April-June 2007

Y4 Project Quarterly Report

predictive mineral discovery CRC

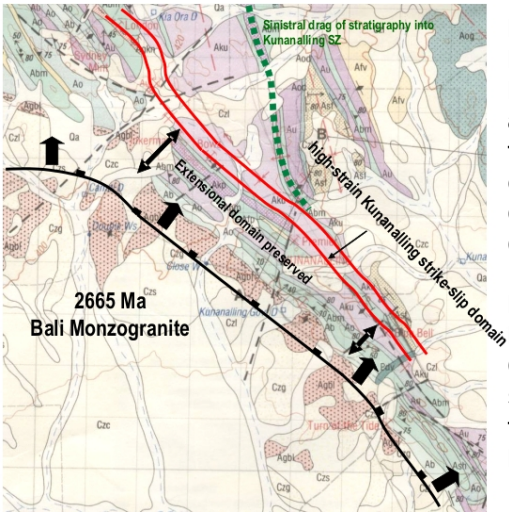
Highlights:

- **Extension and gold**
- **Regional metamorphic update**
- **3D maps: workflow into numerical modelling**
- **Detrital zircons and mapping Black Flags**
- **Better integration of pathways and fluids at St Ives**
- **Embedded Researcher and Student News**
- **Heads up for Kal07**
- **Inversions and improving methodology**

Extension: a critical element in Yilgarn gold?

One of the key results that emerged from the structural work of the Y1-P763 study was the identification that extension (normal faulting) at the time of gold mineralisation was widespread across the Goldfields. Deposits at Lawlers, Leonora, and Laverton were all ascribed to an extensional gold event. More recently, in the July-Sep quarterly report of 2006, extension and vertical flattening were also noted at Victory-Defiance (see also Vearncombe et al., 1988), although how this related to the regional geodynamic history was not clarified. Extension is also the unifying process encompassing Greg Hall's exploration criteria (pers comm., Kal07 Abstract).

Targeted field work around Cazaly's Kunanalling deposits 'discovered' more examples of this extensional gold. Here, the historical mines of Catherwood and Premier clearly show gold associated with extensional C' shear bands. The Blue Bell deposit showed cryptic evidence for earlier extension, but this pit was dominated by gold associated with (or remobilised by) sinistral strike-slip shearing along the Kunanalling Shear Zone. The Catherwood and Premier pits are marginal to the 2665 Ma Bali Monzogranite, which hosts the same extensional fabric as the gold-bearing shears of the greenstones in the hangingwall. Analogies were made with Sunrise Birthday at Lawlers, Gwalia at Leonora, and Lancefield in Laverton (the latter 2 being very extensive to depth).



Left: Map of the Kunanalling area showing the large area of potential extension gold?

Right: Photograph of C' extensional shear bands in the ore zone at Premier

Favourable areas for extensional-style of deposit (can be very depth extensive) are:

- adjacent to large granite domes (2D and 3D map patterns, seismic)
- especially where **old** sequences (>2720 Ma) are adjacent to the domal granite margins. This implies the greatest excision and extension and therefore strain (Lancefield and Leonora are good examples)
- where metamorphic grade jumps occur (see Ben Goscombe's metamorphic work), especially the granulites and high pressure rocks
- where strain is extreme
- where Late Basins are located in the hangingwall
- where the granites have perturbations

For further information see Twiki report, or contact Richard.Blewett@ga.gov.au and Karol.Czarnota@ga.gov.au

