Mineralized Terranes

Targeting criteria for the Eastern Goldfields Superterrane (EGST)

The pmd*CRC Y4 project has conducted a multi-disciplinary and multi-scale study on an Archean Gold mineral system (traditionally called Archean Gold or orogenic/mesothermal gold). One of the most important outcomes was the identification and ranking of the Key Criteria necessary to form giant gold depostits. These Key Criteria and their importance vary between the scales, as does the density of data necessary to make an assessment.

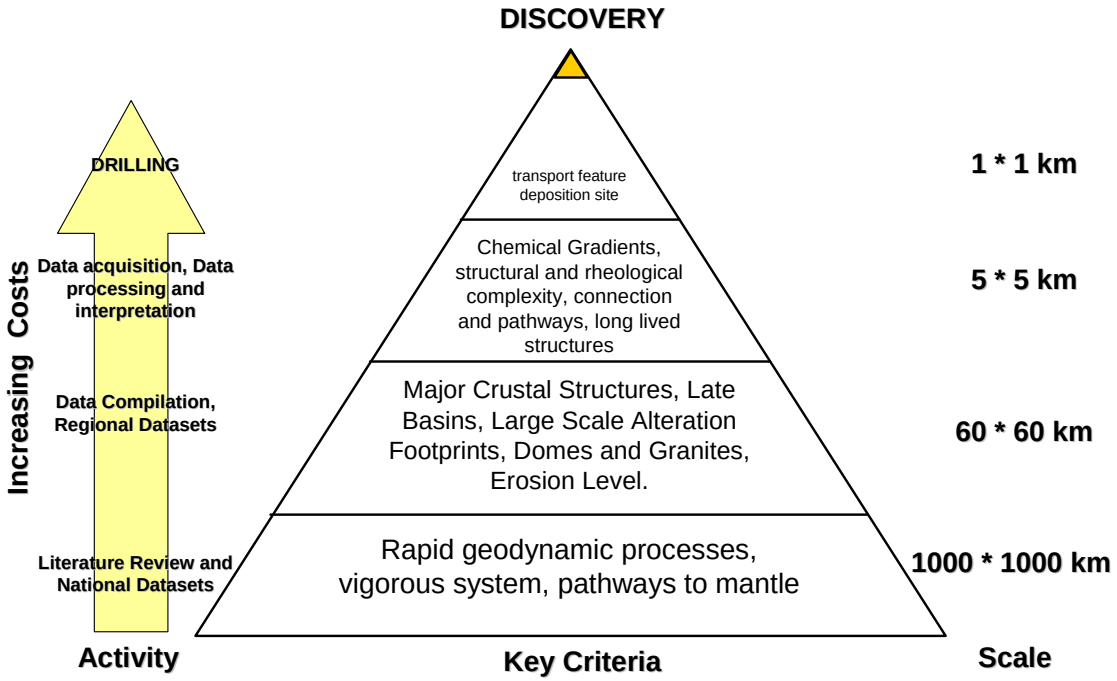

Figure 1: Schematic diagram showing the Key Criteria and main activity to identify them at the four scales (after Simon van der Wielen).

Effective targeting can be considered from the perspective of four nested scales. For each of these four scales a series of questions can be asked:

1. How do I recognise a gold (metal) bearing province in a 1000 km x 1000 km area?

2. Within this large search space, how do I identify the location of major mineral camps in a 60 km x 60 km area?
3. Within this 60 km x 60 km area, how do I identify the location of specific ore deposits that will lie in specific 5 km x 5 km areas?
4. Within this chosen 5 km x 5 km area, where is the best 1 km x 1 km search space for me to drill out to define a resource?

Scale 1: REGIONAL ANALYSIS - How to recognise a gold (metal) bearing province (1000 km x 1000 km area selection)

The following Key Criteria are needed to create a suitable environment for the formation of giant gold deposits:

1 Pathways to a fertile mantle
2 Large-scale heating/melting/fluid systems
3 Vigorous orogenesis
4 Suitable cratonisation and preservation
5 “Convergence” of favourable processes (the ‘right’ age)

The Yilgarn Craton as a whole is a fertile region and is favourable when considered at the 1000 x 1000 km scale (cf. Pilbara which lacks many of these criteria). Groves et al (2005) suggested that giant ore deposits form during periods of major plate reorganisations and associated crustal growth and the Neoarchean was one of those periods. Between 2750-2550 Ma, the time of the first of these major events, was a period of major mineralisation and granite-greenstone formation across the globe (e.g. Yilgarn, Superior, Slave Province).

