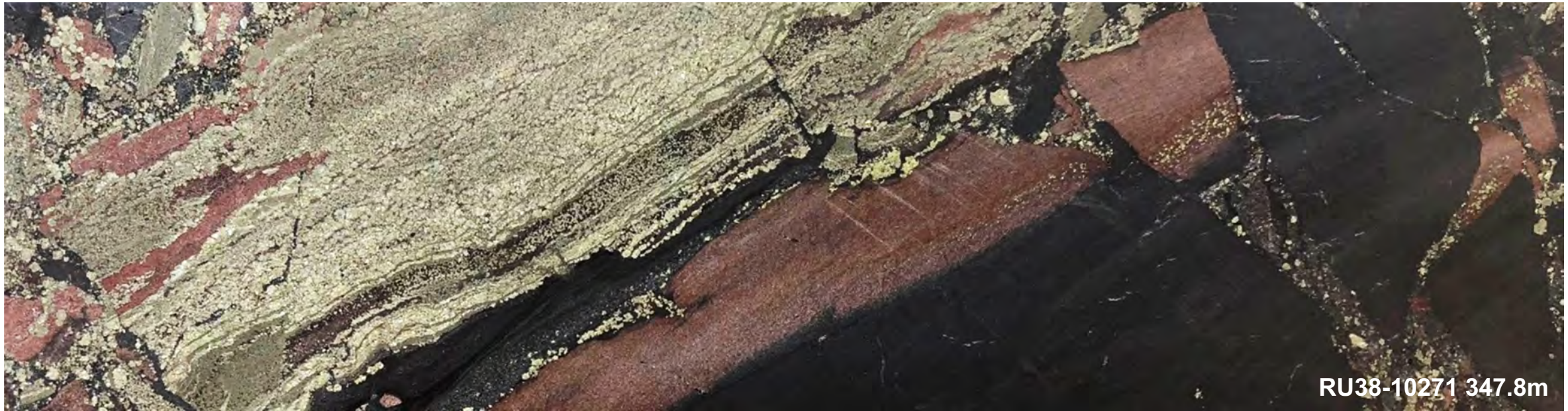
BHP

Insights into the Structural Evolution of Olympic Dam — the not so *boring billion*…

Kathy Ehrig (Superintendent Geometallurgy) and Jesse Clark (Senior Geologist)

29 November 2019 – South Australian Exploration and Mining Conference



Acknowledgements

Disclaimer: The views expressed here are solely those of the presenters

BHP Olympic Dam

- **+130 geoscientists who have worked at Olympic Dam**

University of Tasmania

- Dima Kamenetsky
- Jocelyn McPhie
- Maya Kamenetsky
- PhDs completed: Olga Apukhtina, Qiuyue Huang, Alexander Cherry, Matthew Ferguson
- CODES Laser Ablation Facilities

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Flinders University- Allan Pring

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University of Adelaide

- Nigel Cook
- Cristiana Ciobanu
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- Trace elements in iron oxides project (FOX project)

ARC Industrial Research Transformation Hub

- Copper Uranium Transformation Hub project (IH130200033)
- Transforming the Mining Value Chain project (IH130200004)

ARC Linkage LP130100438- The supergiant Olympic Dam uranium-copper-gold rare earth element ore deposit: towards a new genetic model

ARC Linkage LP160101497- Reverse engineering Nature: metal extraction through mineral replacement

Ore deposit formation and preservation

Olympic Cu-Au Province perspective

✗ PRESERVATION

↑

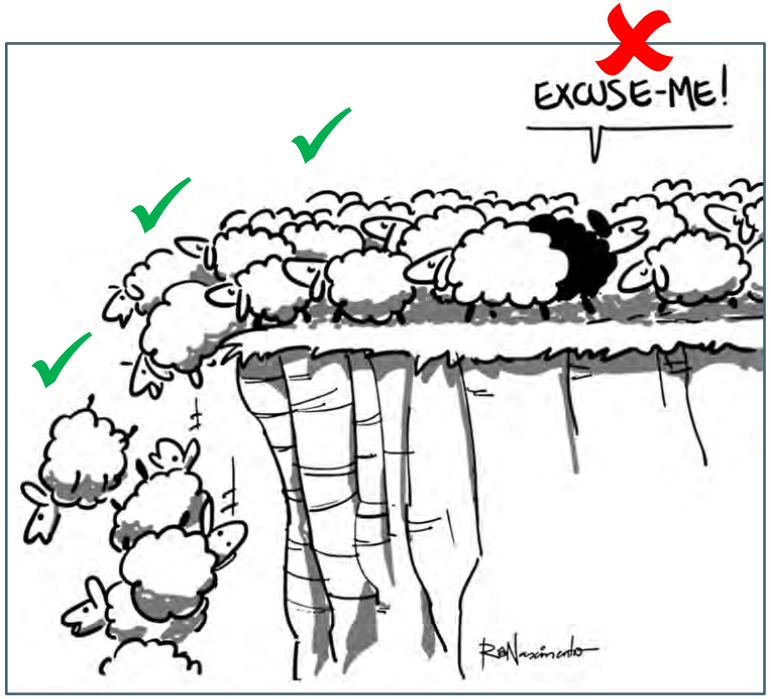
✓✓✓ TRAP

↑

✓✓ TRANSPORT

↑

✓✓✓ SOURCE (metals & energy)



https://www.redbubble.com/people/renascimento/works/26534930-excuse-me-black-sheep?p=canvas-print

Today's presentation

Share our latest geological observations and thoughts:

- summarise previously presented isotopic studies and some recently published dating
- describe deposit structural complexities revealed by recent resource diamond drilling
- our modern attempts to unravel the complex structural evolution of OD
- reflect not only our knowledge gaps, but perhaps those of the wider South Australian geological community.

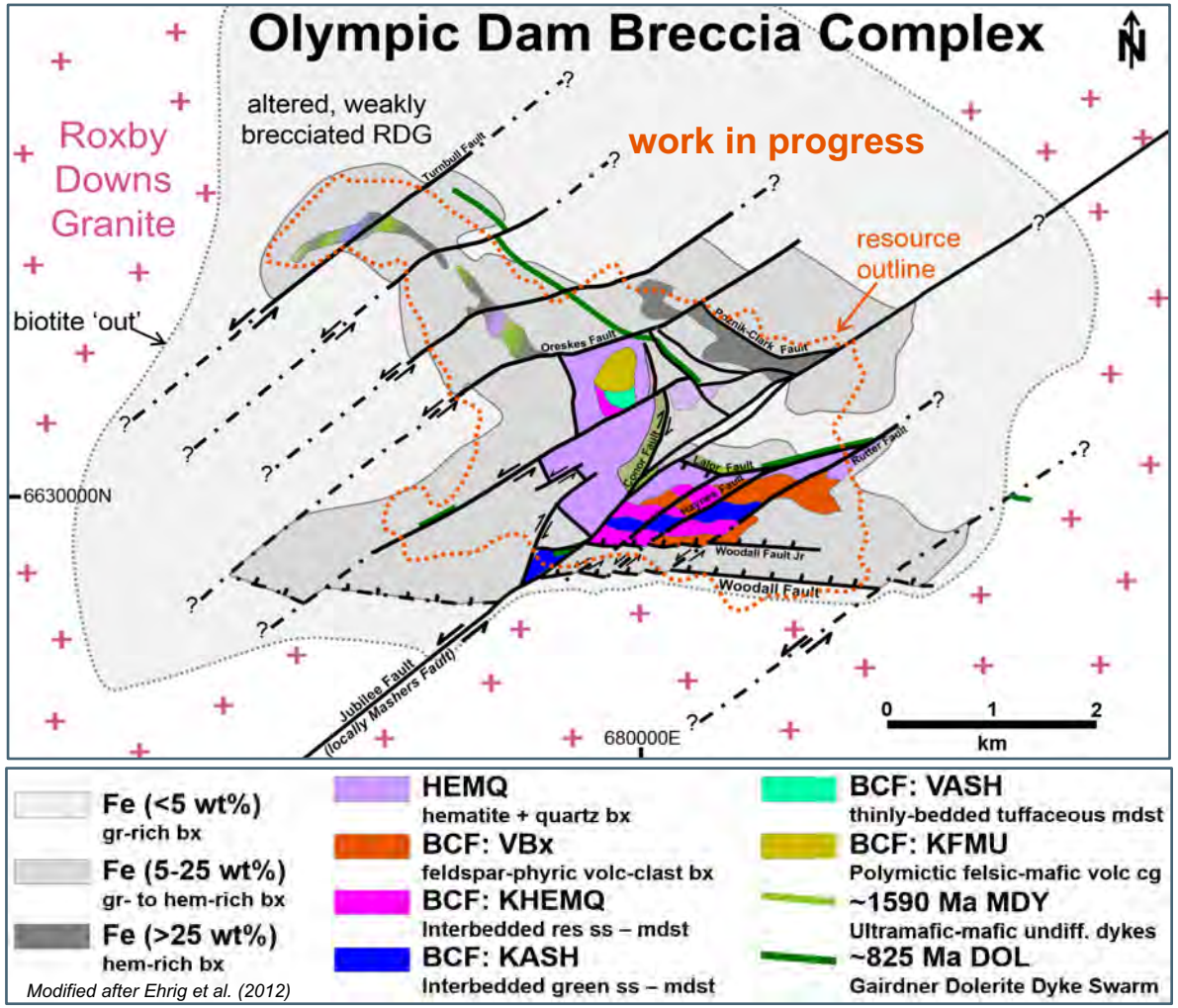
CHALLENGE and perhaps a call to action:

- significant gap in understanding the impact of far-field tectonics on the Stuart Shelf during the ***not so boring billion*** of post 1590 Ma to the Delamerian
- need more focus on **preservation** to discover more mineral deposits on the Stuart Shelf.

(Ken Cross personal communication,
… adapted from a source long forgotten…
However, on deep reflection:
Holden, J.C. and Vogt, P.R., 1977. Graphic solutions to problems of plumacy. EOS Trans. AGU, 58:573-580.

