The significance of protracted magmatism in the Pine Creek Orogen

Pablo Farias[1], Alex Burton-Johnson, Anett Weisheit, Barry L Reno

[1] Senior Geologist, Northern Territory Geological Survey

NORTHERN TERRITORY GEOLOGICAL SURVEY
AGES2026
ANNUAL GEOSCIENCE EXPLORATION SEMINAR

NORTHERN TERRITORY GOVERNMENT

NTGS - Basement Geoscience team

Thank you to
- NTGS Aboriginal Engagement and Land access team
- NTGS core facility
- Multiple companies and geos working on PCO

Pablo Farias, Alex Burton-Johnson, Anett Weisheit, Barry L Reno

Northern Territory Geological Survey

Pine Creek Orogen

Project rationale

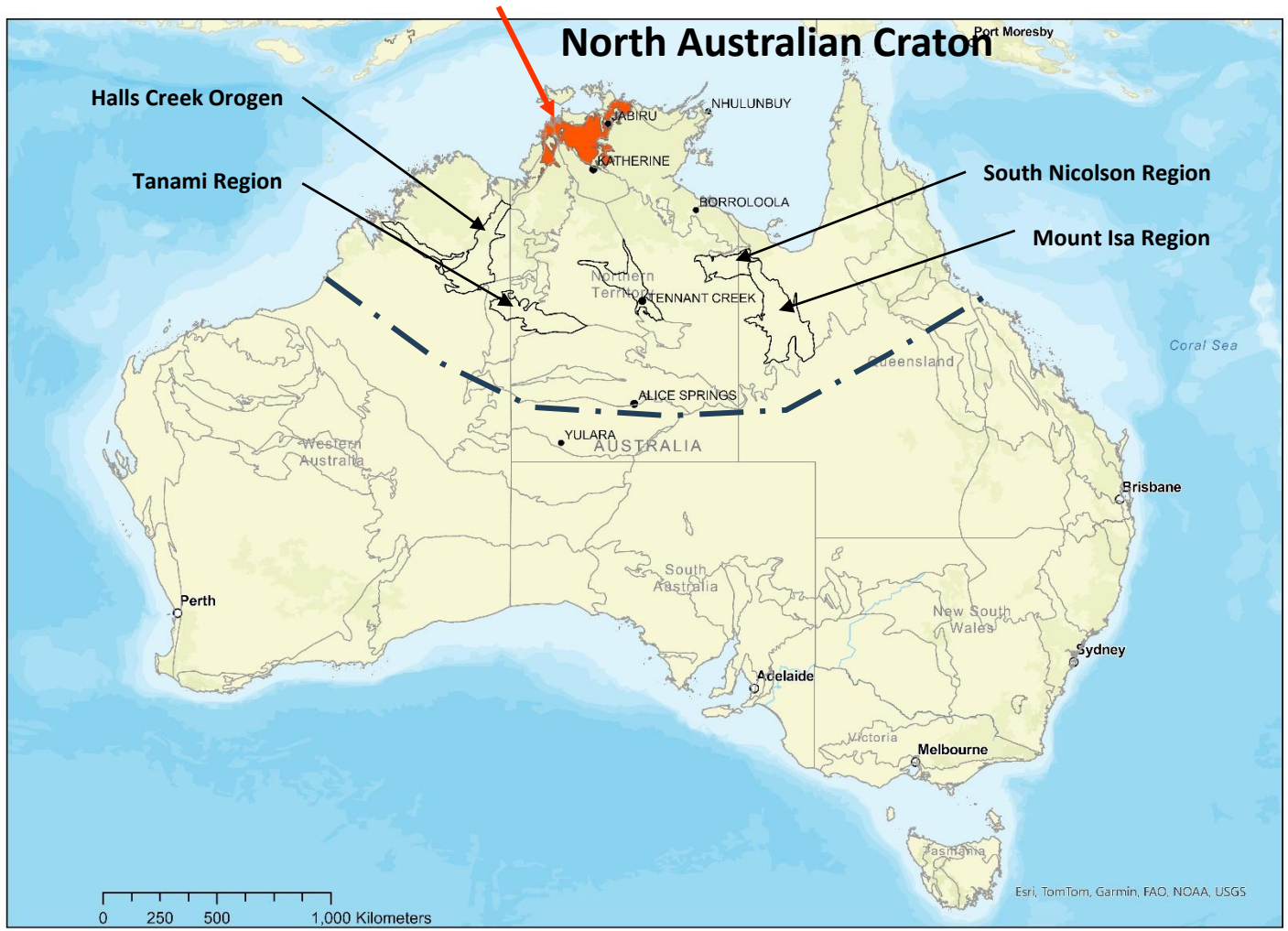
The Pine Creek Orogen is a Paleoproterozoic terrane located in the **North Australian Craton**

- A **globally significant polymetallic province**

Hosts: Au, U, base metals, Fe, Sn–W–Ta, Li, graphite

- Proximity to **key infrastructure** and proven production history

- Our focus is to **refine and advance the geological framework**



Pine Creek Orogen

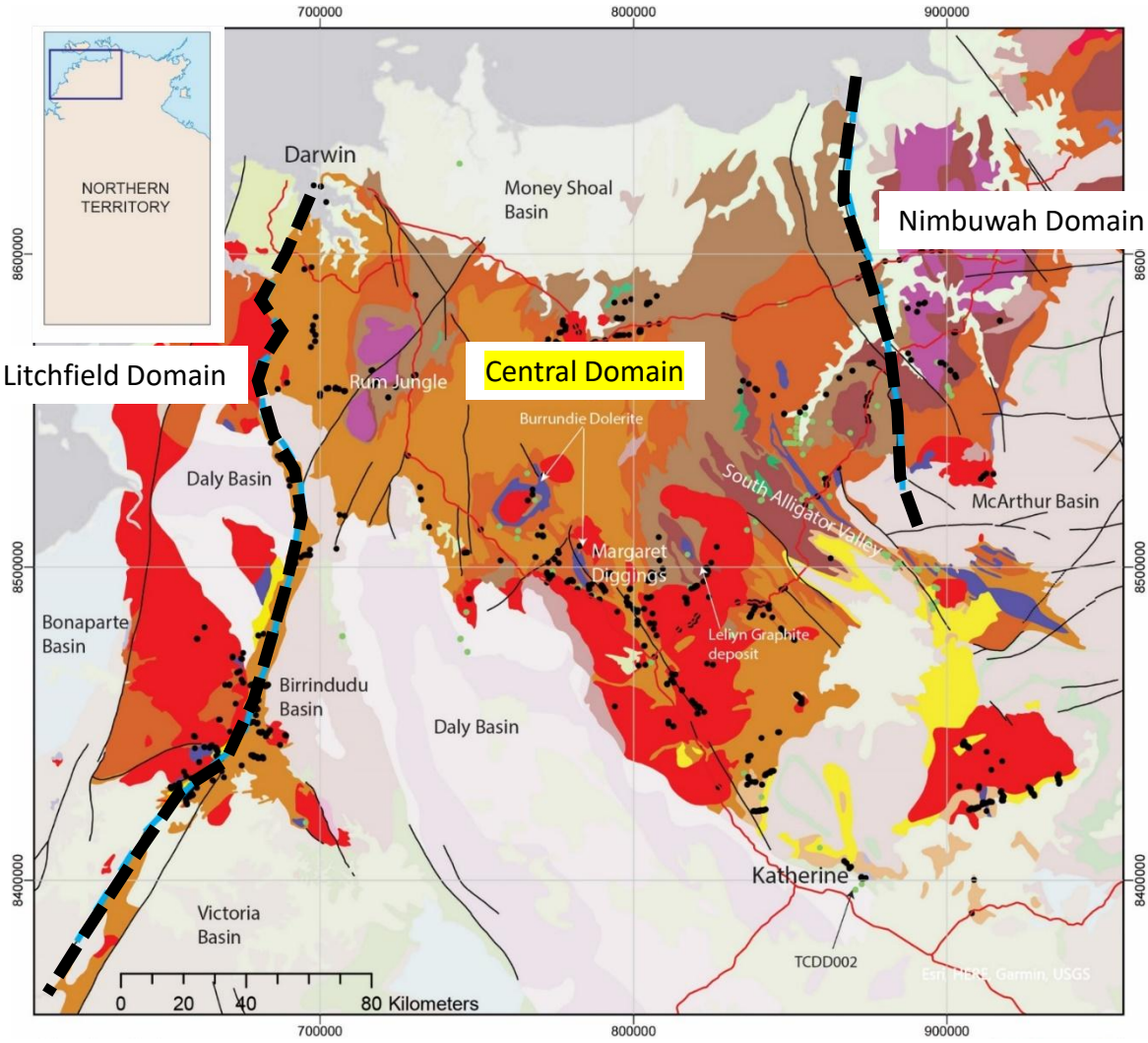
What I will talk about…

- Geology background
- New **geochronology** and **isotopic data** on **mafic** and **felsic** units
- Implications on stratigraphy and tectonic evolution
- Potential impacts on the mineral systems

Pine Creek Orogen

Geological background

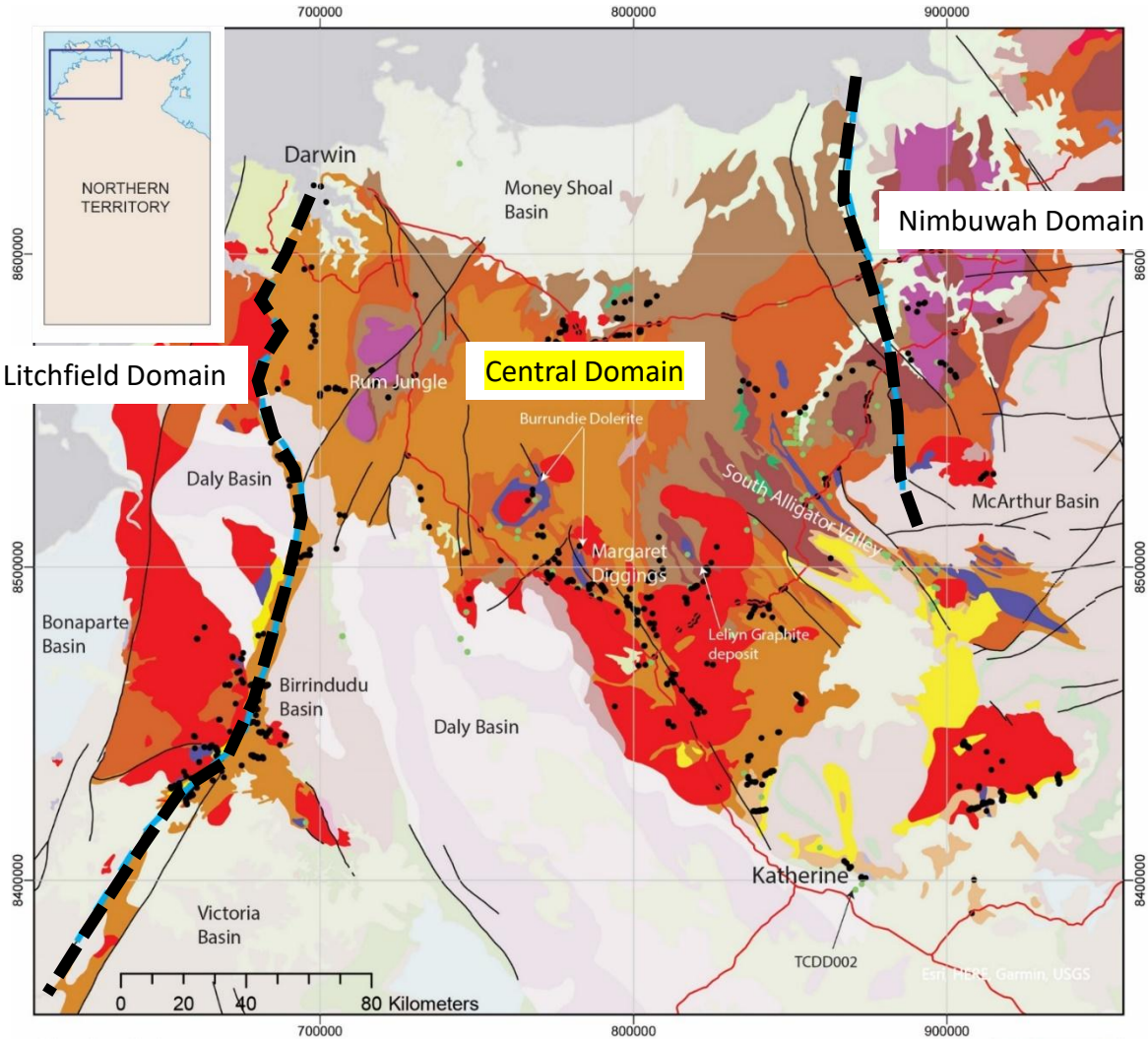
- **Three Domains** defined by different protolith sources and metamorphic grades



Pine Creek Orogen

Geological background

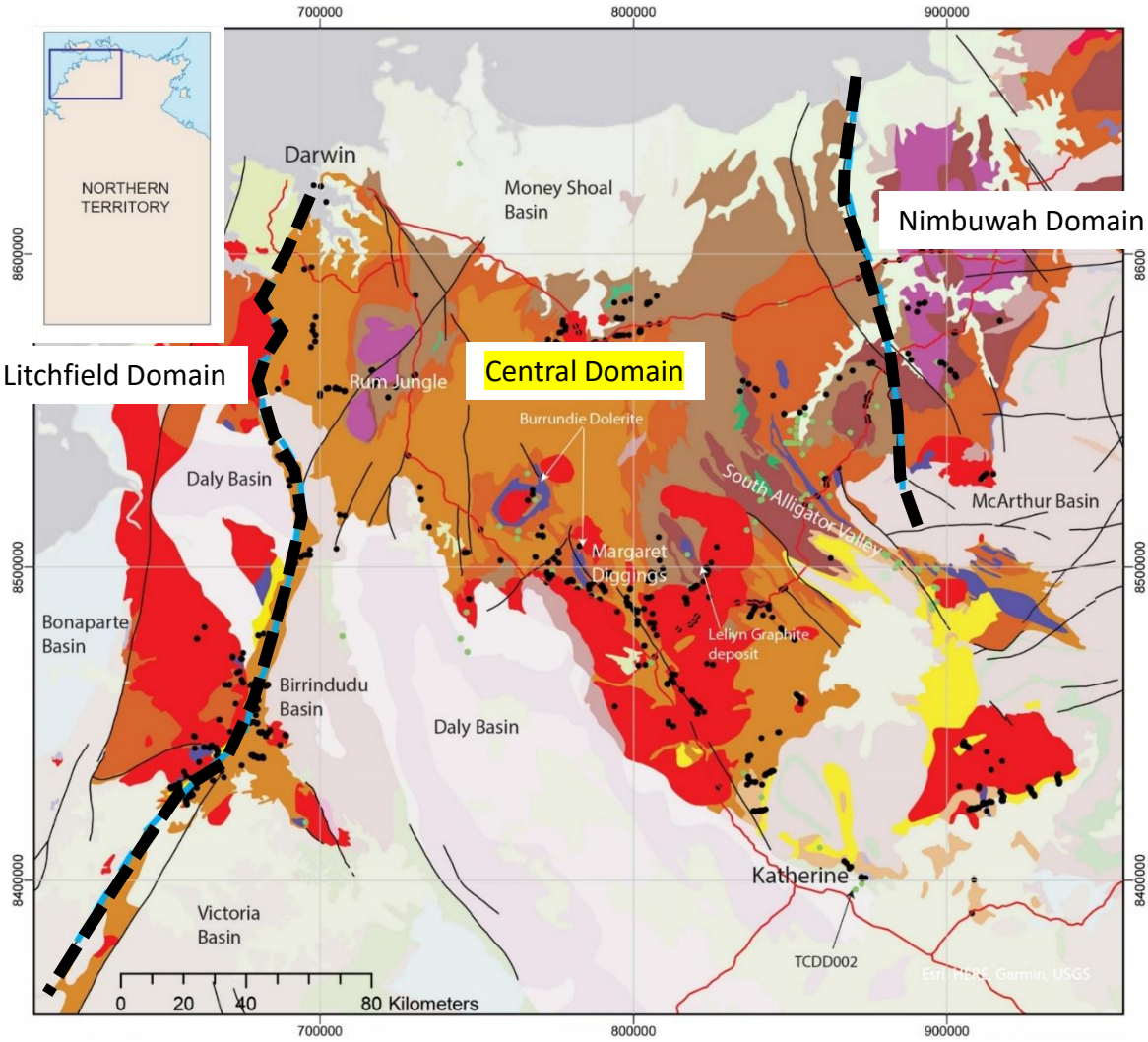
- **Three Domains** defined by different protolith sources and metamorphic grades



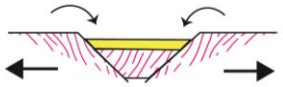
Pine Creek Orogen

Geological background

- **Three Domains** defined by different protolith sources and metamorphic grades



- Early rifting at ca 2.02 Ga > **Woodcutters Supergroup**



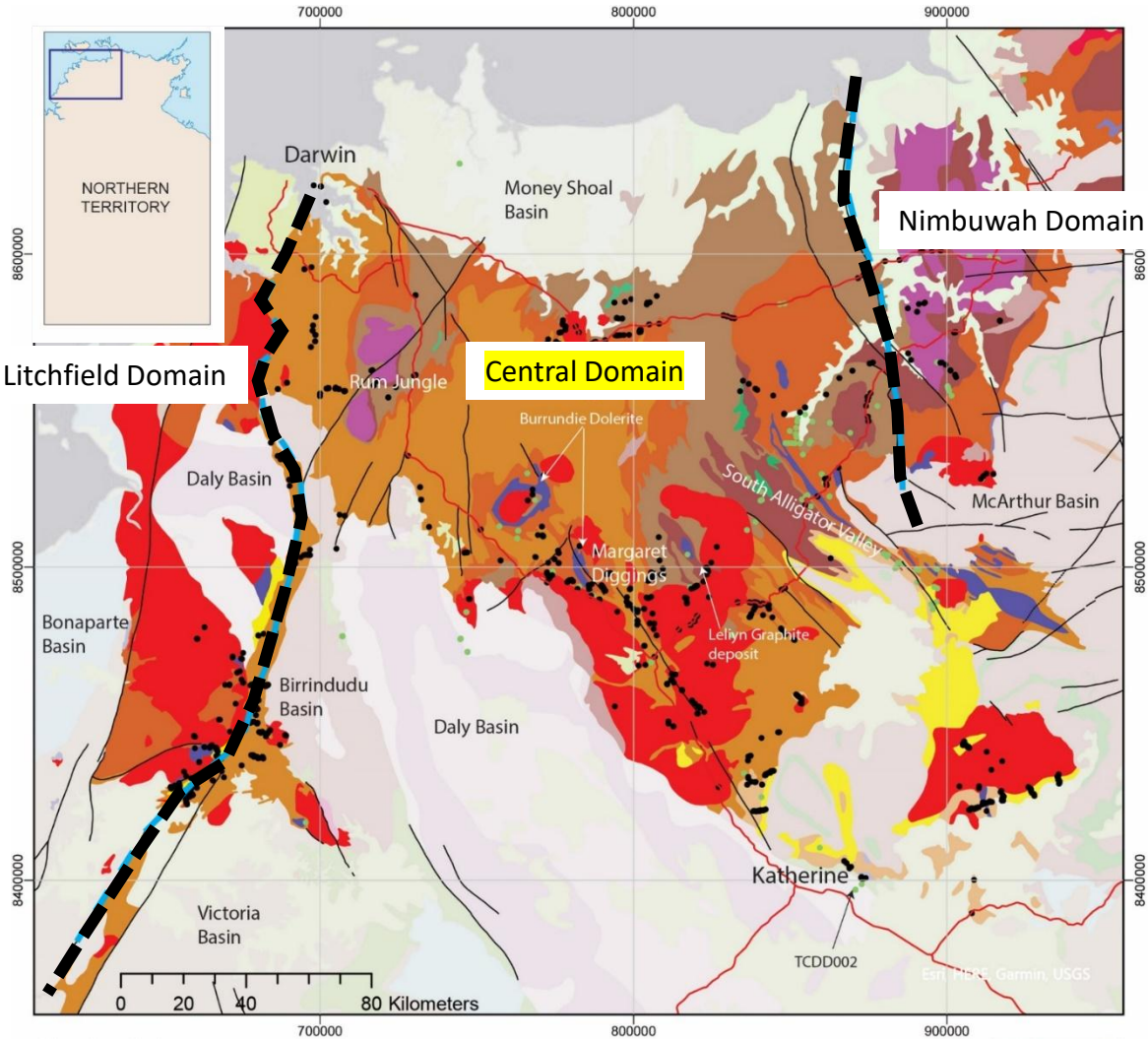
ca. 2.02 Ga Woodcutters Supergroup

Archean basement

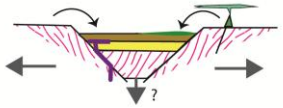
Pine Creek Orogen

Geological background

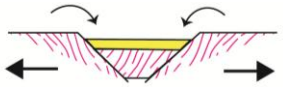
- **Three Domains** defined by different protolith sources and metamorphic grades



- Sag-basin / foreland basin at ca 1.86–1.87 Ga > **Cosmo Supergroup + mafic magmatism**



- Early rifting at ca 2.02 Ga > **Woodcutters Supergroup**



Dolerites — ca. 1.87–1.86 Ga Cosmo Supergroup

ca. 2.02 Ga Woodcutters Supergroup

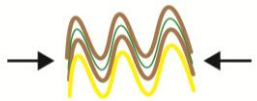
Archean basement

Pine Creek Orogen

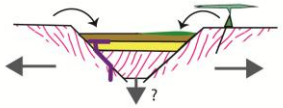
Geological background

- **Three Domains** defined by different protolith sources and metamorphic grades

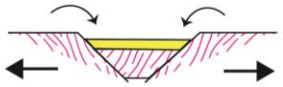
- Deformation and metamorphism (~1.86–1.85 Ga)



- Sag-basin / foreland basin at ca 1.86–1.87 Ga > **Cosmo Supergroup + mafic magmatism**



- Early rifting at ca 2.02 Ga > **Woodcutters Supergroup**

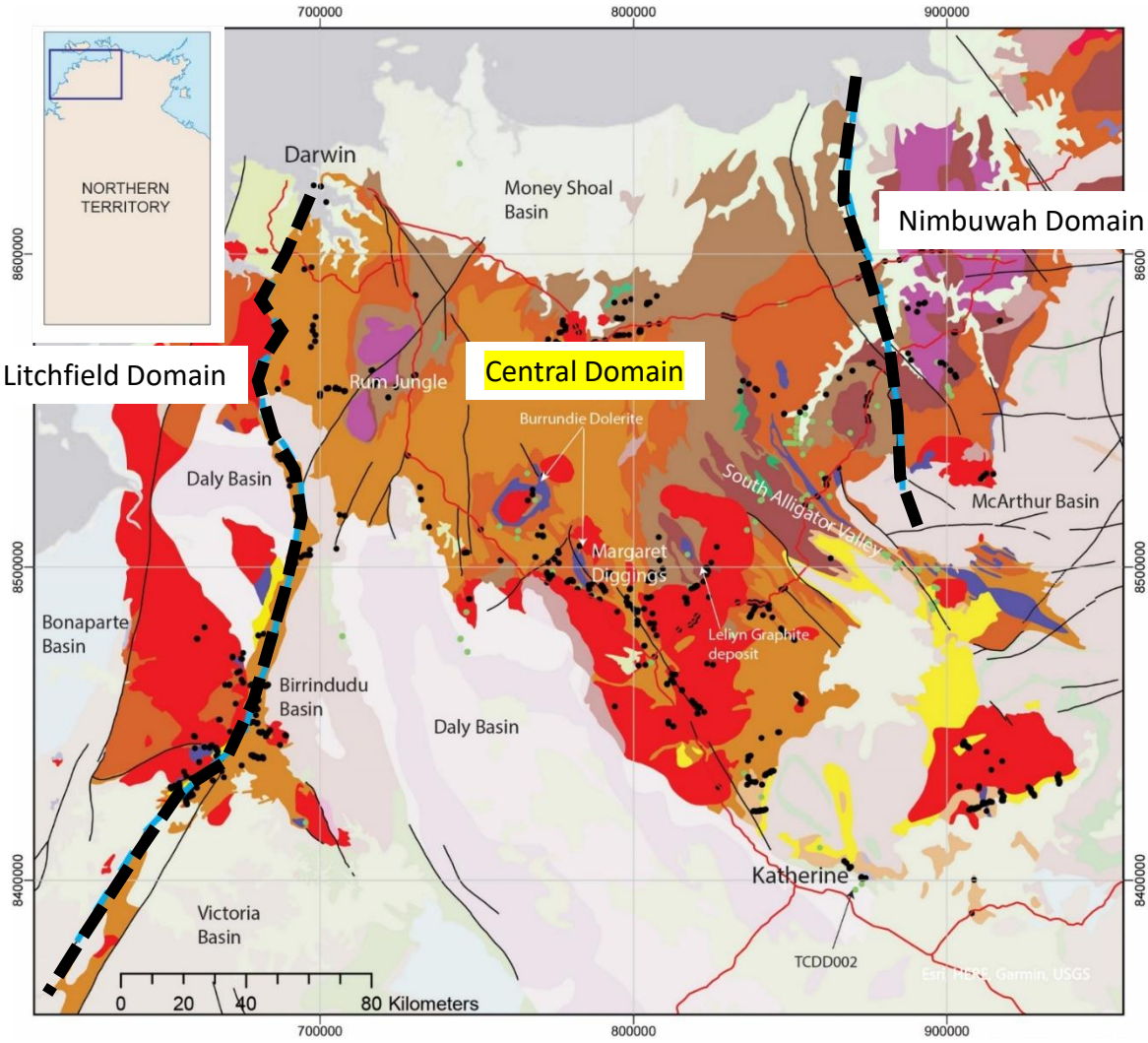


Dolerites

ca. 1.87–1.86 Ga Cosmo Supergroup

ca. 2.02 Ga Woodcutters Supergroup

Archean basement



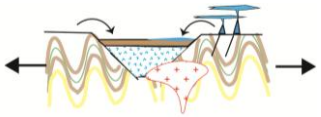
NORTHERN TERRITORY GOVERNMENT

Pine Creek Orogen

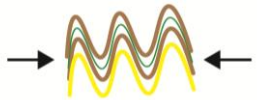
Geological background

- **Three Domains** defined by different protolith sources and metamorphic grades

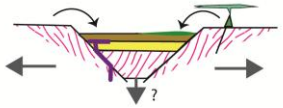
- Later extension, post-orogenic magmatism, and sedimentation at ca 1.83 Ga



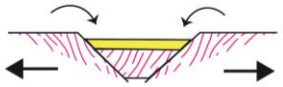
- Deformation and metamorphism (~1.86–1.85 Ga)



- Sag-basin / foreland basin at ca 1.86–1.87 Ga > **Cosmo Supergroup + mafic magmatism**



