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

# Exposing the Eucla basement: what separates the Albany–Fraser Orogen and the Gawler Craton?

## PART 2

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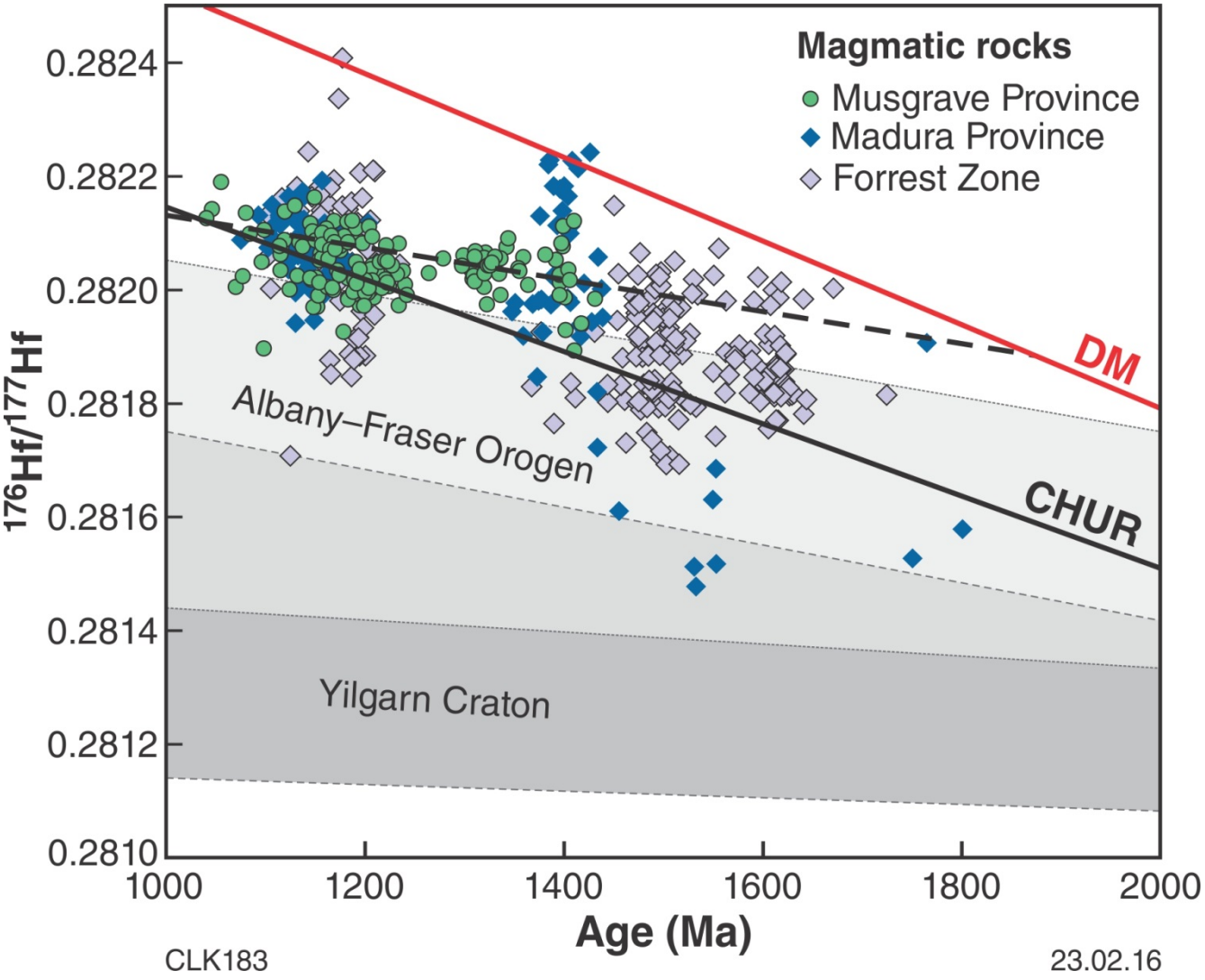
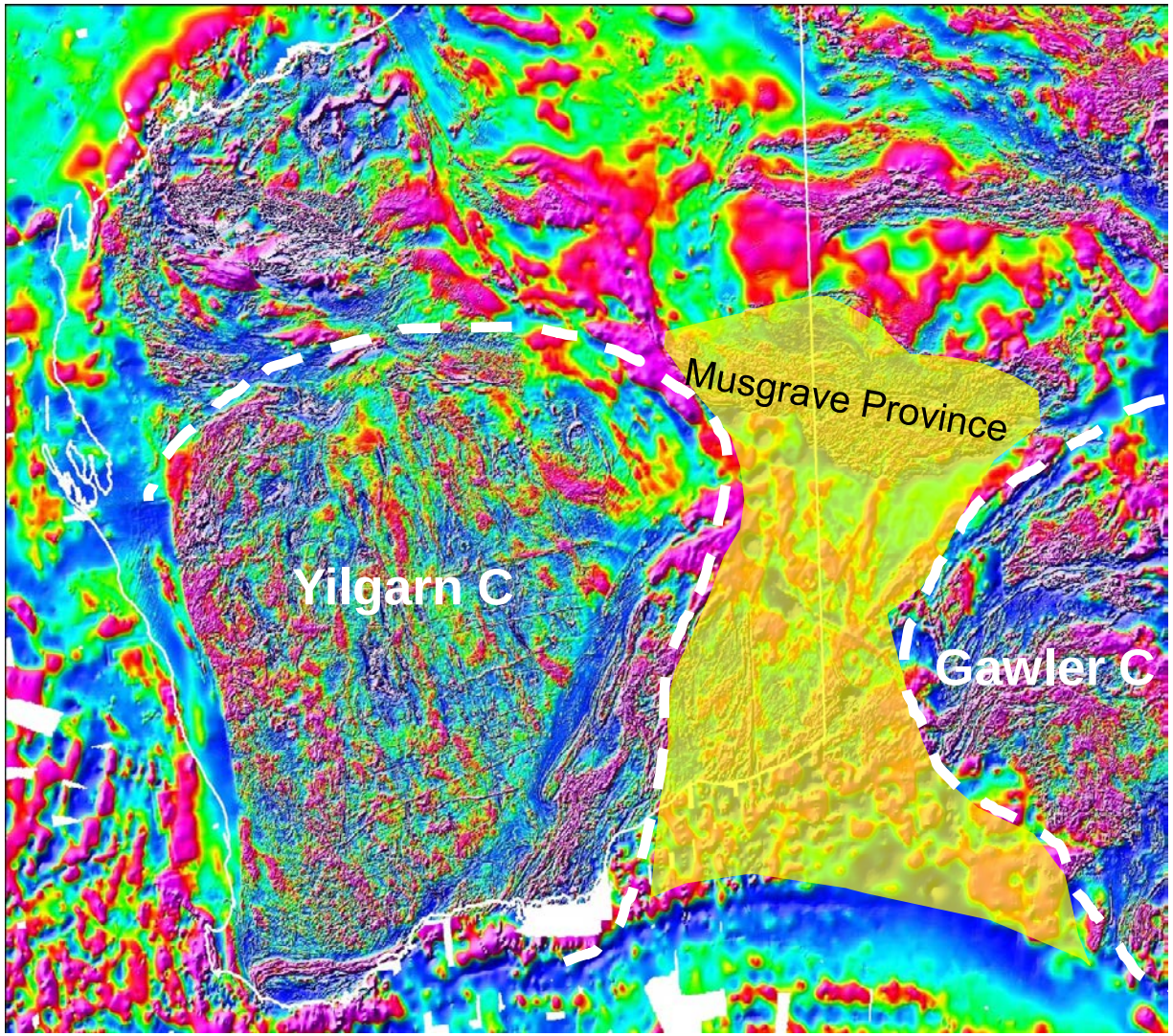
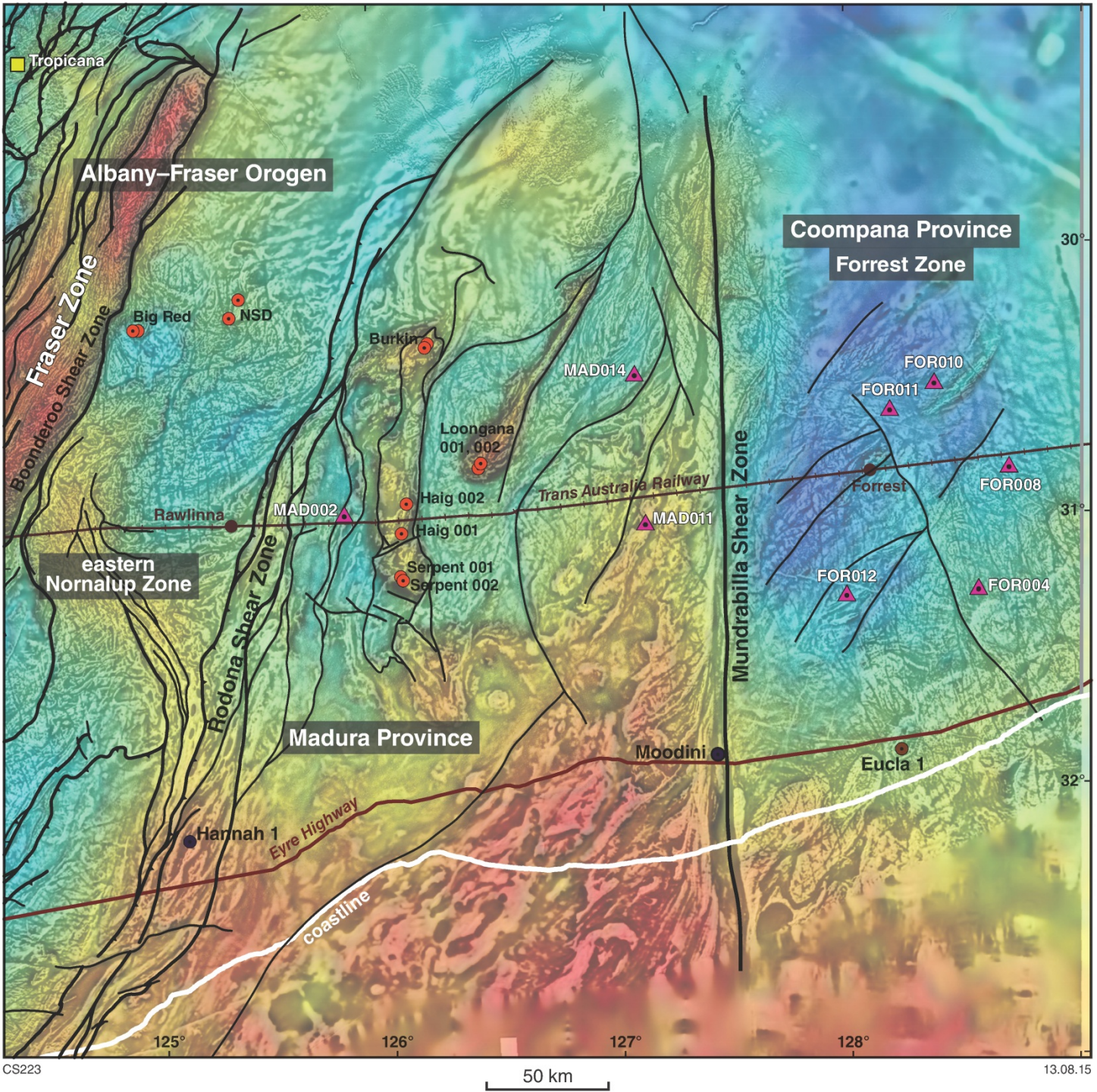
EXPLORATION INCENTIVE SCHEME

# Forrest Zone, Madura Province and Musgrave Province developed on the same piece of juvenile mafic (oceanic!) crust created at c. 1950 Ma



