‘Deep Mining Queensland: A new view of Structural-Stratigraphic-Magmatic, Cu-Au-Mo Prospectivity in the southern Cloncurry Belt’

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Geological Survey of Queensland

SMiBRC
WH Bryan Mining & Geology Research Centre

FUTORES II Townsville, June 2017
Deep Mining Queensland Project - southern Cloncurry Belt
‘Prospectivity - Mineability - Viability’
Overall aims to reduce risk of exploring for large, mass-mineable deposits at depth in the southern Cloncurry Belt.

Brief overview of Results & Products TODAY

DMQ Project Team
Dr Travis Murphy (Exploration & Mine Geology)
Dr Mark Hinman (Exploration & Mine Geology)
Dr Mark Pirlo (Exploration Geochemistry)
John Donohue (Exploration Geophysics)
Rick Valenta (new BRC Program Leader)
Mark Jones (Software Engineering)
Adrian Pratt (Mining Engineer)

Acknowledgements
Chinova ... data including detailed geophysics, detailed prospect mapping & historic project databases
GSQ ... Future Resources Program; pre-release 100K mapping, geochron database
Historic Work... Leishman, 1970s-80s; Searl, 1952; ... & many others; many companies
Deep Mining Queensland Project Location

Eastern Fold Belt between Cloncurry & Osborne

approx 180x50km
DMQ Geological Re-interpretation
Regional vs Detailed Magnetics

GA Mag tmi-rtp v6 (2015) 80m grid
Chinova detailed Mag merge vrmi-2vd (2010) 10m grid

Very significant difference in resolution

... has allowed a high fidelity interpretation
> package continuity
> package architecture
> fine faulting architecture
Updated DMQ 2017 version of 2000 NWQMP T-x Chart
Updated DMQ 2017 version of 2000 NWQMP T-x Chart

- Reflects current understanding of EFB package relationships gleaned from the DMQ interpretation & latest geochronology (Withnall-Parsons, 2007-2009; NWQMEP, 2011; GSQ geochron database, Withnall, 2016)

- Updated Isan Deformation Events to reflect D1, D2, D2b, D3 & D4 in common usage.

- TIMESLICES reflecting DMQ re-packaging of mapped Formations, Members & units.
DMQ-reinterpreted Solid Geology

DMQ Solid Geology PRODUCTS
• ~1:50K Solid Geology Interpretation
DMQ-reinterpreted Solid Geology

DMQ Solid Geology PRODUCTS
• ~1:50K Solid Geology Interpretation
• GIS Package of TIMESLICED Geology
• GIS Event-attributed Structures
DMQ-reinterpreted Solid Geology

DMQ Solid Geology PRODUCTS
• ~1:50K Solid Geology Interpretation
• GIS Package of TIMESLICED Geology
• GIS Event-attributed Structures
• Detailed ~1:5-10K Local Compilations
• 29-step EFB Assembly Model
Assembly Model of the southern Cloncurry Belt

Series of maps sequentially highlighting....

Depositional TIMESLICES, Deformation EVENTS, and Magmatic EPISODES

... ~1900Ma to ~1400Ma
... culminate in Cu-Au-Mo mineralisation

Insights into package relationships, their origins, compositions & nature of their structural juxtapositioning ...

... in particular, the stratigraphic and structural juxtapositioning of contrasting Redox packages

... which is integral to DMQ Cu-Au-Mo Propsectivity Analysis
Highlights 29 phases of Accumulation in TIMESLICES, Deformation EVENTS and Episodes of Magmatism in relation to Mineralisation.... but time short!
~1515-1500 Ma
early D4 Faulting/re-Activation
WILLIAMS Magmatism
Cu-Au, Au-Cu, Mo-Cu

Post-peak meta-times, at shallower crustal levels, NW-directed shortening results in early D4 Faulting/re-Activation of older structures. Focuses Cu-Au-Mo minz

- D4 Faults (cf D1-D2-D3) are small scale with small displacements; many so small that not mapped.
- Circulating highTemp oxidised brines that have scavenged metal are focused in BRITTLE fracture-breccia zones to form ...
- Spectrum of Cu-Au-Mo deposits as function of scavenged metal content, magmatic metal input, reduced S available at deposition site and P-T-x conditions en route & at site of deposition.
Surficial ± Formational Fluid Source IOCG Model

- WILIAMS Suite
  - HEAT source - circulation driver - metal contribution

DMQ Time-Space Control

Barton & Johnson (2004), Williams et al. (2005), Williams et al. (2010)
WILLIAMS Suite
- HEAT source - circulation driver - metal contribution
Isan D4
- BRITTLE, shallow crustal deformation > permeability

