

South Australian Uranium Mineral Systems: A spectrum of mineralisation across the ages and across styles.

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PACE

plan for accelerating exploration

HOT PROSPECTS



Government of South Australia
Primary Industries and Resources SA

www.minerals.pir.sa.gov.au

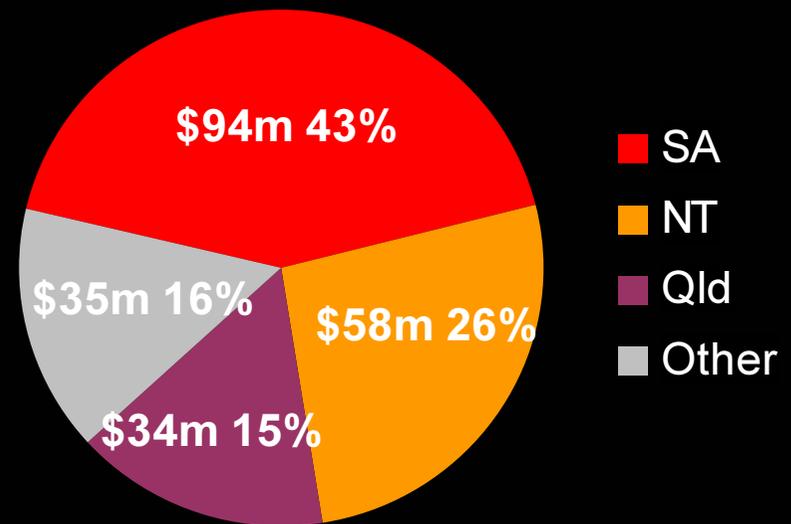
Overview

- Update of Existing Uranium Mining Operations
- Exploration Projects to Watch
- Exploration Overview
- Mineral Potential Modelling (IOCG±U)
- Summary



Uranium exploration expenditure in Australia - 2008

- South Australia continued to lead the nation as the primary state to explore for uranium in 2008.
- Expenditure for uranium exploration in 2008 was \$94 million accounting for 43% of Australia's total uranium exploration expenditure.
- Hosts two of Australia's three uranium mines, Olympic Dam & Beverley, with a third under construction at Honeymoon.
- Recent discoveries include:
 - Four Mile (Quasar & Alliance Resources)
 - Hillside (Rex Minerals)
 - Mullaquana (Uranium SA)





Uranium deposits

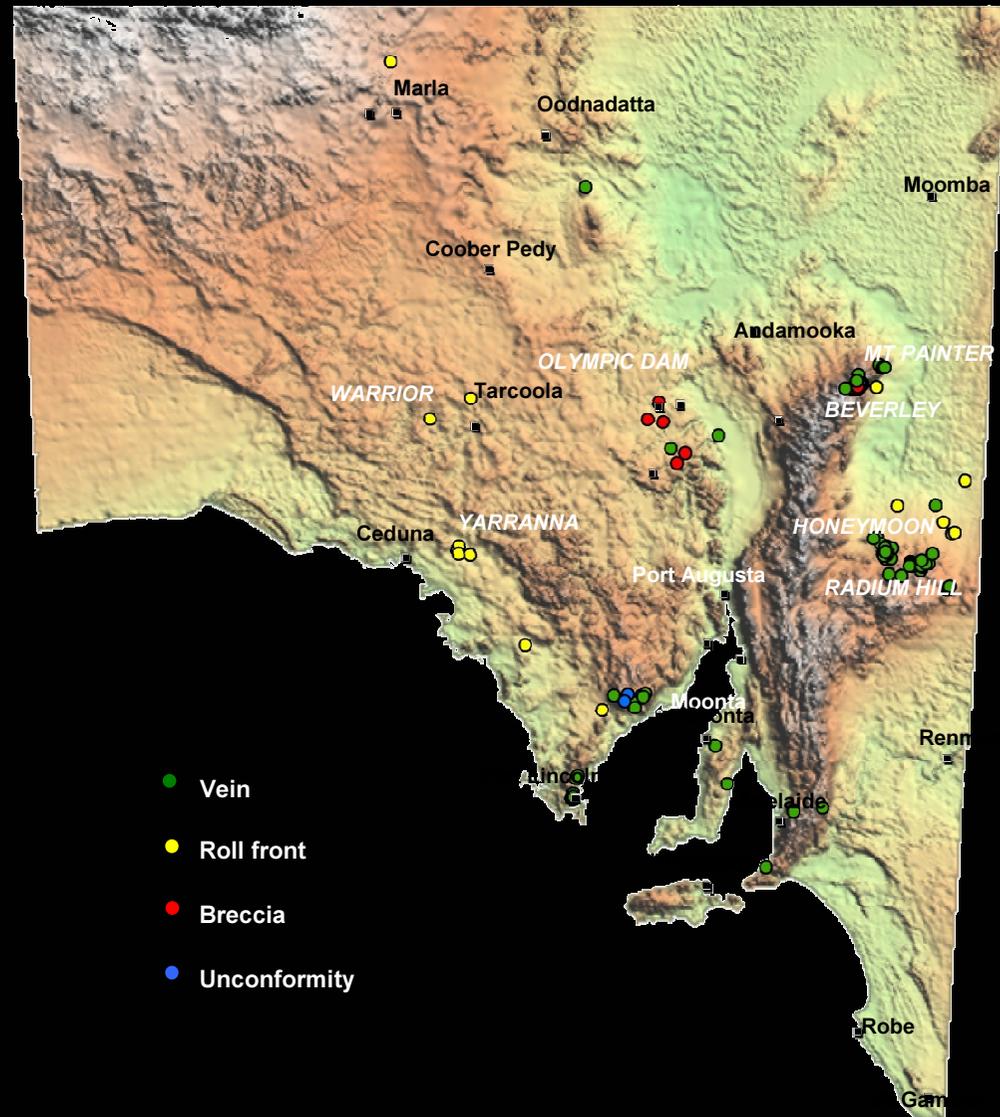
- 1 Acropolis
- 2 Beverley
- 3 Crocker's Well
- 4 Emmie Bluff
- 5 Goulds Dam
- 6 Honeymoon
- 7 Mount Painter
- 8 Myponga
- 9 Oak Dam
- 10 Olympic Dam
- 11 Radium Hill
- 12 Warrior
- 13 Wirrda Well
- 14 Yarranna 1

FIGURE 1: Geology and uranium deposits of South Australia



TYPES OF URANIUM DEPOSITS (known and potential)

- Breccia complex e.g. OD
- Sandstone(roll-front) e.g. Beverley, Honeymoon, Warrior
- U/C redox related?
- Vein style e.g. Crocker Well, Radium Hill
- Calcrete-hosted?



Olympic Dam – Copper-Gold-Uranium-Silver

BHP Billiton Ltd

Olympic Dam

- Largest uranium deposit, fourth largest remaining copper deposit and fifth largest gold deposit in the world. Also contains significant quantities of silver.
- Total Resource 8339 Mt at 0.88% Cu, 0.028% U₃O₈, 0.31 g/t Au and 1.5 g/t Ag
 - Gold only (non-sulfide) resource 151 Mt at 1.0 g/t Au.
- Reserve (ore) 399 Mt at 1.87% Cu, 0.058% U, 0.68 g/t Au and 4 g/t Ag.
- Production 2007/08 – 170 000 t Cu, 4144 t U₃O₈, 780 000 oz Ag, 80 517 oz Au.



www.bhpbilliton.com

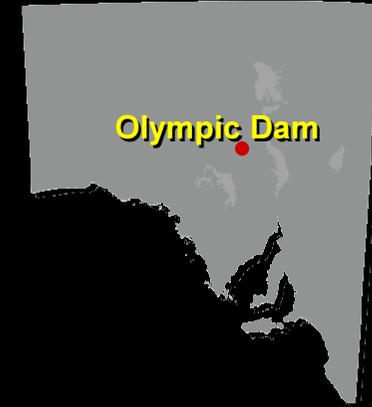


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***Olympic Dam* – Copper-Gold-Uranium-Silver**

BHP Billiton Ltd



CURRENT ACTIVITIES:

- Expansion study continuing.
- Full Environmental Impact Statement released May 2009.
- Full production is set down for 2014.
- New 60 Mtpa Olympic Dam will have an approximate annual production of:
 - 750 000 t Cu, 19 000 t U₃O₈, 800 000 oz Au, 2 900 000 oz Ag.



www.bhpbilliton.com



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Olympic Dam – Copper-Gold-Uranium-Silver BHP Billiton Ltd

Olympic Dam

Olympic Dam – open pit outline compared to
Adelaide Central Business District



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Beverley Mine – Uranium **Heathgate Resources Ltd**



- Largest in-situ leach operation in the world.
- Total Resource 7.7 Mt at 0.27% U_3O_8 for a contained commodity of 21 000 t U_3O_8 .
- Production 2007/08 – 719 t U_3O_8 .
- Expansion of the Beverley Uranium Mine approved August 2008.

CURRENT ACTIVITIES:

- Successful exploration has continued in the east and south of the current mineral lease as part of the Beverley Expansion.



www.heathgateresources.com.au



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Honeymoon – Uranium

Uranium One Inc – Mitsui & Co. Ltd



- Construction commenced, production to commence in 2010.
- Indicated Resource 1.2 Mt at 0.24% containing 2900 t (6.5 Mlb) U_3O_8 .
- Estimated annual production of 400 t U_3O_8 .
- Deposit occurs as five discrete mineralised sand packages in the Yarramba Palaeochannel.
- Structural influence to mineralisation.



www.uranium1.com



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***Four Mile* – Uranium**

Quasar Resources – Alliance Resources Ltd



- Tertiary sandstone-hosted mineralisation in two distinct zones: Four Mile West and Four Mile East.
- Inferred resource of 3.9 Mt at 0.37% U_3O_8 containing 15 000 t U_3O_8 .
- Mining Lease Application submitted in May 2008.
- First Stage mining proposed for early 2010.
- Production estimated between 680-2045 tpa U_3O_8 .



www.quasarresources.com.au
www.allianceresources.com.au



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***Crocker Well – Mt Victoria* – Uranium** **PepinNini Minerals Ltd – Sinosteel**



- Inferred JORC compliant resource 12.5 Mt at 0.5 kg/t (0.05%) U₃O₈ (cut off grade 300 ppm).
- Production scheduled to commenced in 2011.
- Mineral lease application submitted to investigate production of ~ 600 t of U₃O₈ for at least 10 years.



www.pepinnini.com.au



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Projects to Watch

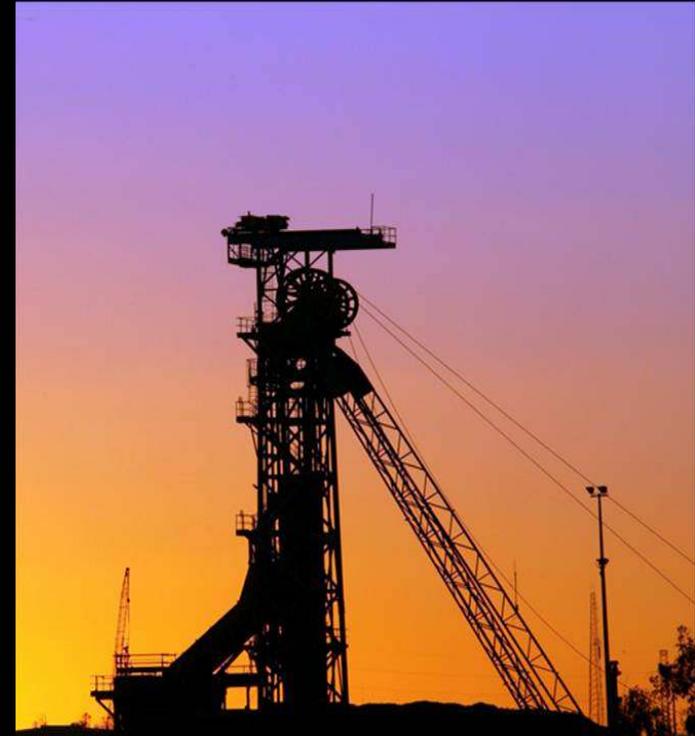


- **Yarranna – 1:** 8m at 626ppm U_3O_8 .
- **Goulds Dam:** Indicated resource 1.7 Mt at 0.12% containing 2000 t U_3O_8 .
- **Oban:** Drillhole CEY376 intersected >5m (above 100ppm e U_3O_8) grade thickness of 0.28m% e U_3O_8 .
- **Mt Gee:** Inferred 51 Mt at 615ppm for 31 400t U_3O_8 .
- **Hillside:** 18m @ 297ppm U_3O_8 , 2m @ 887ppm U_3O_8 .
- **Mullaquana:** Pirie Basin, Eyre Peninsula. Inferred resource estimate 12 Mt at 0.02% e U_3O_8 for 2700 t U_3O_8 .



Undiscovered Resources

- Where to from here?
- “how “to from here?
- Mineral Deposit Models and/or Mineral Systems modelling?



Uranium Deposit Classification

1. UNCONFORMITY-RELATED
2. SANDSTONE
3. QUARTZ-PEBBLE CONGLOMERATE
4. VEIN
5. BRECCIA COMPLEX
6. INTRUSIVE
7. PHOSPHORITE
8. COLLAPSE BRECCIA PIPE
9. VOLCANIC
10. SURFICIAL
11. METASOMATITE
12. METAMORPHIC
13. LIGNITE
14. BLACK SHALE
15. OTHERS



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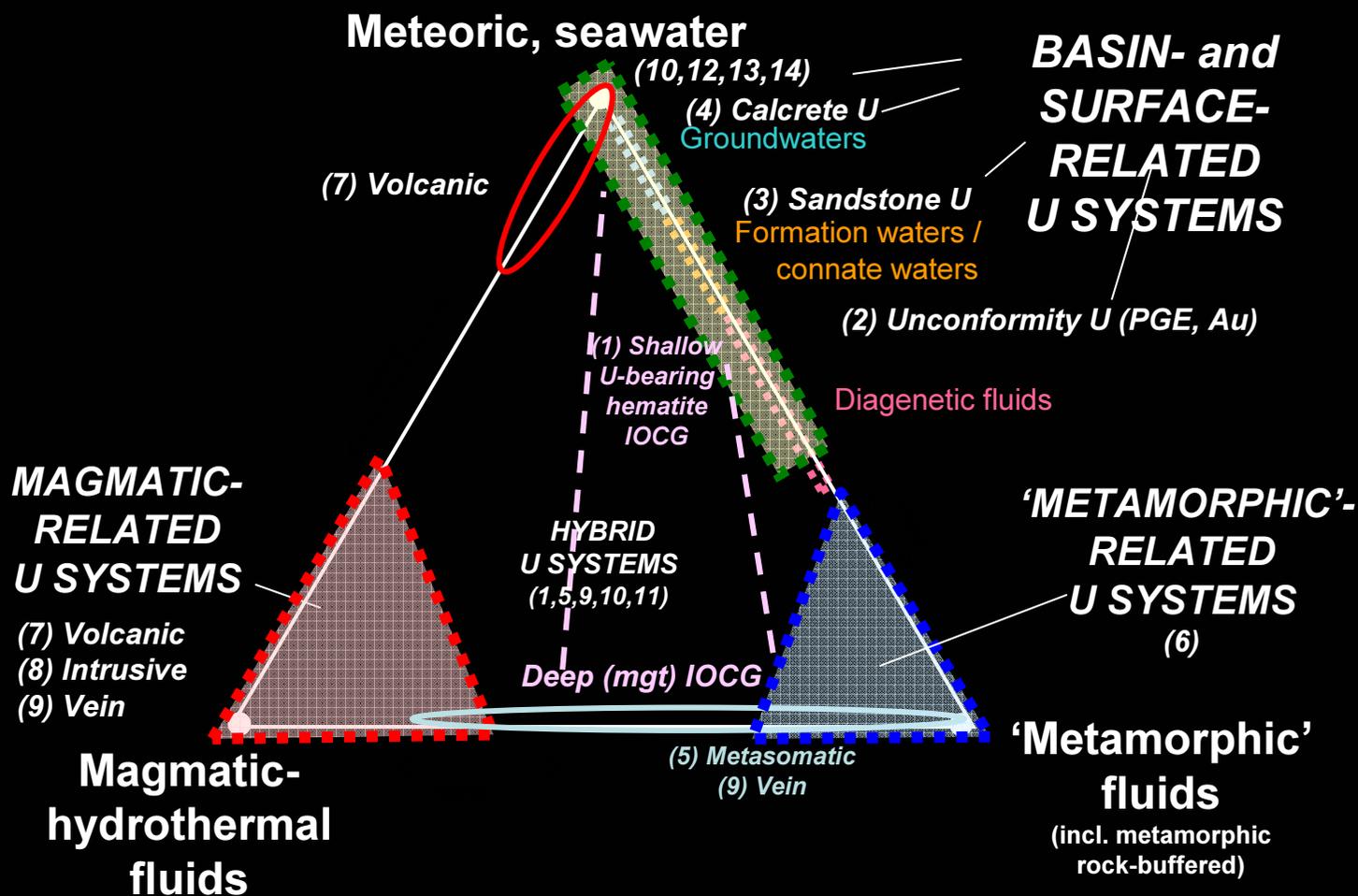