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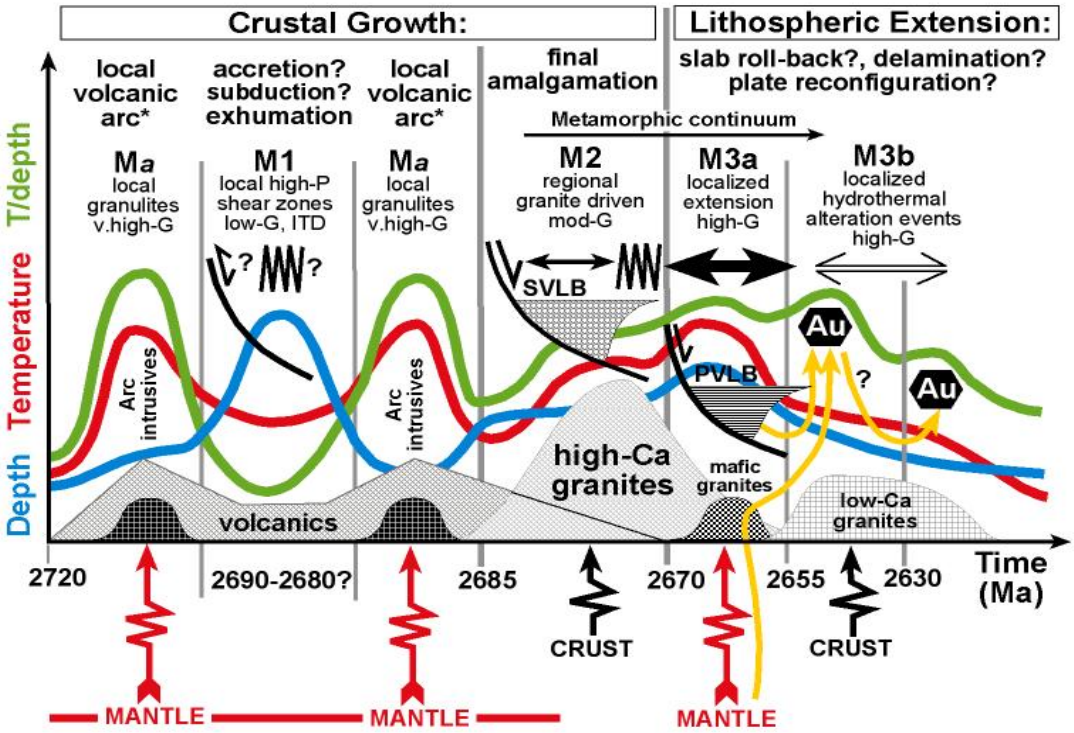
Questions 1 and 3 insights for the Yilgarn: Integrating metamorphism with geodynamics

New constraints on the metamorphic evolution of the Eastern Goldfields Superterrane (EGST) have been defined from geological relationships, relative garnet Lu-Hf chronology, absolute PT calculations and spatial database of metamorphic parameters across all domains of the EGST. The post-2720 Ma thermo-barometric evolution is divided into 5 broad periods of contrasting metamorphic style, conditions and possible thermo-mechanical/tectonic setting. Unlike stress fields, thermal event switching involves slow rates, conductive delays and a history less punctuated than the structural evolution; necessitating broad thermal events and continuums between them, particularly from M2 to M3a and M3b.

A major tectono-thermal change occurred between 2665-2650 Ma, driven by lithospheric extension, resulting in post-volcanic Late Basin rifts, listric growth fault architecture, input of mantle components into the shallow crust such as mafic granites and CO_2-metal-rich fluid, M3a post-kinematic thermal perturbation resulting in Low-Ca (granite) crustal melting, H_2O-rich fluid release and fluid driving and ultimately resulting in fluid mixing and primary Au-mineralization.

A lagging cause and effect outcome is secondary Au-mineralization, by remobilisation during the M3b thermal perturbation associated with emplacement of the Low-Ca crustal melts and development of suitable mineralisation sites by strike-slip reactivation of structures. Contact Ben.Goscombe@adelaide.ed.au for further information.



Generalised evolution of metamorphic parameters (T, P or depth and average thermal gradient) with time, juxtaposed with crust formation events (volcanism, plutonism and sedimentary basins) and deformation in the EGST. The pre-2685 Ma period is an entirely schematic representation of multiple local events distributed across a spatially complex mosaic of different tectonic settings. SVLB-syn-volcanic Late Basin, PVLB-turbiditic post-volcanic Late Basin.

