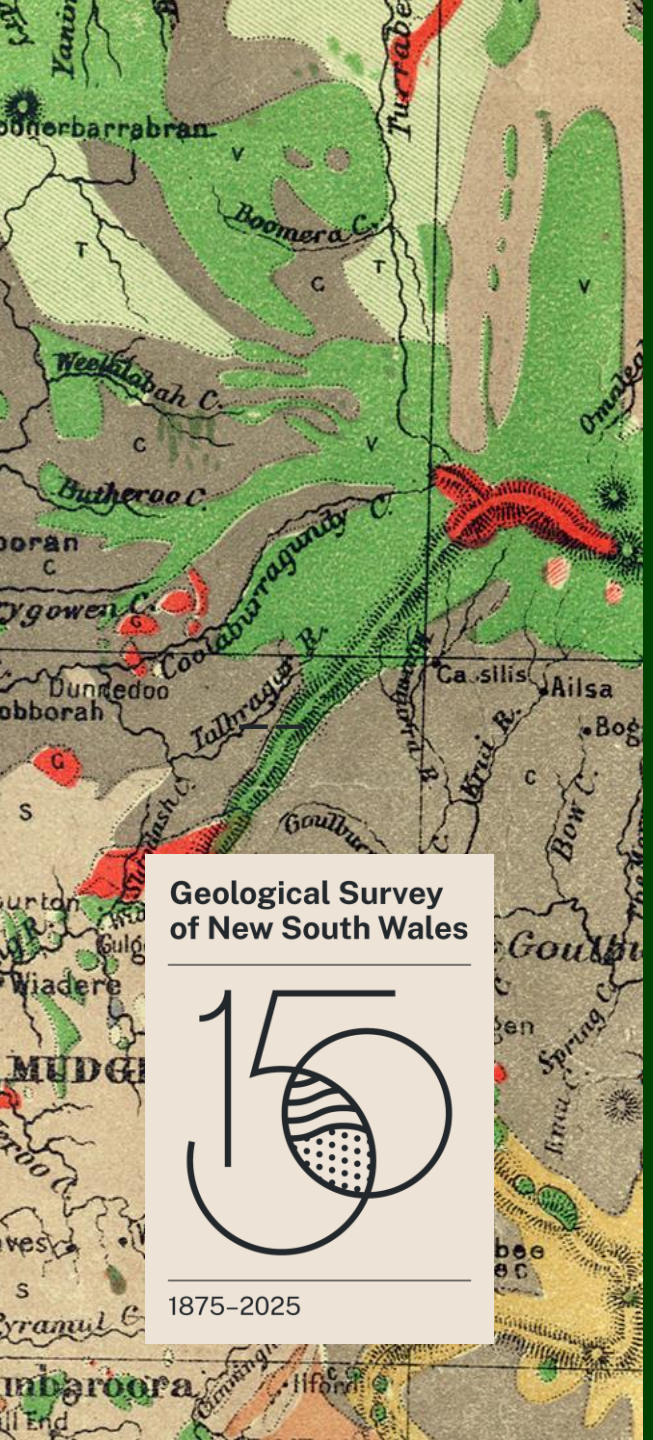


Geological Survey of New South Wales

150

1875–2025

Regional-scale thermal and isotopic mapping –

redefining the exploration space in NSW

Project Team (Mineral Systems Group)

Daniel Logan (Manager), Joel Fitzherbert, Brenainn Simpson, Kyle Hughes, Mark Eastlake, Peter Downes

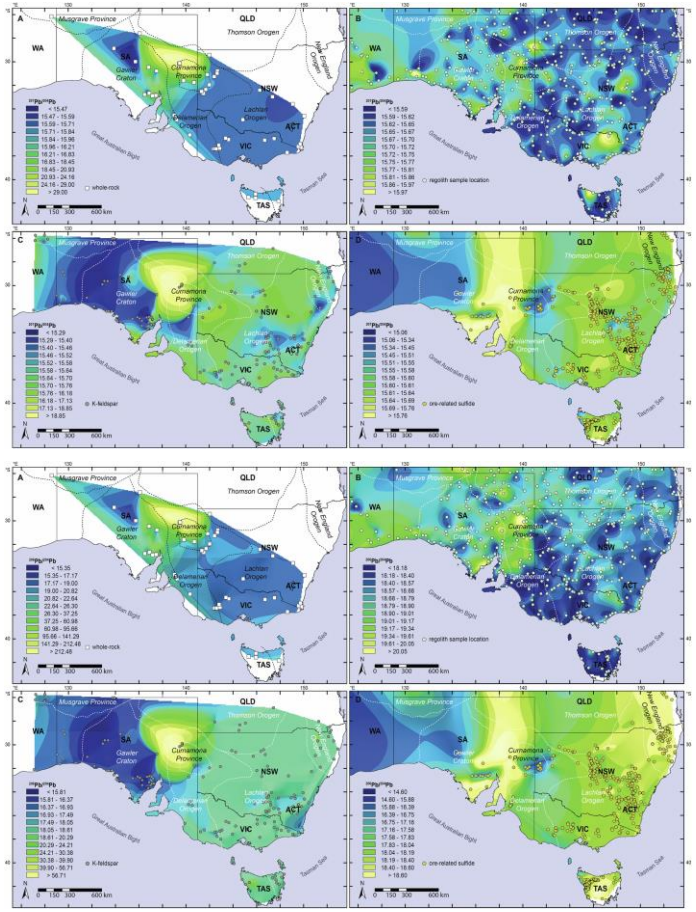
Presenter Joel Fitzherbert (Principal Geologist)

9 May 2025

NSW GOVERNMENT

Contents

Mineral systems mapping – what and why?



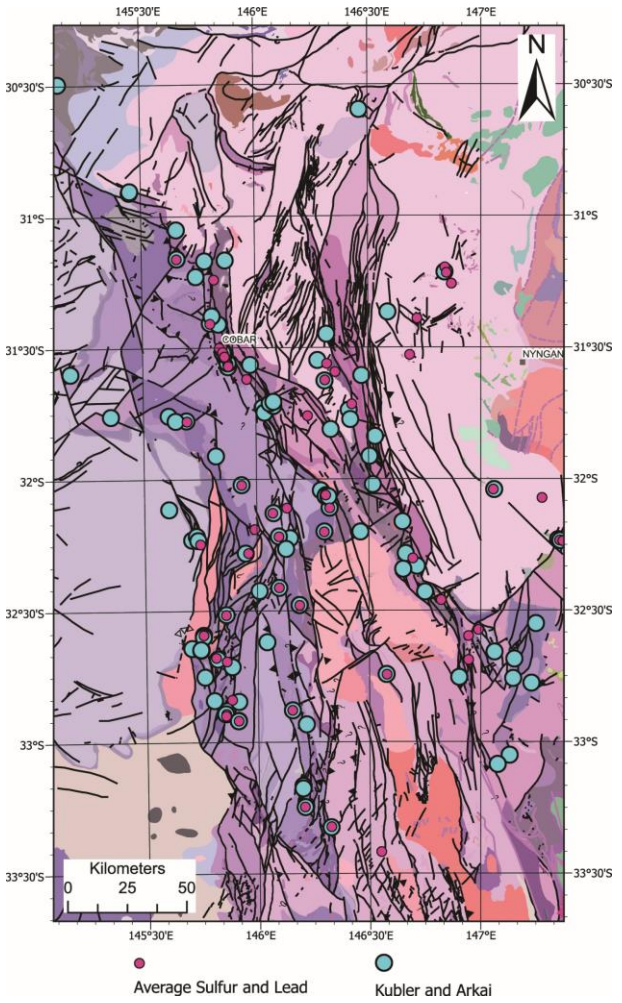
A crustal Pb isotope map of southeastern Australia

Source: J. Liebmann, B. Ware, D. R. Mole, C. L. Kirkland, G. Fraser, K. Waltenberg, S. Bodorkos, D. L. Huston, N. J. Evans, B. J. McDonald, K. Rankenburg, P. Datta & S. Tessalina. Scientific Data volume 11, Article number: 1222 (2024)

Isotopic mapping (Geoscience Australia)

National-scale data:

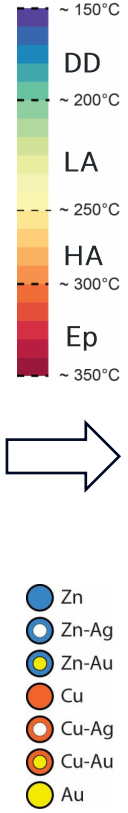
- Crustal-scale understanding
- Selective data sets (Pb and Sm/Nd/Sr)

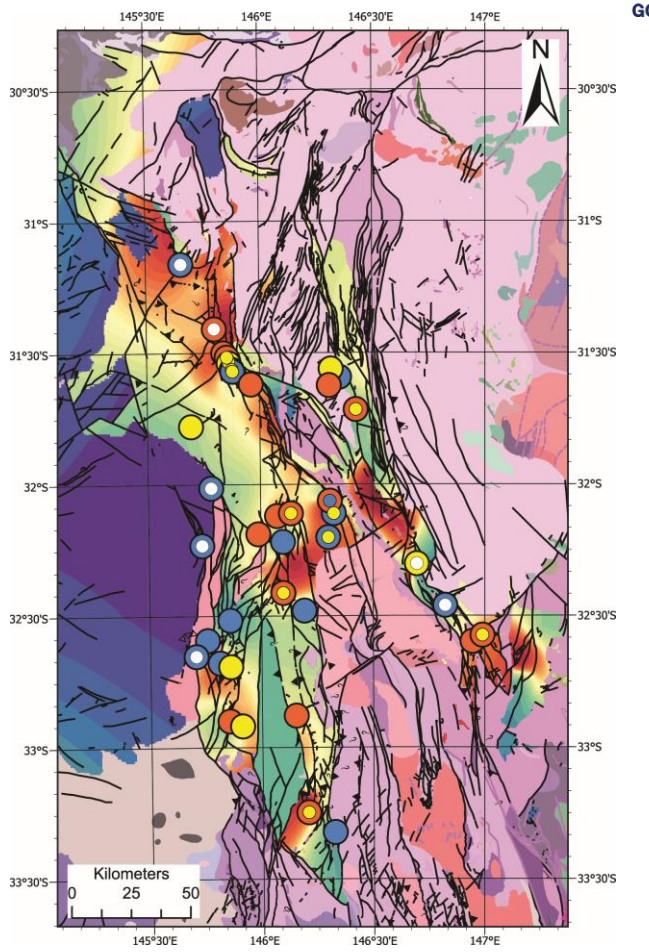


Mineral systems data (GSNSW)

District- to camp- (even deposit) scale:

- More datasets related to wholistic mineral system
  - Today we consider – **Temperature – Sulfur – Lead**





Mineral systems maps

Once made we can compare:

- With other mineral systems maps
  - e.g. isotopes, faults, geophysics
- Commodity, deposit type etc…

