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WH Bryan Mining & Geology Research Centre

The University of Queensland
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GSQ – NW Minerals Province: Exploration Seminar

Deep Mining Queensland (DMQ) Project [2015-2017]

New Concepts for 3D Cu-Au-Mo Prospectivity Analysis in the Southern Cloncurry Belt: Potential for Discovery and Development of Large Ore Bodies at Depth

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Mt Isa, Queensland

27th April, 2017

Support

The Deep Mining Queensland (DMQ) project, a 2 year project commencing in April 2015, is part of the Queensland State Government's investment in priority geoscience projects identified by the mining and petroleum industries. This initiative is part of the Geological Survey of Queensland's (GSQ) Future Resources Program.

The DMQ project represents a wholistic approach to resource prospectivity, from discovery through to an assessment of 'mineability', and will focus on the highly endowed Cloncurry Cu-Au district from Cloncurry township to south of the Osborne mine (totalling 8,743km2).

Sponsored by: Queensland Government – Department of Natural Resources and Mines – Geological Survey of Queensland

In-kind support: chinova resources

Software & data processing: DATAMINE, Fullagar Geophysics, HiSeis

DMQ Project Team

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Deep Mining Queensland (DMQ) Project

Deep exploration is an industry area of focus given depletion of shallow resources and the likely/predicted mineral endowment under-cover adjacent to mature mining fields.

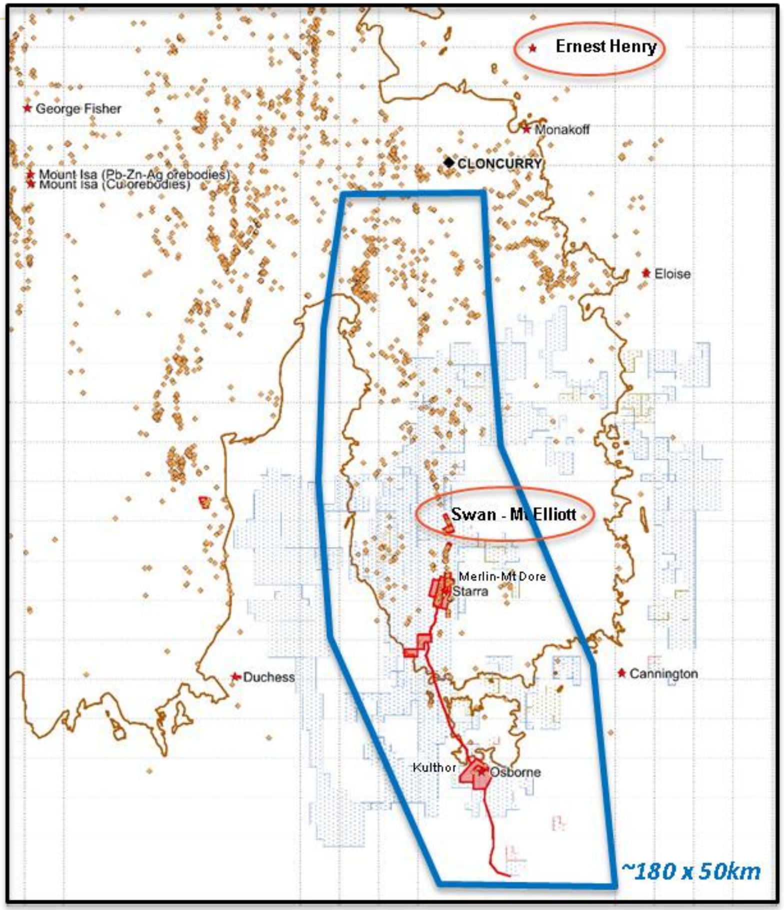
The DMQ project aims to reduce the risk profile of exploring at depth in the Cloncurry field by identifying tracts of ground, through enhanced understanding of the mineral systems architecture, which are:

- **Prospective for deep, large and/or high-value deposits (of IOCG affinity), and**
- **Are amenable to cost-effective extraction.**

The research draws on local expertise in the BRC with respect to mass-mining methods and the qualitative assessment of geological impacts on mass-mining design and operation.

Mining Informed Targeting/Prospectivity

- The research project is centred on part of the Eastern Fold Belt encompassing the Osborne-Kulthor Cu-Au mine, Starra line of Au-Cu deposits and mines, Mt Dore Cu deposit, Merlin Mo deposit, Mt Elliott Cu-Au complex (SWAN, Domain 81, Corbould, Mt Elliott) and numerous historic mining operations and prospects.
    - District with multiple Cu-Au mines, lots of smoke, yet only one large mass-mineable deposit (Ernest Henry), and a large prospective resource (SWAN – *Mt Elliott*).
- What are the prospects for discovery of additional mass-mineable deposits if we deepen the search space to 2km below surface?.....and what would a mineable deposit need to look like at this depth?

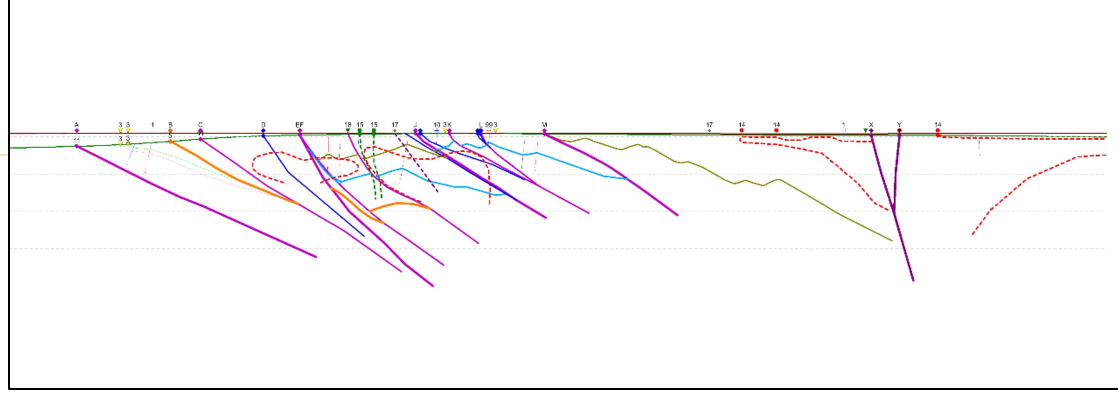


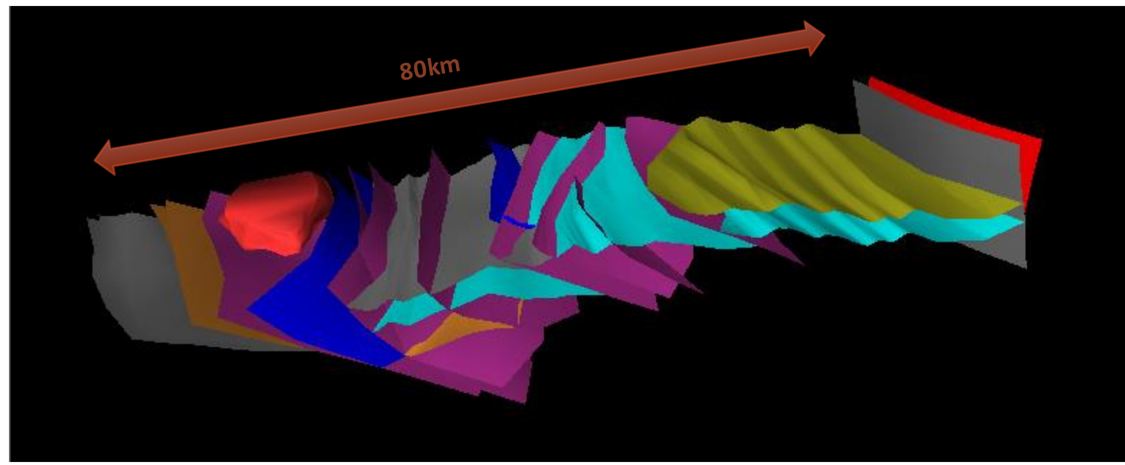
	Mt	Cu (%)	Au (g/t)
Ernest Henry[1]	220	1.1	0.5
Swan[2]	375	0.44	0.25

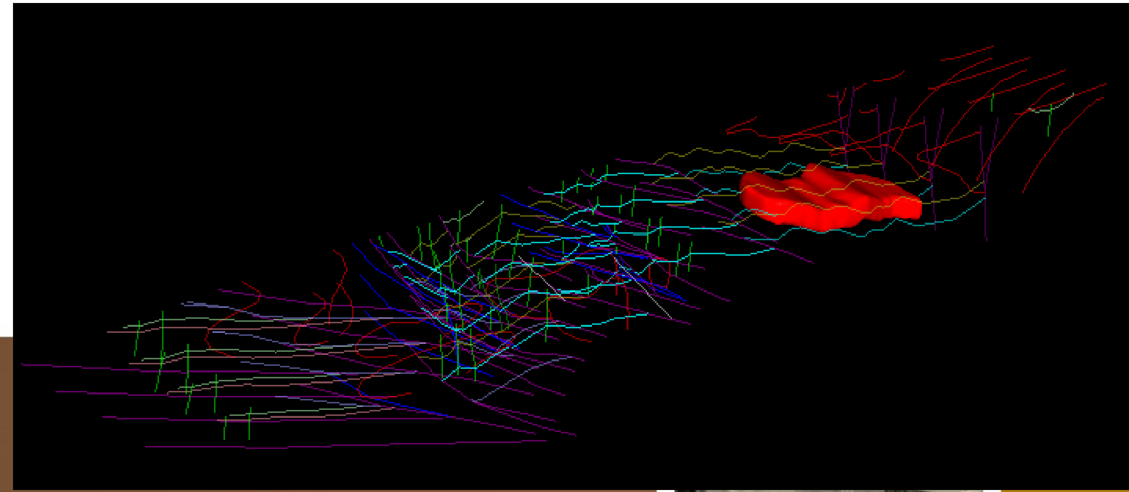
[1] Glencore Reserves & Resources, 2014 [2] AMC – Mt Elliott Scoping Study, 2012

DMQ aims to reduce the risk of deep exploration in the Cloncurry Cu-Au district through:

- Detailed geological understanding, informed by comprehensive analysis of geological, geophysical and geochemical datasets
- Considered interpretation of the controls on known orebody location, geometry, and tenor
- Insights into economic viability as affected by variations in deposit size, geometry, grade, depth, and proximity to transport and services infrastructure.







DMQ – summary of activities

- Synthesis and interpretation of government and Chinova datasets
- Updated solid geology interpretation
- Detailed 4D tectonostratigraphic interpretation based on solid geology
  - 47 4km-spaced sections
  - 3D surfaces for structures and key stratigraphic boundaries
- Updated model of granite geometries in the region
  - Qualitative interpretation of gravity data
  - Geologically-informed gravity inversion modelling of intrusive geometries
- Analysis of geochemical datasets
  - Assessment of potential methods for exploration under cover
- Consideration of grade and depth constraints for (deep) underground mining
  - Target and prospect evaluation tool…..for geologists
- Analysis of existing mineralization in light of new model
  - Key process criteria for localization of mineralized systems
- Propagation of those criteria to search for new targets in the district model

GLOBAL IOCG REVIEW

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

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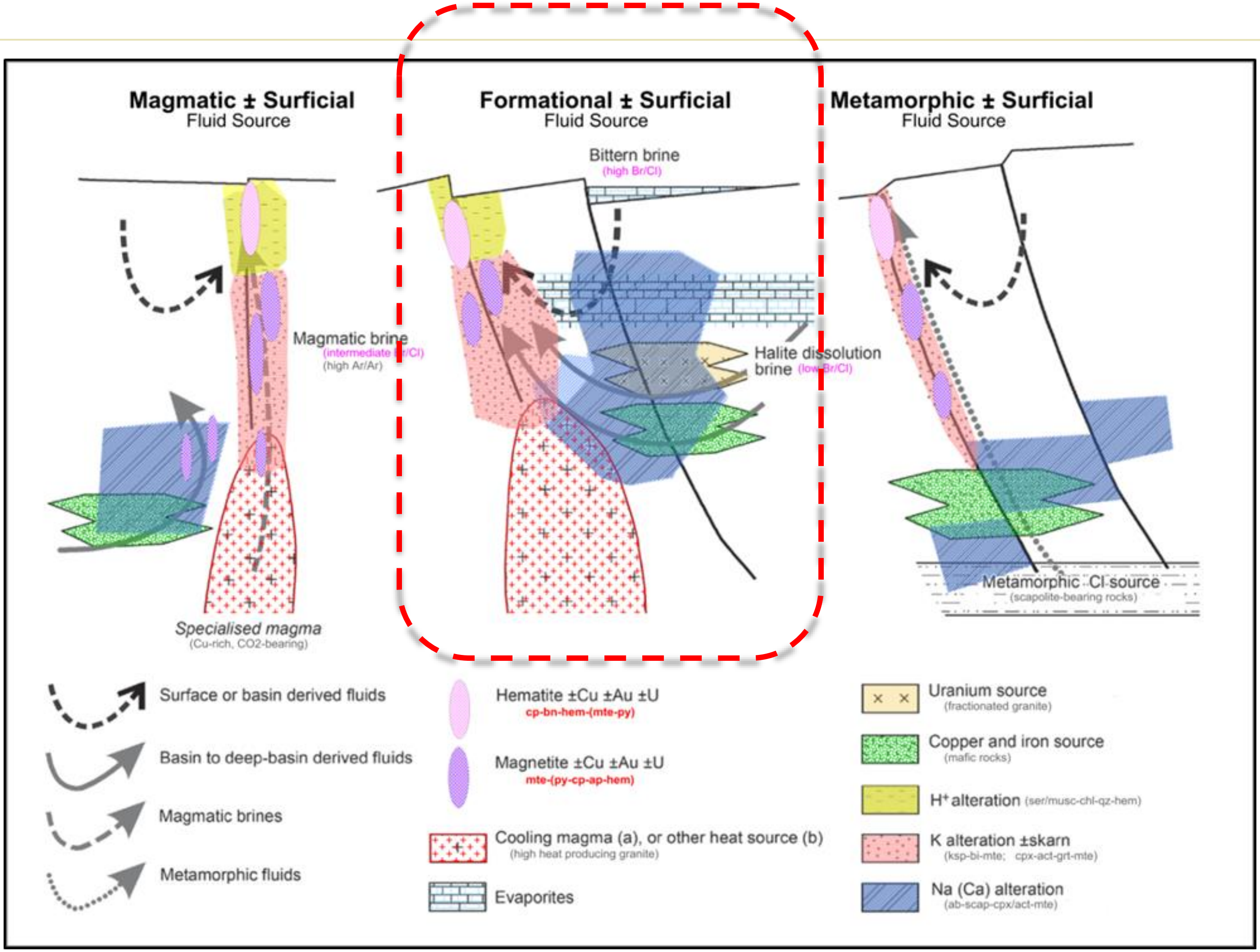
'IOCG' – Common Characteristics

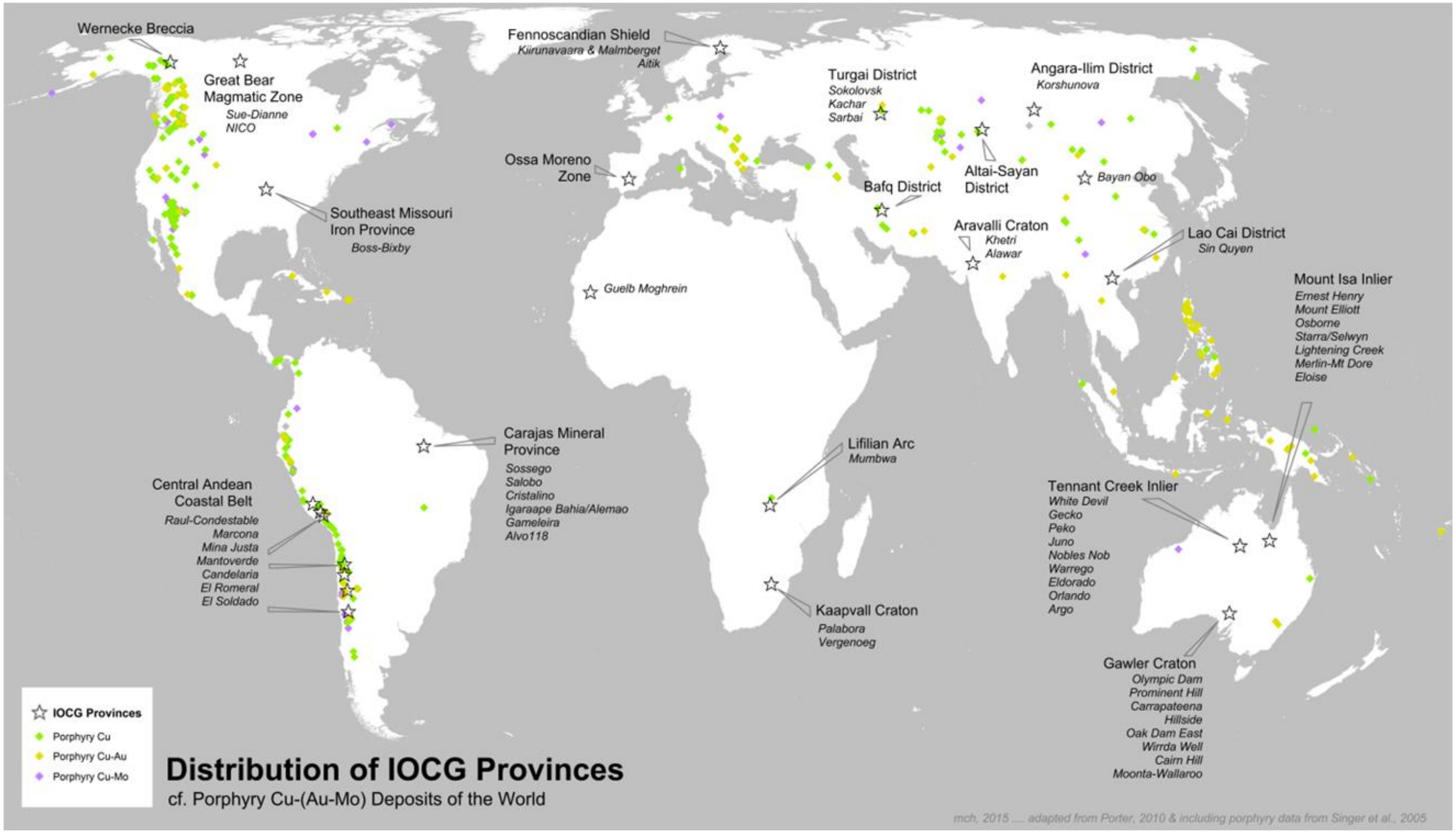
The generally-agreed, empirical/geochemical, uniting characteristics of the IOCG family are (Barton & Johnson, 1996, 2004, 2015; Hitzman, 1992, 2000; Williams et al., 2005; Porter, 2010):

- abundant, low-Ti, Fe-oxides: magnetite and/or hematite,
- Cu ± Au at economic grades
- a distinctive suite of minor elements: (differing mixes of) Ag, REE, U, Mo, F, P, Ni, As, Co, & Ba
- an association with extensive & pervasive alkali alteration – both sodic-calcic, Na-(Ca) and potassic, K
- formed in shallow crustal environments, in brittle regimes (in the 2-12km depth range)
- prominent structural ± lithological control
- most commonly coeval, but (usually) not proximal to magmatism (in the form of plutons & batholithic complexes)
- common district association with Cu-Au-barren, Fe-oxide deposits



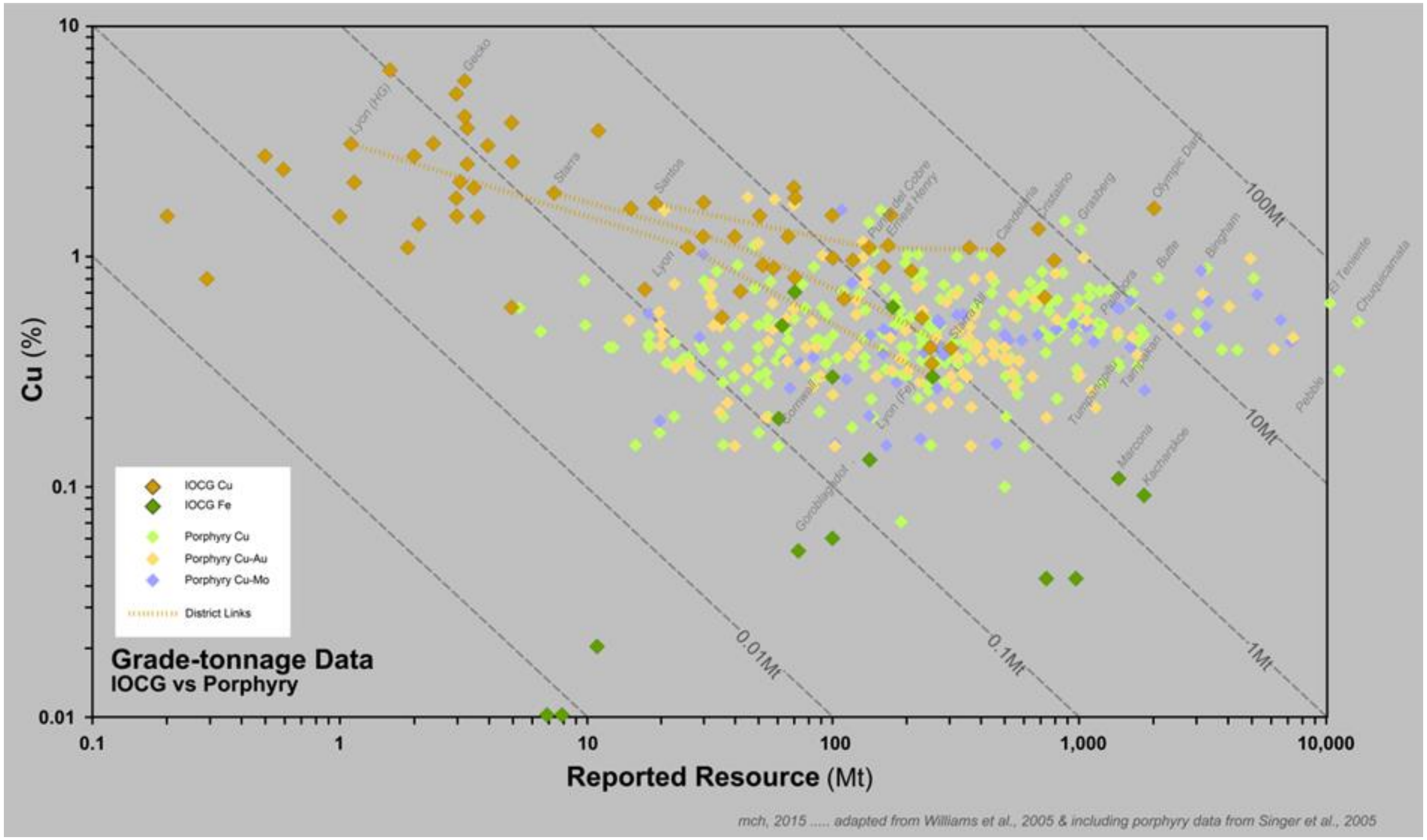
Schematic end-member models of IOCG formation highlighting the diverse range of fluid system permutations. Figure originally produced by Barton & Johnson (2004) and subsequently modified by Williams et al. (2005) and Williams et al. (2010) incorporating source rock concepts of Hayes et al. (1995), Williams (1994) and Hitzman & Valenta (2005).

IOCG Provinces - Worldwide



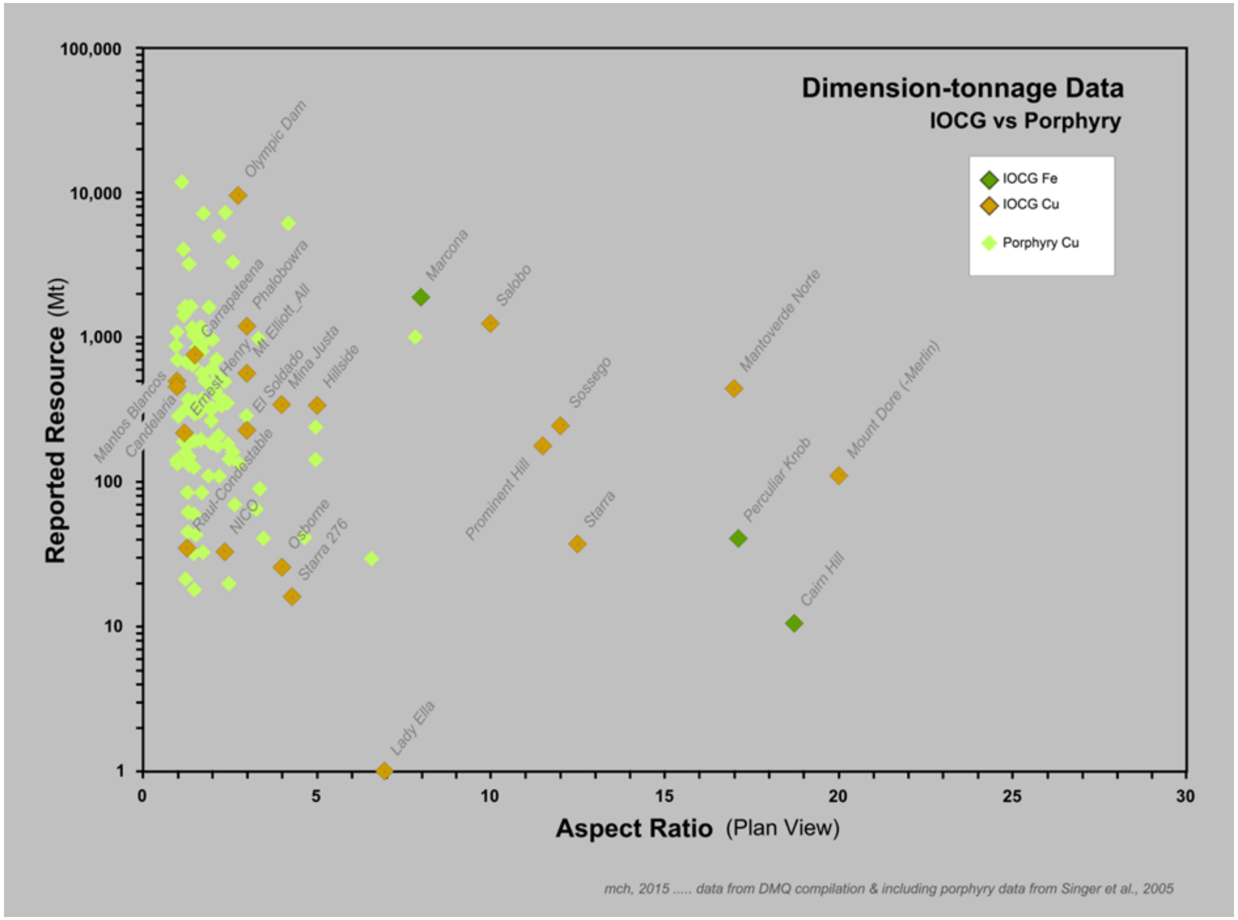
Distribution of global IOCG provinces. Figure adapted from Porter (2010) and includes data from Singer et al. (2005). Note the coincidence of IOCG province with Andean porphyry Cu belts and absence of IOCG deposits in other porphyry belts.

IOCG vs Porphyry: Resource Size & Grade



Grade-tonnage data for IOCG deposits compared to porphyry Cu deposits. Figure adapted from Williams et al. (2005) and includes data from Singer et al. (2005). Tie lines connect deposits within a single district and highlight the spread of deposit tonnages developed within districts.

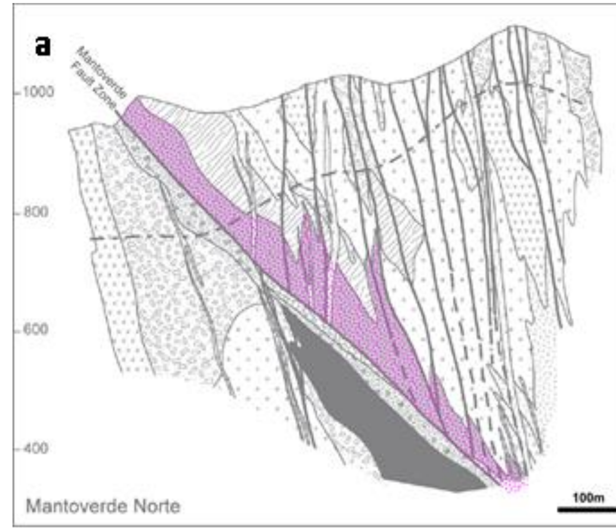
IOCG vs Porphyry: Resource Size & Geometry

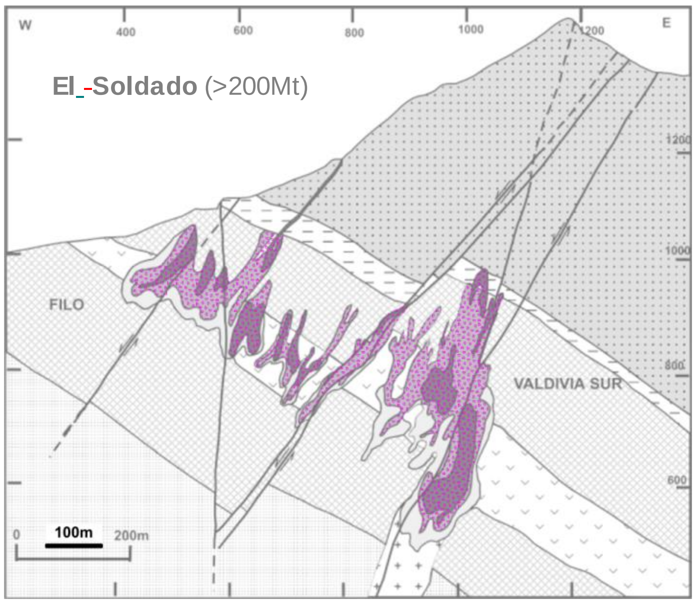


Plan View Aspect Ratios for IOCG deposits compared with porphyry Cu deposits. IOCG data from DMQ compilation and porphyry data from Singer et al. (2005).

Structural Control

Deposits with high degrees of structural control (and lesser lithological control) can tend to be highly planar. At Mantoverde Norte (440Mt), ore is hosted in breccias directly associated with the Mantoverde Fault Zone (Reiger et al., 2010a, 2010b) and the ore body has a high degree of planarity.





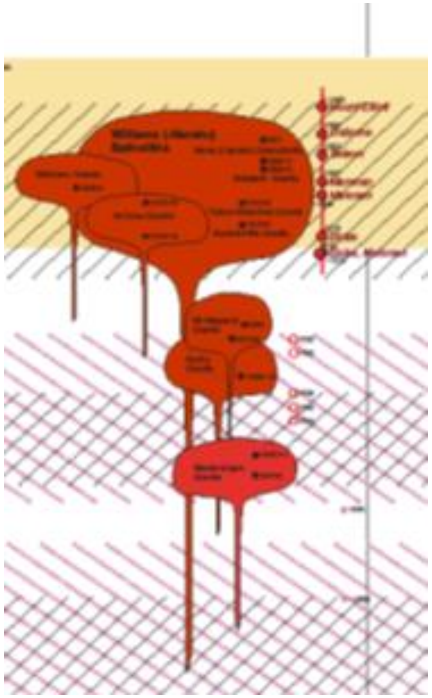
In many IOCG deposits replacement is a stronger control on orebody geometry. At El Soldado (>200Mt), ore is most strongly developed within a particular rhyodacite unit where it is intersected by identified fluid feeder structures (Boric et al, 2002). Ore is in lobate ‘cigar-shaped’ bodies lying along the intersection of variably-striking, steep structures with the dipping, receptive lithology.

Very commonly a ‘late’, brittle reactivation of pre-existing ductile structures is implicated in mineralisation.

Magmatism & Alteration

- The broad synchronicity of crustal magmatism with IOCG formation has been highlighted by many researchers in numerous review papers: Hitzman (1992, 2000), Williams et al. (2005), Porter (2010), Barton & Johnson (2004, 2015).

- Alteration systems associated with 'IOCG' systems are regional in extent (10 to >1000sqkm) and have been interpreted to extend to at least mid-crustal depths (Haywood & Skirrrow, 2010; Porter, 2010). These characteristics demonstrate the lithospheric scale of the 'IOCG' magmato-fluid systems, focussed by intrusion geometry and pre-existing and re-activating crustal architectures.



Essential Ingredients

A number of critical features of IOCG systems are becoming clearer (Williams et al., 2010) and should influence robust targeting and prospectivity analysis:

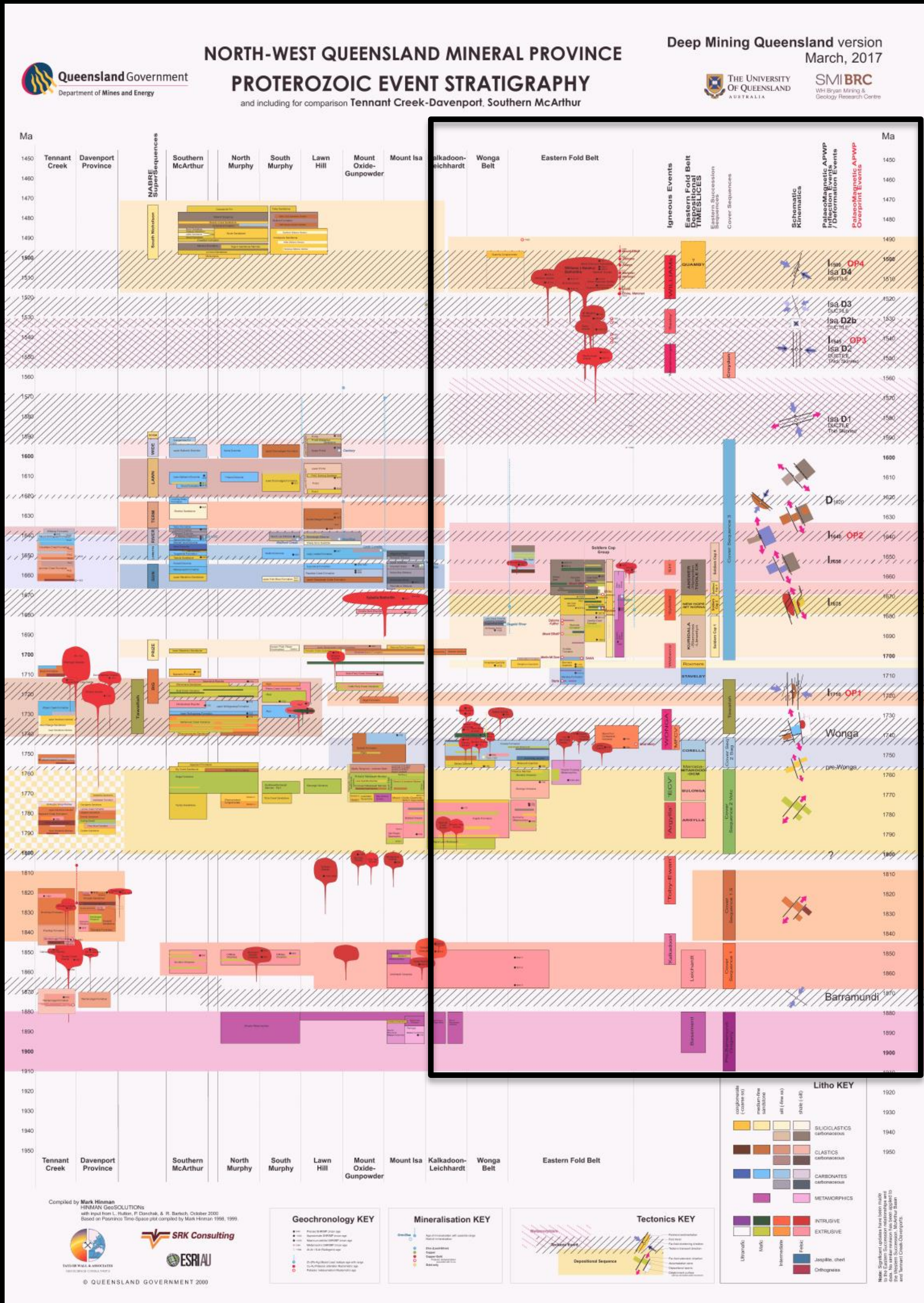
1. The primary **fluid systems are regional in scale**, are high temperature and have extreme metal-scavenging capacity (ie hypersaline).

