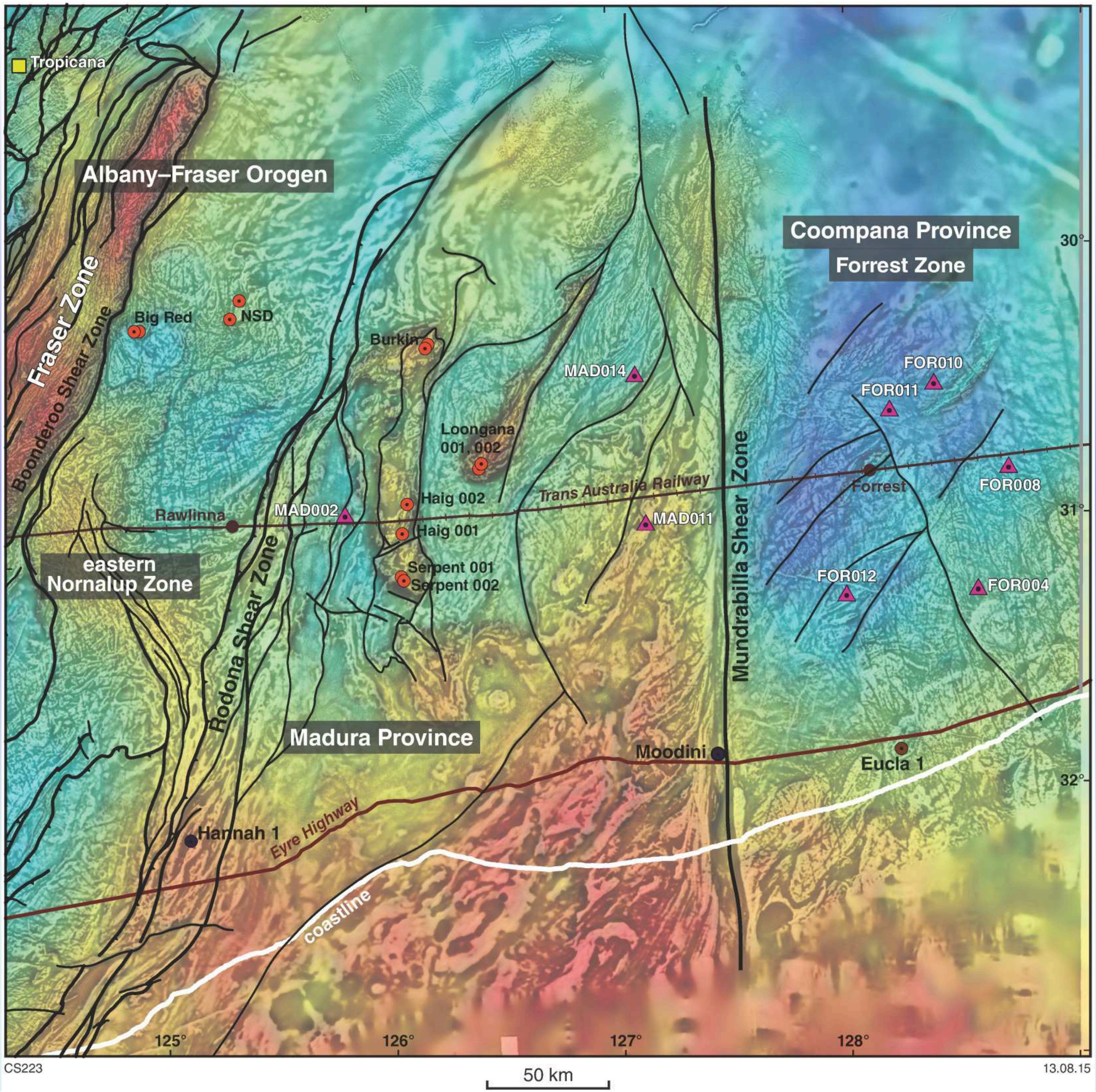
Government of **Western Australia**
Department of **Mines and Petroleum**

Eucla Basement Stratigraphic Drilling – Results Release

Forrest Zone: geochemistry and petrogenesis

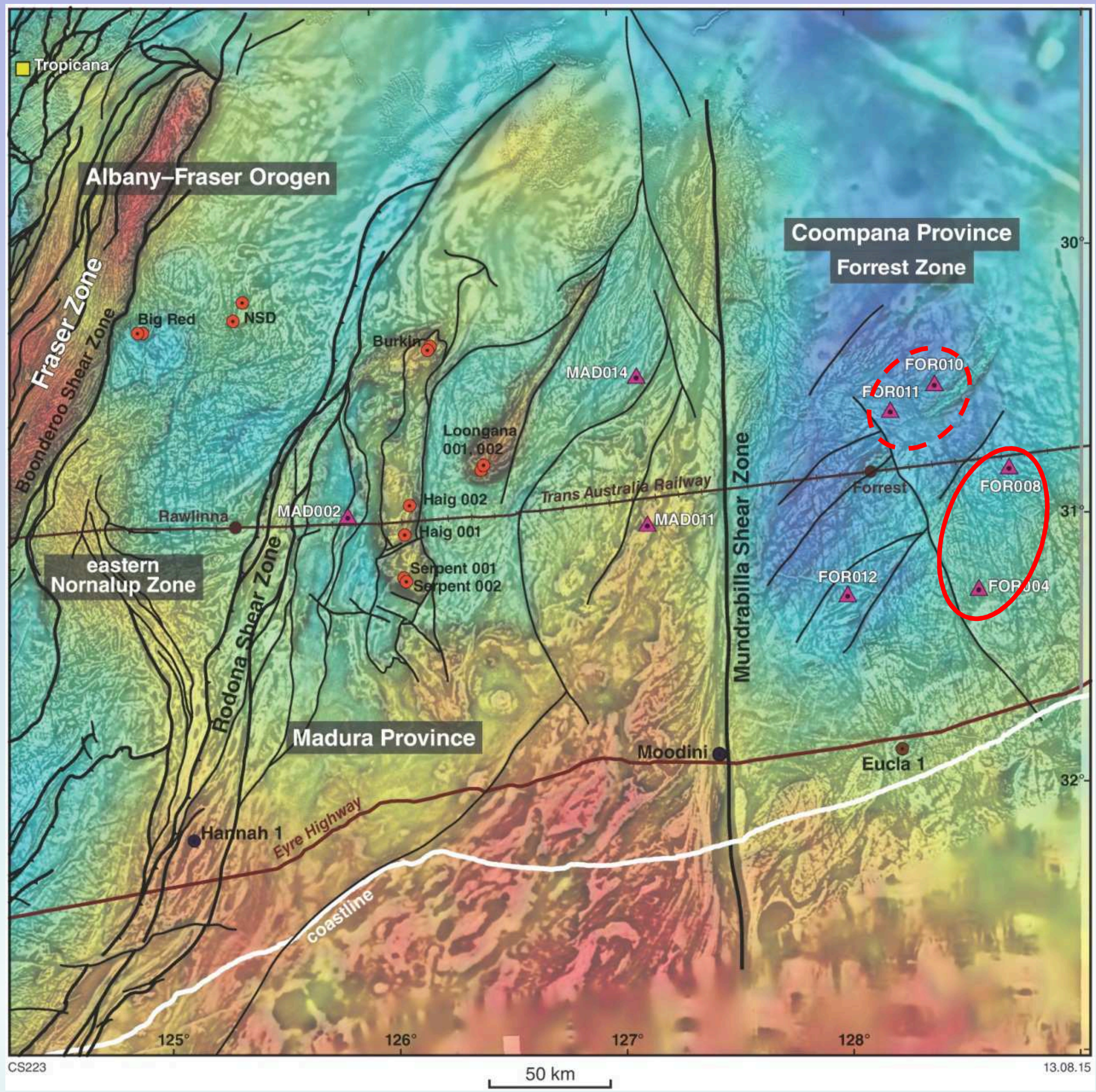
Hugh Smithies, Catherine Spaggiari, Chris Kirkland, Michael Wingate, and Dick England



