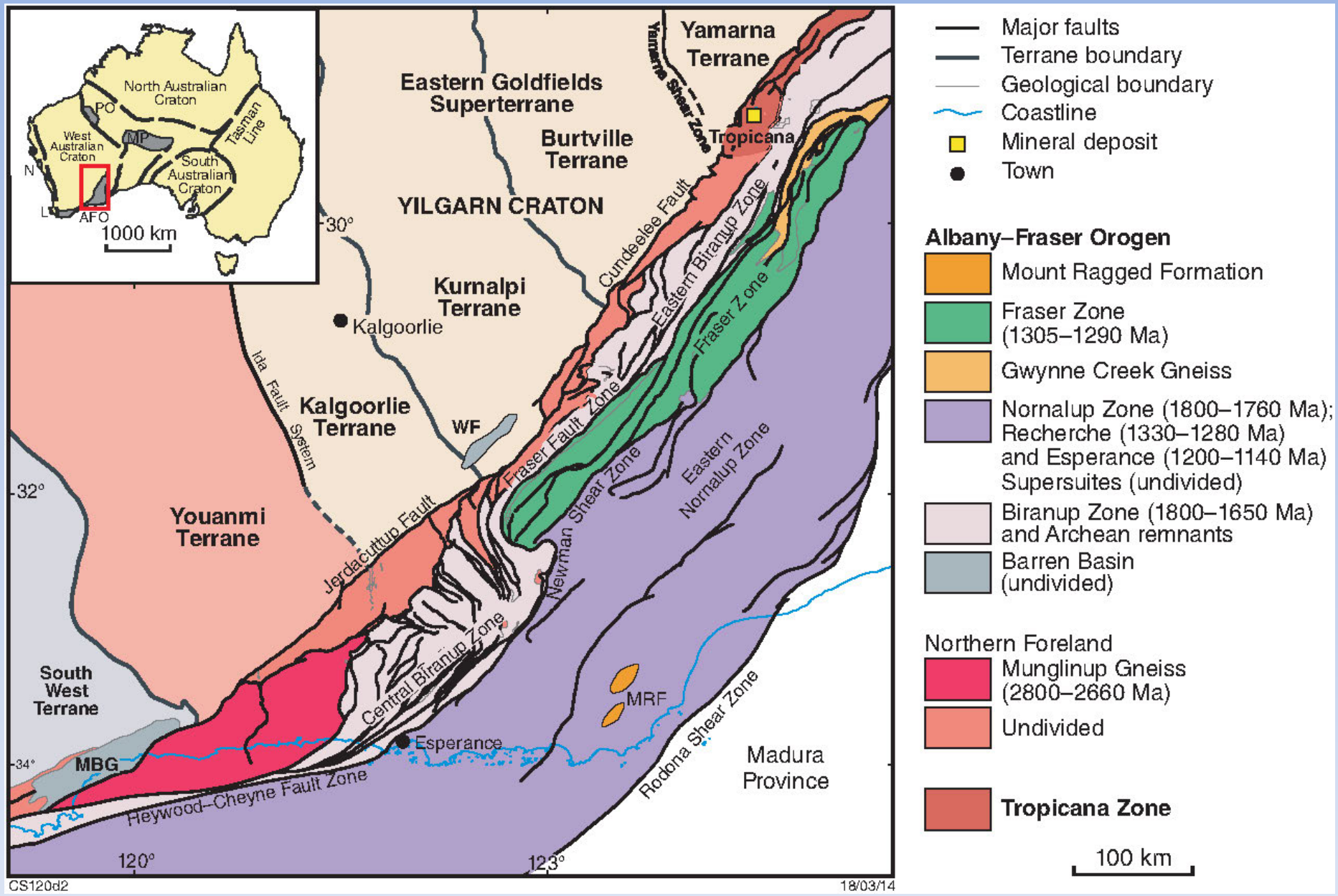
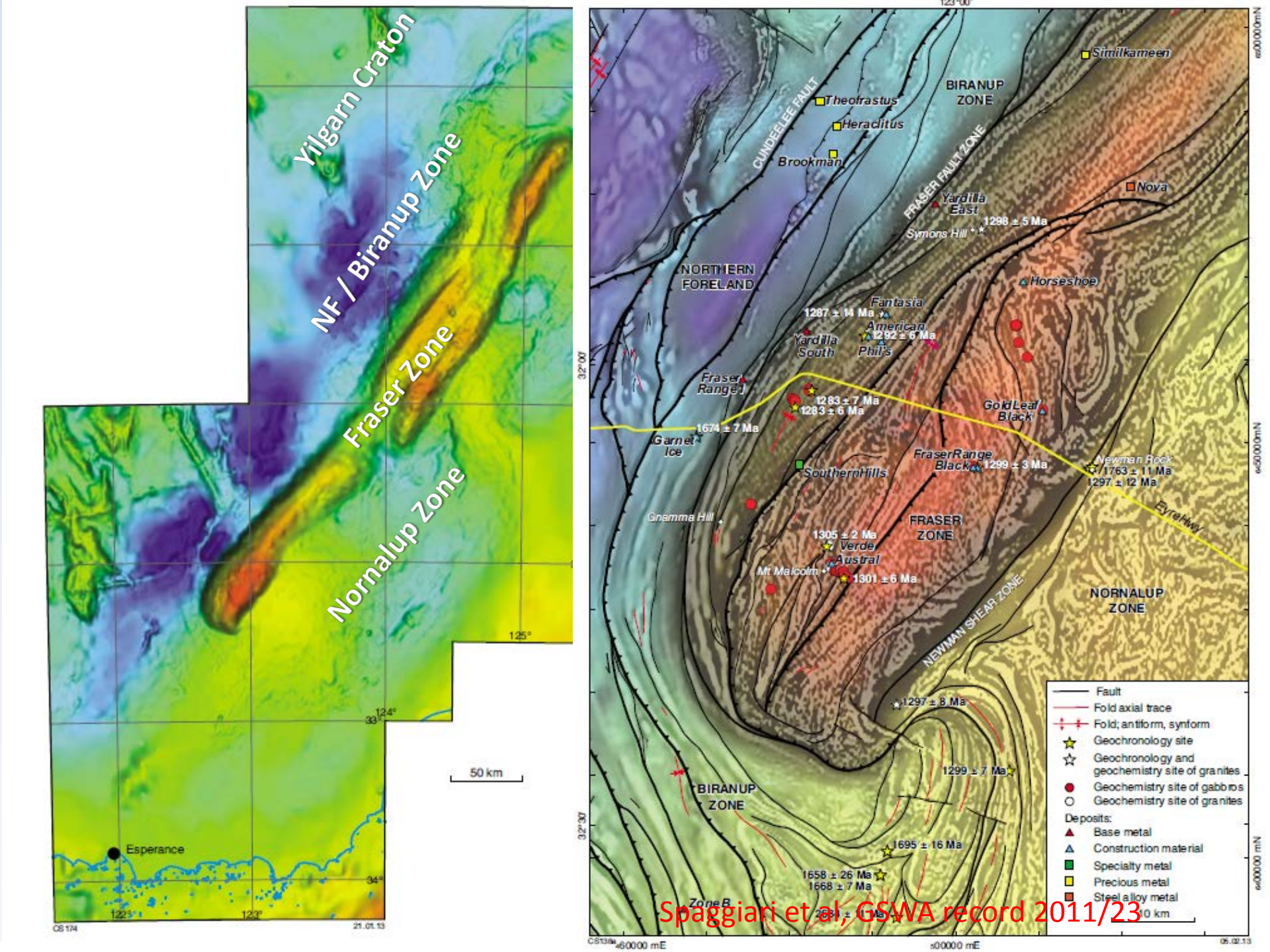
Government of **Western Australia**
Department of **Mines and Petroleum**

Geochemistry and petrogenesis of igneous rocks in the Albany-Fraser Orogen

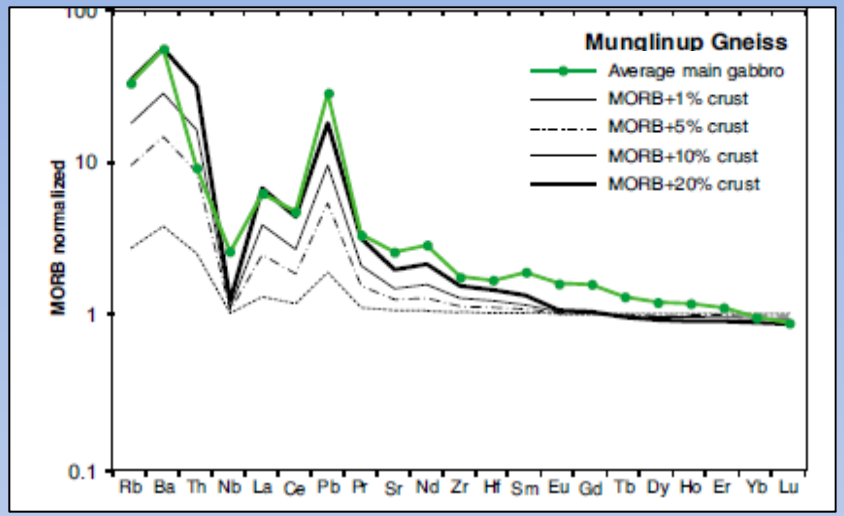
Hugh Smithies, Catherine Spaggiari and Chris Kirkland

Geological Survey of Western Australia


North Australian Craton
PO
MP
West Australian Craton
Tasman Line
South Australian Craton
AFO
1000 km
Eastern Goldfields Superterrane
Yamarna Terrane
Yamarna Shear Zone
Tropicana
Burtville Terrane
YILGARN CRATON
30°
Cundeelee Fault
Eastern Biranup Zone
Fraser Zone
Kurnalpi Terrane
Kalgoorlie
Ida Fault System
Kalgoorlie Terrane
WF
Fraser Fault Zone
Eastern Nornalup Zone
Newman Shear Zone
32°
Youanmi Terrane
Jerdacuttup Fault
Central Biranup Zone
MRF
South West Terrane
MBG
Esperance
34°
Heywood–Cheyne Fault Zone
Rodona Shear Zone
Madura Province
120°
123°
Major faults
Terrane boundary
Geological boundary
Coastline
Mineral deposit
Town
Albany–Fraser Orogen
Mount Ragged Formation
Fraser Zone (1305–1290 Ma)
Gwynne Creek Gneiss
Nornalup Zone (1800–1760 Ma); Recherche (1330–1280 Ma) and Esperance (1200–1140 Ma) Supersuites (undivided)
Biranup Zone (1800–1650 Ma) and Archean remnants
Barren Basin (undivided)
Northern Foreland
Munglinup Gneiss (2800–2660 Ma)
Undivided
Tropicana Zone
100 km
CS120d2
18/03/14



Spaggiari et al, GSWA record 2011/23



Fraser Zone gabbro (c. 1300 Ma)

Regionally extensive mass of closely spaced gabbro sheets and dykes within the Arid Basin. They DO NOT represent a layered complex.

Arid Basin
- c. 1320 Ma max. dep. age
- c. 1300 Ma gabbro intrusion
- gabbro intrusion into granulite facies sedimentary rock at 7-9 kbars (Clarke et al) – so deep intrusion into sedements with depositional ages not much different to the age of intrusion!
- co-magmatic granite

Two subdivisions:

'Main' gabbros = relatively normal low-K tholeiitic rocks. High LREE, Th, La/Nb and ε_{Nd} <0 suggest contamination, but little correlation with (e.g.) $Mg^{\#}$ or SiO_2 suggests that this was early (?lower-crustal) – but NOT necessarily subduction related.

Hybridized gabbros = main gabbros that have undergone further contamination, at or near emplacement level, with either the sedimentary host rocks or with comagmatic granites of the Recherche Supersuite.

MODEL – lower crustal 'hot-zone' in either a distal back-arc or intracontinental rift.

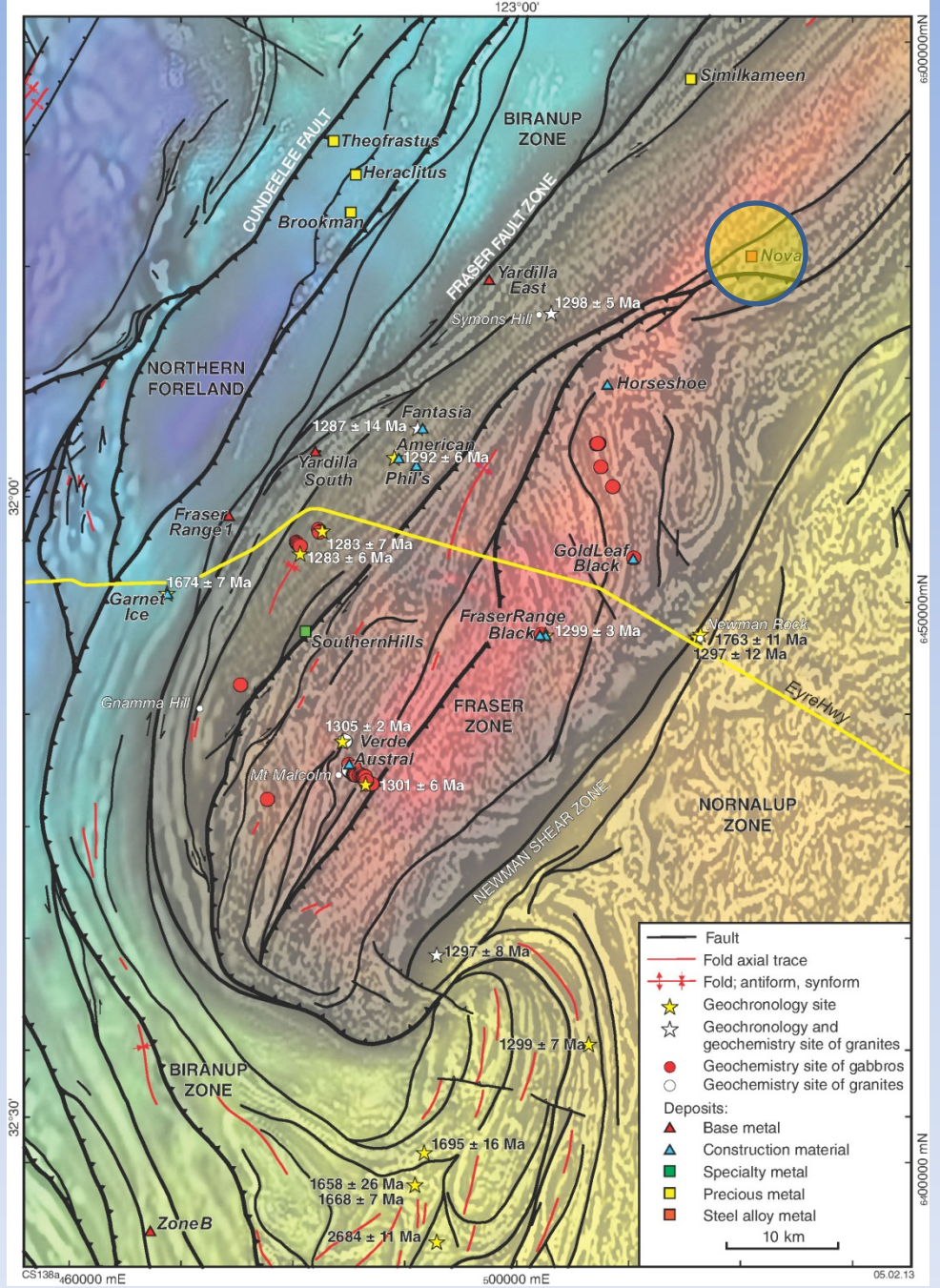
Nova (The Eye) (Sirius Resources)

Mafic and ultramafic rocks within the Fraser Zone.