Between 2720 and 2630 Ma the Yilgarn Craton had a period of wide-spread crustal growth, including thick greenstone-belt formation in the EGST at this time, what makes the EGST prospective at the 1000 x 1000 km scale.

More important though is the evidence of a vigorous tectonic system operating at that time in the Yilgarn Craton, resulting in widespread heating and melting (komatiites to Low-Ca granites), active tectonics (basin formation and inversion) and the development of major elongate and deep fault networks that connect to the mantle (presence of alkaline magmas, chemistry of mafic and granitic rocks that were synchronous with the late basins).

Data: literature review including sourcing public domain databases and maps

Scale 2: District ANALYSIS - How to indentify the location of major mineral camps (60 km x 60 km area selection)

The district scale areas have been selected on the basis that they contain evidence for the following Key Criteria:

1. Connected fluid pathways
2. A suitable complexity in terms of the prospect's fluids and chemistry to provide opportunities for mixing and chemical gradients
3. A suitable structural complexity to aid focussing the fluid
4. Rheological or lithological complexity to aid focussing the fluid
5. Cover and dispersion processes

The tools used at this scale include deep seismic reflection profiling, seismic tomography of shear wave structure of the mantle, magnetotelluric data, Sm-Nd isotope mapping, deep worms, and regional whole-rock geochemistry, and metamorphic mapping-analysis.

The Nd map produced by Champion and Cassidy (2007???) displays the age of the crust and has been refined by the Y4 project. An overlay of gold deposits on the Nd map (Figure 2) shows a clear relationship between mineralisation and intermediate-aged crust (2.9-3.0 Ga, green- to yellow-coloured domains). Based on this empirical observation, the best targets are likely to be found in these

domains, but the reason for this provinciality is not clear. Groves et al (2005) suggested that the most juvenile crust was generally the most endowed, which is the case in the case in the Abitibi Subprovince in Canada (Blewett 2008).