Tropicana
Albany–Fraser Orogen
Fraser Zone
Boonderoo Shear Zone
Big Red
NSD
Burkin
Loongana 001, 002
MAD014
Coompana Province
Forrest Zone
FOR010
FOR011
FOR008
Forrest
Trans Australia Railway
Haig 002
Haig 001
MAD002
Rawlinna
MAD011
Serpent 001
Serpent 002
eastern Nornalup Zone
Rodona Shear Zone
Mundrabilla Shear Zone
FOR012
FOR004
Madura Province
Moodini
Eucla 1
Hannah 1
Eyre Highway
coastline
30°
31°
32°
125°
126°
127°
128°
CS223
13.08.15
50 km

Forrest Zone c. 1610 Ma

Subduction-related magmatism: arc crust



Toolgana Supersuite

FOR004
FOR008
(FOR011)
(FOR010)

Toolgana Supersuite (in FOR004 and FOR008)

- Feldspar-porphyritic granites dated at 1613–1604 Ma which are interleaved with fine- to medium-grained monzodiorite

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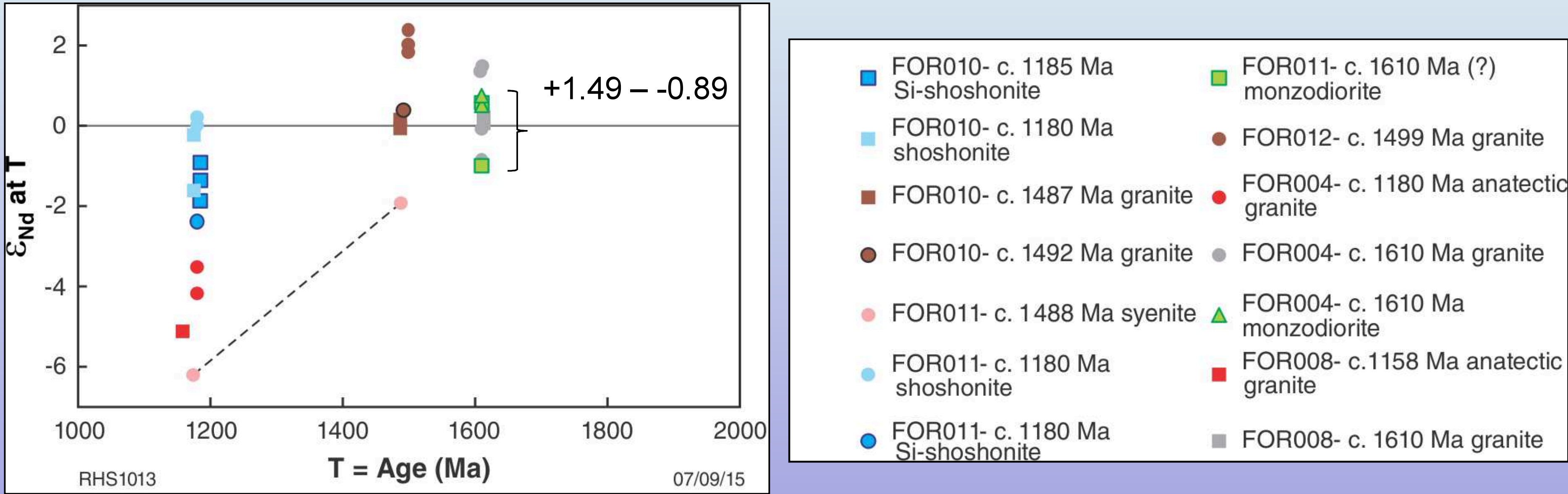
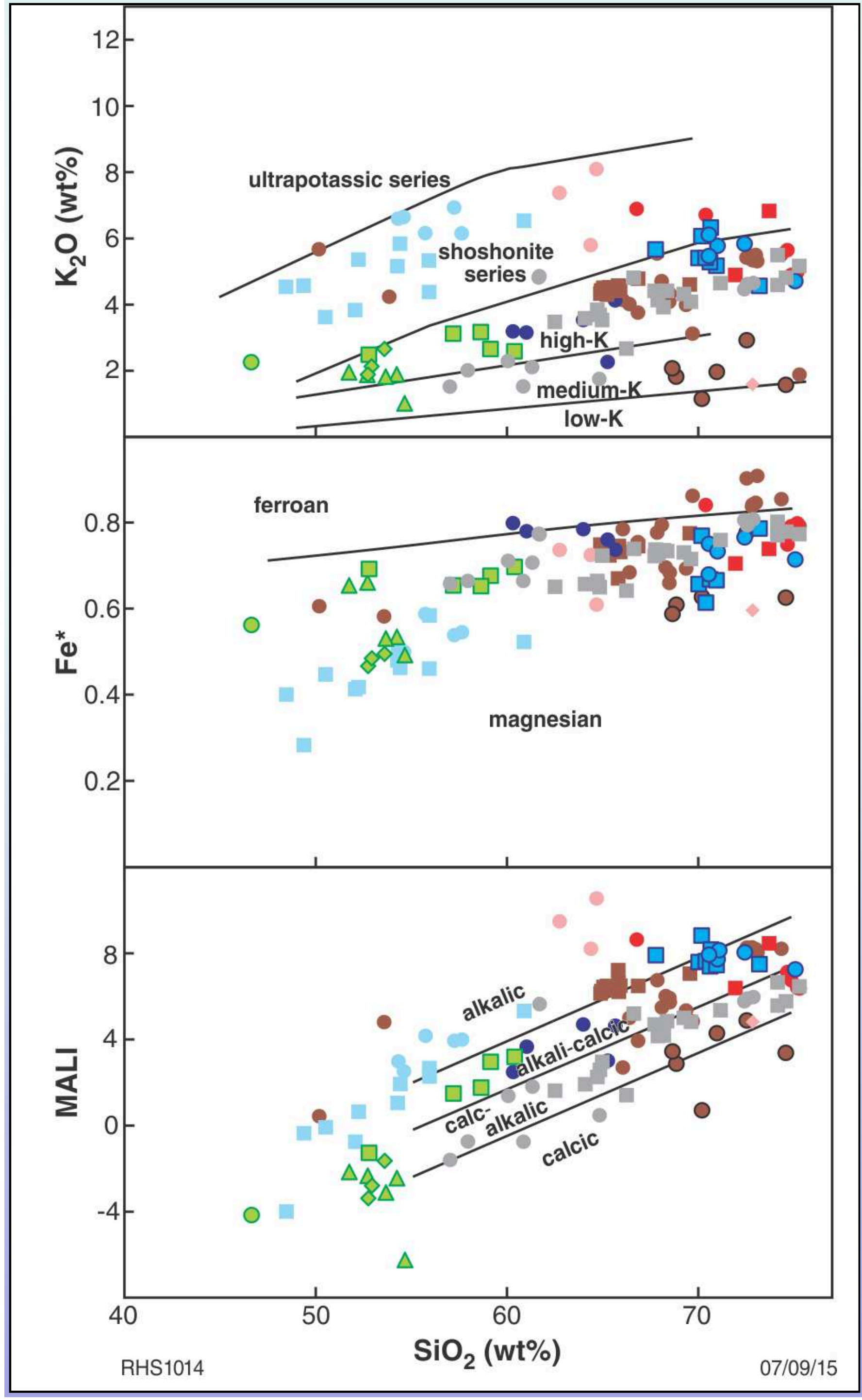
- High-grade metamorphism includes local incipient melting
- Inherited zircon (FOR004) c. 1724 –1671 Ma in age.
- All components show a rather narrow range of relatively juvenile Nd-isotopic compositions