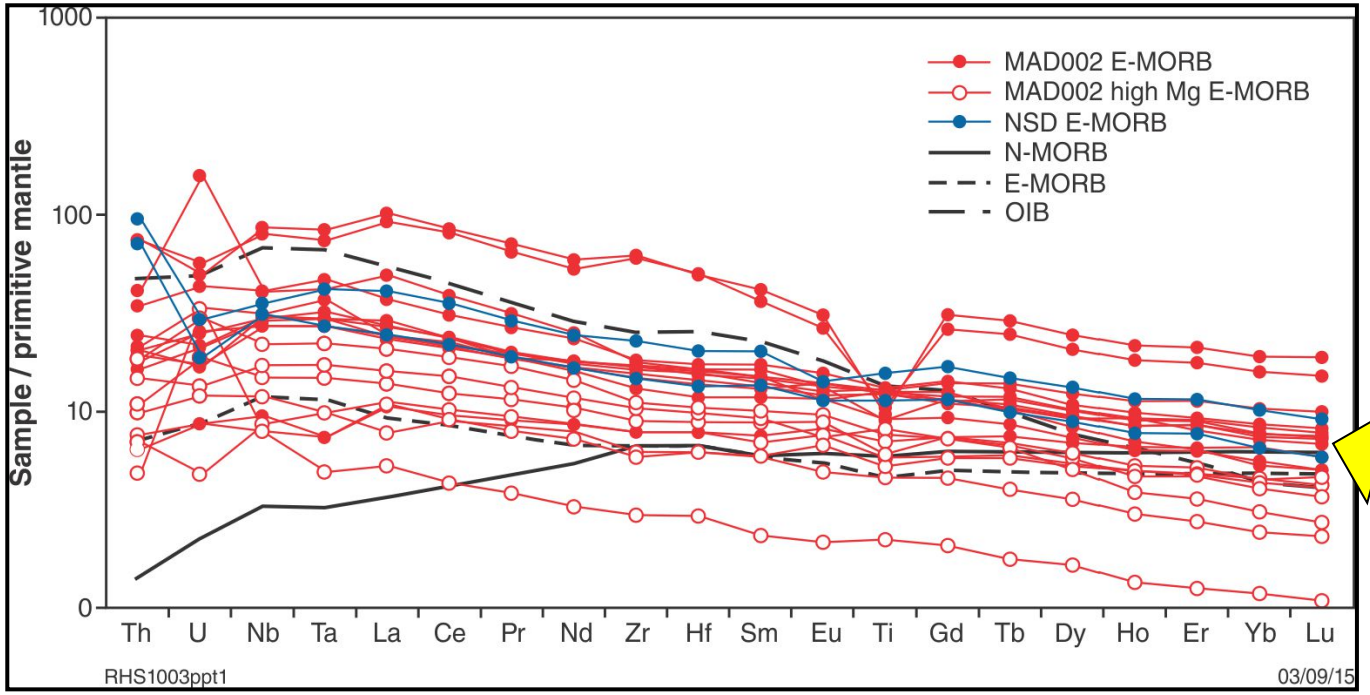



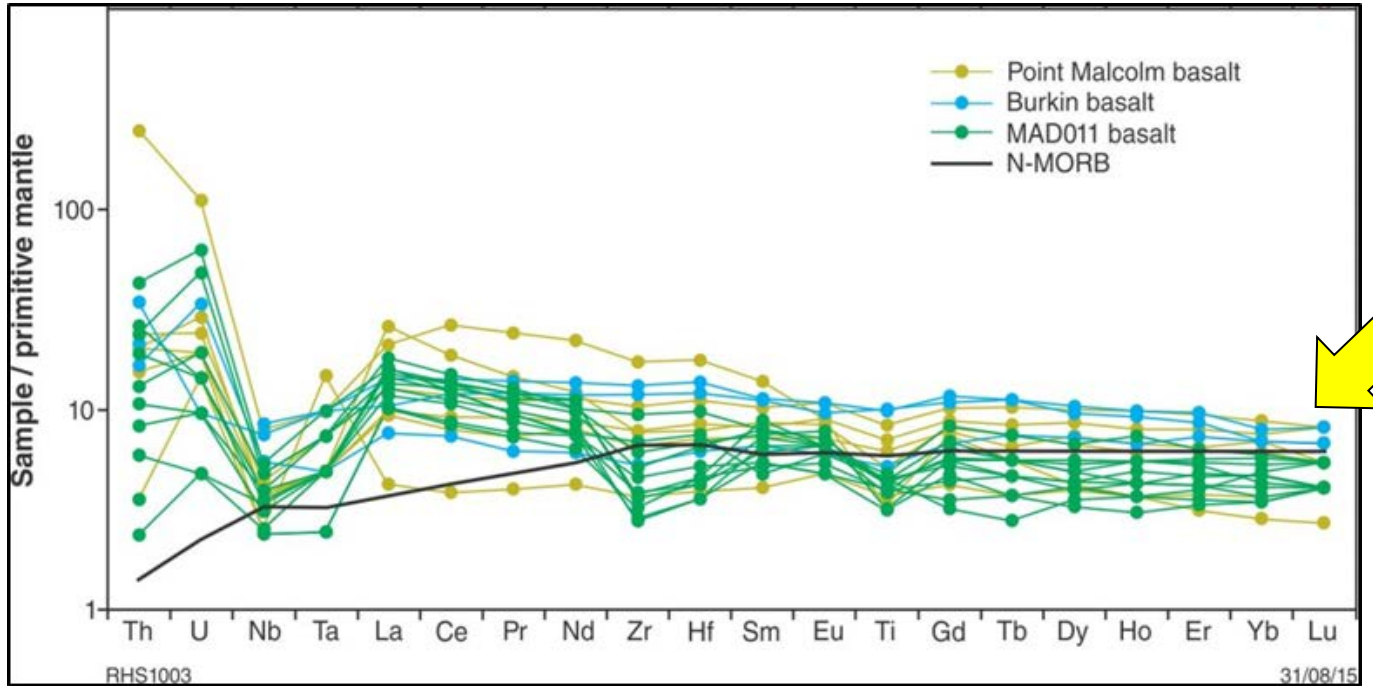


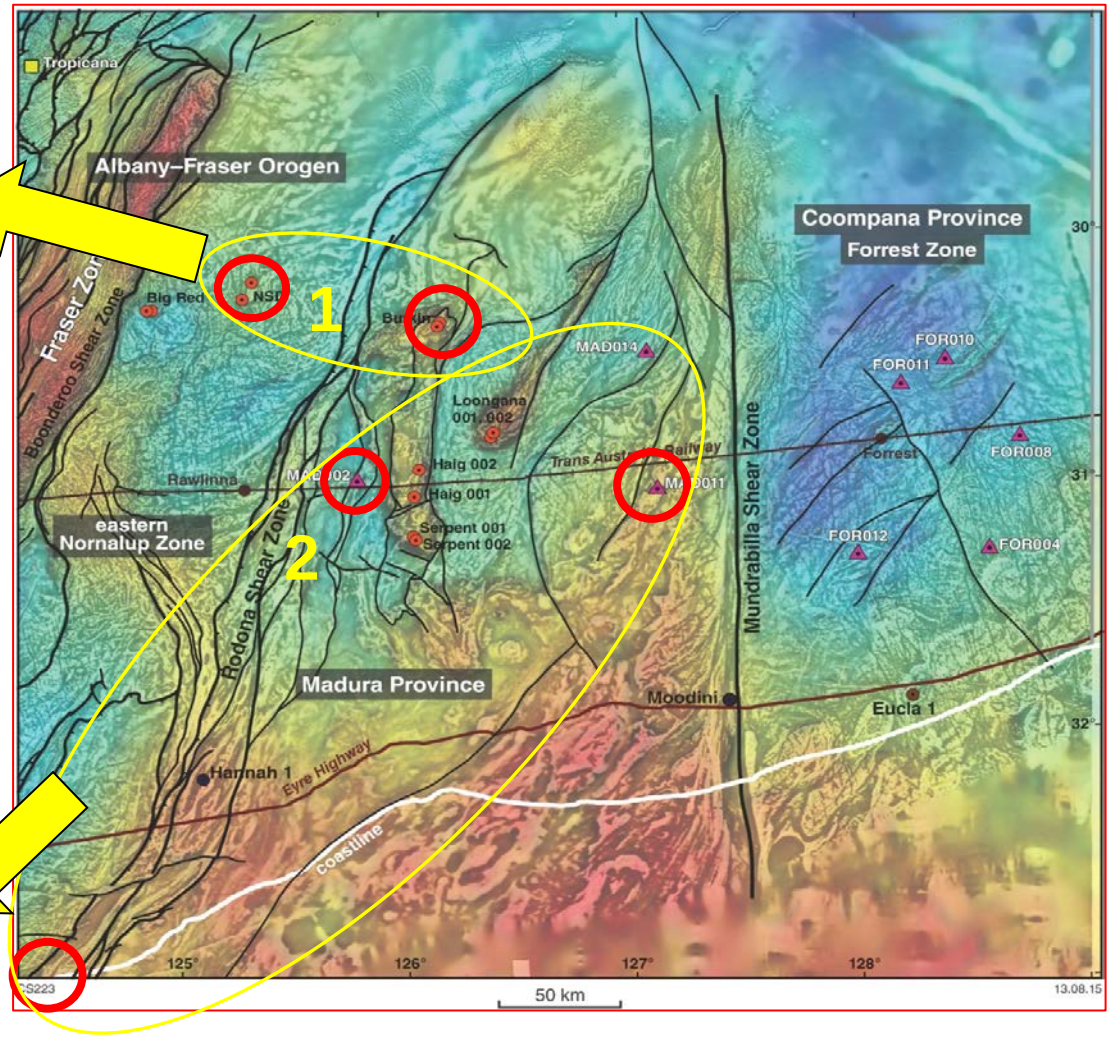

# Pre- c. 1200 Ma tectonic evolution

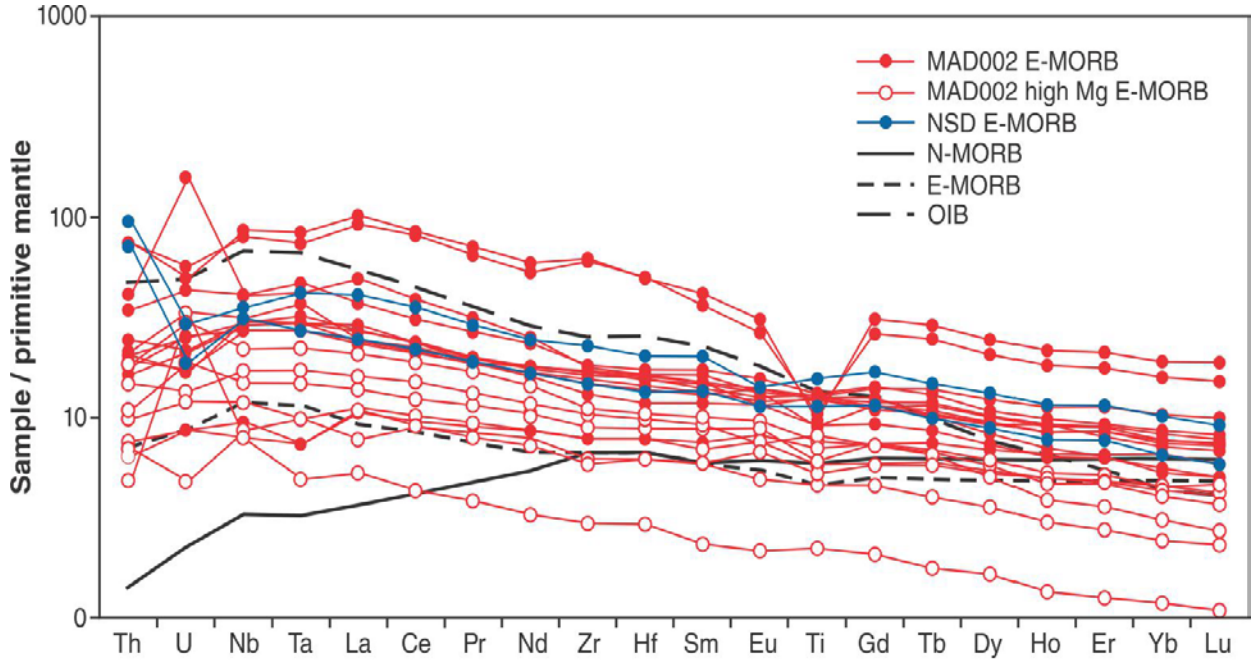
- <1950 – 1600 Ma history of the AFO is one of an ocean-continent transition
- The ocean created at this stage is the c. 1950 Ma mafic crust identified in our isotopic data – i.e. the crust that became the Madura and Musgrave Province and Forrest Zone
- Partially consumed with convergence creating multiple oceanic arcs from c. 1720 – 1600 Ma (FZ) and at c. 1400 Ma (MP)

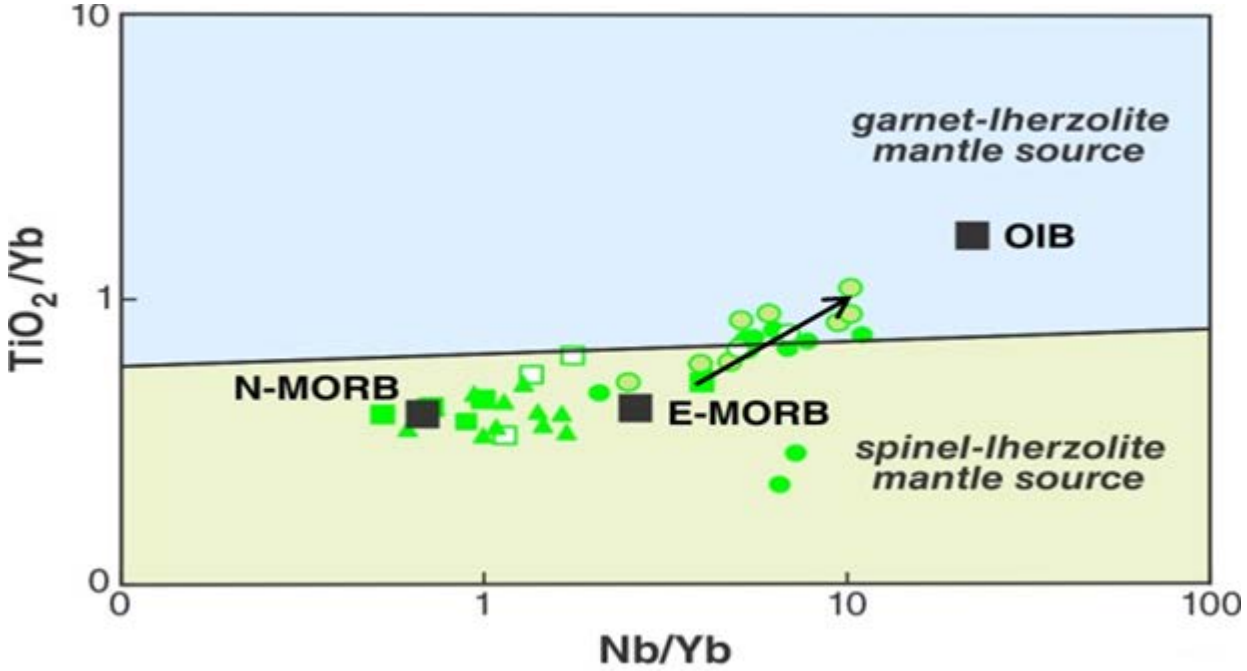
# Basalts
## constrained between 1950 and 1400 Ma