No *a priori* reason to indicate it is not part of the c. 1300 Ma magmatic event or related to the Fraser gabbro.

Significant Ni-Cu sulphide deposit.

Are there more of these in the Fraser Zone?



The Eye EIS core

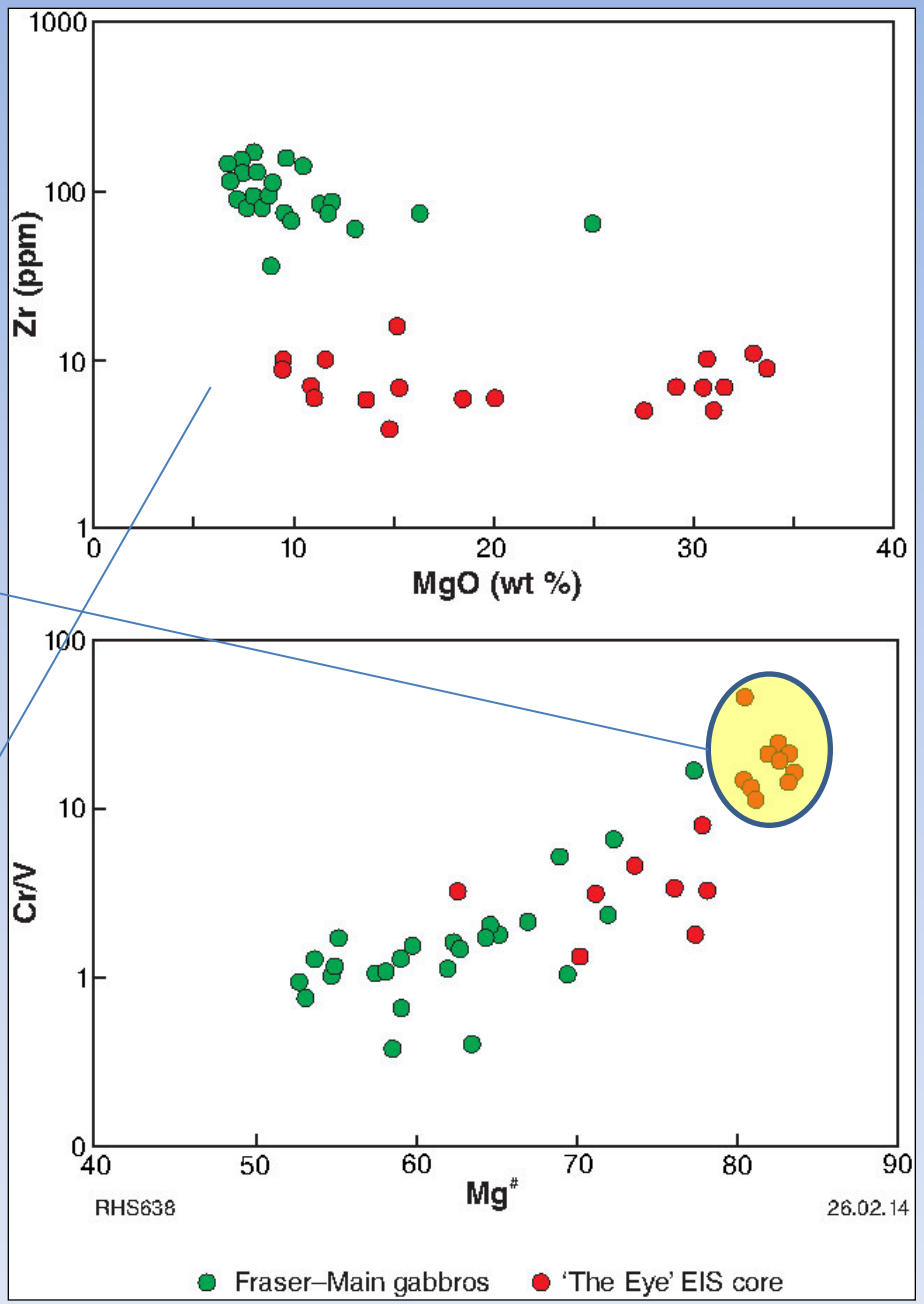
Identifies a series of mafic and ultramafic rocks, with locally abundant disseminated sulphide.

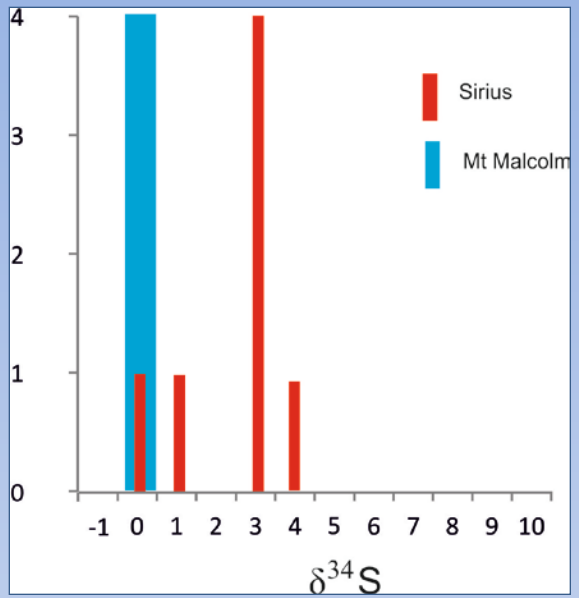
What can we say about these?

1) Crystallized from the most primitive magma so far sampled from the Fraser Zone. BUT, we do get some rather primitive intrusions of Fraser gabbro.

2) Produced a compositionally zoned/layered intrusion – cumulates.

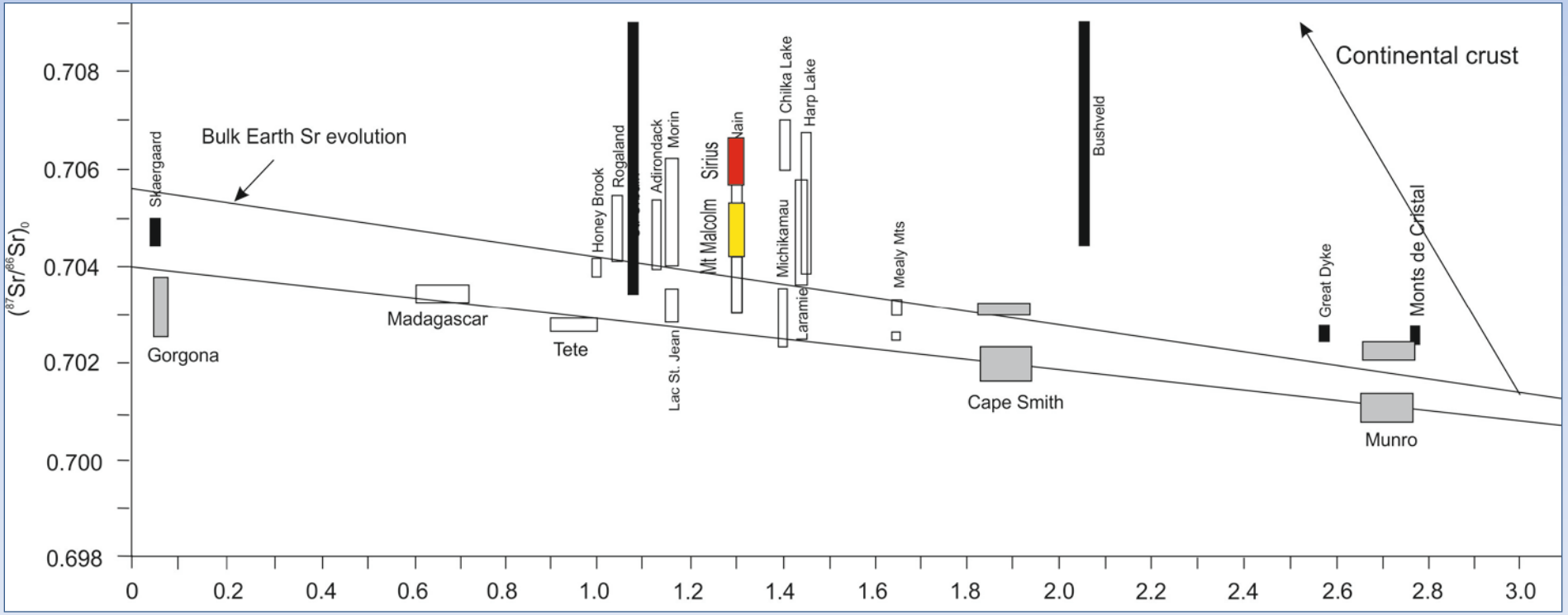
Not characteristic of much of the outcropping portions of the Fraser gabbro, most of which more closely represents liquid compositions.





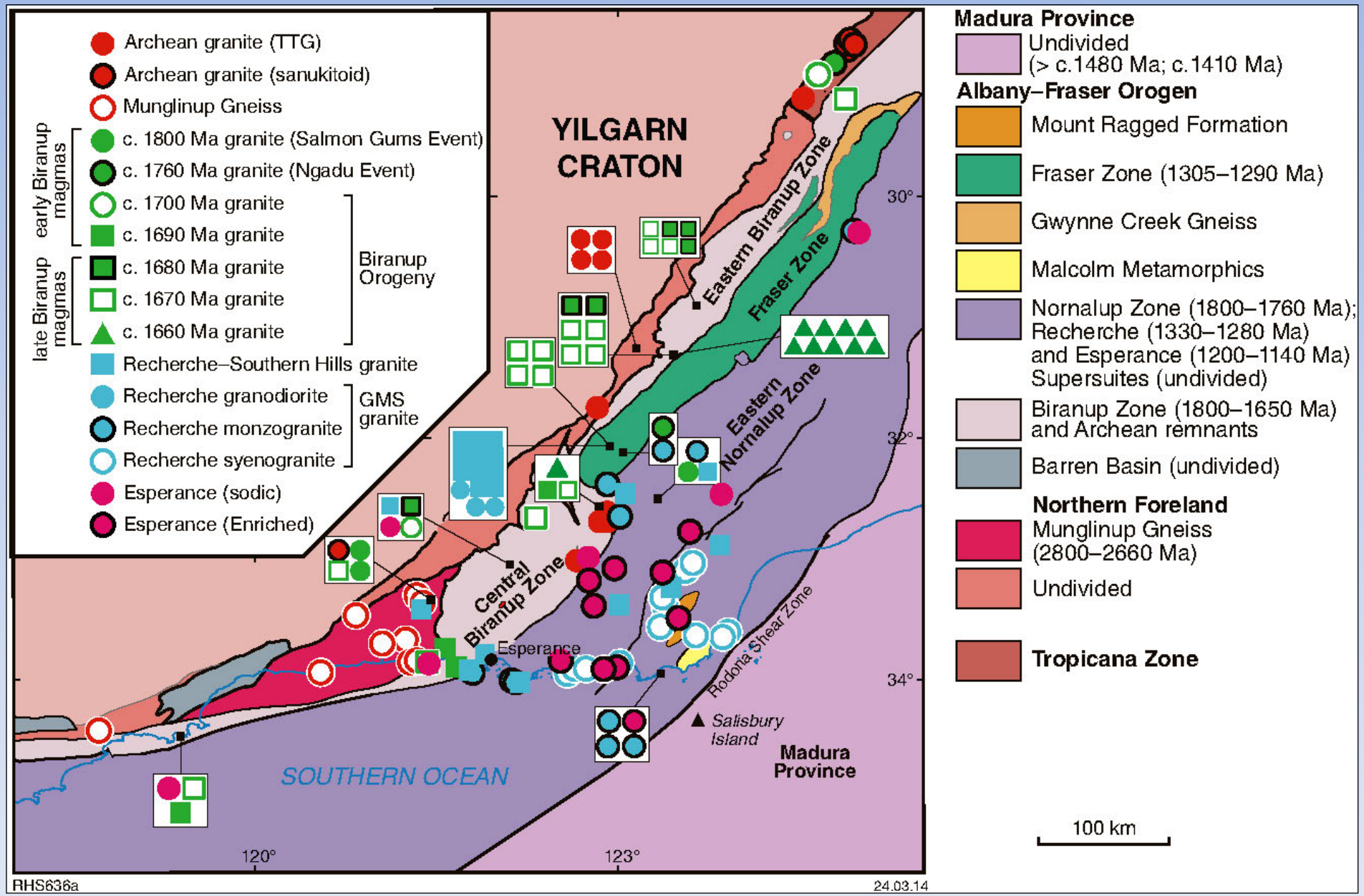
3) Despite the primitive compositions – show significantly greater evidence for crustal contamination than the 'main gabbro' of the Fraser Zone (also shown by difference in La/Nb ratio: Mt Malcolm <3, The Eye >3).