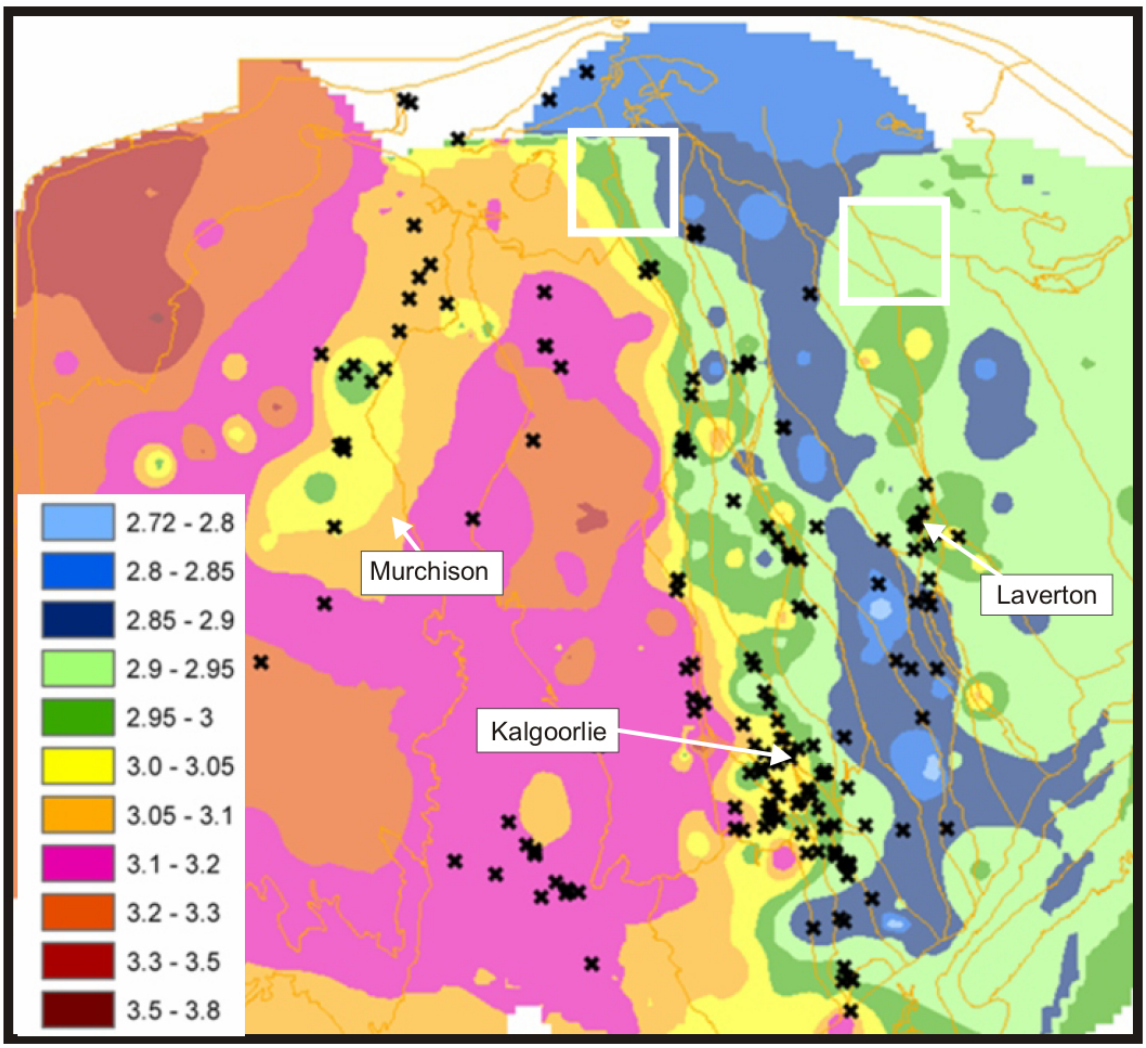

Figure 2: Map of crustal age based on Sm-Nd isotopes for the Yilgarn Craton. Gold deposits are also shown as black crosses. The intermediate aged areas (crustal age 2.9-3.0 Ga) host most of the major deposits. Two suggested target areas are shown as white boxes. Many other areas are also candidates.

Extension is an effective way to 'break' the crust and to develop deep penetrating shear zones. The D3 extensional event occurred at 2665-2660 Ma and introduced significant gold (e.g. Gwalia, Lancefield and the early history of

Sunrise Dam and St Ives). There is much potential for similar systems adjacent to the large granite domes.

Best areas for this style are (Blewett et al 2008):

- adjacent to large granite domes
- where strain is extreme
- where metamorphic grade jumps occur, especially the granulites and high pressure rocks
- where Late Basins are located in the hangingwall
- where old sequences are adjacent to the granite margin. This implies the greatest excision and extension and therefore strain (Lancefield and Leonora are good examples)
- where the granites have perturbations

Regional multi-element whole rock geochemistry data is commonly available from geological surveys (e.g., Geoscience Australia). One first-pass targeting technique that can be applied to these data is to consider the loss on ignition (LOI) values. These values typically represent the amount of volatiles (water and CO2) in any sample. Altered samples are typically higher in LOI %. Typically the regional geologists that collected the original material focused on fresh rock so a high LOI would be unusual and may reflect a previously unrecognised alteration zone. A simple analysis can be conducted where the results can be grouped by lithology. In this example three groups are defined: 1) ultramafic, 2) mafic, 3) the rest. The ultramafic rocks are separated as they contain significant volumes of volatiles and typically have LOI values of >10%. A simple bin of 1,2,4,6 for mafic and 'the rest' rocks and a bin of 5,10,15,20 for the ultramafic samples allows a crude scaling between primary rock types. In ARCGIS a simple colour scheme cold colours to hot colours and increasing symbol size for increasing LOI is applied.

Targets defined on the basis of these data need to be tempered with assessment of other regional datasets, but as an in-expensive technique this approach may be worth attempting (Blewett et al 2008).

Scale 3: District ANALYSIS - How to indentify the location of a specific ore deposit (5 km x 5 km area selection)

Choosing the ‘correct’ 5 km x 5 km search space within a defined district is probably the most important step in the exploration process. Considerable value (cash and opportunity costs) can be wasted in searching in the ‘wrong’ place. This search space is probably the hardest to operate in. The problem in the 5 km x 5 km space is that the search space is sufficiently large to be costly to acquire high density data – especially at a distance from known resources – and yet the regional data are generally too coarse to define the subtle features needed to define targets at this scale. This is where insights from a high level of geological knowledge acquired from being well read and experienced in the region’s geological evolution is important. These insights permit the explorer to maximise the value of the regional data, chose the best targets early, and direct the acquisition of new data (Blewett 2008).

