Till indicator mineral and geochemical signatures of magmatic Ni-Cu deposits, Thompson Nickel Belt

M.B. McClenaghan, S.A. Averill, I.M. Kjarsgaard, D. Layton-Matthews and G. Matile

Shortcourse: Drift Exploration in Manitoba

Manitoba Mining and Minerals Convention
November 19, 2009
Research Objectives

Knowledge Gaps:

- Few indicator mineral studies conducted around magmatic Ni-Cu-PGE deposits; studies focused in soil or till geochemistry. What is mineralogical signature of this deposit type in till?
- Till methods have not been used to explore the TNB. Could till mineralogy and geochemistry be effective exploration techniques here?

Research Objectives:

- Determine mineralogical and geochemical signatures of magmatic Ni-Cu deposits in glaciated terrain, Thompson Ni Belt (TNB) deposits as test site
- Establish practical methods for indicator mineral recovery from glacial sediments and their identification that can be routinely applied in Ni-Cu exploration in glaciated terrain
- Determine effectiveness of till as exploration sampling medium in TNB
- Evaluate potential of Thompson region to host additional undiscovered Ni-Cu deposits
Research Funding

1) CAMIRO Project 04E01 (2005-2009)
   • Document indicator mineral signatures of magmatic Ni-Cu-PGE deposits
   • 4 test sites: West Musgraves, Australia
     Jinchuan, China
     Noril’sk, Russia;
     *Thompson Ni Belt, Canada

2) Geological Survey of Canada, Targeted Geoscience Initiative 3,
   Deep Search Project (2005-2010)
   • Document indicator mineral signatures of base metal deposits

3) Manitoba Geological Survey
Additional GSC Indicator
Mineral Case Studies

• Sudbury Basin; Broken Hammer Cu-(Ni)-PGE footwall resource
• Bathurst Camp; Halfmile Lake Pb-Zn-Cu VMS deposit
• Izok Lake Cu-Pb-Zn-Ag VMS deposit
• Pine Point Pb-Zn MVT deposits (fieldwork 2010)
• Thelon Basin; Kiggavik U deposit (fieldwork 2010)
• Great Bear Magmatic Zone; Nico, Sue Dianne IOCG deposits
TNB Research Team

Geological Survey of Canada: Beth McClenaghan
Overburden Drilling Management Ltd: Stu Averill
Mineralogical Consultant: Ingrid Kjarsgaard
Queen's University: Dan Layton-Matthews
Manitoba Geological Survey: Gaywood Matile, Josef Macek, Christian Bohm
Vale-Inco: Rob Stewart, Crispin Pike, Scott Mooney
Geoscience Labs: Dave Crabtree
Macquarie University, GEMOC: Bill Griffin
Université Laval: Georges Beaudoin
Cabri Consulting Inc: Louis Cabri
**Common heavy indicator minerals for magmatic Ni-Cu massive sulphide deposits**

<table>
<thead>
<tr>
<th>Indicator Mineral</th>
<th>Chemical Composition</th>
<th>Indicator Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>hercynite</td>
<td>FeAl$_2$O$_4$</td>
<td>Al</td>
</tr>
<tr>
<td>olivine *</td>
<td>(Mg,Fe)SiO$_4$</td>
<td>Mg</td>
</tr>
<tr>
<td>orthopyroxene *</td>
<td>(Mg,Fe)$_2$Si$_2$O$_6$</td>
<td>Mg</td>
</tr>
<tr>
<td>low Cr-diopside</td>
<td>Ca(Mg,Cr)Si$_2$O$_6$</td>
<td>Mg, Cr</td>
</tr>
<tr>
<td>chromite *</td>
<td>(Fe,Mg)(Cr, Al)$_2$O$_4$</td>
<td>Cr, Mg, Al (-/+/Zn)</td>
</tr>
<tr>
<td>uvarovite</td>
<td>Ca$_3$Cr$_2$Si$<em>3$O$</em>{12}$</td>
<td>Cr</td>
</tr>
<tr>
<td>Cr-rutile</td>
<td>(Ti, Cr)O$_2$</td>
<td>Cr</td>
</tr>
<tr>
<td>chalcopyrite</td>
<td>CuFeS$_2$</td>
<td>Cu, S</td>
</tr>
<tr>
<td>loellingite</td>
<td>FeAs$_2$</td>
<td>As</td>
</tr>
<tr>
<td>rammelsbergite</td>
<td>NiAs$_2$</td>
<td>Ni, As</td>
</tr>
<tr>
<td>sperrylite</td>
<td>PtAs$_2$</td>
<td>Pt, As</td>
</tr>
<tr>
<td>PGE alloys</td>
<td>PGE</td>
<td>PGE</td>
</tr>
</tbody>
</table>

* occur in other unmineralized ultramafic rocks

(Averill, 2001)
Previous Heavy Mineral Surveys

- Reconnaissance-scale till surveys across central-southern Manitoba conducted in 1990s by Manitoba Geological Survey & Geological Survey of Canada.