Olympic Dam Cu-U-Au-Ag Deposit

A world class ore deposit, by any definition



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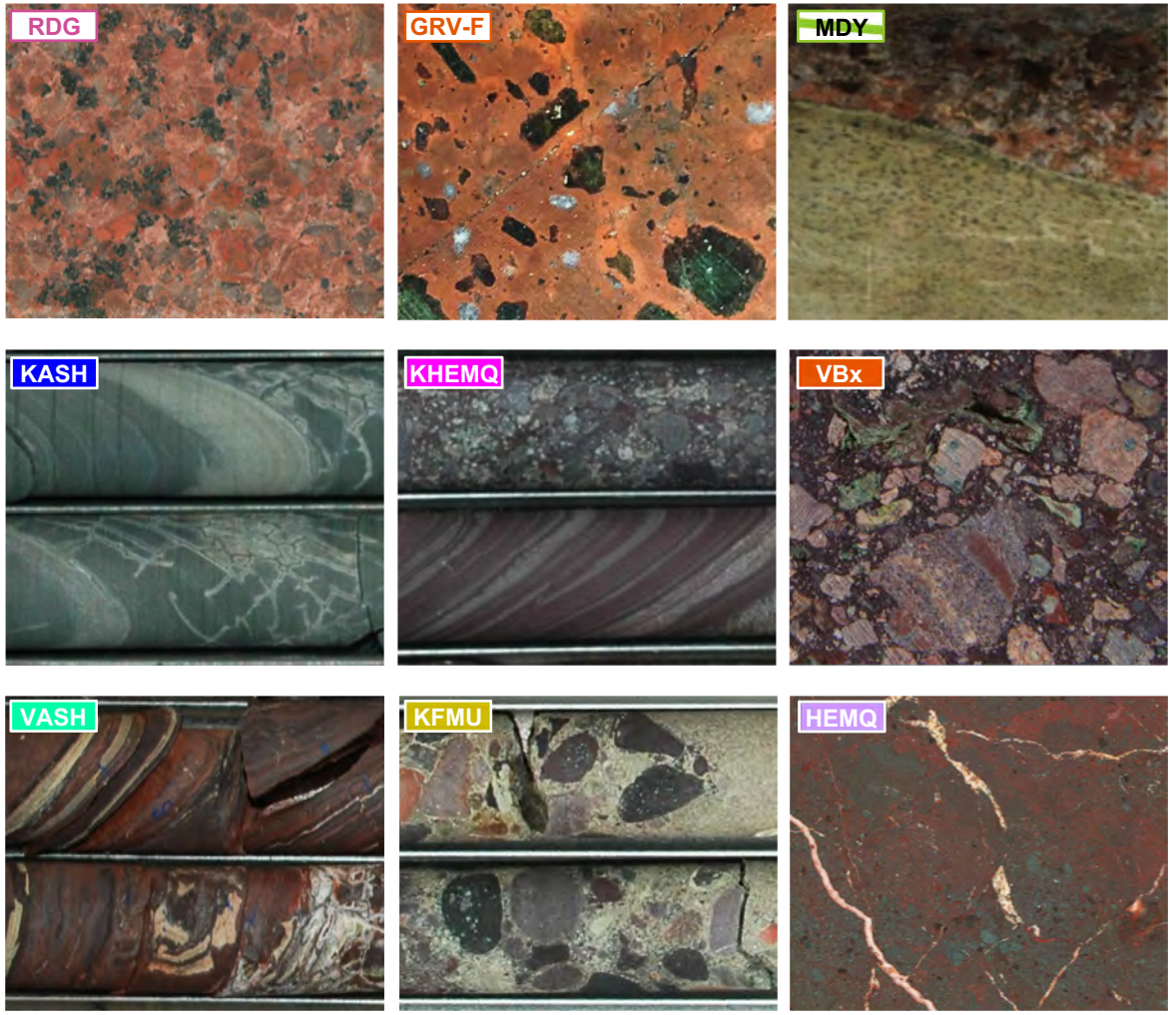
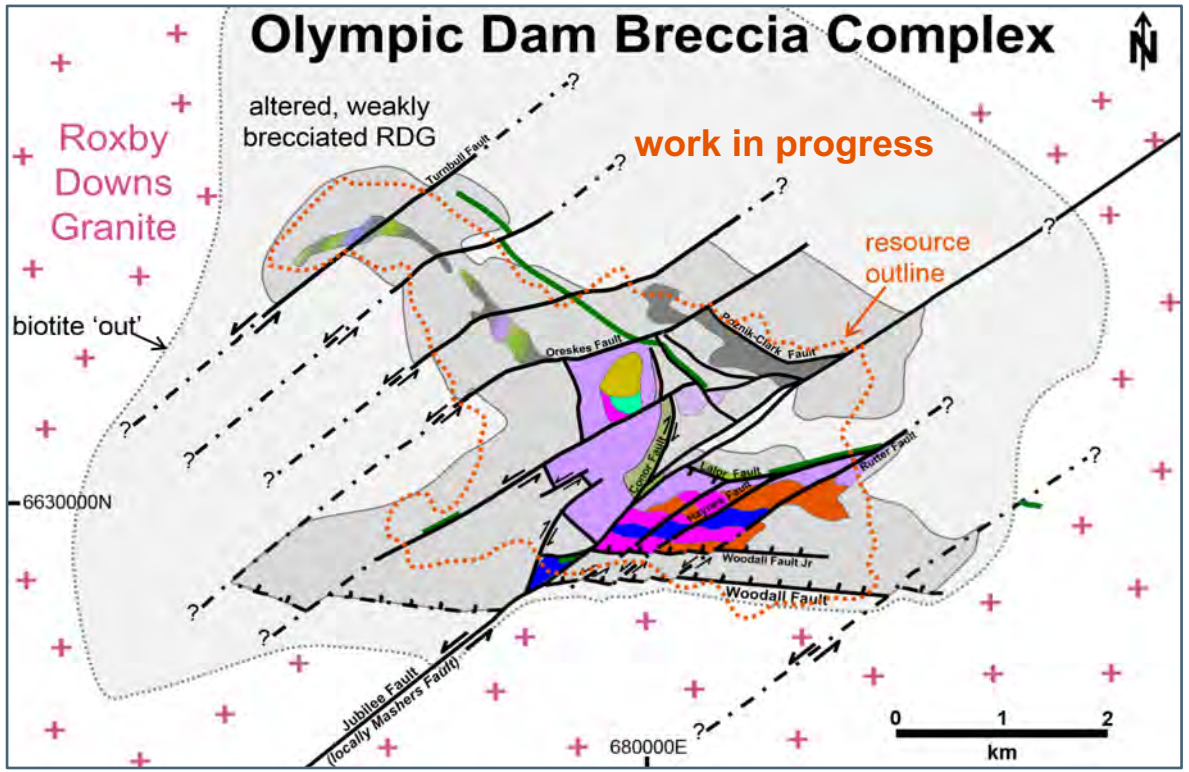


Progressive brecciation and alteration of RDG

Predictability – the granite to HEMQ continuum



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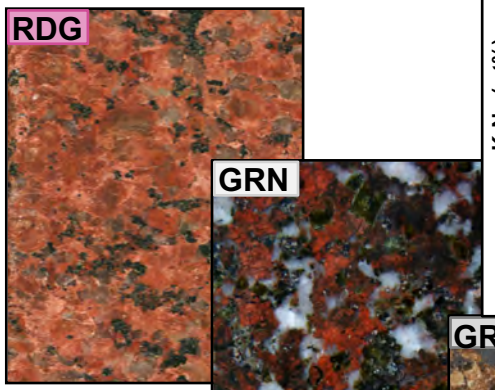
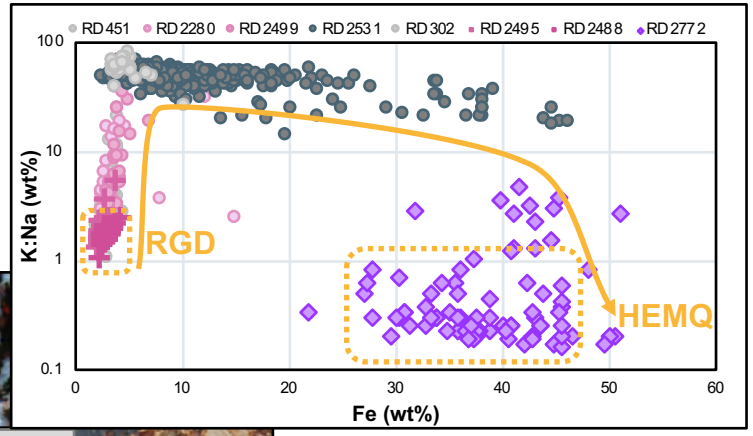
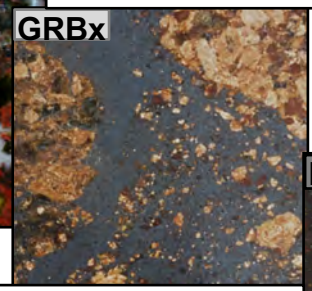
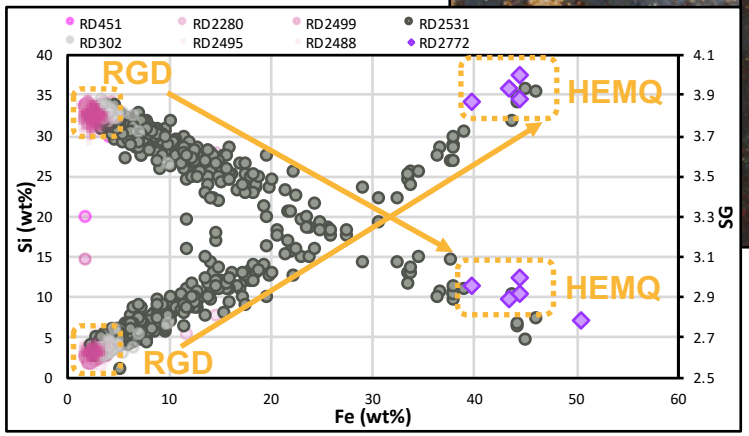
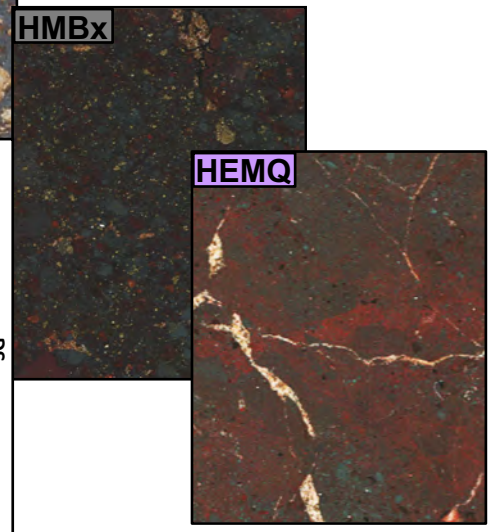