- Early rifting at ca 2.02 Ga > **Woodcutters Supergroup**



McArthur Basin

ca. 1.83 Ga volcaniclastic units

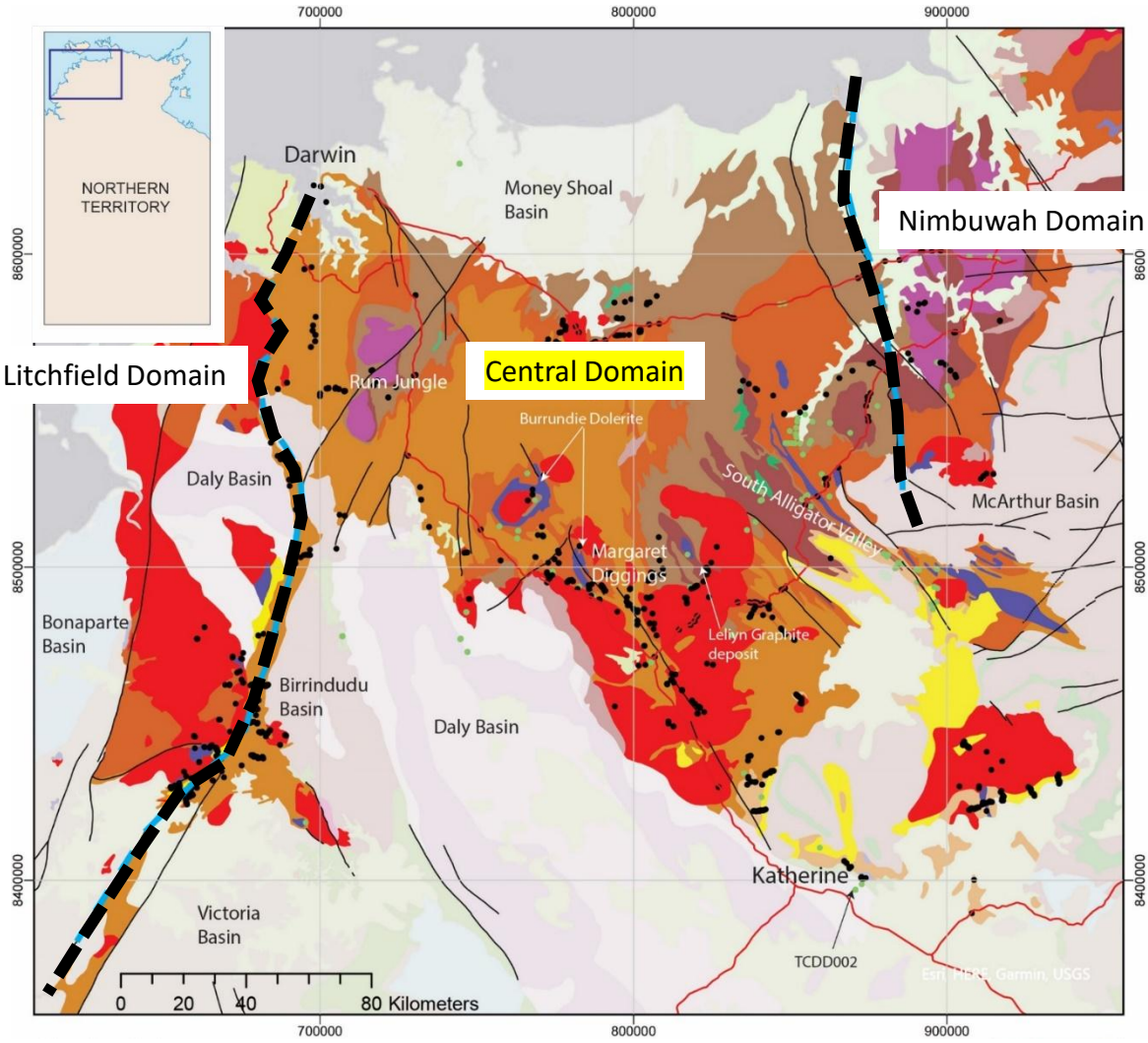
Cullen Supersuite

Dolerites

ca. 1.87–1.86 Ga Cosmo Supergroup

ca. 2.02 Ga Woodcutters Supergroup

Archean basement



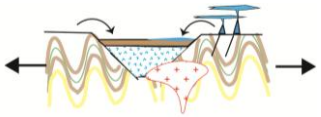
NORTHERN TERRITORY GOVERNMENT

Pine Creek Orogen

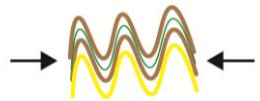
Geological background

- **Three Domains** defined by different protolith sources and metamorphic grades

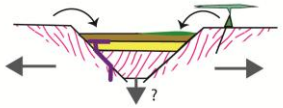
- Later extension, post-orogenic magmatism, and sedimentation at ca 1.83 Ga



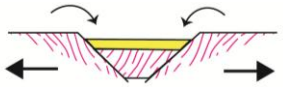
- Deformation and metamorphism (~1.86–1.85 Ga)

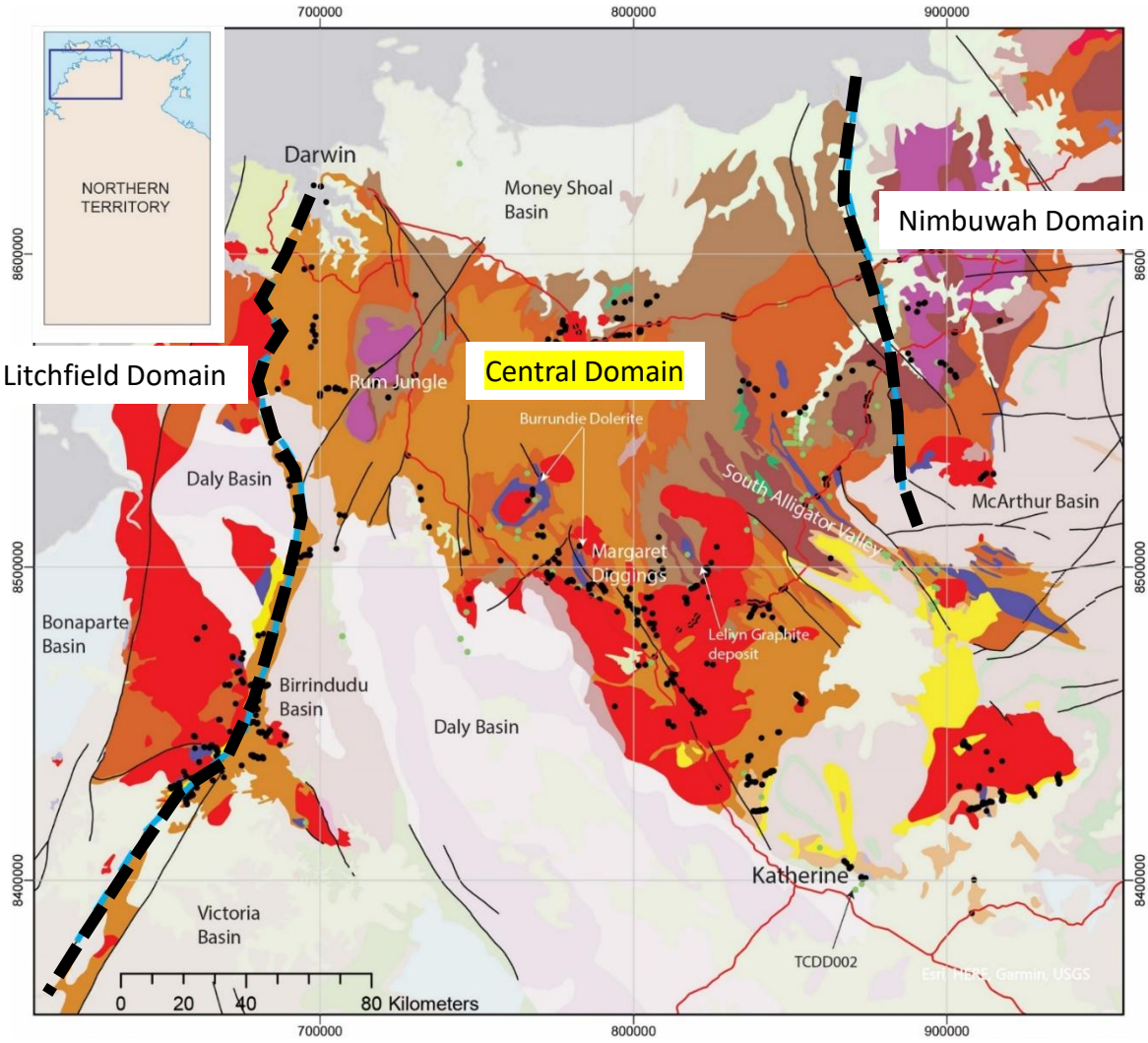


- Sag-basin / foreland basin at ca 1.86–1.87 Ga > **Cosmo Supergroup + mafic magmatism**



- Early rifting at ca 2.02 Ga > **Woodcutters Supergroup**





NORTHERN TERRITORY GOVERNMENT

Pine Creek Orogen

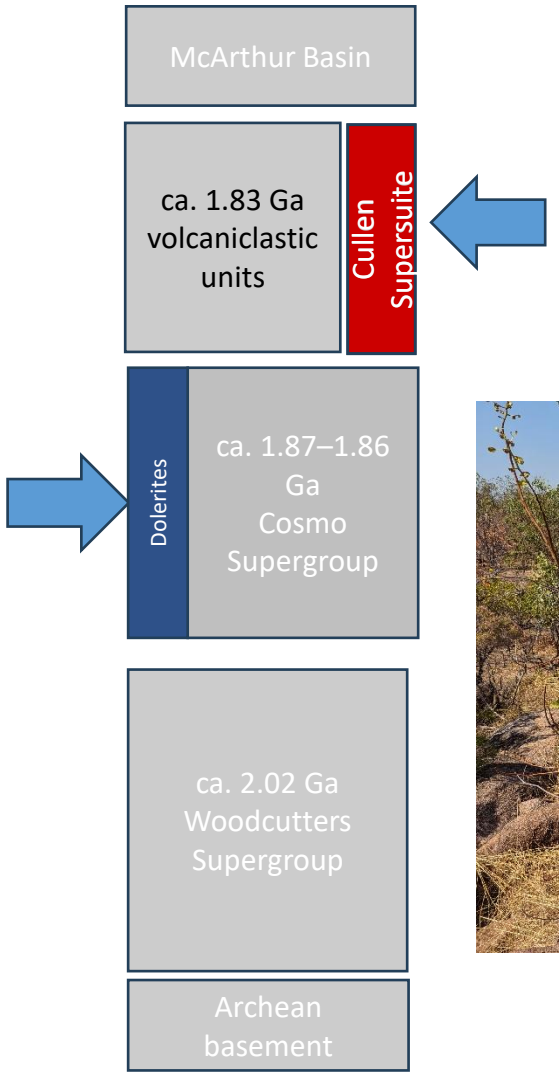
Igneous Stratigraphy

We are interested in the **isotope geochemistry** on felsic and mafic rocks helps us understand:

- **Timing**
- **Magma source/s**
- **Tectonic settings**

Mafic magmatism

New geochronology and isotope geochemistry results



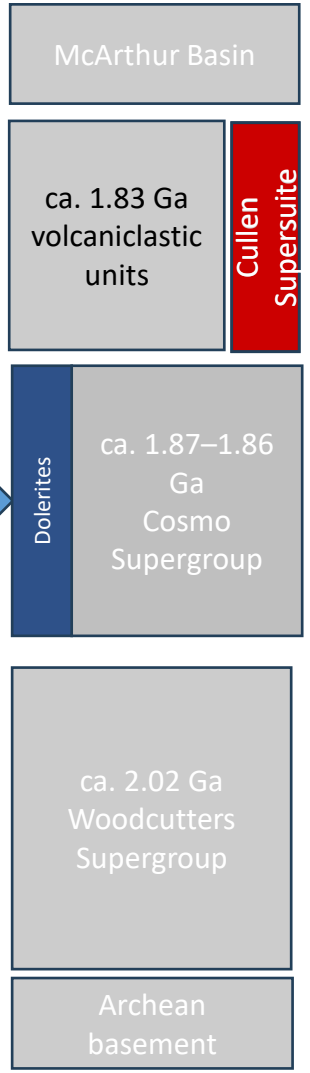
Pine Creek Orogen

Igneous Stratigraphy

We are interested in the **isotope geochemistry** on felsic and mafic rocks helps us understand:

- **Timing**
- **Magma source/s**
- **Tectonic settings**

Mafic magmatism
New geochronology and isotope geochemistry results

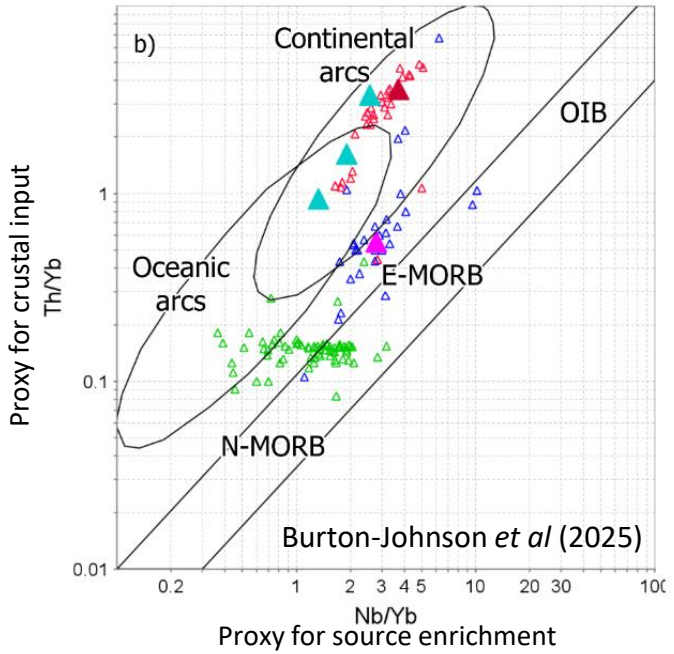


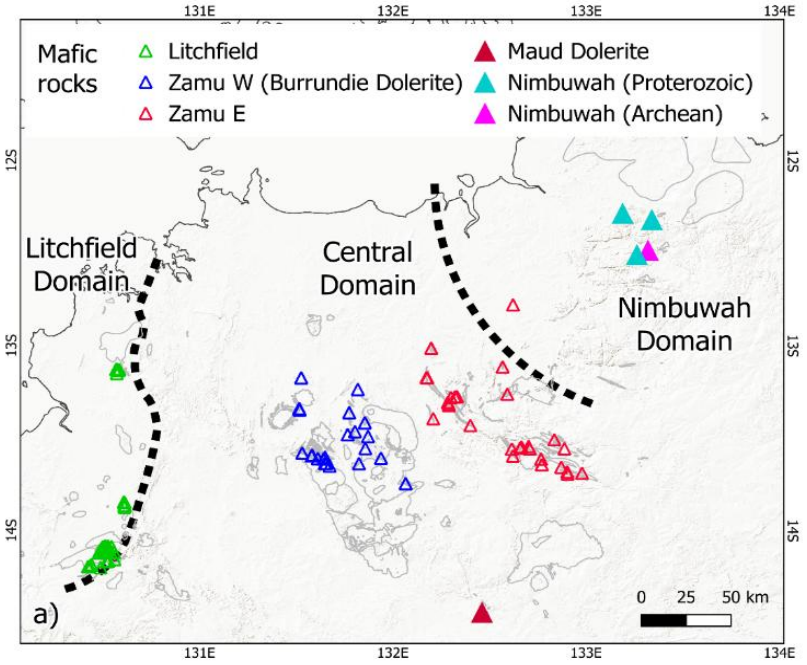
Felsic magmatism

Pine Creek Orogen

Mafic rocks isotopic composition

From last year: Not all dolerites are the same (Ferguson and Needham 1978; Burton-Johnson *et al,* 2025)



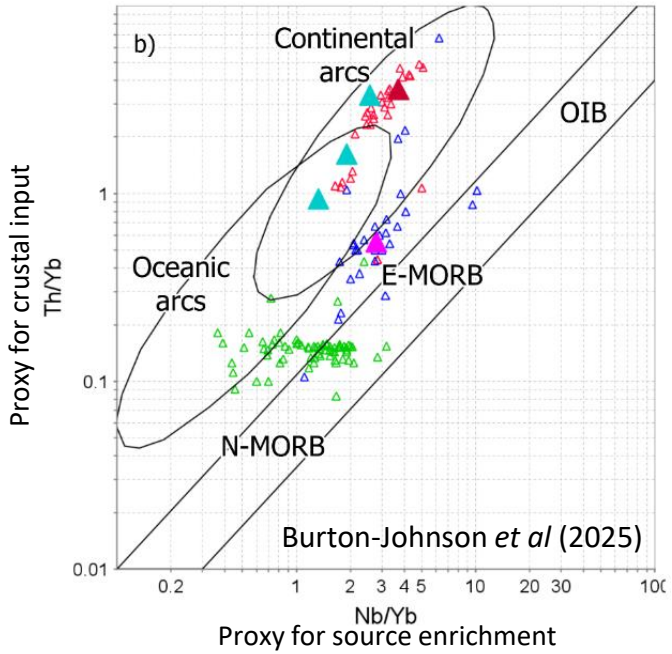


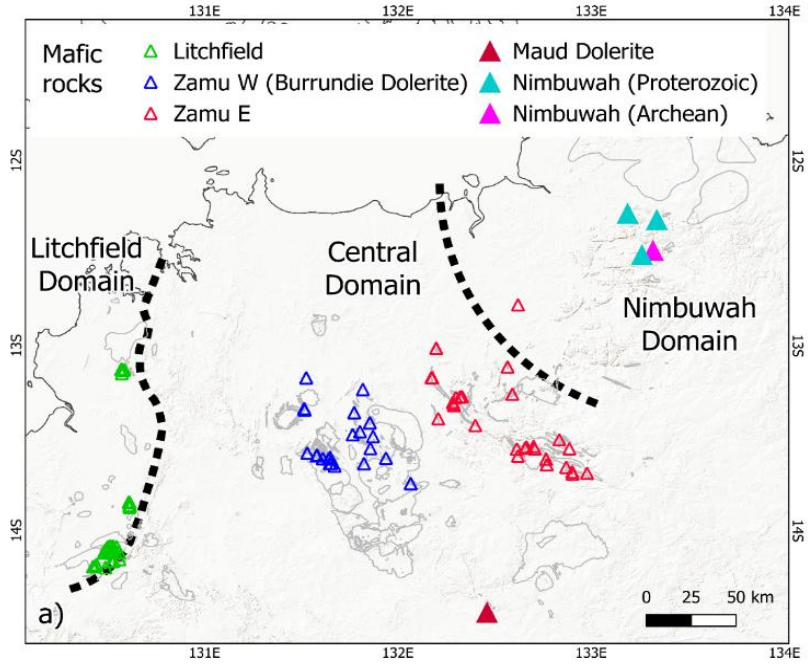
Pine Creek Orogen

Mafic rocks isotopic composition

From last year: Not all dolerites are the same (Ferguson and Needham 1978; Burton-Johnson *et al,* 2025)

New whole-rock Sm/Nd isotopic data confirms previous interpretations

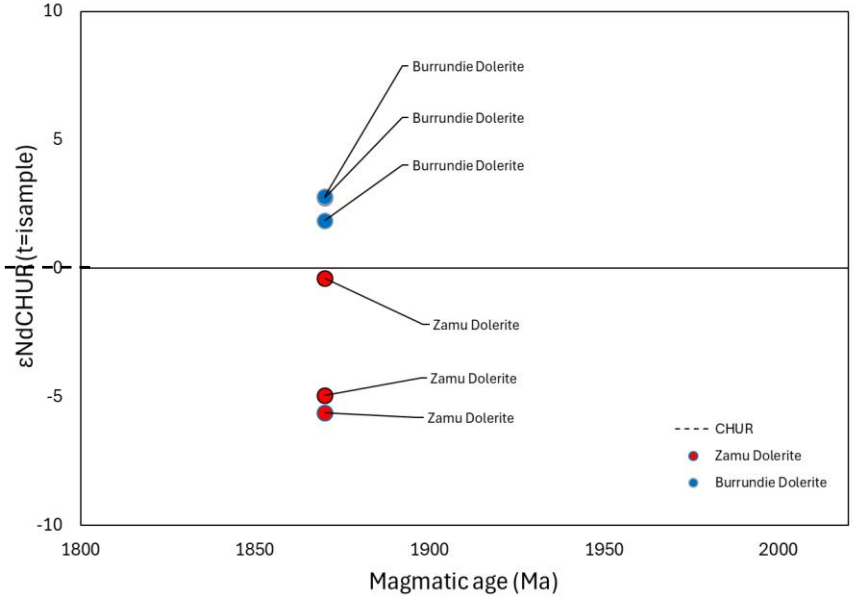




Sample age (Ma) vs Epsilon Nd (CHUR,i)

Mantle source (+)

Continental Crust interaction (-)

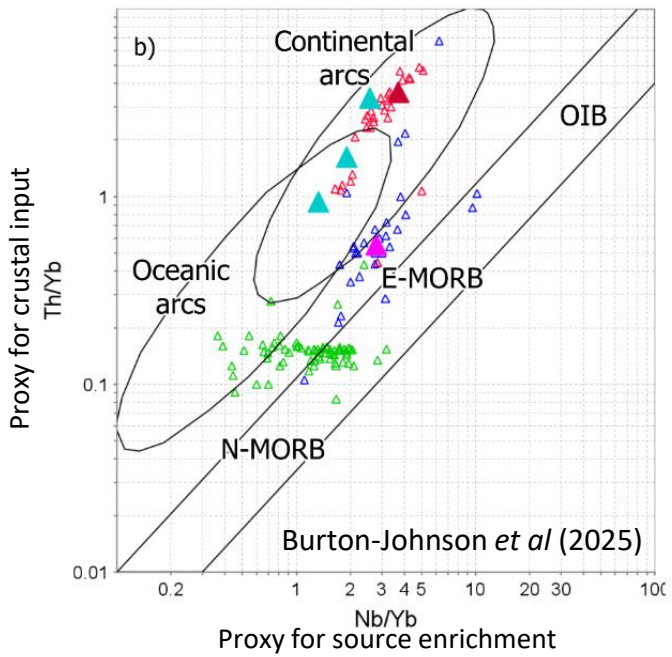


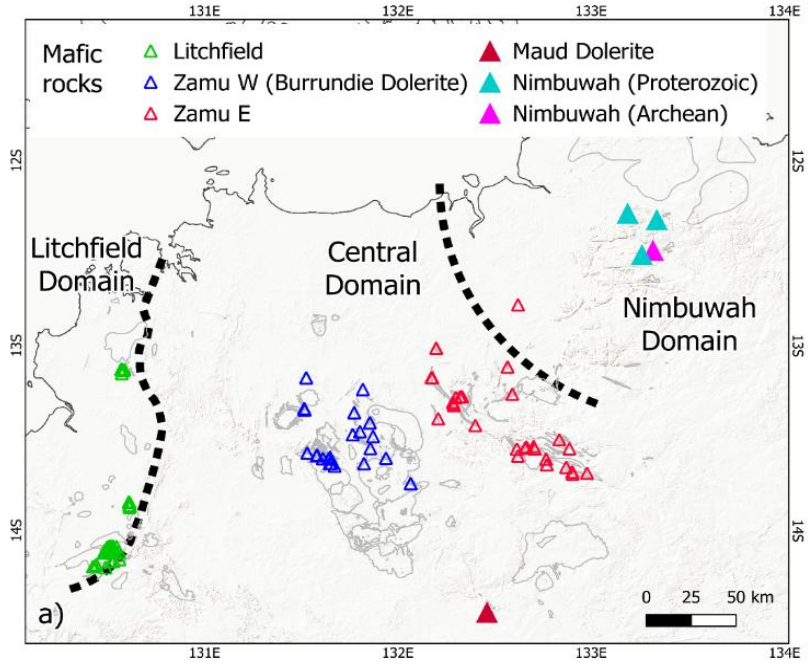
Pine Creek Orogen

Mafic rocks isotopic composition

From last year: Not all dolerites are the same (Ferguson and Needham 1978; Burton-Johnson *et al,* 2025)

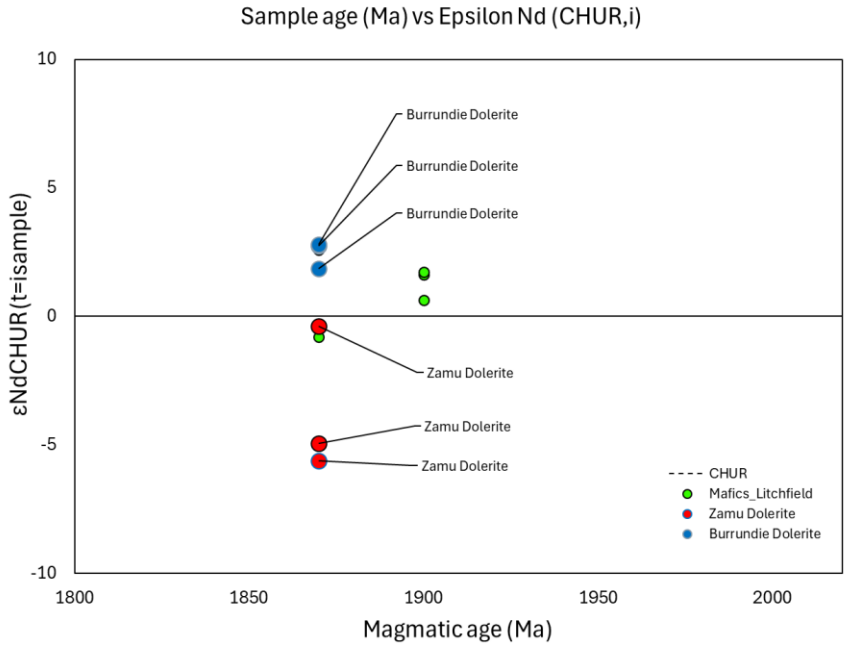
New whole-rock Sm/Nd isotopic data confirms previous interpretations





Mantle source (+)

Continental Crust interaction (-)



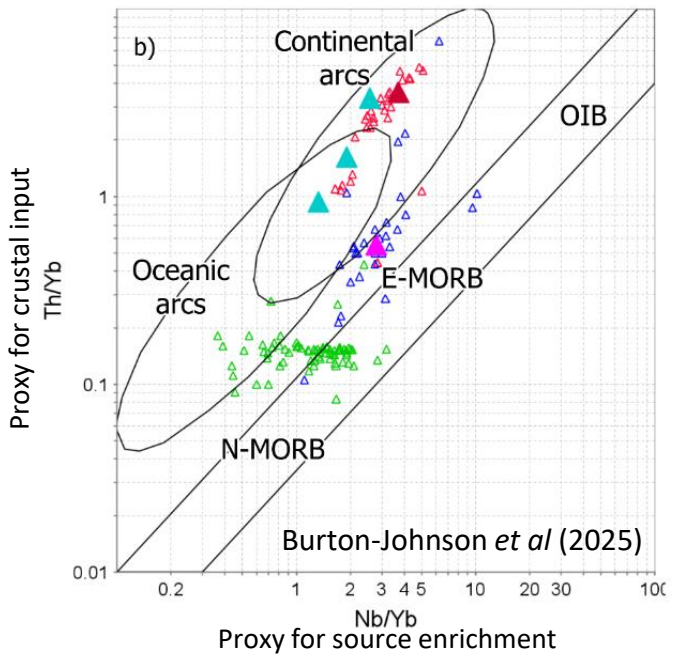
Pine Creek Orogen

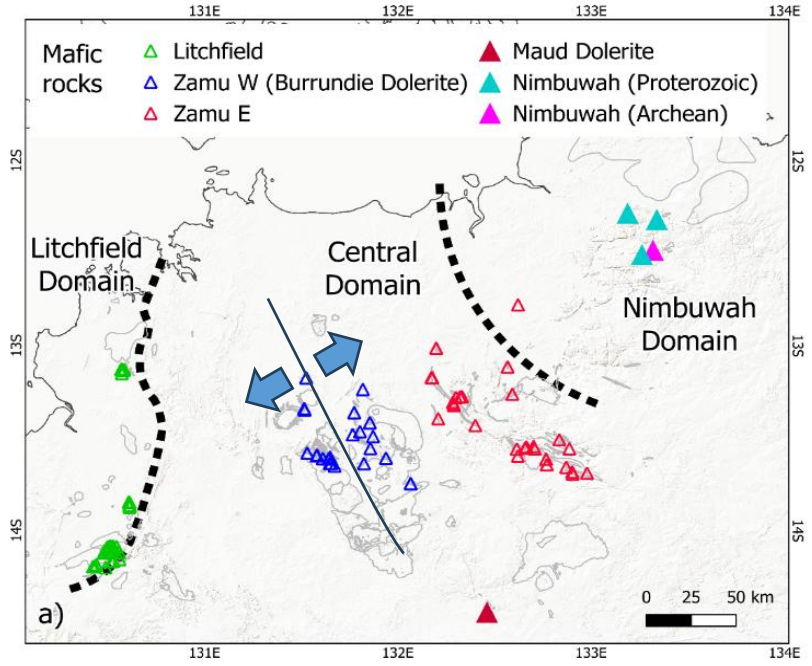
Mafic rocks isotopic composition

From last year: Not all dolerites are the same (Ferguson and Needham 1978; Burton-Johnson *et al,* 2025)

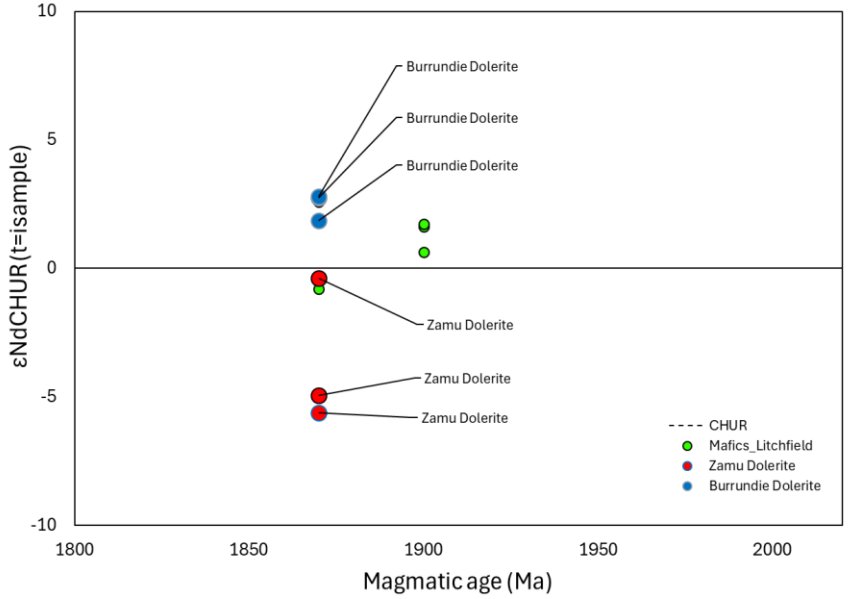
New whole-rock Sm/Nd isotopic data confirms previous interpretations

Interpretation: At ~1.87 Ga, the locus of extension (relatively thinner crust) was situated in the Central Domain (and Litchfield), while thicker continental crust persisted to the east, toward the Nimbuwah Domain.