Mineral Systems

- Based upon understanding all the geological ingredients which comprise the mineral system, and how they vary and relate to each other..... PROCESSES!
- One side effect of utilising the Mineral Systems approach and concentrating on processes is that we are forced to consider related deposit types through time and space
- Case study - Regional IOCG±U potential, particularly using geophysics in areas of limited outcrop (which should work in outcropping areas)



URANIUM MINERAL SYSTEMS and FLUIDS



(#) represent deposit types from IAEA Red Book & Dahlkamp (1990). Skirrow et al, 2009, Geoscience Australia



Mineral Systems

- Based upon understanding all the geological ingredients which comprise the mineral system, and how they vary and relate to each other..... PROCESSES!
- One side effect of utilising the Mineral Systems approach and concentrating on processes is that we are forced to consider related deposit types through time and space.
- We can then delineate the consequences of these processes as mappable criteria
- In SA we can map criteria for sandstone-hosted, unconformity related and IOCG±U potential, particularly using geophysics in areas of limited outcrop (which should work in outcropping areas)



Mineral Systems

- Mappable criteria



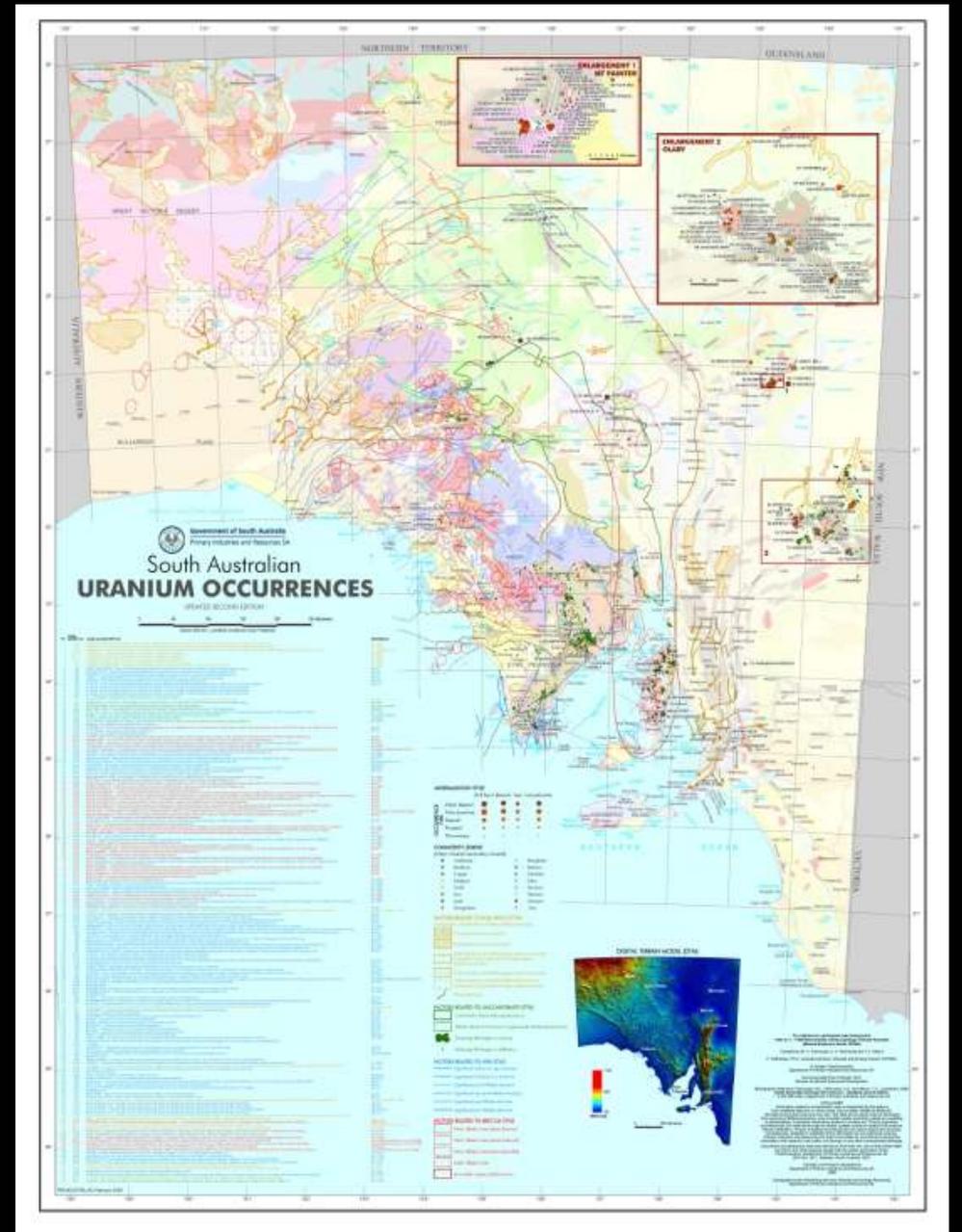
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Uranium Occurrences Map

- Known uranium occurrences and significant geological parameters for each deposit type have been collated and represented spatially as 'key ingredients' maps.
- First step in predictive modelling for different uranium deposit types:
 - IOCG±U
 - Groundwater gradients, chemistry and distance from source.
 - Basement controlling structures.
 - Pandurra Formation 3D Model.

Fairclough, M.C., McAvaney, S.O. and Wilson, T.C. (compilers) 2009. South Australian Uranium Occurrences – Updated second edition. 1:2 000 000 scale. Department of Primary Industries and Resources SA.



Mineral Systems

- In detail for hard rock systems.....



Iron Oxide - Copper - Gold ± Uranium

Hiltaba Intrusions

Gawler Range
Volcanics

44 000sq km

Prominent Hill

Olympic Dam

Carrapateena

Moonta - Wallaroo

Hillside

ADELAIDE

200 km



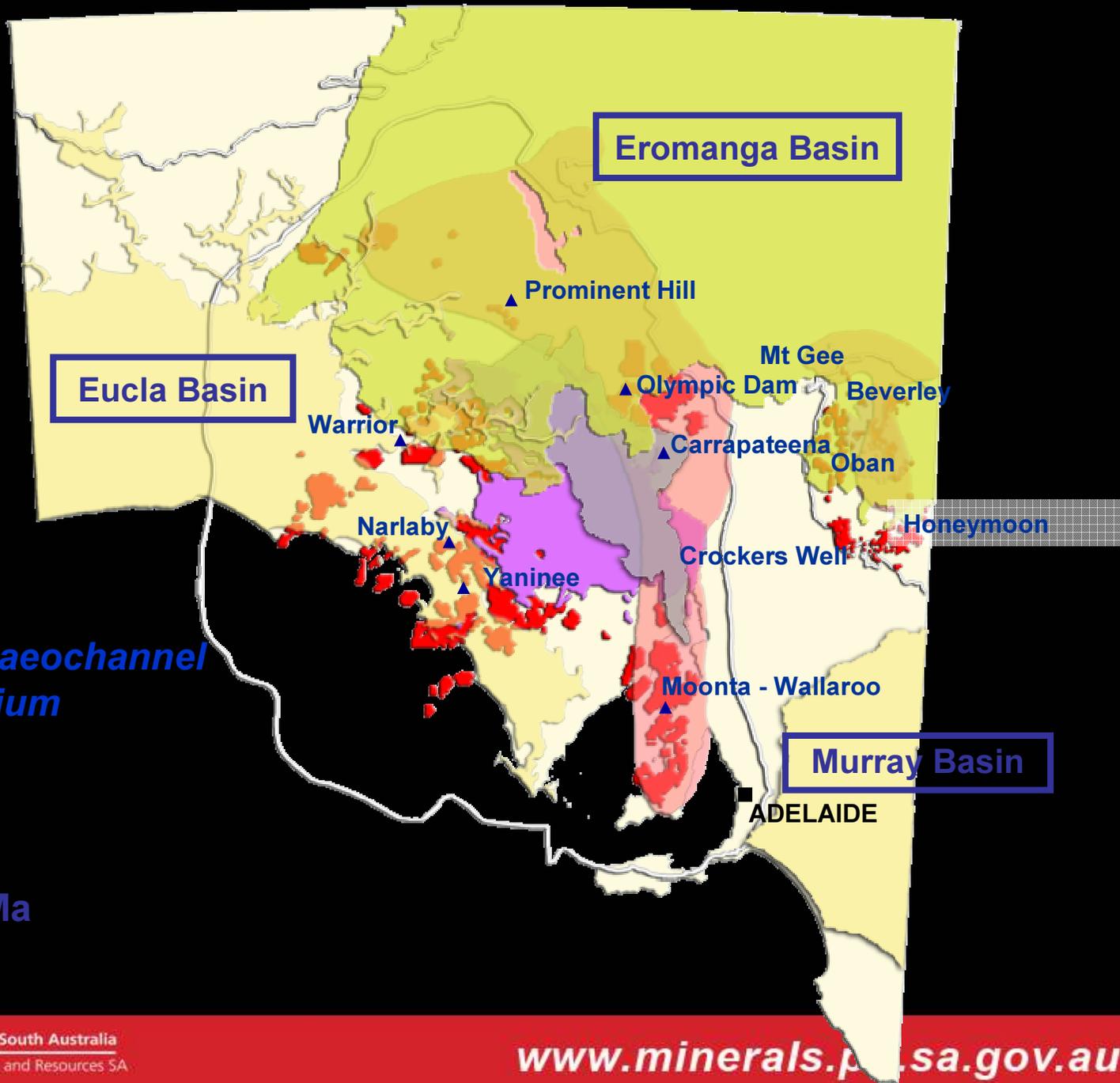
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Mineral Systems

- In detail for soft rock systems.....





*Rollfront/ Palaeochannel
Uranium*

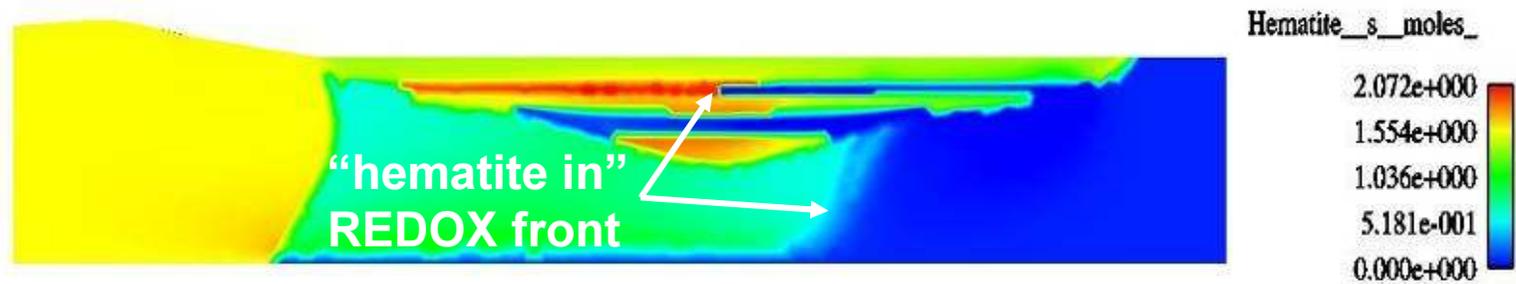
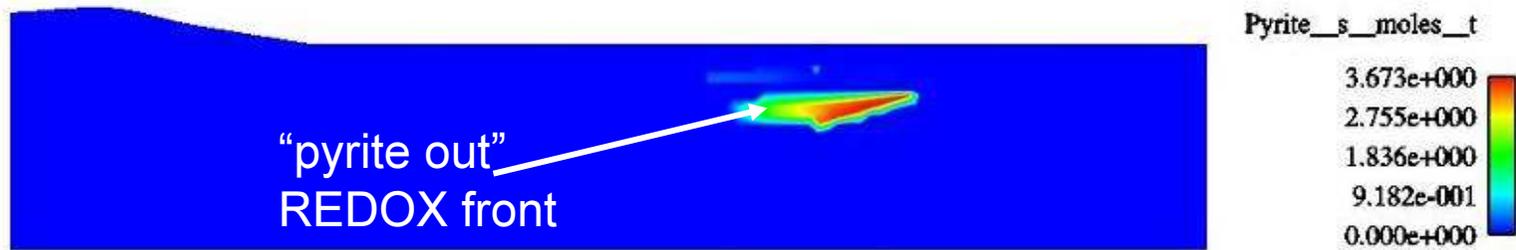
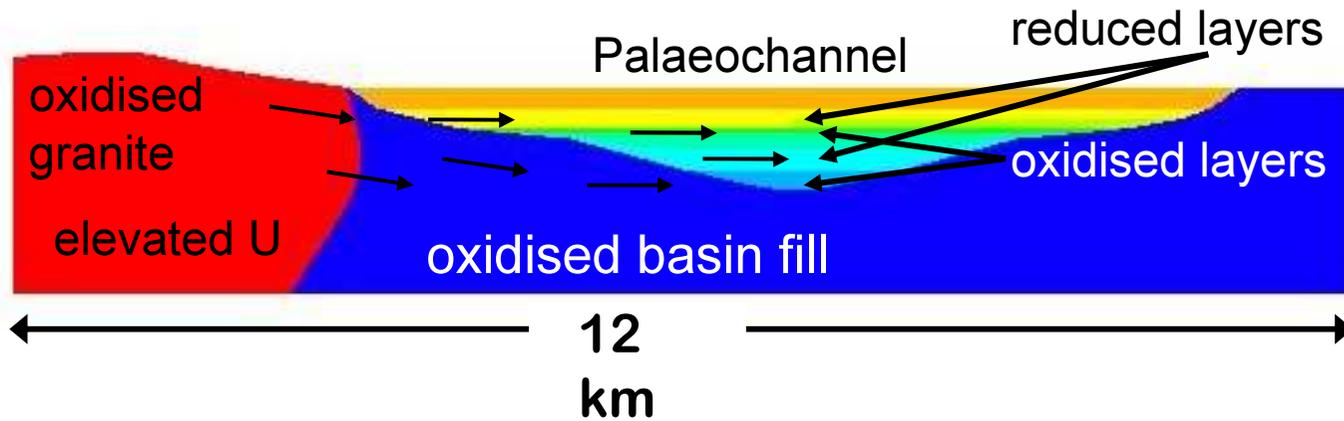
~ 55 to 2 Ma