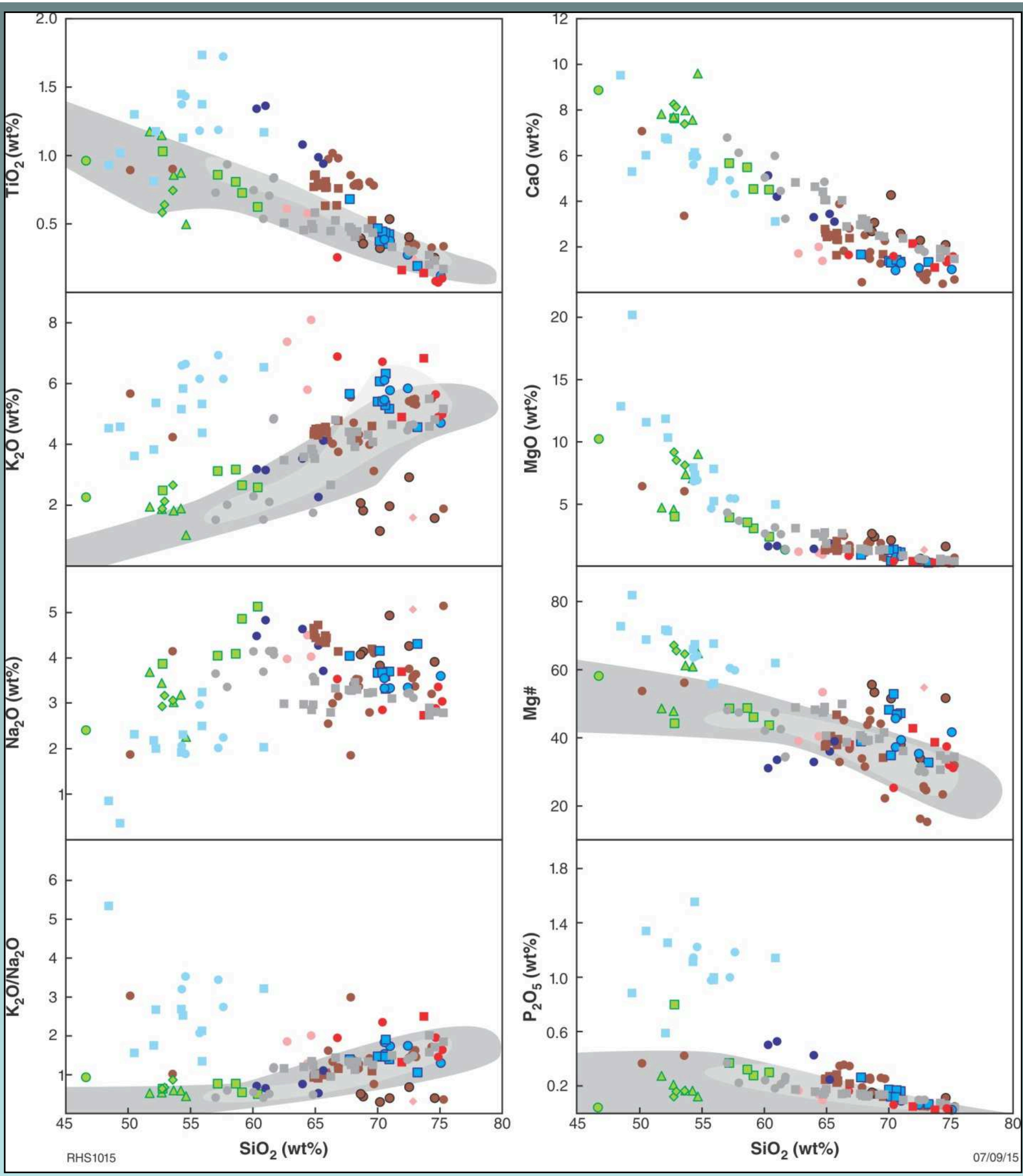




Toolgana Supersuite

- Granites are magnesian and mainly calc-alkalic
- Mainly high-K

FOR010- c. 1185 Ma Si-shoshonite
FOR010- c. 1180 Ma shoshonite
FOR010- c. 1487 Ma granite
FOR011- c. 1610 Ma (?) gabbro
FOR010- c. 1492 Ma granite
FOR011- c. 1488 Ma syenite
FOR011- c. 1180 Ma shoshonite
FOR011- c. 1189 Na granite
FOR011- c. 1180 Ma Si-shoshonite
FOR011- c. 1610 Ma (?) monzodiorite
FOR012- c. 1499 Ma granite
FOR004- c. 1180 Ma anatectic granite
FOR004- c. 1610 Ma granite
FOR004- c. 1610 Ma monzodiorite
FOR008- c.1158 Ma anatectic granite
FOR008- c. 1610 Ma granite
FOR008- c. 1610 Ma monzodiorite
Mallabie 1- c. 1500 Ma



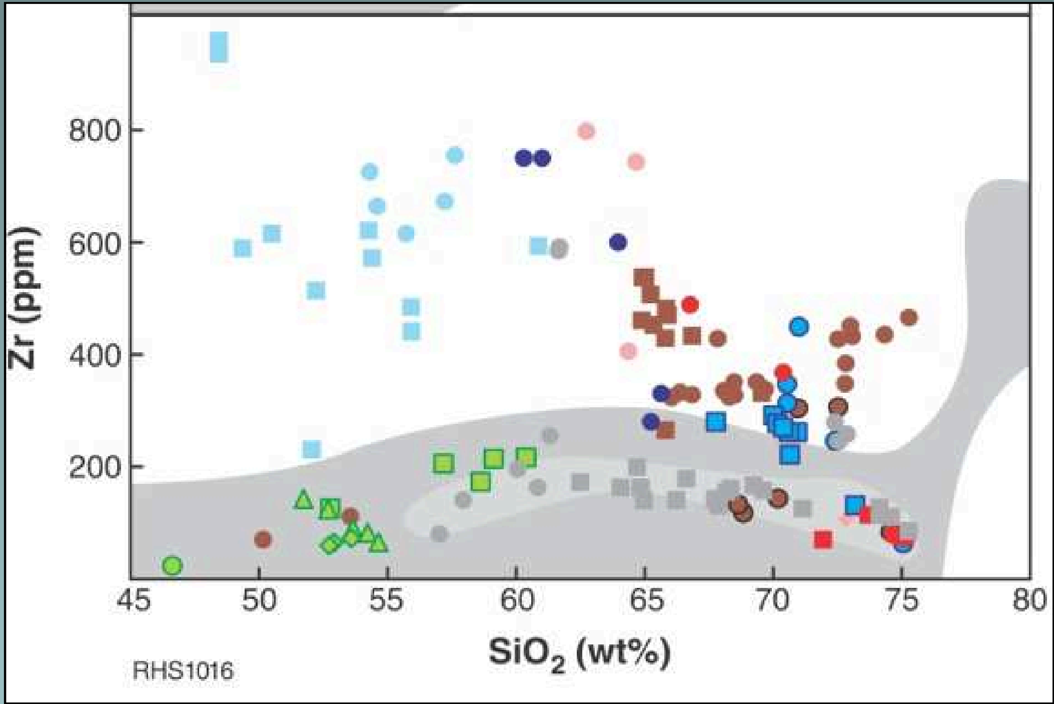
Toolgana Supersuite

Granites

- FOR004
- FOR008

Grey screen = Proterozoic subduction-related suites Wankanki and St. Peter)