Sample age (Ma) vs Epsilon Nd (CHUR,i)



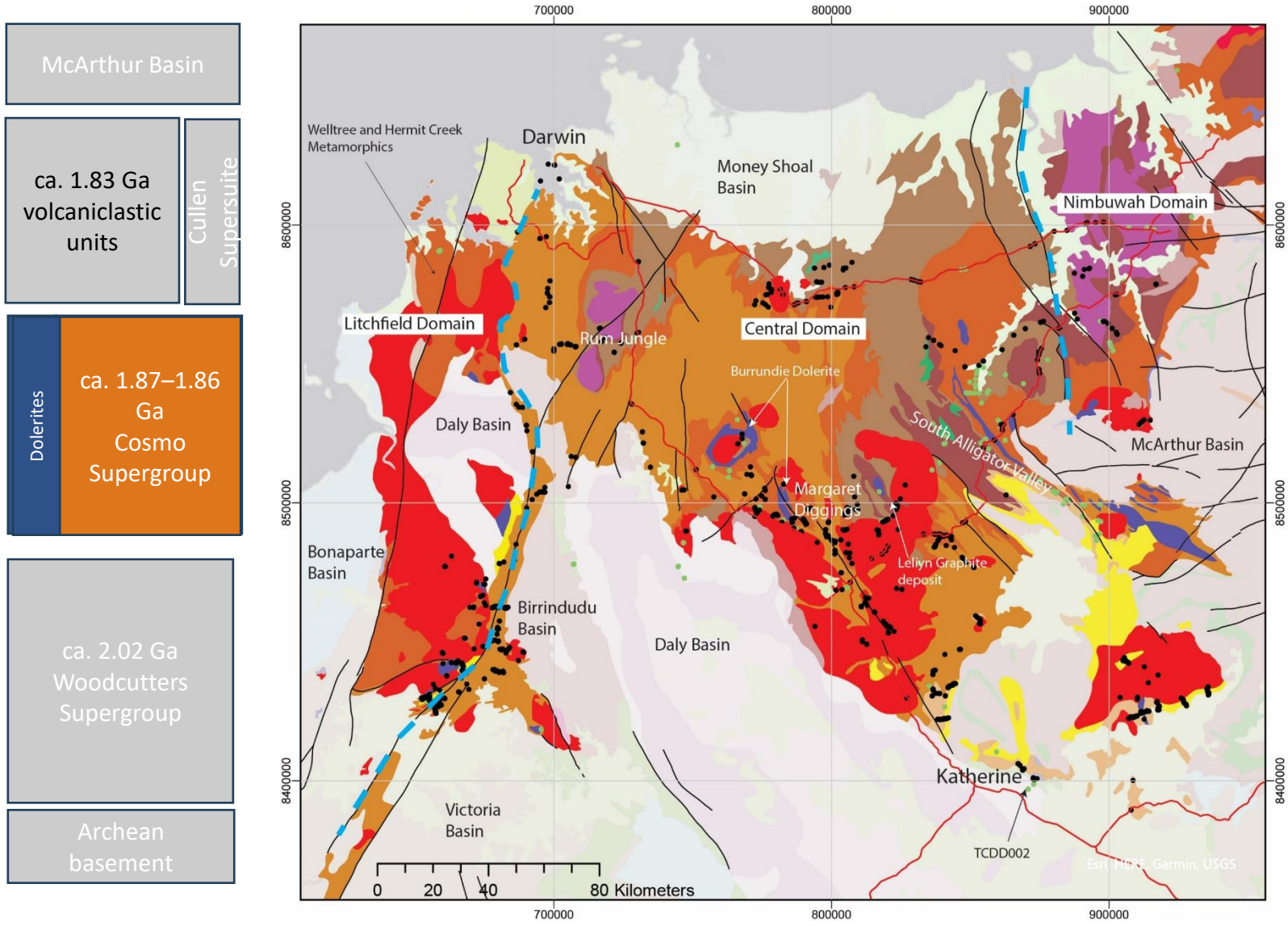
Mantle source (+)

Continental Crust interaction (-)

Pine Creek Orogen

Mafic magmatism

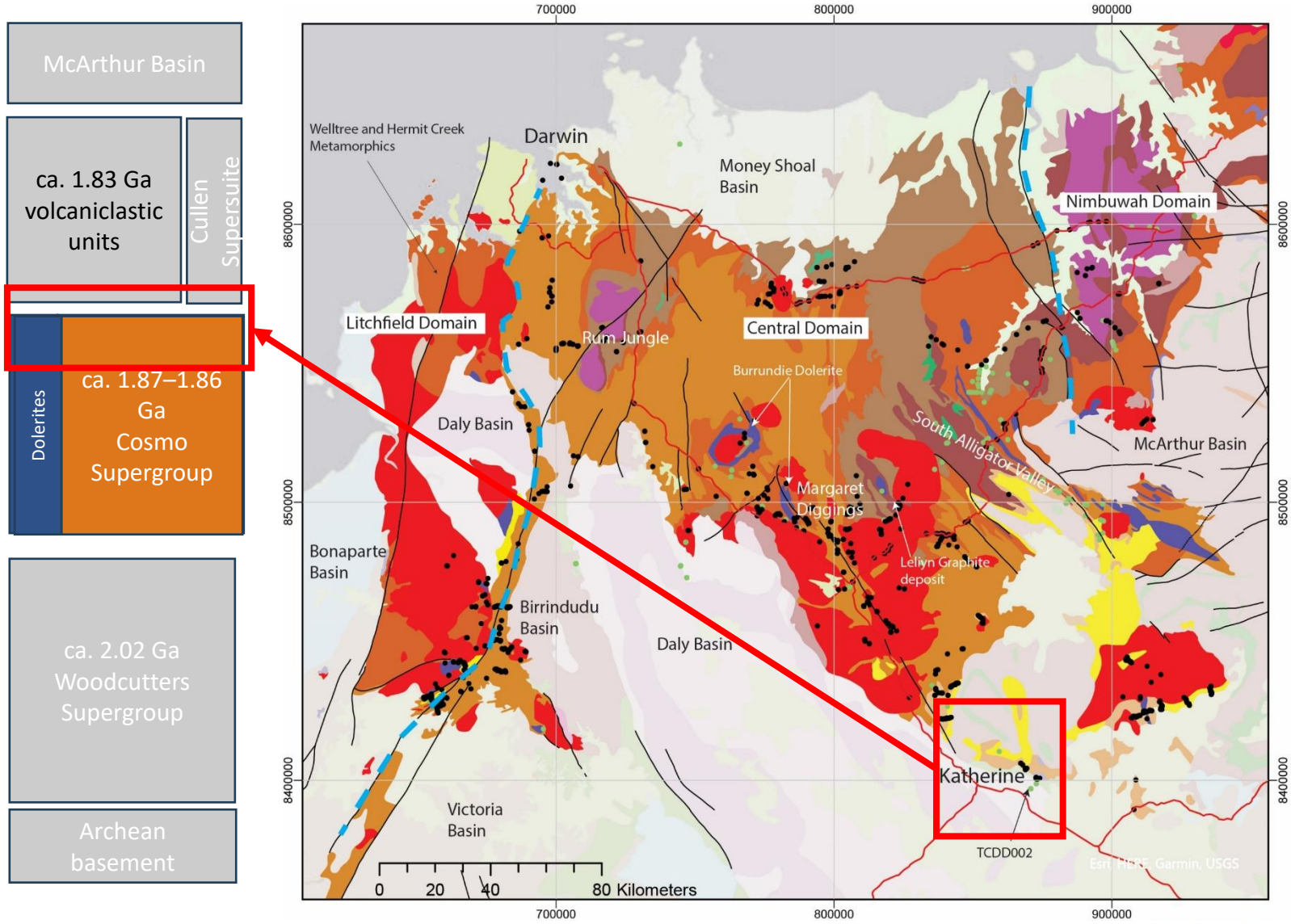
- The south of the PCO is dominated by **upper Cosmo Supergroup (ca. 1.86 Ga)**



Pine Creek Orogen

Mafic magmatism

- The south of the PCO is dominated by **upper Cosmo Supergroup (ca. 1.86 Ga)**



Pine Creek Orogen

Mafic magmatism

- The south of the PCO is dominated by **upper Cosmo Supergroup (ca. 1.86 Ga)**

Tollis Fm
(1.86 Ga)

McArthur Basin

ca. 1.83 Ga volcaniclastic units

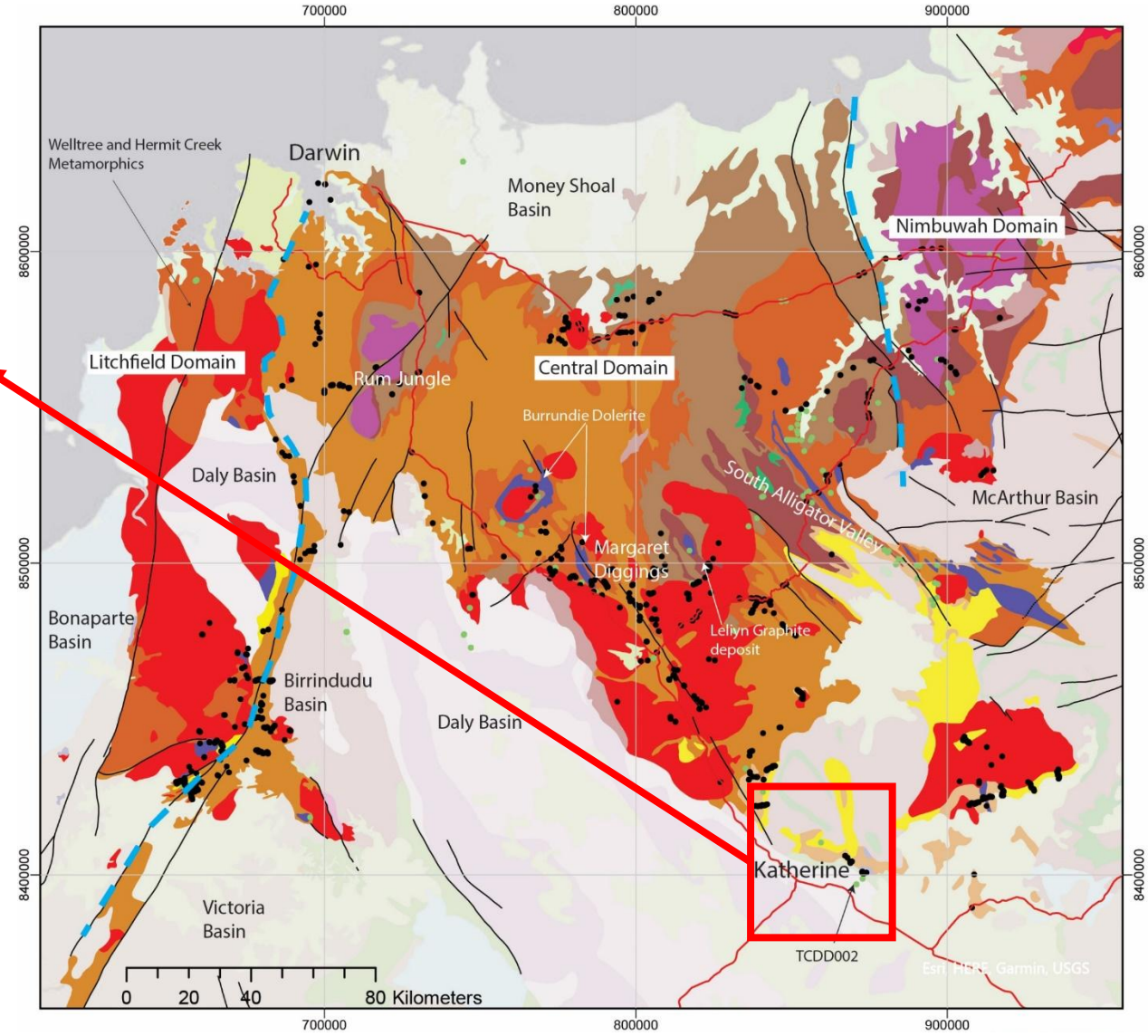
Cullen Supersuite

Dolerites

ca. 1.87–1.86 Ga Cosmo Supergroup

ca. 2.02 Ga Woodcutters Supergroup

Archean basement

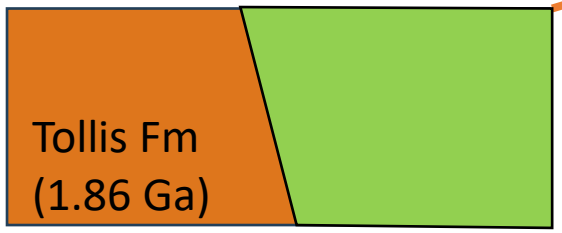


NORTHERN TERRITORY GOVERNMENT

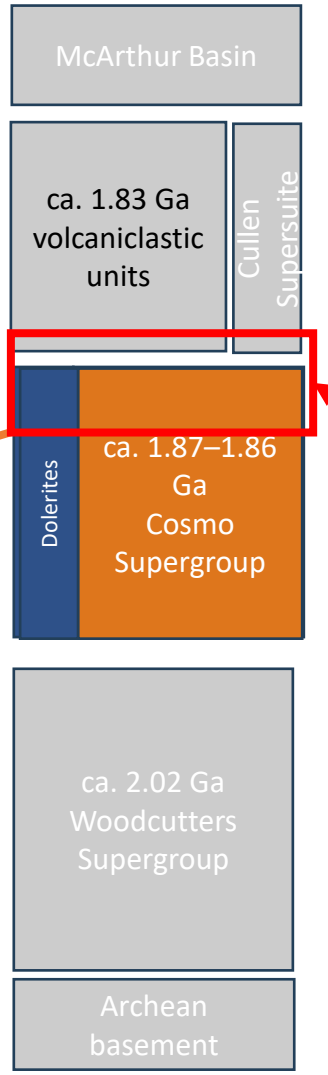
Pine Creek Orogen

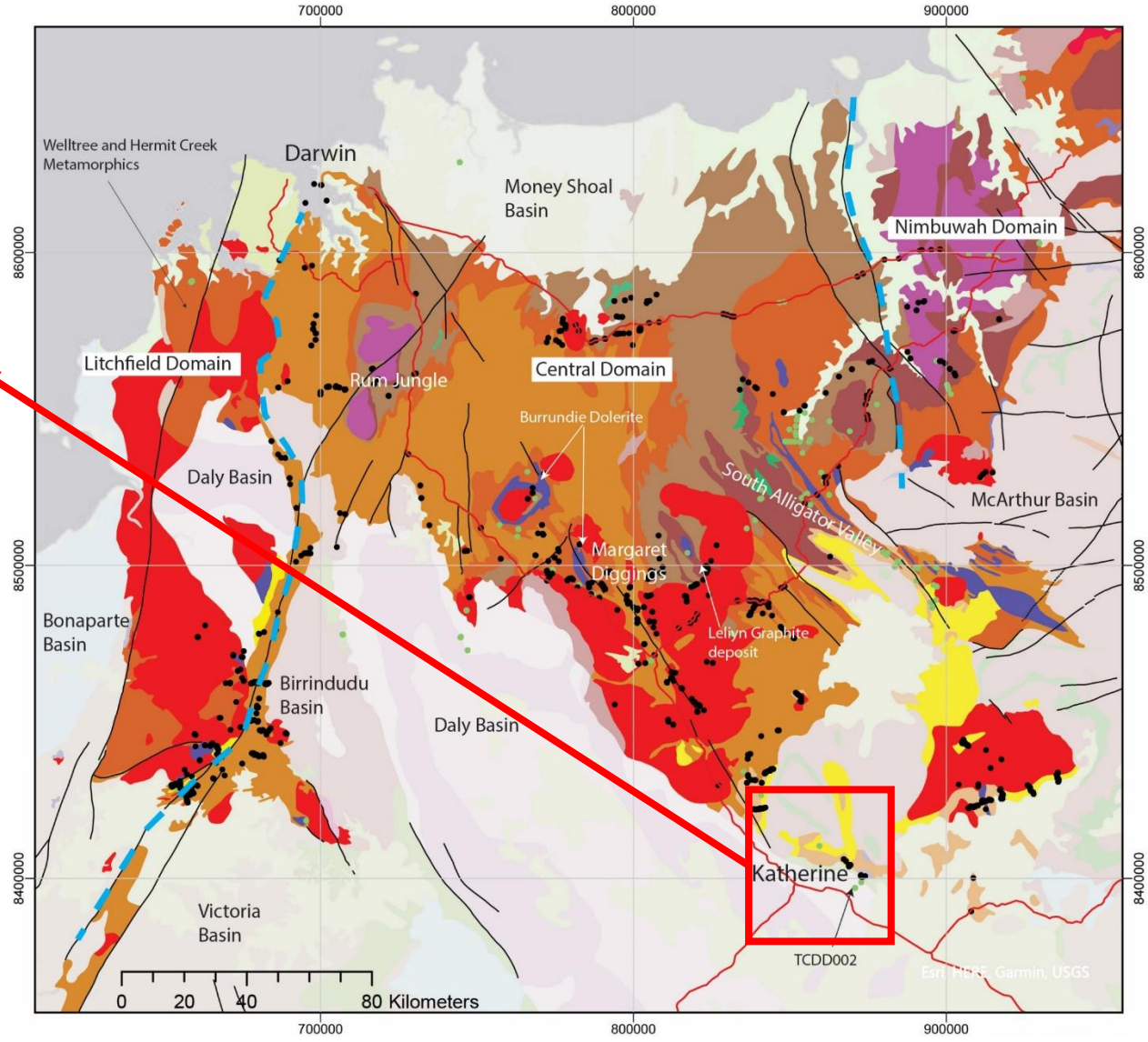
Mafic magmatism

- The south of the PCO is dominated by **upper Cosmo Supergroup (ca. 1.86 Ga)**



Dorothy Volcanic Member (DVM)



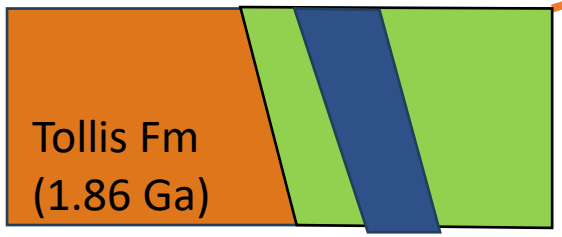


NORTHERN TERRITORY GOVERNMENT

Pine Creek Orogen

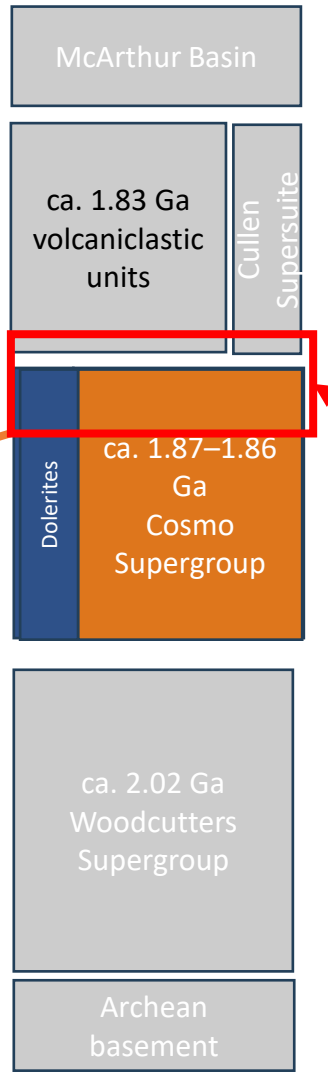
Mafic magmatism

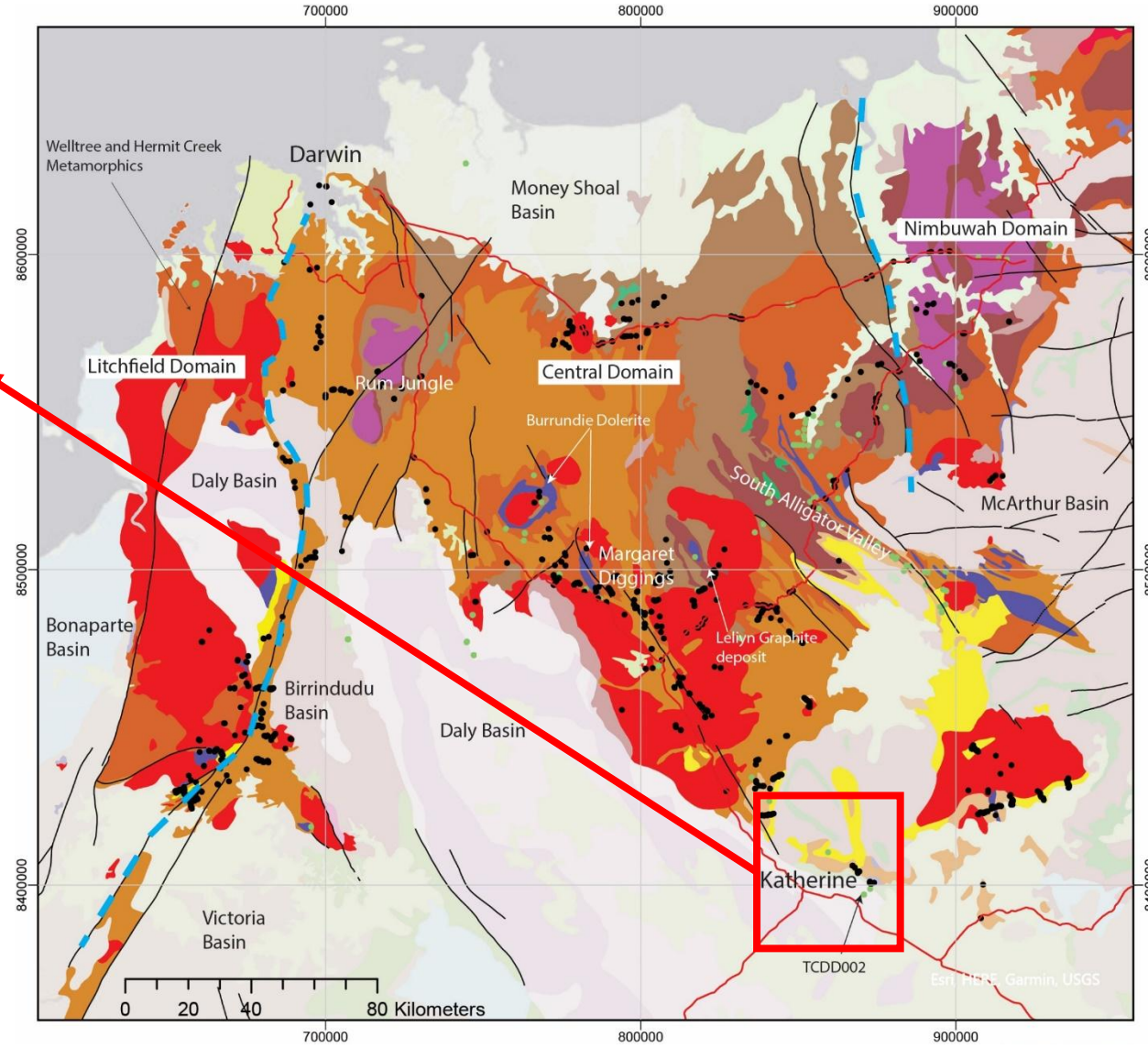
- The south of the PCO is dominated by **upper Cosmo Supergroup (ca. 1.86 Ga)**



Dorothy Volcanic Member (DVM)

