Integrated interpretation case study Bayanhongor Province, Mongolia
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Bayanhongor Province, Mongolia
Acknowledgements

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Outline

Focusing on Mineral Exploration – examine how we can use geology, geochemistry and geophysical data as part of the interpretation involved in exploring using ore system footprints.

Methods to utilise geophysics and geochemistry in this ‘model’ space rather than ‘data’ space.

- the modern mineral exploration context
- role of geophysical data
- role of geochemical data
- mechanics of interpreting ore system footprint
- case studies
The modern exploration context

- the Eureka moment might be in model space, not data space
  - Image depicts the Mineral Potential Index (IOCG); NOT an inverted rock property
The modern exploration context

- Common Earth Model: a single, shared, consistent earth model
- A working hypothesis that can be queried, tested, modified
- Ore system footprint recognition in multi-disciplinary data

- Typical components:
  - Lithology
  - Alteration
  - Structure
  - Geochemistry
  - Mineralisation
  - Physical properties
  - Spatial relationships
  - Topological relationships
Outline

• the modern mineral exploration context
• role of geophysical data
• role of geochemical data
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Role of geophysical data

• “Direct detection”, or components of an ore system footprint model

• Potential Fields
• EM
• DCIP
• Seismic
• MT
• …..
Outline

• the modern mineral exploration context
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Role of geochemical data

• Depth in system
• Fertility
Role of geochemical data; Alteration mapping
### Example – Ore System footprint of Cu Au Porphyry

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Description</th>
<th>Data required</th>
<th>Model representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>direct anomalous Cu Au Mo</td>
<td>anomalous Cu (&gt;124ppm), Au (&gt;5ppb), Mo; (negative anomalies of Mn)</td>
<td>Soils, rock chips, MMI</td>
<td>Polygons interpreted of metal enrichment and metal depletion.</td>
</tr>
<tr>
<td>Heat and metal source: volume, geometry and proximity</td>
<td>The precursor intrusion. The geometry and structural intersections facilitate local transport and trap of the porphyry from the intrusion.</td>
<td>magnetics, gravity, MT, district geology maps</td>
<td>Wireframe of the intrusion</td>
</tr>
<tr>
<td>Porphyry pipe</td>
<td>Felsic intrusive directly associated with Cu Au Mo mineralisation</td>
<td>Mapping, rock chip and soil samples, IP, gravity</td>
<td>Outcrop polygons, wireframe, chargeable volumes. Low density volume modelled from gravity inversion</td>
</tr>
<tr>
<td>chargeability of sulphides (mineralisation and pyrite halo)</td>
<td>Disseminated sulphides directly associated with porphyry mineralisation or porphyry alteration</td>
<td>IP survey</td>
<td>DC/IP inversion</td>
</tr>
<tr>
<td>structures</td>
<td>Structures are utilised as a pathway for the porphyry intrusion, local trapping site for Cu and/or Au veins</td>
<td>magnetics, gravity, DCIP, MT, district geology map, project geology map, Aster satellite data, 1VD, magnetic inversions</td>
<td>Fault traces and fault surfaces</td>
</tr>
<tr>
<td>Potassic alteration</td>
<td>Alteration domain around a porphyry system</td>
<td>soil geochem, ASTER, TMI and RTP 1VD, magnetic inversions</td>
<td>Polygons from geochemical signatures. 3D domains/ wireframe from magnetic inversion</td>
</tr>
<tr>
<td>Phyllic (AKA sericitic) alteration</td>
<td>Alteration domain around a porphyry system</td>
<td>soil geochem, mag inversion and 1VD, surface mapping-quartz, Aster</td>
<td>Polygons.</td>
</tr>
<tr>
<td>Propylitic alteration</td>
<td>Alteration domain around a porphyry system, partly magnetite destructive</td>
<td>soil geochem, mag inversion and 1VD, surface mapping-quartz,</td>
<td>Polygons from geochemical signatures. Possibly magnetic ‘lows’ as 3D wireframes / domains</td>
</tr>
<tr>
<td>Argillic alteration</td>
<td>Alteration domain around a porphyry system</td>
<td>Soil geochem, Mapping, argillic or ‘clay’ polygons.</td>
<td>Polygons from geochemical signature,</td>
</tr>
</tbody>
</table>
Outline