4) Re-Os isotopic data from sulphides gives model ages of ~ 1.82-1.71 Ga. This is clearly not dating the gabbro, but is dating the sulphur source – in this case, crustal sulphur from Biranup Orogeny aged material – a major component of the Arid Basin!



W. Maier personal communication

GRANITES

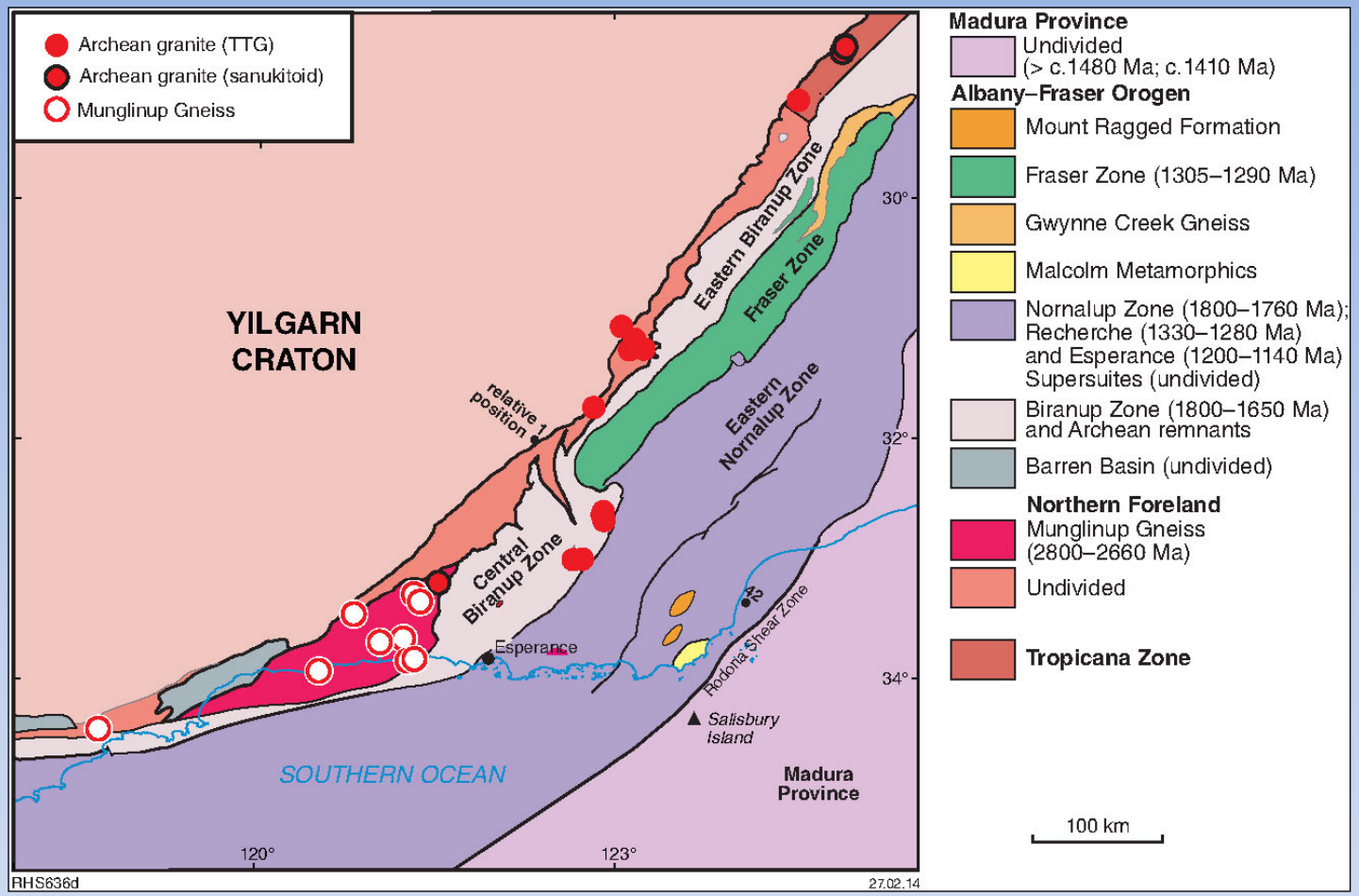

Archean granite (TTG)
Archean granite (sanukitoid)
Munglinup Gneiss
early Biranup magmas
c. 1800 Ma granite (Salmon Gums Event)
c. 1760 Ma granite (Ngadu Event)
c. 1700 Ma granite
c. 1690 Ma granite
late Biranup magmas
c. 1680 Ma granite
c. 1670 Ma granite
c. 1660 Ma granite
Biranup Orogeny
Recherche–Southern Hills granite
Recherche granodiorite
Recherche monzogranite
Recherche syenogranite
GMS granite
Esperance (sodic)
Esperance (Enriched)
YILGARN CRATON
Eastern Biranup Zone
Fraser Zone
Eastern Nornalup Zone
Central Biranup Zone
Esperance
Rodona Shear Zone
Salisbury Island
Madura Province
SOUTHERN OCEAN
30°
32°
34°
120°
123°
Madura Province
Undivided
(> c.1480 Ma; c.1410 Ma)
Albany–Fraser Orogen
Mount Ragged Formation
Fraser Zone (1305–1290 Ma)
Gwynne Creek Gneiss
Malcolm Metamorphics
Nornalup Zone (1800–1760 Ma);
Recherche (1330–1280 Ma)
and Esperance (1200–1140 Ma)
Supersuites (undivided)
Biranup Zone (1800–1650 Ma)
and Archean remnants
Barren Basin (undivided)
Northern Foreland
Munglinup Gneiss
(2800–2660 Ma)
Undivided
Tropicana Zone
100 km
RHS636a
24.03.14

1. Archean granites
2. c.1800 Ma granites; Salmon Gums Event
3. c.1760 Ma granites; Ngadju Event
4. c.1700 Ma granites
5. c. 1690 Ma granites
6. c. 1680 Ma granites
7. c. 1670 Ma granites
8. c. 1660 Ma granites
9. Recherche Supersuite - Stage I of the Albany–Fraser Orogeny
10. Esperance Supersuite - Stage II of the Albany–Fraser Orogeny

