Isotope geology through space & time: a tool for understanding crustal evolution

Case studies from the Yilgarn Craton and its margin

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GEMOC

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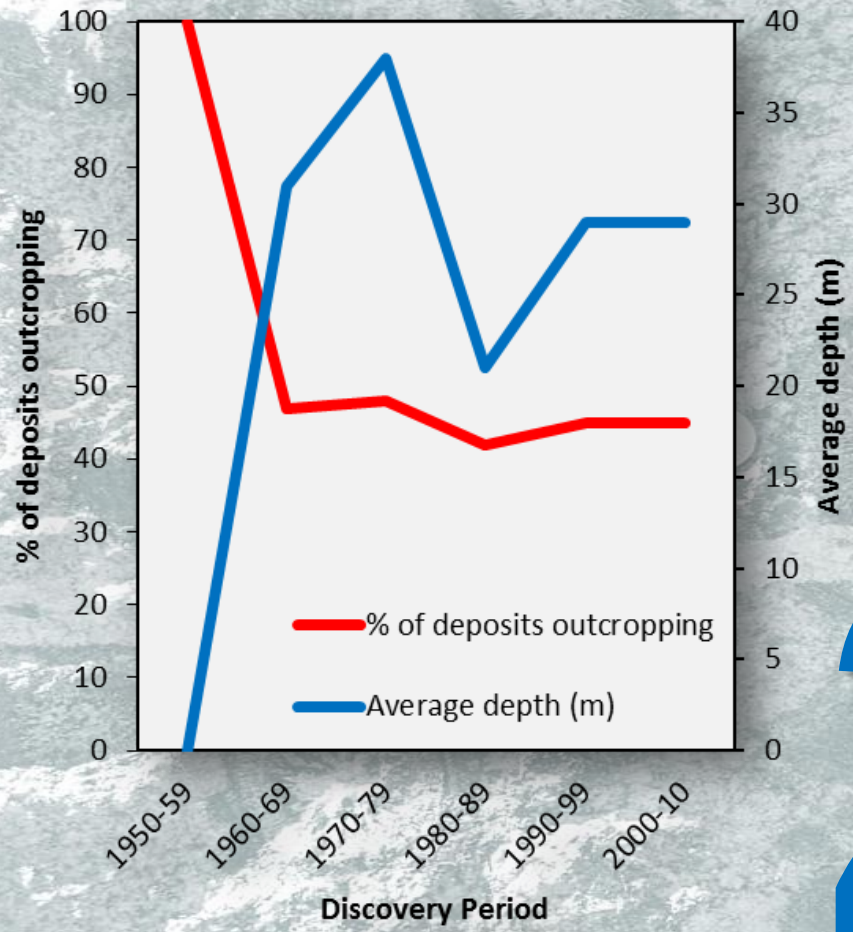
Centre for EXPLORATION TARGETING

The University of Western Australia

ROYALTIES FOR REGIONS
EXPLORATION INCENTIVE SCHEME

Trends in depth of cover for discovery



Global average depth of green-fields gold discoveries (>1 Moz) has remained unchanged since the 1960's

29 meters

Schodde, 2011

Prospectivity mapping: the importance of crustal evolution

Recent gold targeting studies in the Yilgarn indicate the necessity for :

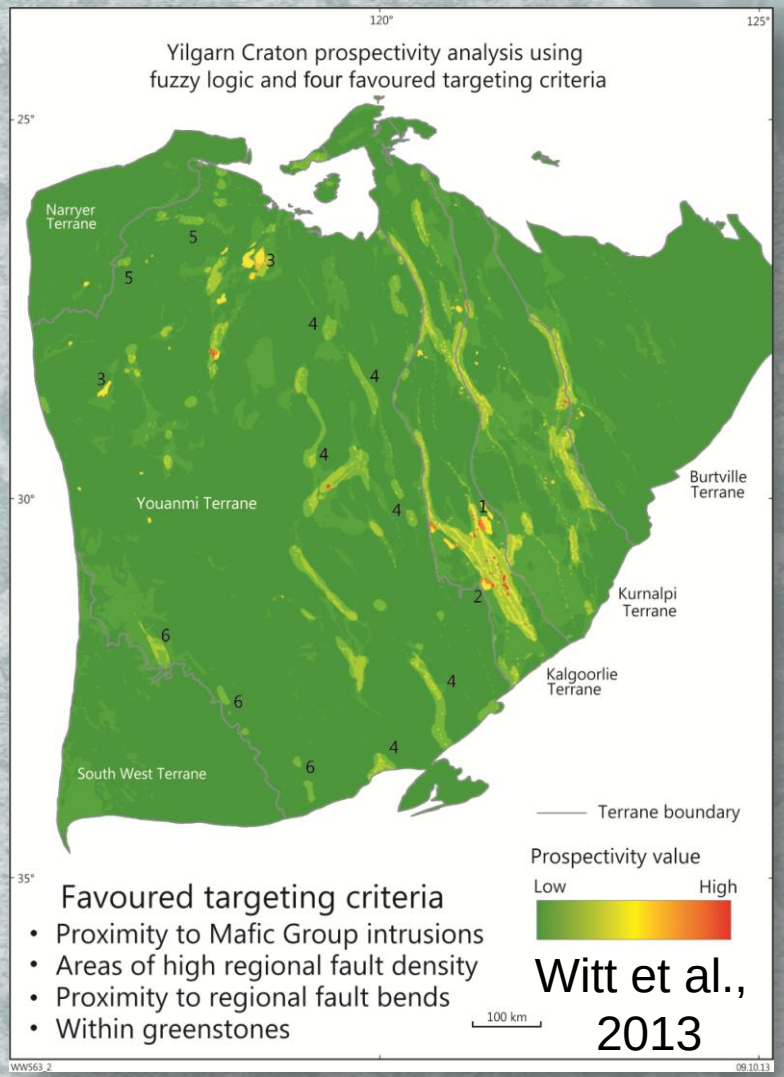
Related to source

Areas of juvenile input (e.g. greenstones)

Related to subsequent events

Structures that move (upgrade) Au

Juvenile input zones move through time – locating these through time is a key means to track prospective zones



Crustal evolution

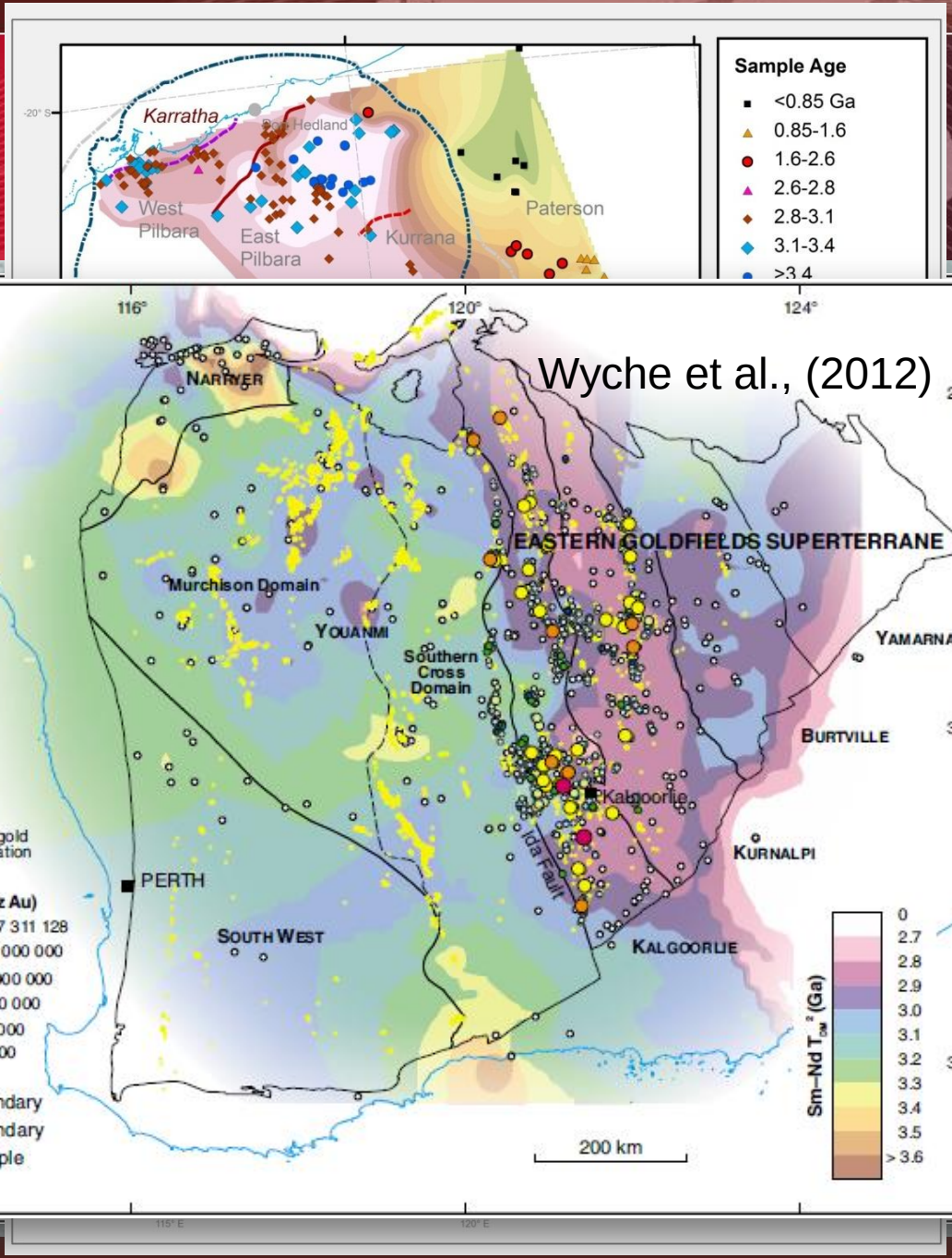
Spatial relationship between regional isotopic maps and mineralisation styles

e.g. komatiite-hosted nickel sulphides, Archean VHMS, iron-oxide copper gold deposits and intrusion-related copper-gold deposits.

Presumably related to

- **Juvenile input, metal endowment**
- **crustal architecture**
- **geodynamic setting**

Champion, 2013



Lu-Hf in zircon

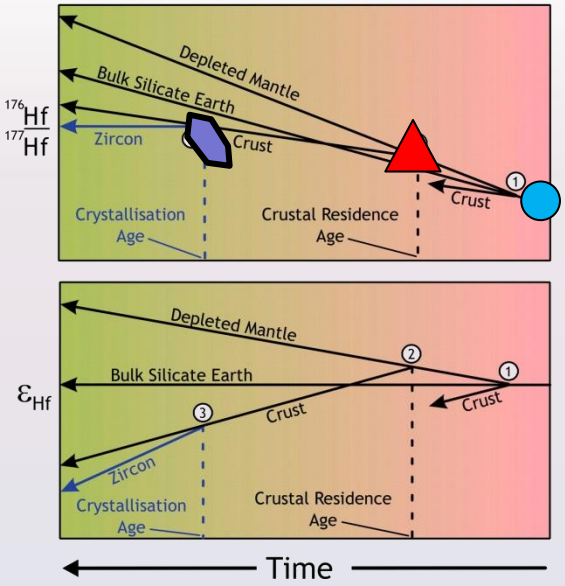
Key advantages:-

Zircon has a very low Lu/Hf value and thus a present-day $^{176}Hf/^{177}Hf$ value that is close to its initial value

