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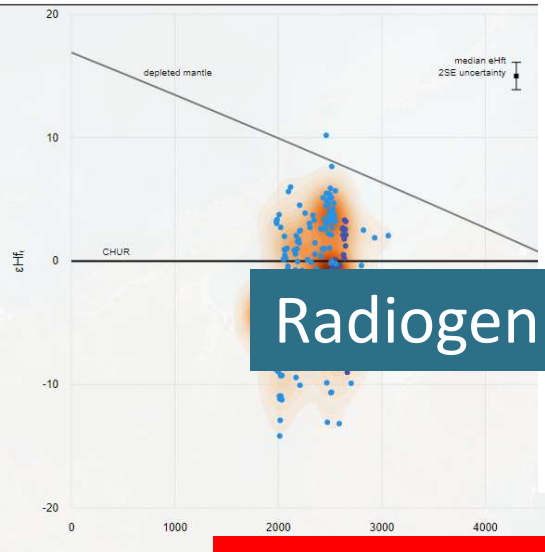
Exploring for the Future

Radiogenic isotope mapping

Identifying controls on mineralisation at multiple scales

David Huston, David Champion, Kathryn Waltenberg, David Mole and Sharon Jones



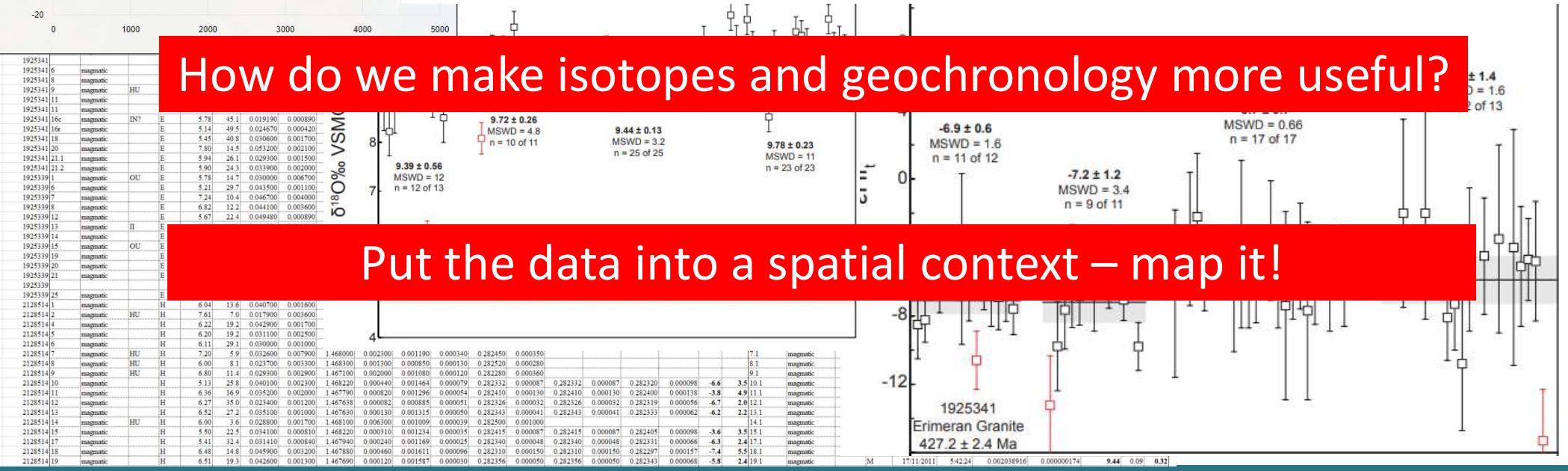
$$(^{206}Pb/^{204}Pb)_i = (^{206}Pb/^{204}Pb)_s - (^{238}U/^{204}Pb)_s(e^{\lambda_{238}t_f} - 1)$$

$$(^{207}Pb/^{204}Pb)_i = (^{207}Pb/^{204}Pb)_s - (^{238}U/^{204}Pb)_s/137.88)(e^{\lambda_{235}t_f} - 1)$$

Radiogenic isotope geochemistry has an image problem

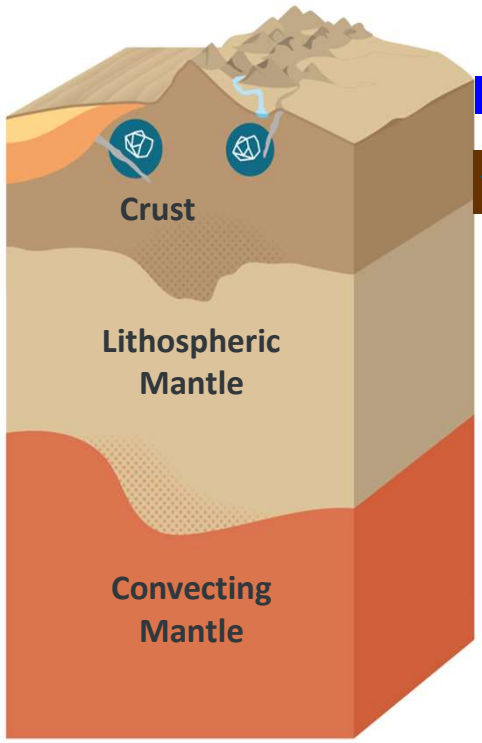
$$(^{208}Pb/^{204}Pb)_i = (^{208}Pb/^{204}Pb)_s - (^{232}Th/^{204}Pb)_s(e^{\lambda_{232}t_f} - 1)$$

How do we make isotopes and geochronology more useful?



Put the data into a spatial context – map it!

What do radiogenic isotope maps map?



U-Th-Pb system – generally ore (galena) analyses

- μ – modelled $^{238}U/^{204}Pb$ of lead source
- Source reservoir – generally upper-crust lead reservoir leached by hydrothermal fluids
- Low μ implies juvenile source

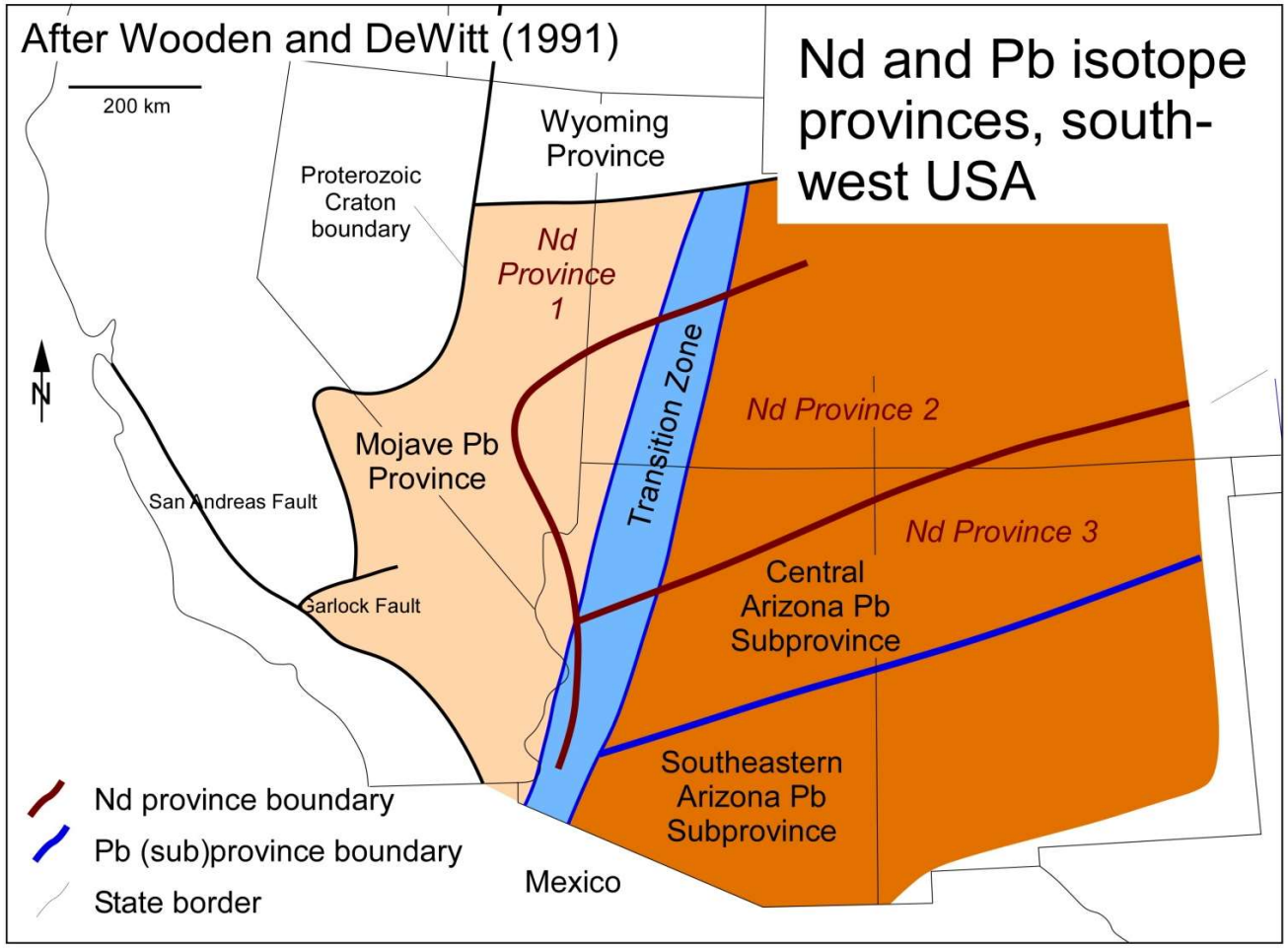
Lu-Hf system – generally zircon analyses

- ε_{Hf} – deviation from bulk earth (CHUR) at the time of zircon crystallisation
- T_{DM}/T_{2DM} – age of extraction of Hf source from depleted mantle (model-based)
- Source reservoir – generally mid- to lower-crust source of melts that crystallised zircon
- Positive ε_{Hf} implies juvenile source
- Multiple reservoirs can be assessed

Sm-Nd system – generally whole rock analyses

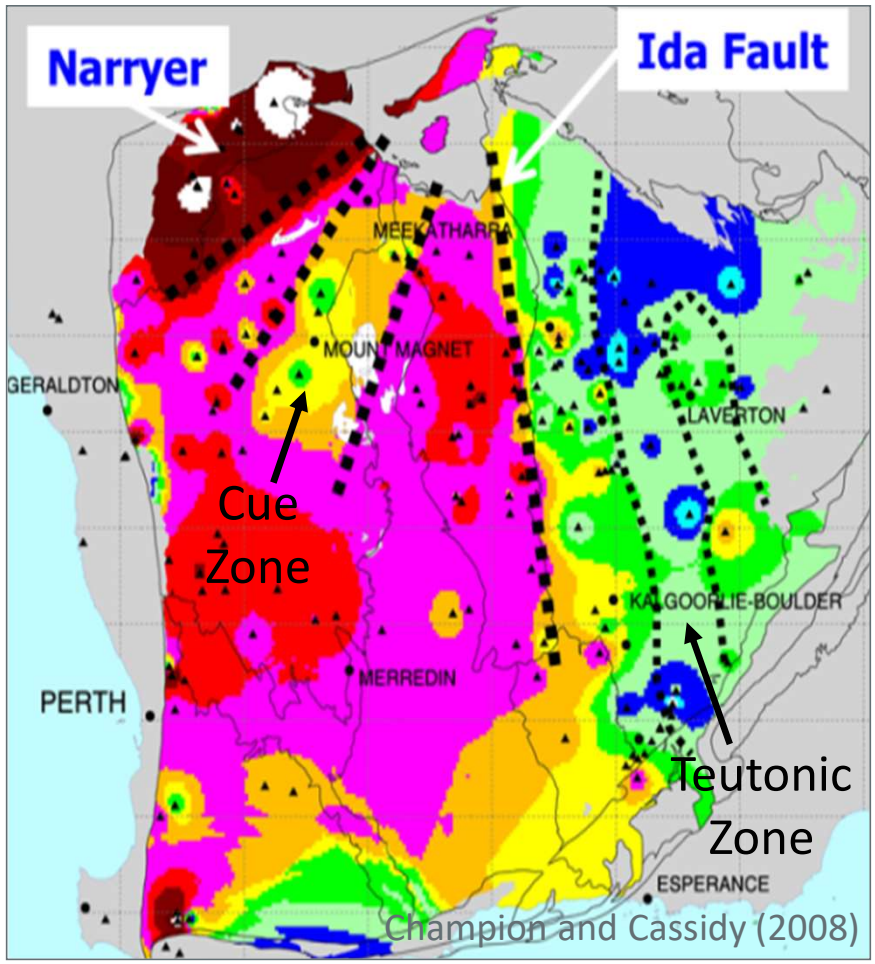
- ε_{Nd} – deviation from bulk earth (CHUR) at the time of (granite) crystallisation
- T_{DM}/T_{2DM} – age of extraction of Nd source from depleted mantle (model-based)
- Source reservoir – generally mid- to lower-crust source of granite melt
- Positive ε_{Nd} or $T_{DM}/T_{2DM} \sim T_{emplacement}$ implies juvenile source