- Documented plume of Cr-diopside extends 300 km southwest.

- Western extent of plume unknown.

- Other indicator minerals reported: chalcopyrite, hercynite, chromite, Cr-rutile, loellingite.

Cr-diopside (>0.5 wt.% Cr$_2$O$_3$) in 0.25 to 2.0 mm fraction of surface till.
• Archean basement gneisses & Early Proterozoic cover rocks along NW margin of Superior Craton
• Hosts world-class magmatic Ni-Cu deposits
• Ni sulphide mineralization associated with, or localized within, ultramafic bodies within lower Proterozoic Ospwagan Group

• Massive sulphide ores:
  1) magmatic sulphide ore, formed by assimilation of sulphide-rich country rocks
  2) Ni-enriched sedimentary sulphide ore, formed by extensive redistribution of Ni (other metals) during high-grade metamorphism, from high grade magmatic sulphides to previously barren sedimentary sulphides in country rock

• Main ore minerals: pyrrhotite, pentlandite, pyrite, millerite, minor chalcopyrite

• Study focused on subcropping Thompson, Pipe and Birchtree Ni-Cu deposits in north part of belt

(Zwanzig 2001)
**Surficial Geology**

- Late Wisconsinan glaciation, competing ice centers
  1) southward flow from Keewatin ice center
  2) westward flow from Hudson/Labrador ice center

- Both ice flow events well represented in striation record

- Deposited silty sand till, ideal for indicator mineral surveys

- ~8ka region inundated by glacial Lake Agassiz, thick deposits of glaciolacustrine clay and silt deposited over bedrock and till

- 1970s - Inco conducted till geochemistry case study

- Till geochemistry & indicator mineral methods not used to explore TNB
2005-2006 Ice Flow Mapping

Thompson Mine, South pit

1. 196°
2) 280°

Pipe Mine, open pit

1) 220°
2) 280°

Ice flow

Thompson Mine, South pit

1. 200°
2) 280°

Pipe Mine, open pit
**2005-2006 Bedrock Sampling**

- 50 bedrock samples
- Thompson and Pipe open pits and drill core
- Regional samples along belt, east and west
- Ore, intrusions, regional rocks

**Setting Fm**
- quartzite, metapelite, mafic sills

**Pipe Fm**
- iron formation, chert, metapelite

**Thompson Fm**
- calc-silicate, metapelite

**Manasan Fm**
- quartzite, metapelite

**Basement Gneiss**
Till sampling: regional scale

- collected from flanks of bedrock outcrop, backhoe trenches, river sections, open pits

- Collected ~25 kg bulk sample
  - 15 kg - processed for indicator minerals
  - +2 mm - pebble counts
  - 2 kg - archive at GSC
  - 6 kg - <0.063 mm geochemistry

- Till geochemistry (<0.063 mm fraction)
  - Pt, Pd, Au: fire assay/ICP-MS
  - Trace elements: Aqua regia ICP-ES/MS
  - Majors/traces: LiBO₂fusion/nitric ICP-ES/MS
Till Sampling

- Till overlain by glaciolacustrine clay & silt
- Fresh till exposures: grey, fissile
- Till matrix contains 50% sand- ideal for heavy mineral sampling
- Abundant mineralized clasts in till
Till Sampling: deposit scale

Thompson Mine Site

- South pit: 5 till samples
- B pit: 1 till sample
- C pit: 2 till samples
- Mine site, south of pits: 9 till samples
Till Sampling: deposit scale

Pipe Mine Site

Mine site, open pit, south & west: 13 till samples
Till sampling sites

- Backhoe trench
- Open pit section
- River section
- Roadside outcrop

Manasan River
Recovery of Indicator Minerals:
Overburden Drilling Management Ltd, Ottawa