Maud Dolerite



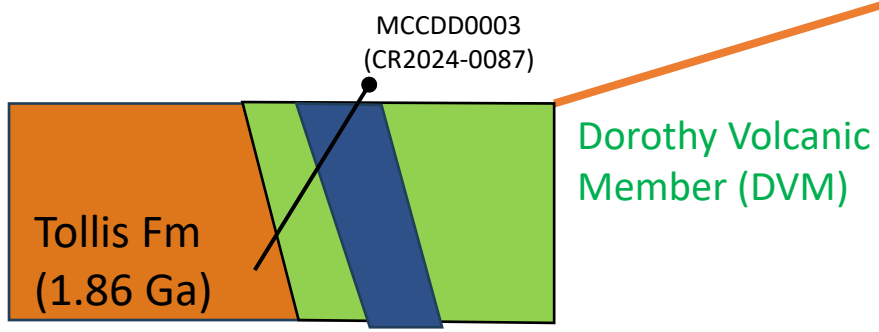


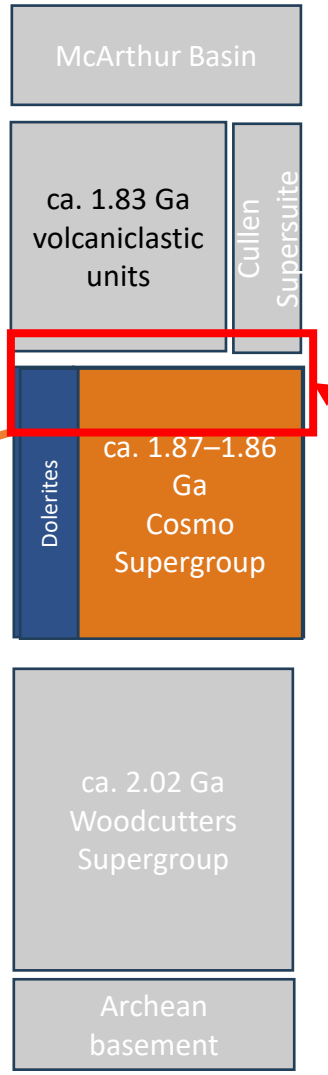
NORTHERN TERRITORY GOVERNMENT

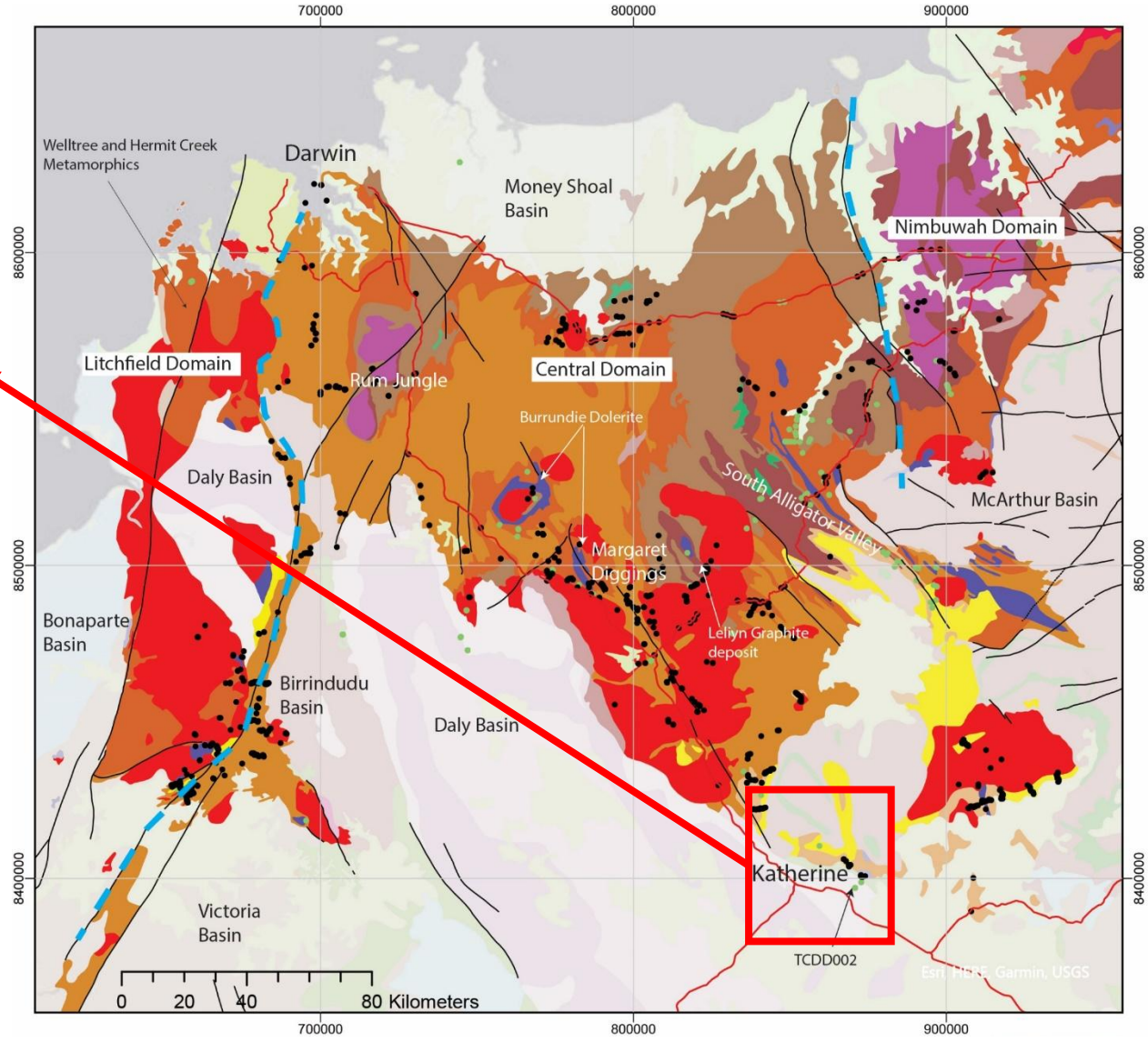
Pine Creek Orogen

Mafic magmatism

- The south of the PCO is dominated by **upper Cosmo Supergroup (ca. 1.86 Ga)**





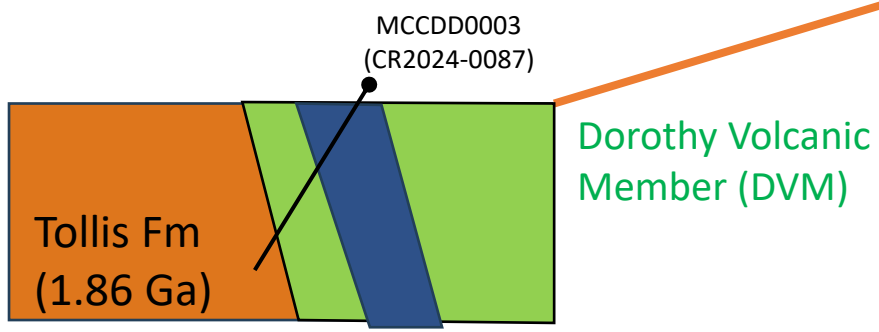


NORTHERN TERRITORY GOVERNMENT

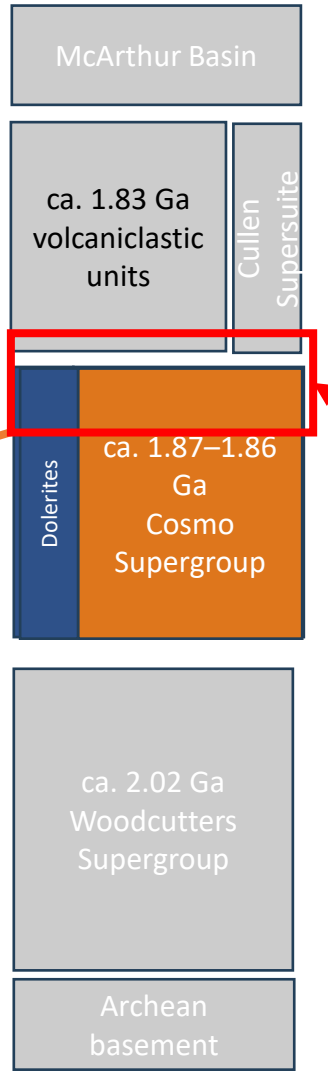
Pine Creek Orogen

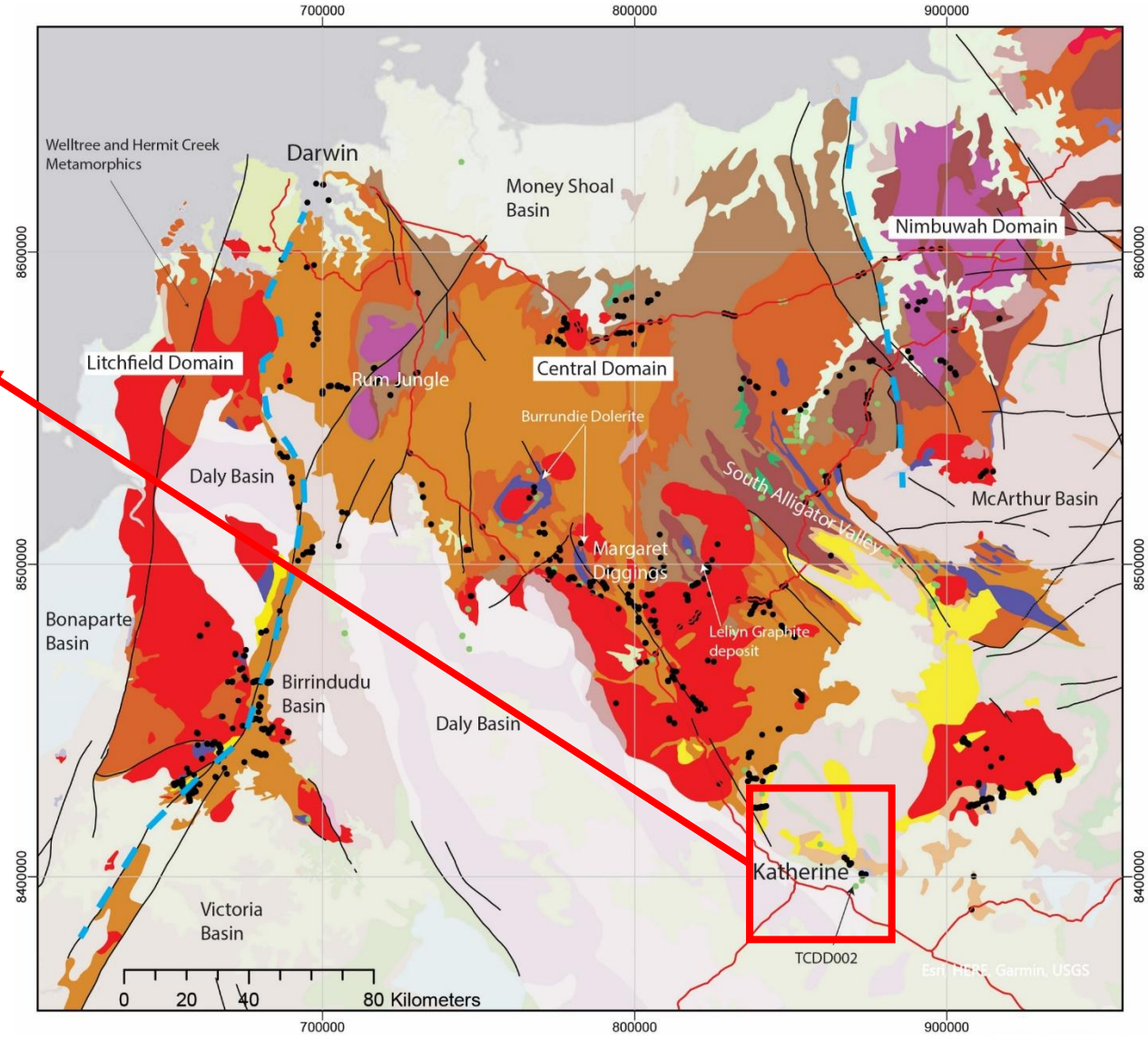
Mafic magmatism

- The south of the PCO is dominated by **upper Cosmo Supergroup (ca. 1.86 Ga)**



We dated Maud Dolerite…



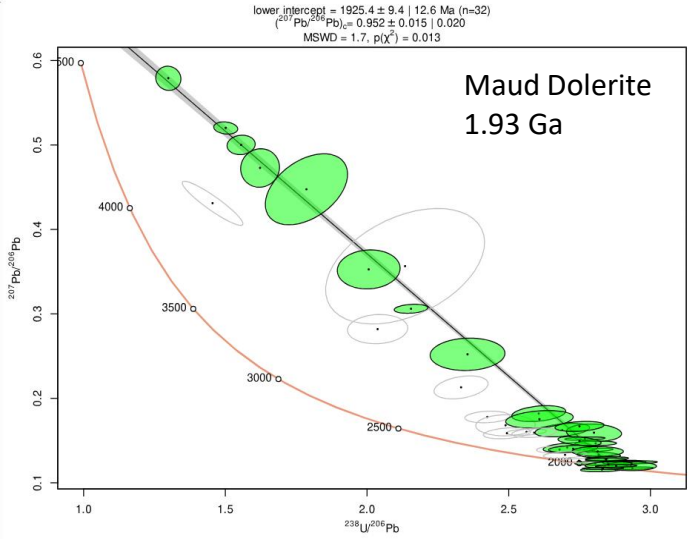


NORTHERN TERRITORY GOVERNMENT

Pine Creek Orogen

Mafic magmatism

In situ igneous **titanite U-Pb** age of **ca. 1.93 Ga**



McArthur Basin

ca. 1.83 Ga volcaniclastic units

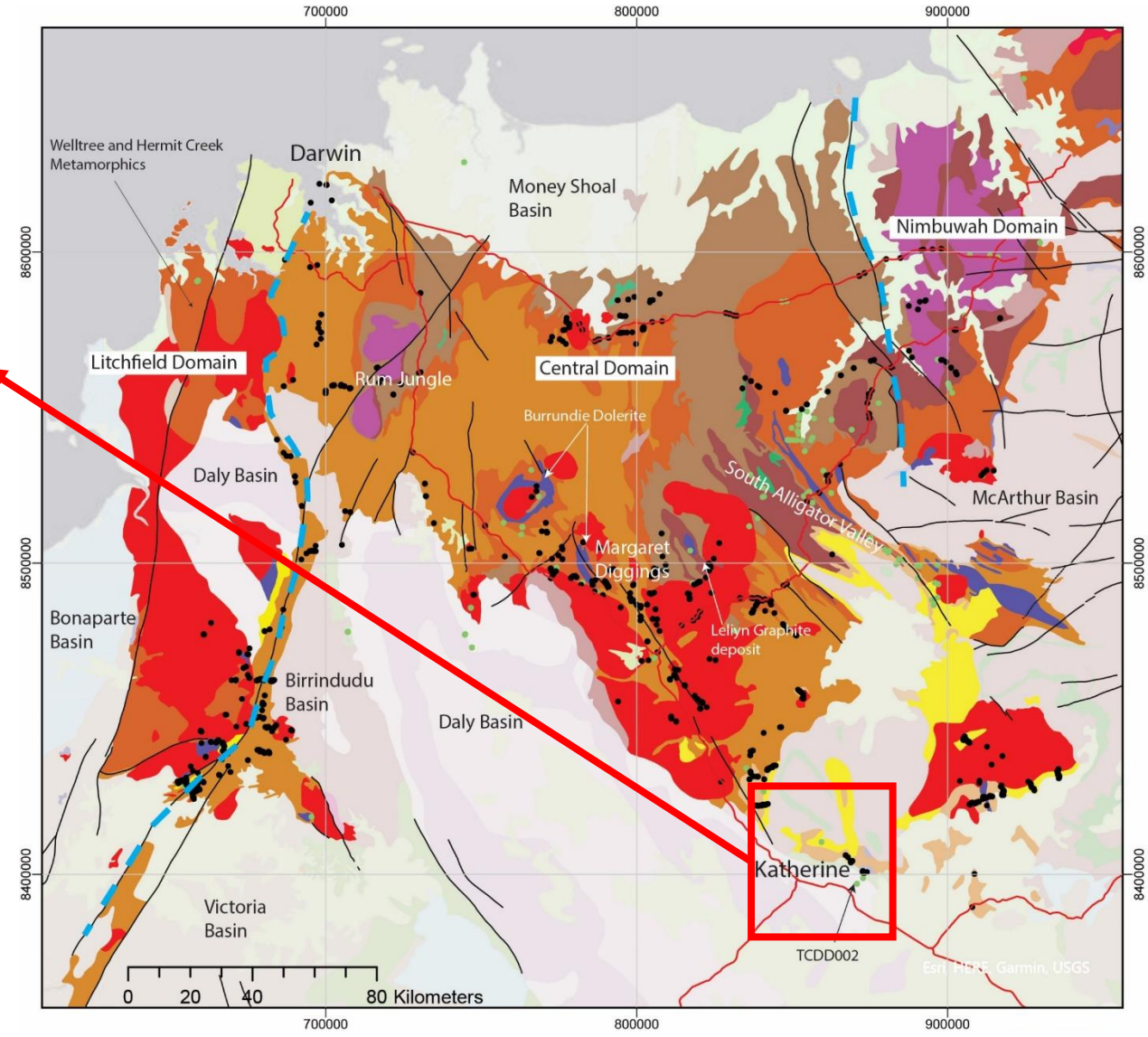
Cullen Supersuite

Dolerites

ca. 1.87–1.86 Ga Cosmo Supergroup

ca. 2.02 Ga Woodcutters Supergroup

Archean basement

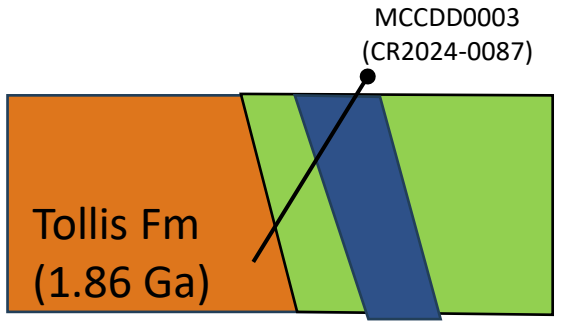


NORTHERN TERRITORY GOVERNMENT

Pine Creek Orogen

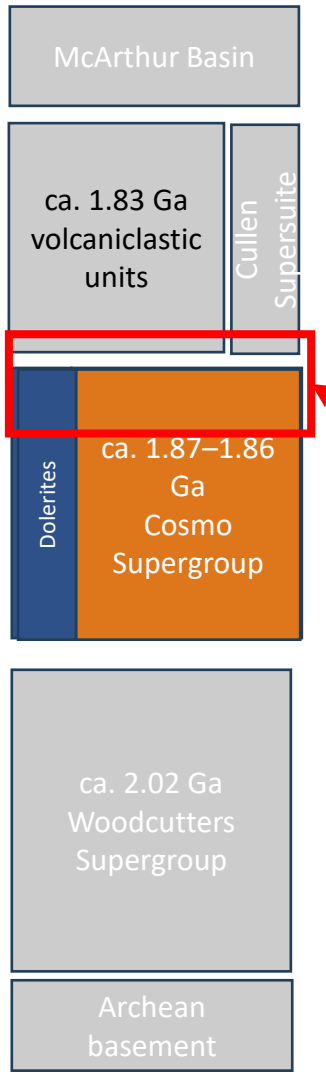
Mafic magmatism

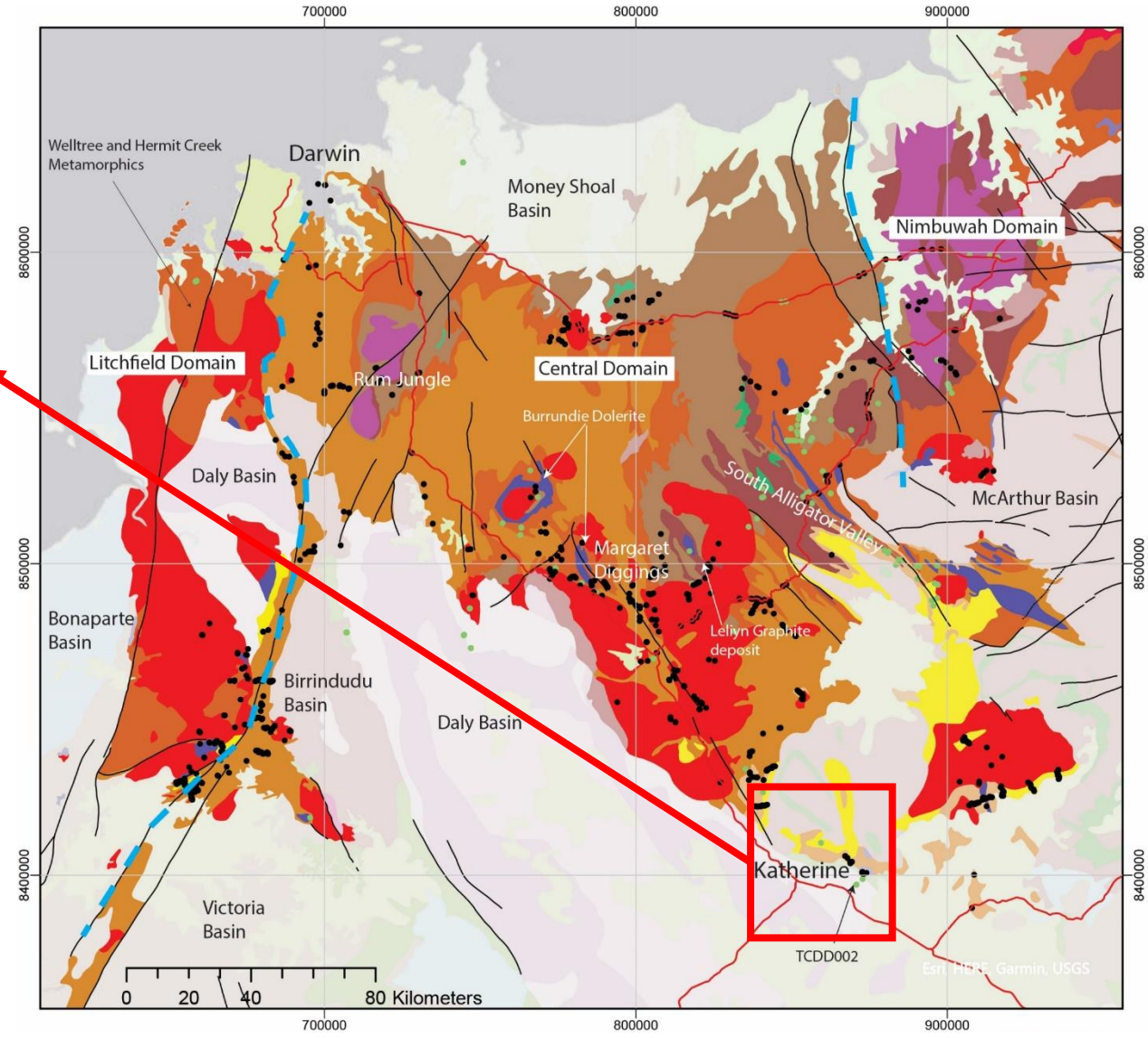
Let's have a closer look at the Maud Dolerite host: DVM



Dorothy Volcanic Member (DVM)

Maud Dolerite



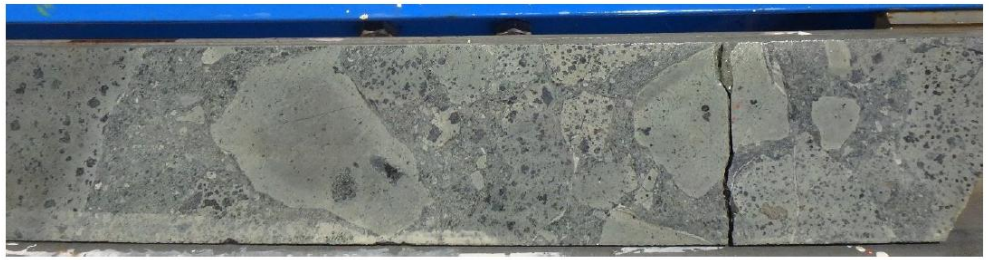


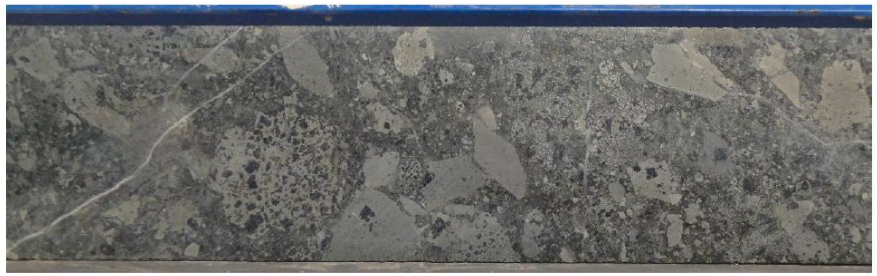
NORTHERN TERRITORY GOVERNMENT

Pine Creek Orogen

Mafic magmatism

- DVM is a thickly bedded, olivine-augite-phyric **polymictic basalt breccia** (McPhie 2023)

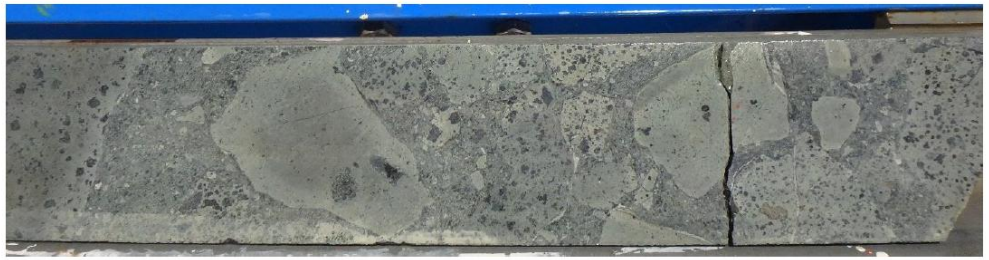


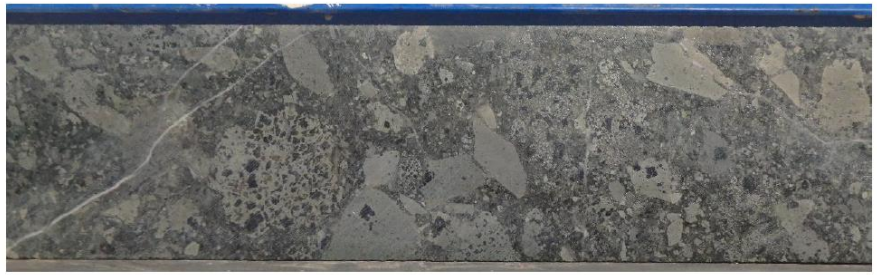


Pine Creek Orogen

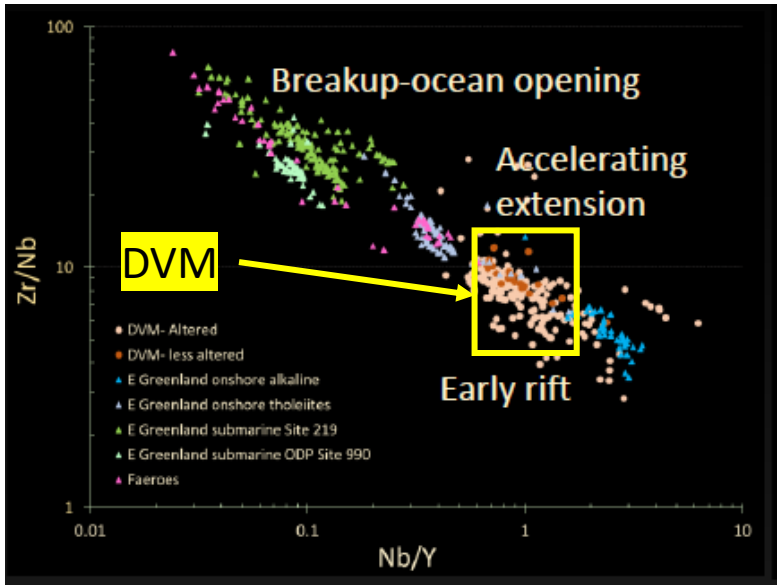
Mafic magmatism

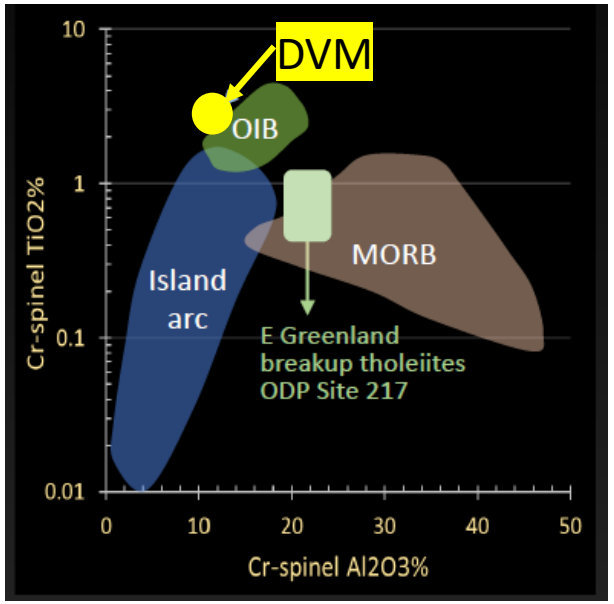
- DVM is a thickly bedded, olivine-augite-phyric **polymictic basalt breccia** (McPhie 2023)





