‘New insights into the Architectural Development of the southern Cloncurry IOCG Terrain - Controls and Timing of Mineralization’

Mark Hinman
Deep Mining Queensland Project - southern Cloncurry Belt

‘Prospectivity - Mineability - Viability’
Overall aims to reduce risk of exploring for large, mass-mineable deposits at depth in the southern Cloncurry Belt.

Reported here:
(1) Updated solid geology, structural, & tectono-stratigraphic interpretation which builds on the published GSQ 100K solid geology, utilizing the smaller scale prospect geology & detailed geophysics made available by Chinova
(2) Some resource-scale examples of timing and controls on IOCG-style mineralisation

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Acknowledgements
Chinova ... data including detailed geophysics, detailed prospect mapping & project ddh databases
GSQ ... pre-release 100K mapping (Selwyn, Mount Angelay), geochron database
Historic Mapping ... Leishman, 1970s-80s; Searl, 1952; ... & others
Personal ... understanding gained during contract work for Ivanhoe, Inova & Chinova, 2011-2015
Deep Mining Queensland Project Location

Eastern Fold Belt between Cloncurry & Osborne

*approx 180x50km*
Regional vs Detailed Magnetics

Very significant difference in resolution

... has allowed a high fidelity interpretation

> package continuity
> package architecture
> faulting and fine structure
KEY POINTS

DMQ southern Cloncurry IOCG Belt

• IOCG-style mineralisation focuses within late Isan (D3), brittle, fracture-breccia networks that are controlled by local competency contrast & strain partitioning.

• Ore deposition is focused within brittle, breccia/fracture networks that are ubiquitously post-peak metamorphic.

• D3 structuring comprises short-strike / small-displacement faults, and localised reactivation of older structures .... in contrast with, D2 faults which are regional in strike & commonly juxtapose packages of contrasting lithology & age.

(Dichotomy: D2 structure well imaged (mapping, seismic, geophysics ..) cf. D3 structures, likely highly seismic, but generally not well imaged!)

• In D3 time, crystallising granites (that drive the high temp, IOCG fluid systems) themselves locally play roles in strain partitioning which drives the brittle failure focusing IOCG mineralisation.

• Pre-orogenic architectures likely play critical roles in the geometries of intrusion, brittle deformation, IOCG fluid circulation, & the localisation of ore formation.
Tectono-Stratigraphic Development of Eastern Fold Belt

Updated 2000 NWQMP Tx Chart
to reflect current understanding of EFB package relationships & latest geochronology (Withnall-Parsons, 2007-2009; NWQMEP, 2011)

Re-built EFB Solid Geology
highlighting packages & deformation events that impact their geometry
~1775-1765Ma

**Bulonga**

- **Argylla**
- **Kalkadoon**
- **Leichardt Volcs**
- **Barramundi**

**Legend:**
- FRF = Fountain Range Fault
- PFZ = Pilgrim Fault Zone
- HT = Highway Thrust
- OF = Overhang Fault
- CF = Cloncurry Fault
Marraba-Mitakoodi-Double Crossing Meta

~1765-1755Ma

Marraba-Mitakoodi-DCM

Bulonga Argylla

Kalkadoon Leichardt Volcs

Barramundi

SMI BRC
W&H Bryan Mining & Geology Research Centre

F Fountain Range Fault
PFZ Pilgrim Fault Zone
HT Highway Thrust
OF Overhang Fault
CF Cloncurry Fault
~1755-1740 Ma

Corella

Marraba-Mitakoodi-DCM
Bulonga
Argylla

Kalkadoon
Leichardt Volcs

Barramundi

FRF = Fountain Range Fault
PFZ = Pilgrim Fault Zone
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11

WONGA Extension
~1740-1745Ma
Mount Fort Constantine Volcanics

~1740Ma

Kalkadoon
Leichardt Volcs

Barramundi

Wonga
MFCV

OF = Overhang Fault
CF = Cloncurry Fault

FRF = Fountain Range Fault
PFZ = Pilgrim Fault Zone
HT = Highway Thrust
OP1 Deformation