2. **Cool, oxidised, surficial fluids have interacted with the more deeply-sourced, high temperature hypersaline fluids** to produce high grade ore in many deposits. Alteration mineral assemblages and oxide/sulphide mixes can be highly variable and their diversity needs to be appreciated in geochemical and geophysical exploration planning.

3. Deeper systems may not manifest cool, surficial fluid interaction and will present different alteration and ore assemblages. **Some but not all deeper systems do exhibit geochemical evidence of magmatic input** but only rare examples (of the handful of well-studied deposits) display dominantly magmatic input.

4. **Hypersaline IOCG ore fluids demonstrate a significant contribution from evaporitic sources**; either surficial (bitterns, drawn down into circulation), formational (in the path of circulation) or metamorphic (also in path of circulation, or via metamorphic release).

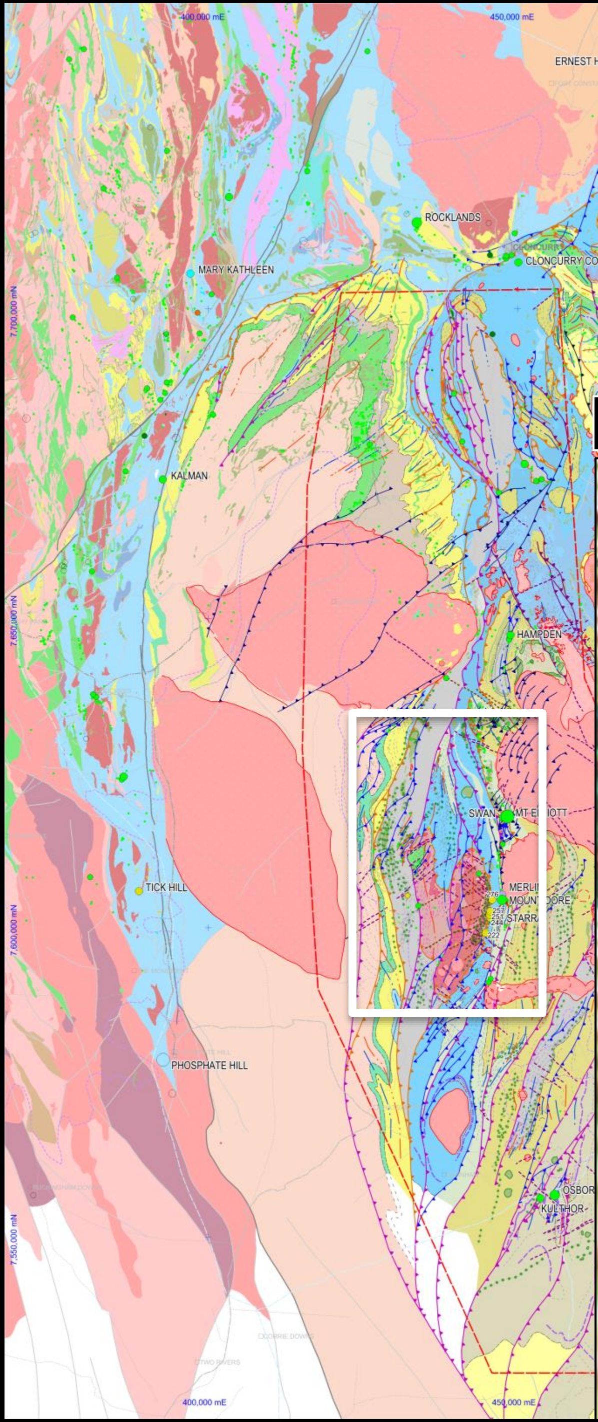
INSIGHTS INTO LITHOSTRATIGRAPHIC ARCHITECTURE OF THE CLONCURRY DISTRICT



Updated DMQ 2017 version

of 2000 NWQMP T-x Chart

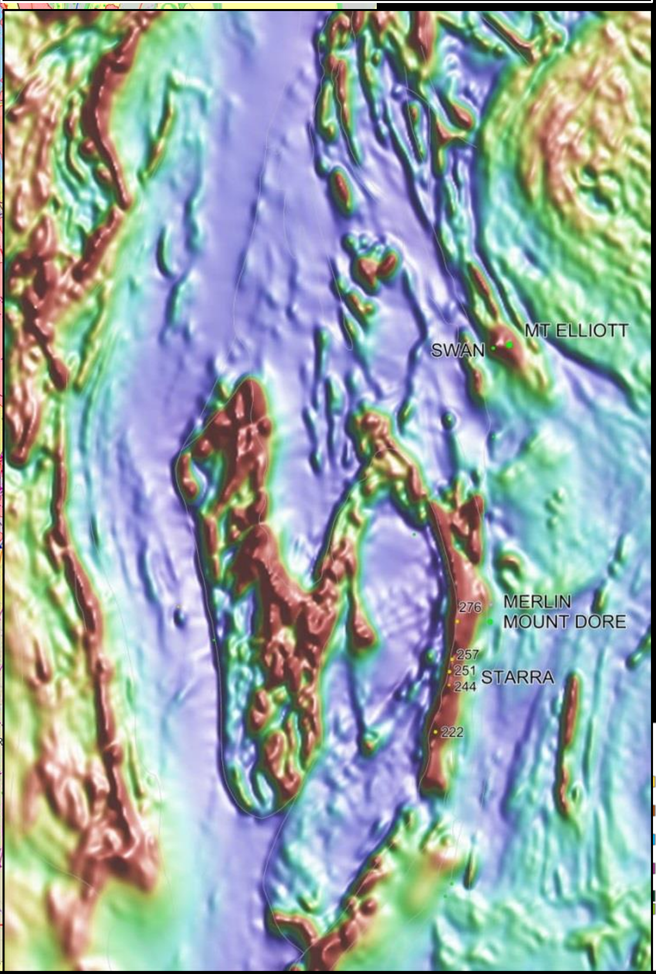
- Reflects **current DMQ understanding** of **EFB package relationships** & **latest geochronology** (Withnall-Parsons, 2007-2009; NWQMEP, 2011; GSQ geochron database, Withnall, 2016)
- **Updated Isan Deformation Events** to reflect **D1, D2, D2b, D3** & **D4** in common usage.
- **TIMESLICES** reflecting **DMQ re-packaging** of mapped Formations, Members & units.



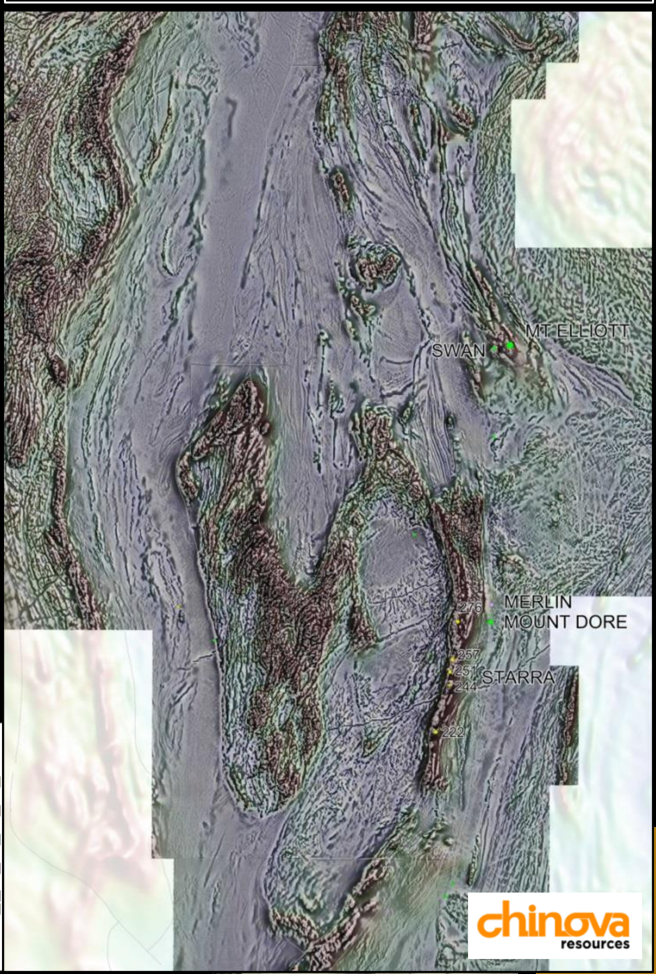
DMQ-rebuilt Solid Geology

- **Leveraged ultra-detailed Chinova geophysics**
  Allowed a high fidelity interpretation of package continuity & fine fault architecture

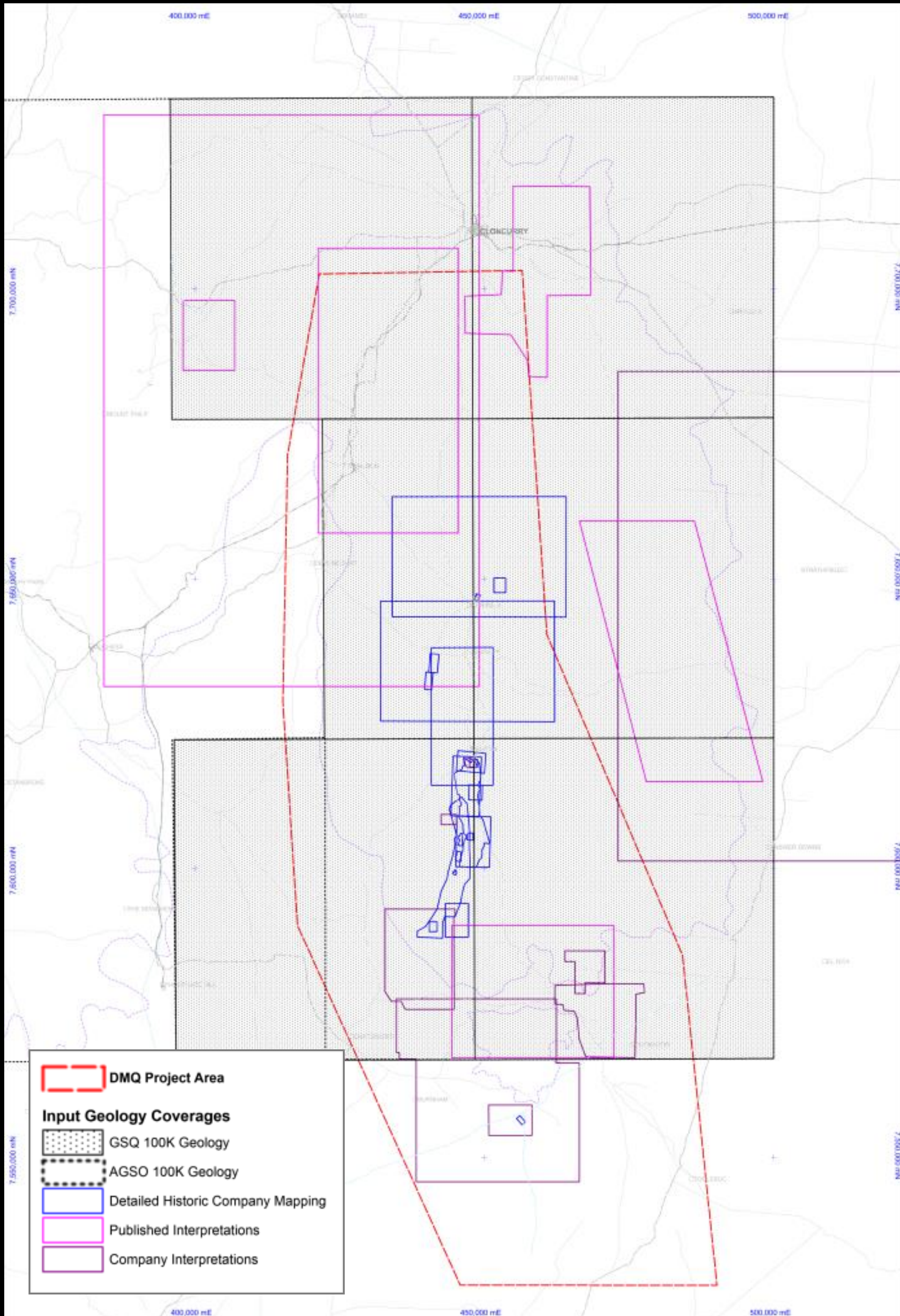
GA Mag tmi-rtp v6 (**2015**) 80m grid



Chinova detailed Mag vrmi-2vd (**2010**) 10m grid



DMQ-rebuilt Solid Geology



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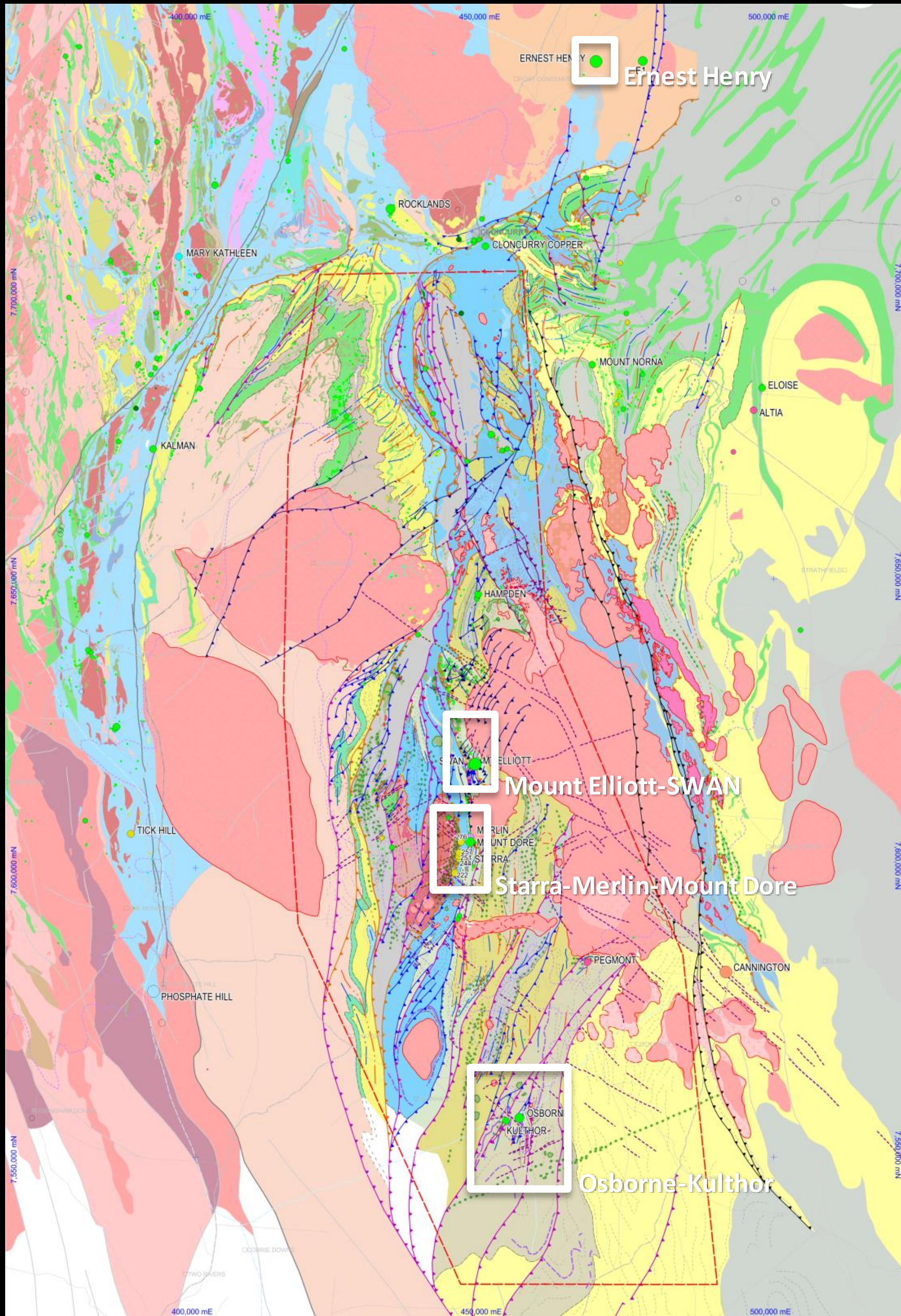
- **Incorporated prospect-scale geology …**

  Historic mapping, including in particular that of John Leishman (1970s-1980s); previous company interpretations & journal-published maps …

  … building on the GSQ 100K series Maps



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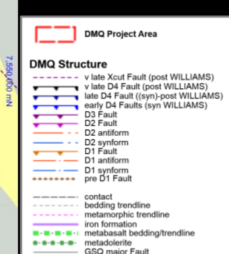
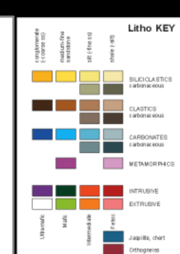
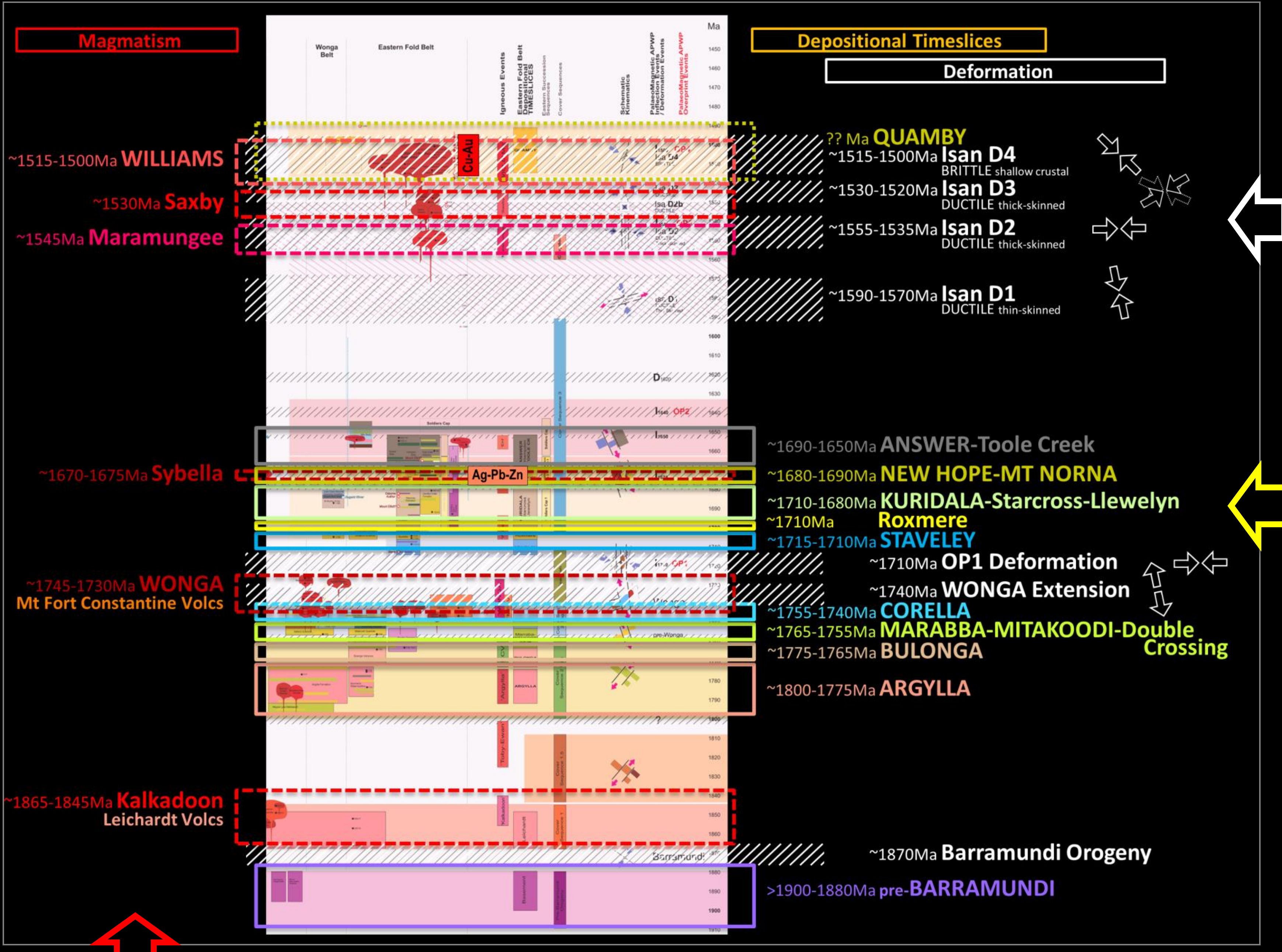
DMQ PRODUCTS

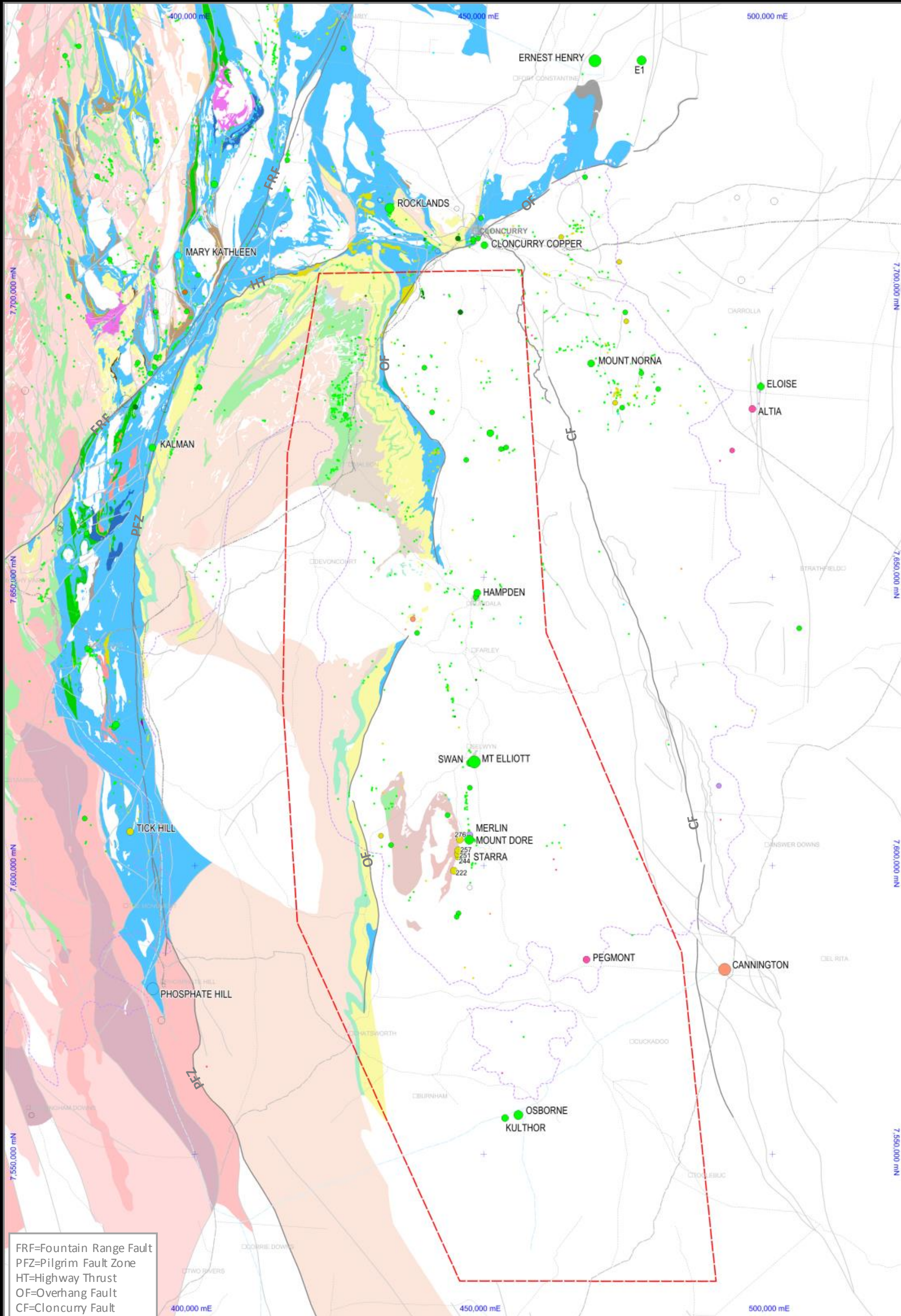
- **~1:50K Solid Geology Interpretation**
- **GIS Package of TIMESLICED Geology**
- **GIS Event-attributed Structures**
- **Detailed ~1:5-10K Local Compilations**
- **29-step EFB Assembly Model**







DMQ Assembly Model highlights geometries & impacts of **29 episodes** of: TIMESLICED **Accumulation**, **Deformation** EVENTS and Episodes of **Magmatism** in relation to mineralisation

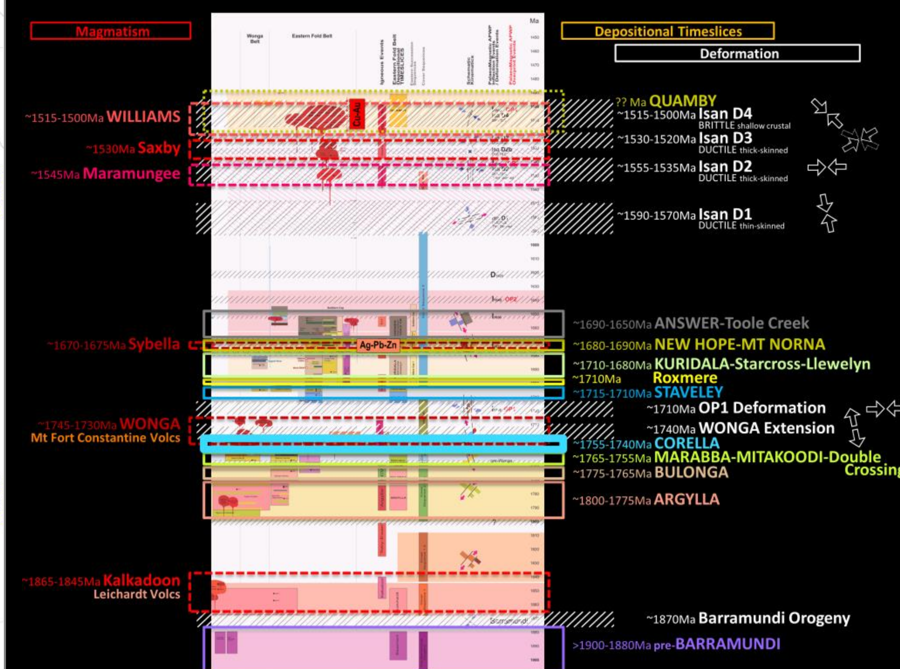


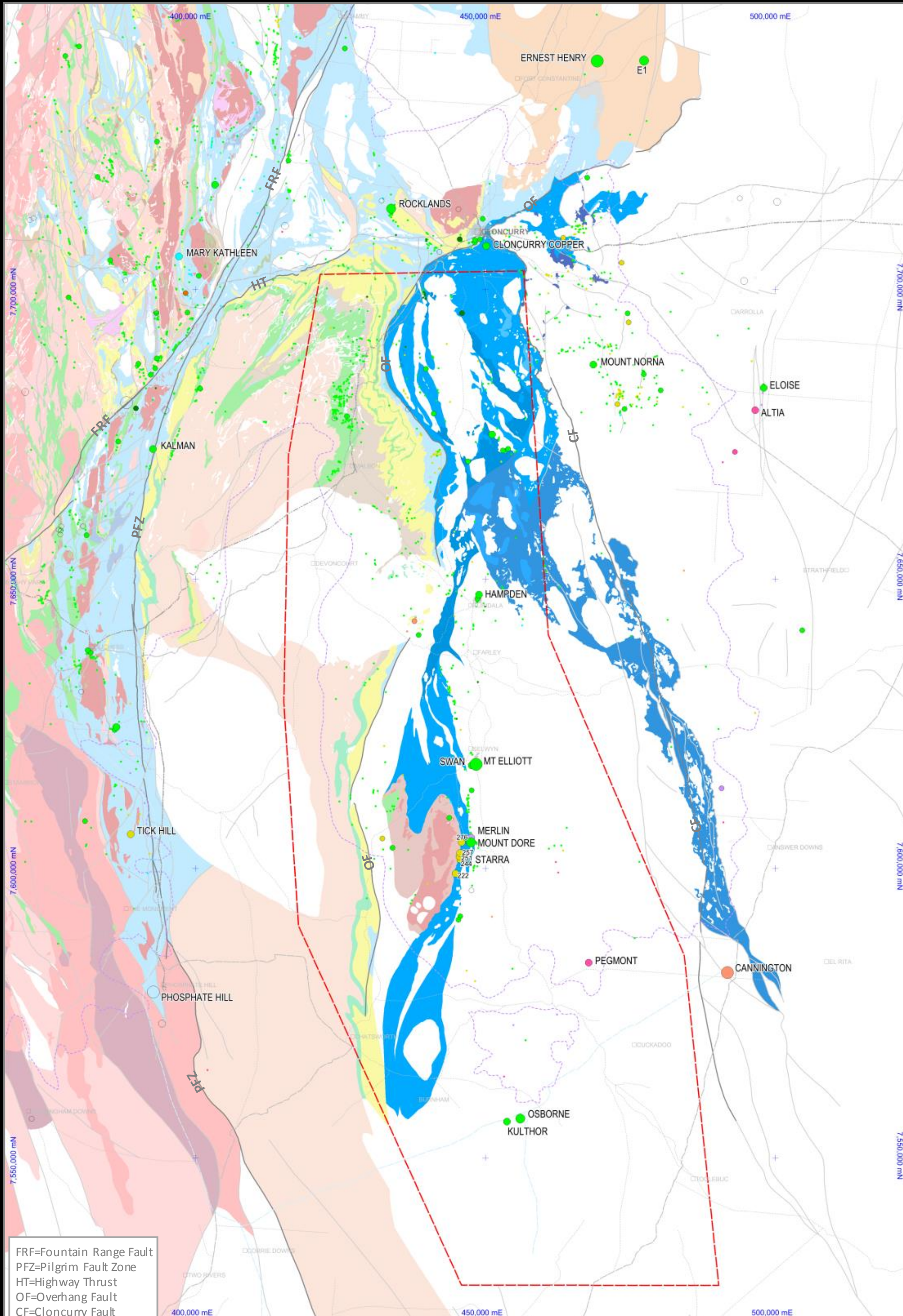
~1755-1740Ma
CORELLA

Corella Formation, Overhang Jasperlite, Chumvale Breccia, Lime Creek Metabasalt Member

Calcareous sandstone-siltstone, limestone, calcareous scapolitic granofels, calc-silicates, marble, minor quartzose sandstone, laminated siltstone-jasperlite, metabasalt-amphibolite, schist, shale-pelite, minor feldspathic granofels, minor contact aureole pyroxene hornfels-skarn

- **Pre-WONGA**, CORELLA timeslice entirely preserved **west of the Overhang Fault Zone**, and **north of the NE extension** of the Overhang Fault Zone
- CORELLA onlaps Ballara Quartzite west and north of Fountain Range Fault Zone
- Much of Corella Formation, and all of the Staveley & Doherty Formations removed from CORELLA timeslice and re-allocated to later STAVELEY carbonate timeslice



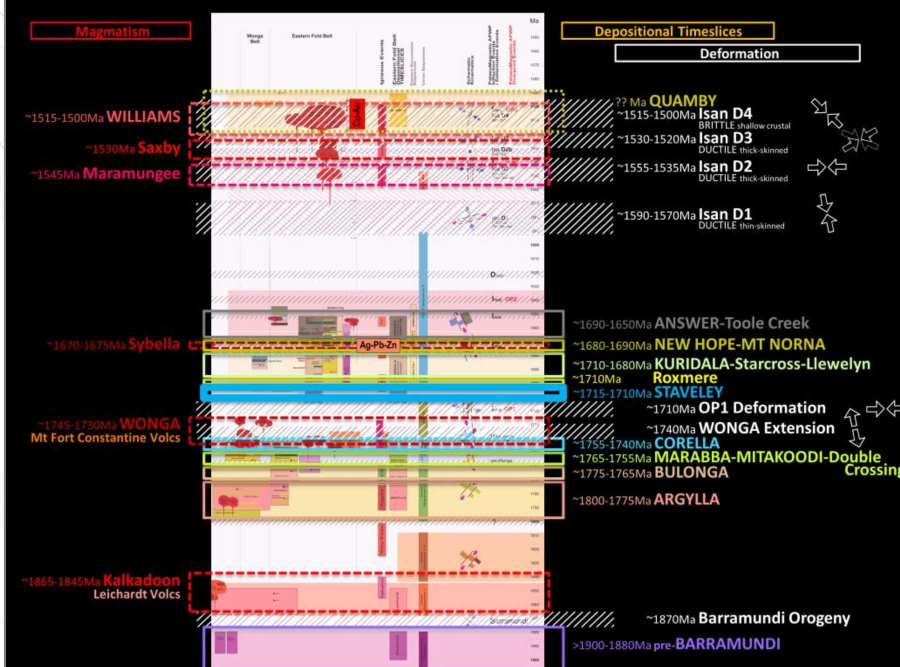


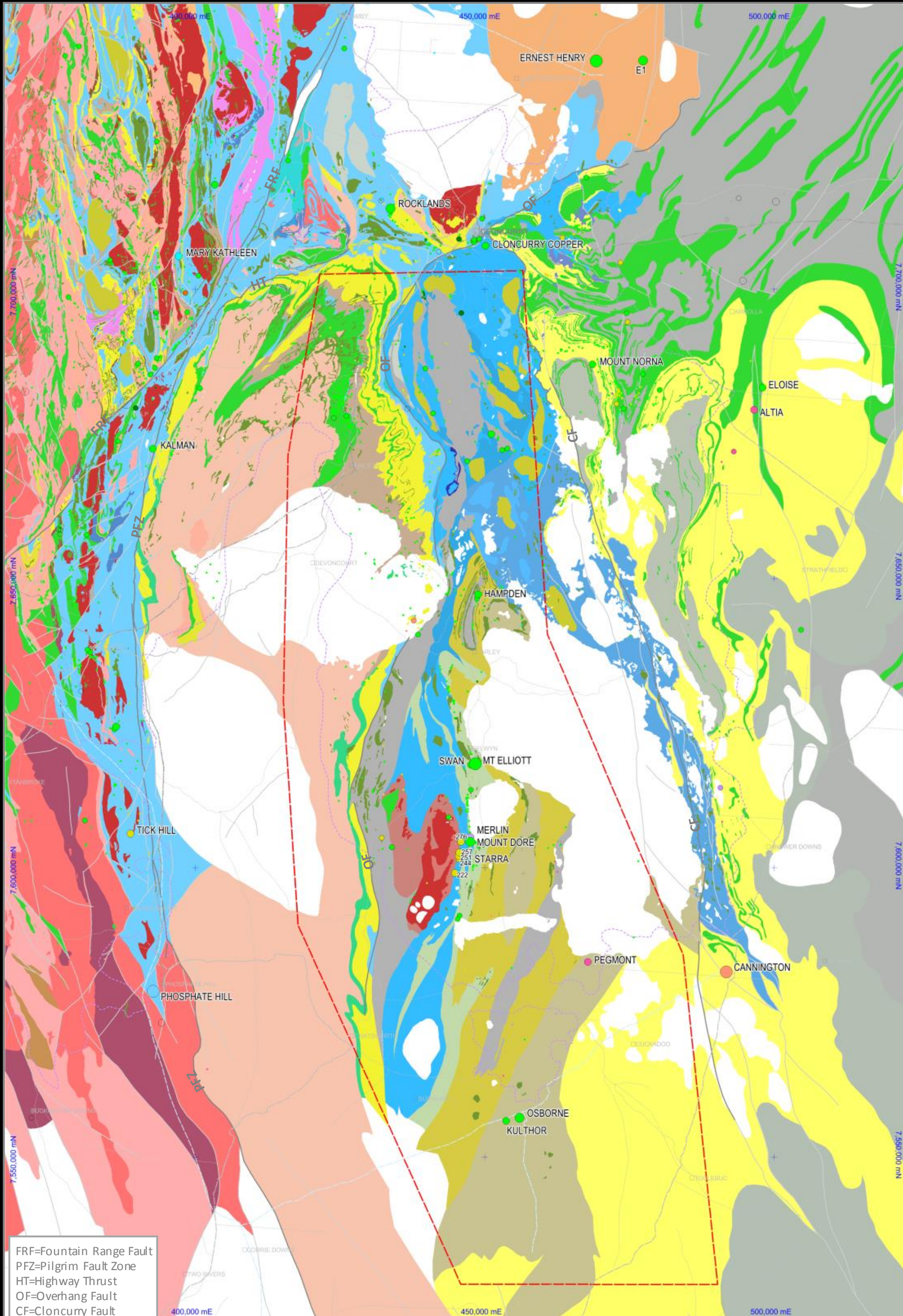
~1715-1710Ma
STAVELEY

Staveley Formation, Doherty Formation, significant parts of Corella Formation

Interbedded, variably calcareous, sandstone-siltstone, calc-silicates, calc-silicate granofels, breccias of all; impure limestone, marble

- **Post WONGA**, STAVELEY timeslice includes **significant areas of previously-allocated Doherty & Corella Formation** and their brecciated variants
- STAVELEY timeslice now found **entirely east and south of the Overhang Fault Zone** and its NE extension … in sharp **contrast with the distribution of the CORELLA package**
- **Basal STAVELEY obscure.** Underlying packages not identified if conventional wisdom is correct and **lower portions of STAVELEY are ubiquitously in fault contact** with older packages along the **Overhang Fault** (against CORELLA and MITAKOODI packages) and along the **Starra Shear** (against 'Double Crossing Metamorphics' & 'Gin Creek Granite')
- An alternative is that STAVELEY is in depositional (rather than D1 thrust) contact with 'Double Crossing Metamorphics' & 'Gin Creek Granite' around the northern and eastern sides of the Gin Creek Block. However, high angle discordances (in detailed geophysics) between STAVELEY bedding and the STAVELEY-DCM contact round the northern margins of the Gin Creek Block argue against this interpretation.