Zircon's remarkable durability enables information from early Earth history

Hf in zircon is resistant to disturbance

Lu-Hf in zircon



Depleted mantle

Fractionation event

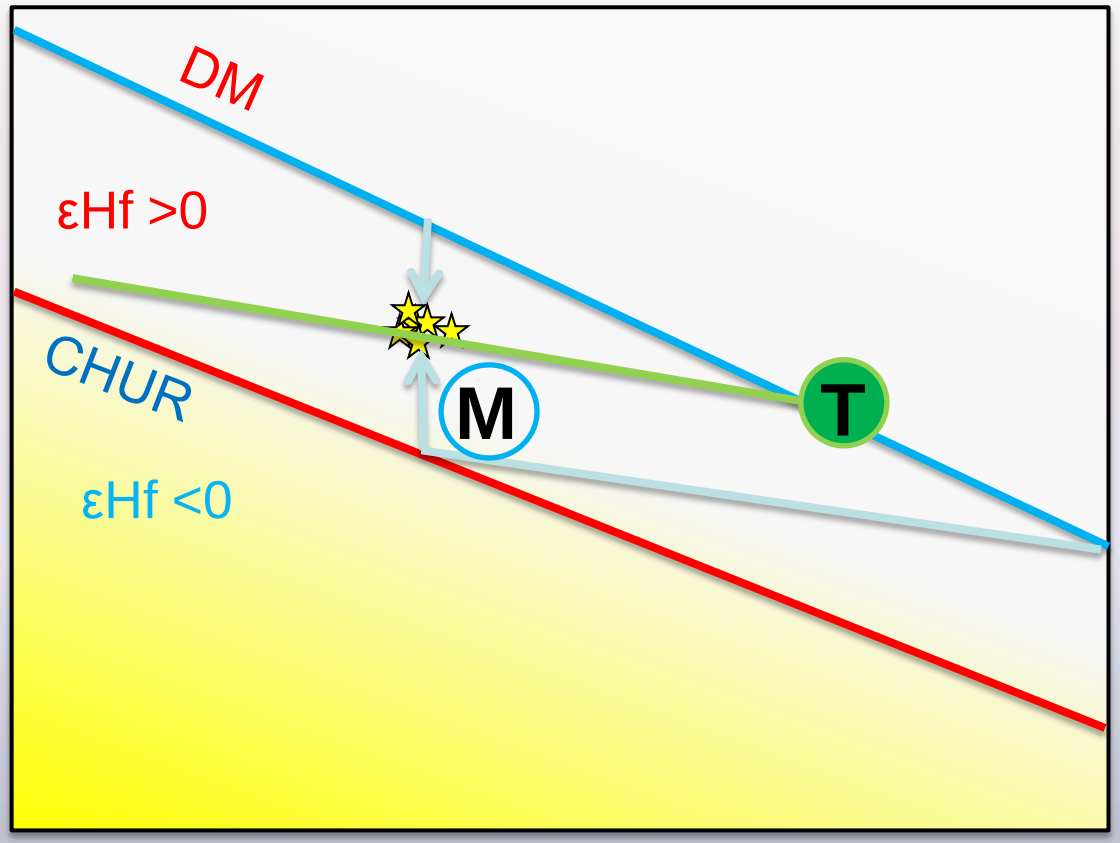
mantle

U-Pb age

$^{176}Hf/^{177}Hf$

Crust

Interpreting Hf arrays

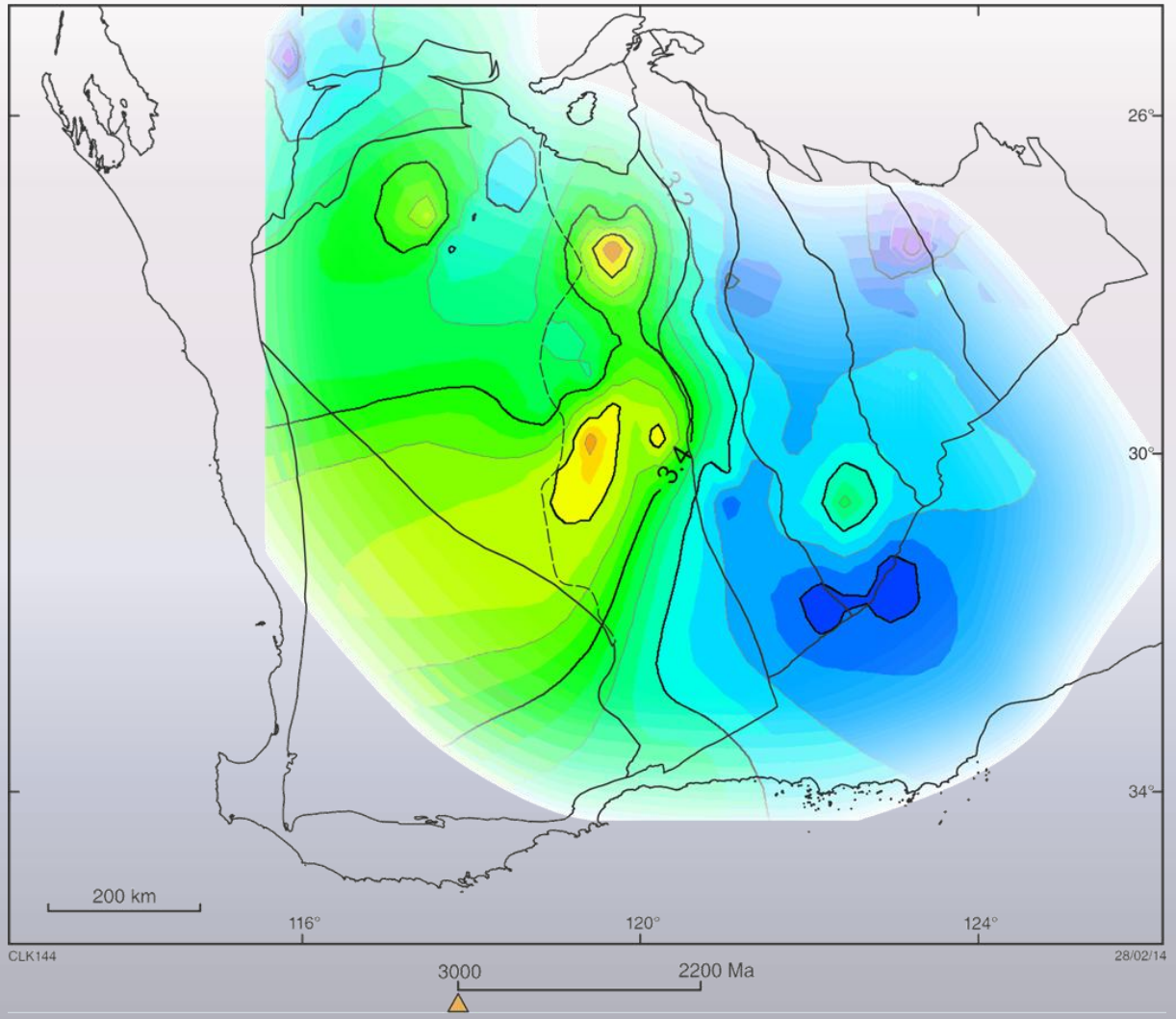


Hf data could be interpreted as reworking of a source extracted from the mantle at time T

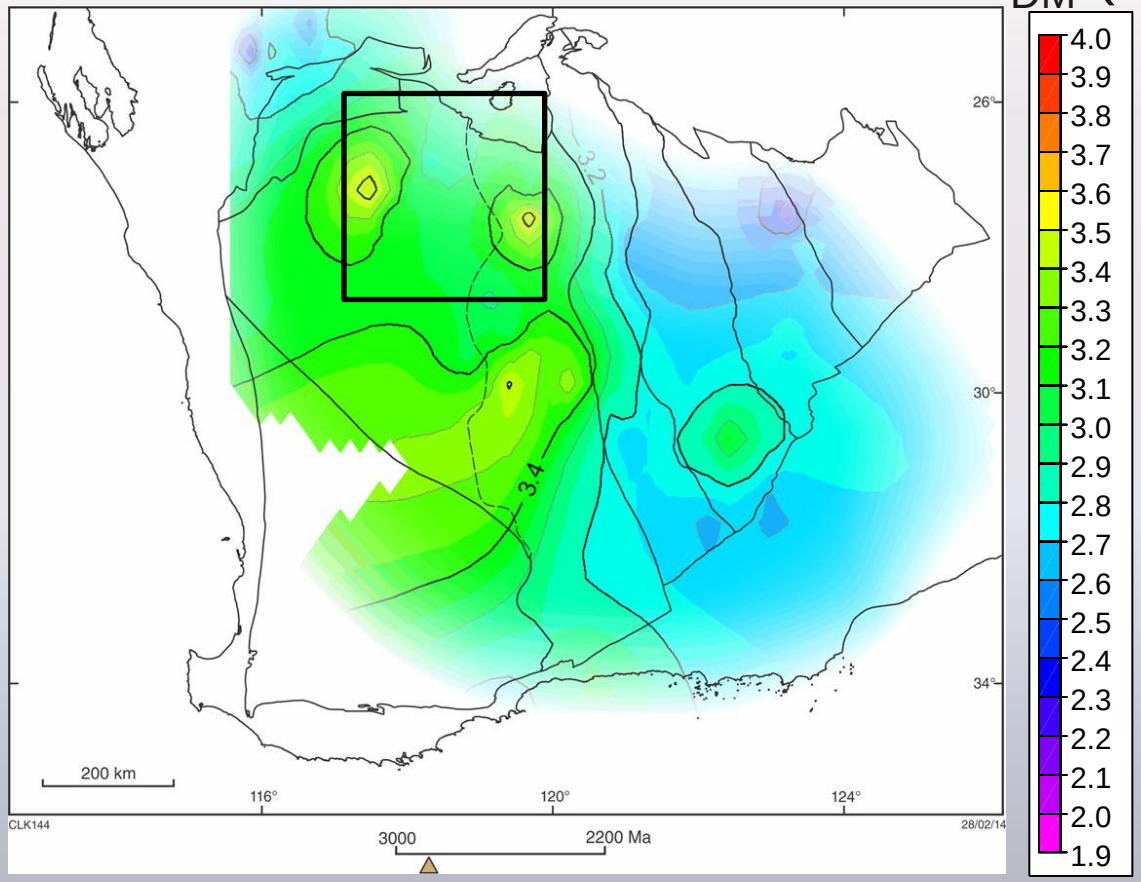
or….. could also be a result of mixing at time M

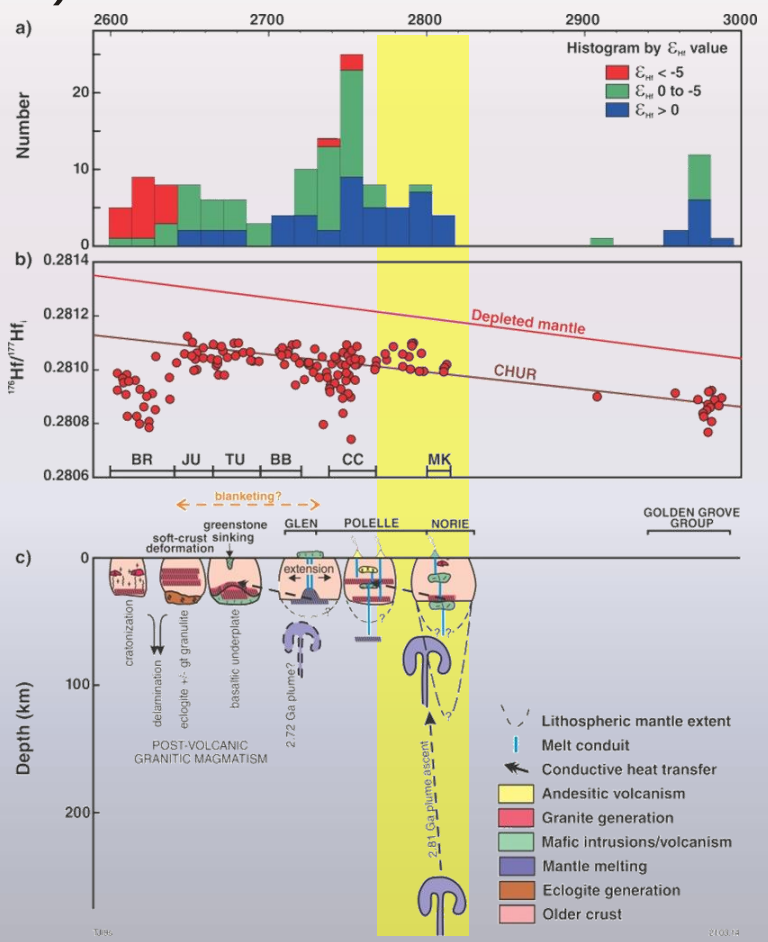
4D spatial perspective on Hf datasets

Each in situ measured Hf analysis has its **time of crystallization** independently constrained and has its **geographic location known** = integrated approach (using U-Pb and Lu-Hf) can image crustal evolution in both space and time.

