

Example of 5 km x 5 km targeting in a 60 km x 60 km and 1 km x 1 km targeting chosen 5 km x 5 km favourable search spaces (St Ives camp)

Richard Blewett pmd*CRC and Janet Tunjic (Goldfields St Ives)

Introduction

An exercise was undertaken at the St Ives offices in Kambalda 27-28 September 2007. The following section is an account of the processes used, science discussed and decisions made throughout the two days. The experiment involved the Y4 team splitting into two and each team being integrated with staff from the St Ives exploration team. Both teams had equal numbers of geophysicists, structural geologists, geochemists, 3D specialists, and exploration geologists. It was clear that all these skills were needed during the exercise. Two teams of 7-8 (rather than one big team) was decided because this was the optimal size in terms of team dynamics (everyone contributes) and still maintain the necessary skill base. Two teams also tended to compete and each team was required to report back to the other and justify the decisions made. In keeping with local tradition, a 'fun' environment was also created by naming the two teams after the leaders (Nelson and Napoleon) of the Trafalgar battle.

Each team had access to regional geological and geophysical data at a scale typically provided by a geological survey or available in the public domain (for the targeting at this scale). The aim of the two days was to independently develop a set of targets of approximately 5 km x 5 km, chose the top six targets and within these select two for further follow up with a 1 km x 1 km exercise. It was important to try and capture not only the targeting process being undertaken over the two days, but to also define why certain targeting criteria were important and discuss the science.

The following section was written from the combined notes of Janet Tunjic (Napoleon) from Goldfields St Ives and Richard Blewett (Nelson) from the pmd*CRC. The Y4 project is very grateful to Goldfields St Ives for the opportunity to test our concepts on a real world example. The team benefited enormously from this experience and it helped shape the entire Part II section of the report.

The datasets used in the exercise included:

- Geology and solid geology – for context and geometrical and spatial-temporal framework
- gravity –for structure, edges and boundaries, buried granites
- magnetics – for structure and geometry, alteration
- sub-audio magnetics – for structure
- whole rock geochemistry especially As, Bi, Li, Mo, Te, W – pathfinder elements (P for enriched porphyries)
- lithogeochemistry – for confirming the solid geology maps
- spectral data – for alteration and gradients
- Min Mole derivative of geochemistry
- seismic reflection – for 3D understanding and regional context

- thickness of cover – for structure and palaeosurface definition
- gridded gold by RL – for target ranking

Process

A review of the ‘straw man’ findings from a previous Y4 project meeting held in May 2007 highlighted the important data sets required to target on a 60 km x 60 km in any Archaean terrain, not just specific to the Yilgarn or St Ives area (Appendix 2.2). The scientific reasoning and geological processes behind why those datasets were important to gold mineralisation was also discussed at length through the entire two days. Many of the concepts were new and derived out of the *pmd**CRC findings, other concepts were well known and reaffirmed as being important such as proximity to anticlines, with further discussions as to why well known concepts were important and supported by new geological understanding. This review was conducted with both teams present.

Following this group discussion, the groups broke up. Both teams went through an exercise of trying to understand the geological context of the area. Napoleon’s team (who probably performed more systematically) suggested the best approach was to understand the geology and regional structures at the 60 x 60 scale based on the regional datasets provided. These datasets were selected as representing data that would be available in the public domain and not relying on detailed mine data. The group set out to map major intrusions, sedimentary boundaries, major faults and folds. Alteration patterns were mapped out on a regional scale using non stratigraphic magnetic units to show areas of possible oxidized alteration and “washed” out magnetic zones detecting zones of more reduced alteration.

From our learnings the best targets were selected that satisfied the important criteria as defined by the project. On many occasions targets were highlighted that correspond to known ore body positions which reassured the sponsors.

Granitic Intrusions

As it was believed that intrusive bodies have a spatial, temporal and/or genetic relationship with gold mineralisation (e.g., in Yilgarn and Superior), emphasis was placed on locating these bodies in the potential field and map data. At the 60 km x 60 km scale, the position of intrusions based on interpretation of regional gravity and magnetic imagery, and GSWA 1:100 000 scale geology maps. Through out the entire process of mapping out the intrusions the group constantly interchanged between datasets. It became obvious fairly quickly that the regional gravity dataset (11 km spaced) was of less value than the detailed gravity dataset (1-5 km spaced) and was swapped, but the team often did refer back to the regional image. This was an approach both teams underwent.

