

SMI BRC

WH Bryan Mining &
Geology Research Centre



DMQ Project Completion Forum 2017

‘Southern Cloncurry IOCG/ISCG Terrain - Deposit Controls: District to Local’

Mark Hinman



Geological Survey of Queensland



*Fullagar
Geophysics Pty Ltd*

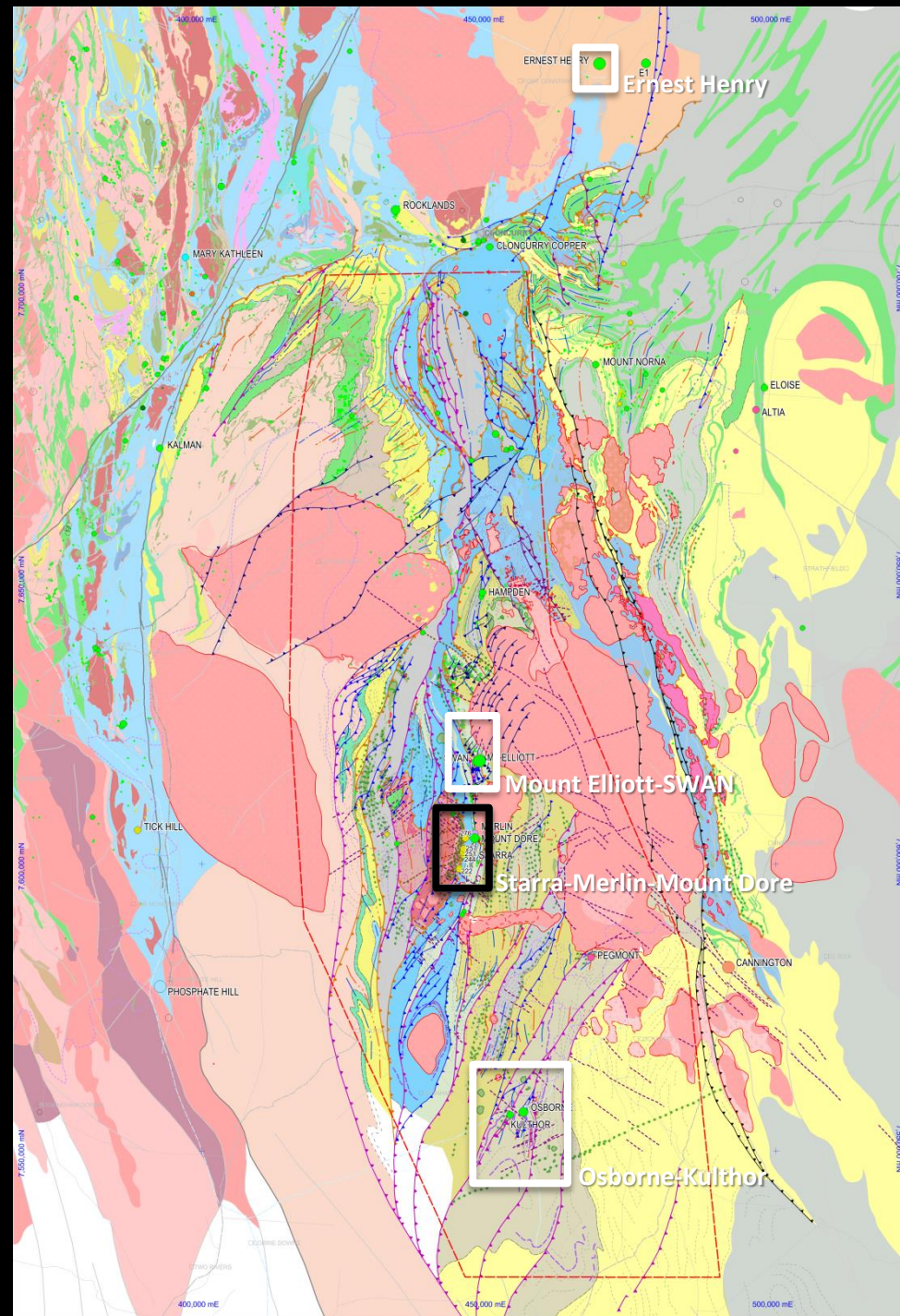
chinova
resources

Deposit Controls: District to Local

Four areas

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

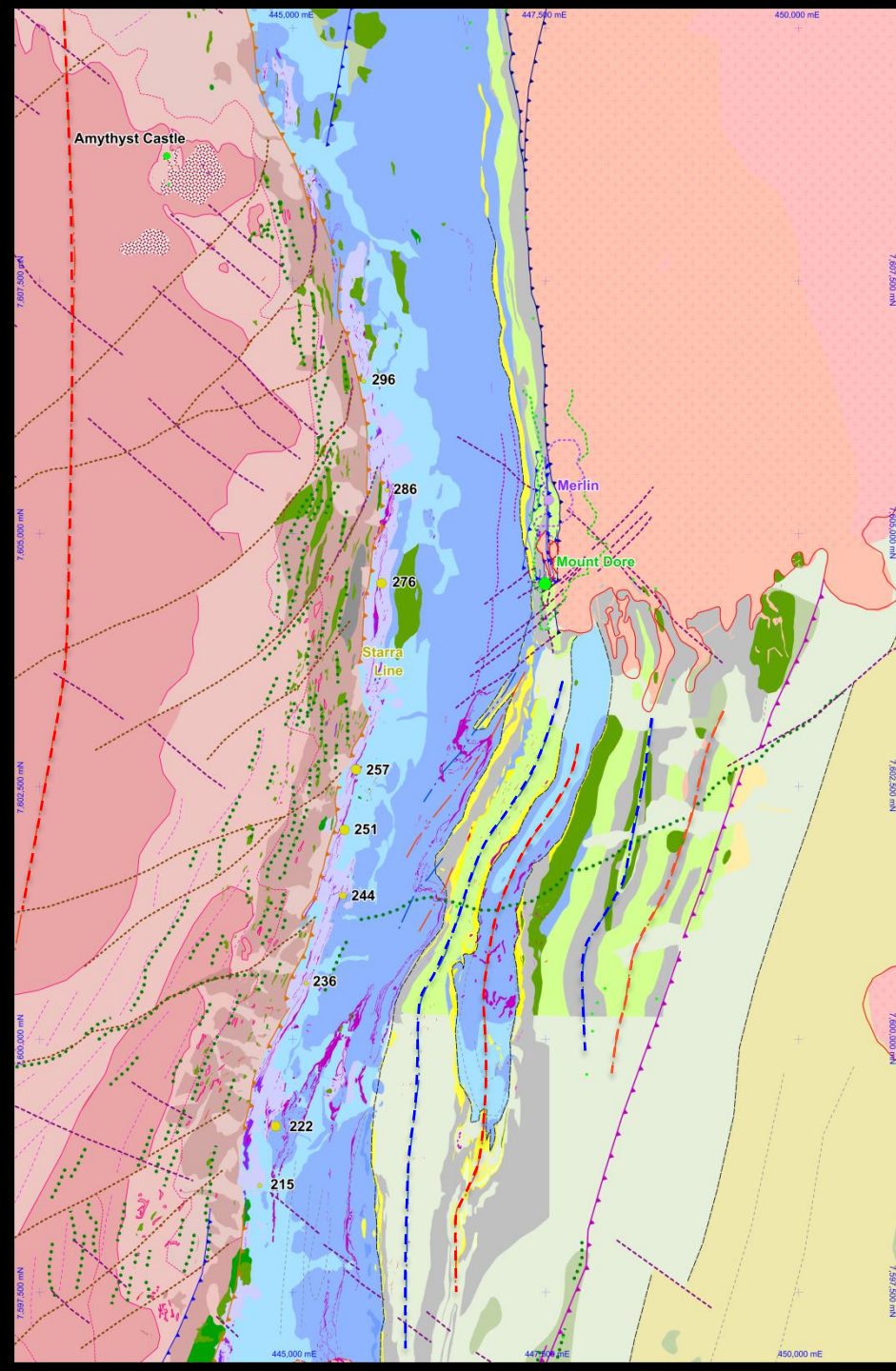
FIRST to Starra-Merlin-Mount Dore



Starra-Merlin-Mount Dore

5K-10K Leishman Geology (1970s-1980s)

DMQ Mag Interpretation (2016)

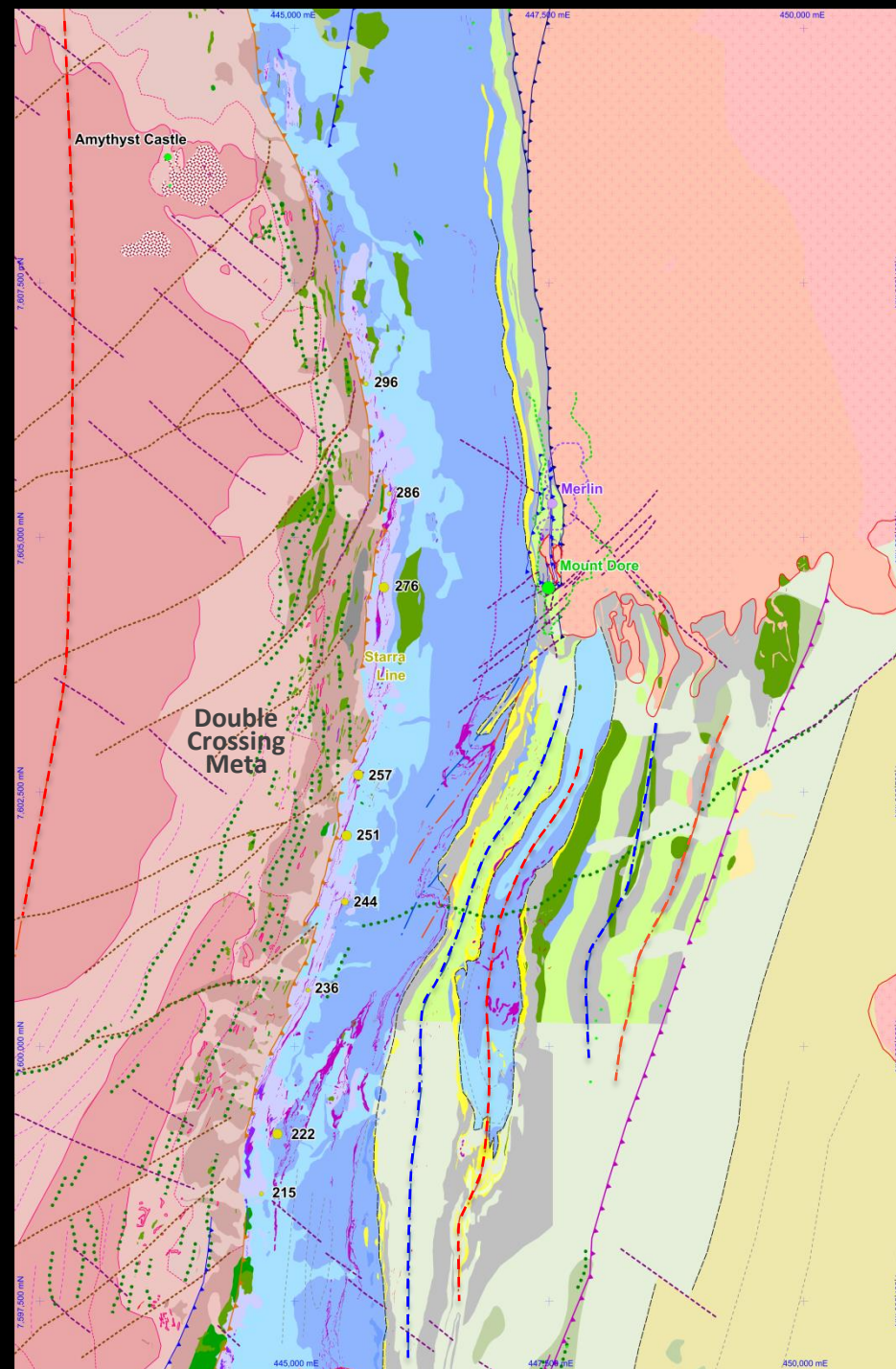


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MARRABA-MITAKOODI-Double Crossing Metamorphics



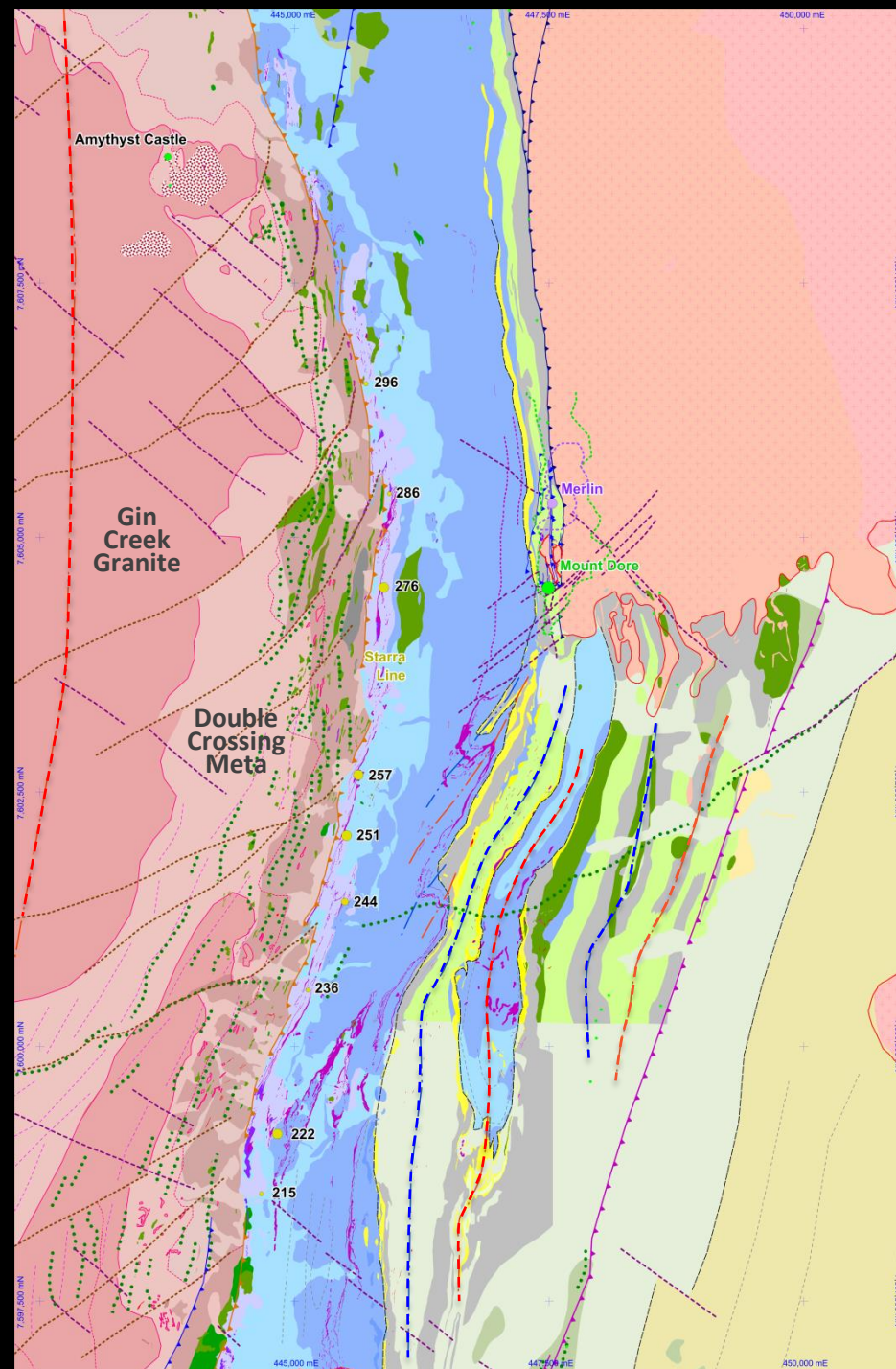
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syn-deformational **WONGA Gin Creek Granite**



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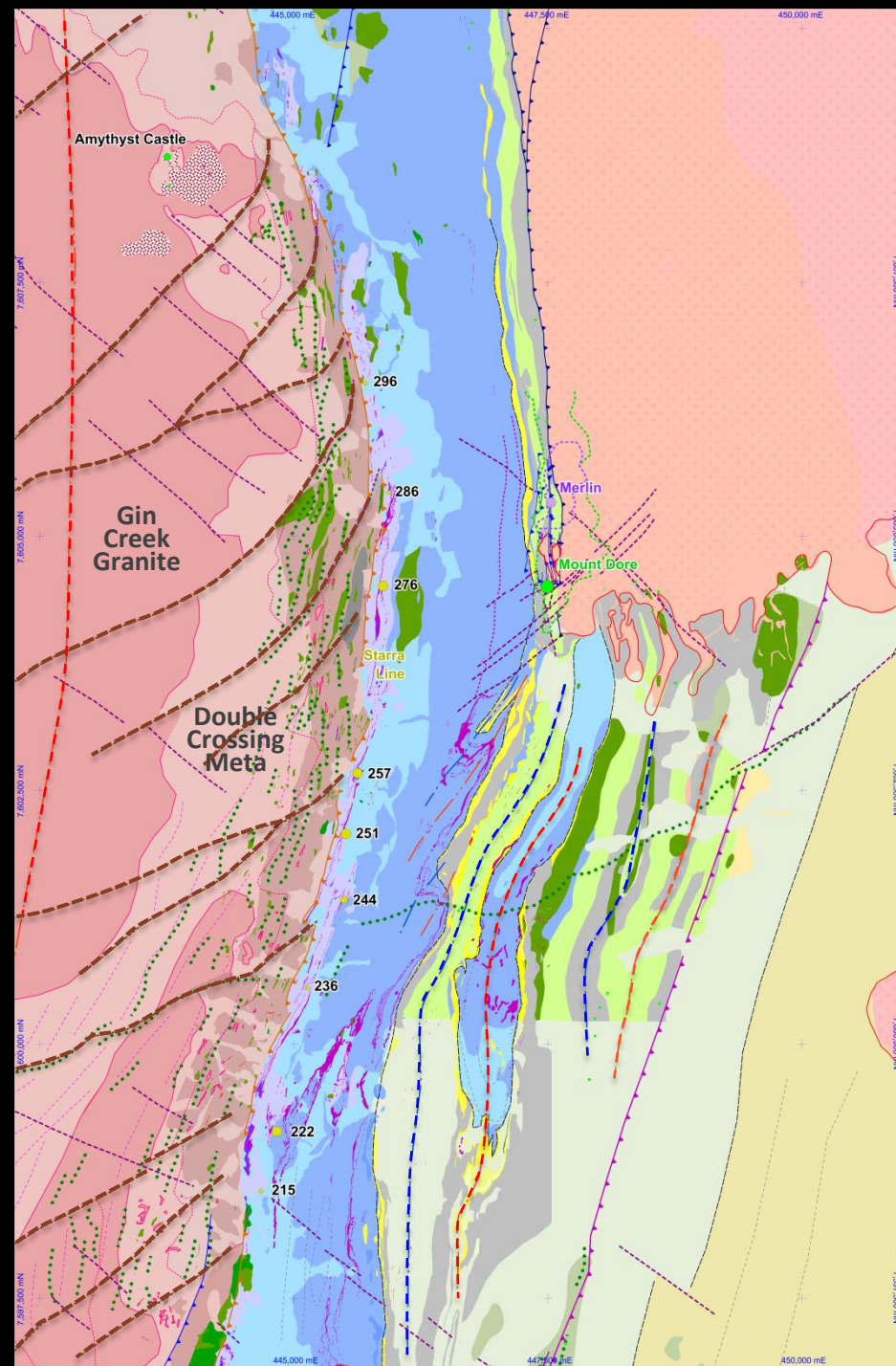
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OP1 Exhumation of DCM-GCG ... Block Faulting

Significant offsets of GCG-DCM



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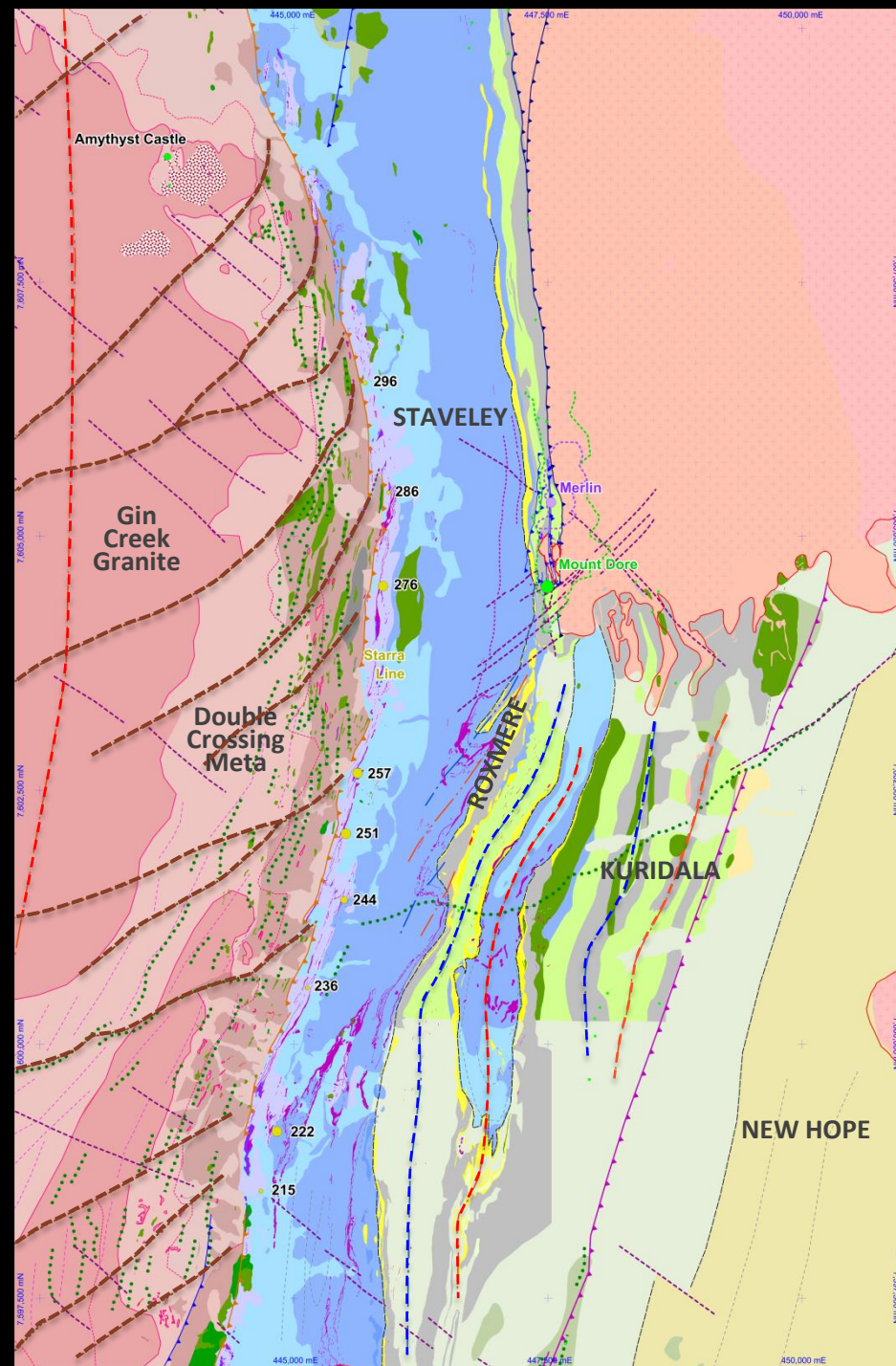
Significant offsets of GCG-DCM

STAVELEY

ROXMERE

KURIDALA

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



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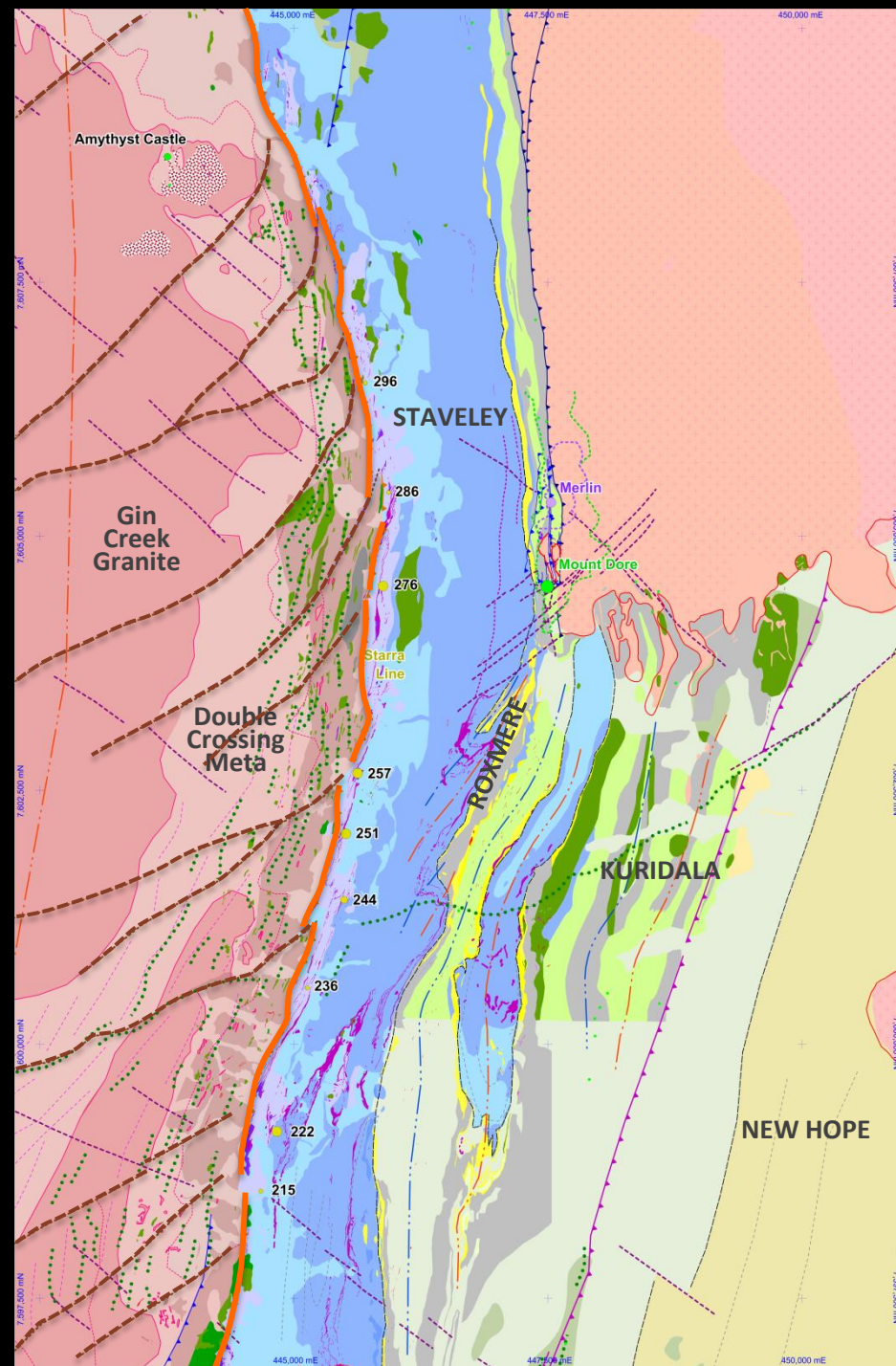
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(*Starra Shear*)

E-W Folds; highly attenuated/folded MIF-HIF; over FW architecture



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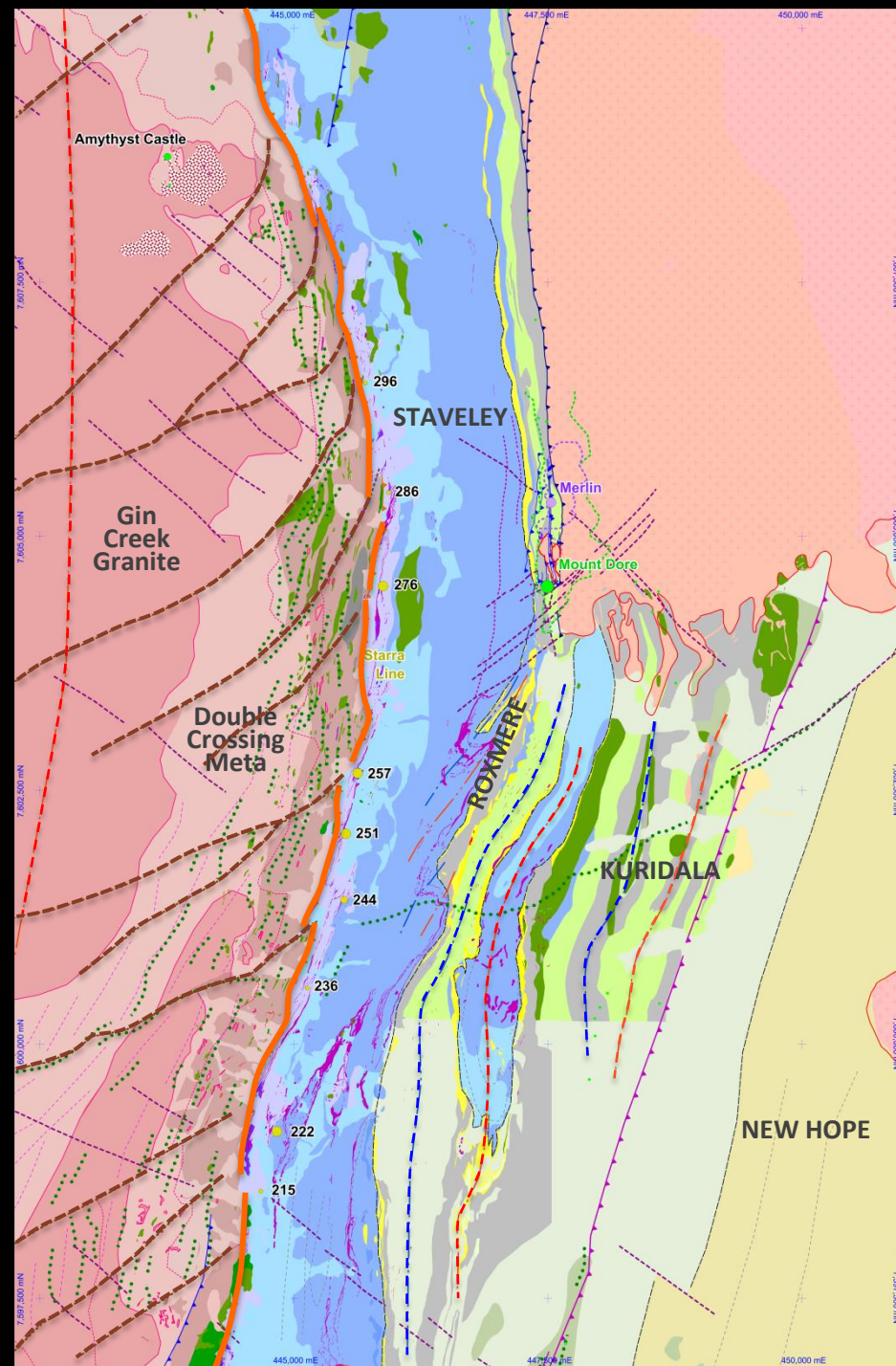
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D2 EW-shortening Folding

D1 *Starra Shear* folded to sub-vertical; F1 folds steep in *Starra Shear* of sub-horizontal F2 Folds >> steep ribbons & rootless folds of MIF



Starra-Merlin-Mount Dore

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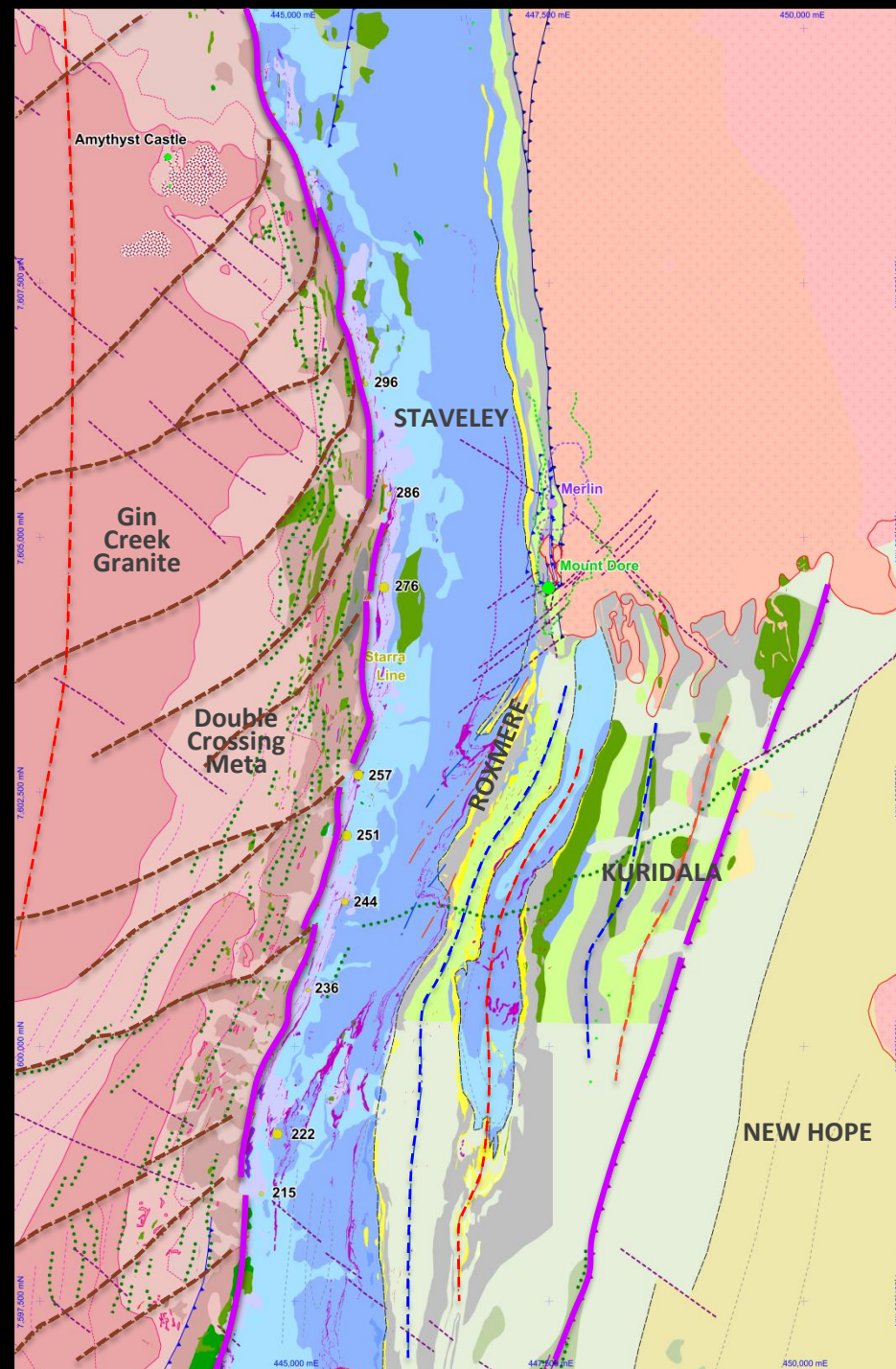
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Re-activated D1 *Starra Shear*; new F2 Folds



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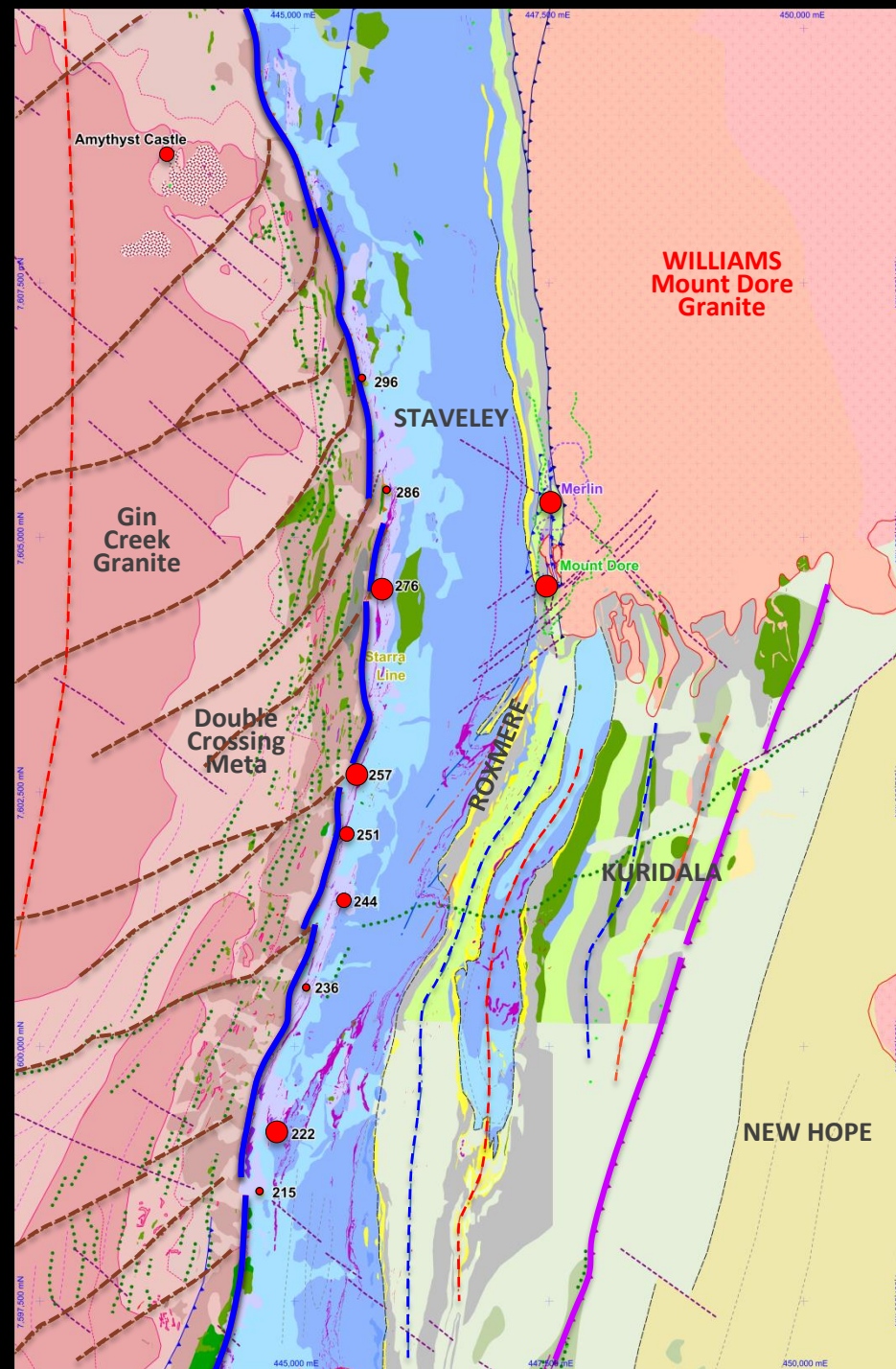
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Re-activated D1 *Starra Shear*; new F2 Folds