APWP for the Palaeo-MesoProterozoic of Northern Australia (Idnurm, 2000)

FRF = Fountain Range Fault
PFZ = Pilgrim Fault Zone
HT = Highway Thrust
OF = Overhang Fault
CF = Cloncurry Fault
~1710 Ma
Roxmere

SMI BRC
W.H. Bryan Mining & Geology Research Centre

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Wonga
MFCV

Kalkadoon
Leichardt Volcs

Barramundi

Roxmere

OP1
WONGA
Marra Mitakoodi DCM
Bulonga
Argylla

Fraser Fault

FRF = Fountain Range Fault
PFZ = Pilgrim Fault Zone
HT = Highway Thrust
OF = Overhang Fault
CF = Cloncurry Fault
~1710-1680Ma

Kuridala-Starcross-Llewelyn

FRF = Fountain Range Fault
PFZ = Pilgrim Fault Zone
HT = Highway Thrust
OF = Overhang Fault
CF = Cloncurry Fault
~1680-1670Ma

New Hope-Mt Norna

Wonga MFCV
Kalkadoon Leichardt Volcs
Barramundi

New Hope-Mt Norna
Kuridala-Starcross-Llewelyn Boxmore Stavely OP1 WONGA Marraba-Mitakoodi-DCM Bulonga Argyilla

FRF = Fountain Range Fault
PFZ = Pilgrim Fault Zone
HT = Highway Thrust
OF = Overhang Fault
CF = Cloncurry Fault
~1670-1650Ma
Answer-Toole Creek

Wonga MFCV
Kalkadoon Leichardt Volcs
Barramundi

Answer-Toole Creek
New Hope-Mt Norna
Kuridala-Starcross-Llewelyn
Boxmore Stavely
OP1
WONGA
Arbilla
Marraba-Mitakoodi-DCM
Bulonga
Argylla

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Whitby Mining & Geology Research Centre
Isan D1 Folding & Thrusting
THIN-SKINNED

~1590-1575Ma

FRF = Fountain Range Fault
PFZ = Pilgrim Fault Zone
HT = Highway Thrust
OF = Overhang Fault
CF = Cloncurry Fault
~1555-1535Ma
Isan D2 Folding
THICK-SKINNED

FRF = Fountain Range Fault
PFZ = Pilgrim Fault Zone
HT = Highway Thrust
OF = Overhang Fault
CF = Cloncurry Fault
~1555-1535Ma Isan D2 Faulting
THICK-SKINNED

~1545Ma Maramungee

FRF = Fountain Range Fault
PFZ = Pilgrim Fault Zone
HT = Highway Thrust
OF = Overhang Fault
CF = Cloncurry Fault
Williams Suite
~1515-1500Ma
early D3 Faulting

Cu-Au, Au-Cu, Mo-Cu
Williams Suite

~1515-1500Ma

early D3 Faulting

Williams

Saxby
Maramungee

Kalkadoon
Leichardt Volcs

Barramundi

Wonga
MFCV

Quamby

Cu-Au, Au-Cu, Mo-Cu

Surficial ± Formational Fluid Source IOCG Model

~1515-1500Ma

Faulting

Fountain Range Fault

Pilgrim Fault Zone

Highway Thrust

Overhang Fault

Cloncurry Fault

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

Cu-Au, Au-Cu, Mo-Cu

Williams

Saxby
Maramungee

Kalkadoon
Leichardt Volcs

Barramundi

Wonga
MFCV

Quamby

D3

D2

D1

Answer-Toole Creek
New Hope-Mt Norna
Kuridala-Starcross-Llewelyn
Boxmore Steavley
OP1
WONGA
Lamilla
Marraba-Mitakoodi-DCM
Bulonga
Argylla

OF = Overhang Fault

CF = Cloncurry Fault

Fountain Range Fault Zone
Williams Suite

~1515-1500 Ma

late D3 Faulting

~1505-1490 Ma

Quamby

Cu-Au, Au-Cu, Mo-Cu

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

~1515-1500Ma Williams Suite

~1530Ma Saxby

~1545Ma Maramungee

Surficial ± Formational

Fluid Source IOCG Model

Williams Suite - HEAT source - circulation driver

Isan D3 - BRITTLE, shallow crustal deformation

Quamby Basin - continental, oxidised, evaporitic?