- DVM composition suggest **alkaline to subalkaline basalt erupted during early stages of rifting** (GDC-CR2024-0087; Crawford, 2024)
- DVM in situ chromite composition (Kamenetsky et al. 2001) also suggests **early-stage rifting** of continental crust (GDC-CR2024-0087; Crawford, 2024)





Crawford (2024) – CR2024-0087

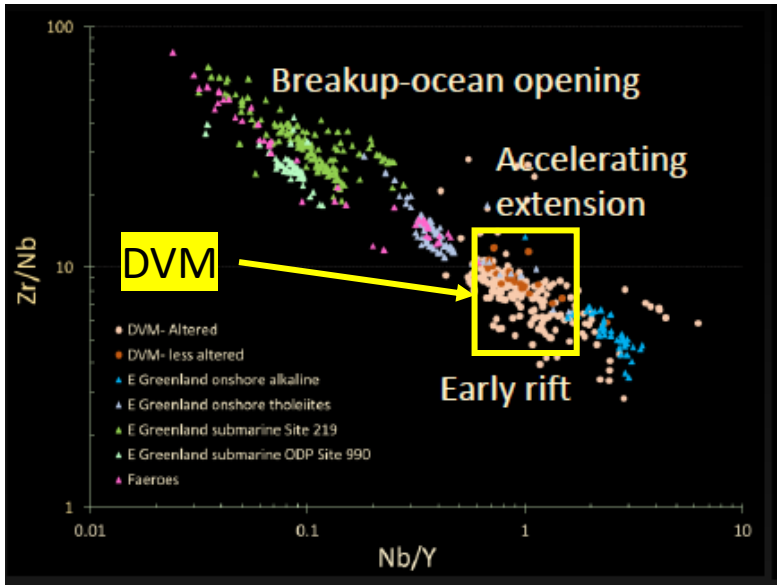
Pine Creek Orogen

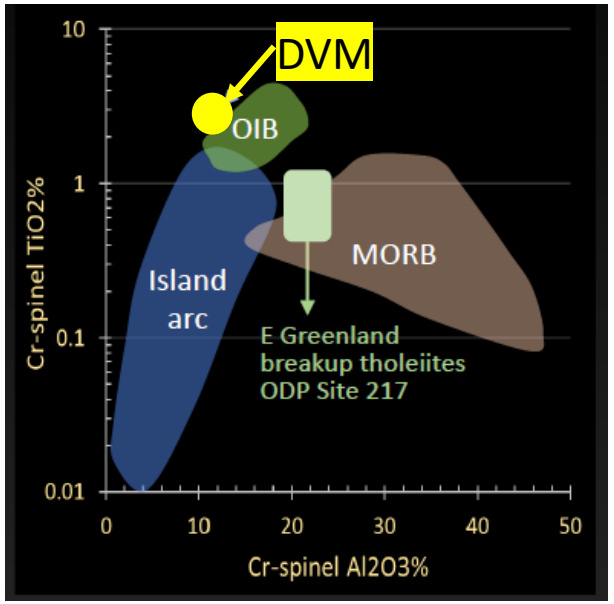
Mafic magmatism

- DVM is a thickly bedded, olivine-augite-phyric **polymictic basalt breccia** (McPhie 2023)

Early rifting tectonic settings = Woodcutters Supergroup

- DVM composition suggest **alkaline to subalkaline basalt erupted during early stages of rifting** (GDC-CR2024-0087; Crawford, 2024)
- DVM in situ chromite composition (Kamenetsky et al. 2001) also suggests **early-stage rifting** of continental crust (GDC-CR2024-0087; Crawford, 2024)





Crawford (2024) – CR2024-0087

Pine Creek Orogen

Mafic magmatism

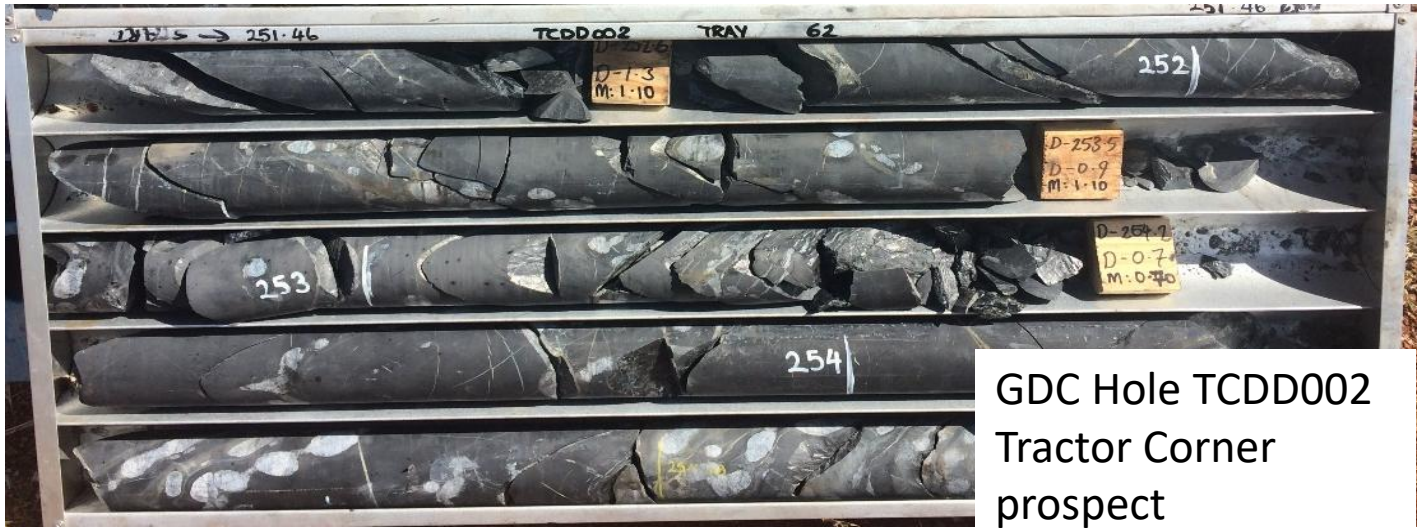
Not far from there, under Cambrian-aged Daly Basin…..

Pine Creek Orogen

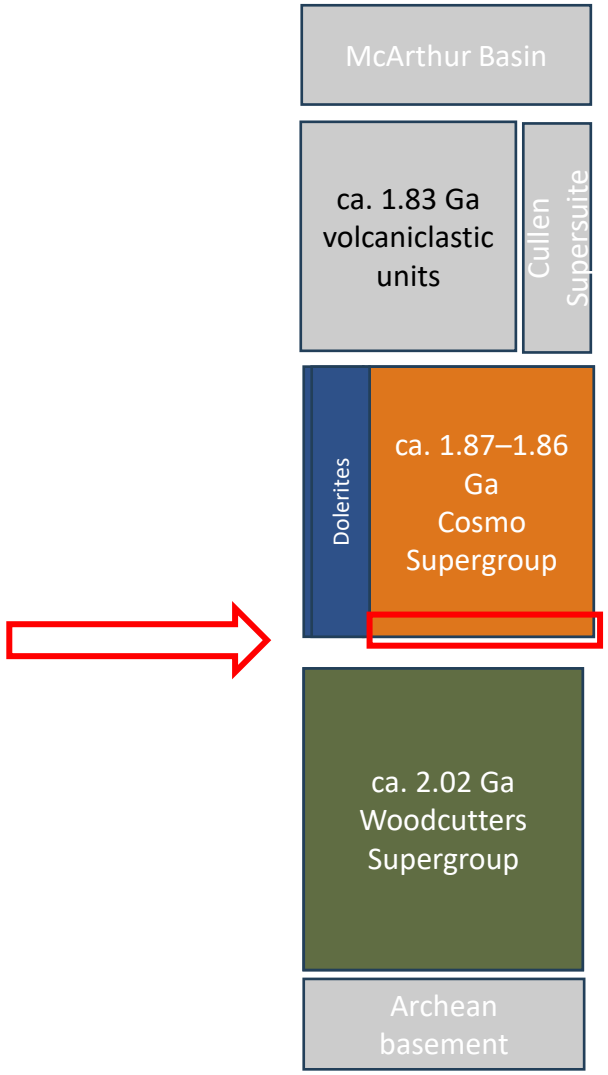
Mafic magmatism

Not far from there, under Cambrian-aged Daly Basin…..

GDC Drillhole TCDD002 intersected laminated, Fe-rich, carbonaceous and chert-rich metasiltstone (**Koolpin Formation**?)



GDC Hole TCDD002 Tractor Corner prospect



Pine Creek Orogen

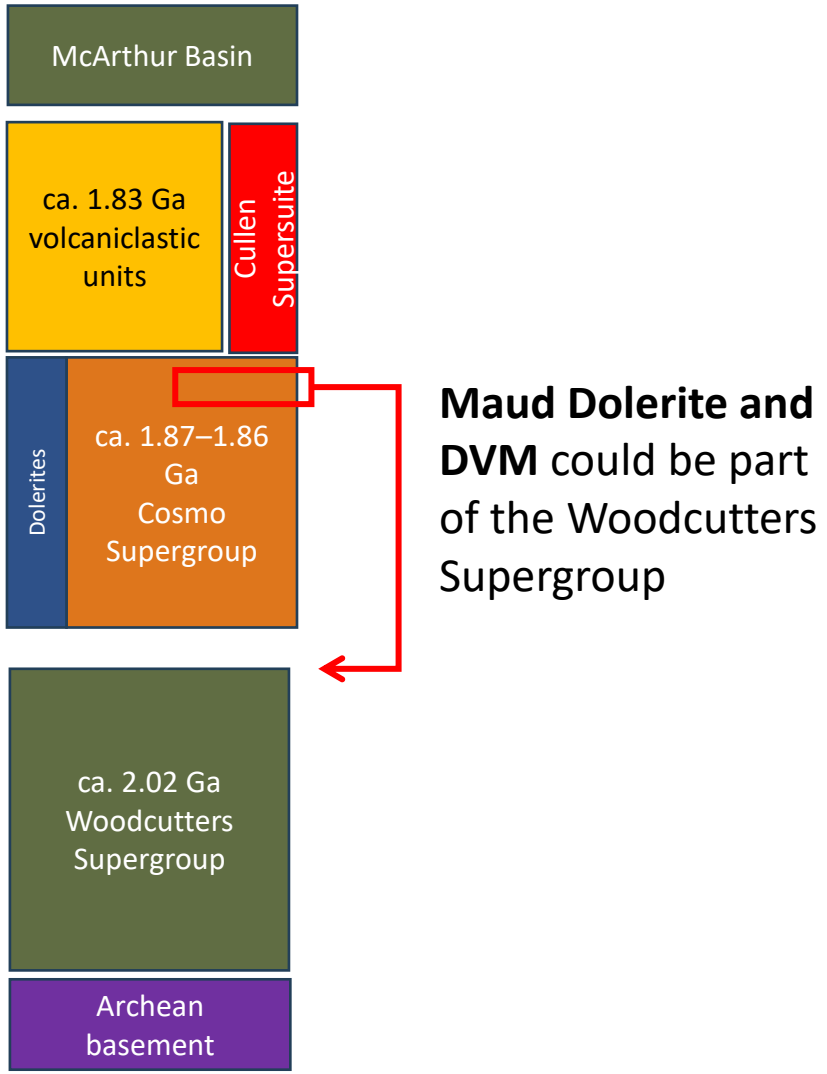
Mafic magmatism

Potential **Woodcutters Supergroup** and **Koolpin Formation** south of PCO

- Lithologically heterogeneous and chemically reactive units

- Woodcutters Supergroup is the main host for polymetallic systems including
  - Polymetallic systems / Browns and Woodcutters deposits (Cu-Ni-Co-Pb; Zn-Pb-Ag)
  - Graphite
  - Uranium
  - Magnesite
  - Phosphate…

- **Expansion of target areas for mineral exploration**



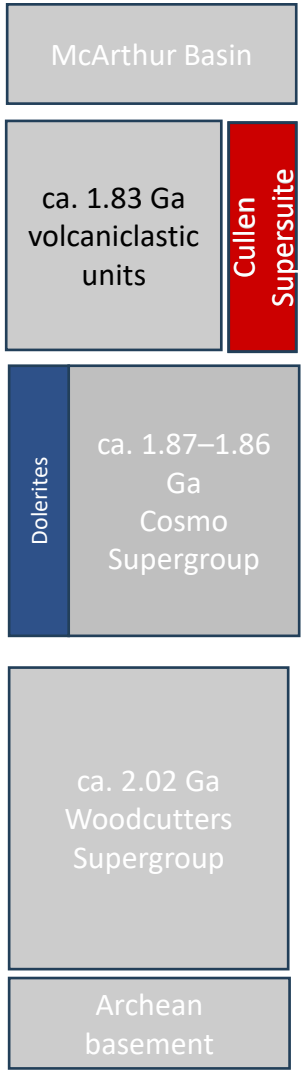
Pine Creek Orogen

Igneous Stratigraphy

We are interested in the **isotope geochemistry** on felsic and mafic rocks helps us understand:

- **Timing**
- **Magma source/s**
- **Tectonic settings**

Mafic magmatism
New whole-rock isotopic composition



Felsic magmatism
New zircon isotopic compositions

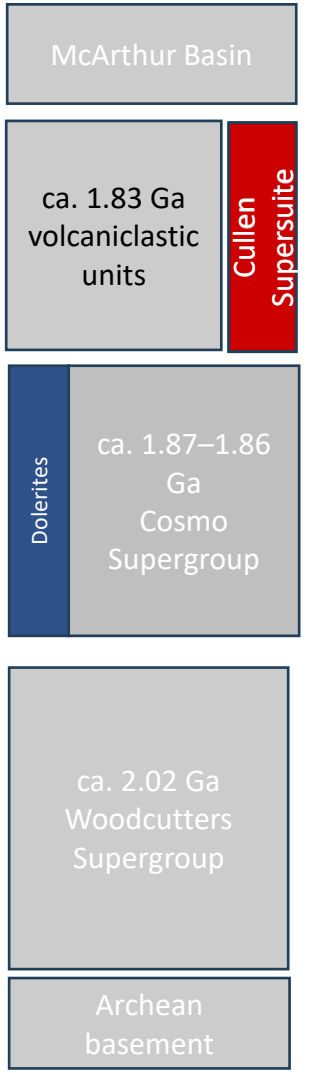
Pine Creek Orogen

Igneous Stratigraphy

We are interested in the **isotope geochemistry** on felsic and mafic rocks helps us understand:

- **Timing**
- **Magma source/s**
- **Tectonic settings**

Mafic magmatism
New whole-rock isotopic composition

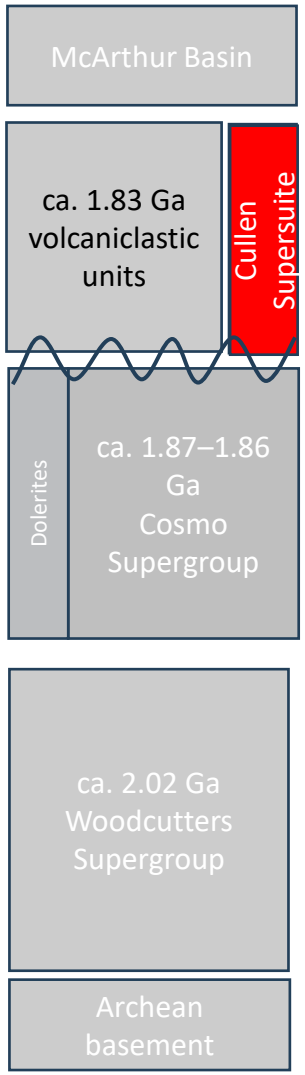


Felsic magmatism
New zircon isotopic compositions

Pine Creek Orogen

Zircon isotopic data – Cullen Supersuite

Previous studies concluded that the main phase of emplacement of the Cullen Supersuite in the Central Domain was **ca 1.83–1.82 Ga after deformation** (Wyborn *et al* 1997, Worden *et al* 2008a, Ahmad and Hollis 2013)

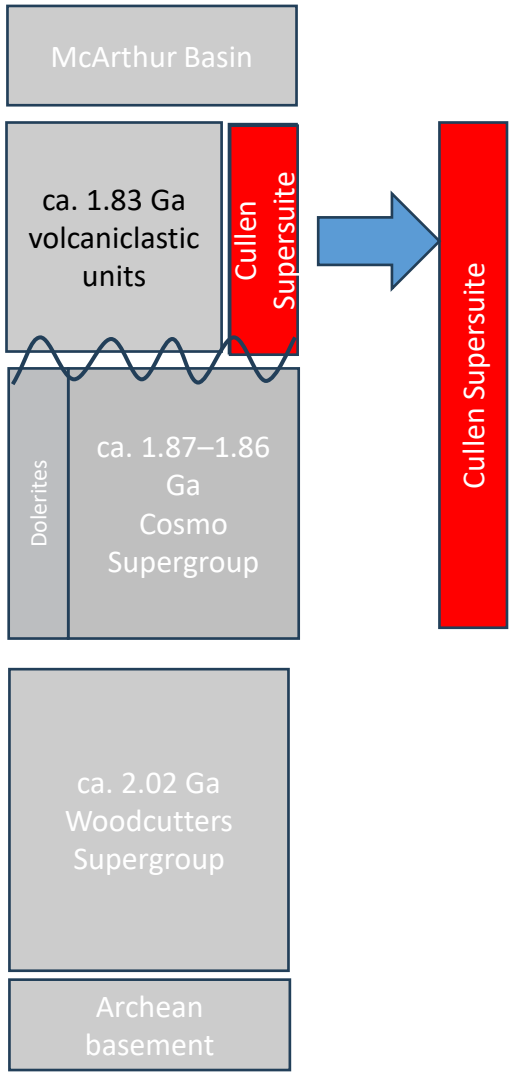


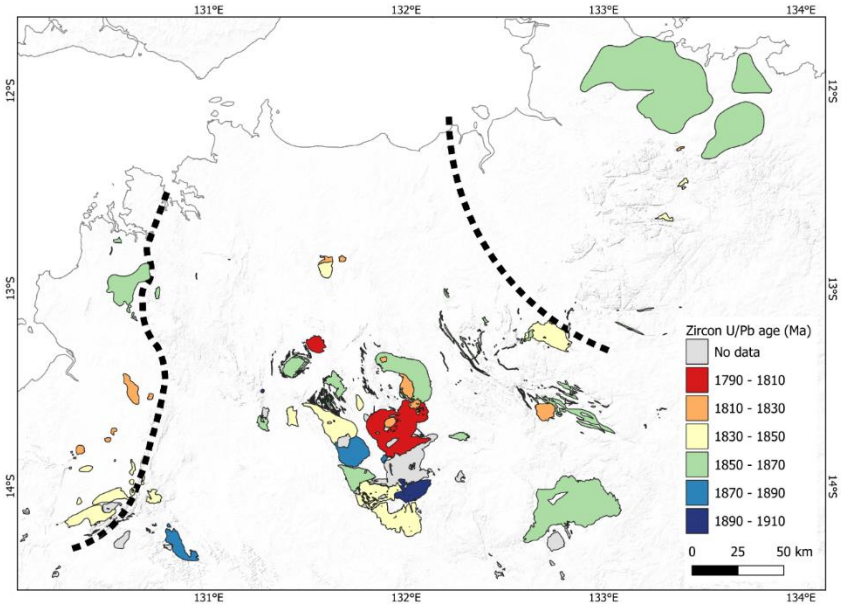
Pine Creek Orogen

Zircon isotopic data – Cullen Supersuite

Previous studies concluded that the main phase of emplacement of the Cullen Supersuite in the Central Domain was **ca 1.83–1.82 Ga after deformation** (Wyborn *et al* 1997, Worden *et al* 2008a, Ahmad and Hollis 2013)

- New zircon U–Pb LA–ICP–MS data extends the period of felsic magmatism of the Cullen Supersuite to **between ca 1.90 and ca 1.80 Ga**





Burton-Johnson *et al* (2026)

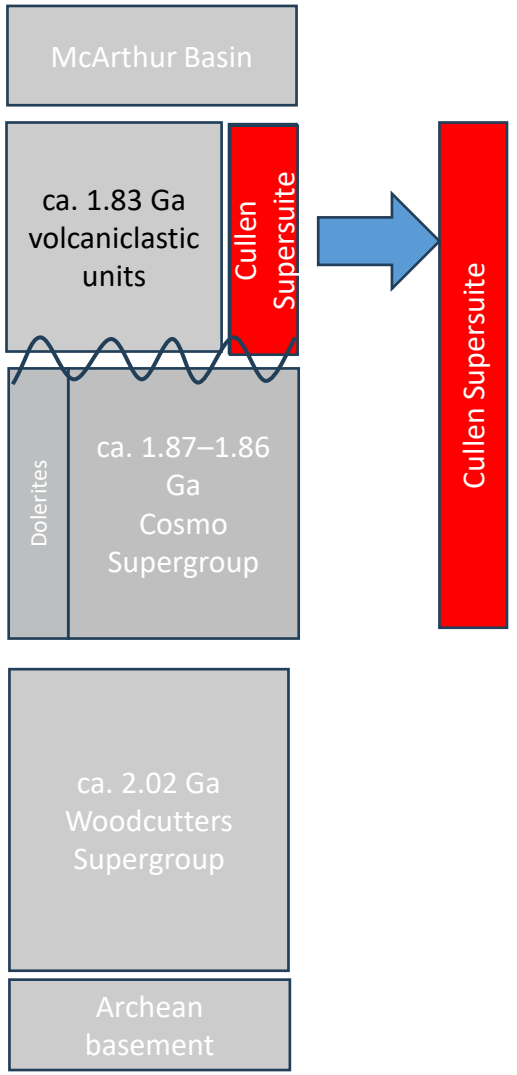
Pine Creek Orogen

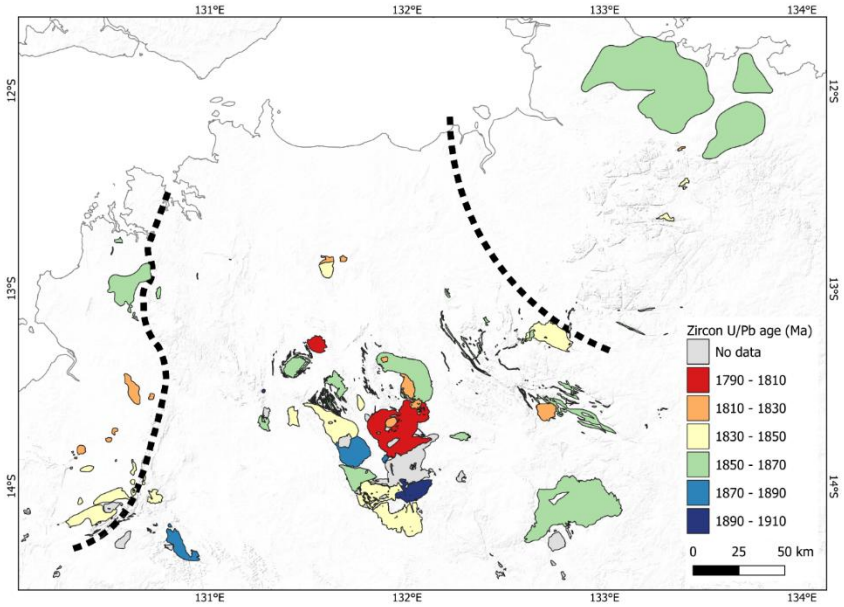
Zircon isotopic data – Cullen Supersuite

Previous studies concluded that the main phase of emplacement of the Cullen Supersuite in the Central Domain was **ca 1.83–1.82 Ga after deformation** (Wyborn *et al* 1997, Worden *et al* 2008a, Ahmad and Hollis 2013)

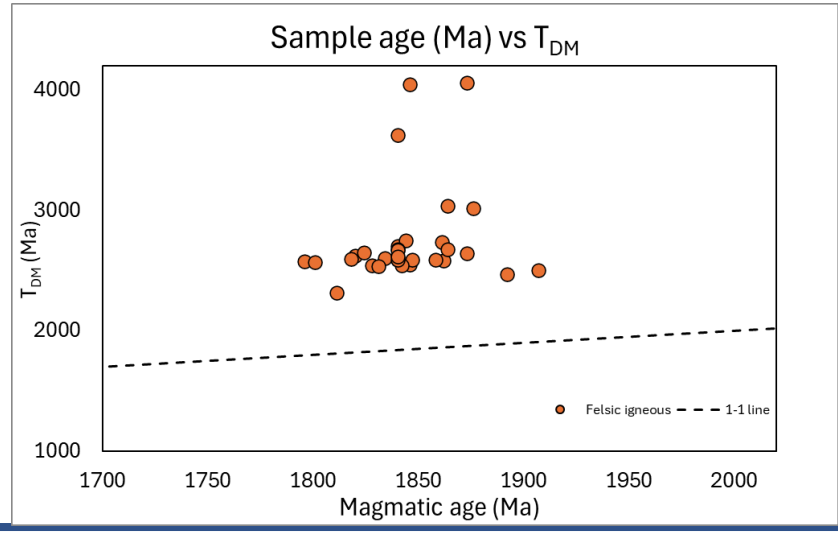
- New zircon U–Pb LA–ICP–MS data extends the period of felsic magmatism of the Cullen Supersuite to **between ca 1.90 and ca 1.80 Ga**

- Model ages mostly ~ **2.5 – 2.6 Ga** – **Archean sources**





Burton-Johnson *et al* (2026)