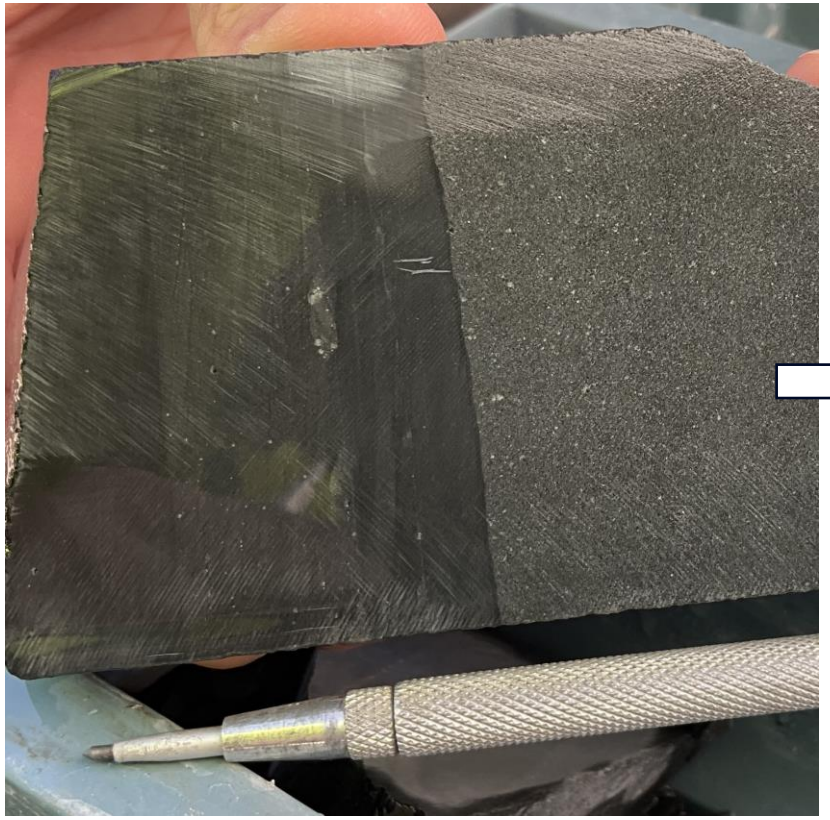
1

Cobar Basin example – 3 datasets

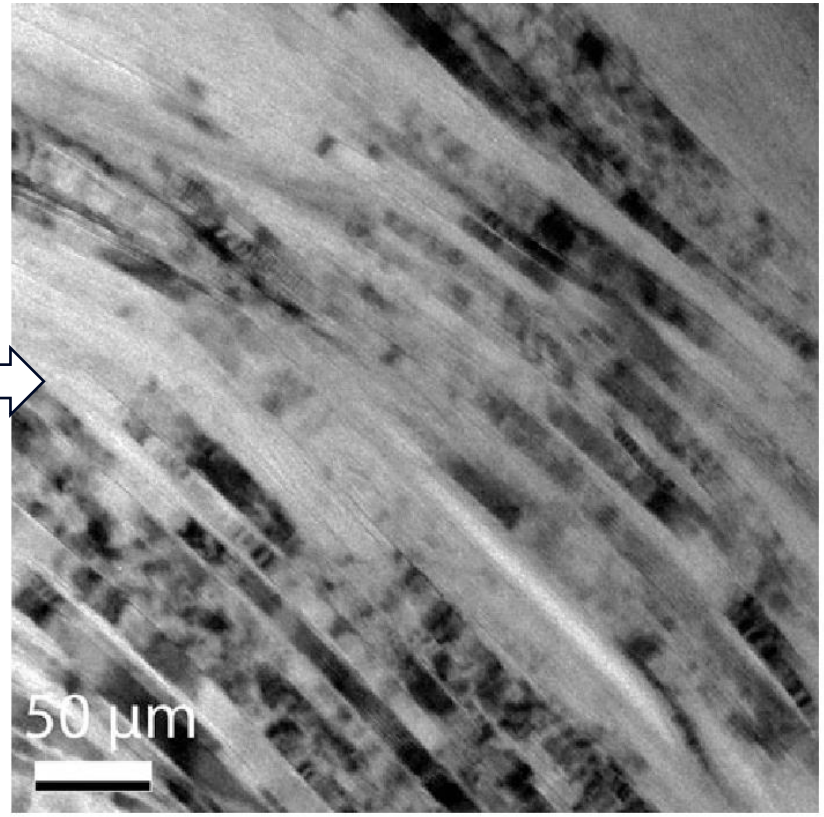
Thermal mapping

Dataset 1 – thermal mapping (energy/deposition)

Shale bed Achillies prospect – drillhole A3DD006



TEM image of stacked illite crystallites



Source: M. D. Buatier, B. Lacroix, P. Labaume, V. Moutarlier, D. Charpentier, J. Pierre Sizun, A. Trave. 2012. Microtextural investigation (SEM and TEM study) of phyllosilicates in a major thrust fault zone (Monte Perdido, southern Pyrenees): impact on fault reactivation. Swiss Journal of Geosciences 105(2)

The humble shale

Looking for authigenic micas

- Formed in their current position
  - metamorphic
  - hydrothermal
- Fine-grained pelitic rocks are the most likely to experience recrystallisation of detrital micas

Mica crystallinity

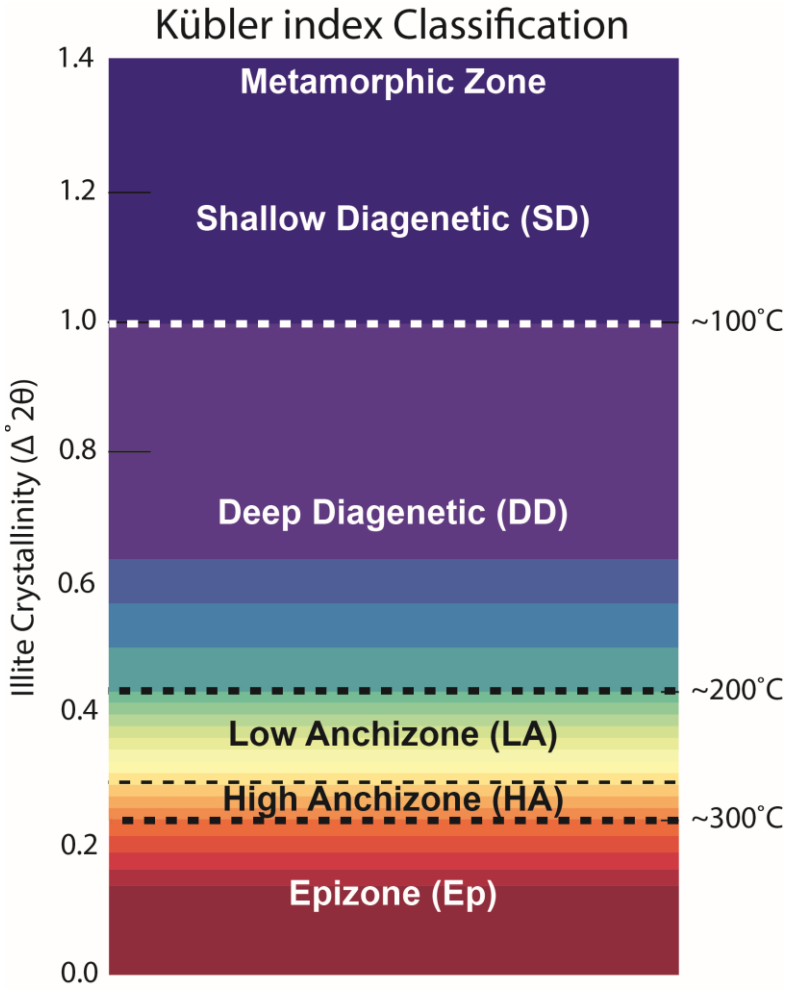
Look at the individual crystalline structures that are the basic building blocks of mica sheets – crystallites

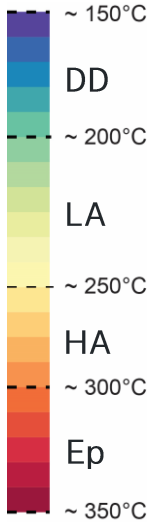
Crystallite thickness increases systematically with temperature

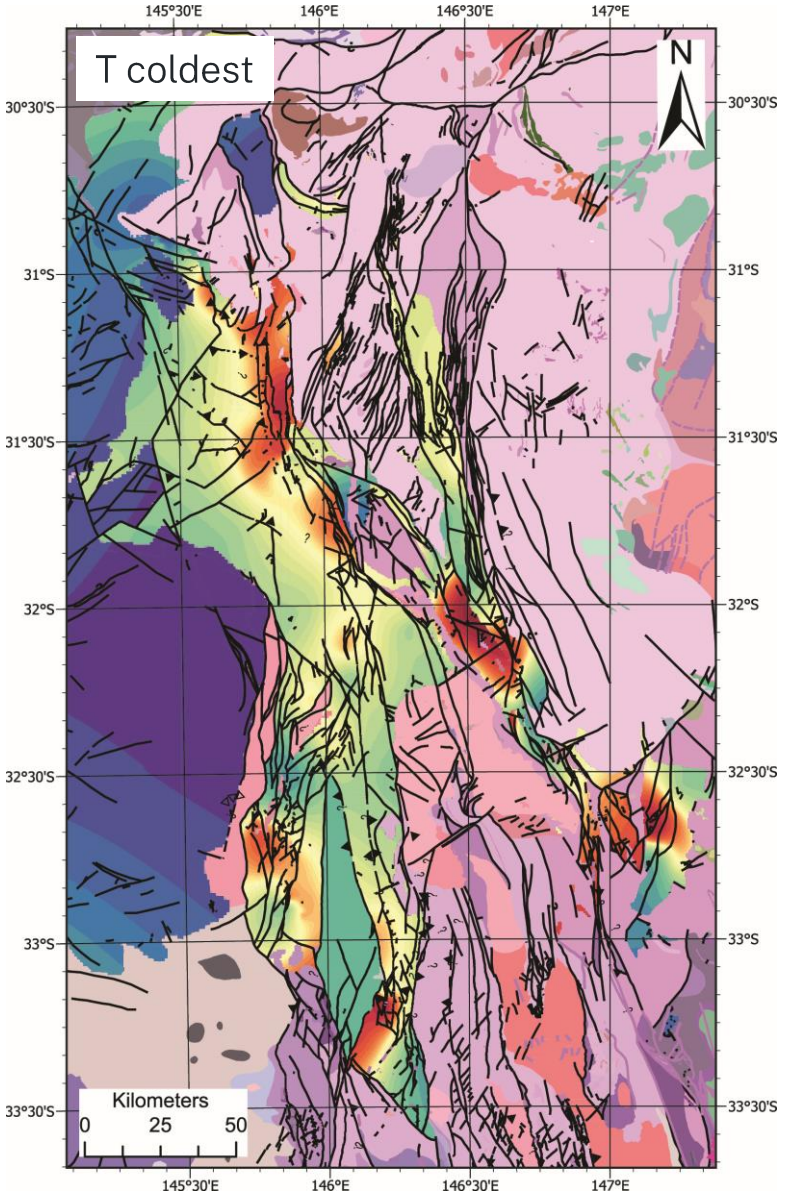
Measure crystallite thickness using XRD and generate an index based on spectra

- Kübler index (white mica)
- Árkai index (chlorite)

Dataset 1 – thermal mapping (Kübler index)