15 kg till sample;
2 kg bedrock sample

Preconcentrate heavy minerals on shaking table

Pan gold, sulphide & PGM grains

Electron microprobe and LA ICP-MS analyses

Visual picking: 0.25-0.5, 0.5-1.0, 1.0-2.0 mm fractions
*Counts normalized to 10 kg weight

Ferro & paramagnetic separations

Heavy liquid separation in MI, SG 3.2 g/cm³
Results: Sulphides

Pentlandite:
- Present in till only proximal (<500 m) to mineralization at the Thompson Mine
- Present only in fresh, unweathered till
- up to 41,000 grains/10 kg in 0.25-0.5 mm fraction
- 100s grains/10 kg in 0.5-1.0 mm fraction
- few grains/10 kg in 1.0-2.0 mm fraction
- Background = 0

Indicators proximal to mineralization:
- pentlandite, pyrrhotite, millerite
Results: Sulphides

Chalcopyrite:
- Present in till proximal and distal to mineralization
- Present in fresh and weathered till
- up to 2100 grains/10 kg in 0.25-0.5 mm fraction
- 10s-100s grains/10 kg in 0.5-1.0 mm fraction
- few grains/10 kg in 1.0-2.0 mm fraction
- Background = 0-5 grains

Indicators of mineralization, broader distribution, more robust:
chalcopyrite, pyrite, loellingite
Sperrylite grains/10 kg

Sperrylite (PtAs$_2$):
- Present in till up to 750 m down-ice (W) of mineralization
- Size range 15 to 250 µm
- Used Pd & Pt values for till matrix to guide re-panning of some concentrates and find more grains
- Anomalous counts >1 grain; max 15 grains/10 kg
- Background = 0 grains

Sperrylite grains from till sample 05-MPB-010, shoulder of B pit, Thompson Mine
Results: Platinum Group Minerals

Till sample 05-MPB-010, shoulder of B pit, Thompson Mine

- <0.25 mm non-ferromagnetic heavy mineral fraction processed using hydroseparation to recover fine grained PGM
- 4 fractions prepared & examined using SEM scan <45µm, 45-75µm, 75-150µm, 150-250 µm
- <45µm fraction: SEM backscatter image euhedral irarsite (Ir,Ru,Rh,Pt)AsS with outer zone of euhedral hollingworthite (Rh,Pt,Pd)AsS
- Examination of <0.25 mm fraction in progress to recover fine grained PGM in selected till samples, to provide more information on nature of PGM content of mineralization

CNT-HS11 hydroseparator, CNT Mineral Consulting
Results: Chromite

Chromite:
- Present in fresh and weathered till
- up to 349 grains/10 kg in 0.25-0.5 mm fraction
- few grains/10 kg in 0.5-1.0 mm fraction
- none in 1.0-2.0 mm fraction
- Background = 0 to 5 grains
- Anomalous values >10 grains
- Highest counts associated with mineralized rocks and ultramafic intrusions
- Unknown source(s) east of TNB
- Physical appearance- sharp edges, no resorbed surfaces such as common with kimberlite

Chromite grains/10 kg

Ice flow

Cuthbert Lake Dyke

Chromite in till sample

1.0 mm
Results: Chromite/Spinel

- $\text{Cr}_2\text{O}_3$ vs $\text{MgO}$ discrimination plot, commonly used for kimberlitic chromite
- very low $\text{MgO}$ contents for mineralized rocks
- low $\text{MgO}$ compositions unknown for TNB, previous studies identified much higher contents
- broader spread of compositions in till
Results: Chromite/Spinel

- Threshold identified at 2 wt.% ZnO between mineralized and unmineralized
- Chromite from mineralized bedrock contains 2 to 8 wt.% ZnO
- Previous TNB bedrock or till studies, ZnO <2 wt.%
- Chromite/spinel in till at Thompson & Pipe deposits display similar signature to bedrock, contain up to 18 wt.% ZnO
Source of Zn in chromite/spinel?
- Equilibration with sulphides during high grade metamorphism
- Spinel grains and rims of some magnetite in sulphide ore are ZnO-rich
- S. Barnes documented elevated ZnO content in chromites from unmineralized UM rocks, but not as high values as this study
- High ZnO contents in this study related to high grade metamorphism of sulphide ore
- LA ICP-MS study of Zn and other trace elements in chromite/spinel in progress

