Viable indicators in surficial sediments for two major base metal deposit types: Ni-Cu-PGE and porphyry Cu

Presented by Stu Averill
OVERBURDEN DRILLING MANAGEMENT LIMITED
May 31, 2009
Selected Properties of Indicator Minerals

1. Heavy (due to low abundance)
2. Coarse-grained (>0.25 mm; unless ultra-heavy – e.g. gold and PGMs)
3. Resistant to weathering (eliminates most sulphide minerals; increases dependence on alteration minerals)

High pressures and temperatures increase mineral density and grain size
Viable indicators in surficial sediments for two major base metal deposit types: Ni-Cu-PGE and porphyry Cu

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Dispersal of Cr-diopside from Thompson Ni-Belt

Courtesy: Harvey Thorliefson
There are different indicator mineral suites and subsuites for:

- Ni-Cu-PGE and porphyry Cu deposits
- the successive mineralizing events or processes that form these deposits
- each hydrothermal alteration zone
Outline 1 – Ni-Cu-PGE Indicator Minerals

Four mineral subsuites indicating:

1. a fertile melt
2. rapid, localized fractionation of cumulus minerals from the melt (promotes sulphide saturation)
3. assimilation of felsic rocks by the melt (also promotes sulphide saturation)
4. actual mineralization
The Garnet Peridotite Connection for Ni-Cu-PGE and Kimberlite Indicators

Courtesy: Bruce Kjarsgaard, GSC

Courtesy: Smithsonian Institution
Outline 1 – Ni-Cu-PGE Indicator Minerals

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Indicators of a Fertile Melt

- orthopyroxene (enstatite – $\text{Mg}_2\text{Si}_2\text{O}_6$)
- olivine (forsterite – $\text{MgSiO}_4$)
- Cr-diopside – $\text{Ca(Mg,Cr)}\text{Si}_2\text{O}_6$
- chromite – $(\text{Fe,Mg})(\text{Cr,Al})\text{O}_4$
Cr-diopside

Non-kimberlitic
<1.25% Cr$_2$O$_3$

Kimberlitic
>1.25% Cr$_2$O$_3$
Chromite

Non-kimberlitic  Kimberlitic  Lateritic
Dispersal of chromite from fertile Timmins komatiites

10s to 100s of chromite grains

50 km
Chromite Dispersal in the Attawapiskat River

Modified from: Ontario Geological Survey
Chromitite Grains, Attawapiskat River

1.0 mm
“Ring of Fire” Chromitite Discoveries

Modified from: Ontario Geological Survey
70 m of Massive Chromitite

Courtesy: Noront Resources Ltd.
Role of Sulphide Saturation

- Causes sulphide liquid to separate from silicate melt
- Sulphide liquid collects Ni-Cu-PGE from silicate melt
- Heavy sulphide liquid settles in pools or layers, further concentrating metals
Outline 1 – Ni-Cu-PGE Indicator Minerals

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Indicators of Concentrated Cumulus Segregation

- orthopyroxene (enstatite – Mg$_2$Si$_2$O$_6$)
- olivine (forsterite – MgSiO$_4$)
- Cr-diopside – Ca(Mg,Cr)Si$_2$O$_6$
- chromite – (Fe,Mg)(Cr,Al)O$_4$
Ruby Corundum \((\text{Al,Cr})_2\text{O}_3\)
Dispersal of Cr-andradite from Lac des Iles Intrusive Complex

Cr-andradite

Cr-grossular

Courtesy: Peter Barnett
Outline 1 – Ni-Cu-PGE Indicator Minerals

Four subsuites indicating:

1. a fertile melt
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3. assimilation of felsic rocks by the melt (also promotes sulphide saturation)
4. actual mineralization
Relative stabilities of Fe-sulphides and Ni-Cu-PGE ore minerals

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni-sulphides</td>
<td>unstable</td>
</tr>
<tr>
<td>PGE-sulphides</td>
<td>unstable</td>
</tr>
<tr>
<td>PGE-tellurides</td>
<td>unstable</td>
</tr>
<tr>
<td>pyrrhotite</td>
<td>unstable</td>
</tr>
<tr>
<td>pyrite</td>
<td>unstable</td>
</tr>
<tr>
<td>chalcopyrite</td>
<td>significantly stable</td>
</tr>
<tr>
<td>FeNi and PGE-arsenides</td>
<td>stable (but silt-sized)</td>
</tr>
<tr>
<td>PGE-antimonides</td>
<td>stable (but silt-sized)</td>
</tr>
<tr>
<td>native Au and PGE</td>
<td>very stable (but silt-sized)</td>
</tr>
</tbody>
</table>
**Definition**