Developing workflows from 3D maps to numerical modelling

The Y4 project has developed new workflows for integrating 3D maps with numerical modelling programs. Numerical modelling applies mathematical laws and numerical codes to 3D objects using different parameters in order to simulate a variety of geological processes. It enables the researcher to test a range of different hypothesis using a variety of techniques including:

- Reactive transport,
- Stress, strain and volumetric changes,
- Heat flow - convection and conduction.

This process requires 3D objects to be of suitable quality for the requirements needed for the numerical modelling purpose, including:

- Surfaces must be well constructed with no duplicate facets – especially at the edges,
- Surfaces should have appropriate complexity and ideally be made with relatively homogenous facets,
- Two parallel surfaces depicting a fault volume should be the same perpendicular distance away from each other to eliminate flow constriction during numerical modelling.

These techniques have been applied to the 3D architecture of the Laverton region. The outcome from this process will be the determination of high shear-strain and volumetric strain locations during a variety of different stress directions. These data will indicate the spatial distribution of regions displaying preferential dilation favourable for fluid flow. For further information contact Paul.Henson@ga.gov.au and Yanhua.Zhang@csiro.au

Targeting News at St Ives - technical success

Conceptual targets have been developed by the Y4 team using 3D models of the Victory-Defiance gold complex. Goldfields St Ives geologists have justified and ranked these targets using their internal target assessment process, and will drill test according to site ranking priority. The 3D model of Victory-Defiance has been further improved through recognition of possible continuous layers logged to date as “sediments” in the ultramafic/mafic pile. However, these "sediments" occur in strategic positions, typically wrapping around competent dolerite intrusions and locally cutting across the intrusions. Our interpretation is that some of these layers actually represent shear zones which locally host significant mineralisation. Importantly, this interpretation also allows the prediction of further layers beneath the Repulse thrust. Two deep underground diamond drill holes recently drilled stratigraphically beneath the Conqueror deposit confirmed further flat structures beneath the Conqueror and Repulse structures as predicted by St Ives geologists and the Y4 research team. For further information contact Peter Neumayr at pneumayr@cyllene.uwa.edu.au

Student News

Joanna Hodge (UWA):

- Has a job in Vancouver

Nick Williams (UBC):

- See article on inversions from Nick
- Been to Sweden on UBC field trip and Yellowknife (Slave Craton) for GAC-MAC meeting

Elena Belyavtseva (CET)

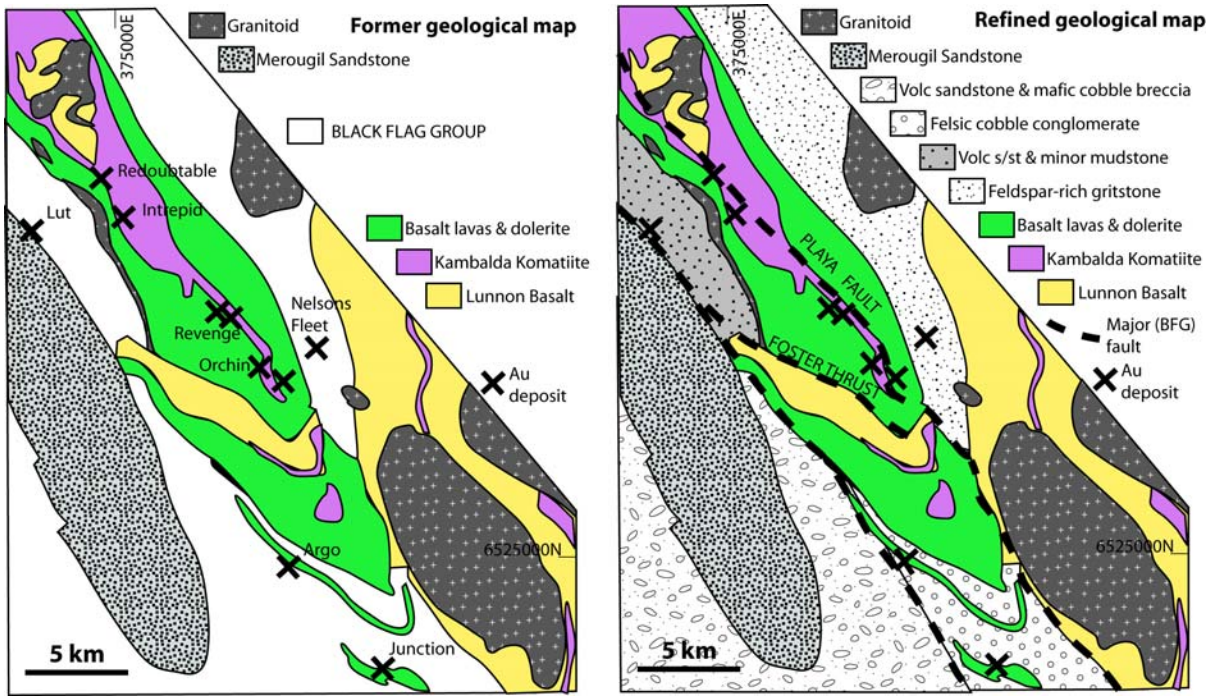
- Joined the project in April and has been reading and compiling data for prospectivity analysis of the Yilgarn using Y2-Y4 data.