05-MPB-R04, Pipe ore
Euhedral spinel grain in contact with sulphide minerals
- Outer rim: chromite, 4.5 wt.% ZnO
- Core: Cr-magnetite, 1.32 wt.% ZnO
Results: Cr-diopside

Cr-diopside (>0.5 wt.% Cr₂O₃):
- Present in fresh and weathered till
- up to 373 grains/10 kg in 0.25-0.5 mm fraction
- few grains/10 kg in 0.5-1.0 mm fraction
- none in 1.0-2.0 mm fraction
- Highest counts associated with ultramafic intrusions
- Pattern similar to chromite
- No rocks in TNB found to contain Cr-diopside
- Unknown bedrock source east of TNB with fresh CPX
Results: Olivine

Olivine:
- Present in fresh and weathered till
- up to 800 grains/10 kg in 0.25-0.5 mm fraction
- few grains/10 kg in 0.5-1.0 mm fraction
- none in 1.0-2.0 mm fraction
- Highest counts associated with ultramafic intrusions
- Pattern similar to chromite, Cr-diopside, enstatite
- Unknown bedrock source(s) east of TNB

Physical appearance:
- Tend to be smaller vs kimberlitic olivine
- Paler to colourless vs more colourful kimberlitic pale yellow to pale green
- Inclusions of Cr-magnetite or Fe-chromite impart paramagnetism vs kimberlitic nonparamagnetic character
L. Hulbert analyzed olivine from mineralized drill core from TNB (Burnham et al. 2003).

- Olivine crystallizing from sulphide-bearing magma is depleted in Ni compared to olivine from non-mineralized ultramafic rocks because Ni partitions into the sulphide melt.
- Ni-poor olivine may be used as Ni-mineralization indicator.
- For TNB, <3000 ppm Ni, and Fo content between 78 and 91.

Analyses of olivine in till samples and evaluation of usefulness of these thresholds are in progress.
Results: Till Geochemistry

Ni

Maximum value: 3760 ppm

<table>
<thead>
<tr>
<th>Ni ppm (aqua regia-ICP-MS)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;98 (4)</td>
<td>607.1-3760</td>
</tr>
<tr>
<td>95-98 (5)</td>
<td>319.2-607.0</td>
</tr>
<tr>
<td>90-95 (8)</td>
<td>132.8-319.1</td>
</tr>
<tr>
<td>75-90 (25)</td>
<td>67.8-132.7</td>
</tr>
<tr>
<td>50-75 (41)</td>
<td>37.3-67.7</td>
</tr>
<tr>
<td>&lt;50 (83)</td>
<td>4.2-37.2</td>
</tr>
</tbody>
</table>

Cu

Maximum value: 215 ppm

<table>
<thead>
<tr>
<th>Cu ppm (aqua regia-ICP-MS)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;98 (4)</td>
<td>96.68-215.20</td>
</tr>
<tr>
<td>95-98 (5)</td>
<td>76.85-96.67</td>
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<tr>
<td>90-95 (8)</td>
<td>56.73-76.84</td>
</tr>
<tr>
<td>75-90 (25)</td>
<td>35.11-56.72</td>
</tr>
<tr>
<td>50-75 (41)</td>
<td>24.33-35.10</td>
</tr>
<tr>
<td>&lt;50 (83)</td>
<td>2.31-24.32</td>
</tr>
</tbody>
</table>

(McClenaghan et al. 2009)
Results: Till Geochemistry

- Pd and Pt values are highest in metal-rich till at Thompson and Pipe deposits.
- Pd:Pt ratio in metal-rich till >3, similar to Pd:Pt ratios in ore.
- Anomalous sites W & SE of TNB.
## Till Geochemical Signatures of Magmatic Ni-Cu-PGE Deposits