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• role of geochemical data
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• case studies
mechanics of interpreting ore system footprints

geological starting model

gridded geological model

reference model

physical rock properties, weights, bounds, etc

Geophysical or geochemical data

Joutel Mining Camp, Abitibi Greenstone Belt, Quebec
Inversion applied to geological models

VPmg framework for geological parameterization

Pillara, Western Australia

Inversion applied to geological models

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• the modern mineral exploration context
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• case study - modified from Earth Modelling to show a public case study
Mount Dore region 3D Mineral Potential Study

- 175km x 70km
- detailed 3D prospectivity analysis
Methodology

- Geological modelling: GOCAD/SKUA
- Geophysical inversion: MAG3D, GRAV3D, VPmg, EmaxAIR
- Pseudo-lithology prediction: LogTrans
- Quantitative exploration targeting: 3D weights of evidence
The Mount Dore Project Region

- Several significant IOGC deposits
- Rich company and public domain data
- High discovery potential
Mount Dore Project – geophysical datasets

- 300m BHP Geotem data
- Company and GSQ (4km) Gravity
- Company and government 400m TMI Magnetics data
- 2006-9 GSQ Geological mapping
- 2009 GSQ Magnetotelluric surveys
- 2006 GSQ-GA Deep seismic profiles
Geometry inversion as geological modelling tool

• Granite body starting depths estimated on cross sections and modelled in 3D

• Gravity inversion used to change the depth of the granites.

• **EQUALS:** Geophysics doing geological modelling

Base of granite elevation before (left) and after inversion (right).
Mount Dore Project – inversion and pseudo-lithology workflow

1. Geological block model
2. Susceptibility model
3. Density model
4. Inverted-lithology
5. Conductivity model
Regional gravity inversion (900m cells)

- Initial homogenous unit gravity inversion
- Heterogenous unit inversion: cells 500m vertical, increasing with depth

3D regional density model
900m X 900m cells
RMS misfit = 0.4mgal
Heterogeneous unit magnetic inversion

observed TMI

900m cell susceptibility model (VPmg)

300m cell susceptibility model (MAG3D)
A detailed look at the AEM at Mt Dore

- 1998 Geotem data
- CDI (image to right) shows strong coupling between early to late time channels with shale units
- Not a definitive test for identifying massive sulphides
- Unlikely to create ‘direct detection’ drill targets

Processing:
- Conductivity-depth sections produced with EmaxAIR
- CDI sections interpolated into 3D grid
How useful was AEM for quantitative targeting

• Useful for improving the geology model
• Useful for assigning ‘inverted lithology’ units

• AEM has the highest statistical correlation with known IOCG after ‘surface geochemistry’ samples over sub-cropping deposits

• BUT HOW? – we saw that AEM was largely responding to geology – not identifying massive sulphides directly
Exploration criteria – regional and local scales

- Anomalous surface geochemistry
- Crustal plumbing system
- Close to Mafic Intrusives
- Plumbing system intersecting intrusives
- Dilational zones on the Fault Network
- Geological contacts between shale and other rock types
- Surface Uranium anomalism
Regional targeting – targeting criteria

- Distance to mafic volcanics
- Distance to crustal faults
- Near anomalous Au
- Uranium anomalism ($U/\text{Th}$)
- Dense and magnetic rocks
- AEM – but what?
Distance to conductive edges

Related to rheological geological boundaries – a local structural trap for IOCG mineralisation
The success of AEM

- In the main mineralisation corridor
  - A zone within 300m of the rheological contact identified through geological and AEM modelling identified 8 of the 11 known significant IOCG deposits

- Regionally 26 (triangles in the image) of the 36 known significant IOCG deposits are within 300m of the rheological contact identified through geological and AEM modelling
3D Weights of Evidence (WoE) Targeting

- Of the 22 proposed exploration criteria,
- only 11 had significant correlation with mineralisation in the Mount Dore area.