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Reactive Transport Modelling

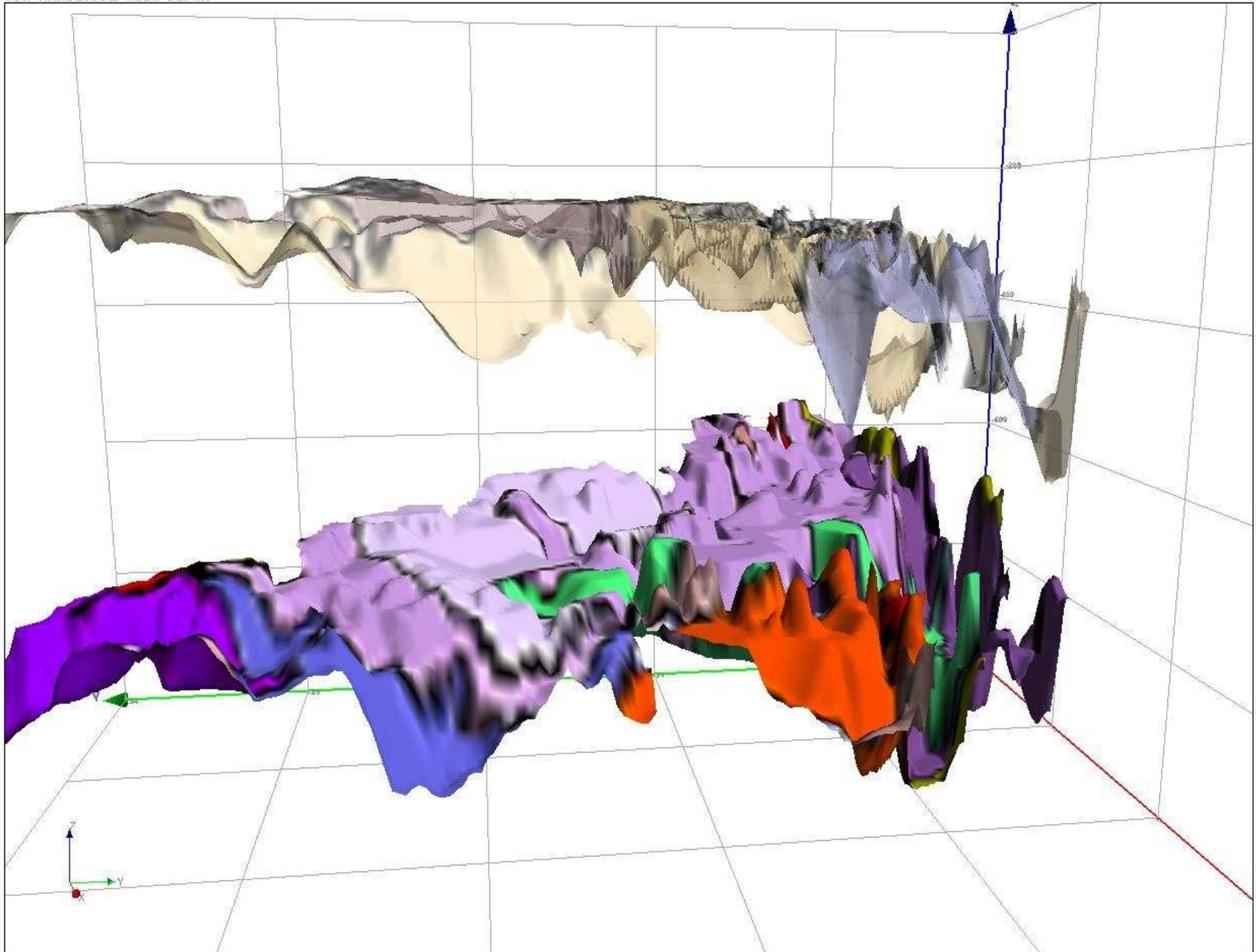


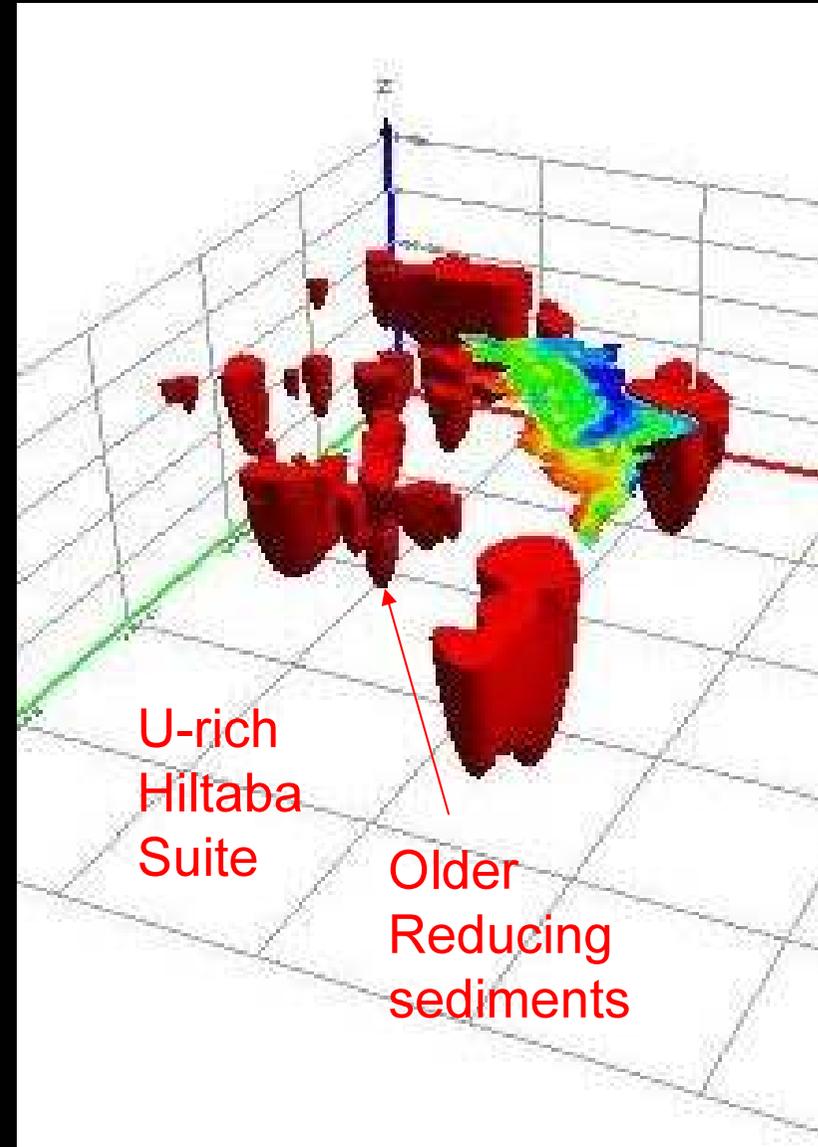
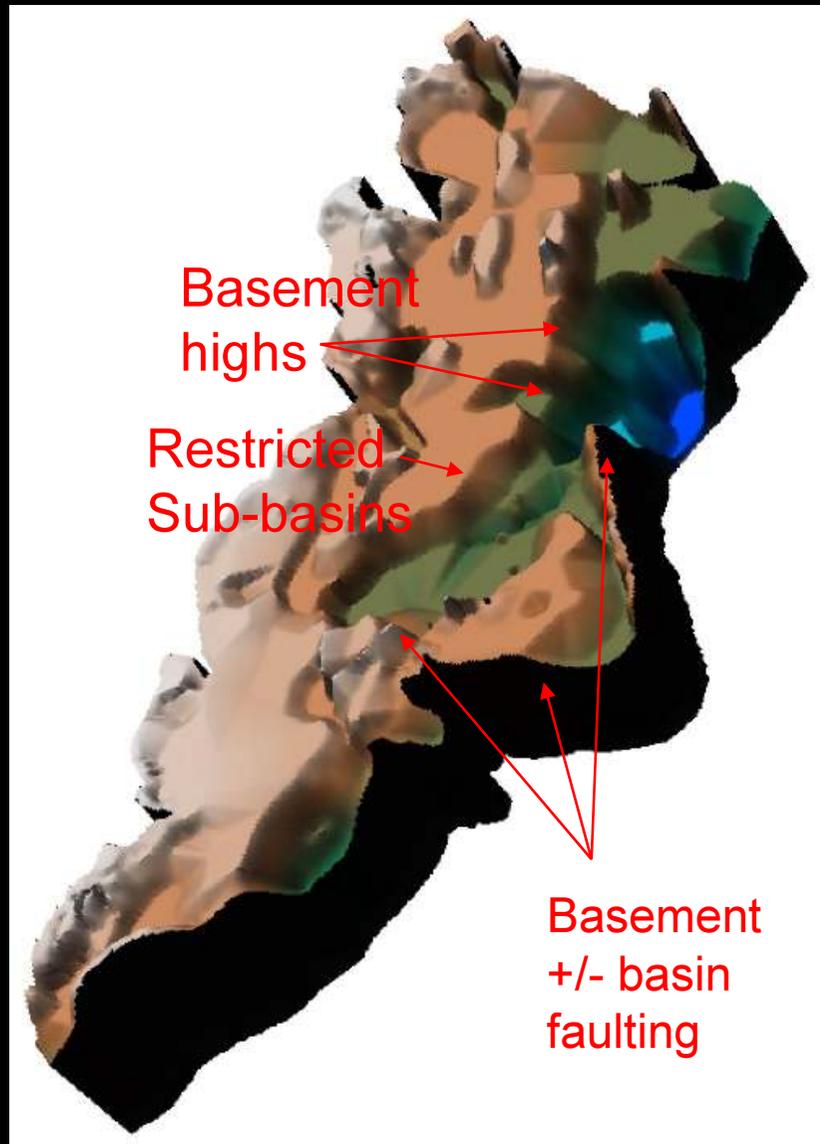
Mineral Systems

- In detail for hard/soft rock systems.....



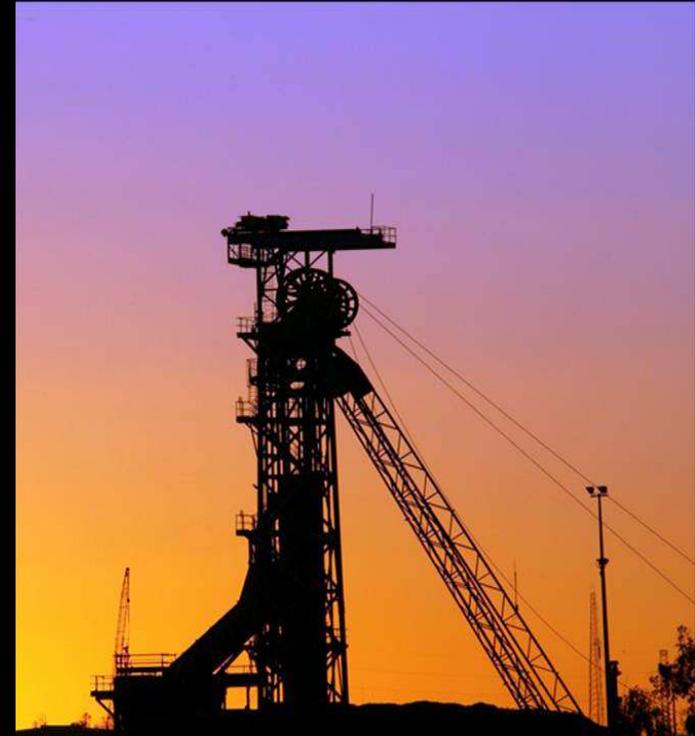
TOP PANDURRA2 TEST DEPTH





Mineral Systems

- In detail for IOCG systems.....



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Deposit Style

Proterozoic Fe Oxide-Cu-Au+/-U Deposits.

- Examples of this style of deposit include Olympic Dam, Henry, Starra, La Candelaria, Osborne. The major districts of these deposits in Australia are the Gawler Craton (South Australia), Mt Isa Eastern Succession (Queensland) and the Chile Coastal Belt.

Important characteristics for this class include Age, Tectonic Setting, Association with Igneous Activity, Structural Control, Morphology

- Three of the most important are alteration, mineralogy and structure
 - Host rocks are intensely altered (sodic potassic, potassic or hydrolytic alteration)
 - Abundance of Fe-oxide (not iron sulphides) and a suite of metals that may include U, Cu, Au, Ag, Mo, Co, As, Zn and minor REE's
 - Strong potential field characteristics – easily mappable!



Reduced

Oxidized

Ernest Henry

- Magnetite
- K-feldspathization
- Cpy
- Breccia-hosted
- Minor shearing

Sue Dianne

- Hematite
- K-feldspathization
- Cpy-Bnt
- Breccia-hosted

Olympic Dam

- Hematite
 - Sericitization
 - Cpy-Bnt-Cct
 - Breccia-hosted
-

High T

Deep (5-6 km)

Low T

Shallow (<2 km)



Olympic Dam

Geology and structure

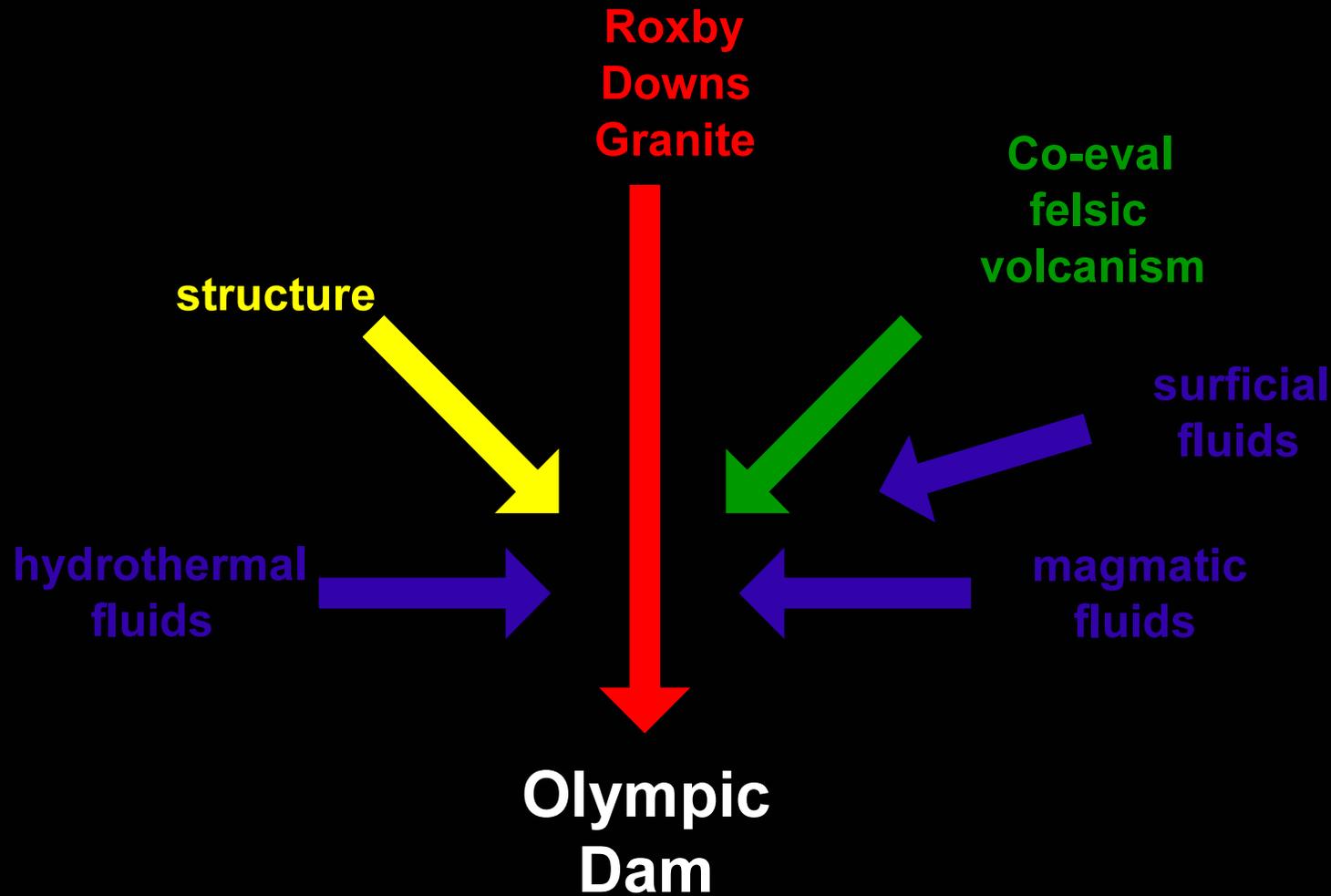


Roxby Downs Granite	Haematite-matrix-rich granite breccias	Barren quartz - haematite breccias	
Granite and granite breccias	Heterolithic granite and haematite breccias	Volcaniclastics	
Granite-rich breccias	Haematite-rich breccias		