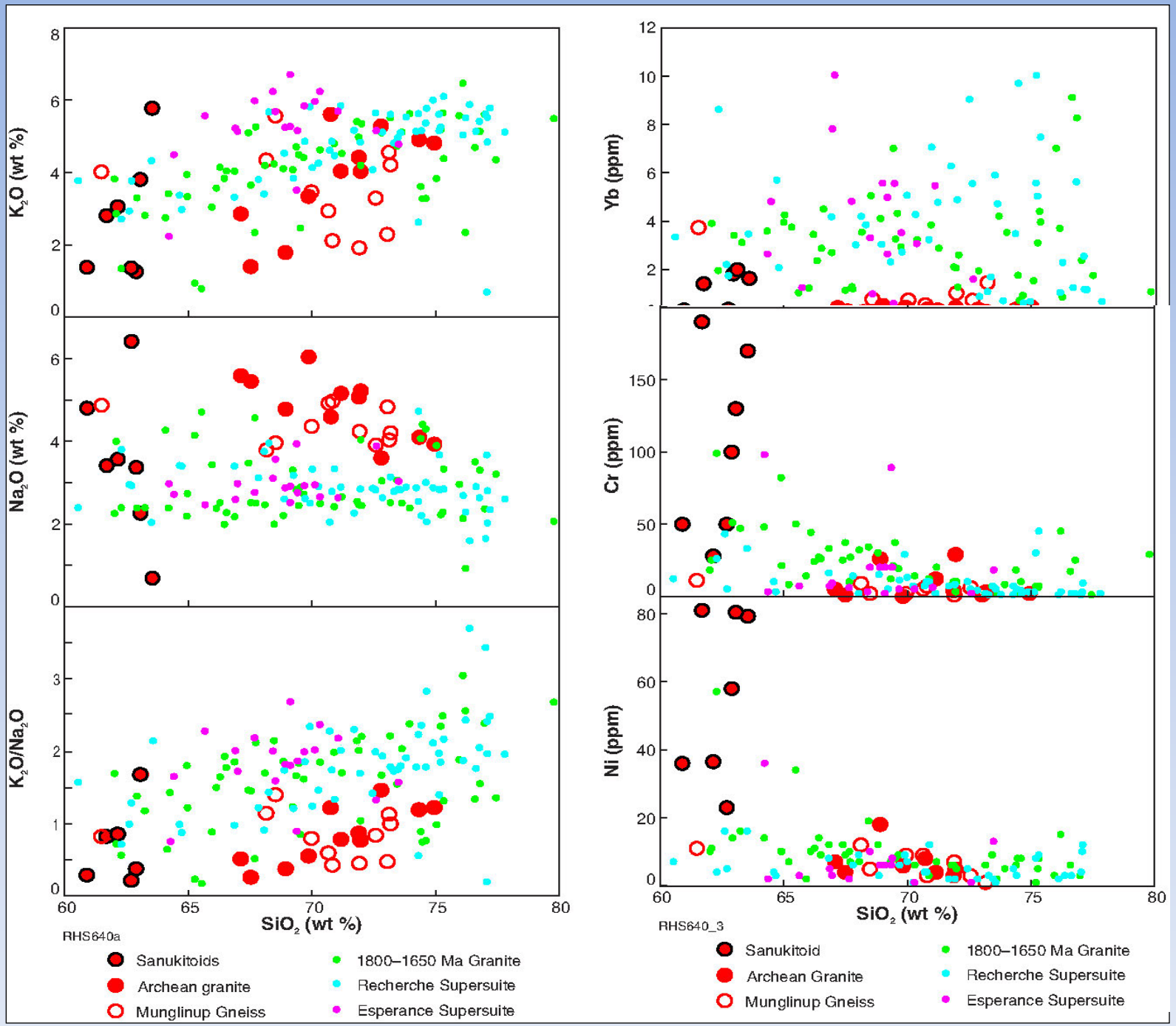
Early Biranup magmas

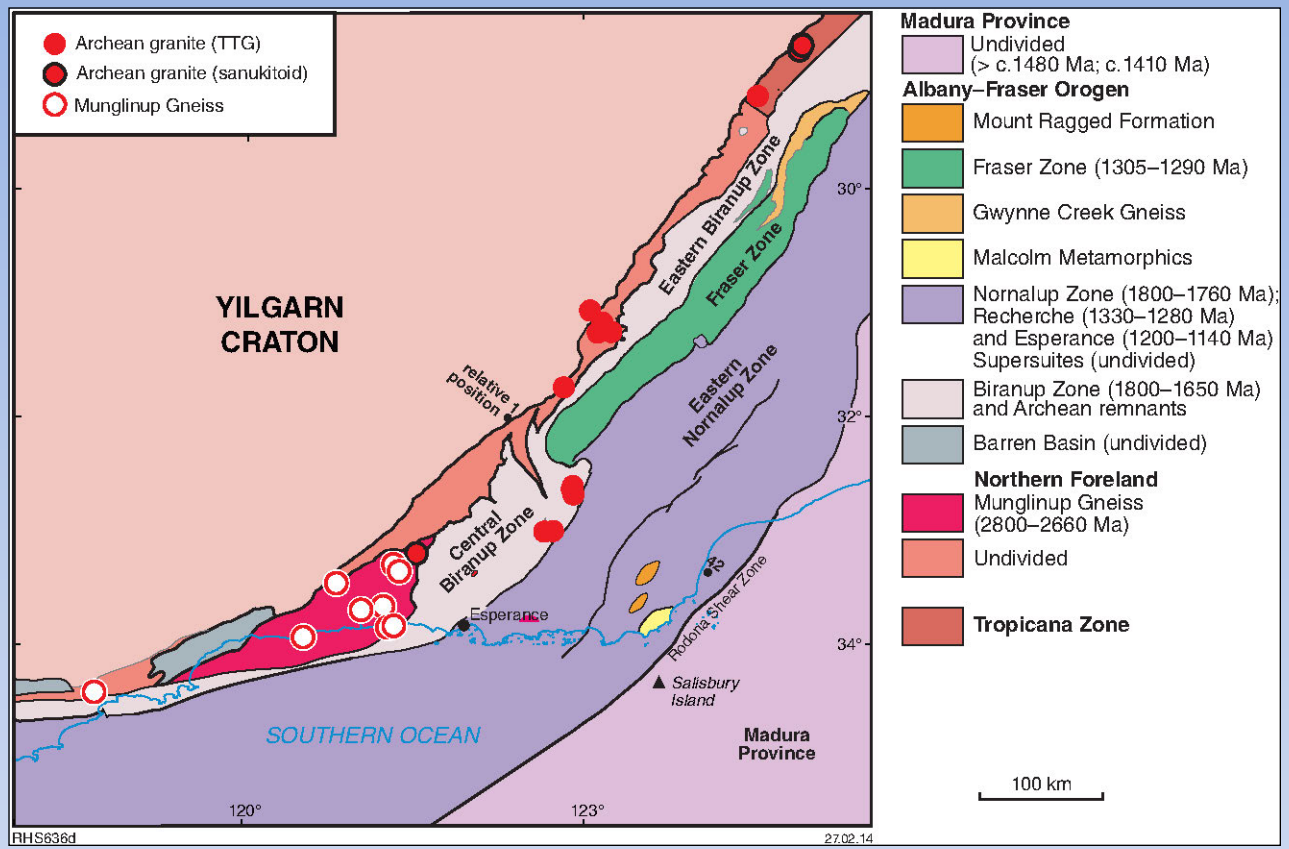
Late Biranup magmas

Biranup Orogeny

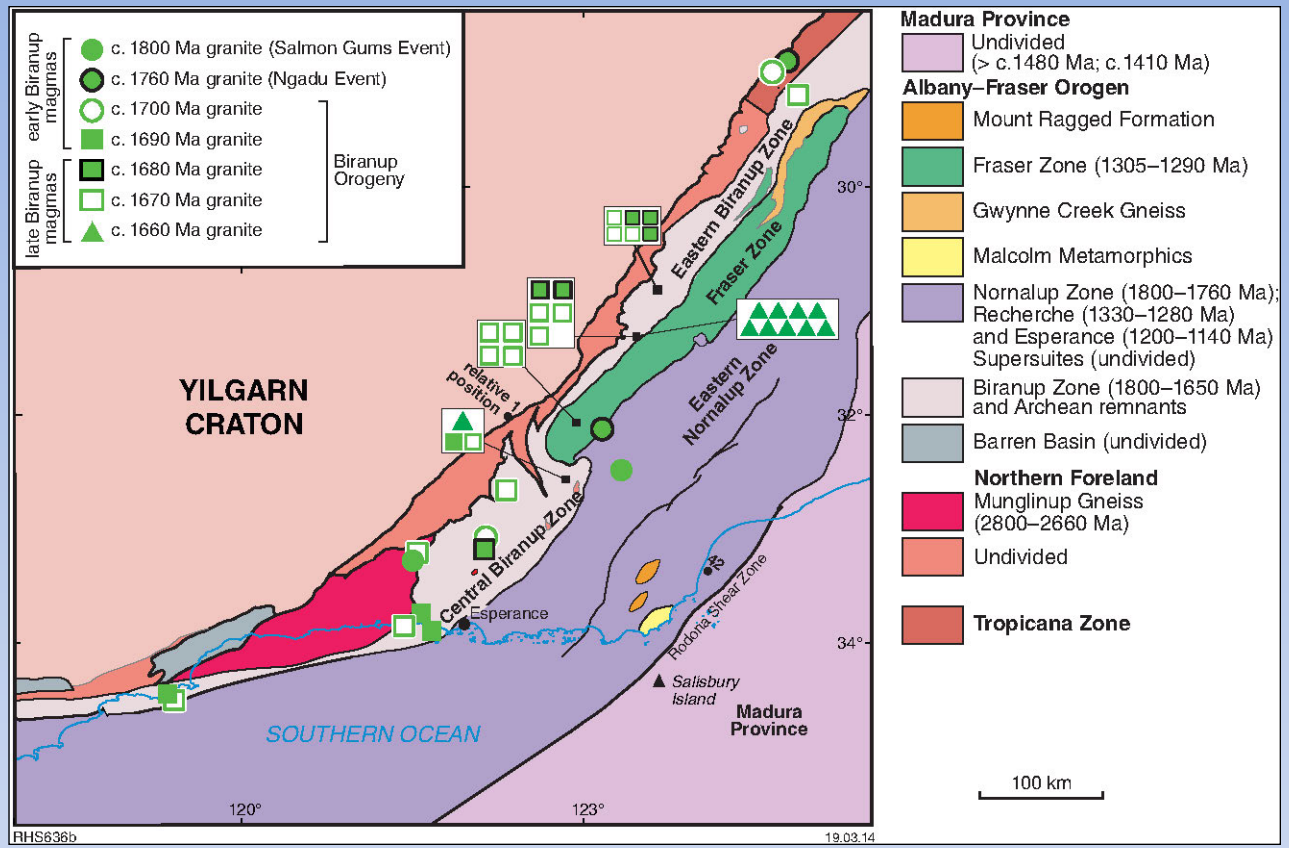


1a) Isolated fragments of Archean crust that remains in the Northern Foreland, Tropicana Zone and Biranup Zone can be divided between granites representative of the TTG series and Archean sanukitoids.


K2O (wt %)
Na2O (wt %)
K2O/Na2O
SiO2 (wt %)
RHS640a
Sanukitoids
Archean granite
Munglinup Gneiss
1800–1650 Ma Granite
Recherche Supersuite
Esperance Supersuite
Yb (ppm)
Cr (ppm)
Ni (ppm)
SiO2 (wt %)
RHS640_3
Sanukitoid
Archean Granite
Munglinup Gneiss
1800–1650 Ma Granite
Recherche Supersuite
Esperance Supersuite



1b) The presence of sanukitoids suggests a subduction-modified Archean mantle source and hence probably also close proximity to an Archean crustal plate boundary.


early Biranup magmas
c. 1800 Ma granite (Salmon Gums Event)
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c. 1700 Ma granite
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late Biranup magmas
c. 1680 Ma granite
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Biranup Orogeny
YILGARN CRATON
relative 1 position
Eastern Biranup Zone
Fraser Zone
Eastern Nornalup Zone
Central Biranup Zone
Esperance
Rodonia Shear Zone
Salisbury Island
Madura Province
SOUTHERN OCEAN
30°
32°
34°
120°
123°
RHS636b
19.03.14
Madura Province
Undivided (> c.1480 Ma; c.1410 Ma)
Albany–Fraser Orogen
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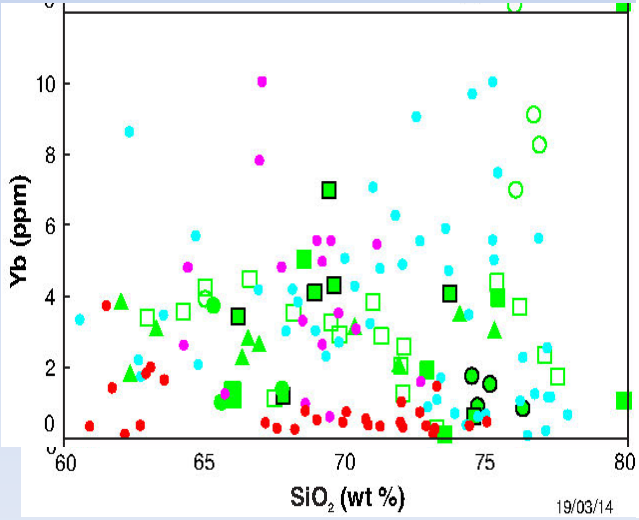
Undivided
Tropicana Zone
100 km


Yb (ppm)
0
2
4
6
8
10
60
65
70
75
80
SiO2 (wt %)
19/03/14


Archean granite
early Biranup magmas
1800 Ma granite (Salmon Gums Event)
1760 Ma granite (Ngadu Event)
1700 Ma granite
1690 Ma granite
late Biranup magmas
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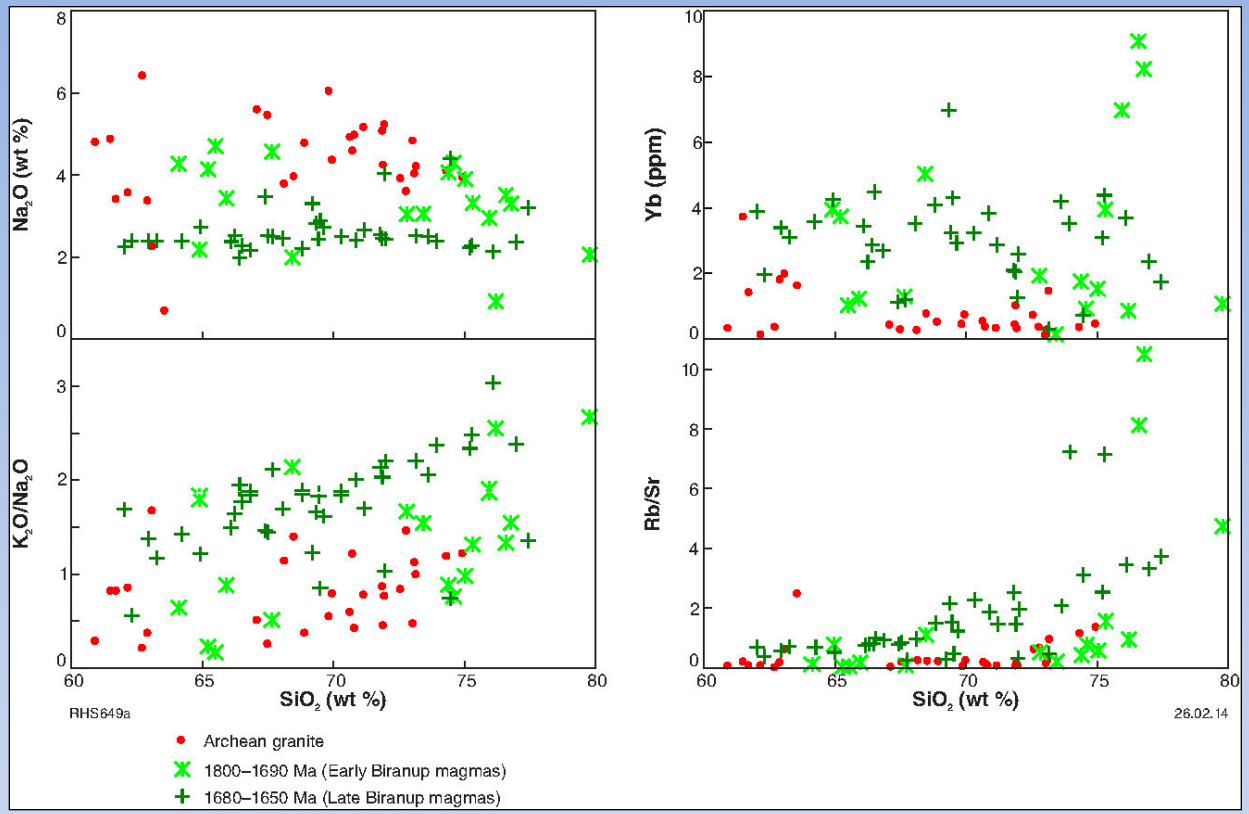
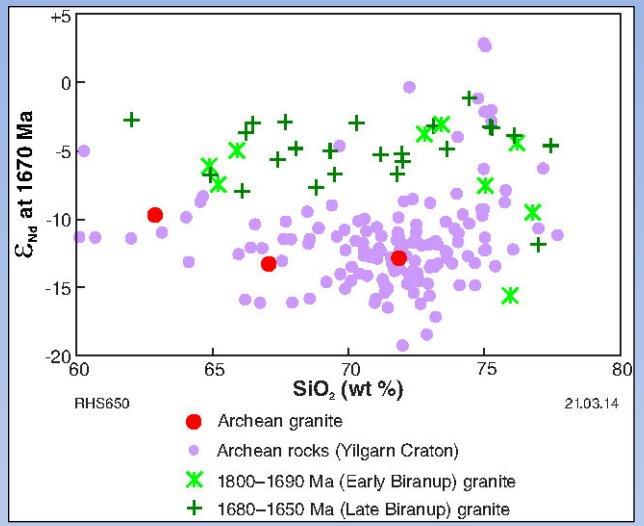
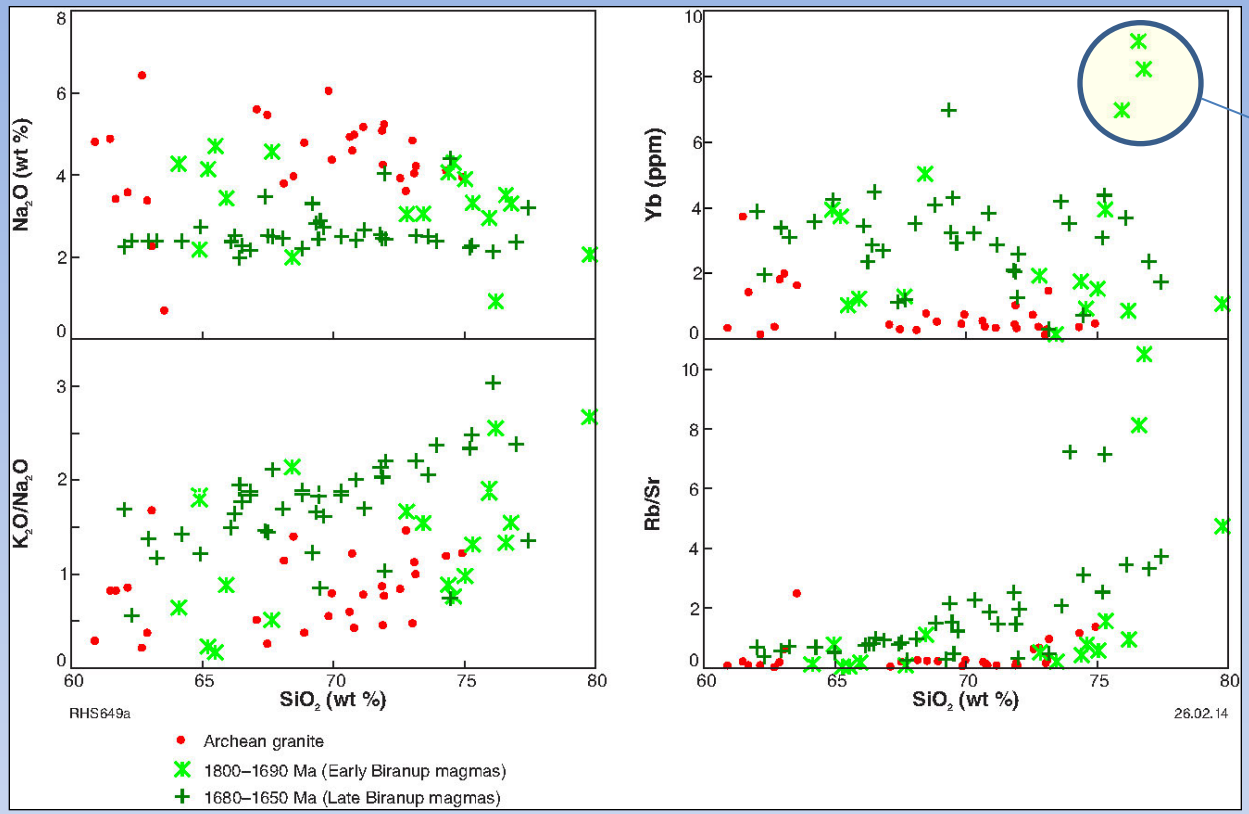
Biranup Orogeny
Recherche Supersuite
Esperance Supersuite

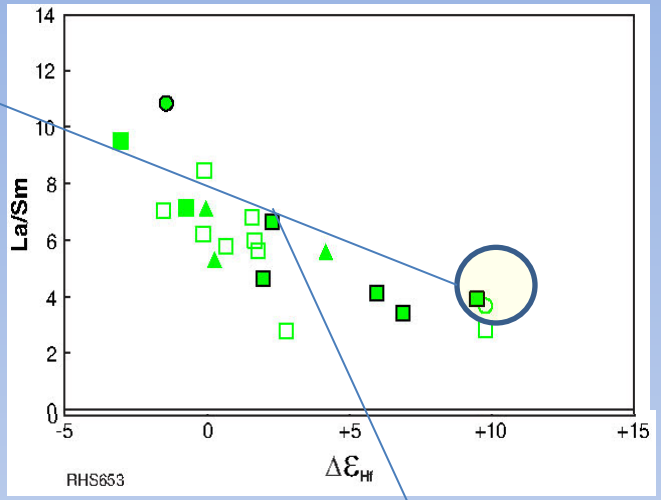


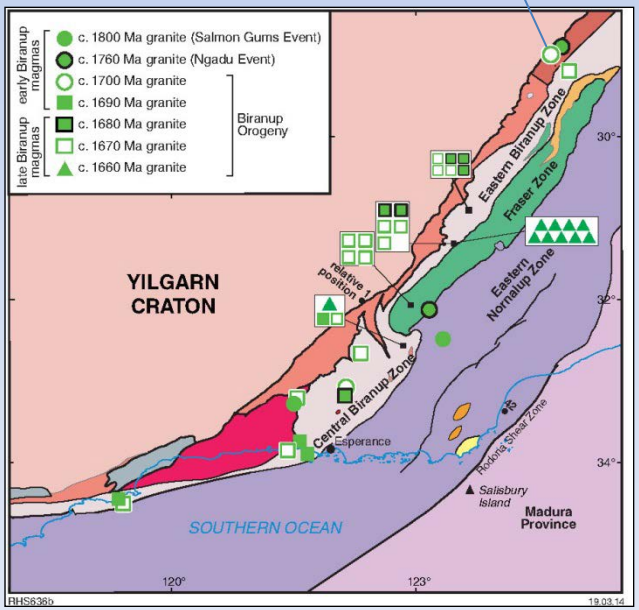


2) Geochemical and isotopic data suggest that a large proportion (possibly the majority) of AFO crust (at least the Biranup Zone) is multiply reworked Archean crust, with juvenile mantle additions (e.g. Kirkland et al). These reworking events progressively mask, but do not destroy, the Archean compositional heritage of the crust.