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



Starra-Merlin-Mount Dore

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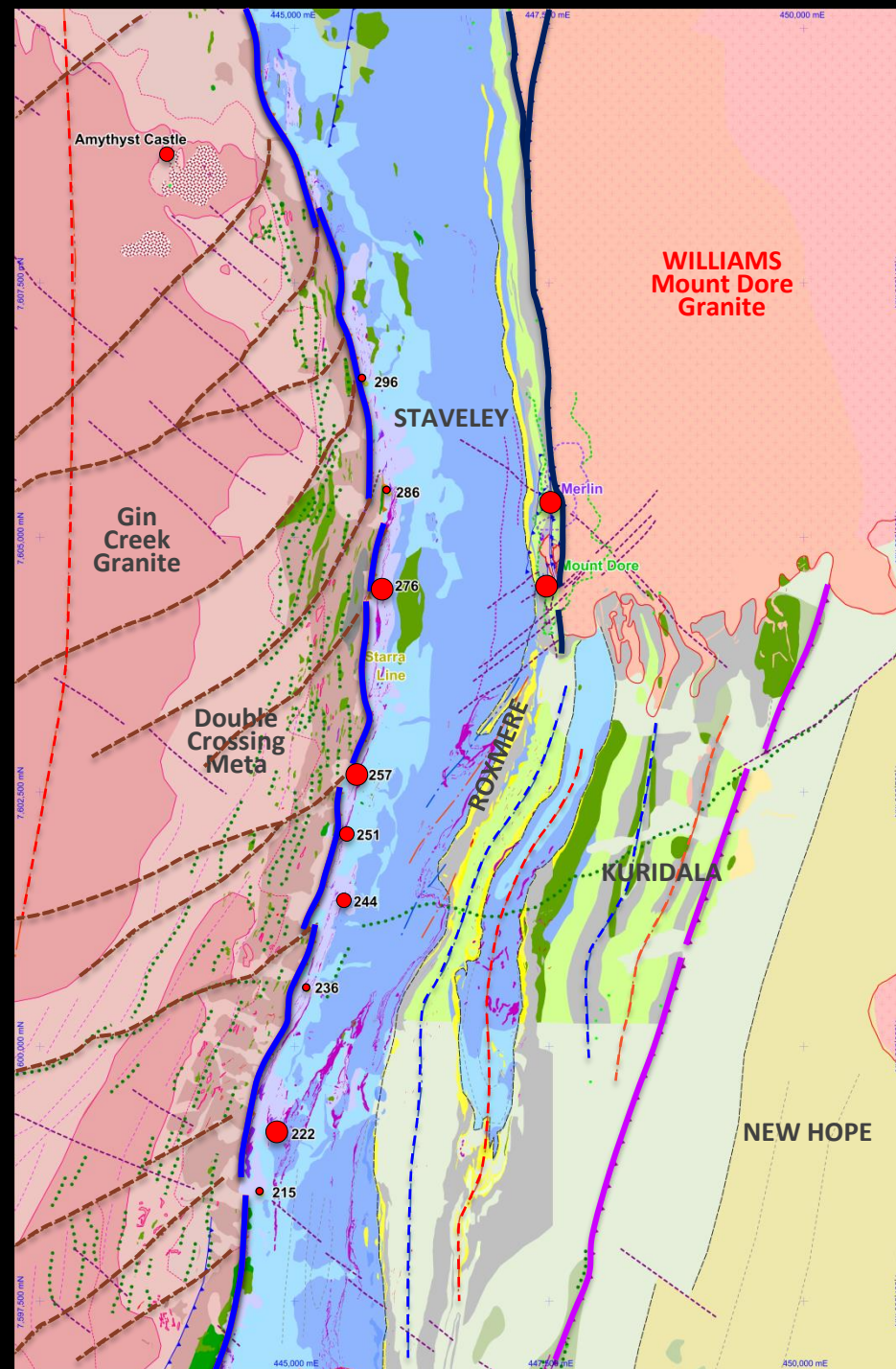
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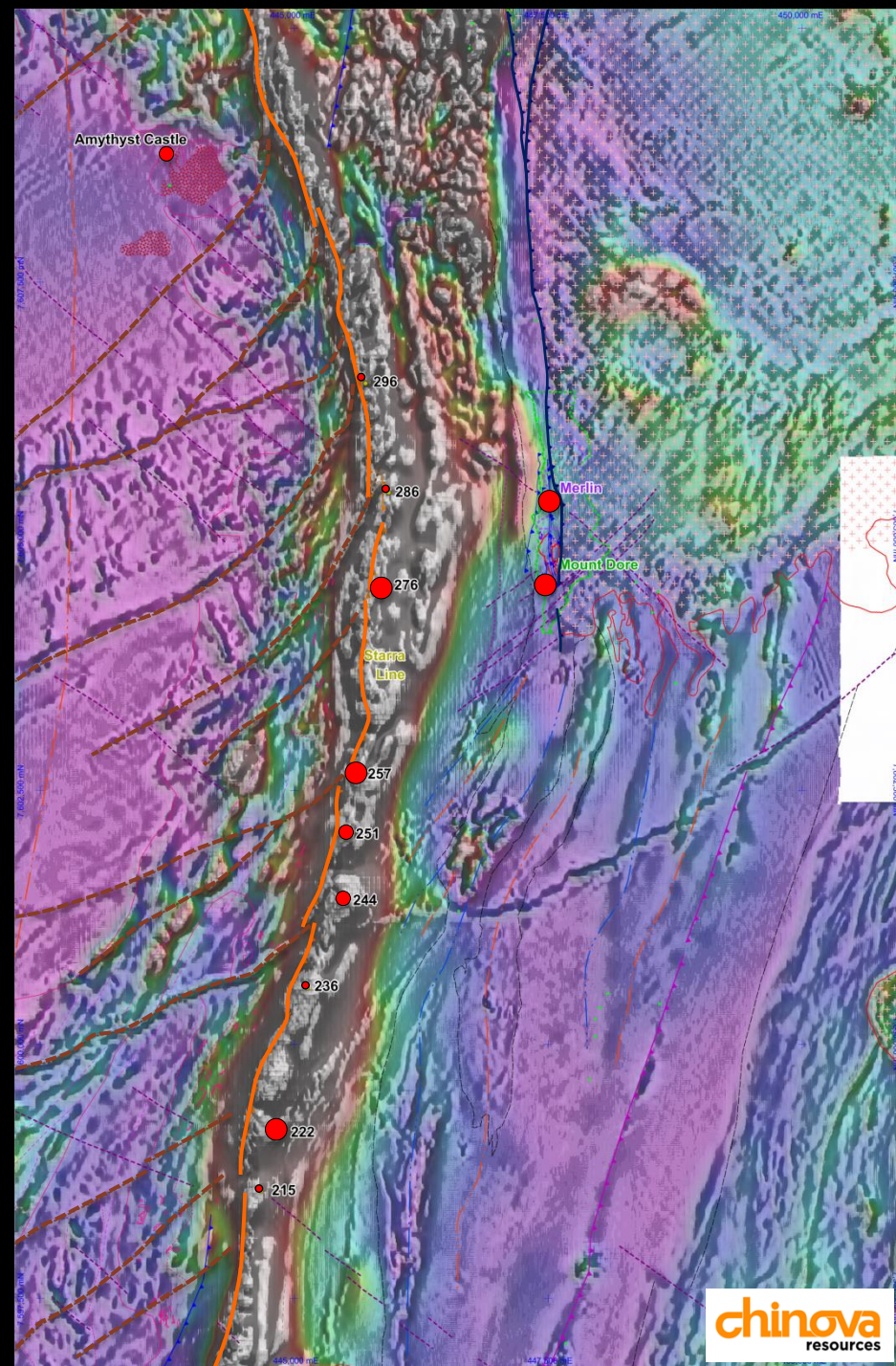
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Late D4, post-mineral Faulting

Mount Dore Granite over *Merlin-Mount Dore* *Cu-Au-Mo*





Starra

Chinova detailed vrmi-2vd over tmi-rtp

magHIGH along Starra Line

NOT massive Magnetite Iron Formation (MIF) ...

Starra

Chinova detailed **vrmi-2vd** over **tmi-rtp**

magHIGH along Starra Line

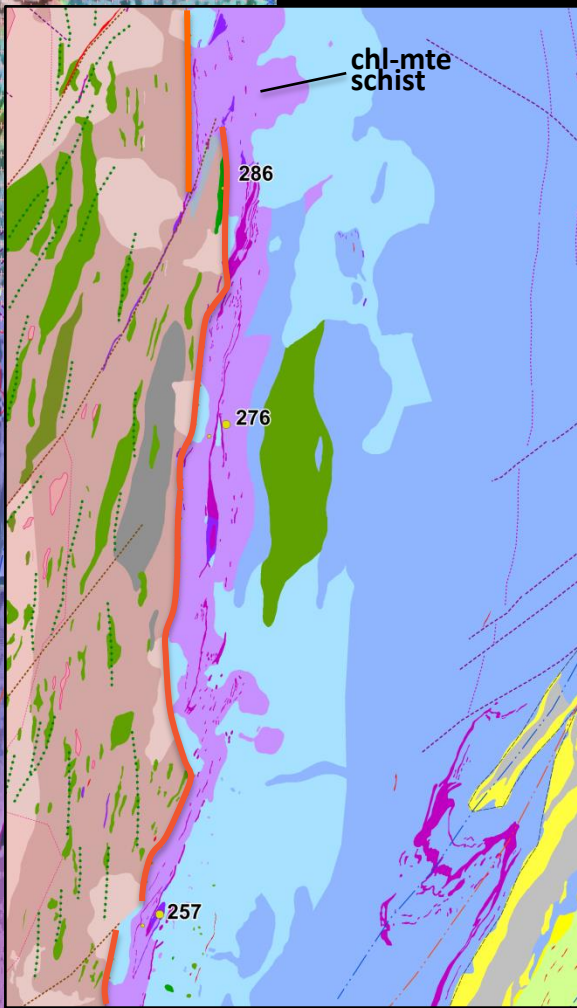
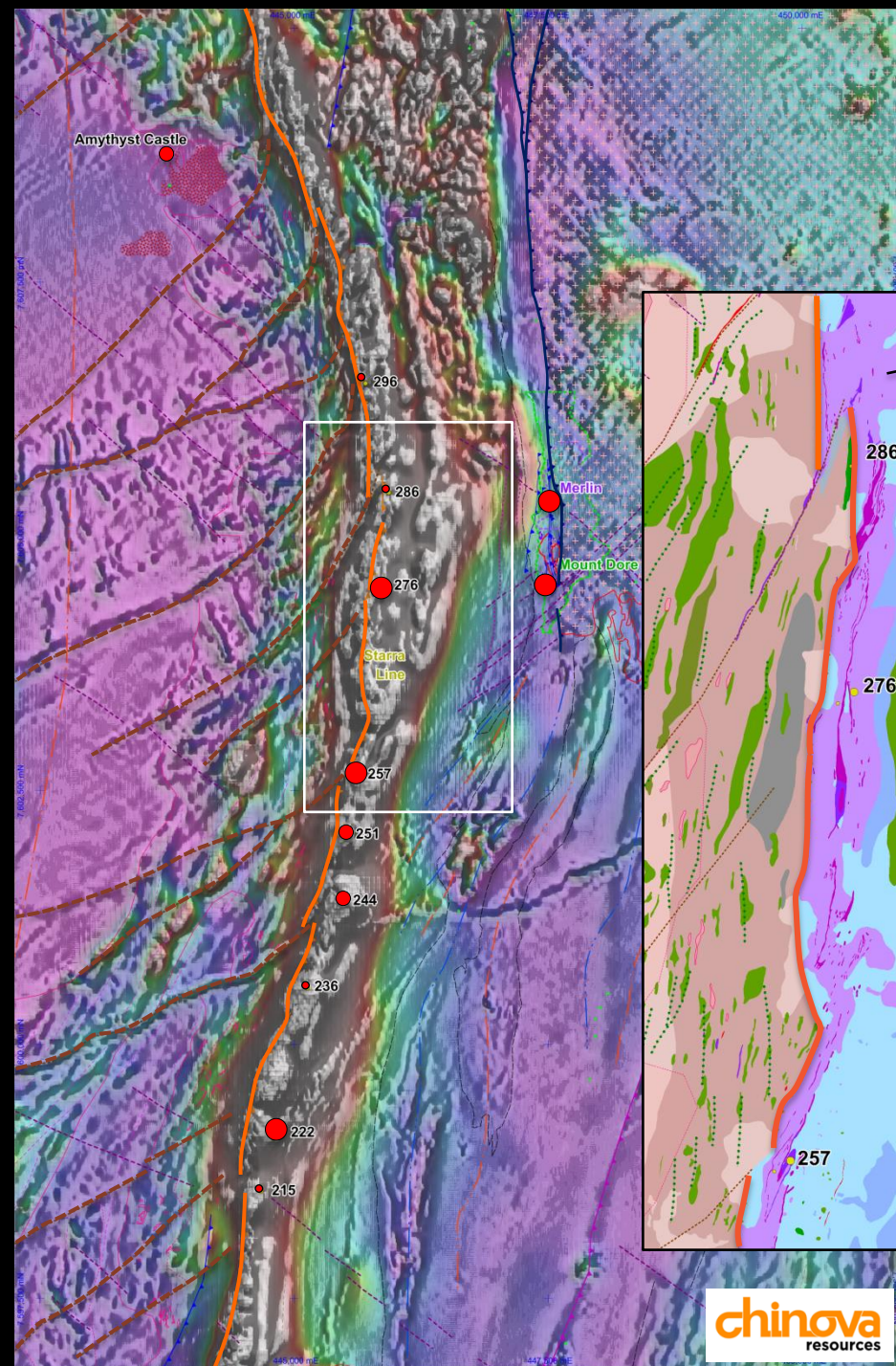
NOT massive Magnetite Iron Formation (MIF) ...

... large volume of **chl-mte schist**

containing steeply-plunging, remnant D1
ribbons & rootless folds of MIF & HIF

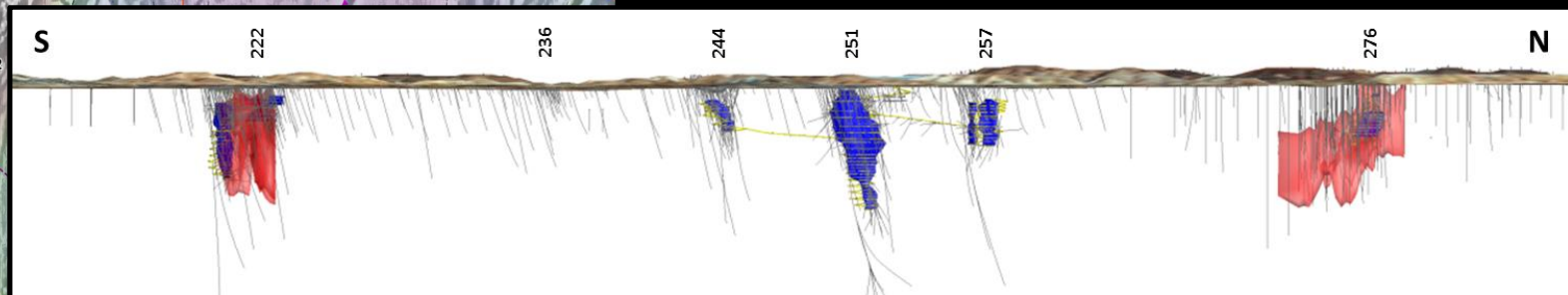
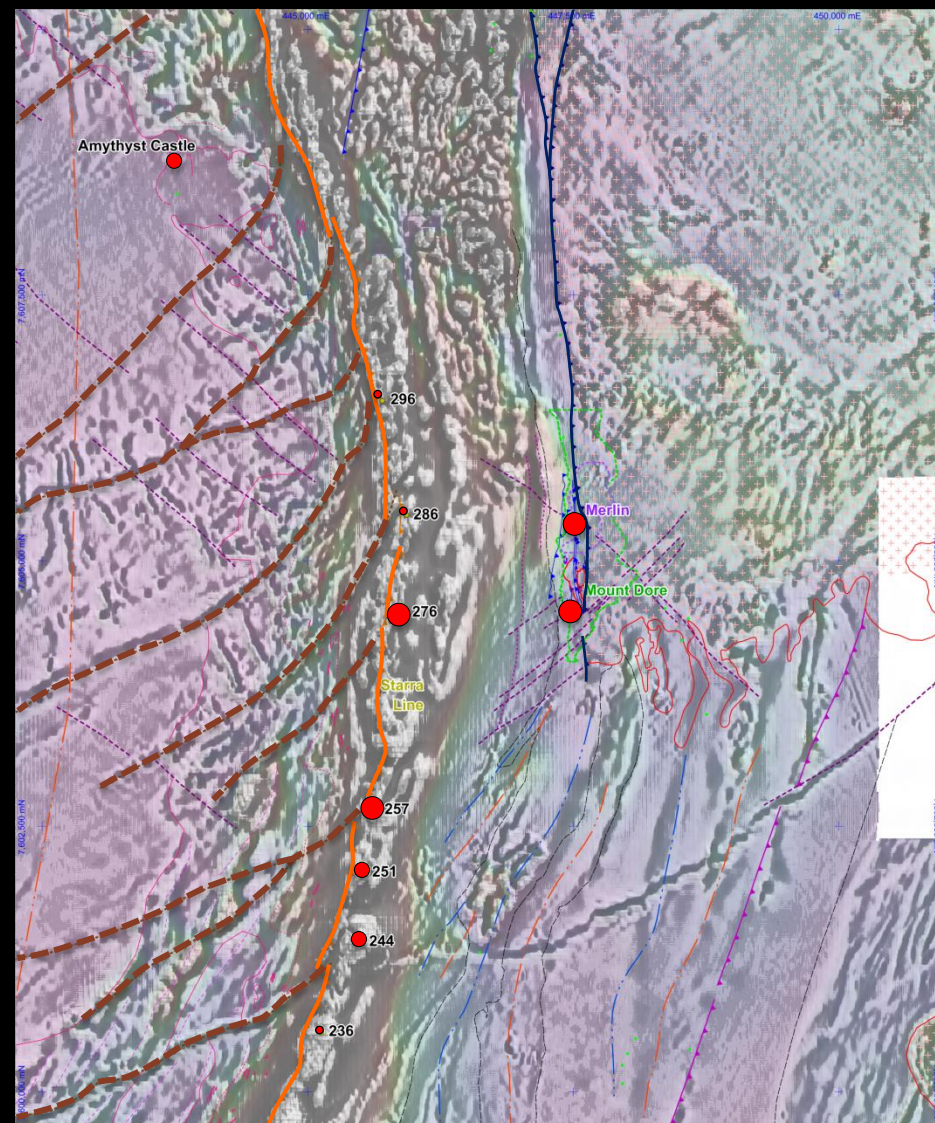
... significantly more
massive HIF *cf* MIF

**Very important for the
availability of BRITTLE hosts
during D4 re-activation**



Starra Mineralisation Model

D4 sinistral transpressive re-activation of the *Starra Shear*



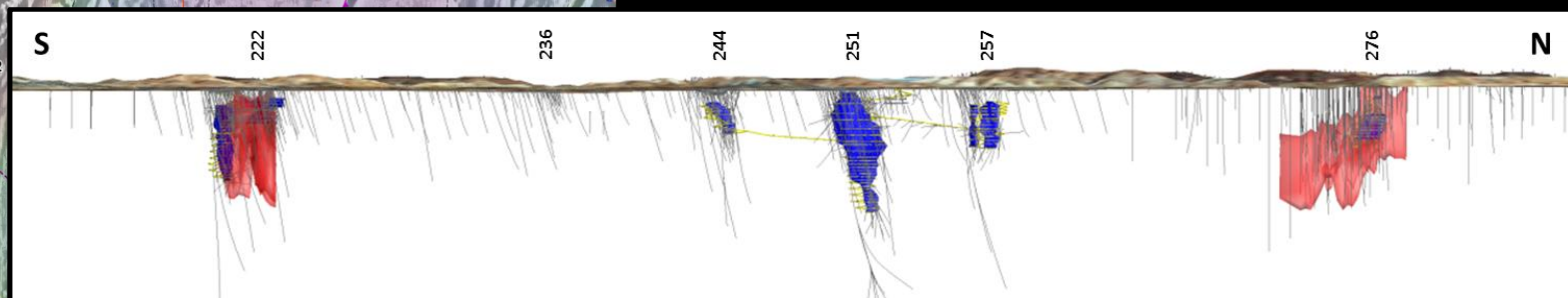
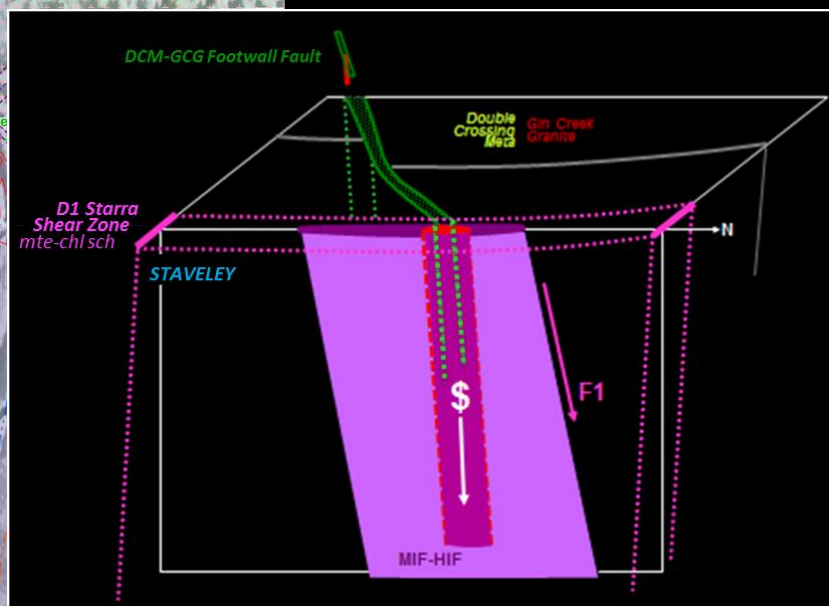
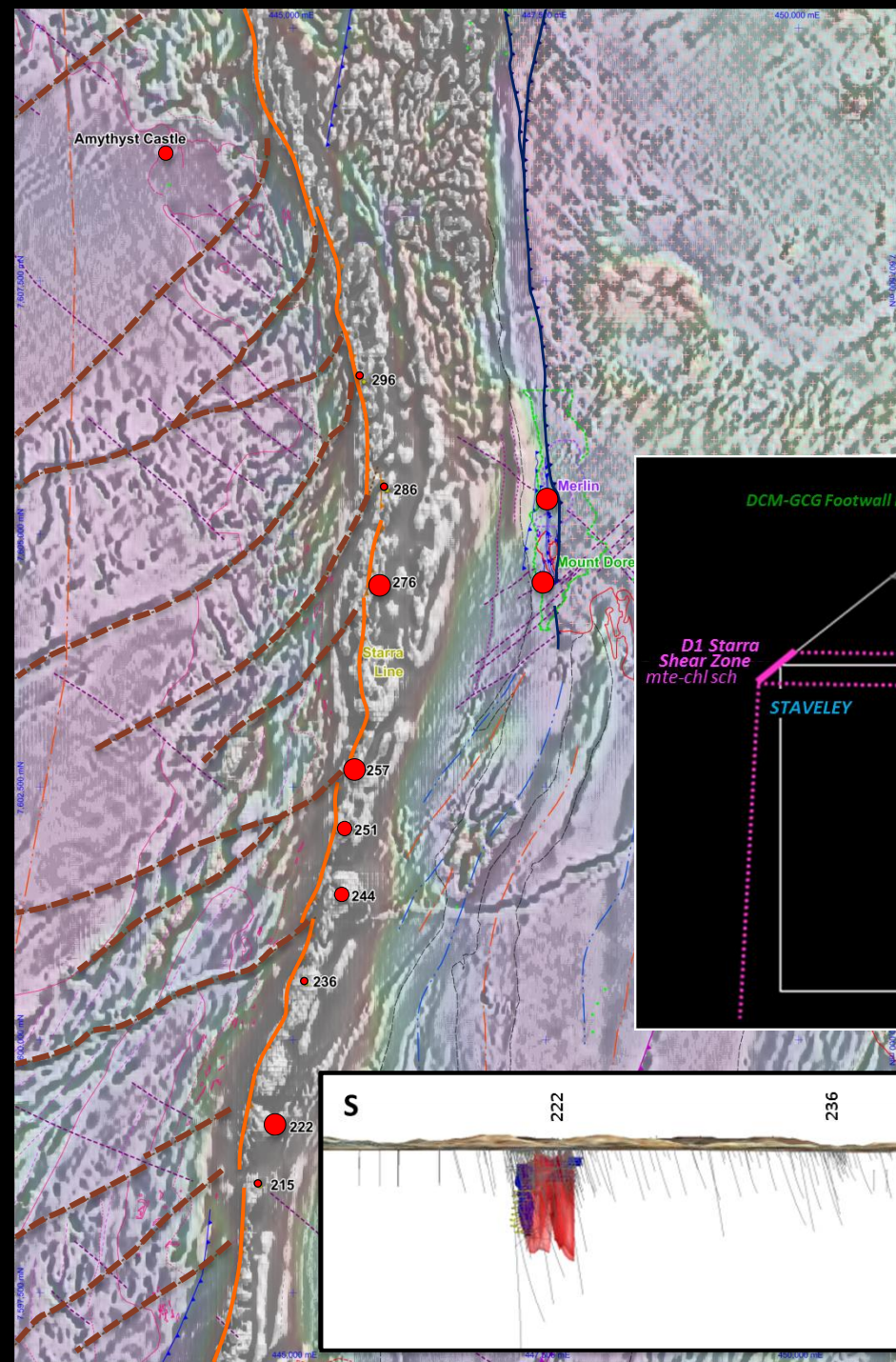
Starra Mineralisation Model

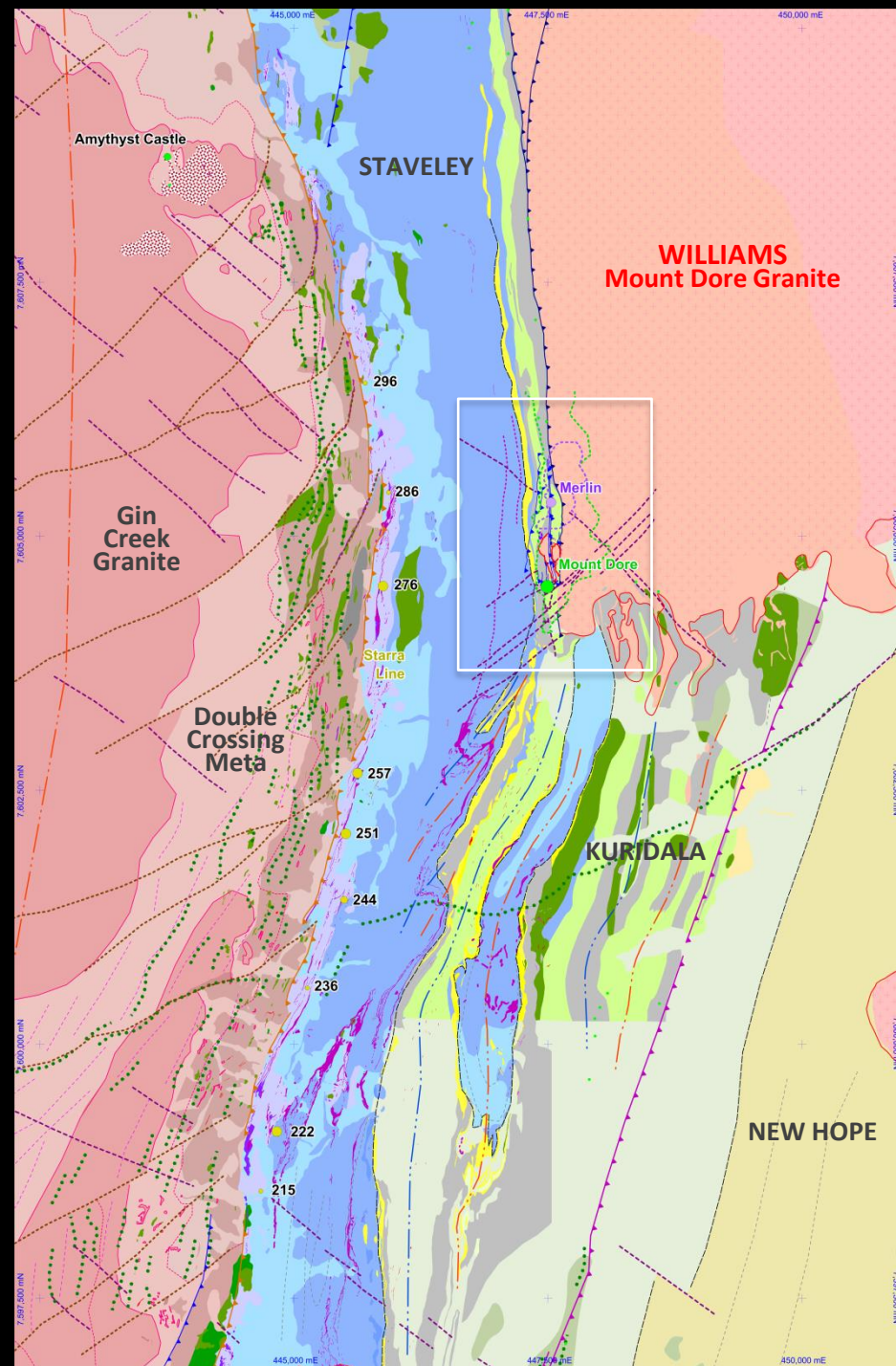
D4 sinistral transpressive re-activation of the *Starra Shear*

FOCUS requires the coincidence of (1) a remnant BRITTLE ribbon of IF with (2) footwall Fault that contributes to the focused BRITTLE deformation ... **Permeability > Cu-Au**

Large volume of **chl-mte schist** accommodates the D4 re-activation by slip on existing fabrics ... NO Permeability

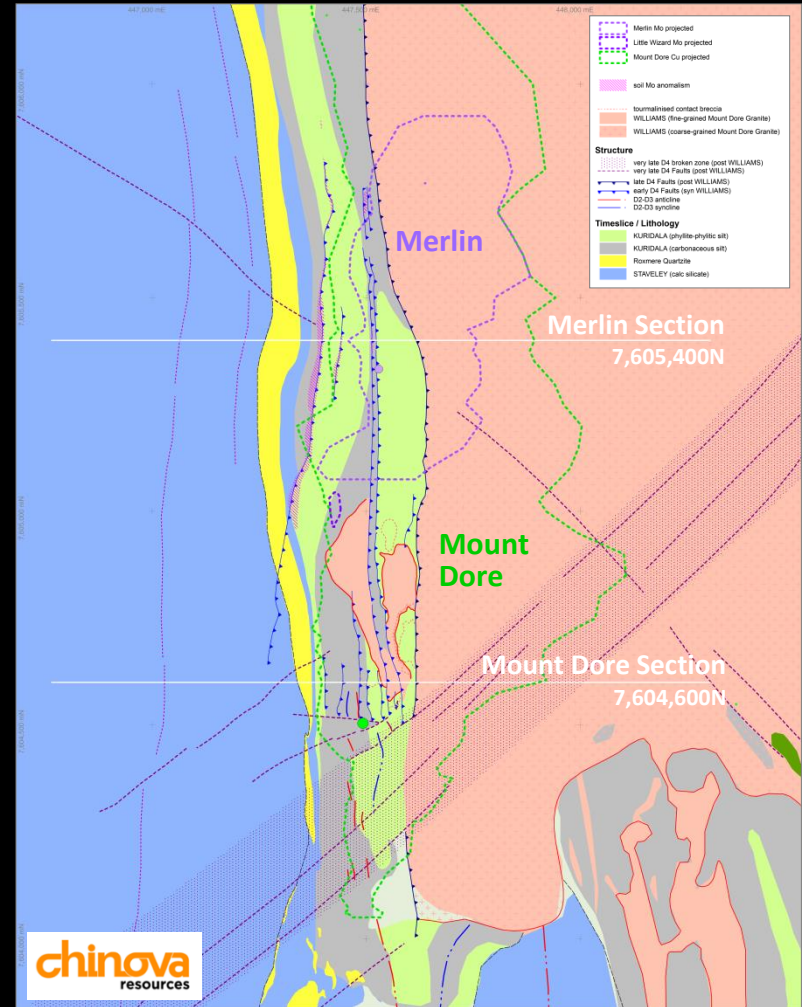
Orebody plunge reflects intersection of the FW Fault with the Starra Shear NOT the plunge of the rotated D1 ribbons & folds of IF





Merlin-Mount Dore

5K-10K Leishman Geology (1970s-1980s)
 MCH Mapping & Logging (2011-2012)
 DMQ Mag Interpretation (2016)



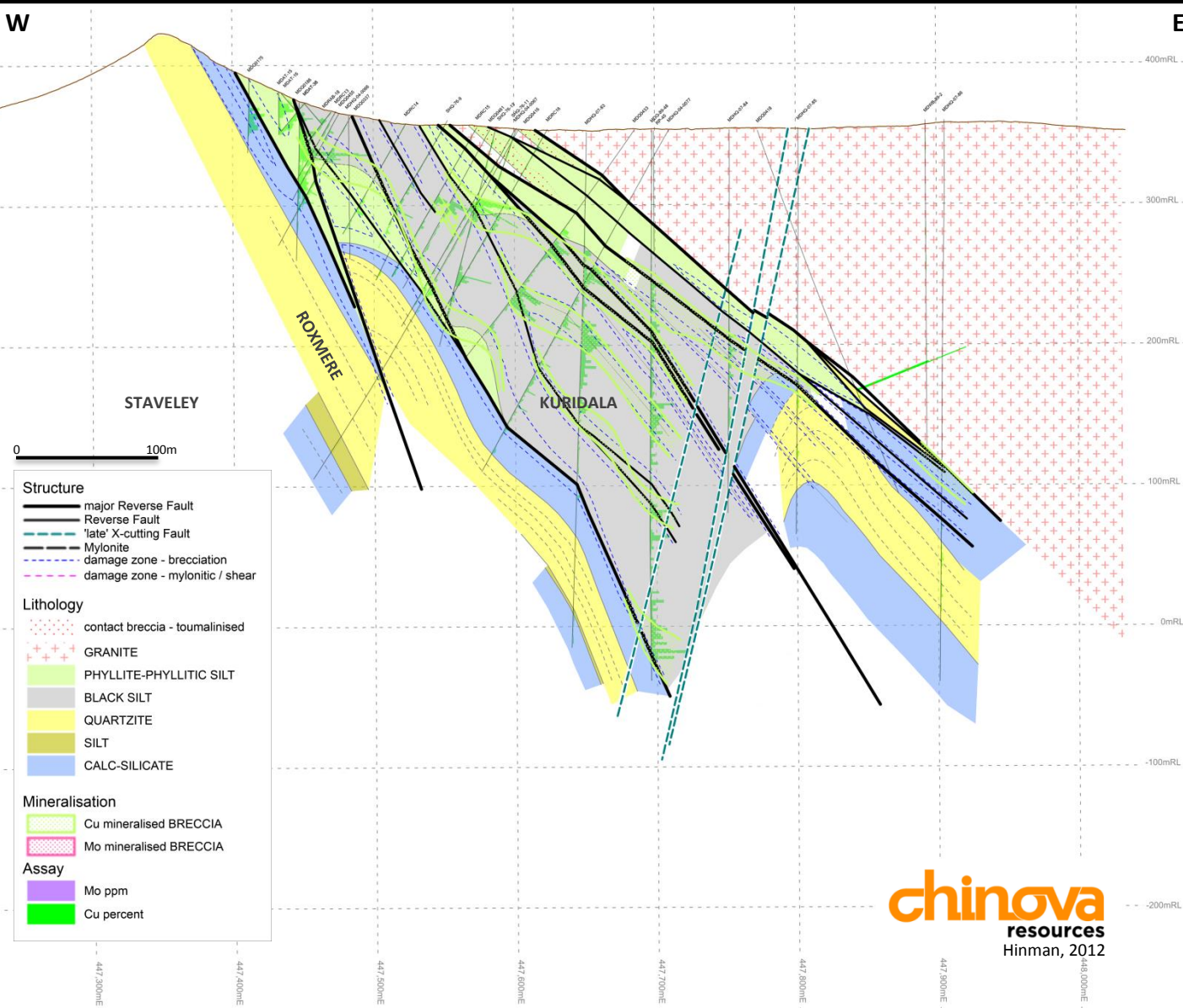
small & subtle, D4 Faults
ONLY mappable at 1:500