From Reynolds (2001) 201035-006

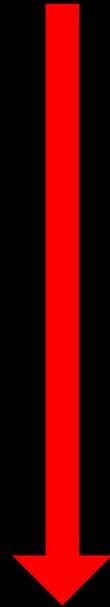


Contributors to the formation of Olympic Dam



Contributors to the formation of Olympic Dam

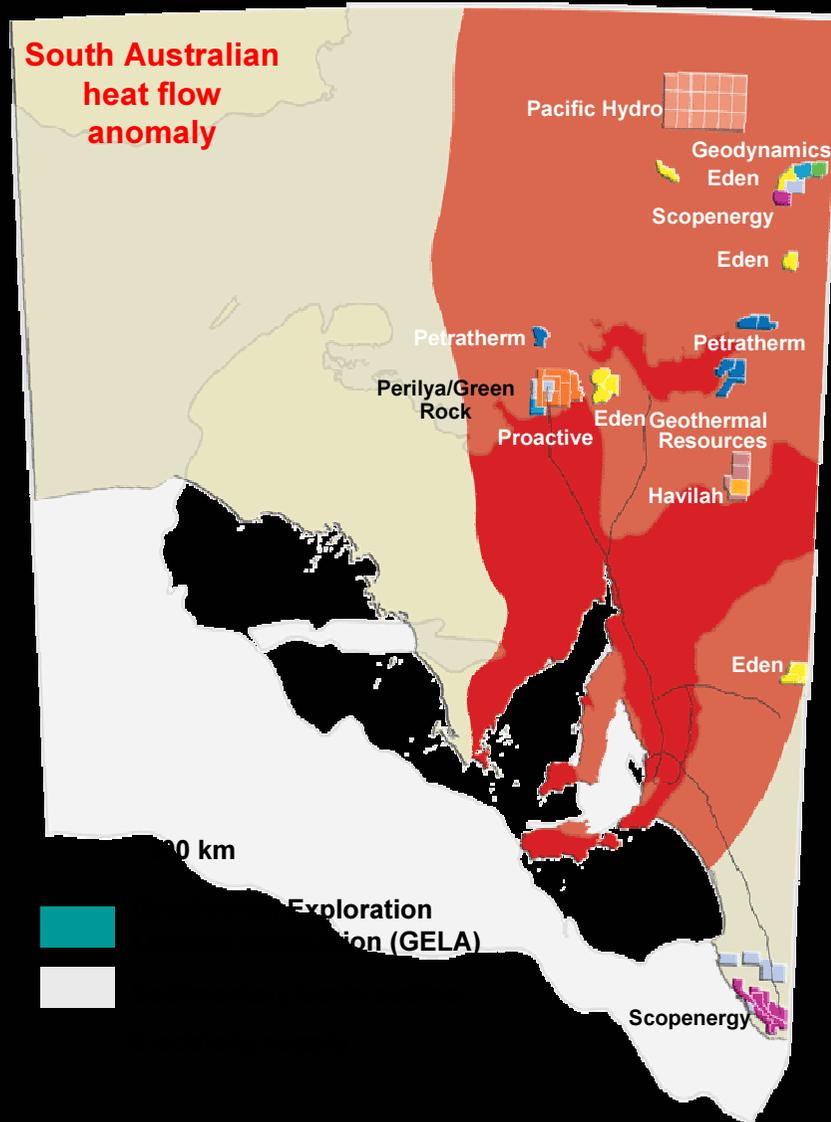
**Roxby
Downs
Granite**



**Olympic
Dam**



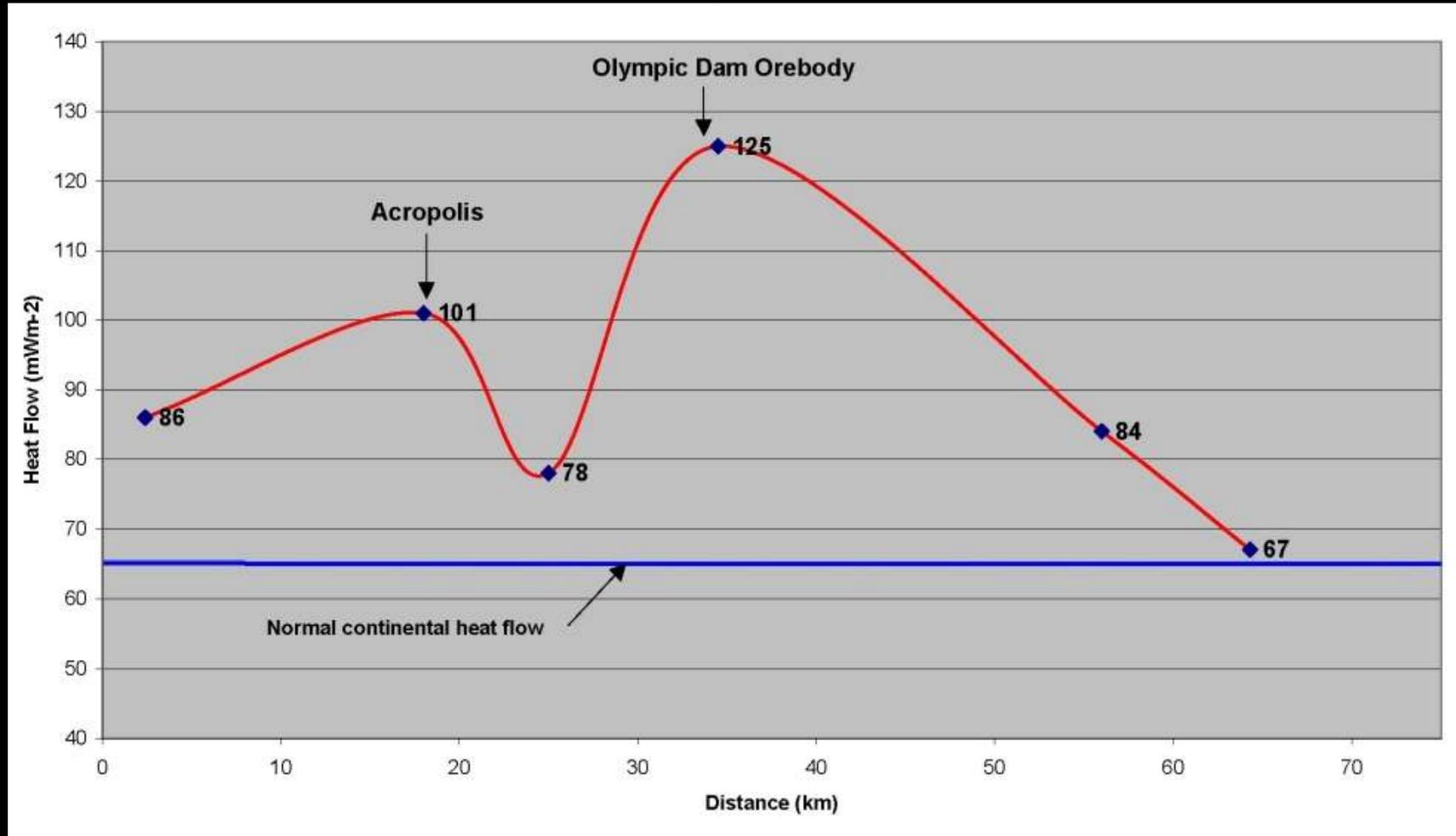
HOT GRANITES



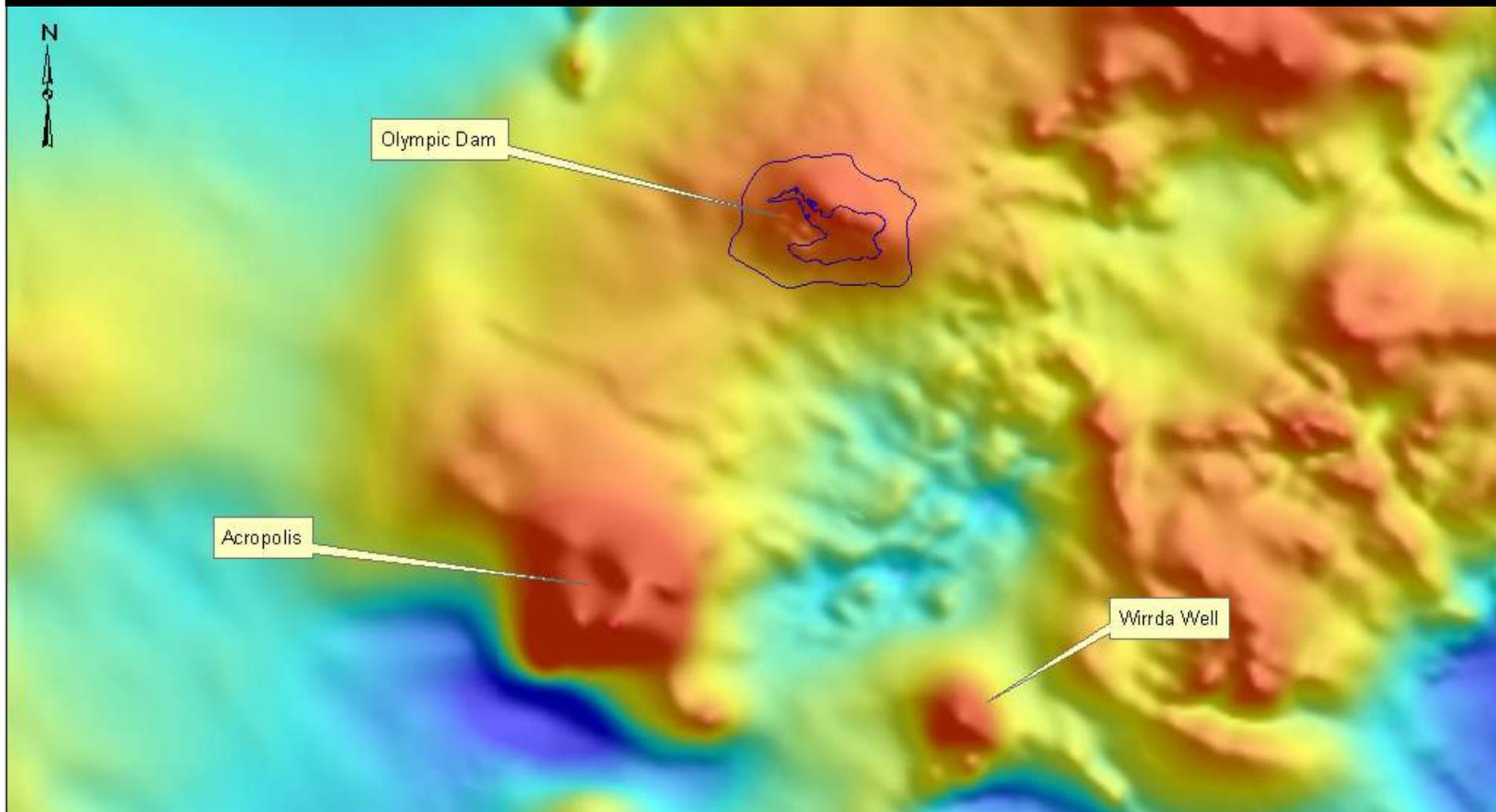
- 9 Geothermal Licensees or applicants
- 60 Geothermal Exploration Licences over 27,968 km²
- Only some will eventuate – but the total indicative 5-year work programs correspond to more than \$400 Million
- Just 1 GEL has hot rock emission-free energy potential to yield electricity equivalent to several Snowy Mountain Hydro Schemes
- 1 SM approx 550 MWe