~1650Ma

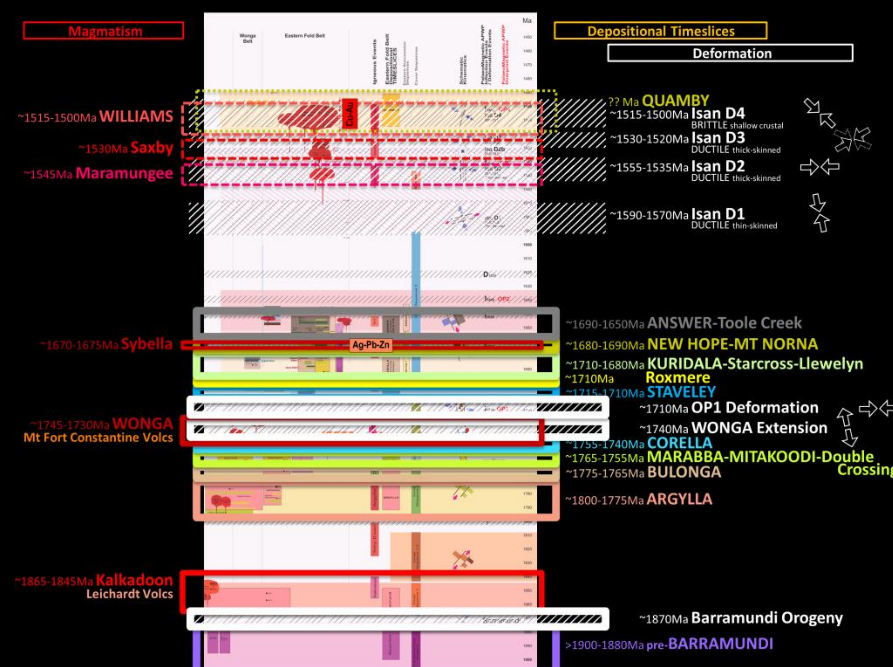
End of Accumulation

By 1650, accumulation in the Eastern Fold Belt is all over.

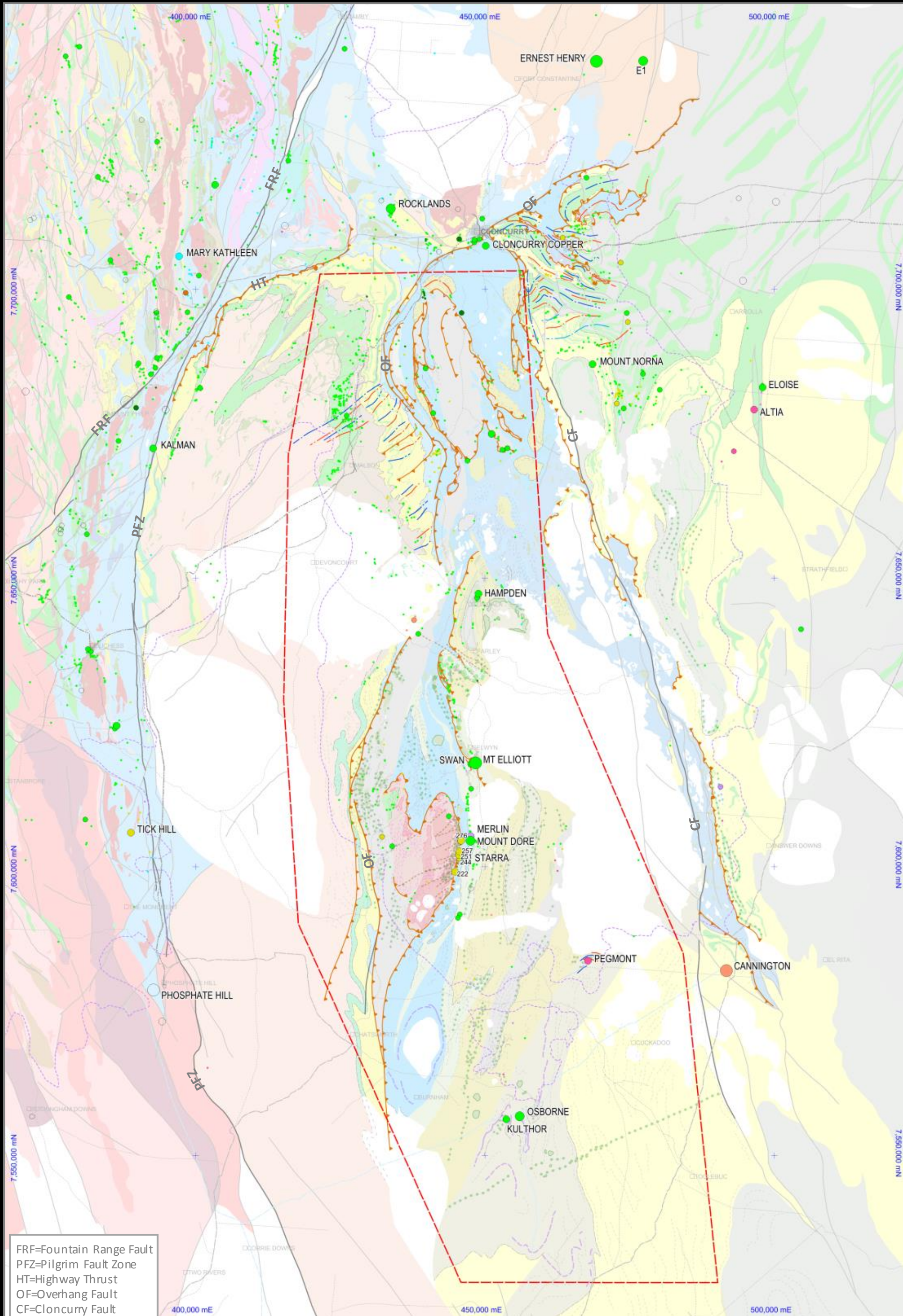
Rock relations at this time would have incorporated the deformation and magmatic effects and inputs of ... **Barramundi Orogeny**

- the **Wonga Extension** including mid-crustal extensional detachments with associated magmatism and possible upper-crustal extensional faulting, tilt blocks and basin compartments (MFCVs)
- significant E-W shortening during the **OP1 Deformation/Orogeny** that in the EFB is implicated in the exhumation of Double Crossing Metamorphics & Gin Creek Granite to surface or at least to upper crustal levels.

In addition, spatially-focused magmatic input in the form of syn-depositional metadolerite silling is present in the NEW HOPE-MOUNT NORNA and TOOLE CREEK packages.

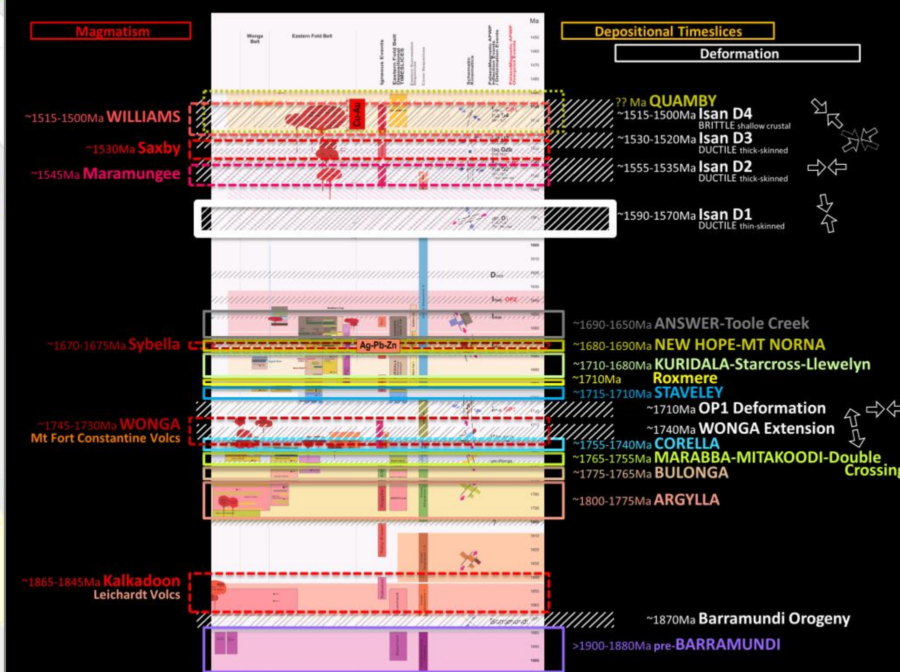


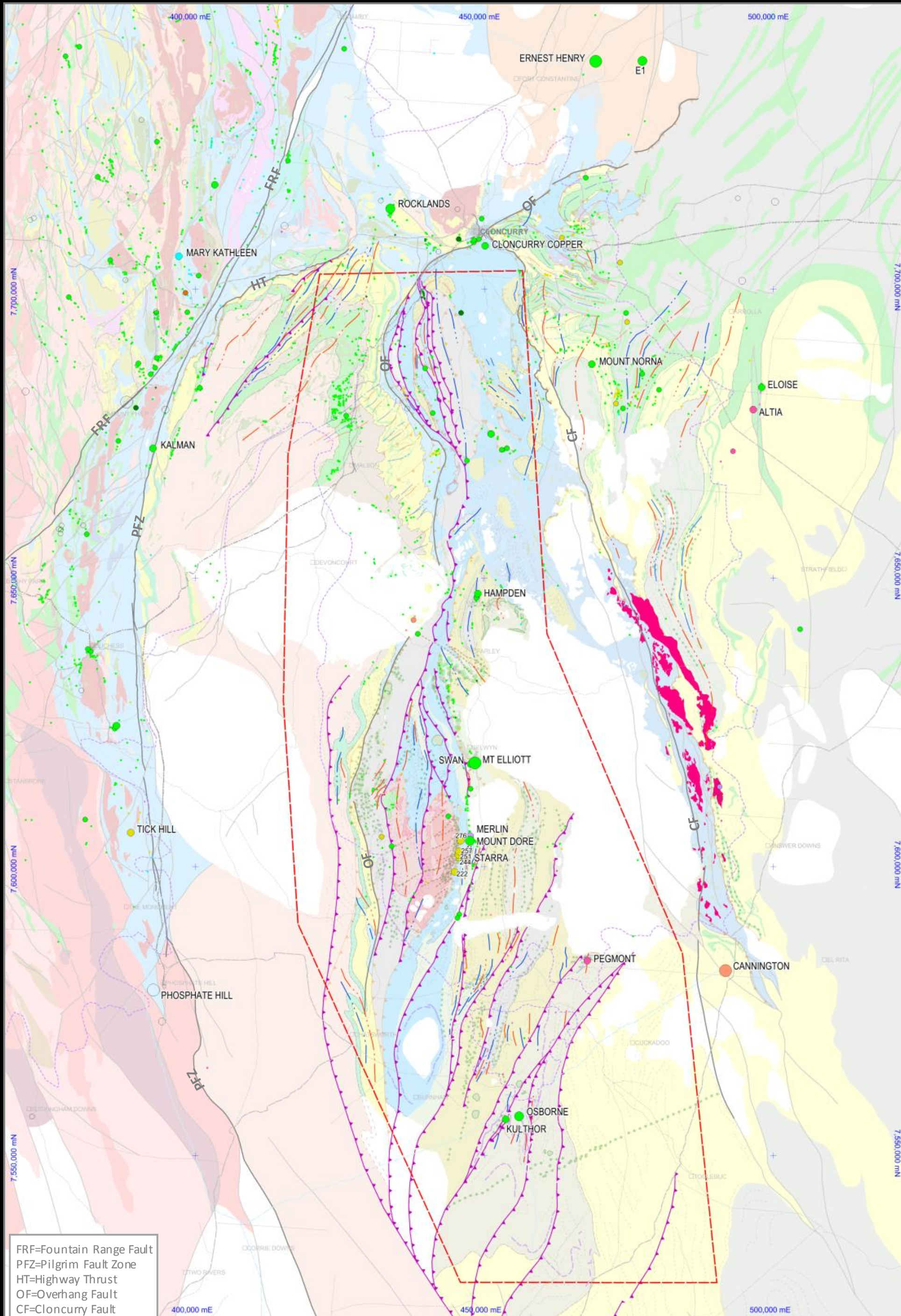
~1600-1570Ma
thin-skinned, **D1 Folding** & **Thrusting**



Thin-skinned Isan D1 characterised by **N-S to NNW-SSE shortening** with **N(NW)-directed movement** on major, **shallow-dipping thrusts** (and potential ramps) and is associated with, locally-preserved/identified **F1 folding**.

- **Overhang Fault** including NE extension, **Starra Shear** (following conventional wisdom), **Marimo Thrust** & associated structures, and **Mount Elliott-Hampden Fault**.
- **Cloncurry THRUST** (distinct from the Cloncurry FAULT) have been assigned to D1 on basis of …..
- North of Snake Creek Anticline, D1 folding (folded by D2) is seen to be well developed in the D1 thrust hanging wall over windows of footwall STAVELEY.
- D1 thrust surface may itself be folded in D1 shortening. These geometries may be influenced by their proximity to the Overhang Fault extension which marks some form of Mount Fort Constantine Volcanic (MFCV) basin margin
- F1 folding is also well developed in footwall of Overhang Fault (O'Dea et al., 2006) on the west side of the project area.
- North-south meridional trends of the D1 Thrusts reflect larger-scale, meridional D2 folding of the earlier flatter-lying D1 structures.
- Many D1 thrusts, folds and linked-ramp structures likely remain unidentified; in particular within highly deformed and metasomatised STAVELEY packages (Marshall, 2003) significant



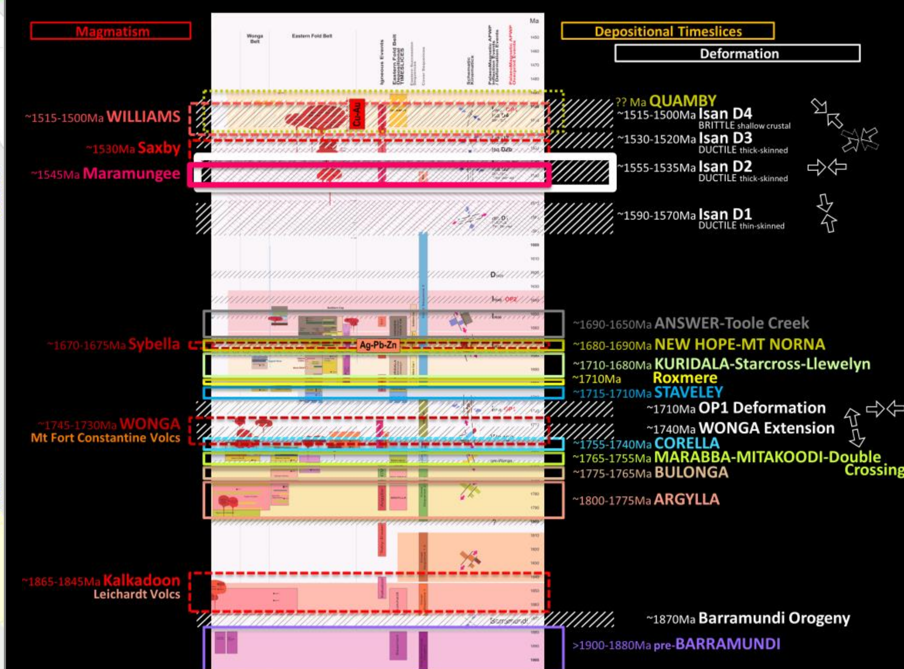


~1555-1535Ma thick-skinned, **D2 Folding & Faulting**

~1555-1535Ma **Maramungee Magmatism**

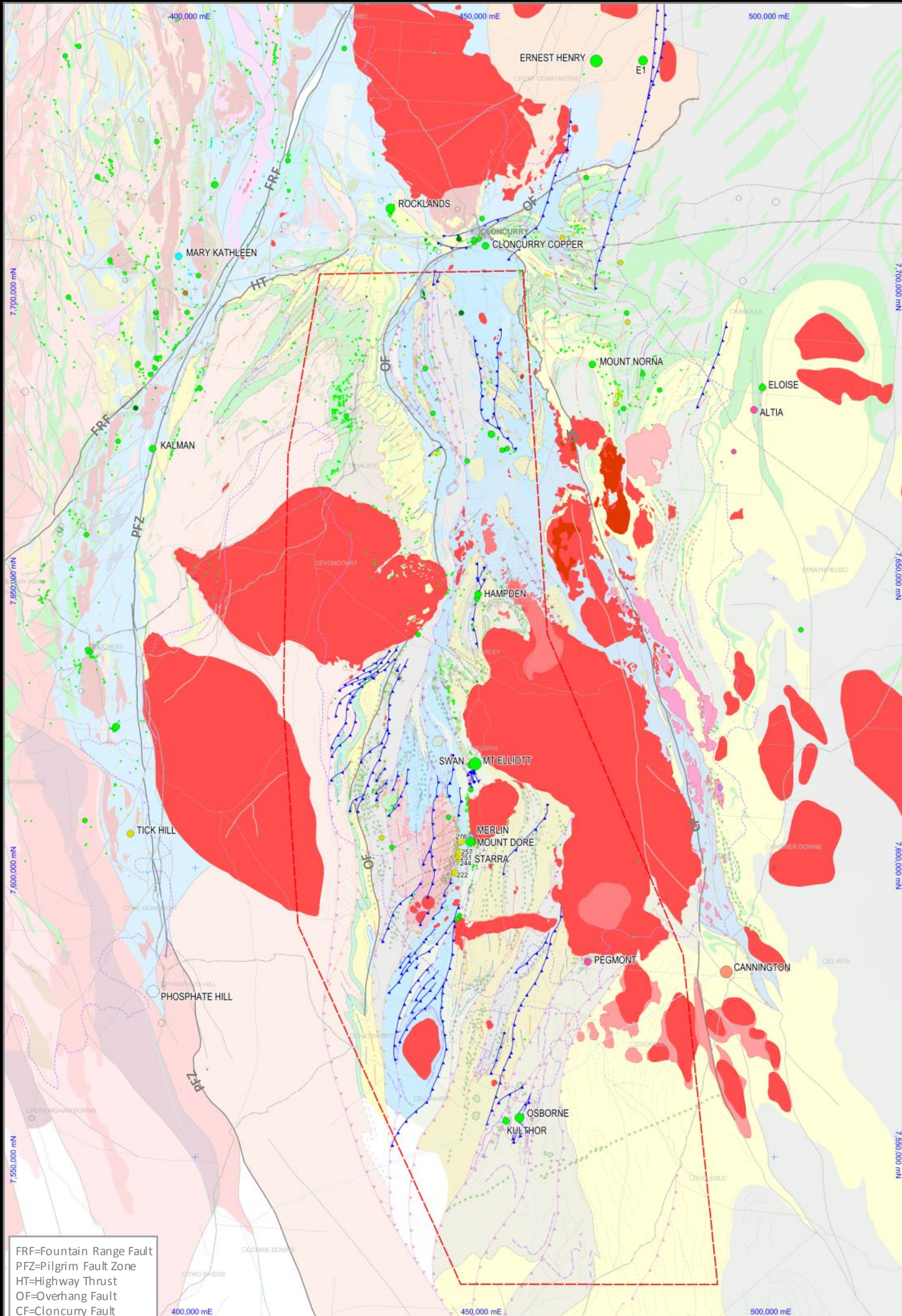
Thick-skinned, D2 EW shortening produces **N-S meridional folds** of **stratigraphy** and earlier D1 structures. Progressive D2 shortening not accommodated by further folding and/or fold tightening and **D2 reverse fault failure** initiates.

- D2 reverse faults are widespread and are **ubiquitously W-vergent**
- They have very **significant strike lengths** and **major throws**, juxtapositioning packages of contrasting ages and compositions.
- Progressive **highTemp-highPress metamorphism** at this time yields some syn-deformational intrusives east of the project area **… the Maramungee Suite.**



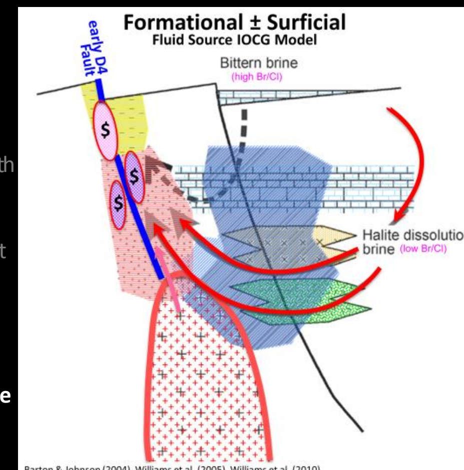
~1515-1500Ma
early **D4 Faulting/re-Activation**

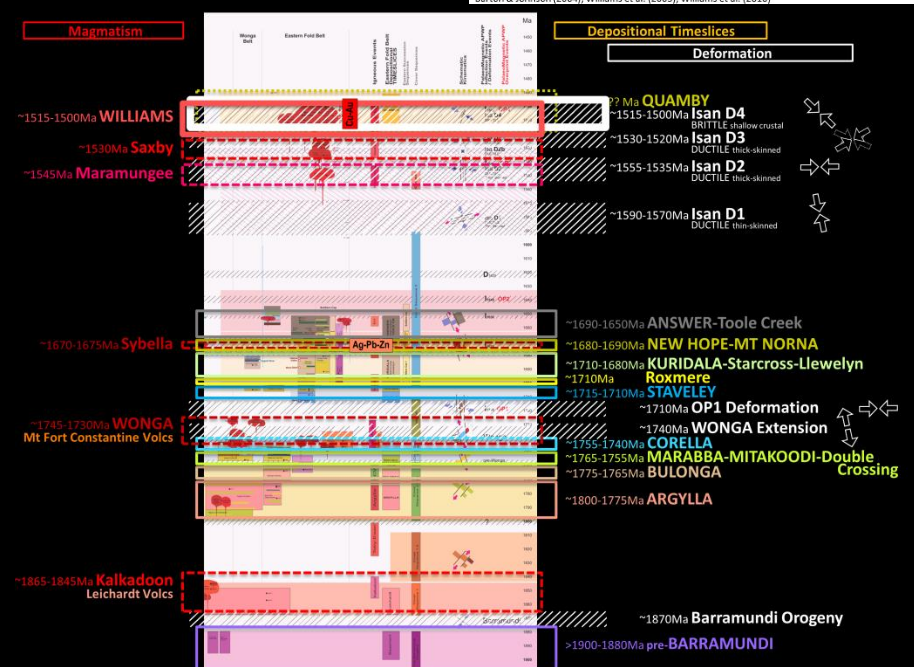
~1515-1500Ma
WILLIAMS Magmatism
Cu-Au, Au-Cu, Mo-Cu



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.





Magmatism

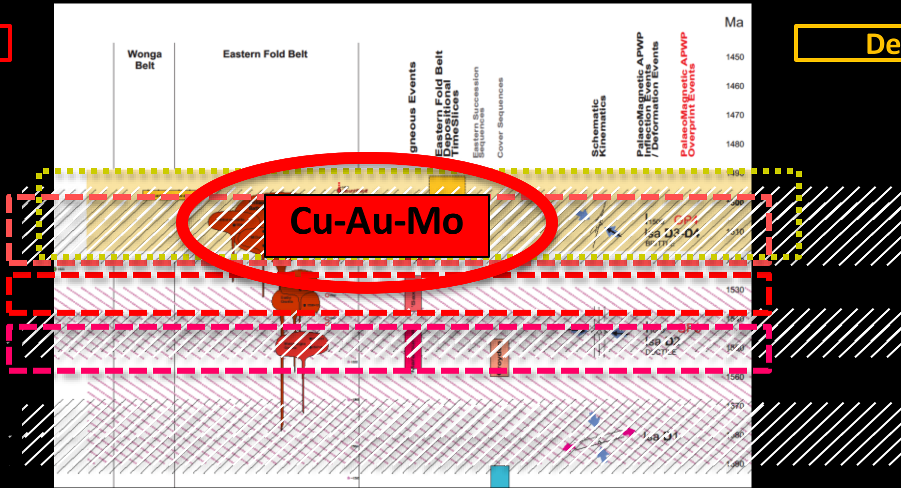
Depositional Timeslices

Deformation

~1515-1500Ma **Williams**

~1530Ma **Saxby**

~1545Ma **Maramungee**

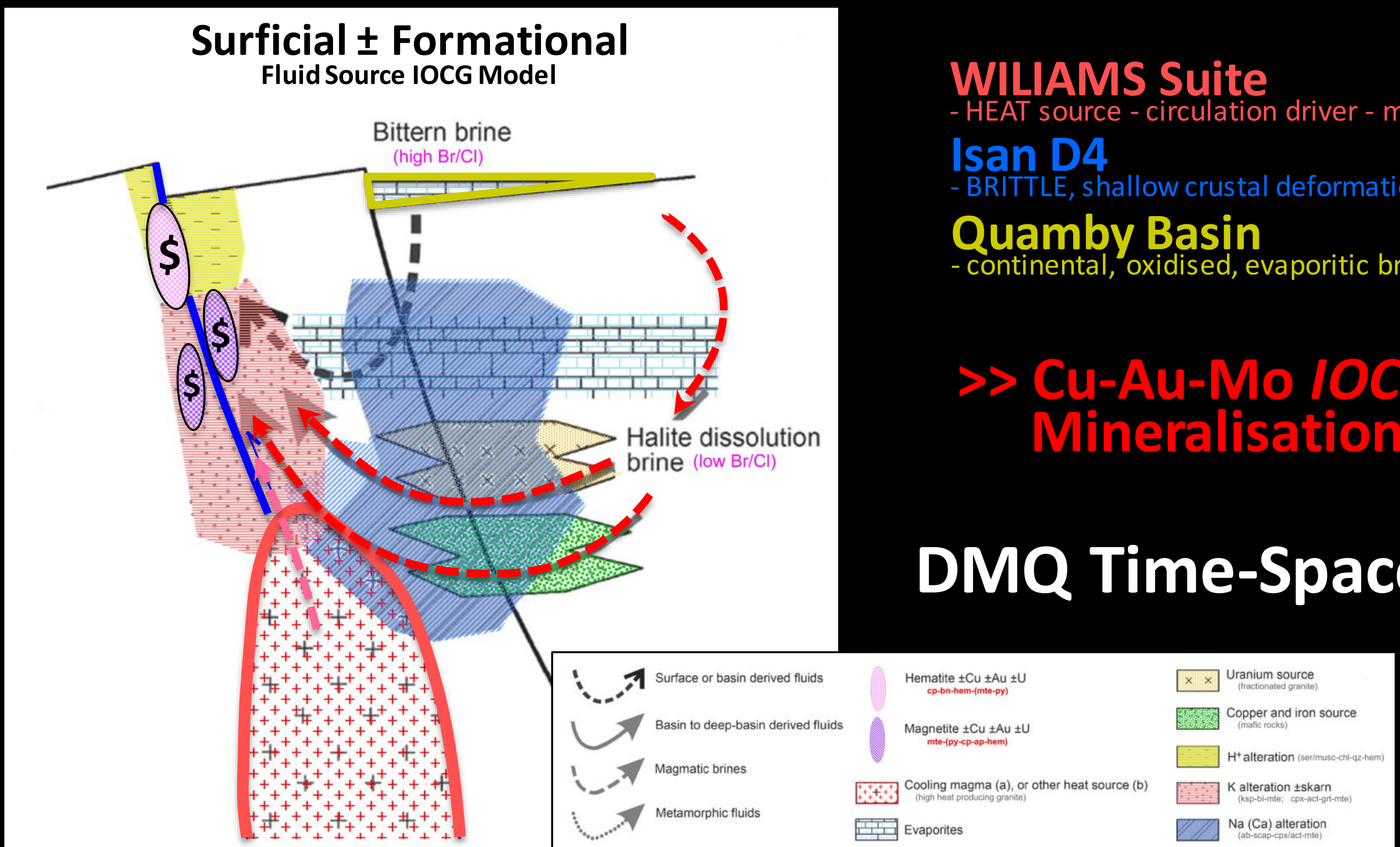


?? Ma **Quamby**

~1520-1490Ma **Isan D4**
BRITTLE shallow crustal

~1590-1570Ma **Isan D2**
DUCTILE thick-skinned

At ~1515-1500Ma …



Barton & Johnson (2004), Williams et al. (2005), Williams et al. (2010)

WILIAMS 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/ISCG* Mineralisation

DMQ Time-Space Control

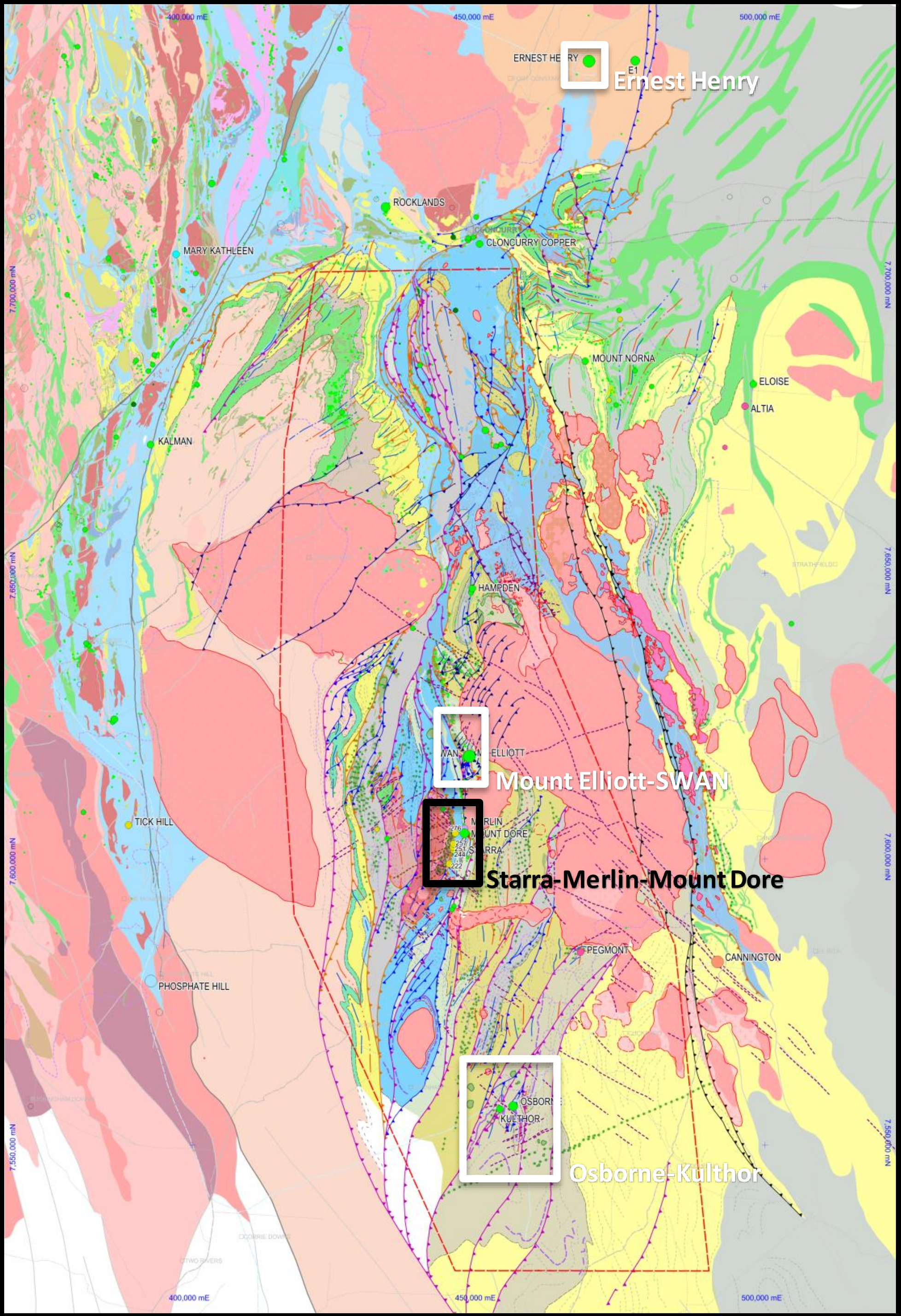
CLONCURRY COPPER-GOLD DEPOSIT CONTROLS

DMQ Deposit Controls:
District to Local

Looked at four areas > detailed compilations & interpretations of mineralisation control ....