The exploration model also incorporated the need for chemically enriched mafic-type granite or syenitic intrusions that are typically biotite-rich and oxidized with distinct chemical and magnetic properties compared to the early TTG type intrusions (commonly larger plutons and batholiths). Due to the high oxidation state of the syenitic/mafic intrusions a magnetic rim is often formed as observed in magnetic

imagery. Latter on in the targeting exercise the significance of highly oxidized stratigraphy adjacent to granites became evident when looking at geochemical gradients for targeting gold deposits. The map drawn by Nelson's team was broad brush as this team focussed on the large structures and gross architecture. Another difference in approach between the groups was in using the GIS to search for Mafic-type and syenitic intrusions in the GSWA geological dataset. This failed to generate any result as the team struggled with the legend and tried to convert this into the different granite types. Better local to regional geological knowledge of the granite types was missing from the team, resulting in a gap (see below).

On a surface map the mafic-type granitic intrusions display a superficial linear trend, which was interpreted to be associated with intrusion pathways utilising the early extensional architecture. The apparent distribution of granites and differing map patterns of granites was noted and attributed to varying emplacement level. Irregularities in intrusive edges or obvious "bumps" were reviewed in detail. Structural complexity that forms around irregularities in rigid granitic contacts was considered and the significance to localisation of gold bearing fluids discussed in detail. For many of us this type of target was new and understanding the behaviour that structures form around these bumps followed directly out of the work of the structural geologists of the *pmd**CRC.

Potential ambiguity in using gravity lows as direct inference to intrusions without considering other possible gravity low sources was briefly mentioned. With intrusions occurrences of less certainty given dashed outlines. Nelson's team focussed on the central Kambalda Anticline and looked for gravity lows (as proxies for concealed granite domes) within the corridor in the regional data. These were followed up in the chosen 5 km x 5 km area, but required the high-resolution gravity data to better define the geometry of the likely granite domes.

Structure and Stratigraphy

Major structural features were interpreted based on magnetic, gravity imagery and complexity in stratigraphy as defined by the GSWA geology maps. To develop an understanding of the geology of the area, the data were interrogated in detail to define broad stratigraphic domains of mafic or sedimentary stratigraphy in 2D context with the intrusions. The relationship to structures and added complexity such as offsets in stratigraphy were also noted and mapped. The outcome was a solid geology base map drawn on transparent film overlays to create a solid geology map.

Large-scale faults were interpreted using magnetic and gravity data. The regional gravity dataset defined the very broadest architecture and any deep cross structures that might have intersected the main north-northwest trends. Stepping out to the very broadest scale of the Goldfields was also used to ensure the team had the 'right' context in terms of the large structures. These large structures were believed to have developed as accommodation or transfer structures during the original D1 extensional event. There was much debate around the importance of various domains as this was important in deciding where to place the 5 km x 5 km boxes.

Sedimentary contacts (e.g., Merougil Basin) were interpreted based on magnetic imagery. It was suggested that many late basins "edges" in the Yilgarn display a

faulted/thrusted contact. The basin formation may in place, be controlled by the location and geometry of large scale faults, some of which were interpreted to be long lived. The eastern edge of the Merougil Basin was interpreted to be structurally controlled and the magnetic alteration patterns observed attributed to fluid movement along the faulted contact. The significance of sedimentary/mafic contact to gold mineralisation was mentioned as providing a rheological contrast important for focussing gold and also an important local source of a reductant for deposition of gold. Geological maps and lithogeochemistry point data were both used to identify these rock types.

The process of creating a geological map was laborious and involved the entire group working together, going back to basic geological principles discussing stratigraphic sequences and defining younging directions. Antiforms, synforms and domal positions were mapped out and possible plunge directions and dips interpreted. At this stage it was difficult not to get “caught up” in the detail of specific complex areas where accommodation zones between faults systems and cross structures were noted, and complexity on fold hinges and limbs.

Fluids and Alteration

Both teams used the regional magnetic image to define the broad-scale redox alteration patterns at the 60 x 60 scale. Defining the alteration patterns at this scale was less challenging than initially thought. Once a greater understanding of the geological map was known, non-stratigraphy magnetic zones were identified together with areas of ‘washed out’ magnetic areas mapped out. The 1:100 000 GSWA map proved mostly reliable for this purpose at this scale. The model was that non-stratigraphic magnetic high zones mapped magnetite (oxidised alteration signature), and the ‘washed out’ magnetic low zones were conversely interpreted to be areas of reduced fluid alteration. The oxidised domains therefore defined and the proximity to the interpreted mapped enriched mafic intrusions and surrounding magnetised rock around the intrusions were compared.

