Mineral Systems and Exploration Targeting

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Mineral Geoscience Masters
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Premise

• Exploration is an exercise in sequential volume reduction, involving ground selection decisions at a variety of scales.

• Each decision based on recognition of the signature, or ‘footprint of the mineralising system at the relevant scale.

• Effective exploration requires understanding:
  – What the multiscale expressions of mineralising systems look like.
  – What geoscience datasets or derivative interpretative products are required to map them.
Mineral systems science

- Mineral deposits = expressions of multiscale earth processes focussing energy and mass transfer at a range of scales
- In exploration for new high quality mineral districts under cover, it is the largest scale footprint of the deposits that is relevant to our targeting models
- These large scale footprints differ substantially from the local expressions captured by traditional analogue models
Deposit Footprints – Traditional Approach

- Leakage around ore deposits (mineralogical, geochemical & geophysical expression)
- Analogue models
- Useful, but challenged under cover
- Challenged to distinguish size – small deposits look like big deposits

Large et al (2001)
Anomaly detection in arid, old complex landscapes of Australia

After Anand and Paine 2002
Distal Footprints: The Broader Perspective

Hronsky 2010
Mineral System Framework: Ore Genesis as the Focus of a Scale-Hierarchical Mass Concentratative System

- **Regional Scale**
- **Camp Scale**
- **Deposit Scale**

Map architecture

Then map chemistry onto architecture

McCuaig and Hronsky, 2013
An example of a large scale footprint

Understanding large scale mineralisation footprints quickly narrows the search space for large mineral districts
We need non-traditional datasets to see large footprints

Magnetotelluric Section through Olympic Dam

Modified after Hayward, 2004; Magnetotelluric section provided R. Gill, Uni. Adel; “hotter” colours are more conductive

Government and industry should to acquire such datasets
Steps in Exploration Targeting

Hronsky and Groves (2008)
Targeting approaches

• Empirical
  – correlations of geoscience datasets with known mineral deposits in well-explored, data-rich terranes
  – Harder to apply in the new search space under cover

• Conceptual
  – Combination of geological elements from mineral deposit models
  – mineral systems approaches

In reality, targeting approaches are a mixture between empirical and conceptual
A mineral systems approach

Focus must be on understanding the geological PROCESSES as opposed to CHARACTERISTICS.

Critical Success Factors

- Mass trapping
- Mass scrubbing (addition or removal)

Source(s) - Migration - Throttle - Scrubber

Source - Release - Migration - Trap - Seal
The mineral system concept of ore body formation

Simple in concept, complex in detail!
Target Generation from Mineral Systems – Orogenic Au

**Critical Processes** (ranking level)
- Source - fluid, magma, metals
- Active Pathway
- Physical throttle
- Chemical scrubber
- Preservation

**Constituent Processes** (thinking level)
- **Fluid Mixing**
- Reaction with wallrock reduces metal solubility
- Pressure change induces chemical change and reduces solubility

**Targeting Elements** (Geological features indicating the processes)
- Key alteration minerals
- Rocks of favourable chemistry
- Recognise a chemical gradient

**Translation into mappable targeting criteria (proxies and predictor maps)**
- Solid geology interpretation
- Remote sensing response
- Lithogeochemistry
- Geophysical response

Manually or through automated process query datasets for combination of evidence

Weight by confidence, quality, support
Target Generation from Mineral Systems – Komatiitic Ni

**Critical Processes** (ranking level)
- Source - fluid, magma, metals
- Active Pathway
- S saturation
- Trap
- Preservation

**Constituent Processes** (thinking level)
- Focussed magma along lithospheric craton margins
- Rifts

**Targeting Elements** (Geological features indicating the processes)
- Co-eval felsic volcanics
- Total komatiite volume
- Coeval sulfidic sedimentary units
- Solid geology interpretation
- Remote sensing response
- Magnetics
- Soil geochemistry

**Translation into mappable targeting criteria (proxies and predictor maps)**
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What controls "camps"?

No known resources

ADK and AUK

2.9 Ga

524 kNiT

2.7 Ga

1476 kNiT

7238 kNiT

AUK only

Gold Camps
1. Wallaby-Granny Smith
2. Sunrise Dam
3. Karratha
4. Mount Magnet
5. Agnew-Lawlers
6. Leonora
7. Norseman
8. Plutonic
9. Kambalda
10. Mundaring
11. Kundra
12. Plural
13. Marda
14. Marla
15. Badger
16. Norseman
17. North Arrow
18. South Barron
19. South Cross
20. Boddington

Dominantly clastic sedimentary rock
Volcanic rock
Gneiss
Grafitoid rocks
Sedimentary rocks
Major fault zone
Gold deposit (>150, >30, >3 t Au)

Centre for EXPLORATION TARGETING

Figure 1 - Simplified geological map of the Yilgarn Craton. Major towns.
Lithosphere architecture and mineral systems location through time

- Isotopic maps as proxies for terrane architecture through time
- Explains stratigraphic variations
- Explains distributions of Ni (red), Au (gold)

McCuaig et al., 2010
Kalgoorlie Terrane
Kalgoorlie Terrane
St. Ives

- Fundamental architecture reactivated through time
- Successful targets generated in mature camp

Miller et al. 2009
Detection technologies abound at camp-prospect scale

Miller et al. 2009
Exploration Targeting needs to be more effective after McCuaig and Hronsky 2000.

Predicting mineral camps sits largely in the conceptual space.