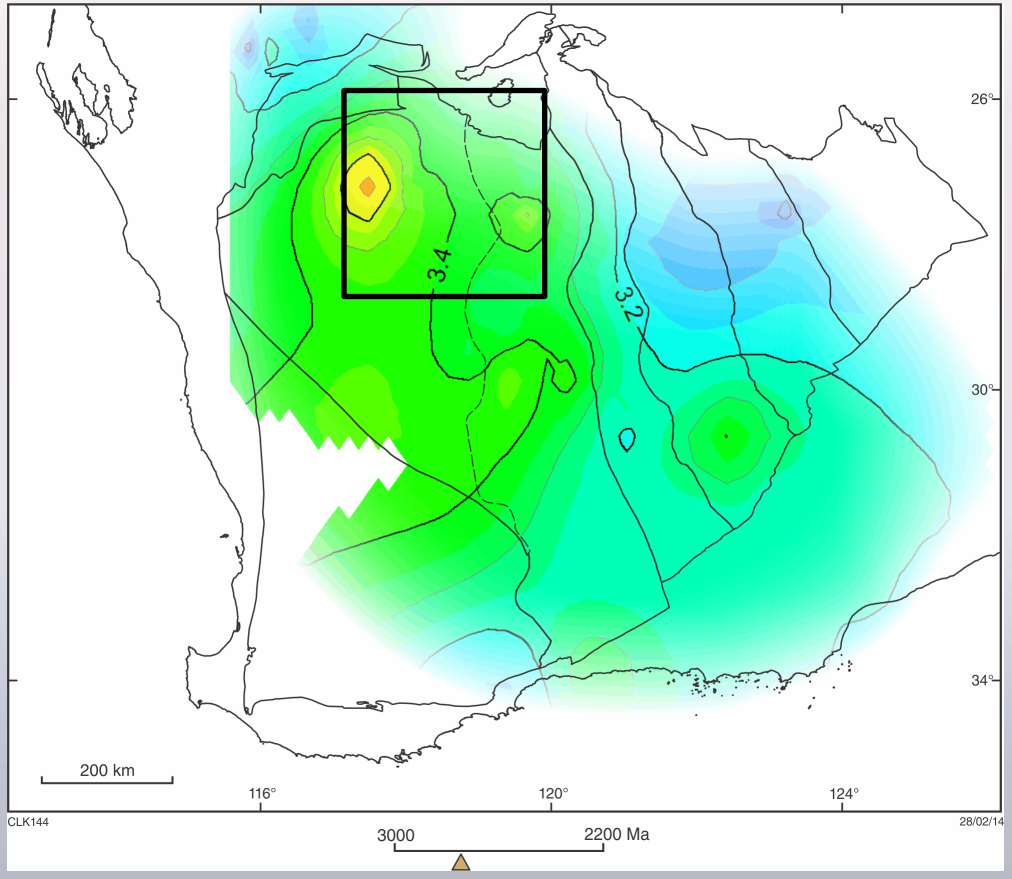


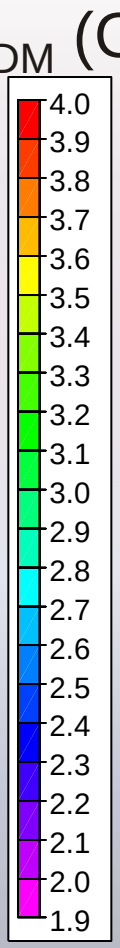
Spatial perspective on Hf datasets

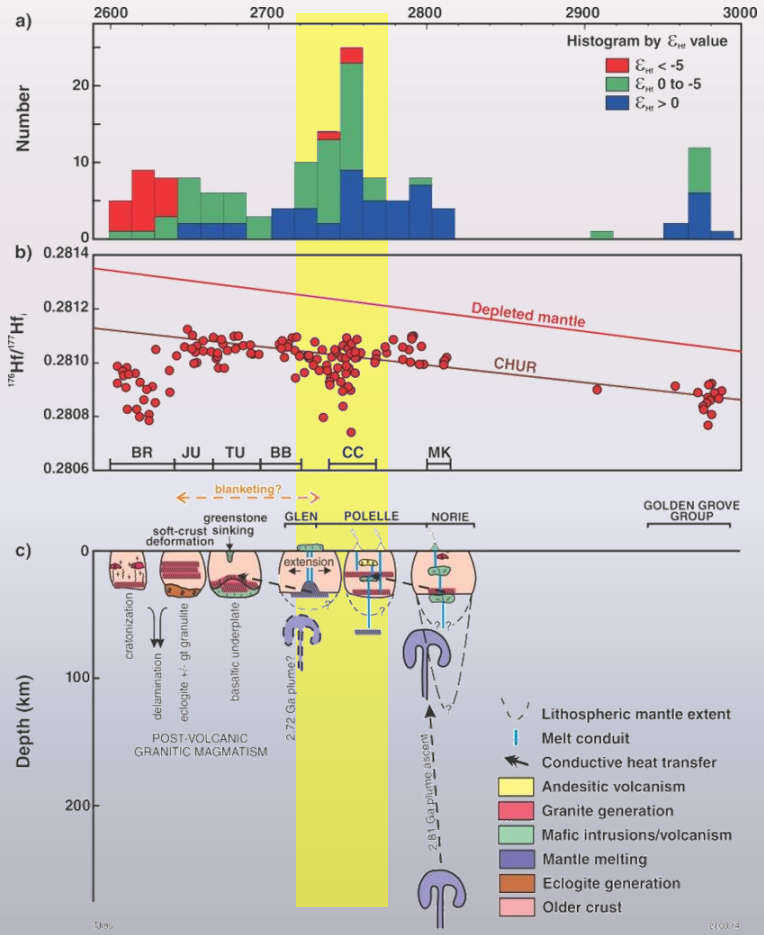




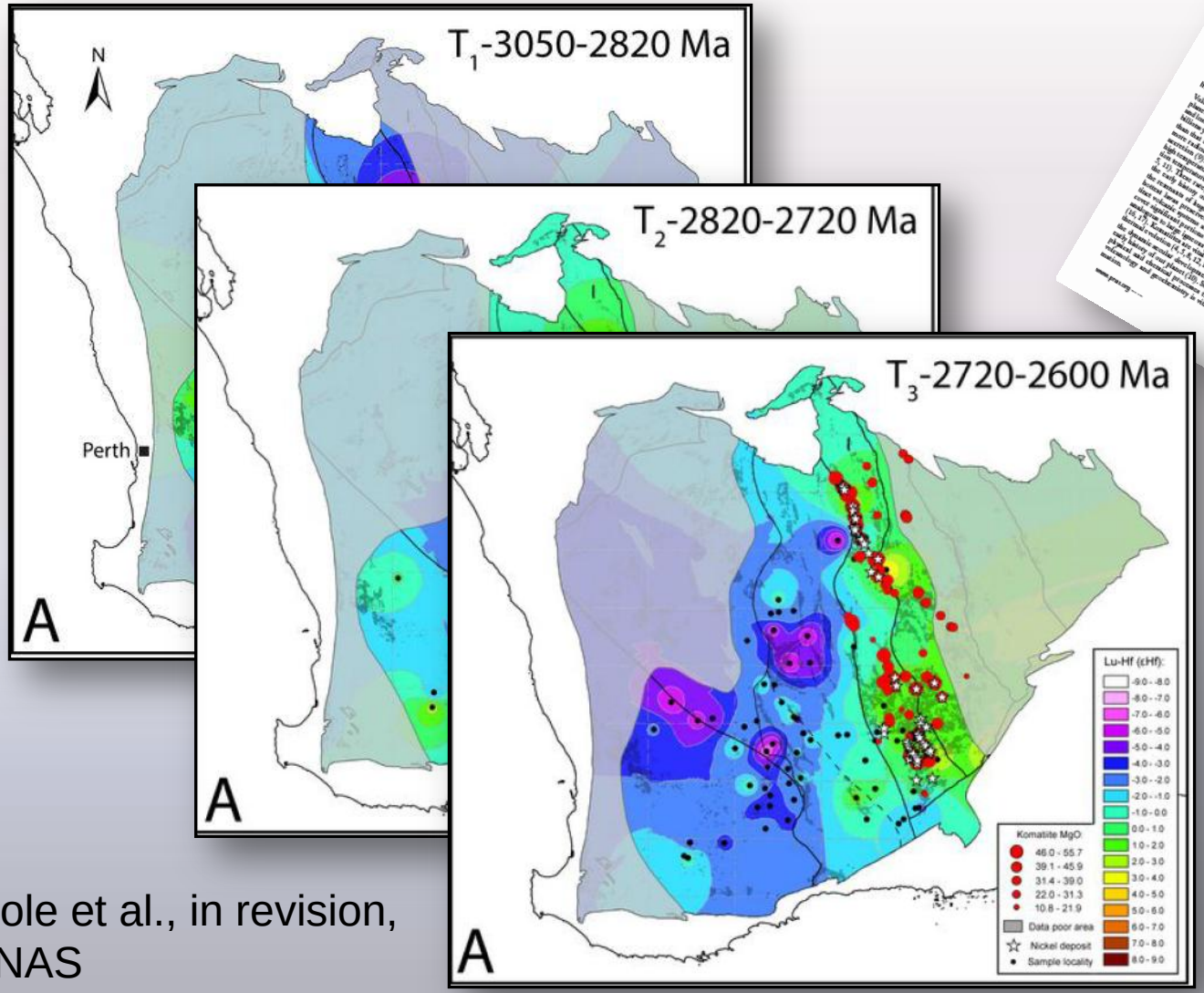
Spatial perspective on Hf datasets







Spatial perspective on Hf datasets




Archean komatiite volcanism controlled by the evolution of early continents

Mole et al., in revision, PNAS

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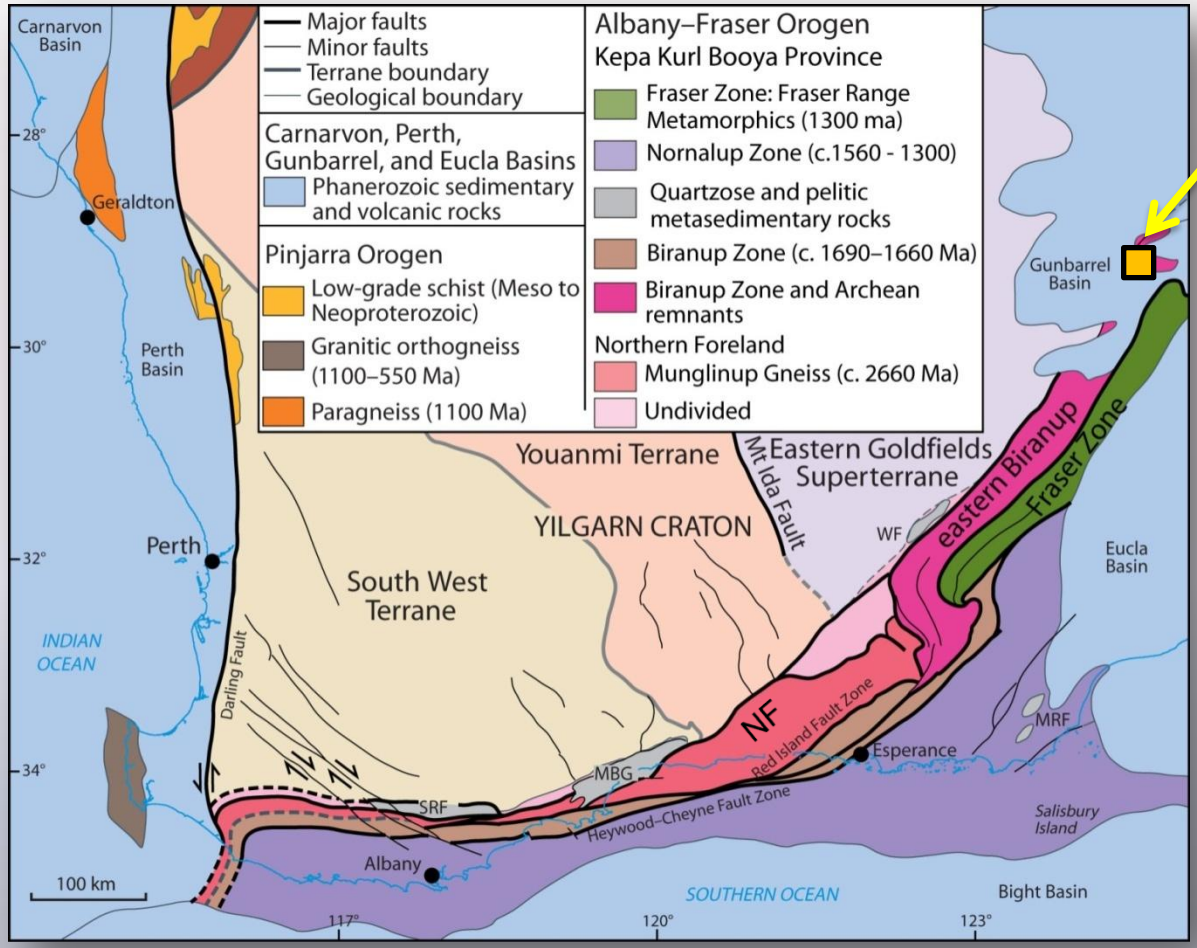
Albany-Fraser Orogen: tectonic units



TROPICANA GOLD

- **Northern Foreland** reworked Yilgarn (includes Munglinup Gneiss)
- **Biranup Zone** major piece of c. 1760 to 1650 Ma crust (includes Dalyup and Coramup Gneisses)
- **Fraser Zone** interpreted as c. 1305 to 1290 Ma lower crustal hot zone