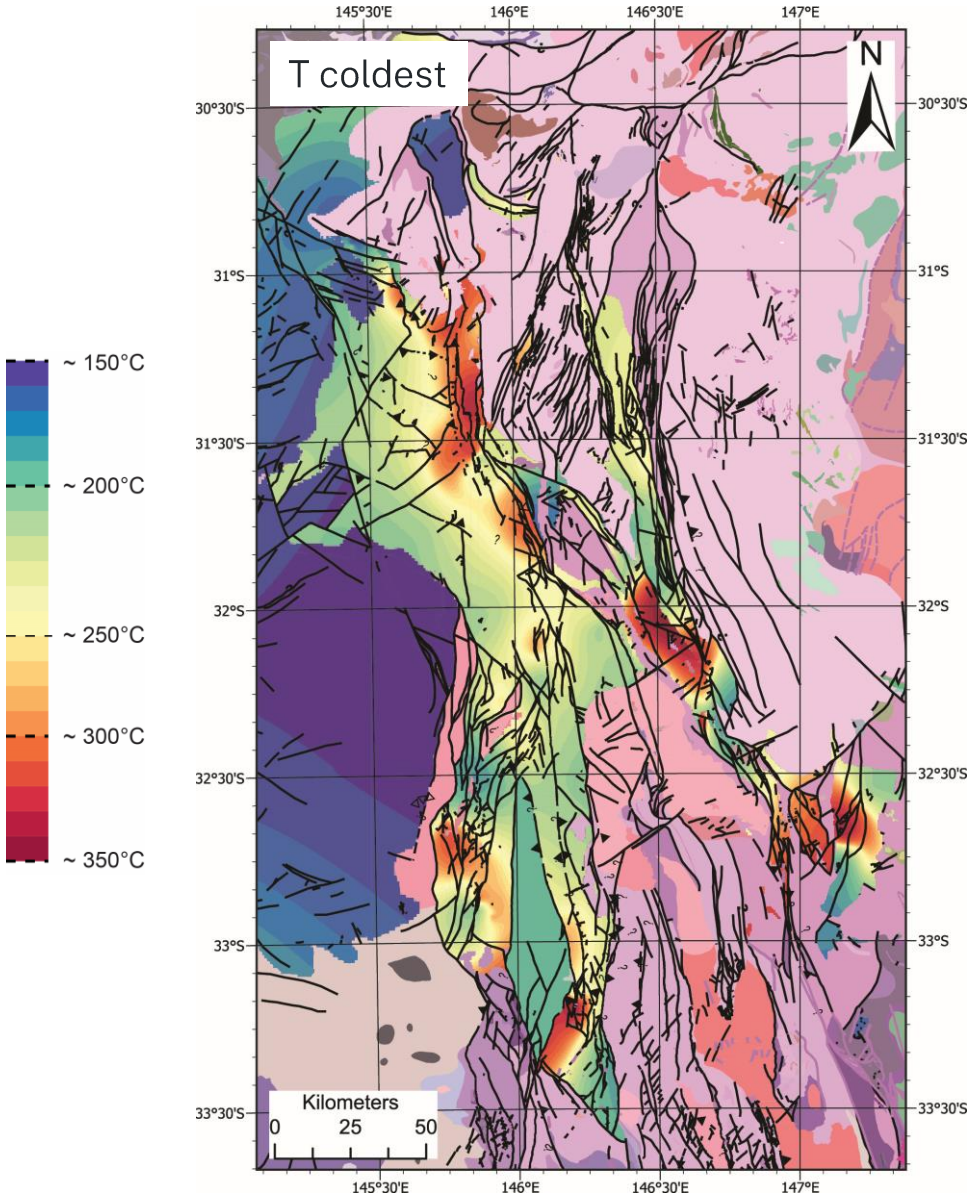




Kübler index (illite crystallinity)

Calibrated for low-grade metamorphic zones (shallow diagenetic to the epizone).
In Cobar we will focus on the deep diagenetic to the epizone.

Dataset 1 – thermal mapping (Kübler index)



Kübler coldest (regional)

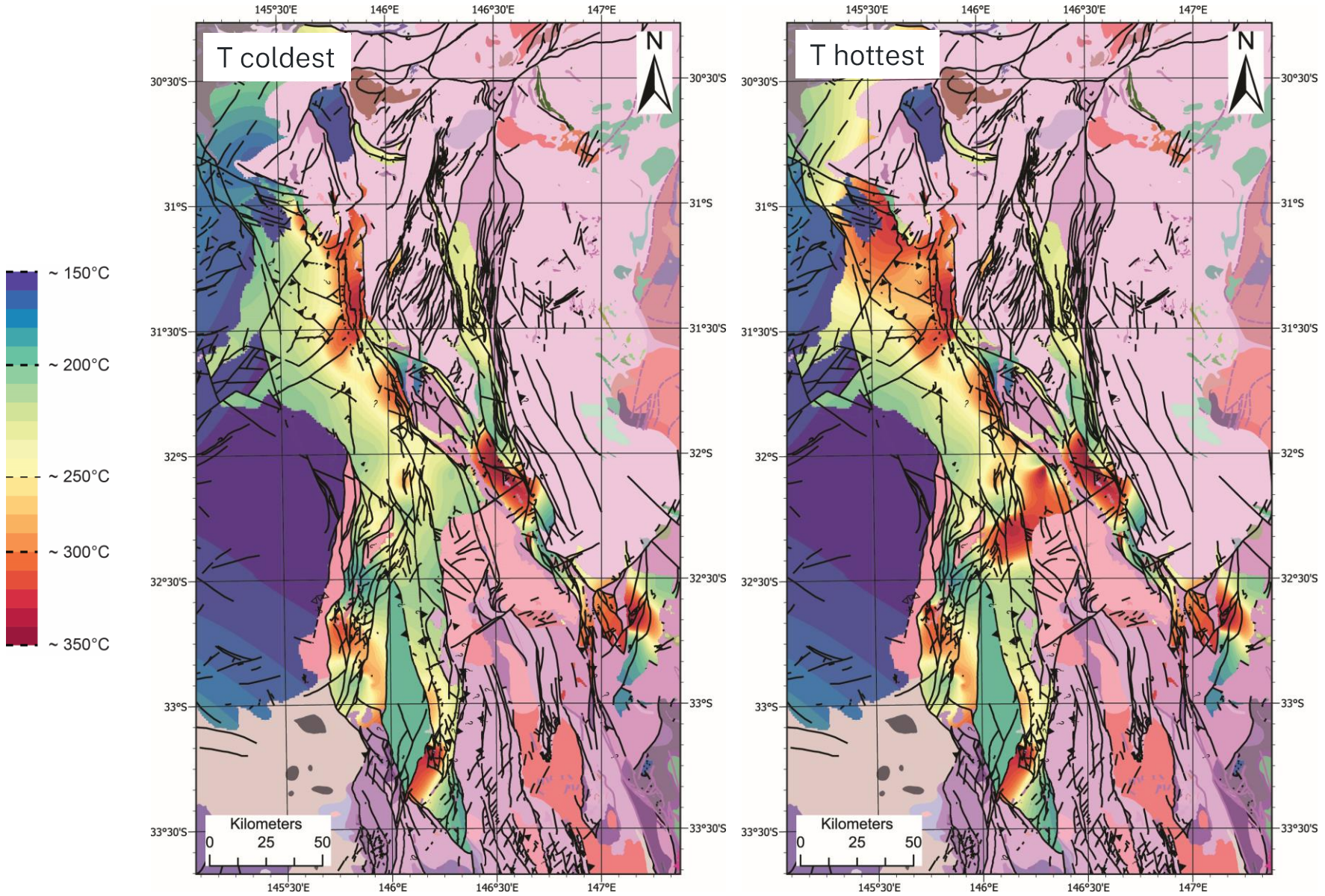
Represents shales most distal from mineralisation – *Regional metamorphism*

Key features are:

- Winduck Shelf Deep Diagenetic
- Cobar Basin regional Low Anchizone
- Isolated zones of Epizone
  - Cobar Mineral Field
  - Achillies zone
  - Mineral Hill

- Questionable zones of Epizone
  - Western Mount Hope
  - Central Kopyje

Dataset 1 – thermal mapping (Kübler index)



Kübler hottest (hydrothermal)

Represents shales most proximal to mineralisation – **hydrothermal heat**

Key features

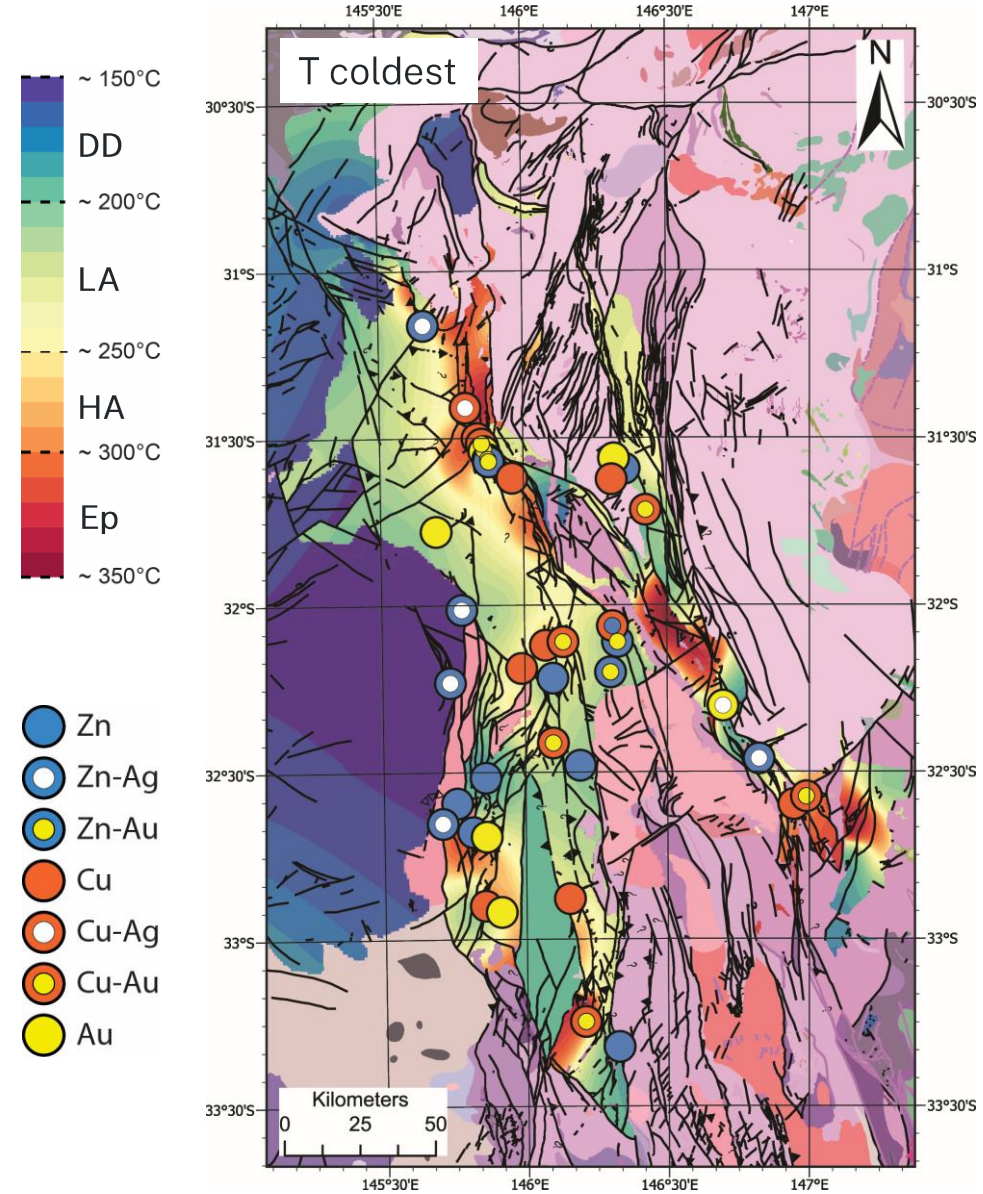
- Winduck Shelf – **no change**
- Cobar Basin regional – **no change**
- Nymagee – Hera – Federation zone
  - Epizone – **significant change**

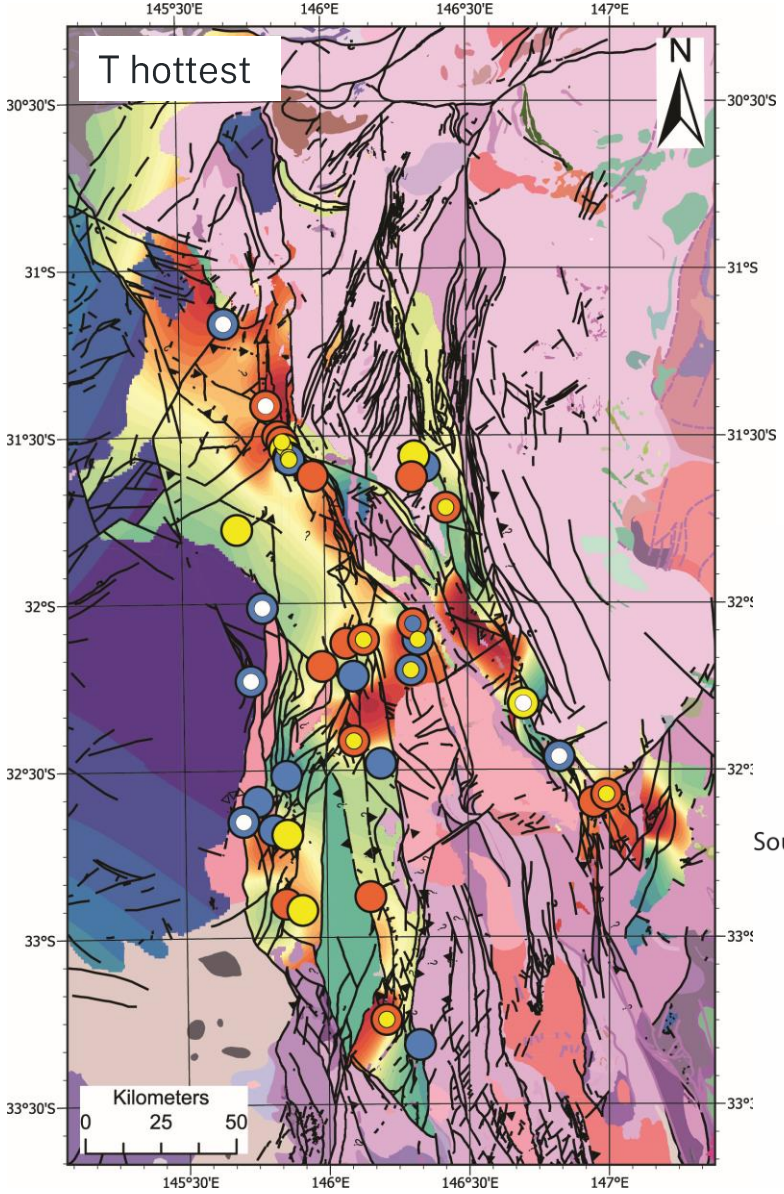
Why is there a difference?