>> IOCG Mineralisation

Barton & Johnson (2004), Williams et al. (2005), Williams et al. (2010)
<1500Ma post Isan Faulting widespread
<1500Ma post Isan Faulting widespread & appears to reflect ....

... older, pre-orogenic architectures ‘significant crustal penetration & persistance’

**NE architecture**
Wonga-reactn>MFCV margin
Mitakoodi culmination D2 folding
D1 & D2 deformation partitioning
post-Williams reactn

**NW architecture**
Williams margins
D2 deformation partitioning
post-Williams reactn

**older NNW architecture**
post-Williams reactn

>>> speculated to reflect CoverSeq1 & 2,
and pre-Barramundi (?Archaean) depositional architectures

>>> significant influence on IOCG mineral system geometry
and ultimate sites of metal accumulation in D3

FRF = Fountain Range Fault
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Starra-Merlin-Mount Dore
DMQ Interpretation (2016)
Starra-Merlin-Mount Dore
DMQ Interpretation (2016)

- unconformable onlap of Answer Slate

Gin Creek Granite
Double Crossing Meta
Answer Slate
Post Script: Recent, post conference, field work suggests Leishman’s Answer Slate, west of the Starra Shear, is more likely lower-grade, Double Crossing Metamorphics. A pre-D1 Starra Shear block architecture still exists west of the Starra Line and likely still impacts brittle deformation & mineralisation along the Starra Line in D3-4 time.
Starra-Merlin-Mount Dore
DMQ Interpretation (2016)

- unconformable onlap of Answer Slate
Starra-Merlin-Mount Dore
DMQ Interpretation (2016)
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Starra-Merlin-Mount Dore
DMQ Interpretation (2016)

- unconformable onlap of Answer Slate
- D1 N’ward overthrust of Staveley over Answer
  > EW F1 folds; highly attenuated/folded MIF-HIF
  > preserves FW block architecture
Starra-Merlin-Mount Dore
DMQ Interpretation (2016)

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- D2 folding of D1 overthrust into vertical
  > F1 fold sub-vertical vs sub-horiz F2 folds
Starra-Merlin-Mount Dore
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  - F1 fold sub-vertical vs sub-horiz F2 folds
- D3 shortening: transpressive BRITTLE reactivation
  - at Starra, footwall architecture contribution to fract-bx
  - at Merlin-Mt Dore, strain intensification

Mount Dore Granite

Answer Slate

Kuridala Fm

Roxmere Quartzite

Staveley Fm

Double Crossing Meta

Gin Creek Granite

Eastern Fold Belt Timespace
Starra-Merlin-Mount Dore
DMQ Interpretation (2016)

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Starra-Merlin-Mount Dore

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  > at Merlin-Mt Dore, strain intensification
- post-mineral reverse faulting of MDG over M-MD

Mount Dore Granite

D3

D2

D1

Answer Slate

Kuridala Fm

Roxmere Quartzite

Staveley Fm

WONGA

Double Crossing Meta

Gin Creek Granite

Eastern Fold Belt Timespace
Starra Line - Long Section

2012 Resource Model - mined/probable
Mt Dore - Cross Section
7,604,600N

Gradational stratigraphy:
Staveley-Roxmere-(SF)-Kuridala
Kuridala: carb silt dominant
Gradational stratigraphy: Staveley-Roxmere-(SF)-Kuridala
Kuridala: carb silt dominant

D3 Faulting: complex, curvilinear, anastomosing
Mt Dore - Cross Section
7,604,600N

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Staveley-Roxmere-(SF)-Kuridala
Kuridala: carb silt dominant

D3 Faulting:
complex, curvilinear, anastomosing

Brittle, fracture & breccia
Damage Zones ...