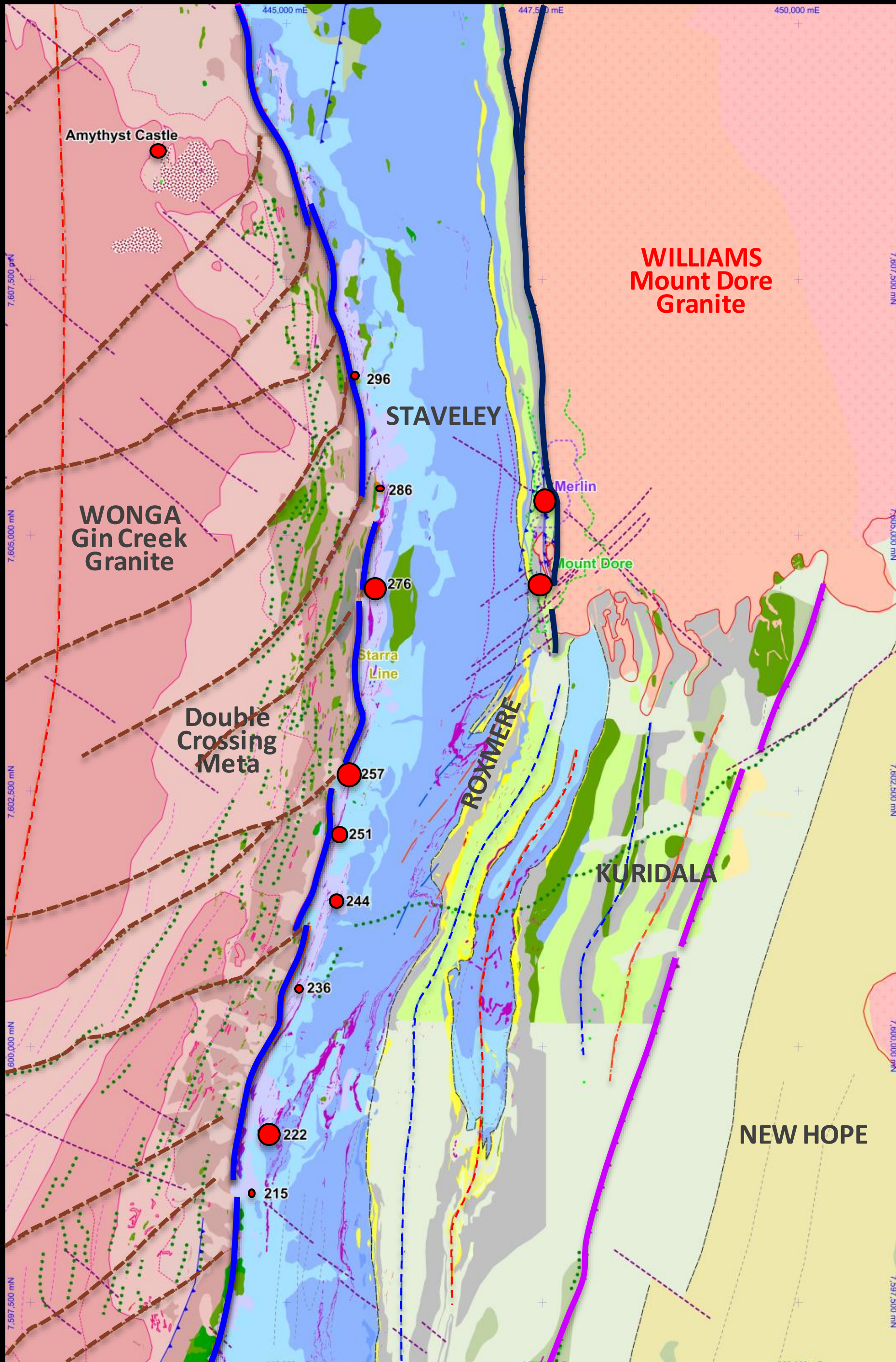
Starra-Merlin-Mount Dore
Mount Elliott-SWAN
Osborne-Kulthor
Ernest Henry

Starra-Merlin-Mount Dore



Starra-Merlin-Mount Dore

5K-10K Leishman Geology (1970s-1980s)
DMQ Mag Interpretation (2016)



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

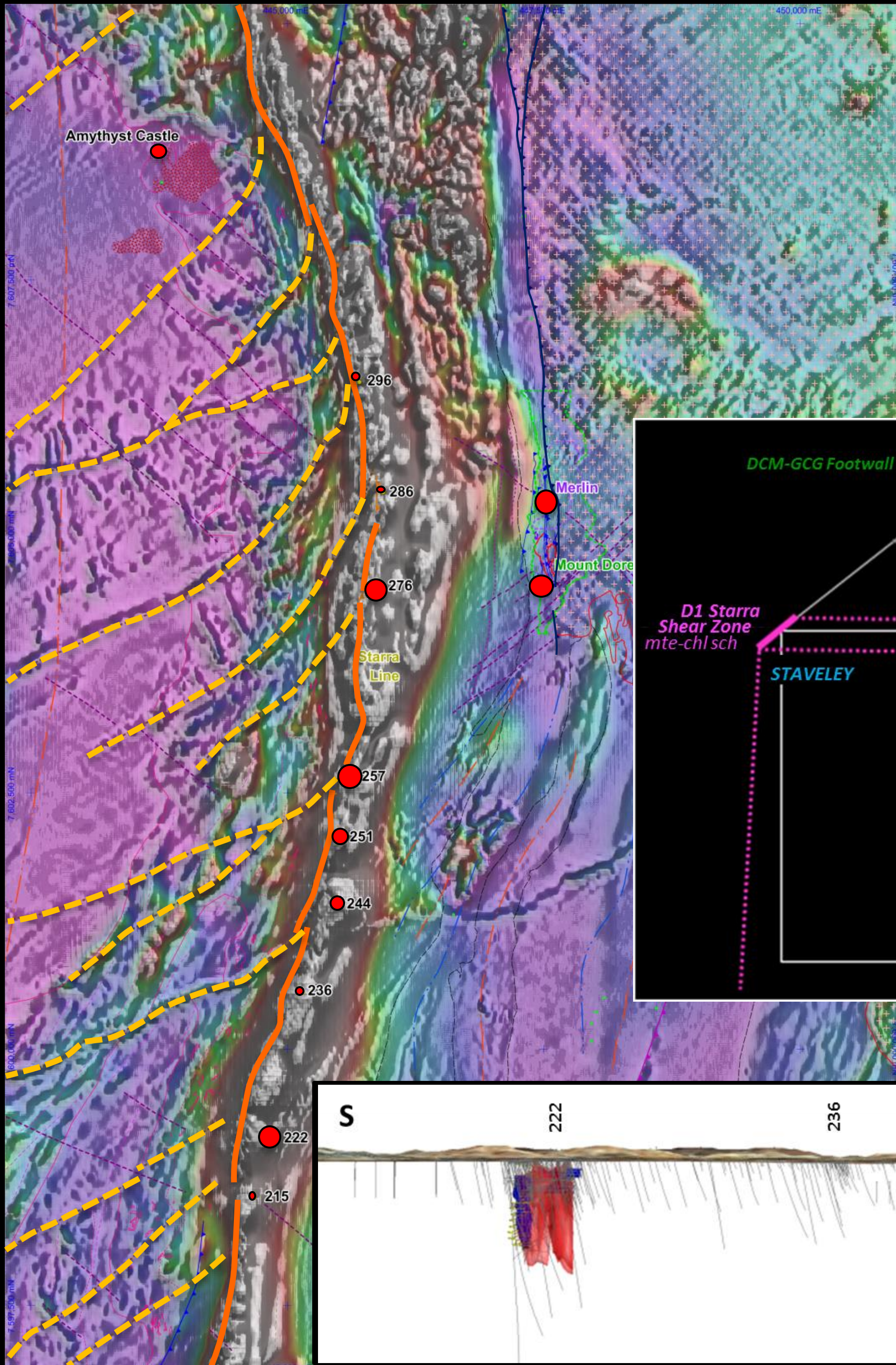
thin-skinned, sub-horiz, D1 NNW-overthrust of STAVELEY-ROXMERE-KURIDALA-NEW HOPE over DCM-GCG *(Starra Shear)*
Thrust HW STAVELEY E-W Folds; highly attenuated/folded MIF-HIF; over FW architecture

… Folding & Reverse Faulting/re-Activation
…-vertical; F1 ribbons & rootless folds of IF in … orientations *cf* sub-horizontal F2 Folds; D2 re- … *…ear*; new F2 Folds

… r Crustal Levels, NW-directed, … ssive Re-activation *of Starra Shear*
… with …
WILLIAMS Mount Dore Granite intrusion

Cu-Au-Mo 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

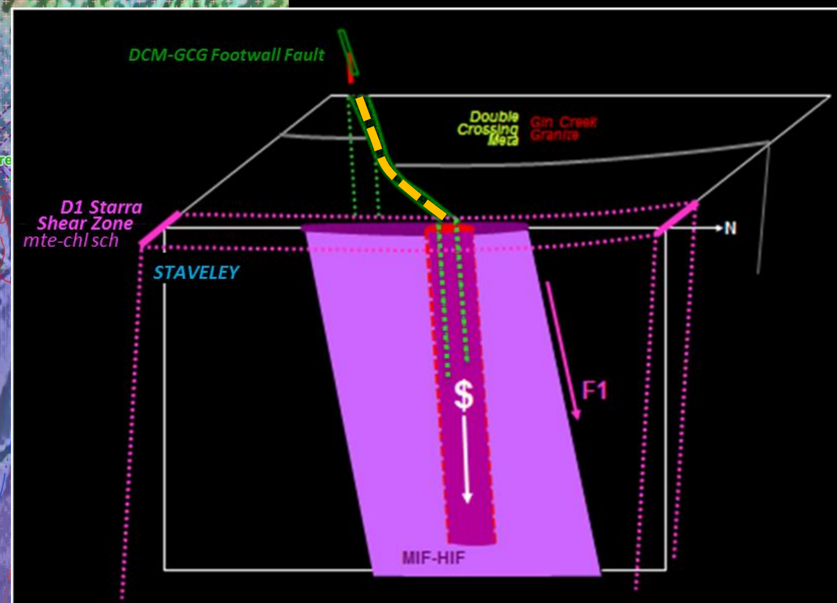
Late D4, post-mineral Faulting
Mount Dore Granite over *Merlin-Mount Dore*



Starra Mineralisation Model

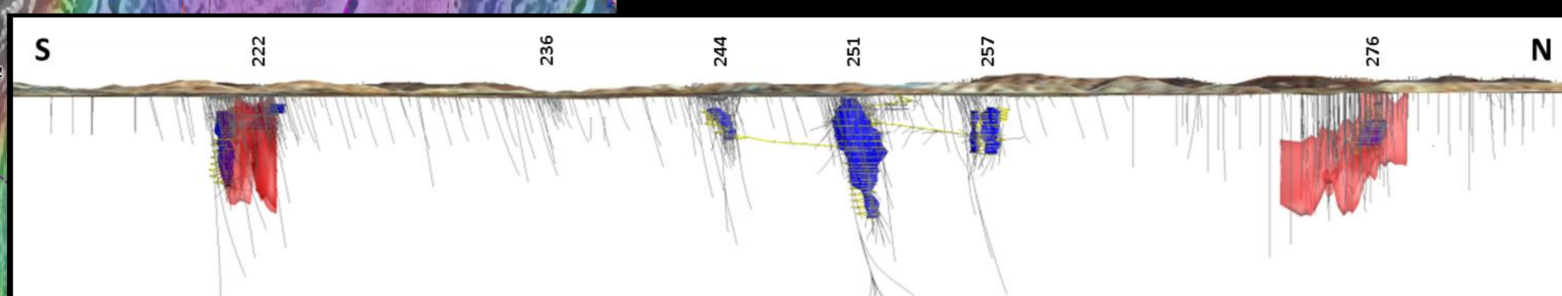
Mineralisation forms during ..
D4 sinistral transpressive re-activation of *Starra Shear*

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



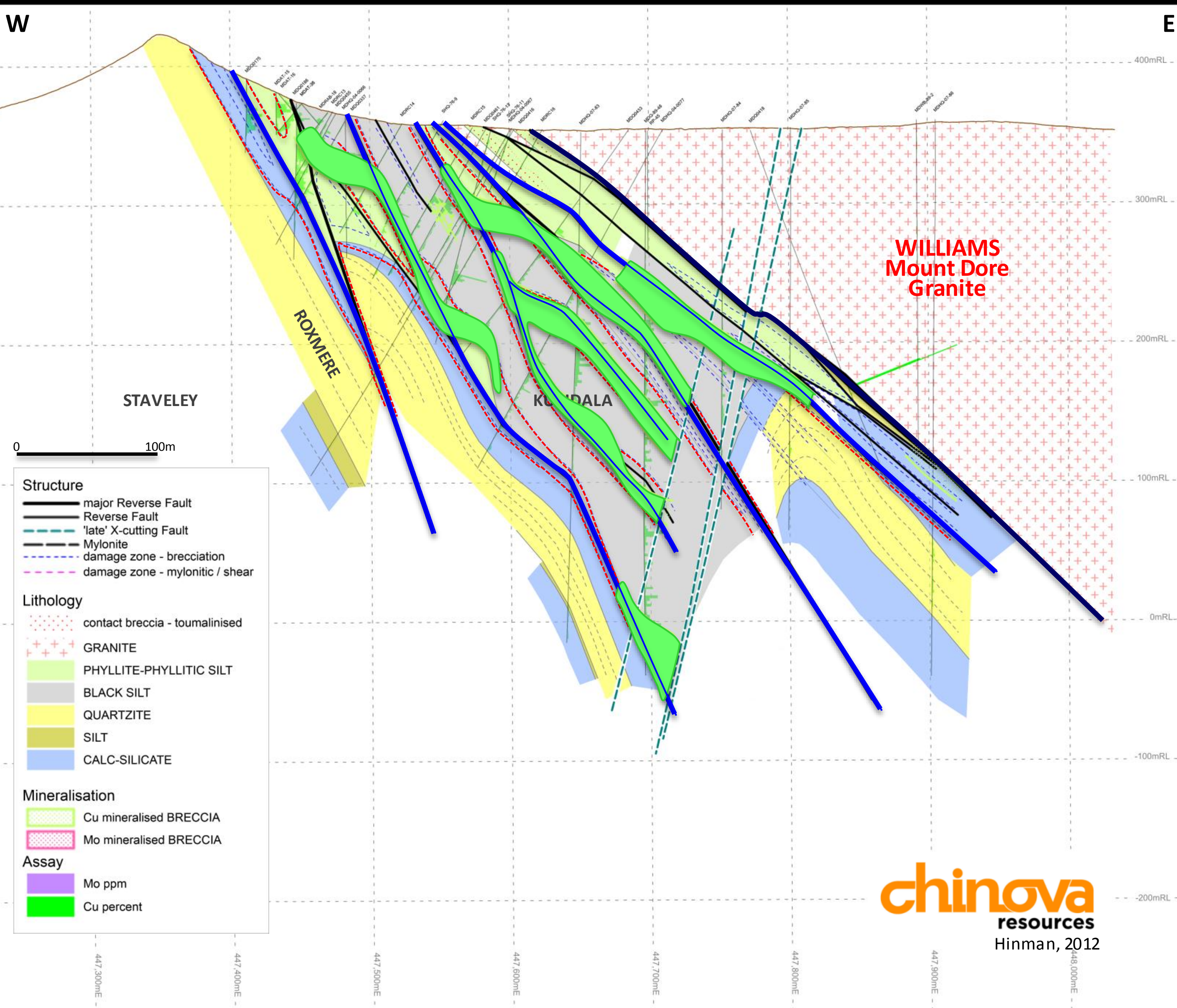
Large volumes of *chl-magnetite schist* accommodates the D4 re-activation by slip on existing fabrics … NO Permeability

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



Mt Dore - Cross Section

7,604,600N



chinova resources

Hinman, 2012

Gradational stratigraphy:
STAVELEY-ROXMERE-(S)-KURIDALA
KURIDALA: carb silt dominant

D4 Faulting:
complex, curvilinear, anastomosing

BRITTLE, fracture & breccia Damage Zones ...
... in carbonaceous silts
& along reactivated contacts
.. host Cu-Au minz

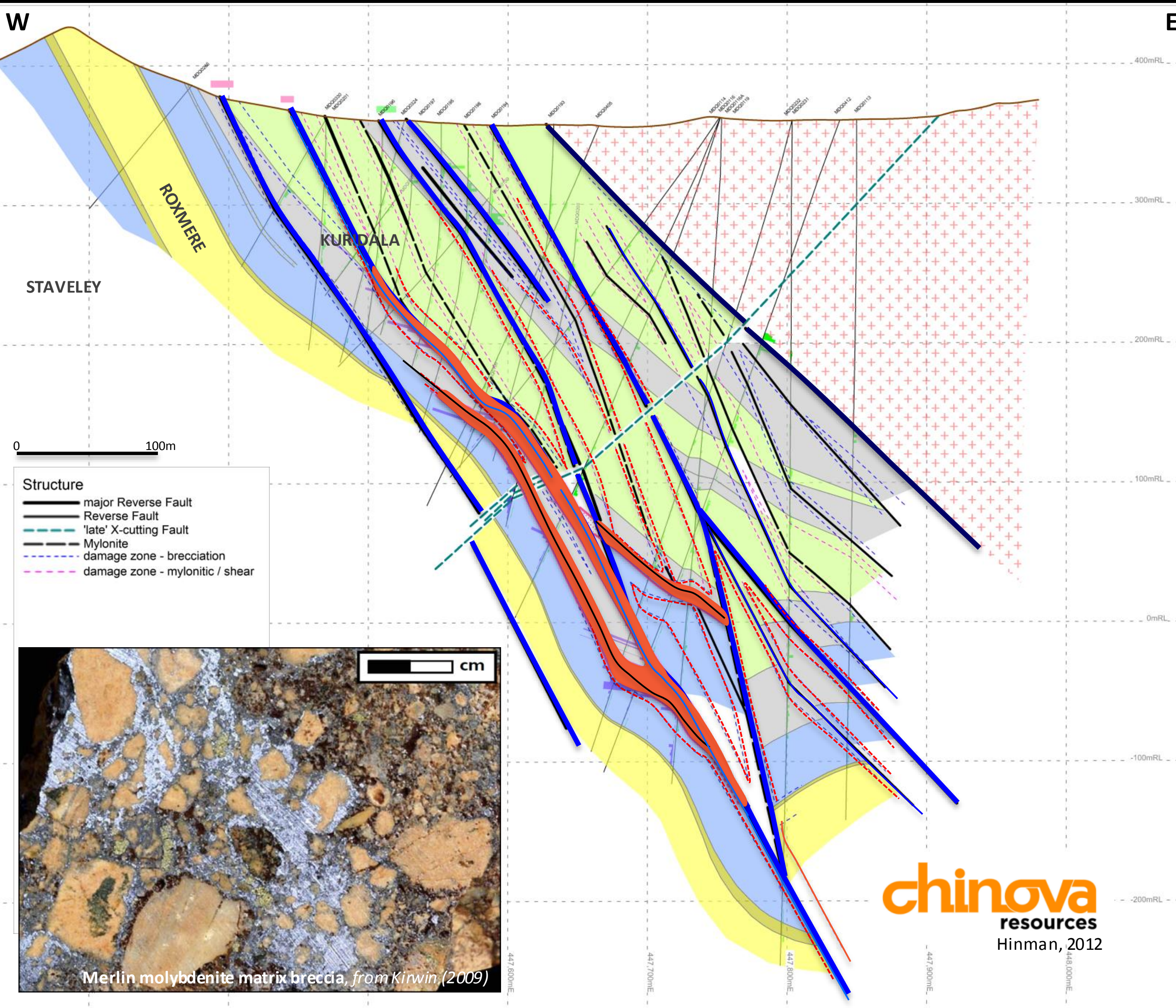
D4 Faults ... small throws!
NOT Regional Structures

Granite Reverse Fault
highly planar, post-mineral, significant throw ..

.. Late D4 Fault

Merlin - Cross Section

7,605,400N



Merlin molybdenite matrix breccia, *from Kirwin (2009)*

Gradational stratigraphy:
STAVELEY-ROXMERE-(S)-KURIDALA
KURIDALA: phyllite dominant

D4 Faulting: complex, curvilinear, anastomosing
brittle in calc-silicate, carb silt
ductile (*mylonitic*) in phyllite

BRITTLE, fracture & breccia zones host Mo minz …
.. along reverse fault where calc-silicate & carbonaceous silt are brecciated, and
.. where normal calc-silicate /carb silt contact is brecciated in FW & HW of reverse fault

D4 Faults … small throws!
NOT Regional Structures

Granite Reverse Fault
highly planar, significant throw
post-mineral > reactivation
> Mo-matrix breccias …

SUMMARY

DMQ Deposit Control Insights

In D4 time …

Need **BRITTLE** lithology in a D4 structural setting that drives it to **BRECCIATE**

MOST COMMONLY NOT Major Structures ….

….. often **insignificant Faults** (not mappable) & **insignificant re-Activations** of older structures

But **NEED BRITTLE** Rock 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**

Structural abutting of BRITTLE lithology against D4 re-activating D2-structures … **KULTHOR**

BRITTLE lithologies against small-displacement D4 Faults …. **MERLIN-Mt DORE**

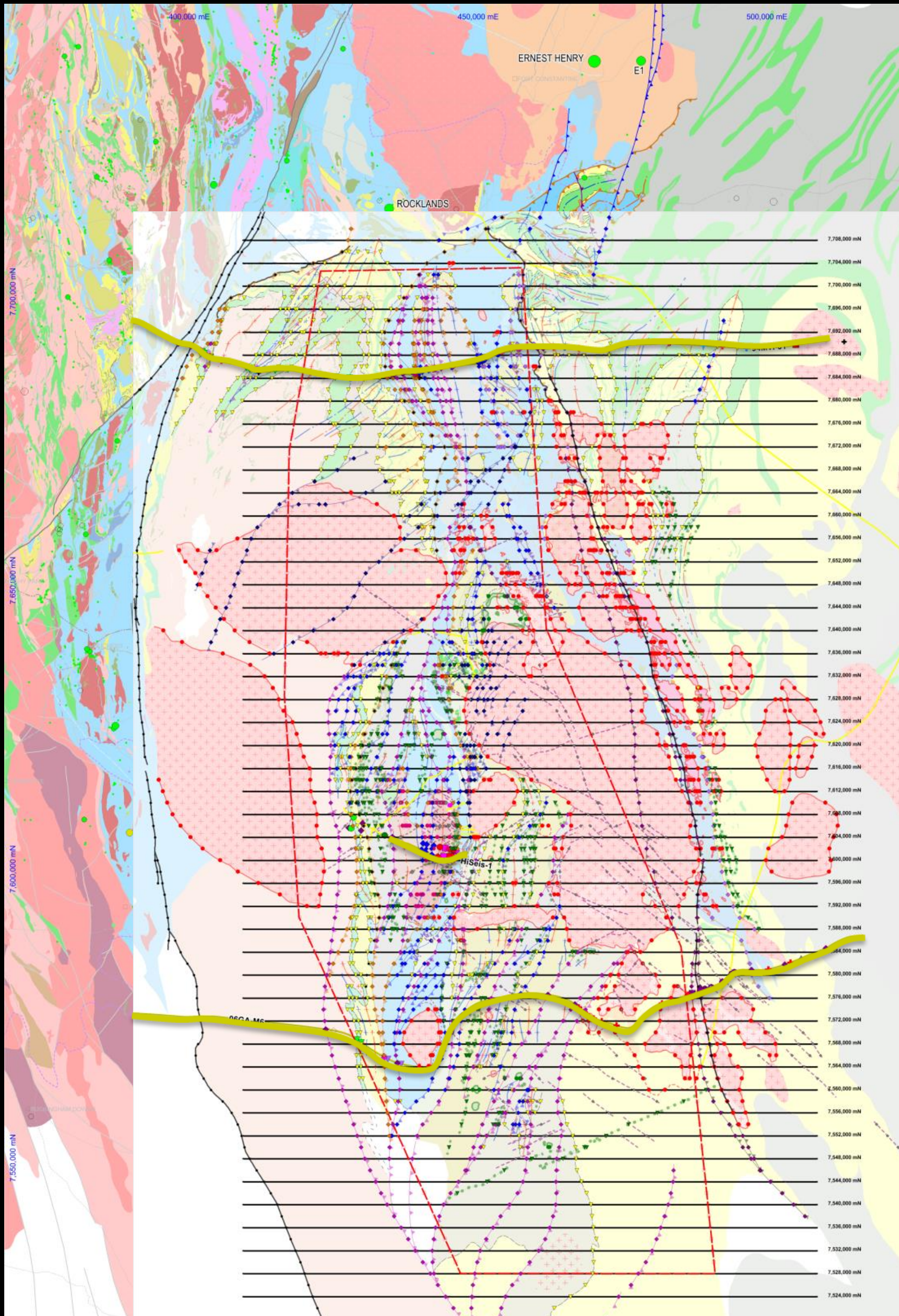
BRITTLE D1-remnants of IF coincident high angle FW weakness …. **STARRA**

BRITTLE lithologies within D4 strain partitioning domains … **Mt ELLIOTT-SWAN, EH**

Different Games in Different Camps

NO D4 Silver Bullets

But **ALL** synchronous with **WILLIAMS** intrusion!



DMQ 3D Geological Model

DMQ <u>Particular Focus</u> on …

- **Explore-able Depths** .. 0-2km
- **Production of a robustly-constrained 4D-Prospectivity Analysis**
- **NOT a crustal-scale Analysis …**

… but given importance of upper crustal architecture and mid-upper crustal magmatism …

Held Interpretation FOCUS within a 6-12km deep volume

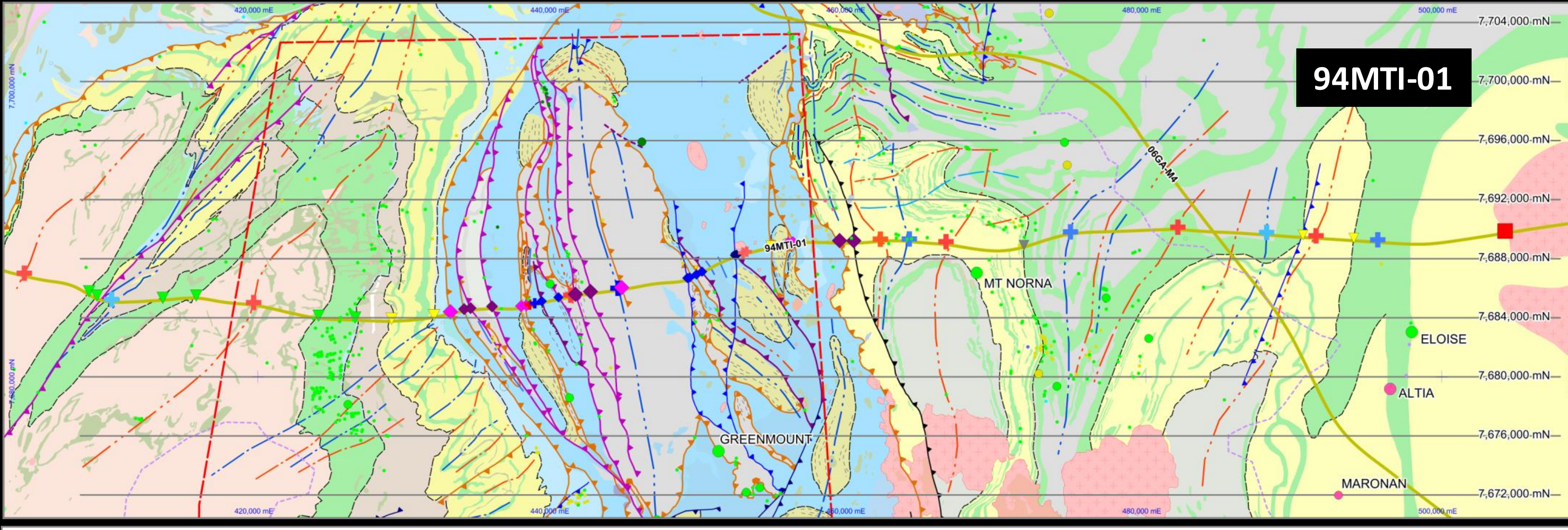
DMQ produced …

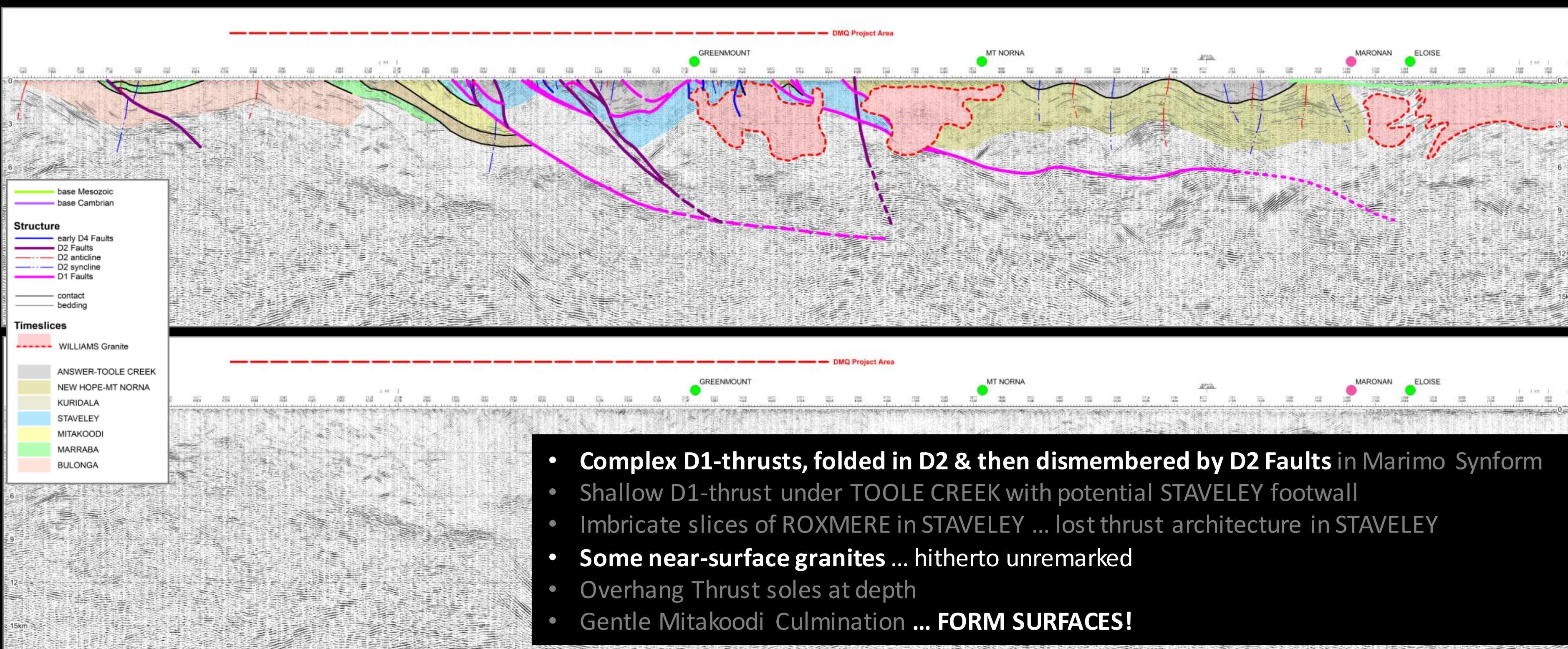
<u>Forty-seven, 4km-spaced SECTIONS</u>

… heavily leveraged Solid Geology
… and 3 Seismic Lines

… acknowledge chinova resources HiSeis

94MTI-01

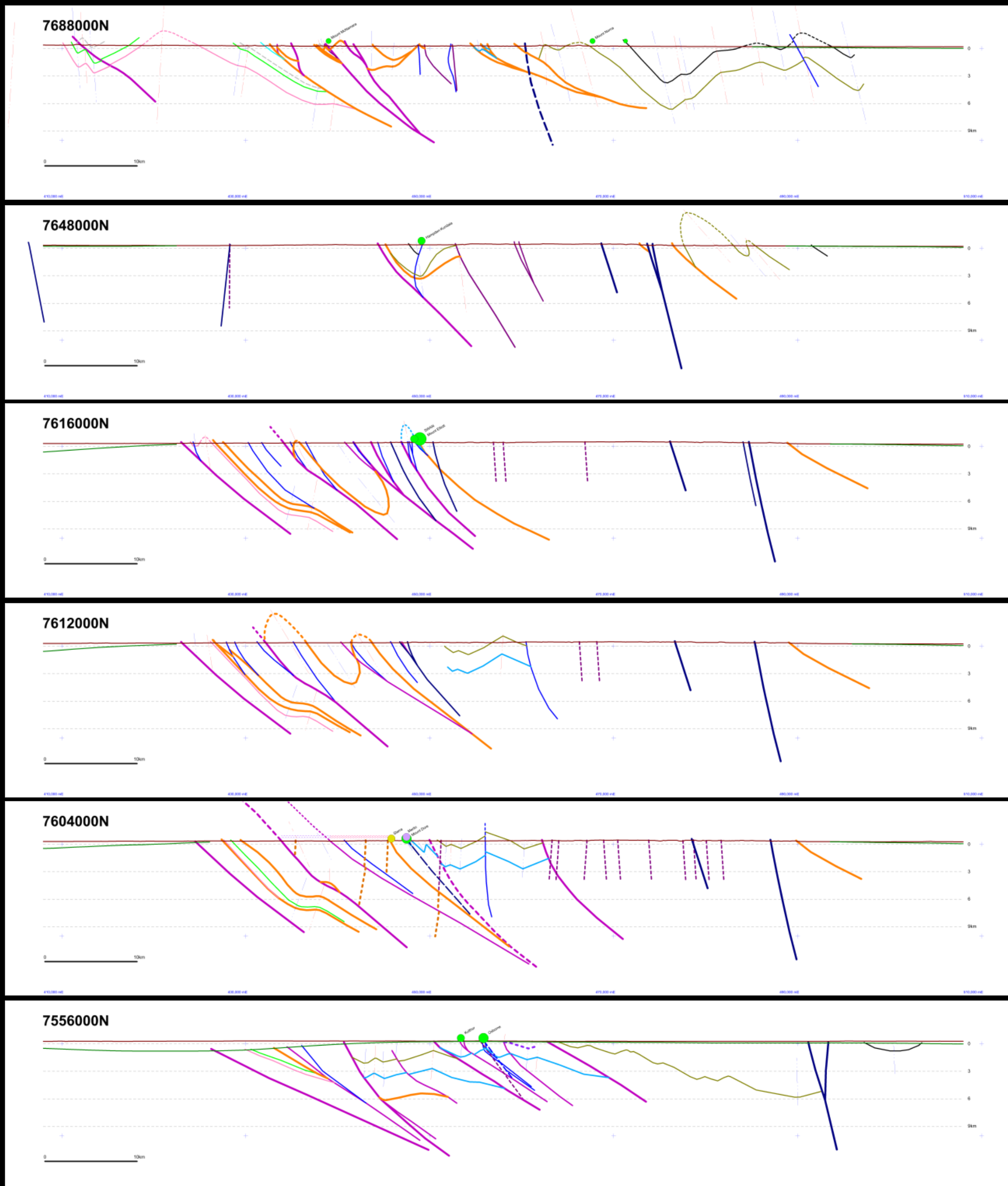




- **Complex D1-thrusts, folded in D2 & then dismembered by D2 Faults** in Marimo Synform
- Shallow D1-thrust under TOOLE CREEK with potential STAVELEY footwall
- Imbricate slices of ROXMERE in STAVELEY … lost thrust architecture in STAVELEY
- **Some near-surface granites** … hitherto unremarked
- Overhang Thrust soles at depth
- Gentle Mitakoodi Culmination **… FORM SURFACES!**

DMQ 4D Geological Model

selected Sections from the forty-seven, 4km-spaced Sections



- Interpreted to ~9km
- Honoring surface DMQ Solid Geology
- FAULTS attributed by Event (initiation)
- Top-of-TIMESLICE surfaces attributed

.... but NO granites!