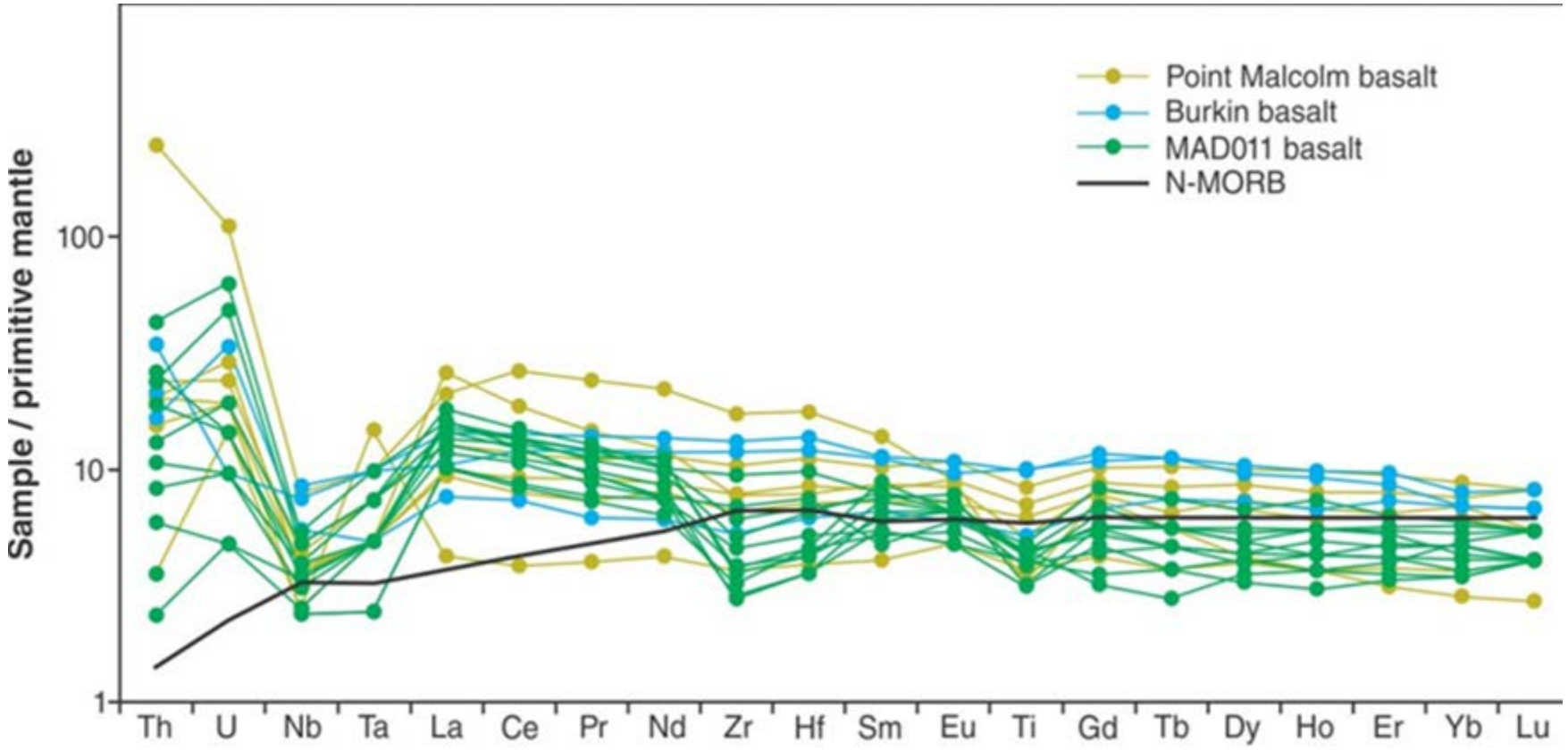



# 1

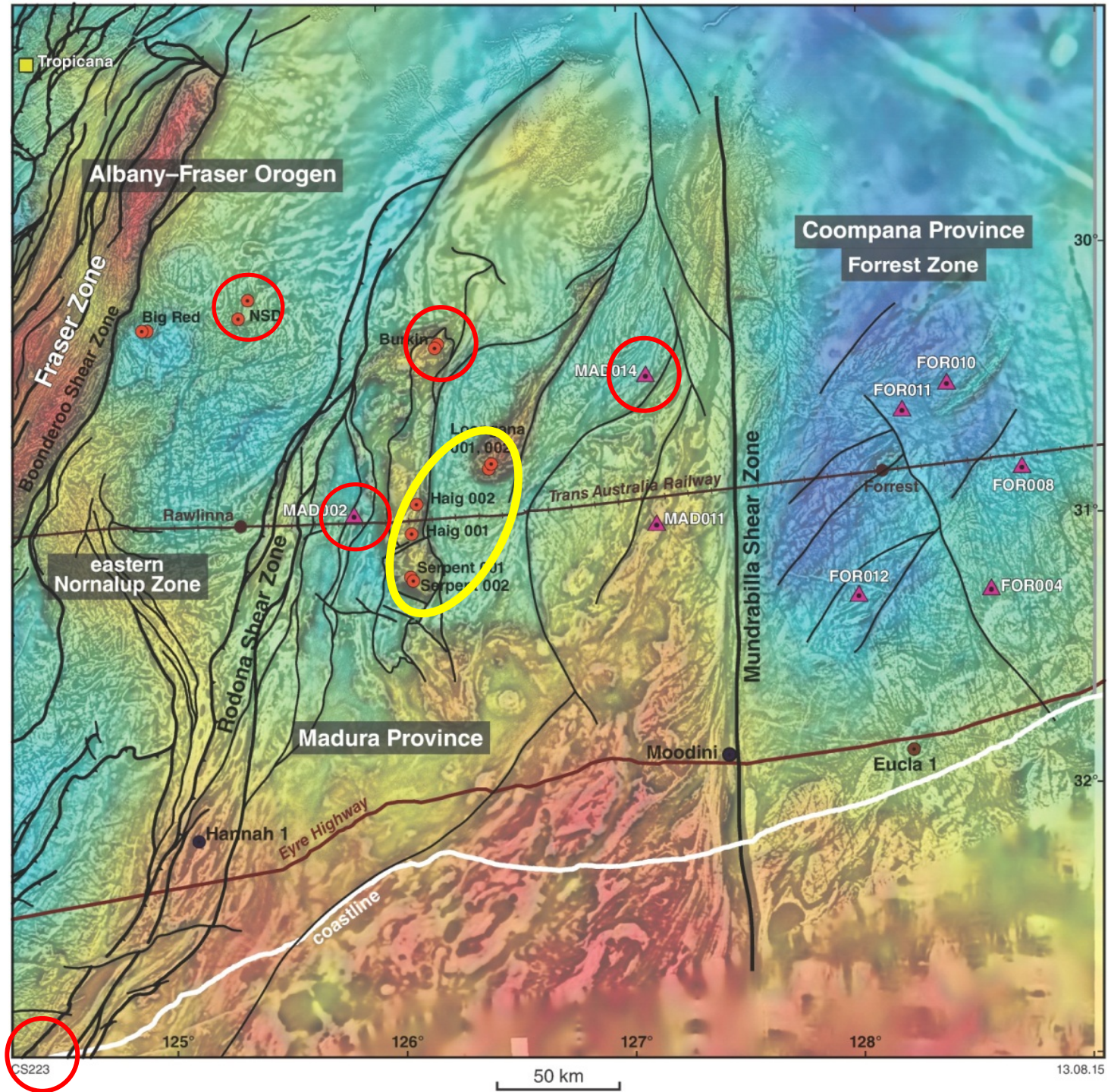
- Primitive ($Mg^{\#}$ up to 75, very high Cr and Ni)
- Strongly enriched, with no negative Nb anomaly
- Trace element patterns similar to E-MORB
- High Ti/Yb ratios reflecting a garnet-residual mantle source

**Reflects asthenospheric upwelling and are an expected result of continental rift → OCT.**



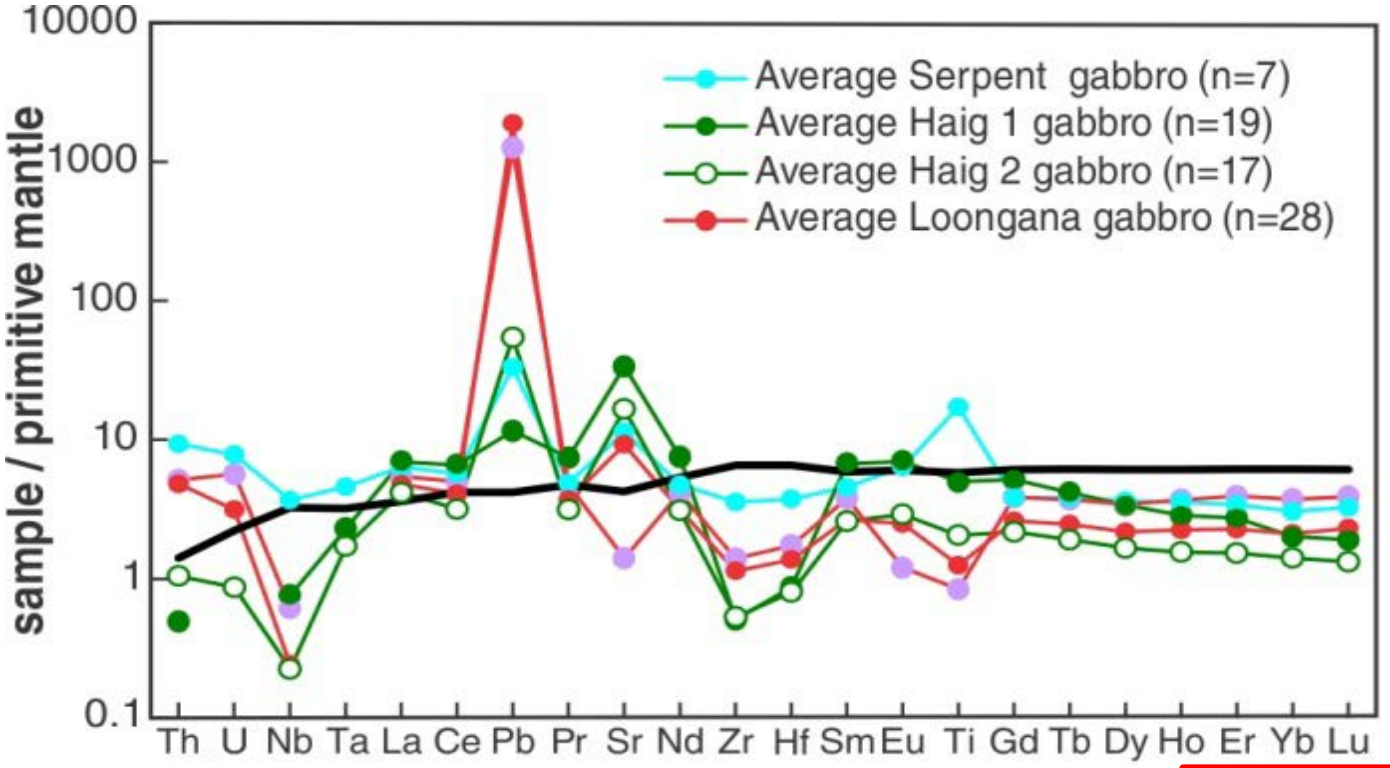

**2**

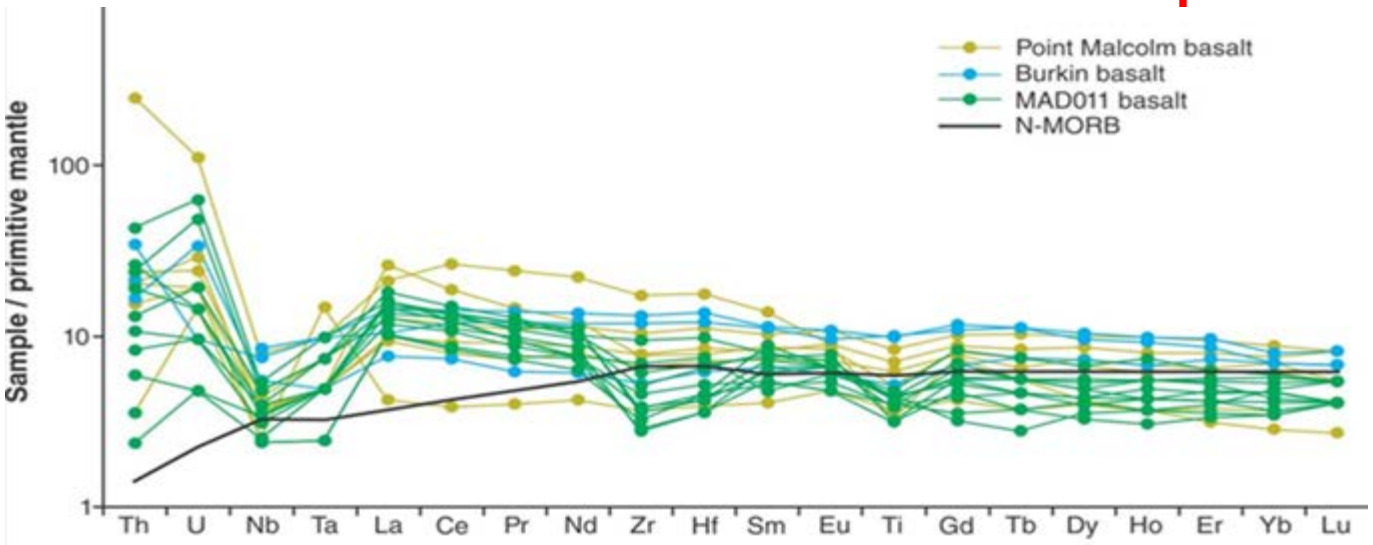
- Relatively flat to weakly enriched normalized trace element patterns.
- Trends for HFSE and Yb suggest a source very similar to N-MORB source.