Hinman, 2012
Mt Dore - Cross Section
7,604,600N

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Staveley-Roxmere-(SF)-Kuridala
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D3 Faulting:
complex, curvilinear, anastomosing

Brittle, fracture & breccia
Damage Zones ...
... in carbonaceous silts
& along reactivated contacts
.. host Cu mineralisation
Gradational stratigraphy: Staveley-Roxmere-(SF)-Kuridala
Kuridala: carb silt dominant

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Brittle, fracture & breccia Damage Zones ...
... in carbonaceous silts & along reactivated contacts
... host Cu mineralisation

D3 Faults ... small throws!
NOT Regional Structures
Mt Dore - Cross Section
7,604,600N

Gradational stratigraphy:
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Brittle, fracture & breccia Damage Zones ...
... in carbonaceous silts & along reactivated contacts .. host Cu mineralisation

D3 Faults ... small throws!
NOT Regional Structures

Granite Reverse Fault
highly planar, post-mineral, significant throw
Mount Elliott - SWAN
Close proximity to D1 structure

... juxtaposes, with significant HW truncations, strong mag-character package against benign Staveley-Kuridala packages
Toole Creek SWAN diorite

Staveley Fm (calc-silicates)

Kuridala Fm (schists)

Squirrel Hills Granite

Eastern Fold Belt Timespace
SWAN - Mount Elliott - Corbould
2150mRL ... 250m below surface
SWAN - Mount Elliott - Corbould
2150mRL ... 250m below surface
SWAN $0.75\text{eq}\%Cu$
Long Section ... looking SW through SWAN
**SWAN 0.75eq%Cu**

Long Section ... looking SW through SWAN

- post-mineral D3 Faults
SWAN $0.75\text{eq}\%\text{Cu}$

Long Section ... looking SW through SWAN

- post-mineral D3 Faults
- family cuts Squirrel Hills Granites
Kulthor-Osborne
Kulthor-Osborne

[Map of geological formations and locations including New Hope-Mount Norna, Starcross, and Kuridala areas]

New Hope-Mount Norna
Starcross - Kuridala

[Legend for map symbols]
Kulthor-Osborne

- disharmonic D2 folding during high grade metamorphism
  > meta pelites-psammites, amphibolites, MIF
Kulthor-Osborne

- disharmonic D2 folding during high grade metamorphism
  > meta pelites-psammites, amphibolites, MIF

- D2 Faulting ... short limb, transpressive failure .. DUCTILE
Kulthor-Osborne

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- at Kulthor, D2 fault-juxtapositioning of opposite facing limbs
Kulthor-Osborne

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- D3 fault reactivation .. BRITTLE (where lithology allows!)
Kulthor-Osborne

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Kulthor & Osborne Cu-Au

New Hope-Mount Norna
Starcross -Kuridala

WONGA

OP1
Both Kulthor & Osborne associated with similar, siliceous, meta psammitic-siltstone, amphibolite ± MIF packages (BRITTLE)

... in a sea of DUCTILE migmatitic, granoblastic & pegmatitic, interbedded meta-pelites & psammites.
Both Kulthor & Osborne associated with similar, siliceous, meta psammitic-siltstone, amphibolite ± MIF packages (BRITTLE)

... in a sea of DUCTILE migmatitic, granoblastic & pegmatitic, interbedded meta-pelites & psammites.

Kulthor

sulphide-dominated

ISC

Osborne

oxide-dominated

IOCG
Both Kulthor & Osborne associated with similar, siliceous, meta psammitic-siltstone, amphibolite ± MIF packages (BRITTLE)

... in a sea of DUCTILE migmatitic, granoblastic & pegmatitic, interbedded meta-pelites & psammites.

Kulthor
sulphide-dominated
ISCOG

Osborne
oxide-dominated
IOCG

Both post-peak metamorphism & brittle, fracture & breccia controlled
Kulthor Section 8

D2 Faults

Hinman, 2012
Kulthor Section 8

Central Block comprising ....