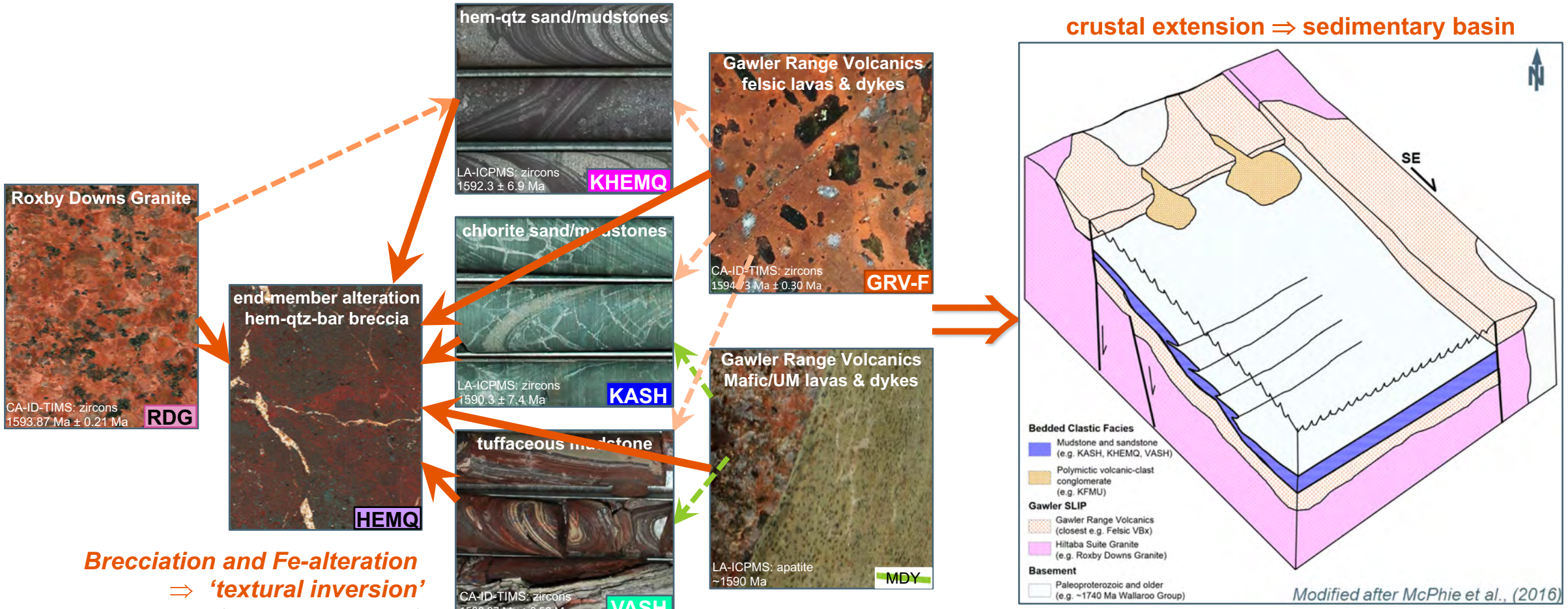




~60 wt% Fe

Subordinate lithologies and their provenance

The key to unlocking the structural evolution of the deposit…



Brecciation and Fe-alteration
⇒ 'textural inversion'
(Reeve et al. 1990)

Zircon and Fe-oxide dating

The main mineralising event at Olympic Dam was ~1590 Ma (no question)

Roxby Downs Granite intruded into and likely partially assimilated:

- ~1760 Ma magnetite-bearing protoliths
- Moonta Group metasediments

– LA-ICPMS using world's first hematite geochronology standard

Courtney-Davies *et al.* (2019, submitted to Ore Geology Reviews)

Ages of:

- felsic GRV lava clasts at OD
- Roxby Downs Granite
- felsic GRV ash at OD

– well constrained by high precision ID-TIMS

Cherry *et al.* (2017)

Courtney-Davies *et al.* (2019, submitted to Economic Geology)

Hematite ages:

- 1591.27 ± 0.89 Ma
- ~1-2 Ma of youngest magmatic zircon

– well constrained by high precision ID-TIMS

– world's first ID-TIMS age on hematite

Courtney-Davies *et al.* (2019)

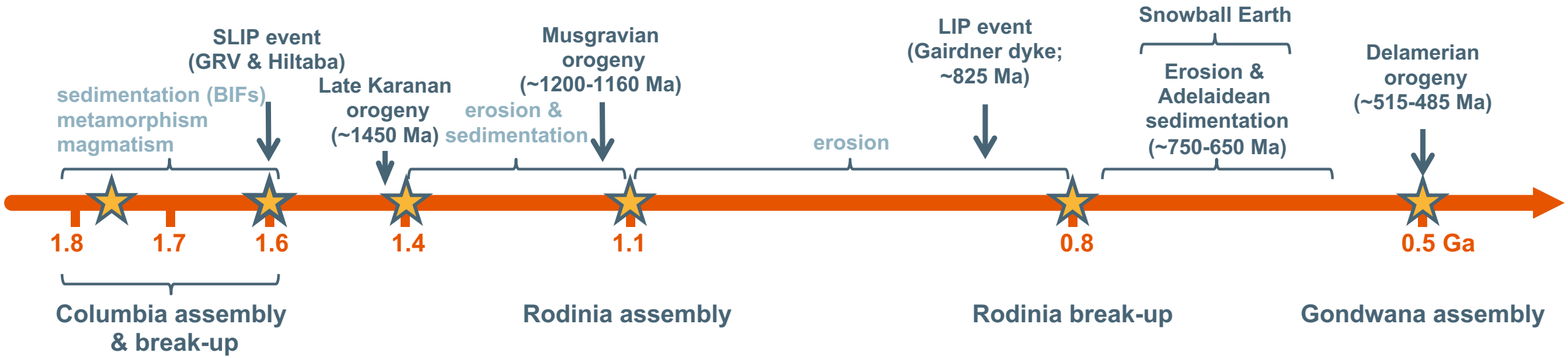
Courtney-Davies *et al.* (2019, submitted to Economic Geology)

Uraninite dating and the Pb-isotope story

Link to continental scale tectonics

Uraninite ages, textures, REY patterns, trace element chemistry, high precision $^{238}U/^{235}U$, Pb- and Sm-isotope, and Pb-isotopes on sulfides:

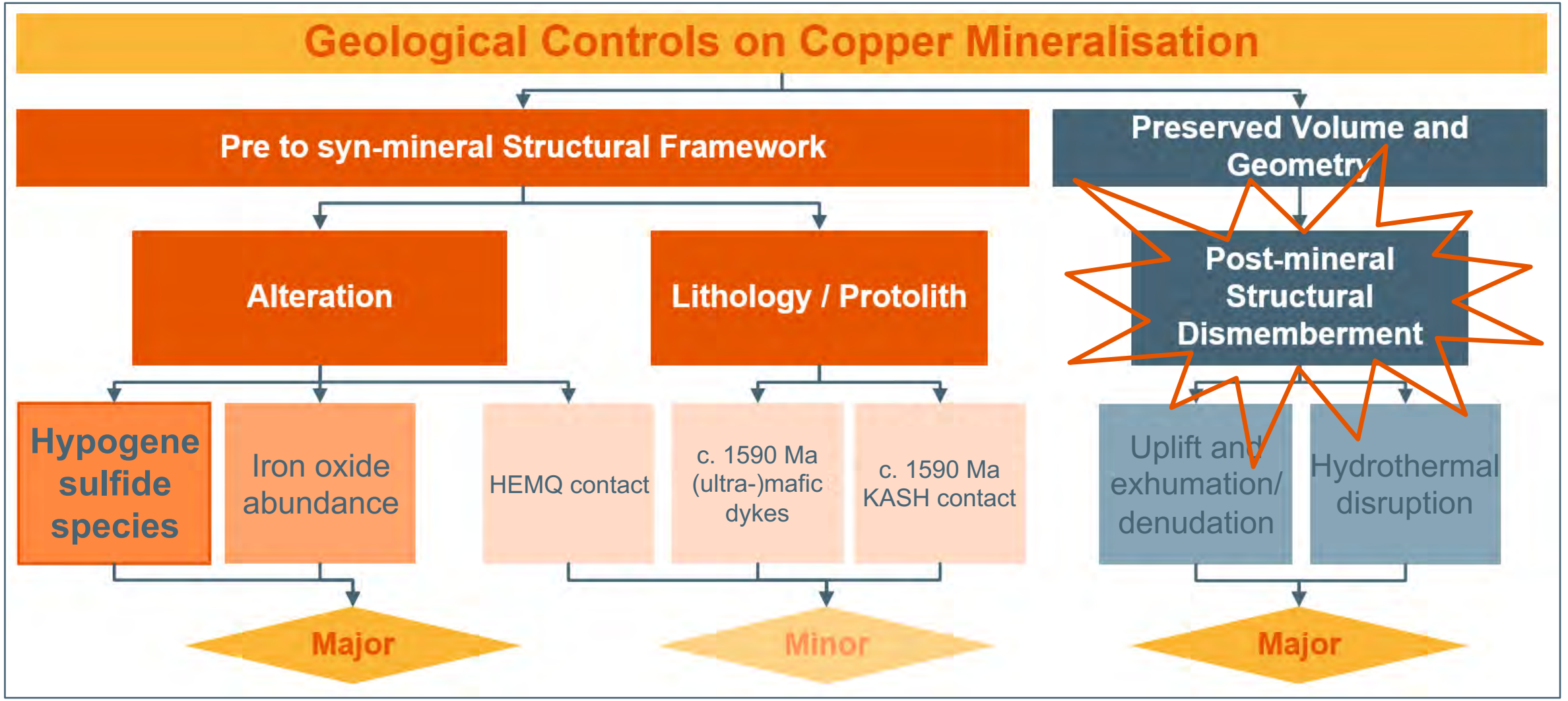
- Remobilisation of ~1590 Ma uranium until the Delamerian, with possibility of minor U addition ~1200-1100 Ma
- Significant addition (or remobilisation) of uranium into Olympic Dam during the Delamerian
- Pb-isotopes → deposit-scale re-crystallisation of the sulfides ~1100 Ma