# Gabbros

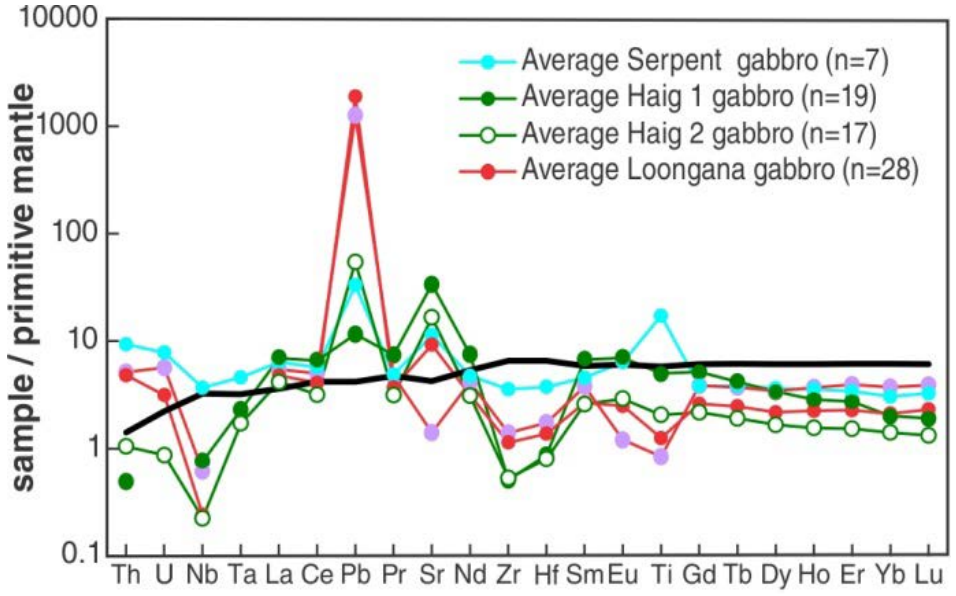
Loongana
Haig
Serpent




- Broadly low-K tholeiitic
- Same flat to weakly enriched normalised trace element patterns, with negative Nb and Zr, as the second (eastern) group of basalts – but with some positive 'spikes' reflecting cumulate minerals.
- Also in common with those basalts, trends in HFSE (Nb, Zr, Ti) and Yb broadly parallel N-MORB and reflect a similarly depleted mantle source (N-MORB source)

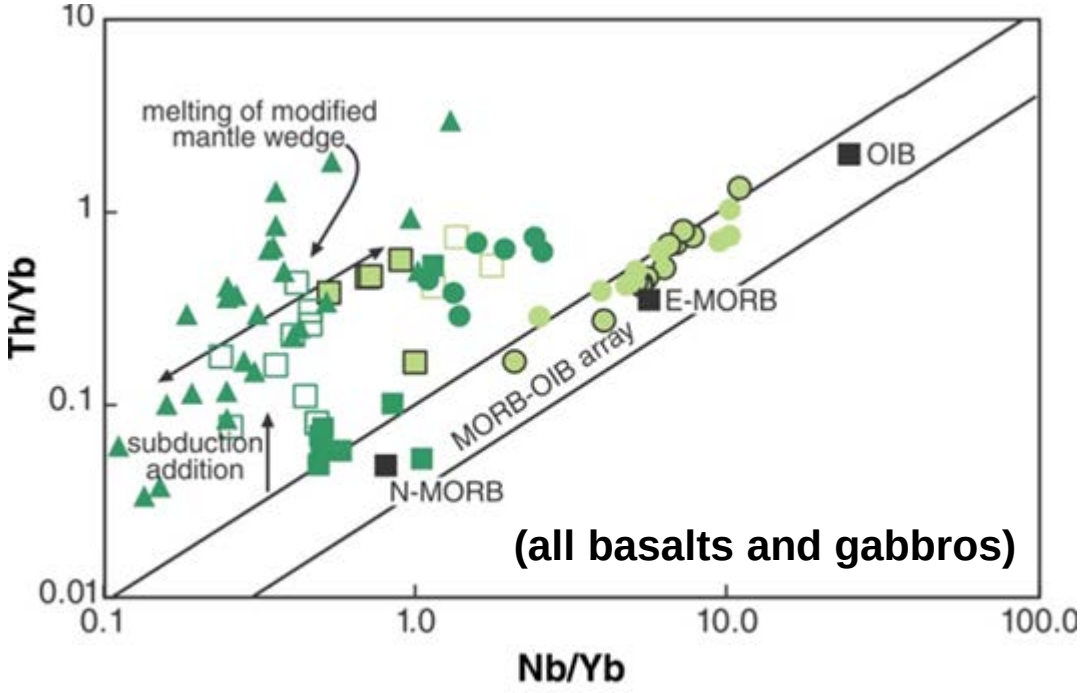
**Source and petrogenesis probably very similar to the basalts**

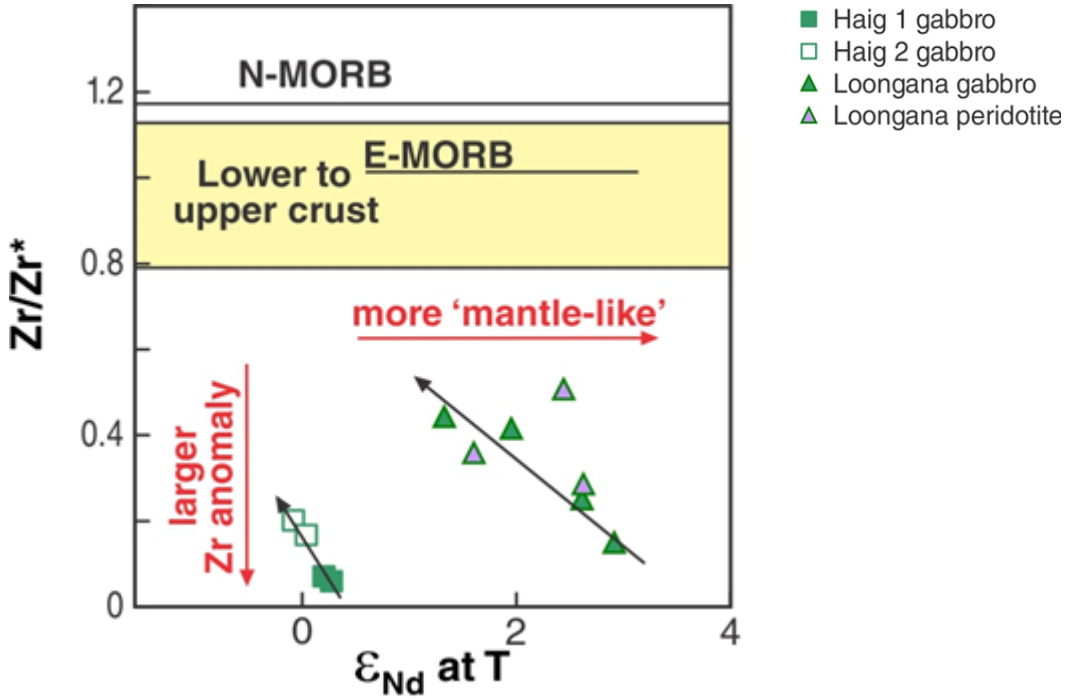



Enriched patterns reflect either a subduction-enriched mantle source (i.e. subduction) OR simply crustal contamination of a mantle-derived melt.

NEED to demonstrate which applies!!!

Isotopically primitive terrain gives us one clue – but various trace element arguments also provide very strong support for a subduction setting.



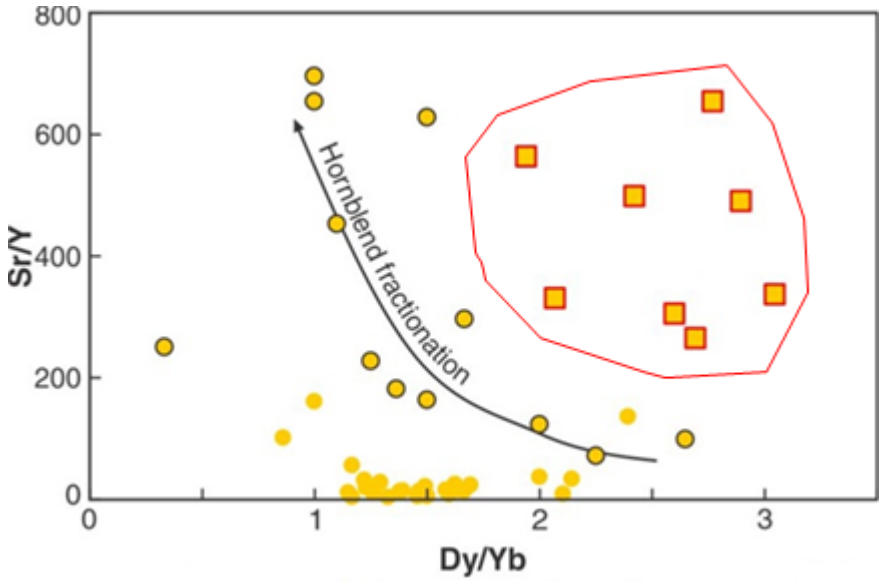



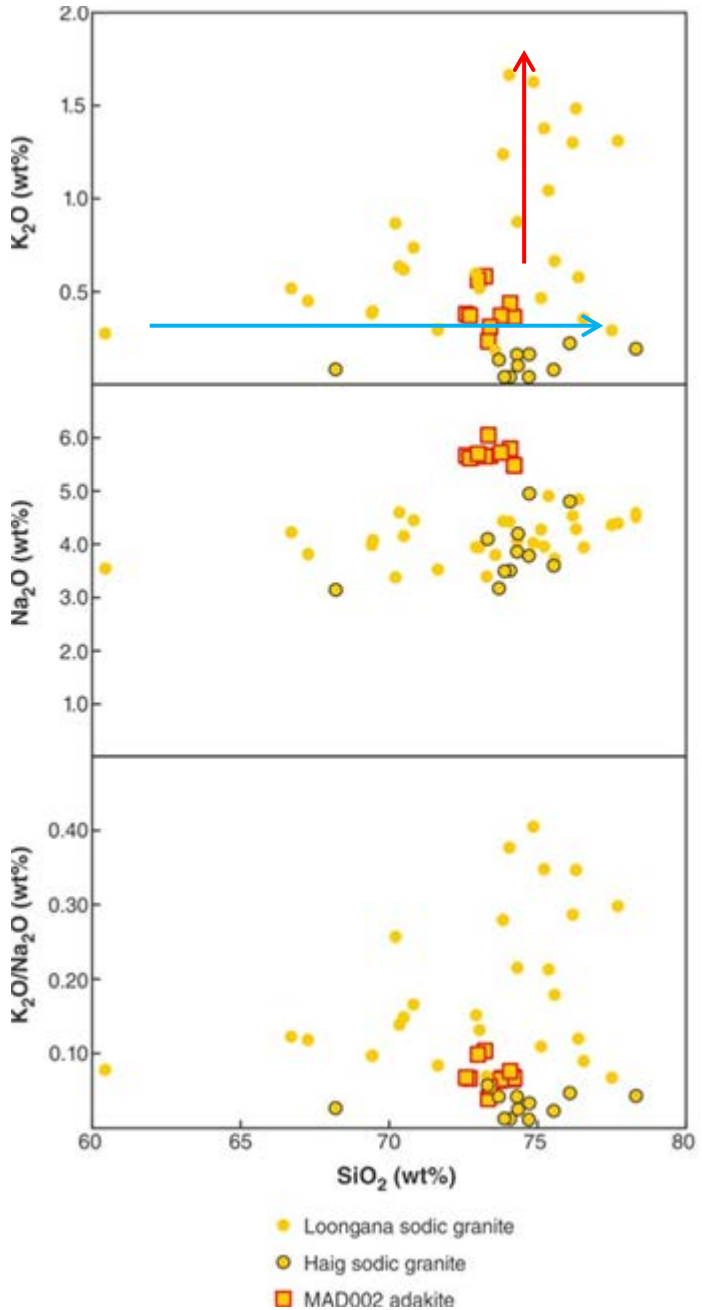
# Gabbros and the E-MORB in MAD002 are intruded by c. 1400 Ma sodic granites

**Two types recognised**

1) ‘Oceanic’ plagiogranites,
   a) some showing a purely ‘oceanic’ (i.e. mafic) source (→)
   b) some showing slight K-enrichment (source incorporates minor hyper extended AFO crust)(→)

2) Adakite – intruding E-MORB in MAD002. Very high Sr/Y and La/Yb rations and extreme depletions in HREE reflecting high-pressure melting of a subducted oceanic slab.