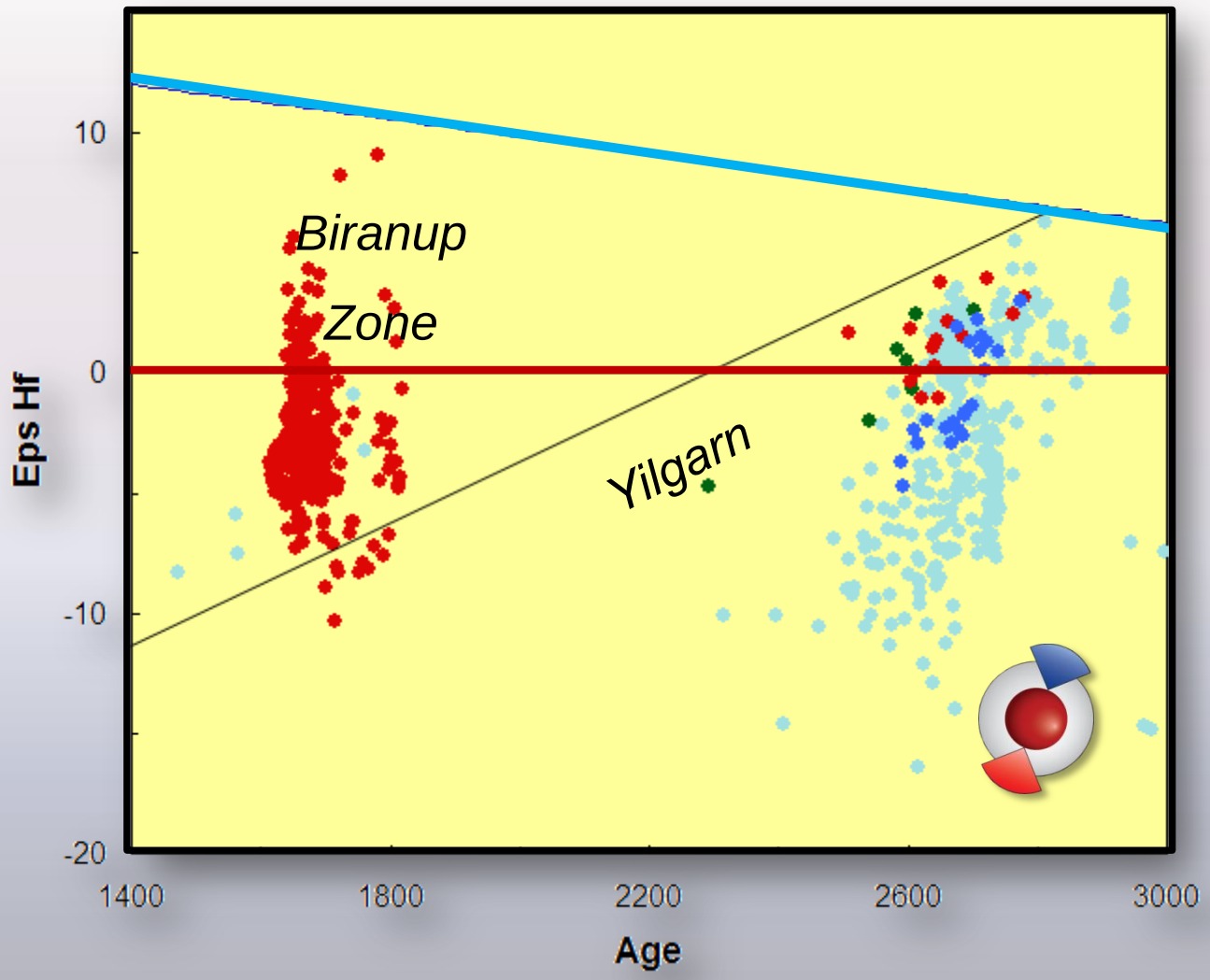
Albany-Fraser Orogen: Lu-Hf datasets

- Yilgarn Craton
- Biranup Zone
- Northern Foreland

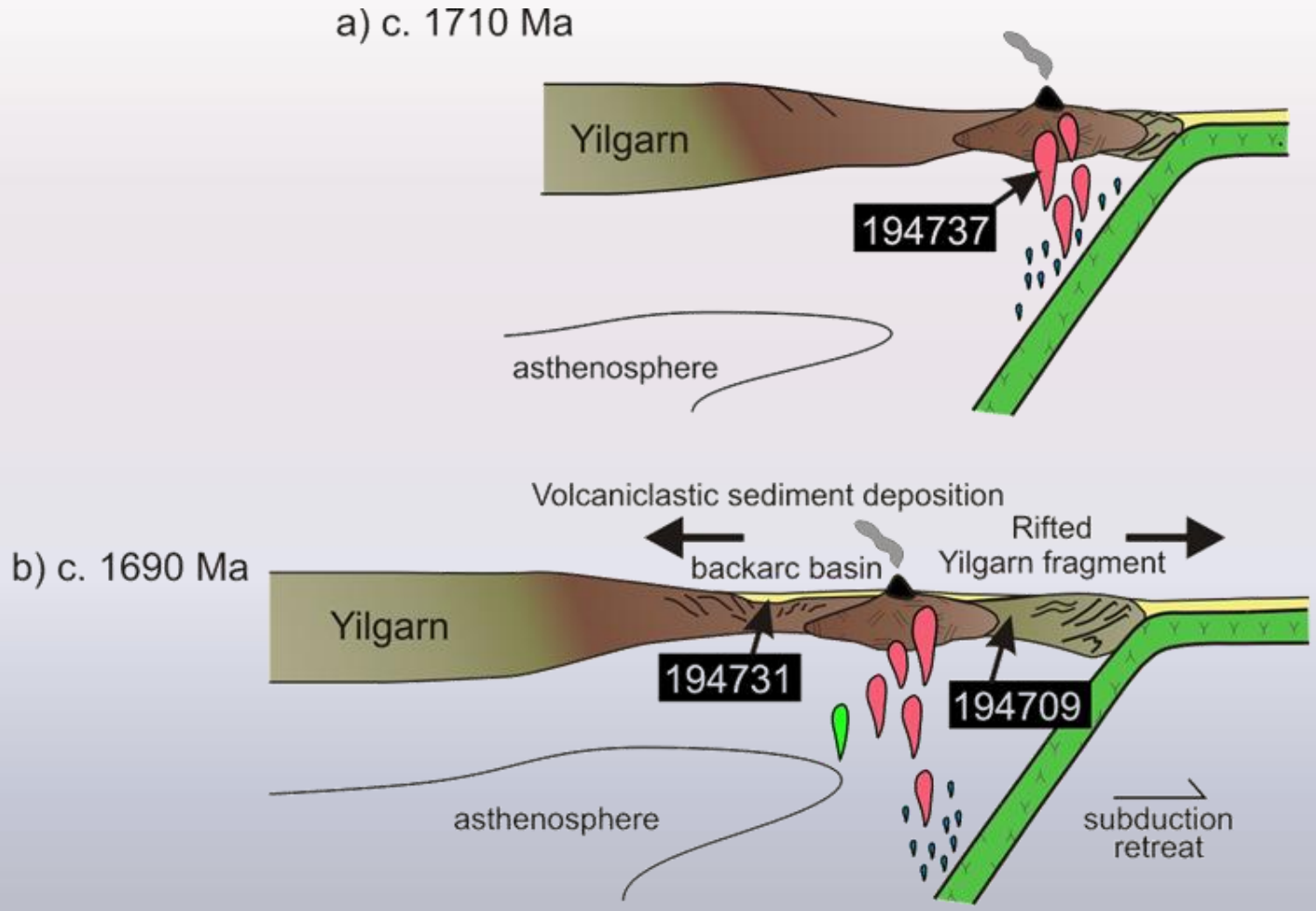
Northern Foreland = reworked Archean Yilgarn Craton.

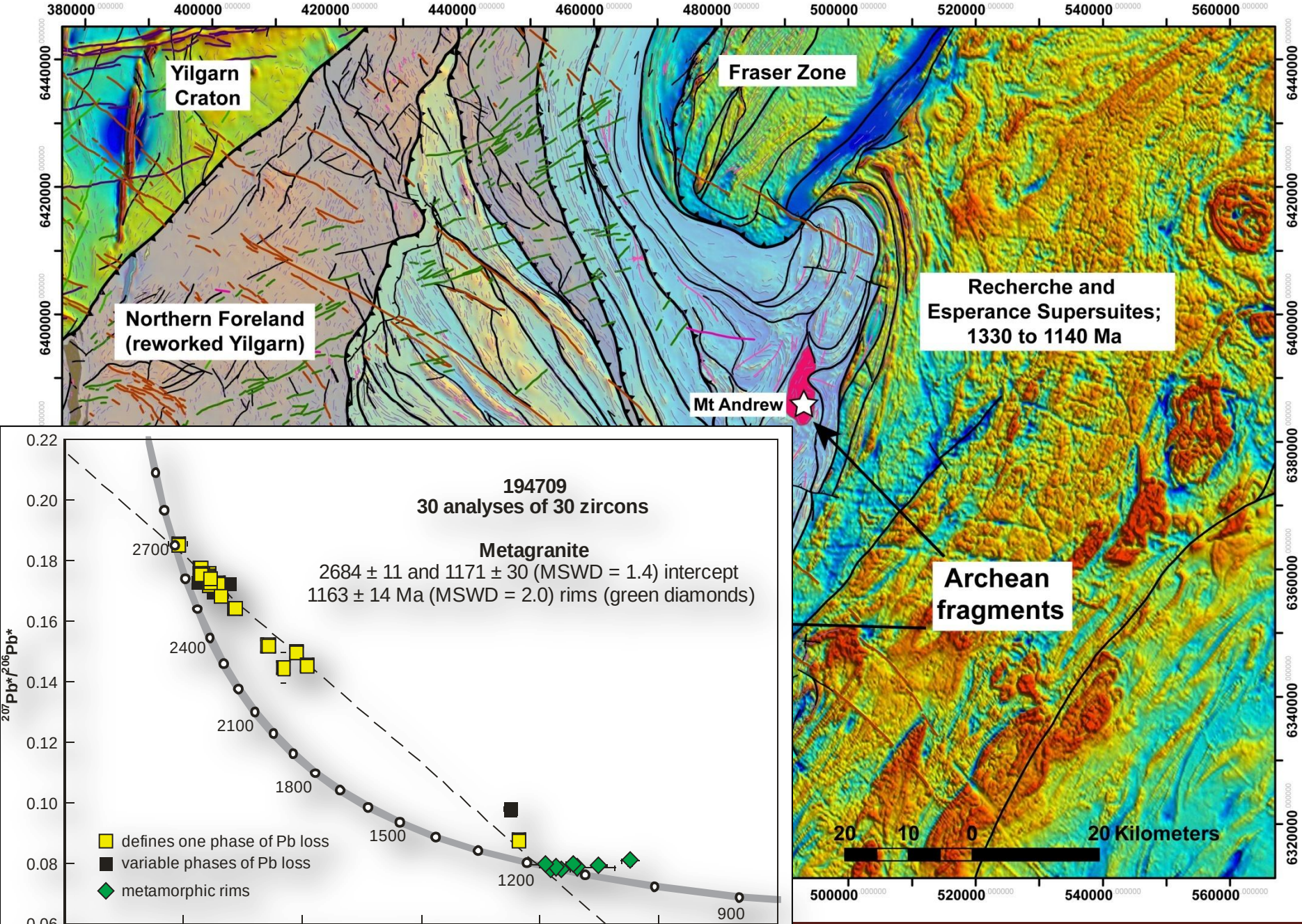
The Biranup Zone = reworked Archean Yilgarn component. Through time a greater juvenile mantle-derived component consistent with increasing lithospheric attenuation.

Results indicate autochthonous development



Albany-Fraser Orogen: tectonic model




Yilgarn Craton
Fraser Zone
Northern Foreland (reworked Yilgarn)
Recherche and Esperance Supersuites; 1330 to 1140 Ma
Mt Andrew
Archean fragments
20 10 0 20 Kilometers
194709
30 analyses of 30 zircons
Metagranite
2684 ± 11 and 1171 ± 30 (MSWD = 1.4) intercept
1163 ± 14 Ma (MSWD = 2.0) rims (green diamonds)
2700
2400
2100
1800
1500
1200
900
defines one phase of Pb loss
variable phases of Pb loss
metamorphic rims
$^{207}Pb^*/^{206}Pb^*$
$^{238}U/^{206}Pb^*$