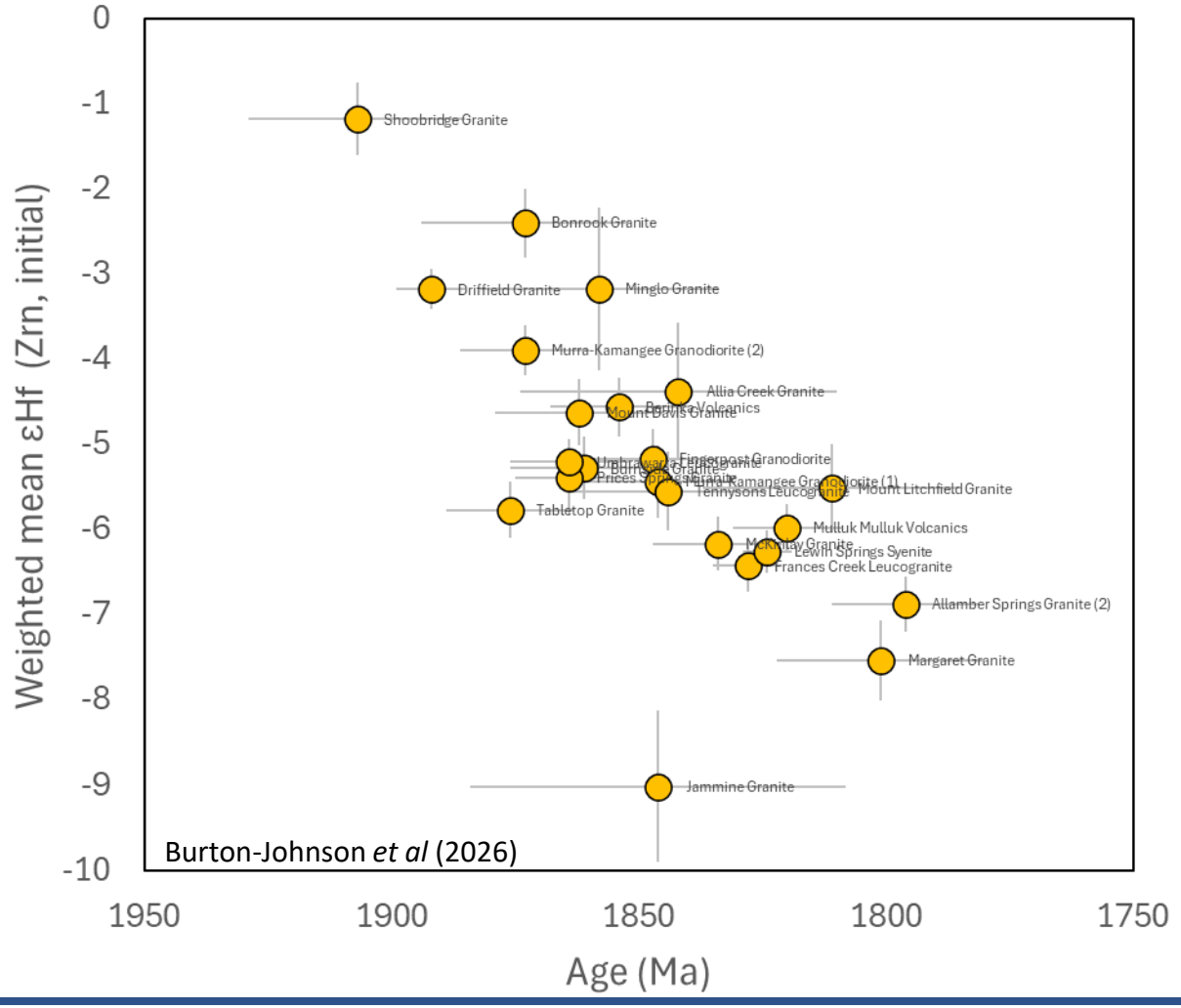


Pine Creek Orogen

Zircon isotopic data – Cullen Supersuite

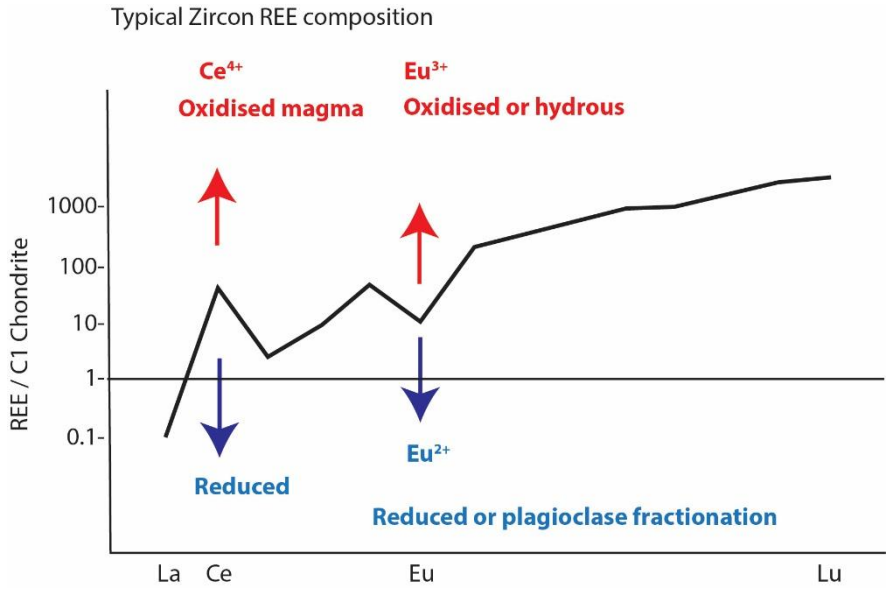
Magmatic zircon Lu-Hf (εHf) to understand magma source / evolution

- Zircon Hf composition show progressive decrease in εHf, indicating **increasing involvement of evolved crustal material** (reworking or assimilation?)



Pine Creek Orogen

Zircon isotopic data – Cullen Supersuite



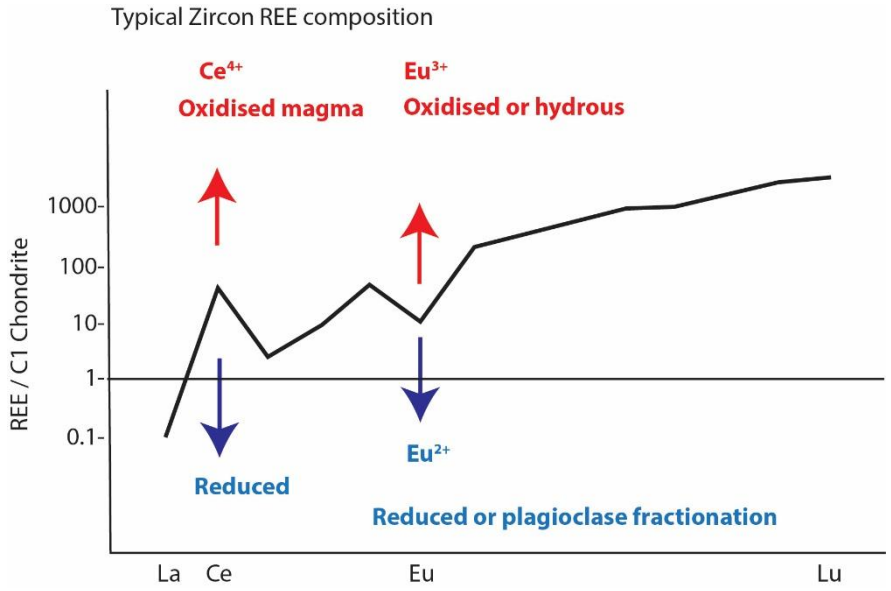
Oxidised magmas:

$Ce^{+3} <$ **Ce^{+4} – Ce^{+4} fits perfectly on Zircon structure**

$Eu^{+2} <$ **Eu^{+3} – Eu can not fit into Plagioclase, so it goes to Zircon**

Pine Creek Orogen

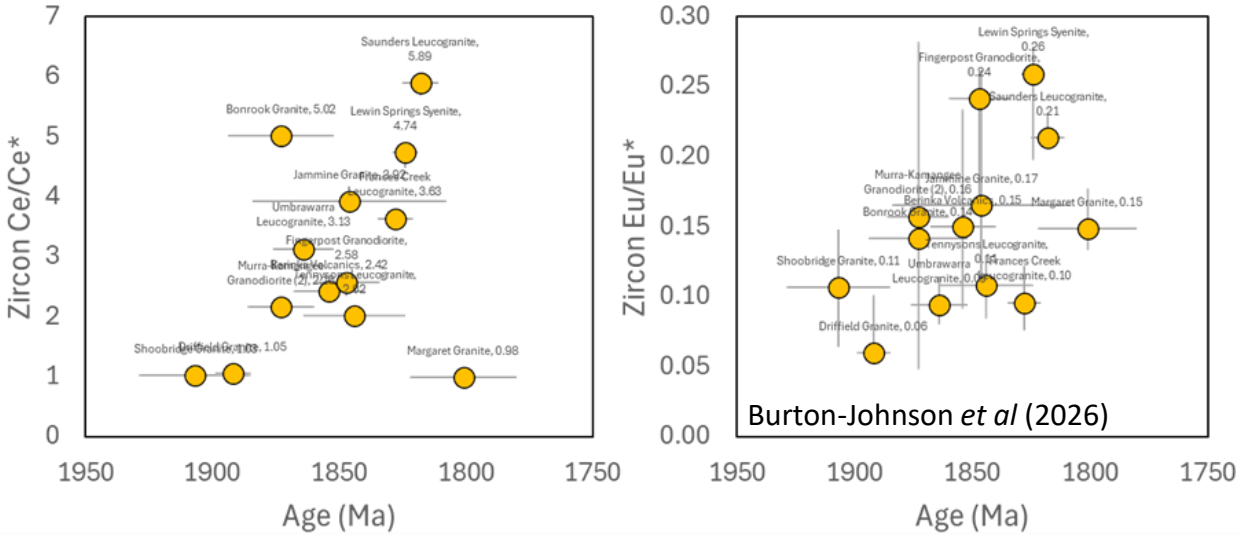
Zircon isotopic data – Cullen Supersuite



Oxidised magmas:

$Ce^{+3} < Ce^{+4}$ – **Ce^{+4} fits perfectly on Zircon structure**

$Eu^{+2} < Eu^{+3}$ – **Eu can not fit into Plagioclase, so it goes to Zircon**

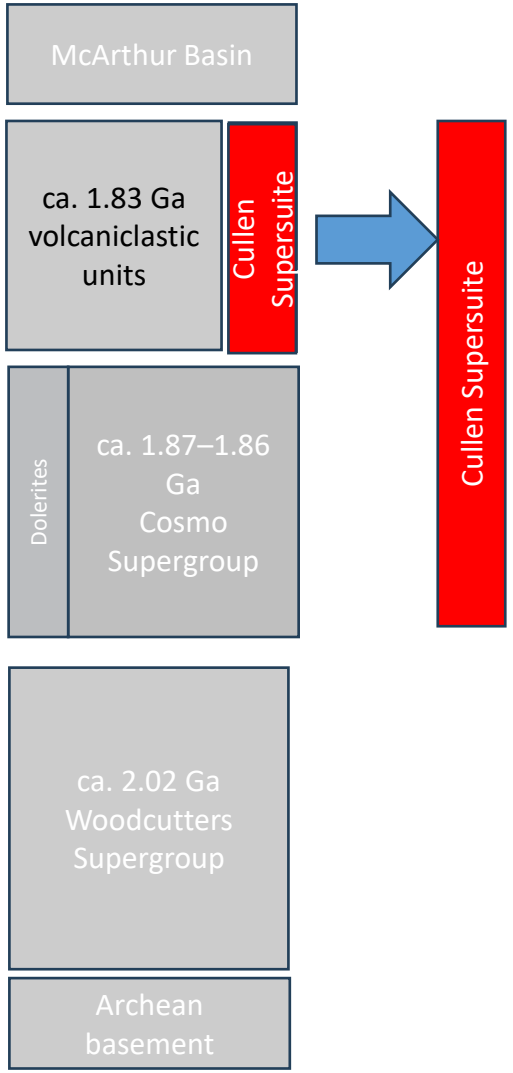


- increase in zircon Ce/Ce* and Eu/Eu* anomalies with time suggest an **increase in the oxidation state** of granitic magmas

Pine Creek Orogen

Long-lived felsic magmatism

Coeval granite emplacement and deposition → prolonged magmatism in an extensional setting

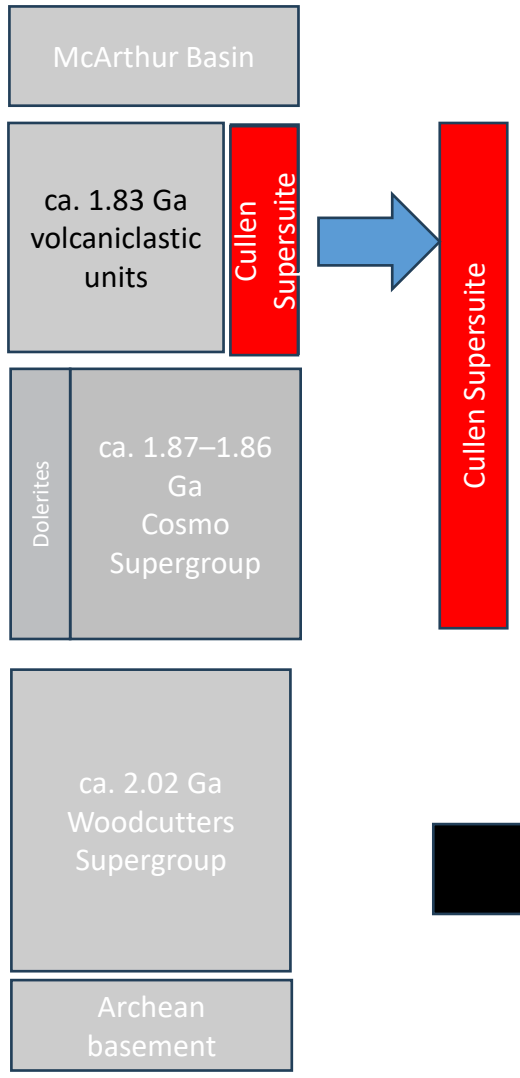


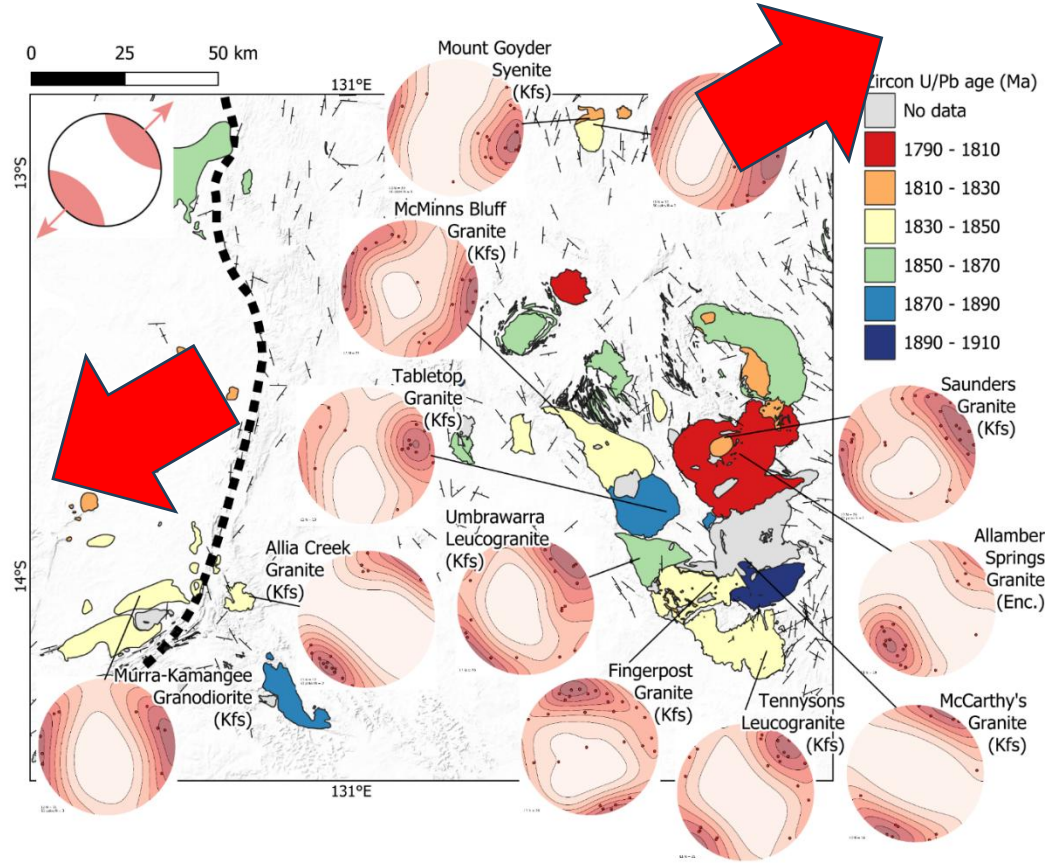
Pine Creek Orogen

Long-lived felsic magmatism

Coeval granite emplacement and deposition → prolonged magmatism in an extensional setting

Magmatic fabric suggests **NE-SW oriented extensional strain during emplacement of granites** (Burton-Johnson *et al* 2025) **but the host rocks record a NE-SW shortening….**





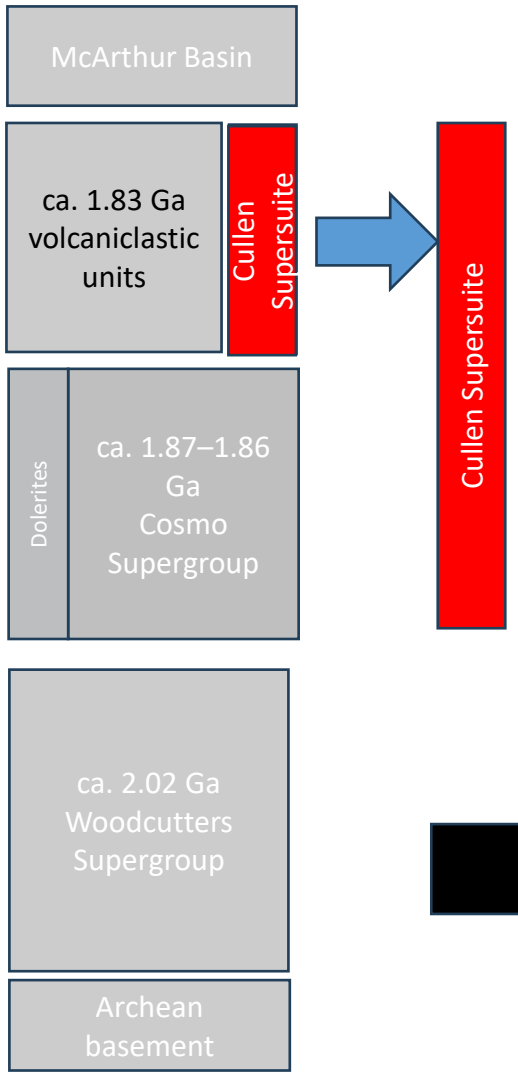
Pine Creek Orogen

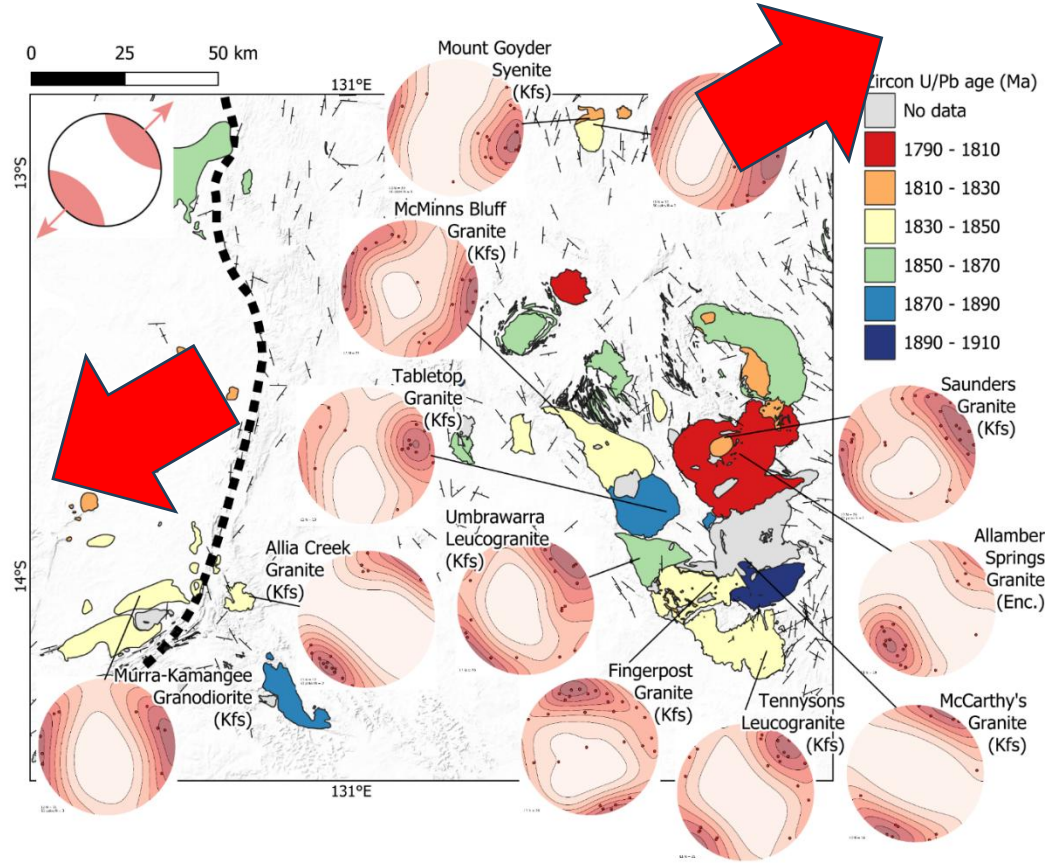
Long-lived felsic magmatism

Coeval granite emplacement and deposition → prolonged magmatism in an extensional setting

Magmatic fabric suggests **NE-SW oriented extensional strain during emplacement of granites** (Burton-Johnson *et al* 2025) **but the host rocks record a NE-SW shortening….**

Let's have a closer look at the metasedimentary rocks around the granites





Pine Creek Orogen

Long-lived felsic magmatism

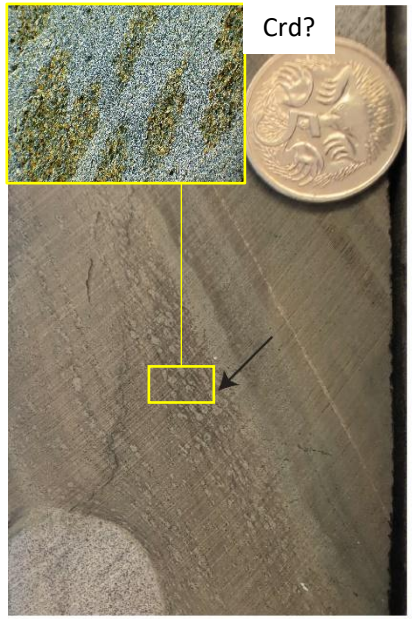
Contact metamorphism

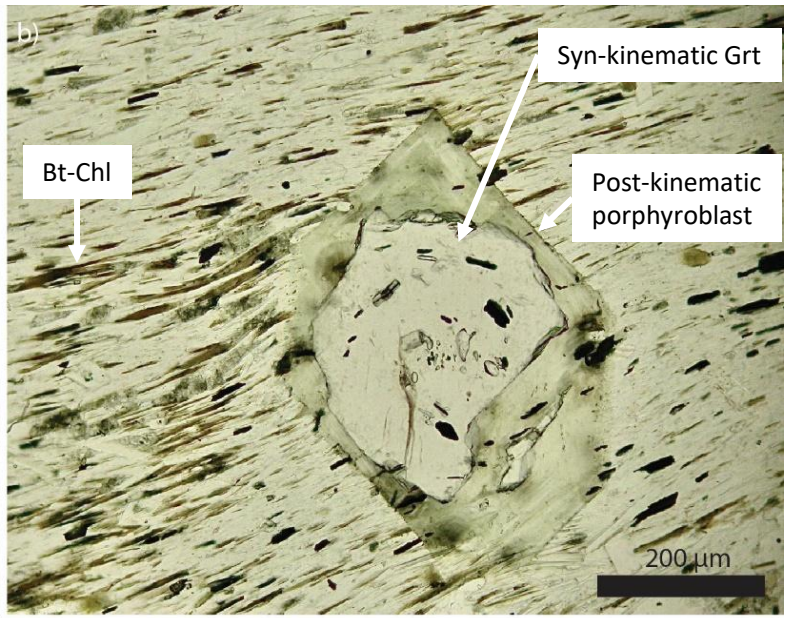
Evidence of **pre- syn- and post**-kinematic porphyroblasts

- Pre-kinematic foliated cordierite and/or andalusite
- Syn-kinematic garnet
- Post-kinematic randomly oriented andalusite

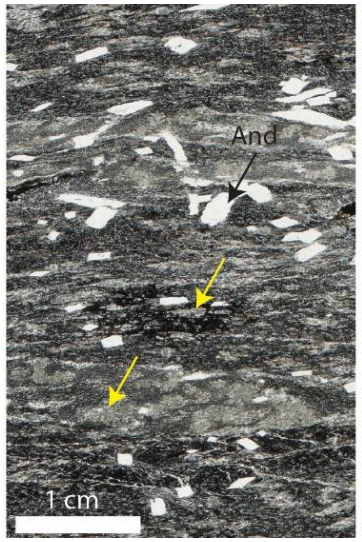
Interpretation:

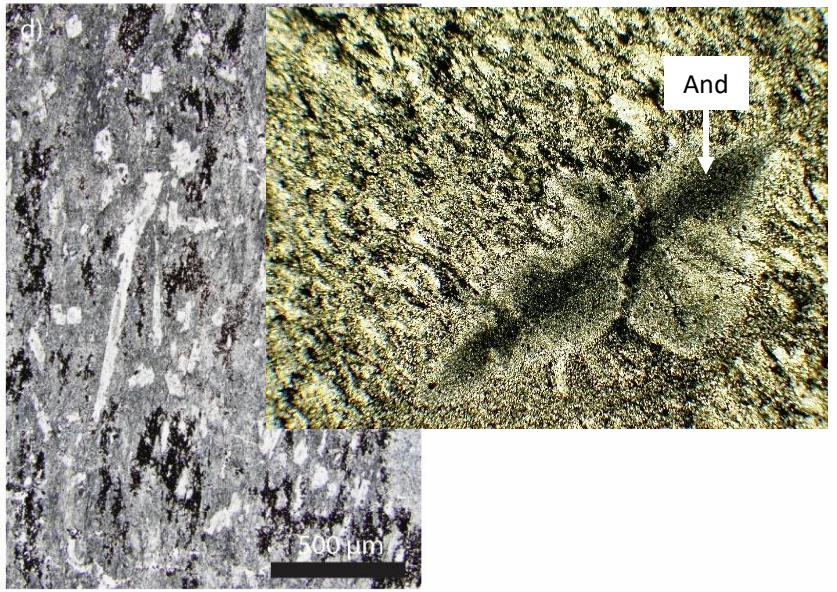
- Magmatism was protracted and **not exclusively post-orogenic**.
- The emplacement of the Cullen Supersuite occurred during a regime of **alternating extensional and compressional tectonics**.