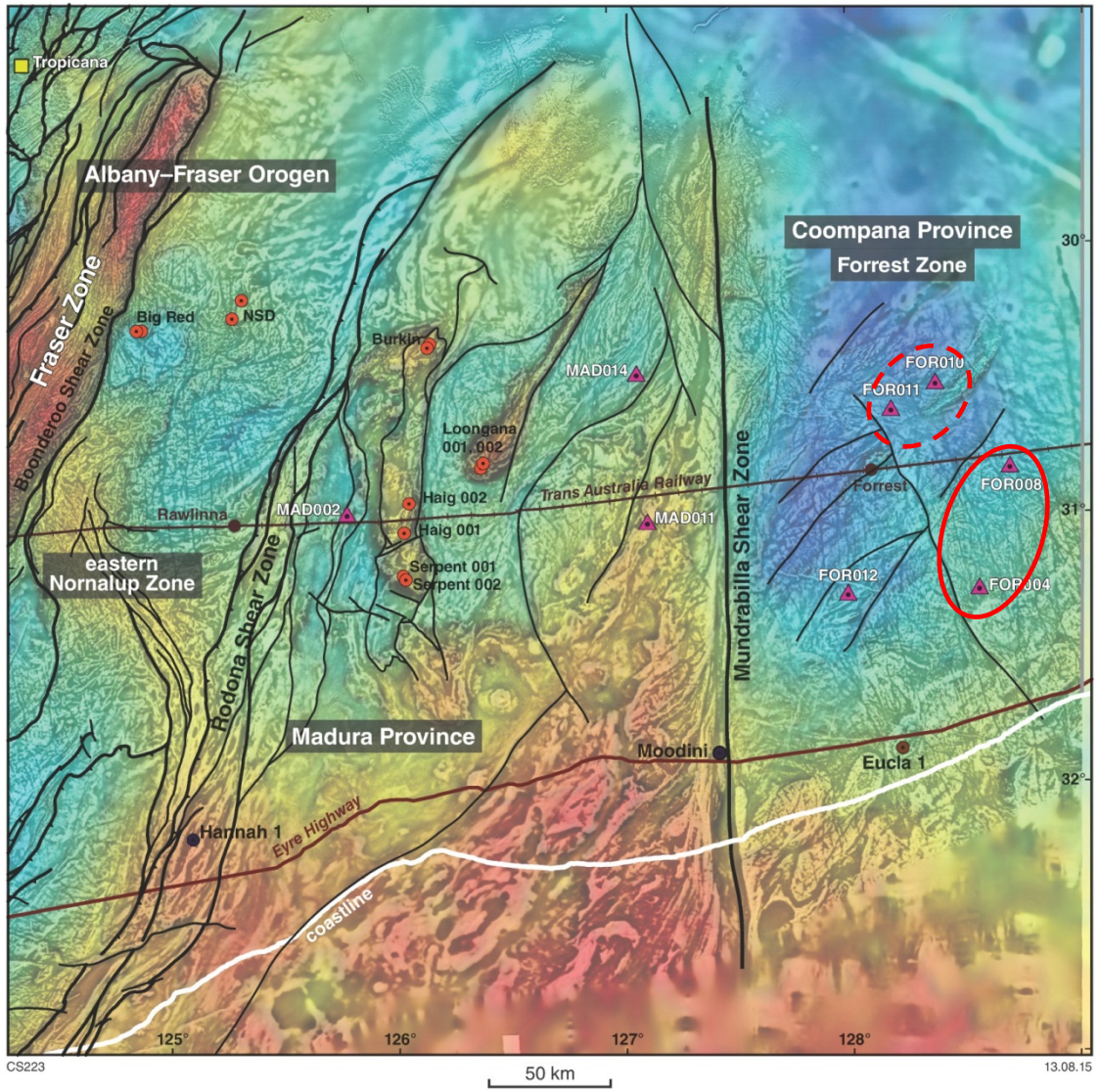



# Madura Province (pre c. 1200 Ma)

- **Early E-MORB in the west – remnants of the early ocean-continent transition phase.**
- **Widespread basalt and c. 1400 Ma gabbro with the signature of a N-MORB source that was weakly subduction-modified - likely reflects oceanic arc or fore-arc.**
- **Plagiogranites form part of the oceanic arc sequence and include types typically found in ophiolites and most clearly evolved from a source free of significant 'continental' material**
- **1400 Ma adakites intrude much older E-MORB, indicate hot subduction of oceanic lithosphere, and likely formed to the east of an east-dipping slab.**

# Forrest Zone c. 1610 Ma (c. 1720 and 1670 Ma inheritance)

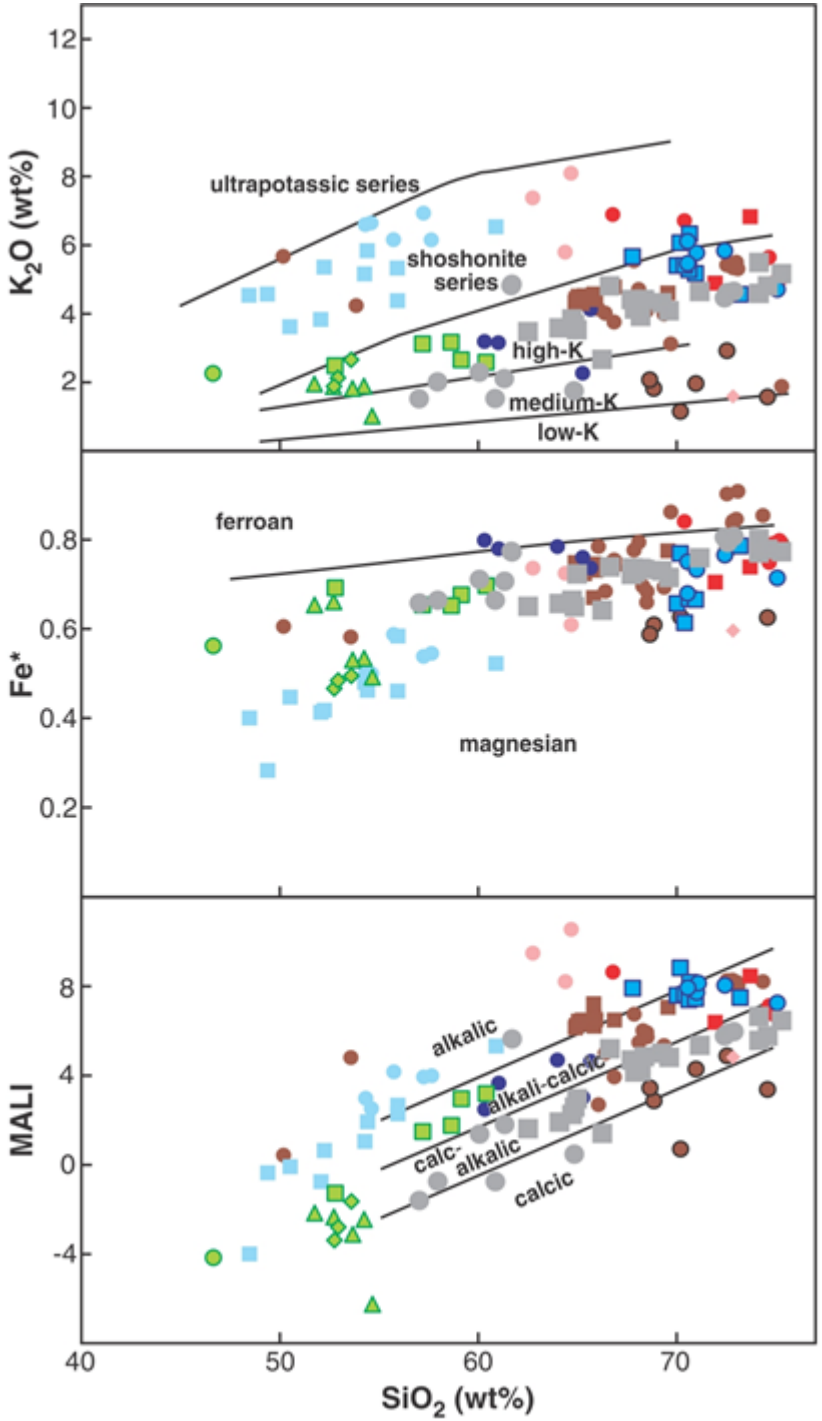
## Subduction-related magmatism: arc crust




Toolgana Supersuite

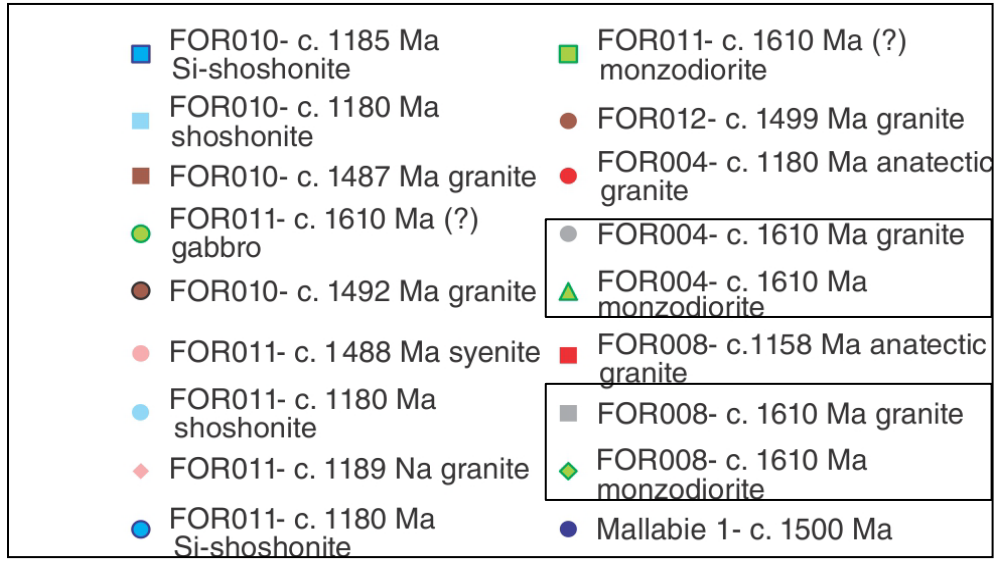
FOR004
FOR008

Undated but compositionally the same
(FOR011)
(FOR010)



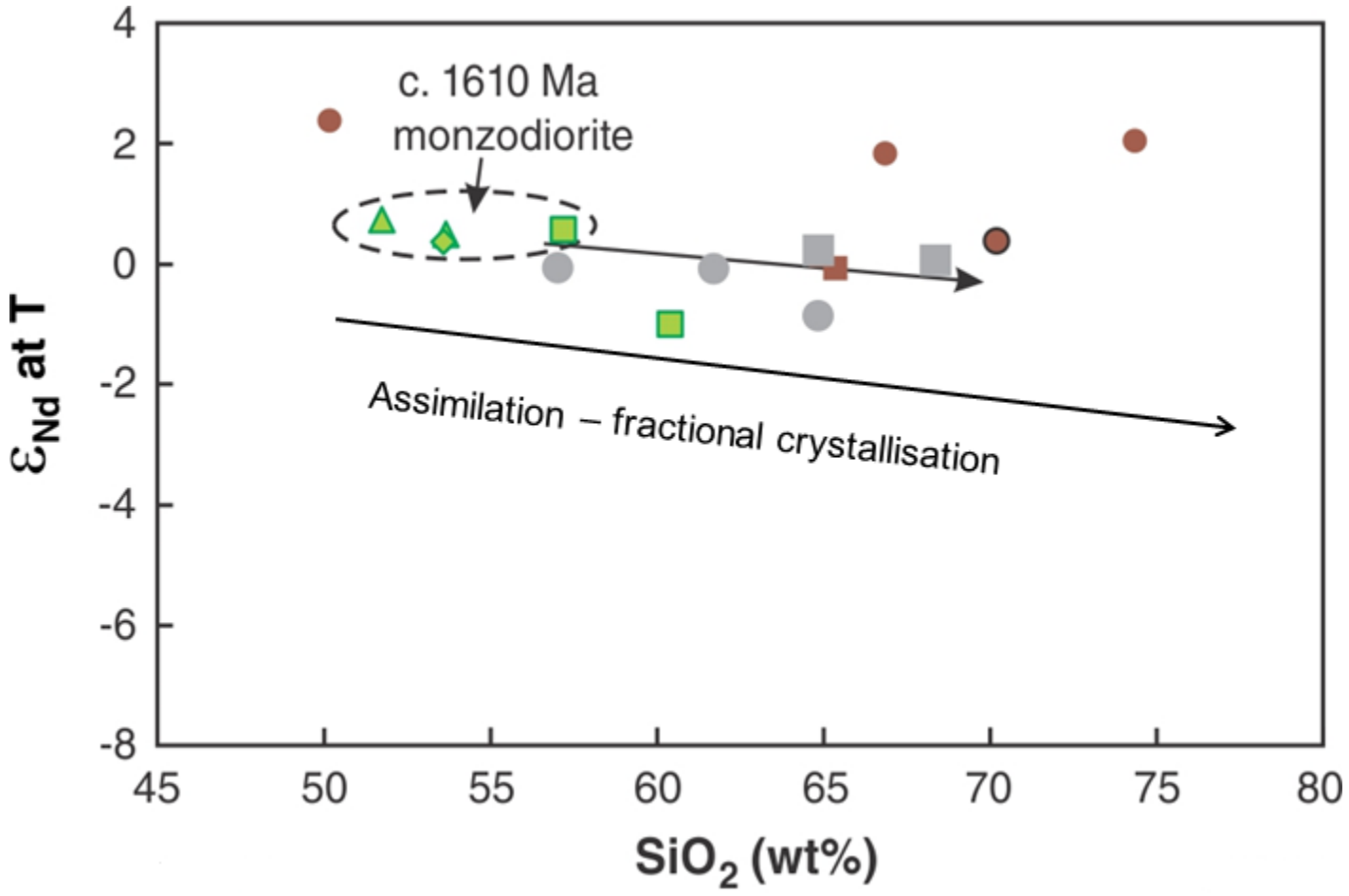

# Toolgana Supersuite

- Granites are magnesian and mainly calc-alkalic
- Mainly high-K
- Associated with abundant mafic equivalents