Radiogenic isotope mapping – the beginnings



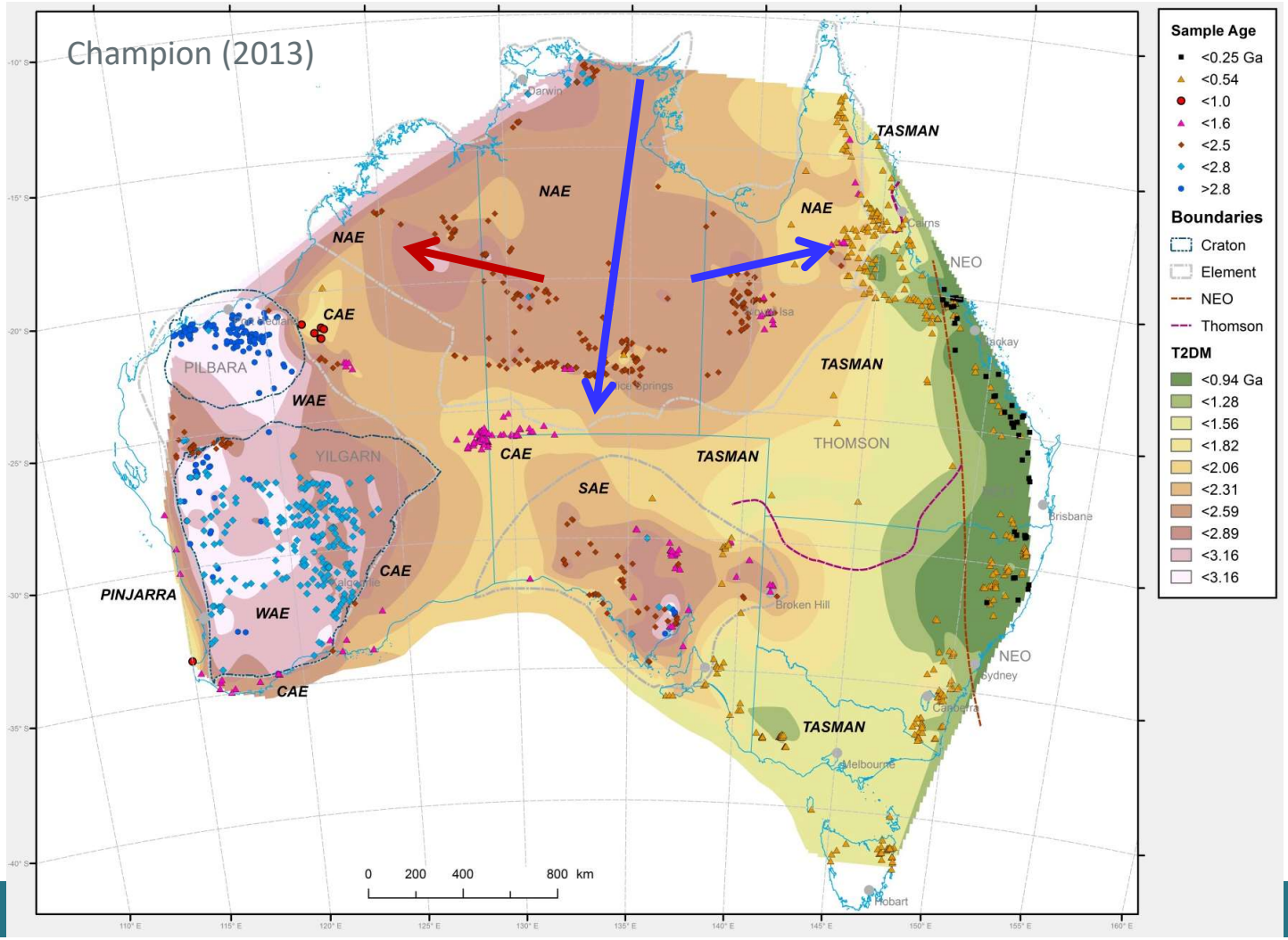
- Zartman (1974) identified lead isotope provinces in western USA
- Wooden and co-workers provide more details of the provinces in early 1990s
- Some of these isotope province boundaries correspond to geological province boundaries
- Bennett and dePaolo (1987) identified Nd isotope provinces in the same region

Nd isotope mapping (T_{2DM}) in Australia – the Yilgarn Craton (first edition)



- The diagram to the left is the first radiogenic isotope variation map I am aware of
- Published in 2008 by Champion and Cassidy; existed in unpublished form several years beforehand
- Cool colours indicate young model ages; warm colours indicate older model ages
- Maps known major boundaries – Ida Fault and boundary between Narryer and Youanmi Terranes
- Also identifies linear domains with young model ages – Cue and Teutonic zones
- Volcanic-hosted massive sulfide deposit are preferentially associated with these zone

National-scale Nd isotope mapping (T_{2DM}) in Australia



Oldest

West Australian Element – Pilbara and Yilgarn Cratons

North and South Australian Elements

Central Australian Element

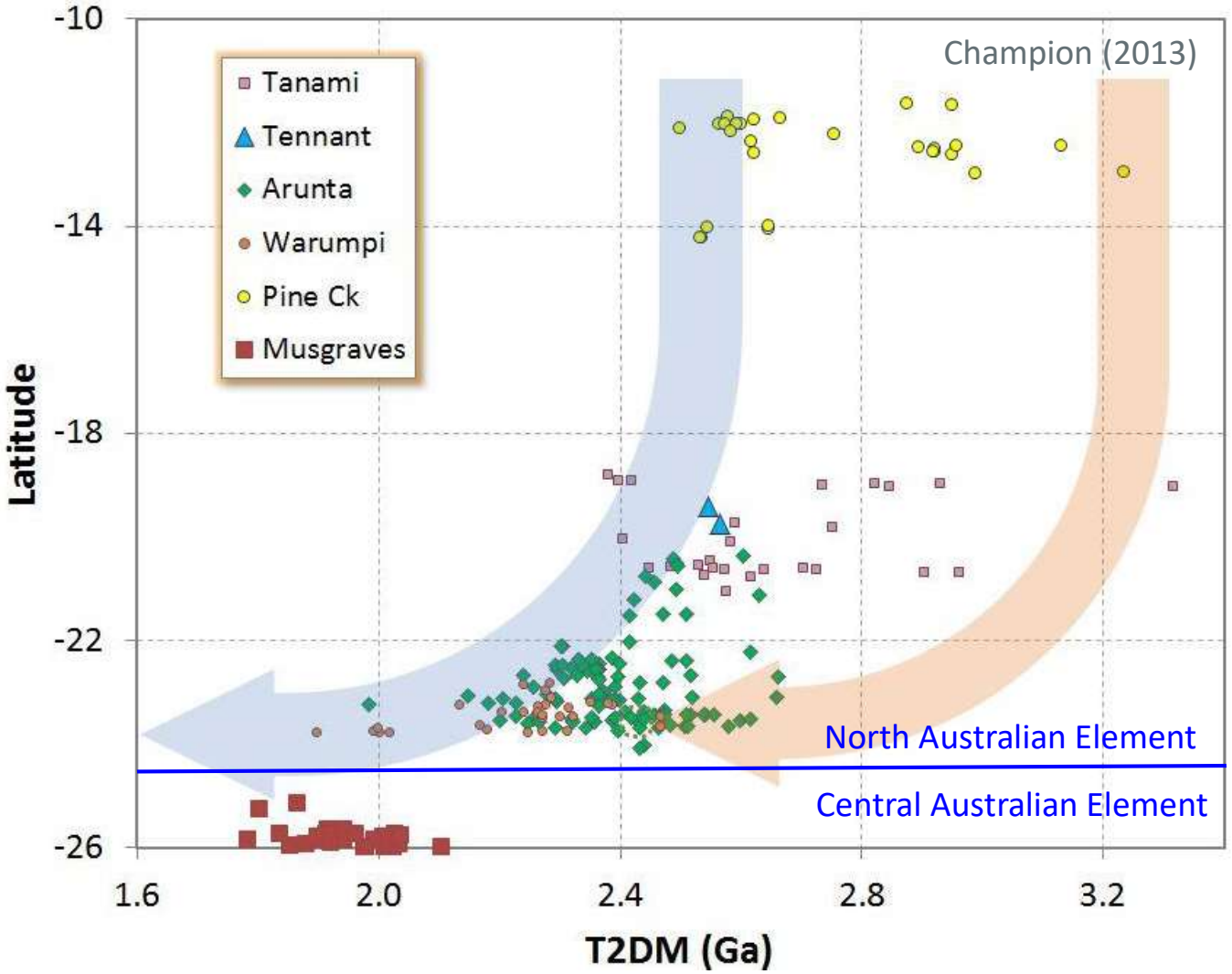
Delamerian, Lachlan, Thomson and Mossman orogens

New England Orogen

Youngest

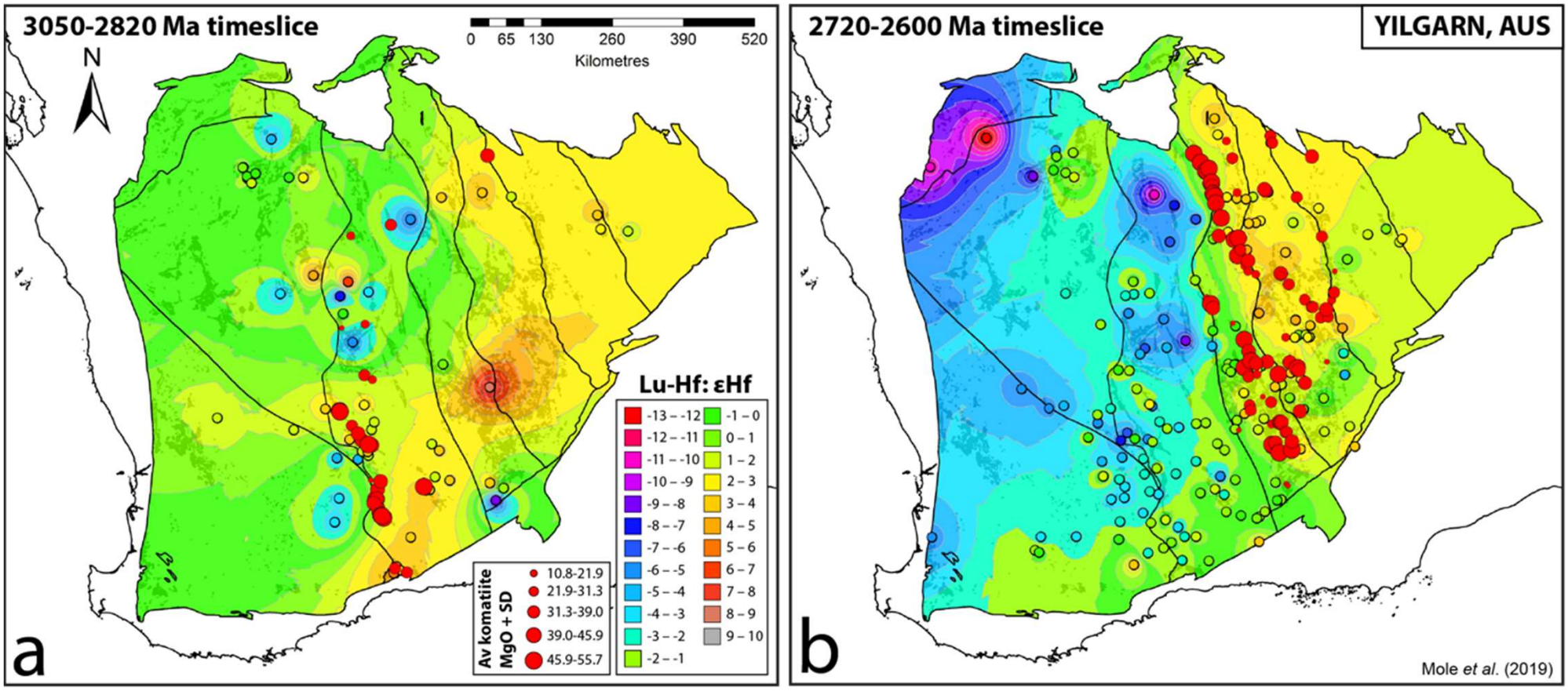
- Common gradients within elements
- Gradients at edges of elements