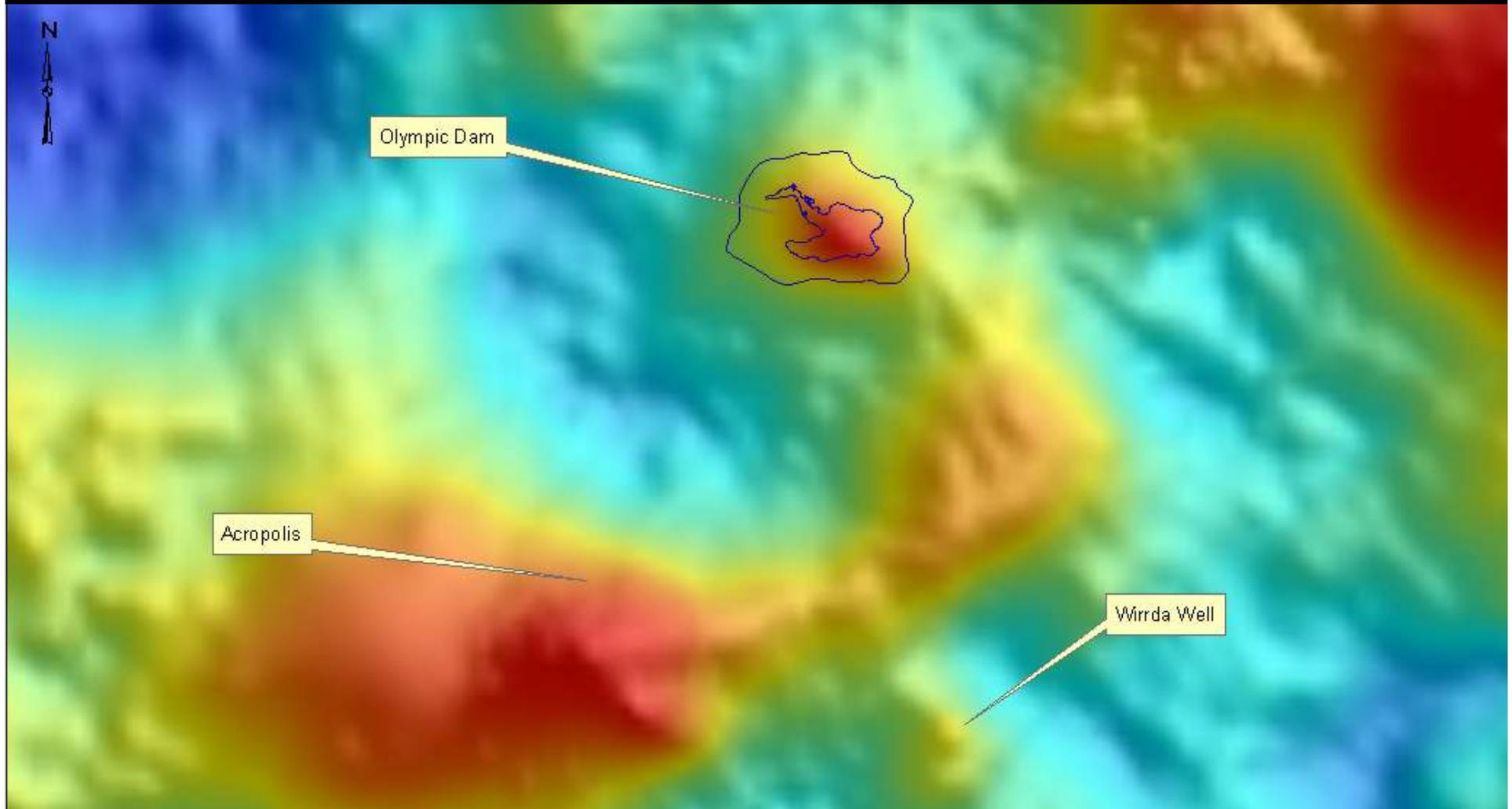
HOT GRANITES



POTENTIAL FIELD - MAGNETICS



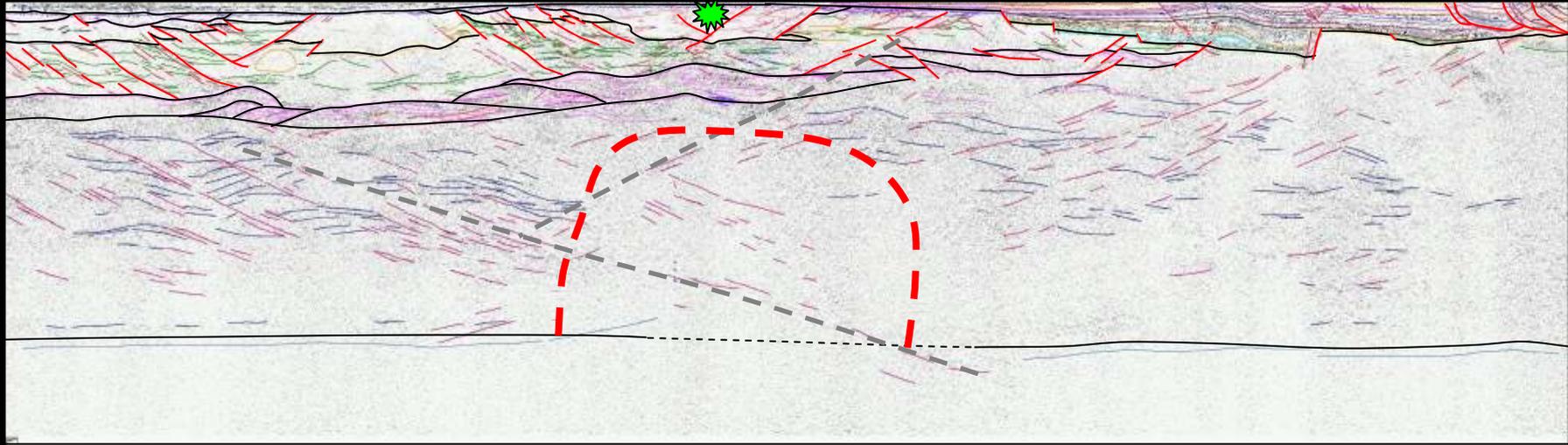
POTENTIAL FIELD - GRAVITY



S

N

OD



V=H

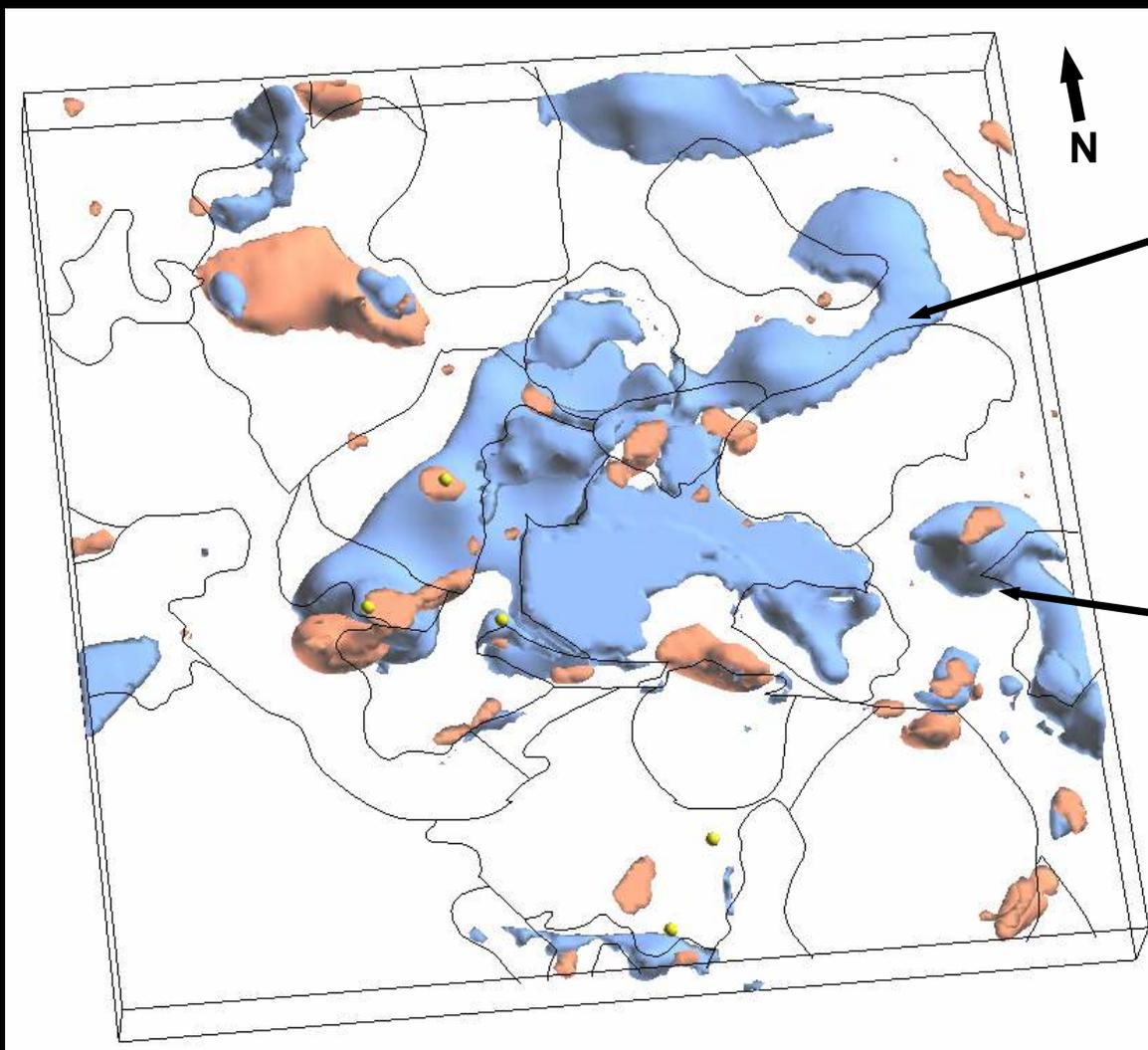
50 km



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POTENTIAL-FIELD INVERSION



1.5% “magnetite”

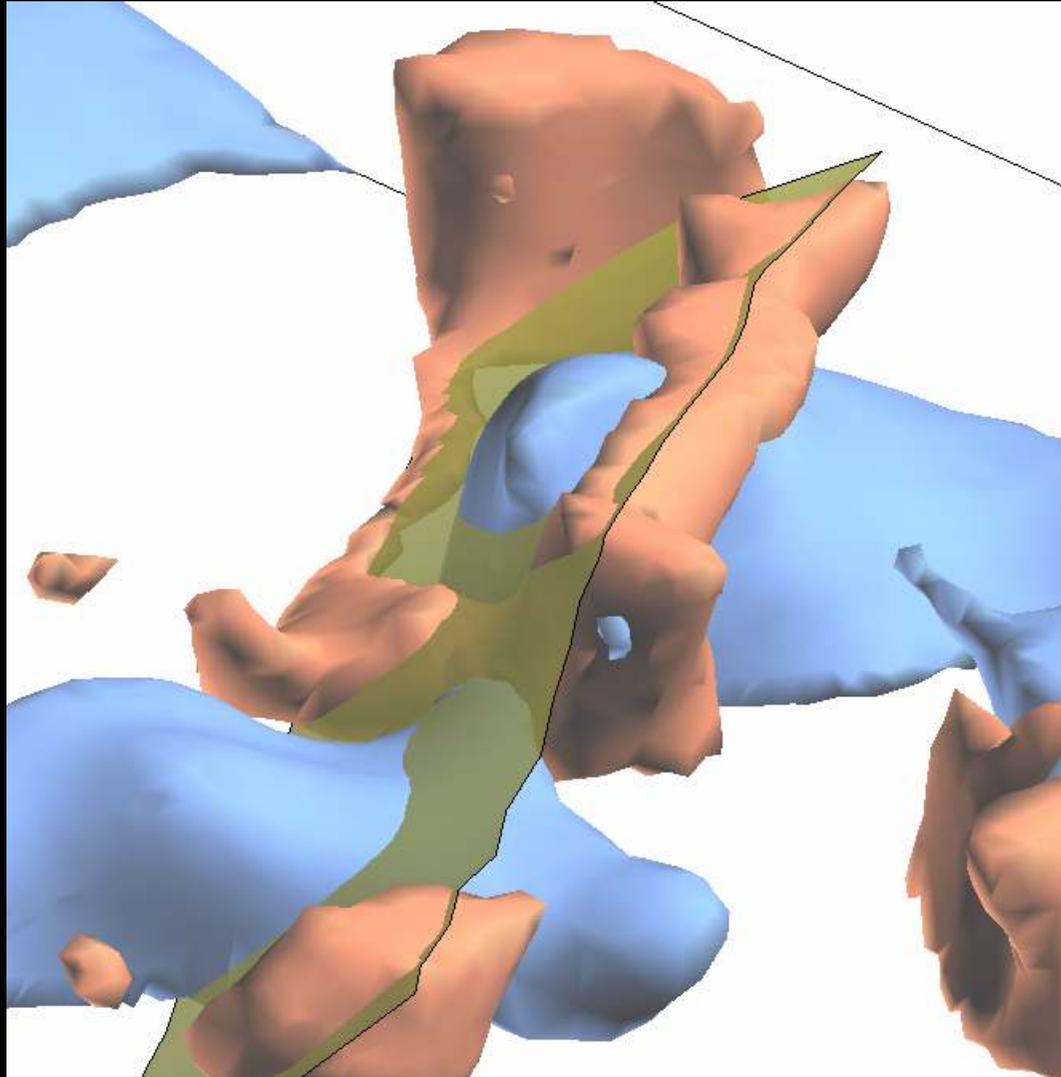
Includes all susceptible minerals as their magnetite equivalent

0.5% “hematite”

Includes hematite, sulfides, other dense minerals, and remanent magnetisation



POTENTIAL-FIELD INVERSION

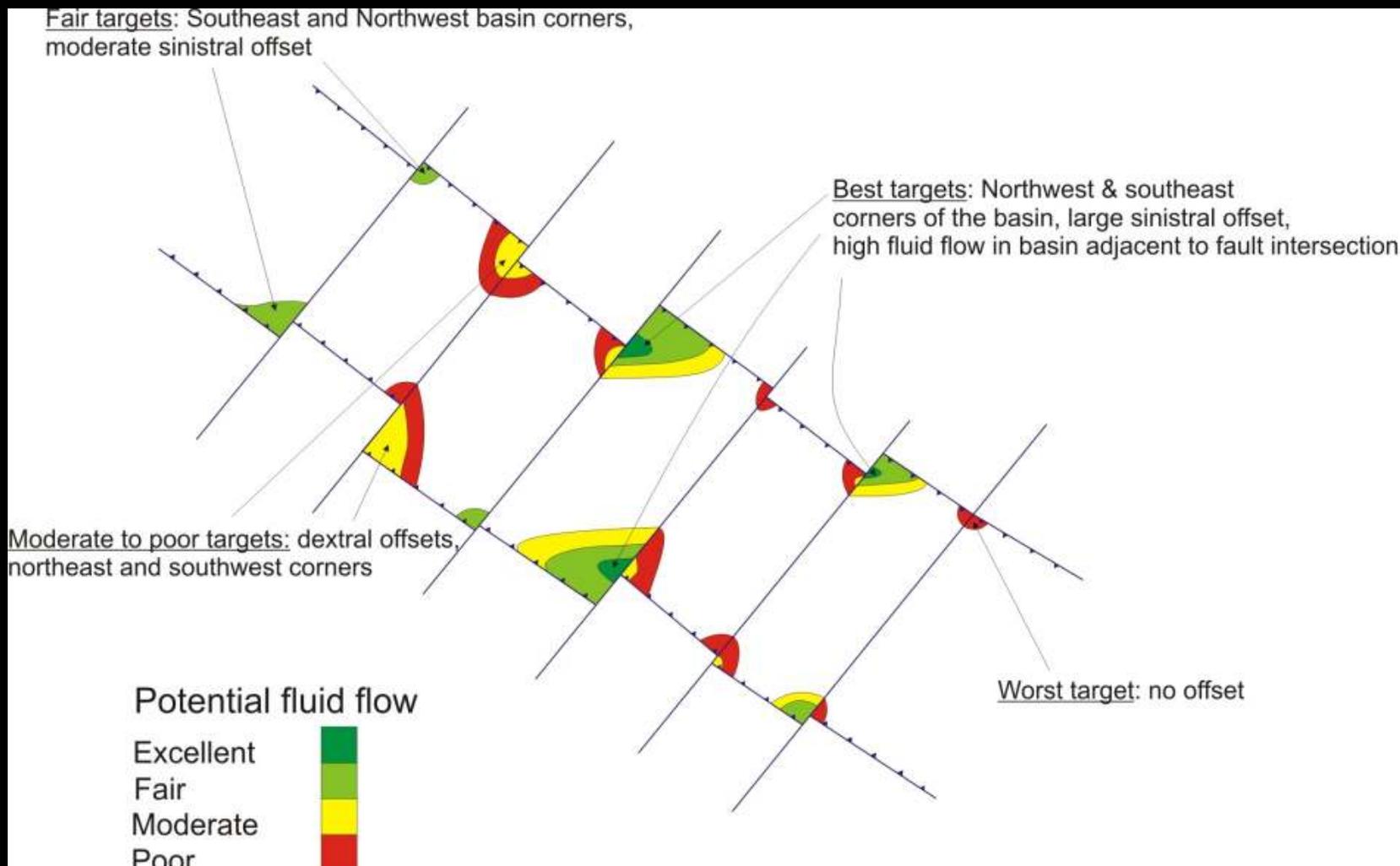


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10 km

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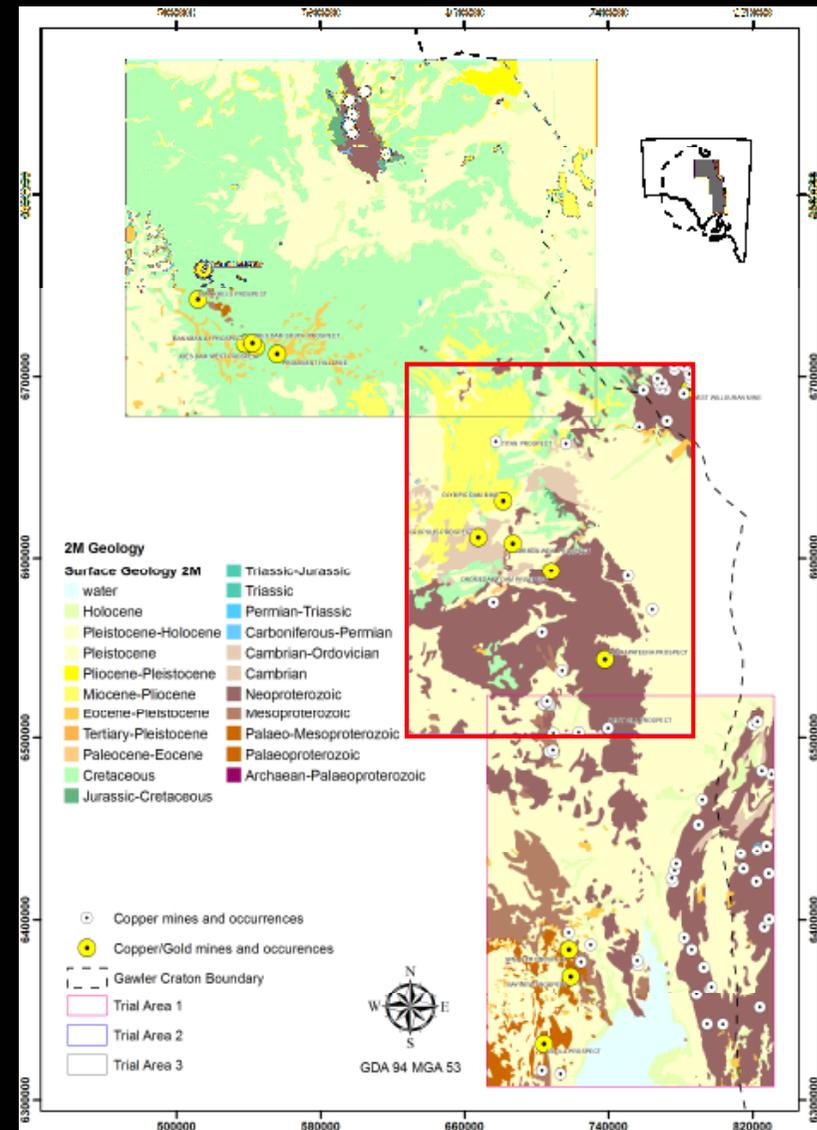
Targeting of zones of high fluid flow eastern Gawler Craton