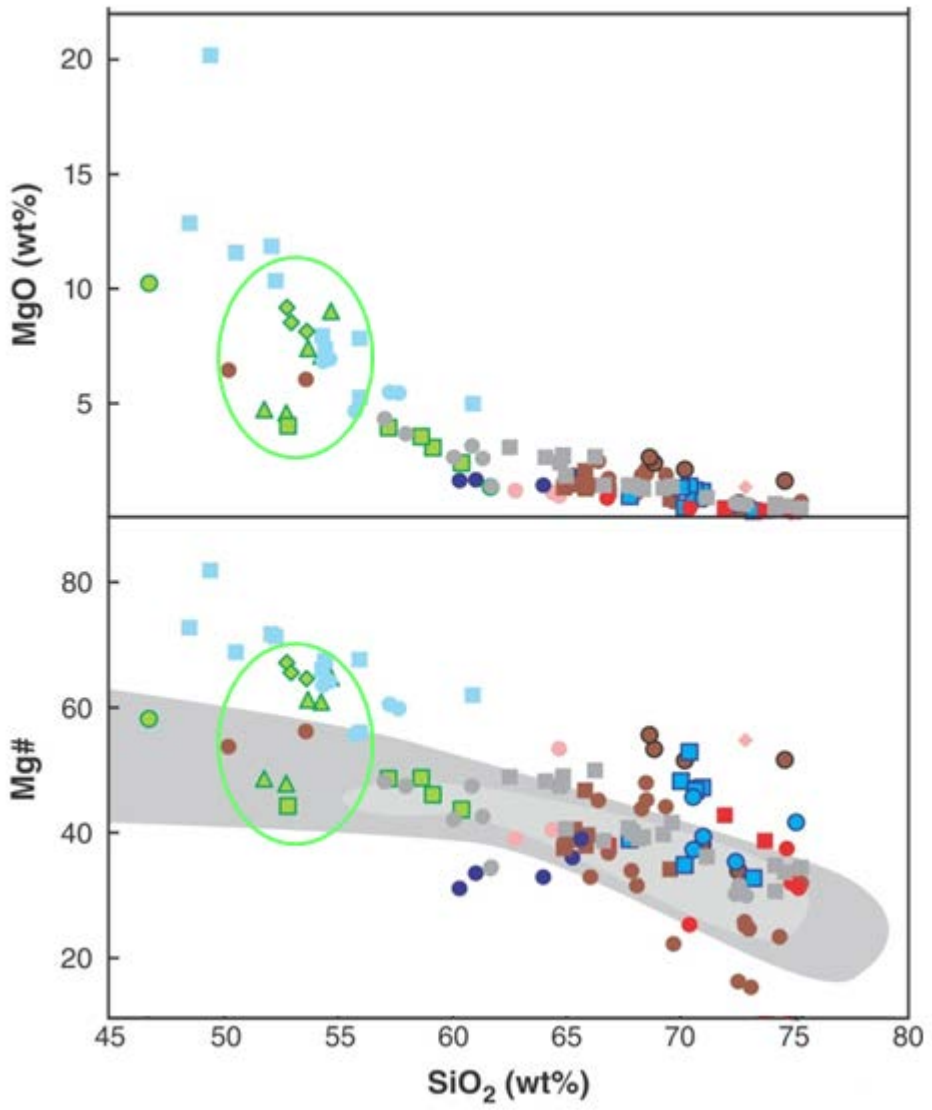
# Toolgana Supersuite

Nd isotopic composition on the granites become slightly less radiogenic over a large increase in $SiO_2$, suggesting AFC type processes involving only very minor progressive contamination (? the inherited 1724 – 1671 Ma component) and/or an isotopically similar contaminant.




Monzodiorite and granite form co-genetic suites that have intruded c. 1720-1670 Ma crust that is compositionally similar – recycling of slightly earlier arc crust - **Composite arcs!!**

# Toolgana Supersuite - monzodiorite

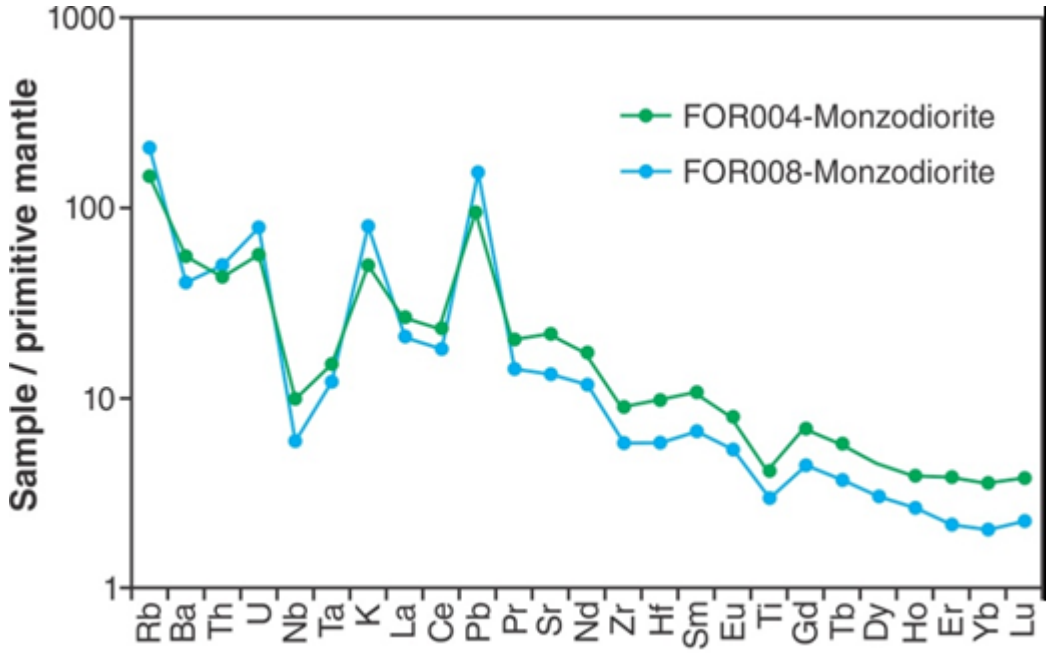



The most primitive samples have:

$SiO_2$ ~ 52 wt%
MgO > 9.0 wt%
Mg > 65
Ni up to 187 ppm

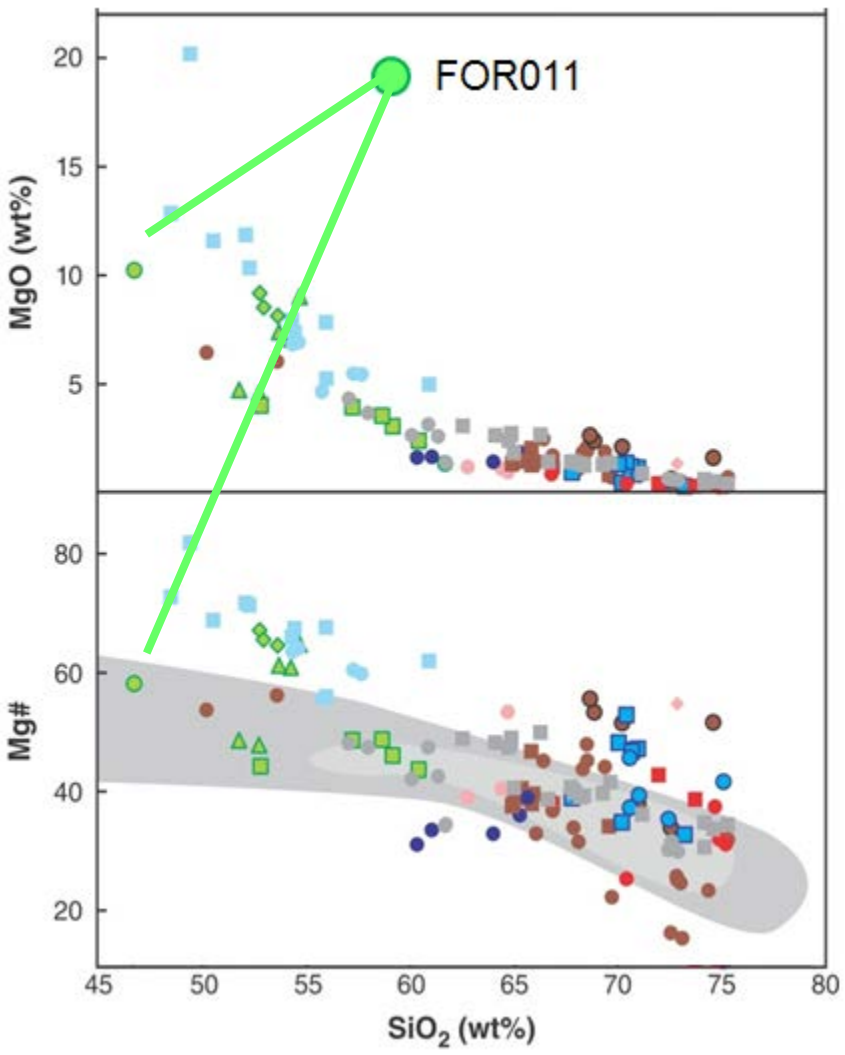
Rules out significant fractional crystallisation

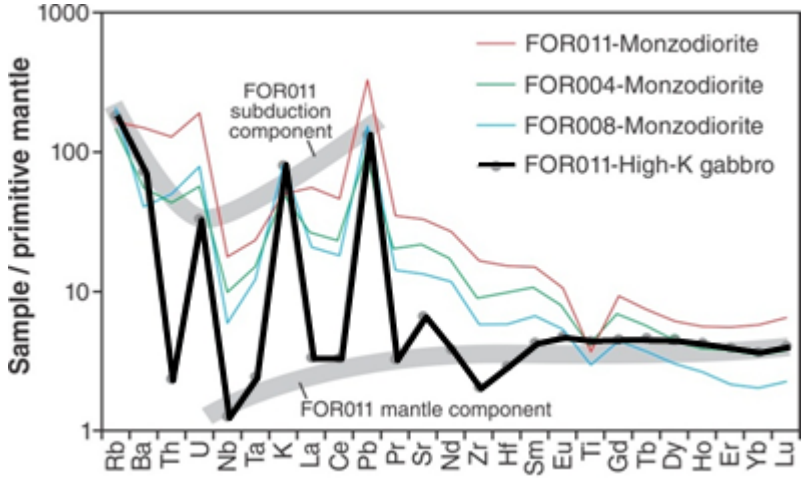
But are also significantly enriched in highly incompatible trace elements, with high LILE/HFSE ratios (i.e. subduction-like patterns)



# Toolgana Supersuite

K-rich gabbro (2.26 wt% $K_2O$ at 46.63 wt% $SiO_2$) also occurs in FOR011.




Depleted mantle source

Significant enrichment in fluid-mobile trace elements

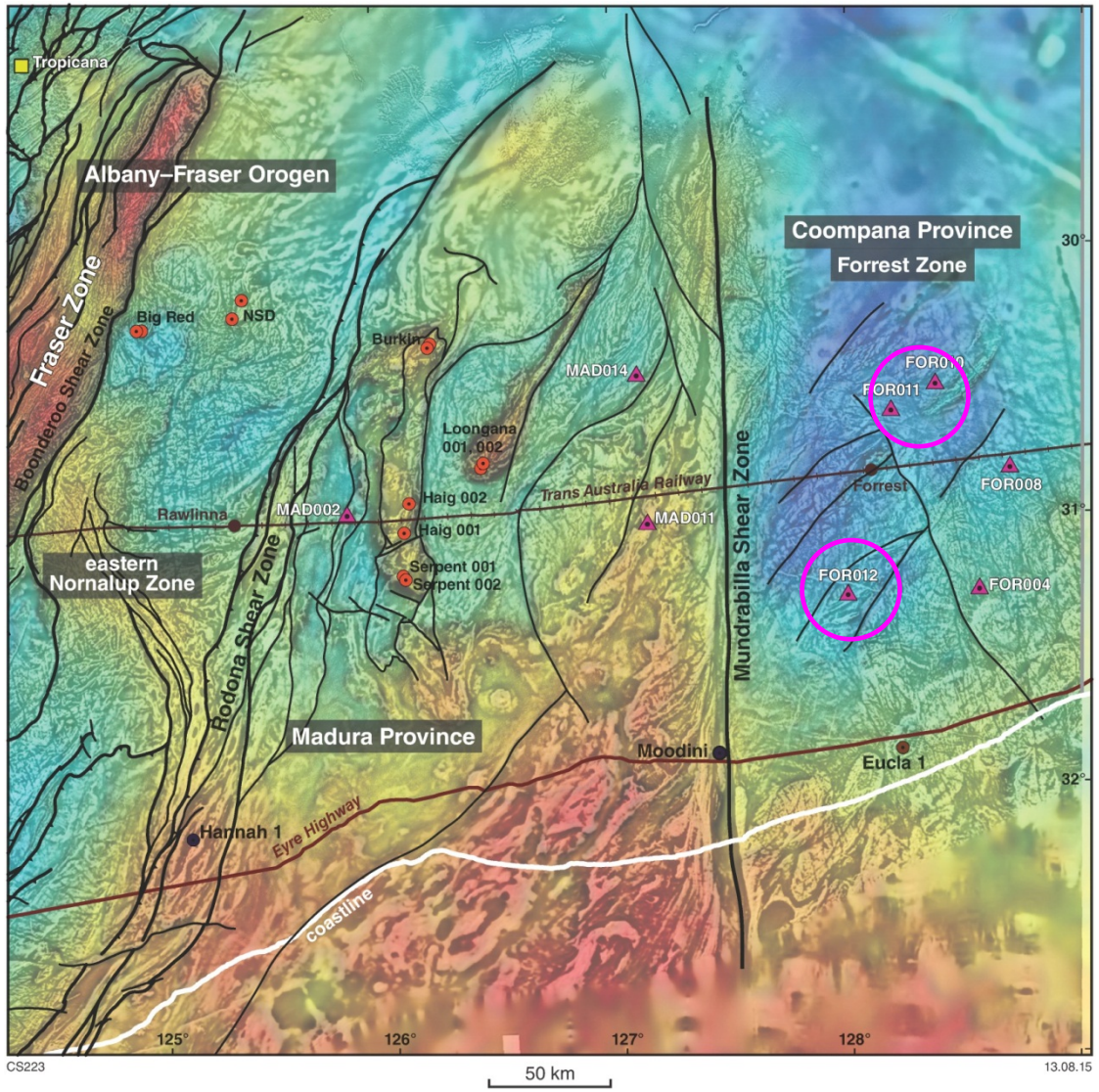
NO crustal addition

Enrichment pattern that resembles that in other c. 1610 Ma rocks

Fore arc or back arc tholeiite; and added confidence that the Toogana SS is subduction-related