LEGEND

surface
base of cover

Structure

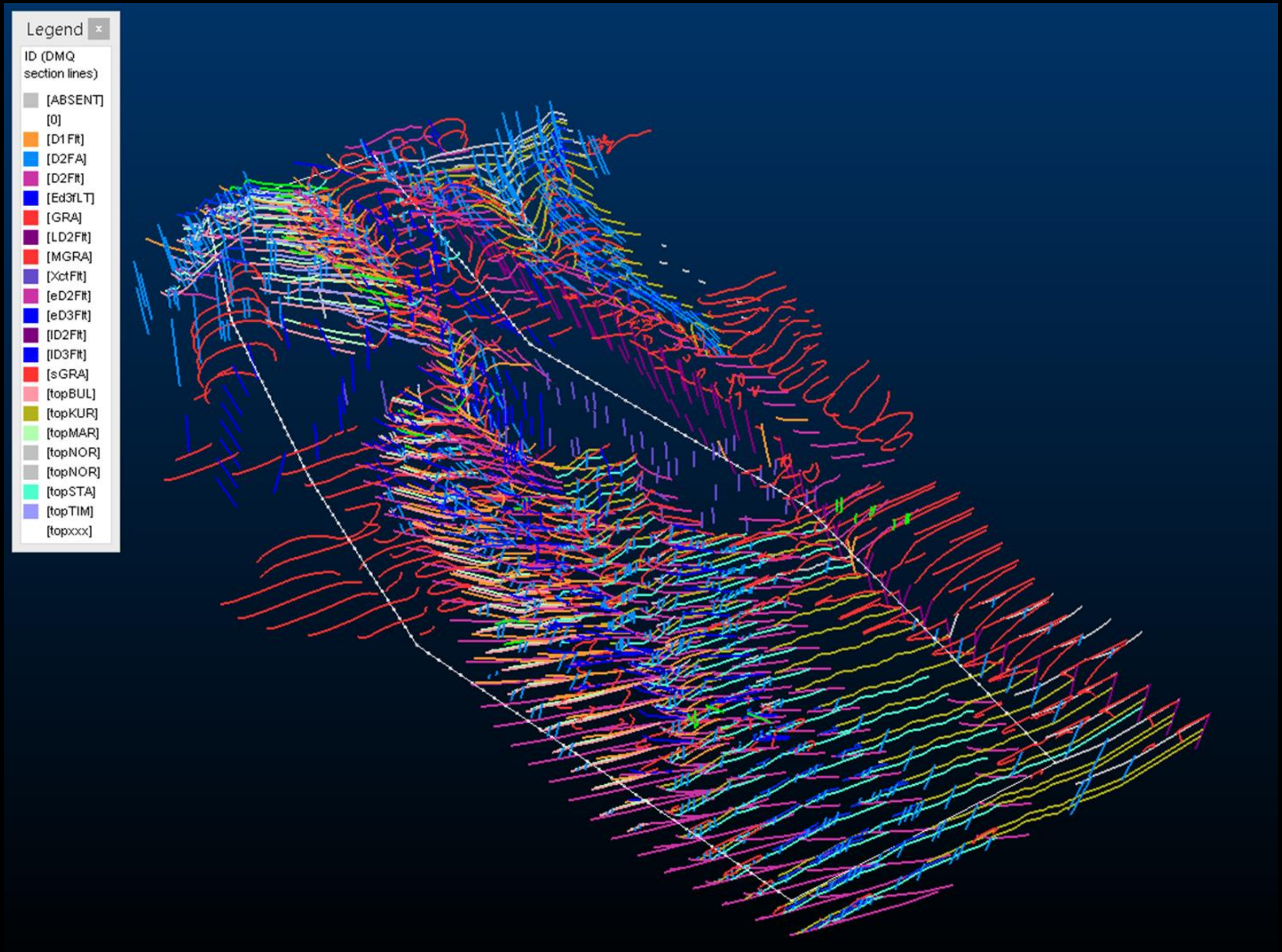
v late D4 Fault (post WILLIAMs)
late D4 Fault ((syn)-post WILLIAMs)
early D4 Fault (syn WILLIAMs)
D3 Fault
D2 Fault
D2 Fault (major)
D2 synform
D2 antiform
D1 Fault

Stratigraphy

top NEW HOPE-MT NORNA (base ANSWER-TOOLE CREEK)
top KURIDALA-STARCROSS (base NEW HOPE-MT NORNA)
top STAVELEY (base KURIDALA-STARCROSS)

top MITAKOODI (base CORELLA)
top MARRABA (base MITAKOODI)
top TIMBEROO (base MITAKOODI)
top BULONGA (base MARRABA)

DMQ 3D Geological Model
4km-spaced Serial Sections

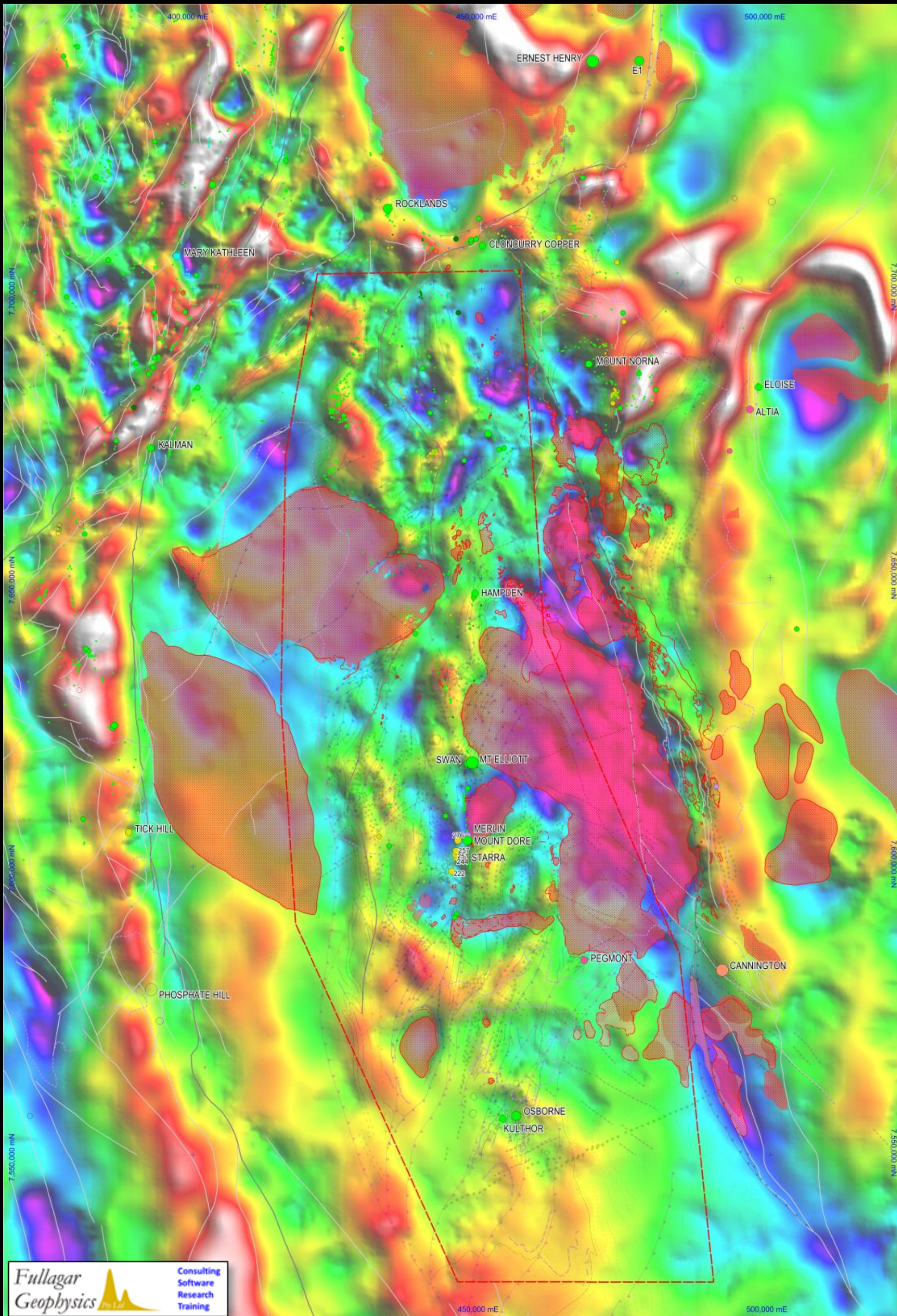


colour-coded strings pre-wireframing

SUBSURFACE INTRUSIVE GEOMETRIES INFORMED BY CONSTRAINED GRAVITY INVERSION

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

SMI BRC
WH Bryan Mining & Geology Research Centre

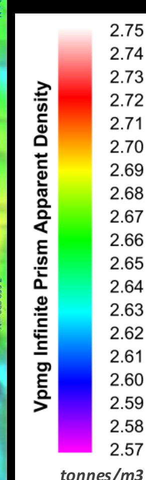


What about the Granites?

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 *… JD can elaborate*

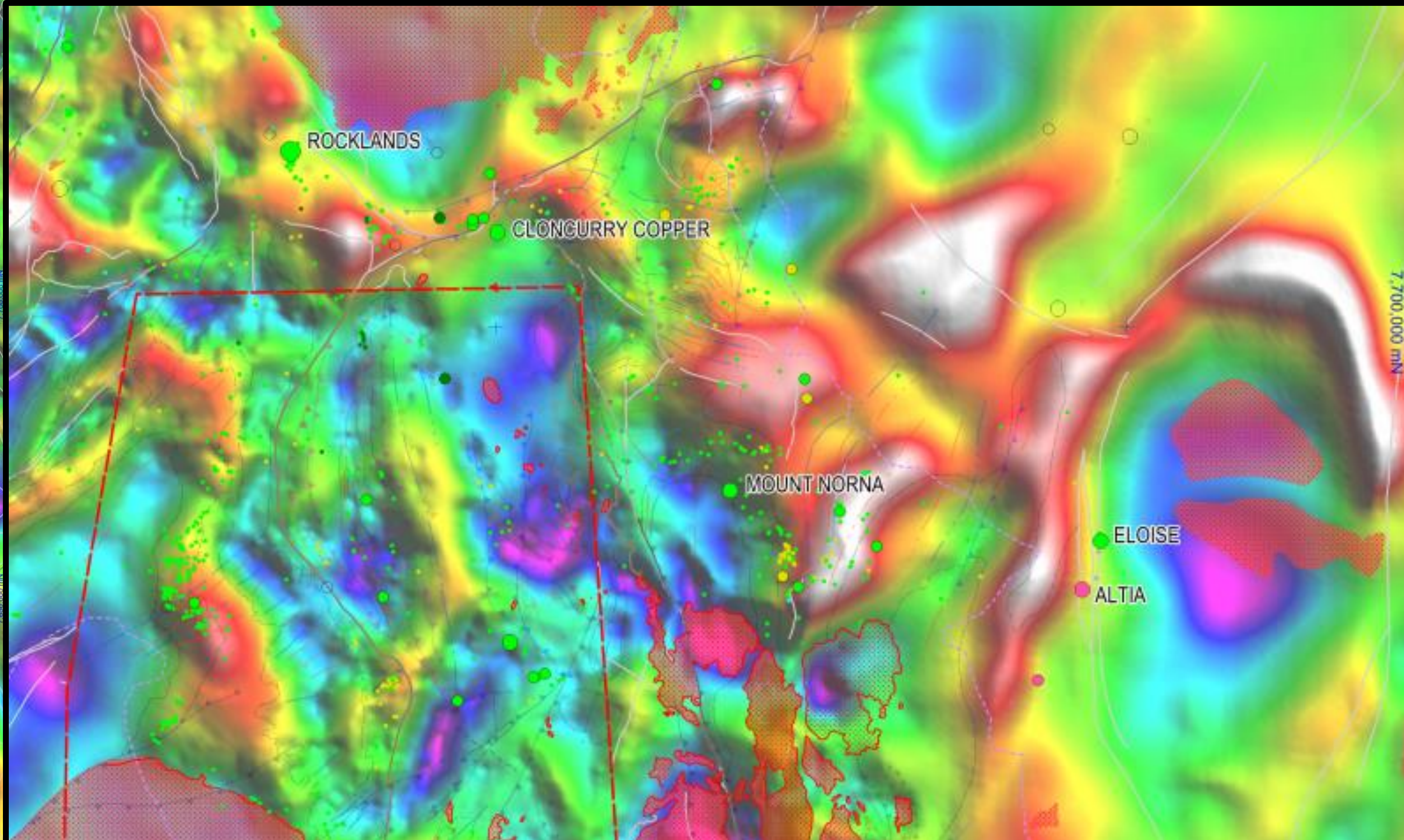
- Assumes no crustal architecture but usefully highlights density ***deficits*** & ***surpluses***
- Suggests granite is far more extensive than the mapped/interpreted WILLIAMS outcrop extent



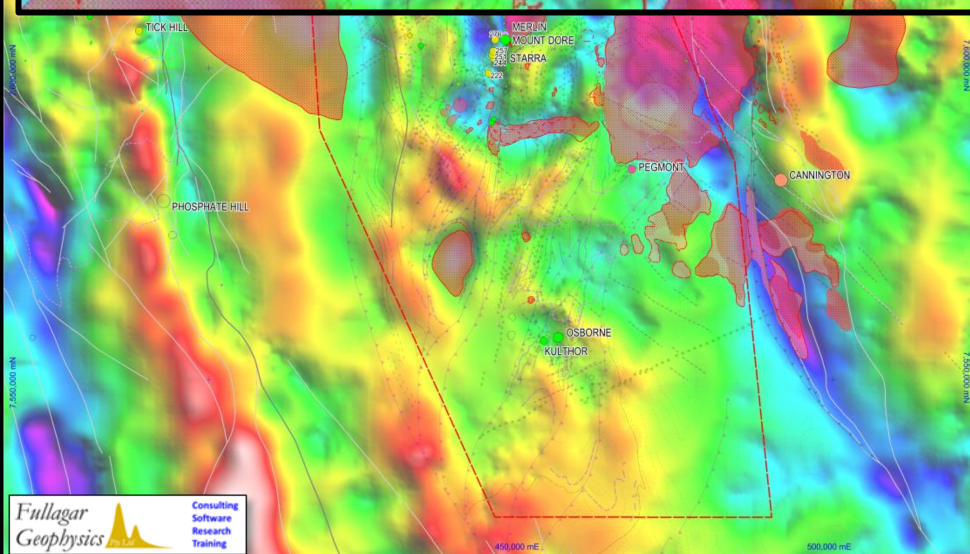
This image drove DMQ into the quest for defining subsurface granite morphologies

… and the 'joys' of 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



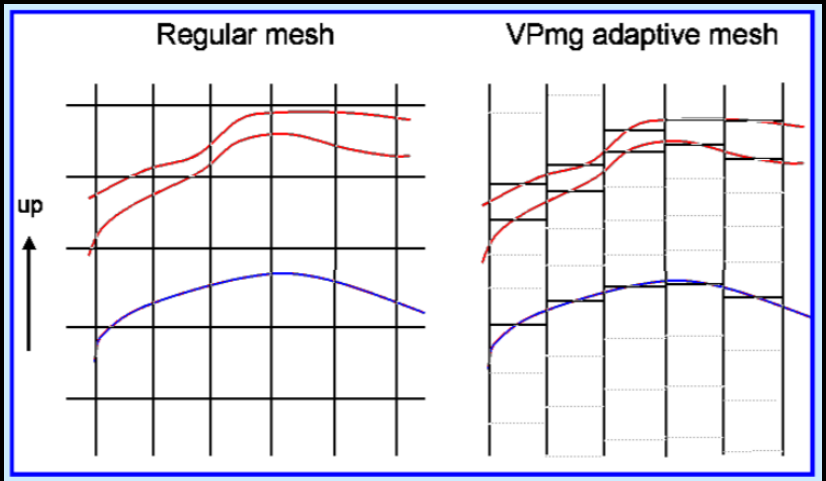
Highlights a LACK of deposits & occurrences in the roof zones of those intrusives …

.. 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

Does not diminish the significant metasomatism in the roof zones of sub-surface granites … alone **NOT enough!**

Constrained *Vpmg* Gravity Inversion

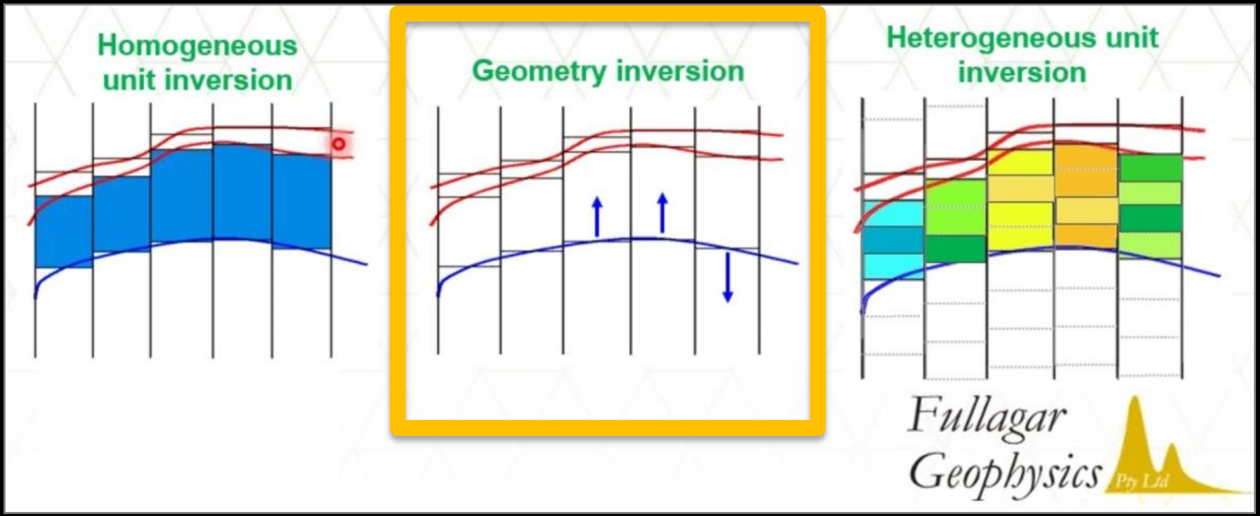


Fullagar Geophysics
Consulting
Software
Research
Training

Fullagar Geophysics *VPmg* advantages …

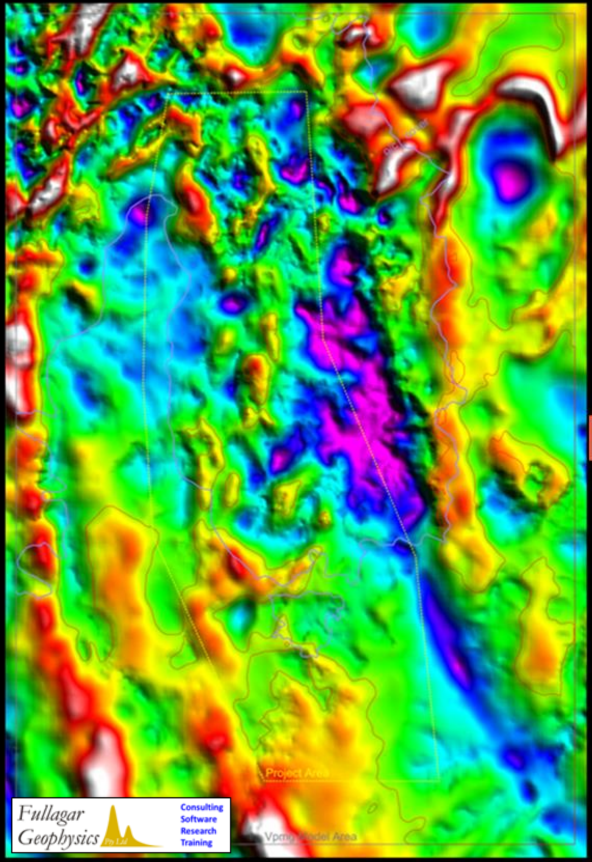
- Adaptive mesh better fits known geometries
- 3 styles of inversion available
- DMQ made use of all of them …

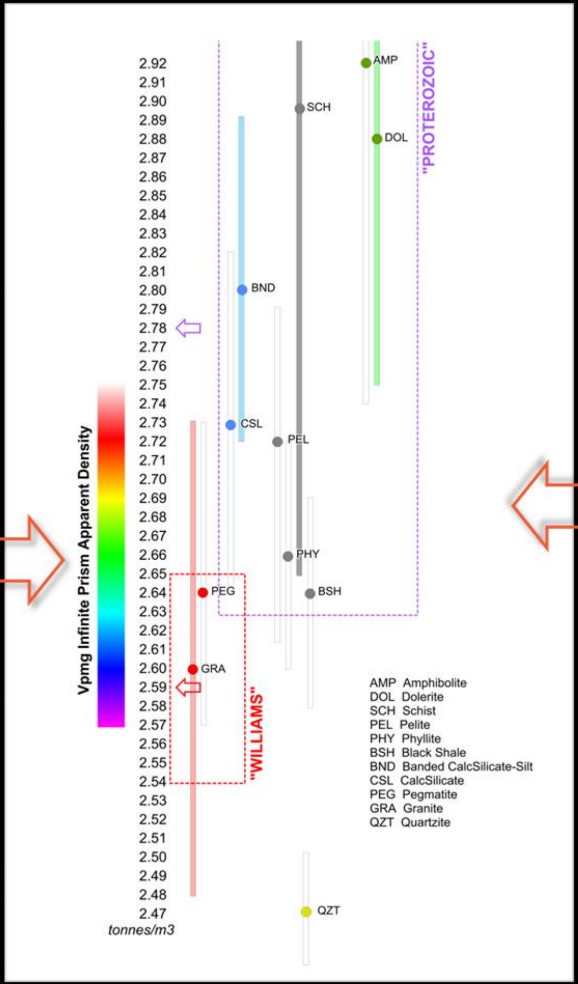
  … but heavy use of **GEOMETRY INVERSION**

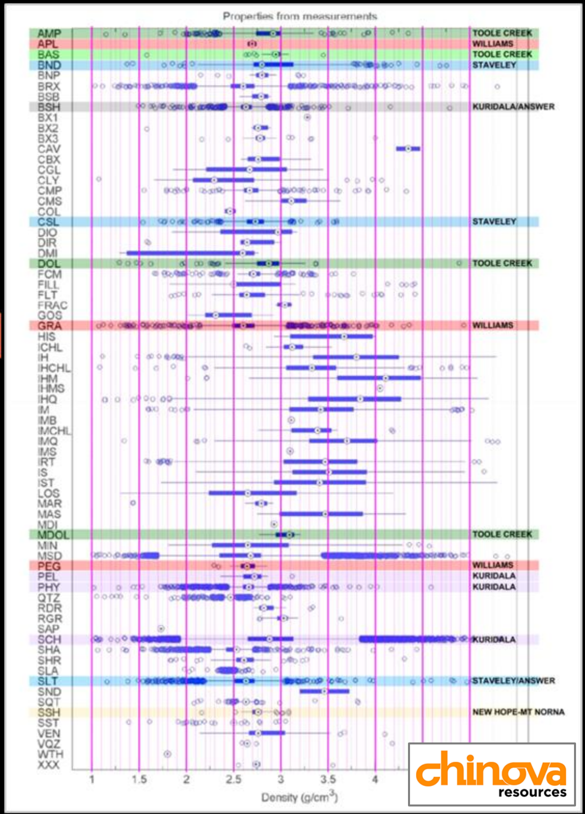


Density Constraints

Vpmg **Apparent Density Model**





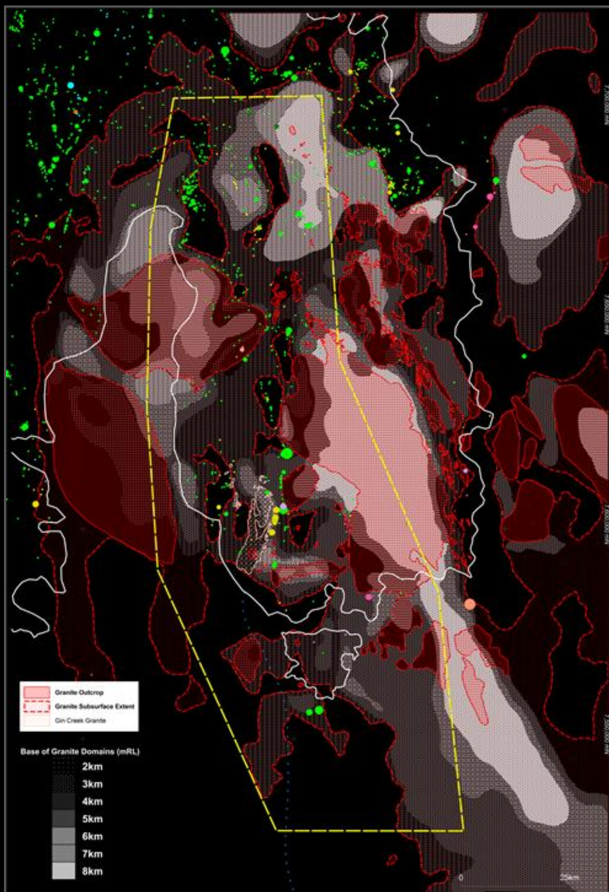


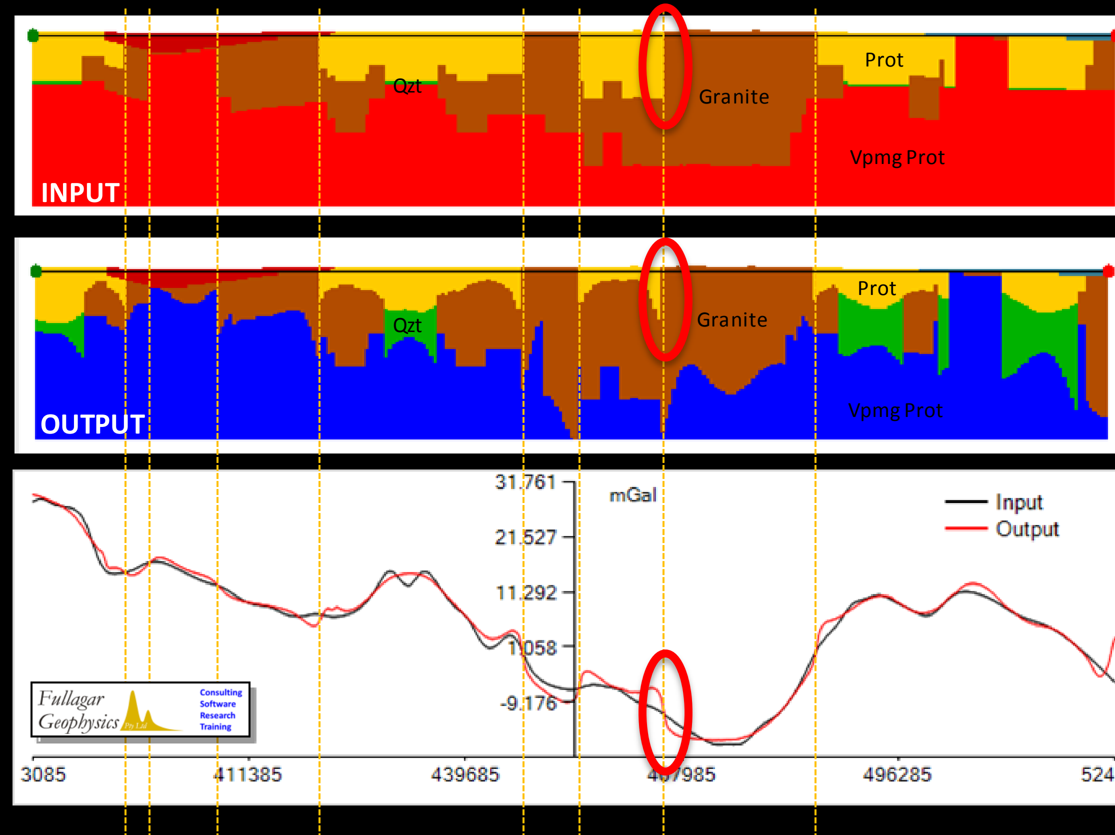
Chinova DDH density data

	LOW		MEDIUM		HIGH	
b/g	2.67	contrast	2.67	contrast	2.67	contrast
'Cover'	2.45	-0.22	2.45	-0.22	2.45	-0.22
'Cover LST'					2.54	-0.13
'Granite'	2.61	-0.06	2.61	-0.06	2.59	-0.08
'Proterozoic'	2.73	+0.06	2.79	+0.12	2.78	+0.11

Constrained *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



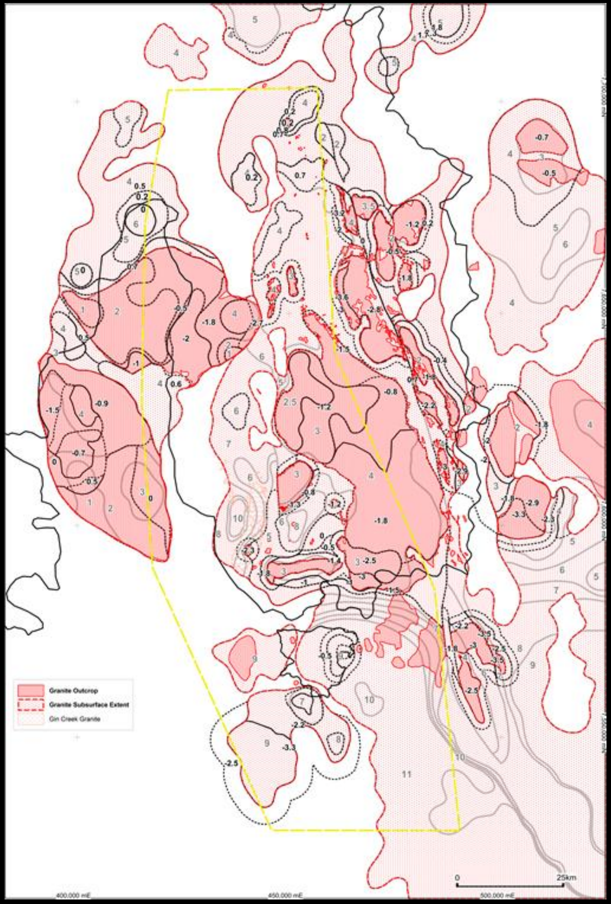


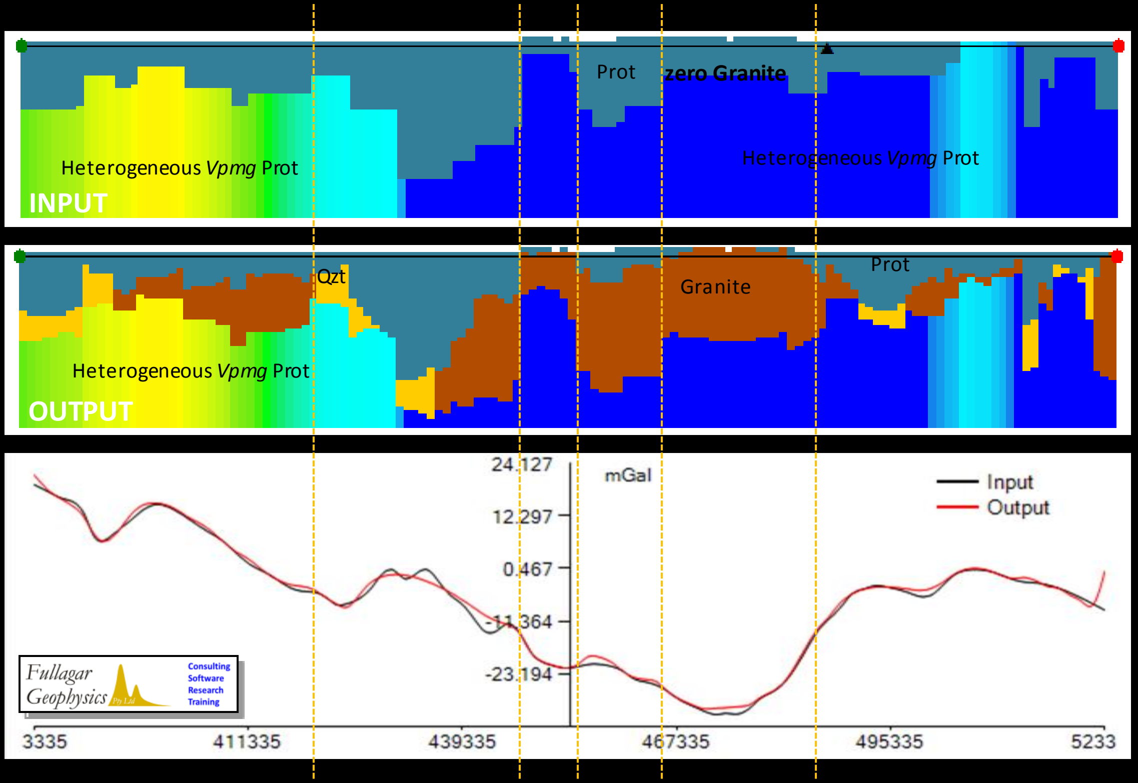
FAILED!