Typical calc-alkaline trends



Toolgana Supersuite

Granites

- ○ FOR004
- □ FOR008

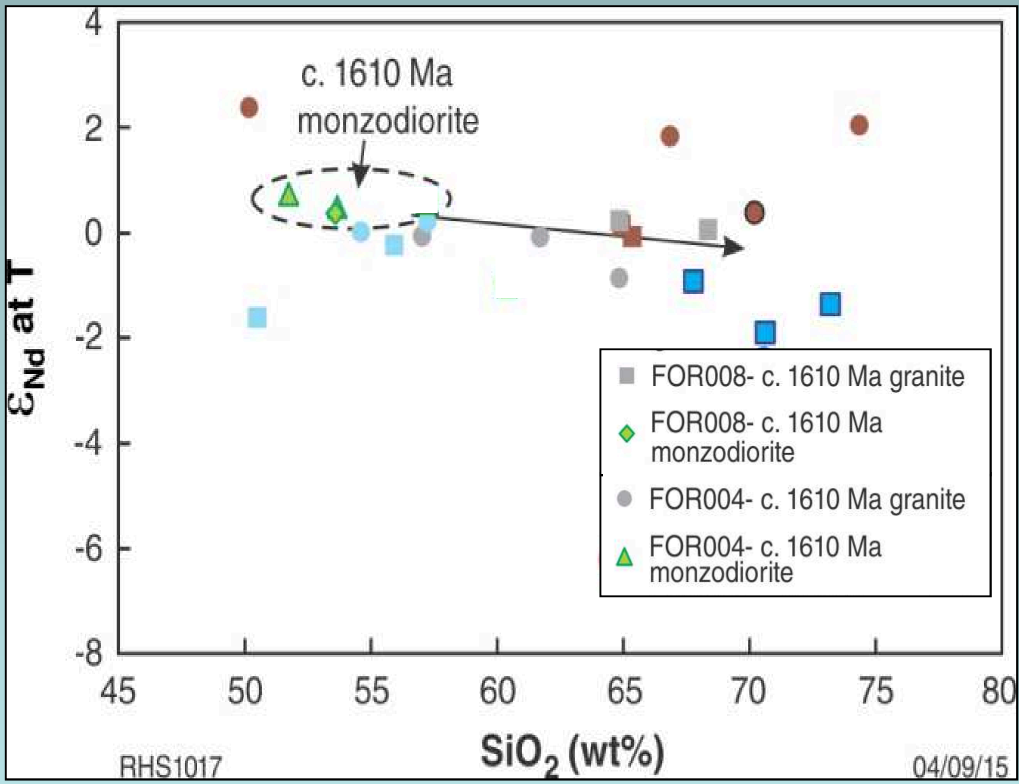
Grey screen = Proterozoic subduction-related suites (Wankanki and St. Peter)

Zr vs SiO_2 shows a distinction between 'subduction-related' suites and typically non-subduction related magmas (strongly enriched source; dry, hot melting…..)

Toolgana Supersuite

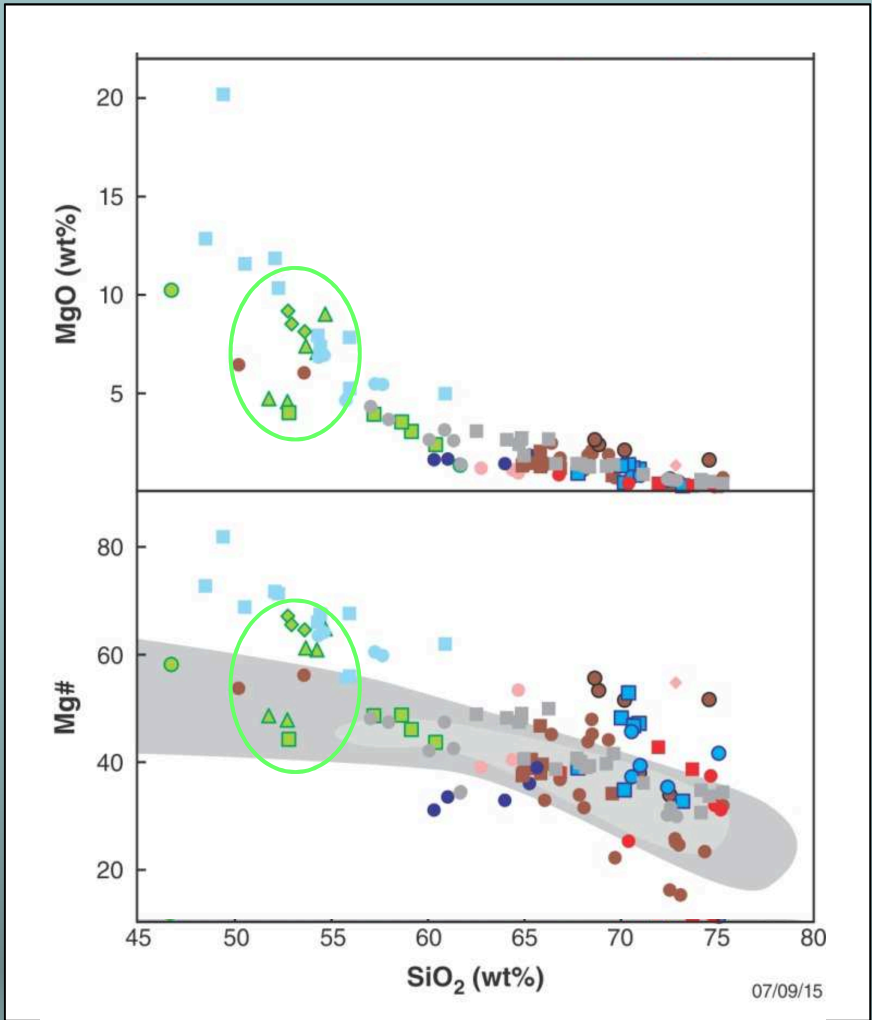
Nd isotopic composition on the granites become slightly less radiogenic over a large increase in SiO_2, suggesting AFC type processes involving only very minor progressive contamination (? the inherited 1724 – 1671 Ma component) and/or an isotopically similar contaminant.

Monzodiorite forms the mafic end of the trend, consistent with other compositional and textural evidence for a co-genetic relationship.



Monzodiorite and granite form co-genetic suites that have intruded crust that is compositionally similar

Toolgana Supersuite - monzodiorite



The most primitive samples have:

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

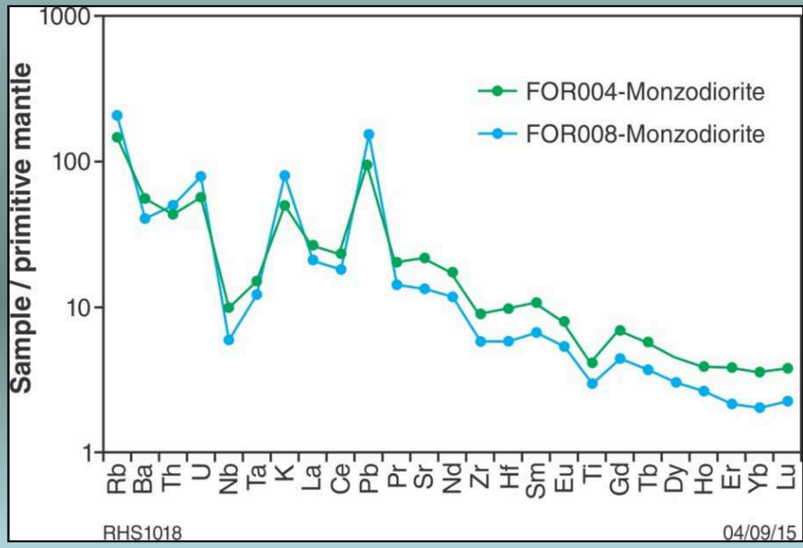
Rules out significant fractional crystallisation

But are also significantly enriched in highly incompatible trace elements such as;

Th (up to 5 ppm)
La (up to 20 ppm)

Likely a source enrichment

With high LILE/HFSE ratios (i.e. subduction-like patterns)



Toolgana Supersuite - monzodiorite

Crust added to mantle melt or crust added to mantle melt source!