North-south Nd isotope transect across North Australian Element



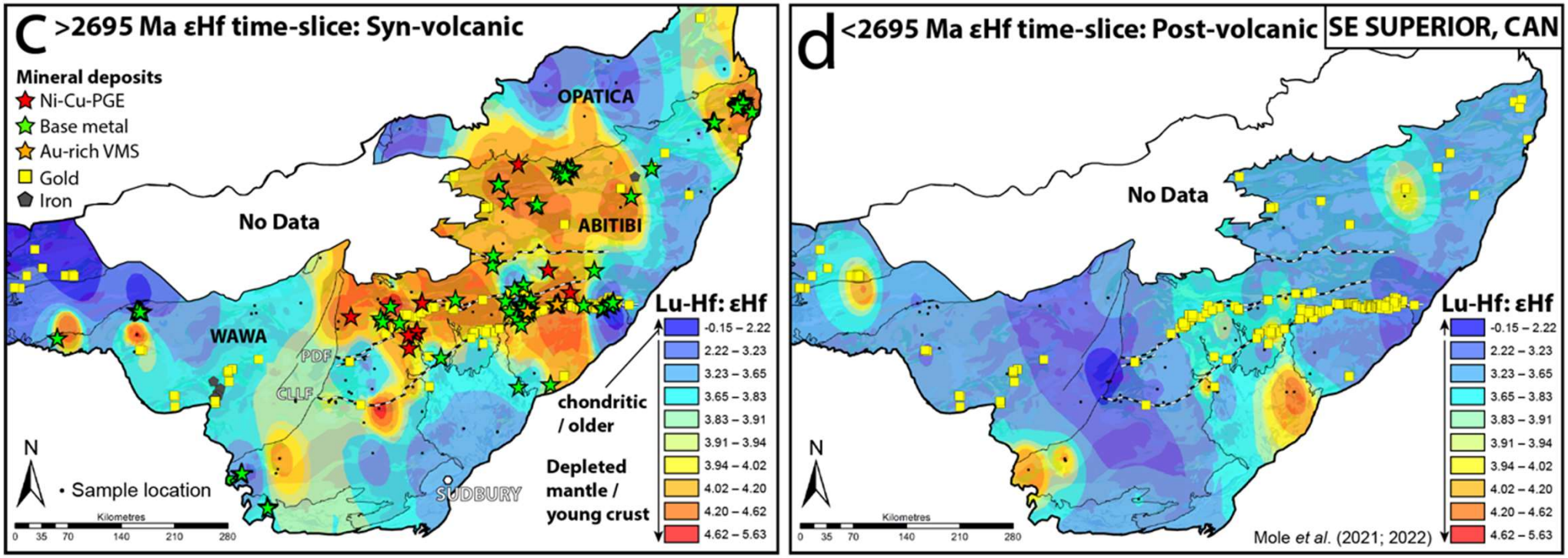
- Consistent younging of T_{2DM} southward to margin of North Australian Element
- Stepped younging in T_{2DM} from North to Central Australian Element
- Interpreted as the result of a long-lived, south-facing convergent margin on southern margin of the North Australian Element

Hf isotope mapping (ε_{Hf}) in Australia – Yilgarn Craton



Mole et al. (2019)

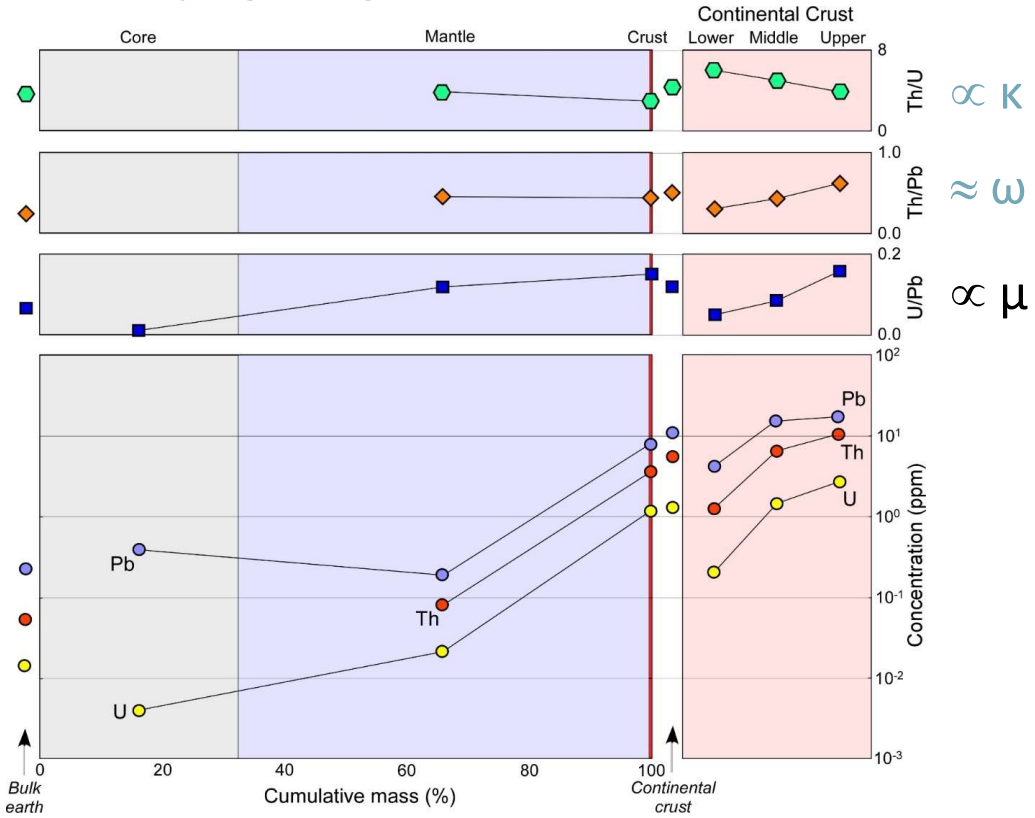
Hf isotope mapping (ε_{Hf}) in Canada – Abitibi-Wawa Subprovince



Mole et al. (2021, 2022)