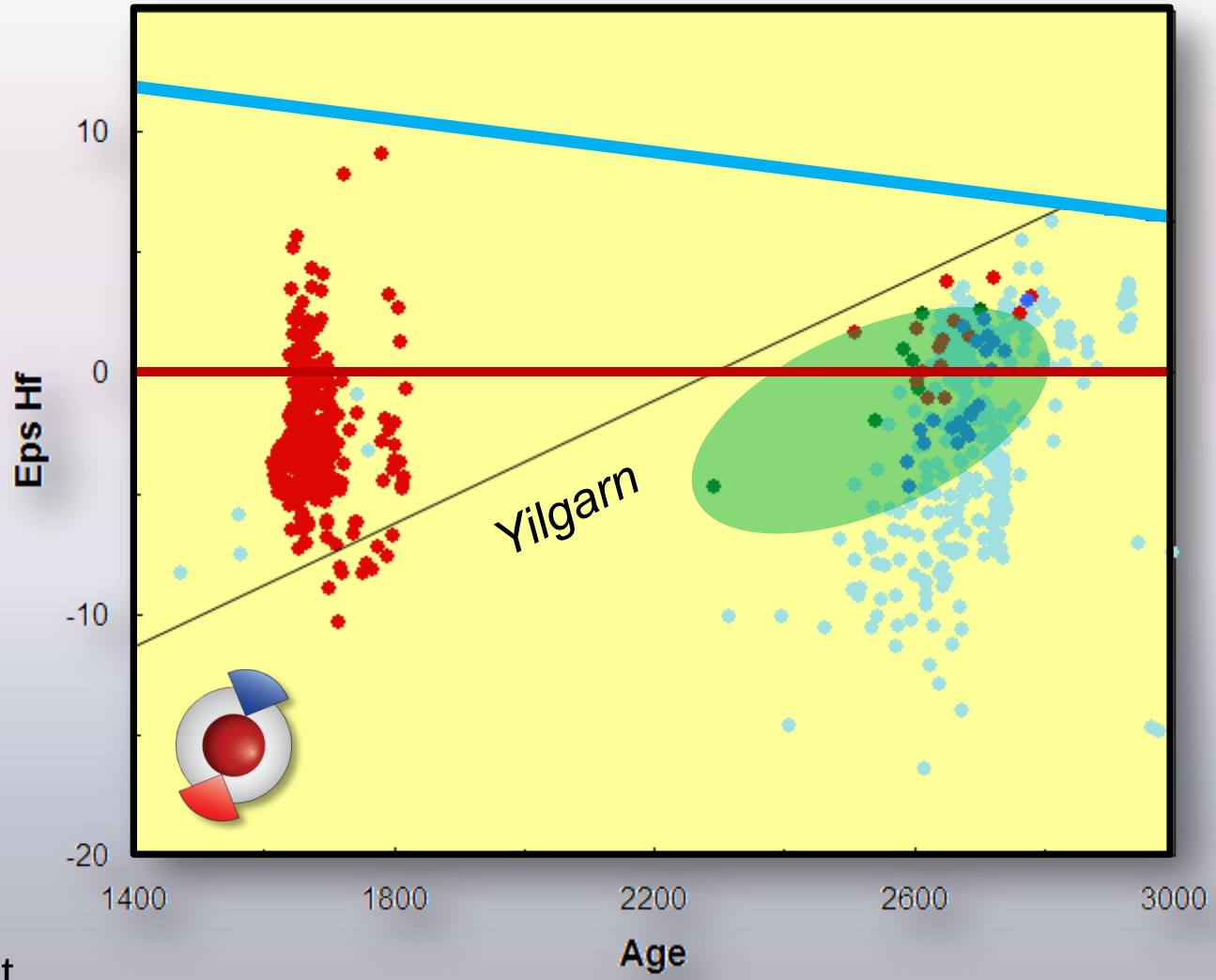
Albany-Fraser Orogen: Northern Foreland

- Yilgarn Craton
- Biranup Zone
- Northern foreland
- Yilgarn Craton fragment

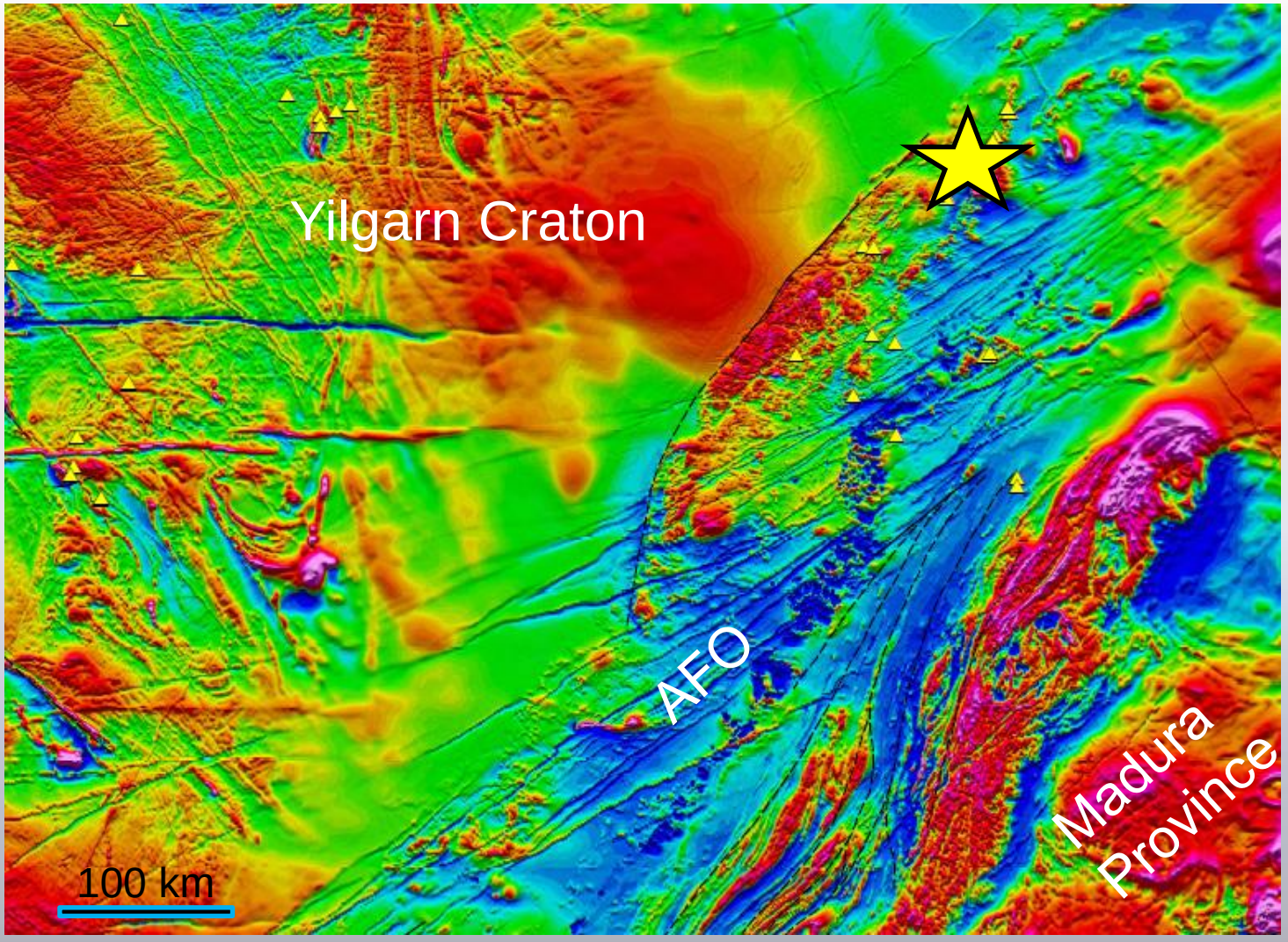
Northern Foreland = reworked Archean Yilgarn Craton

The Biranup Zone = reworked Archean Yilgarn component. Through time a greater juvenile mantle-derived component consistent with increasing lithospheric attenuation

Results indicate autochthonous development



Albany-Fraser Orogen: Tropicana Zone

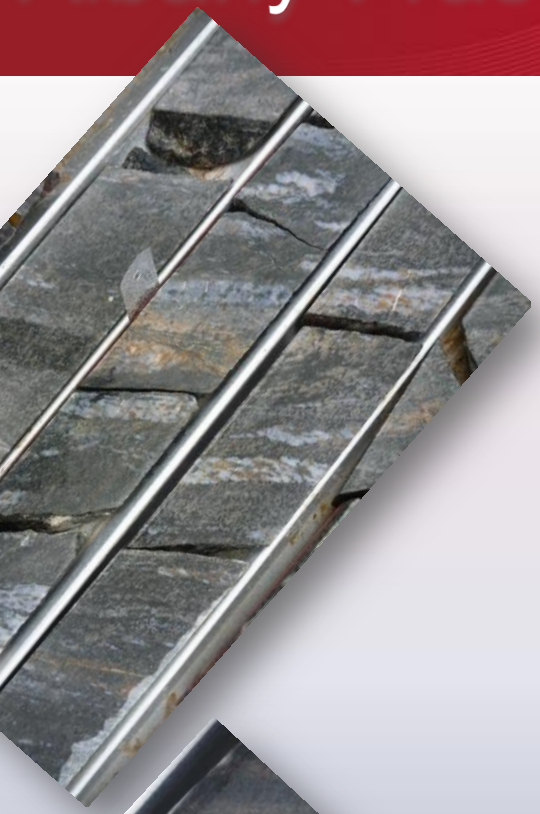


Tropicana Zone relatively unknown except from drillcore and seismic imaging

appears to comprise Archean granites with dioritic compositions

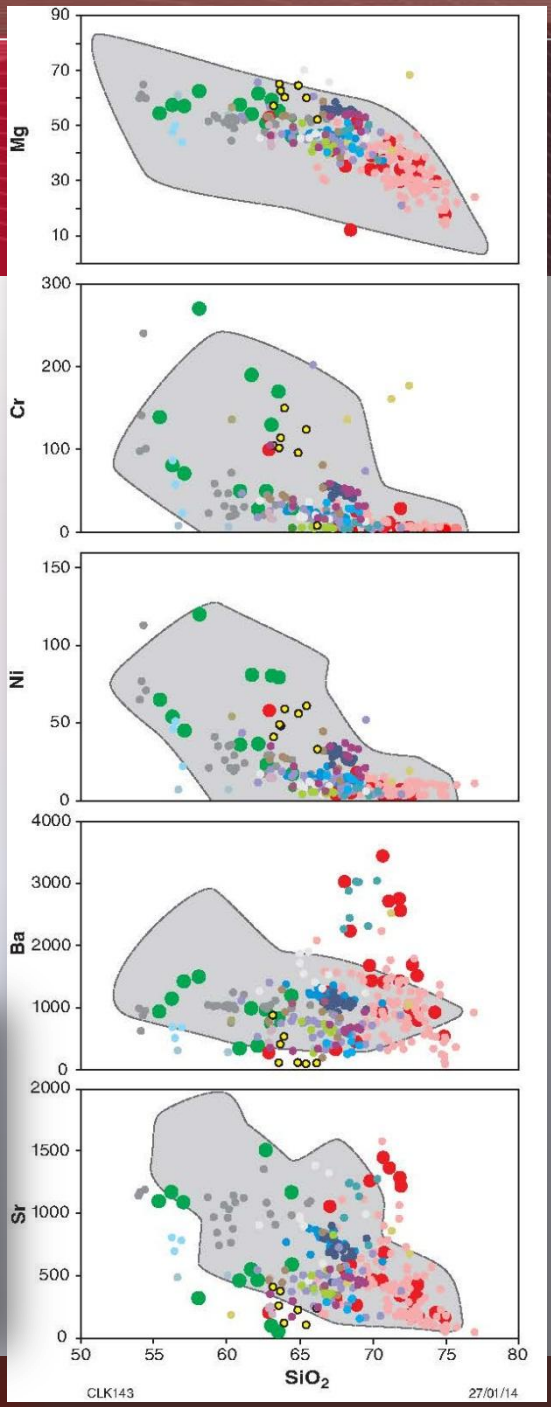
intruded by late Paleoproterozoic granites

Albany-Fraser: Tropicana Zone

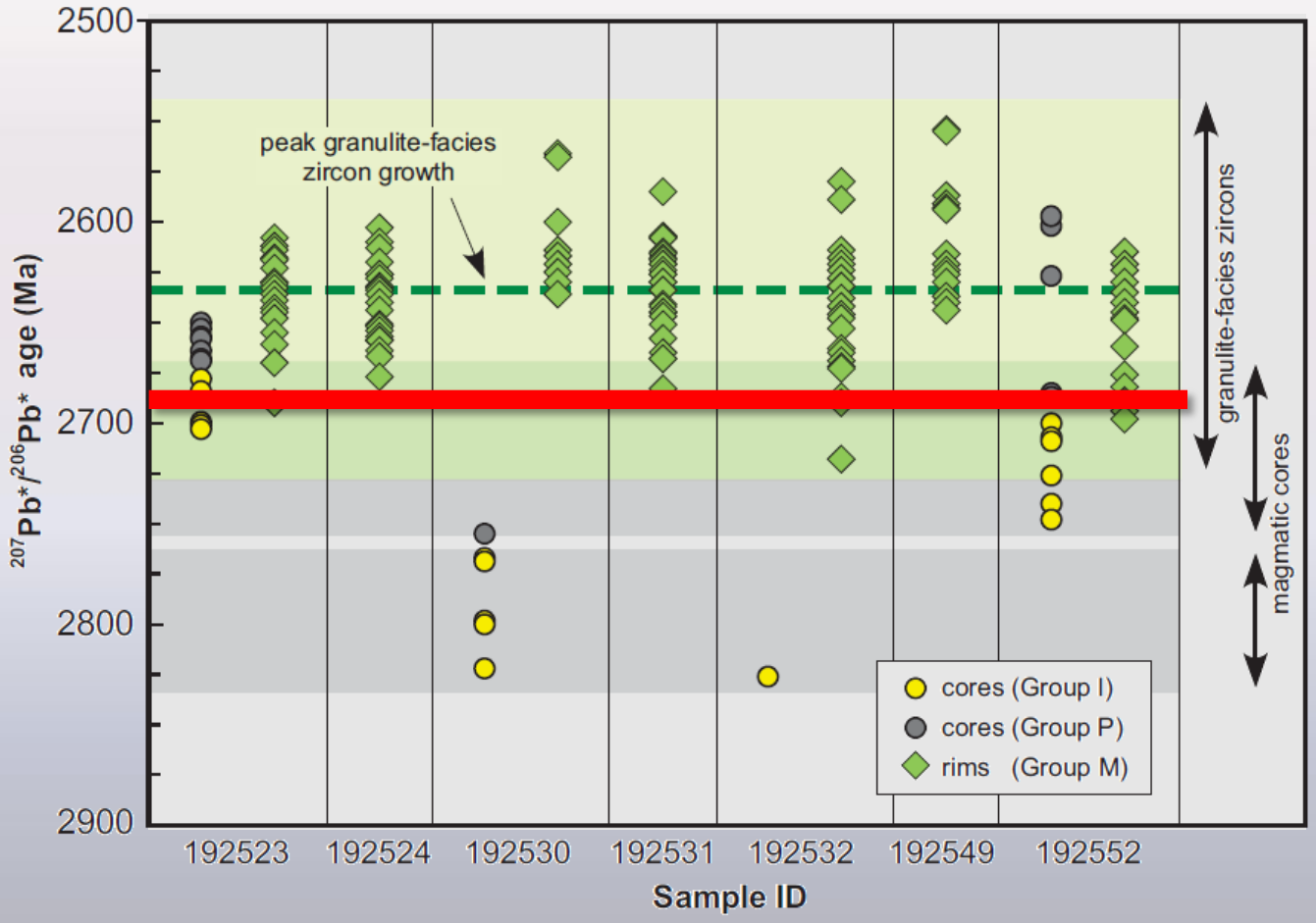


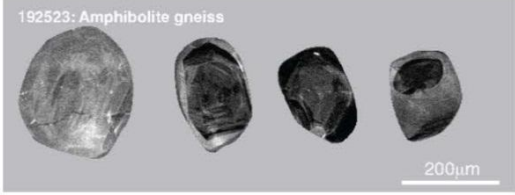
Tropicana Zone granites dioritic to quartz-monzodioritic compositions, low silica values, unusually high MgO (to 5.27 wt%), Cr (to 270 ppm) and Ni (120 ppm).