Mineral Potential Modelling

IOCG±U Potential – Method

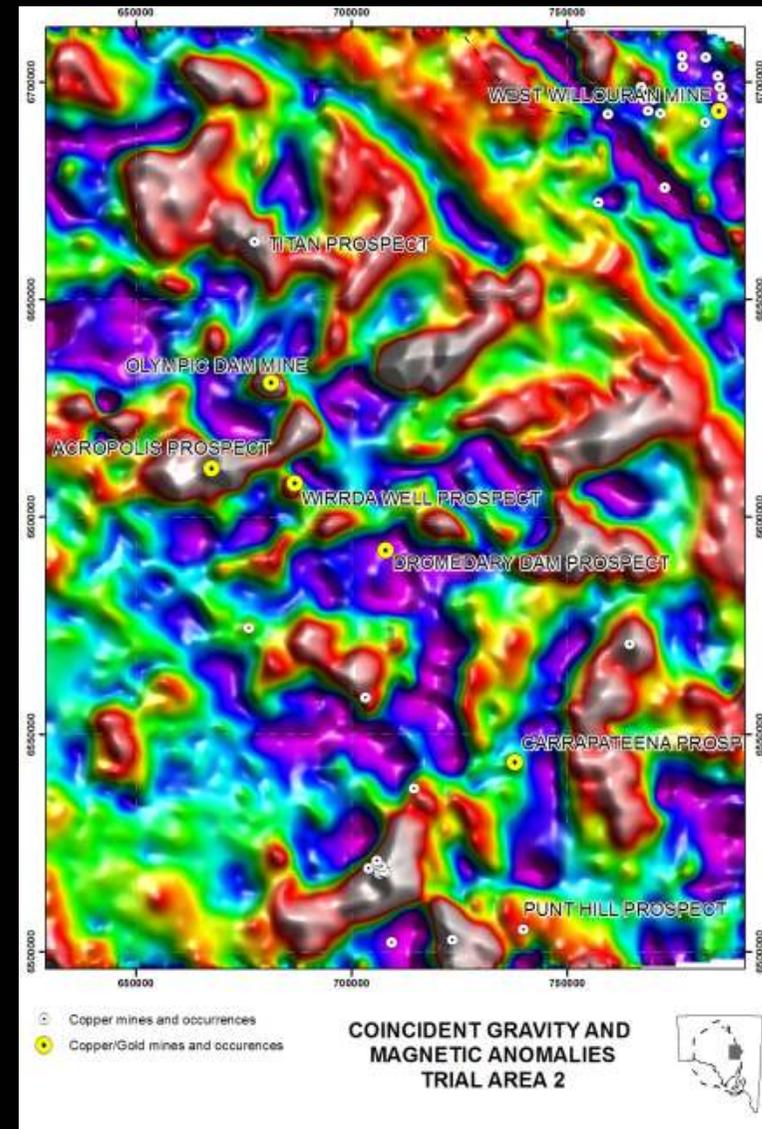
- Area selection.



Mineral Potential Modelling

IOCG±U Potential – Method

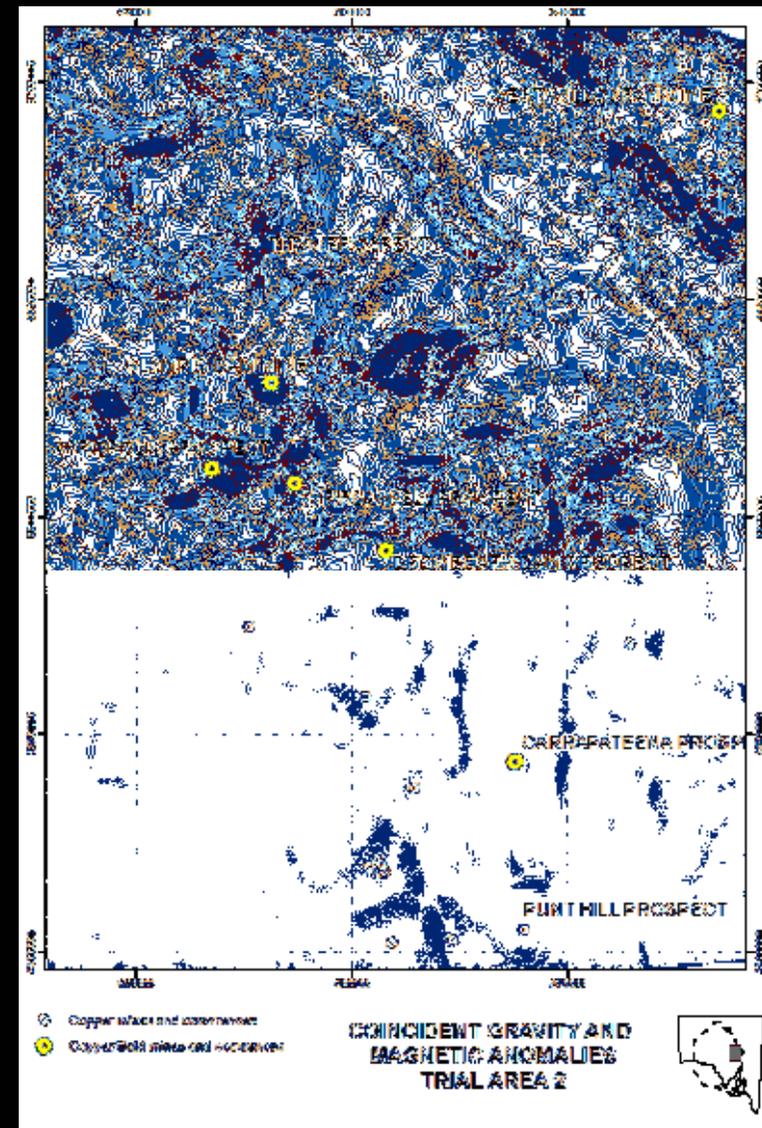
- Area selection.
- Residual gravity and residual RTP TMI.



Mineral Potential Modelling

IOCG±U Potential – Method

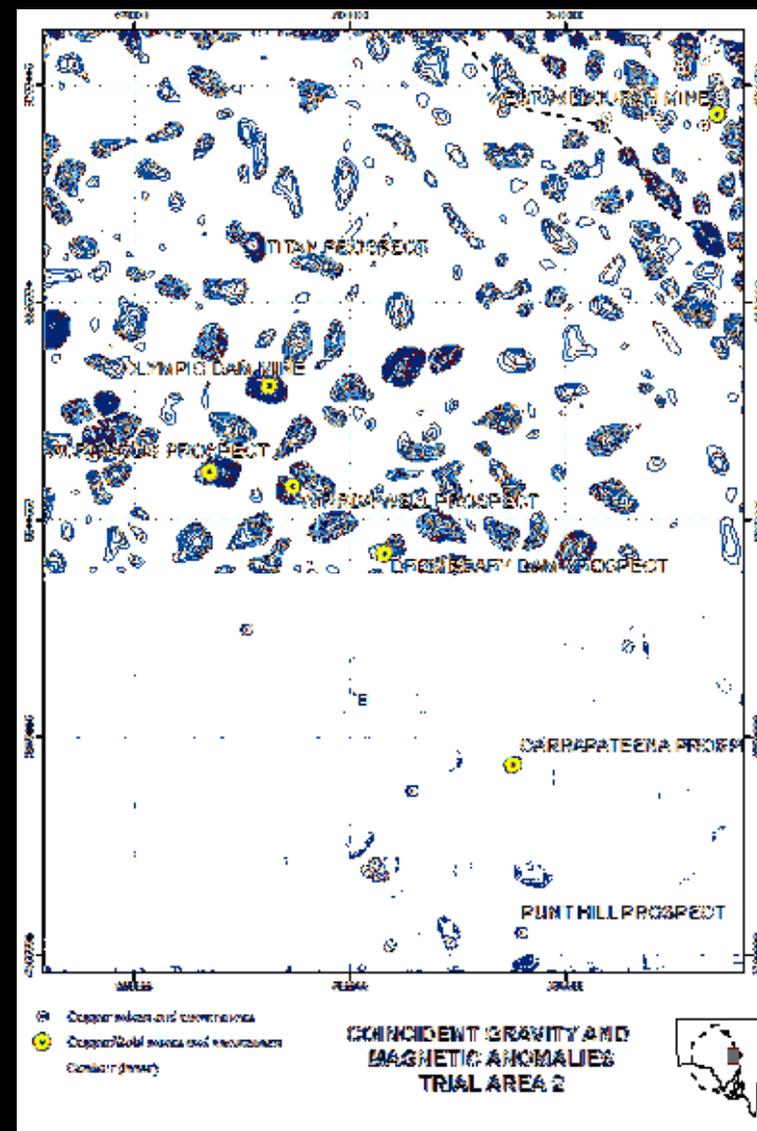
- Area selection.
- Residual gravity and residual RTP TMI.
- Contouring.



Mineral Potential Modelling

IOCG±U Potential – Method

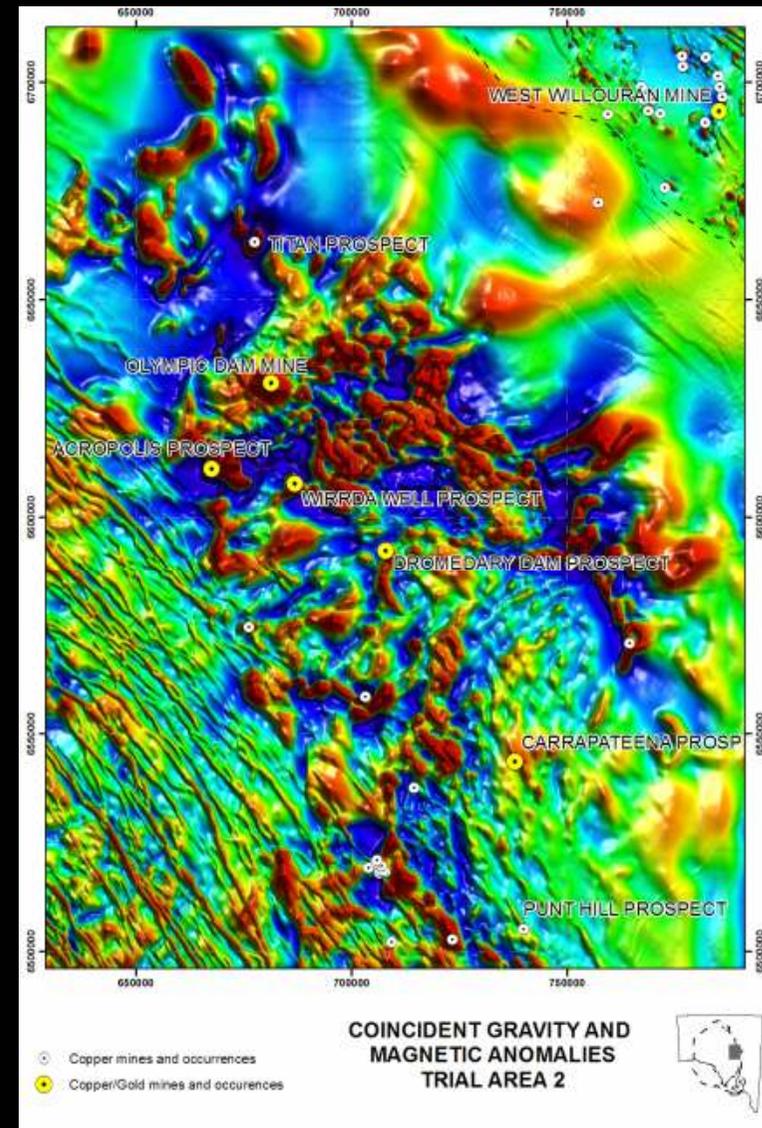
- Area selection.
- Residual gravity and residual RTP TMI.
- Contouring.
- Selection of anomalies.



Mineral Potential Modelling

IOCG±U Potential – Method

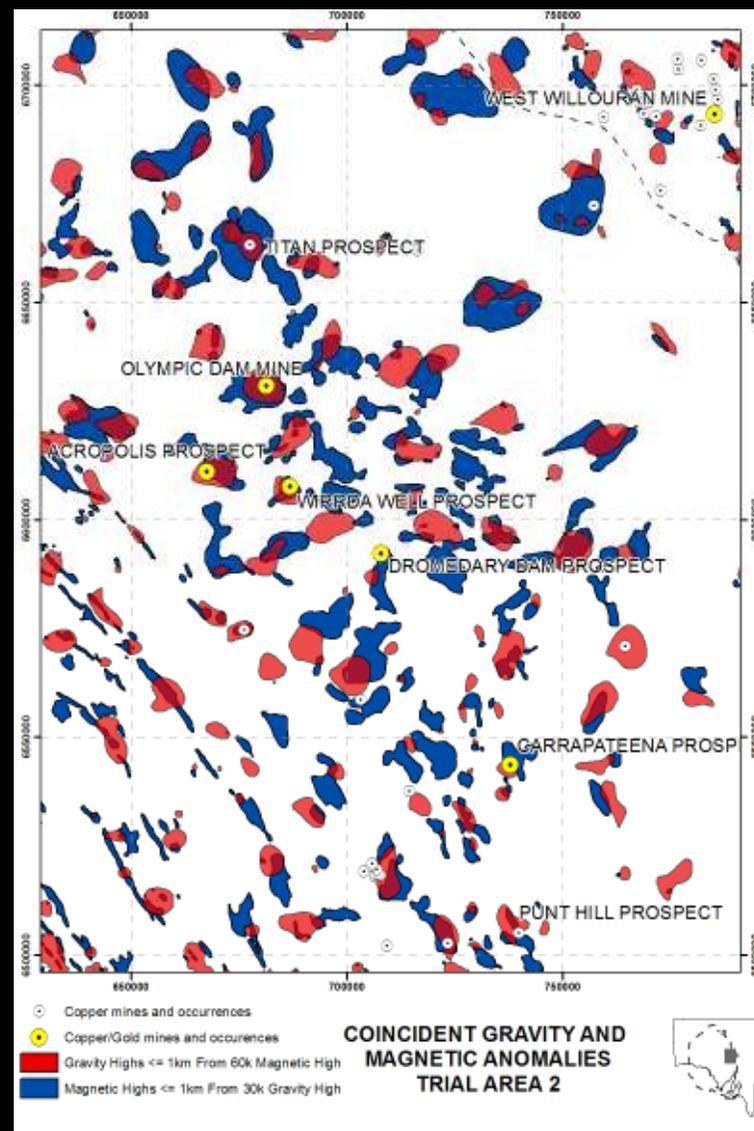
- Area selection.
- Residual gravity and residual RTP TMI.
- Contouring.
- Selection of anomalies.
- Determine geophysical highs - gravity.
- Determine geophysical highs - magnetics.