Key times in the complex geological evolution of Olympic Dam

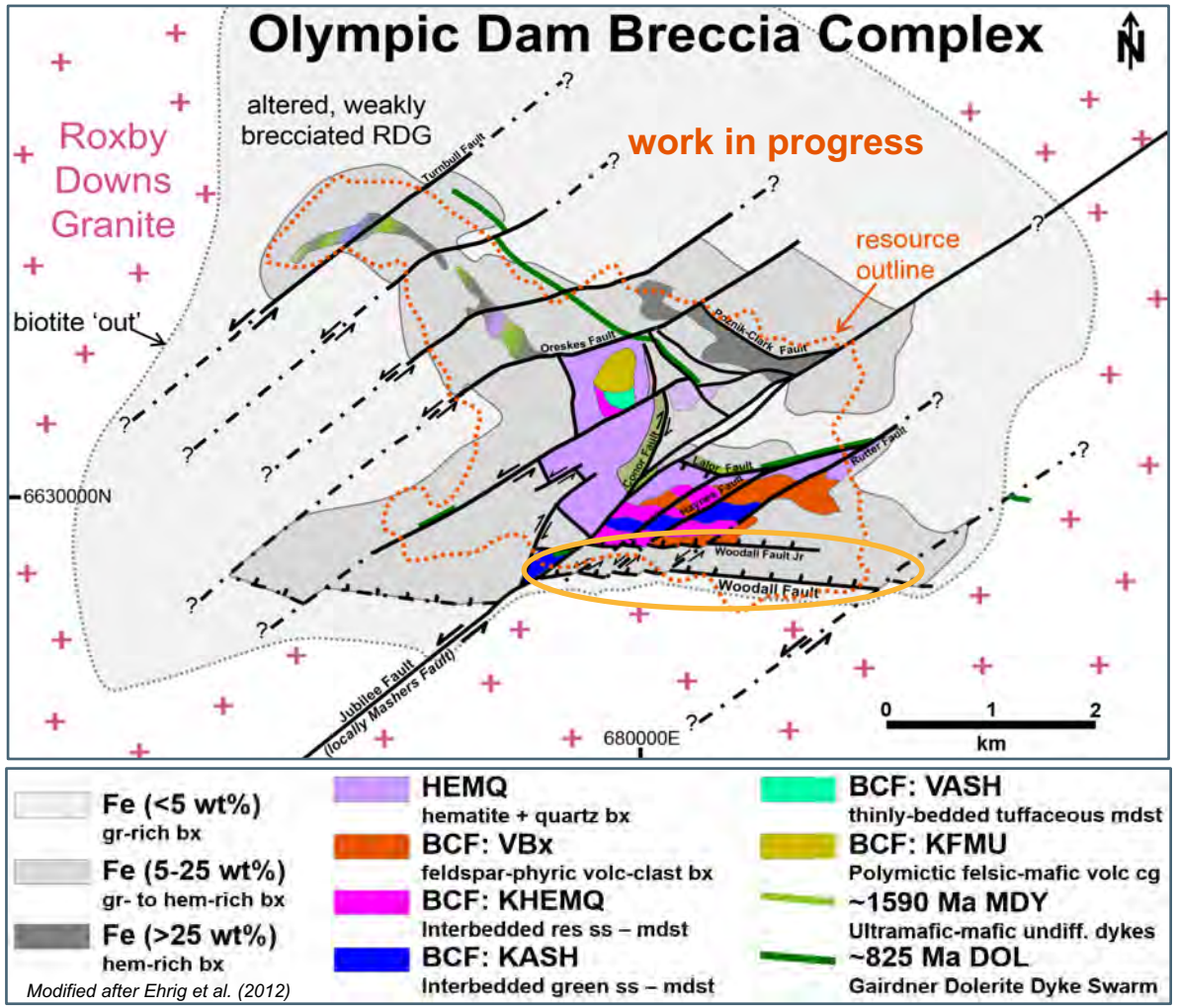
Controls on Mineralisation

Well understood - one major and three minor controls on mineralisation



Post-mineral preservation is paramount

Preservation of the shallowest parts of the IOCG mineralizing system is critical



Modified after Ehrig et al. (2012)

The outer margins of the ODBC are defined by the last occurrence of biotite in 'fresh' RDG

- Altered RDG does occur in the area label as RDG, but biotite does not occur within the ODBC.
- In the northern part of the ODBC, transition from >5% Fe contour to the edge of the ODBC occurs over lateral distances of at least 2-3 kms.
- Thus, it is reasonable to expect an alteration envelop of several kms wide around the deposit.
- However, in the southern ODBC, this transition occurs over a distance <500 m – 1 km.

Possible explanations:

- Fault with at least several kms of lateral offset…, but no preserved evidence of this in the regional geophysics

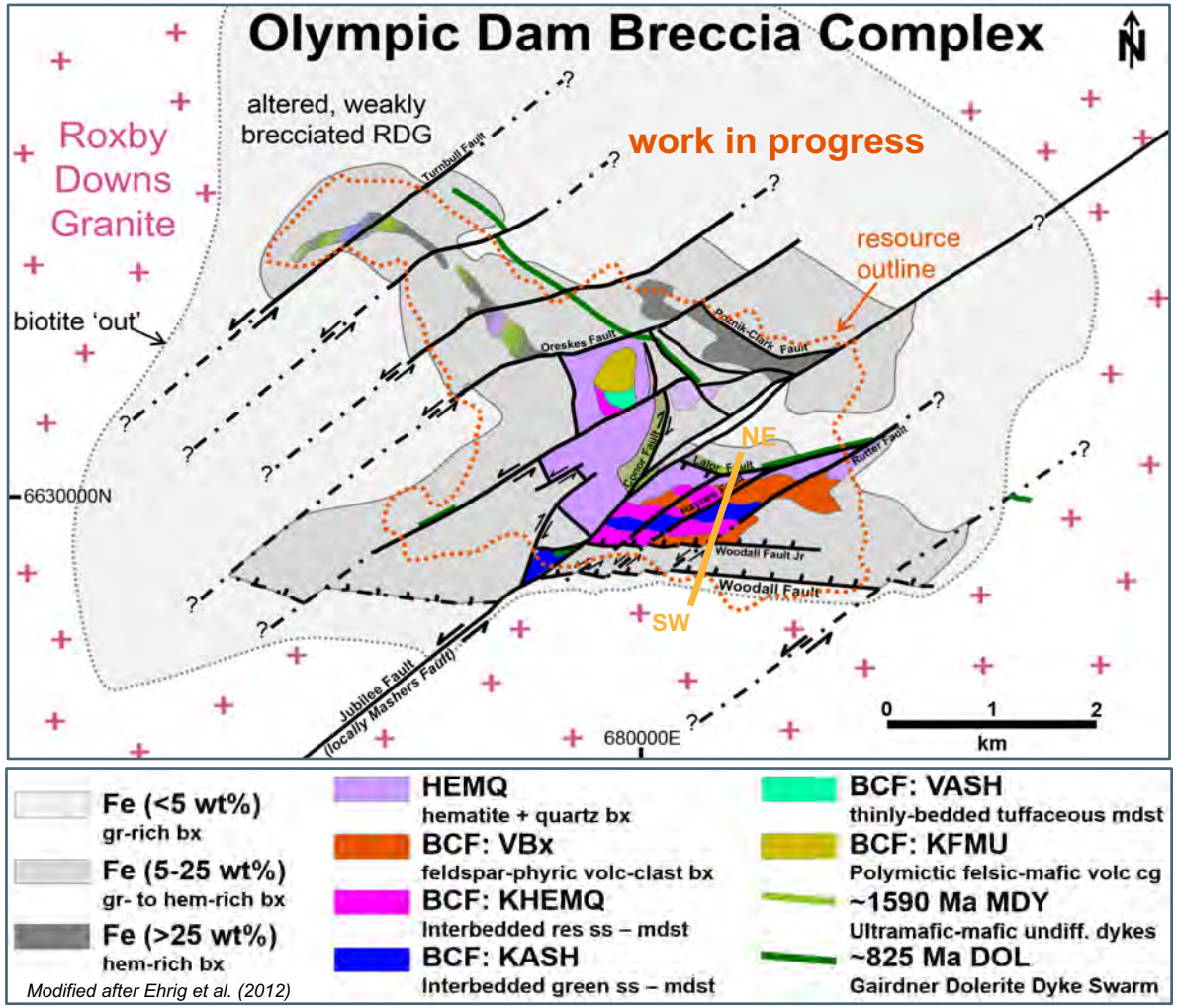
OR

- RDG south of the ODBC was uplifted at least 2-3 km relative to the ODBC. This also helps to explain why BCF near the southern margin of the ODBC occurs at a depth >1.8 km.