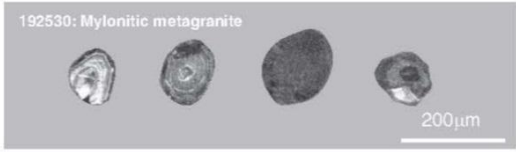
Sanukitoids: equilibration with mantle peridotite, direct derivation from a mantle source region previously enriched through interaction with subducted slab derived partial melts

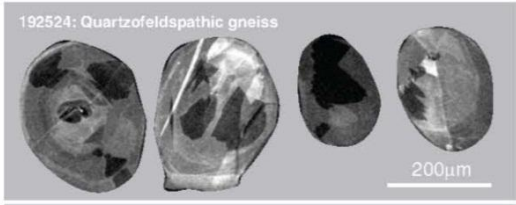


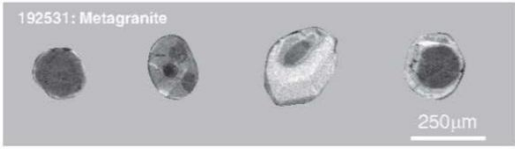
Albany-Fraser: Tropicana Zone

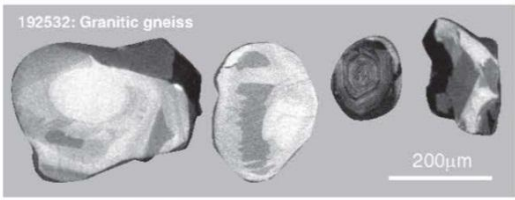


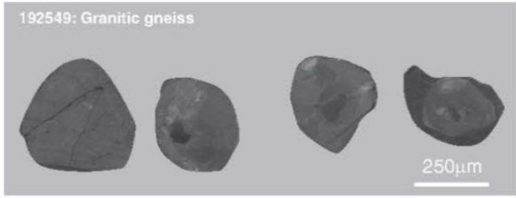


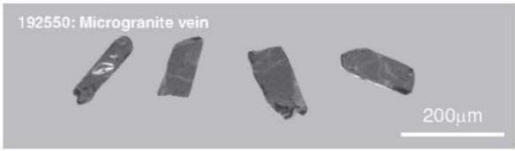


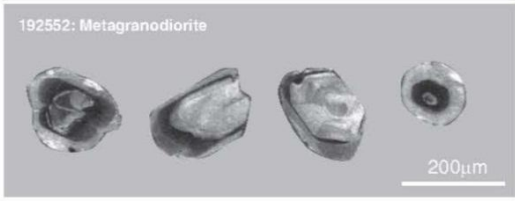












Albany-Fraser: Tropicana Zone

crystallization of sanukitoid protoliths 2692 ± 16 Ma

prolonged granulite-facies metamorphic zircon growth at 2718–2554 Ma

deeper crustal level of the Yilgarn Craton

Tropicana Zone was attached to the craton at or before c. 1780 Ma

Re-Os dating of pyrite suggests an age of c. 2.1 Ga for associated gold mineralization

sanukitoid magmas likely source of gold in the Tropicana Zone

Gold formation was not coeval with high-grade metamorphism

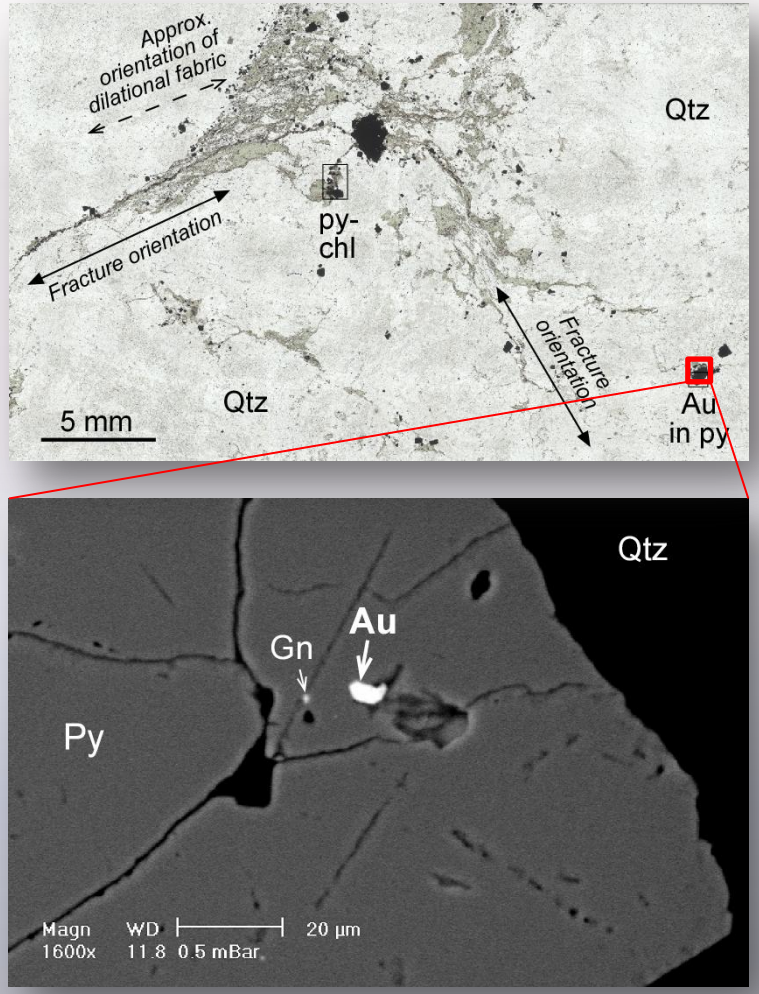
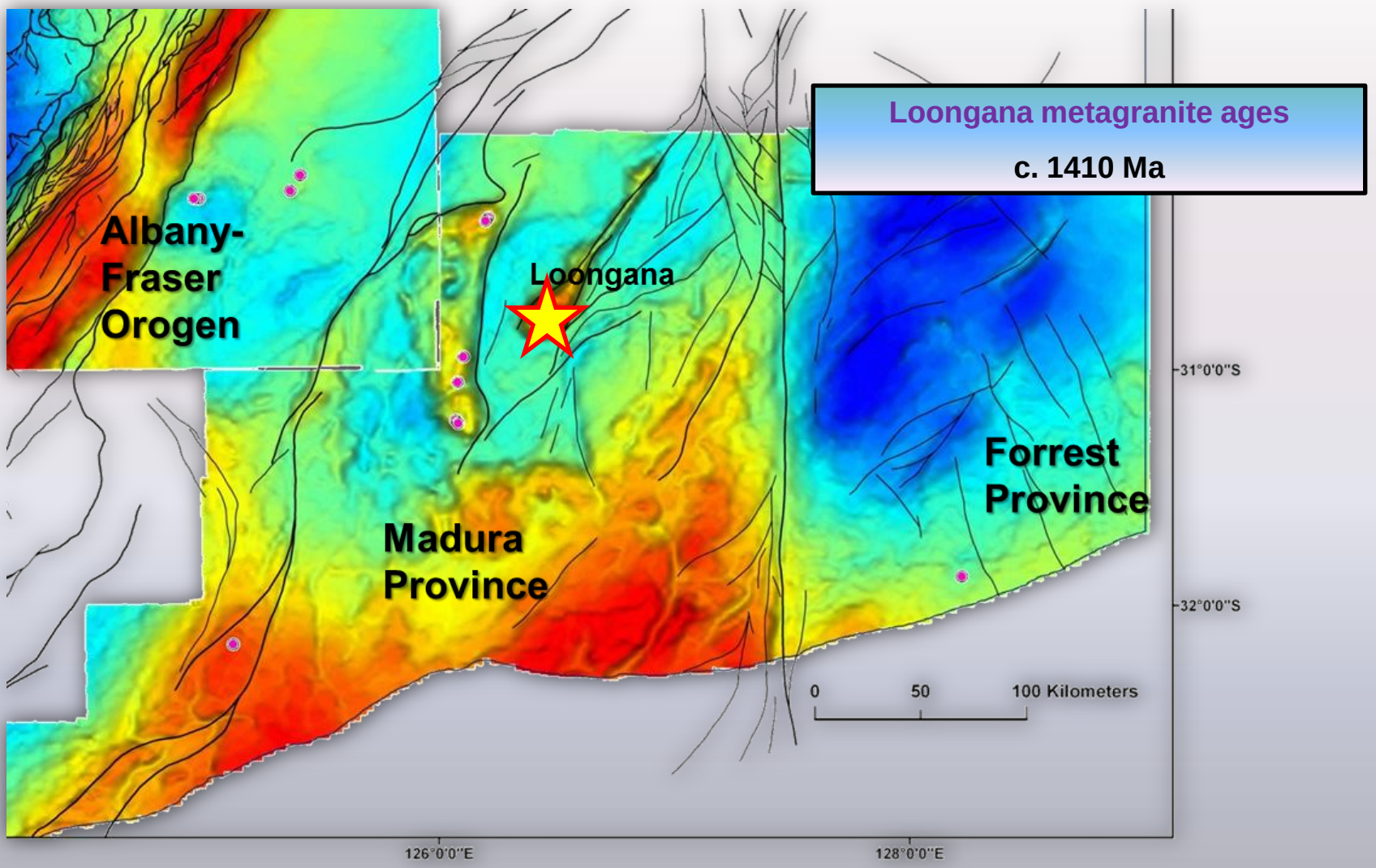


Image CSIRO; Sweetapple

Madura Province



Madura Province: oceanic crust

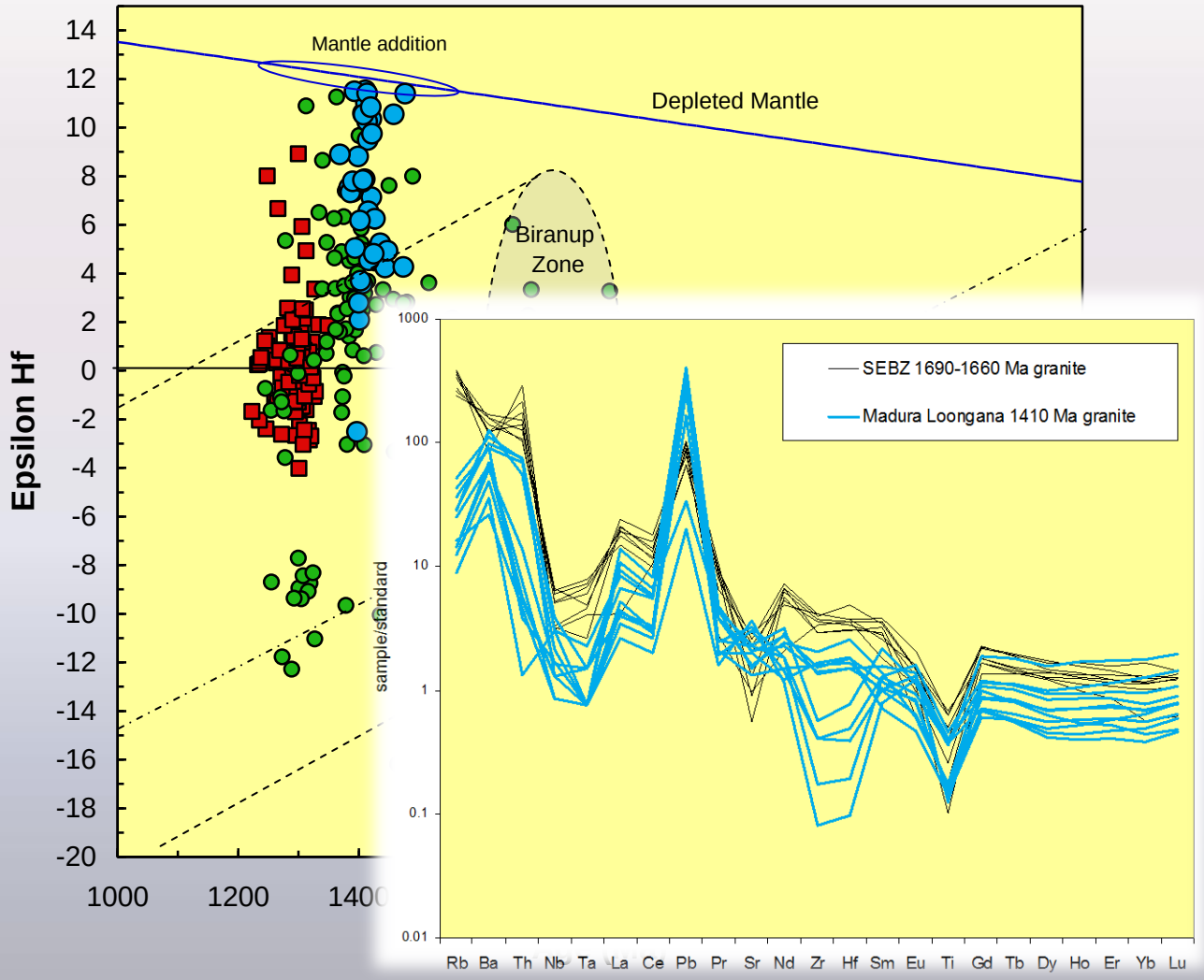
- **Loongana (Madura Province)**
- **Fraser Zone magmatic rocks**
- **Fraser Zone sediments**

Loongana = initial-Hf isotope ratios consistent with juvenile source

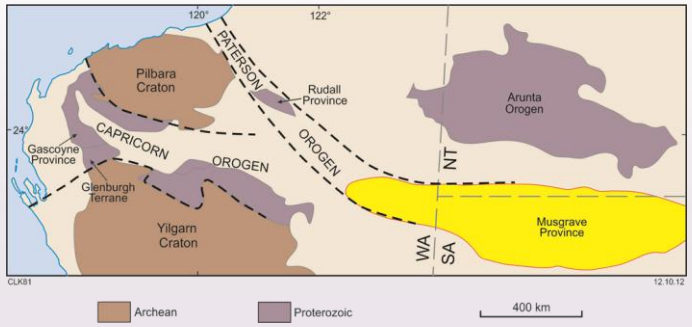
Provenance for much of Fraser Zone sediments