1) Primitive compositions don't allow much FC or crustal contamination

2) Nd-isotope trends indicate only very weak crustal contamination – even in the felsic rocks

3) Incompatible trace element enrichments > 10 x MORB – but no known c. 1600 Ma (or older) crustal component able to do this (given the primitive compositions), including the 1724 – 1671 Ma inherited component.

The enrichments were more likely to a mantle source

Toolgana Supersuite is derived from a subduction-modified (enriched) mantle source

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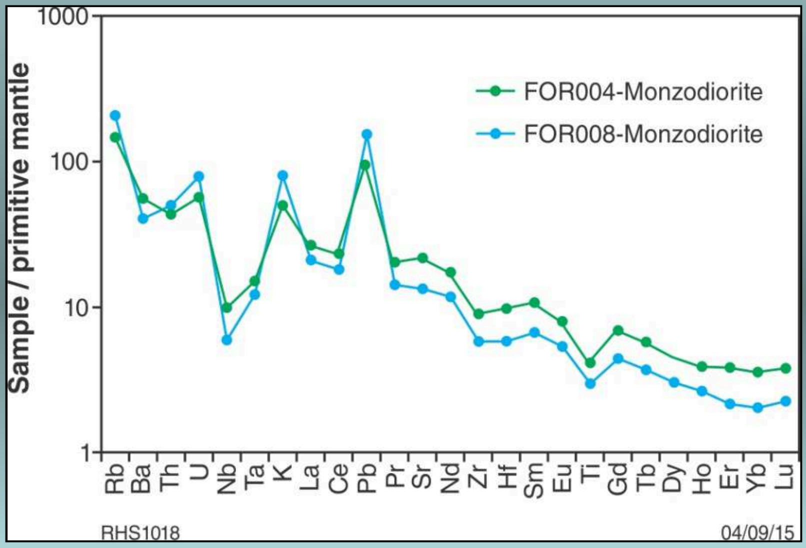
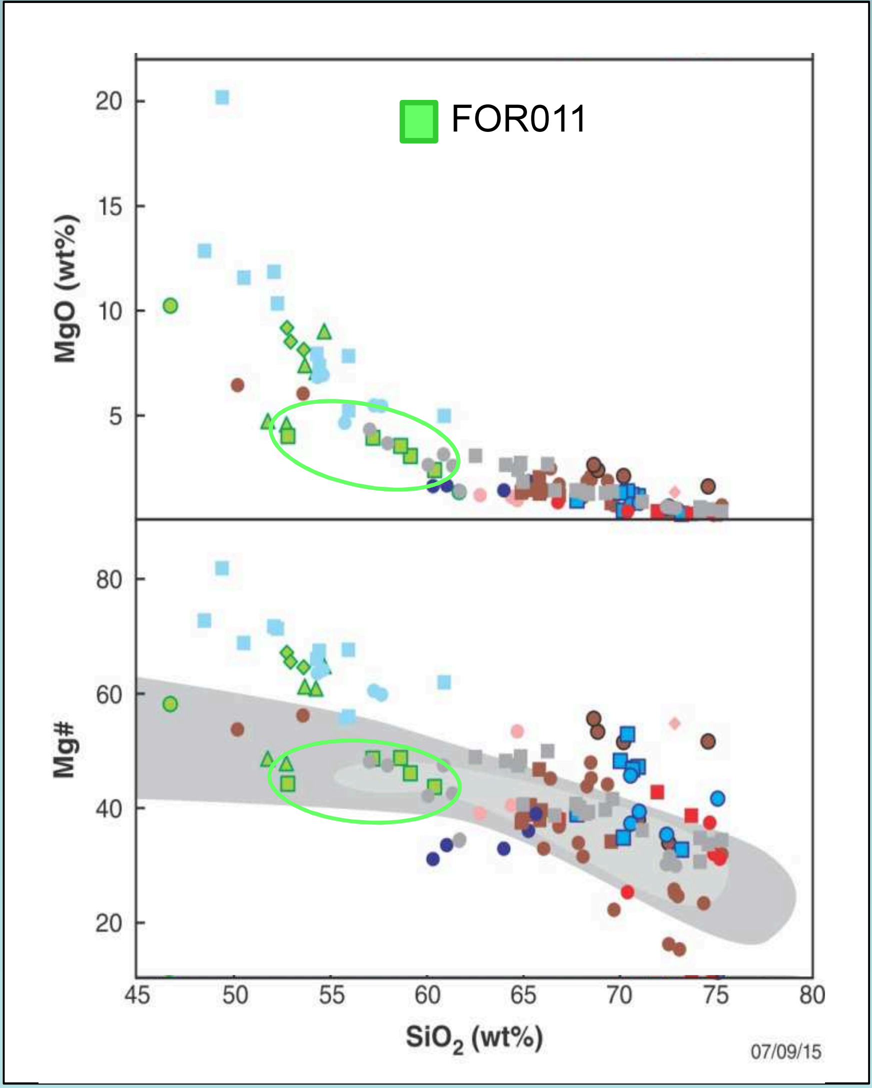
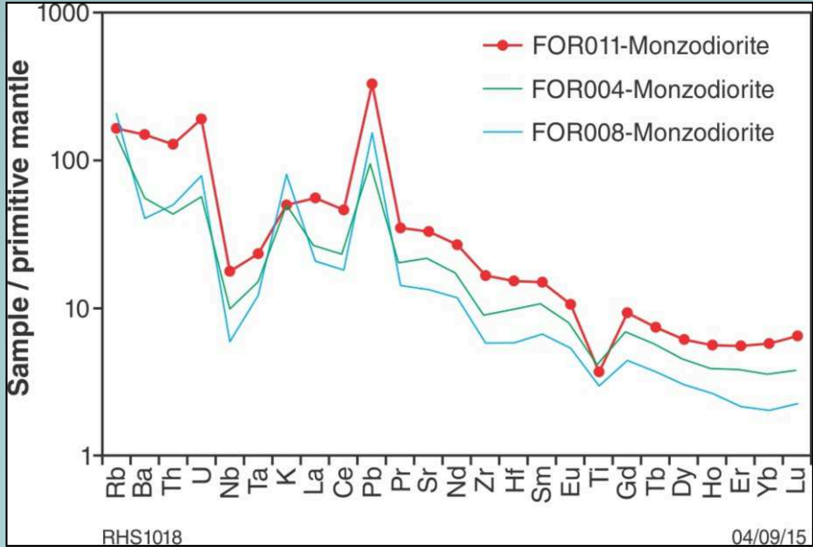
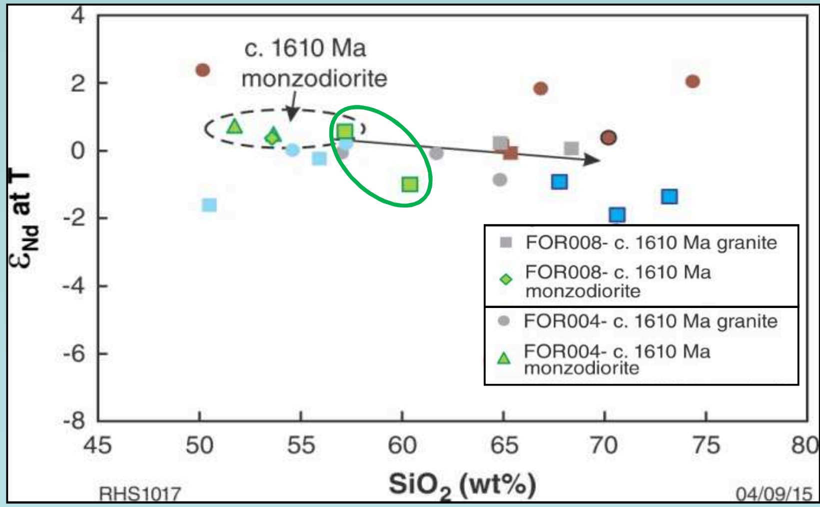


Probable c. 1610 Ma Toolgana Supersuite in FOR011

Mozodiorite also occurs in FOR011 and although undated, structural relationships suggest this is an ‘older’ component.