➢ Woodall Fault series

Olympic Dam Cu-U-Au-Ag Deposit

A world class ore deposit, by any definition



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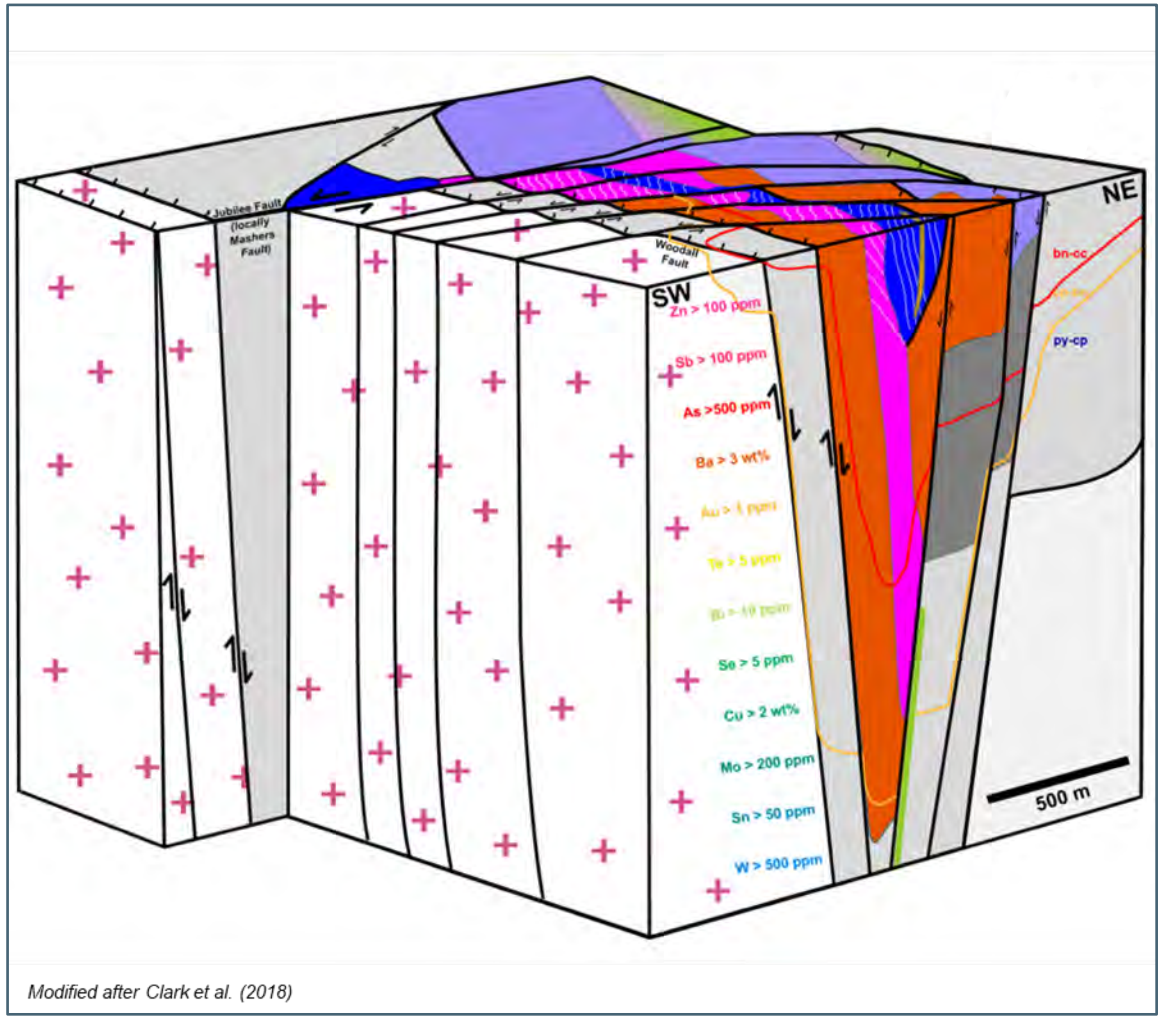
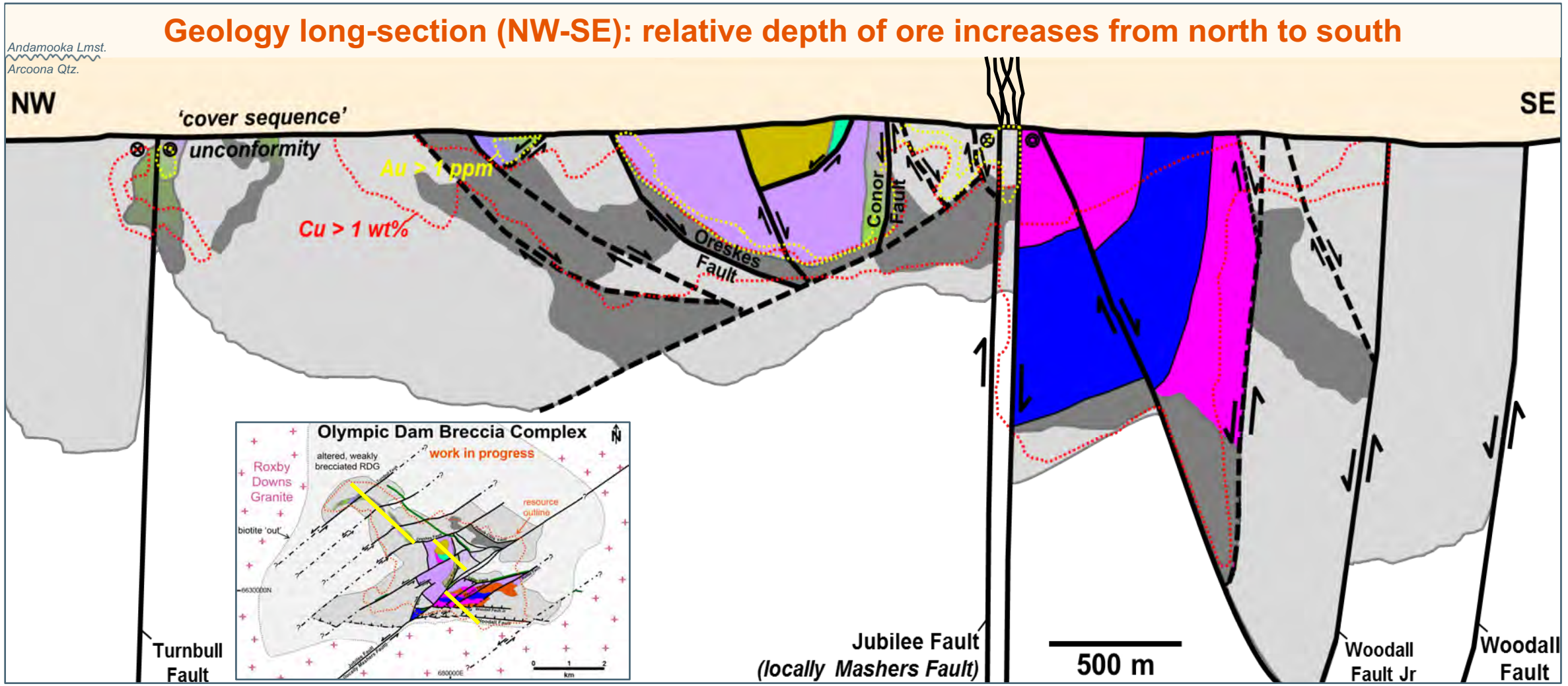


Modified after Clark et al. (2018)

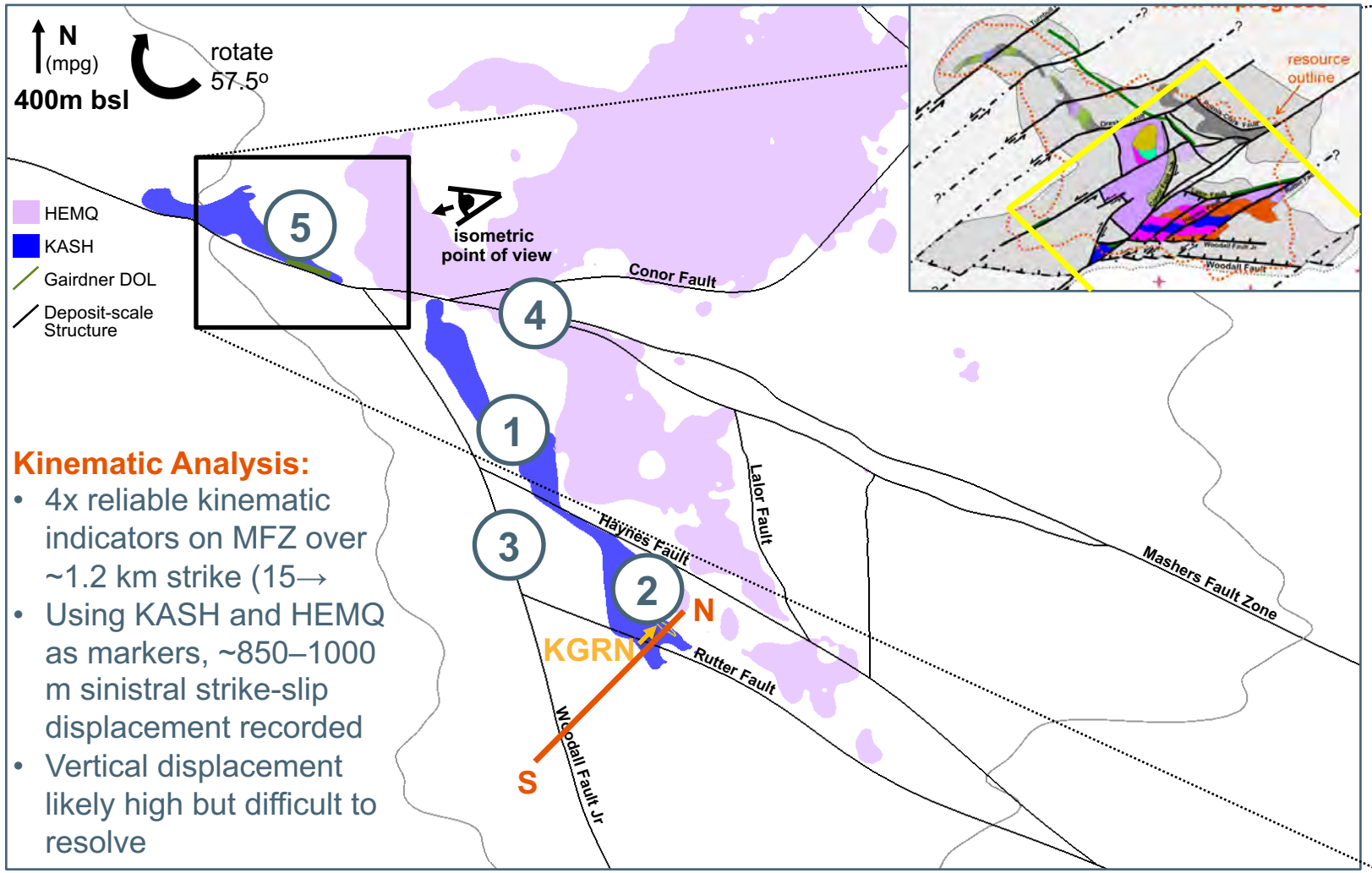
Insights into post-mineral structural disruption

Burial & orebody dislocation is the most fundamental control to present-day geometry



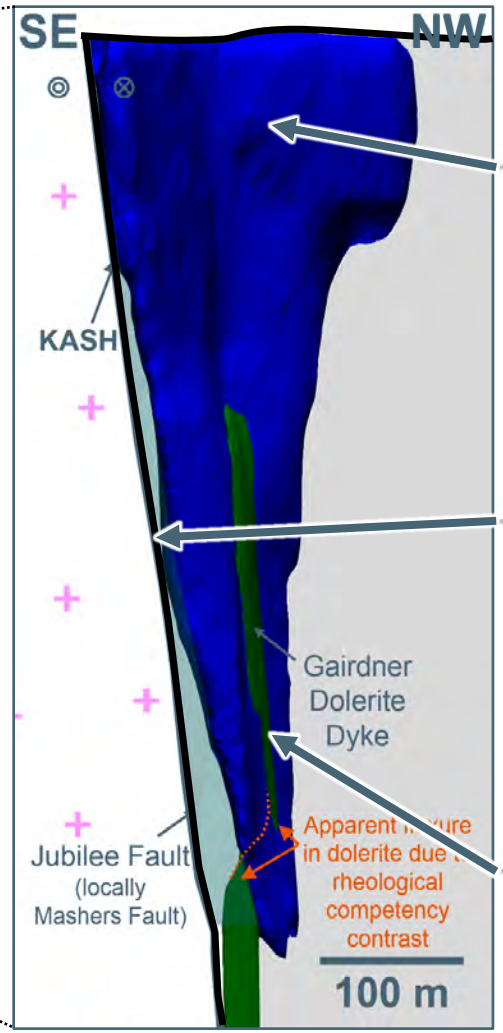
Insights into post-mineral structural disruption

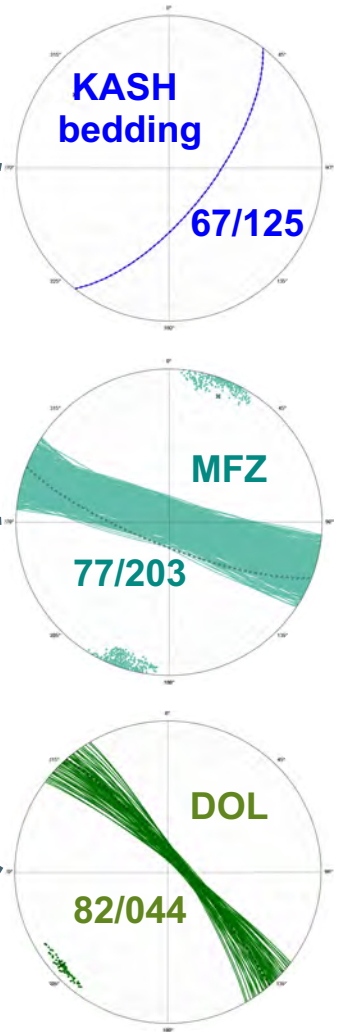
Major transtensional dislocation of tilted ~1590 Ma BCF sediments