Nathan Coleman and Louise Soroka (ANU-GA)

- Have been compiling the tectonic histories of Birrimian of west Africa (endowed Proterozoic) and the Massive Central of France (non-endowed Palaeozoic) to compare with the endowed Late Archaean of the Eastern Goldfields.
- Results show that there are similarities in gross process with the key to endowment being a mantle connection with magmatism
- A more complete report will be available next quarter.

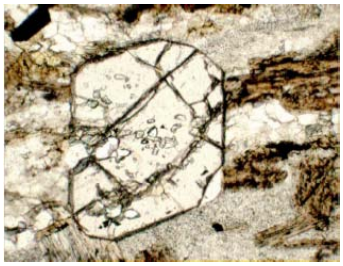
Mapping Black Flags in the St Ives camp

The first tool exploration geologist pick up when targeting new deposits is the regional geological map. However, such maps from the St Ives region have received only modest improvements over the last few decades despite the acquisition of abundant geophysical and geochemical data, and the drilling of thousands of kilometres of diamond core. To address this shortcoming, we have produced a new, dramatically revised map of the 30-km-wide corridor between the Kambalda dome and Tramways Fault that integrates many of the recent refinements in understanding of the region's structural and stratigraphic architecture. The new map, which will have important implications for tectono-magmatic and metallogenic evolution of all Archaean terranes, is currently being drafted and will available within the next few months. For further information contact Rick.Squire@sci.monash.edu.au or Edward.Stolz@goldfields.com.au (Ned).



Simplified geological maps showing the old (left) and revised (right) interpretation of the structural and stratigraphic architecture of the St Ives region. Note how the major deposits display a close spatial relationship to the major structures that bound dramatically different lithofacies of the Black Flag Group (e.g., the Playa Fault).

Metamorphic Report number 5 delivered



Ben Goscombe has been busy compiling the mother of all metamorphic databases (see DVD to sponsors) as part of his 5th report (see Twiki for previous postings). This report and database is too large for Twiki and has most of the appendices that will comprise the final metamorphic report in Deliverable 3 (*Maps and Reports of regional metamorphism and PTt history integrated with structural and alteration history*). For more information contact Ben.Goscombe@adelaide.edu.au.

