A Mineral Systems approach to exploration

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Discovery day, 2014
Take home messages

• Ore deposit formation is a complex natural phenomenon requiring a multi-scale (and multi-disciplinary) exploration process

  → Data integration

• Mineral system approach focuses on answering the question of “Where?” ore deposits form rather than “How?”

  → Architecture is key!

• CET the “go to” place for mineral system R&D
Traditional ore deposit study

• Deposit models → Built from deposit-scale observations
  – Scale at which we can more readily study them

• A taxonomical approach – deposit styles
  – Carlin style Au, Kambalda style NiS, Bushveld style PGE, Witswatersrand style Au, Olympic Dam style IOCG…

• More comprehensive syntheses encompass multiple deposit styles
  – High Sulphidation versus low sulphidation epithermal, Epithermal-Porphyry transition, Continuum model for Orogenic Au, Unconformity uranium

• Good summaries of variations between deposit styles

• Can be excellent summaries of deposit scale
Epithermal Au

Corbett 2004
Porphyry to Epithermal Cu-Au Deposit Model

Corbett 2004
Archaean Orogenic Gold Deposit Model - Crustal Continuum for Au

Timing late tectonic = ca. 2640-2630 Ma in Yilgarn

Fluid Sources metamorphic-dominated

Groves et al., 1993
Deposit models - limitations

• Often too many ‘variations on a theme’ for practical application
  – Porphyry model variants
  – Uranium – 14 models, 22 submodels

• Struggle to be predictive
  – Where predictive = local scale
  – Finds analogues of what you have already found

• Show that giant deposits and small showings often have similar fluids and deposit scale features (Groves, 2009)
  – E.g. fertile magmas hard to differentiate from infertile on deposit scale (Cooke et al, 2009)
Deposit models struggle to be predictive

- We have a much better (albeit very incomplete) understanding of the processes controlling mineralisation than 40 years ago.

- So our targeting must be more effective, yes?
  - No
  - Find new deposits in brownfields, but struggle to find new ore systems in greenfields terranes.

- DEPOSIT MODELS ARE AT WRONG SCALE for large scale greenfields exploration decisions!
Prediction-detection tradeoff

- **High** Relative Effectiveness
- **Low** Relative Effectiveness

- **Broad Regional** Scale
- **Prospect** Scale

Camp scale decision

**Detection**

**Prediction**

after McCuaig and Hronsky 2000
We must see beyond Deposit-Scale Complexity

Sillitoe (2010)
Predictive Power comes from the Larger Scale

Sillitoe (2010)
Mineral Systems – WHY?

• Conceptual organising framework
  – Much more powerful than predecessor - traditional Deposit Models

• Required to open up new mineral districts
  – Captures variations of thought process with scale
  – Allows for the undiscovered deposit styles
Mineral Systems Science: Conceptual Basis

- Based on the premise that:
  - Ore deposits (particularly large deposits) represent the foci of large-scale systems of mass and energy flux
  - the only way to predict their location or their metal endowment is to understand the entire system

- These systems comprise a scale-dependant hierarchy of processes:
  - the largest observable scale of process is usually continental-scale
Goals of Mineral System Science

- Define the key *generic, unifying* process elements that govern ore-formation (at all scales)

- Map these elements to physical rock volumes (*essential for predictive targeting*)

- Develop frameworks for evaluating the relative endowment potential of systems
Physical considerations can change our perspective

• Ore formation requires concentrating metal, initially in low abundances in large volumes of rock, into small volumes of rock at high abundances

• Only plausible mechanism: large-scale advective fluid flux

• Necessary physical processes for ore formation provide fundamental constraints on what can be a viable Mineral System
Basic Physics of Ore Formation

- Diffuse Metal Source Region
- Concentrated Metal Deposit
- Fluid Sink
- Advective Fluid flux (= Energy Flow)
- Diffuse Metal Source Region
Conceptual Mineral System

Knox-Robinson and Wyborn, 1997
Context:
The Evolution of Perspective in Economic Geology

- Ore specimen-centric
- Host Rock-centric
- Structure and chemistry-centric
- Fluid flux and physics-centric