... **NO** regional structures



Mt Dore - Cross Section

7,604,600N

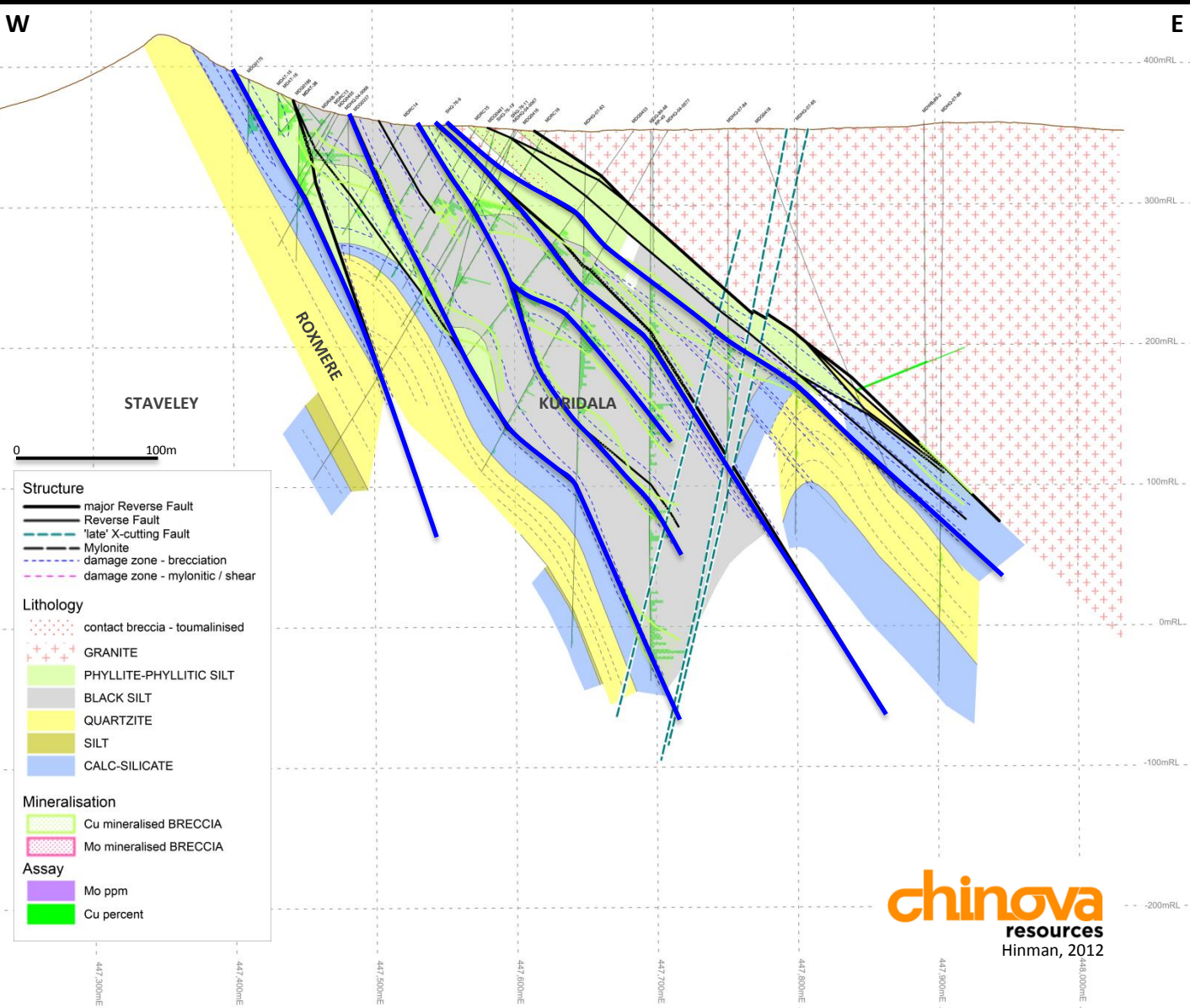


Gradational stratigraphy:
STAVELEY-ROXMERE-(S)-KURIDALA
KURIDALA: carb silt dominant



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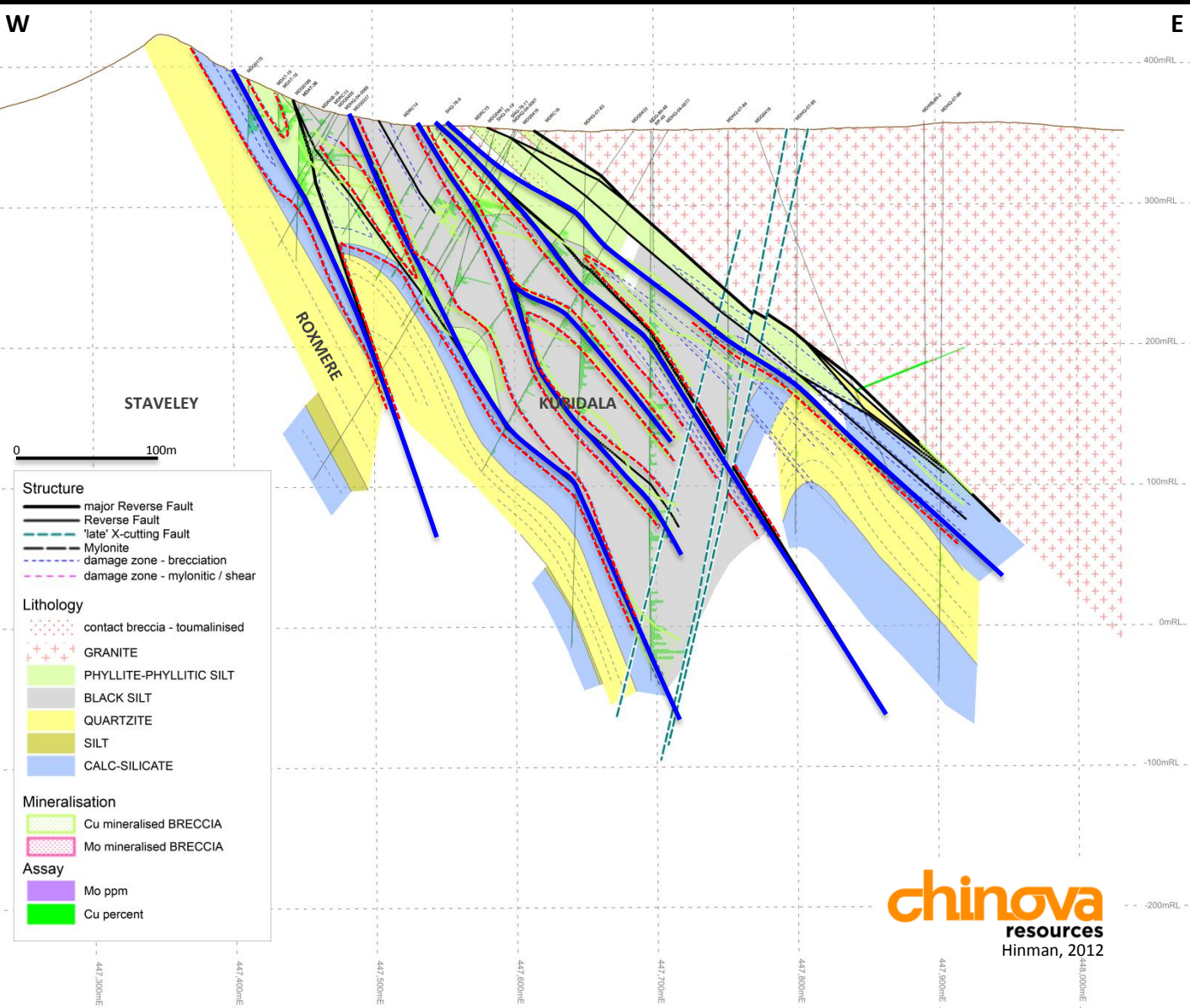
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D4 Faulting:
complex, curvilinear,
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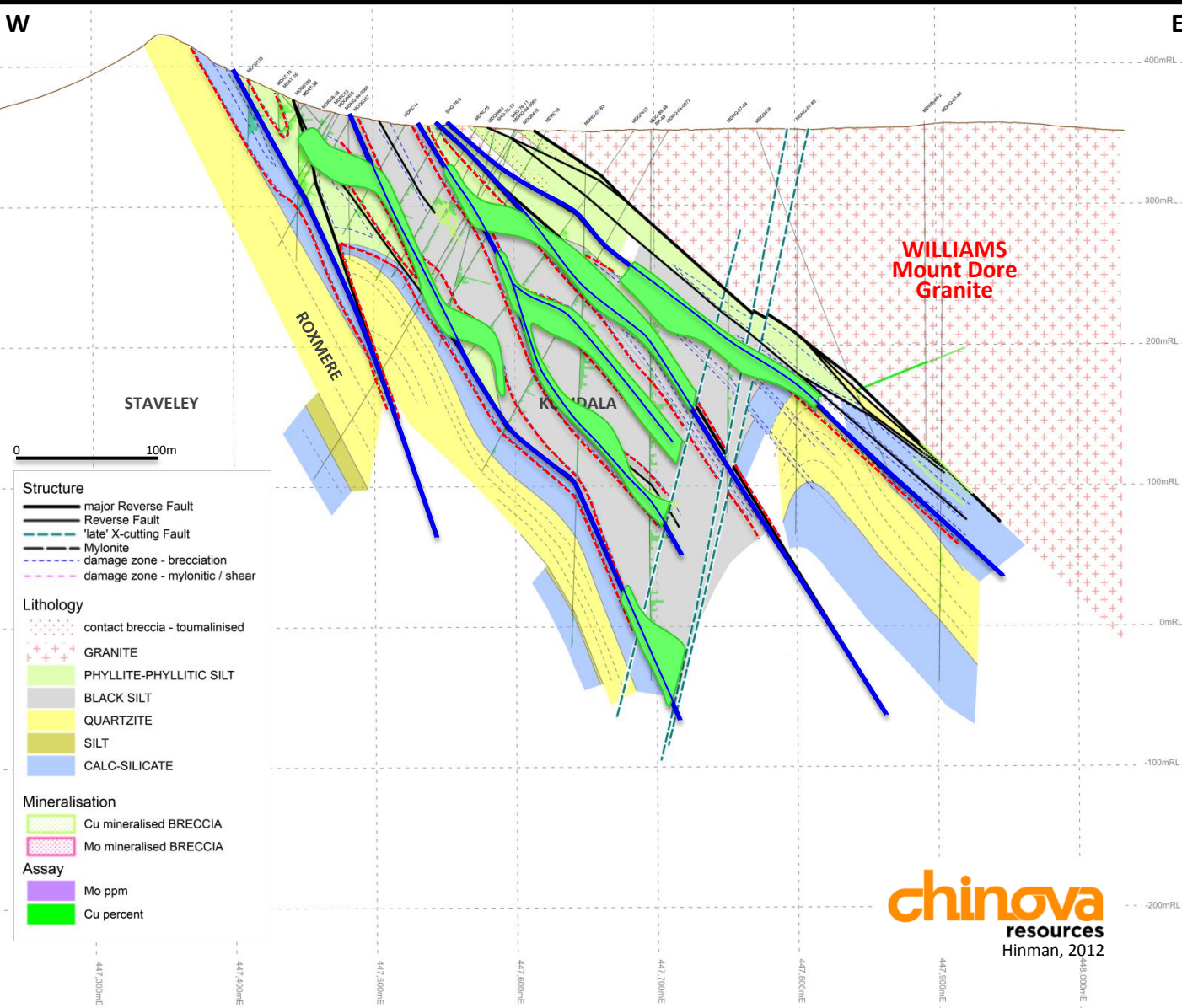
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**BRITTLE, fracture & breccia
 Damage Zones ...**



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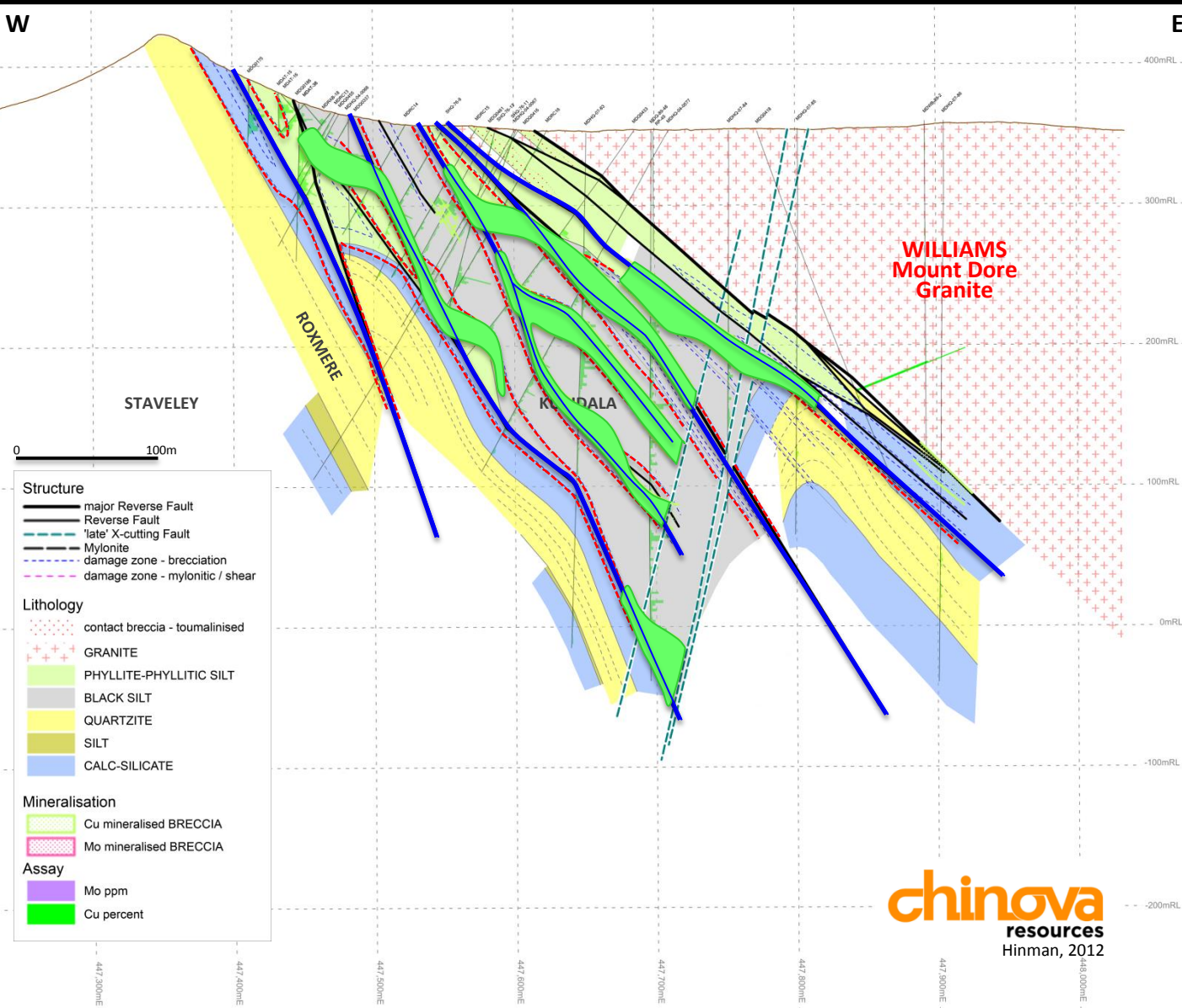
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**BRITTLE, fracture & breccia
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 ... in carbonaceous silts
 & along reactivated contacts
 .. host **Cu-Au minz**



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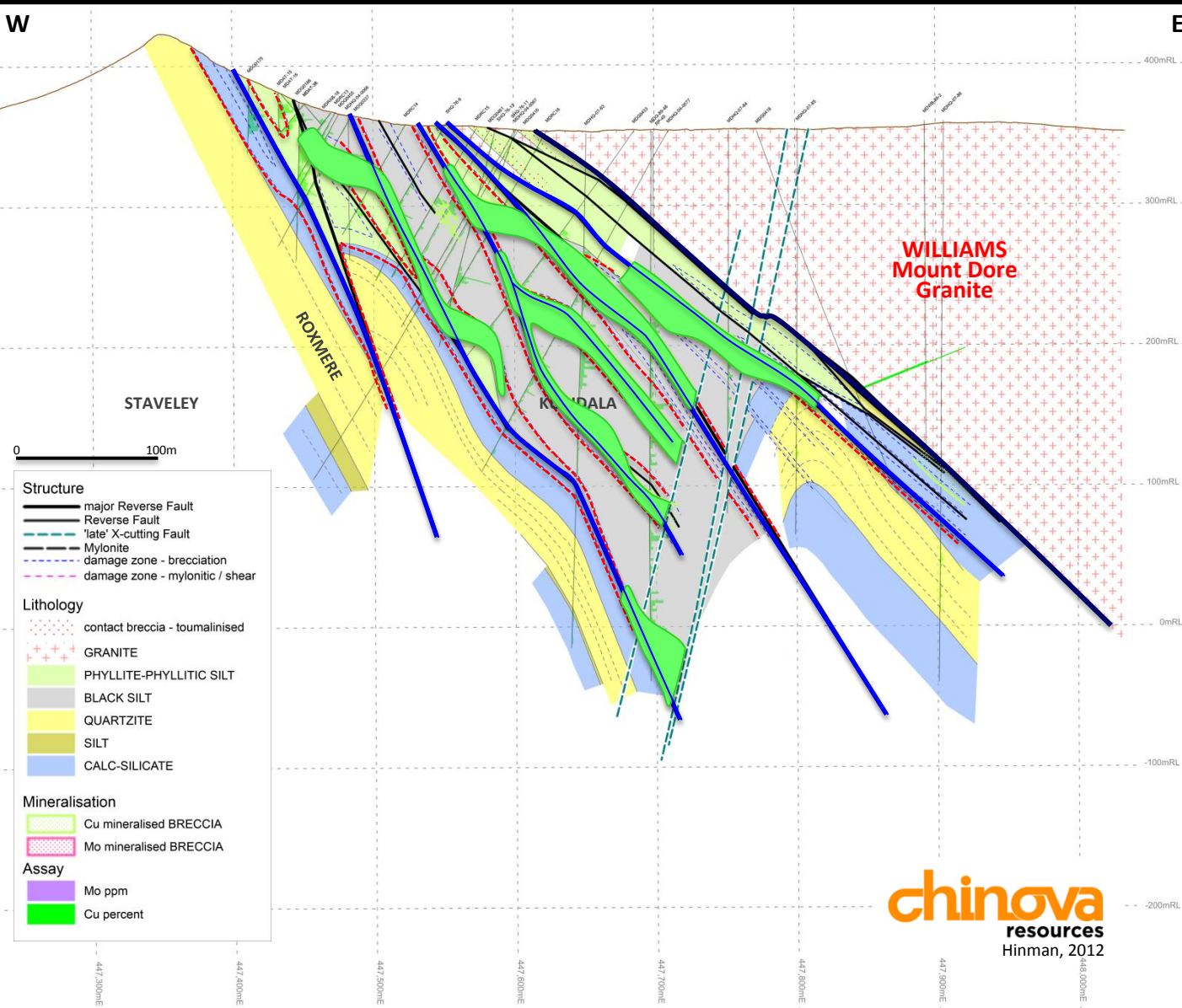
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**D4 Faults ... small throws!
 NOT Regional Structures**



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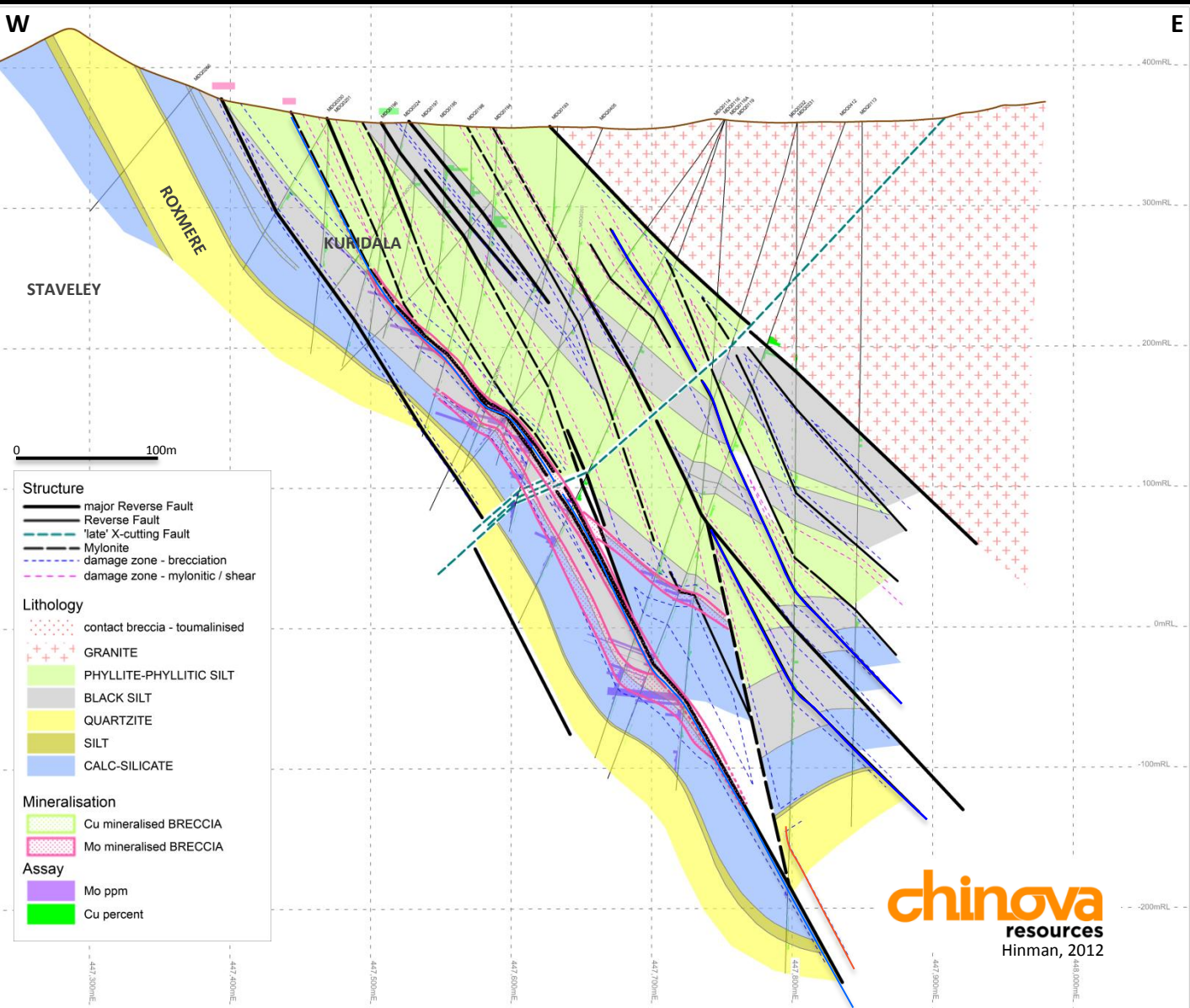
**Granite Reverse Fault
 highly planar, post-mineral,
 significant throw ..**

.. Late D4 Fault



Merlin - Cross Section

7,605,400N



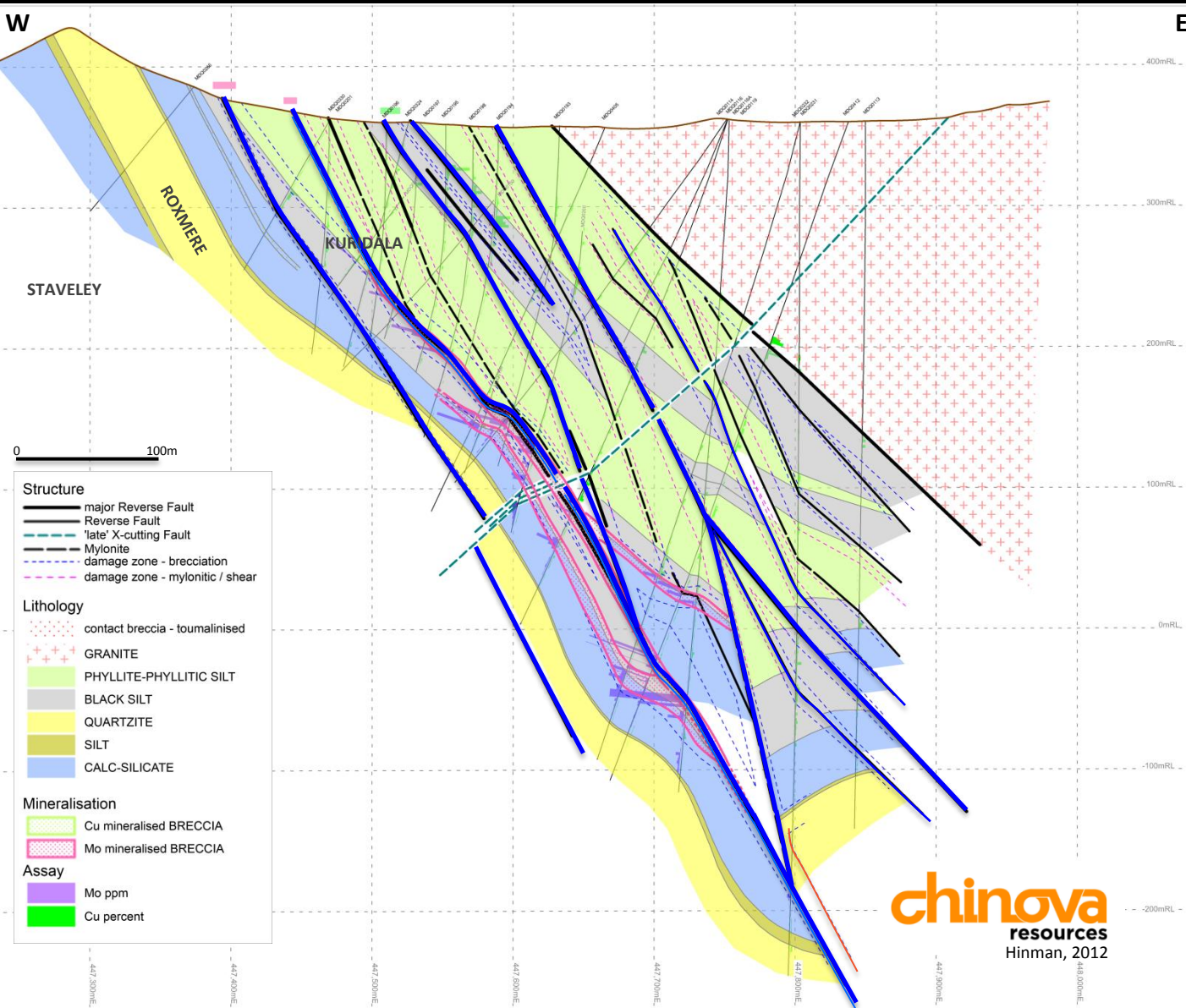
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chinova
 resources
 Hinman, 2012



Merlin - Cross Section

7,605,400N



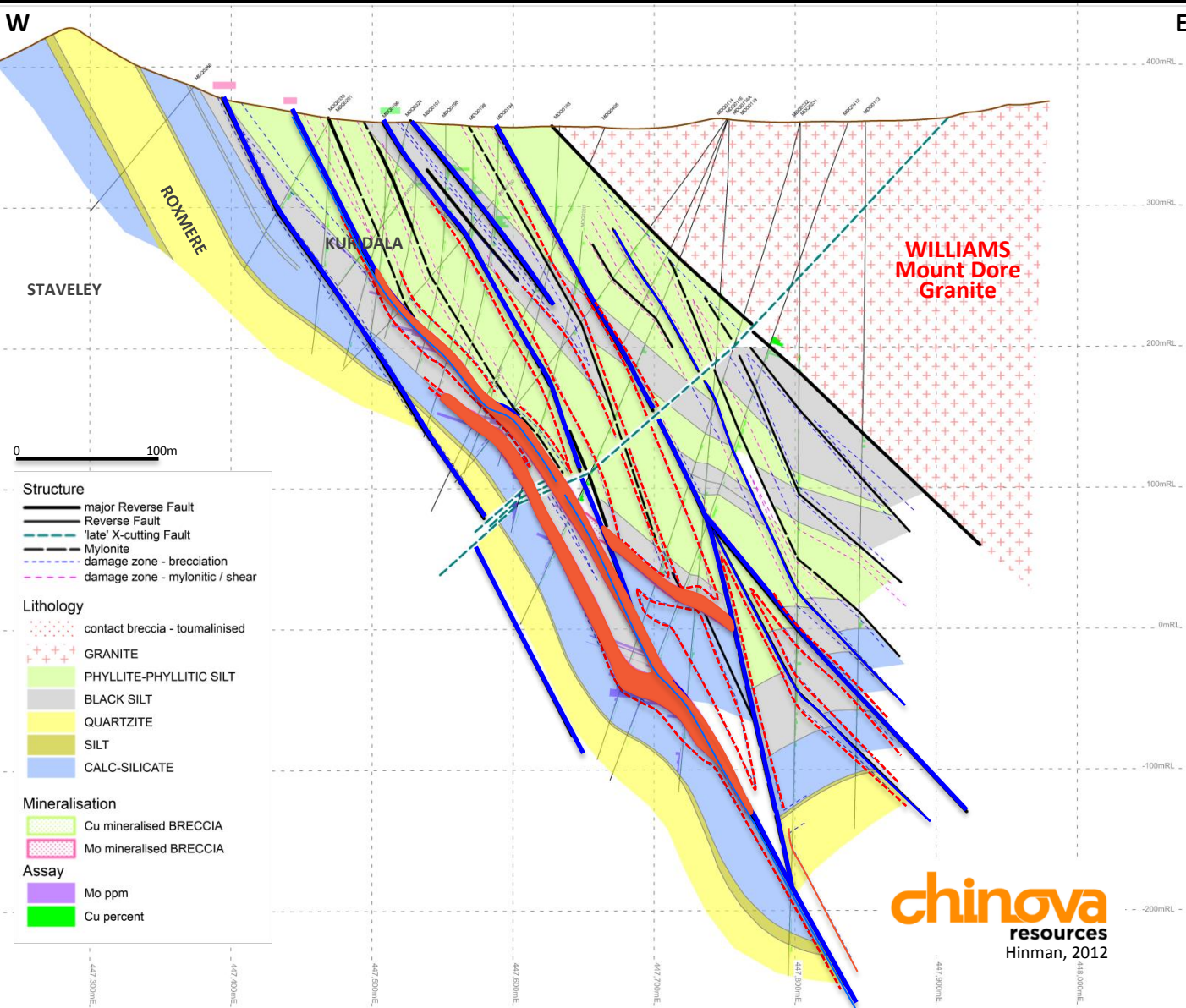
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D4 Faulting: complex, curvilinear, anastomosing
brittle in calc-silicate, carb silt
ductile (mylonitic) in phyllite



Merlin - Cross Section

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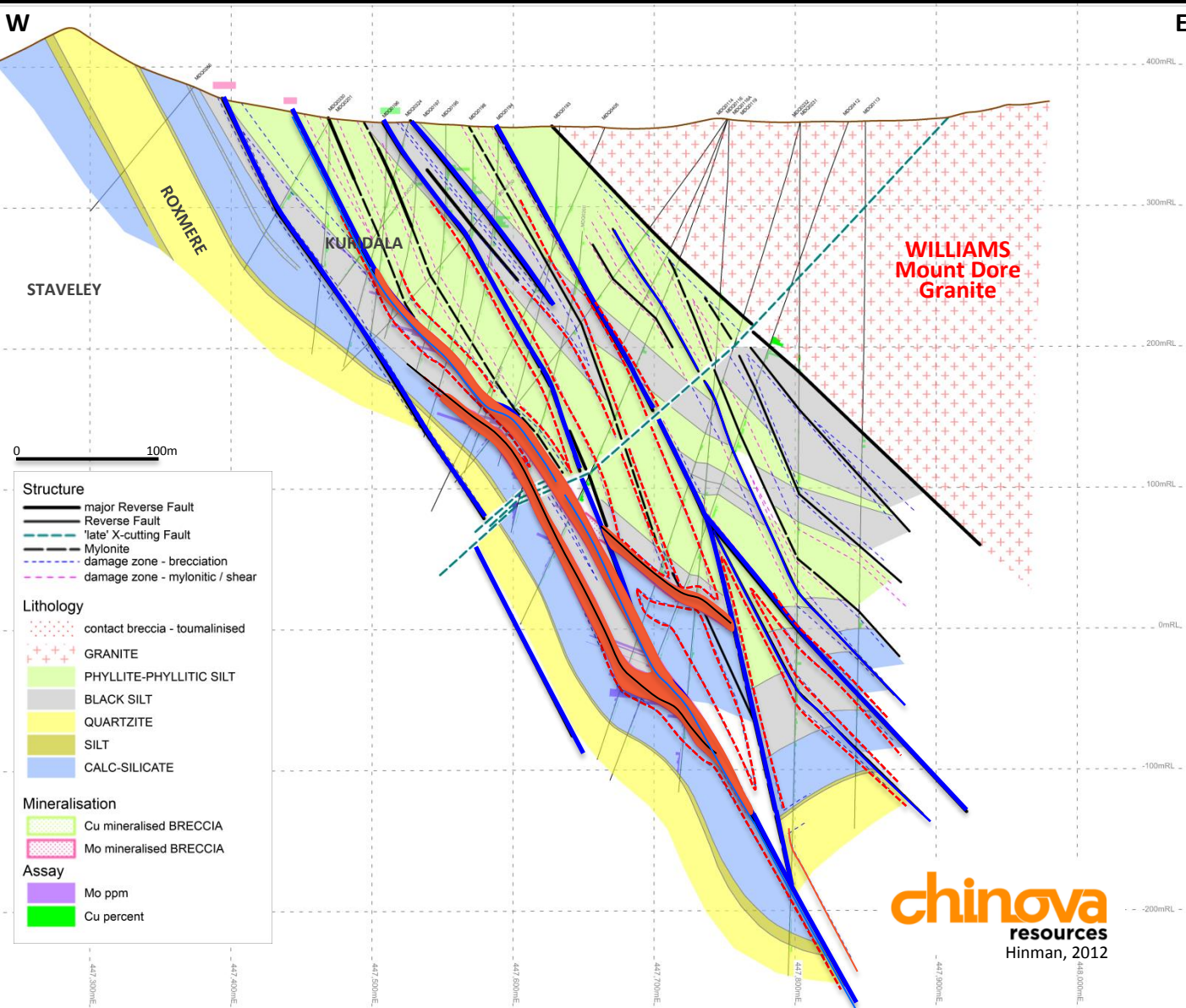
BRITTLE, fracture & breccia zones host **Mo minz** ...