Focused flow vs dispersed flow

- In Cobar we couldn't escape hydrothermal footprint – extensive dispersed fault networks
- At Hera–Nymagee–Federation we got outside the hydrothermal footprint – very focused on 'major' faults

Dataset 1 – thermal mapping (Kübler index)





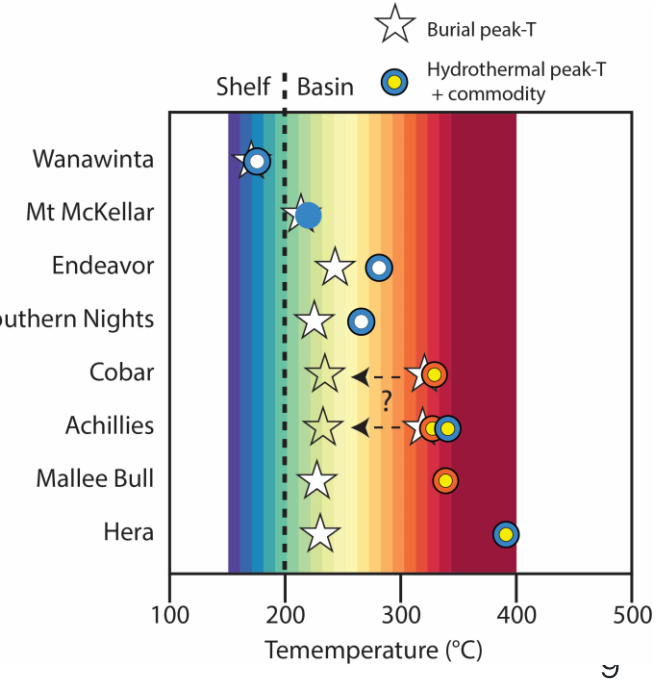
Temperature vs commodity

Metamorphic and hydrothermal temperature

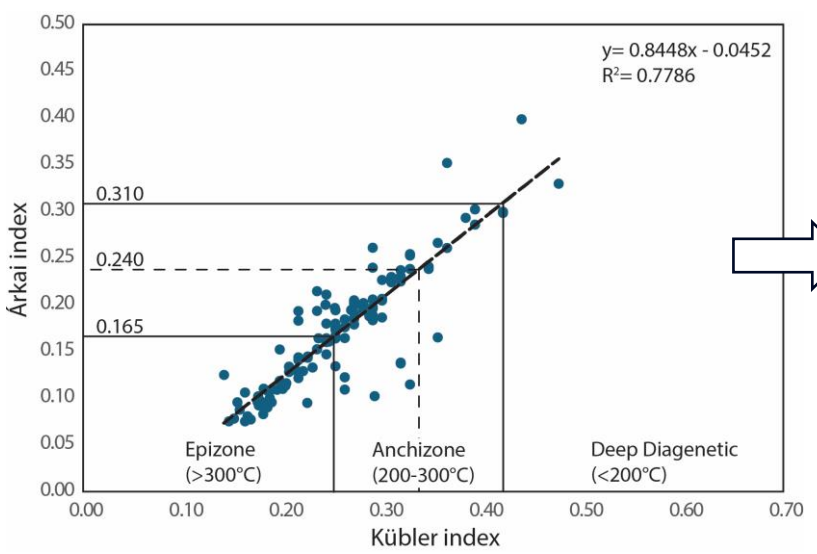
- Zn/Pb/Ag = cold
- Cu/Au /Ag or Zn/Au = hot

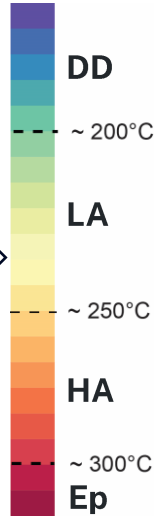
Thermal contrast

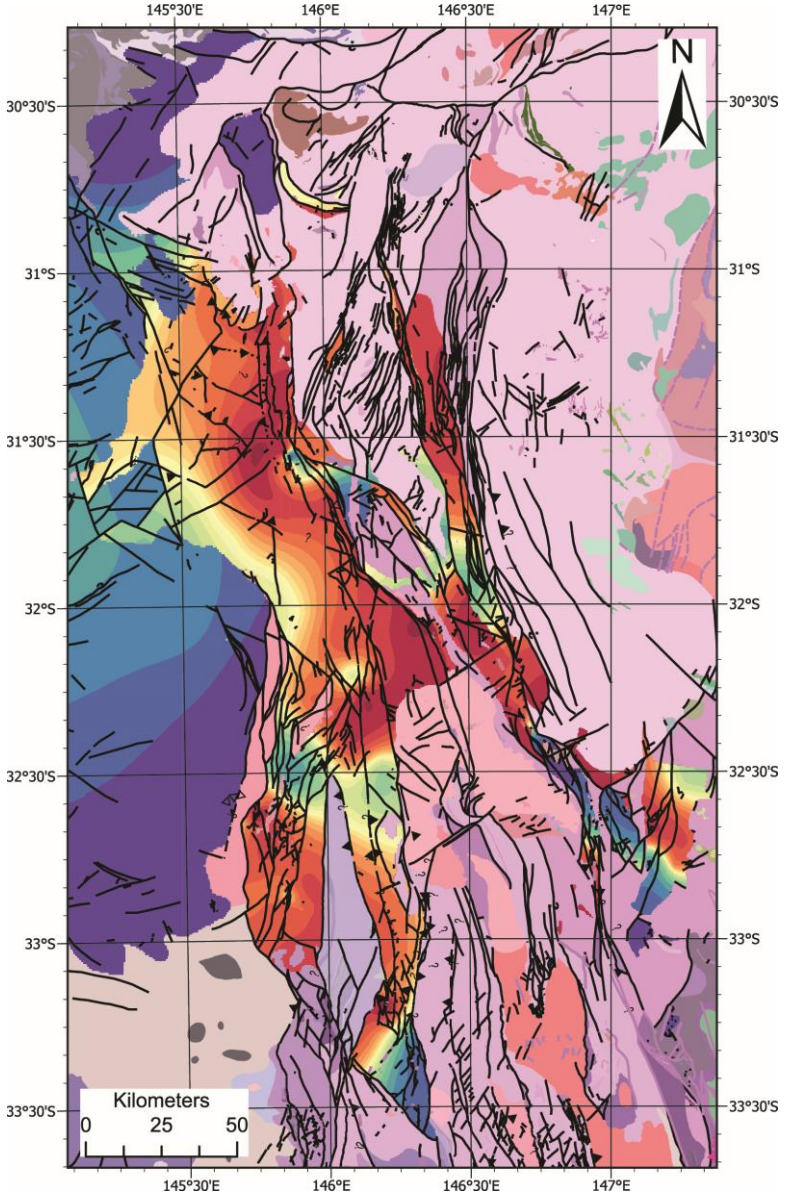
- Hera–Mallee Bull = **large**
- Zn/Pb/Ag = **small + cold**
- Cobar–Achillies = **small? + hot**



Dataset 1 – thermal mapping (Árkai index)







Árkai index (chlorite)

No set index boundaries for temperature

- If the data are good, it will have a linear correlation with Kübler index.
- But gradient varies according to Fe/Mg ratio of host rock
  - must calibrate it against Kübler index for local basin sedimentary rock Fe/Mg composition.

What should it show us?

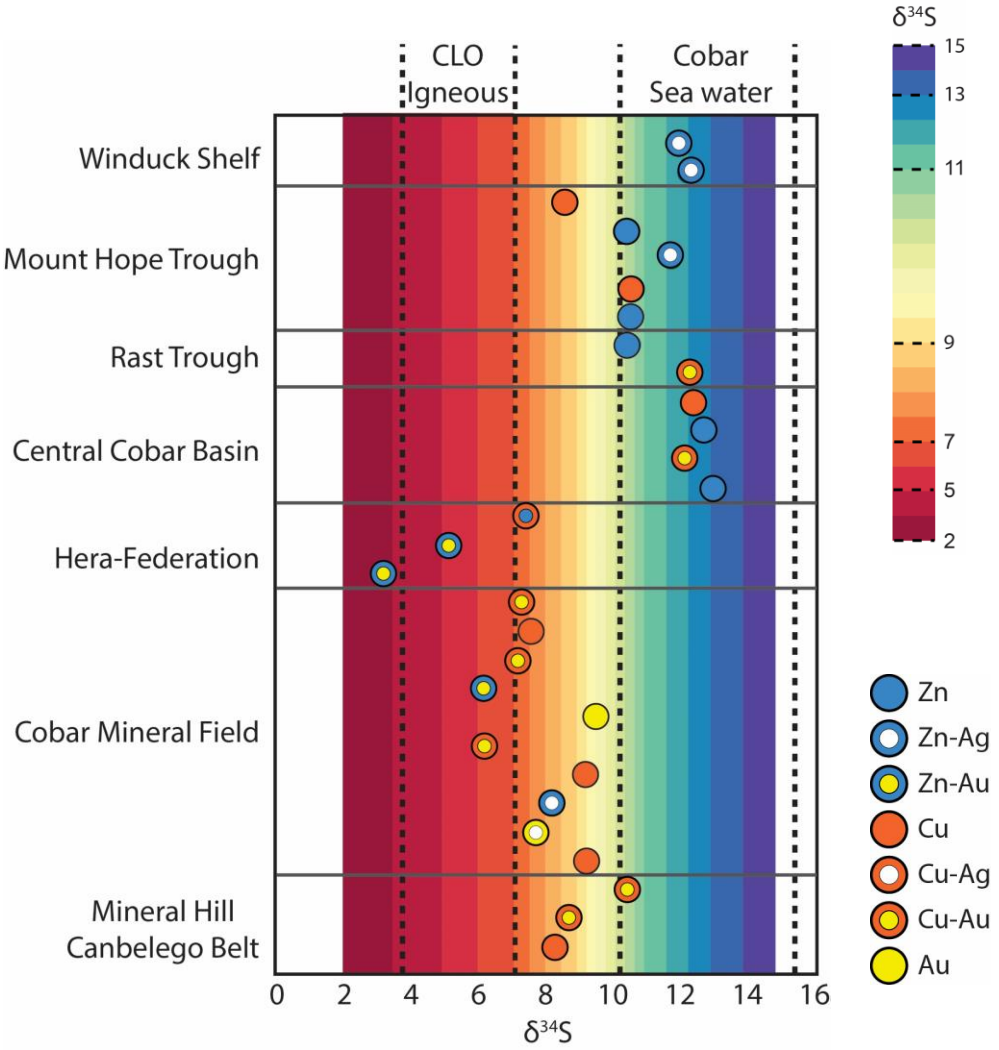
- Excellent independent test of Kübler index
  - in a perfect world should be similar
- There are various reasons why it may diverge from the Kübler index
  - reactivity of basin detritus
  - e.g. biotite vs muscovite.