### C horizon till <0.063 mm fraction - Anomaly thresholds

<table>
<thead>
<tr>
<th>Location</th>
<th>Values</th>
<th>Pt ppb</th>
<th>Pd ppb</th>
<th>Au ppb</th>
<th>Ni ppm</th>
<th>Cu ppm</th>
<th>Cr ppm</th>
<th>Source of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thompson Ni Belt (this study)</td>
<td>95th percentile</td>
<td>2.4</td>
<td>3.6</td>
<td>7.0</td>
<td>135</td>
<td>72</td>
<td>73</td>
<td>this study</td>
</tr>
<tr>
<td>Sudbury Basin-north half, ON</td>
<td>95th percentile</td>
<td>2.8</td>
<td>3.2</td>
<td>29.5</td>
<td>97</td>
<td>193</td>
<td>91</td>
<td>Bajc and Hall (2000)</td>
</tr>
<tr>
<td>Sudbury-Strathcona Embayment, ON</td>
<td>95th percentile</td>
<td>3.0</td>
<td>4.7</td>
<td>189</td>
<td>671</td>
<td></td>
<td></td>
<td>Bajc and Hall (2000)</td>
</tr>
<tr>
<td>Lac des Iles-Powerhouse Zone, ON</td>
<td>95th percentile</td>
<td>9.1</td>
<td>61.3</td>
<td>7.9</td>
<td>185</td>
<td>109</td>
<td></td>
<td>Searcy (2001)</td>
</tr>
<tr>
<td>Lac des Iles-Baker Zone, ON</td>
<td>95th percentile</td>
<td>4.3</td>
<td>12.8</td>
<td>3.7</td>
<td>229</td>
<td>94</td>
<td></td>
<td>Searcy (2001)</td>
</tr>
<tr>
<td>Lac des Iles area, ON</td>
<td>95th percentile</td>
<td>8.4</td>
<td>15.2</td>
<td>7.0</td>
<td>193</td>
<td>99</td>
<td>259</td>
<td>Barnett (2007)</td>
</tr>
<tr>
<td>Rottenstone Lake, MAN</td>
<td>highest value</td>
<td>6.0</td>
<td>4.0</td>
<td>4.0</td>
<td>200</td>
<td>207</td>
<td>133</td>
<td>Coker et al. (1989; 1991)</td>
</tr>
<tr>
<td>Tulameen, BC</td>
<td>mean</td>
<td>52.8</td>
<td>8.9</td>
<td>8.4</td>
<td></td>
<td></td>
<td></td>
<td>Cook &amp; Fletcher (1992)</td>
</tr>
<tr>
<td>Shebandowan, ON</td>
<td>95th percentile</td>
<td>3.4</td>
<td>3.8</td>
<td>34.3</td>
<td>68</td>
<td>113</td>
<td>87</td>
<td>Bajc (2000)</td>
</tr>
</tbody>
</table>

*calculated without open pit data
Conclusions

TNB magmatic Ni-Cu deposits have mineralogical signatures in till

- Broad suite identified that are useful for exploring in TNB and elsewhere

- Ultramafic host rocks: chromite, olivine, enstatite, Cr-diopside
  - ilmenite not useful, too abundant in regional rocks

- Mineralization: pentlandite, pyrrhotite, chalcopyrite, pyrite, millerite, loellingite, sperrylite, (arsenopyrite)
  - chalcopyrite & sperrylite most likely to survive glacial transport and surficial weathering
  - chromite >2 wt.% ZnO
  - olivine <3000 ppm Ni and Fo content 78 to 91

- Physical characteristics of chromite and olivine can be used to distinguish UM versus kimberlitic sources

- Mineral abundance data and chemistry to be published in GSC open files in 2010
TNB magmatic Ni–Cu deposits have geochemical signatures in till

- <0.63 mm fraction, aqua regia ICP-MS
- pathfinders: Ni, Cu, Pd, Pt, Co, As, Cd, Ag, Sb, Bi, Se, S, and Te
- Pd:Pt ratio >3
- till geochemistry data published in GSC Open File 6005

Till is an effective exploration medium in TNB and region

- Strong signatures from known deposits
- New targets for exploration identified
  - unknown bedrock source(s) of chromite, Cr-diopside, olivine, enstatite E of TNB
  - till SE of Belt anomalous for Pt, Pd, Cu, Mo, Sb, Bi, Fe
Recommendations for Exploration

- Use indicator minerals to explore Ni-Cu-PGE and broad spectrum of other commodities
- All these minerals can be recovered from same heavy mineral concentrate
- Use till geochemistry in combination with indicator minerals
- Use till sampling methods from other clay belts; river, lakeshores, backhoe, overburden drill

Common indicator minerals:
- Magmatic Ni-Cu minerals
- Gold grains
- Kimberlite indicator minerals
- Platinum Group minerals
- Sulphide minerals
- Metamorphosed massive sulphide minerals - e.g. gahnite
- Native copper
- Scheelite
- Cassiterite
- Cinnabar
- Fluorite, topaz
- Uraninite, thorianite

Chalcopyrite
Gold, native copper, pyromorphite
Gahnite
Kimberlite indicator minerals
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