BRITTLE, siliceous, SULPHIDIC, finely-laminated sediment
amphibolite
psammite-dominant
mixed psammite-pelite

.... in a FW and HW sea of DUCTILE migmatitic, granoblastic & pegmatitic, interbedded meta-pelites & psammites.

Hinman, 2012
Kulthor Section 8

Post-D2 relaxation phase, probably still at high grade ...

mega-coarsely crystalline DOLOMITE
Kulthor Section 8

Post-D2 relaxation phase, probably still at high grade...

mega-coarsely crystalline DOLOMITE

D3 contact reactivation, breccia & fracture network in DOL .. Main or KM Lode
Kulthor Section 8

Post-D2 relaxation phase, probably still at high grade ...

- mega-coarsely crystalline DOLOMITE

- D3 contact reactivation, breccia & fracture network in DOL
- Main or KM Lode
- D3 complex, breccia & fracture zones in thickest DOL
- Central or KC Lodes
Kulthor Section 8

Post-D2 relaxation phase, probably still at high grade...

- mega-coarsely crystalline DOLOMITE

D3 contact reactivation, breccia & fracture network in DOL .. **Main** or **KM Lode**
D3 complex, breccia & fracture zones in thickest DOL .. **Central** or **KC Lodes**

... largely where the **BRITTLE, sulphidic** package juxtaposes the D3 brittly-reactivated FW D2 structure & the thickest development of DOLOMITE
Kulthor Section 8

Post-D2 relaxation phase, probably still at high grade ...

- mega-coarsely crystalline DOLOMITE

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**Abundant local supply of sulphide >> ISCG ore**
Kulthor Section 8

Post-D2 relaxation phase, probably still at high grade ...

**mega-coarsely crystalline DOLOMITE**

D3 contact reactivation, breccia & fracture network in DOL .. **Main** or **KM Lode**
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**Abundant local supply of sulphide >> ISCG ore**
Kulthor-Osborne

Kulthor
sulphide-dominated
ISC

Osborne
oxide-dominated
IOCG

Both post-peak metamorphism & brittle, fracture & breccia controlled
Kulthor-Osborne

Kulthor
sulphide-dominated
ISC

Osborne
oxide-dominated
IOCG

Both post-peak metamorphism & brittle, fracture & breccia controlled

1595Ma Re-Os molybdenite
Gauthier et al (2001)

VS
Merlin
Deformed Molybdenite

Kulthor-Osborne

Kulthor
sulphide-dominated
ISCG

Osborne
oxide-dominated
IOCG

Both post-peak metamorphism & brittle, fracture & breccia controlled

1595Ma Re-Os molybdenite
Gauthier et al (2001)

Merlin molybdenite-matrix breccia (from Kirwin, 2009)
Merlin Mo1-Mo2, Subira Sharma CODES (2015)

Kulthor-Osborne

Both post-peak metamorphism & brittle, fracture & breccia controlled

1595Ma Re-Os molybdenite
Gauthier et al (2001) VS
Merlin Mo1-Mo2, Subira Sharma CODES (2015)

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

**Kulthor-Osborne**
- Sulphide-dominated
- Oxide-dominated

Both post-peak metamorphism & brittle, fracture & breccia controlled

1595 Ma Re-Os molybdenite
- Gauthier et al (2001)

Kulthor
- Deformed Molybdenite

Merlin molybdenite-matrix breccia (from Kirwin, 2009)
Merlin Mo\textsubscript{1}-Mo\textsubscript{2}, Subira Sharma \textsc{codes} (2015)

- **Mo\textsubscript{1}** primarily precipitated, inclusion-rich, Re-rich
- **Mo\textsubscript{2}** deformed-kinked, inclusion-cleared, Re-depleted

Kulthor
- sulphide-dominated ISCG

Osborne
- oxide-dominated IOCG

Both post-peak metamorphism & brittle, fracture & breccia controlled


**1595Ma Re-Os molybdenite**

Gauthier et al (2001)