Increasing Scale of Observation

Early 1900s
21st Century
A PHYSICAL PROCESS BASED MINERAL SYSTEM MODEL - FLUID CENTRIC

Can develop proxies for every component because they all map to a physical rock volume!
Ore Genesis as the Focus of a Scale-Hierarchical Mass Concentratative System
We must see beyond Deposit-Scale Complexity

Sillitoe (2010)
Predictive power comes from larger scale

Deposit Scale

Camp Scale

After Sillitoe (2010)
Evaluating the lithospheric architecture of the Archean Yilgarn Craton in space and time: implications for komatiite volcanism and earth evolution

Dr David Mole
4D modelling of the Palaeoproterozoic Granites-Tanami Orogen and its mineral systems

PhD: D.B. Stevenson

Location of the Granites-Tanami Orogen (GTO) overlain by the free-air corrected, upward continued gravity anomaly image (colour scale), and the dynamic range compression processed aeromagnetic image (greyscale).

Selected gridded and processed potential field data sets.

Bottom right: reflection seismic fence diagram adapted from Goleby et al. (2006).
4D evolution of the world class Siguiri orogenic gold district and Siguiri Basin: implications for gold targeting in Birimian terranes (Guinea, West Africa)

From pit mapping and paleostress reconstruction…

… to 3D modelling and regional integration and targeting
But What About Chemical Processes?

- Much more diverse, complex and difficult to predict than fundamental physical processes

- Metal-bearing fluids in the upper crust encounter steep physical and chemical gradients - many potential depositional mechanisms

→ Explains why most metallogeny in upper 10km of crust

- However, chemical processes still important and define type of mineral system and precise location of ore formation
Mapping Chemical Processes to the Physical Mineral Systems Model

• Key is defining a set of generic elements that represent important chemical processes but can also be related to rock volumes

• These rock volumes are by definition a subset of those in the Physical Mineral Systems Model

• Four critical elements:
  – 1. Pre-fertilisation of the fluid source region
  – 2. Metal/Other Critical Solute source regions
  – 3. Fluid Fractionation Site
  – 4. Metal Depositional Site

• If proxies for the rock volumes relating to these four elements can be defined, it will possible to significantly refine the generic Physical Mineral Systems Model
1. Pre-Fertilised Fluid Source Region (eg enriched upper mantle)

2. Metal and/or Critical Solute (eg Cl, S) source region

3. Fluid Fractionation Site

4. Ore Depositional Site – either in conduit or at discharge site

Exposures of metasomatised lithospheric mantle

Understanding the spatial and genetic link between metasomatised lithospheric mantle and magmatic mineral systems

Locmelis et al., in preparation
Isotopic mapping in Lhasa Terrane, Tibet

Two juvenile blocks where porphyry Cu deposits cluster
Effective metal transfer from the mantle to the crust

Record from xenoliths
Investigation of metal variability in mantle source

Variable distribution of sulphate melt metasomatism

→ So what?

Oxidised melts may carry more S (and metals)

Where are (or have been) oxidised domains in the mantle?

How do we map them?

Giuliani et al., 2013 EPSL

Cross-Theme initiative
Petrogenesis of intrusive rocks in the Telfer region, Paterson Orogen, Western Australia: implications for gold mineralisation
PhD: Christian Schindler

Telfer dome gold mineralisation (Grade distribution)

Laser ICP-MS on fluid inclusions

Fluid inclusion study
4D modelling of the geometry and genesis of the giant Obuasi gold deposit, Ghana
PhD: Denis Fougerouse

Multistage mineralization process in giant gold deposits?

Map view of an underground drive (L43#1 XC169); the first gold event (arsenopyrite) is syn-D2 and the late mineralization (visible gold) is syn-D3.

Gold remobilization?

Sample 215-7b: a) High contrast BSEM image; b) Au and Ni distribution (Synchrotron X-ray fluorescence elemental mapping, XFM beamline, Maia detector).
Ore Genesis as the Focus of a Scale-Hierarchical Mass Concentrative System

Map architecture

Then map chemistry onto architecture
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