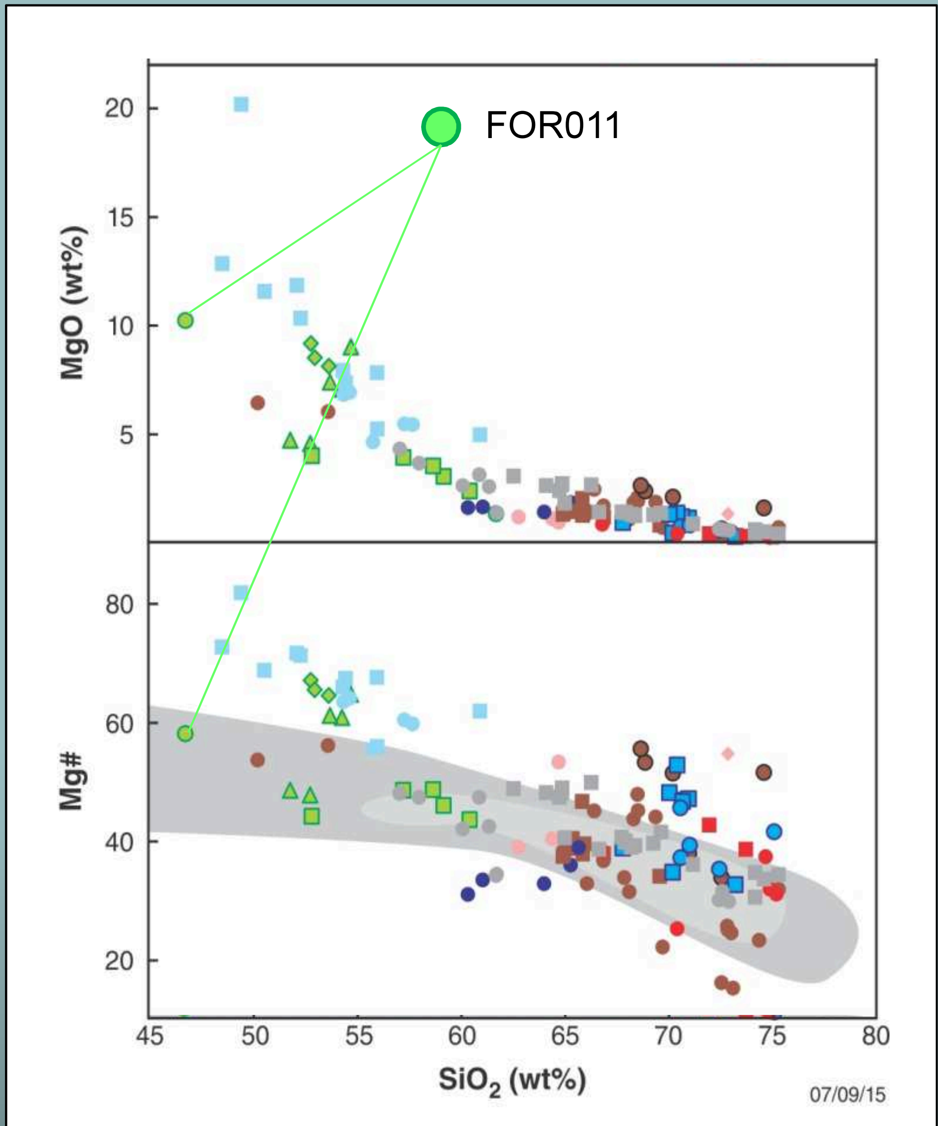


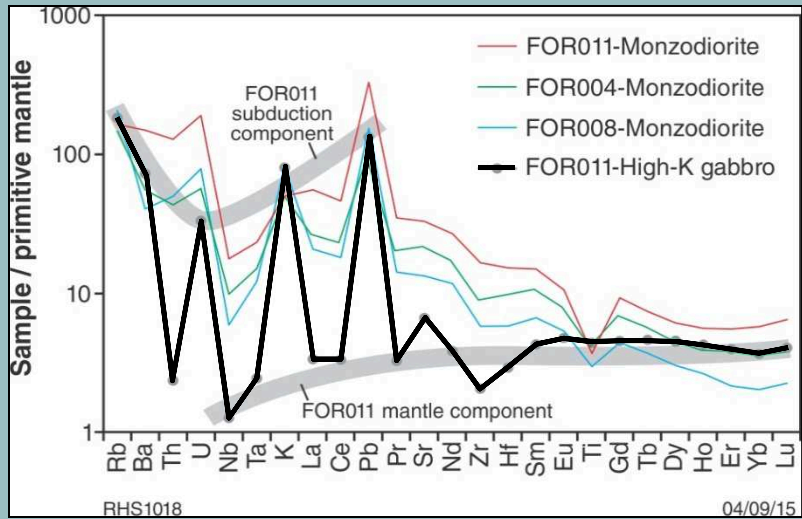




Probable c. 1610 Ma Toolgana Supersuite in FOR011

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

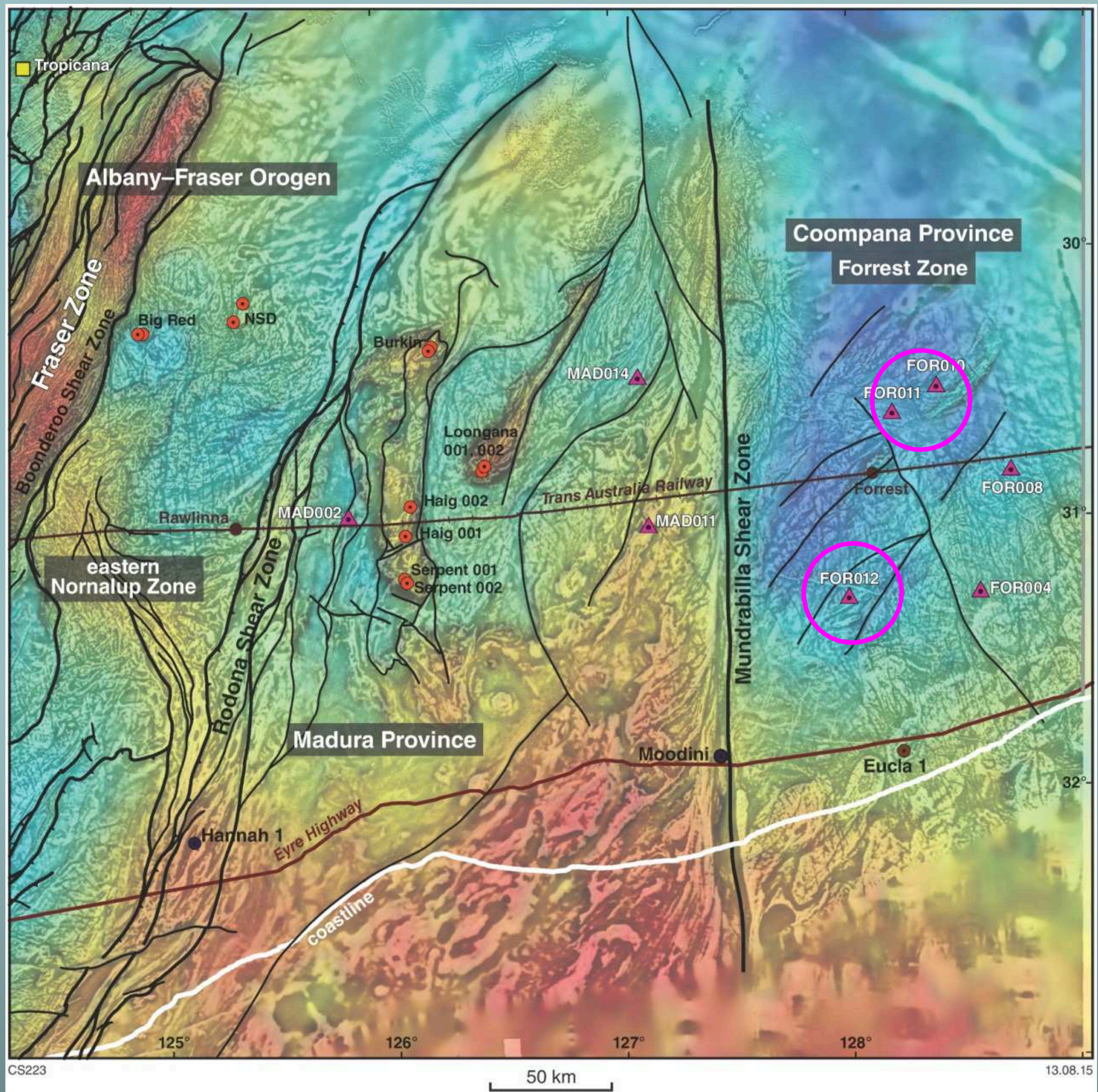
NO crustal addition

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