Disturbed Re-Os system

Re-depletion > older ages
Merlin Mo1-Mo2, Subira Sharma CODES (2015)

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

Kulthor-Osborne

Both post-peak metamorphism & brittle, fracture & breccia controlled

Merlin molybdenite-matrix breccia (from Kirwin, 2009)

1595 Ma Re-Os molybdenite Gauthier et al (2001)
IOCG Process Models

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

Magmatic ± Surficial
Fluid Source

Magmatic brine
(intermediate Br/Cl)
(high Ar/Ar)

Specialised magma
(Cu-rich, CO2-bearing)

Formational ± Surficial
Fluid Source

Bittern brine
(high Br/Cl)

Halite dissolution brine
(low Br/Cl)

Metamorphic ± Surficial
Fluid Source

Metamorphic ± Cl-source
(scapolite-bearing rocks)

Surface or basin derived fluids
Basin to deep-basin derived fluids
Magmatic brines
Metamorphic fluids

Hematite ±Cu ±Au ±U
(cp-br-hem-(mte-py))

Magnetite ±Cu ±Au ±U
mte-(py-cp-ap-hem)

Cooling magma (a), or other heat source (b)
(high heat producing granite)

Uranium source
(fractionated granite)

Copper and iron source
(mafic rocks)

H+ alteration
(sen/musc-chl-opz-hem)

K alteration ±skarn
(ksp-br-mte; cpx-act-grt-mte)

Na (Ca) alteration
(ab-scop-cpx/act-mte)
IOCG Process Models
Barton & Johnson (2004), Williams et al. (2005), Williams et al. (2010)

Magmatic ± Surficial
Fluid Source

Formational ± Surficial
Fluid Source

Specialised magma
(Cu-rich, CO2-bearing)

Magmatic brine
(intermediate Br/Cl)
(high Ar/Ar)

Bittern brine
(high Br/Cl)

Halite dissolution brine
(low Br/Cl)

Surface or basin derived fluids
Basin to deep-basin derived fluids
Magnetic brines
Metamorphic fluids

Hematite ±Cu ±Au ±U
(cp-bi-hem-mte-py)

Magnetite ±Cu ±Au ±U
(mte-py-cp-ap-hem)

Cooling magma (a), or other heat source (b)
(high heat producing granite)

Uranium source
(fractionated granite)

Copper and iron source
(mafic rocks)

H+ alteration
(seen/musc-chl-op-hem)

K alteration ±skarn
(ksp-bi-mte; cpx-act-grt-mte)

Na (Ca) alteration
(ab-xsc-op/cpx/act-mte)
IOCG Process Models

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

Re-Os moly ages ... HANDLE WITH CARE!
IOCG Geochronology

Re-Os moly ages ... HANDLE WITH CARE!

Other isotopic ages on well-constrained, K-alteration minerals directly associated with IOCG-style ore will yield mineralisation timing constraints ...
IOCG Geochronology

Re-Os moly ages ... HANDLE WITH CARE!

Other isotopic ages on well-constrained, K-alteration minerals directly associated with IOCG-style ore will yield mineralisation timing constraints ...

... more in line with the geological observations of:

- Post-peak metamorphism,
- K-alteration overprinting Na-Ca alteration
- D3-4 brittle control, and
- Temporal & spatial association with Williams magmatism
CONCLUSIONS

DMQ southern Cloncurry IOCG Belt

• IOCG-style mineralisation forms via a complex interplay in the geometries of thermally-driven, circulation of (?basinal) brines, and the contemporaneous Isan D3 patterns of brittle, fracture-breccia deformation
CONCLUSIONS

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• IOCG-style mineralisation forms via a complex interplay in the geometries of thermally-driven, circulation of (?basinal) brines, and the contemporaneous Isan D3 patterns of brittle, fracture-breccia deformation

• Local competency contrasts & strain partitioning play critical roles in the geometries of brittle failure & ore localisation
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