Kinematic Analysis:

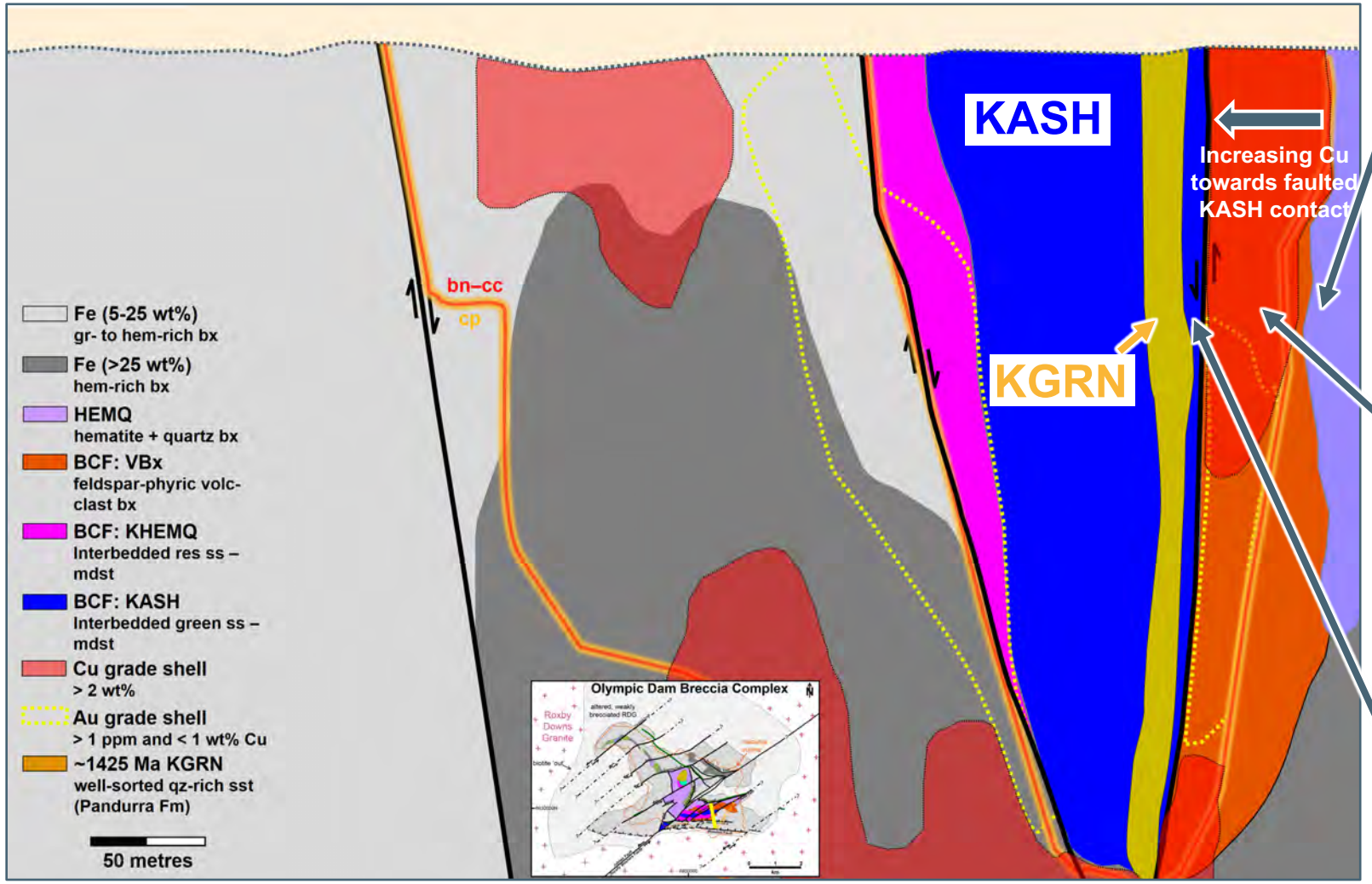
- 4x reliable kinematic indicators on MFZ over ~1.2 km strike (15→
- Using KASH and HEMQ as markers, ~850–1000 m sinistral strike-slip displacement recorded
- Vertical displacement likely high but difficult to resolve

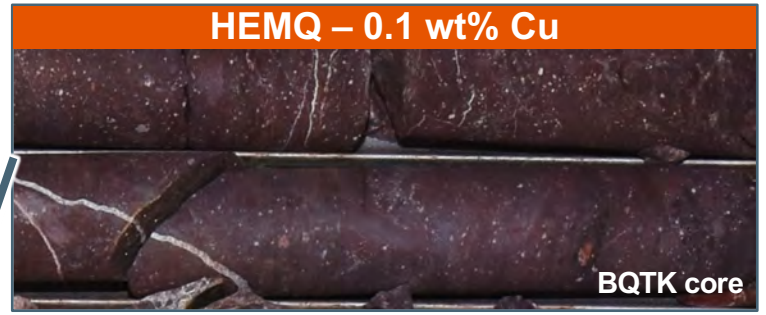




KASH lithology: minor local-scale ore control

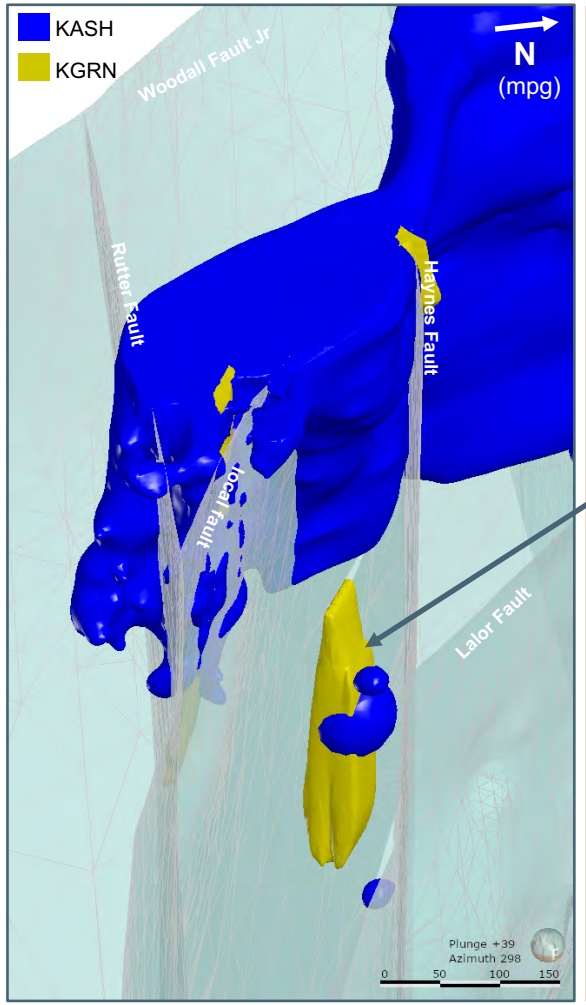
Highly chemically reactive protolith down-faulted during post-mineral structural deformation

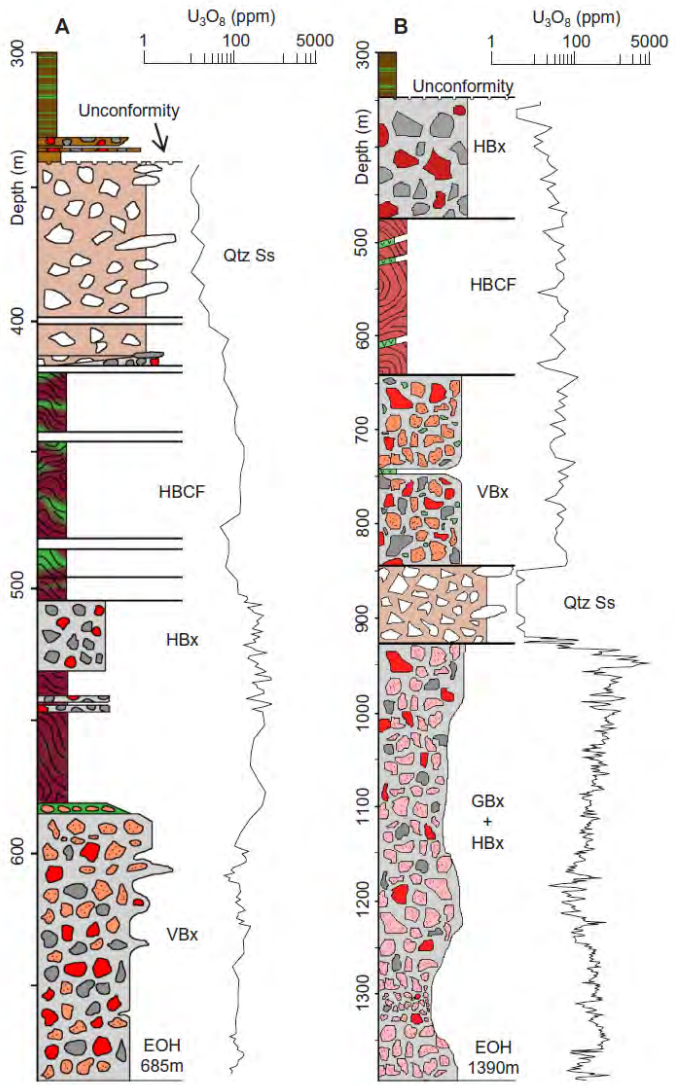




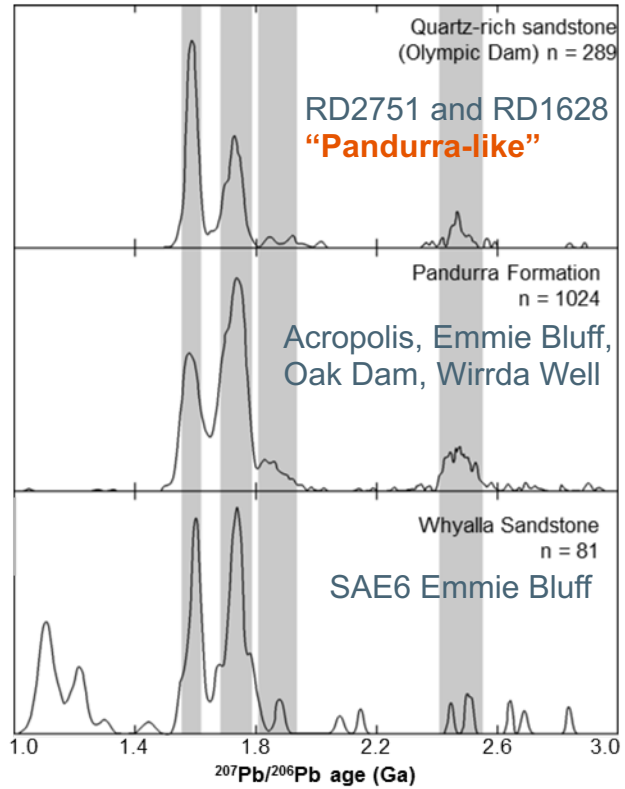
A bit of a conundrum (slide from SAEMC 2018)

brecciated, qtz-rich sandstone (Olympic Dam)





post-1590 Ma units deep within the ODBC? How is this possible?