DMQ Time-Space Control

Barton & Johnson (2004), Williams et al. (2005), Williams et al. (2010)
<table>
<thead>
<tr>
<th>Time Window</th>
<th>Event</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>~1515-1500Ma</td>
<td>Williams Suite</td>
<td>Barton &amp; Johnson (2004), Williams et al. (2005), Williams et al. (2010)</td>
</tr>
<tr>
<td>~1530Ma</td>
<td>Saxby</td>
<td></td>
</tr>
<tr>
<td>~1545Ma</td>
<td>Maramungee</td>
<td></td>
</tr>
<tr>
<td>~1515-1500Ma</td>
<td>Quamby Basin</td>
<td>- continental, oxidised, evaporitic brine source</td>
</tr>
<tr>
<td>~1520-1490Ma</td>
<td>Isan D4</td>
<td>- BRITTLE, shallow crustal deformation &gt; permeability</td>
</tr>
<tr>
<td>~1590-1570Ma</td>
<td>Isan D2</td>
<td>DUCTILE thick-skinned</td>
</tr>
<tr>
<td>~1570Ma</td>
<td>Williams WILIAMS Suite</td>
<td>- HEAT source - circulation driver - metal contribution</td>
</tr>
<tr>
<td>~1515-1500Ma</td>
<td>DMQ Time-Space Control</td>
<td></td>
</tr>
</tbody>
</table>
~1515-1500Ma **Williams**

~1530Ma **Saxby**

~1545Ma **Maramungee**

~1870Ma **Barramundi Orogeny**

**Surficial ± Formational Fluid Source IOCG Model**

- **WILLIAMS Suite**
  - HEAT source - circulation driver - metal contribution

- **Isan D4**
  - BRITTLE, shallow crustal deformation > permeability

- **Quamby Basin**
  - continental, oxidised, evaporitic brine source

**Cu-Au-Mo IOCG/ISCN Mineralisation**

**DMQ Time-Space Control**

Barton & Johnson (2004), Williams et al. (2005), Williams et al. (2010)
DMQ District to Local: Deposit Controls

detailed geological compilations
& interpretations of geodynamic mineralisation control

Starra-Merlin-Mount Dore
Mount Elliott-SWAN
Osborne-Kulthor
Ernest Henry
Starra-Merlin-Mount Dore

5K-10K Leishman Geology (1970s-1980s)
Ivanhoe-Chinova Mapping (2000s)
DMQ Geophysical Interpretation (2016)
Starra-Merlin-Mount Dore

5K-10K Leishman Geology (1970s-1980s)
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MARRABA-MITAKOODI-Double Crossing Metamorphics

syn-deformational WONGA Gin Creek Granite

OP1 Exhumation of DCM-GCG ... Block Faulting
Significant offsets of GCG-DCM

STAVELEY ROXMERE KURIDALA NEW HOPE ... deposited somewhere to the south(-east)

D1 thin-skinned, sub-horizontal, NNW-overthrust of
STAVELEY-ROXMERE-KURIDALA-NEW HOPE over DCM-GCG
(Starra Shear)
E-W Folds; highly attenuated/folded MIF-HIF; over FW architecture

D2 EW-shortening Folding
D1 Starra Shear folded to sub-vertical; F1 folds steep in Starra Shear cf
sub-horizontal F2 Folds >> steep ribbons & rootless folds of MIF

D2 EW-shortening Reverse Faulting/re-Activation
Re-activated D1 Starra Shear; new F2 Folds

D4 NW-directed, BRITTLE Transpressive Re-activation;
WILLIAMS Mount Dore Granite intrusion;
Mineralisation
Along Starra Line: FW block architecture contribution to Fr-Bx where
remnant MIF coincident with FW Faults
At Merlin-Mount Dore: strain intensification; small-scale D4 Faulting

Late D4, post-mineral Faulting
Mount Dore Granite over Merlin-Mount Dore Cu-Au-Mo
Starra Mineralisation Model

**Cu-Au Mineralisation** forms during ..
D4 sinistral transpressive re-activation of D1 *Starra Shear*

FOCUS requires the coincidence of ...  
(1) a D1 remnant BRITTLE ribbon of massive IF with  
(2) pre-D1 FW Fault that contributes to the focused BRITTLE deformation ... *Permeability > Cu-Au*
**Starra Mineralisation Model**

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2. pre-D1 FW Fault that contributes to the focused BRITTLE deformation ... *Permeability > Cu-Au*

