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
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Properties of an Indicator Mineral

- source-specific
- heavy
- reasonably stable in weathered sediments
- coarse-grained (>0.25 mm; unless ultra-heavy – e.g. gold and PGMs)
Fresh heavy minerals recovered by reverse circulation drilling
Indicator Minerals for Magmatic Base Metal Sulphide Deposits

Separate mineral suites exist for:

• each type of deposit
• each stage of mineralization
• each alteration zone
Outline 1 – Ni-Cu-PGE Indicator Minerals

Four mineral subsuites indicating:

- a fertile melt
- rapid, localized fractionation of cumulus minerals from the melt (promotes sulphide saturation)
- assimilation of felsic rocks by the melt (also promotes sulphide saturation)
- actual mineralization
Outline 2 – Porphyry Cu Indicator Minerals (PCIMs®)

1. Indicator subsuites for each alteration zone:
   • potassic
   • propylitic
   • phyllic (sericitic)
   • Advanced argillic/epithermal Au

2. Arid weathering is beneficial; it converts unstable hypogene sulphides into stable, useful supergene indicators
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$_3$
Dispersal of Cr-diopside from Thompson Ni-Belt

Courtesy: Harvey Thorliefson
Chromite

Non-kimberlritic  Kimberlritic  Lateritic
Dispersal of chromite from fertile Timmins komatiites

10s to 100s of chromite grains
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
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Indicators of Concentrated Cumulus Segregation

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

Courtesy: Peter Barnett
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:

• a fertile melt
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• assimilation of felsic rocks by the melt (also promotes sulphide saturation)
• 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>marginally 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>
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</table>
Definition – Indicator Mineral

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

Chalcopyrite
Sperrylite
Goethite

Broken Hammer Gossan
How to Use Ni-Cu-PGE Indicators: The Step-by-Step Path to Discovery

1. Recover and identify all four subsuites of indicator minerals
2. Differentiate the crossover Mg and Cr-rich indicators from kimberlite indicators
3. Use any large anomalies in these minerals to locate a fertile intrusion or flow belt
4. Tighten sample spacing; locate areas of potential sulphide saturation using cumulus and hybrid indicators
5. Further tighten spacing and search for anomalous levels of chalcopyrite and other ore indicator minerals
Outline 2 – Porphyry Cu Indicator Minerals (PCIMs®)

1. Indicator subsuites for each alteration zone:
   - potassic
   - propylitic
   - phyllic (sericitic)
   - Advanced argillic/epithermal Au

2. Arid weathering is beneficial; it converts unstable hypogene sulphides into stable, useful supergene indicators
Alteration zones, Escondida, Chile
Arid landscape, Atacama Desert, Chile
<table>
<thead>
<tr>
<th>Mineral</th>
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<tbody>
<tr>
<td>Diaspore</td>
<td>3.4</td>
<td>AlO(OH)</td>
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<tr>
<td><strong>Alunite</strong></td>
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<td><em>(K,Na)Al₃(SO₄)₂(OH)₆</em></td>
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<tr>
<td>Dravite</td>
<td>3.0</td>
<td>NaMg₃Al₆(BO₃)₃(Si₆O₁₈)(OH)₄</td>
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<tr>
<td>Andradite</td>
<td>3.9</td>
<td>Ca₃Fe₂(SiO₄)₃</td>
</tr>
<tr>
<td>Barite</td>
<td>4.5</td>
<td>BaSO₄</td>
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**Hypogene suite:**

**Supergene suite:**

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<td>Atacamite</td>
<td>3.8</td>
<td>Cu₂Cl(OH)₃</td>
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<tr>
<td><strong>Turquoise</strong></td>
<td><strong>2.8</strong></td>
<td>CuAl₆(PO₄)₄(OH)₈·5H₂O</td>
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<td>Malachite</td>
<td>4.0</td>
<td>Cu₂CO₃(OH)₂</td>
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**Proven porphyry Cu indicator minerals (PCIMs®)**
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Proven porphyry Cu indicator minerals (PCIMs®)
Dispersal of Cr-andradite from Lac des Iles Intrusive Complex

Cr-andradite

Cr-grossular

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
Jarosite + turquoise in alluvium, Quebrada Blanca

Courtesy: Aur Resources
Barite in alluvium, Quebrada Blanca

Courtesy: Aur Resources
PCIM® Summary - What We Know in 2007

- Ten minerals are proven as PCIMs®
- PCIM® anomalies are strong and large, therefore detectable with small (0.5 kg), widely spaced samples (1 per km²)
- Arid weathering increases the number and importance of indicator mineral species
- If cover <20 m, anomalies are very specific; individual alteration zones are readily outlined
- If cover >20 m, RC drilling will improve anomaly definition
- Andradite garnet is the “holy grail” of PCIMs
What We Hope to Learn by 2017!

- Is the trace element chemistry of andradite or other nine proven PCIMs® useful?
- The following five minerals also appear promising. Can we upgrade them to PCIM® status?
  - red rutile
  - rose zircon
  - blond titanite
  - apatite
  - sapphire corundum
- PCIMs® prove that physical, variably soluble particles of both mineralization and alteration are plentiful in surface alluvium. QUESTION: Are any geochemical anomalies actually caused by upward migration of ions through thick, dry alluvium?????