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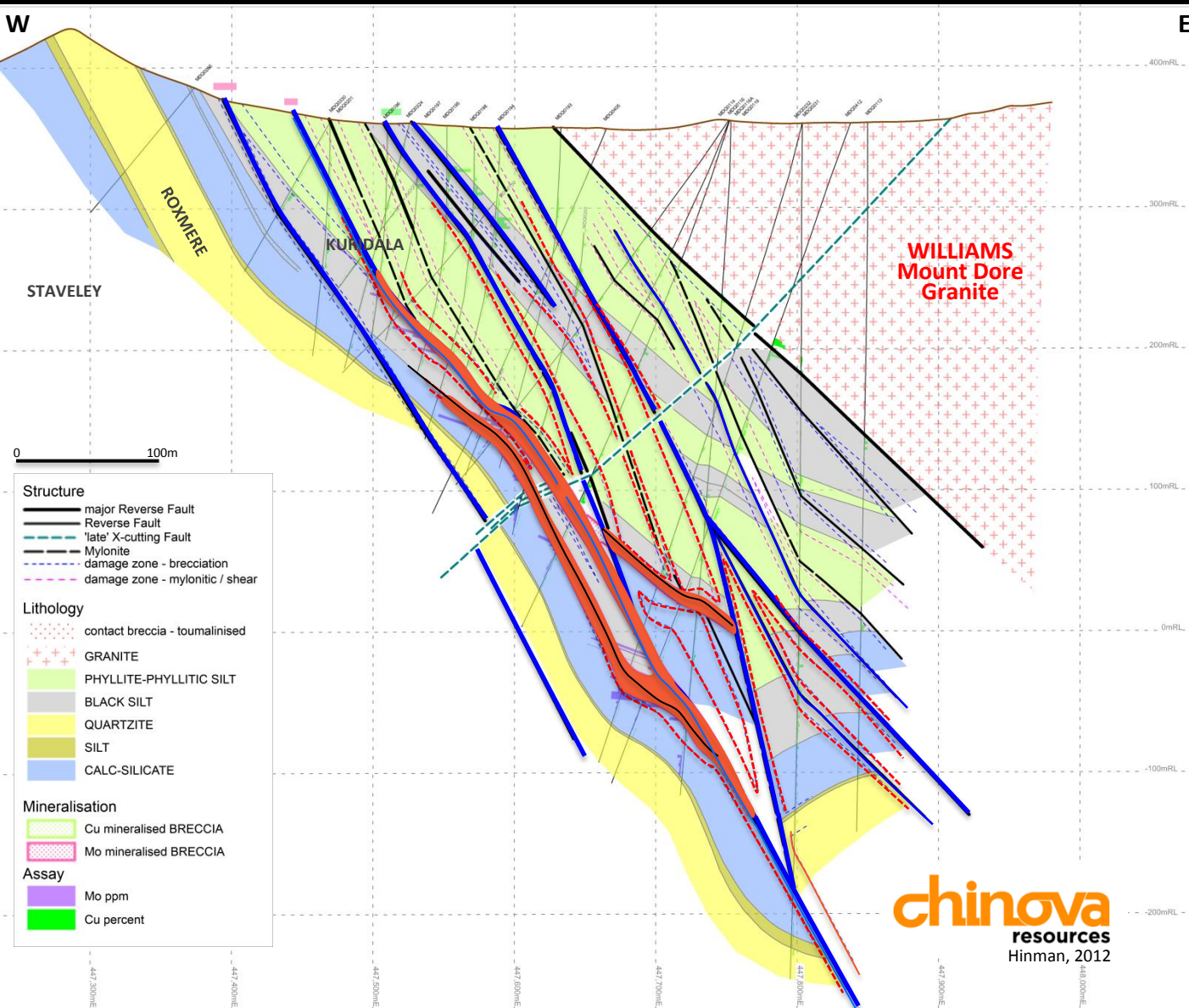
.. along reverse fault where calc-silicate & carbonaceous silt are brecciated, and .. where normal calc-silicate /carb silt contact is brecciated in FW & HW of reverse fault

chinova
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 Hinman, 2012



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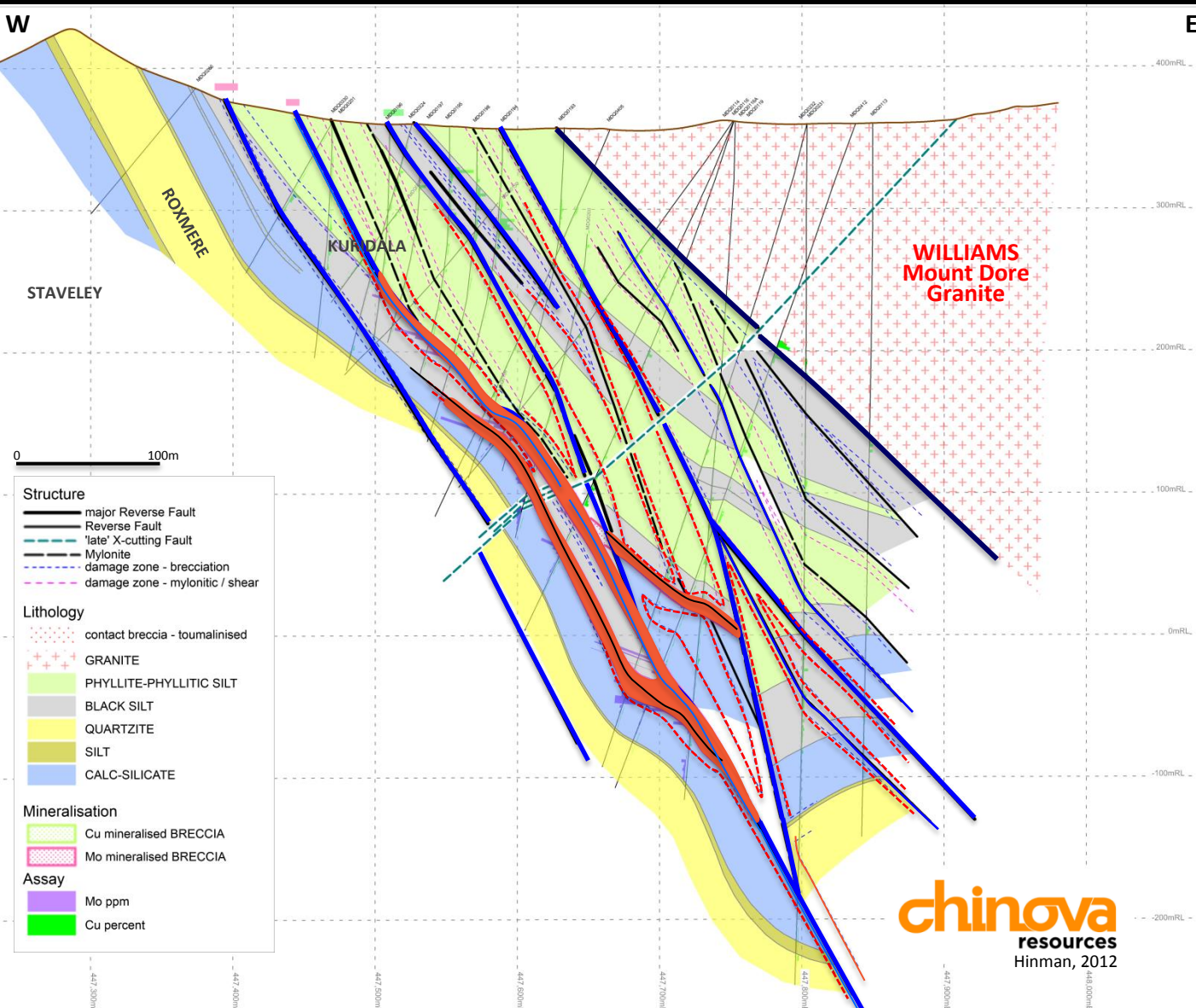
D4 Faults ... small throws!
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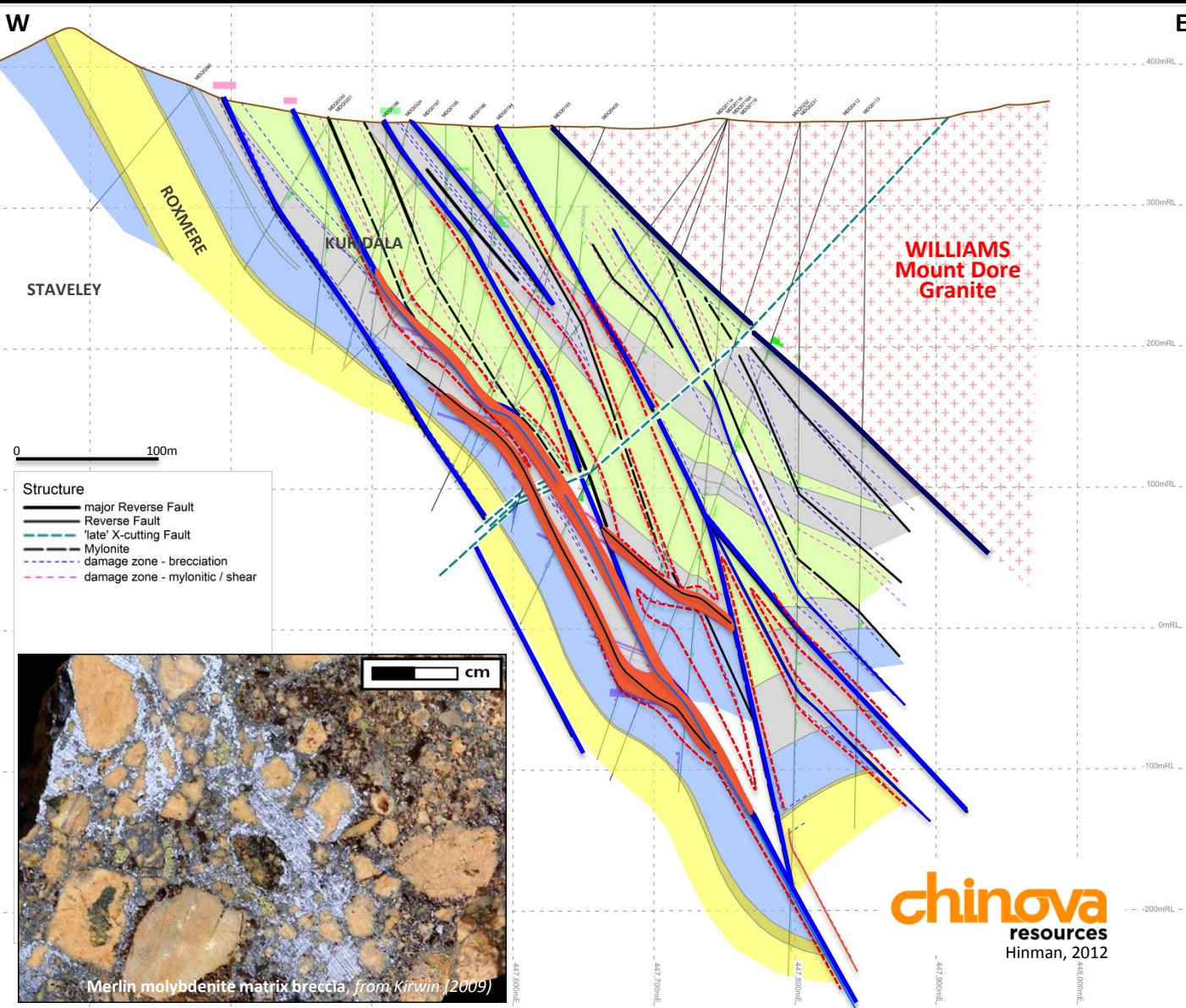
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 > Mo-matrix breccias ...

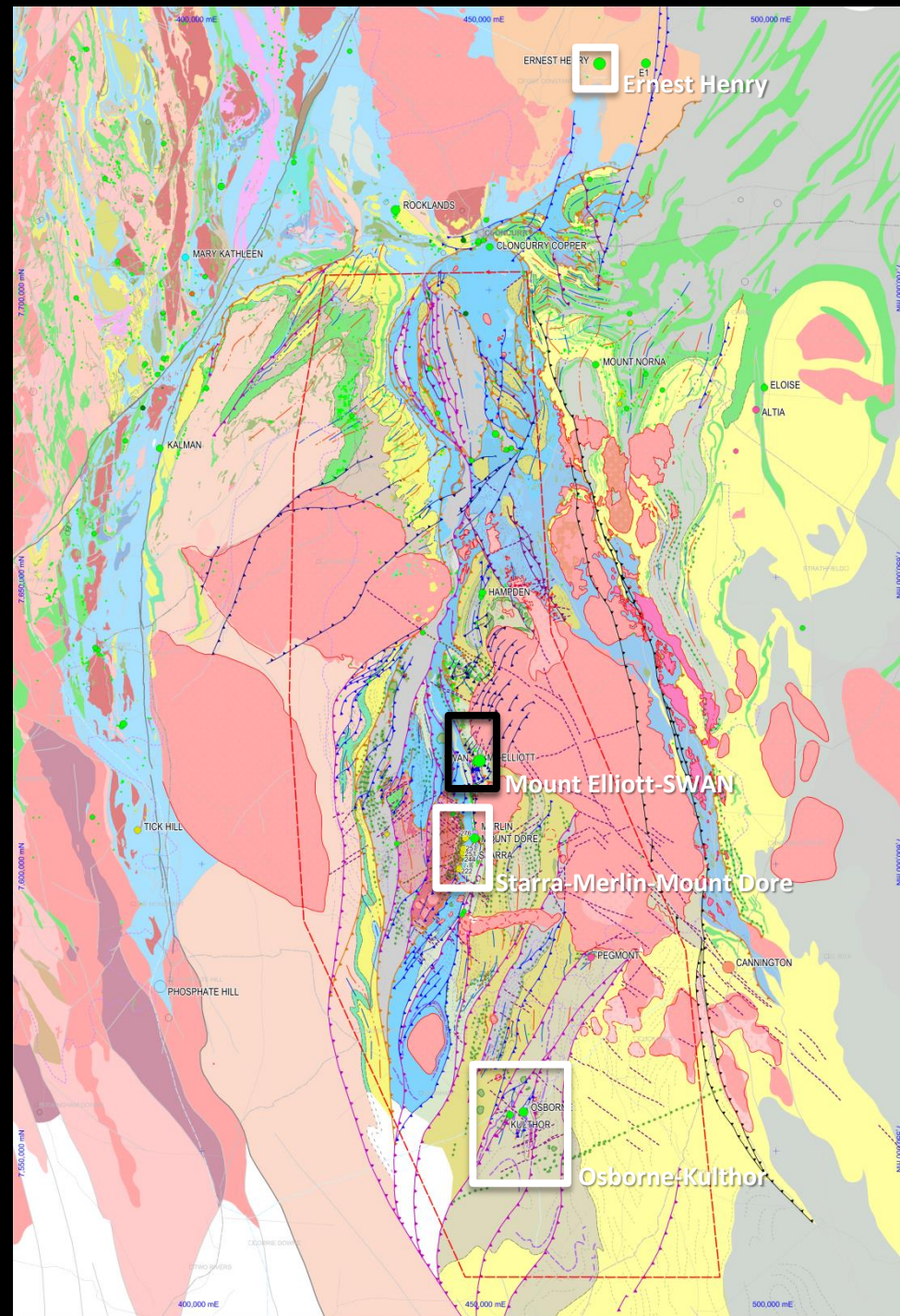


Deposit Controls: District to Local

Four areas

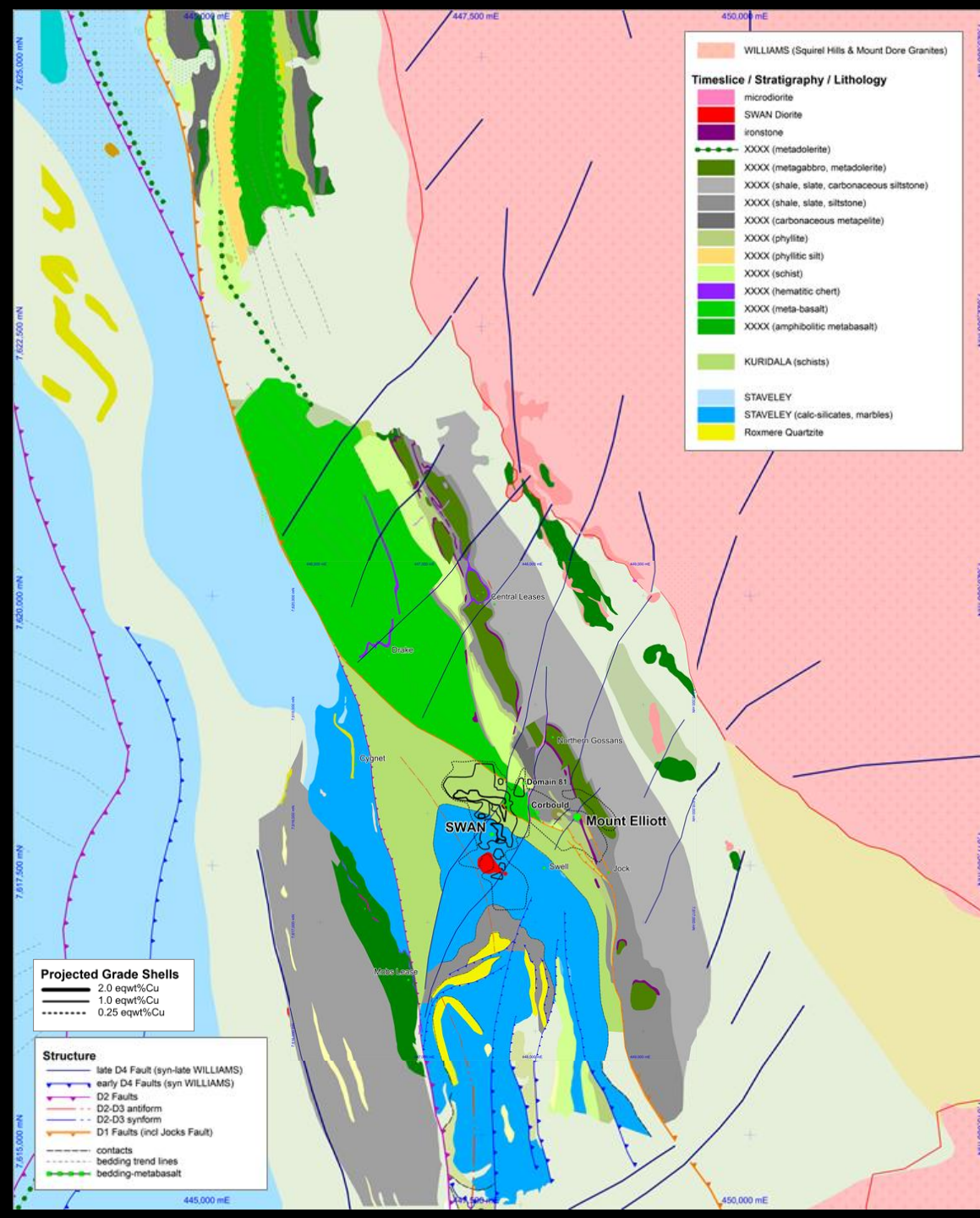
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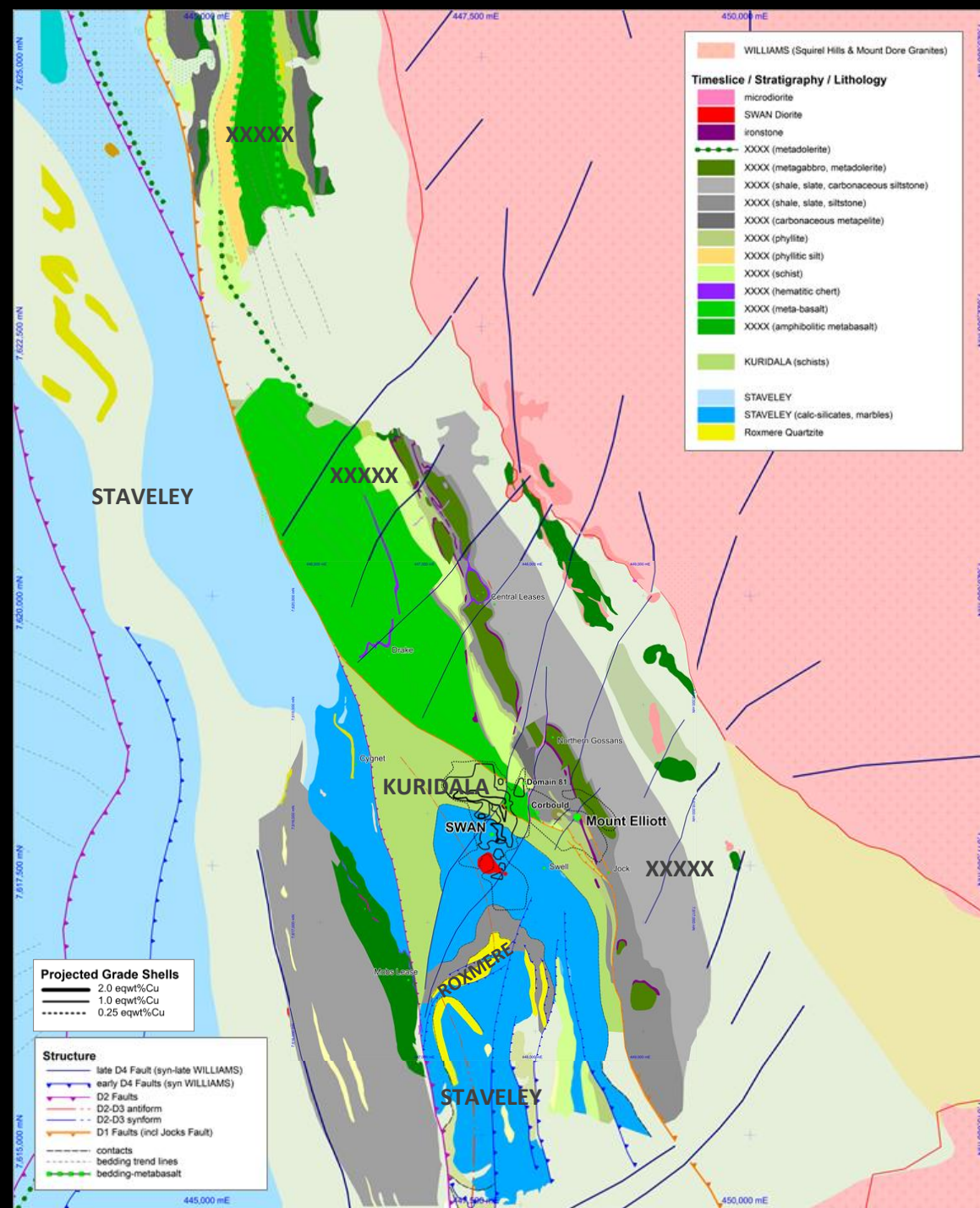
NEXT to Mount Elliott-SWAN



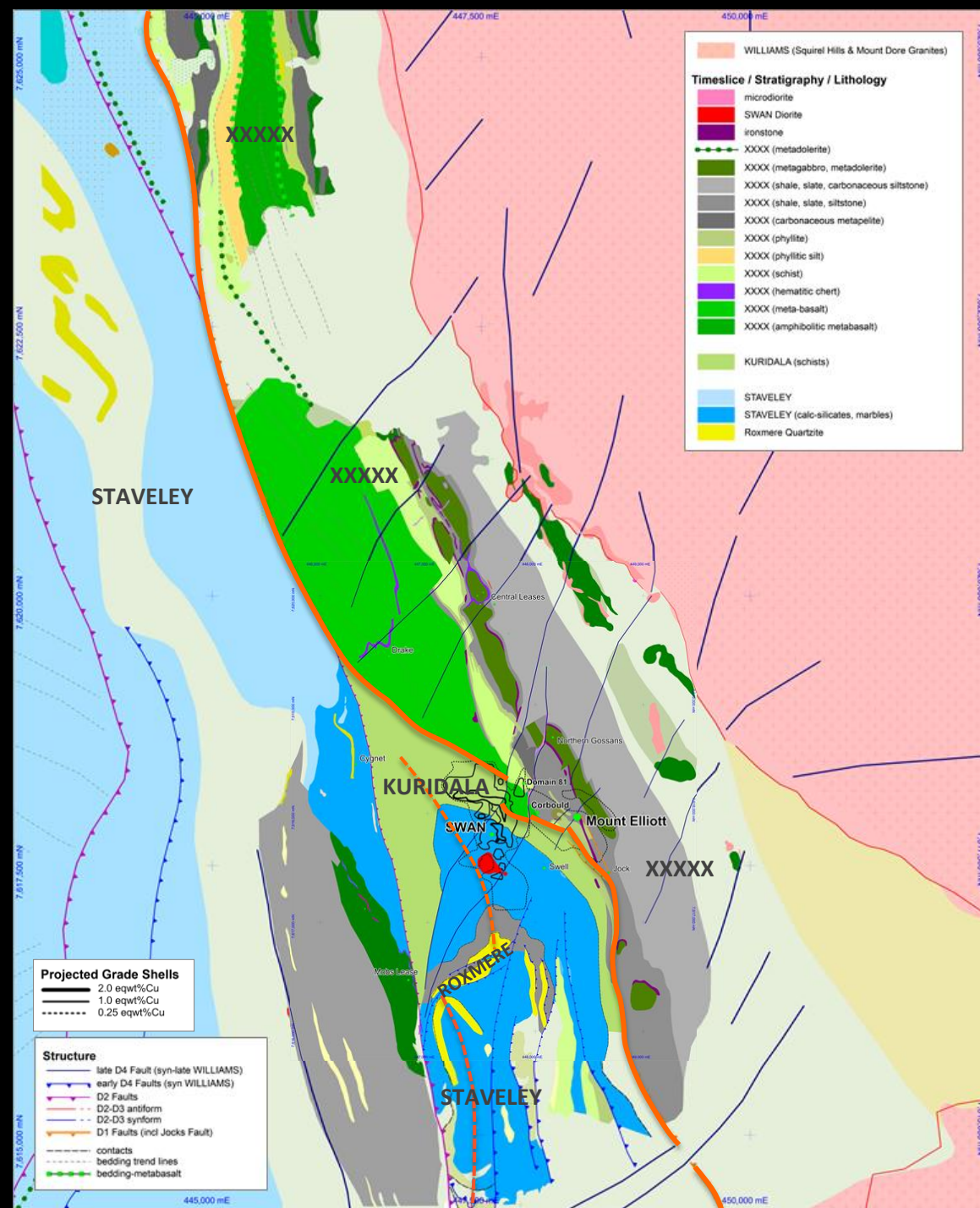
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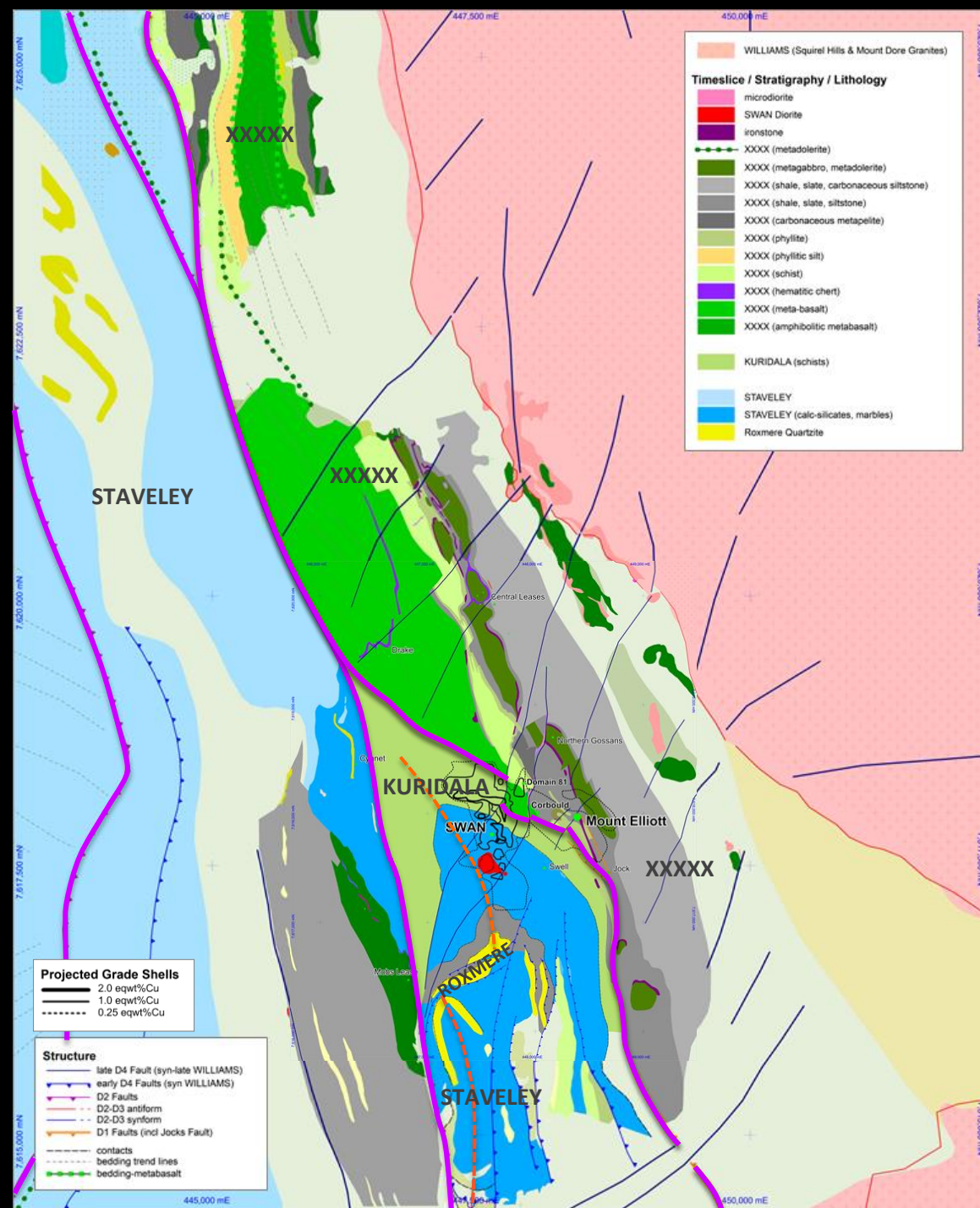
STAVELEY
ROXMERE (yellow)
KURIDALA
XXXXX package of metabasalts, carbonaceous metaseds, phyllites & significant metadolerite
 potentially **TOOLE CREEK** ??



**STAVELEY
ROXMERE (yellow)
KURIDALA**

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possible subhorizontal EW D1 fold of STAVELEY-KURIDALA in FW of flat D1 Thrust; **XXXXX truncations**

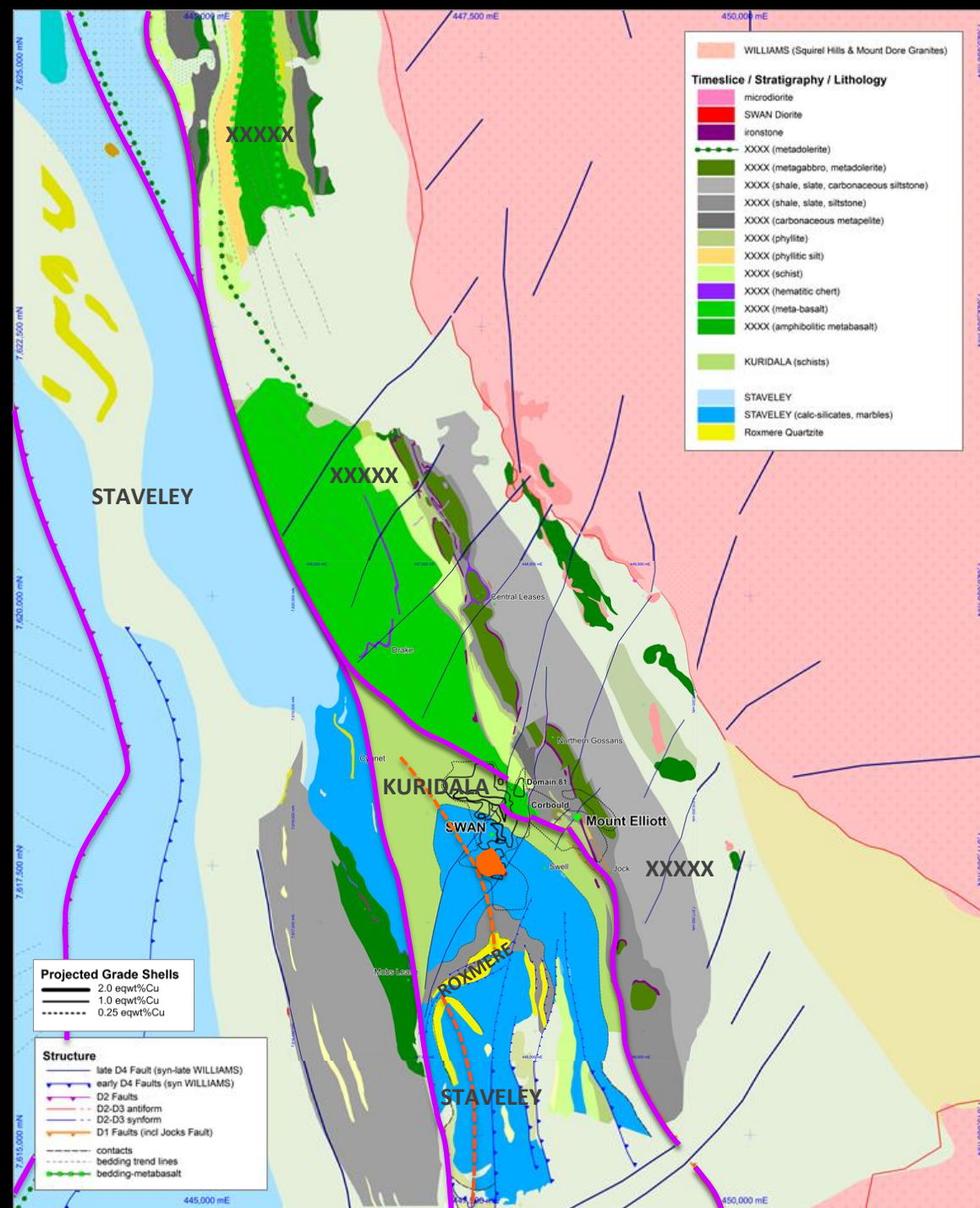


**STAVELEY
ROXMERE (yellow)
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EW D2-shortening Folding & Reverse Faulting
Rotation of D1 Thrust and D1 Fold to steep orientations;
New D2 Faults & re-activation of D1 Structures



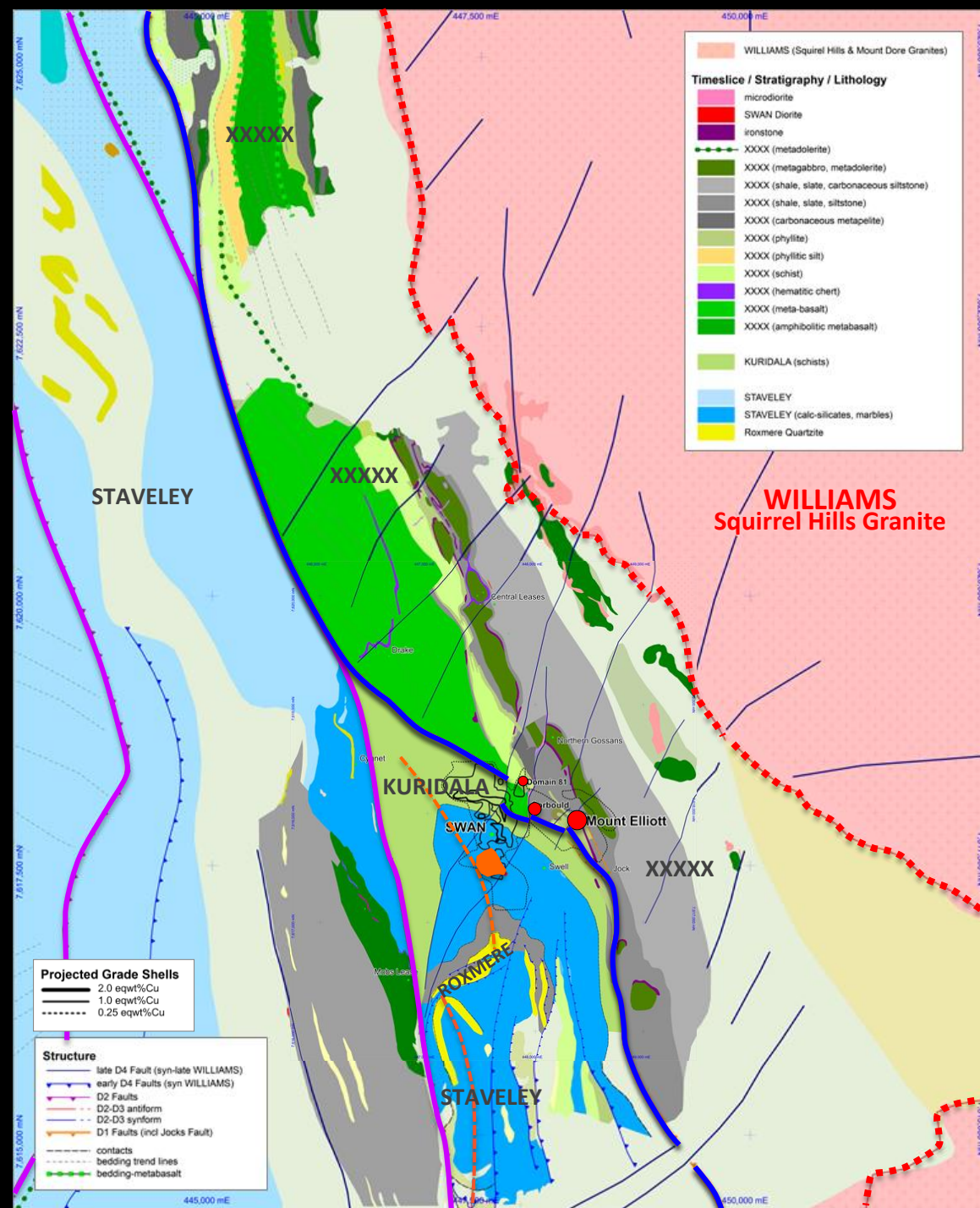
**STAVELEY
ROXMERE (yellow)
KURIDALA**

XXXXX package of metabasalts, carbonaceous metaseds, phyllites & significant metadolerite
.... potentially **TOOLE CREEK ??**

NNW-directed D1 overthrust of XXXXX over STAVELEY-KURIDALA (*Mt Elliott-Jocks Faults*)
possible subhorizontal EW D1 fold of STAVELEY-KURIDALA in FW of flat D1 Thrust; **XXXXX truncations**

EW D2-shortening Folding & Reverse Faulting
Rotation of D1 Thrust and D1 Fold to steep orientations;
New D2 Faults & re-activation of D1 Structures

Pre-D4 Intrusion of SWAN Diorite
into upper STAVELEY; marble hornfelsing precondition