Primitive chemistry

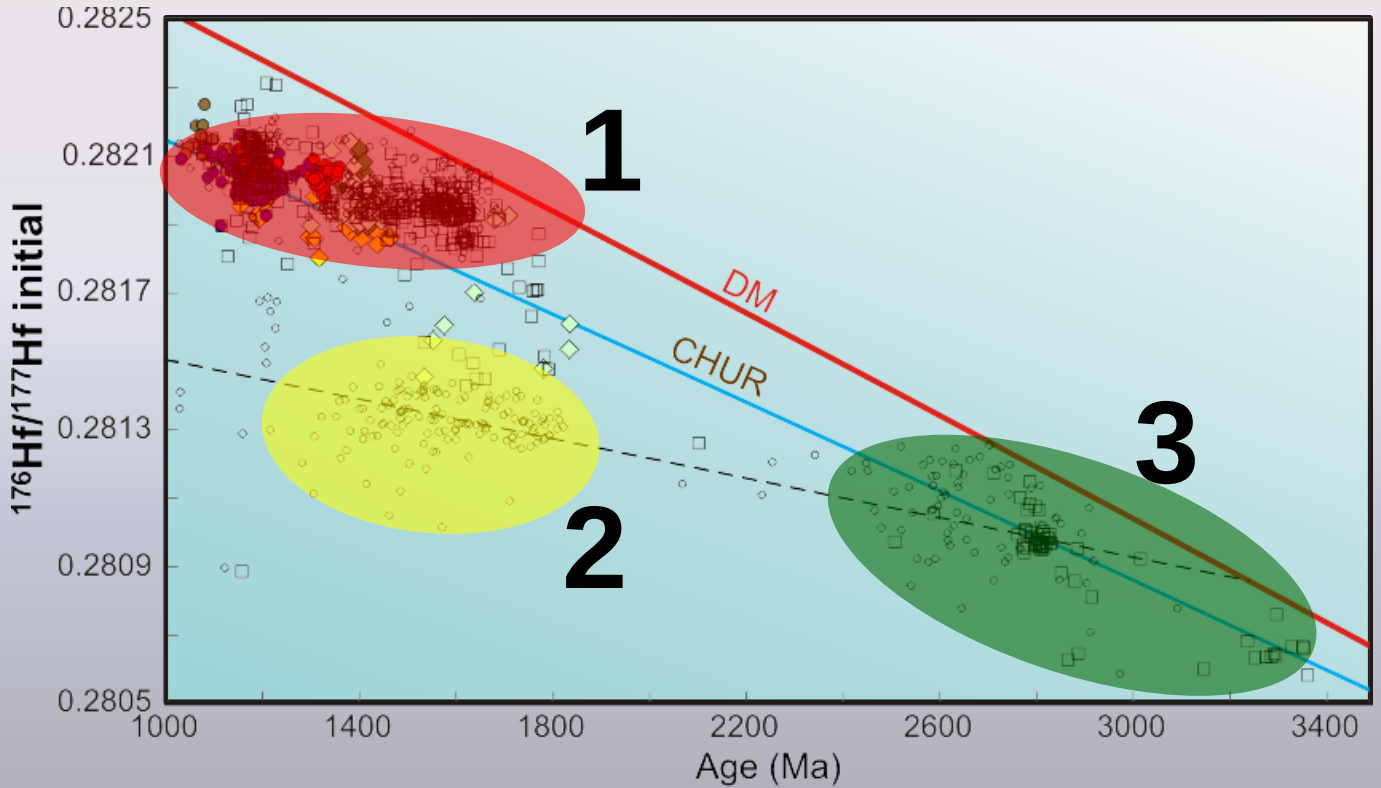
Oceanic crust



Musgrave Province

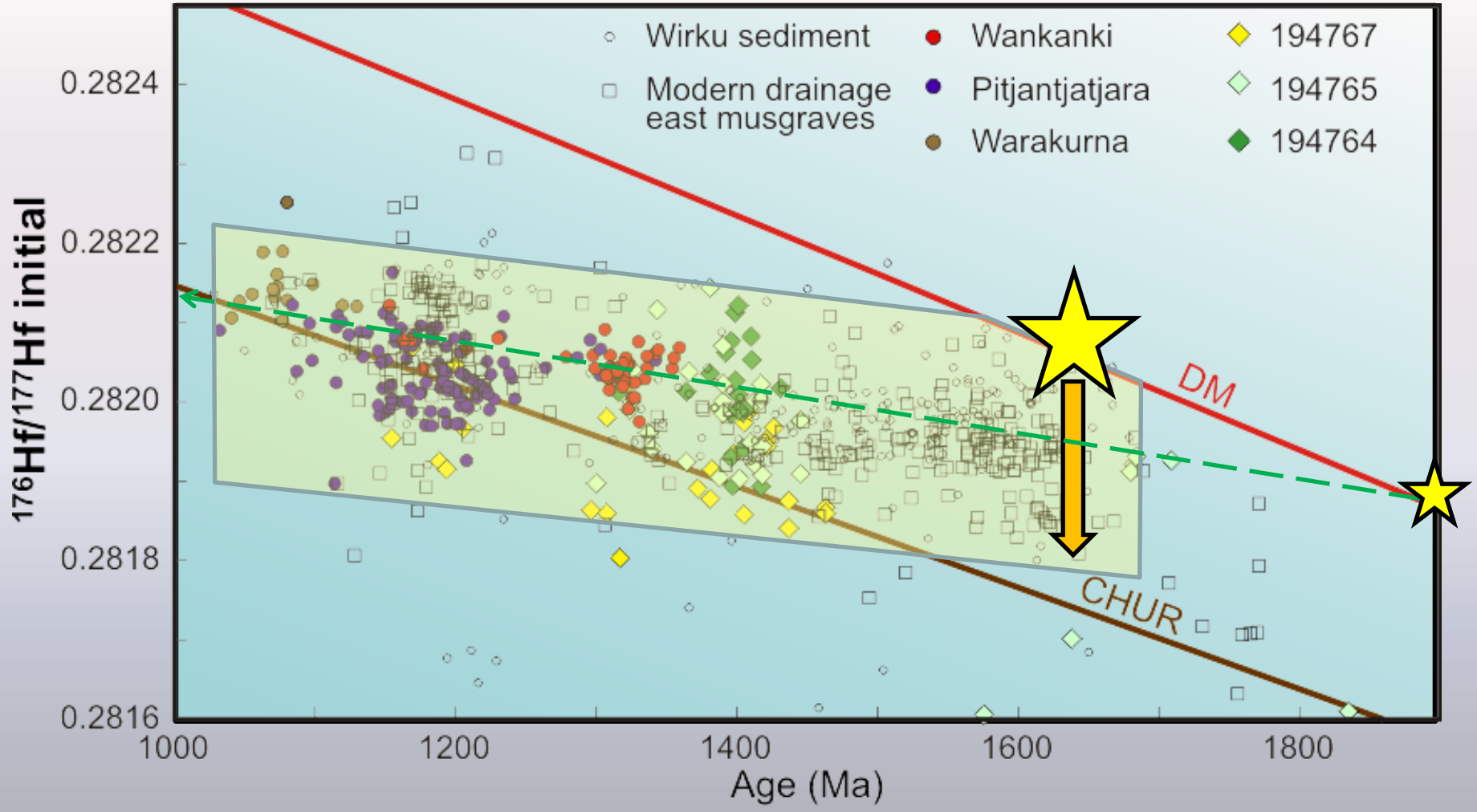


Musgrave Province lies at the convergence of Australia's main Proterozoic structural trends that reflect the amalgamation of the North, West and South Australian Cratons



Musgrave Province: two major juvenile Proterozoic crust-formation events; 1600–1550 & 1950–1900 Ma and (transported) Archean crust

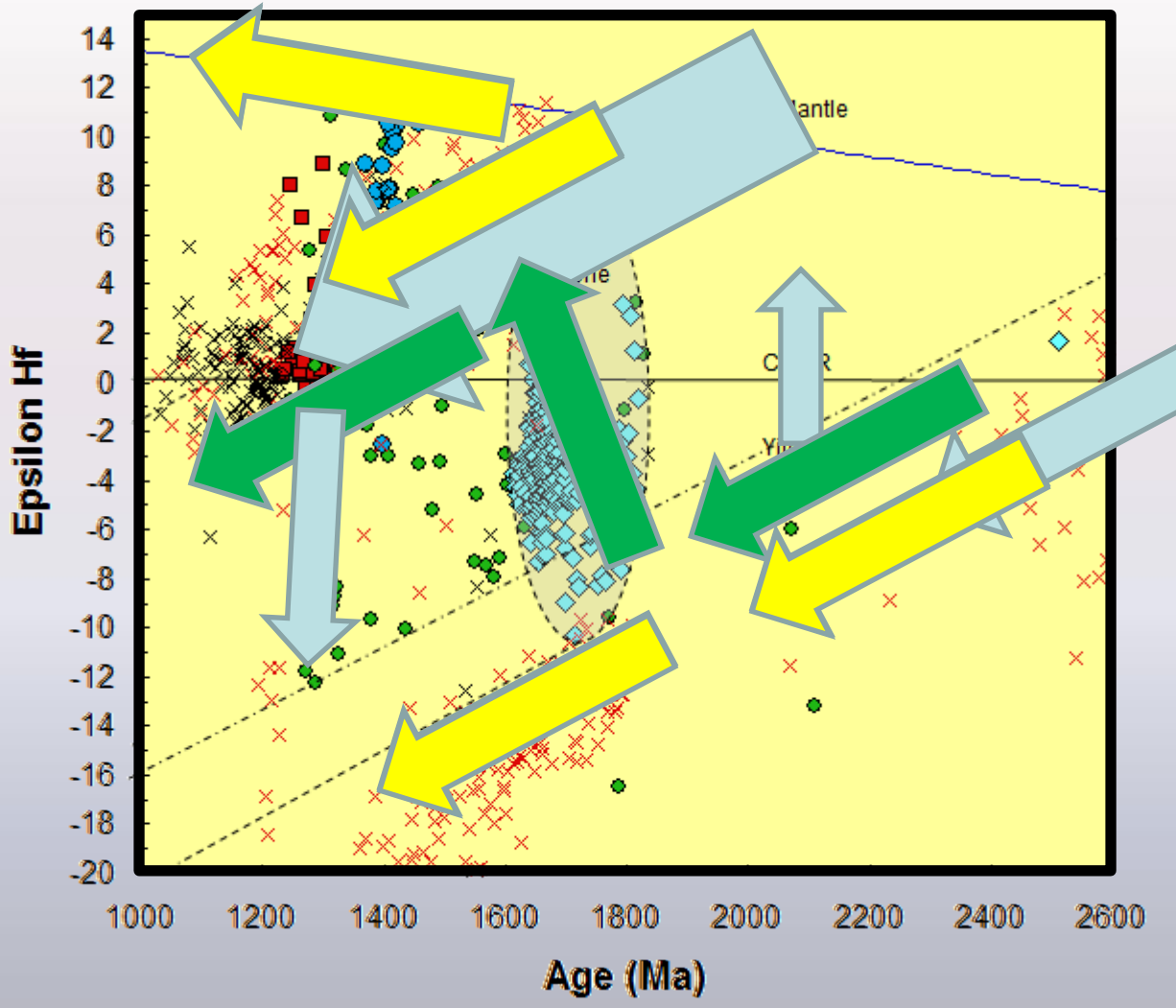
Musgrave Province: cryptic Hf arrays



WAC marginal units

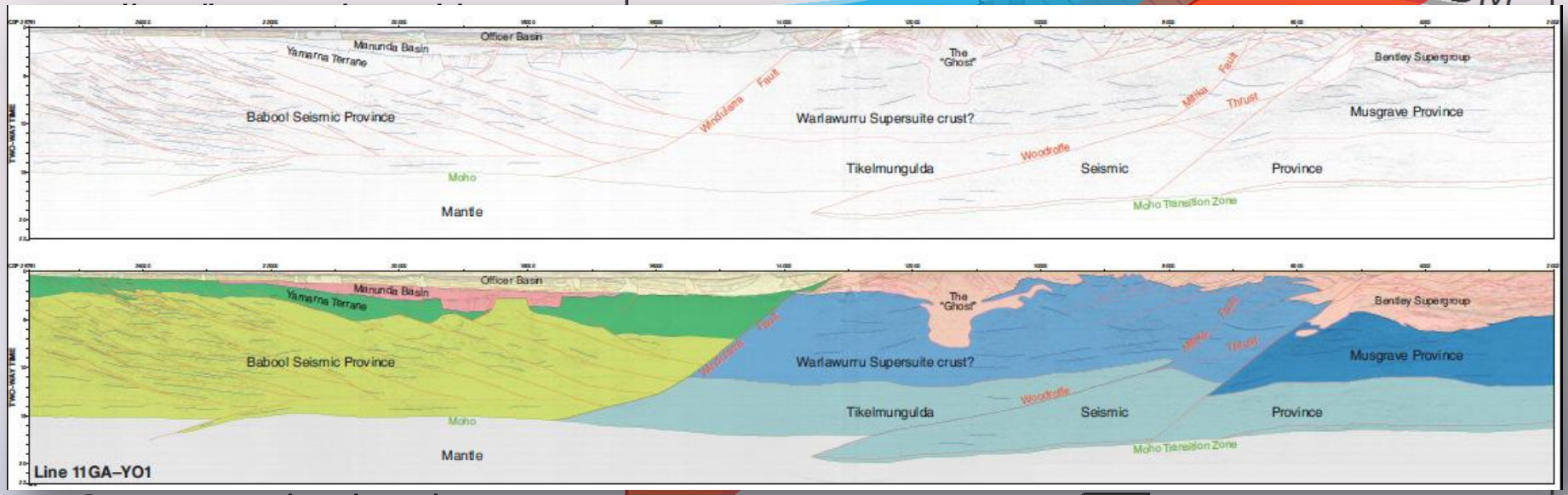
Currently two different models to explain isotopic evolution of the WAC and its marginal terranes

Differences reflect interpretation of the importance of isotopic mixing and the times of juvenile input