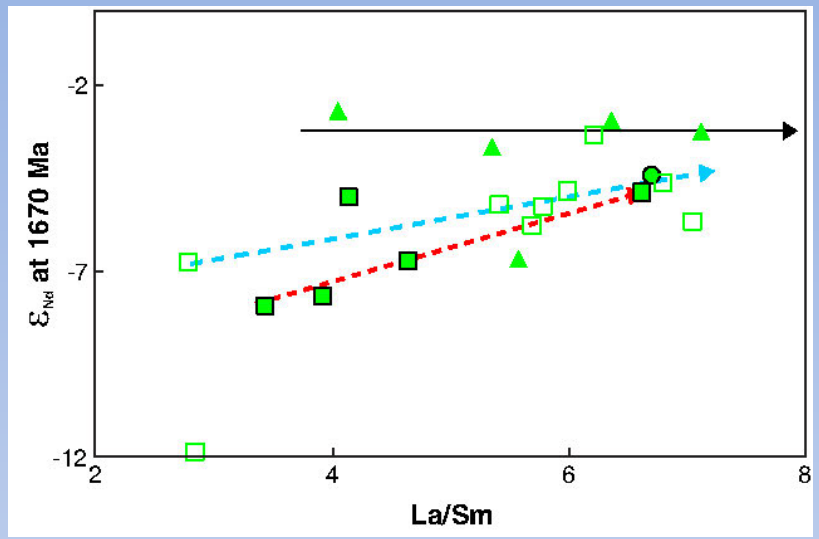
‘Late Biranup’ magmatism (c. 1680 to c. 1650 Ma) heralds a change in the style of crustal evolution, involving recycling of previously recycled Archean felsic crust, with more significant mantle additions.

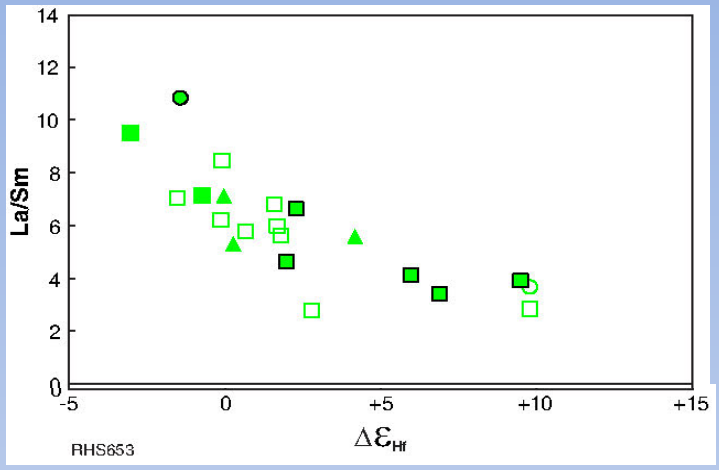


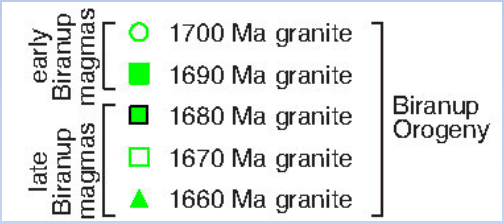


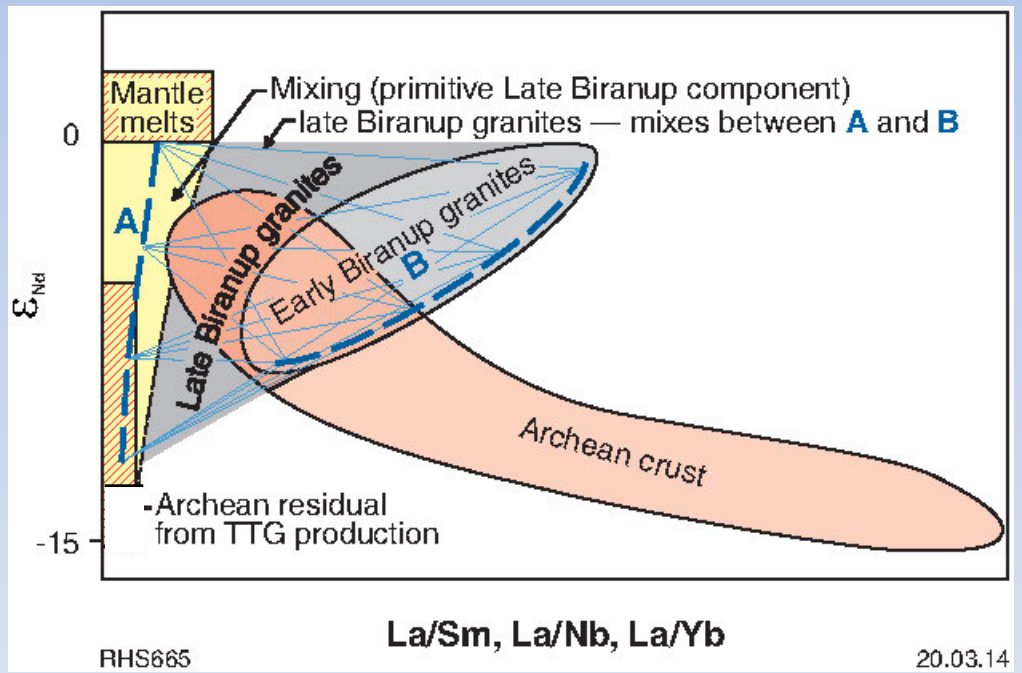


3) Bobbie Point - A-type compositions reflecting very high-temperature melting of an Archean crustal source itself with a pre-history of melting at depths within the garnet stability field. But further melting to form the Bobbie Point granites was at higher crustal depth where garnet was no longer stable.

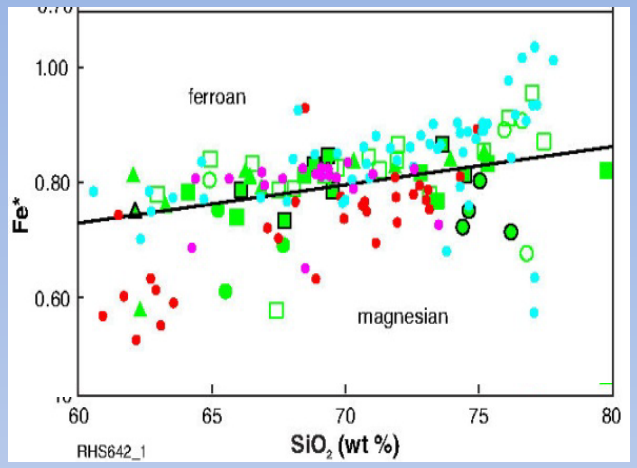


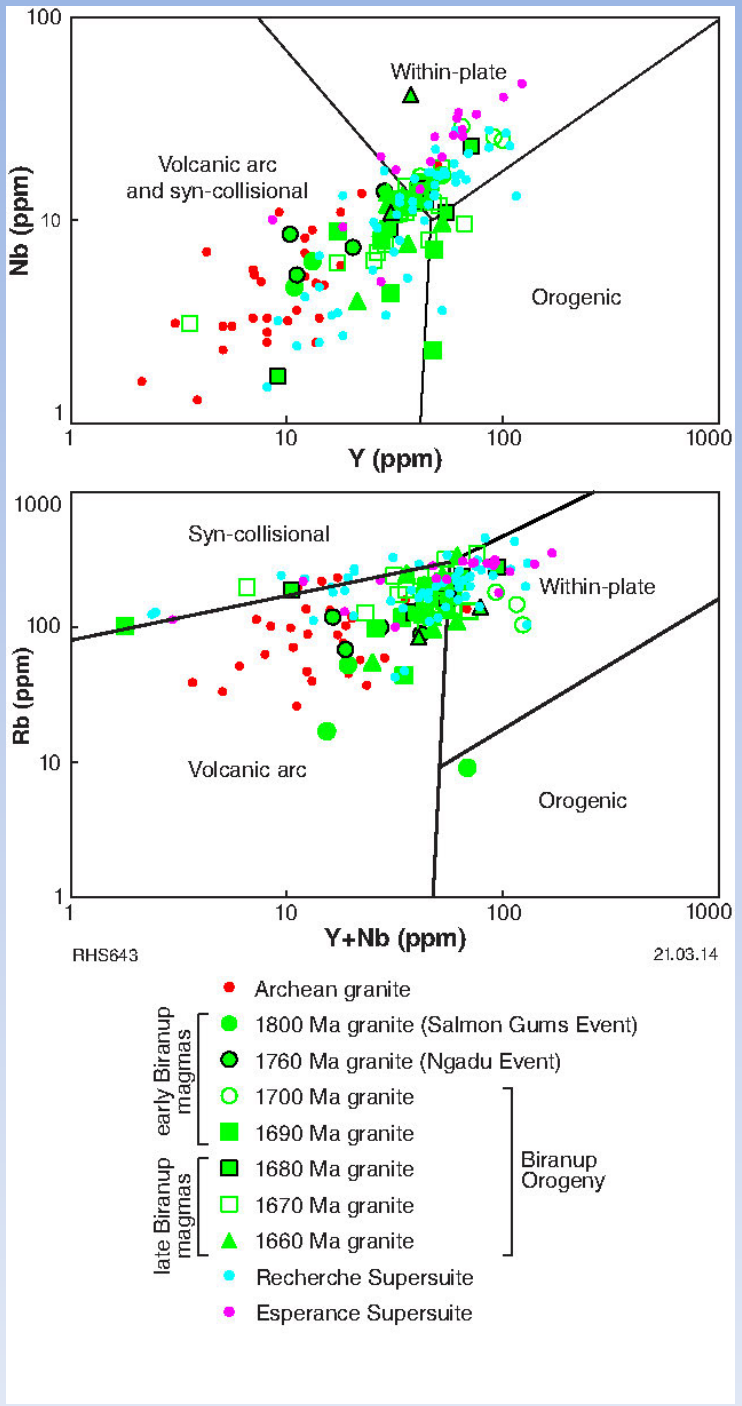






4) Late Biranup magmas – source includes the deep refractory crust left behind after extraction of Archean TTG – but again, re-melting was likely at lower P and much higher T.





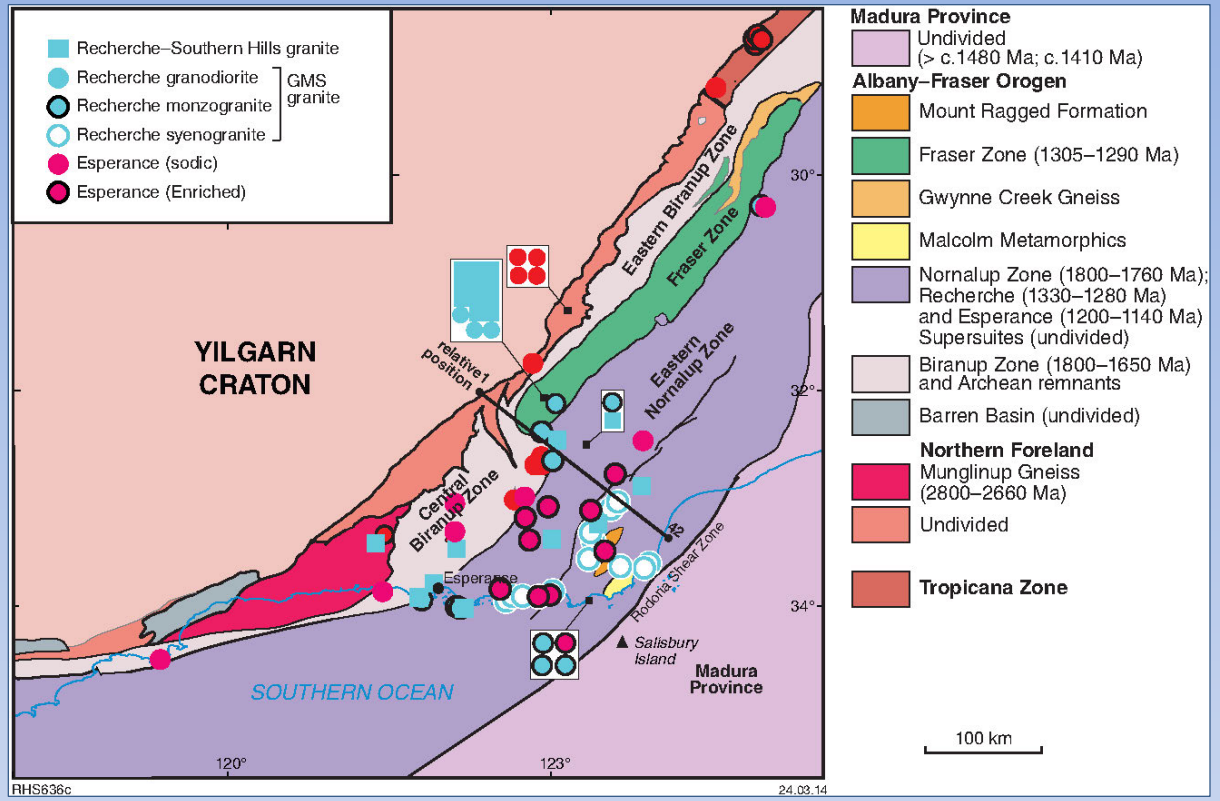
5) A common theme for the Biranup Orogeny is crustal recycling, more or less continuous mantle addition, with deep crustal source components elevated to higher crustal levels and melted at high temperatures. This is also reflected in a transition to more Fe-rich and ‘A-type’ characteristics.