Mineral Potential Modelling

IOCG±U Potential – Result

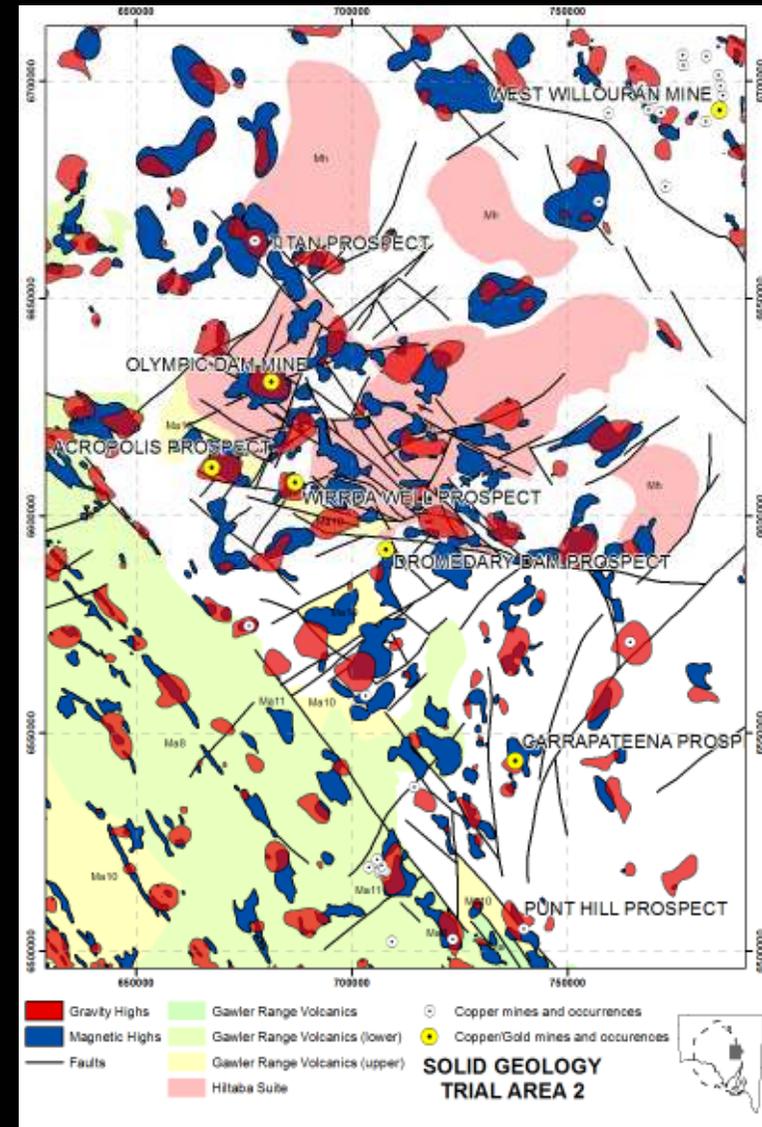
- The result, coincident gravity and magnetic anomalies offset by no more than 1 000 metres.



Mineral Potential Modelling

IOCG±U Potential – Uses

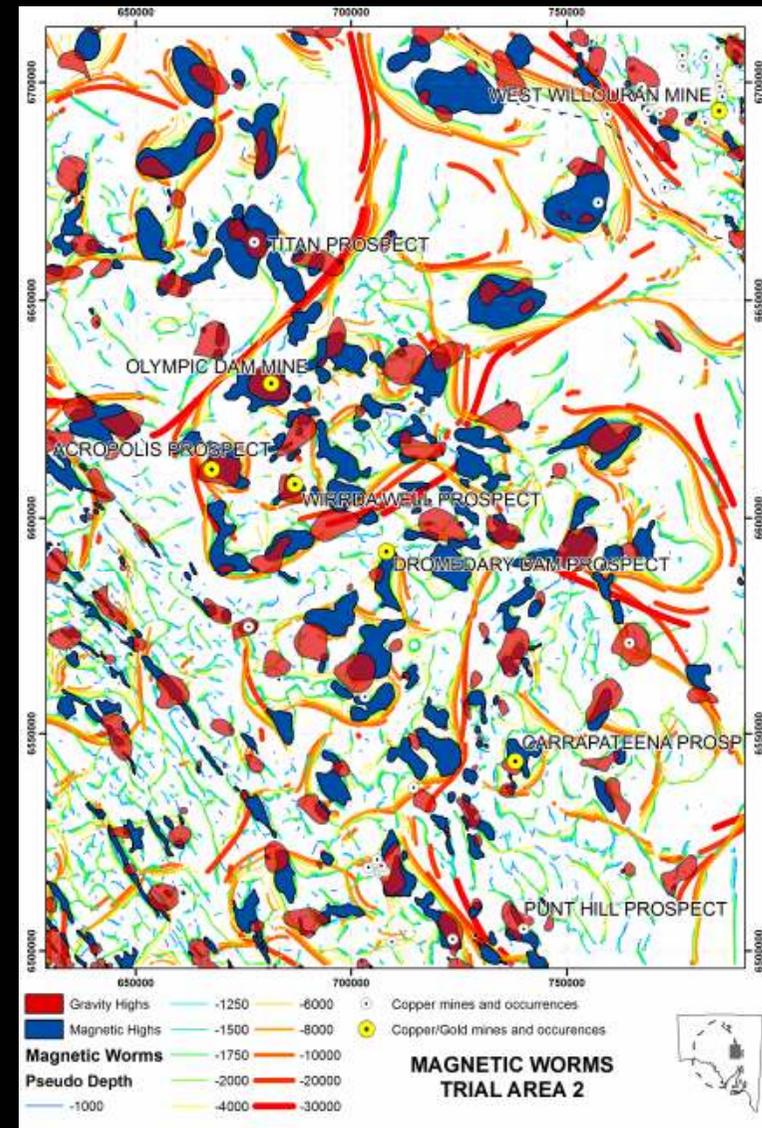
- Preliminary exploration site selection.
- Key Ingredients Mapping:
 - Coincident anomalies.
 - Hiltaba Granites.
 - Gawler Range Volcanics.
 - Faults.
 - Depth to basement.



Mineral Potential Modelling

IOCG±U Potential – Uses

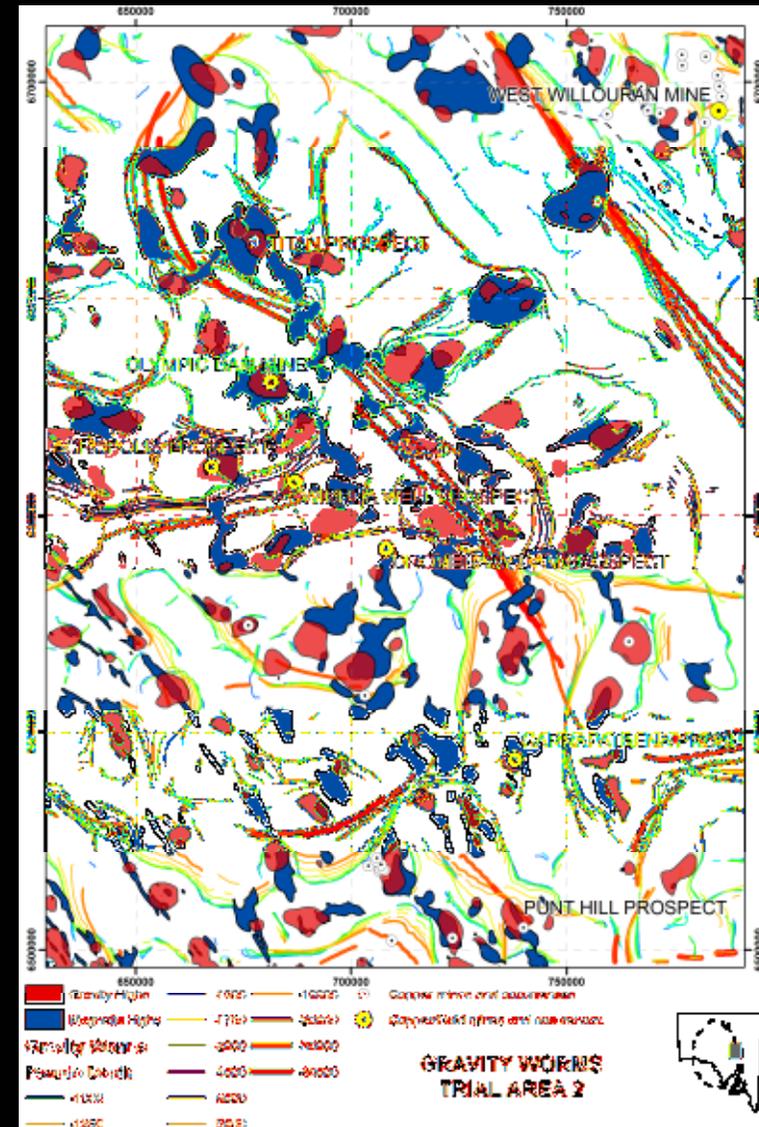
- Preliminary exploration site selection.
- Key Ingredients Mapping.
- Mineral Potential Models:
 - Weights of evidence.
 - Neural network.
 - Expert system.



Mineral Potential Modelling

IOCG±U Potential – Uses

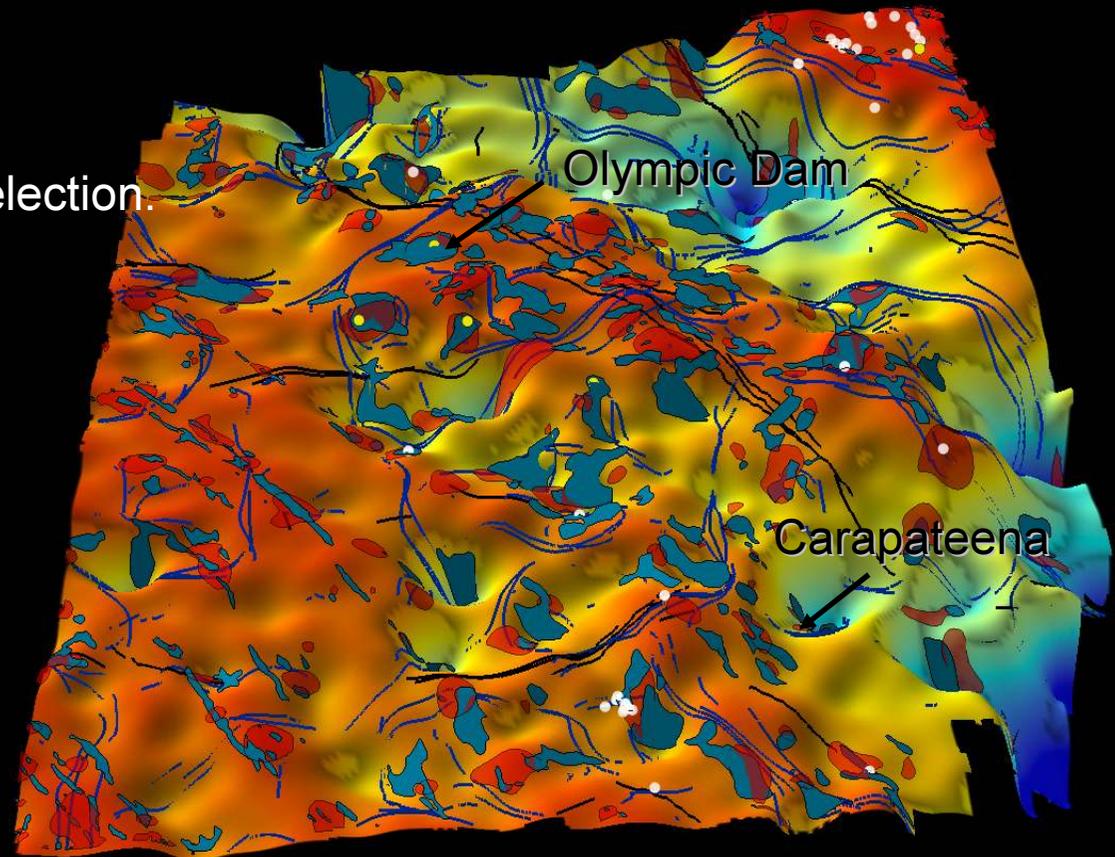
- Preliminary exploration site selection.
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 - Weights of evidence.
 - Neural network.
 - Expert system.



Mineral Potential Modelling

IOCG±U Potential – Uses

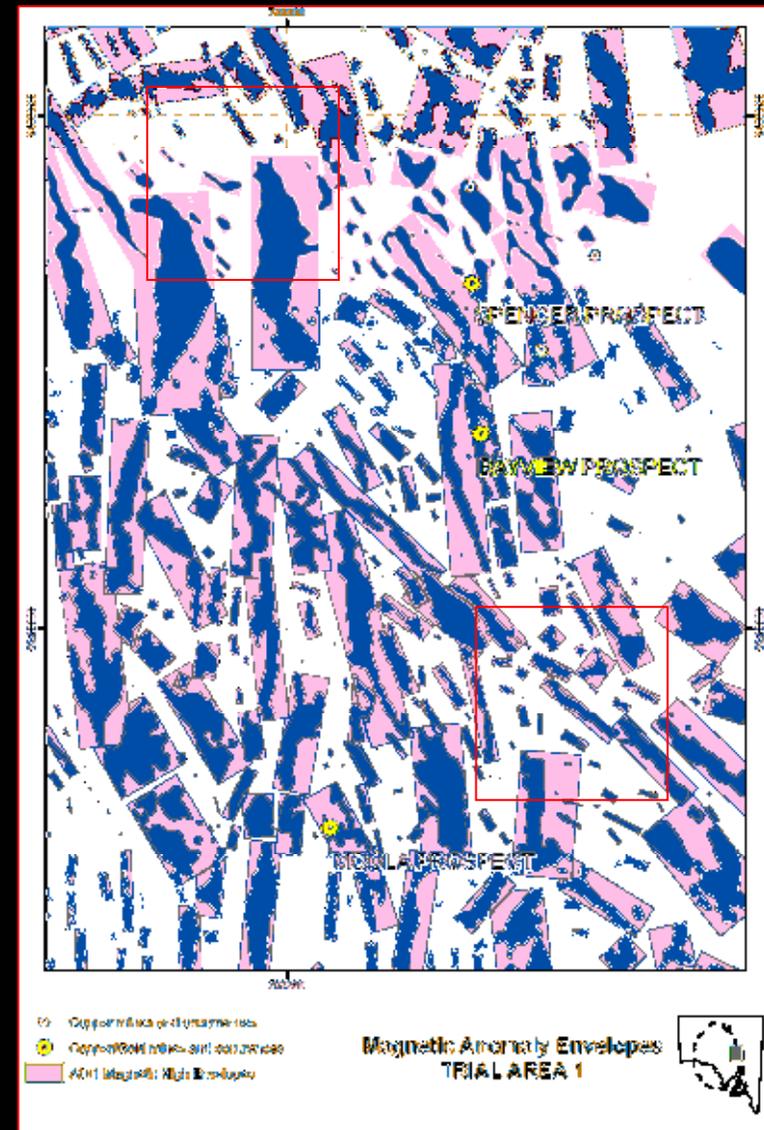
- Preliminary exploration site selection.
- Key Ingredients Mapping.
- Mineral Potential Models.
- 3D visualisation.