Lead isotopes – the theory

Major global geochemical reservoirs

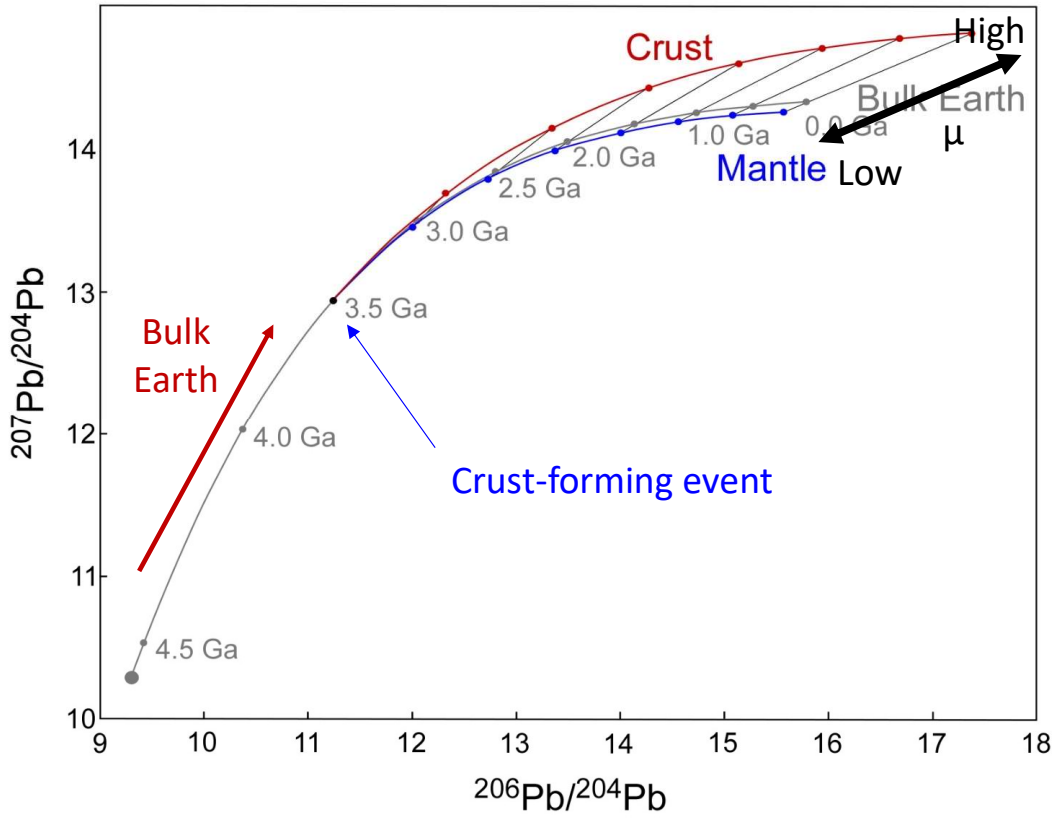


$\propto \kappa$

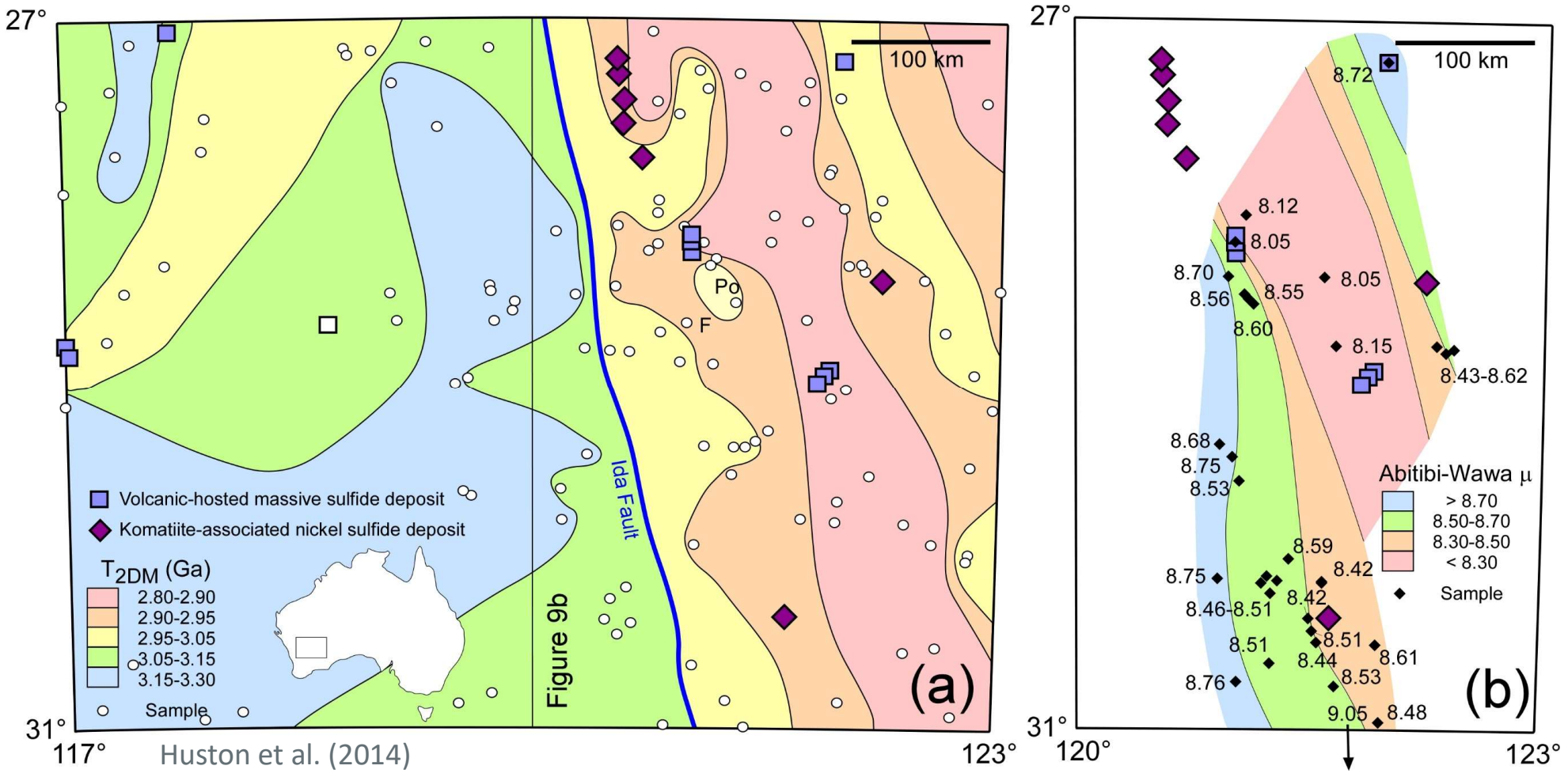
$\approx \omega$

$\propto \mu$

Lead growth due to uranium decay

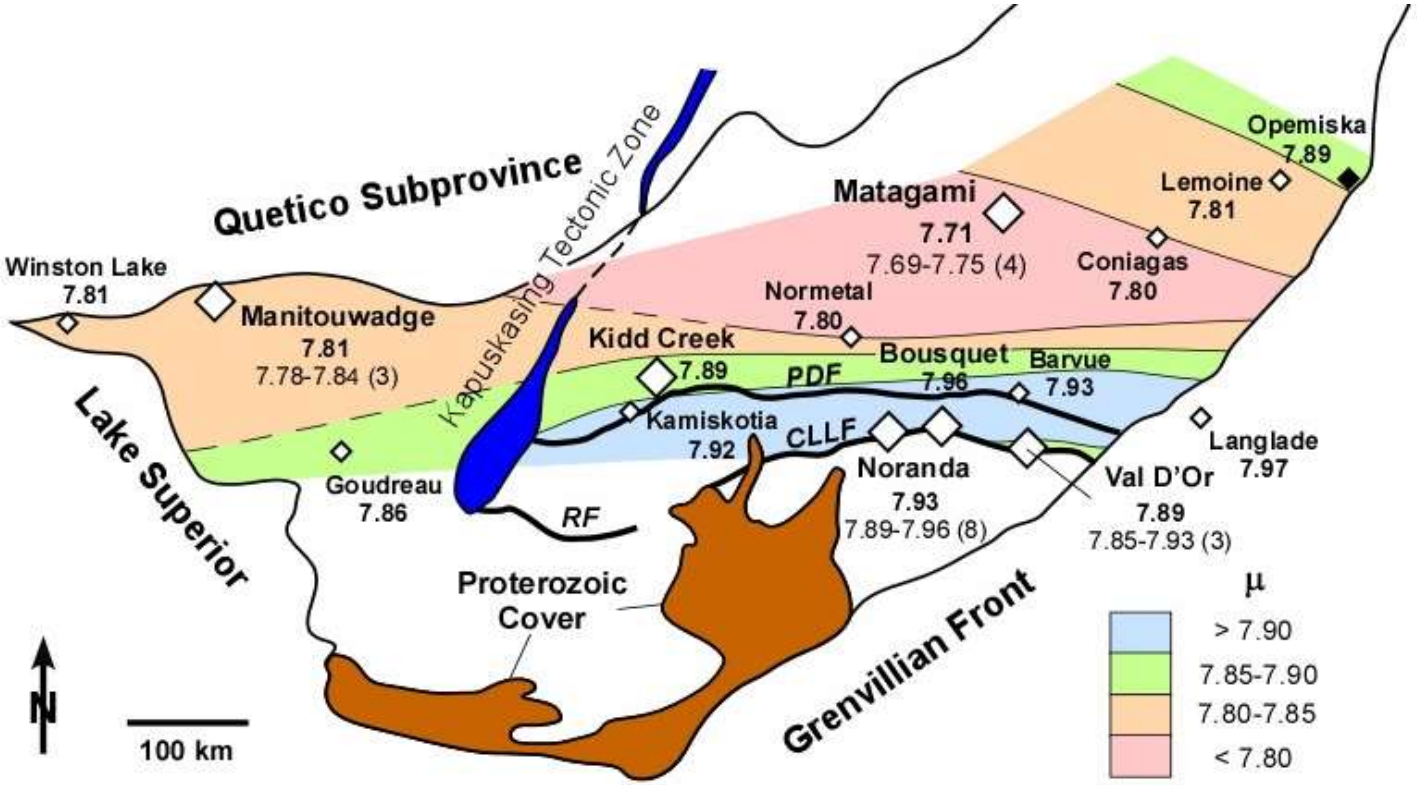


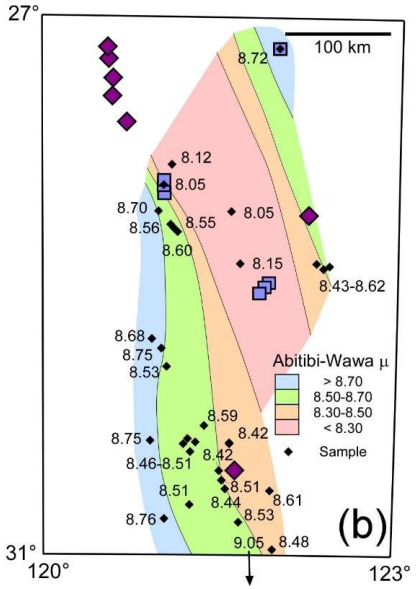
μ versus T_{2DM}, Yilgarn Craton



Huston et al. (2014)

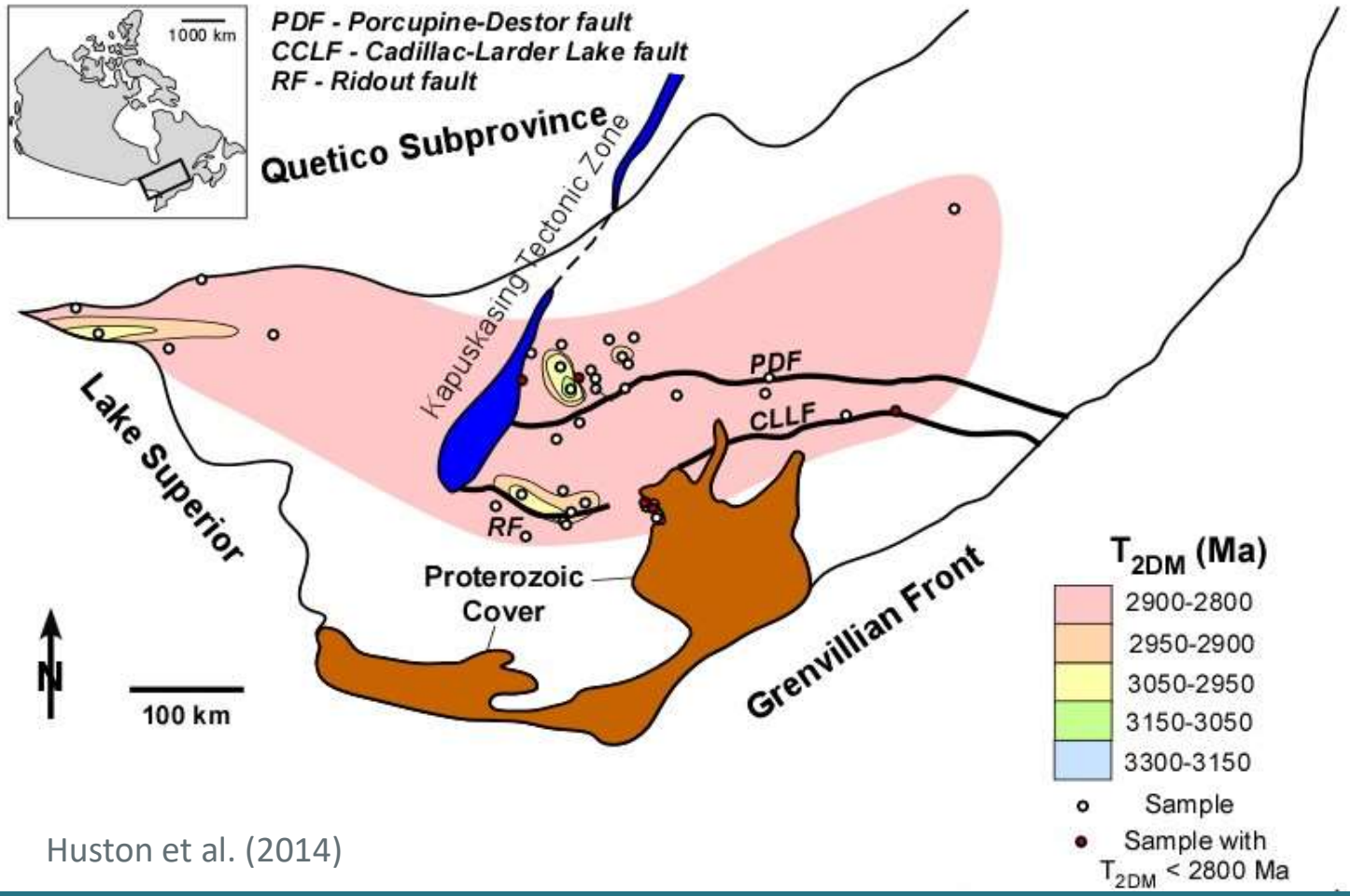
μ variations, Abitibi-Wawa Subprovince (Canada)

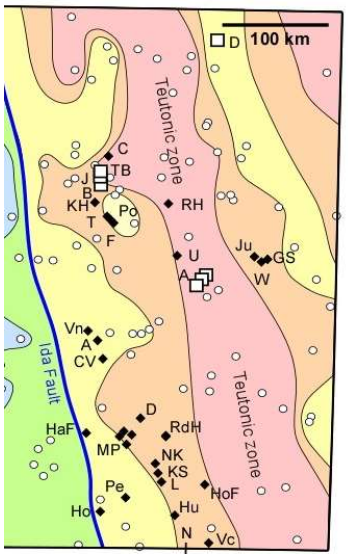




Huston et al. (2014)