Orebody plunge reflects intersection of the pre-D1 FW Faults with the *Starra Shear*, NOT the plunge of the rotated IF D1 ribbons & folds

Strong magnetic signature >

Large volumes of *chl-magnetite schist* accommodates the D4 re-activation by slip on existing fabrics ... NO Permeability
SUMMARY CONCLUSIONS DMQ Deposit Control Insights

In D4 time ... Need BRITTLE lithology in a D4 structural setting that compels it to BRECCIATE
SUMMARY CONCLUSIONS  DMQ Deposit Control Insights

In D4 time ... Need BRITTLE lithology in a D4 structural setting that compels it to BRECCIATE

MOST COMMONLY NOT Major Structures ....

..... often insignificant Faults (not mappable) & insignificant re-Activations of older structures
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But NEED BRITTLE Host that survives into POST-PEAK META times ...

... BRECCIATES > PERMEABILITY > Mineralisation

Vast volumes mod-high grade schists (-gneisses) in POST-PEAK META times ...

accommodate D4 shortening by slip on existing peak-metamorphic fabrics

... NO BRECCIATION > NO PERMEABILITY > No Mineralisation
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Structural abutting of BRITTLE lithology against D4 re-activating D2-structures ... KULTHOR
BRITTLE lithologies against small-displacement D4 Faults .... MERLIN-Mt DORE
BRITTLE D1-remnants of IF coincident high angle FW weakness .... STARRA
BRITTLE lithologies within D4 strain partitioning domains ... Mt ELLIOTT-SWAN, EH

Different Geodynamic Games in Different Camps
NO D4 Structural Silver Bullets
SUMMARY CONCLUSIONS

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Different Geodynamic Games in Different Camps

NO D4 Structural Silver Bullets

ALL in proximity to juxtapositoning of Redox-contrasting packages!

But ALL synchronous with WILLIAMS intrusion!
DMQ 3D Geological Model

Particular Focus on ...

- Exploreable Depths .. 0-2km
- Production of a robustly-constrained 4D-Prospectivity Analysis
- Purposely NOT a crustal-scale Analysis
DMQ 3D Geological Model

Particular Focus on …

• Exploreable Depths .. 0-2km
• Production of a robustly-constrained 4D-Prospectivity Analysis
• Purposely NOT a crustal-scale Analysis

DMQ produced …

Forty-seven, 4km-spaced SECTIONS

... heavily leveraged Solid Geology ...
... and 3 Seismic Lines

... acknowledge
- Complex D1-thrusts, folded in D2 & then dismembered by D2 Faults in Marimo Synform
- Shallow D1-thrust under TOOLE CREEK with potential STAVELEY footwall
- Imbricate slices of ROXMERE in STAVELEY ... lost thrust architecture in STAVELEY
- Some near-surface granites ... hitherto unremarked
- Overhang Thrust soles at depth
- Gentle Mitakoodi Culmination ... FORM SURFACES!
DMQ 3D Geological Model
built on forty-seven, 4km-spaced Sections

- Shallow Interpretation to ~9km
- FAULTS & TIMESLICE surfaces fully attributed

.... but NO granites!

colour-coded strings pre-wireframing
What about the Granites?

Vp\text{mg} \text{ Apparent Density Inversion Model of the GA 2011 Gravity Data}

Models a single density to each of a mesh of 900m x 900m x 25km deep prisms to match the gravity data...

- Assumes no crustal architecture but usefully highlights density \textit{deficits} & \textit{surpluses}

- Suggests granite is far more extensive than the mapped/interpreted WILLIAMS outcrop extent
What about the Granites?

**Vpmg** Apparent Density Inversion Model of the GA 2011 Gravity Data

Models a single density to each of a mesh of 900m x 900m x 25km deep prisms to match the gravity data...

- Assumes no crustal architecture but usefully highlights density *deficits & surpluses*

- Suggests granite is far more extensive than the mapped/interpreted WILLIAMS outcrop extent

This image drove DMQ into geologically-constrained Gravity Inversion Modelling!
... but more importantly!

Highlights the location many Cu-Au deposits & occurrences OVER margins & shoulders of what DMQ interpret to be WILLIAMS intrusives at depth
... but more importantly!

Highlights a LACK of deposits & occurrences in the roof zones of those intrusives...

.. which suggests that fertile Cu-Au mineralising fluids FLOW UP the margins and NOT out of the roofs of the intrusives...