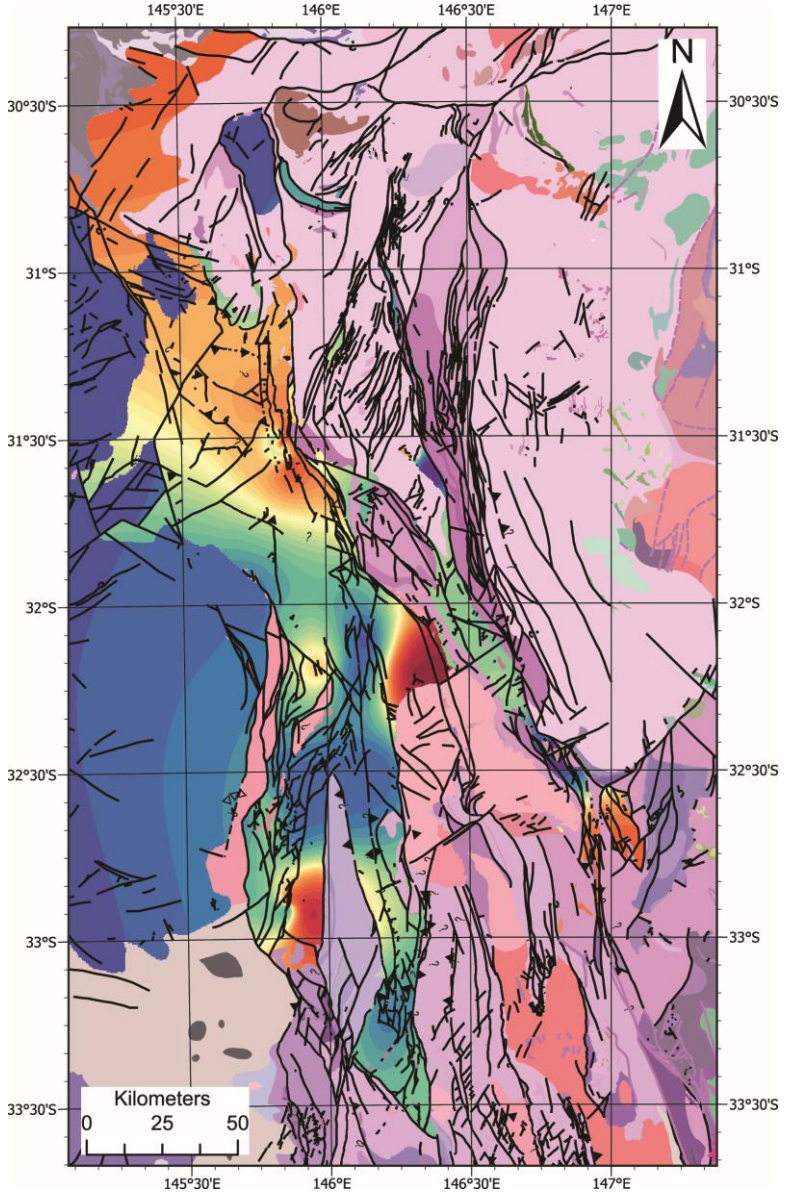
2

Cobar Basin example – 3 datasets

Sulfur mapping

Dataset 2 – sulfur mapping (sulfur source)





Sulfur source $\delta^{34}S$

Ratio of $^{34}S/^{32}S$ in sample relative to a reference standard expressed in parts per thousand (‰).

We compare the $\delta^{34}S$ in sulfide minerals relative to geologically important reservoirs.

Consider 2 simple S reservoirs:

- Central Lachlan Felsic Igneous
- Cobar Basin Formational

Why do we care?

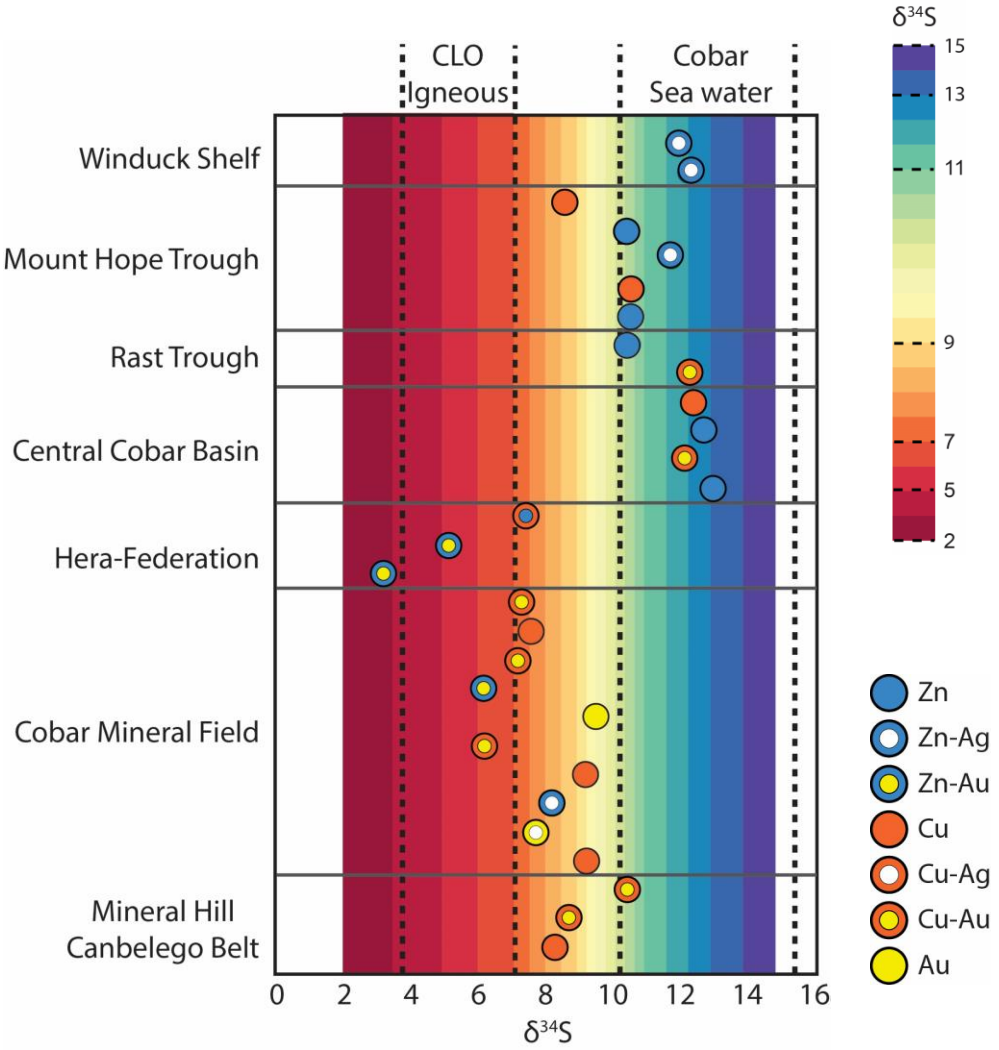
Sulfur is variable spatially

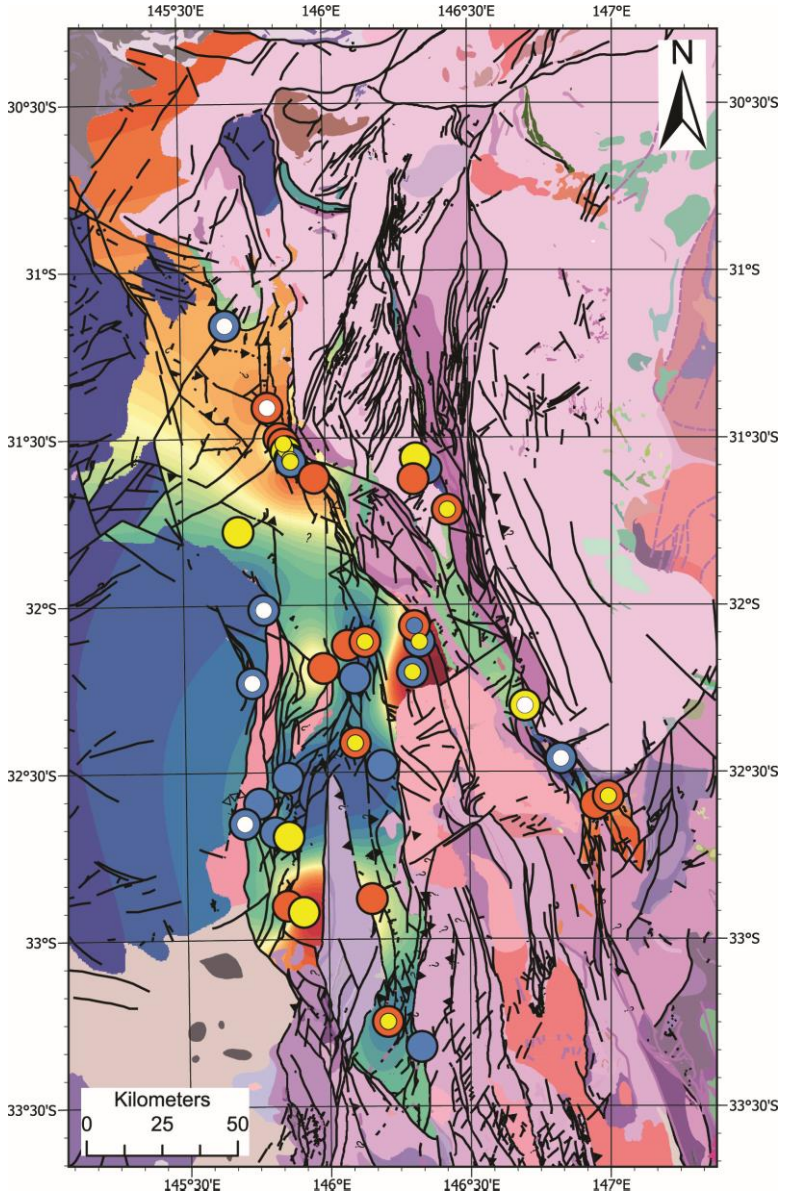
- Hera–Federation–Nymagee
  - **low** – least interaction with basin sulfur – most magmatic
- Central Basin/Mount Hope/Rast
  - **high** – basinal sulfur
- Cobar Mineral Field
  - **moderate** – mixed signature

Sulfur is variable against commodity

- Zn/Pb/Ag = **high** – **sea water**
- Cu/Au/Ag or Zn/Au = **low** – **magmatic**

Dataset 2 – sulfur mapping (sulfur source)