Unable to produce geologically-reasonable & smooth transitions from outcrop into the subsurface; nasty dipoles on contacts

Constrained *Vpmg* Gravity Inversion
Domained RL, mid-Granite 'PERT' Models

Domained zero-thickness Granite START
... NO Granite outcrop!
High Density *Vpmg* basement fixes 'PERT' *Vpmg* function to drive 'growth' equally up & down from START depth

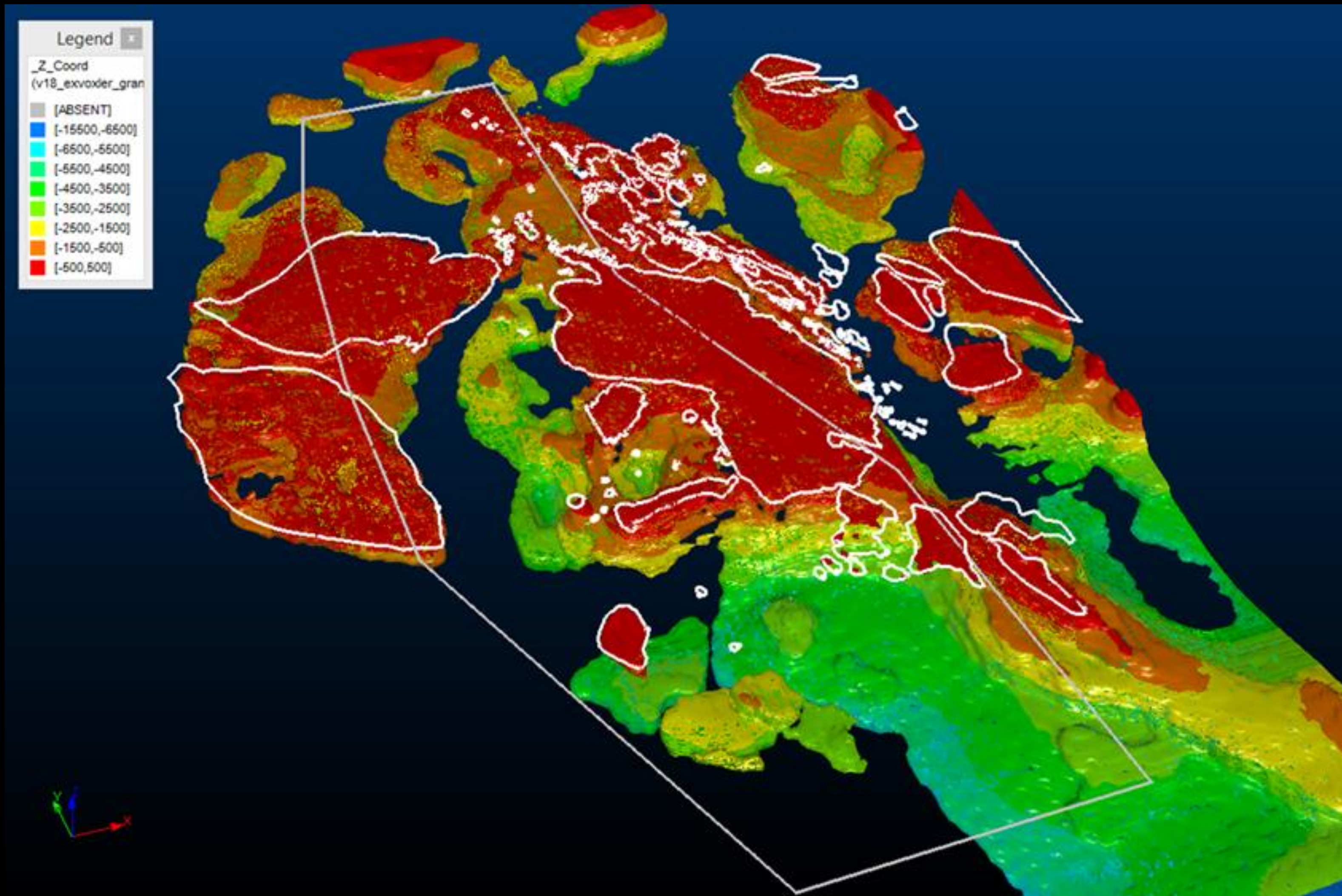




Ultimately **SUCCESSFUL!**

Produce geologically-reasonable granite morphologies; built outcrop where required; matched sub-surface geological constraints & produced smooth transitions from outcrop

Constrained *Vpmg* Gravity Inversion
Domained RL mid-Granite 'PERT' Models



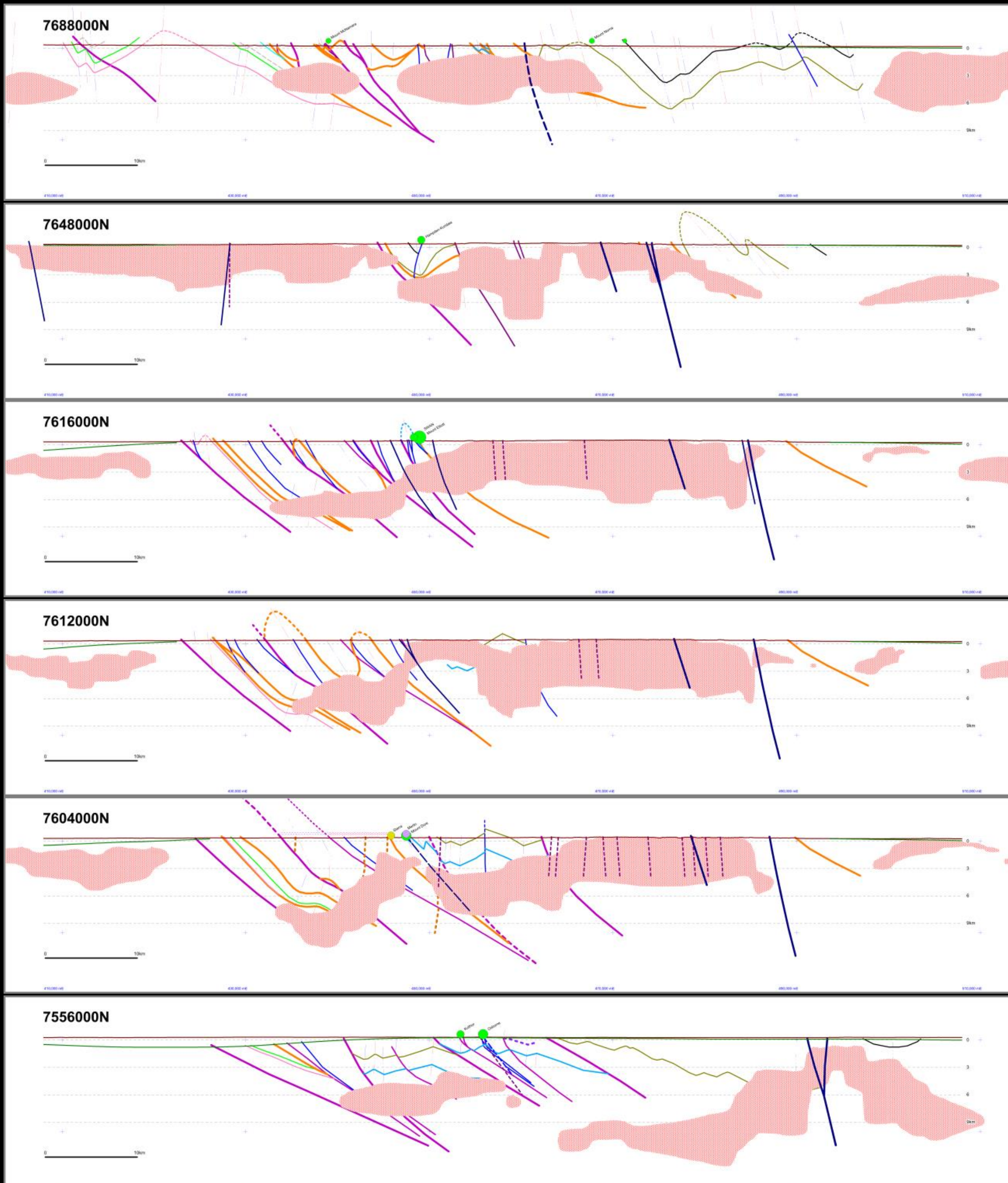
Version 18 DMQ Granite Model
... into 4D geological model & DMQ Prospectivity Analysis

DMQ 4D Geological Model

selected **Sections from the forty-seven, 4km-spaced Sections**

.. including ver18 Granites!

with pre- & post-WILLIAMS structures



3D DMQ Geological Model ready for Prospectivity Analysis

LEGEND

- surface
- base of cover

Structure

- v late D4 Fault (post WILLIAMs)
- late D4 Fault ((syn)-post WILLIAMs)
- early D4 Fault (syn WILLIAMs)
- D3 Fault
- D2 Fault
- D2 Fault (major)
- D2 synform
- D2 antiform
- D1 Fault

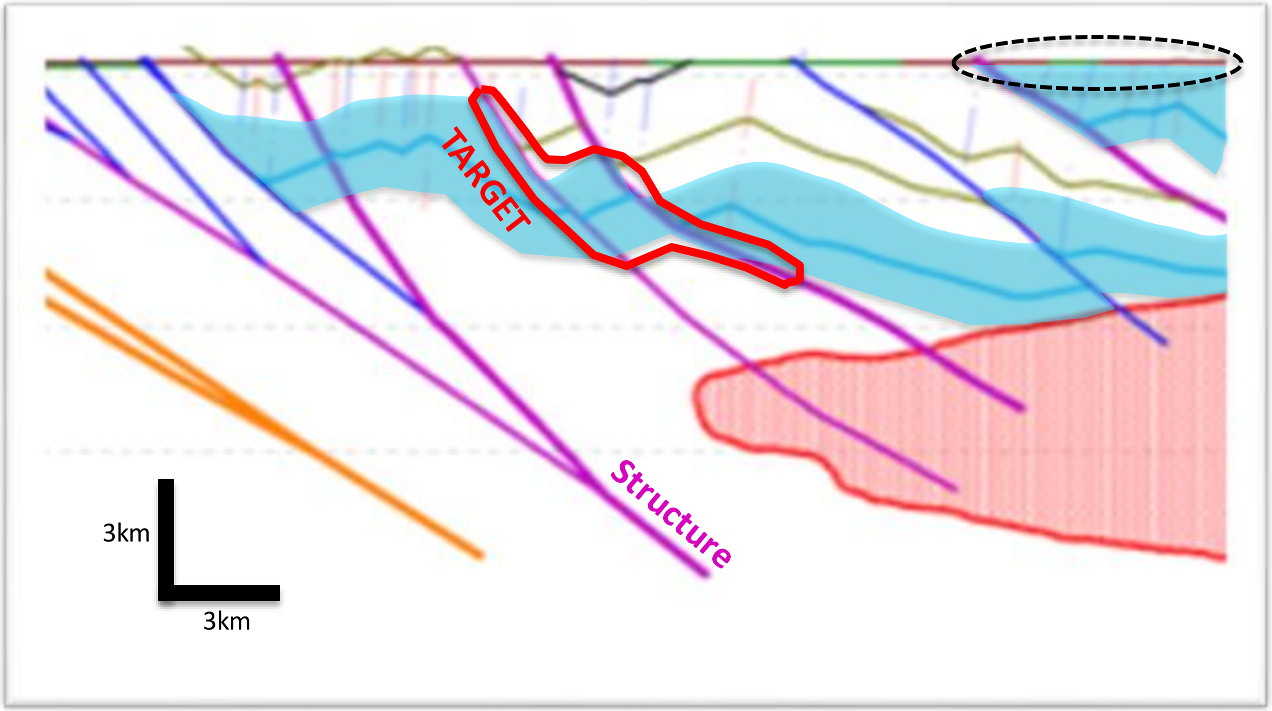
Stratigraphy

- top NEW HOPE-MT NORNA (base ANSWER-TOOLE CREEK)
- top KURIDALA-STARCROSS (base NEW HOPE-MT NORNA)
- top STAVELEY (base KURIDALA-STARCROSS)
- top MITAKOODI (base CORELLA)
- top MARRABA (base MITAKOODI)
- top TIMBEROO (base MITAKOODI)
- top BULONGA (base MARRABA)

3D PROSPECTIVITY ANALYSIS

The Case for 3D Prospectivity Analysis

We don't live in a 2D world!



WOFE Inputs from here
= barren

Host sequence

Intrusives

Groups by Deposit-style

1. Deposits Hosted Within the Upper Staveley/Lower Kuridala Stratigraphy.

- Rheological contrast between Calc-silicates, Roxmere Quartzite, and Kuridala schists seen as a focus for deformation and exploited during mineralization in late D3.
- ‘Other’ rigid bodies at this stratigraphic position, e.g. SWAN Diorite, offer further rheological contrast and focusses brecciation/secondary permeability and potential to host mineralization if within a fluid cell.
- Redox potential of Staveley in contact with overlying reduced rocks (Figure 5.2) inferred as an important ingredient.
- Presence of ironstones yields discrete targets within this broader stratigraphic package.
- E.g. Osborne-Kulthor, Mt Elliott-SWAN, and Merlin-Mt Dore deposits.

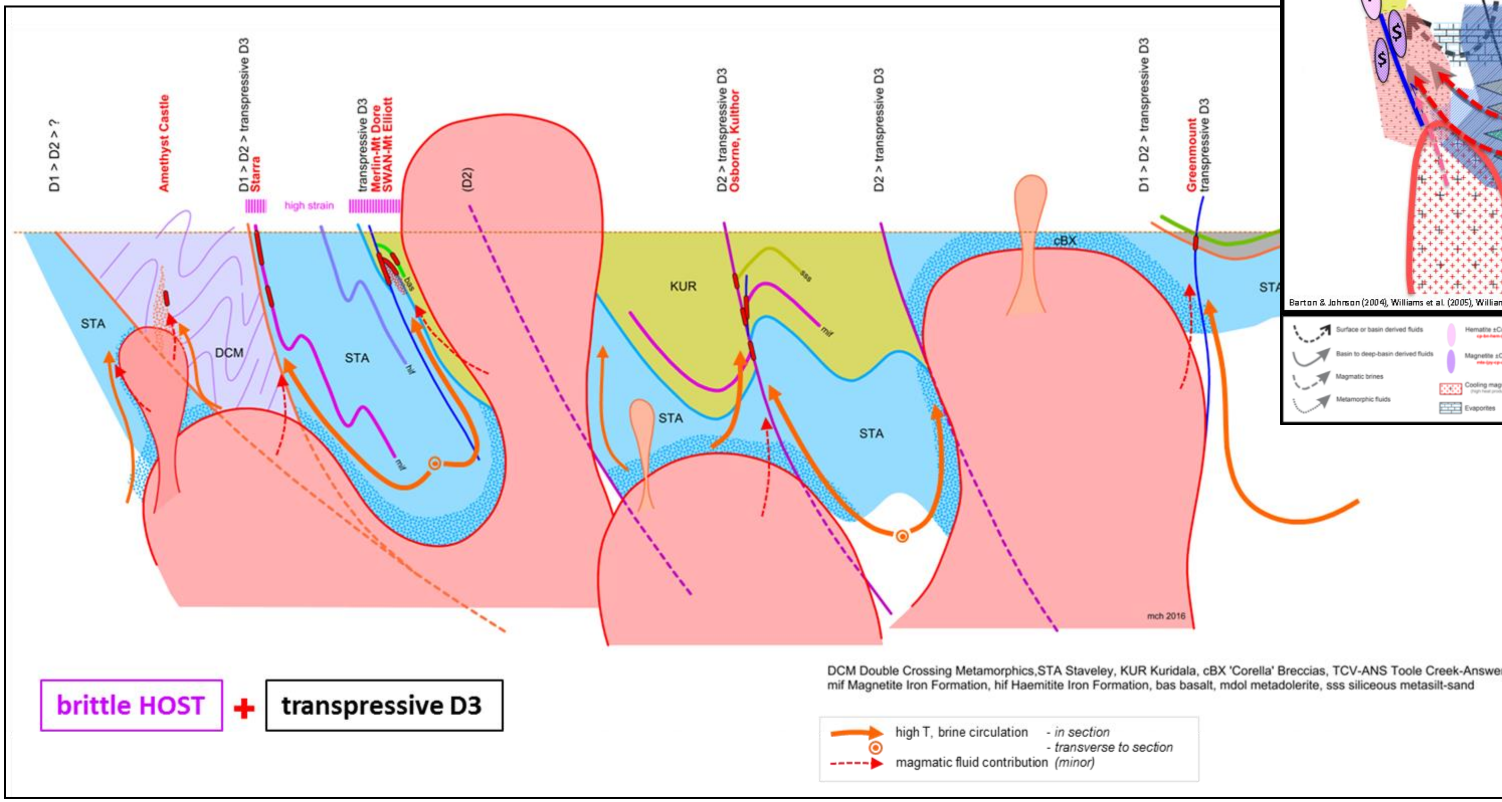
2. Structural juxtaposition of Staveley with Other (Reduced) Packages.

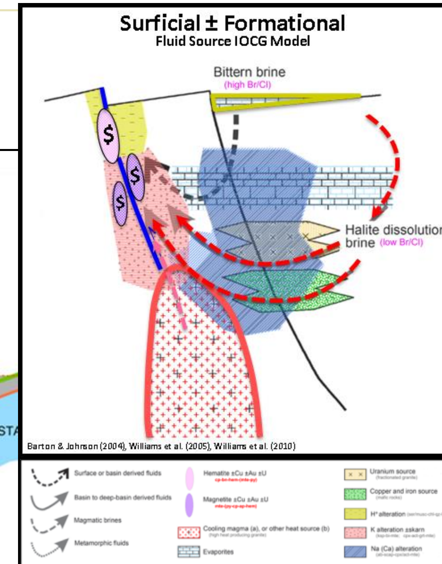
- Likely to be evidently structurally-controlled/hosted
- Greater potential expected where Staveley is in structural contact with reduced packages such as Answer Slate/Toole Creek Formation.
- Focussing relationship of early structural features, likely reactivated basement structures.
- E.g. Starra line of deposits.

3. Deposits hosted in Overlying Sequences, but Related to Staveley:Granite:Fault Association at Depth.

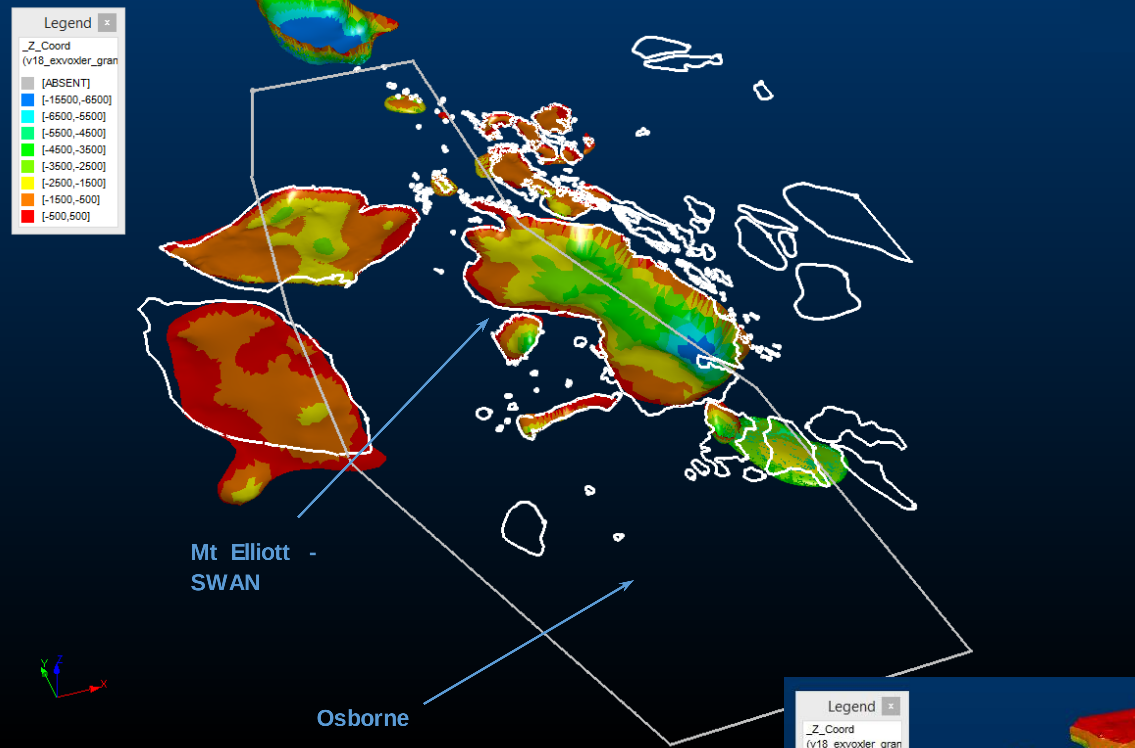
- Highly variable deposit-style possible.
- Deposits may be structurally-focussed or within broader breccia bodies.
- Intrusion of granite into the Staveley calcareous sequence inferred as driver for brecciation (CO_2 release).
- E.g. EH, Eloise

Schematic Section – Deposit controls



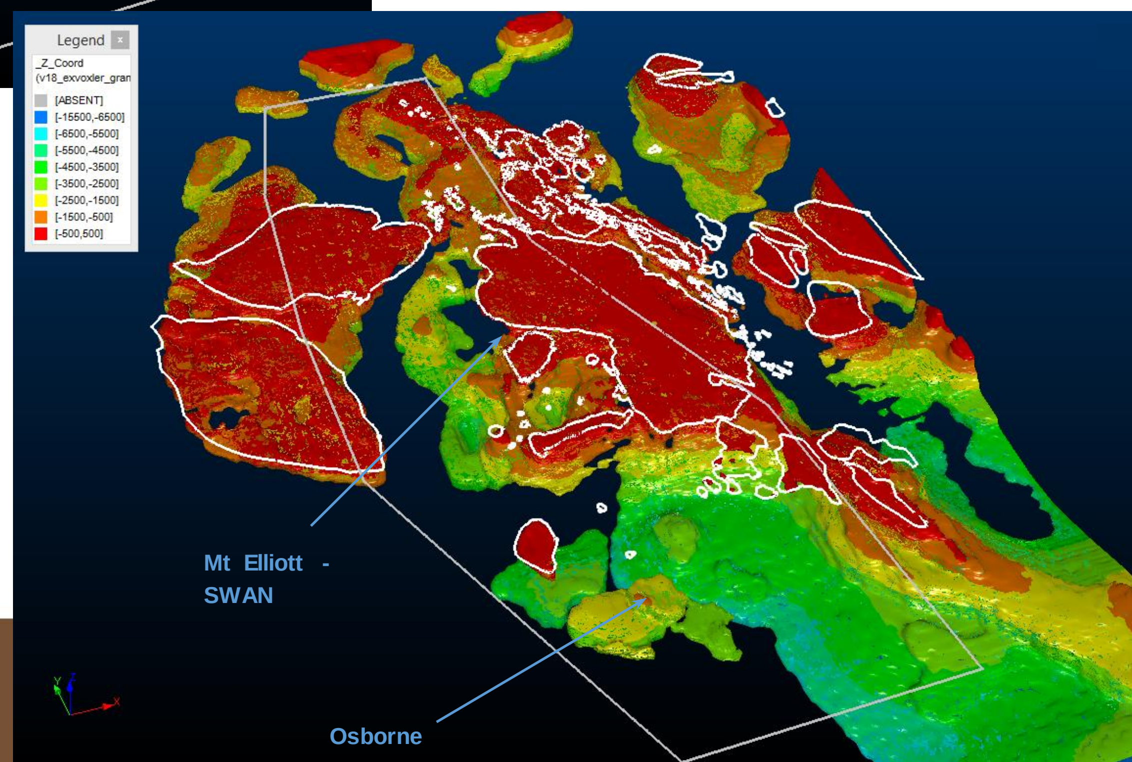


Schematic cross-section illustrating inferred controls on deposit styles in the DMQ project area. Essential ingredients required for each of the identified deposit styles. Orange arrows represent high temperature brine circulation, red arrow represent magmatic fluid contribution.



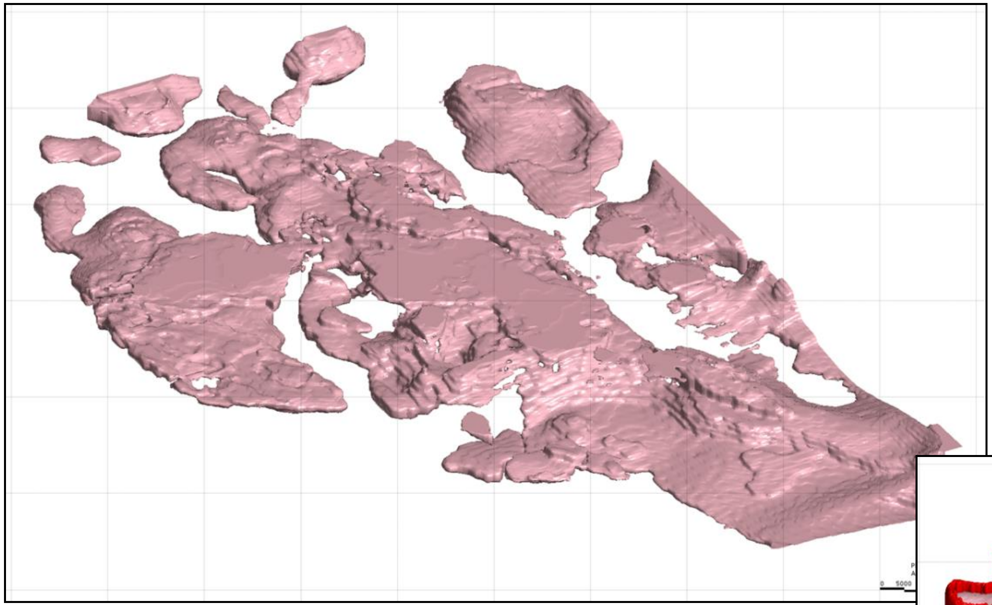
(Mira Geoscience, 2011)

If granites are that important, then we need good approximation of the 3D subsurface geometry and distribution

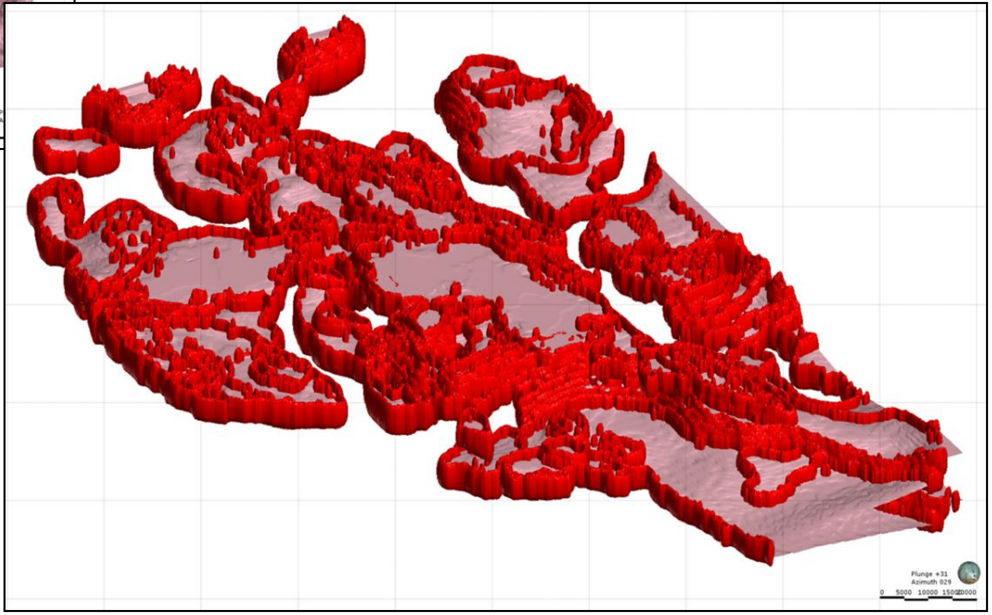


(DMQ, 2017)

3D Intrusives

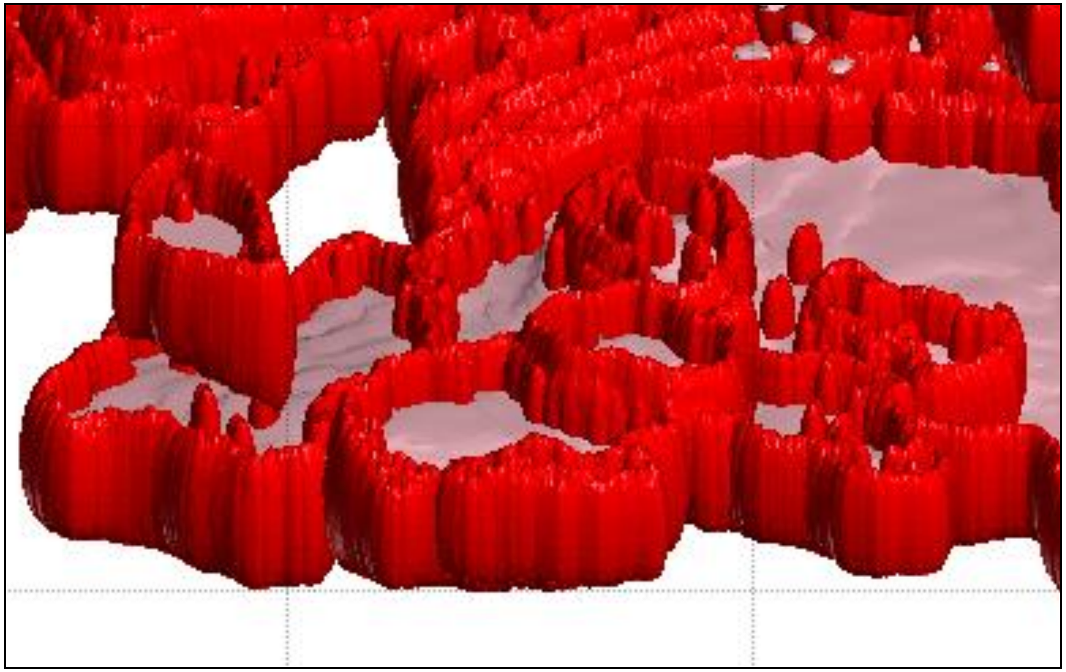


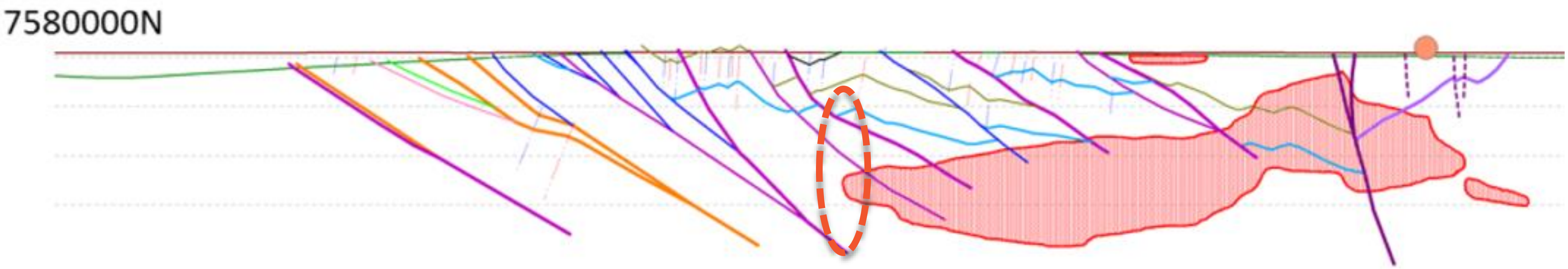
3D view of the Williams-age felsic intrusions in the study area, as determined through geologically-constrained gravity inversion. Looking northeast.



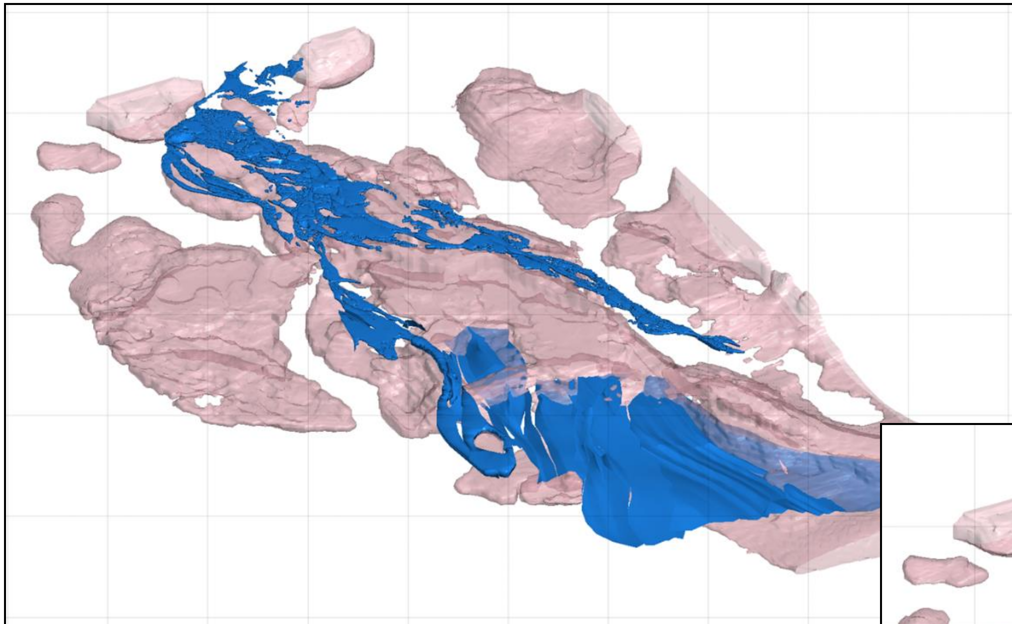
Anisotropic buffer applied to the 3D felsic intrusive geometry.

3D Intrusives – Buffering (in detail)

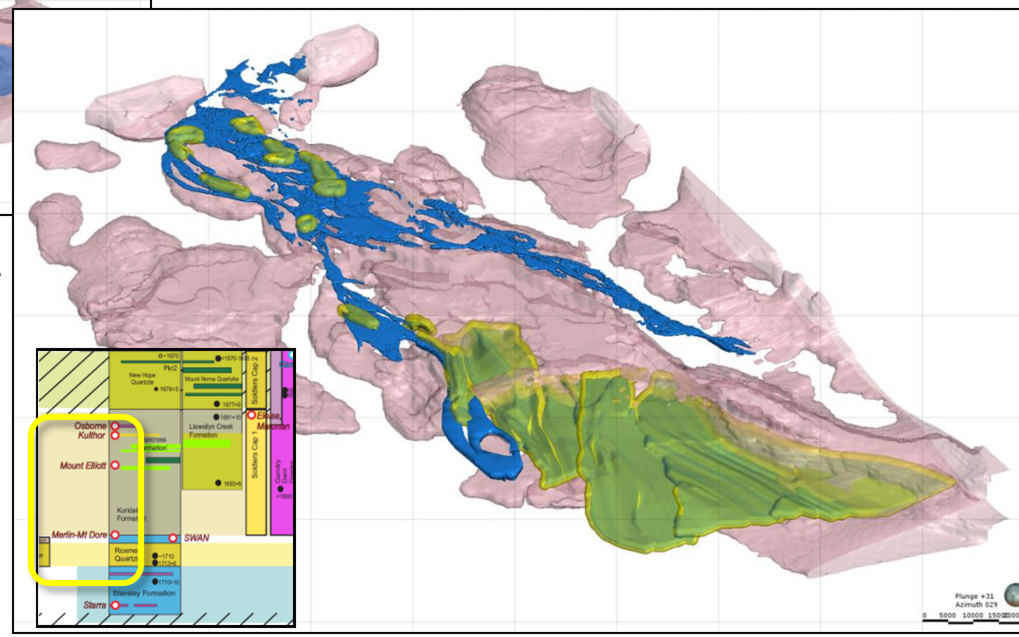




3D Host-rock distribution

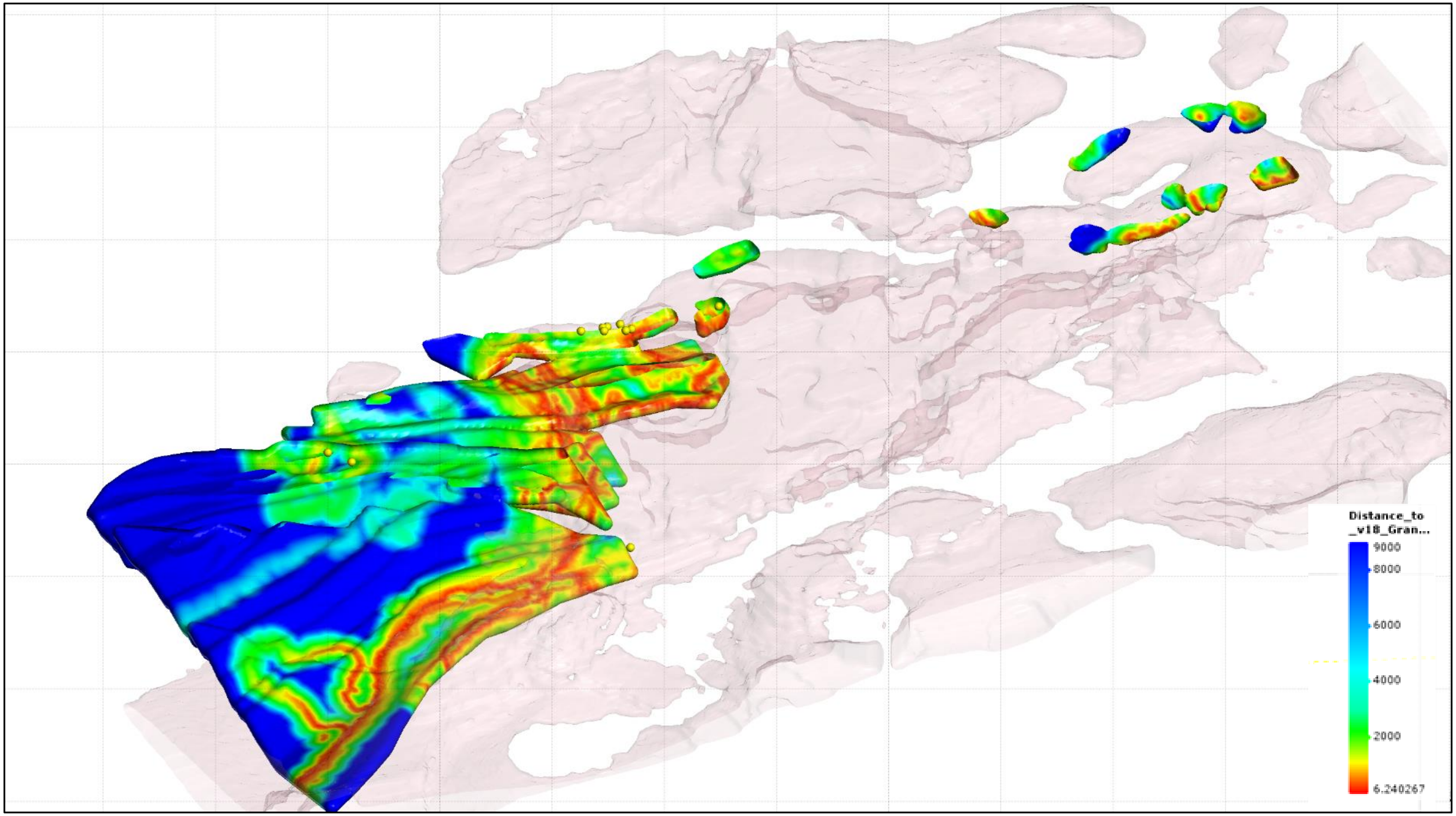


Top of Staveley Formation stratigraphic surface (blue) in bottom right hand corner of image (south), and outcropping Staveley Formation and equivalents represented by blue solid in the top left of image (north).

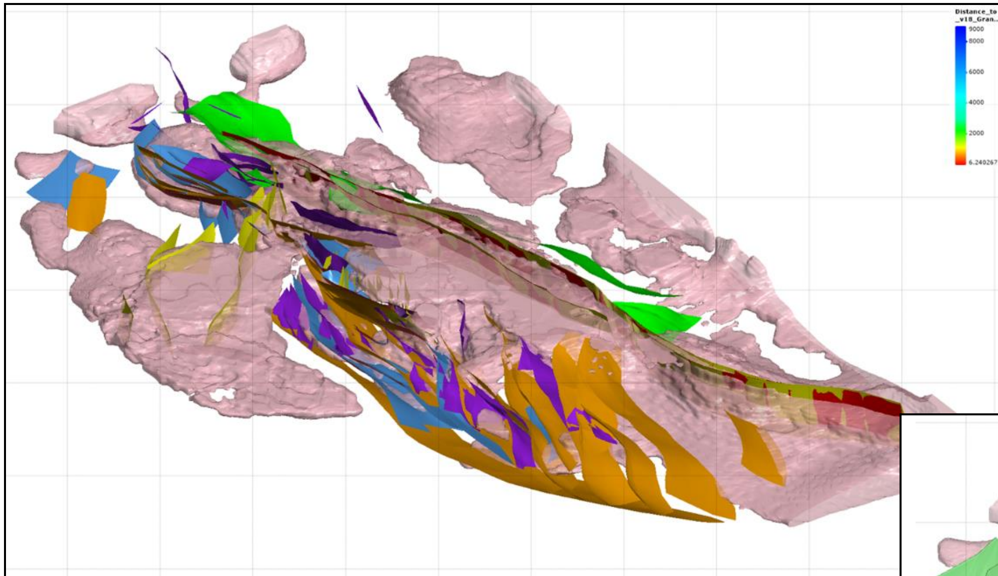


Asymmetric buffering (yellow) of the Top of Staveley Formation stratigraphic surface (-300m/+1500m).