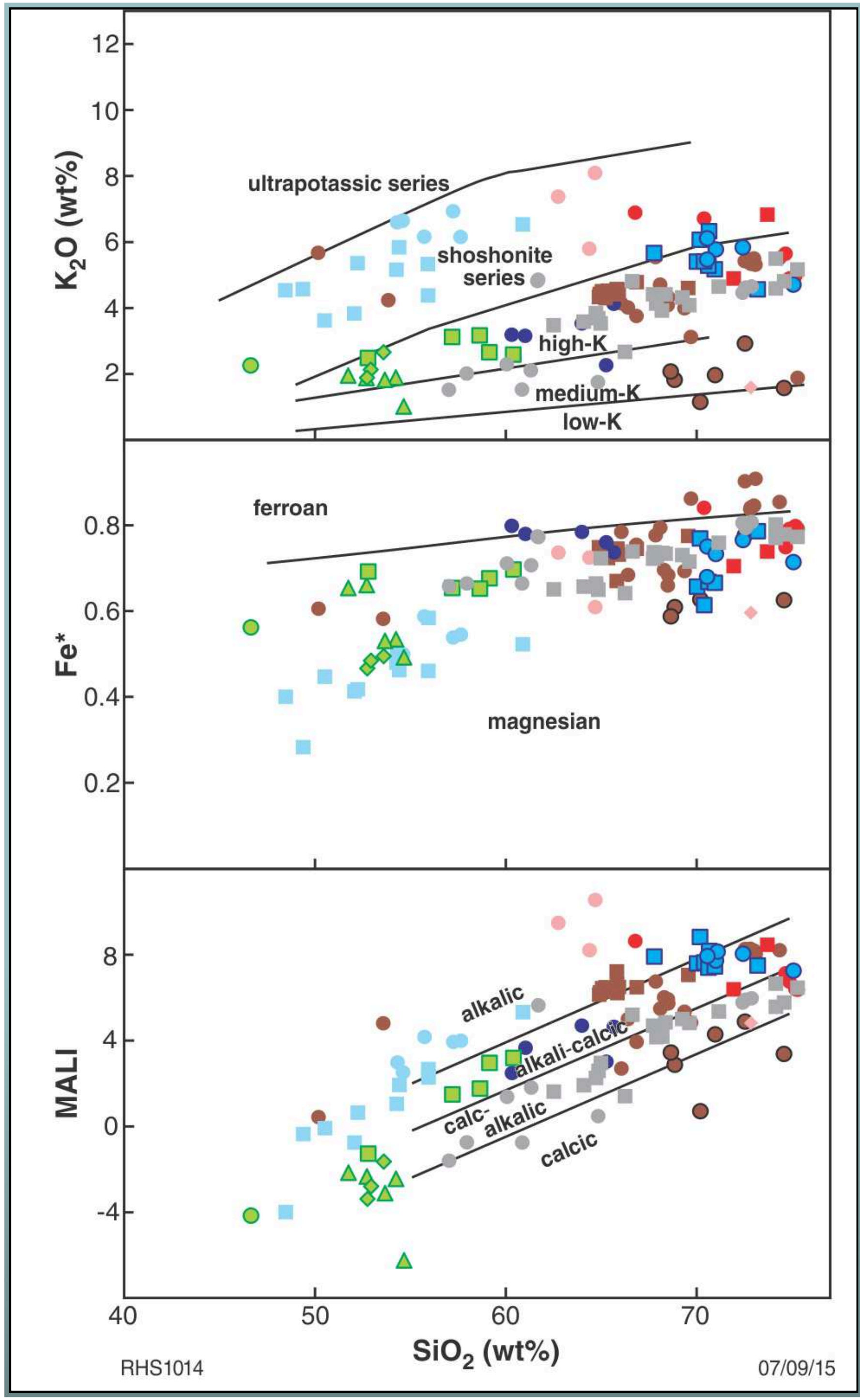
Forrest Zone c. 1500 Ma

Extension (rift) related granites



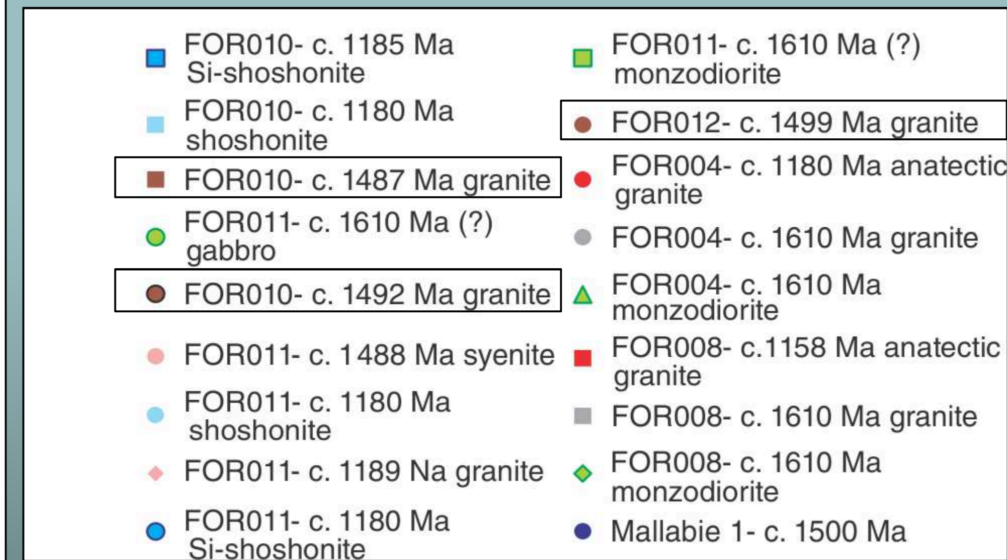
Undawidgi Supersuite

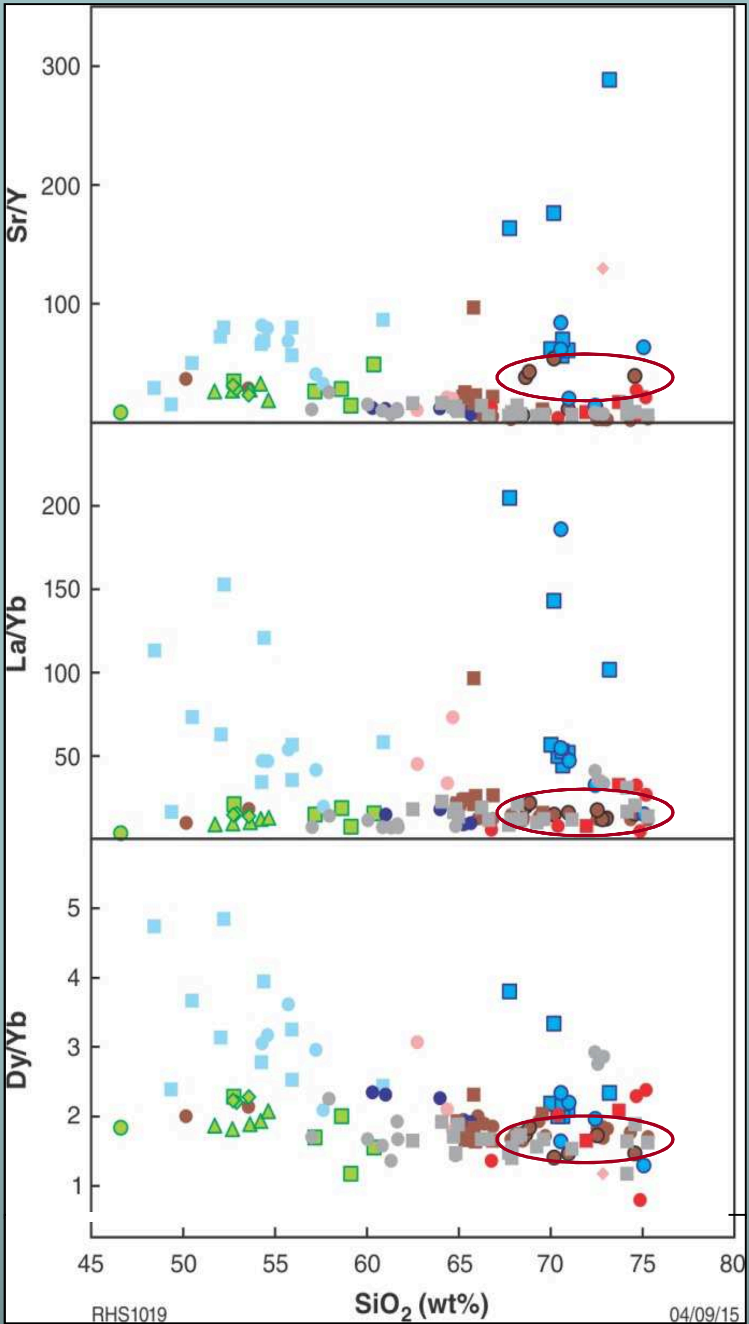
FOR012
FOR010
FOR011



Undawidgi Supersuite

- All quite silicic
- one group is sodic (low-K), magnesian, and calc-alkalic to calcic (FOR010)