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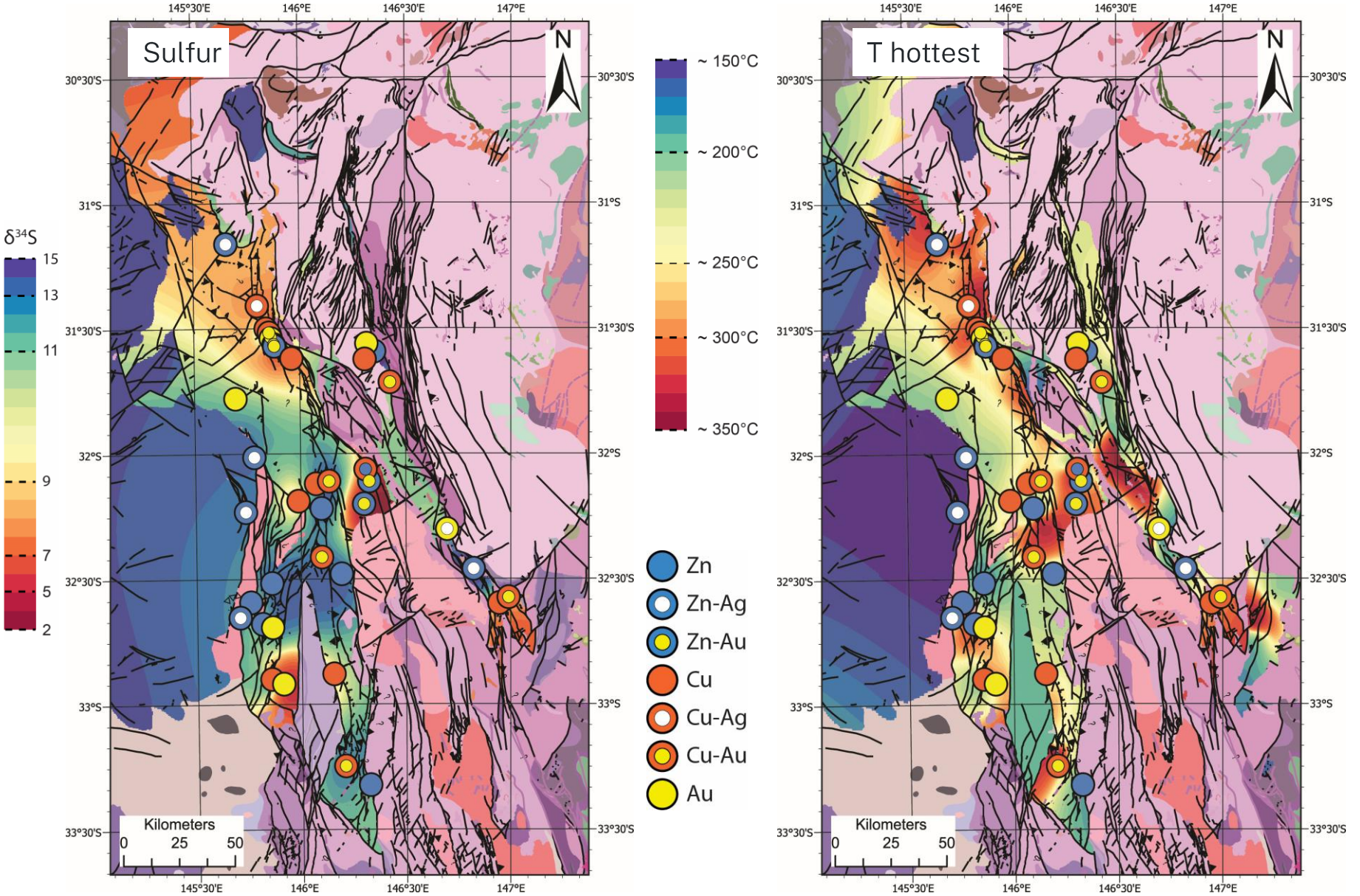
Datasets 1 and 2 – combining heat and sulfur



An example of ‘combine to win’

Sulfur and peak hydrothermal temperature display very similar spatial distribution, and when compared with commodity:

- Zn/Pb/Ag = **high S/low T**
- Cu/Au /Ag or Zn/Au = **low S/high T**

What does it mean?

Lower temperature (also limited thermal contrast) and **high sulfur** is consistent with basinal fluids moving around faults during inversion:

- No deep or hot source
- Endemic sulfur and commodities
  - Pb-Zn-Ag
- Dominates western, northern and southern basin

Higher temperature (can be significant thermal contrast) and **low sulfur** is consistent with limited basin interaction.

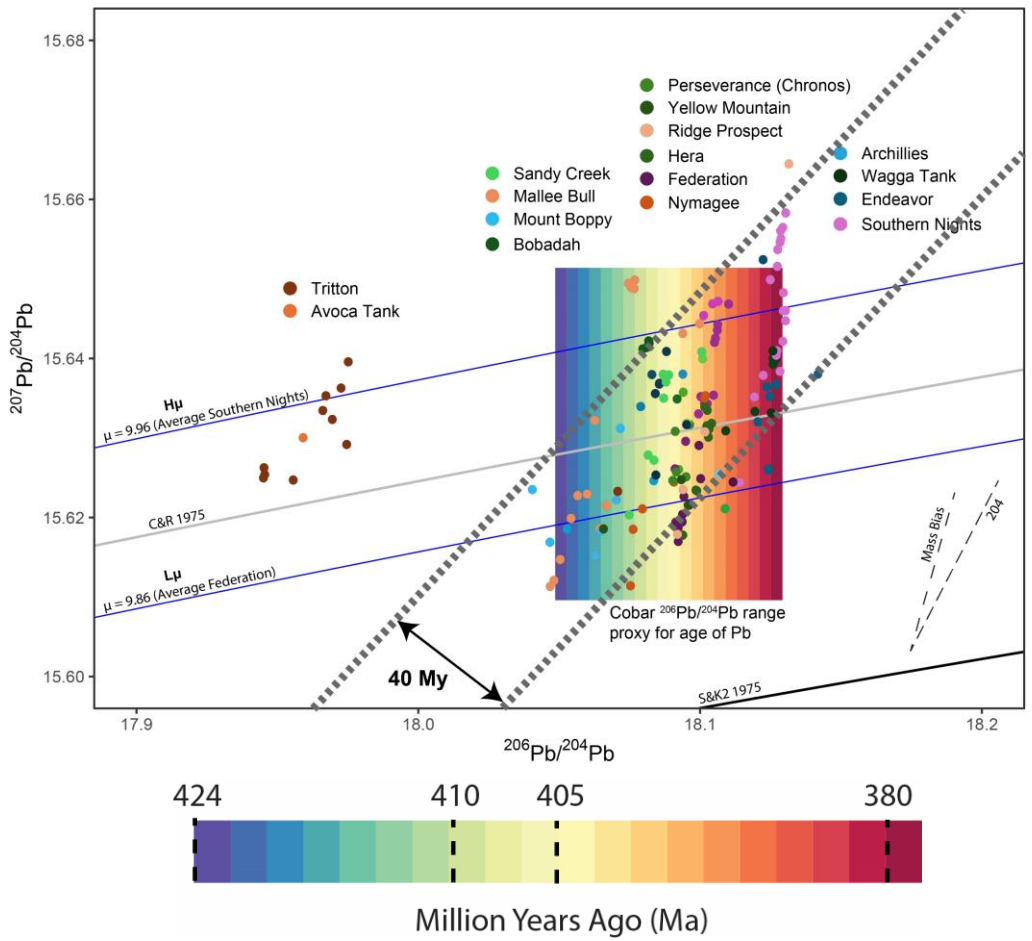
- Hot source, and fluid retained heat
- Cosmopolitan sulfur and commodities
  - Au-Cu (Zn-Pb-Ag)
- Dominates the eastern basin

3

Cobar Basin example – 3 datasets

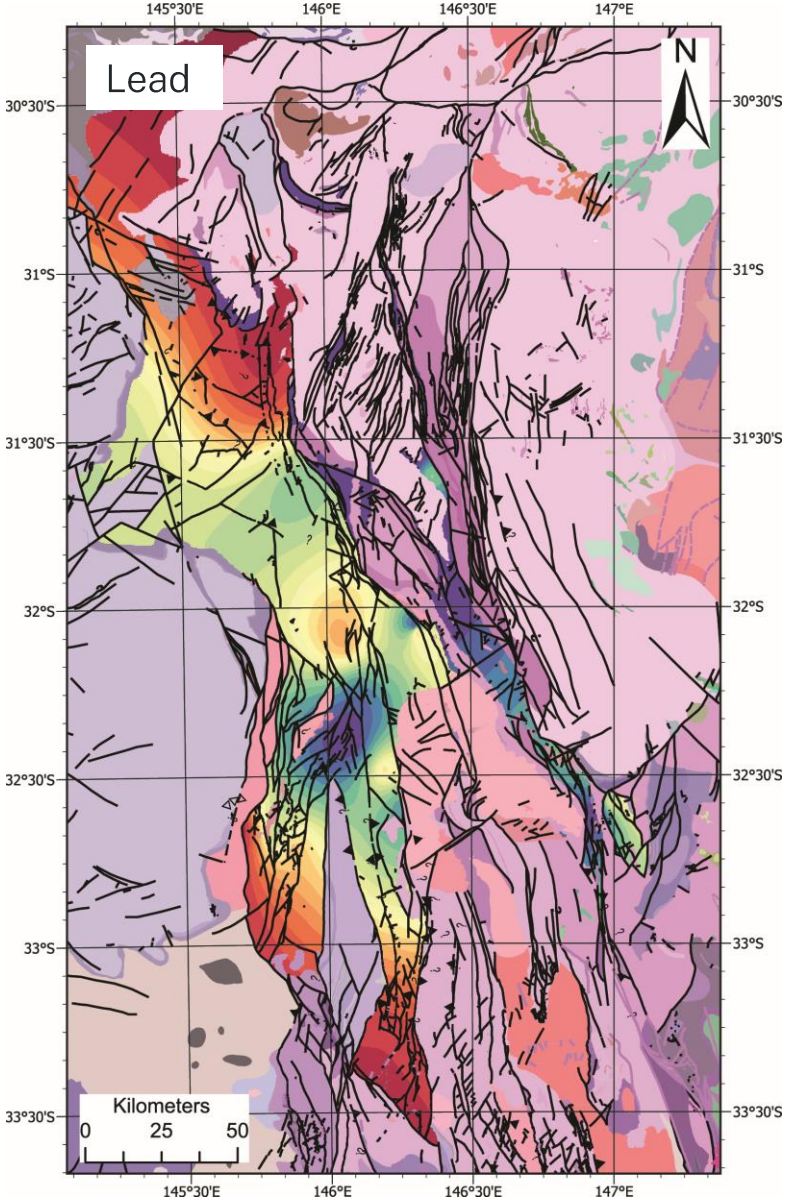
Lead mapping

Dataset 3 – lead mapping (metal source)



U–Pb and Ar–Ar calibration of $^{206}Pb/^{204}Pb$

- Mallee Bull (cassiterite) and Mineral Hill Ar–Ar ~424 Ma
- Chronos (titanite) and Hera Titanite ~410 and 405 Ma
- Endeavor (white mica) ~380 Ma



Pb isotopes

Plot of $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$

Plot our data relative to a crustal evolution or growth curve. Look at 2 parameters:

1) Pb source – μ (mu) $^{238}U/^{204}Pb$
   - Mostly look at mantle vs crust
   - Not useful in Cobar (all crustal Pb)
2) Model age
   - Age the Pb was extracted from the source. Determined form isochrons that intersect the growth curve.

What does it mean in Cobar?

See Pb-isotope data fall between x2 isochrons that span ~40 My

Calculate model ages using Lachlan specific growth curves, but also…such a strong control from $^{206}Pb/^{204}Pb$ so we can use it as an ~ proxy for age.

Spatial variation of average $^{206}Pb/^{204}Pb$

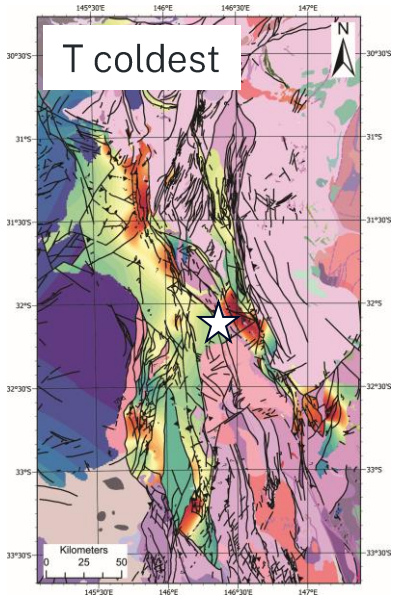
- Central basin and Kopyje Shelf
  - old galena (~424 Ma)
- Rast / Mount Hope / Northern Basin
  - young galena (~380 Ma)
- The rest… 410–400 Ma galena