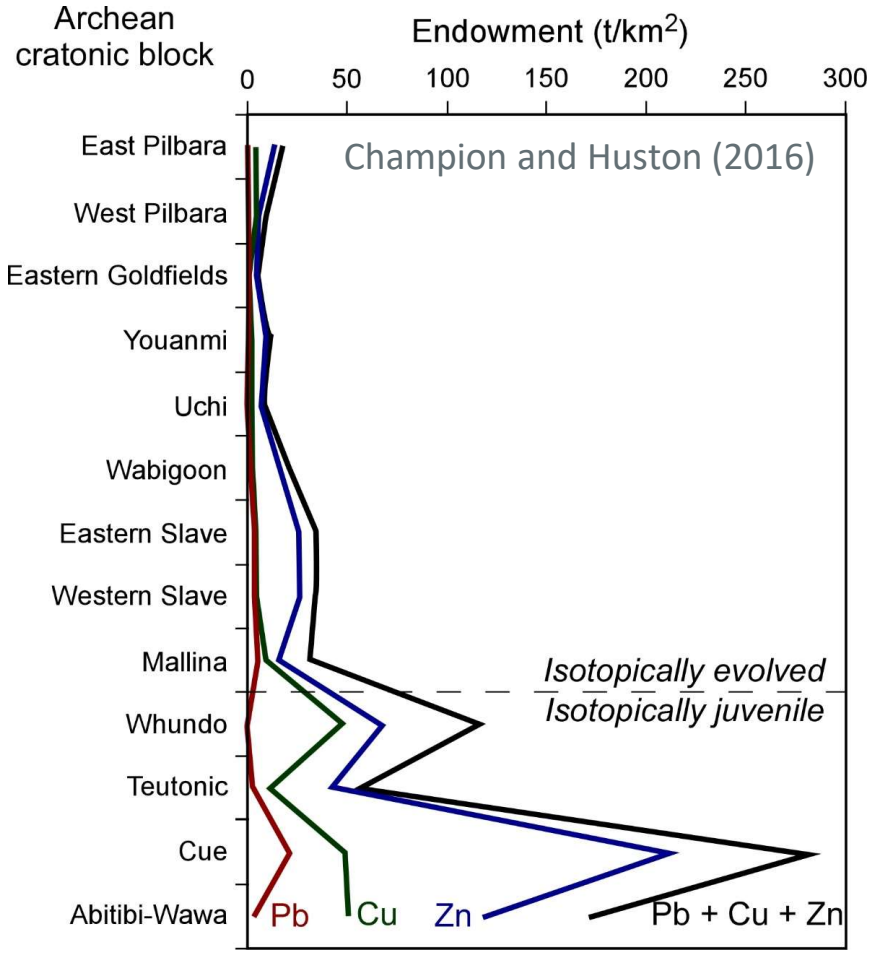
T_{2DM} variations, Abitibi-Wawa Subprovince (Canada)





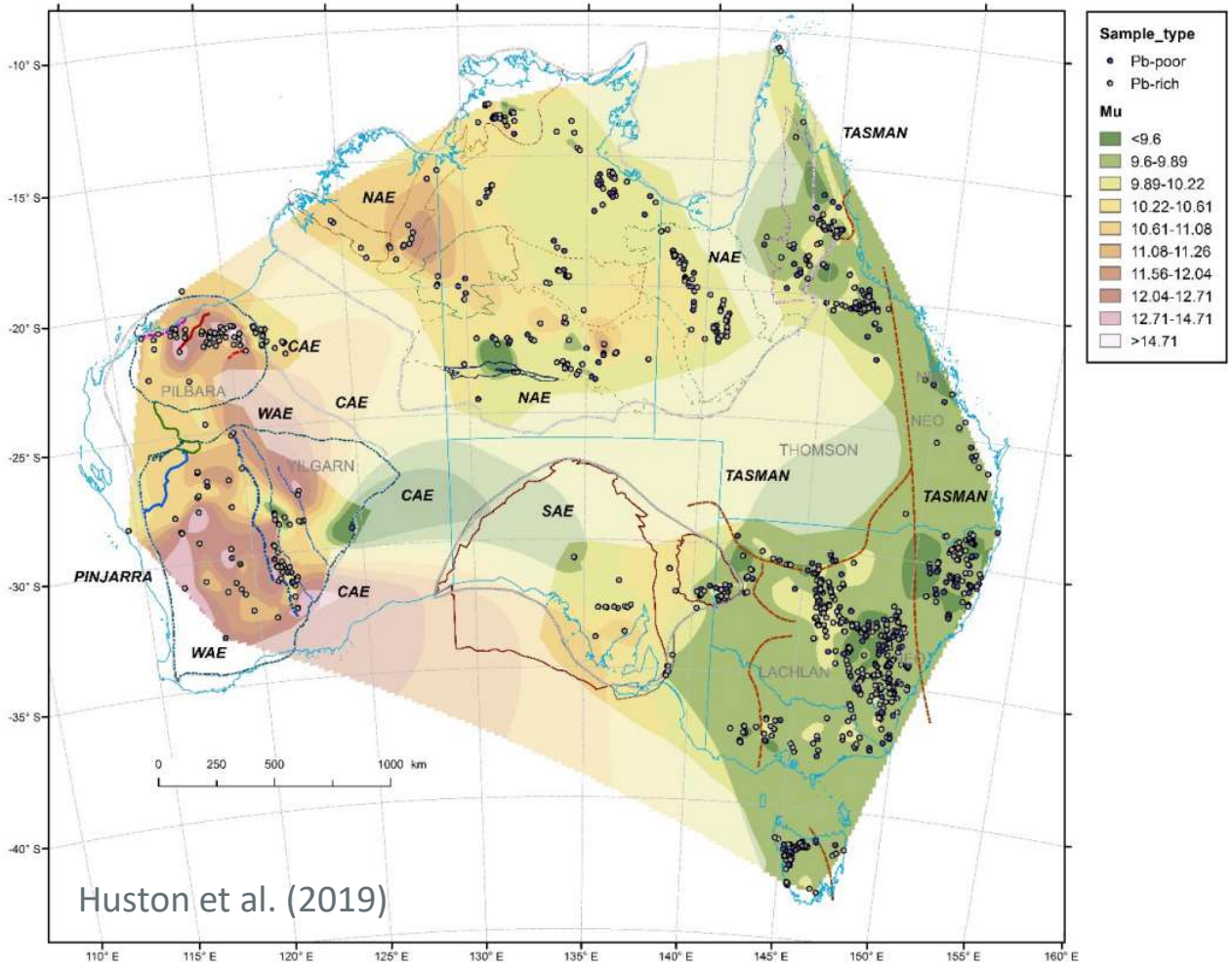
Huston et al. (2014)

Mineral potential & isotopic character – VHMS deposits



- Major Archean VHMS districts associated with juvenile crust – low μ, positive ε_{Nd} or young T_{2DM}
- Also applies to Paleoproterozoic and, possibly, Phanerozoic deposits
- Related to high heat flow and structuring associated with juvenile crust – enhances endowment
- KANS deposits associated with more evolved crust
- Orogenic gold deposits associated with gradients (i.e. structural boundaries)

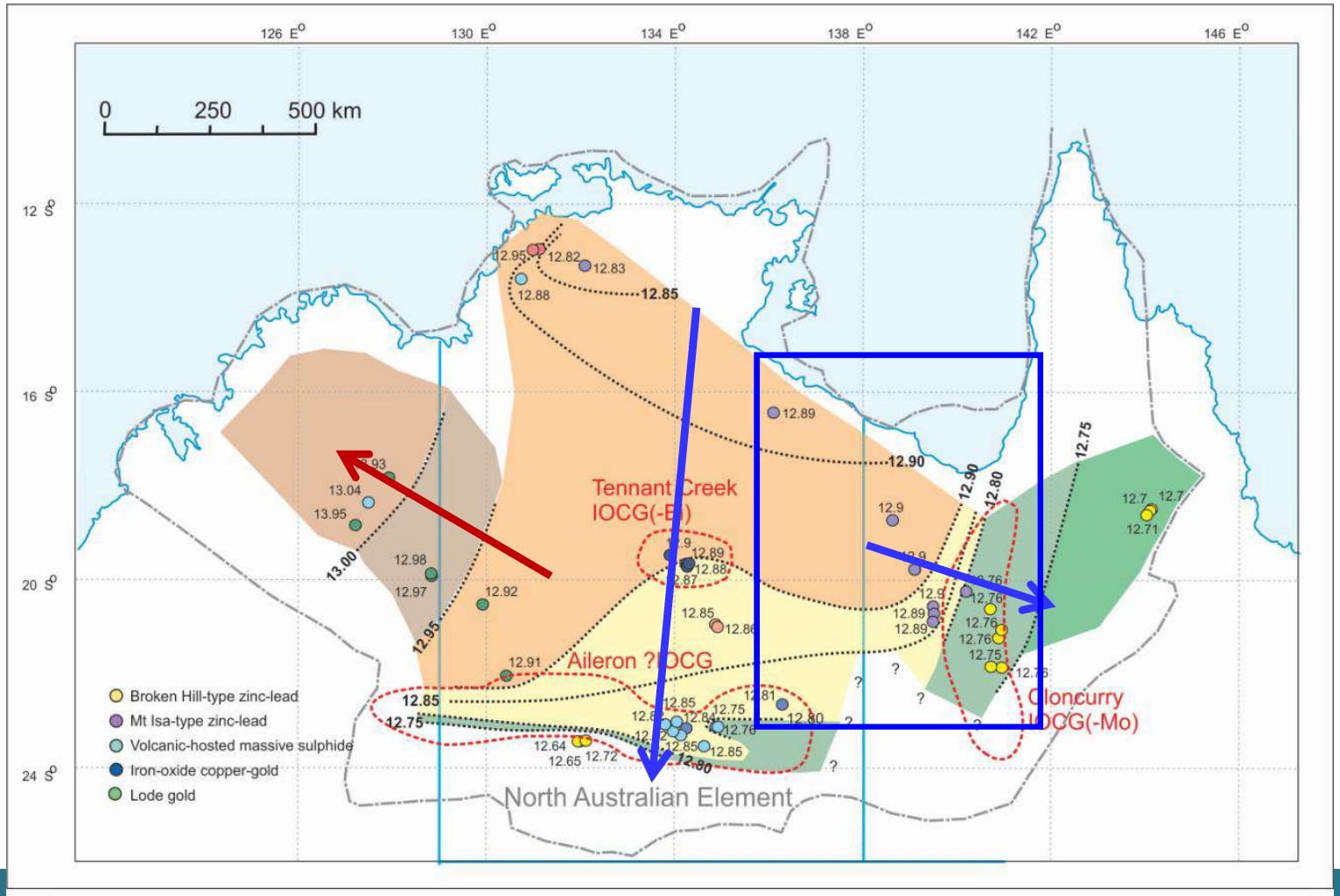
Australian national μ map – first edition (2019)



Huston et al. (2019)

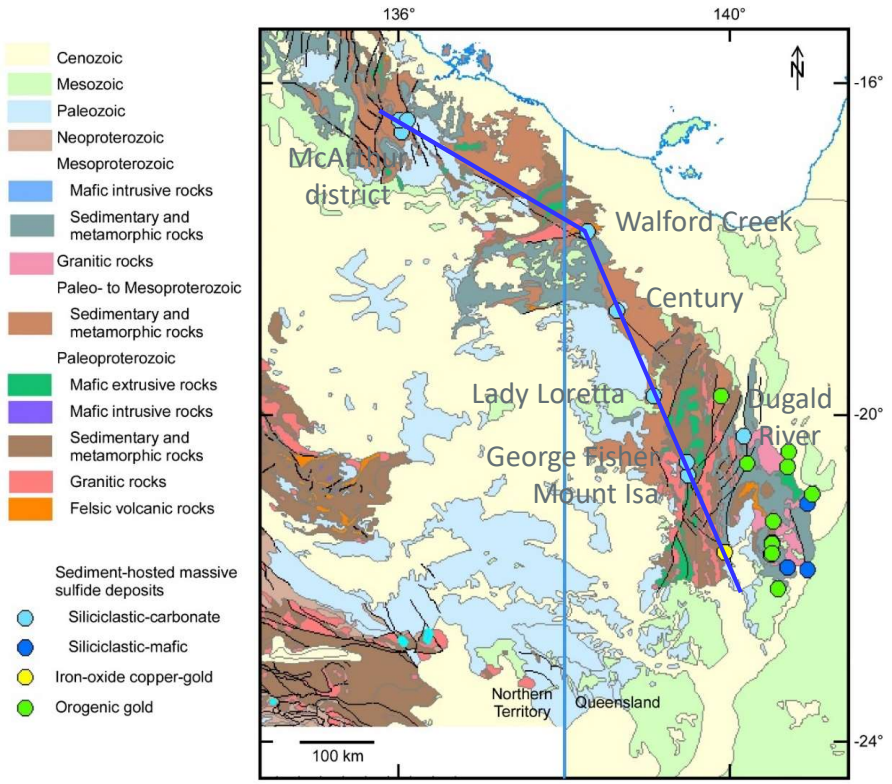
- Evolved in west – Pilbara and Yilgarn cratons
- Intermediate in centre – North and South Australian Cratons
- Juvenile in east – Tasman Orogen
- Similar to Nd isotope T_{2DM} patterns