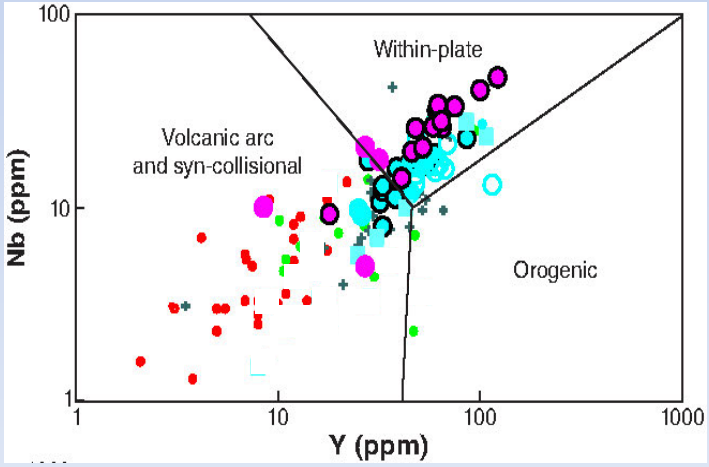
Dominant tectonic regime is probably extensional

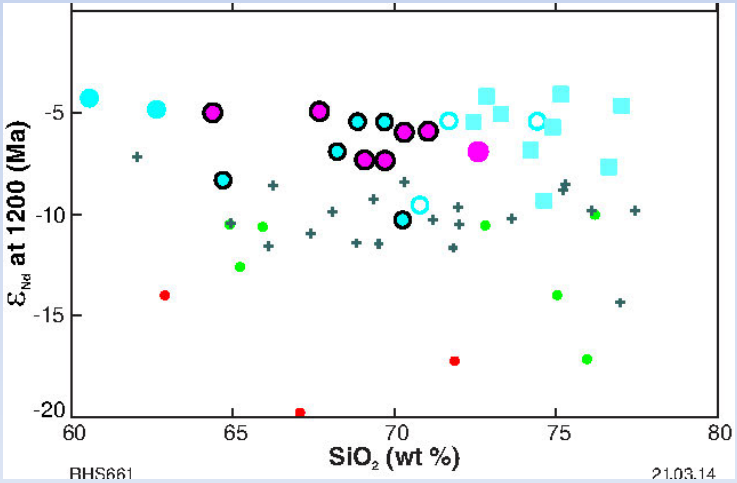
Albany–Fraser Orogeny

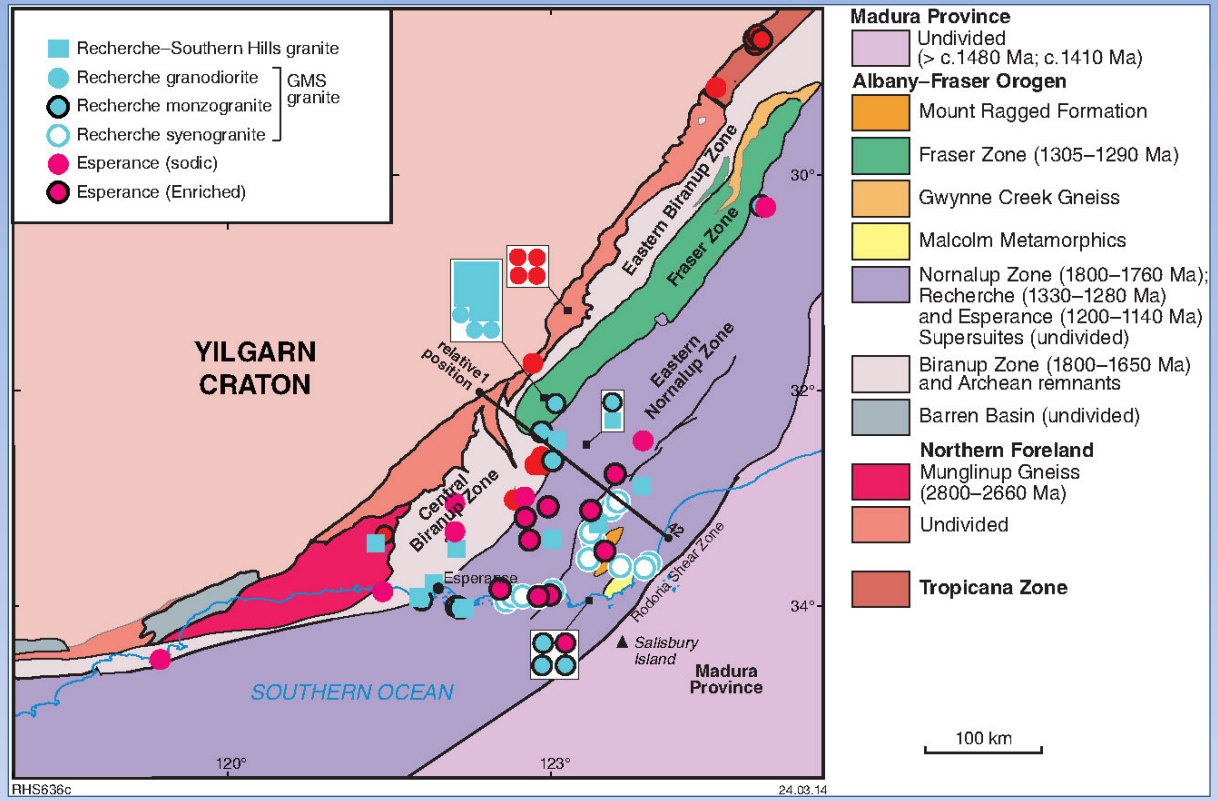
Stage I (1345–1260 Ma)
[Recherche Supersuite]

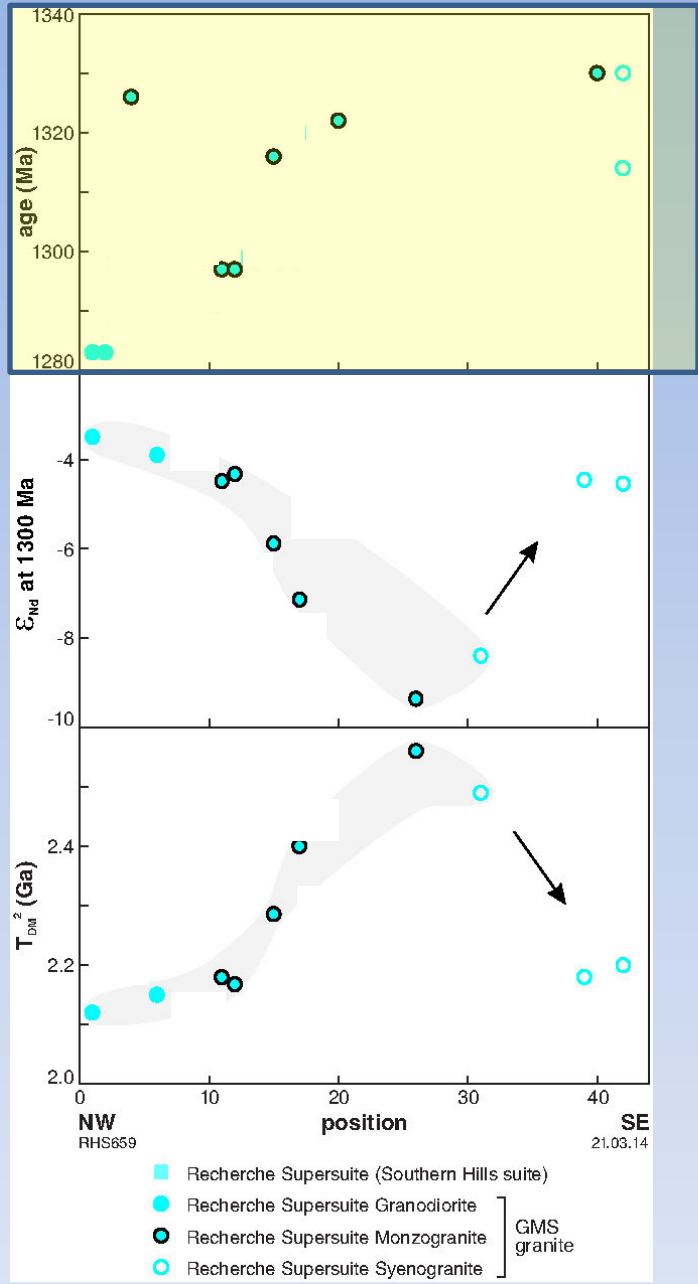
Stage II (1215–1140 Ma)
[Esperance Supersuite]