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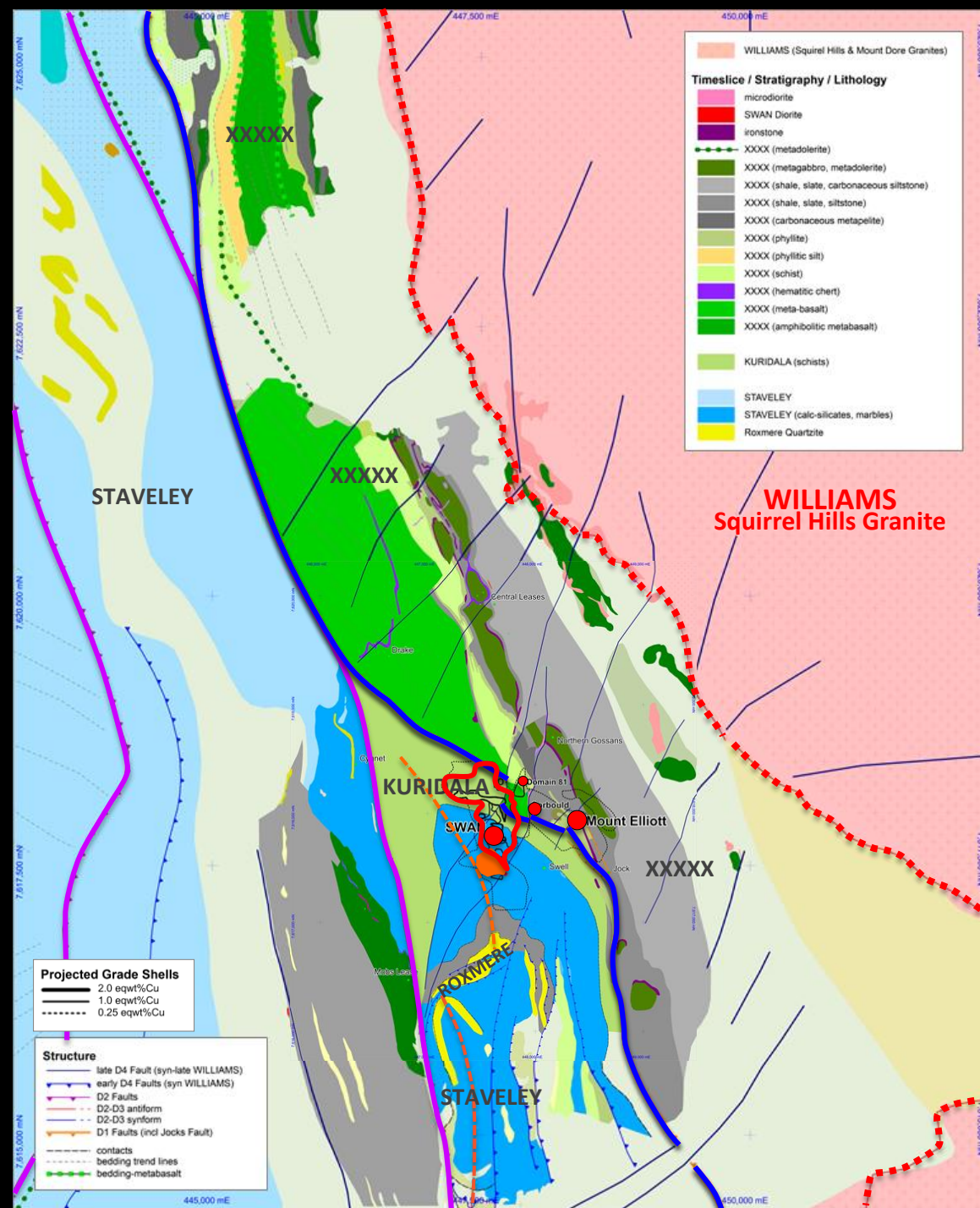
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1515Ma WILLIAMS Squirrel Hills Granite intrudes (into shallower crust)
... during NW-directed, D4 Shortening

D4 Strain Partitioning in the HW of the re-activating Mt Elliott Thrust **between solidifying SqHG & metabasalt wedge** > metadolerite boudinage, and in the HW contact of metabasalt
> **Mount Elliott-Corbould Mineralisation**



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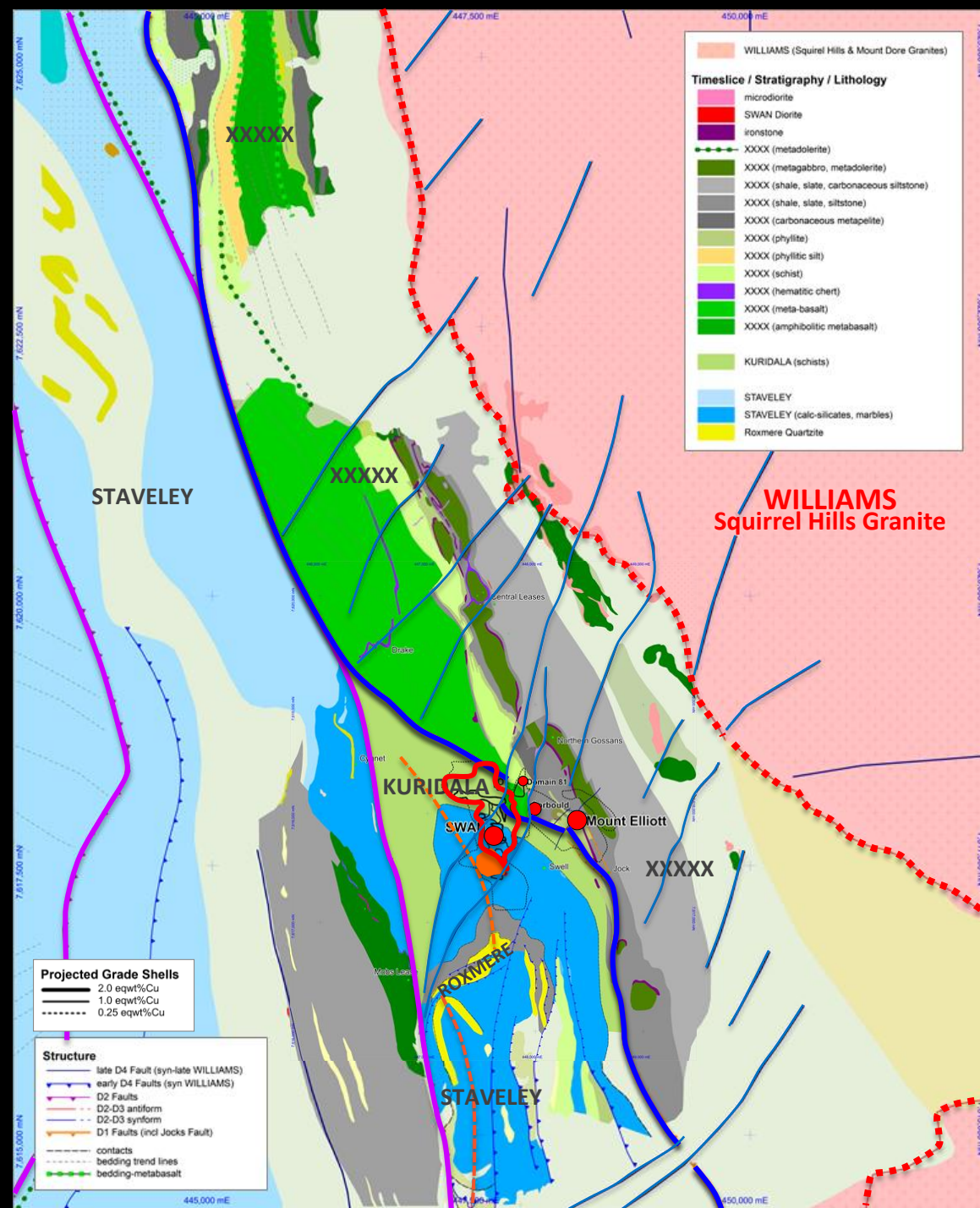
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D4 strain partitioning in the FW of the re-activating Mt Elliott Thrust **between the rigid SWAN Diorite & weak KURIDALA schists** > brecciation of **BRITTLE STAVELEY marbles & calc-silicates**
> **SWAN Minz**



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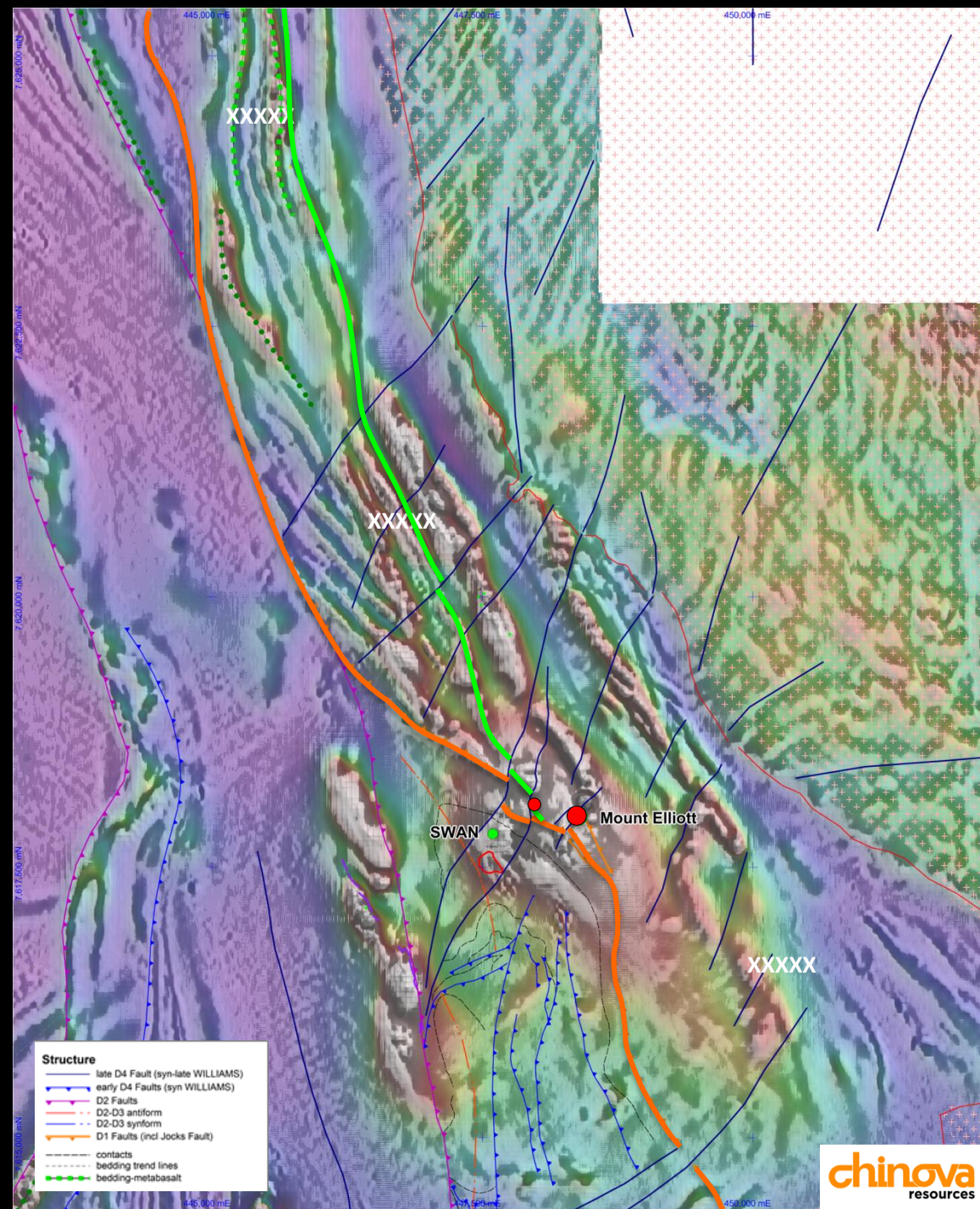
Late D4 Faults cut fully-crystallised WILLIAMS SqHG and cuts & deforms mineralisation
Domain81 mineralisation in one of these faults

Mount Elliott-SWAN

Chinova detailed vrmi-2vd over tmi-rtp

Detailed vrmi-2vd over tmi-rtp highlights ...

- Strong magnetic signature of **Mount Elliott-Corbould-SWAN**
- Truncations of the XXXXX Package against the D1 Thrust
- Location of **Mount Elliott-Coubould** at the metabasalt wedge termination
- Late D4 faulting of the **WILLIAMS Squirrel Hills** granite ... and the entire assembled & mineralised package



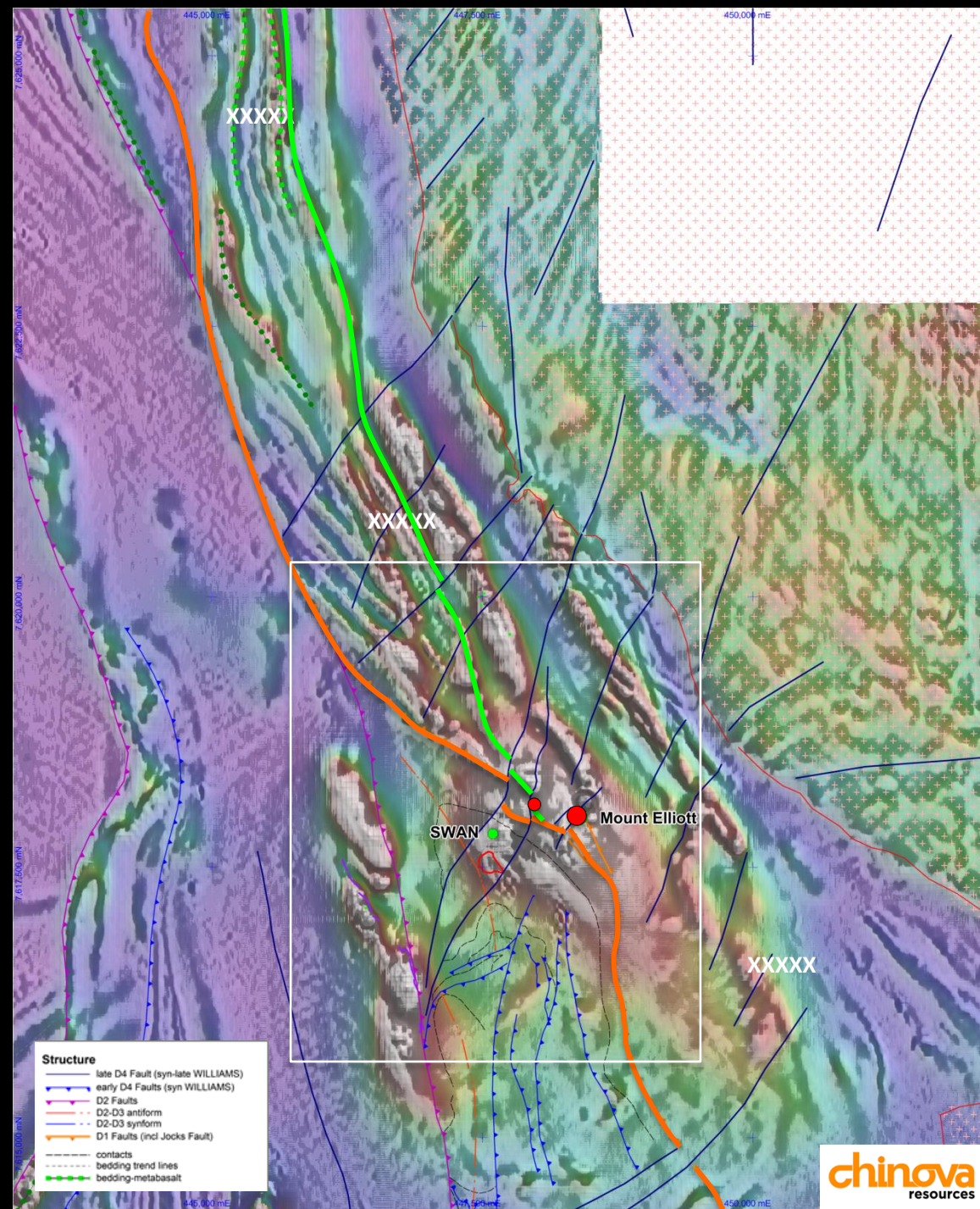
Mount Elliott-SWAN

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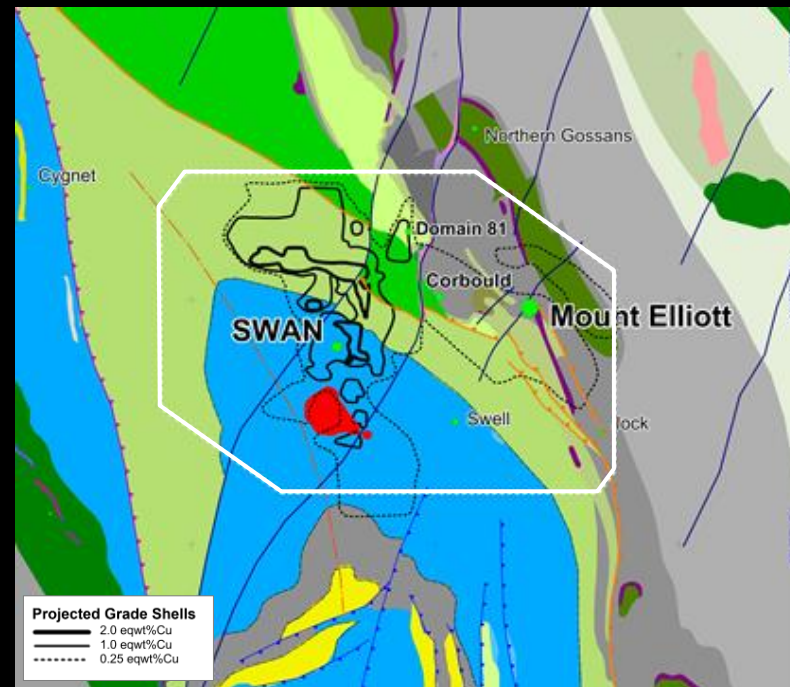
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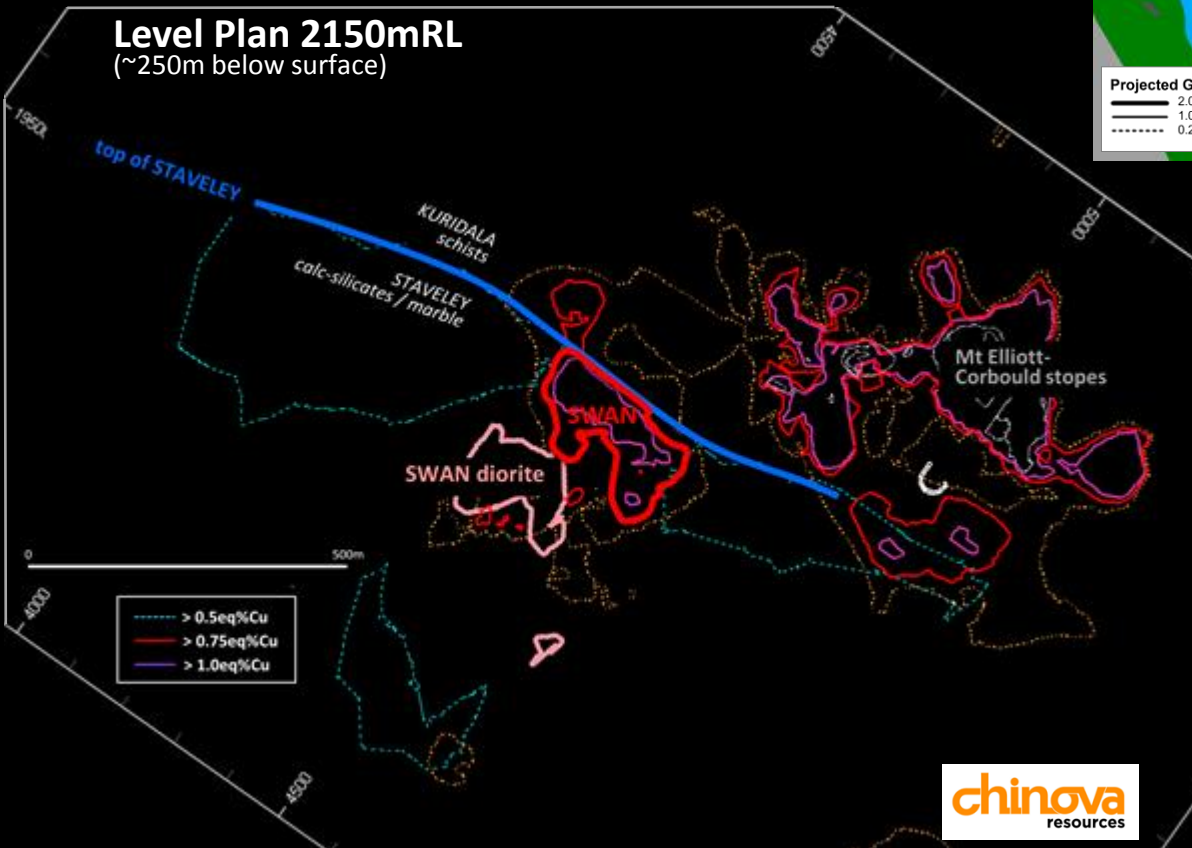
Zoom back to Mount Elliott-SWAN ...



Mount Elliott-SWAN



Level Plan 2150mRL
(~250m below surface)



0.75 eqwt%Cu shell highlights ...

- Tight spatial control on **SWAN mineralisation** with Top-of-STAVELEY
- Location between **SWAN Diorite** and the unmineralised KURIDALA schists

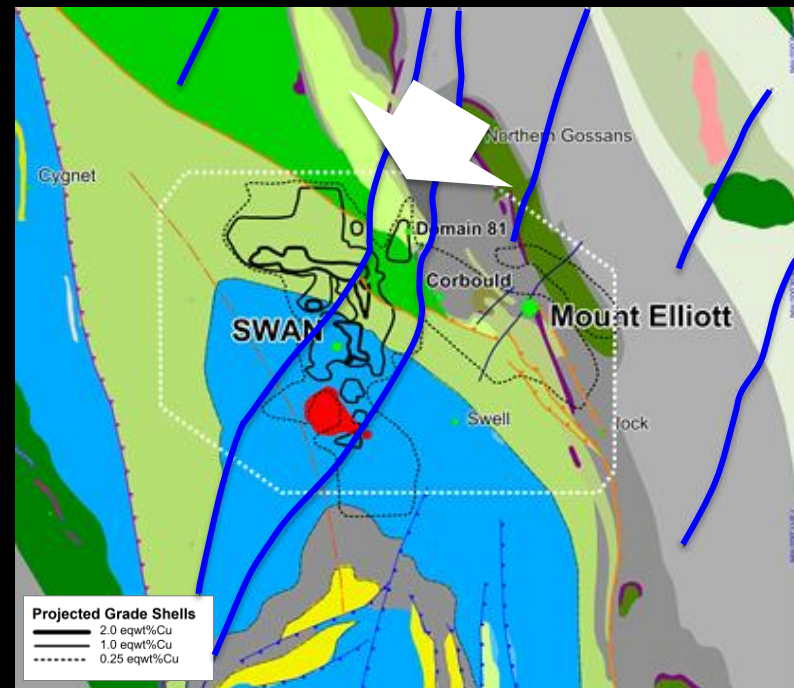
Note: not modelled Mt Elliott-Jocks D1 Fault, basaltic wedge & Late D4 Faults



Mount Elliott-SWAN

0.75eqwt%Cu

Long Section ... looking SW through **SWAN** towards the **SWAN DIORITE**



Post-mineral, late D4 Faults dislocating ...

- **SWAN Diorite**
- **SWAN mineralisation**

Same family of faults that cut **WILLIAMS Squirrel Hill Granite**

Chinova Domain81 mineralisation

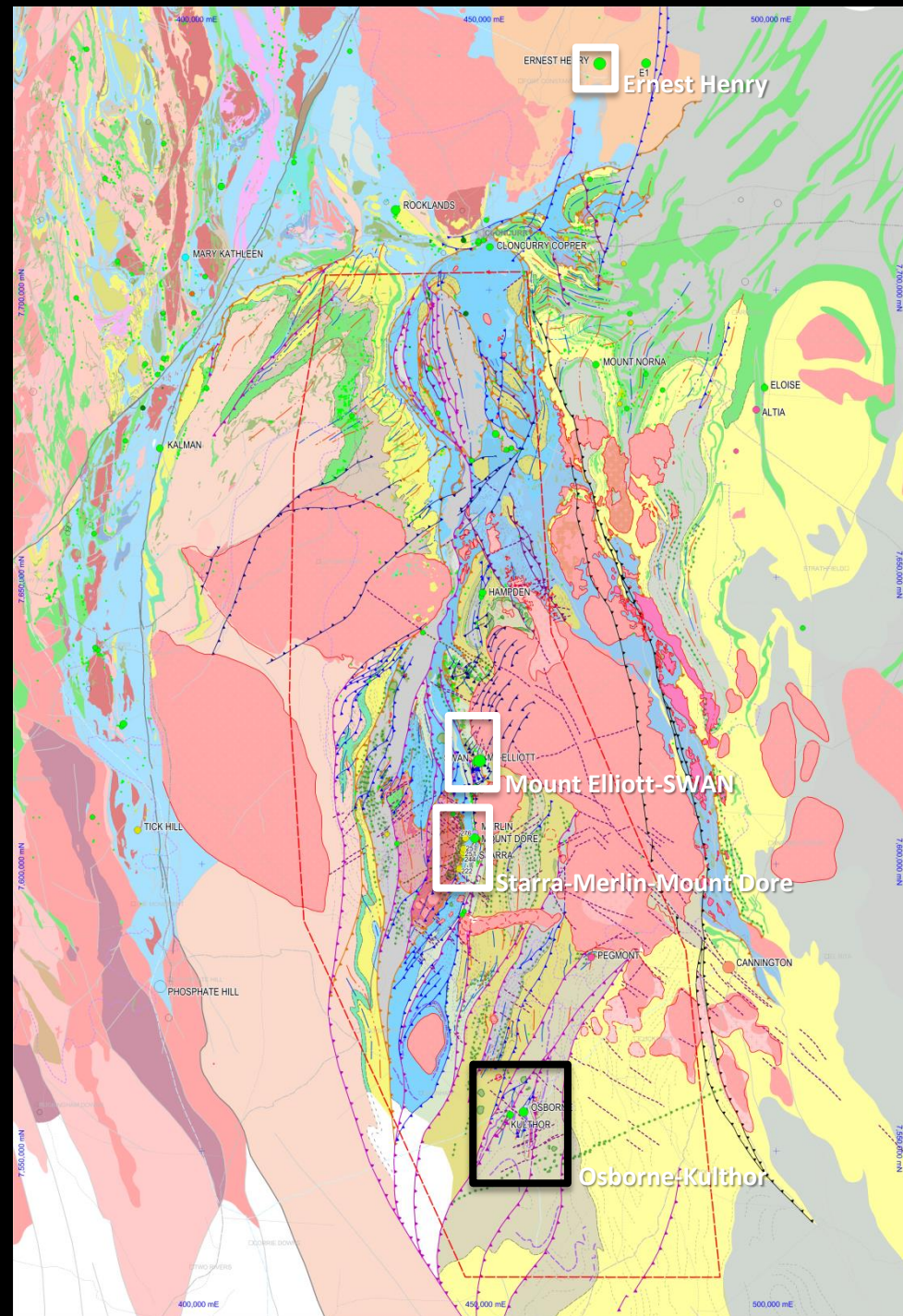


Deposit Controls: District to Local

Four areas

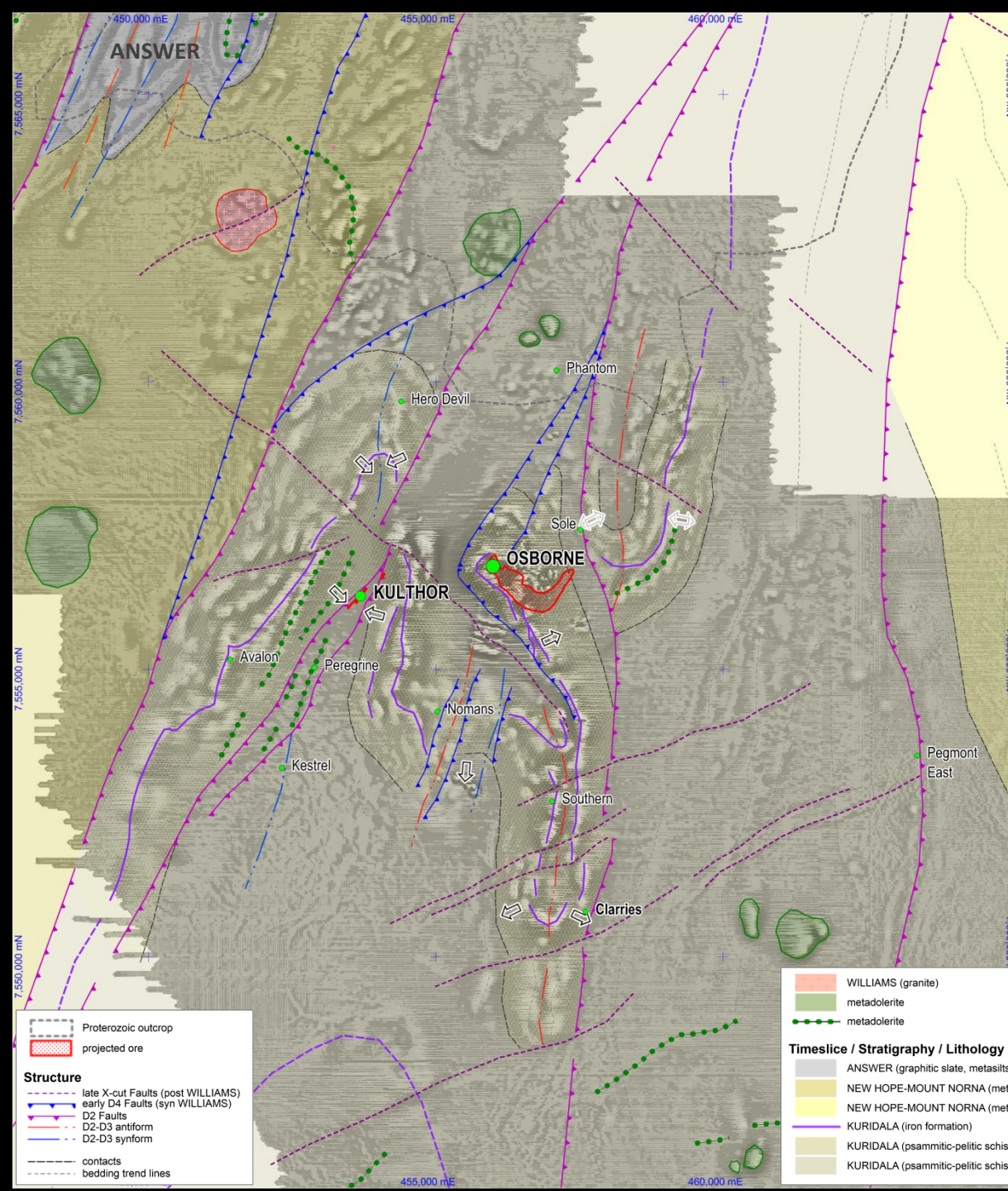
Starra-Merlin-Mount Dore
Mount Elliott-SWAN
Osborne-Kulthor
Ernest Henry

NEXT to Osborne-Kulthor



Kulthor-Osborne

Covered by Cretaceous
DMQ Mag Interpretation (2016)
Previous Company Interps (*incl Morrison, 2002*)



 Proterozoic outcrop
 projected ore
Structure
--- late X-cut Faults (post WILLIAMS)
--- early D4 Faults (syn WILLIAMS)
--- D2 Faults
--- D2-D3 antiform
--- D2-D3 synform
 contacts
 bedding trend lines

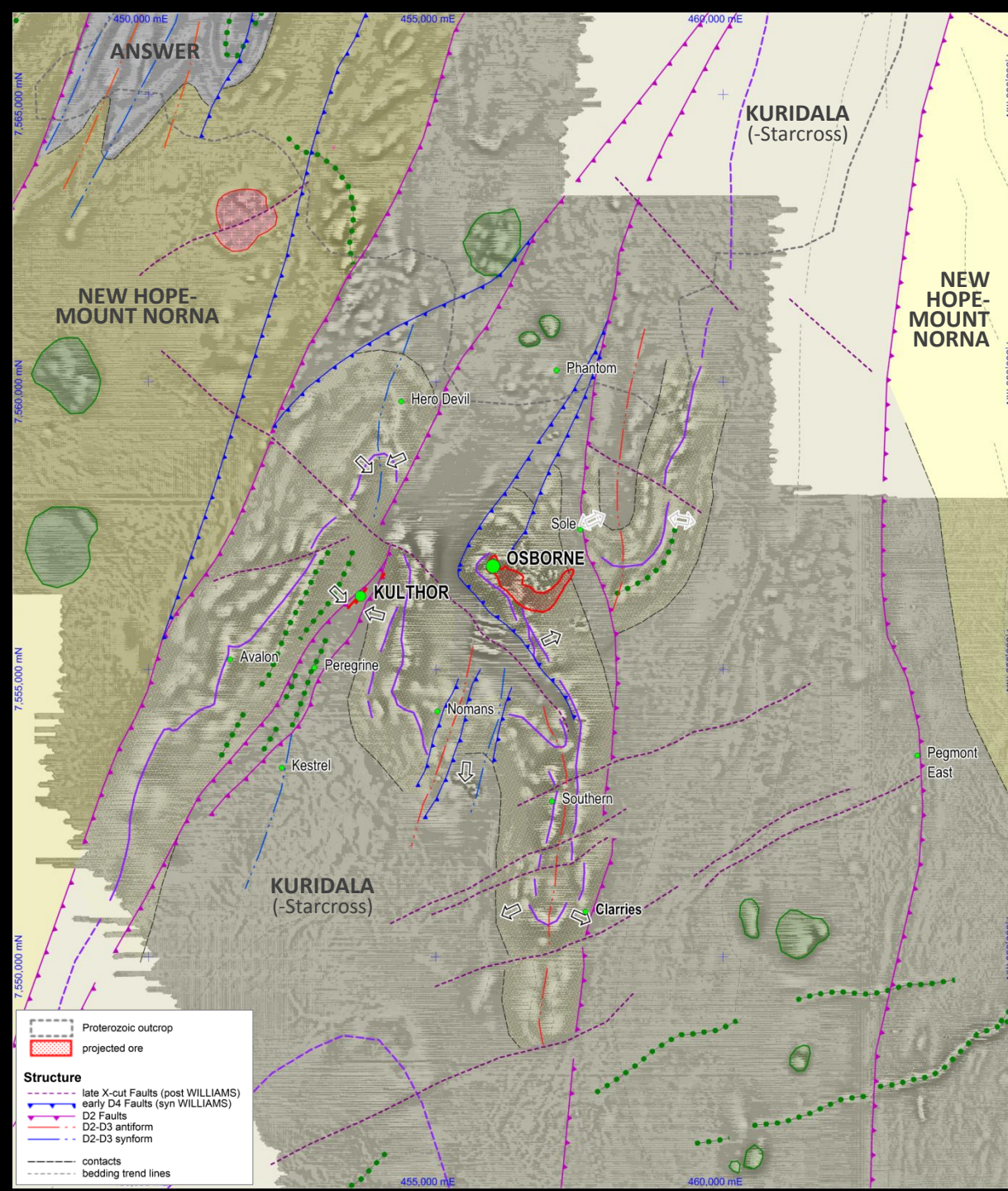
 WILLIAMS (granite)
 metadolerite
●●● metadolerite
Timeslice / Stratigraphy / Lithology
 ANSWER (graphitic slate, metasiltstone)
 NEW HOPE-MOUNT NORNA (meta sandstone, qz-mica schist)
 NEW HOPE-MOUNT NORNA (meta sandstone, qz-mica schists)
 KURIDALA (iron formation)
 KURIDALA (psammitic-pelitic schist; amphibolite; iron formation)
 KURIDALA (psammitic-pelitic schist with garnet, staurolite, andalusite)



Kulthor-Osborne

Covered by Cretaceous
DMQ Mag Interpretation (2016)
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KURIDALA (-Starcross)
psammitic unit distinctive Mag, MIF, amphibolites
NEW HOPE-MOUNT NORNA
ANSWER-TOOLE CREEK