# Forrest Zone c. 1500 Ma

## Extension (rift) related granites

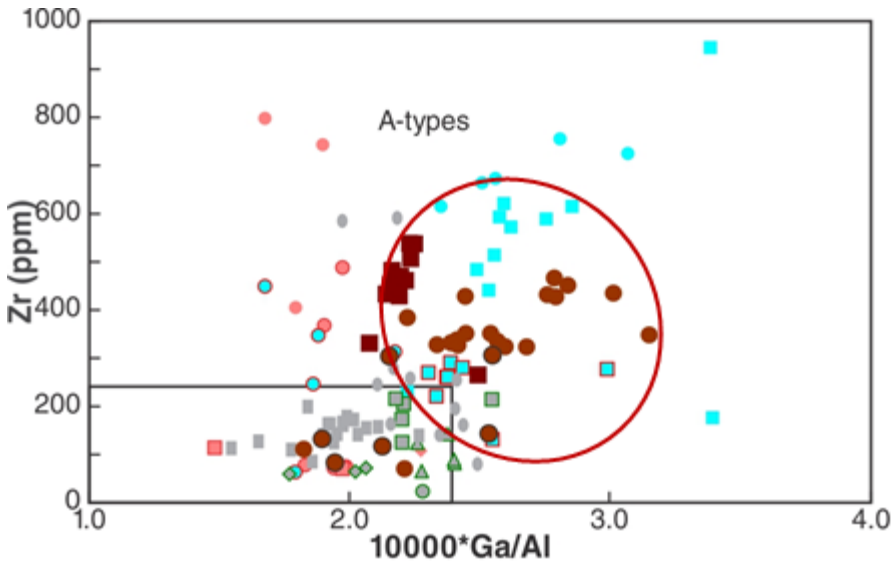


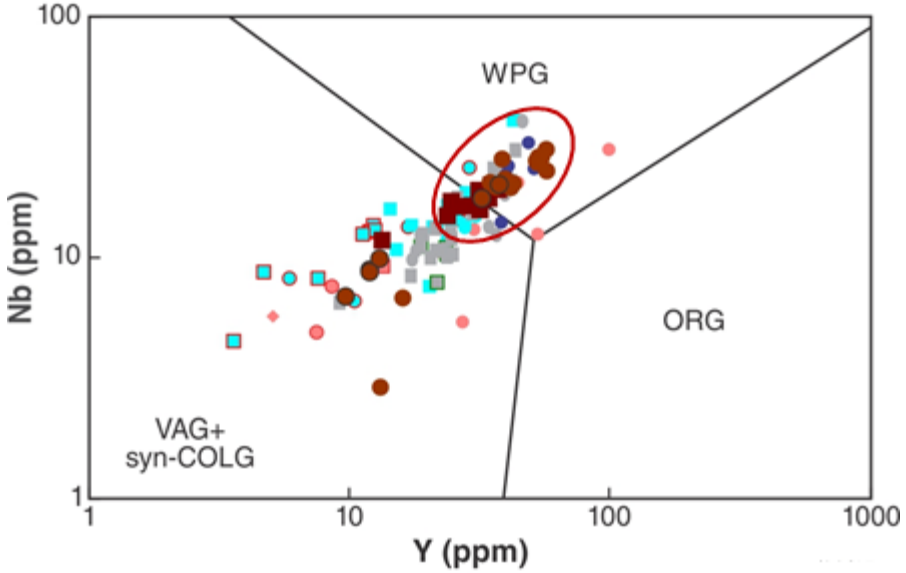

<u>Undawidgi Supersuite</u>

FOR012
FOR010
FOR011

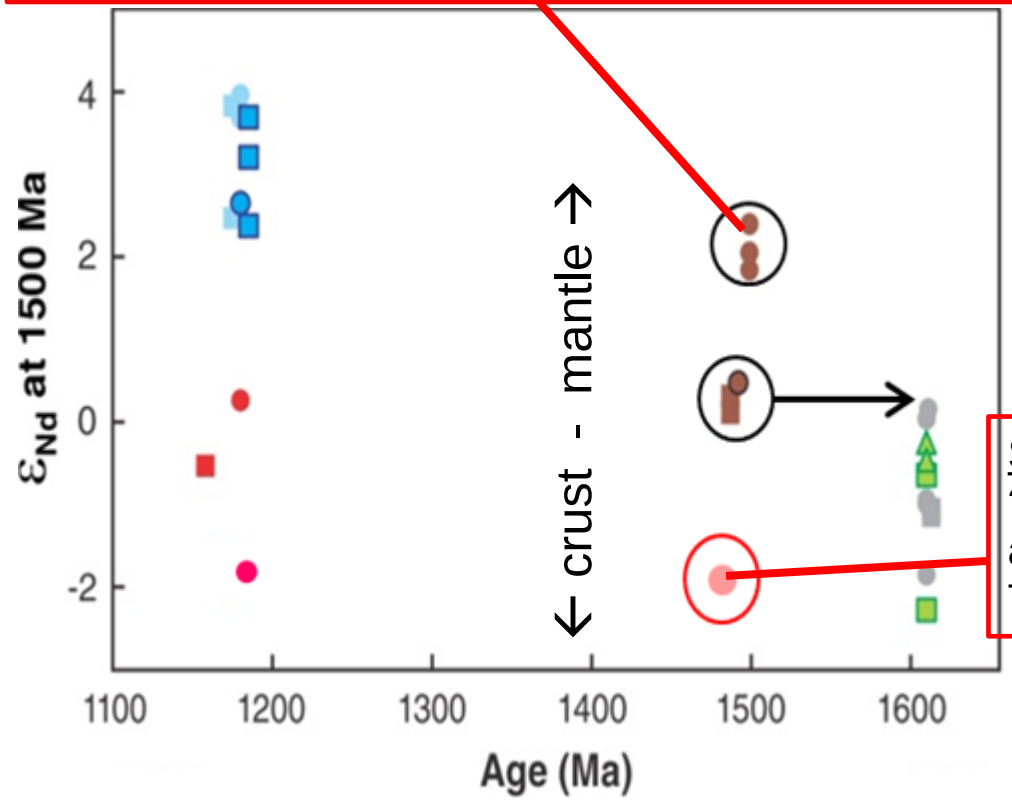
# High-K Undawidgi Supersuite

Show enrichments in $TiO_2$, $P_2O_5$, HFSE, Ga, Zn, REE typical of hot and dry A-type magmas.




High-K granites ! addition of a more radiogenic component (e.g. mantle) — and if this was upwelled asthenospheric mantle this would additionally be consistent with their more ferroan compositions




Syenite
? Remelting of strongly alkali-metasomatised Toolgana crust

## Forrest Zone (pre c. 1200 Ma)

- **Toolgana Supersuite c. 1600 Ma subduction-related (super)suite. Little isotopic evidence for the type of 'continental' input we would expect to see at a continental margin – so probably largely oceanic. History of arc magmatism and recycling spans at least 1720 – 1600 Ma (earlier than the preserved subduction record in the Madura Province)**

- **Undawidgi Supersuite c. 1500 Ma Range of rocks each with compositional features that distinguish them from earlier arc-related rocks (source). Influence of hot, dry, asthenospheric input likely in an extensional environment (rift, arc extension)**

# late (1220 - 1150 Ma) reworking of entire region, including the cratonic margins

**The Maralinga Event**

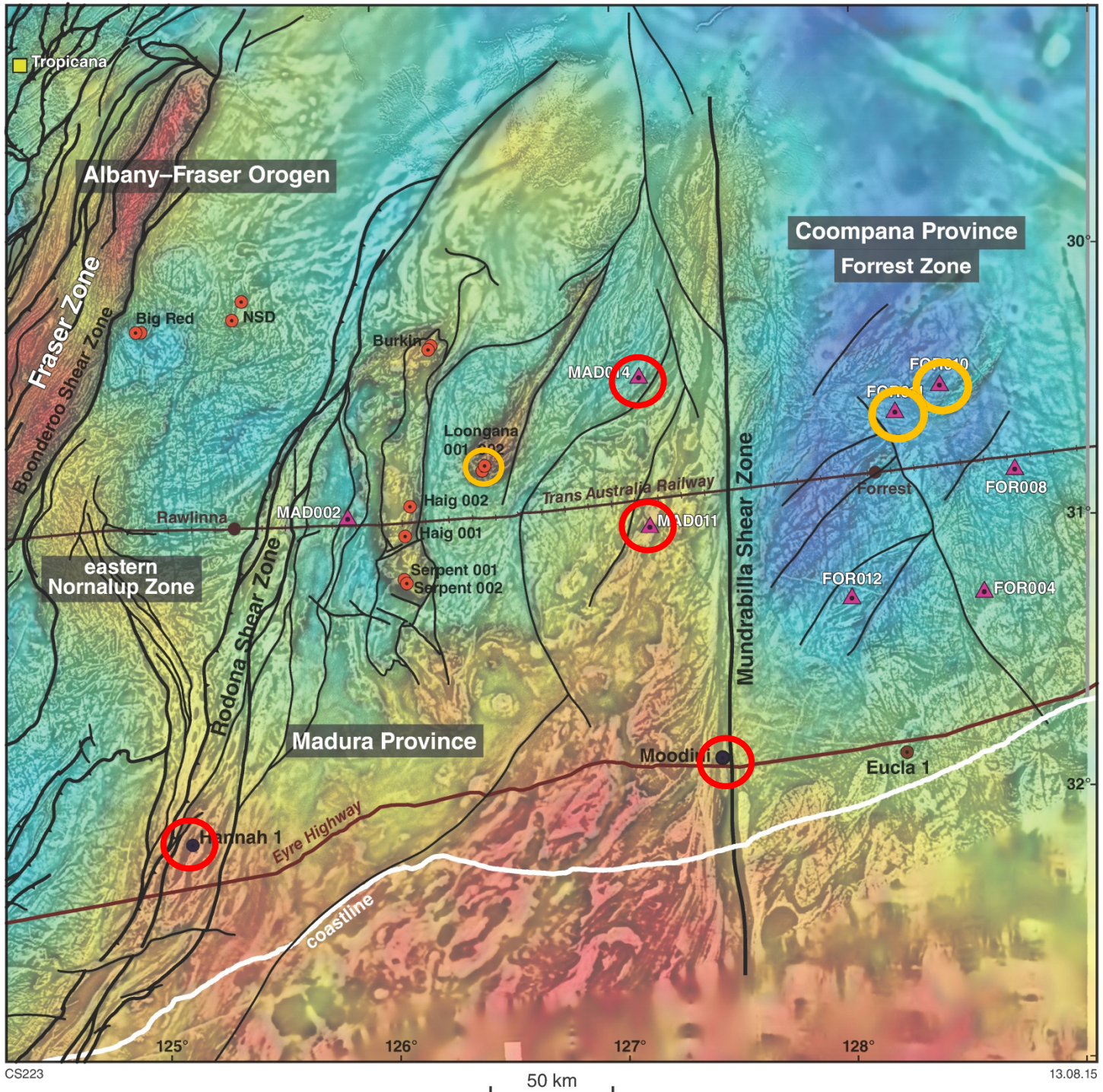
**Albany-Fraser Orogeny Stage II**

**Musgrave Orogeny**

Great central Australian meltdown

# Madura Province and Forrest Zone (1190 Ma onwards)

- **Our record of oceanic plate consumption and arc formation ends at c. 1400 Ma.**
- **Final stages of convergence continues as oceanic terrains were thrust over the AFO (not sure what happened on the other ?"Gawler"side of the ocean).**
- **Very little activity is recorded between c. 1290 and 1220 Ma anywhere in the Madura, Forrest, Musgrave or Albany-Fraser regions.**
- **At c. 1200 Ma however, we begin the most extraordinary regional magmatic or thermal event which fundamentally changes the geochemical composition – but NOT the isotopic heritage – of large portions of the entire region.**