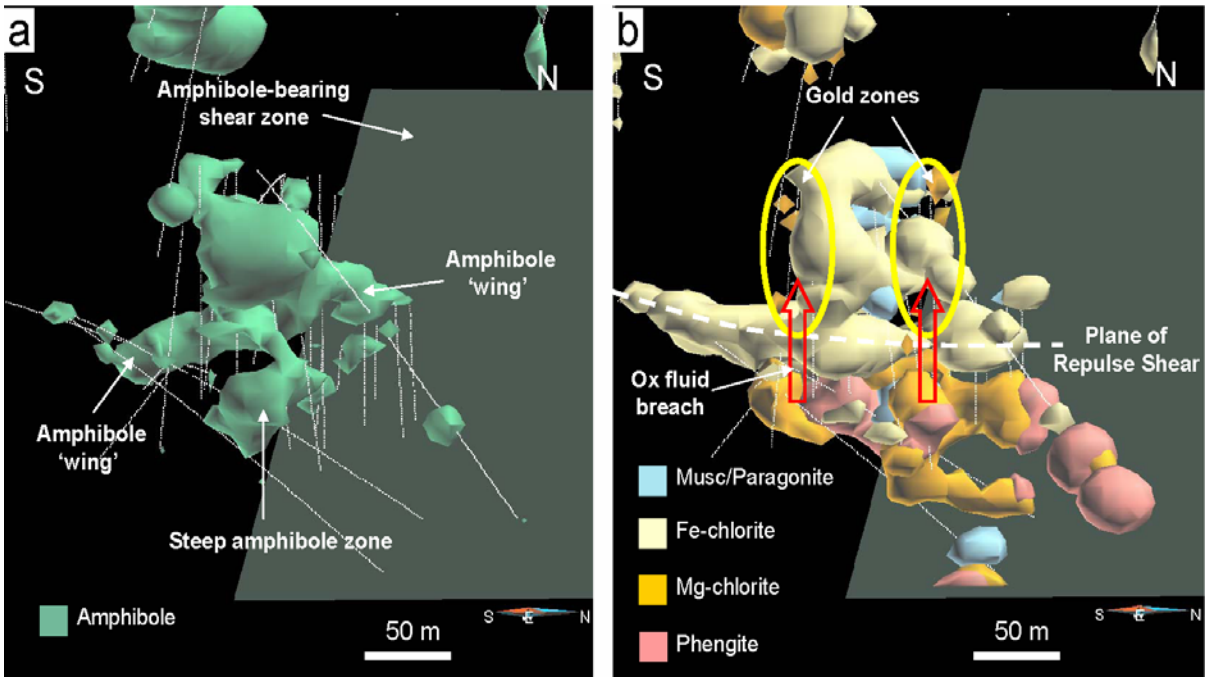
DID YOU KNOW?

Gold mineralisation was associated with dramatic and rapid changes in the gradients of either (or both) pressure and temperature in the Eastern Goldfields, Abitibi, Birrimian, and Variscan of Europe. In most cases exhumation (pressure drop) was involved.

Fluid pathways and depositional mechanisms: St Ives

Within the Greater Revenge Area (GRA) model, a new amphibole and Fe-chlorite index delineated a series of foliation zones that stretch north-south from Agamemnon to Delta, and to NRK in the east. The shallowly-dipping structures are in part located in the footwall of intermediate porphyry and in the hangingwall of the gold-hosting 'W66' foliation zone. The positions of the structures indicate that they were important in the compartmentalisation of gold-stage oxidised and reduced fluids in the mid- to upper-levels of the GRA.

Within the Leviathan model, the amphibole index delineates west-dipping shear zones and E-W trending vein arrays that were mapped underground in Victory during July 2006. The amphibole within these structures is a proxy for reduced fluid flow (Figure a). The Repulse Fault is delineated by Fe-chlorite that, in conjunction with muscovite/paragonite, replaced amphibole alteration. Fe-chlorite and muscovite/paragonite are an acid-reduced style of alteration that reflects the degradation of the fluid with time. Proxies for oxidized fluid – Mg-chlorite and phengite – mainly lie under the Repulse, but the steep amphibole zone breached the latter to allow oxidized fluid through to form pipe-like gold lodes (Figure b). Hyperspectral modelling of REDOX/pH-affiliated mineral assemblages has proven to be a reliable method of tracking fluid pathways to gold mineralisation. Contact Anthony.Roache@goldfields.com.au for further information.