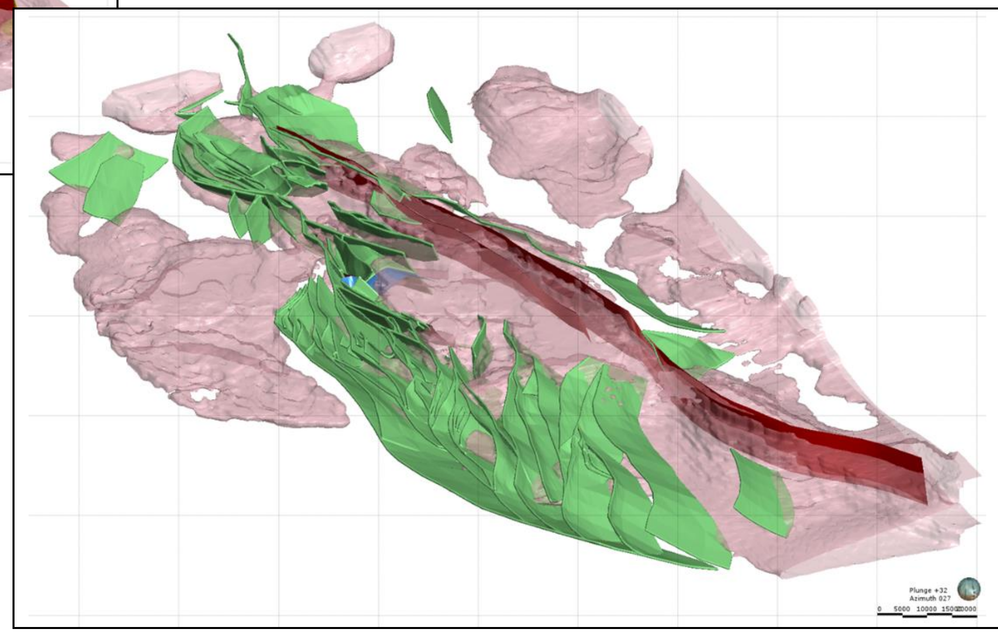
Staveley Buffer Coloured by Proximity to Granite Edges



3D Structure

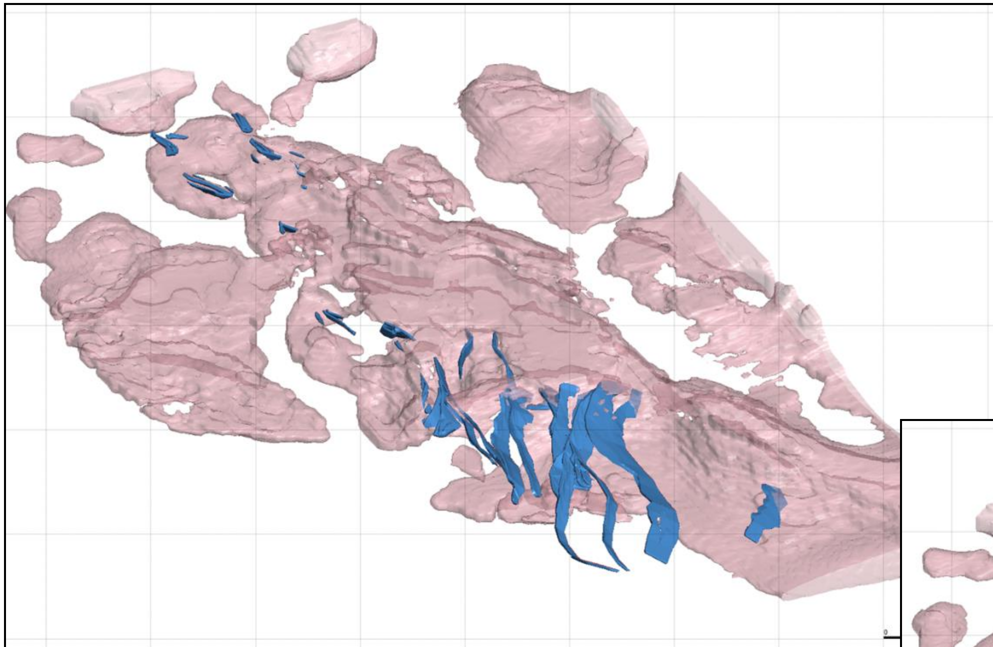


Modelled faults displayed as coloured surfaces. D1 faults: blue, D2 faults: orange, D3 faults: navy, early-D4 faults: purple, late-D4 faults: red/yellow.

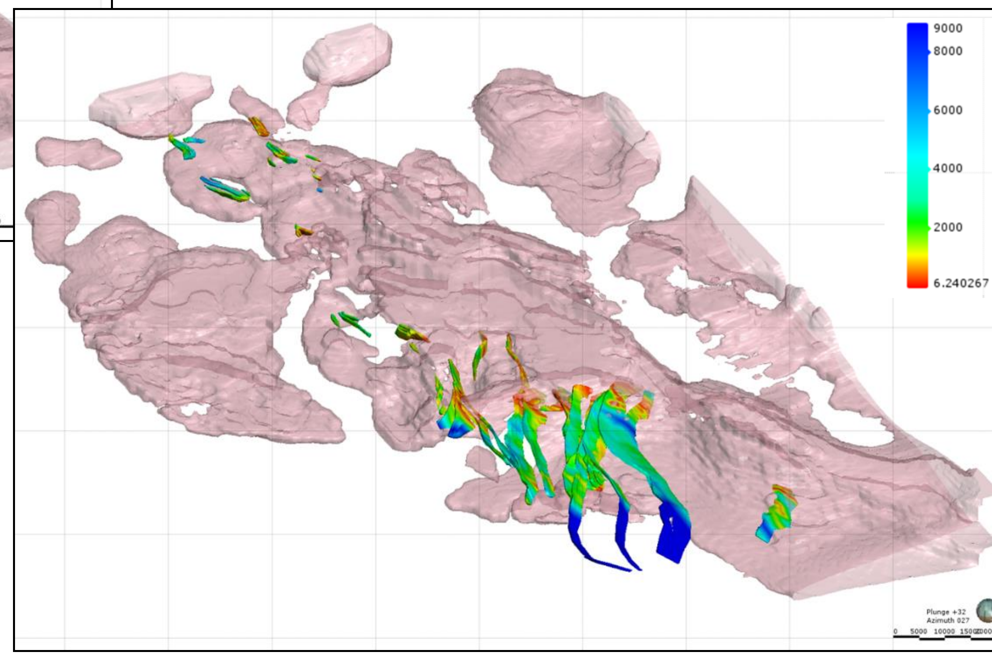


Buffered faults (green) where interpreted to predate the latter stages of D4. The green buffer is ±250m each side of the modelled faults.

3D Structure and Strat Buffer Intersection

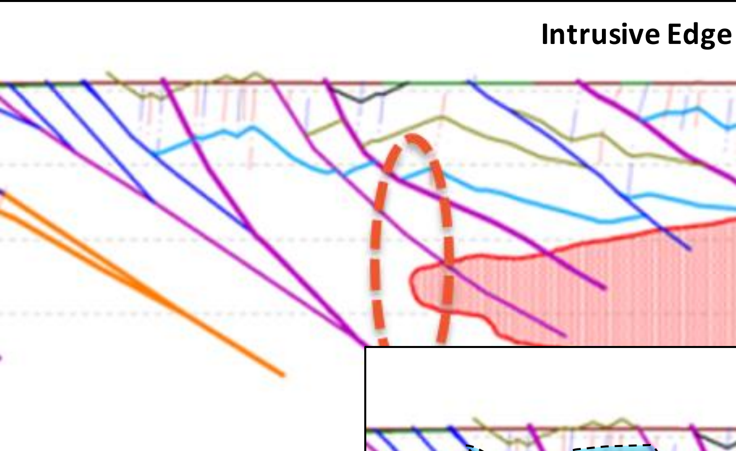


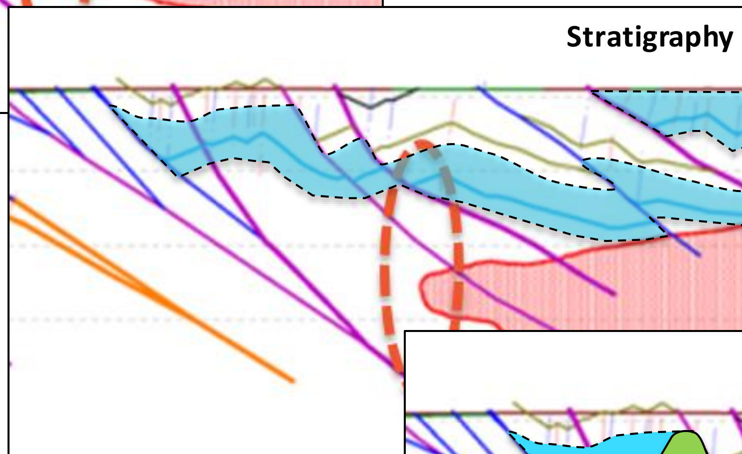
Resultant volumes after intersection of structural and stratigraphic buffer domains.

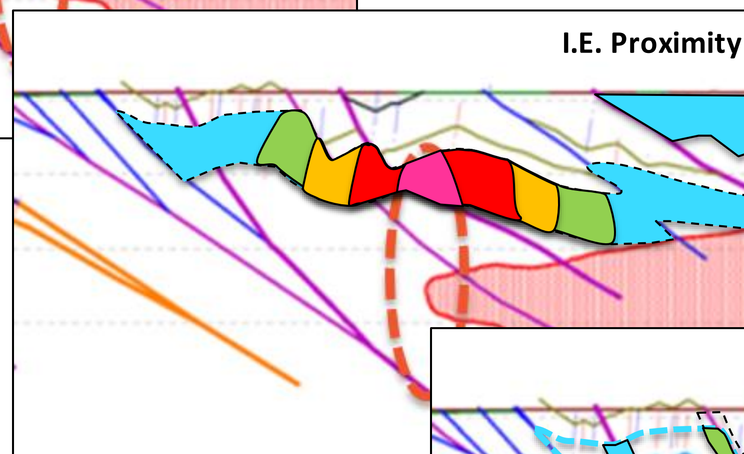


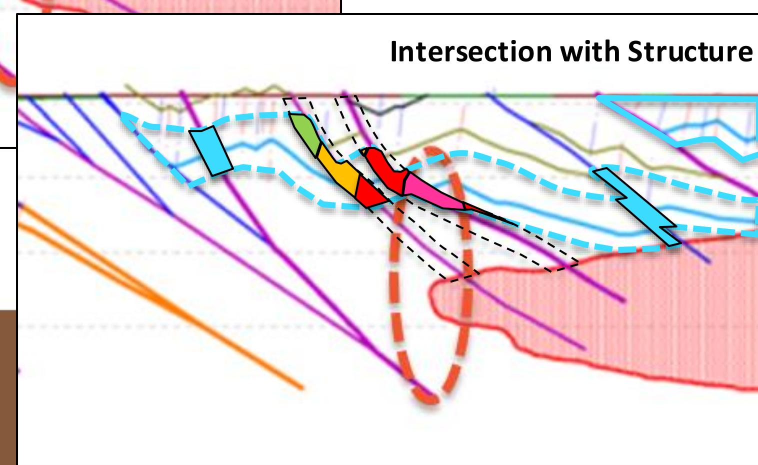
Coloured by proximity to intrusive buffer zones (as per legend).

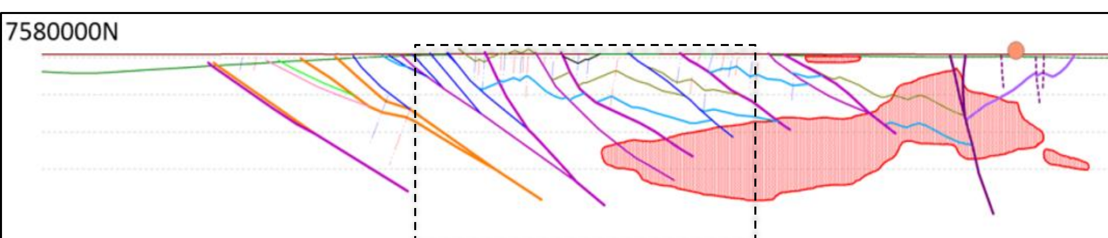
Buffering Process (Osb/MtD/SWAN) - Schematics



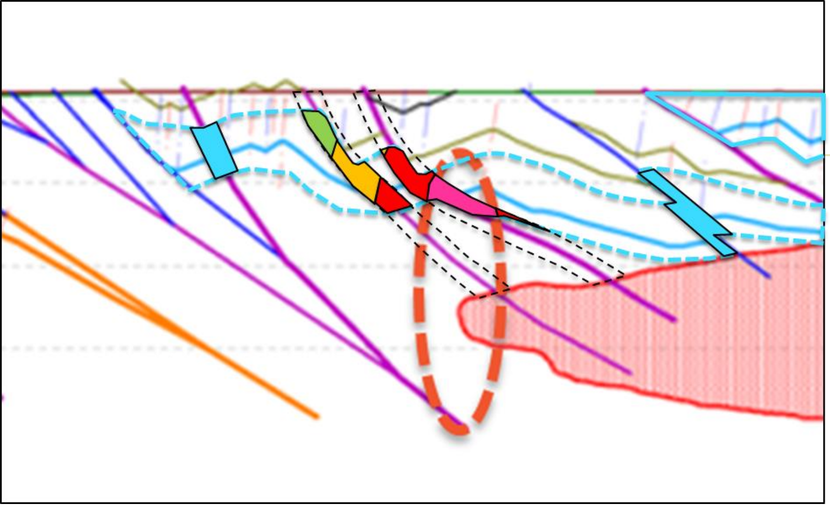


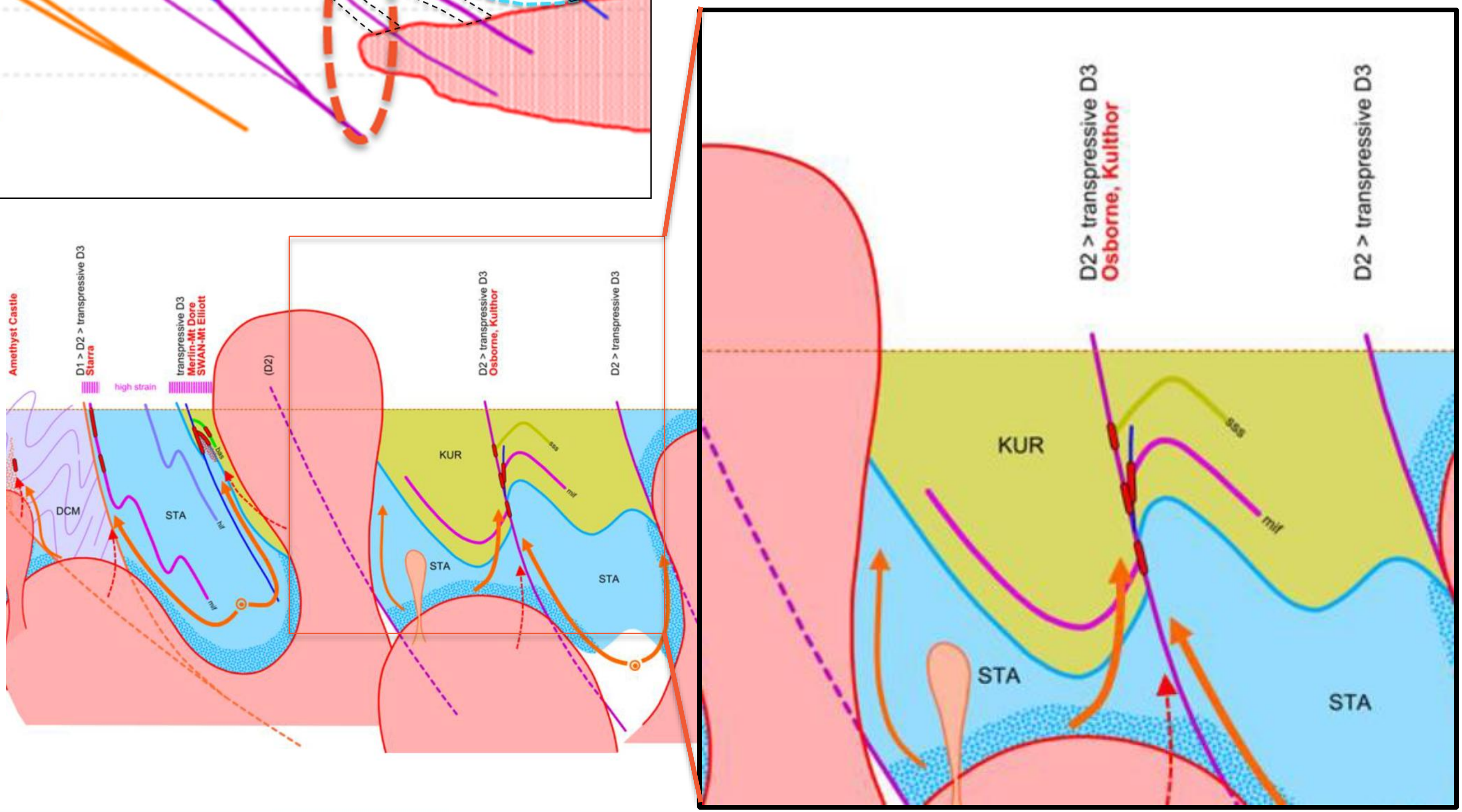






Osborne - Kulthor





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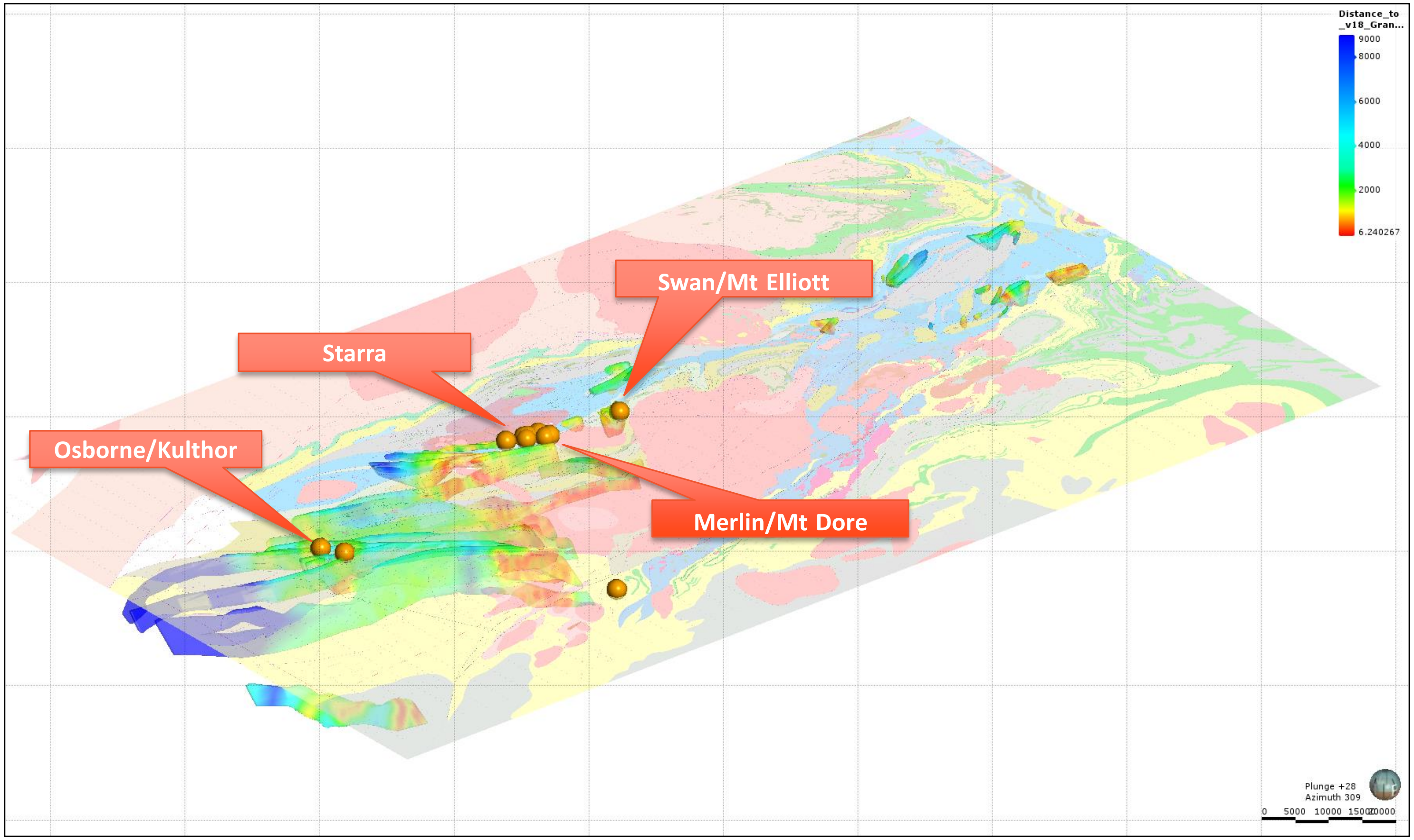
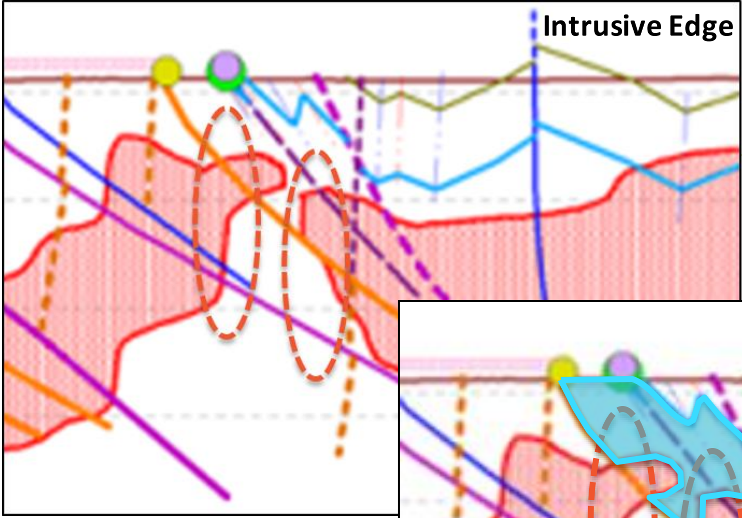
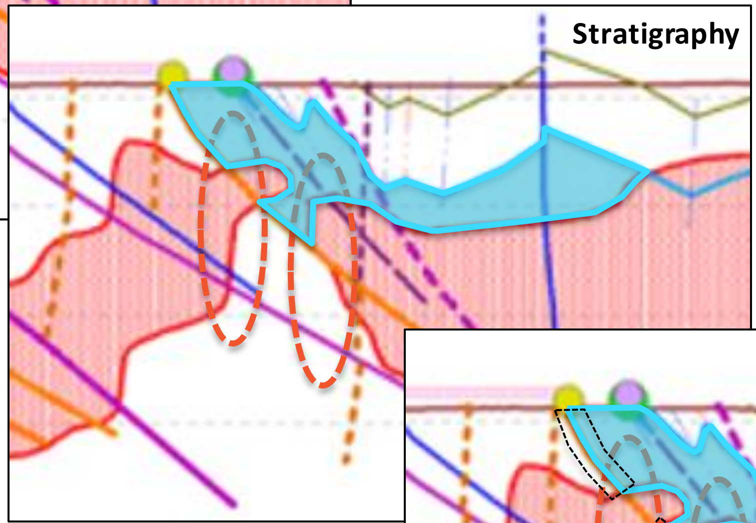
Applying Criteria to the District Model

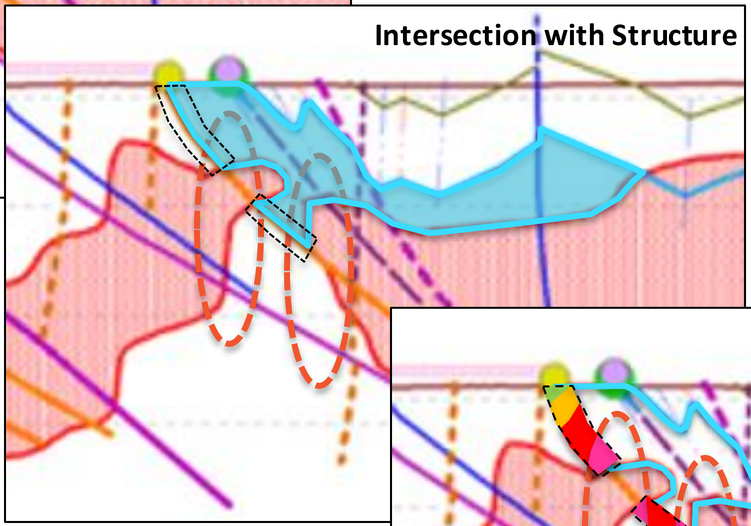


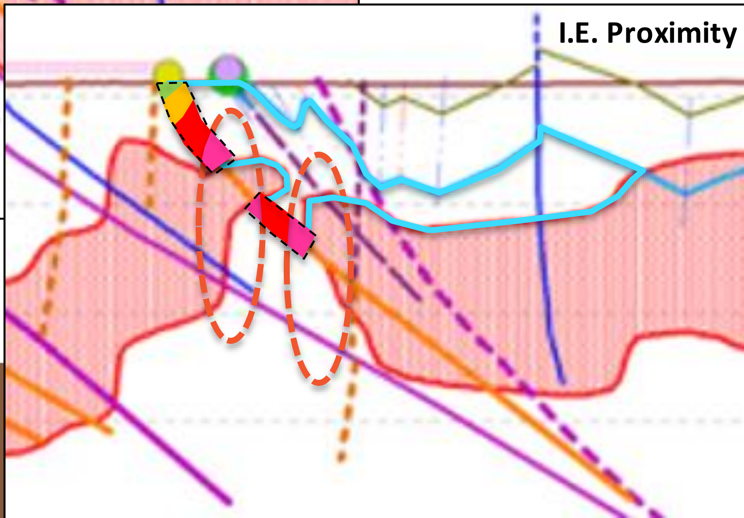
Location of significant deposits and mines relative to the inferred areas of enhanced prospectivity.

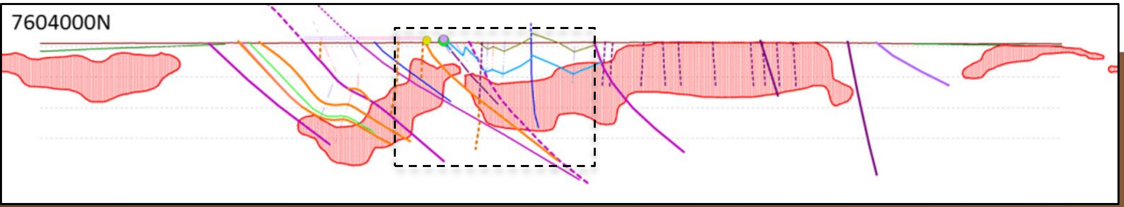
Buffering Process (Starra) - Schematics



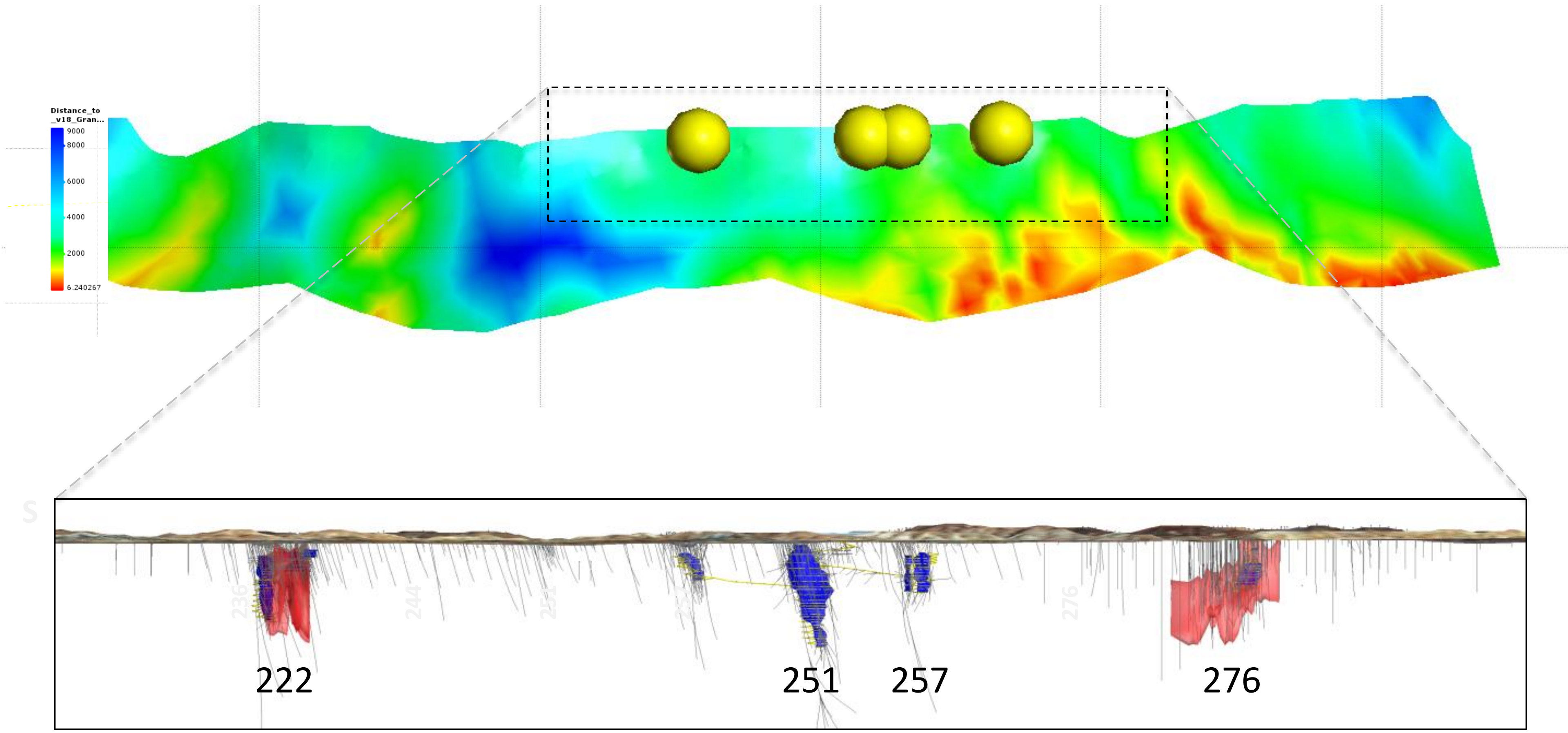






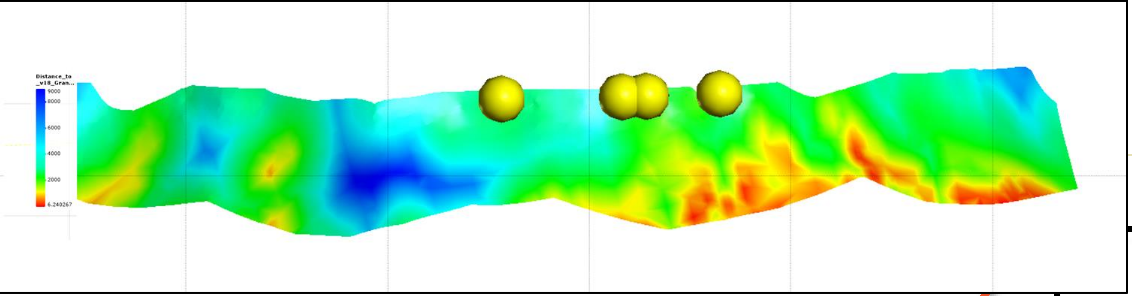


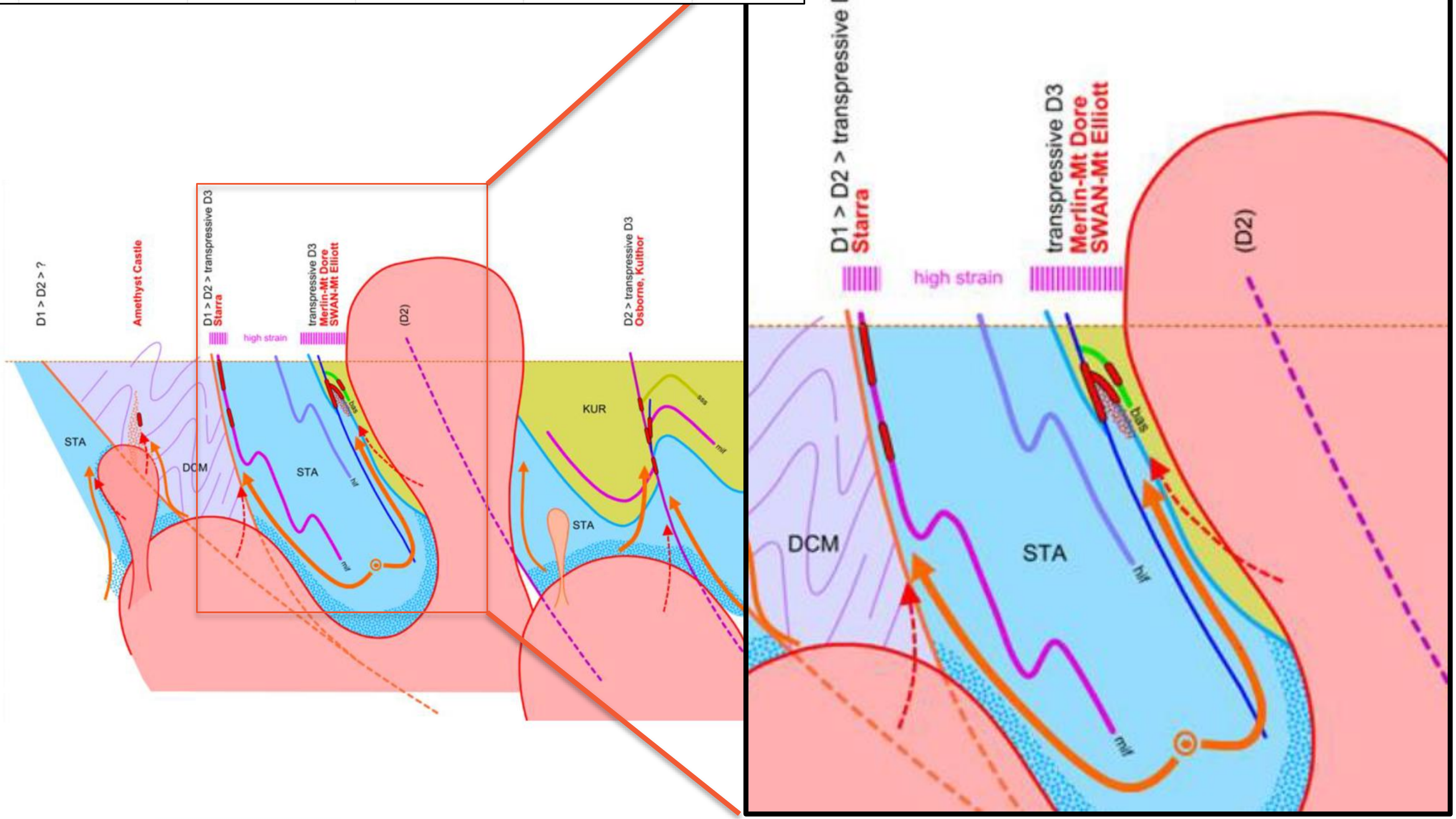
Starra Line



Courtesy – Chinova Resources. Longitudinal Projection – looking West

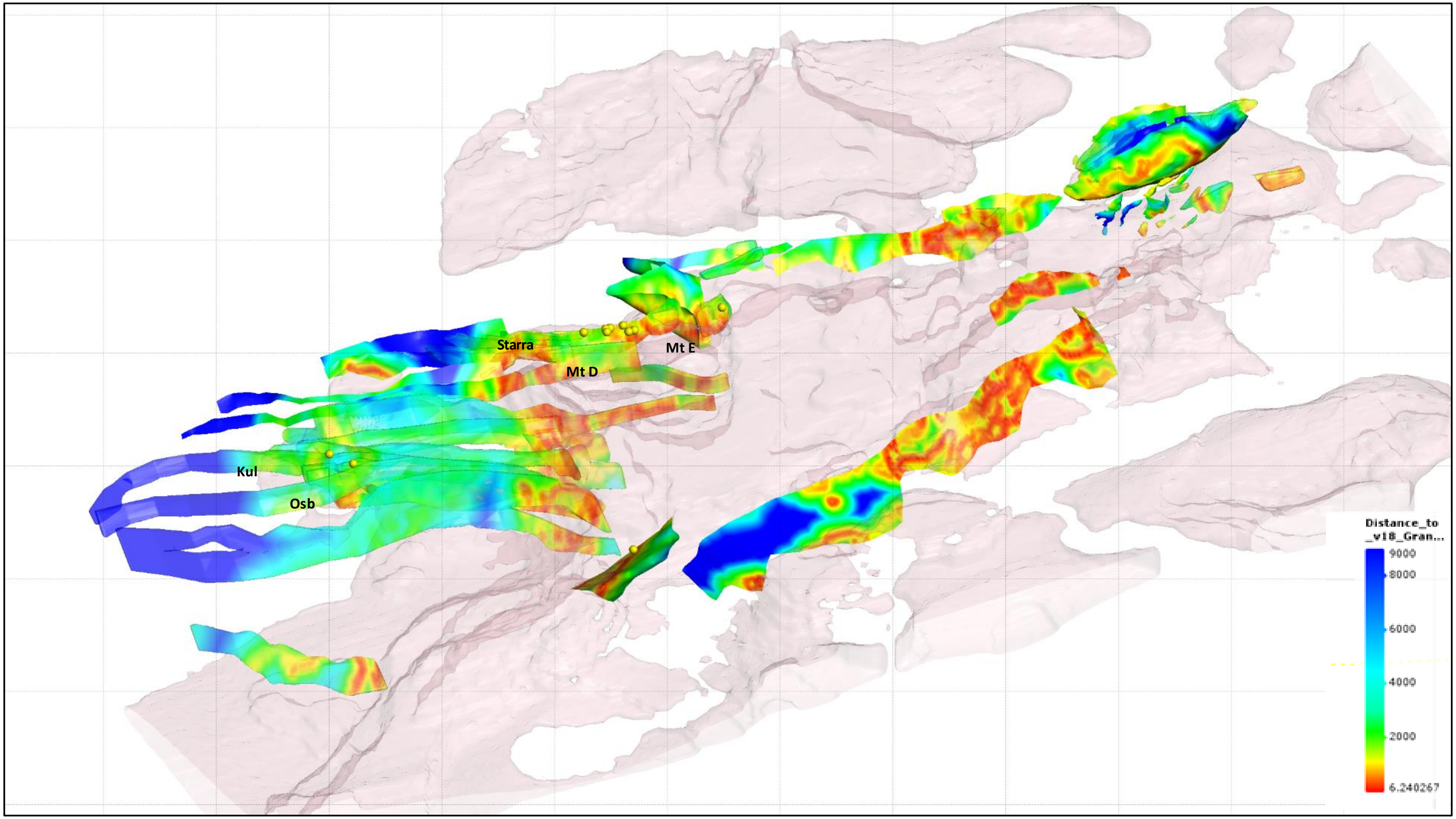
Starra





D1 > D2 > ?
Amethyst Castle
D1 > D2 > transpressive D3
Starra
high strain
transpressive D3
Merlin-Mt Dore
SWAN-Mt Elliott
(D2)
D2 > transpressive D3
Osborne, Kulthor
KUR
STA
DCM
hif
mif
bas

Combined Target Types – More Upside!



