb), Pd (509 ppb), Au (97 ppb) as determined by lead fire assay/ICP-MS and Cu (3454 ppm), and Ag (159 ppb) as determined by aqua regia/ICP-MS. The maximum Pt and Pd values reported here are some the highest ever reported in the literature for the <0.063 mm fraction till. Pt/Pd ratios in till are 1:2 in the most anomalous samples and 1:1 in moderately to weakly anomalous samples. Less abundant but associated pathfinder elements in till include various combinations of: Ni, Cd, Sb, Bi, and Te. This preliminary till pathfinder element assemblage at Broken Hammer is similar to those reported for deposit-scale and regional till studies reported by Bajc and Hall (2000) in the Sudbury region.

IMPLICATIONS FOR EXPLORATION FOR CU-PGE DEPOSITS

Over 50% of 2006 exploration expenditures in the Sudbury polymetallic Ni-Cu-PGE camp were concentrated on Footwall-hosted systems due to the high Cu and precious metal content of the systems. PGE in Sudbury are both bound with and spatially associated with Cu, Au, Ag, As, Sb, Sn, Hg, Pb, Zn, Bi, Te and their trace minerals. The increased trace element content of the footwall and offset ores relative to the contact Ni-Cu orebodies (Ames and Farrow, 2007) might be detected in the trace element content of common minerals in Sudbury ores such as (ie. magnetite, apatite, hydrothermal titanite, Ni in epidote) and thereby provide indicator minerals as a vector for Cu-PGE footwall hosted mineralization. The current use of chlorine as a geochemical vectoring tool for footwall-style deposit exploration must be cautioned due to Cl-rich scapolite present in the non-ore as well as ore-forming environment.

Preliminary till results indicate that the resistate minerals gold and sperrylite ($PtAs_2$) are effective indicators for footwall Cu-PGE mineralization and can be detected in till at least 150 m down-ice. Cassiterite (Sn) is also expected in the tills as a result of the sulfide ore mineralogy and trace element content. Geochemical pathfinder elements in till include Pt, Pd, Au, Cu, Ag, Ni, Cd, Sb, Bi, and Te. Historically, till and lithogeochemistry techniques have not been used for Cu-Ni-PGE exploration in Sudbury. This study demonstrates that indicator mineral methods combined with till and bedrock geochemistry are useful exploration methods for detecting this style of mineralization. Till sampling will be most effective in the north and west parts of the Sudbury Basin, up-ice of the main Sudbury deposits where bedrock outcrop is less and till cover is more continuous and thicker.

In the future, indicator minerals will be picked from both bedrock and till non-ferromagnetic heavy mineral concentrates and will include metallic, oxide and silicate minerals that reflect the footwall deposits of the Sudbury basin. Potential mineralogic and geochemical vectors for Cu-PGE in Sudbury are being developed as deposit models, exploration techniques and genetic models evolve in Canada's premier mining camp.

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