... implies that fluid circulation, NOT simple magmatic exhalation, is IMPORTANT

Highlights the location many Cu-Au deposits & occurrences OVER margins & shoulders of what DMQ interpret to be WILLIAMS intrusives at depth
Geologically-constrained $V_{pmg}$ Gravity Inversion

Fullagar Geophysics $V_{pmg}$ advantages ...
- Adaptive mesh better fits known geometries
- 3 modes of inversion available
- DMQ made use of all of them ...
  ... but heavy use of GEOMETRY INVERSION
Table: Density Constraints

<table>
<thead>
<tr>
<th></th>
<th>LOW</th>
<th>MEDIUM</th>
<th>HIGH</th>
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<tr>
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<td>'Granite'</td>
<td>2.61</td>
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<td>-0.08</td>
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<tr>
<td>'Proterozoic'</td>
<td>2.73</td>
<td>2.79</td>
<td>2.78</td>
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<tr>
<td></td>
<td>+0.06</td>
<td>+0.12</td>
<td>+0.11</td>
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</tbody>
</table>
Geologically-constrained $V_{pmg}$ Gravity Inversion

Honoured Granite outcrop
Domained RL Base-of-Granite START depths
Granite free to ‘grow’ top and/or bottom
Geologically-constrained \textit{Vpmg} Gravity Inversion

**Domained RL, Base-of-Granite Models**

Honoured Granite outcrop
Domained RL Base-of-Granite START depths
Granite free to ‘grow’ top and/or bottom

**FAILED!**
Unable to produce geologically-reasonable & smooth transitions from outcrop into the subsurface; nasty dipoles on contacts
Geologically-constrained \( V_{p, mg} \) Gravity Inversion

**Domained RL, mid-Granite ‘PERT’ Models**

**Domained** zero-thickness Granite START
... NO Granite outcrop!

High Density \( V_{p, mg} \) basement fixes
‘PERT’ \( V_{p, mg} \) function to drive ‘growth’
equally up & down from START depth

![Diagram showing geological constraints and gravity inversion models](image)

**INPUT**
- Heterogeneous \( V_{p, mg} \) Prot
- Zero Granite

**OUTPUT**
- Heterogeneous \( V_{p, mg} \) Prot
- Granite

![Graph showing gravity anomaly between input and output](image)
Geologically-constrained $V_{p/mg}$ Gravity Inversion

**Domained RL, mid-Granite ‘PERT’ Models**

Domained zero-thickness Granite START

... NO Granite outcrop!

High Density $V_{p/mg}$ basement fixes
‘PERT’ $V_{p/mg}$ function to drive ‘growth’
equally up & down from START depth

**Ultimately SUCCESSFUL!**

Produce geologically-reasonable granite morphologies; built outcrop where required; matched sub-surface geological constraints & produced smooth transitions from outcrop
Geologically-Constrained Vpmg Gravity Inversion
Domained RL mid-Granite ‘PERT’ Models

Version 18 DMQ Granite Model
... into 4D geological model & DMQ Prospectivity Analysis
Geologically-Constrained \textit{Vpmg} Gravity Inversion

Domained RL mid-Granite ‘PERT’ Models

Version 18 DMQ Granite Model
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(Mira, 2010)
Prospectivity Analysis built on ...

... 3D WILLIAMS Intrusives
Prospectivity Analysis built on...

... 3D WILLIAMS Intrusives

Applied an Anisotropic BUFFER to...

Margins, Shoulders & Apophyses of WILLIAMS Intrusives
Top-of-STAVELEY
Stratigraphic Redox Contact

BUFFER

Asymmetric BUFFER applied to Top-of-STAVELEY
Pre-D4 Structures with potential Redox juxtapositioning
Asymmetric BUFFER applied to STAVELEY structural juxtapositioning

... Footwall & Hangingwall
Combined Redox Stratigraphic & Structural BUFFERs ... intersected with WILLIAMS intrusive BUFFER Distance

Hot colours indicate proximity to projected WILLIAMS Margins, Shoulders & Apophyses at depth
Successful Prediction .... 
.... & Lots of Upside Potential at depth!
DEEP MINING QUEENSLAND
PROSPECTIVITY ANALYSIS IN THE SOUTHERN CLONCURRY BELT

Detailed presentations at  https://brc.uq.edu.au/project/brc-deep-mining-queensland
DMQ FINAL REPORT to be released on QDEX .... after review

T-x Chart, GIS Solid Geology, EFB Assembly Model, Leapfrog Viewer Model, DXFs, Geophysical Library, Geochemistry Review, Prospect Evaluation Tool-PEET, on-line A3 Report