WAC marginal units

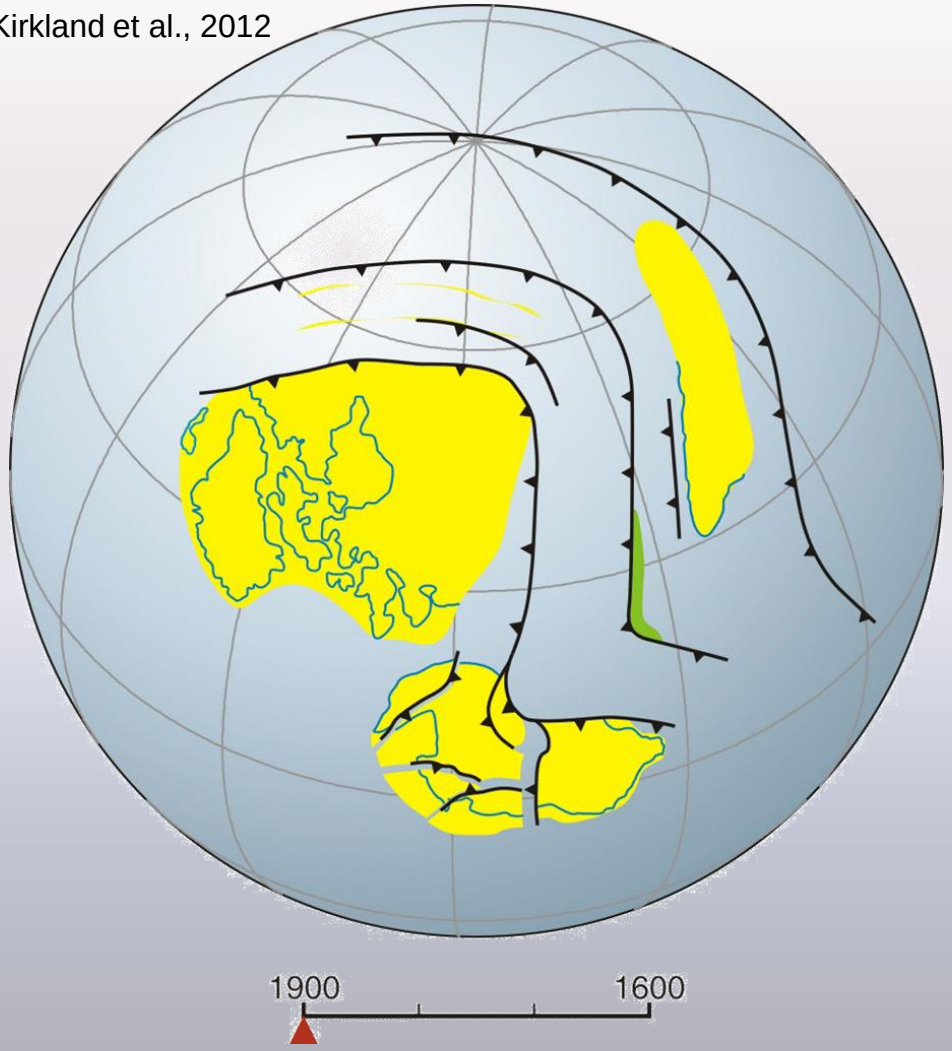
Whole rock Nd isotopic data important; comes from igneous intrusions



AFO more evolved and post crystallization has a dramatically different composition to Musgraves and Madura Province

Tectonic reconstruction

Kirkland et al., 2012



- A basement component in the Musgrave Province was likely the Madura oceanic block
- Under plating of the Madura oceanic block under the WAC formed the deep basement in the Rudall and Capricorn after c. 1450 Ma
- The Proterozoic AFO reflects the attenuated margin of the Archean Yilgarn Craton
- Archean blocks with sanukitoid magmas in this margin are fertile for gold mineralization

Conclusions

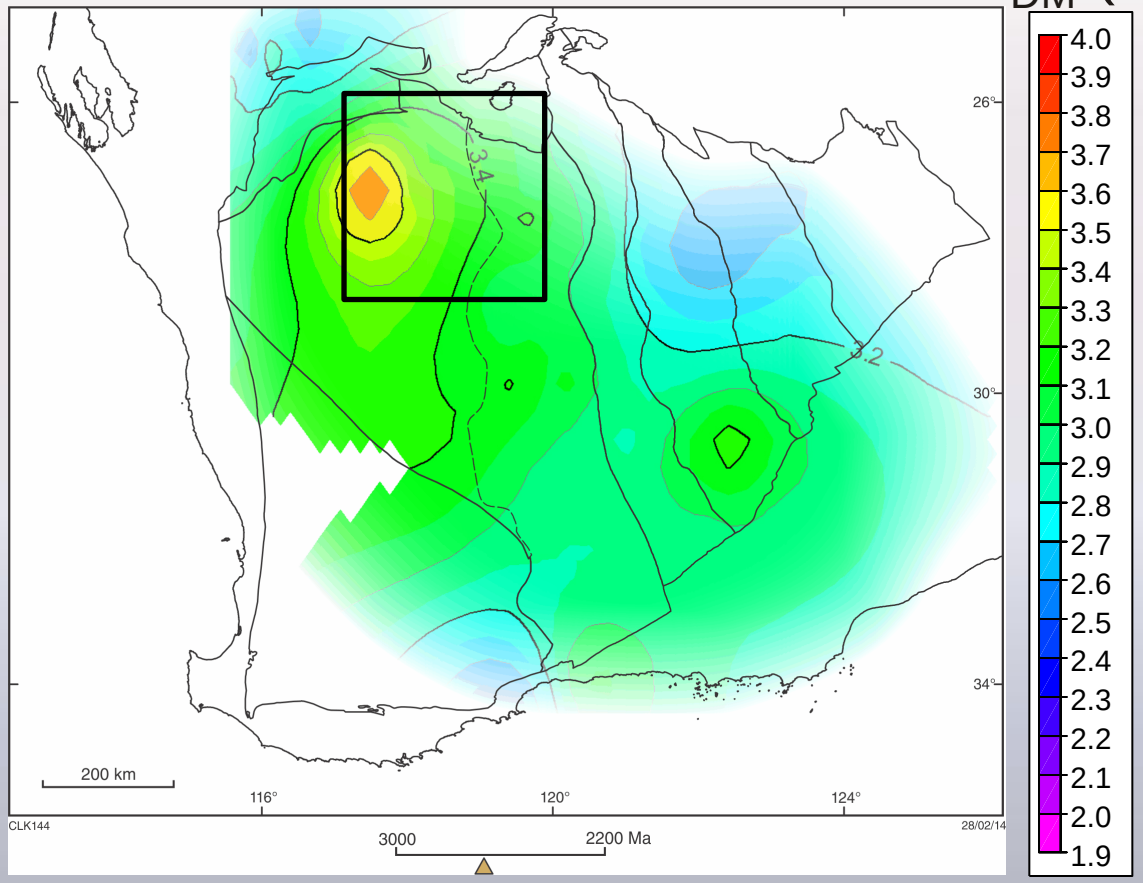
Lithospheric architecture (craton margins, rift zones, subduction zones) are a **first-order control on** the localization of gold, iron and nickel **mineralized systems**.

The **age and source characteristics** of lithosphere are **heterogeneous in both space and time**, e.g. cratonic margins and rifts are transient or migrate.

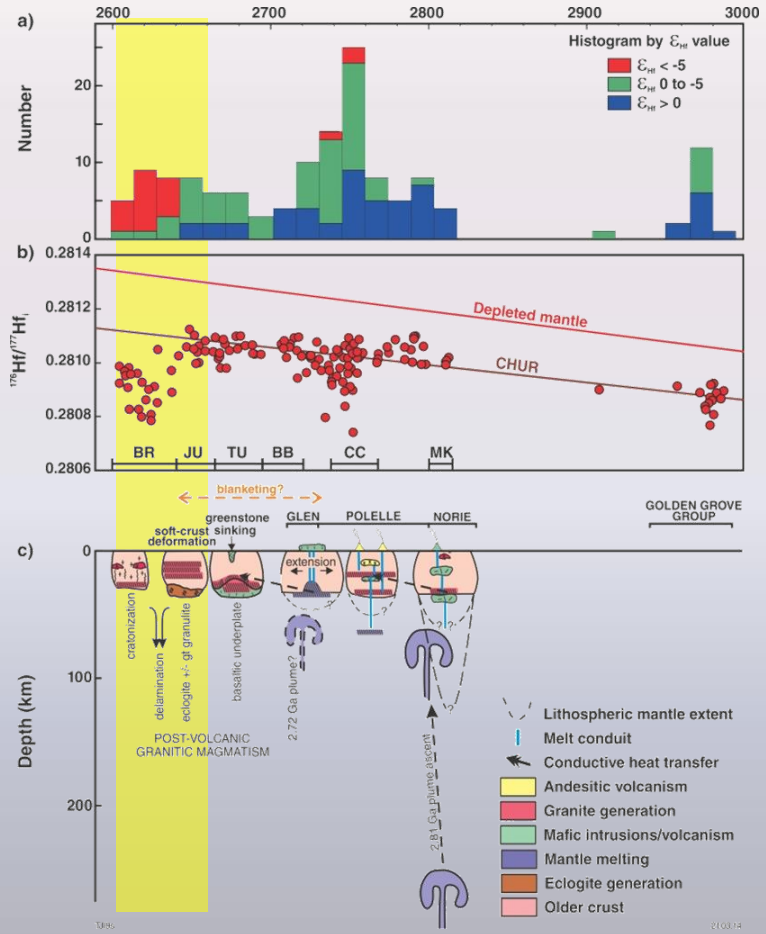
The **location and movement through time** of these cratonic entities is **recorded by the varying Nd and Hf signatures** of melts that tap various levels of the assembled crustal pile.

Isotopic evolution "maps" lithospheric discontinuities where nickel, iron and gold mineral systems can be concentrated, in both space and time.

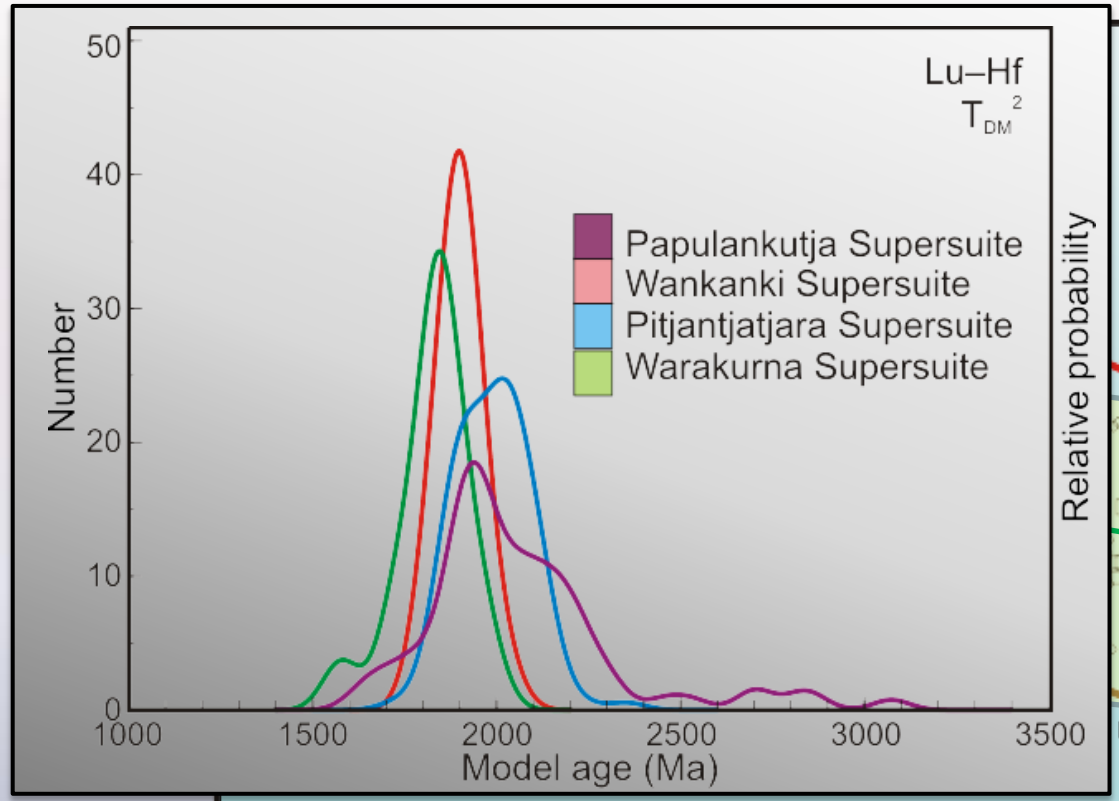
Spatial perspective on Hf datasets



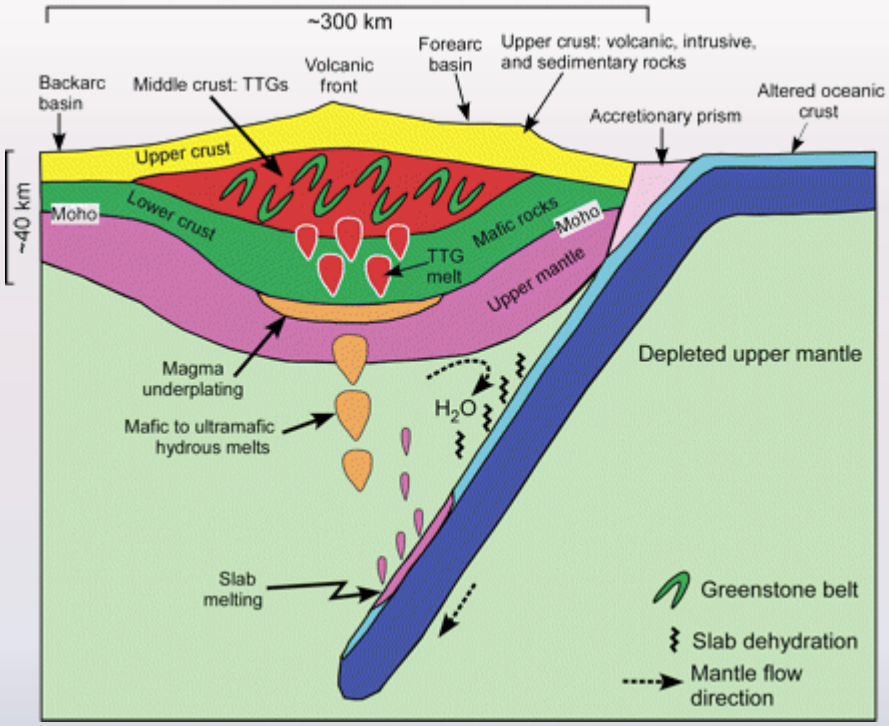
T_{DM} (Ga)



Musgrave Province: cryptic Hf arrays



Crustal growth zones: why are they important?



Crustal growth viewed as the result of "subduction factory" processes.

e.g. differentiate of mantle-derived magma introduced into arcs.