Investigating indicator minerals for magmatic sulfide deposits using LA-ICP-MS and μXRF

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Accumulation of immiscible sulfide liquids from silicate magmas

Some of the world’s most valuable ore deposits – ~trillion dollars worth of metals (Ni, Cu, PGE) in the Norilsk camp

Source of 100% of world’s platinum (and associated elements), 38% of world’s Ni
Magmatic Ni-Cu Sulfide Deposits

- Occur in small mafic-ultramafic bodies (very common)
- Few are mineralised
- Indicator minerals would be very useful!

Why do we need indicators minerals

- To determine if a target is likely mineralised or unmineralised with the least drilling ($$) possible

What makes a good indicator mineral?

- Chemistry indicative of mineralisation
- Resistant to weathering
- Easily identified and separated
Ruthenium in Chromite
Locmelis et al. 2018

*If sulphides are present Chromite will have low (<150 ppb) Ru*

Noril’sk-Talnakh – The highest single resource of Ni-Cu-PGE in the world

Role of degassing of the Noril’sk nickel deposits in the Permian–Triassic mass extinction event

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Oxides as a possible indicator- Noril’sk case study

• Chromite chemistry

Trace elements – Noril’sk Chromite

- **Shape**: Noril'sk 1, Talnakh, Kharaelakh, Barren
- **Colour**: sulphide, silicate, pyroxene, bubble
- **Enclosing Phase**: bubble, pyroxene, silicate

Graphs showing the distribution of Mg/(Mg+Fe^2+): Ti_ppm, Mn_ppm, Co_ppm, Zn_ppm, V_ppm, Cr_ppm.
Thus far...

Ru in Chromite below detection limit
(<5-10 ppb)
LA-ICP-MS
Laser ablation inductively coupled plasma mass spectrometer
LA-ICP-MS

Laser ablation

193nm ArF Excimer Laser – Photonmachines/Teledyne + Agilent 7700 quadrupole ICP-MS

Trace Elements in minerals, *in-situ*

**Pros**
- Limits of detection of ppb
- >30 isotopes at once
- Rapid analysis
- Fully quantitative
- Individual mineral analysis
- Minimal Sample prep.
- U-Th-Pb isotope dating system

**Cons**
- Destructive (<150μm spot)
- Non-Portable
Quantitative Maps

- Spatially resolved trace element data
- Can be quantitative or semi-quantitative
- Low detection limits
- Only destructive to top few microns
- Can measure “tricky” elements like Lithium
Case Study – Lithium in Pisoliths

Perfect pair to other techniques

X-ray mapping + microscope images can be directly loaded into the software

• Target key areas,
• Easy navigation
• Allows for spatial context
μXRF mapping with Maia

micro X-ray Fluorescence mapping

MINERAL RESOURCES
www.csiro.au
Microbeam X-Ray Fluorescence Mapping

• Technique for making elemental maps of rock slabs and polished sections from micron to decimetre scale

• Variety of systems in current use:
  • synchrotron based (1-2 micron resolution) – thin sections to slabs
  • Lab based - ~20-40 micron resolution, large samples (drill core, cut slabs)
  • Commercial e.g. Bruker Tornado, custom – CSIRO Maia Mapper

Applications:
• Quantitative mineralogy
• Textural analysis of rocks and ores
• Geochemical/petrogenetic studies
Maia Mapper

• Exploits new developments
  • Excillum high flux, liquid metal micro-focus source
  • New X-ray lenses for higher energies >20 keV

Maia Mapper: high definition XRF imaging in the lab

## Comparison of microbeam scanning/mapping techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Spatial resolution (pixel size) microns</th>
<th>Dwell times (ms)</th>
<th>Scan time per cm² (hours)</th>
<th>Lightest element mappable</th>
<th>Limit of detection (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMP/SEM (e.g. MLA)</td>
<td>1-2</td>
<td>10</td>
<td>100</td>
<td>C</td>
<td>1000-10,000</td>
</tr>
<tr>
<td>LA-ICPMS</td>
<td>10-50</td>
<td>10</td>
<td>2</td>
<td>Li</td>
<td>0.01</td>
</tr>
<tr>
<td>Tornado XFM</td>
<td>40</td>
<td>10</td>
<td>.3</td>
<td>Al</td>
<td>1000</td>
</tr>
<tr>
<td>Synchrotron XFM with Maia</td>
<td>1-2</td>
<td>1</td>
<td>3</td>
<td>Si</td>
<td>100</td>
</tr>
<tr>
<td>Maia Mapper</td>
<td>30</td>
<td>5</td>
<td>.2</td>
<td>Si</td>
<td>100</td>
</tr>
</tbody>
</table>
Platreef (world’s major Pt resource) S Africa
Olivine inside pyroxene oikocrysts

A new indicator?
Possible new indicator for magmatic sulphide mineralisation – zoned pyroxene
“Barren”
Zoning you can see

Kotalahti - Finland

Aus. Synchrotron
Log Cr Fe Ca

Desktop XRF

Bruker Tornado
Diagram modified from Barnes et al. (2016)

Thank you

Feel free to contact me if you have further questions

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