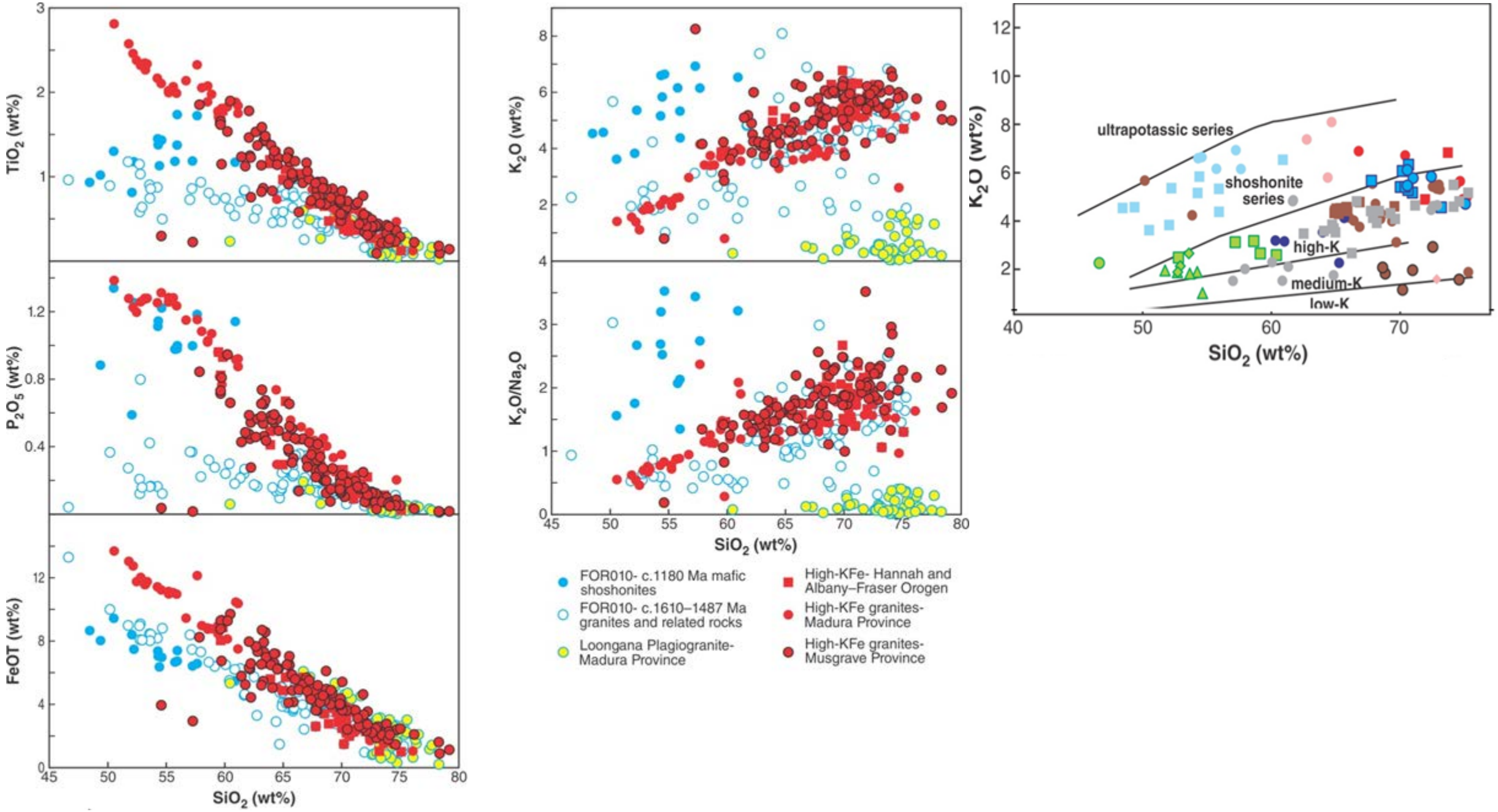

# Moodini Supersuite - Two strongly contrasting styles of magmatism

1) **Madura Province c. 1180 – 1125 Ma**
   High-KFe (ferrodiorite to A-type granite) magmatism. Regionally voluminous, mainly in the Madura and Musgrave Provinces but also in the AFO; high magnetic signature. (*Not sampled in the Forrest Zone but aeromagnetic traces suggest their presence.)

2) **Forrest Zone c. 1185 – 1150 Ma**
   High-KMg (shoshonite and shoshonitic granite) magmatism – mainly in the Forrest Zone. (*Voluminous in the Forrest Zone but only one occurrence – at Loongana – of thin dykes in the Madura Province.)

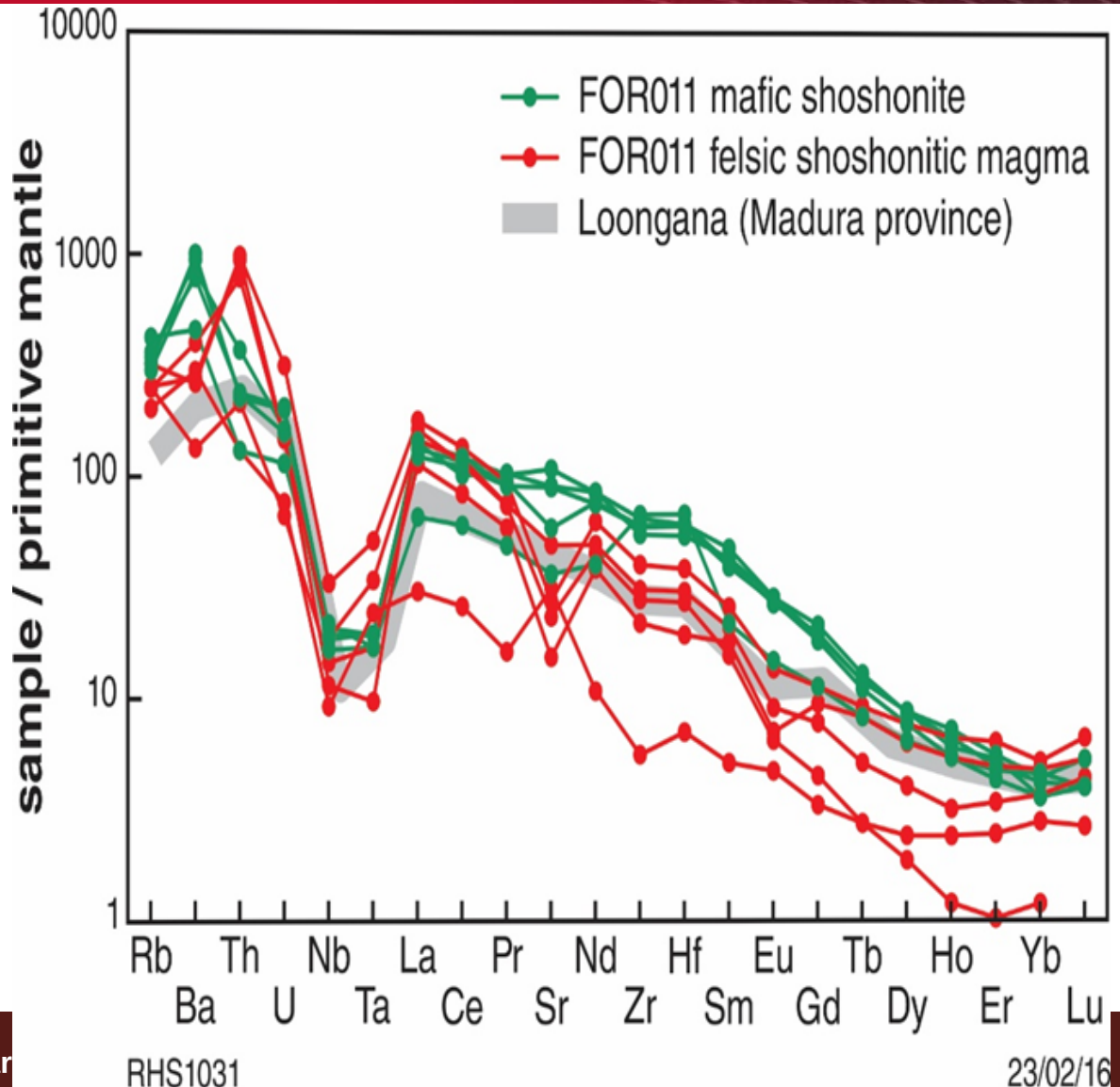
# High-KFe series: high-T melting of extended lower crust

- Include orthopyroxene- and pigeonite-bearing monzodiorite and monzonite (jontunites) to biotite-monzogranite.
- Geochemically specialised – high K, Fe, Ti, P, HFSE, REE, Th, U – A-type (or ‘Charnockite type”)
- Intrusive temperatures often > 900°C (mafic member >1000°C).
- Geochemical and isotopic characteristics suggesting melting, under very high temperatures and dry and reduced conditions, of refractory lower-crust with significant material and thermal contribution from asthenospheric mantle.


TiO2 (wt%)
P2O5 (wt%)
FeOT (wt%)
SiO2 (wt%)
K2O (wt%)
K2O/Na2O
SiO2 (wt%)
ultrapotassic series
shoshonite series
high-K
medium-K
low-K
K2O (wt%)
SiO2 (wt%)
FOR010- c.1180 Ma mafic shoshonites
FOR010- c.1610–1487 Ma granites and related rocks
Loongana Plagiogranite-Madura Province
High-KFe- Hannah and Albany–Fraser Orogen
High-KFe granites-Madura Province
High-KFe granites-Musgrave Province

# High-KMg series – melting of subduction metasomatised lithosphere

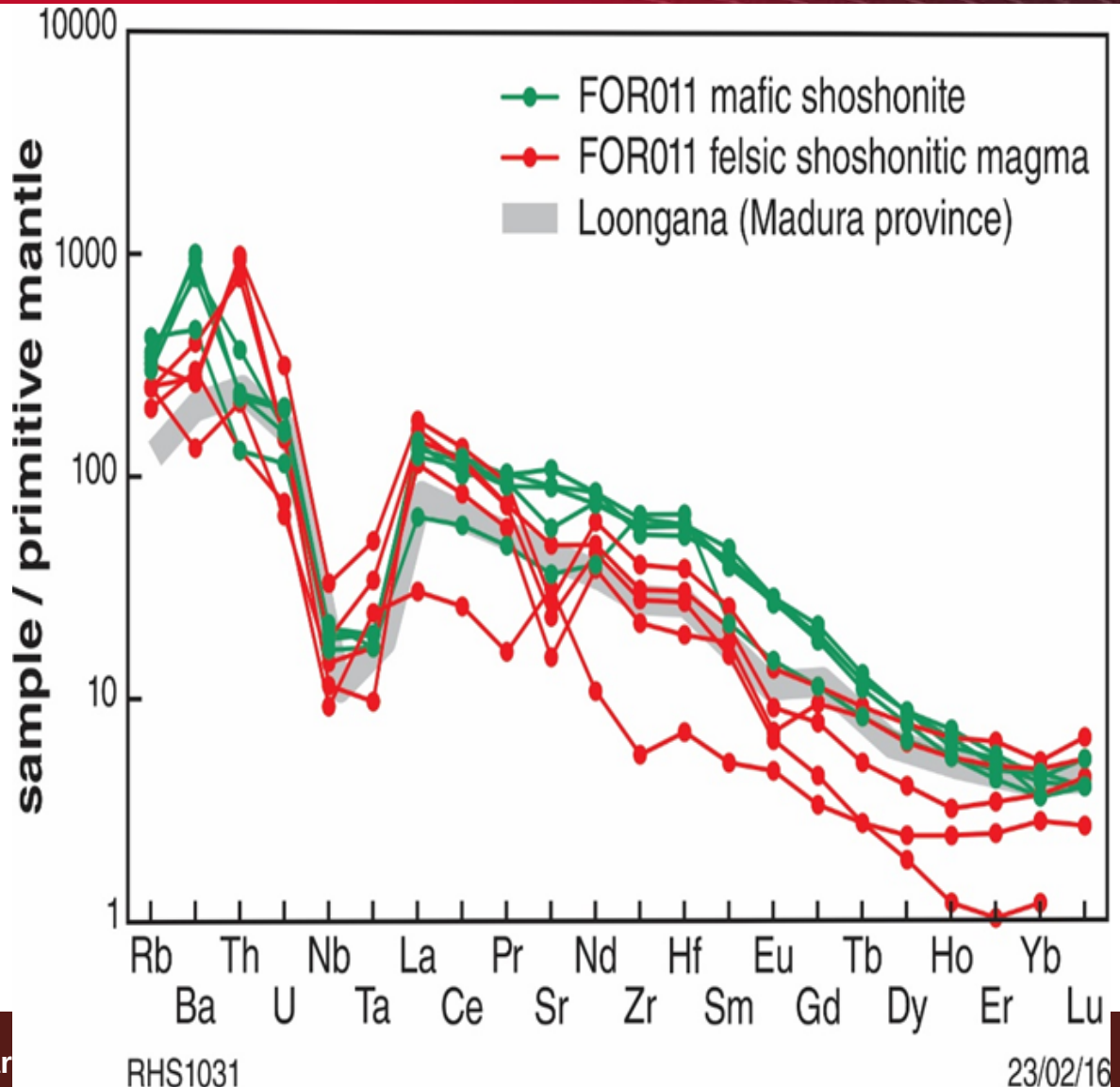
- Form a major component (up to 25%).
- Mafic (shoshonite) ($SiO_2$ 48.45 – 60.87 wt%) and high silica (shoshonite series) ($SiO_2$ 67.78 – 75.08 wt%) groups - each type occurring in both cores. Most isotopically juvenile magmas at that age.
- The combination of extremely high $Mg^{\#}$ and strong enrichments in incompatible trace elements points clearly to a lithospheric mantle source.



# High-KMg series – melting of subduction metasomatised lithosphere

- This metasomatised lithospheric source was thick (within the garnet stability field) and wet and/or oxidized, and compositional evolution of the magmas was controlled by hornblende fractionation – high $f_{H_2O}$. These rocks show close compositional similarities with Cu-Au mineralised shoshonites in the Early Silurian Macquarie Arc (NSW).

- Single occurrence in the Madura Province represents melting at lower pressures (thinner lithosphere?)



**Originally the same piece of mafic (oceanic) crust – related to the same ocean-opening event recorded in the AFO ocean-continent transition (relict E-MORB)**

**Pre c. 1200 Ma history of ocean closure/consumption and formation of mainly oceanic arcs – extensively in the Forrest Zone from c. 1720 to 1600 Ma; perhaps less extensively in the Madura Province – only recognised at c. 1400 Ma (although zircon inheritance also suggests an event at c. 1470 Ma)**

**Post c. 1200 Ma history of crust/lithosphere reworking (Great meltdown). Concurrent production of extremely contrasting magma types**

- **high-KMg magmas from thick, wet, and oxidized subduction modified lithosphere mainly in the Forrest Zone;**

- **very high-T, dry and reduced high-KFe magmas in zones of highly thinned crust mainly in the Madura Province.**

**As far as we can tell, high-KMg and -KFe magmatism is mutually exclusive in any one area. As with its occurrence in the Forrest Zone, the single sample of high-KMg shoshonite in the Madura Province is in 'arc-crust" at Loongana. High-KMg restricted to areas where thick lithosphere was developed (or remained!). Perhaps high-KFe magmatism indicates areas where thick lithosphere never developed, or where it was removed. Aeromagnetics should allow us to map these regions.**