<table>
<thead>
<tr>
<th>Exploration Criteria</th>
<th>Weight +</th>
<th>Weight -</th>
<th>Contrast</th>
<th>Stud. Contrast</th>
<th>Favourable Range - Start</th>
<th>Favourable Range - End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coincident Gravity High-Magnetic High</td>
<td>2.29</td>
<td>-0.2</td>
<td>2.49</td>
<td>5.9</td>
<td>0.81</td>
<td>0.246</td>
</tr>
<tr>
<td>Distance C-Sharp Filter ISO &lt;35</td>
<td>2.88</td>
<td>-0.91</td>
<td>3.79</td>
<td>11.09</td>
<td>0m</td>
<td>300m</td>
</tr>
<tr>
<td>Distance to Crustal faults</td>
<td>0.74</td>
<td>-0.32</td>
<td>1.06</td>
<td>3.12</td>
<td>0m</td>
<td>964m</td>
</tr>
<tr>
<td>Distance to faults intersecting mafics</td>
<td>1.12</td>
<td>-0.29</td>
<td>1.41</td>
<td>4</td>
<td>0m</td>
<td>921m</td>
</tr>
<tr>
<td>Fault Roughness</td>
<td>2.79</td>
<td>-0.17</td>
<td>2.96</td>
<td>6.63</td>
<td>0</td>
<td>0.00015</td>
</tr>
<tr>
<td>Geological Complexity</td>
<td>1.8</td>
<td>-0.35</td>
<td>2.15</td>
<td>6.09</td>
<td>0.107</td>
<td>0.0198</td>
</tr>
<tr>
<td>Normalised Susceptibility</td>
<td>3.25</td>
<td>-0.14</td>
<td>3.39</td>
<td>7.03</td>
<td>0.372</td>
<td>0.0884</td>
</tr>
<tr>
<td>Regional Density Model</td>
<td>3</td>
<td>-0.08</td>
<td>3.08</td>
<td>5.11</td>
<td>0.426</td>
<td>0.32</td>
</tr>
<tr>
<td>Uranium divided by Thorium</td>
<td>2.12</td>
<td>-0.58</td>
<td>2.7</td>
<td>8.1</td>
<td>1.289</td>
<td>0.274</td>
</tr>
<tr>
<td>Distance to Gold Anomaly &lt;150</td>
<td>5.16</td>
<td>-0.29</td>
<td>5.45</td>
<td>14.15</td>
<td>0m</td>
<td>304m</td>
</tr>
<tr>
<td>Distance to Copper Anomaly &lt;2000</td>
<td>5.72</td>
<td>-0.75</td>
<td>6.47</td>
<td>19.35</td>
<td>0m</td>
<td>250.7m</td>
</tr>
</tbody>
</table>

Variables with the highest studentised contrast values (C/stdevC) are the most significant contributors to the mineral potential model.
Mineral Potential Index

- The Binary evidential properties and their associated weights are combined to create a Mineral Potential Index.
- Final result is model-driven 3D mineral prospectivity potential volume

Mt Dore
Mineral Potential Index
Conclusions

• Geophysics can act as a key ingredient to exploration methods based around Ore System Footprints – not designing drill holes in data space
• integrated interpretation requires a single, shared earth model
• geophysical responses are usually dominated by the 3D geometry of geological boundaries
• inversion is most usefully deployed to modify geological domain geometry and bounded physical property distributions
• key technologies:
  • 3D geological modelling
  • physical property analysis
  • rapid, iterative geologically-based forward modelling and inversion

*interpretational effectiveness demands interactive, iterative geological and geophysical modelling by a multi-disciplinary team*
Moving forward – using the study outcomes

• A specific model needs to be planned for the specific business purpose

• Strategy needs to be devised for making the model
  • What is available as a way of testing for uncertainty or updating the model e.g. do certain components of the model respond to magnetics

• The show case study integrates science, technology, and economics to produce a scientific basis from which further exploration can be undertaken

• This method provides greater confidence and efficiency, resulting in increased economic, social and environmental benefit.