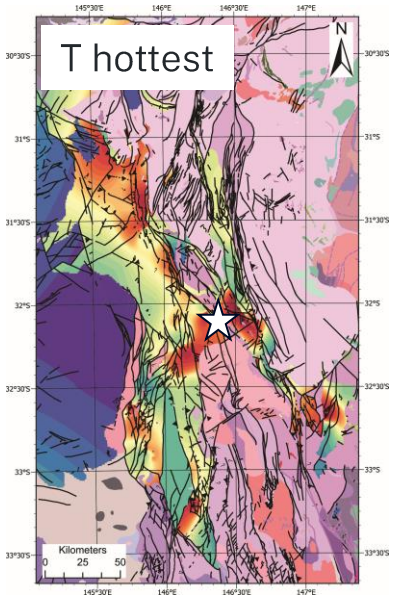
4

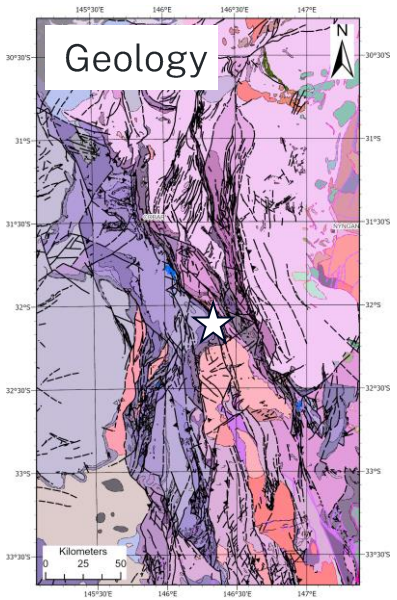
Summary and future direction

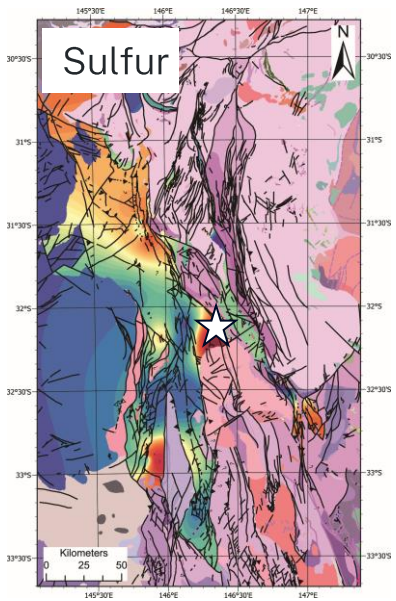
Evolving to statewide mineral system mapping

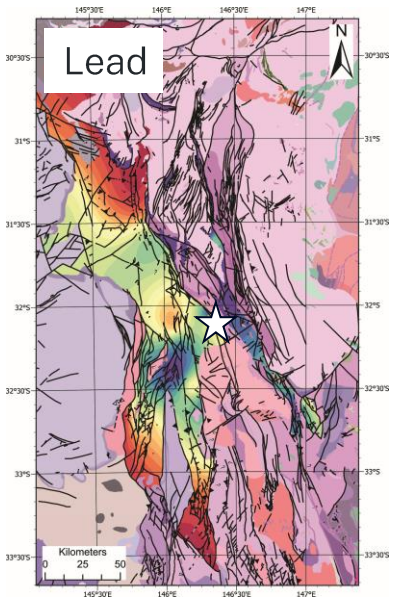
Summary and application

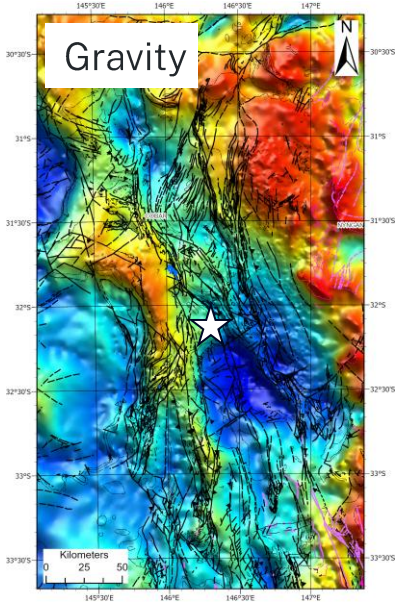












Holistic mineral system maps

Building large mineral systems datasets and translating them to mappable criteria.

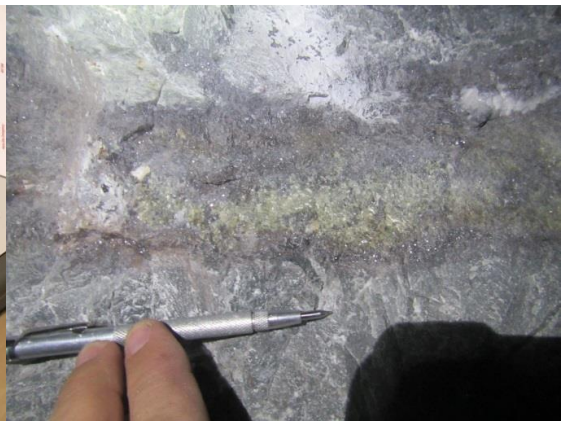
Only considered 3 maps:

- thermal (energy and deposition)
- sulfur (source and transport)
- lead (source).

Application

3 examples

- Hera
- Mt McKellar
- Cobar



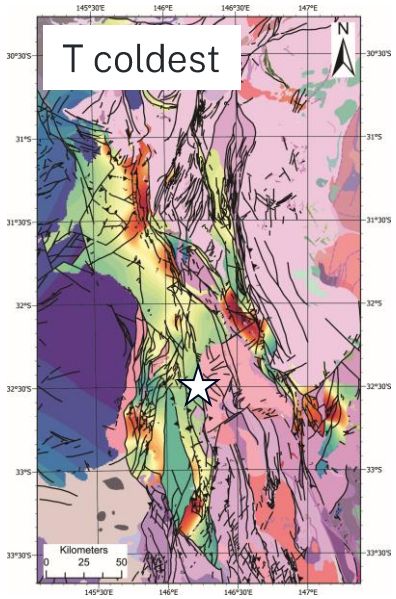
Hera – Au-Zn

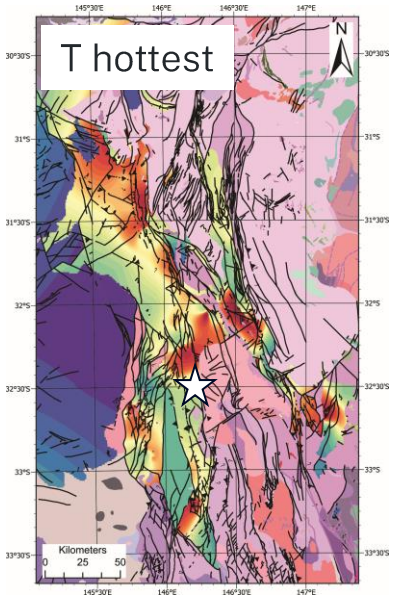
What do we think it is?

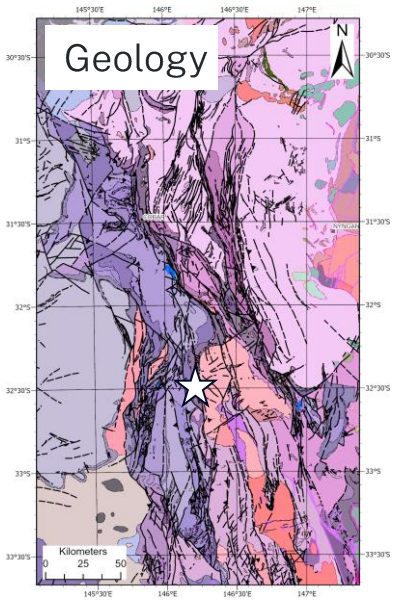
Combination of hottest with narrow thermal footprint and lowest sulfur

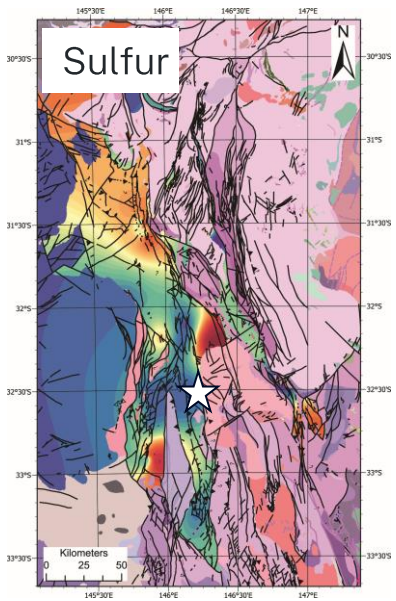
- Basement is the north plunging Erimeran Granite
  - Discrete large faults that focused fluid flow
- Sulfur consistent with magmatic source (non-basin)
- Hot with large thermal contrast
- Consistent with a fault-focused magmatic fluid that had little interaction with the basin sedimentary rocks at ~405 Ma.

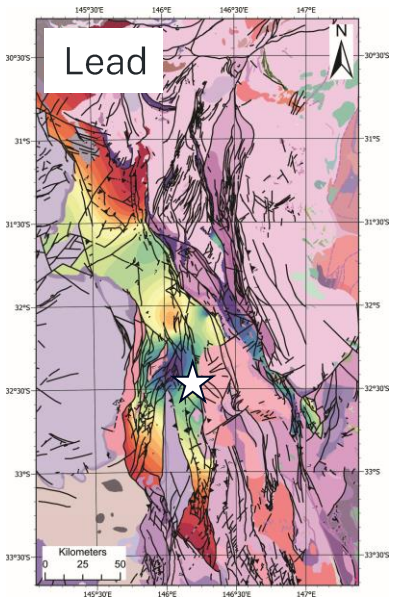
Summary and application

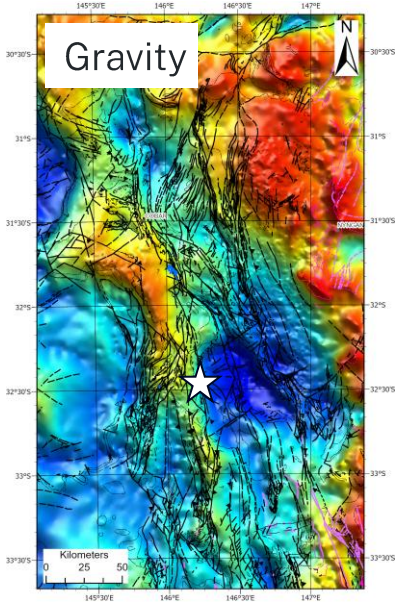












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- Mt McKellar
- Cobar

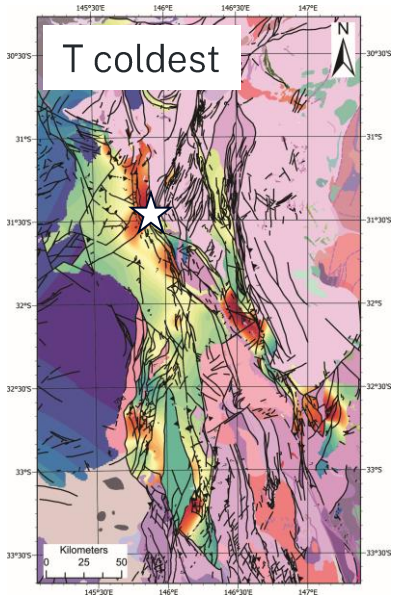
Mt McKellar – Zn-Pb

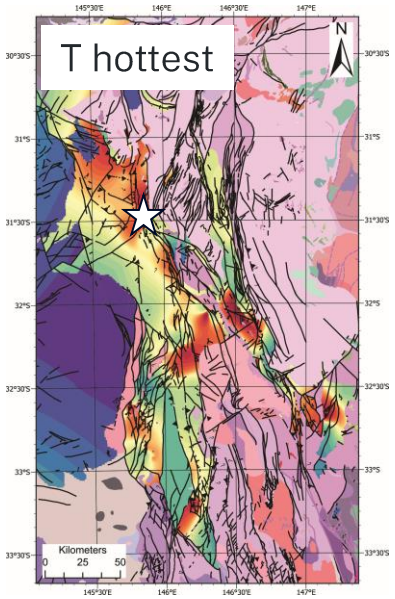
What do we think it is?