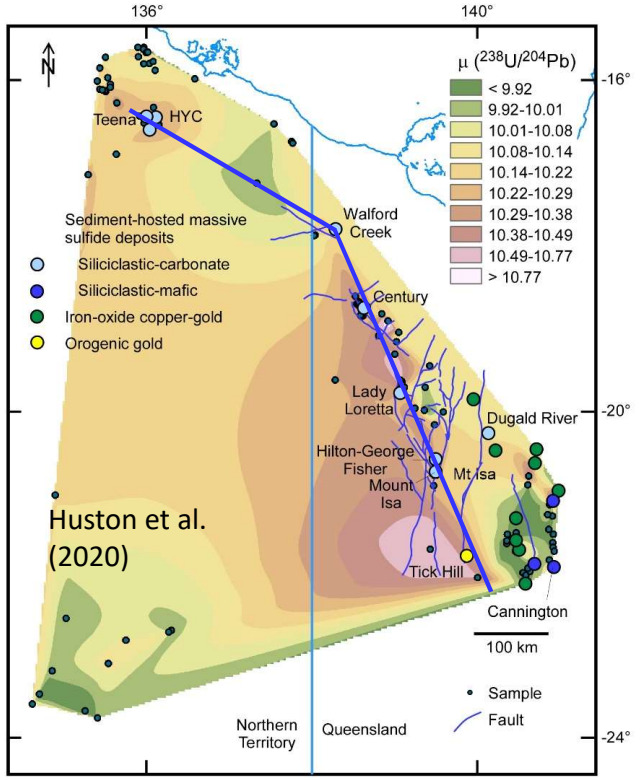
North Australian Element µ map – 2009 version



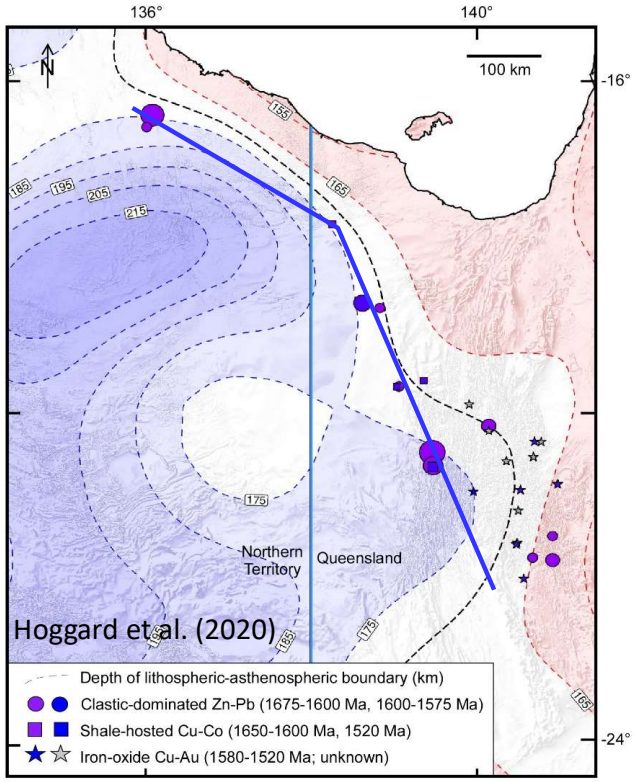
- µ gradients present:
  - Decrease to east and south
  - Increase to the west
- Similar to Nd isotope patterns

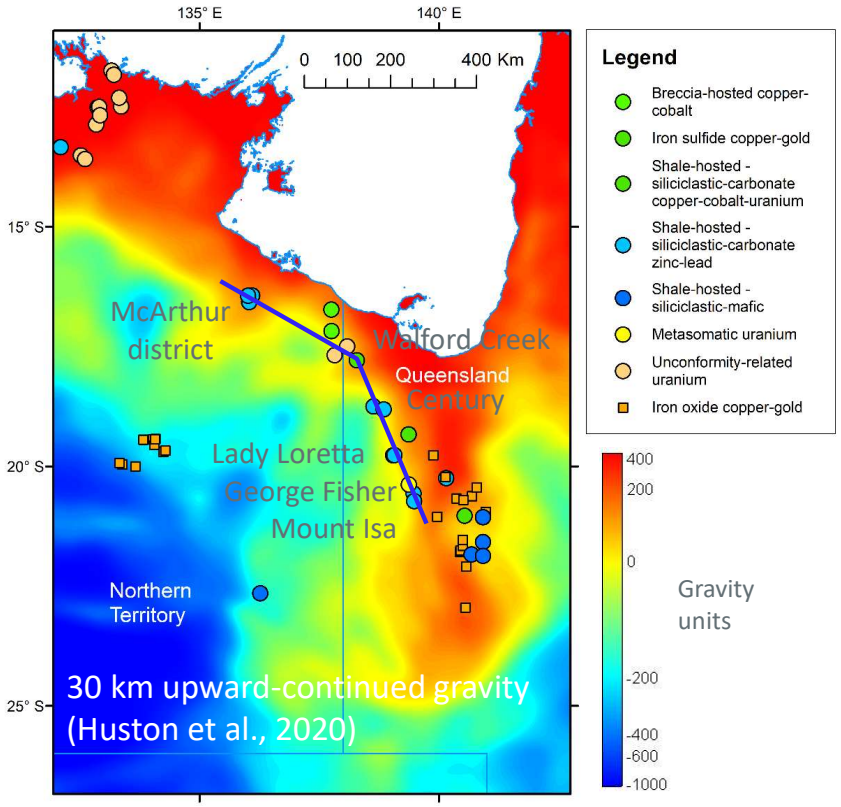
Geology and μ variations – North Australian Zinc Belt



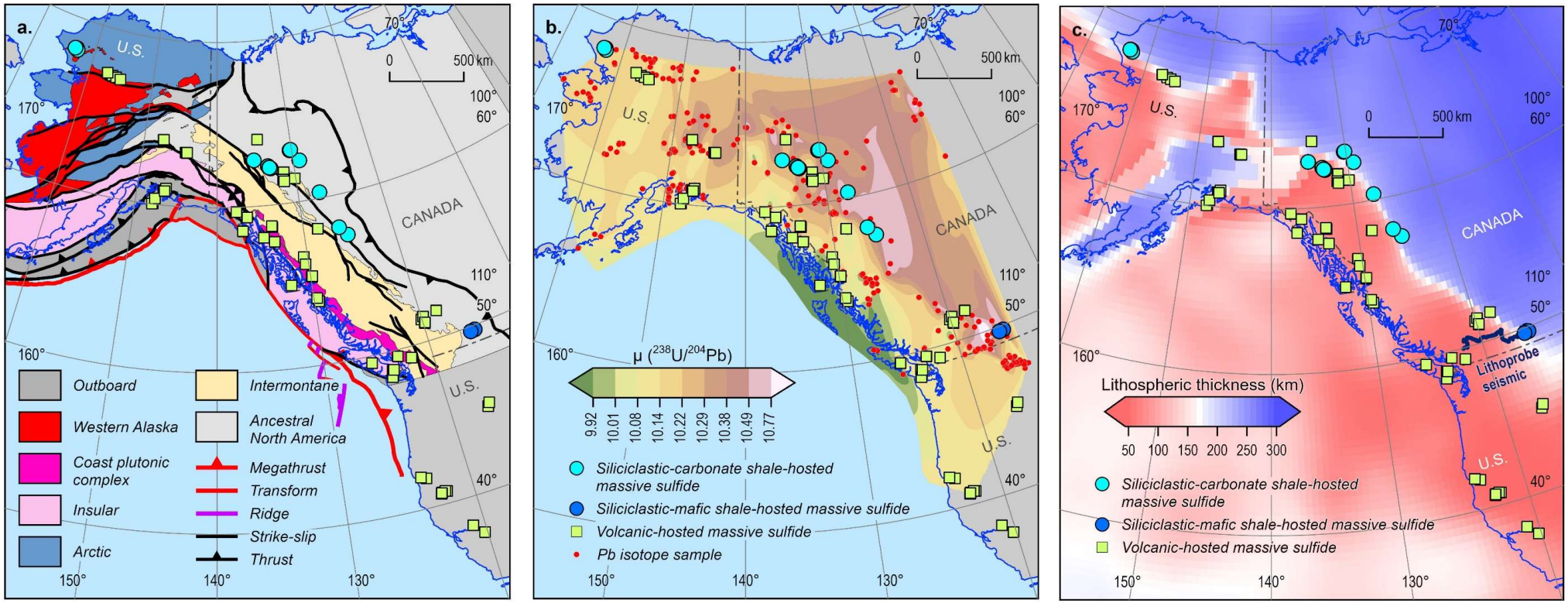


LAB and gravity variations – North Australian Zinc Belt



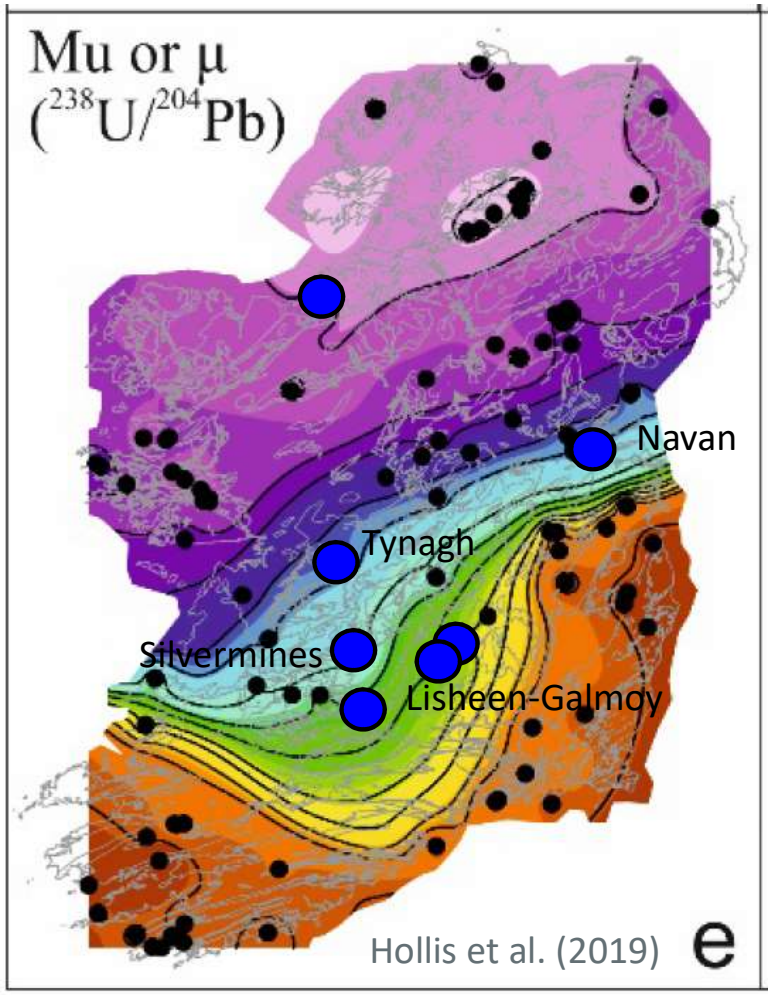


μ and LAB variations – Northern Cordillera, western North America



Huston et al. (in revision)

μ variations – Irish Midlands Zinc Belt (Hollis et al., 2019)