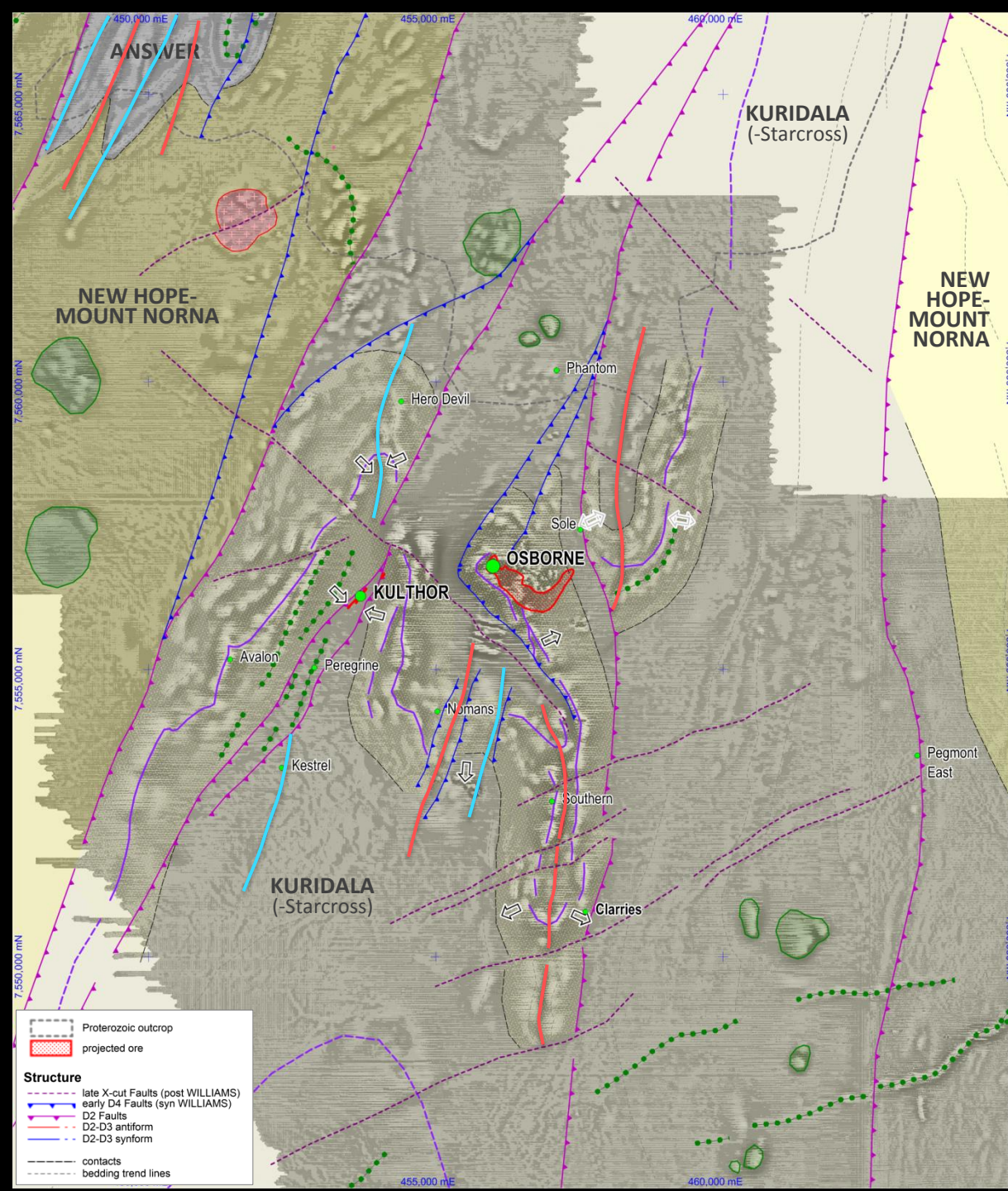
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DUCTILE disharmonic D2 Folding
of KURIDALA ... EW-shortening during high
grade Upper Amphibolite metamorphism
migmatitic-granoblastic metapelites-psammities,
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partial melting; Contrasts with ANSWER D2 Folds



Kulthor-Osborne

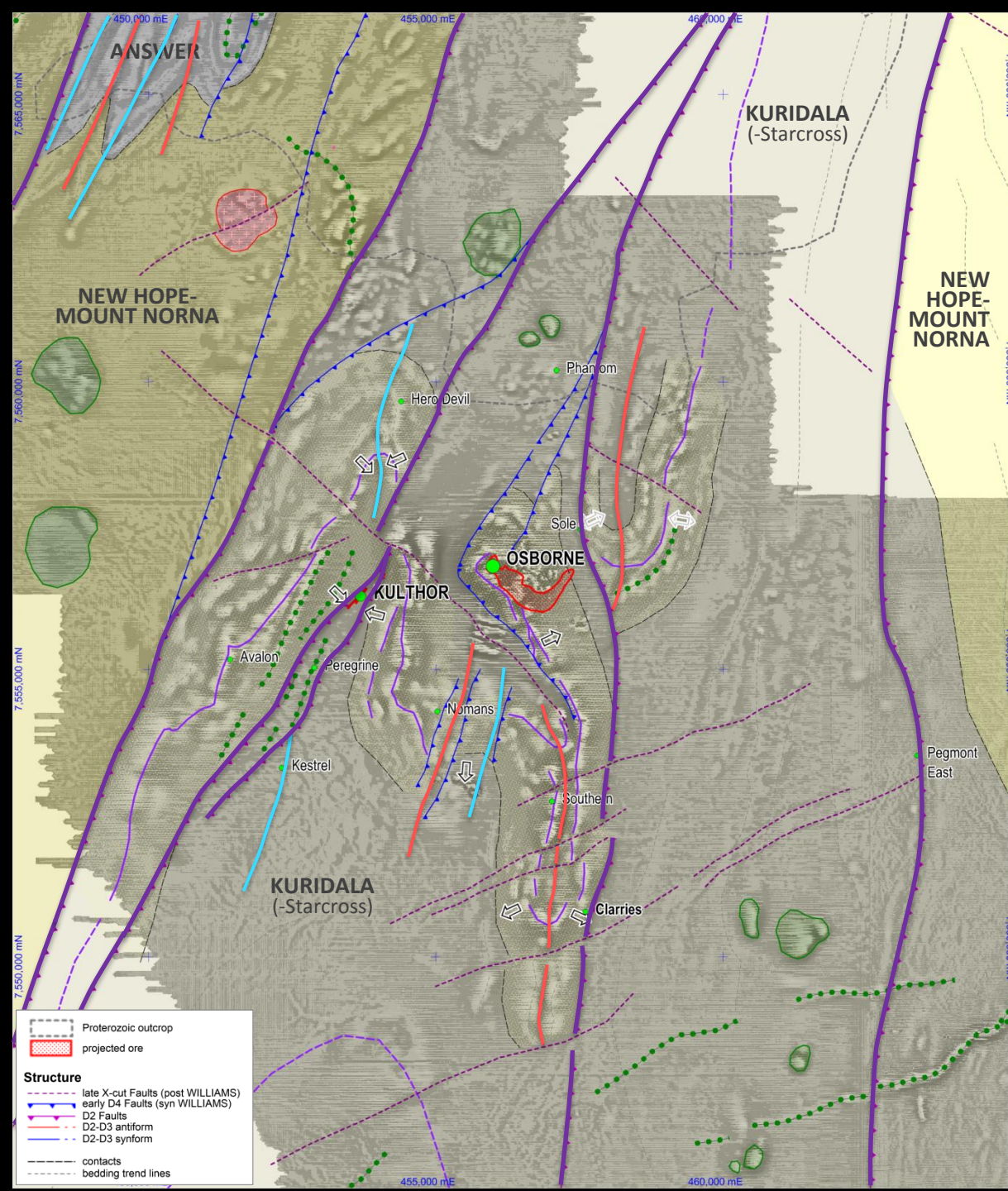
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Ongoing EW D2 Shortening ..
D2 Transpressive Faulting
Dismembers folded high grade meta packages;
Short Limb Failures;
Kulthor: juxtapositioning of opposite facing limbs



Kulthor-Osborne

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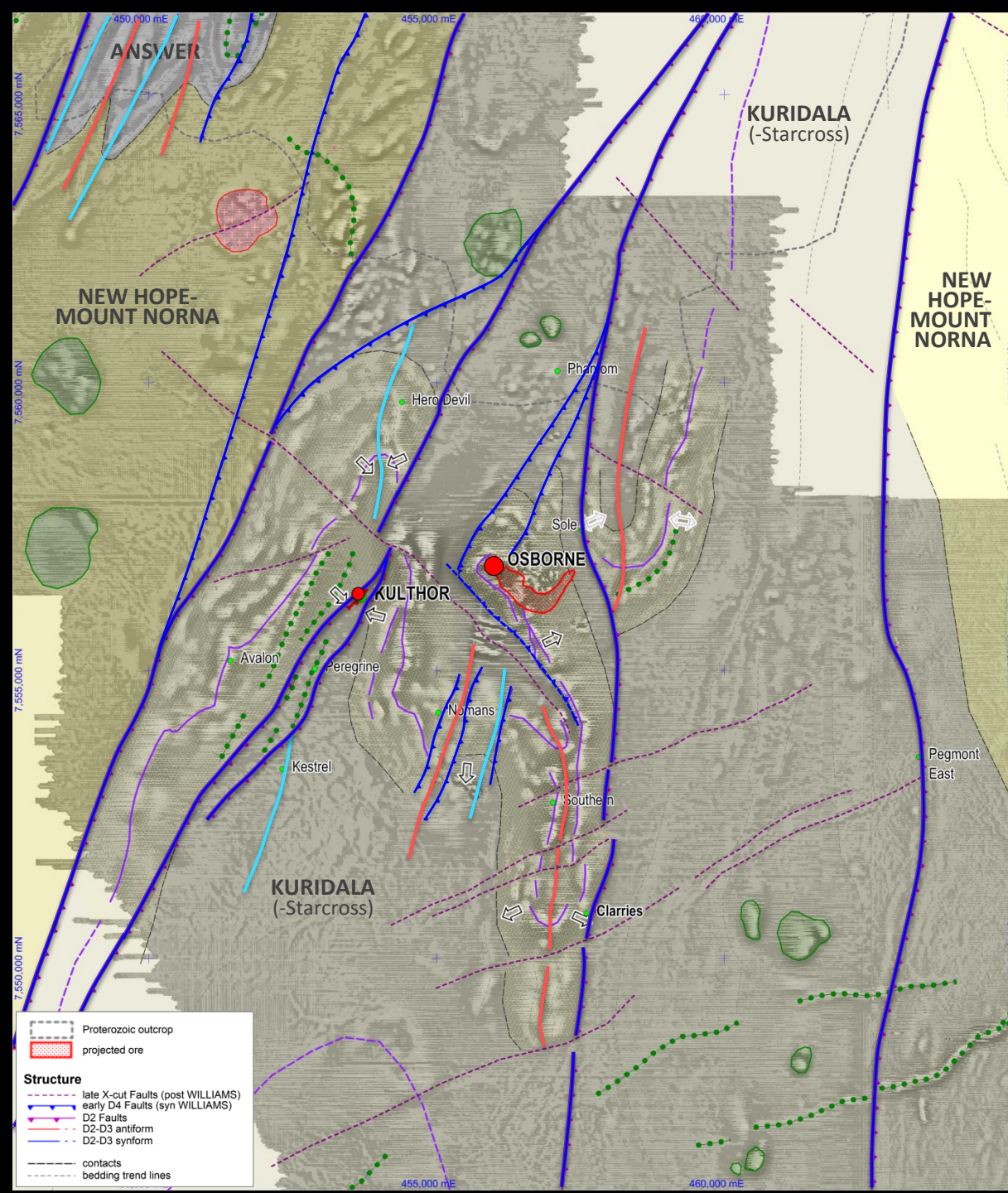
Ongoing EW D2 Shortening ..
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Dismembers folded high grade meta packages;
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Kulthor: juxtapositioning of opposite facing limbs

Post-peak metamorphic, shallower crust,
D4 Sinistral Transpressive re-activation ..
NW-Directed Shortening

... drives **BRITTLE** deformation
where **Lithology** allows

Kulthor & Osborne Mineralisation

... significantly different
mineralisation styles



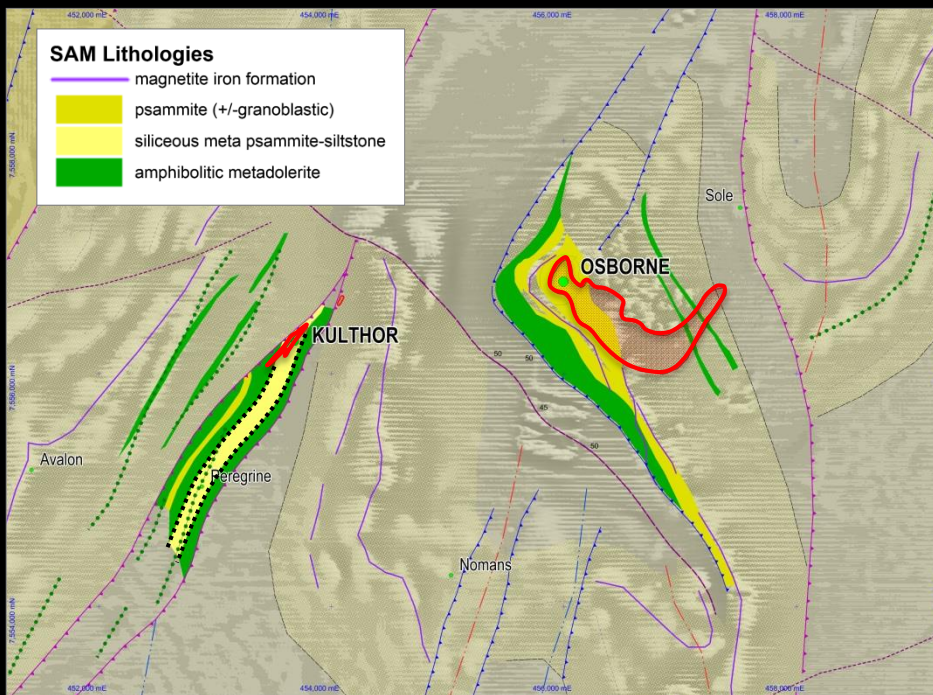
Kulthor-Osborne Mineralisation Controls

Both **Kulthor & Osborne** associated with **UNUSUAL siliceous, meta-psammitic to meta-siltstone ± MIF & amphibolite** (locally 'SAM') packages ... (and commonly described as 'low grade meta')

DMQ hypothesis: siliceous meta-sediments & MIF do NOT express high grade metamorphism by virtue of their mineral composition ...

.. and remain BRITTLE in post-peak metamorphic times

... in stark contrast with the voluminous, migmatitic, pelitic & psammitic meta-sediments that bring strong fabrics to post-peak metamorphic times that accommodate progressive D4 re-activation.



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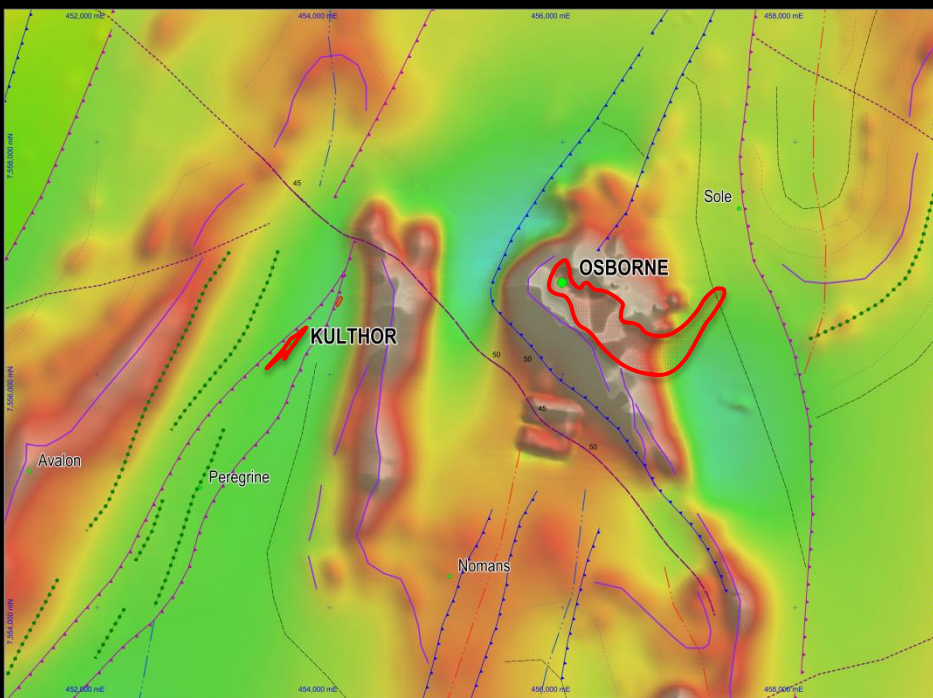
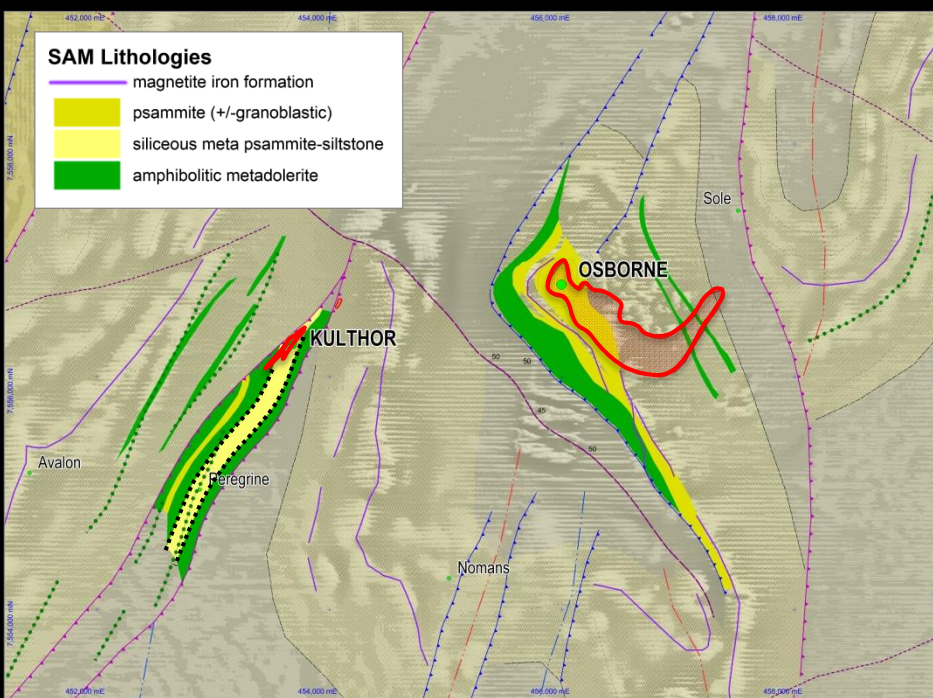
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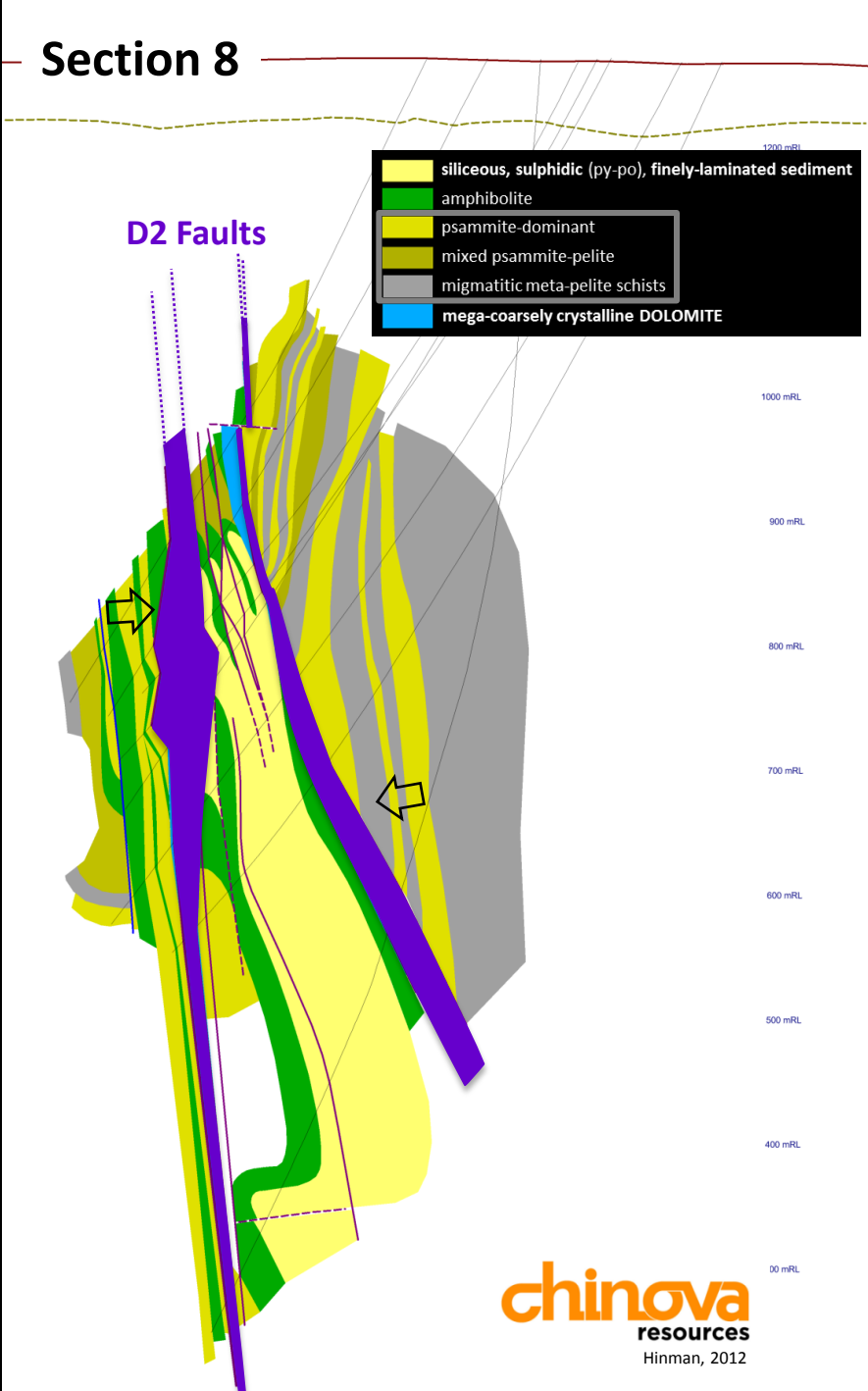
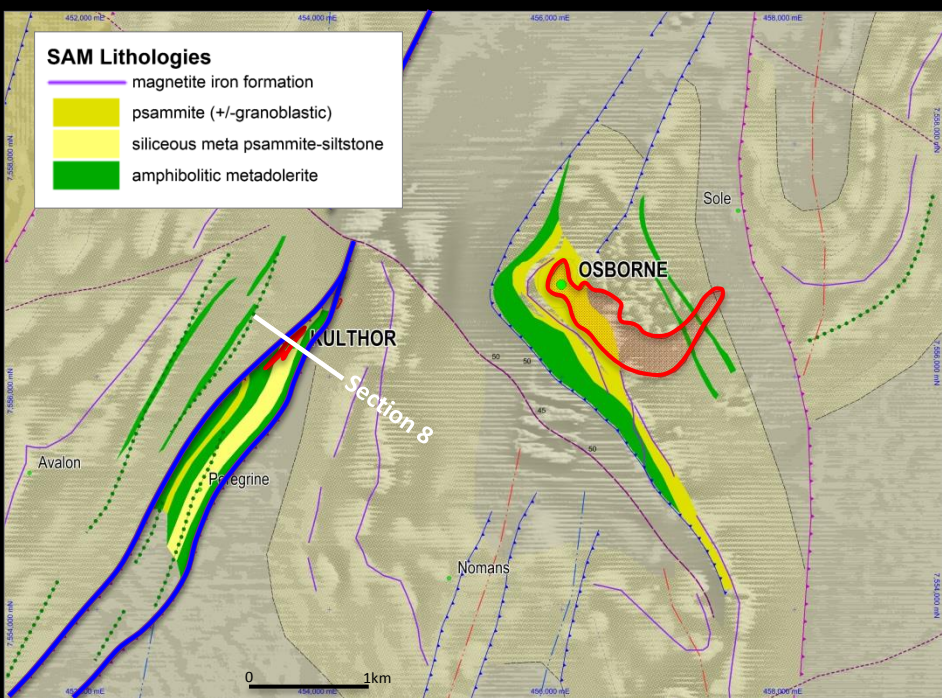
Kulthor & Osborne significantly contrasting ..

Kulthor Fe-sulphide dominated .. NO Mag expression '**ISCG**'
Osborne Fe-oxide dominated .. Strong Mag expression '**IOCG**'

DMQ disagrees the syn-metamorphic timing for Osborne (based on moly Re-Os; Gauthier et al., 2001) ...

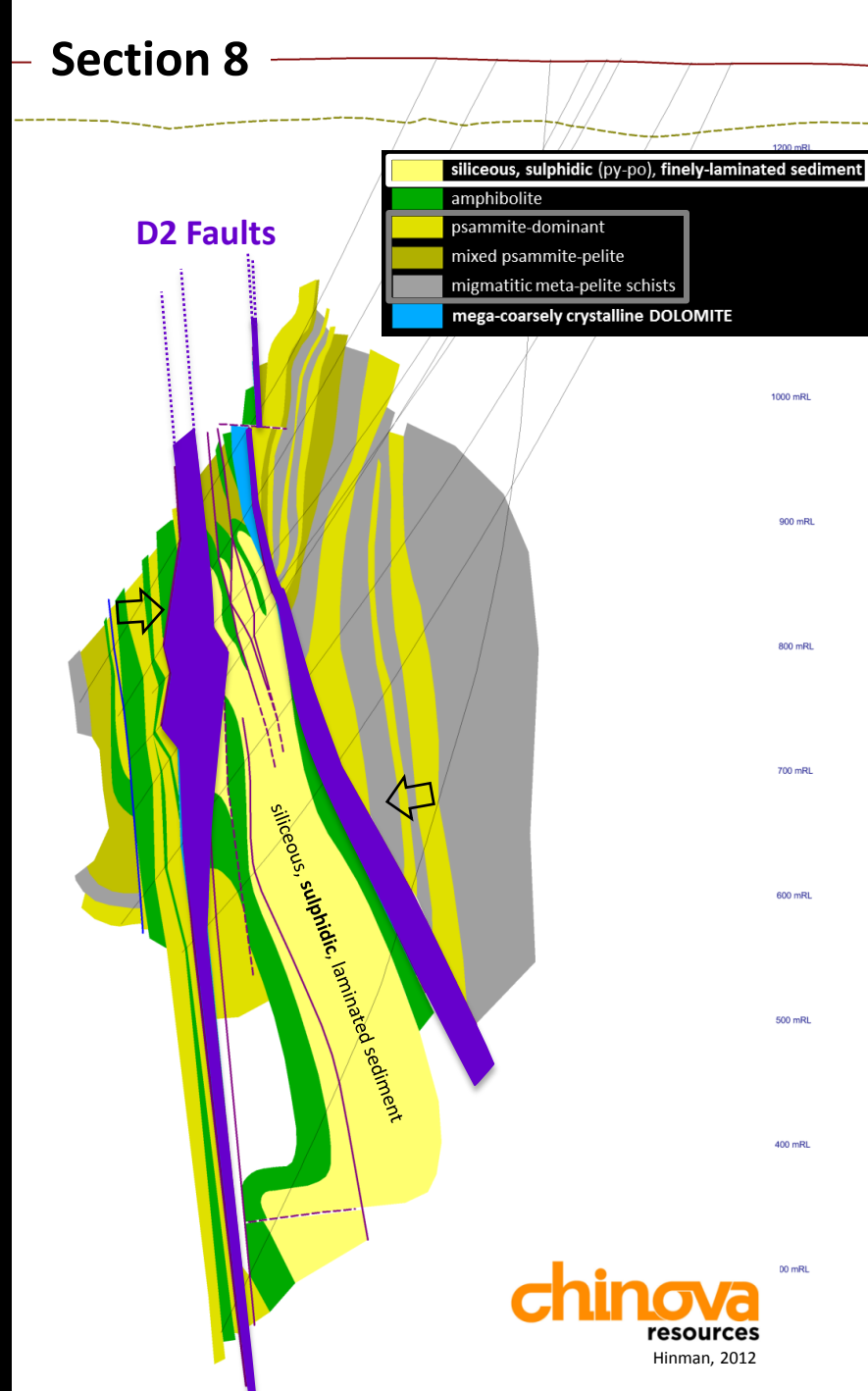
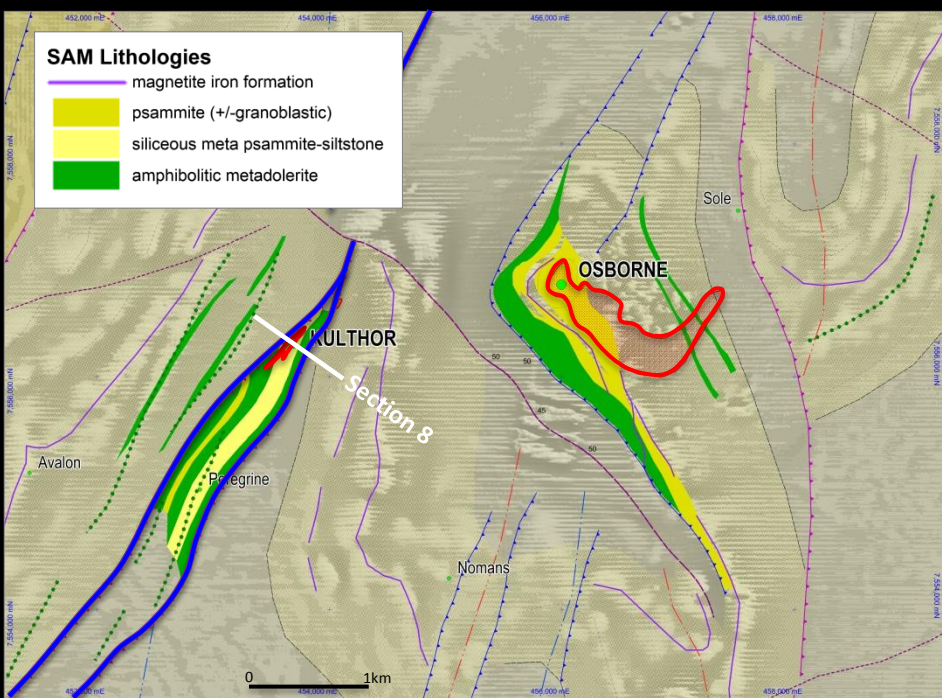
Detailed structural work by Adshead (1995), King (2001) at Osborne & myself at Kuthor (2012) indicate post-peak metamorphic timing and BRITTLE fracture & breccia control on **Cu-Au mineralisation in both systems.**





Section 8 through **Kulthor** ...

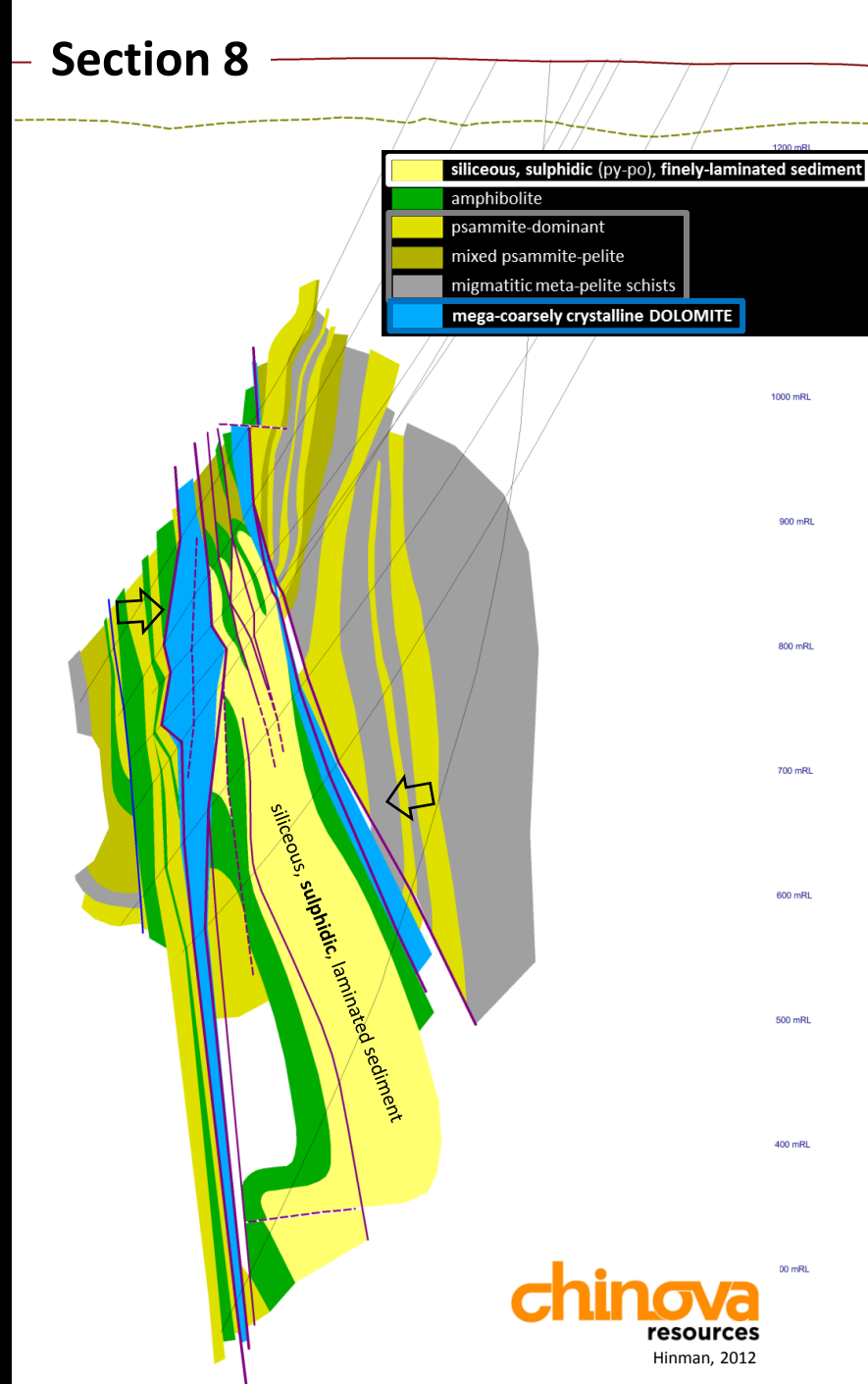
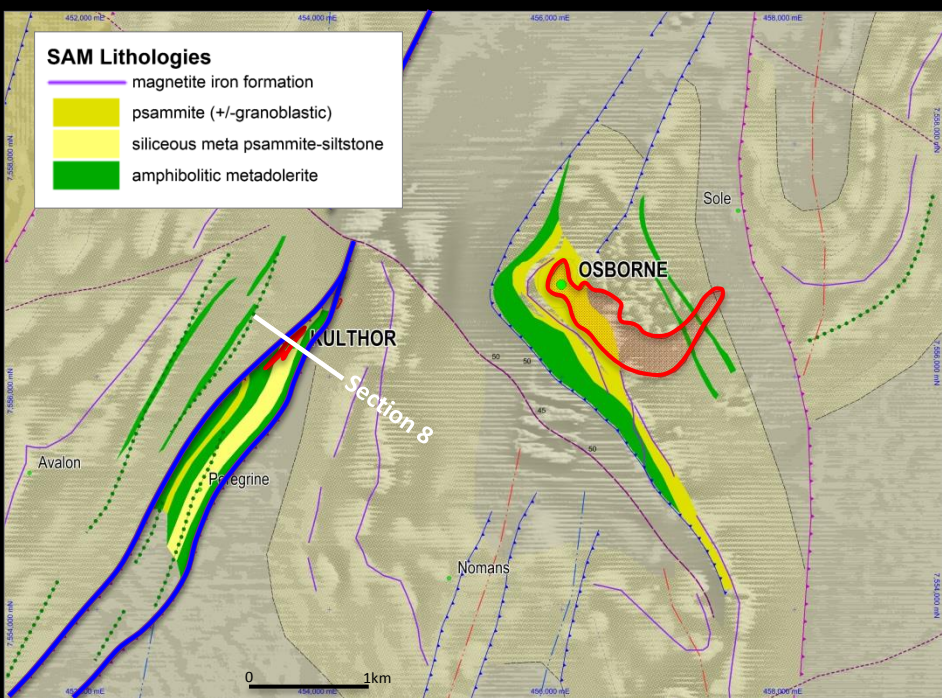
Twin D2 Faults juxtapose opposite facing packages
 FW & HW dominated by migmatitic-granoblastic meta pelites-psammites



Section 8 through **Kulthor** ...

Twin D2 Faults juxtapose opposite facing packages
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Central package: siliceous, sulphidic, finely laminated sediment



Section 8 through **Kulthor** ...