Camp scale decision

Relative effectiveness

Broad regional

Prospect scale

Detection

Cost

Prediction

Flexibility

Alteration halos
High definition geophysics
Drilling
Geochemistry

Where do we focus the more systematic, detailed and expensive detection technologies?
Controls on location of large mineral systems

Granitoid Nd™ after Cassidy and Champion 2007
Yilgarn Au after Robert et al. 2005
Lithospheric architecture and mineral systems through time

- Isotopic maps as ‘paleogeophysics’ to image paleoarchitecture
- Correlation of interpreted paleoarchitecture with stratigraphic, structural and metamorphic variations in upper crust.
- Heat and energy flux from mantle to surface occurs preferentially at major lithosphere discontinuities
- Time slices can provide insights into spatial distribution of multiple mineral systems through time ➔ PREDICTIVE TOOL
- Shift from 2D to 4D visualisation of lithosphere required
Mineral systems → Targeting systems

We need datasets and targeting proxies to map the largest scale footprints under cover.

McCuaig et al., 2010

Orogenic Gold scale dependent targeting criteria

This is the scale we traditionally focus on

McCuaig et al. 2010
We need datasets and targeting proxies to map the largest scale footprints under cover.

McCuaig et al. 2010

<table>
<thead>
<tr>
<th>Source</th>
<th>Active Pathway</th>
<th>S saturation (chemical)</th>
<th>Trap (physical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical</td>
<td>High degree partial melts</td>
<td>Lithospheric architecture</td>
<td>Olivine-rich cumulate</td>
</tr>
<tr>
<td>Major metallogenic epoch</td>
<td>Paleocraton margins</td>
<td>Magmatic sulphides</td>
<td>Channels and channel size</td>
</tr>
<tr>
<td>Less relevant</td>
<td>Synvolcanic crustal architecture</td>
<td>Chalcophile enrichment</td>
<td>Amygdaloidal flows</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Structural complexity</td>
</tr>
</tbody>
</table>
Scale dependence of Targeting Elements – mafic-hosted Ni-Cu-S

At Camp to regional scale, many common aspects between different mineral systems!
Mineral Systems Advantages

- More amenable to probabilistic targeting
- Addresses all scales of systems
- In particular, useful at camp and larger scale, where conceptual targeting challenge lies for new mineral system discovery
- Can focus further data gathering and scientific investigation to leverage maximum impact on targeting
Target Generation from Mineral Systems – Orographic Au

**Critical Processes (ranking level)**
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- Preservation

**Constituent Processes (thinking level)**
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**Targeting Elements (Geological features indicating the processes)**
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**Source**
- Fluid
- Magma
- Metals

**Active Pathway**
- Fluid mixing

**Physical throttle**
- Reaction with wallrock reduces metal solubility

**Chemical scrubber**
- Pressure change induces chemical change and reduces solubility

**Preservation**
- Recognise a chemical gradient
Probabilistic Approach to Ranking: assign probabilities to Critical Elements

Rationale for assignment of probability values

- $P = 0.0$ (0% chance): process component definitely did not operate
- $P = 0.5$ (50% chance): not known whether process component operated or not; equally likely that process operated or that it did not; too little information about process component to make a judgment
- $P = 1.0$ (100% chance): process component definitely operated

Hence, probability values

- $<0.5$ indicate that processes likely did not operate
- $>0.5$ indicate that process components likely operated
Probabilities assigned to Critical Success Factors

Subjective probabilities are assigned to each component

- $P_1 =$ source
- $P_2 =$ plumbing system
- $P_3 =$ trap
- $P_4 =$ metal deposition

Target / prospect ranking according to $P_{total}$ value

<table>
<thead>
<tr>
<th>Prospect Name</th>
<th>$P_1$</th>
<th>$P_2$</th>
<th>$P_3$</th>
<th>$P_4$</th>
<th>$P_{total} = P_1 \times P_2 \times P_3 \times P_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospect X</td>
<td>1.0</td>
<td>0.8</td>
<td>0.7</td>
<td>0.9</td>
<td>0.50</td>
</tr>
<tr>
<td>Prospect Y</td>
<td>0.5</td>
<td>0.8</td>
<td>0.9</td>
<td>0.9</td>
<td>0.32</td>
</tr>
<tr>
<td>Prospect Z</td>
<td>0.5</td>
<td>0.8</td>
<td>0.9</td>
<td>0.5</td>
<td>0.18</td>
</tr>
</tbody>
</table>
Subjective assignment of probabilities

<table>
<thead>
<tr>
<th>Numerical value</th>
<th>Corresponding verbal prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.98–1.00</td>
<td>Proven; definitely true</td>
</tr>
<tr>
<td>0.90–0.98</td>
<td>Virtually certain; convinced</td>
</tr>
<tr>
<td>0.75–0.90</td>
<td>Highly probable; strongly believe; highly likely</td>
</tr>
<tr>
<td>0.60–0.75</td>
<td>Likely; probably true; about twice as likely to be true as untrue; chances are good</td>
</tr>
<tr>
<td>0.40–0.60</td>
<td>Chances are about even, or slightly better than even or slightly less than even</td>
</tr>
<tr>
<td>0.20–0.40</td>
<td>Could be true but more probably not; unlikely; chances are fairly poor; two or three times more likely to be untrue than true</td>
</tr>
<tr>
<td>0.02–0.20</td>
<td>Possible but very doubtful; only a slight chance; very unlikely indeed; very improbable</td>
</tr>
<tr>
<td>0.00–0.02</td>
<td>Proven untrue; impossible</td>
</tr>
</tbody>
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