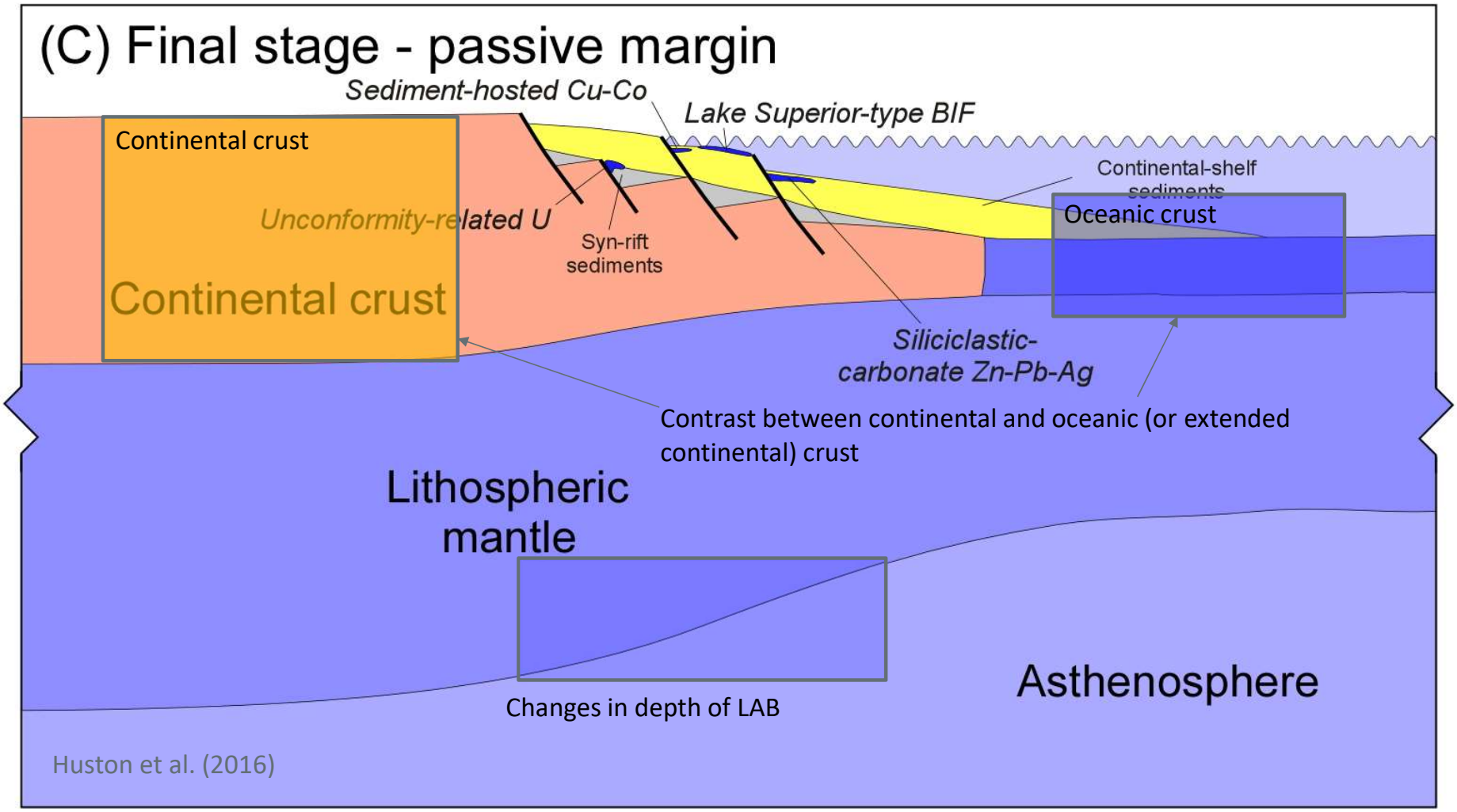
Low

μ

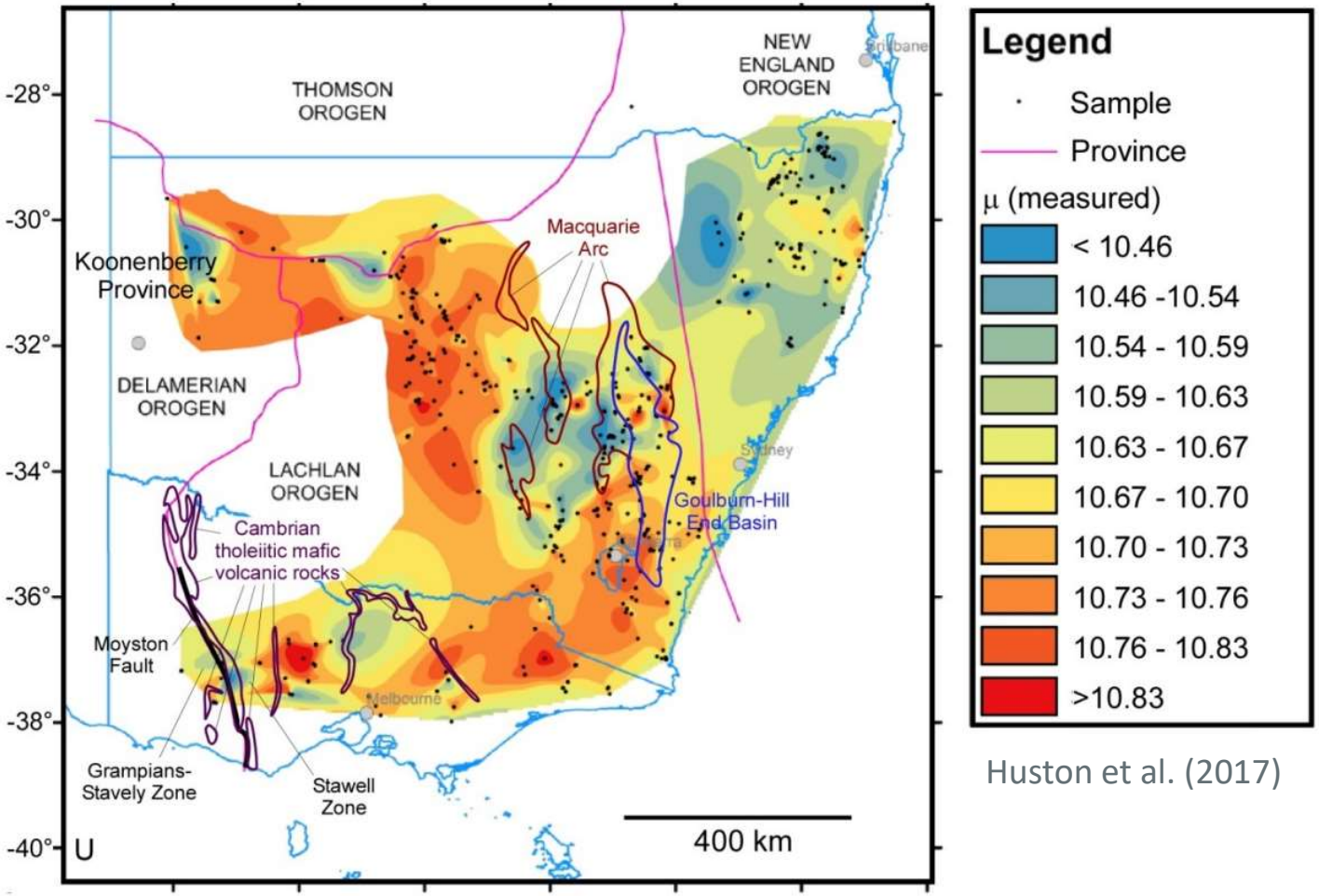
High

- National-scale NNW-SSE gradient in μ: low in north and high in south
- Gradient in μ corresponds to Iapetus suture (also visible on European μ map)
- Major Irish Zn-Pb deposits (Navan, Tynagh, Silvermines and Lisheen-Galmoy) associated with μ gradient

Gradients in μ, LAB, gravity and (MT) data – mapping edges



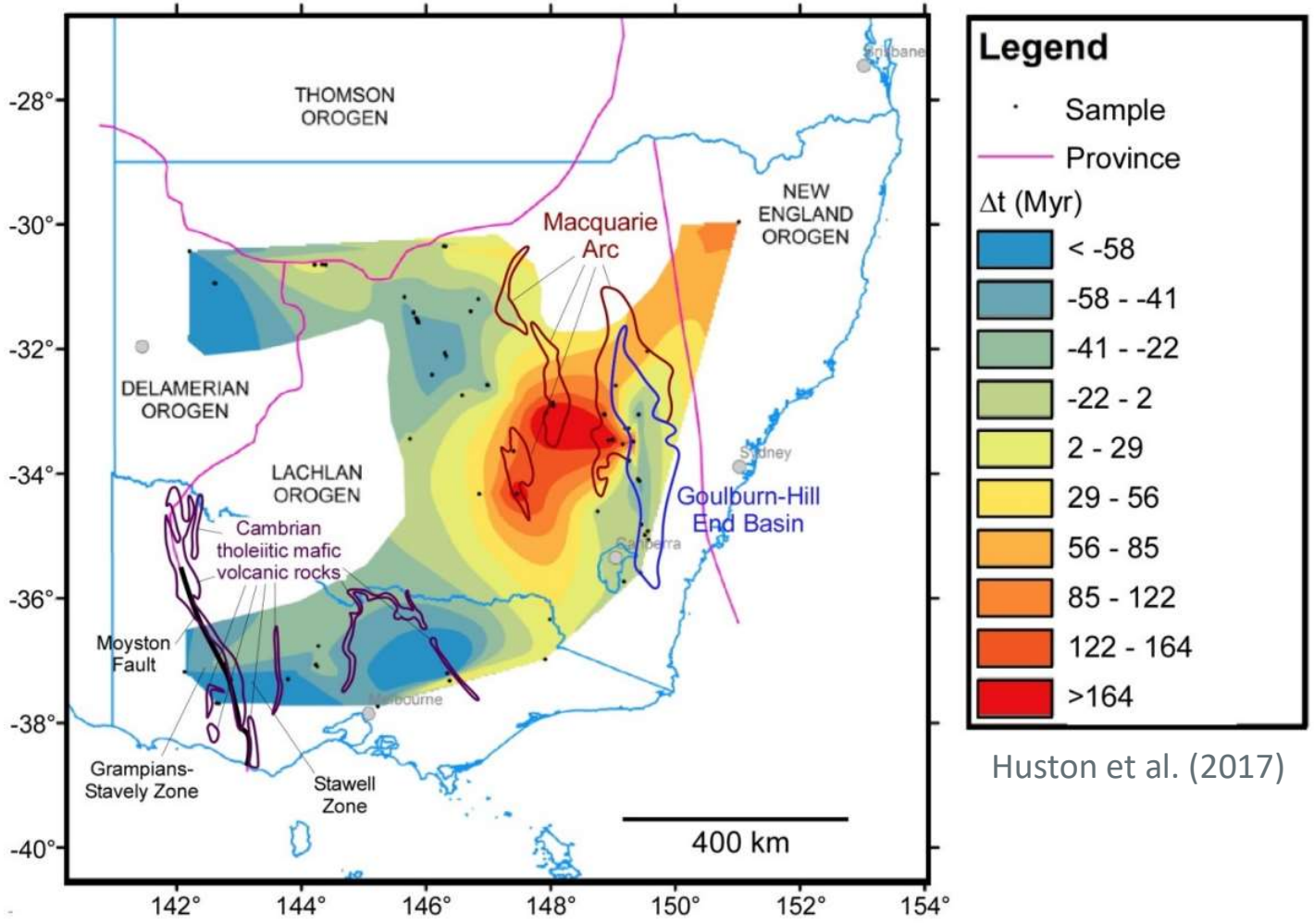
Lead isotope mapping in southeast Australia – μ



Huston et al. (2017)

- New England Orogen generally more juvenile
- Lachlan Orogen generally more evolved and variable
- Complexity in New England Orogen related to orocline
- Macquarie Arc most juvenile – porphyry copper deposits
- Central Lachlan more evolved – granite-related rare metal (Sn, Mo, W) deposits