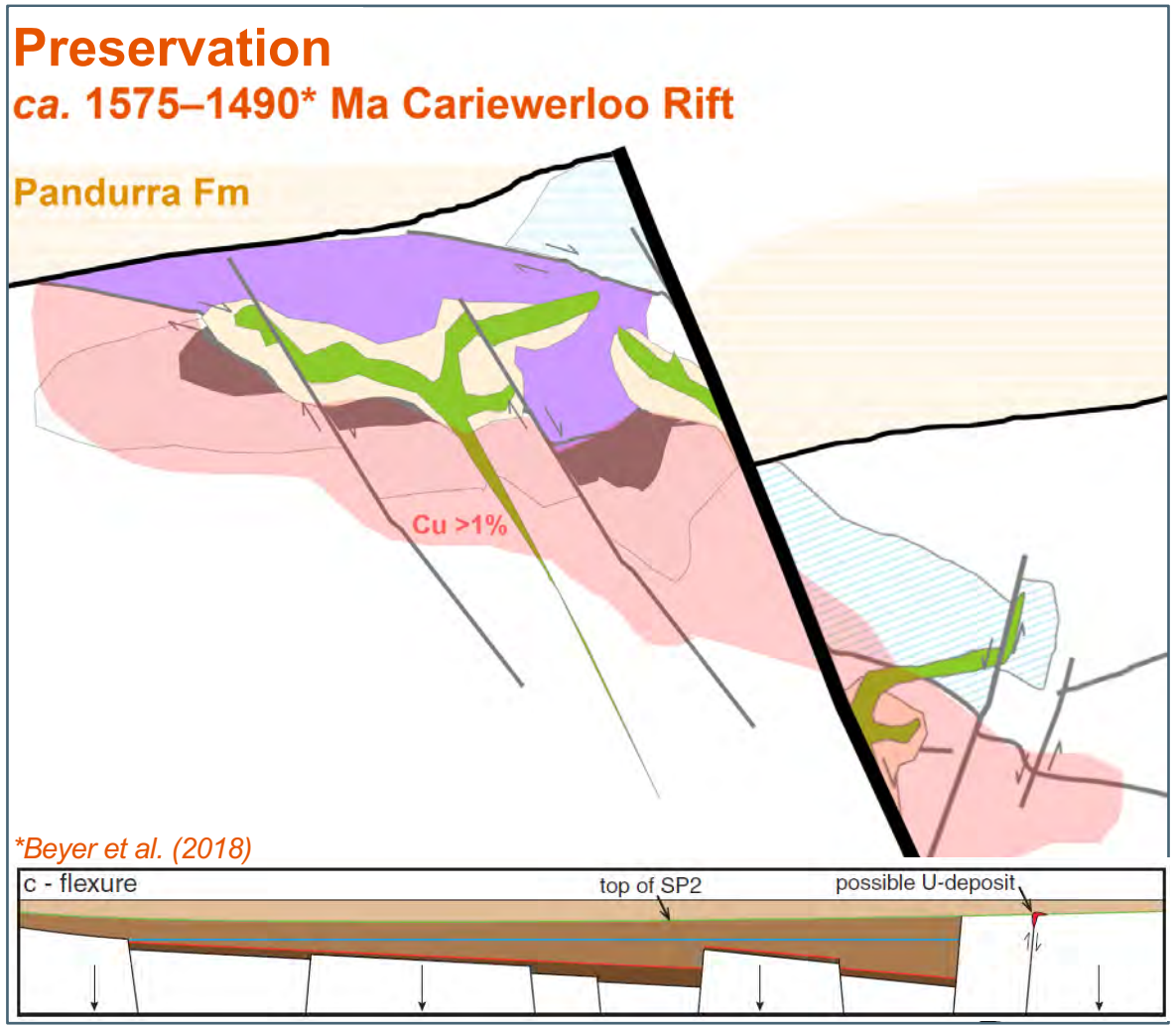


Cherry et al. (2017)

Cherry et al. (2017)
authigenic apatite age

Unravelling the Olympic Dam 'mineral system'

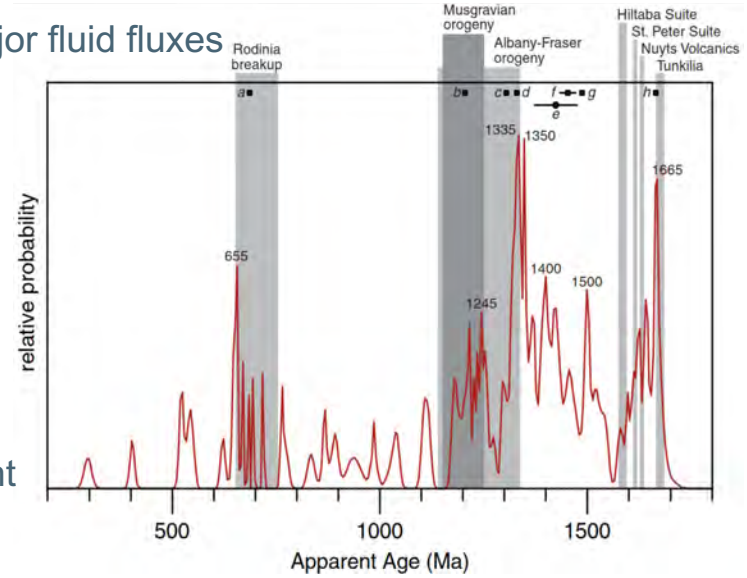
Source, transport and trap are well understood; 'preservation' is not…



The most important ingredient to discover a large IOCG deposit…

What do we know about the post-1590 Ma tectonothermal evolution of the eastern Gawler Craton?

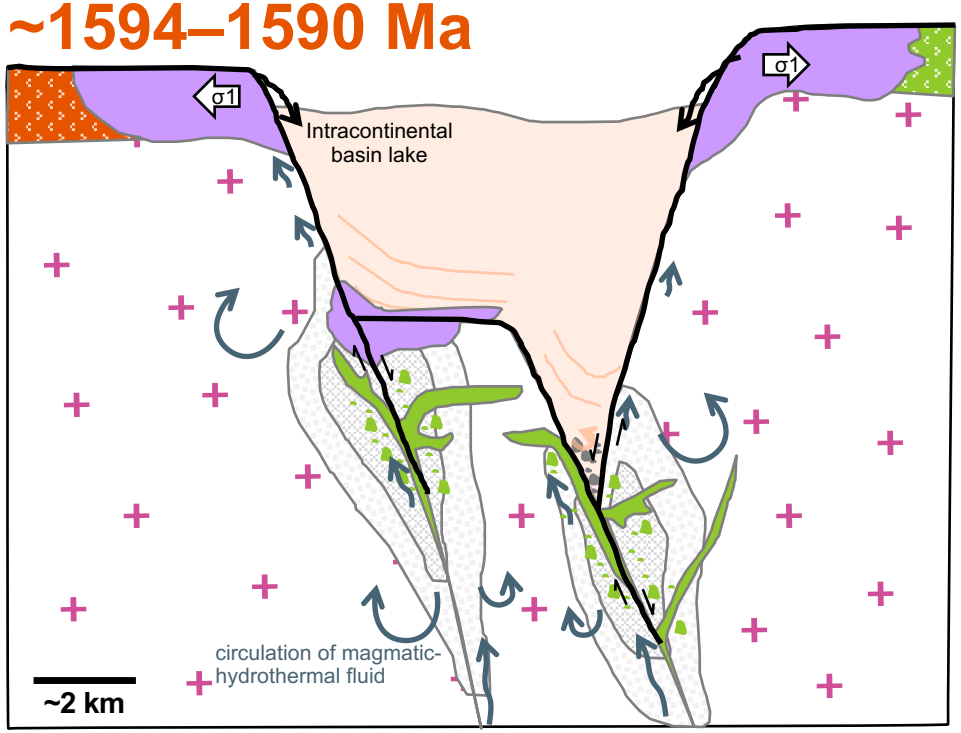
- ~1500 Ma – Cariewerloo rift initiation
- ~1490 Ma – oldest diagenetic illite in Pandurra
- ~1440 Ma – possible fault re-activation, far-field Kararan tectonism
- ~1300-1100 Ma – major fluid fluxes during Albany-Frazer orogeny and Musgravian orogeny
- ~1100 Ma - possible uplift/exposure of Pandurra
- ~686 Ma – Pandurra probably re-buried, post-Sturtian sediment loading on the Stuart Shelf.