S-N cross-section through Leviathan. Drillhole traces that spectra were collected from are shown in white. a) Steeply-dipping, E-W trending amphibole zone delineated by spectral index dMgOH/dFeOH. The 'wings' on the steep amphibole zone are controlled by a W-dipping amphibole-bearing shear zone. b) Repulse Fault delineated by Fe-chlorite that in conjunction with muscovite/paragonite replaced amphibole. Mg-chlorite and phengite (proxies for oxidized fluid) mainly lie under the Repulse Fault, but the steep amphibole zone breached the latter to allow oxidized fluid (red arrows) through.

Deliverables next quarter

All activities next quarter will be focussed on writing up the project and Kal 07 (delivering previously presented material). The writing will be a challenge as always, with people departing and no-one to backfill. The project leader and others will be ensuring that the Final Report is delivered for desktop publishing by Christmas 2007 ☺

Kalgoorlie 2007 conference: Y4 a major presence

Y4 has a major presence (21-27 Sep) with 10 invited papers (listed below and available on Y4 Twiki) and a pre-conference field trip (draft guide on Y4 Twiki). We will also be presenting a number of posters on numerical modelling, geodynamics and structure, and the pmd*CRC will have a booth, so drop in and meet the team. For more information and registration see http://www.kalgoorlie07.org

Invited Oral Presentations

David Champion: An overview of the Yilgarn Craton and its evolution
Richard Blewett: Tectonic framework of the Eastern Goldfields Superterrane
Ben Goscombe: Constraining the metamorphic history of the Eastern Goldfields Superterrane
Rick Squire: Recent advances in understanding the Black Flag Beds
Paul Henson: How does the 3D architecture of the Yilgarn control hydrothermal fluid focussing?
James Cleverley: Tracing deep fluid sources in the gold deposits of the Eastern Goldfields
Heather Sheldon: Regional scale models: importance of understanding the metamorphic story!
Peter Neumayr: Redox boundaries: a critical parameter in gold genesis?
John Miller: Importance of structural targeting: case studies from the Eastern Goldfields Superterrane
Warren Potma: Understanding deformation and fluid flow modelling: case studies from the Eastern Goldfields Superterrane

Pre-conference Field Trip: Goldfields Structure

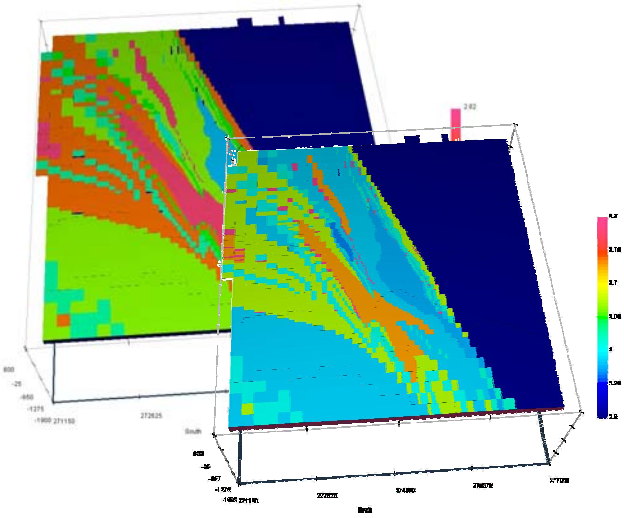
This four-day excursion will traverse the central corridor of the Eastern Yilgarn Super-terrane, and will provide a unique view of the differing styles of mineralisation and the structural setting of some of the 'Goldfields' classic mines. We begin in the west at Lawlers/Agnew and finish east of Laverton, visiting the Leonora district and some granite localities en route.

The aim of the trip is to link gold mineralisation with structure within a new overall geodynamic evolution for the Eastern Yilgarn. This trip will be the first time that non-sponsors of the AMIRA P763-Y1 project be able to see the results. A field guide is being prepared that draws on the P763 report.