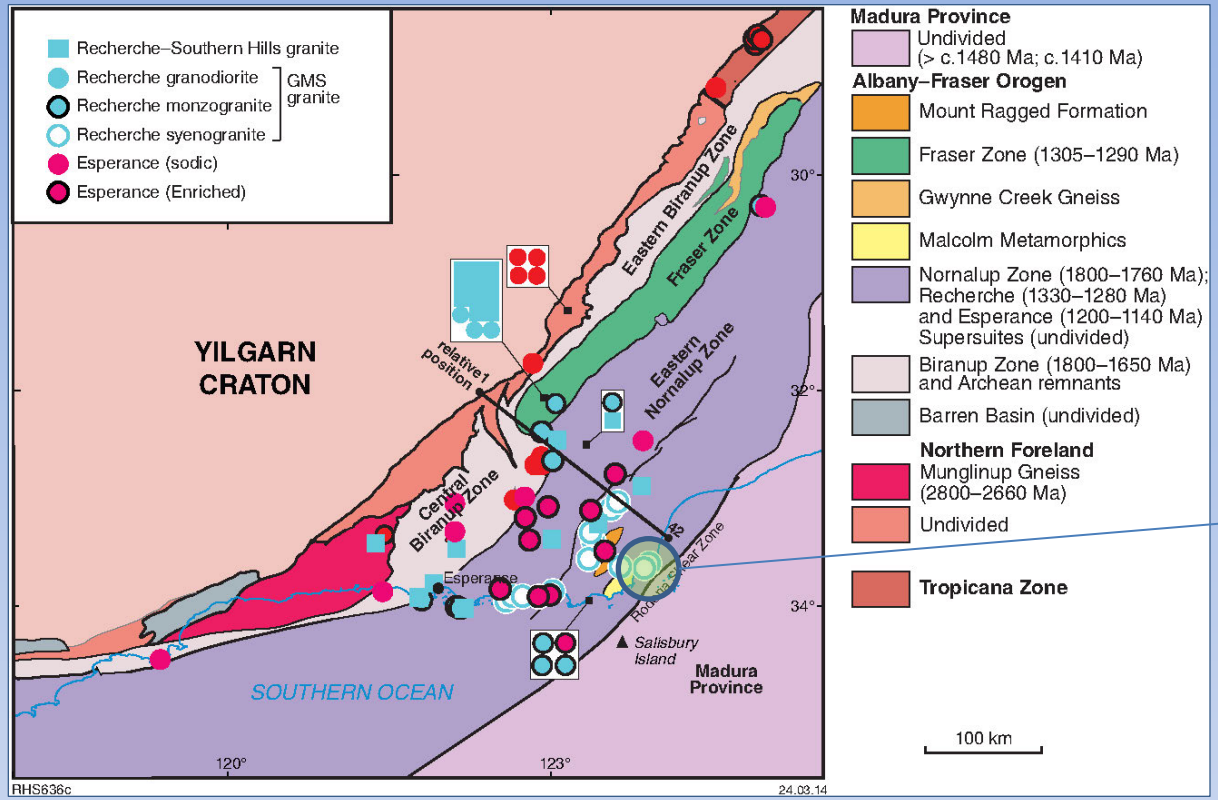


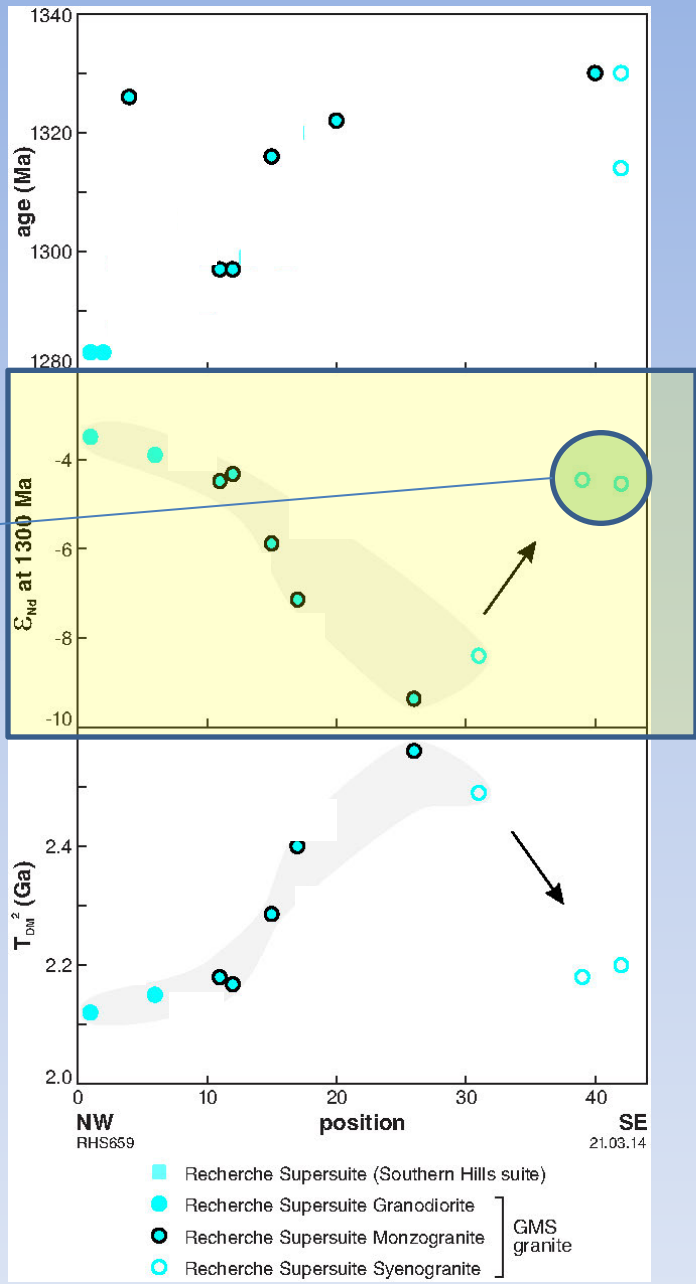




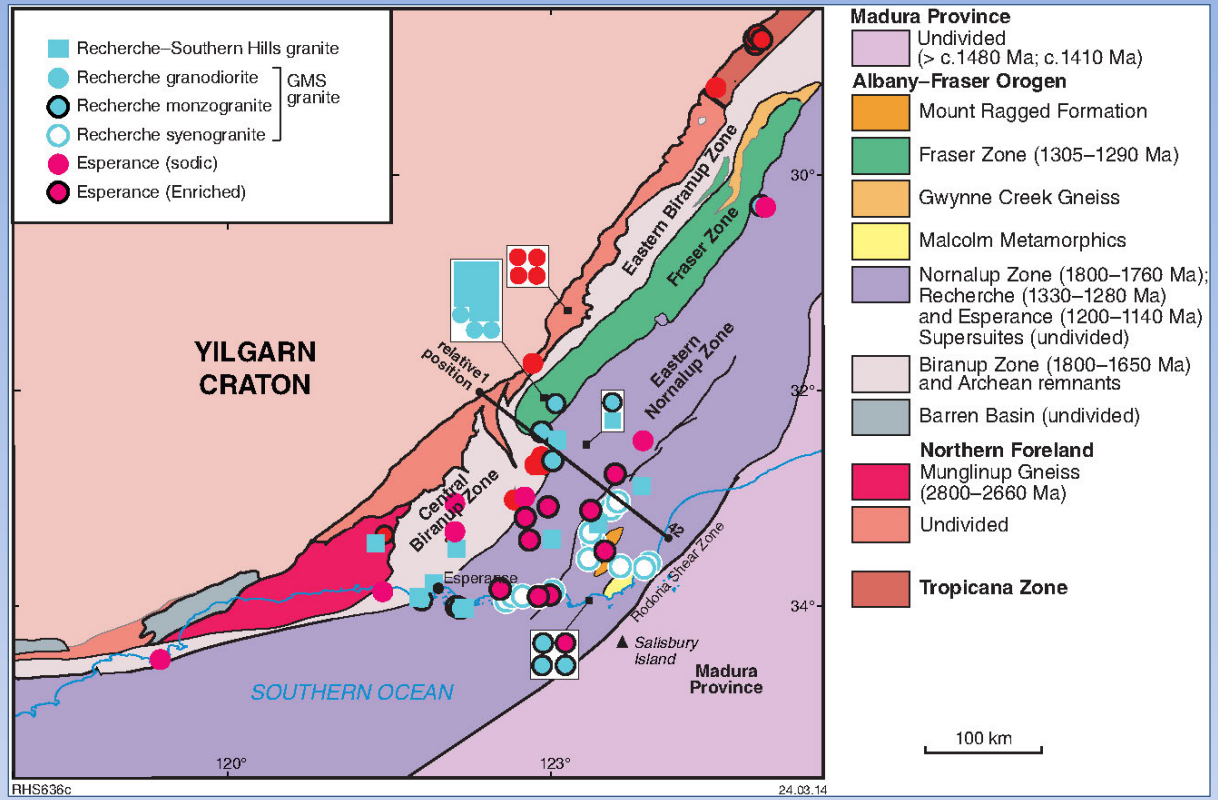


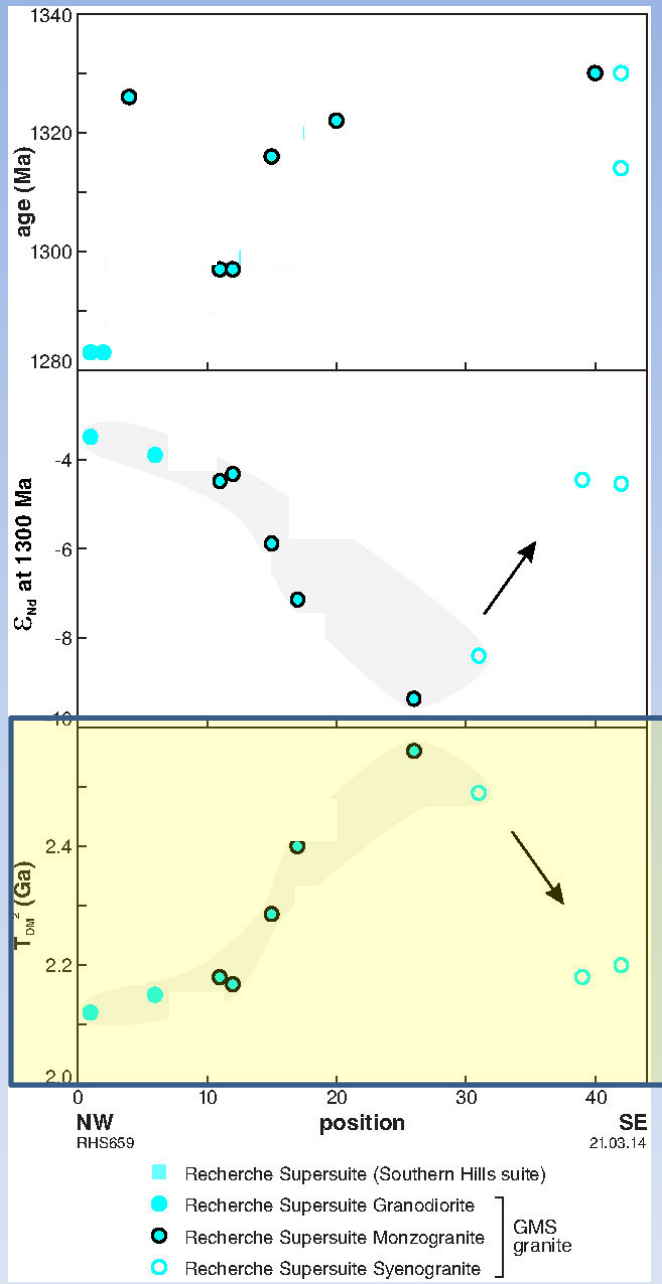
6) Like earlier granites, the Recherche granites represent mixing between a crustal source (ultimately recycled Archean) and mantle material similar to that which formed the Fraser gabbro (Fraser Zone). This occurred in an orogeny wide lower crustal hot zone and the magmatically active portion migrated from southeast to northwest with decreasing age – and we see systematic compositional variations with time and with location.





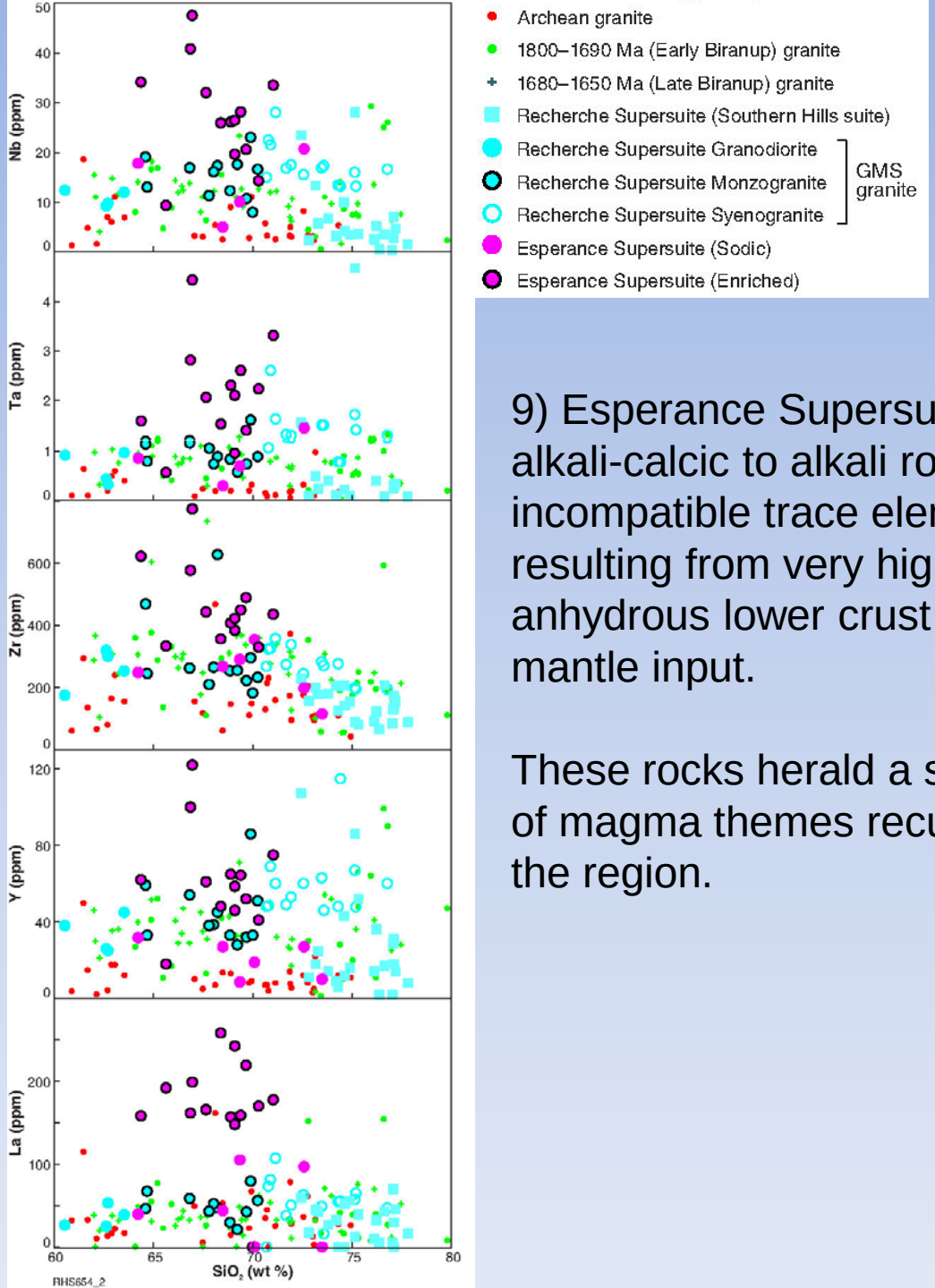
7) The Recherche granites overstep the transition between the Nornalup Zone of the Albany–Fraser Orogen and the tectonically juxtaposed Madura Province, which must have been juxtaposed before the earliest magmatism at c. 1330 Ma.





8) A sharp change in the isotopic composition of the GMS magmas across this boundary reflects a significant change in basement composition that also marks the south-eastern edge of reworked Archean.

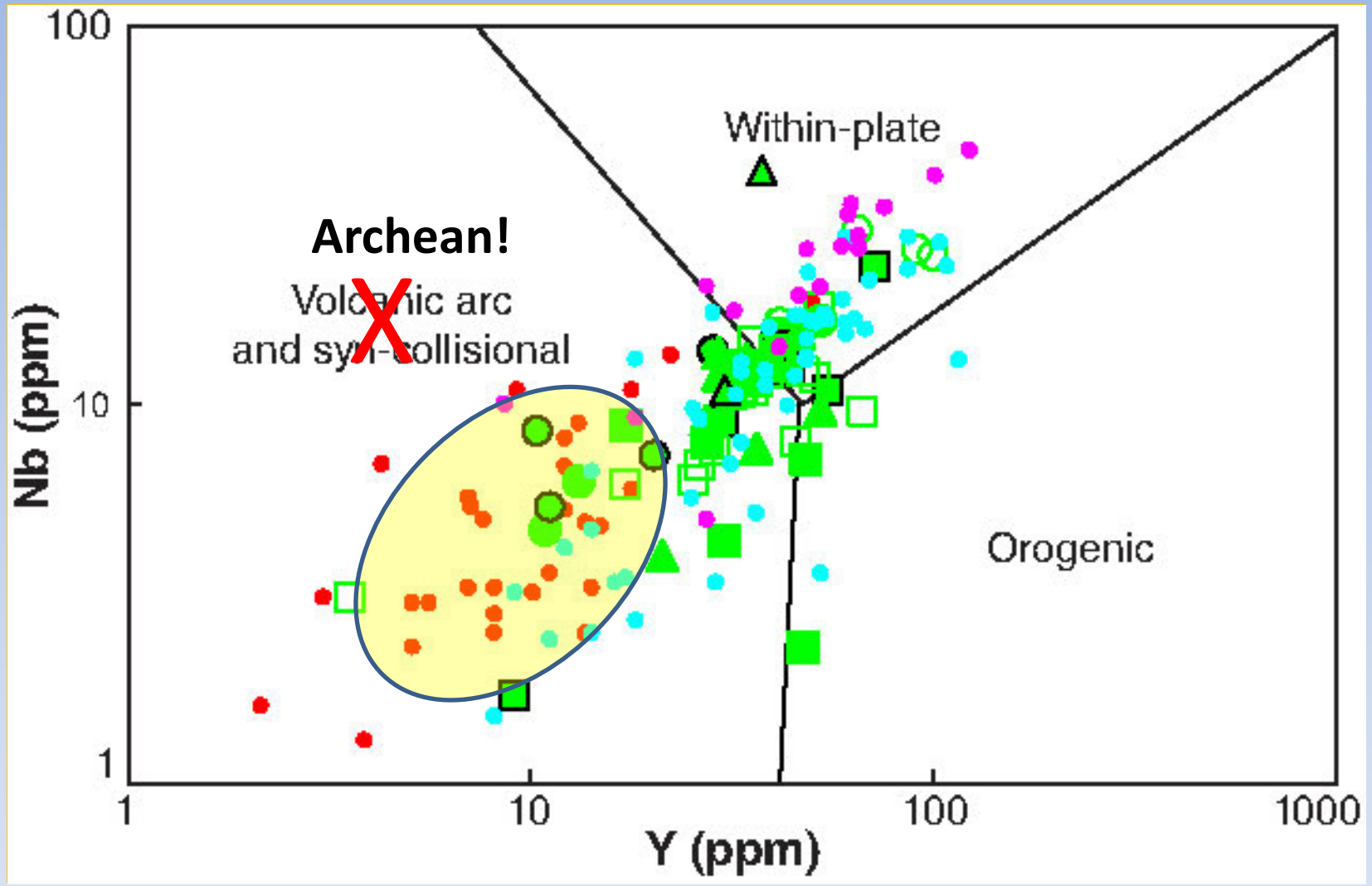
We suggests this stage reflects either the development of a distal back arc (Fraser Zone) or post-accretionary collapse following obduction of the Madura Province