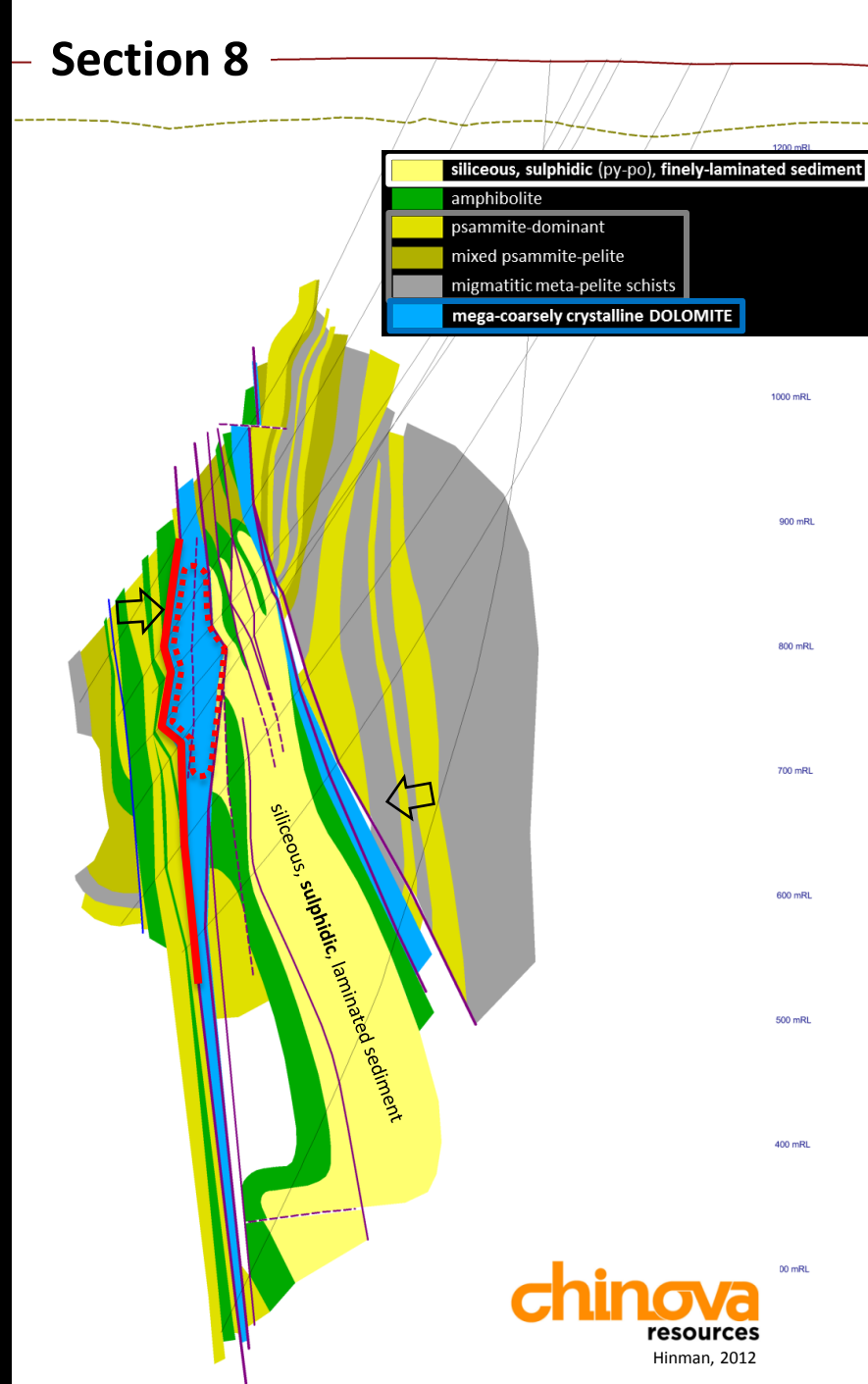
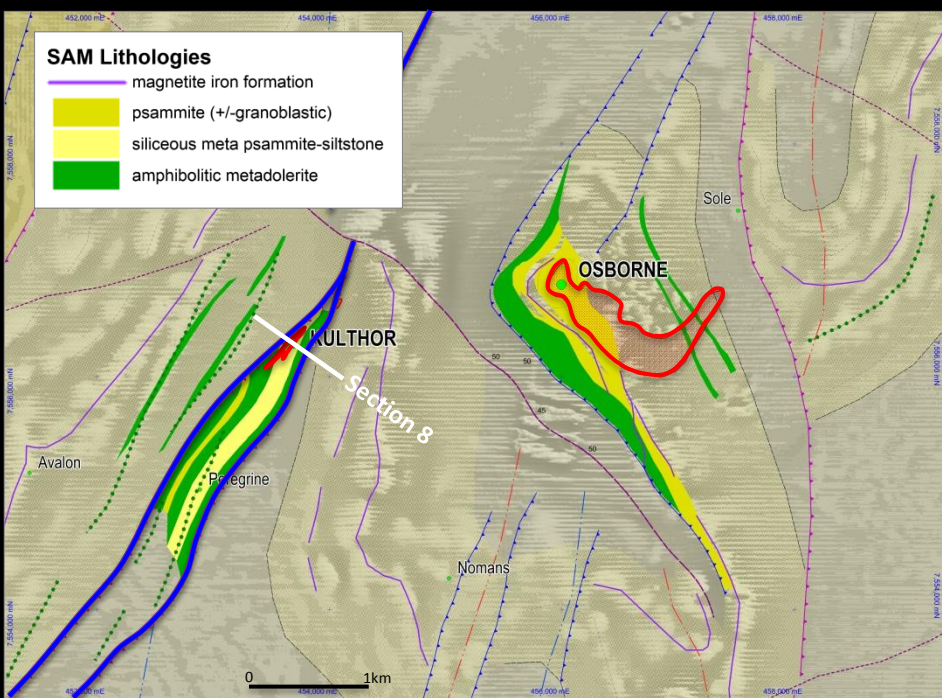
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Post-D2 Relaxation: mega crystalline DOLOMITE

... to DMQ suggests close proximity of STAVELEY beneath



Section 8 through Kulthor ...

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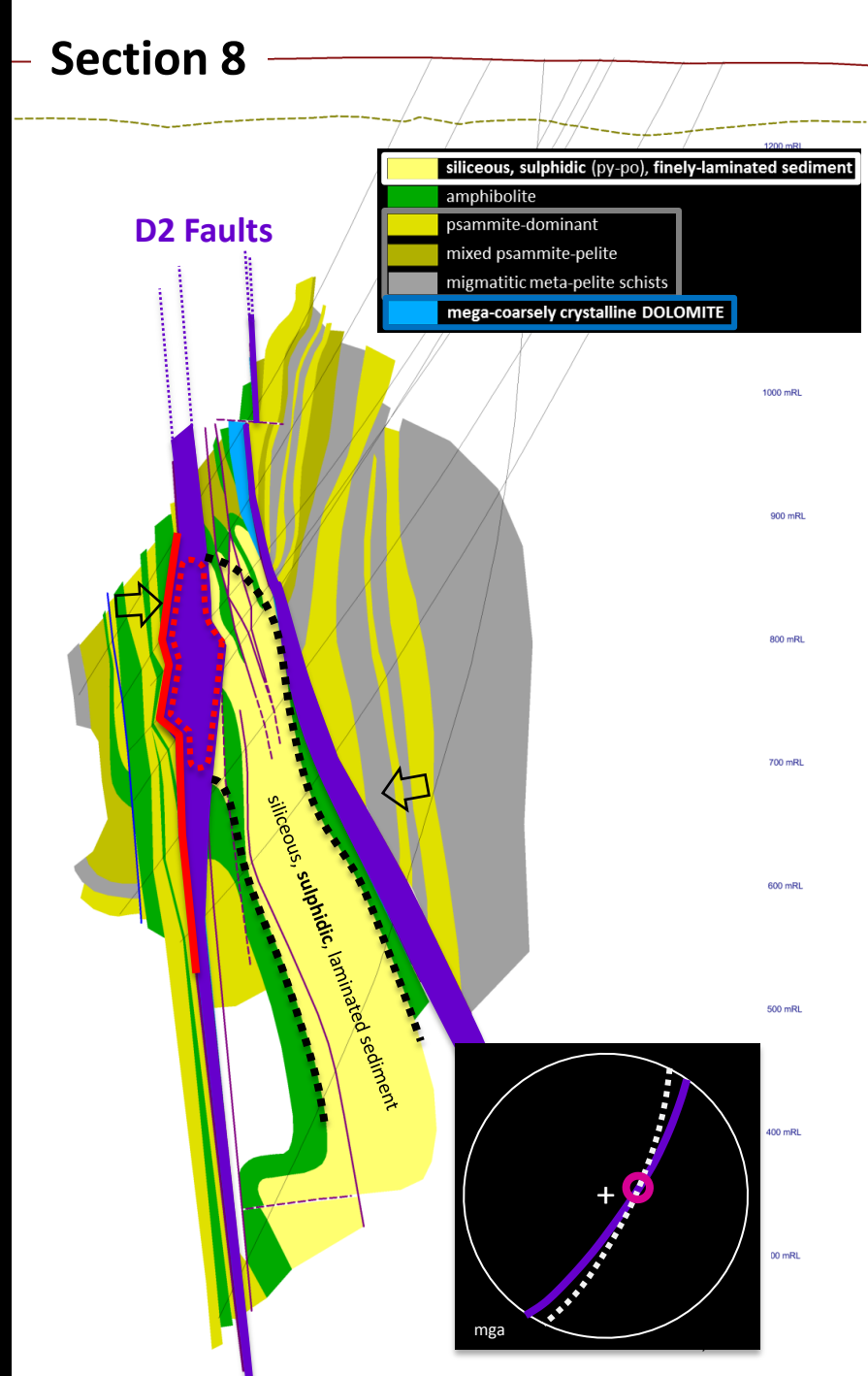
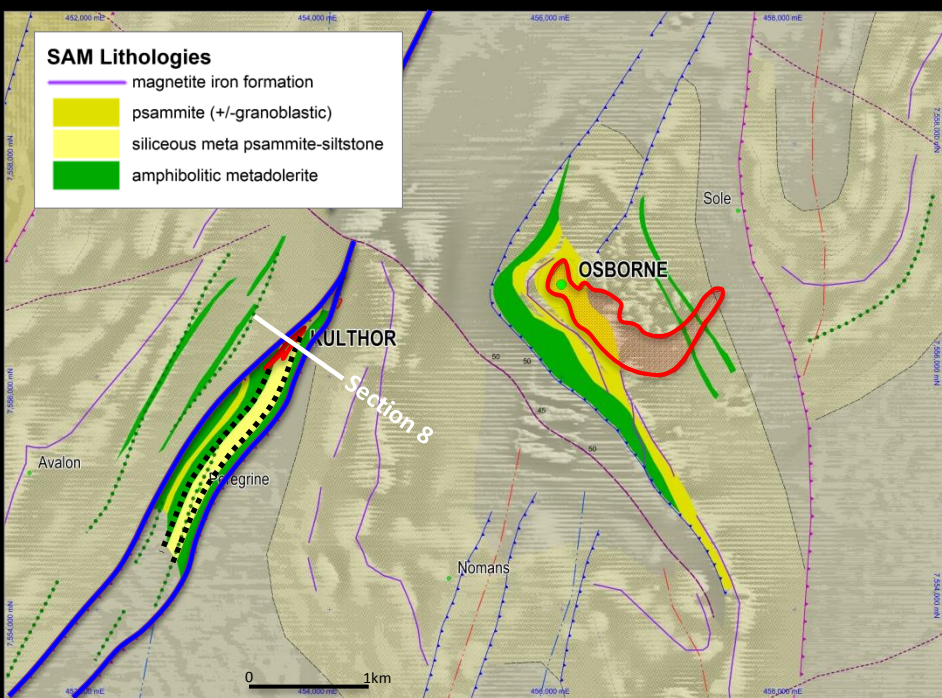
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D4 reverse, re-Activation

Contact BRITTLE breccia-fracture network ... Main or KM Lode

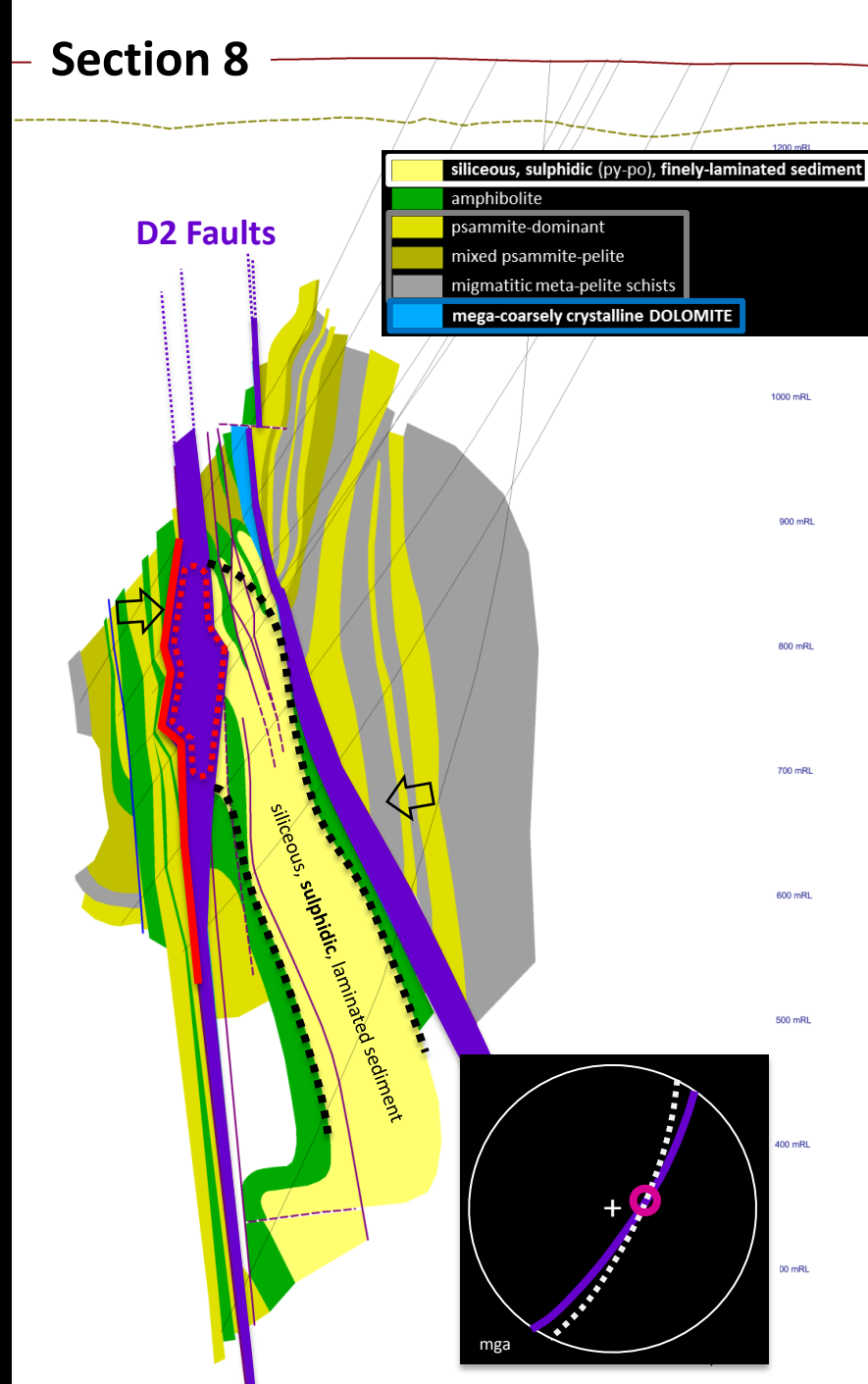
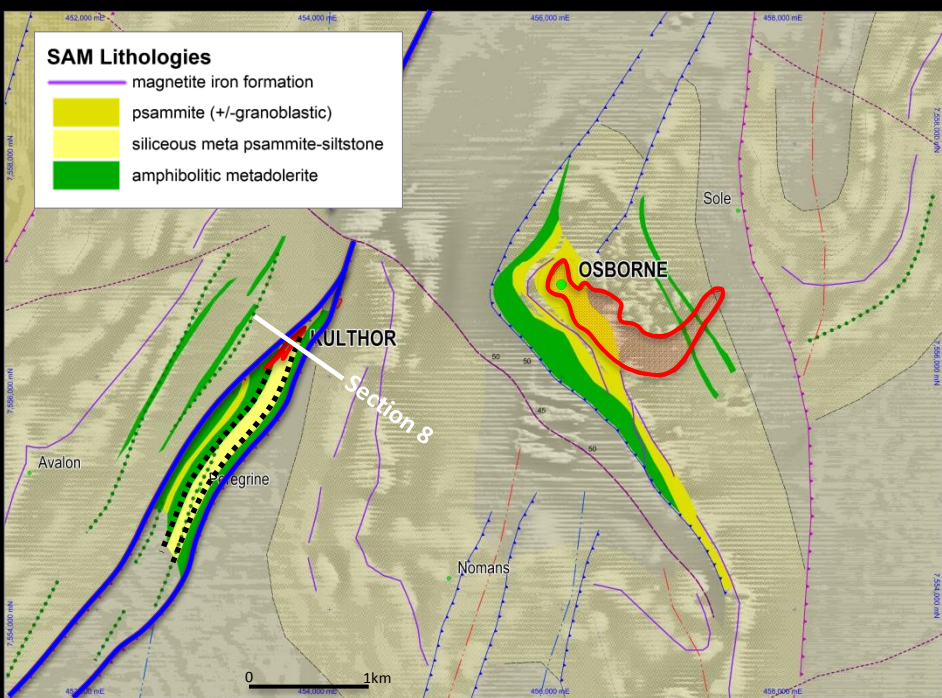
Complex BRITTLE breccia & fracture zones in DOLOMITE ...

Central or KC Lodes



Section 8 through Kulthor ...

- Twin D2 Faults juxtapose opposite facing packages**
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- Contact BRITTLE breccia-fracture network ... Main or KM Lode**
- Complex BRITTLE breccia & fracture zones in DOLOMITE ...**
Central or KC Lodes
- Control: where BRITTLE, siliceous, sulphidic package truncates**
against the D4 reactivating FW Fault Zone .. in Plan & Section



Section 8 through Kulthor ...

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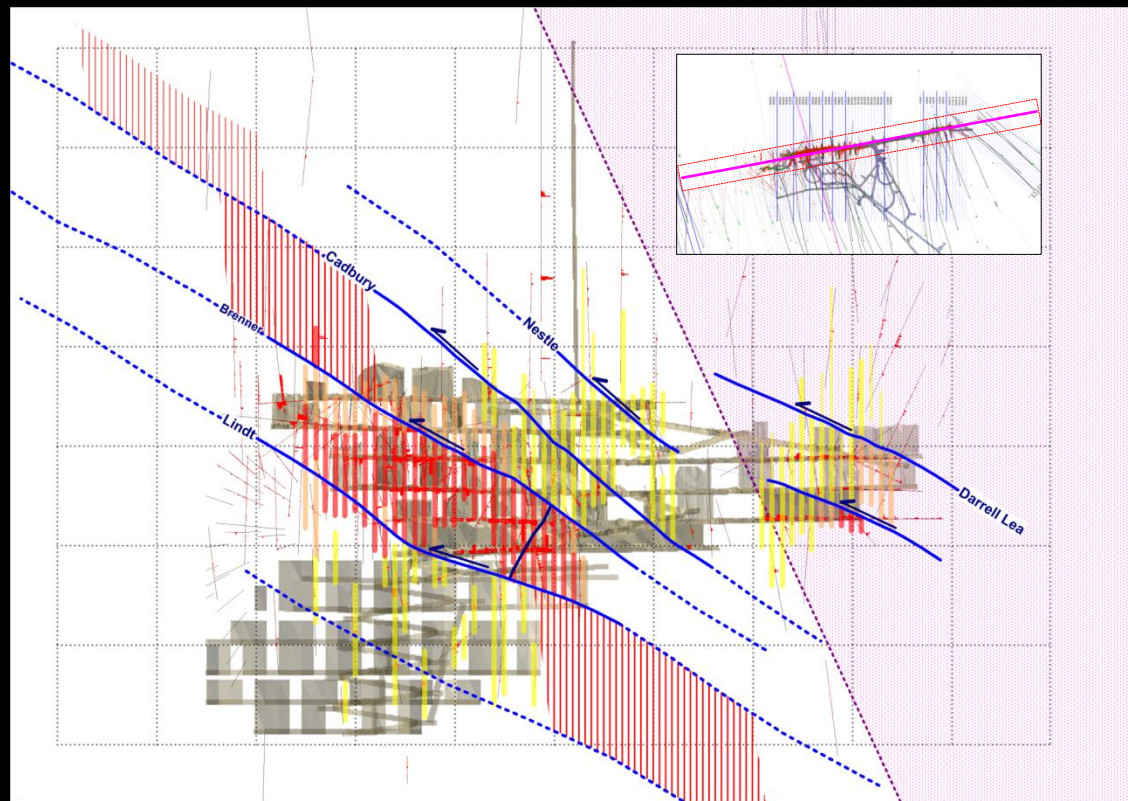
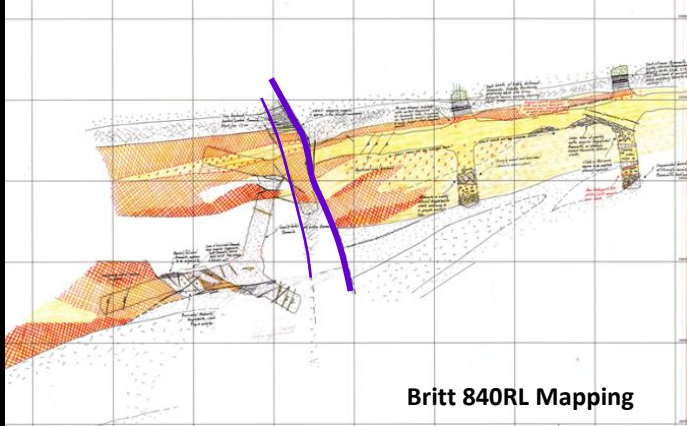
Central or **KC Lodes**

Control: where BRITTLE, siliceous, sulphidic package truncates against the D4 reactivating FW Fault Zone .. in Plan & Section

Local abundant supply of sulphide >> 'ISCG' minz

Kulthor post-mineral Faulting

Long Section looking NW



Several post-mineral, NE-dipping Faults

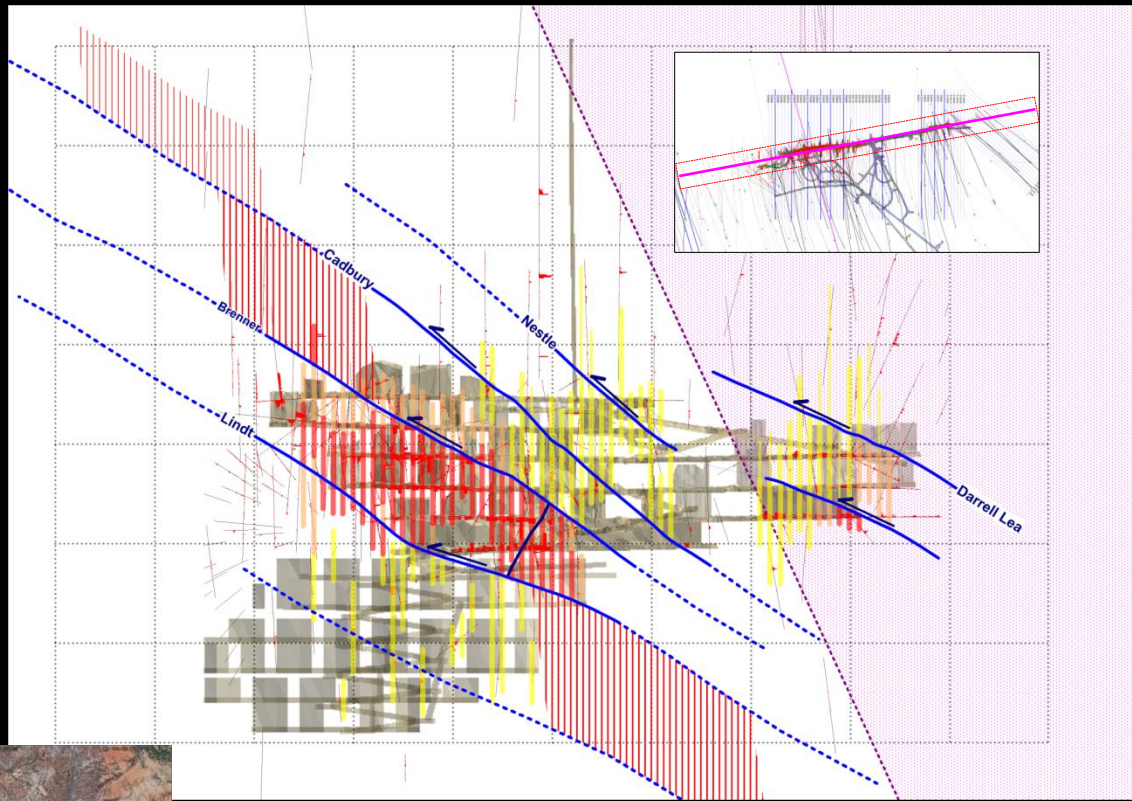
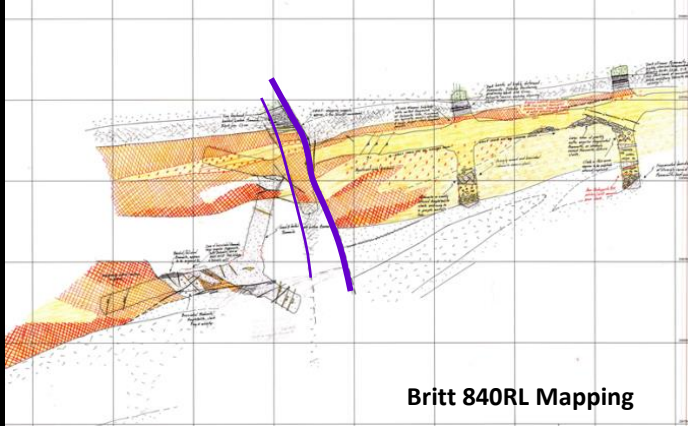
Dislocate **Ore** with significant offsets

.. UG significantly contrasting blocks

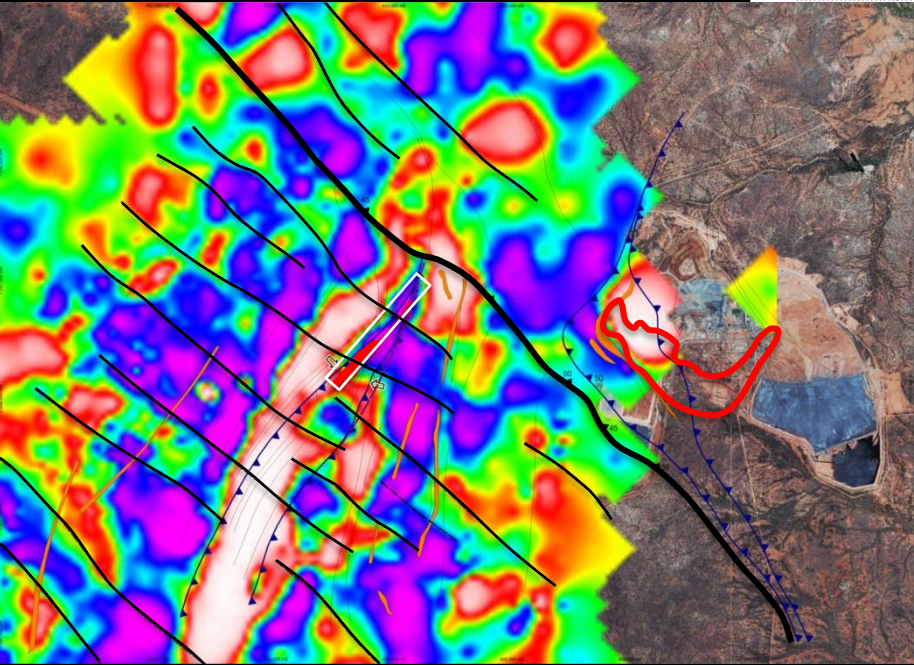


Kulthor post-mineral Faulting

Long Section looking NW



MIF, interp skeleton on gravB C 267p resid



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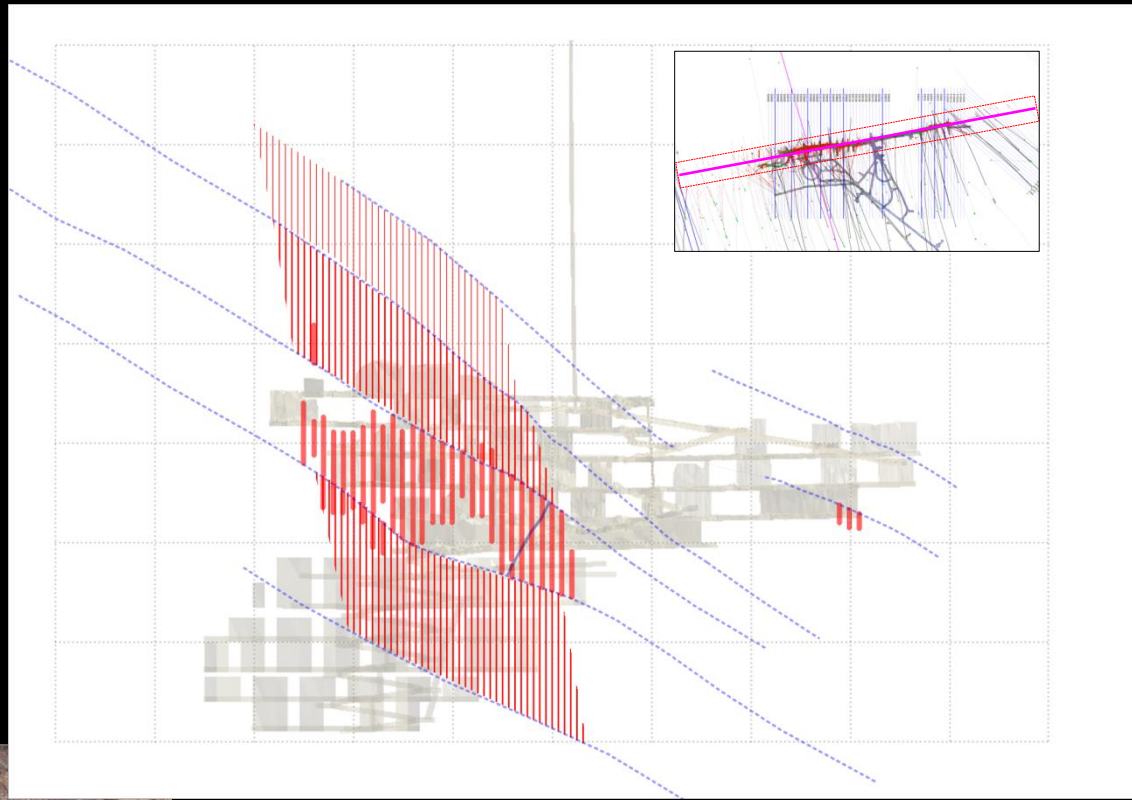
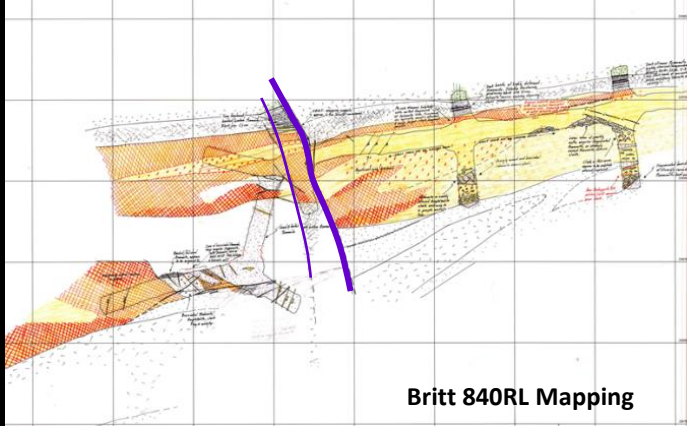
Dislocate **Ore** with significant offsets
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Gravity shows strong block contrasts ...
 ... parallel to major NW Fault that separates **Kulthor & Osborne**

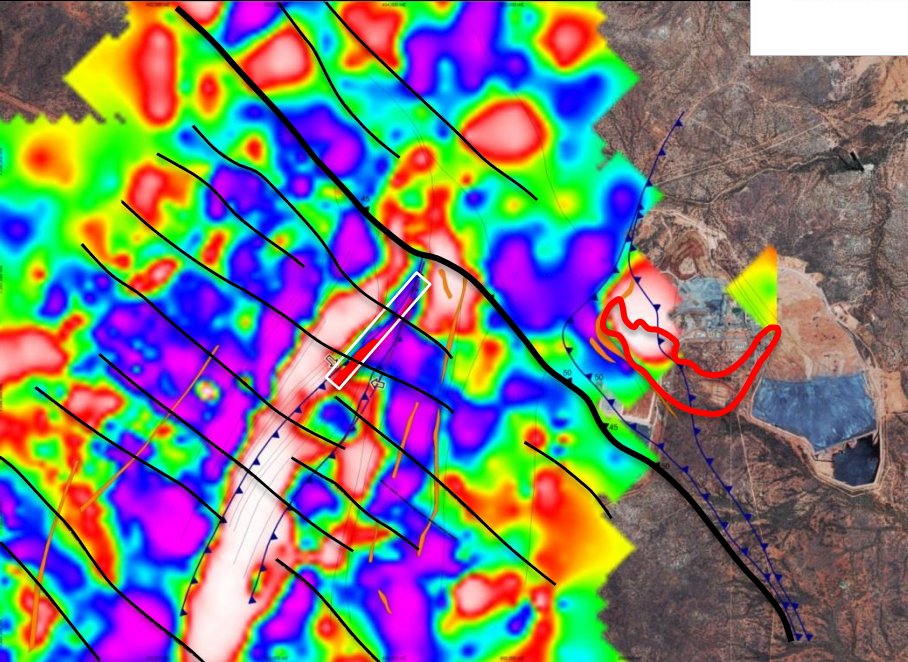


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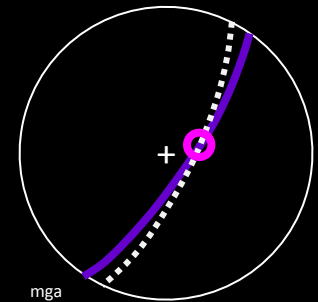


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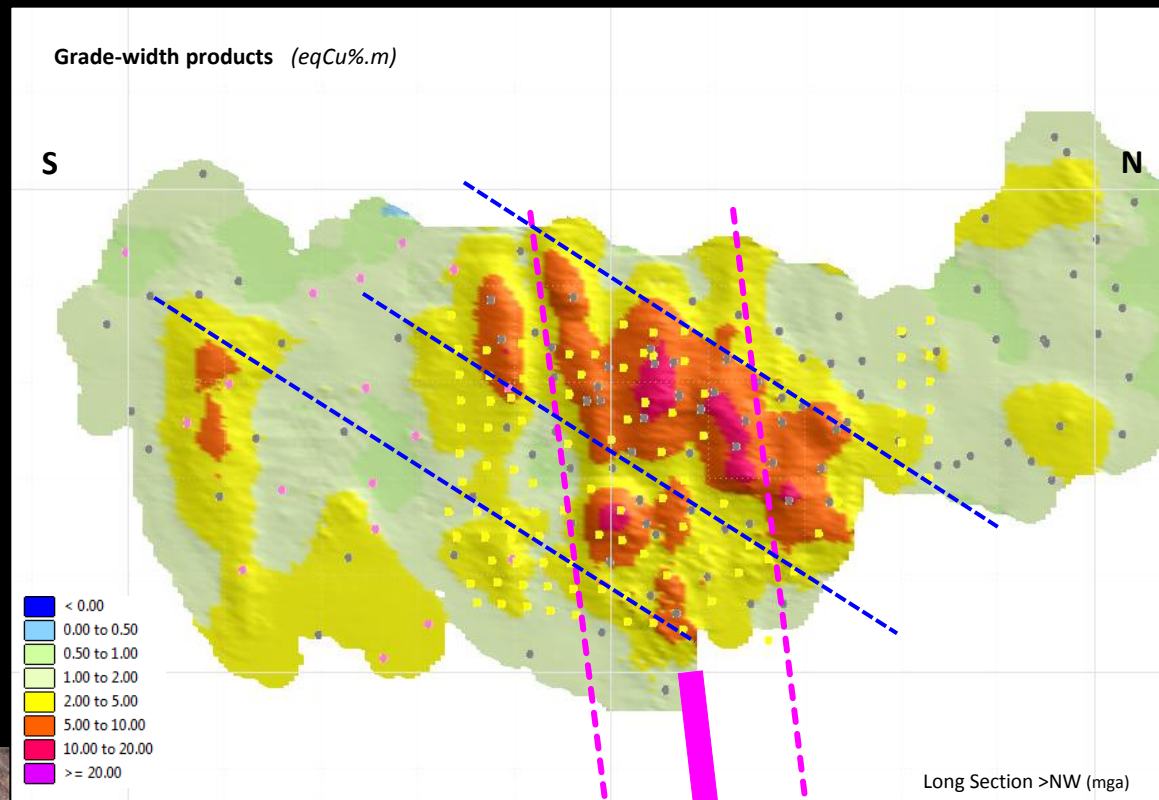
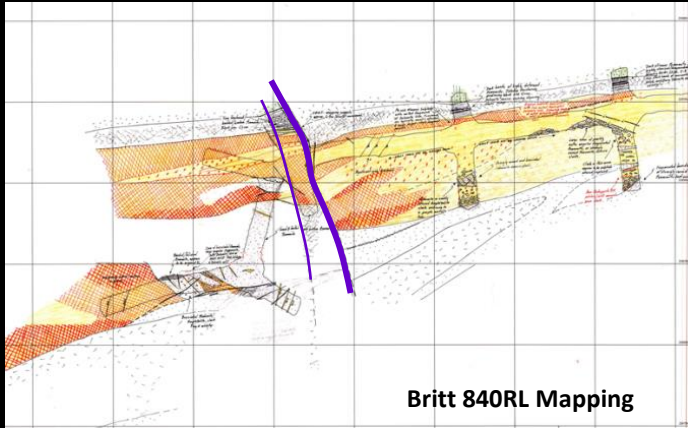
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Reconstruct restores steep plunge