Discussion ranged on the reduced chemistry of the sedimentary basins and that they are thought to be an excellent source of some reduced fluids. The Nelson team also attempted to integrate the geological map with the gold in soils image and with the alteration map derived from the magnetic interpretation. Care was need to understand the context of the gold in soils map as some of the priority target areas had no gold because they were under a lake and the gold RL was not deep enough. Confirmation was made in the depth of cover layer in the GIS.

The group briefly debated new findings of fluid migration during differing regional deformation tectonics as was presented at the Kal 07 conference by Heather Sheldon. It was stated that fluids migrate upwards during contraction deformation events and fluids are dominantly drawn downwards during extensional events.

Gaps in knowledge or data

The experience showed where the gaps in knowledge and tools were, and these included (not in any order), this partly a function of the limited time devoted to the exercise:

- knowledge and maps of ‘acid’ domains
- PIMA data on surface outcrops to
- geochemistry on the different granite types to better assess the enriched types from non enriched types – would have aided ranking with the former favoured
- more structural facts (i.e., dips and strikes) to constrain geometry and confirm kinematic model and predictions of structural interactions
- a big regional seismic line to add context to the high-resolution lines of the camp and to pick the major structures
- multitudes of potential field presentations in terms of different histogram stretches, sun angles, derivatives and combined images to map structure-lithology and alteration
- hydrogeology of the lakes
- a reliable regolith map as well as HyMap and ASTER scenes to add context to the sub-audio magnetic (SAM) data
- better legend and explanatory notes on the 1:100 000 map sheet area.

Examples of target criteria considered

Table 2 is a compilation of the criteria used in selecting a number of the 5 km x 5 km boxes. Note that no one criteria is favoured, but at this scale heavy reliance was made on the magnetic and gravity data and inferences about the major structures together with the distribution of certain lithologies and alteration patterns.

Outcome of 5 km x 5 km targeting

Despite differing approaches in detail, the two teams came up with 6 complementary targets of an approximately 5 km x 5 km area. In some cases identical targets were chosen. The known deposits were deliberately avoided – however they were clearly observable as targets at this scale on the regional datasets and with the approach outlined above.

Table 1 – Target criteria to identify 5 km x 5 km boxes

Target	5 km x 5 km criteria	1 km x 1 km criteria
Target A granite dome margin	<ul style="list-style-type: none"> Enriched type mafic porphyry Major structure with complex flexure adjacent a Proterozoic dyke Subtle magnetic anomaly (blow out) representing (oxidised) alteration? proximity to large dome inferred from gravity 	<ul style="list-style-type: none"> On south side of NW-trending Watcha F (analogue for Playa) and intersection of N-trending A1 structure linking Argo to south. Watcha and Foster Faults act as seals? Gradient is acid (As high) and white mica (Muscovite). Sulphur presence = sulphides. Lithological complexity with BFG boundary and multiple dolerite types. N-S structures in SAM magnetic gradients and complexity Need 160 m x 80 m air-core with stratigraphic diamond drilling to NE and E
Target B	<ul style="list-style-type: none"> Structural complexity mapped in gravity data with 'kinks' in inferred early architecture Proterozoic dyke inferred as pre-existing early pathway positive soil anomaly 	
Target C	<ul style="list-style-type: none"> Favourable corridor along Kambalda Dome – dome at depth (on dome side so need strike-slip faults as breaching pathways) Structural complexity mapped in gravity data with 'kinks' in inferred early architecture Proterozoic dyke inferred as pre-existing early pathway Positive soil anomaly 	<ul style="list-style-type: none"> Similar to A above (need more data) main target is dolerite intersection Expect Alpha Island style D5 dextral gold, expect normal-dextral kinematics and steep veins No enriched porphyries noted – but these are younger and post D3-D4
Target D	<ul style="list-style-type: none"> Deep intrusion inferred from gravity data Likely late intrusion enriched? (non-TTG) as transects the regional grain Large oxidised alteration halo in magnetic data Adjacent a major structure and late basin in the hangingwall for reduced fluid? termination of a linear feature (structural complexity) 	<ul style="list-style-type: none"> Need to test the dome to NW No data for chemistry Pyrrhotite noted in magnetics Disruption in magnetics Low rank
Target E Junction deposit	<ul style="list-style-type: none"> Significant magnetic anomaly in regional data with bleed out of oxidised signal Adjacent magnetic low to the high Near regional anticline structure Gravity break across the main trend – inferred cross structure and pathway Dolerite mapped in geology map 	
Target F	<ul style="list-style-type: none"> Intersection of N-S and NNW trending magnetic structures (inferred as faults) magnetic blow out (oxidised alteration) at structural intersection Stratigraphic complexity with: <ul style="list-style-type: none"> early architecture proximity of granites on uncertain affinity 	
Target G	<ul style="list-style-type: none"> Structural complexity mapped in magnetics with kink in the NNW corridor Complex magnetic patterns Inferred alteration 	
Target H	<ul style="list-style-type: none"> Pronounced gravity gradient striking N-S Magnetic signature with E-W pathway inferred (oxidised fluids) Mapped dolerite (competent lithology) Magnetic alteration anomaly along strike the N-S pathway 	