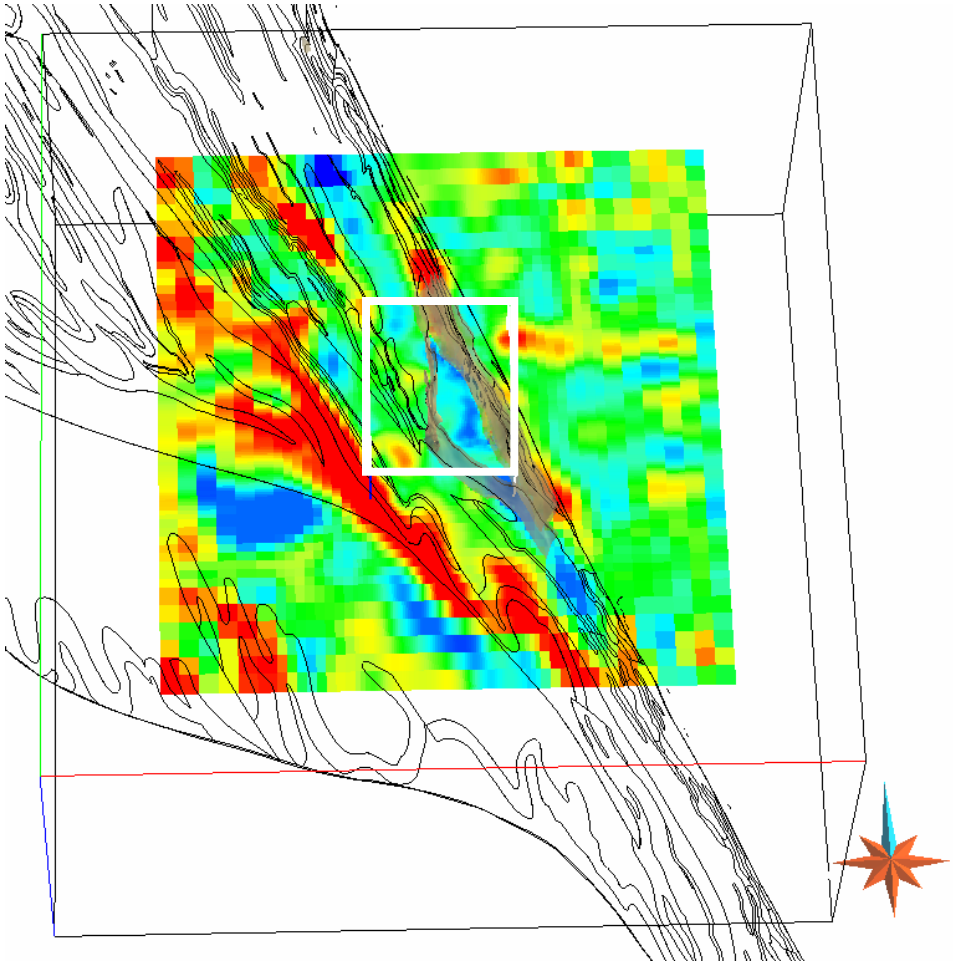
The excursion will demonstrate that there have been multiple gold mineralising events (extensional, compressional and strike-slip, both sinistral and dextral) and that these can be integrated into an overall geodynamic systems understanding through time. One of the aims of the excursion is to challenge the existing structural paradigm by examining its foundations and more generically to examining the first principles by which regional structural event histories are compiled. Inturn we will present a modified regional structural event history primarily based on field relationships integrated with geochronological, geochemical, seismic and map pattern constraints. See https://pmd-twiki.arrc.csiro.au/twiki/bin/view/Pmdcrc/ProjectY4#Kalgoorlie_preconference_field_t for a draft of the field guide.

Towards geologically intelligent inversions at Leinster

Nick Williams is often asked how much time is involved in preparing constrained geological inversions. In three weeks, unassisted, Nick started from raw data, validated and corrected the gravity data processing, developed several large data manipulation utilities from scratch (including a MATLAB map utility), compiled the available physical property data from drilling and field samples into a useful format, built most available geological information into inversion constraints (without needing to building a full 3D model), ran and assessed approximately 30 default and geologically-constrained regional-removal and detailed local inversions, and had to deal with server downtime, software license problems, and other work duties. Given this is just his first-pass for creating these constrained inversions, Nick has produced some interesting models. He suggests that creating useful geologically-constrained inversions should be possible in a matter of days to perhaps a weeks with the right workflow. For more information contact Nick at nwilliams@eos.ubc.ca



Input model of upper and lower boundary constraints (densities) for basement rocks 100 m below surface in a geologically-constrained gravity inversion.