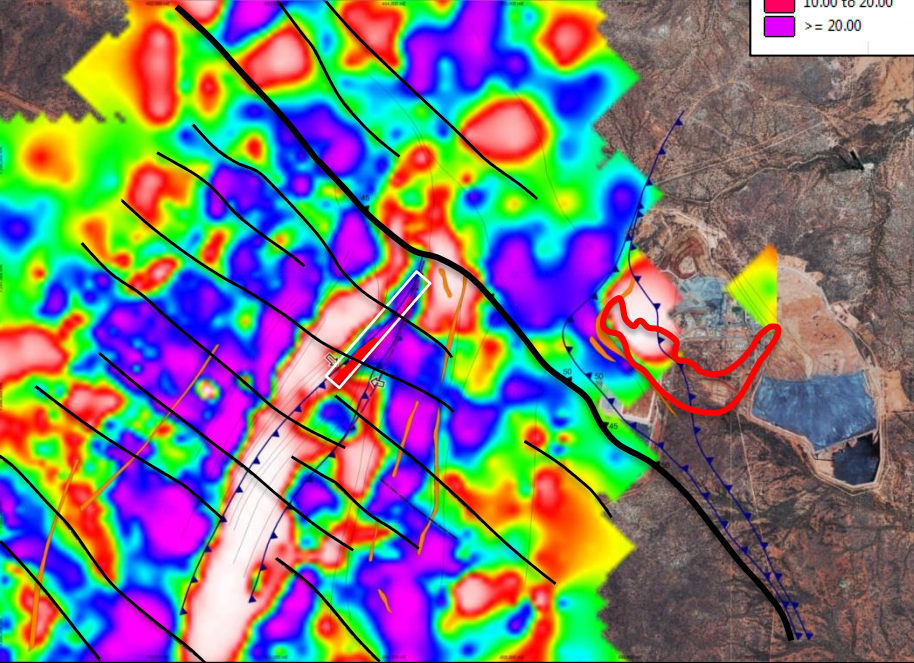


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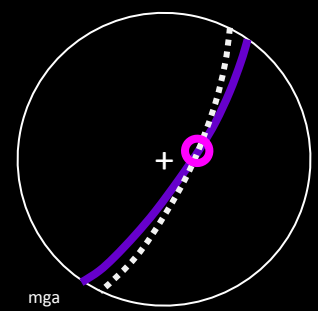
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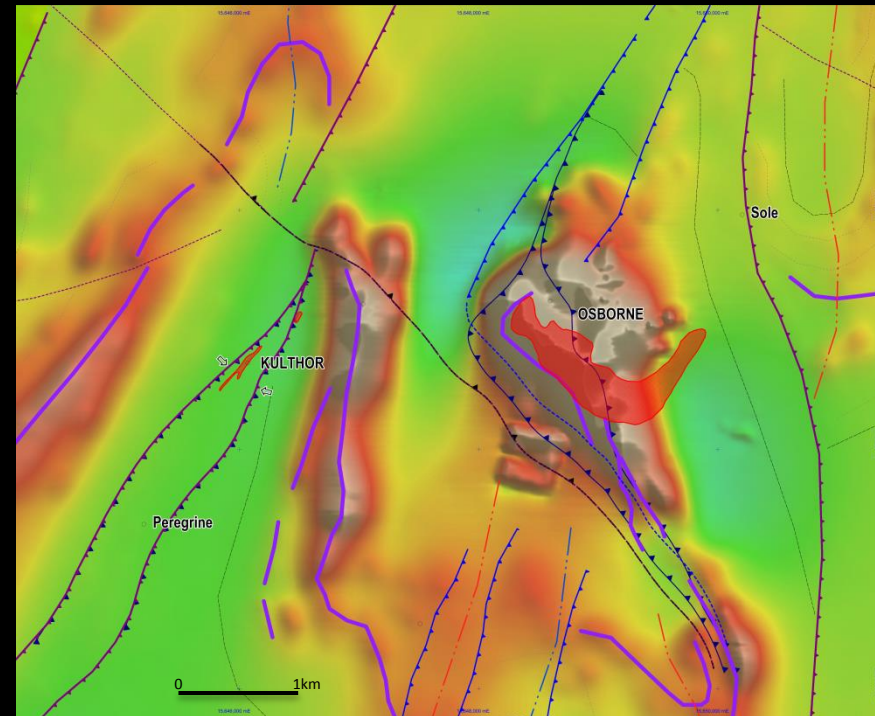
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Reconstruct restores steep plunge

Both orientations reflected in grade-width products



Kulthor-Osborne



Kulthor

sulphide-dominated

ISCG

Osborne

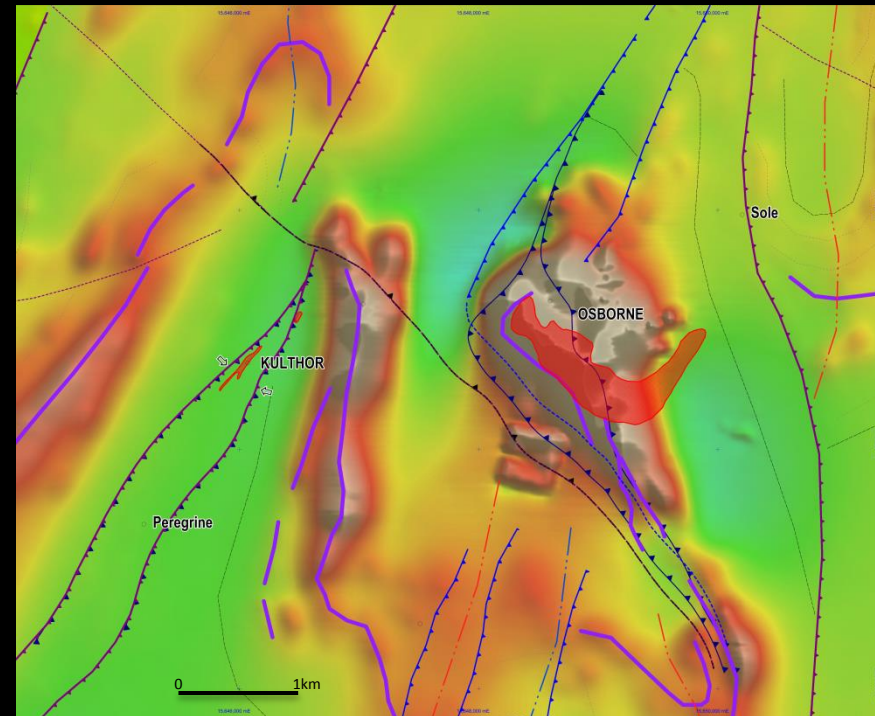
oxide-dominated

IOCG

**Geologically both post-peak metamorphism
& BRITTLE, fracture & breccia controlled**

Adshead (1995), King (2001), Hinman (2012)

Kulthor-Osborne



Kulthor

sulphide-dominated

ISCG

Osborne

oxide-dominated

IOCG

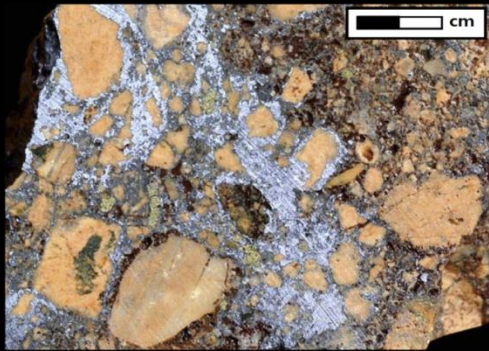
**Geologically both post-peak metamorphism
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Adshead (1995), King (2001), Hinman (2012)

syn-metamorphic, **1595Ma Re-Os molybdenite**

Gauthier et al (2001)

VS

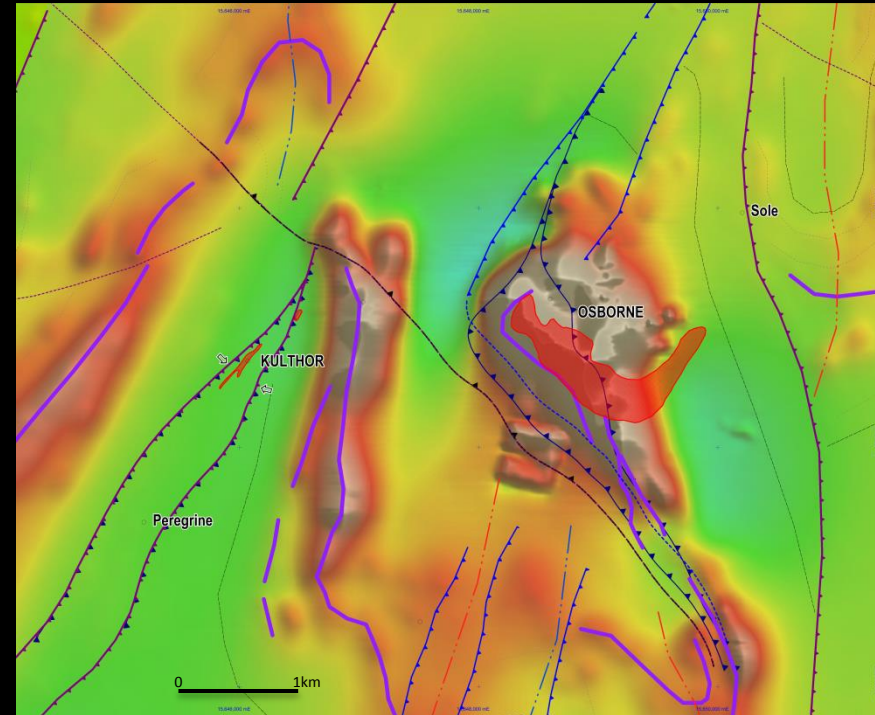


Merlin

Deformed Molybdenite

Kulthor-Osborne

Merlin molybdenite-matrix breccia (from Kirwin, 2009)



Kulthor

sulphide-dominated

ISCG

Osborne

oxide-dominated

IOCG

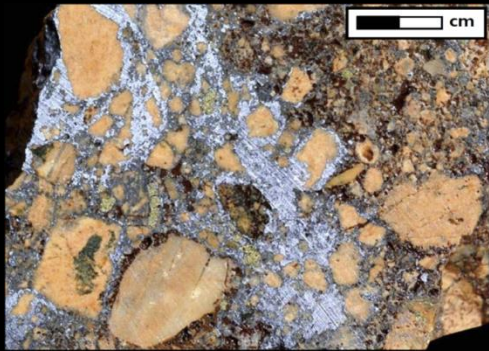
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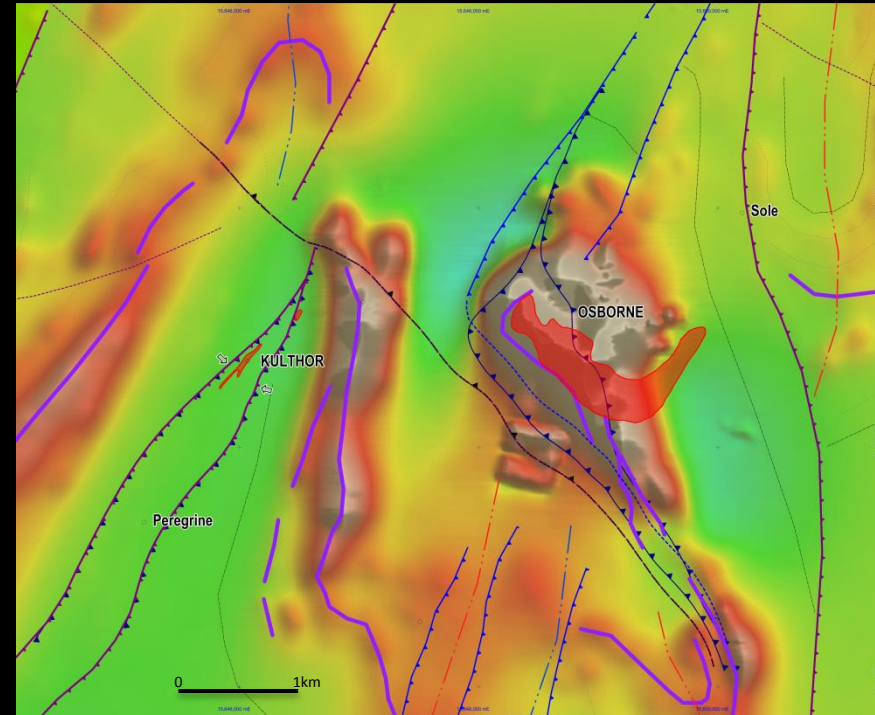
VS



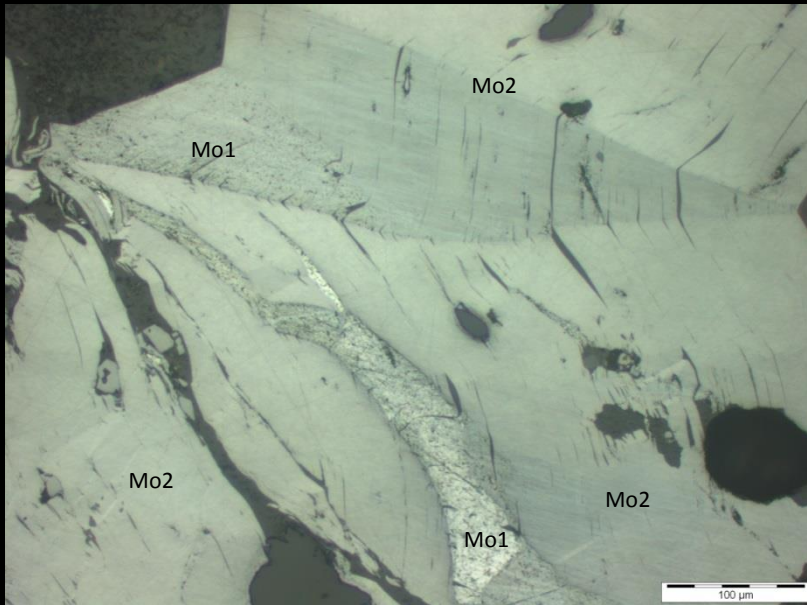
Merlin Deformed Molybdenite

Kulthor-Osborne

Merlin molybdenite-matrix breccia (from Kirwin, 2009)



Merlin Mo1-Mo2, Subira Sharma CODES (2015)



Kulthor
sulphide-dominated
ISCG

Osborne
oxide-dominated
IOCG

Mo1 primarily precipitated, inclusion-rich, ?Re-rich
Mo2 deformed-kinked, inclusion-cleared, ?Re-depleted

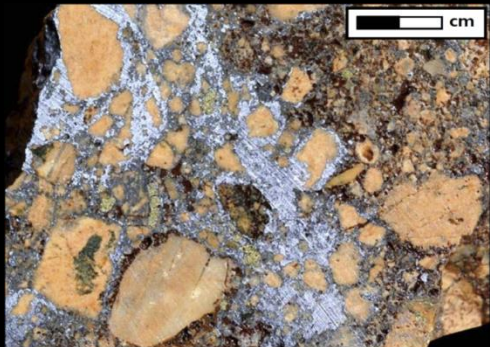
Geologically both post-peak metamorphism & BRITTLE, fracture & breccia controlled

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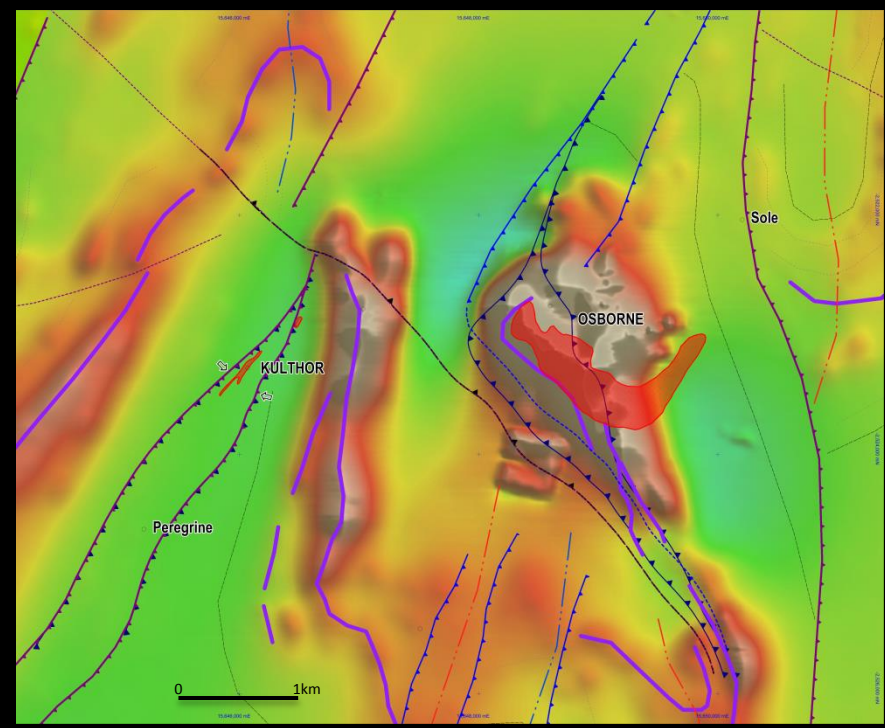
VS



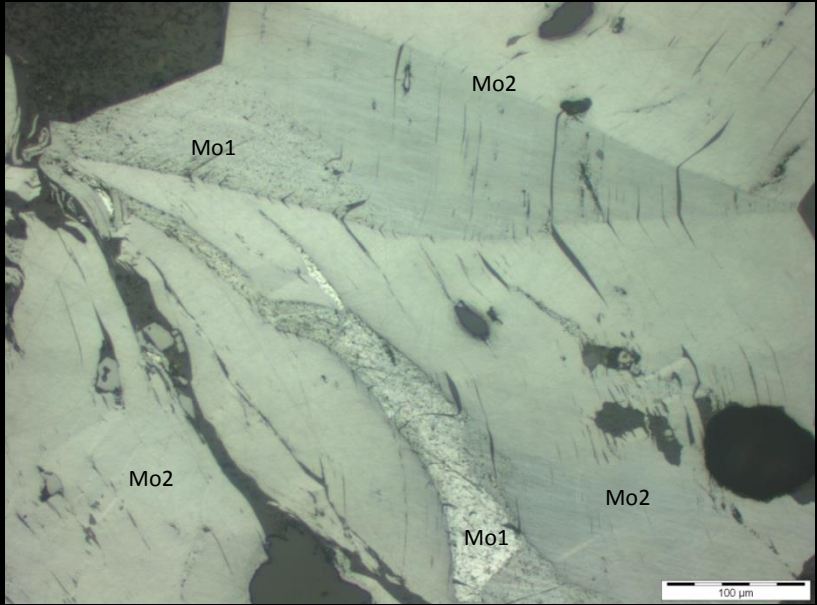
Merlin Deformed Molybdenite

Merlin molybdenite-matrix breccia (from Kirwin, 2009)

Kulthor-Osborne



Merlin Mo1-Mo2, Subira Sharma CODES (2015)



Kulthor
sulphide-dominated
ISCG

Osborne
oxide-dominated
IOCG

Geologically both post-peak metamorphism & BRITTLE, fracture & breccia controlled
Adshead (1995), King (2001), Hinman (2012)

disturbed Re-Os system
Re-depletion > older ages

~~syn-metamorphic, **1.55 Ma** Re-Os molybdenite~~
Gardner et al (2001)

VS

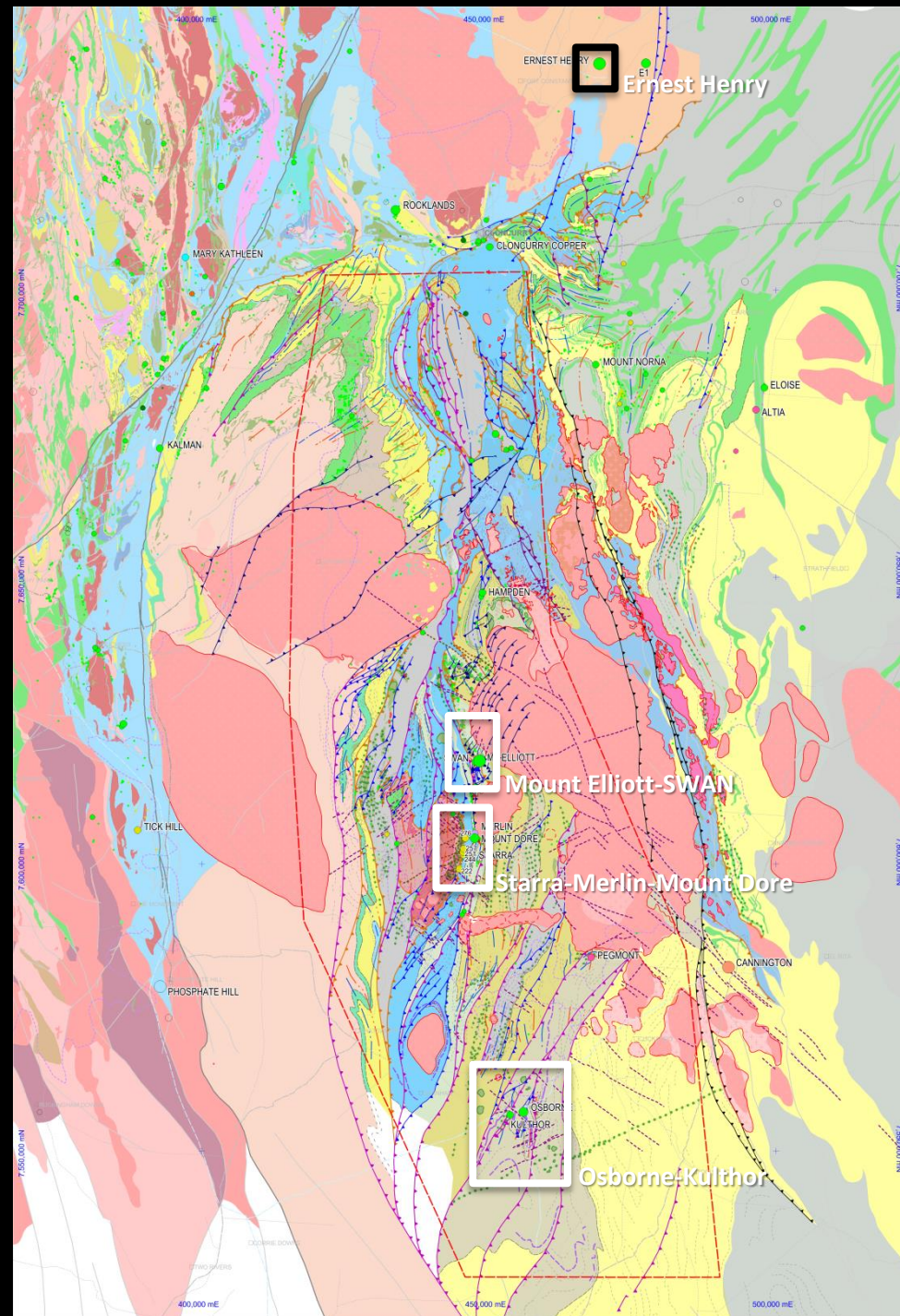
Deposit Controls: District to Local

Four areas

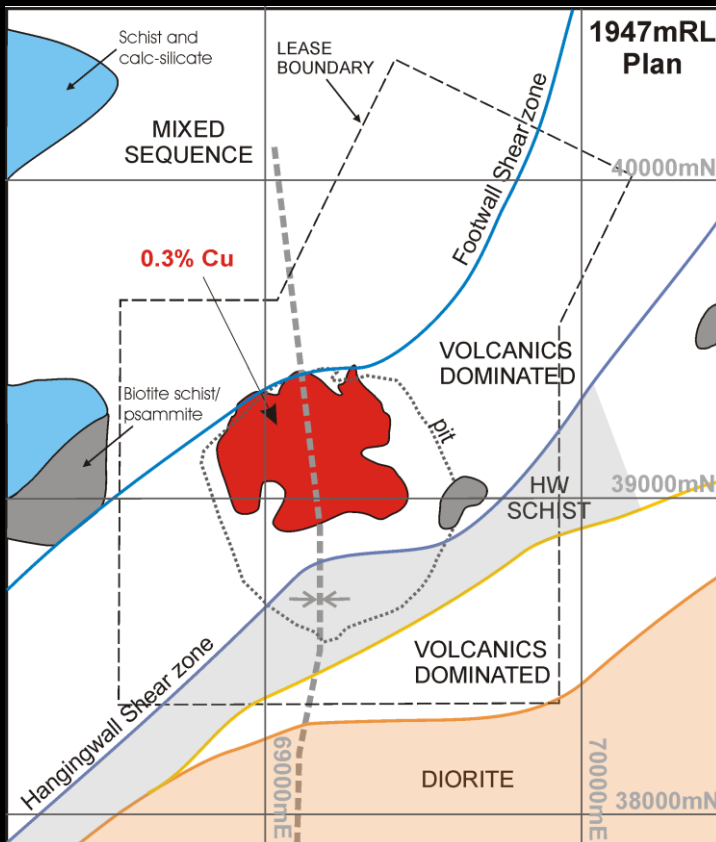
Starra-Merlin-Mount Dore
Mount Elliott-SWAN
Osborne-Kulthor
Ernest Henry

NEXT to Ernest Henry

..... Travis Murphy



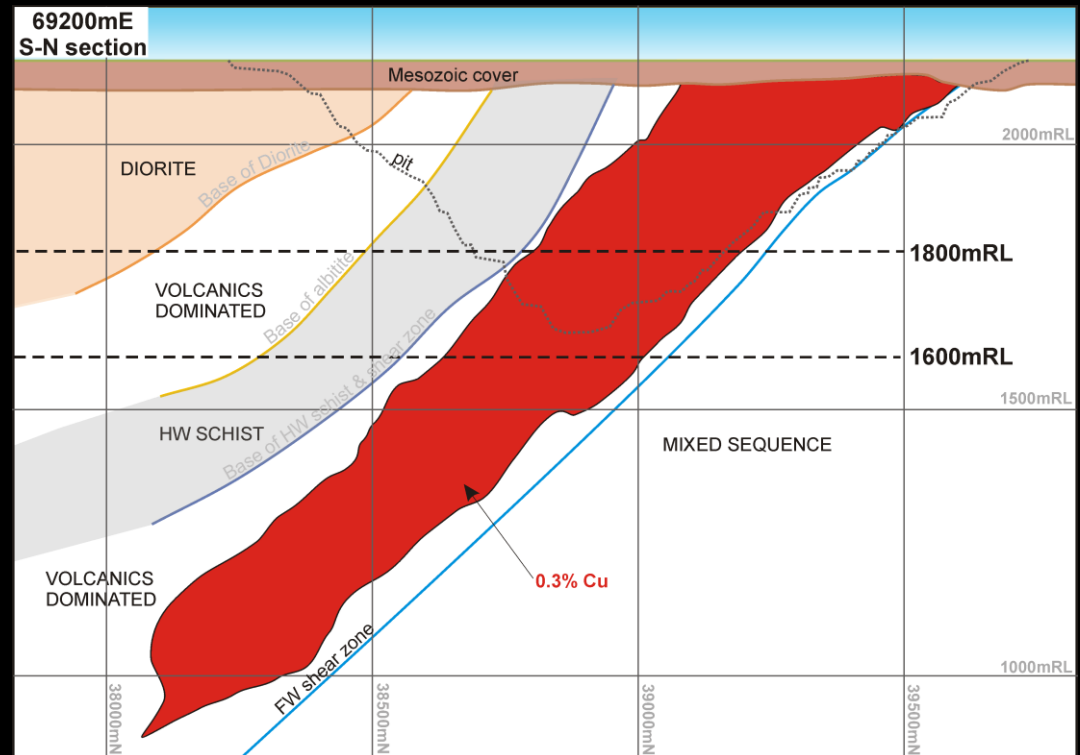
Ernest Henry Mineralisation Controls



Modified after Mark (2006)

- Fault bend or fold? Does it matter?
- Significance of this feature is downplayed in 2D views

- The classic EH cross-section doesn't reveal much regarding the complexity or controls on mineralisation

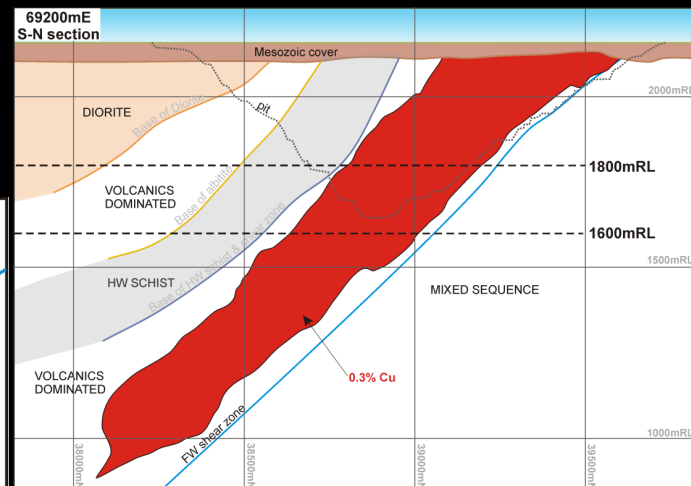
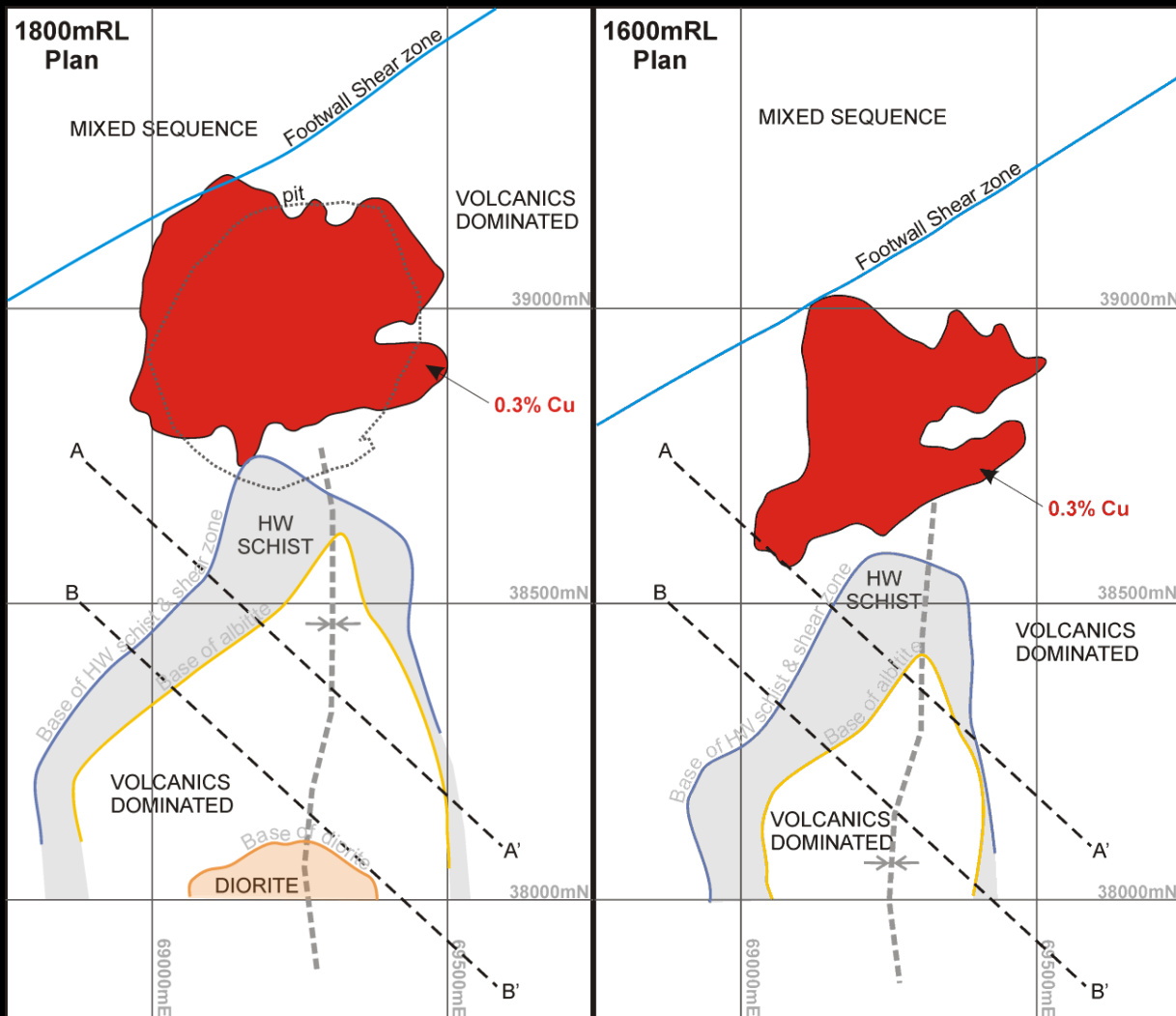




South wall of the Ernest Henry O/C (April 2016)



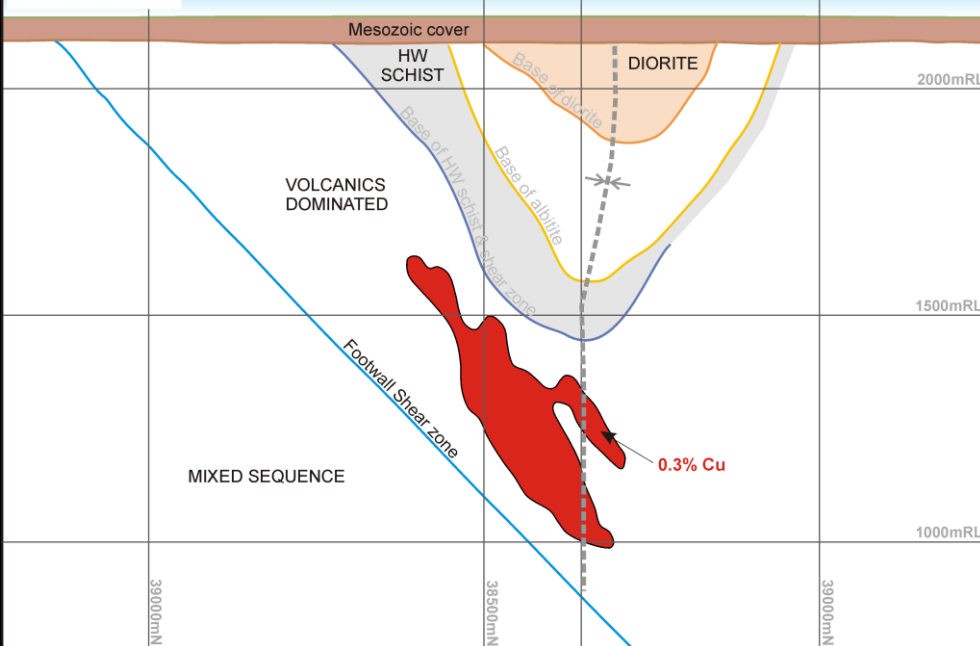
Ernest Henry Mineralisation Controls



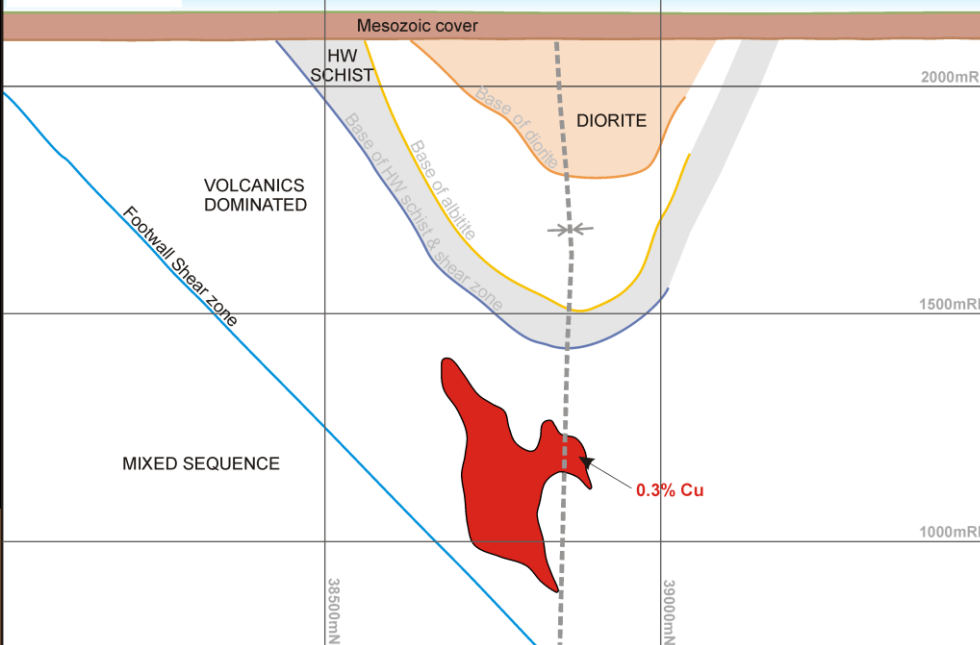
- In plan view, EH becomes less pipe-like; and tabular domains are recognized.
- The plunge of the orebody parallels the fold axis and approximates the hinge position.
- Oblique sections constructed at high angle to both axial trace and tabular domains.



Oblique section
A - A'

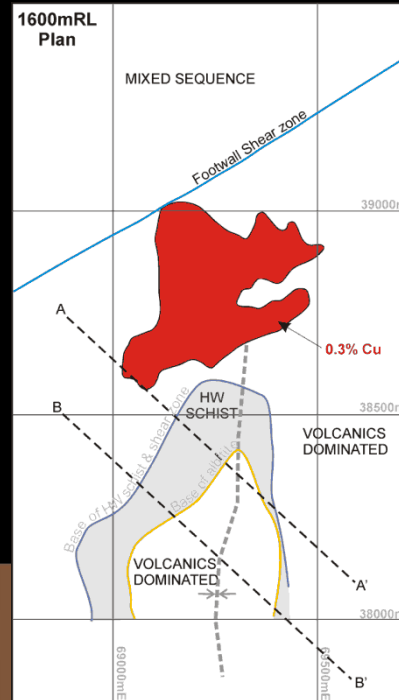


Oblique section
B - B'



Ernest Henry Mineralisation Controls

- In these oblique section views, the orebody is interpreted to be preferentially located on the north-western limb of the fold.
- Empirical relationship suggests that the more brittle volcanic/volcaniclastic sequence had accommodated brittle deformation during D3/4 reactivation/-reworking of an existing D2 fold.



- The role of strain-partitioning around the diorite (and its 3D geometry) is unclear.



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 Structural Silver Bullets

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

ALL in proximity to juxtapositioning of **Redox-contrasting** packages!