The 5 km x5 km scale areas have been selected on the basis that they contain evidence for the following Key Criteria:

1. Evidence for an active hydrothermal system
2. A suitable complexity in terms of the prospect’s fluids and chemistry to provide opportunities for mixing and chemical gradients
3. A suitable structural complexity to aid focussing the fluid
4. A suitable architecture to aid focussing the fluid
5. Rheological or lithological complexity to aid focussing the fluid
6. Understanding the cover and dispersion processes

These Key Criteria at the prospect scale are similar to those required for the district scale. In order to explore in the 5 km x 5 km scale higher resolution data are needed.

Most of the main quality assets in the Eastern Goldfields Superterrane are associated with asymmetric alteration haloes which indicate hydrothermal fluids

with different redox condition and/or the pH. Typically oxidized hydrothermal fluid cells are focused around zones of intense porphyry intrusions either at the apex or at the flanks of submerged intrusive centres. Quality gold assets are typically located at the chemical gradient from oxidized to reduced and/or alkaline to acid hydrothermal alteration cells (Neumayr and Walshe 2008). St. Ives, Kanowna Belle and Wallaby are located at a chemical alteration gradient with the hydrothermal cell typically being focused on buried intrusions. Intrusions are indicated by gravity lows. The targeting concept of Neumayr and Walshe (2008) involves the identification of other buried felsic and intermediate intrusions with demonstrated oxidized hydrothermal fluid flow (linear magnetic anomalies are interpreted to represent the oxidized fluid pathways). Terminations of the positive magnetic anomalies are the most productive zones. Further, the edge of the oxidized hydrothermal cell needs to be identified to find the best 1 km x 1 km targets.

The importance of fault orientation on the regional scale was tested in the Laverton region. Miller and Nungus conducted mine-scale structural analysis at Sunrise Dam and determined through 3D stress analysis that the most favourable fault segments to reactivate during the D_{4b} event were orientated at ~30º towards 310º. Regional scale faults were constrained using both seismic reflection data and to a lesser extent potential field data. These data provided a suitable framework to apply the same fault parameters that were applied to the mine scale faults to highlight suitably orientated segments on the regional scale (Henson and Miller 2008). Miller and Nugus's (2006) work indicated that the dip of a fault is as important to the reactivation process as the dip direction and hence it would not be possible to apply this type of analysis to 2D faults. A well constrained 3D map in contrast is the only potential way of analysing the preferential orientation of faults that will reactive during a specific stress vector. Application of this process highlights areas around Sunrise Dam, Wallaby and Lancefield mines as suitably orientated fault segments and demonstrates that on both a mine and regional scale, highlighting areas of the faults with suitably

orientated 3D segments provides a technique to critically evaluate additional areas for exploration targeting.

Scale 4: ORE SYSTEM ANALYSIS - How to target a 1 km x 1 km search space and make a discovery

The process of targeting at the ore definition stage (1 km x 1 km area) will be target specific, so there will be no single process or methodology. In general however the highest quality of data available should be utilised. Because each target situation can be unique a definitive statement of what data to acquire and at what density would be pointless. However, many of the same datasets and concepts at the higher scales are used at this scale too, and it is preferable to acquire the highest density (e.g., sub 250 m spaced gravity, 100 m spaced magnetics, and sub 250 m spaced PIMA and geochemistry) (Blewett 2008).

To visualize and integrate the data, use the full capacity of image processing and gridding software to filter and maximize the range of data in the chosen 5 km x 5 km target area.

For Transport of fluids and metals, there needs to be suitable architectural features for fluid focus and a suitable chemical architecture for the operation of chemical gradients. For Deposition of fluids and metals there needs to be evidence for an outflow zone and suitable geochemical anomalies as evidence for the deposition (Blewett 2008).

Target identification through:

- Architecture (geophysical tools and 3D modelling)
- Numerical simulations
- Spectral, geochemical, stable isotope analysis

Data used at this scale usually includes drilling and logging, pit and underground mapping, lithogeochemistry, spectral studies (PIMA), stable isotopes (C,O,S), regional to detailed magnetic and gravity data, 1:10 000 scale or better geological maps and solid geology derivatives, integrated 3D modelling and inversions, numerical simulations, and focussed structural mapping to make informed local predictions (Blewett 2008)

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