Pre and post-kinematic And





Pine Creek Orogen

Conclusions

Pine Creek Orogen

Conclusions

New stratigraphic constraints include:

- **Early rifting alkaline mafic** volcanic rocks in **Woodcutters Supergroup stratigraphy south of PCO**– economic implications

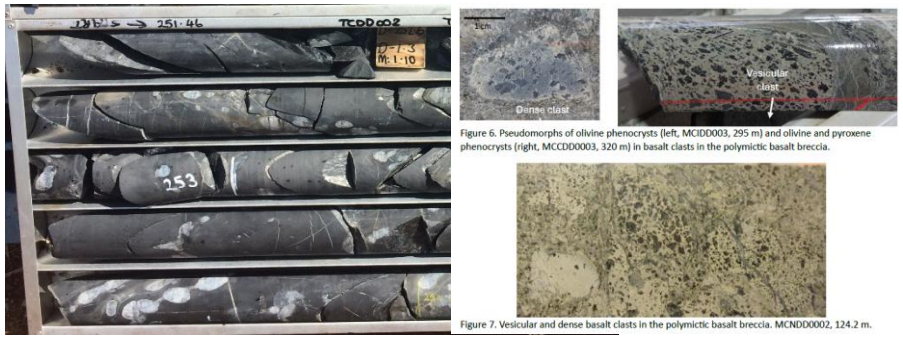


Figure 6. Pseudomorphs of olivine phenocrysts (left, MCIDD003, 295 m) and olivine and pyroxene phenocrysts (right, MCCDD0003, 320 m) in basalt clasts in the polymictic basalt breccia.

Figure 7. Vesicular and dense basalt clasts in the polymictic basalt breccia. MCNDD0002, 124.2 m.

Pine Creek Orogen

Conclusions

New stratigraphic constraints include:

- **Early rifting alkaline mafic** volcanic rocks in **Woodcutters Supergroup stratigraphy south of PCO**– economic implications

Isotopic geochemistry:

- Mafic rocks εNd evolution suggests **higher mantle (juvenile) input in the Central / Litchfield Domain** compared with more continental crust interaction towards the East (Nimbuwah Domain)

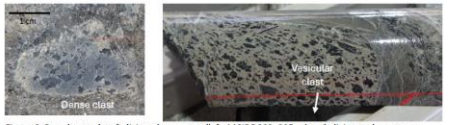


Figure 6. Pseudomorphs of olivine phenocrysts (left, MCIDD003, 295 m) and olivine and pyroxene phenocrysts (right, MCCDD0003, 320 m) in basalt clasts in the polymictic basalt breccia.

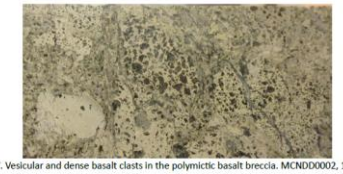
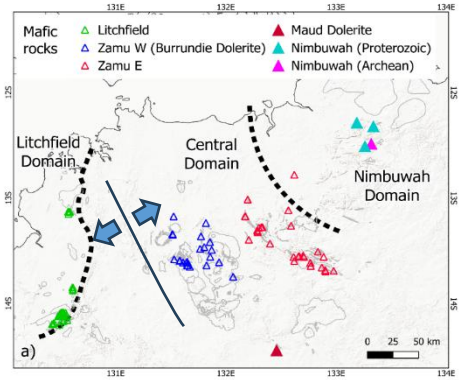


Figure 7. Vesicular and dense basalt clasts in the polymictic basalt breccia. MCNDD0002, 124.2 m.



Pine Creek Orogen

Conclusions

New stratigraphic constraints include:

- **Early rifting alkaline mafic** volcanic rocks in **Woodcutters Supergroup stratigraphy south of PCO**– economic implications

Isotopic geochemistry:

- Mafic rocks εNd evolution suggests **higher mantle (juvenile) input in the Central / Litchfield Domain** compared with more continental crust interaction towards the East (Nimbuwah Domain)

Zircon isotopic composition:

- εHf, Eu/Eu* and Ce/Ce* indicates progressive **crustal assimilation** and changes in **oxidation state** of granites with time

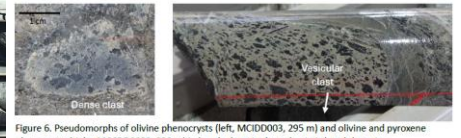


Figure 6. Pseudomorphs of olivine phenocrysts (left, MCIDD003, 295 m) and olivine and pyroxene phenocrysts (right, MCCDD0003, 320 m) in basalt clasts in the polymictic basalt breccia.

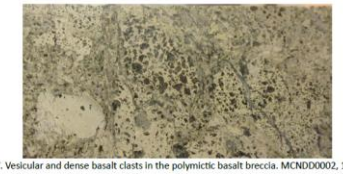
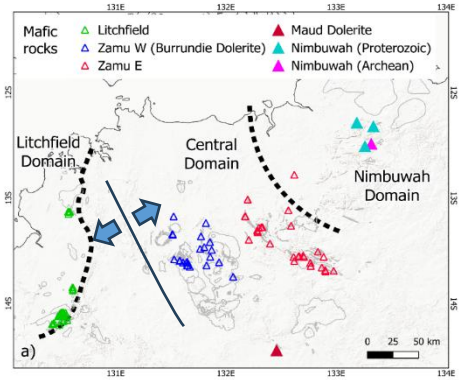
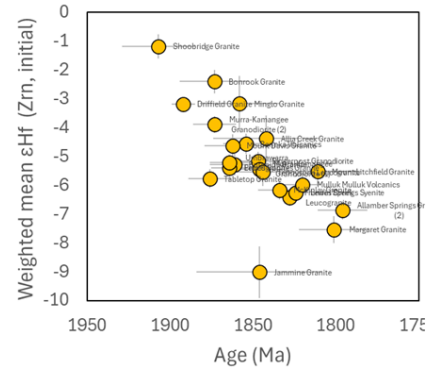


Figure 7. Vesicular and dense basalt clasts in the polymictic basalt breccia. MCNDD0002, 124.2 m.





Pine Creek Orogen

Conclusions

New stratigraphic constraints include:

- **Early rifting alkaline mafic** volcanic rocks in **Woodcutters Supergroup stratigraphy south of PCO**– economic implications

Isotopic geochemistry:

- Mafic rocks εNd evolution suggests **higher mantle (juvenile) input in the Central / Litchfield Domain** compared with more continental crust interaction towards the East (Nimbuwah Domain)

Zircon isotopic composition:

- εHf, Eu/Eu* and Ce/Ce* indicates progressive **crustal assimilation** and changes in **oxidation state** of granites with time

Geochronology of granites:

- **Long-lived felsic magmatism** (1.90-1.80 Ga)
- Evidence of **pre-, syn- and post-kinematic contact metamorphism** indicating dynamic tectonic regimes

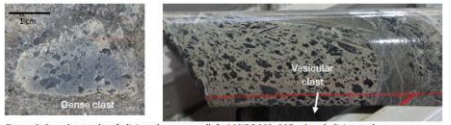


Figure 6. Pseudomorphs of olivine phenocrysts (left, MCIDD003, 295 m) and olivine and pyroxene phenocrysts (right, MCCDD0003, 320 m) in basalt clasts in the polymictic basalt breccia.

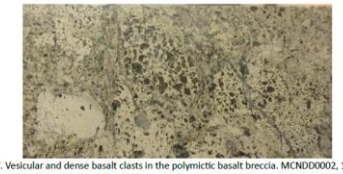
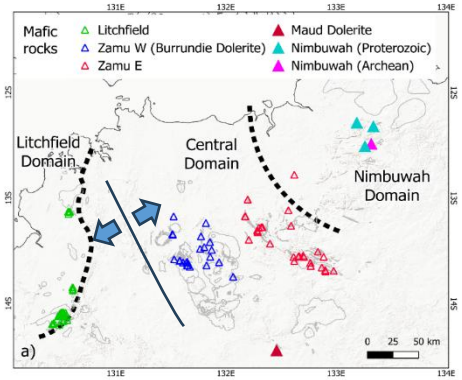
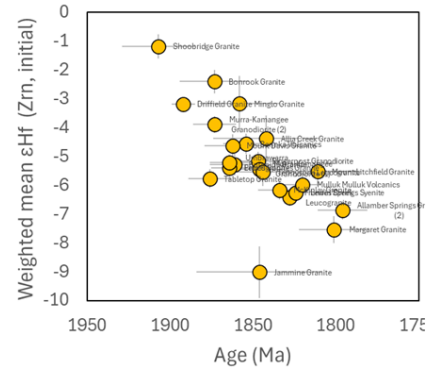
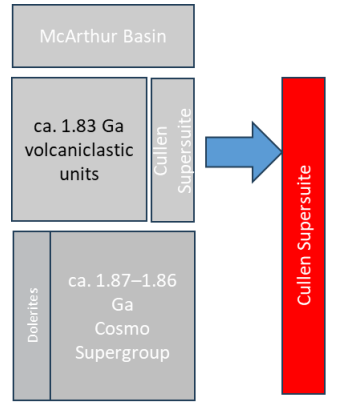


Figure 7. Vesicular and dense basalt clasts in the polymictic basalt breccia. MCNDD0002, 124.2 m.







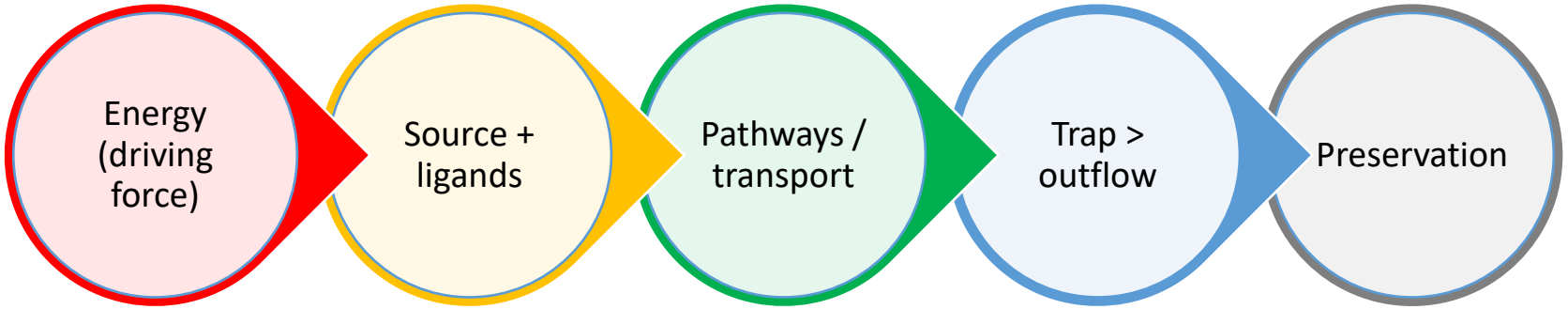
Thank you….

Pine Creek Orogen

Mineral systems implications

Mineral System

Wyborn et al (1994)



- **Long-lived felsic magmatism > sustained heat source and hydrothermal circulation**
- **Granite's oxidation state** changing to more oxidised magmas
- **Tectonic regime switching > Structural reactivations**
- **More Woodcutters SG > Reactive rocks**

PCO mineral systems

- **Sedimentary**

Manganese
Phosphate
Iron ore

- **Basin-related fluid flow**

Unconformity-related U
Unconformity-related REE (?)
Sediment-hosted Cu?
VHMS
Magnesite

- **Magmatic-related hydrothermal**

Skarns Au-W-Mo-Cu
Pegmatites (Sn-Ta-Li) Ce-Be-Nb-Mo-W
Greisen (Cu-W-Mo-Sn-Bi-F)
Hydrothermally enriched Fe deposits
Hydrothermally enriched graphite/Gallium

- **Deformation and metamorphism**

Orogenic gold

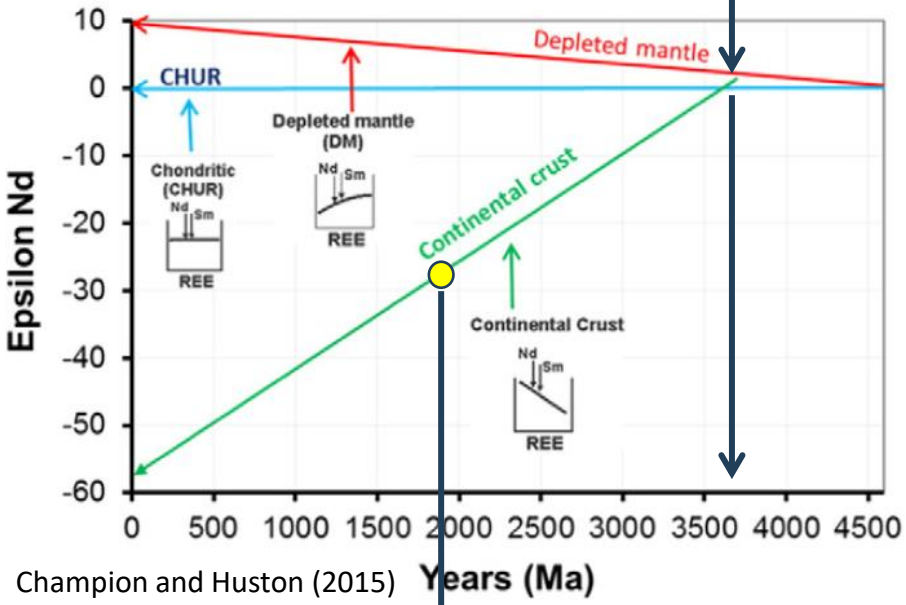
- **Weathering and regolith**

Placer (gold, tin)

Pine Creek Orogen

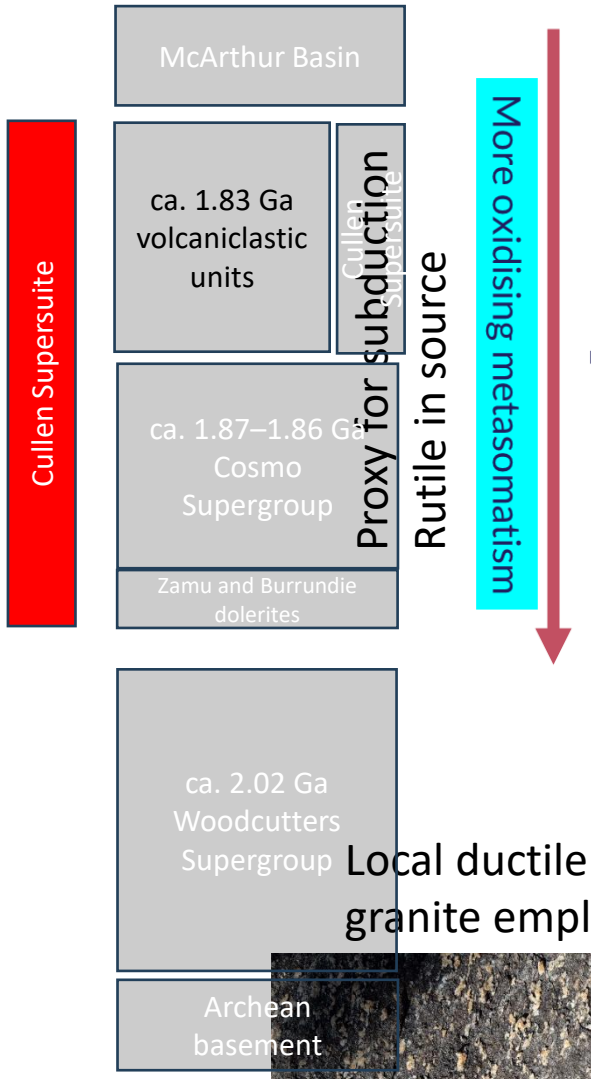
Long-lived felsic magmatism

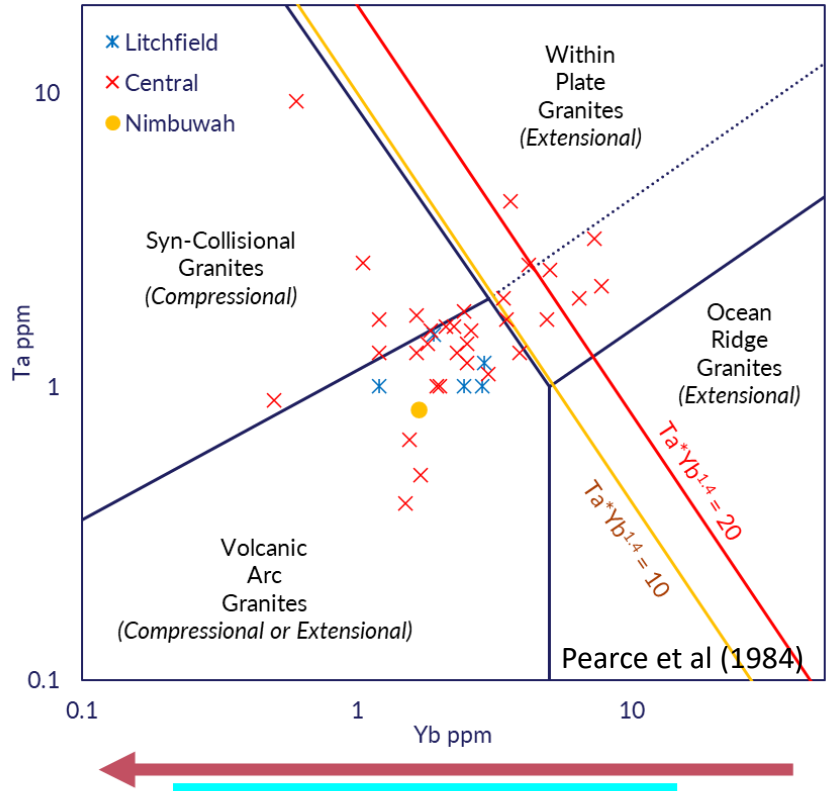
Mixed extensional and compressional tectonics during emplacement of Cullen Supersuite



Champion and Huston (2015)

Crystallization





Local ductile deformation after granite emplacement

AGES2026

Pine Creek Orogen

Mafic magmatism

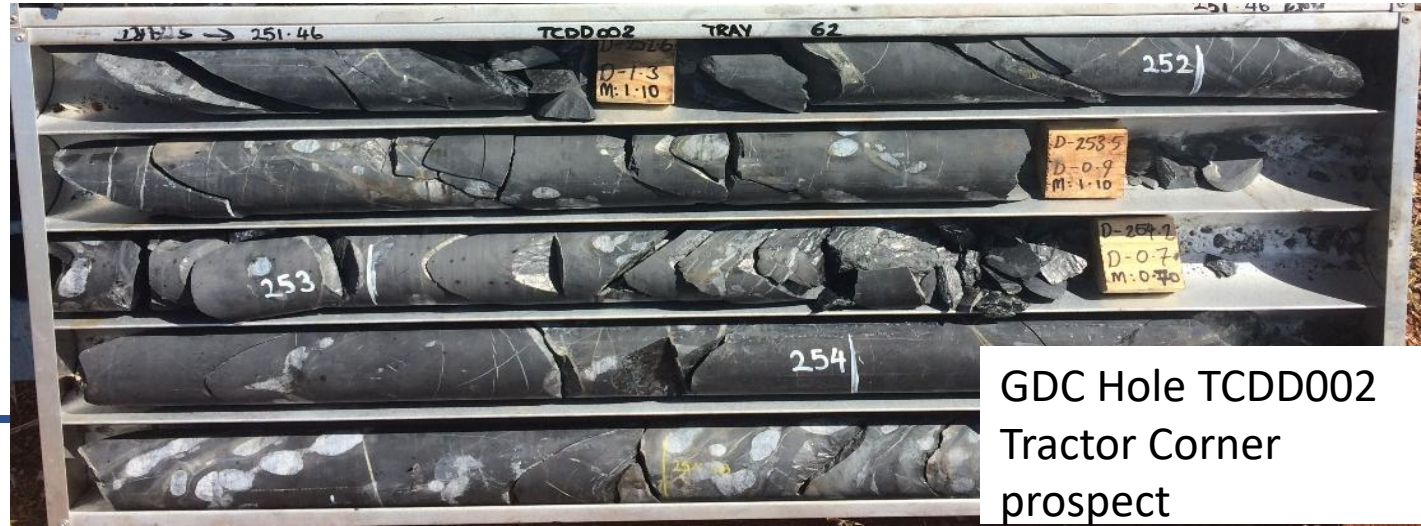
There is more…

Pine Creek Orogen

Mafic magmatism

There is more…

Drillhole TCDD002 intersected laminated, Fe-rich, carbonaceous and chert-rich metasiltstone beneath Cambrian-aged Daly Basin (**Koolpin Formation**?)



GDC Hole TCDD002 Tractor Corner prospect

Pine Creek Orogen

Mafic magmatism

There is more…

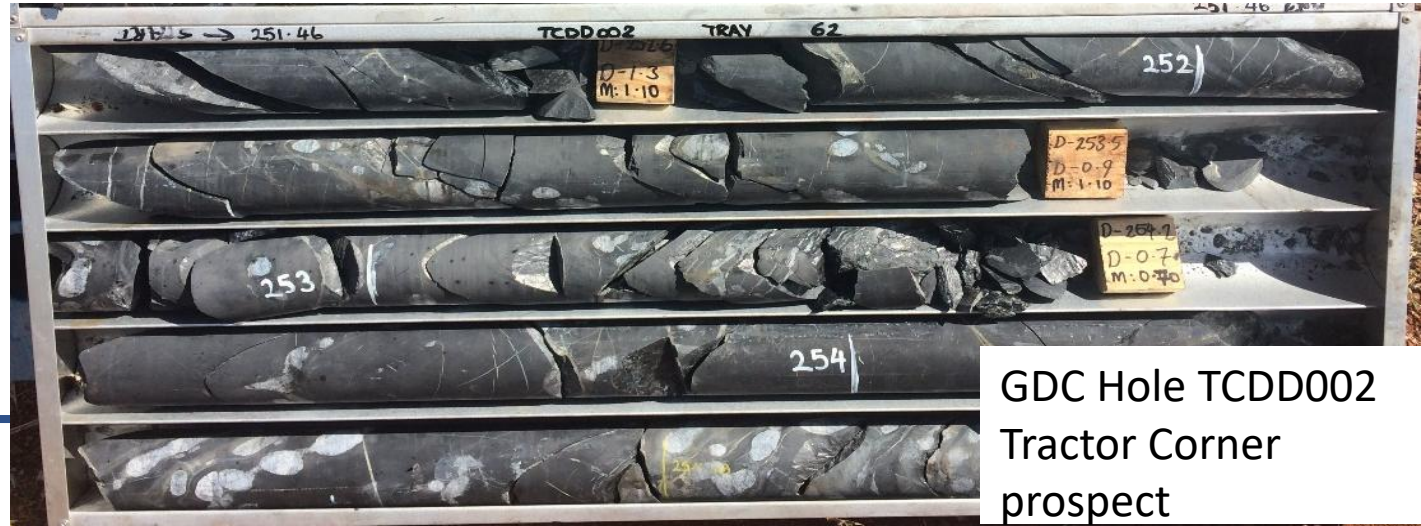
Similar mafic units **hosted in Woodcutters Supergroup** (**Mount Dean Volcanic Member of the Wildman Siltstone** or ca. **2.05 Ga Stag Creek Volcanics**

Mount Dean Volcanic Member Or ca **2.05 Ga Stag Creek Volcanics** of the Woodcutters Supergroup

= (?)

Dorothy Volcanic Member

Drillhole TCDD002 intersected laminated, Fe-rich, carbonaceous and chert-rich metasiltstone beneath Cambrian-aged Daly Basin (**Koolpin Formation**?)



GDC Hole TCDD002 Tractor Corner prospect

Pine Creek Orogen

Mineral systems implications

Preservation of **long-lived terrane**
The PCO records **~200 Myr of geological evolution** including:

- Early rifting
- Basin formation
- **Switching tectonic regime – Extension/shortening**
- **Long-lived magmatism**
- post-orogenic reactivation

each linked to diverse mineral systems

- **Woodcutters Supergroup** > Preservation of ca 2.02-1.90 Ga stratigraphy (early rifting) – Deposits in this supergroup have strong stratigraphic control. **Polymetallic systems** / Browns and Woodcutters deposits (Cu-Ni-Co-Pb; Zn-Pb-Ag); graphite; Uranium; Magnesite, Phosphate…
- **Carbonaceous metasedimentary rocks** act as reductants to metalliferous fluids
- **Granite's oxidation state** changing to more oxidised magmas reflecting Sn-W, greisen to more Au-Cu-Mo ± W, skarns

- Coarser crystalline graphite flakes at Lelyn deposit (Baumgartner and Pejcic 2025)
- Gold release from lollingite during retrogression (Crawford, 2024)

PCO mineral systems

- **Sedimentary**

Manganese
Phosphate
Iron ore

- **Basin-related fluid flow**

Unconformity-related U
Unconformity-related REE (?)
VHMS
Magnesite

- **Magmatic-related hydrothermal**

Skarns Au-W-Mo-Cu
Pegmatites (Sn-Ta-Li) Ce-Be-Nb-Mo-W
Greisens (Cu-W-Mo-Sn-Bi-F)
Hydrothermally enriched Fe deposits

- **Deformation and metamorphism**

Orogenic gold

- **Weathering and regolith**

Placer (gold, tin)

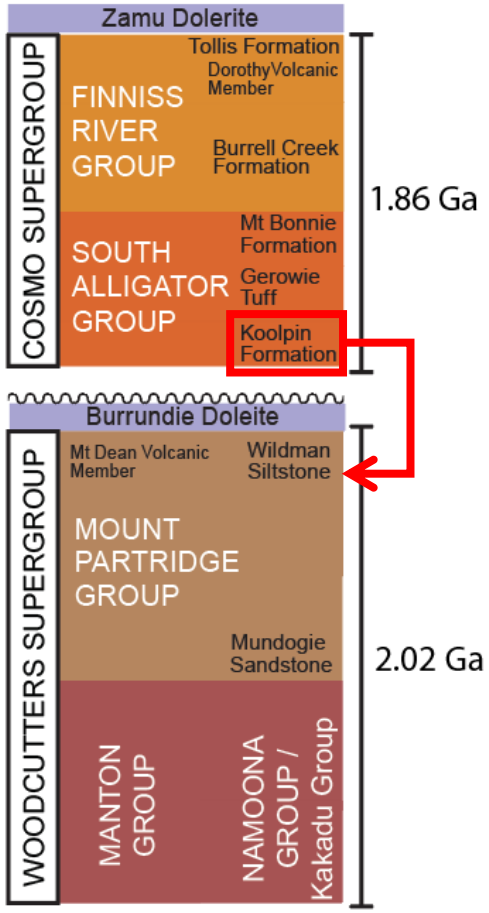
Pine Creek Orogen

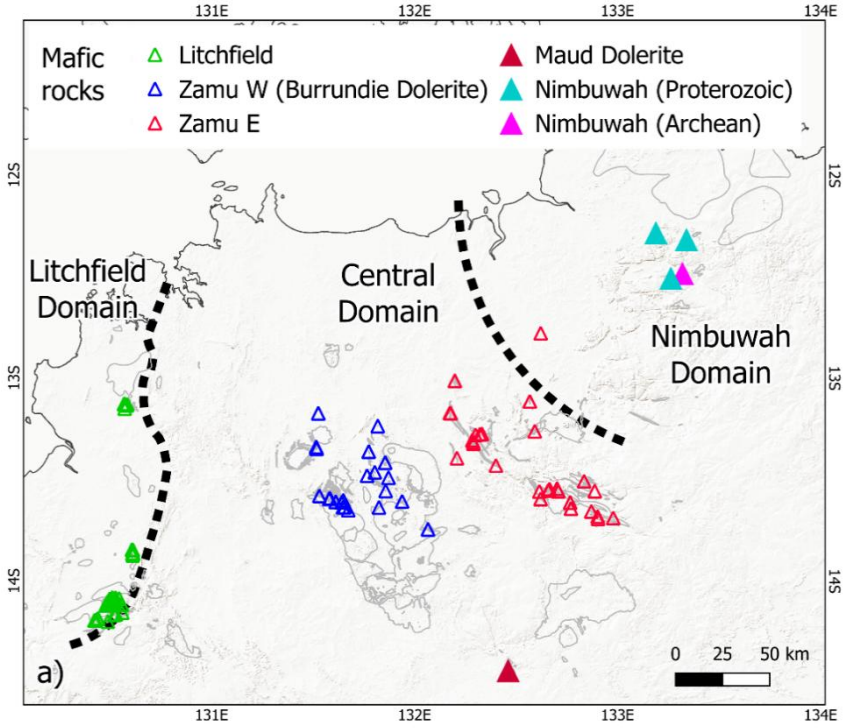
Stratigraphy

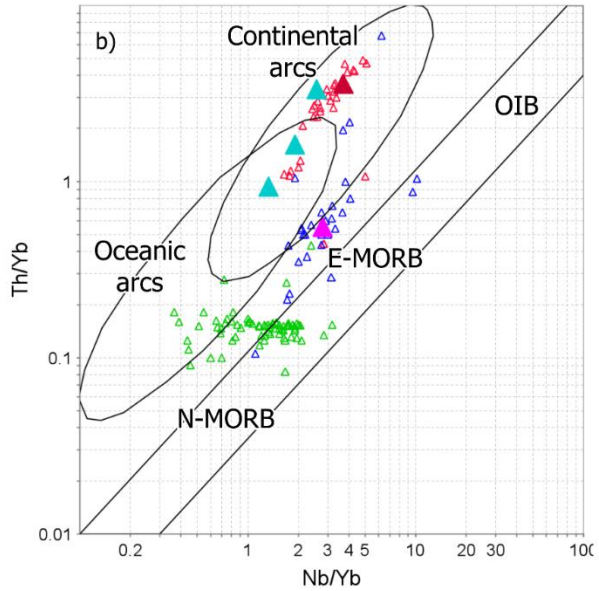
What we mentioned last year (reminder)

- Zamu and Burrundie dolerites are different (Alex; Sener 2005?)