A result from a gravity inversion with the constraints shown above at a depth slice 500 m below surface, as well as interpreted near-surface basement geology linework from BHPB. There is an excellent correlation between the shapes of the density highs (red: mafic rocks) and the interpreted linework. In the centre of the volume (white box) there is a moderate low-density feature corresponding to the known geometry of the serpentinised Perseverance ultramafic lens (shown in transparent wireframes). Volume measures 5.7 km (E-W) × 6.2 km (N-S) × 2.5 km (vertical) and is viewed from the south. No colour bar is shown because Nick is still trying to calibrate the recovered densities to match true rock densities.

List of project events for the quarter

1. Project meetings and Fieldwork

Name	*Date*	*Venue*	*Number of Researchers*	*Number of sponsors*
Curtin SHRIMP RS	28/04-01/05/07	Curtin SHRIMP	1	
Y4 team meeting	2-4/05/07	Perth	20	14
Site Visits DC, RB, KC, PH, AR	5-6/05/07	St Ives	5	3
Fieldwork RB, KC	8-12/05/07	Dry run field trip Kal07	4	
Site visit (RB, KC, PH – CY)	7/05/07	KB	3	1
Fieldwork PH, DC	7/05/07	Coolgardie	2	
Fieldwork RB, KC	13/5/07	Kunanalling	2	
Fieldwork RS	14-18/05/07	St Ives		
Fieldwork RS	18-25/05/07	Agnew	1	
Fieldwork JM	29/05-1/06/07	St Ives	1	2
Cazaly reporting Kunanalling (RB, KC)	12/06/07	Perth	2	3
Fieldwork RS	25-29/06/07	St Ives	1	
Fieldwork, JW, AR, CY	16/04 until 18/04	Wallaby	3	4
Sponsor visit, JW, CY, PN	19/04 until 20/04	Lawlers, Darlot	3	15
Fieldwork, JW, PN, AR,	23/04 until 26/04	St. Ives	3	5
Fieldwork JW, PN, AR	28/05 until 31/05 John until 01/06	St. Ives	3	5
I7 meeting and collaboration JW	18/06 until 30/06	Townsville, Canberra	1	

2. Workshops

Name	Date	Venue	Number of researchers	Number of sponsors
Interpretation of primary volcano-sedimentary textures in drillcore & interpretation of geochem data, RS	05/04/07, 18/05/07 and 25/05/07	St Ives	1	1
3D IVEC	01/06	ARRC	1	
Report writing planning WS, RB, JW, PN,	12/06	ARRC	4	
Modelling discussion	18/05	ARRC	5	

3. Conferences/Symposia

Name	Date	Venue	Number of researchers	Number of sponsors
Proterozoic Mineralisation of WA (RB, KC)	11/06/07	Perth	2	
GAC-MAC (NW)	22-25/05/07	Yellowknife, Canada	1	0

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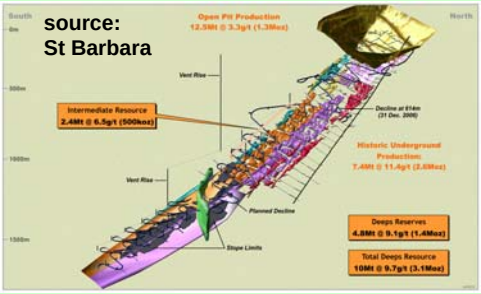
The extensional gold system at Sons of Gwalia extends for >2 km down plunge the extensional stretching lineation. It has an extreme aspect ratio (like a ruler shape) that was controlled by perturbations on the edge of the Raeside Batholith. Exploration strategy is to find a granite dome with a bump, identify the stretching direction and walk this direction to the greenstones. Expect to drill deep and think about steep sections of C' planes (see Twiki for more ideas on this style of mineralisation).