Mineral Potential Modelling

IOCG±U Potential – Further Work

- Shape recognition properties:
 - Elongation
 - Compactness



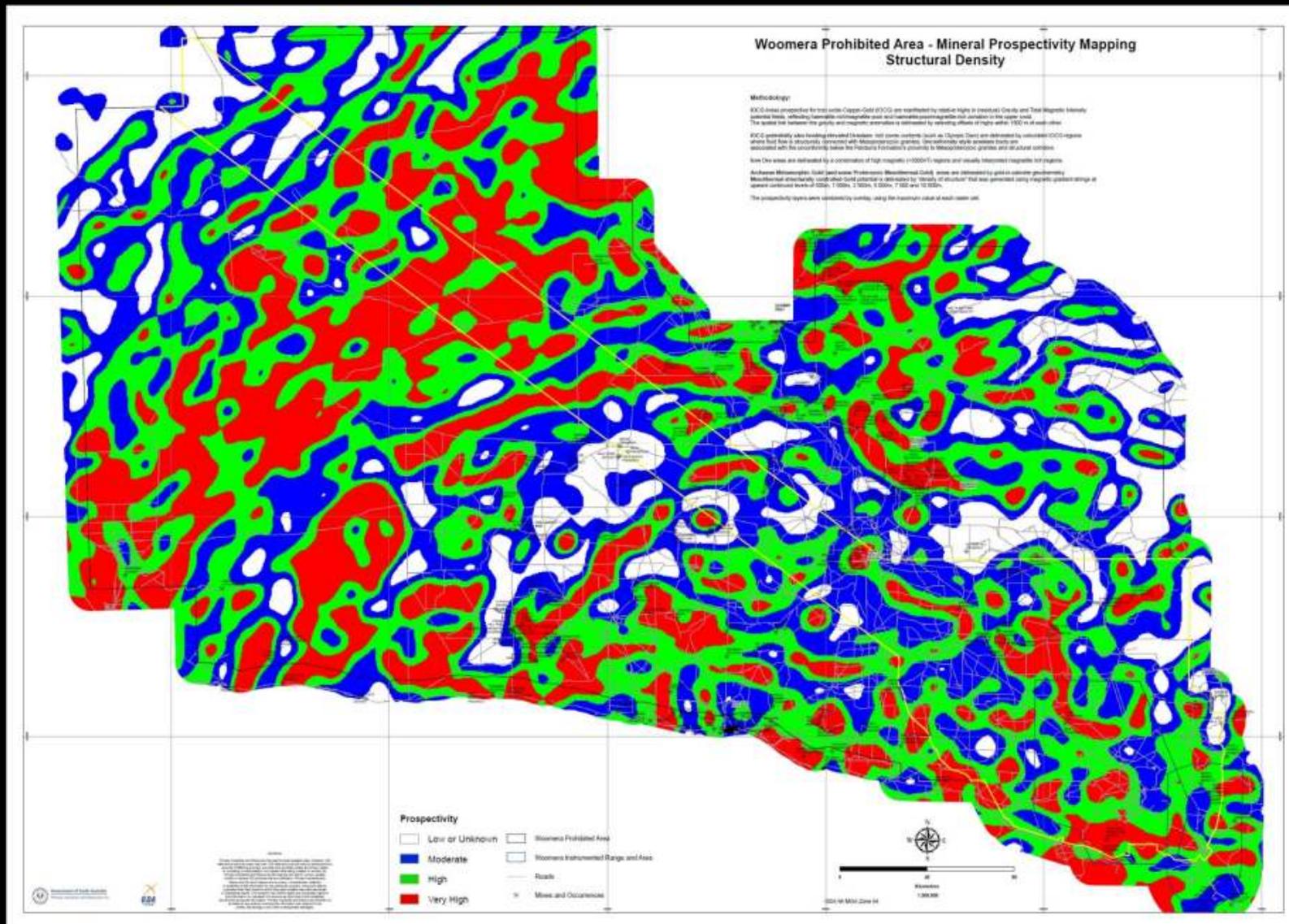
Mineral Potential Modelling

IOCG±U Potential – Uses

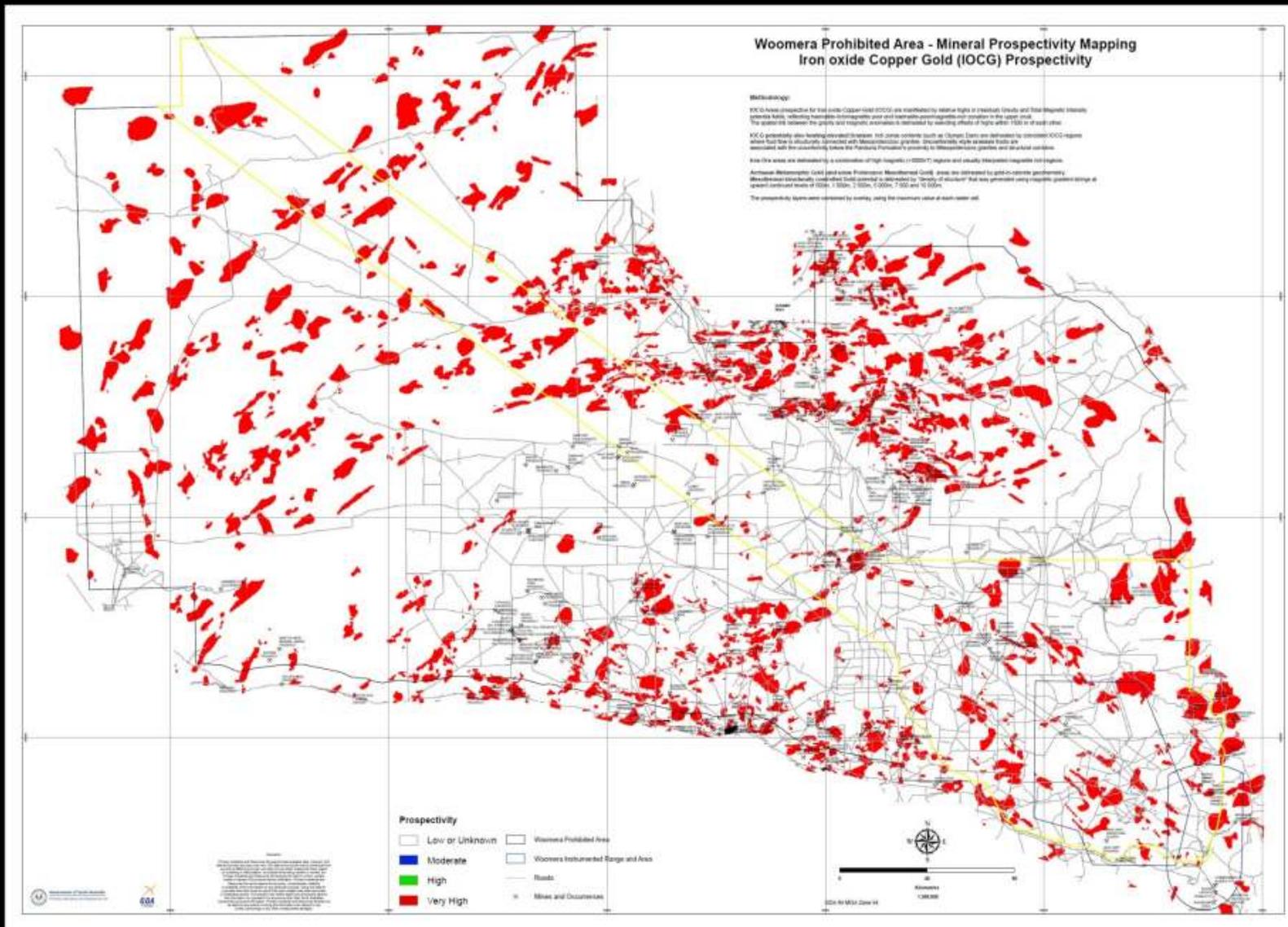
- Extrapolating to other areas



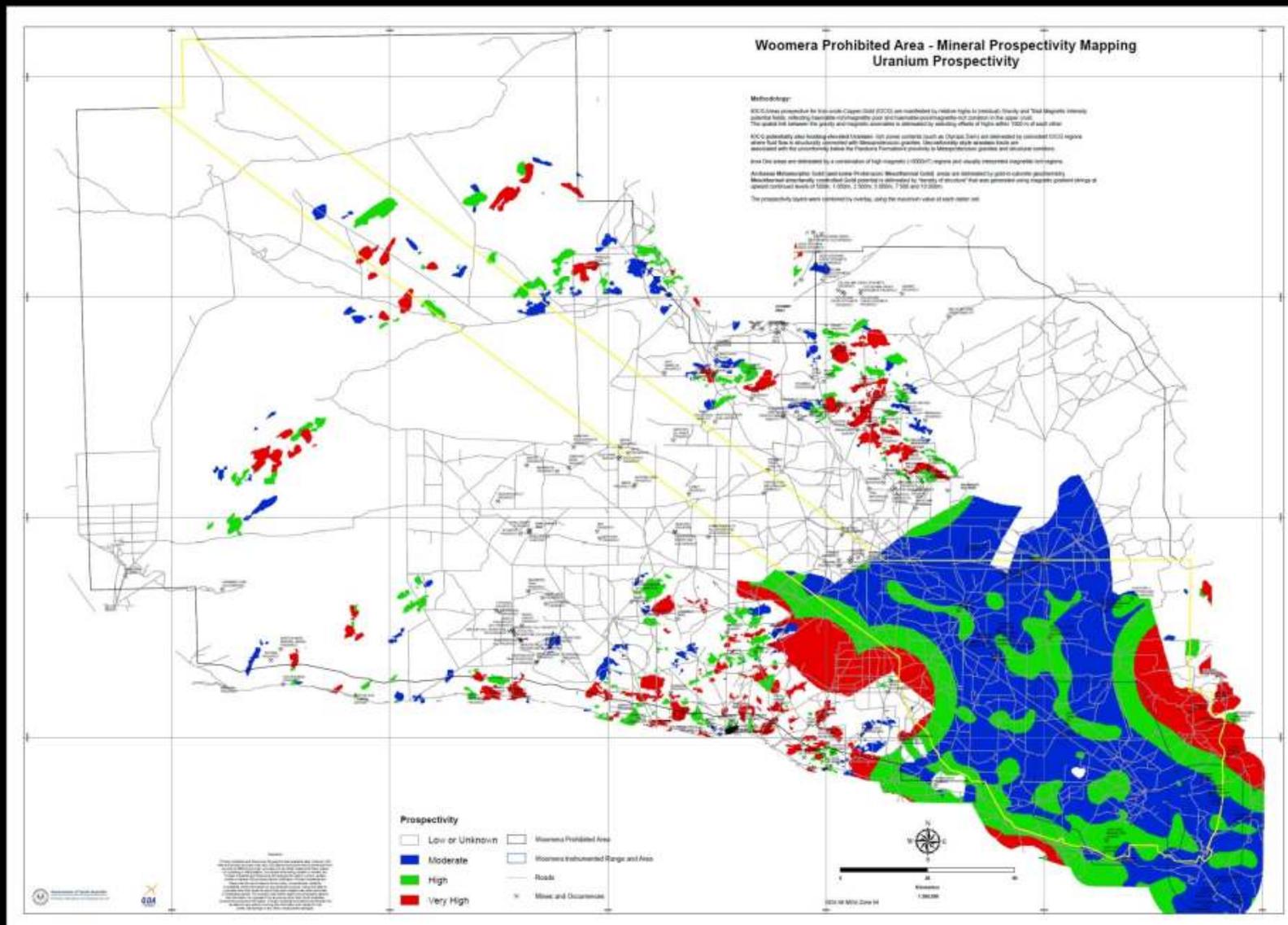
Mineral Potential Modelling



Mineral Potential Modelling



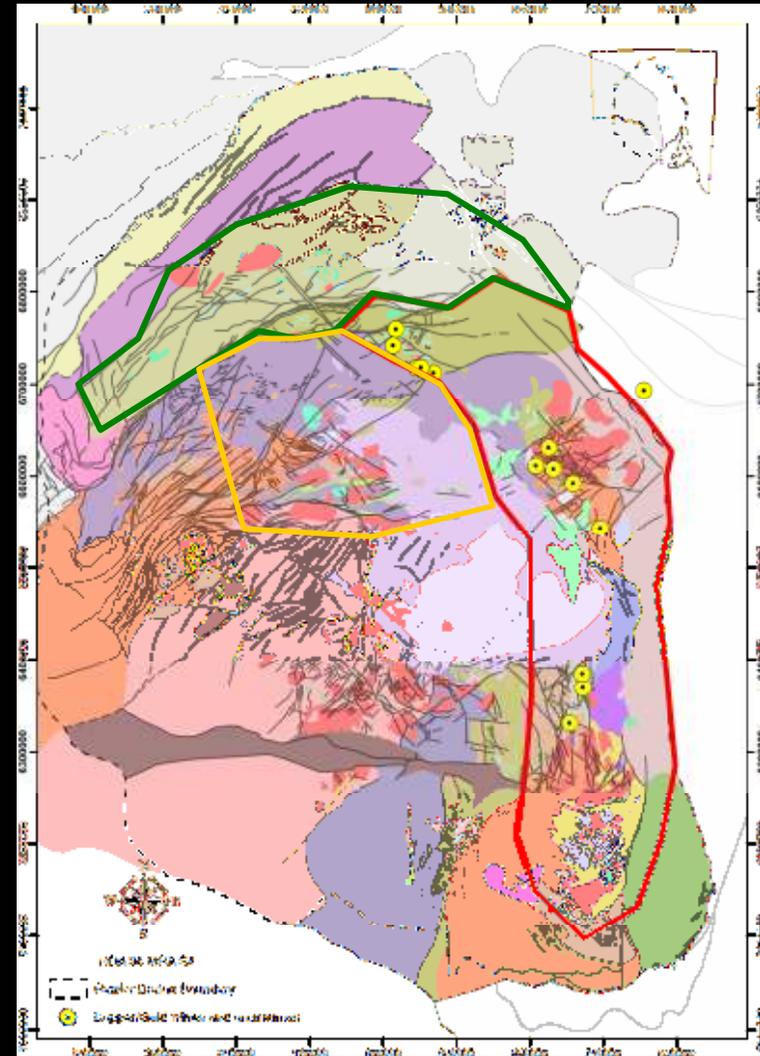
Mineral Potential Modelling



Mineral Potential Modelling

IOCG±U Potential – Further Work

- Shape recognition properties:
 - Elongation
 - Compactness
- Incorporate alteration data:
 - HyLogger
 - Petrological Database
- Apply to the eastern Gawler Craton IOCG±U province...



Summary

- South Australia has 40% of known resources in Uranium.
- Underlying Hiltaba event has generated the largest single uranium deposit in the world and subsequently.....
- Overlying sedimentary successions provide excellent trap sites for world class projects (eg. Four Mile).
- The Mineral Systems approach is a powerful predictive tool for undiscovered resources