- **Indicator Mineral**
  - heavy
  - coarse-grained (unless ultra-heavy; e.g. gold, PGM)
  - reasonably stable in weathered sediments

**Minerals Visible**

- Chalcopyrite
- Goethite
- Sperrylite

**Broken Hammer Gossan**
Outline 2 – Porphyry Cu Indicator Minerals (PCIMs®)

PCIM® anomalies, like Ni-Cu-PGE anomalies are:

1. Big
2. Strong
3. Zoned
Alteration zones, Escondida, Chile
Arid landscape, Atacama Desert, Chile
<table>
<thead>
<tr>
<th>Mineral</th>
<th>Density</th>
<th>Composition</th>
<th>Principal provenance (alteration zone)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Potassic</td>
</tr>
<tr>
<td>Diaspore</td>
<td>3.4</td>
<td>AIO(OH)</td>
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<tr>
<td>Alunite</td>
<td>2.9</td>
<td>(K,Na)Al₃(SO₄)₂(OH)₆</td>
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<tr>
<td>Dravite</td>
<td>3.0</td>
<td>NaMg₆Al₆(BO₃)₃(Si₆O₁₈)(OH)₄</td>
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<tr>
<td>Andradite</td>
<td>3.9</td>
<td>Ca₃Fe₂(SiO₄)₃</td>
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<tr>
<td>Barite</td>
<td>4.5</td>
<td>BaSO₄</td>
<td></td>
</tr>
</tbody>
</table>

**Hypogene suite:**

**Supergene suite:**

| Alunite  | 2.8     | (K,Na)Al₃(SO₄)₂(OH)₆ |          |          |
| Jarosite | 3.1     | (K,Na)Fe₃(SO₄)₂(OH)₆  |          |          |
| Atacamite| 3.8     | Cu₂Cl(OH)₃           |          |          |
| Turquoise| 2.8     | CuAl₁₆(PO₄)₄(OH)₈.₅H₂O |          |          |
| Malachite| 4.0     | Cu₂CO₃(OH)₂           |          |          |

Proven porphyry Cu indicator minerals (PCIMs®)
Alteration zones, Escondida, Chile
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<th>Phyllic</th>
<th>Propylitic</th>
<th>Epithermal</th>
<th>Au</th>
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<td>Diaspore</td>
<td>3.4</td>
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<tr>
<td>Atacamite</td>
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<td>Cu₂Cl(OH)₃</td>
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<tr>
<td>Turquoise</td>
<td>2.8</td>
<td>CuAl₁₂PO₄₄(OH)₈5H₂O</td>
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Proven porphyry Cu indicator minerals (PCIMs®)
Dispersal of Cr-andradite from Lac des Iles Intrusive Complex

Courtesy: Peter Barnett
Andradite garnet – $\text{Ca}_3\text{Fe}_2(\text{SiO}_4)_3$
Alteration zones, Escondida, Chile
Arid landscape, Atacama Desert, Chile
Sample sites, Quebrada Blanca

Courtesy: Aur Resources
Andradite in alluvium, Quebrada Blanca

Courtesy: Aur Resources
Barite in alluvium, Quebrada Blanca

Courtesy: Aur Resources
Conclusions

Ni-Cu-PGE and porphyry Cu systems are very different but they share two key features that are reflected in their indicator mineral footprints:

- Both are *large*. Therefore both have *regional-scale* indicator mineral footprints that can be detected economically with a wide sample spacing (comparable to the footprint of an entire field of kimberlite pipes)

- Both systems are *zonated* in time and space. Each mineralizing event, process or alteration zone supplies a different subsuite of indicator minerals to the regional anomaly. If we *tightly* sample our spacing at the head of this anomaly, we can resolve this zoning and focus on the best targets (comparable to locating the most fertile pipes within a kimberlite field)

Together these features make indicator mineralogy a very effective exploration tool for both Ni-Cu-PGE and porphyry Cu deposits … and possibly for other large-scale magmatic-hydrothermal systems such as IOCG.