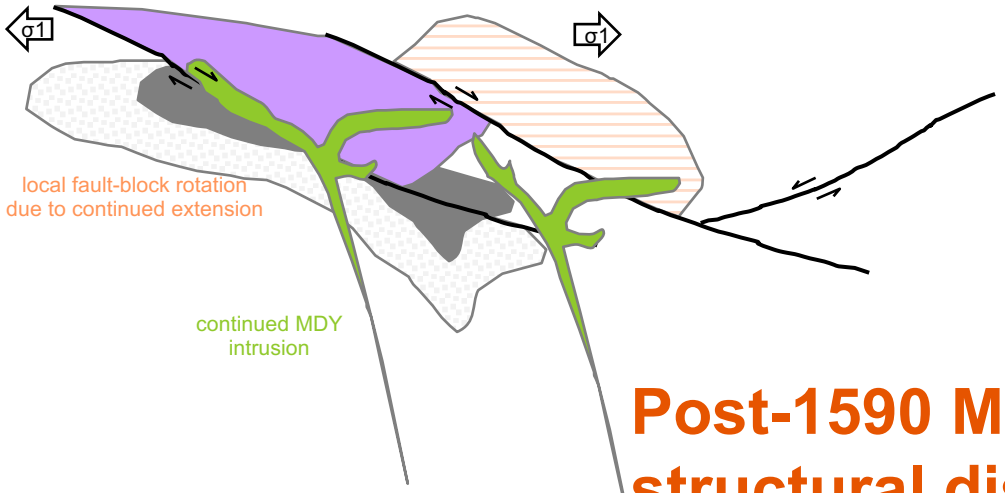
The journey to discovery…

Unravelling a complicated geological evolution

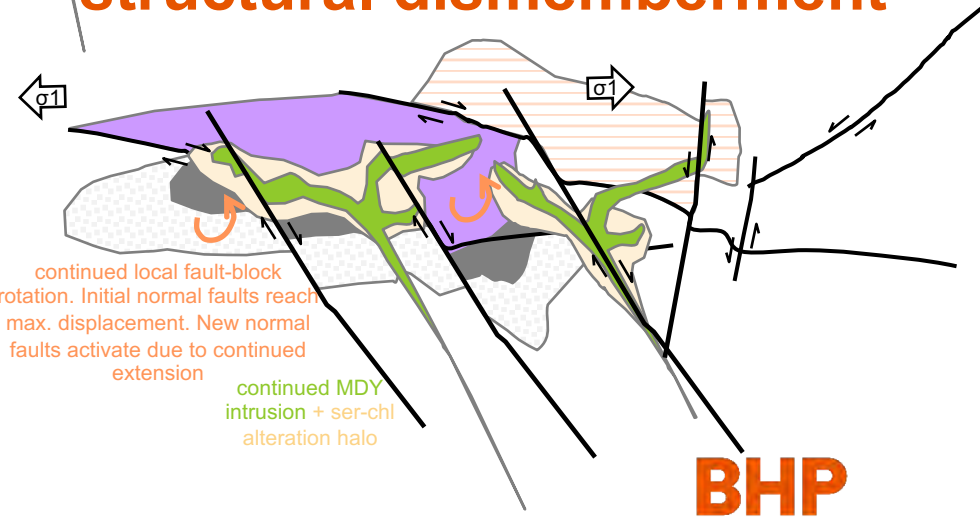
~1594–1590 Ma



~1590 Ma — structural dismemberment



Post-1590 Ma — continued structural dismemberment



RDG
Roxby Downs Granite

Fe (<5 wt%)
gr-rich bx

Fe (5-25 wt%)
gr- to hem-rich bx

Fe (>25 wt%)
hem-rich bx

HEMQ alteration
hematite + quartz bx

Bedded Clastic Facies
Includes all four facies

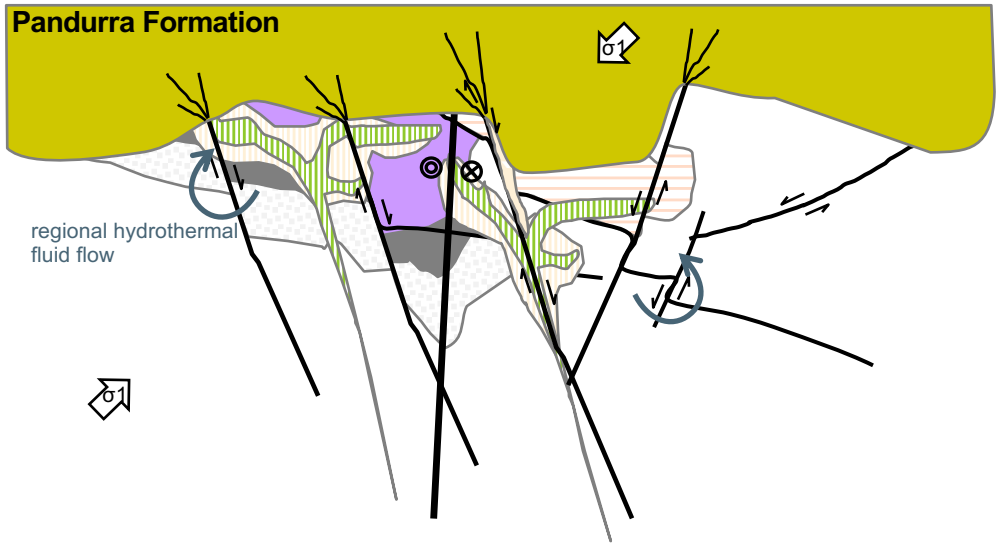
GRV
Felsic / mafic lavas

Mafic-ultramafic dyke
Basalt, picrite, lamprophyre

The journey to discovery…

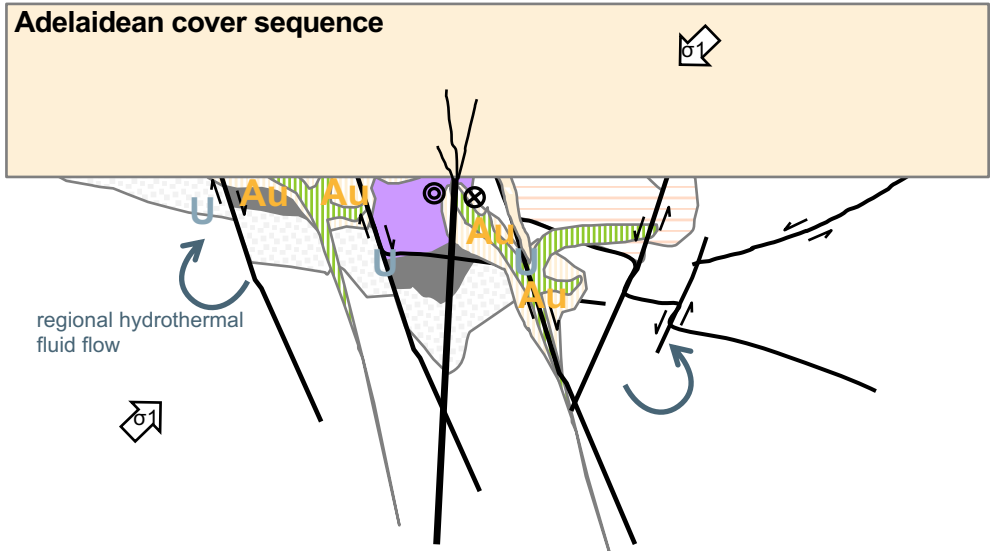
Unravelling a complicated geological evolution

~1200–1050 Ma — erosion + structural reactivation



- Reactivation of MFZ – sinistral (transtensional) wrench
- Significant clockwise fault block rotation
- 0.75-1 km sinistral s.s and minimum 0.45 km normal displacement
- Possible age of >3 km normal displacement observed on Woodall Fault (although likely pre-1200 Ma)

~500 Ma — erosion + Significant hydrothermal fluid flow



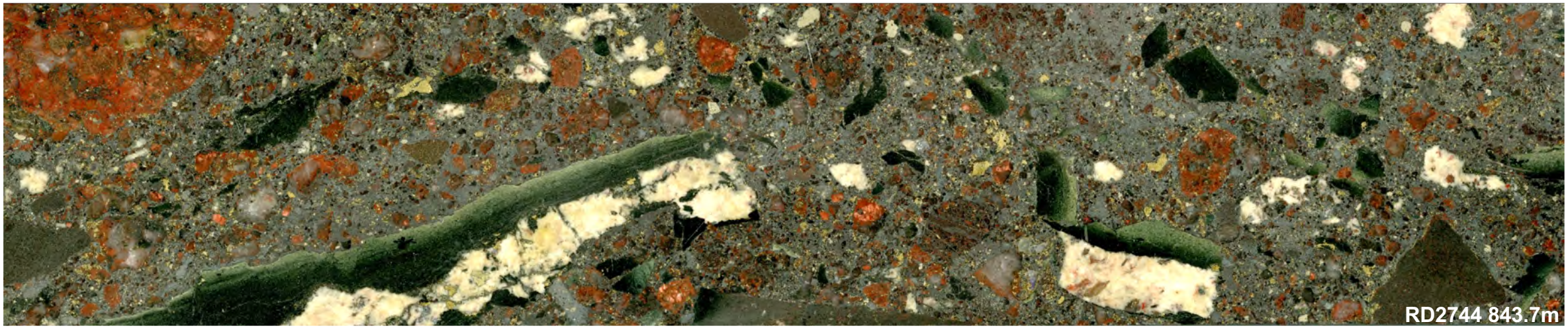
- No significant structural reactivation
- Significant hydrothermal fluid flow remobilised Au, U, minor Cu
- Introduced significant U into deposit
- Potentially caused further sericite alteration

Summary – unravelling a complicated evolution

Well understood - one major and three minor controls on mineralisation

…raising more questions than answers….

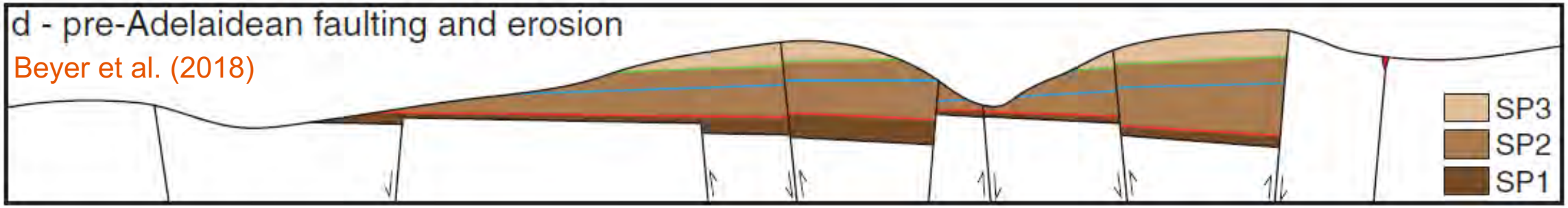
- IOA → IOCG deposit spectrum mineral system and alteration zonation patterns are very well understood
- The most prospective part of an IO**CG** deposit forms at the shallowest crustal levels of the ore forming system (<0.5 – 1km)
- At Olympic Dam, the present orebody geometry does not reflect the pre- or syn-mineralisation structural architecture – rather remnants
- Multiple regional- and local-scale deformation events spanning over the billion years (1.59-0.5 Ga) have dismembered the deposit
- Major normal fault reactivation post-Pandurra deposition but prior to transtensional reactivation of MFZ and related faults (~1100 Ma)
- Major sinistral wrench structural event at *ca.* 1200-1050 Ma(?); scale of vertical displacement unresolved but likely significant
- Major fluid remobilisation events have disrupted the deposit corresponding to major supercontinental cycles, particularly orogenic events
- The key to discovery is predicting shallow facies (litho and alteration) to vector towards shallow, highly prospective min. (e.g. Oak Dam W)



In closing: the unresolved questions

Our interpretations are limited by the regional context link back to the data

Significant potential to discover more mineral deposits on the Stuart Shelf, however, we believe that there needs to be more focus on preservation.



1. What triggered ~1590 Ma BCF and volcanism to shut down / main mineralisation event? [tectonic]
2. How extensive was the Cariewerloo Rift and its impact on basement? [tectonic]
3. What was the overall impact on Olympic Domain during the Musgrave/Grenville/Albany-Fraser orogenic events? [tectonic]
4. When did the Adelaidean sedimentation start? [tectonic]

1+2+3+4. = poor tectonic constraints on post-1590 Ma eastern Gawler Craton geological evolution.

- **Do your prospectivity maps or target models factor in post-mineral deformation?**


BHP