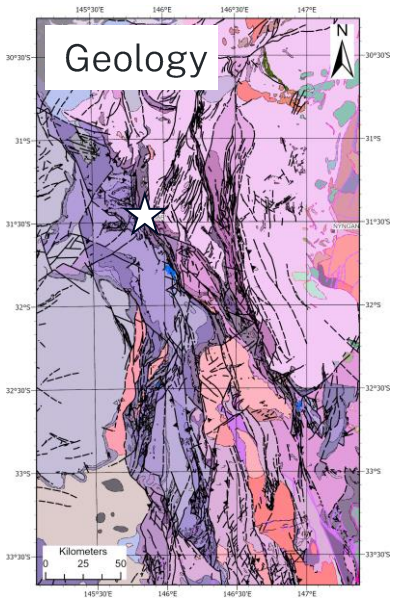
Combination of cold, highest sulfur and no thermal footprint

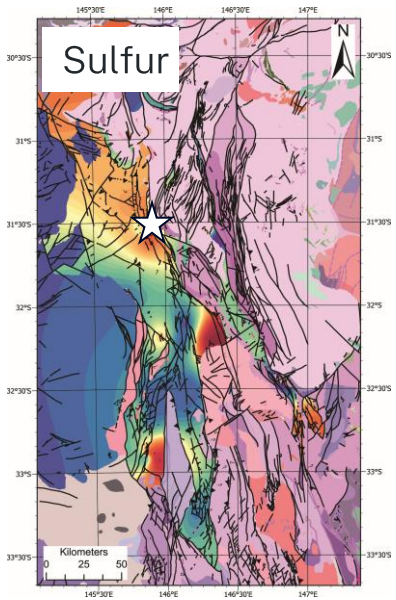
- Sulfur consistent with basin formational fluids
- Lack of thermal contrast or thermal footprint (equilibrium with basin regional footprint)
- Pb-Pb age ~390 Ma.
- Consistent with fault focused / sandstone replacement during basin inversion

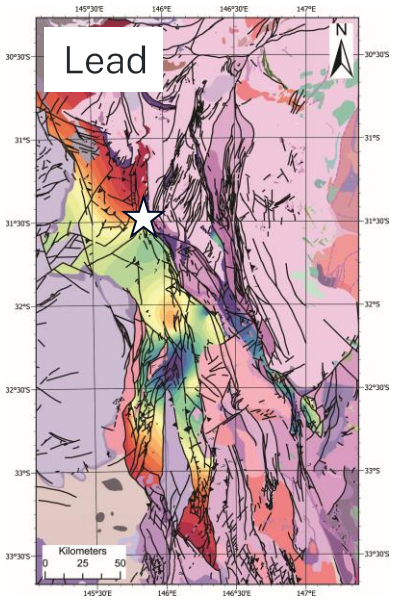
Summary and application

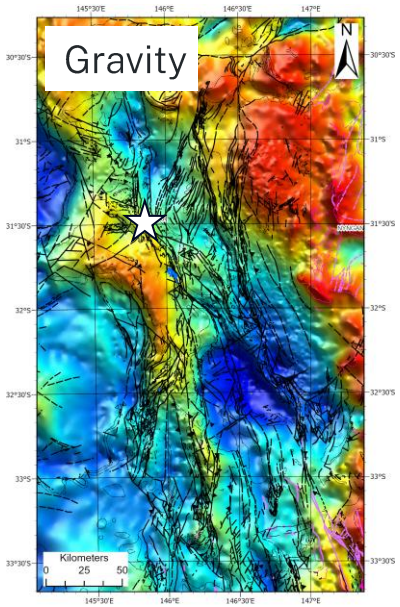












Holistic mineral system maps

Building large mineral systems datasets and translating them to mappable criteria.

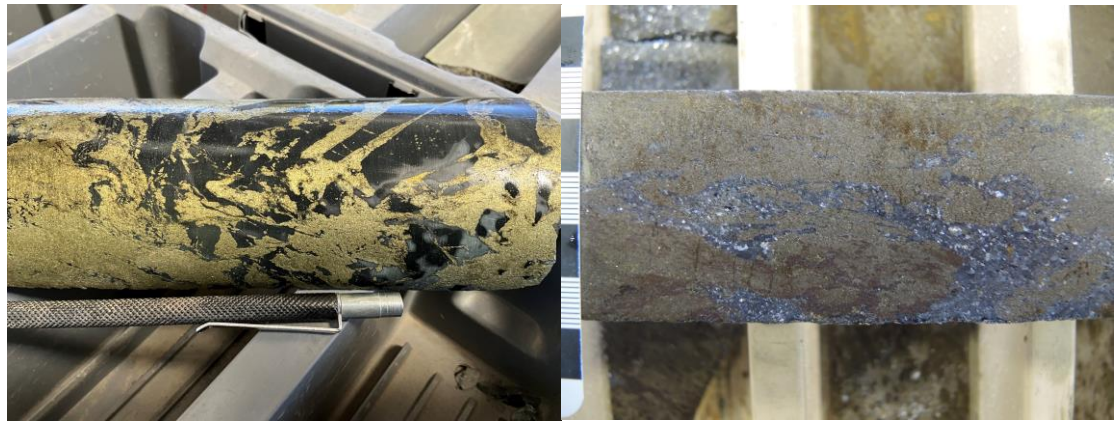
Only considered 3 maps:

- thermal (energy and deposition)
- sulfur (source and transport)
- lead (source).

Application

3 examples

- Hera
- Mt McKellar
- Cobar



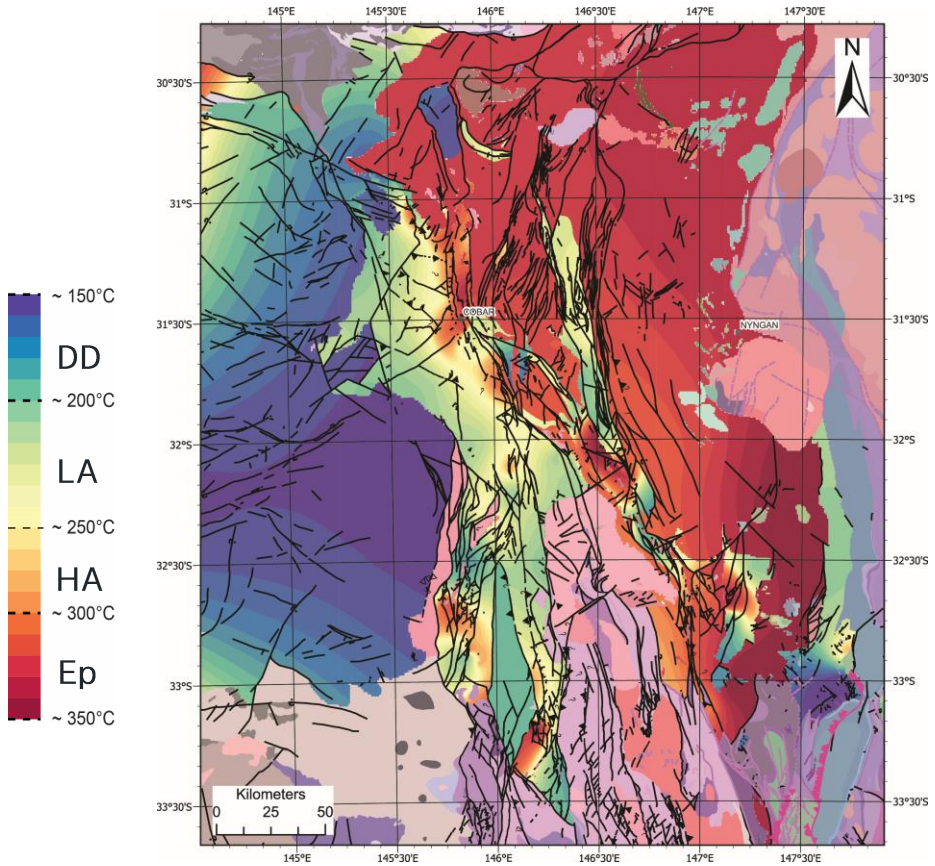
Cobar Mineral Field – Cu-Au-Pb-Zn

What do we think it is?

Moderate to high heat, intermediate sulfur and large thermal footprint

- Basement is Ordovician turbidite
  - Many faults, widely dispersed fluid flow
- Sulfur consistent with mixed basin formational/magmatic fluids
- Moderate to hot with wide thermal footprint
- Consistent with fault-focused magmatic fluids and significant interaction with basin sedimentary rocks at 410–405 Ma.

Watch this space...

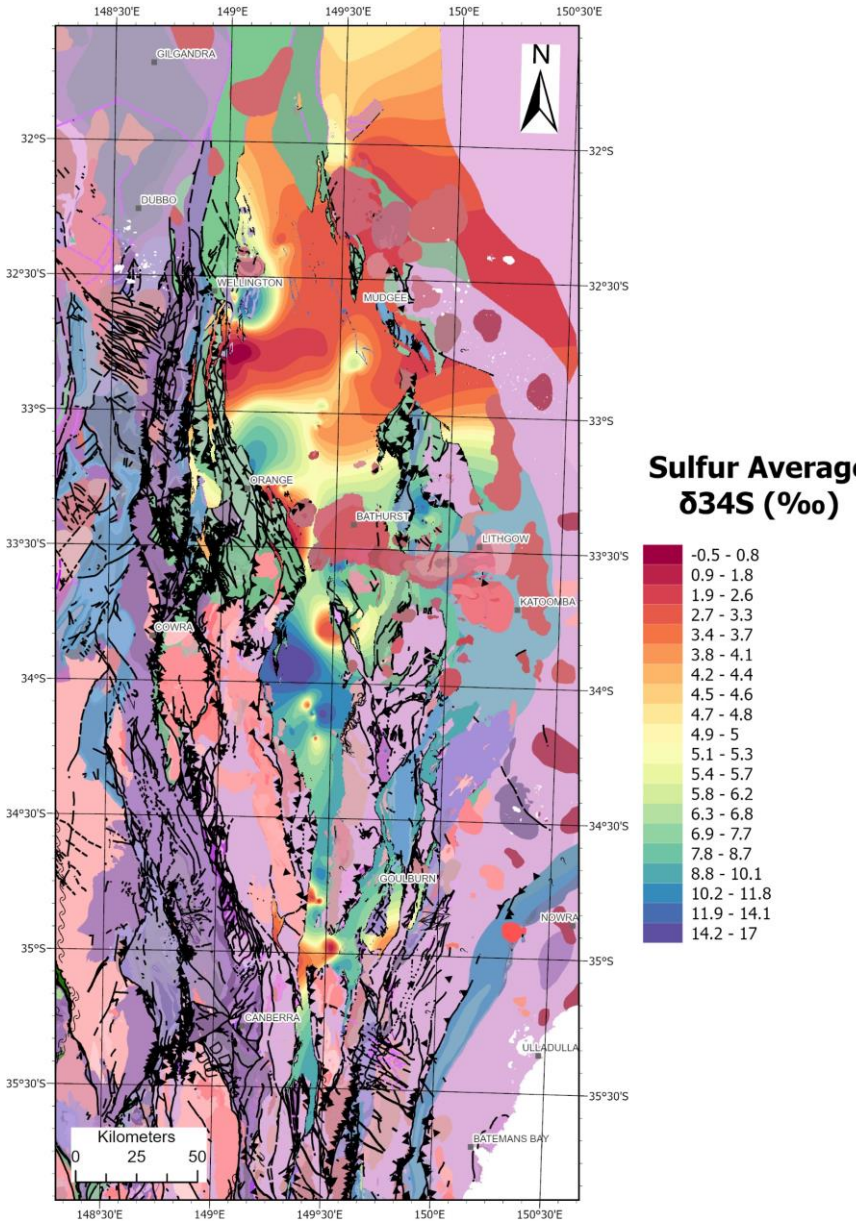


Extending the footprint

We have extended all the datasets over the Hermidale Terrane and into the Derriwong Group.

This map is Kübler Index (coldest) ~ regional metamorphism

- looks reasonable – hotter to the east
- dichotomy between Ballast and Narrama formations



Statewide maps

We will roll this out everywhere we can, starting with every Siluro-Devonian basin

Hill End Trough

Extensive program of isotope sample infill and collection shales for thermal mapping

Example here is our recent sulfur isotope dataset.

At a glance...

Prevalence of low and –ive $\delta^{34}S$ in the north where there is arc basement

- Deep sulfur source?
- Maybe orogenic systems?

Prevalence of high $\delta^{34}S$ in the south where Adaminaby Group is basement

- Maybe just basinal VMS systems e.g. Woodlawn
- Low S blips associated with SD mafic systems e.g. Currawang

Thank you

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