Process of 1 km x 1 km targeting in 5 km x 5 km

The second day involved a review of the first and a group discussion about the process and criteria used to select the targets. Despite the different approaches between the two teams, many similar targets were selected. Considering the time constraints, the group decided focus only two 5 km x 5 km target areas for 1 km x 1 km targeting. Both teams selected the one the same and another different target for further consideration. The following is an account of one of the targets (A) which is located on the southwest side of the camp (north of Argo)

A review of the geology and context of the chosen 5 km x 5 km targets was made. Consideration of the late basin contact, the large gravity anomaly and what this might mean as well as the elongate structure was made.

Detailed datasets were used to further refine the structural model (Table 2). Use was made also of different presentations of the potential field data. For example, the gravity data were examined for Bouguer, high-pass filter, 1st vertical derivative and total horizontal derivative (gradient) presentations. Also, the high-resolution magnetic data were analysed for 1st and 2nd vertical derivatives as well as total magnetic intensity. Geochemistry and regolith informing maps became more prominent.

The model and thought processes described below in Table 2 are to target above an identified a buried granite dome at depth with suitable pathways linking this and providing a 'sea' of oxidised fluids to react (at gradients) with reduced fluids that were controlled by regional structures (Target A).

The target A is on the Watcha Fault, a parallel structure to the Foster thrust to the southwest of the Victory-Defiance complex. shows much more reduced multi-element geochemistry than the Victory-Defiance complex. The Mo, Te, W datasets were not definitive and it was discussed whether this was due to a smaller or deeper controlling pluton, a non-enriched pluton, or lack of a seal to influence fluid flow. Clearly the thinking was influenced (directed) by the models of Victory-Defiance. The group tried to better understand the architecture but time constraints prevented a definitive study on this.

Table 2– datasets used and criteria identified

Dataset	Criteria identified or inferred	Reason
Gravity and its derivatives	Map the deep structure and infer location of buried granite-cored domes	source of fluid? and/or suitable focussing architecture
Magnetics and its derivatives	Map the structure and infer alteration	look for pairs of highs and lows showing likely redox gradients. Speckled zones in 2 nd VD and confirm with the SAM
Litho-geochemistry	Map the structure especially in areas of non-magnetic stratigraphy	subtle offsets in the Paringa Basalt
Assay	Presence of gold	Gold is a good indicator for the presence of gold – but a no gold value does not necessarily mean that there is no gold in the target area.
Multi-element geochemistry	Consider distribution of P, As, Mo, W and Bi	Map likely redox, especially oxidised signals (Bi, Mo) and reduced signal (As). P maps likely enriched porphyries. The W was sporadic (mapping neutral regions) but data density was noted to be insufficient. Similar issues with Mo and Te. The Bi was not very informative – checked against magnetics and derivatives (incl SAM)
thickness of cover	define the geometry and boundaries of the large NW structure inferred from the potential field data	Map pathways and structural complexity
sub-audio magnetics (SAM)	As above - map structure	mapped a series of N-S and NW structures – were attempting to map pathways to the gravity low (granite dome inferred)
White mica index	Redox gradients	Traced a gradient in the oxidised fluid in the SW part of the target area
Detailed geology (architecture) map	Map the relationship of en echelon folds noted with local accommodation structures associated with thrusts	Still struggled with the detail in the map. More time should be devoted to getting this right. In reality a better would be derived and a series of forward model tests conducted on the potential field data.