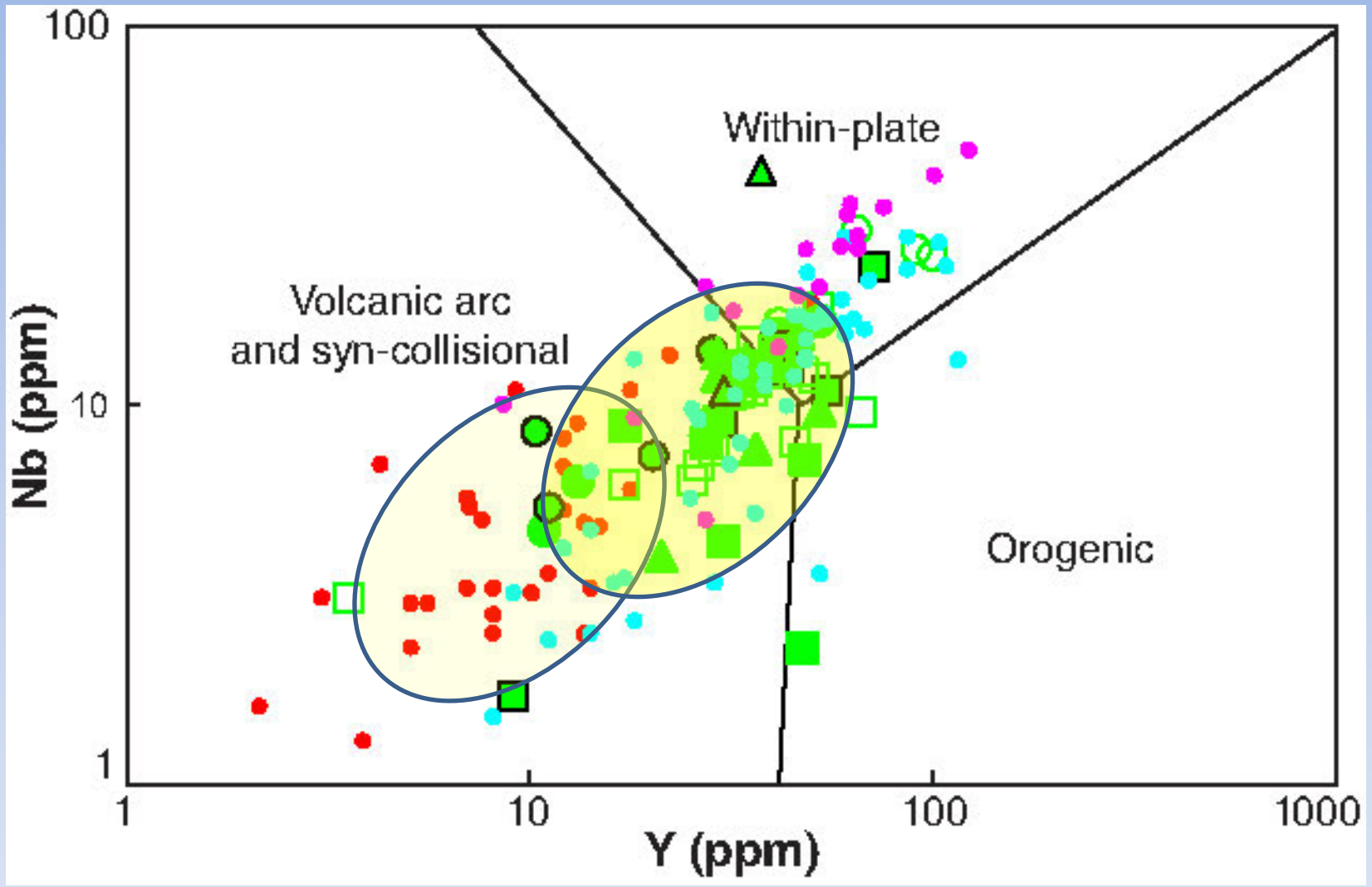
9) Esperance Supersuite granites are mainly ferroan, alkali-calcic to alkali rocks with strong enrichments in incompatible trace elements. They are A-type magmas resulting from very high temperature melting of anhydrous lower crust in association with significant mantle input.

These rocks herald a significant extension or culmination of magma themes recurring throughout the evolution of the region.

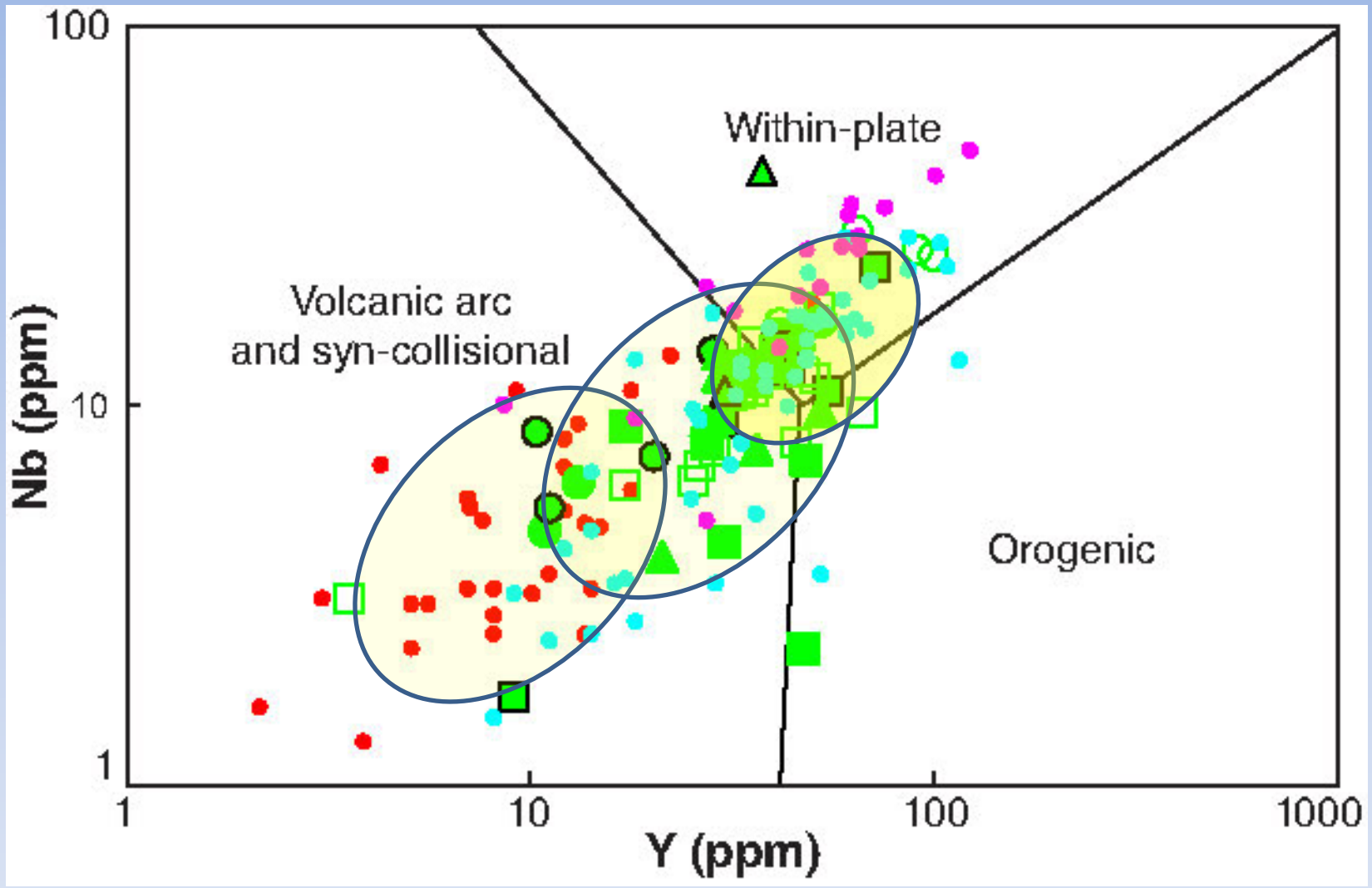
Archean (in the AFO)



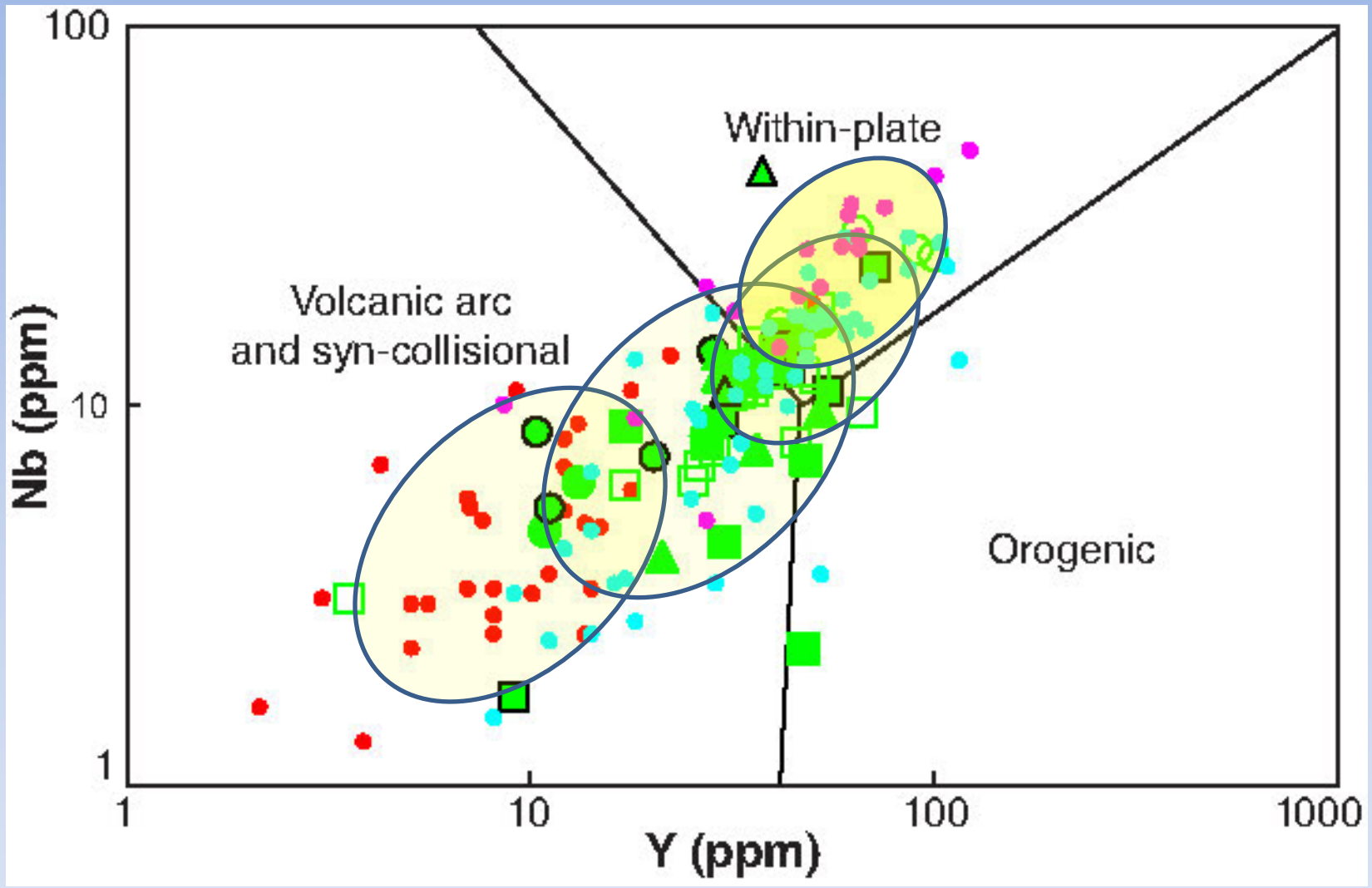
Biranup Zone (1800-1650 Ma)



Albany-Fraser Orogeny (I)



Albany-Fraser Orogeny (II)



Some general themes with decreasing age

1) Archean crustal signature is progressively diluted through REWORKING and regular MANTLE INPUT

2) Crustal sources become drier (more refractory) – crustal-melt component becomes more evolved

3) Melting is probably occurring at lower pressures

4) Melting occurs at higher temperatures

Coincidence of mantle source input and melting of originally deep crustal sources at shallower crustal depths suggests magmatism accompanied periods of crustal extension – and our current models would suggest continuous extension of the Yilgarn margin throughout the Biranup Orogeny (e.g. Spaggiari et al., 2014).

There are no magmatic suites that have a strong subduction flavour