Prospectivity Conclusions

- 2D prospectivity analysis does not inform as to the depth potential for discovery of new mineral deposits.

- Understanding of the key factors required for Cloncurry-style Cu-Au deposit formation, coupled with 3D representations of critical geological features; translates to a process and workflow for spatial 3D prospectivity analysis.

- The DMQ model has not tried to be overly quantitative…..geological intuition is required for deep exploration. This is borne from comprehensive understanding of the deposit-forming conditions, host-rocks, structure, and dynamic partitioning of strain (hence the reason why none of these deposits look the same!)

- As with any Prospectivity Analysis, the determinant of success is the ability to ‘rediscover’ known deposits. The current models achieve this.

TARGET & PROSPECT EVALUATION

Evaluation by Project Stage

Pre- Concept/Scoping-Study Evaluation

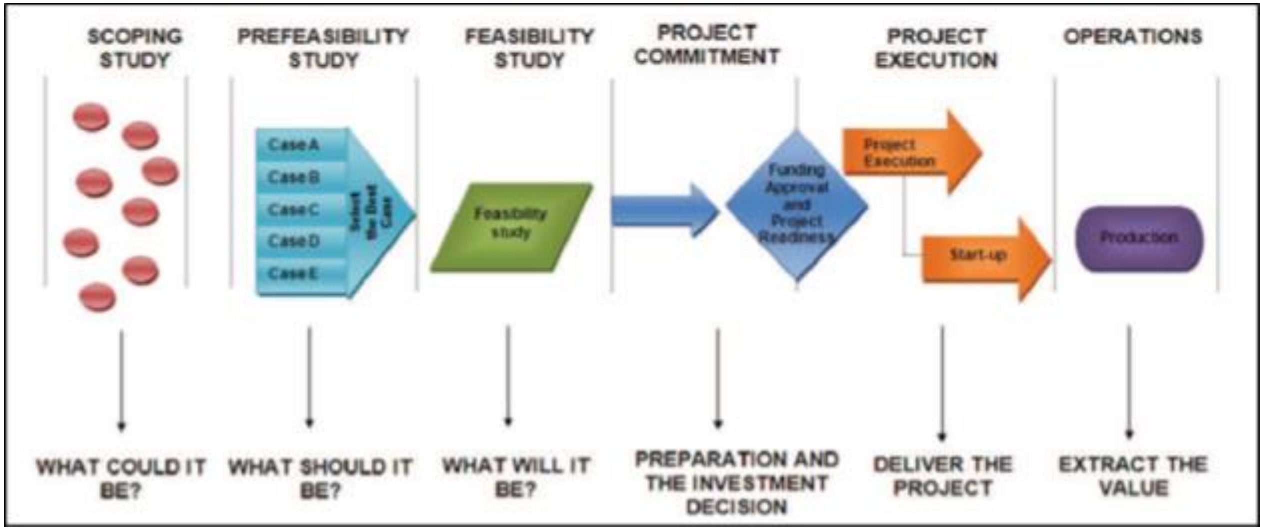
Multidisciplinary Project Evaluation

TARGET GENERATION

WHAT ARE WE LOOKING FOR?

DISCOVERY

HOW DOES IT MEASURE UP?



The progress of studies for mineral projects (Source: AusIMM Cost Estimation Handbook, 2nd ed.)

Company-specific practices

Established Processes and Guidelines

Introduction to PEET-UG

<u>P</u>ROSPECT <u>E</u>CONOMIC <u>E</u>VALUATION <u>T</u>OOL - <u>U</u>NDER<u>G</u>ROUND

Interactive, spread-sheet based tool, for prospect/target evaluation (Pre-'Concept level' analysis) in relative terms.

20170418_PEET-UG

3 key purposes:

1. Where should I be exploring? …..mining constraints on prospectivity utilized in exploration strategy development.

2. Amongst my portfolio of targets/prospects, which of these has the potential to sustain a mining operation? Tool for ranking geological targets in terms of potential viability.

3. Tool for stage-gating the exploration process: is the prospect worth continued effort/expenditure?

The evaluative tool has been constructed to determine relative value of deposits amenable to underground mining, and as a standalone operation.

Key workings of PEET-UG

1. Inputs & Assumptions

- Grade Distribution
- Depth of Cover
- Down-dip Extent
- Length of new road required
- Grade
- Dip
- Width
- Strike-length
- Discount rate
- Metal prices
- Distance to transport hubs
- S.G.
- Mining & Met. recovery
- Exchange rate

2. Derived Quantities

- Tonnage
- In-ground value
- Tonnes/vertical metre
- Mine capex estimates
- Contained metal
- Mining rate potential
- Mining advance rate
- Haulage distances
- Opex estimates (Mining + Geology + Processing + Admin)

3. Mining Method Selection

- Potential mining block height
- SLOS vs SLC vs BC determined by deposit geometry, dip , min. block height, in-ground 'ore' value
- Truck vs Conveyor test (determined by depth below surface and production rate)

4. Project & Prodtn. Schedule

- Mine development by year
- Schedule of ore processed and recovered metal
- Production by year
- Schedule of concentrate produced (tonnes and grade)

Key workings of PEET-UG (cont'd)

5. Revenue Schedule

- Payable metal by year
- Realisation costs by year
- Refining charges per year
- Total Gross Revenue by year

6. Capex Estimate Models

- Declines
- Vertical development
- Fixed plant and Infrastructure
- Processing Plant
- Lateral development
- Mobile equipment
- Infrastructure and services
- Sustaining capex
- Total capex
- Tax deduction for capex

7. Opex Estimate Models

- Mining costs assuming steady state production
- Processing costs " "
- General & Admin costs by year

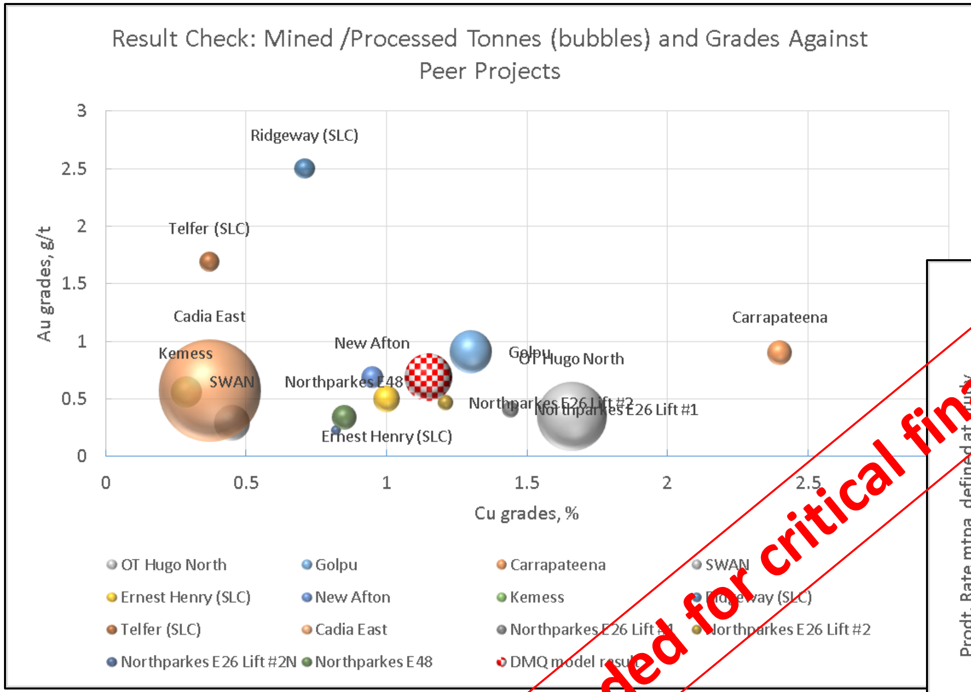
8. Evaluation Model

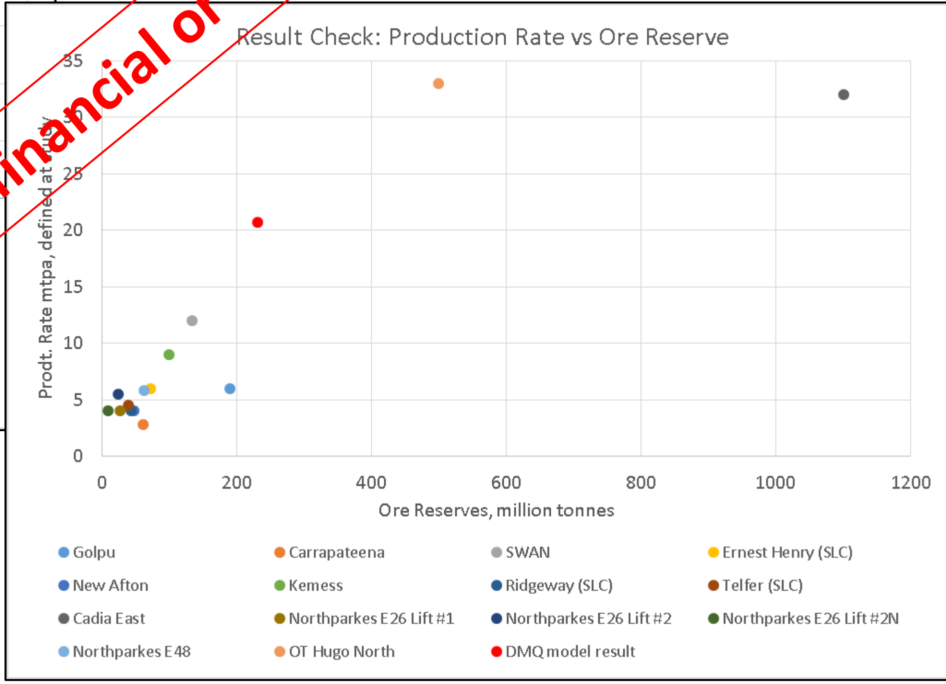
- Collated revenue, capex, opex
- IRR calculation
- Maximum negative cash position
- NPV calculation
- EBITDA
- Time to payback
- Net Cashflow

Results: comparison with peer projects

Summary of Results | Charts

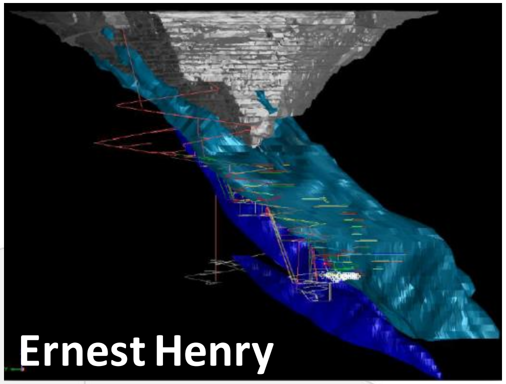
Collated key inputs and outputs on single sheet

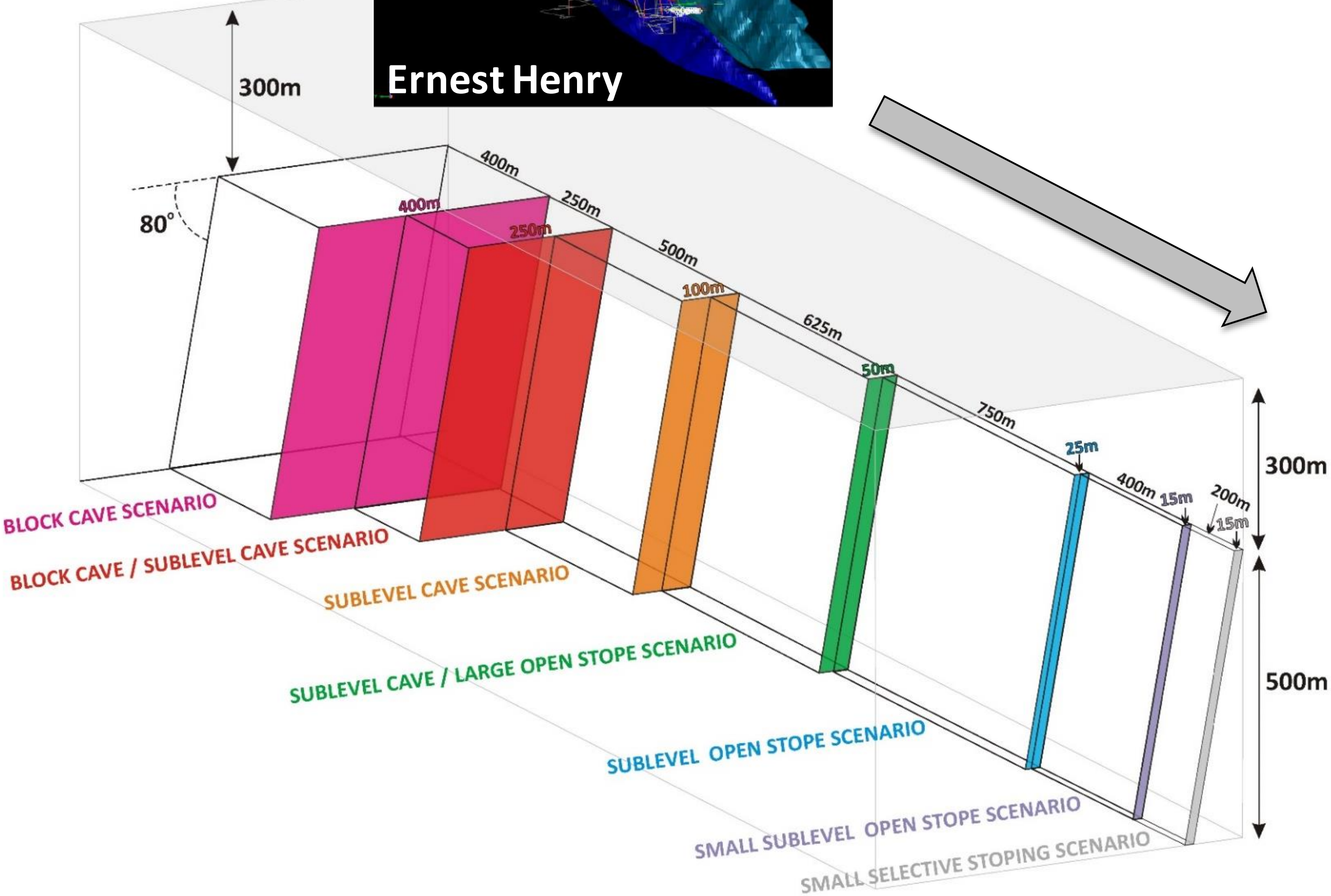


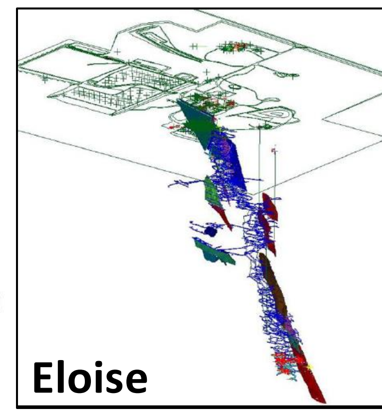


Not intended for critical financial or feasibility analysis

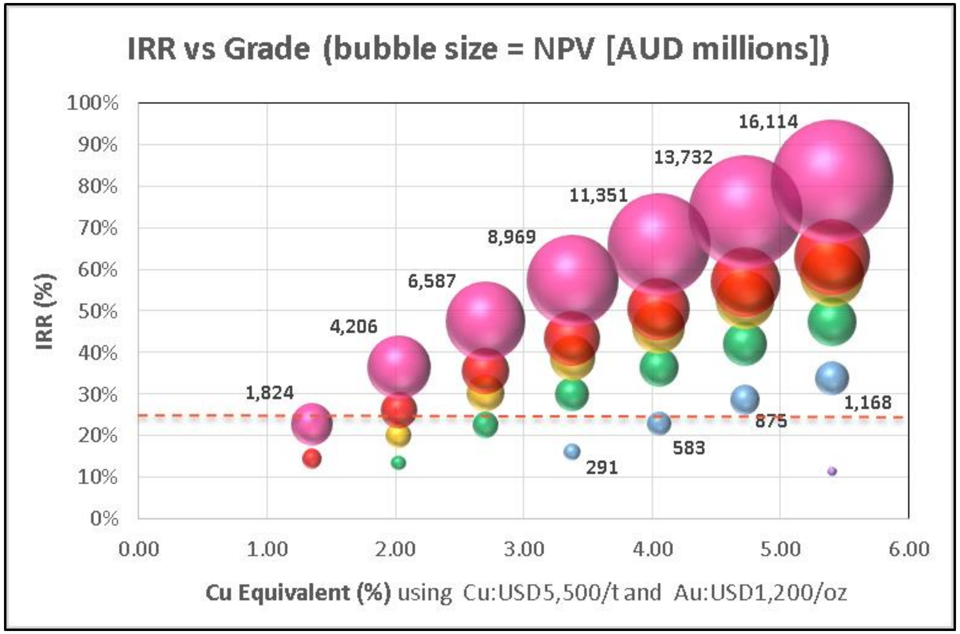
PEET-UG used in anger…..on simulated data

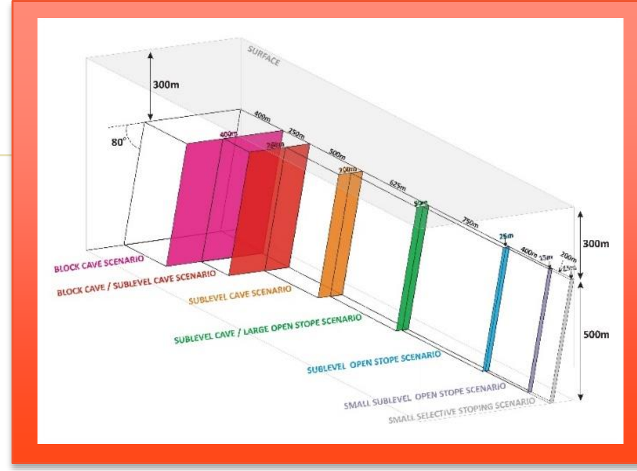






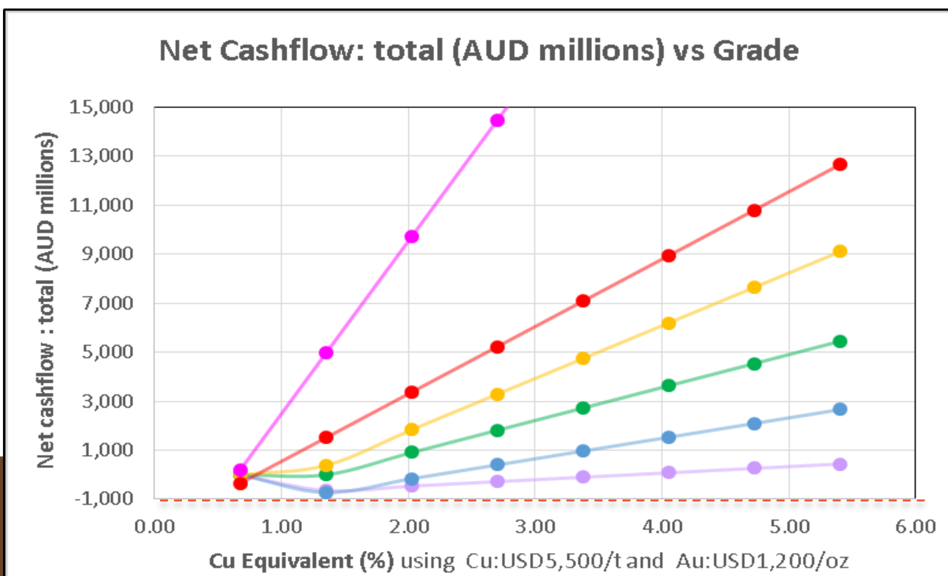
Financial measures vs grade/-tonnage/geometry (mining method)

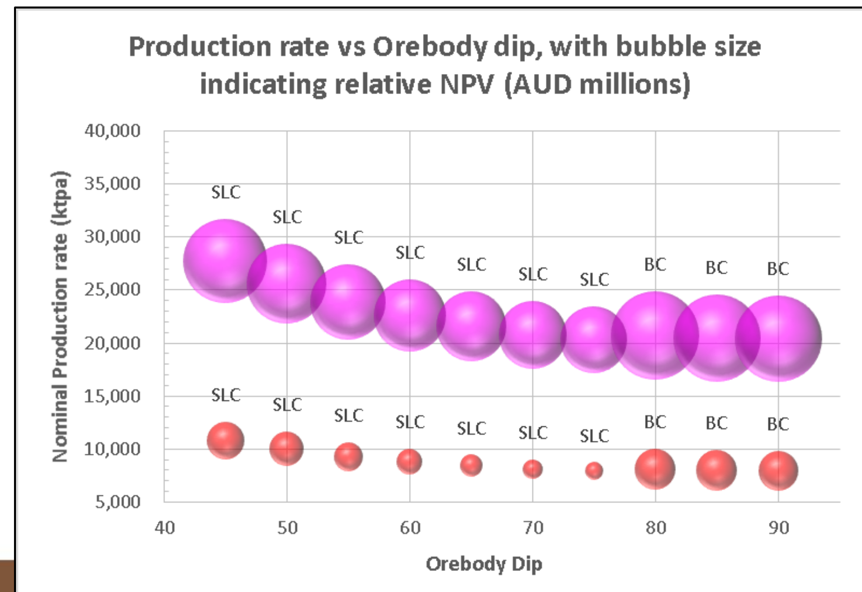


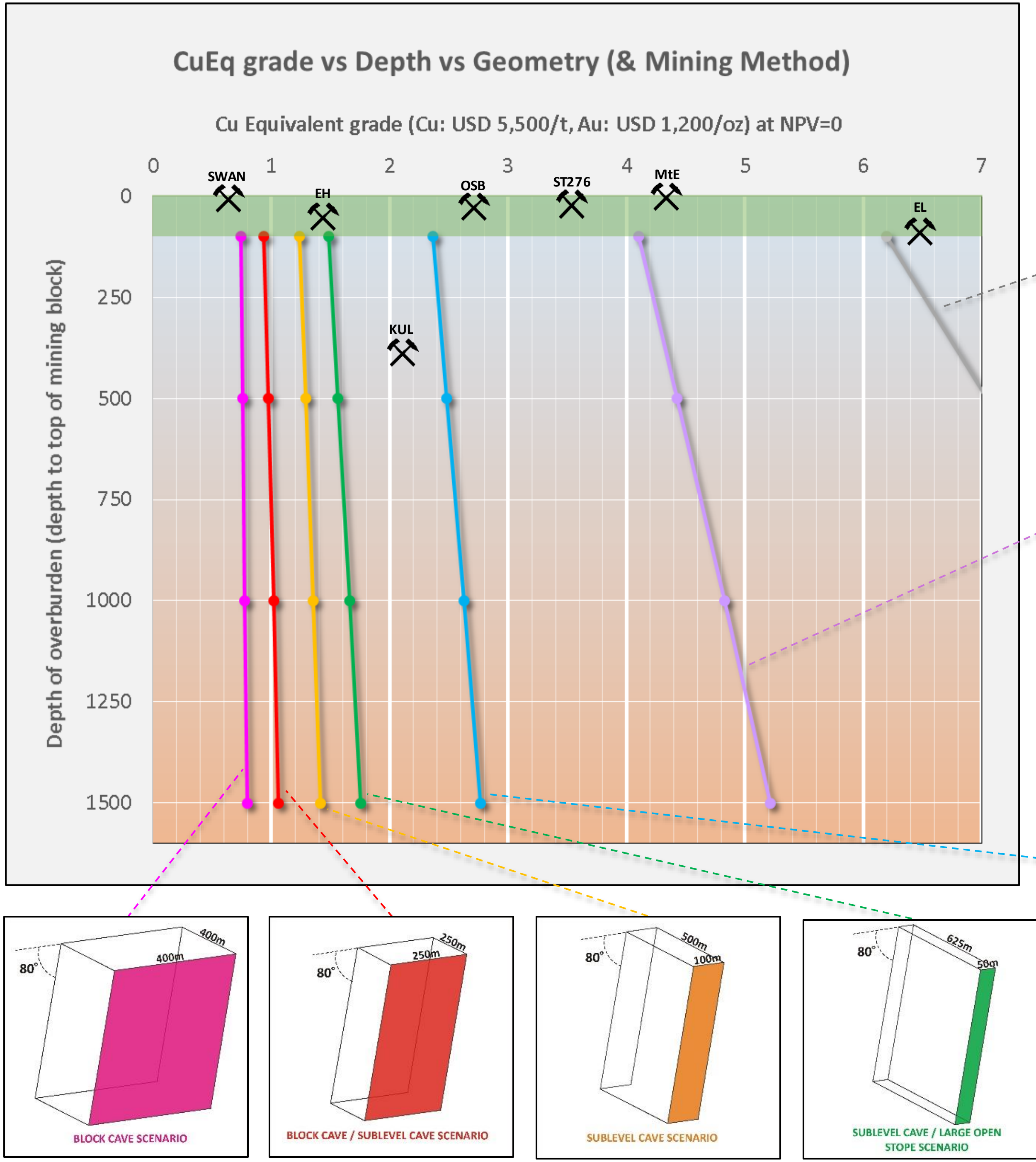


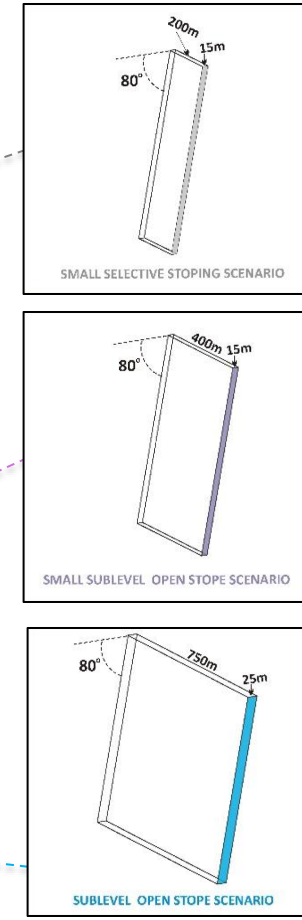
Parameters:

- *300m depth to top of deposit*
- *80 degree dip*
- *CuEq calculation assumed Cu at USD$5500/t, and Au at USD$1200/oz, and a 20k:1 ratio of Cu:Au, as broadly observed in IOCG systems.*





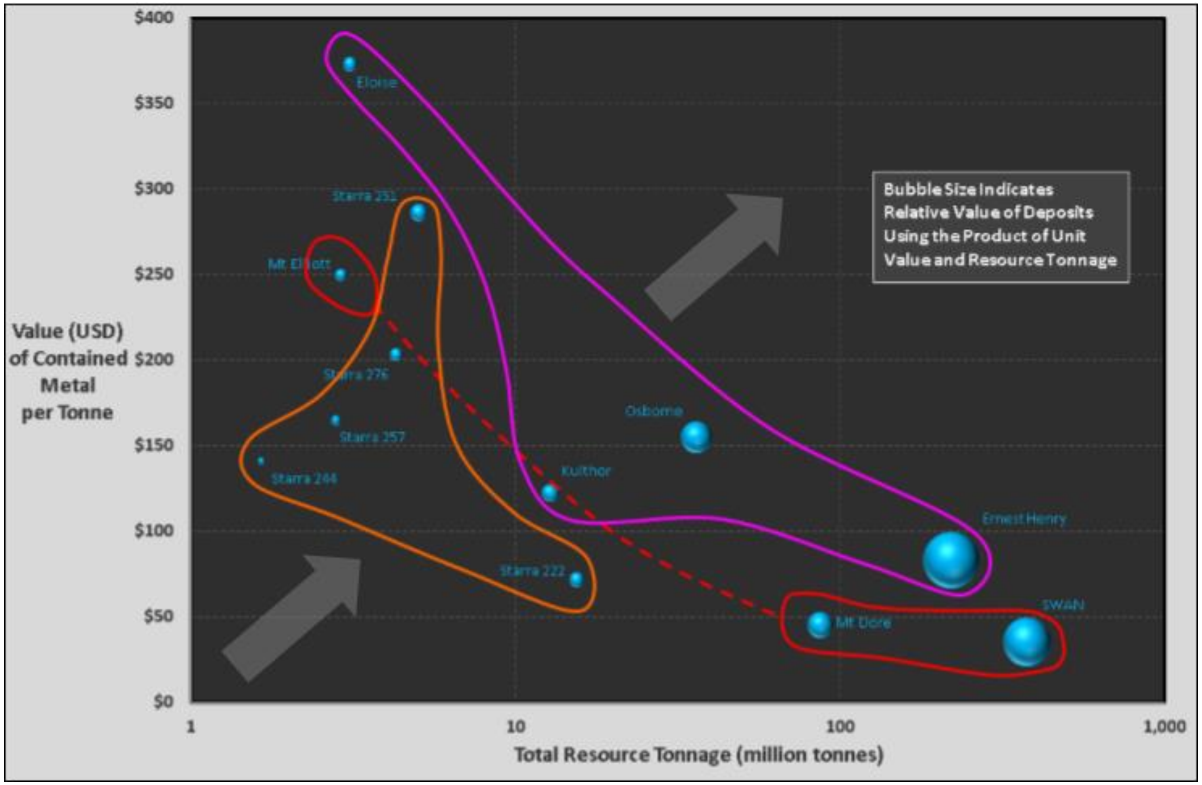




Parameters:

- *500m mining block height only*
- *80 degree dip*
- *CuEq calculation assumed a 20k:1 ratio of Cu:Au, as broadly observed in IOCG systems.*

Are some Cloncurry Cu-Au deposits more prospective than others?



Unit-value per tonne of ore for Cloncurry Cu-Au deposits grouped by deposit-style. Polygons represent grouping of Cloncurry Cu-Au deposits based on the following deposit-styles: Orange polygon: Structural juxtaposition with Staveley Fmn; red polygon: Staveley/Kuridala contact domain, magenta polygon: deposits well into the hangingwall of the Staveley Fmn. Grey arrow indicates the preferred direction, i.e. higher value and higher tonnage.

- The average value per tonne for Cloncurry Cu-Au deposits is $161, with larger deposits (>10Mt) averaging $85/t.
- The smaller deposits have average contained value of $236/t.
- This equates to CuEq of 1.5% for the >10Mt deposits and 4.1% for the remainder of deposits, which are generally <5Mt.

It is apparent that the successful mining of Cloncurry Cu-Au deposits as underground mines has largely been possible due to precursor open-cut mines at the same operation. In other words, the initial extraction method was via open-cut mining and this has covered costs of site access and infrastructure (processing plant, power, water, offices, camp, and tailings storage facility).

DEEP/COVERED EXPLORERS TOOLKIT

- Basement interpretation
- 3D model of geology and structure
- GIS database of key geological, geophysical and geochemical datasets
- 3D GIS of controlling features to mineralisation and their interactions
- Clear understanding of depth constraints for economic mining

CONCLUSIONS

- Deeper/covered exploration is a reality
- Discovery reliant on geophysics, extrapolated geological controls, geological intuition
- Traditional precompetitive data not sufficient in covered areas
- Geological understanding derived from geophysics and known nearby analogous geology will be the key driver for exploration targeting
- The DMQ project is a good example of the precompetitive information required to attract exploration investment for covered and/or deep targets

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DEEP MINING QUEENSLAND (DMQ) PROJECT [2015-2017]

Prospectivity for deep, mineable Cu-Au deposits in the Cloncurry district, Queensland.

Project Completion Forum – Friday April 28th, 2017; 10:00am – 2:00pm, Cloncurry Community Precinct (37 Scarr Street, Cloncurry)

Discussions and presentations to include:

- New insights into the litho-stratigraphic architecture of the Cloncurry region
- Geologically constrained gravity inversion applied to subsurface geological modelling
- Deposit controls: district to local scale
- Prospectivity analysis: expert-informed process utilizing 3D geology inputs
- Methodology and tool for early-stage prospect economic evaluation

Please register your interest in attending this **FREE** event by emailing: Dr Travis Murphy (travis.murphy@uq.edu.au).
For more information about DMQ, see: https://brc.uq.edu.au/project/brc-deep-mining-queensland

Project Sponsors:

Queensland Government
Department of Natural Resources and Mines

Geological Survey of Queensland

chinova resources