- **Zamu Dolerite is ca 1.87 Ga** (U-Pb Baddeleyite)
- **Burrundie Dolerite is ca 2.0 Ga** with reset at ca 1.81 Ga (U-Pb Titanite-Apatite)
- Burrundie Dolerite is **hosted in Koolpin Formation**
  - Koolpin Formation has to be older than previously interpreted (1.86 Ga)







Pine Creek Orogen

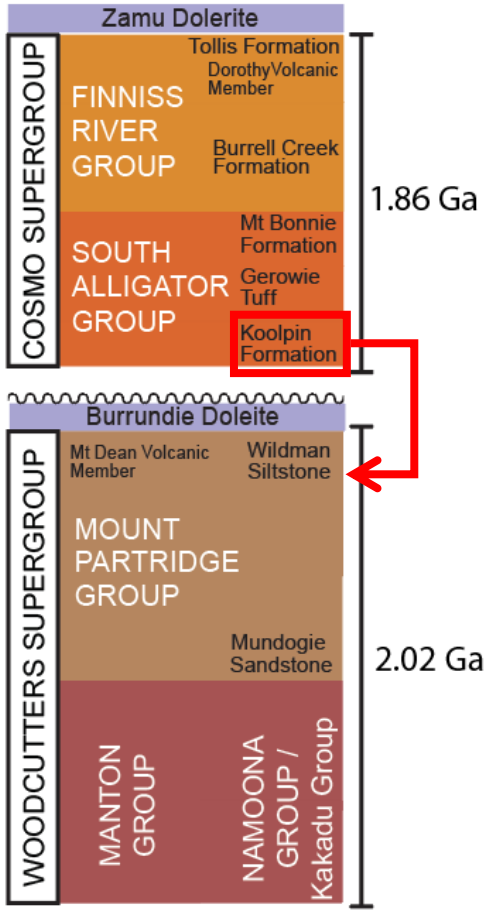
Stratigraphy

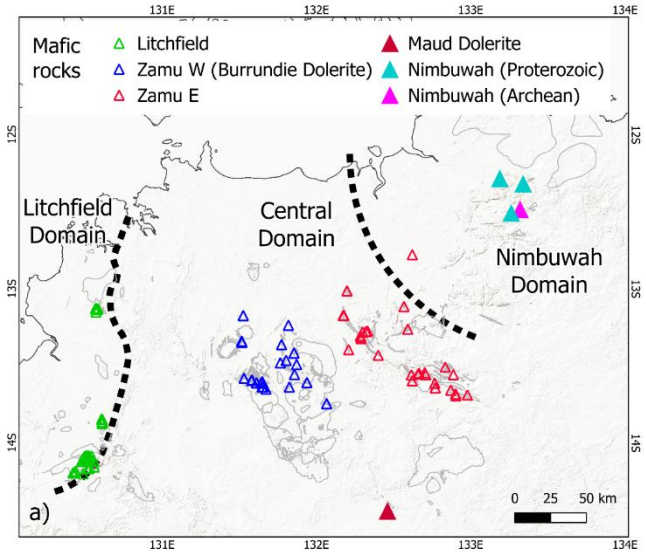
This year:

- No clear unconformity between Woodcutters and Cosmo supergroups
- Similarities between upper Wildman Siltstone and lower Koolpin Formation
  - Both have iron-rich laminated metasiltstone-metasandstone, locally carbonaceous, interbedded with metasandstone beds
  - Evaporitic facies in both units

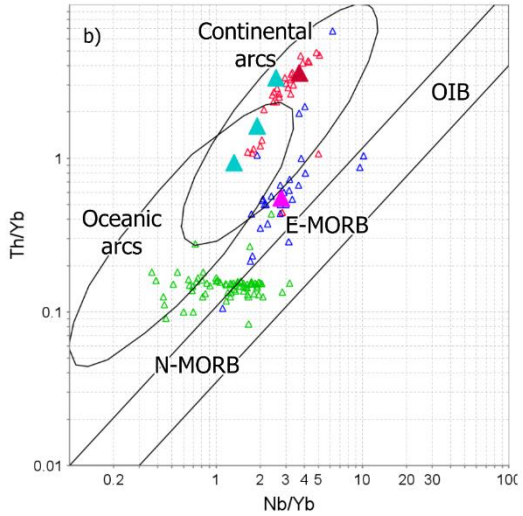
They were once together (Crick et al 1980; Nicholson 1980)

This year we will explore the unconformity further





Quartz pseudomorphs after a possible former evaporitic mineral



Pine Creek Orogen

Mineral systems implications

- **Woodcutters Supergroup** near Katherine + **long-lived magmatism**

Po

Pine Creek Orogen

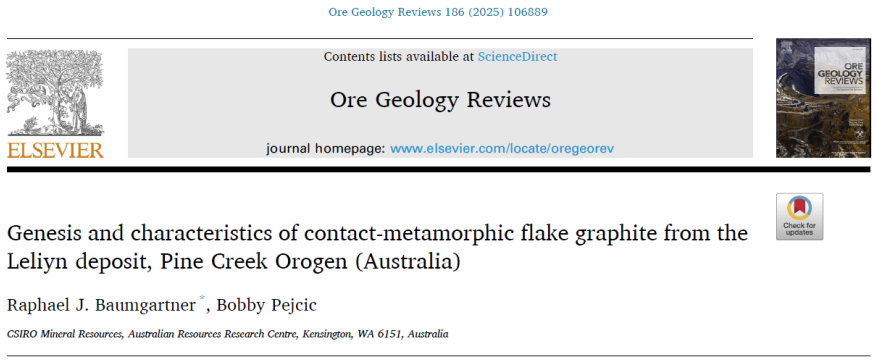
Mineral systems implications

- **Woodcutters Supergroup** near Katherine + **long-lived magmatism**

Leliyn graphite deposit / Woodcutters SG

- sustained heating at ≥ ~600 °C buffered graphite formation
- Degree of graphitization is proportional to distance from granite intrusion

(Baumgartner and Pejcic, 2025)



Ore Geology Reviews 186 (2025) 106889

Contents lists available at ScienceDirect

Ore Geology Reviews

journal homepage: www.elsevier.com/locate/oregeorev

Genesis and characteristics of contact-metamorphic flake graphite from the Leliyn deposit, Pine Creek Orogen (Australia)

Raphael J. Baumgartner *, Bobby Pejcic

CSIRO Mineral Resources, Australian Resources Research Centre, Kensington, WA 6151, Australia

Po

Pine Creek Orogen

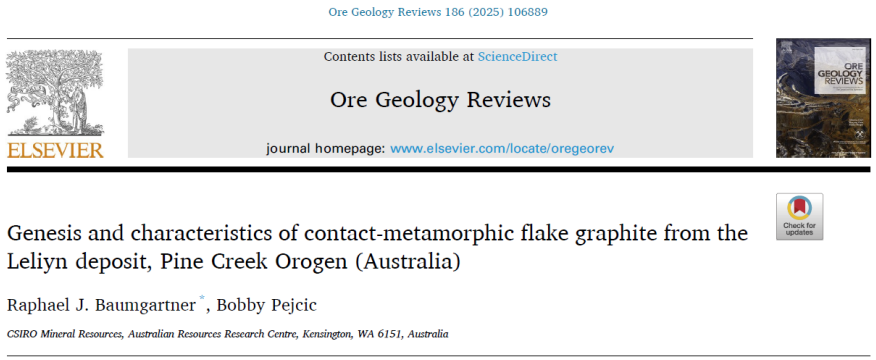
Mineral systems implications

- **Woodcutters Supergroup** near Katherine + **long-lived magmatism**

Leliyn graphite deposit / Woodcutters SG

- sustained heating at ≥ ~600 °C buffered graphite formation
- Degree of graphitization is proportional to distance from granite intrusion

(Baumgartner and Pejcic, 2025)



Ore Geology Reviews 186 (2025) 106889

Contents lists available at ScienceDirect

Ore Geology Reviews

journal homepage: www.elsevier.com/locate/oregeorev

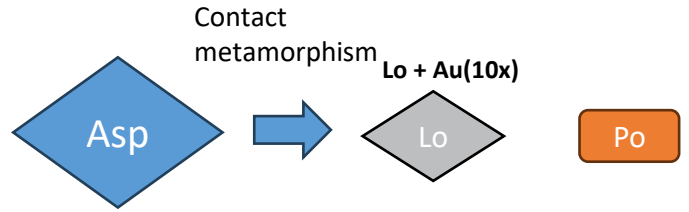
ELSEVIER

Genesis and characteristics of contact-metamorphic flake graphite from the Leliyn deposit, Pine Creek Orogen (Australia)

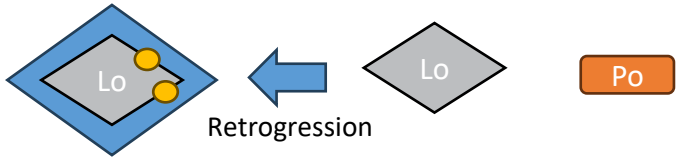
Raphael J. Baumgartner *, Bobby Pejcic

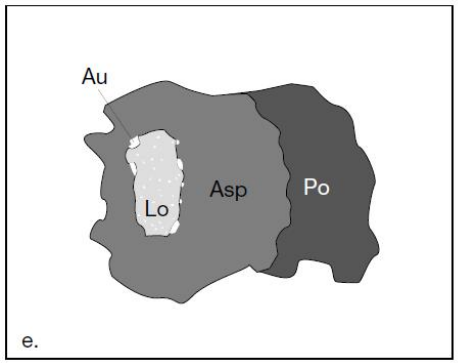
CSIRO Mineral Resources, Australian Resources Research Centre, Kensington, WA 6151, Australia

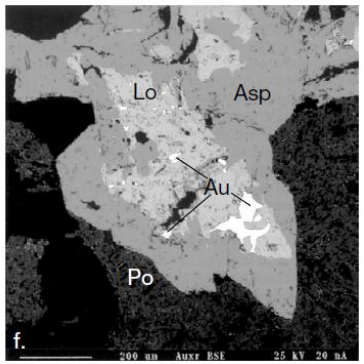
- Refractory gold can be released by contact metamorphism (Tomkins and Mavrogenes 2001; Crawford 2024)

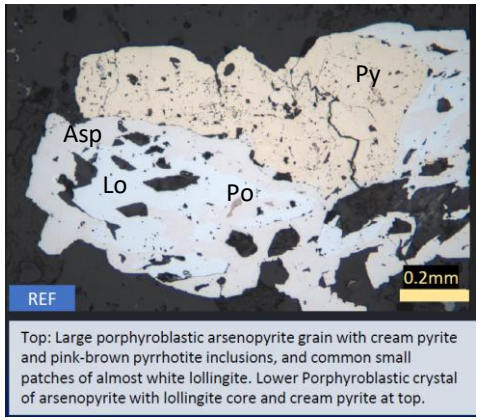


$2FeAsS\ (arsenopyrite \pm Au) \longrightarrow FeAs_2(lollingite) + FeS(pyrrhotite) + S\ (melt/fluid)$







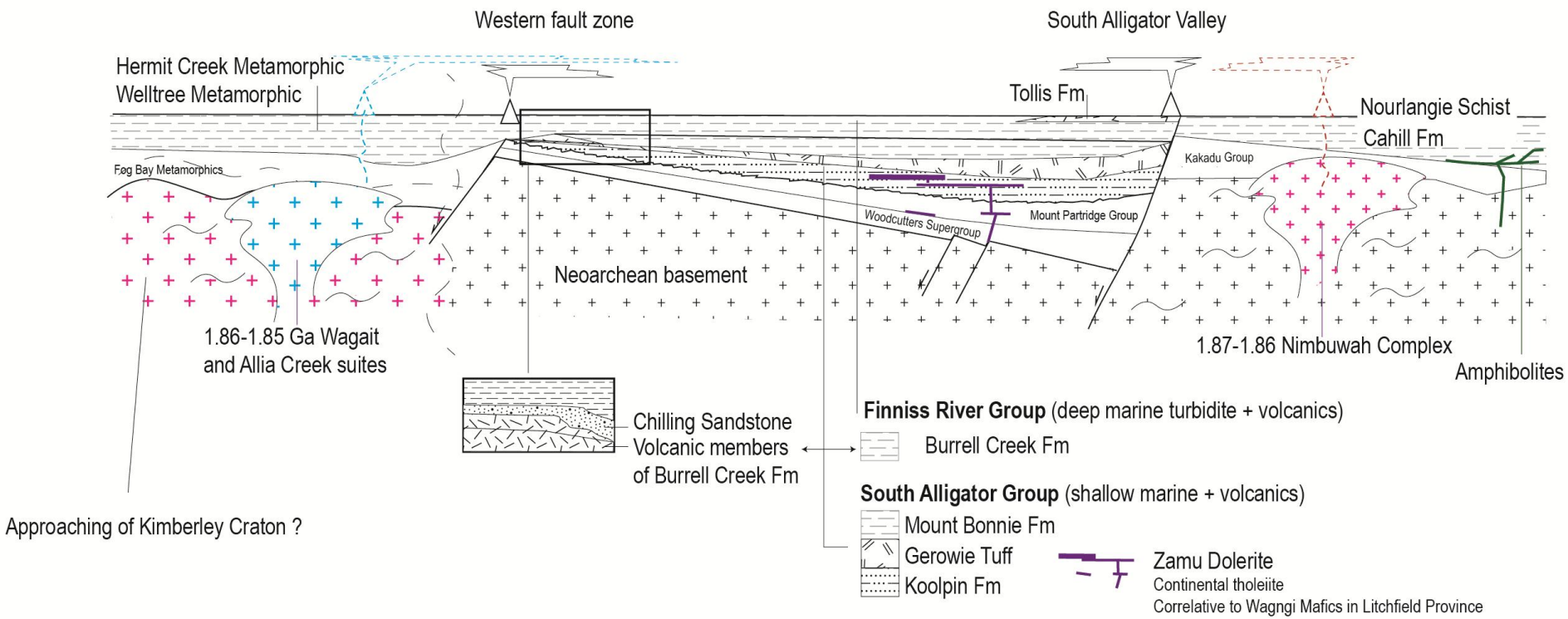


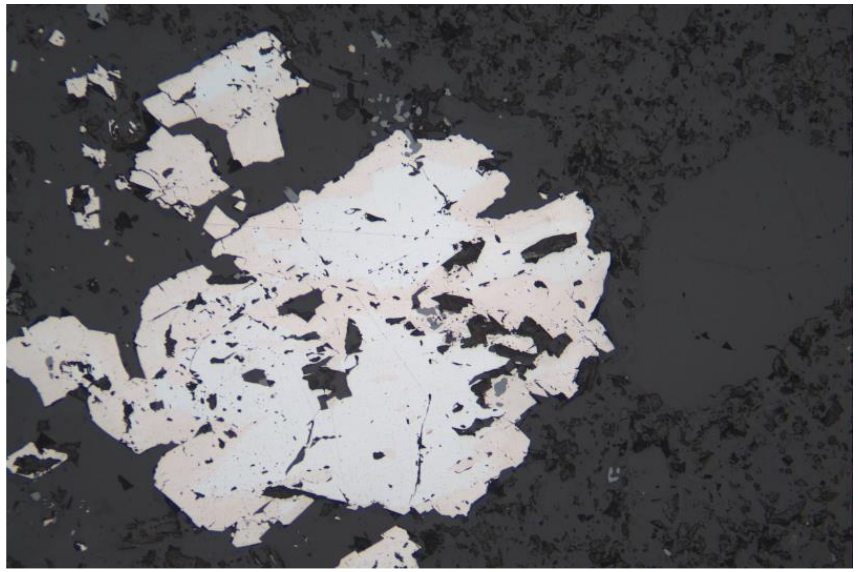
Top: Large porphyroblastic arsenopyrite grain with cream pyrite and pink-brown pyrrhotite inclusions, and common small patches of almost white lollingite. Lower Porphyroblastic crystal of arsenopyrite with lollingite core and cream pyrite at top.

Figure 7 – Tomkins and Mavrogenes (2001)

1.87-1.86 Ga Start of orogeny - Cosmo Supergroup

NW Litchfield Province Central Domain Nimbuwah Domain SE





Arsenopyrite surrounding white lollingite core in porphyroblastic crystal

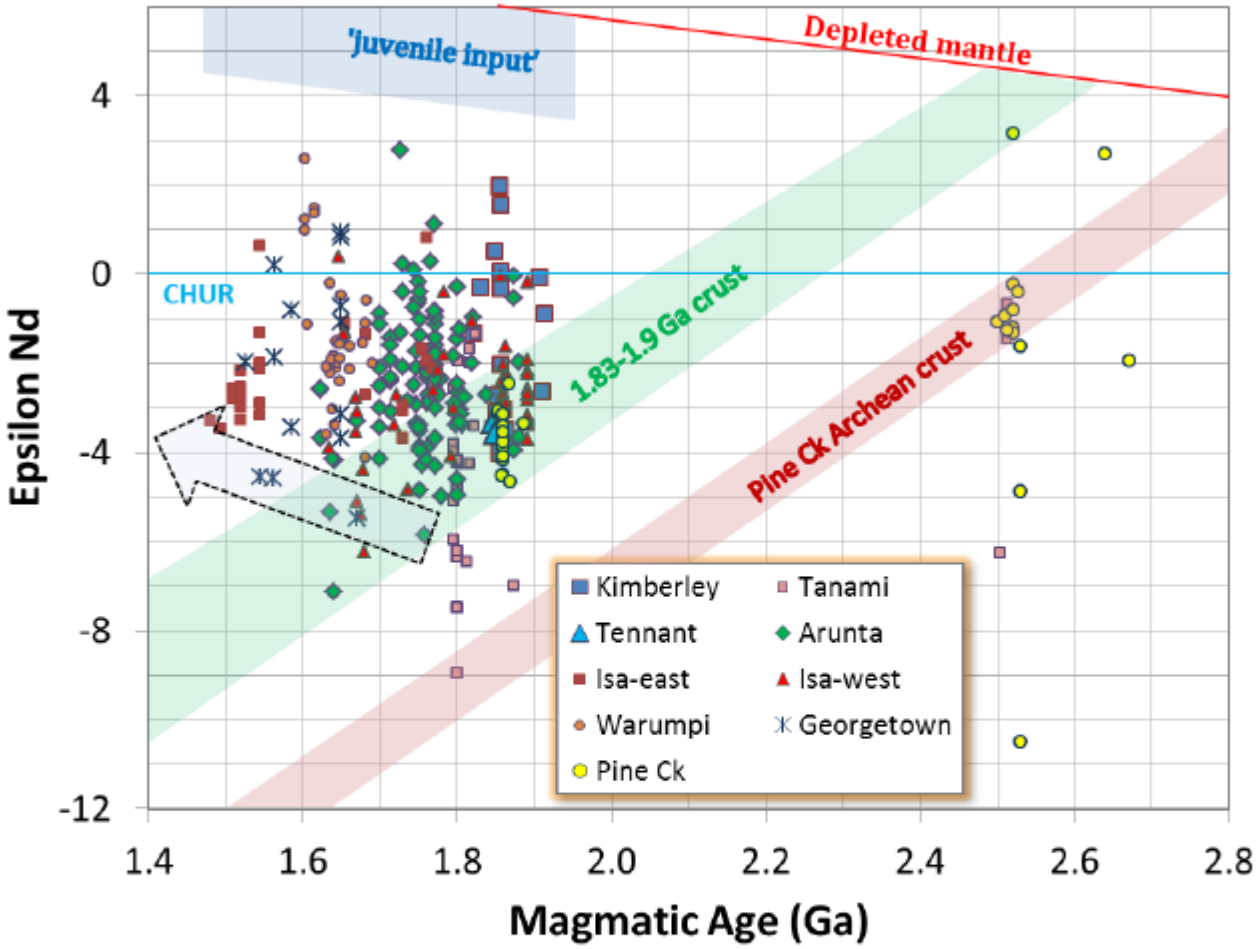


Figure 3.9 Magmatic age versus epsilon Nd (ε_{Nd}) for felsic magmatism of the North Australian Element (NAE). Data and data sources are listed in Appendix B and Appendix C). Note the spread in ε_{Nd} for all geological regions, as well as a trend to decreasing minimum eNd with decreasing magmatic age (highlighted by the arrow). Oblique pink and green shaded zones represent project evolutionary trajectories for Pine Creek Archean crust and Pine Creek 1.9–1.83 Ga crust, respectively. Blue shaded area labelled 'juvenile input' represents expected range of isotopic signatures for mantle material emplaced during 1.93–1.5 Ga. The large arrow highlights the decreasing minimum ε_{Nd} with increasing age.

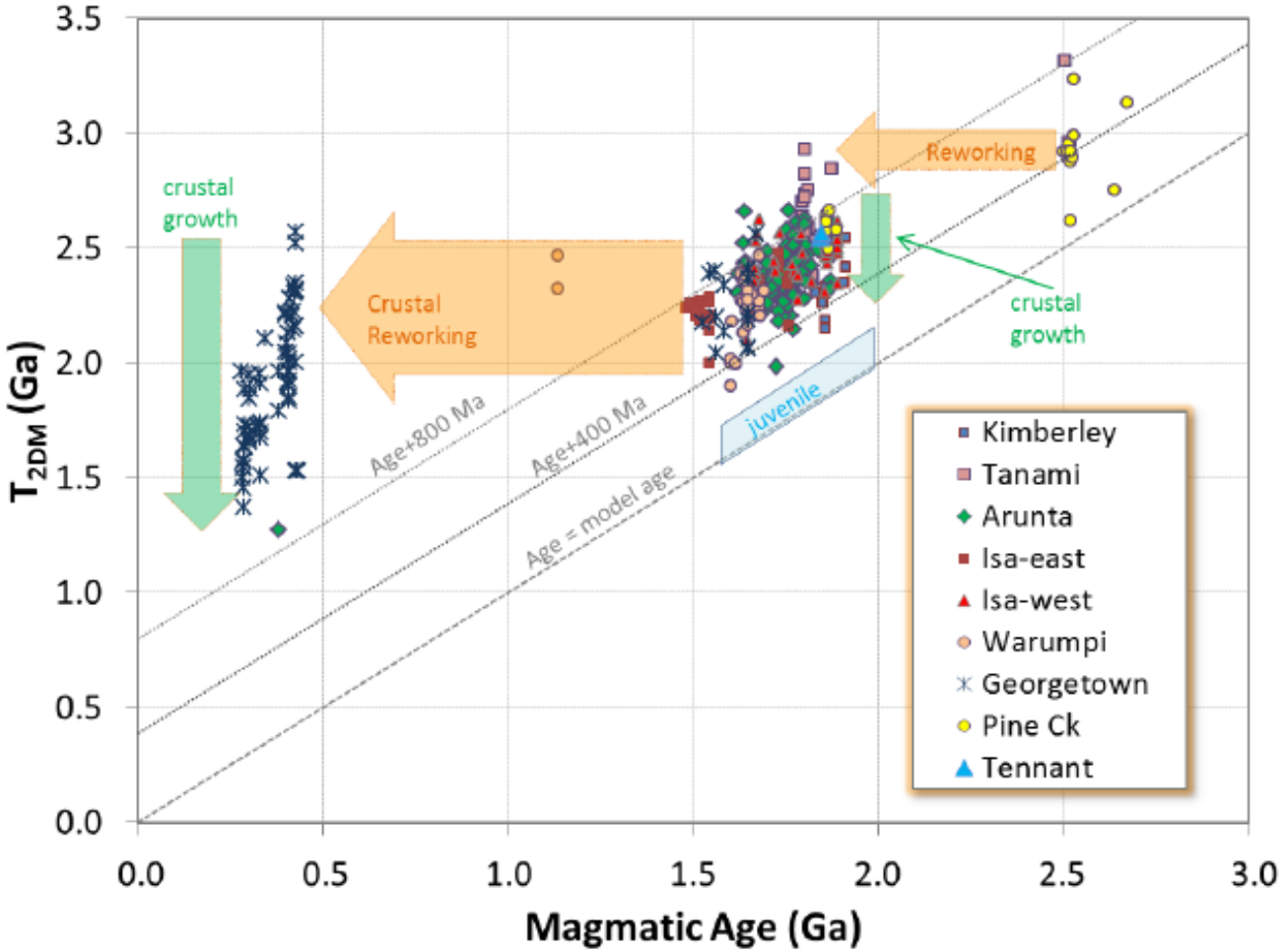


Figure 3.10 Magmatic age versus model age (T_{2DM}) for felsic magmatism of the North Australian Element (NAE). Data and data sources are listed in Appendix B and Appendix C. Note the spread in T_{2DM} for all geological regions, as well as a trend to decreasing T_{2DM} with decreasing magmatic age. T_{2DM} for most Proterozoic samples are 400 Ma to 800 Ma older than the magmatic age, irrespective of age.