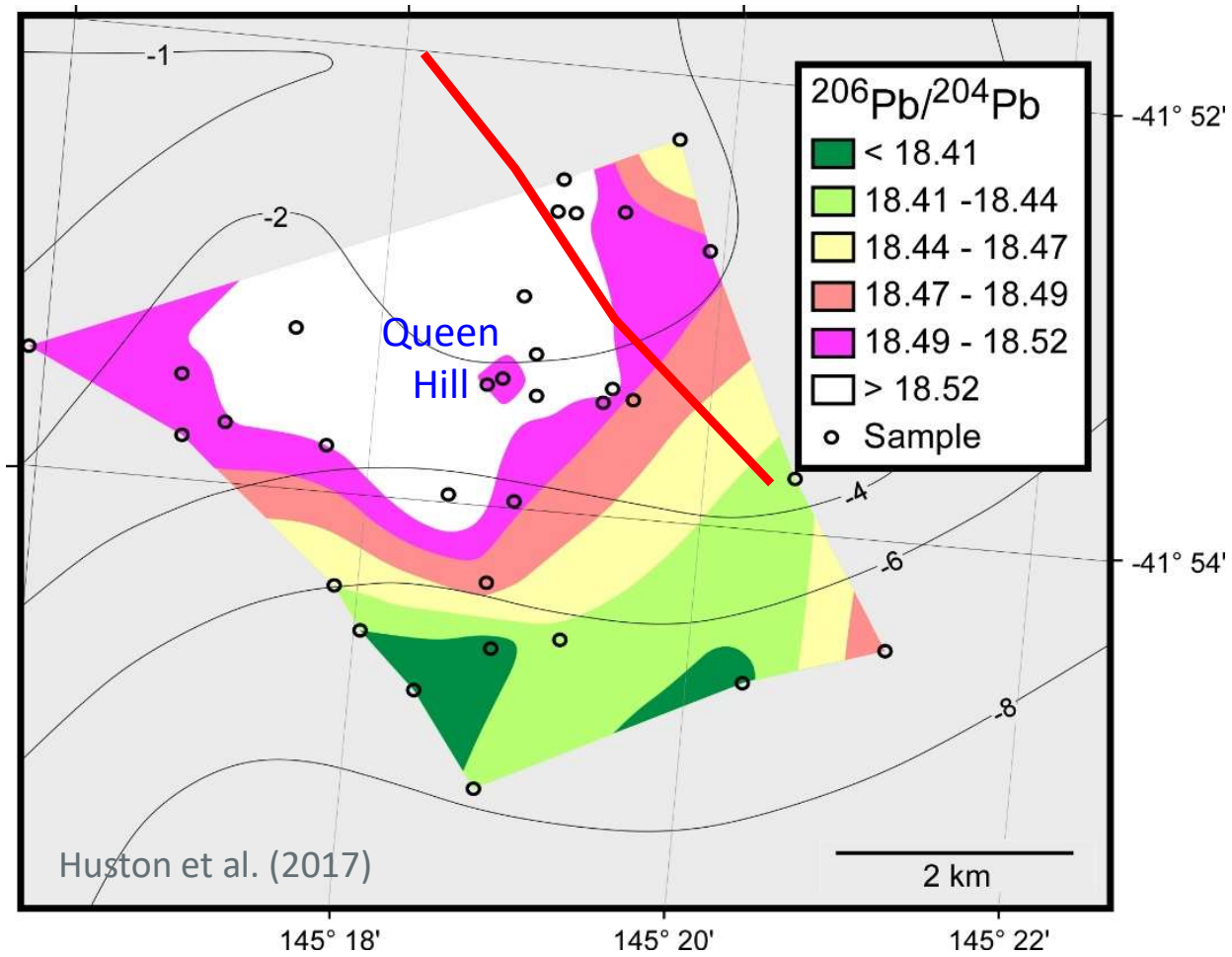
Lead isotope mapping in southeast Australia - Δt



Huston et al. (2017)

- $\Delta t = t_{true} - t_{model}$
- Most of southeast Australia give reasonable model ages – Δt ~ 0 Myr
- Macquarie Arc (and Western Tasmanian Terrane) give young model ages – Δt ~ 100-200 Myr
- Most of southeast Australia give reasonable model ages – Δt ~ 0 Myr
- Two major lead reservoirs in southeast Australia

Lead isotope mapping at the district scale – Zeehan, Tasmania



Zeehan district – dominantly Pb-Ag-Zn vein district associated with Devonian granite intrusion

Centered around Queen Hill tin deposit (6.38 Mt at 1.13% Sn)

Associated with ridge of ca 361 Ma Heemskirk Granite

$^{206}Pb/^{204}Pb$ decreases away from Queen Hill deposit

Pattern interpreted as mixing between ^{206}Pb-enriched granite-related and background lead

Conclusions

- Radiogenic isotope mapping is a relatively new technique – still in developmental stage
- Maps have been developed for the Sm-Nd, U-Th-Pb and Hf-Lu systems
- At the continental- to province-scales, gradients define tectonic boundaries, some of which localise deposits
- District-scale variations may provide vectors to ore (e.g. Zeehan)
- Isotope mapping is at same stage as potential field mapping in the late 1980s – the data and maps will improve

Future directions

- Second editions of national-scale Nd and Pb maps in progress
- First edition of national-scale Hf map is in progress
- Preliminary work on regional scale Pb isotope maps based on granite K-feldspar underway – Curtin University
- Methodologies and initial maps of geochronology maps have begun (e.g. Ar-Ar cooling age; granite ages – ANU/GA)
- Potential for Os isotope maps being assessed

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Thank you

Further information

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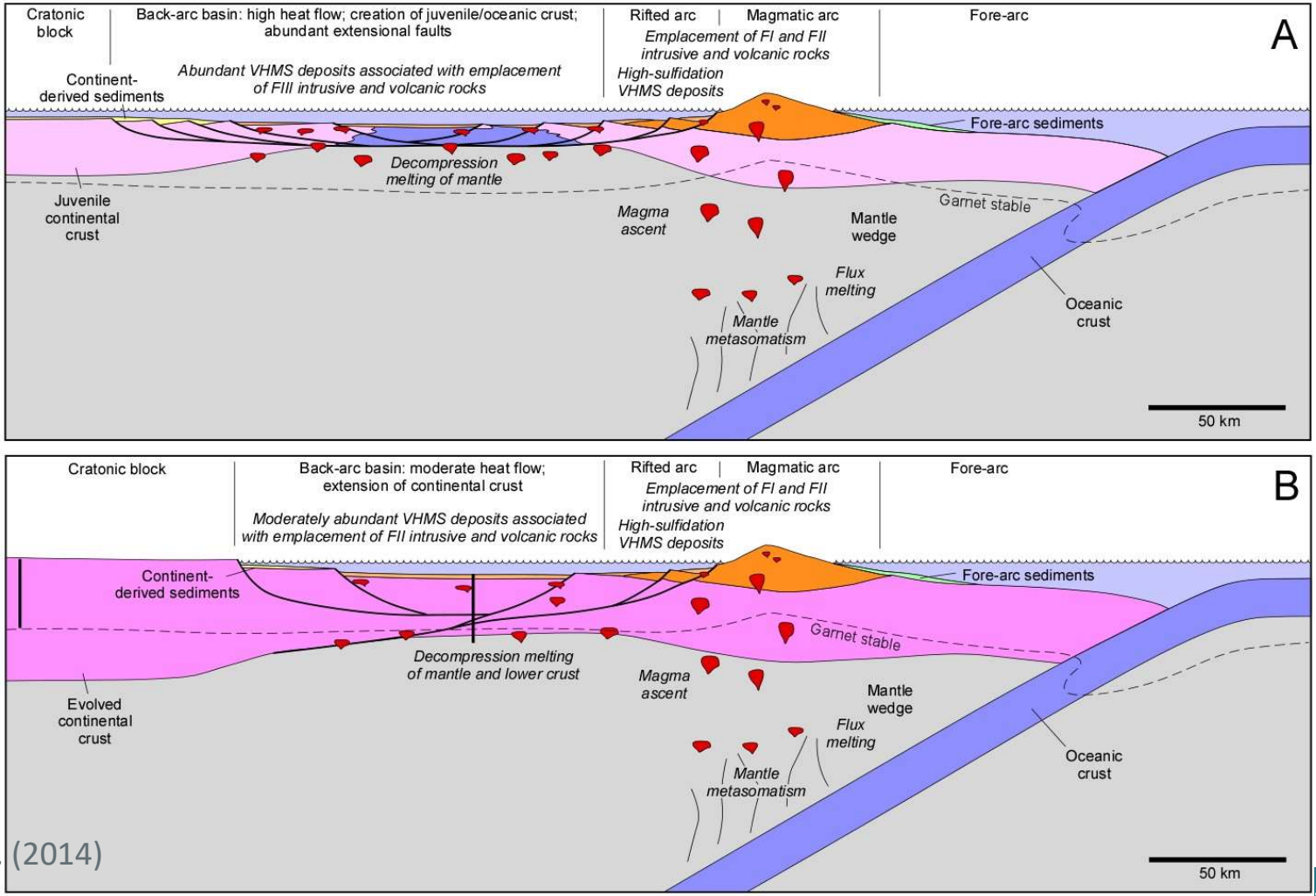
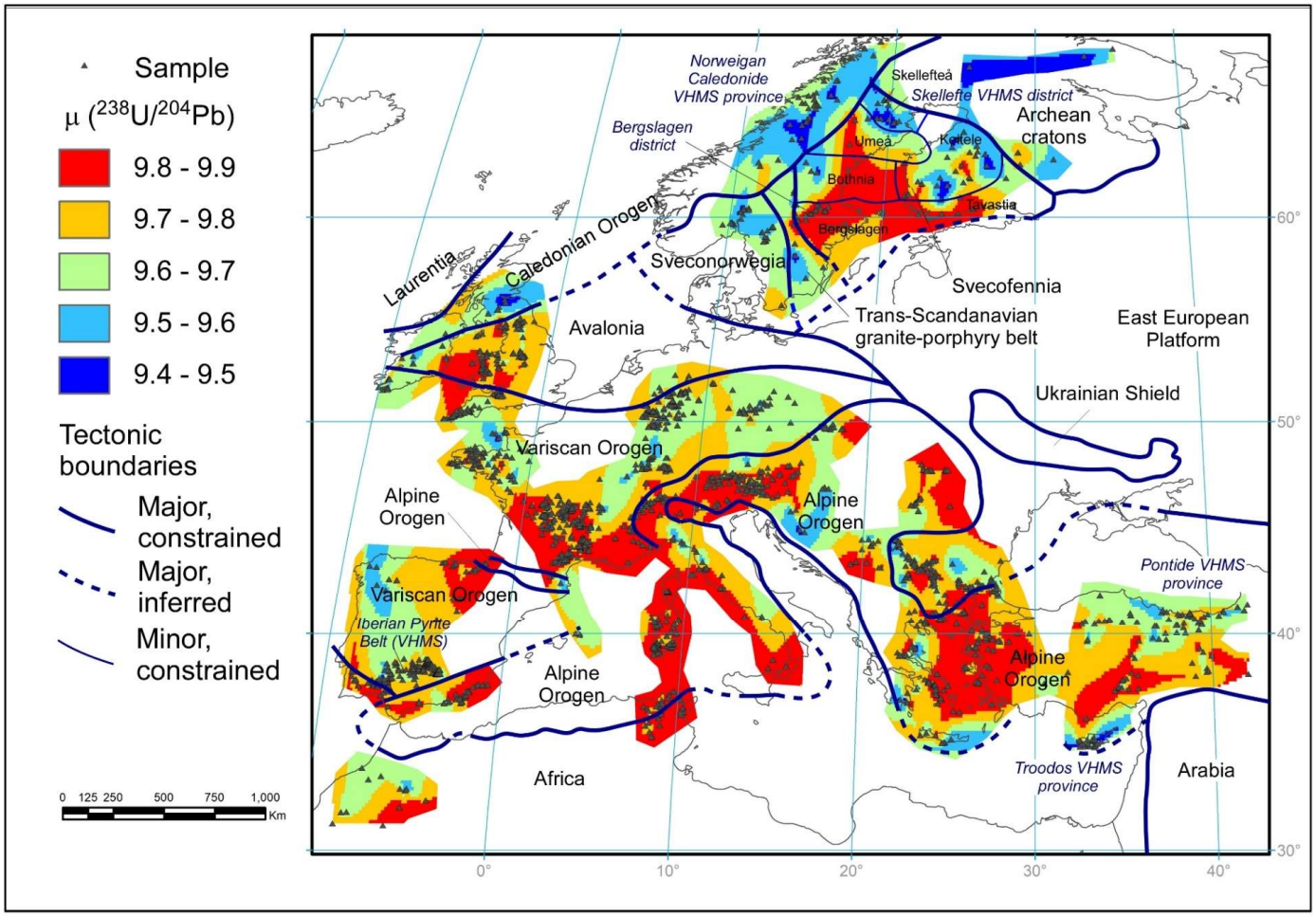
Controls on Archean VHMS endowment



Huston et al. (2014)

European μ map



Lead isotope data from Blichert-Toft et al (2016)