- a second group is high-K, magnesian (FOR010) or transitional to ferroan (FOR012) and alkali-calcic to alkalic
- lack zircon inheritance



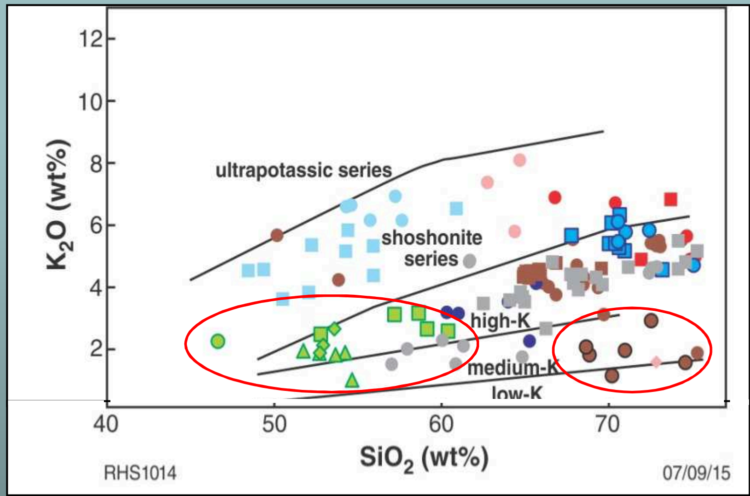


Undawidgi Supersuite

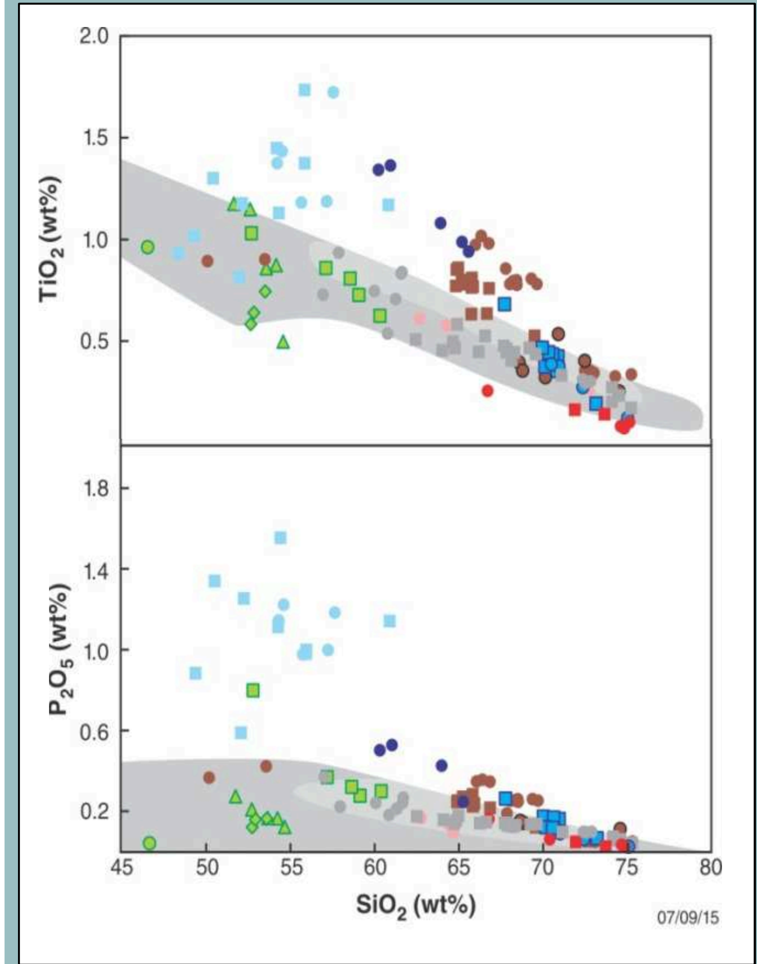
Sodic group

Moderately high Sr and low Y (HREE), but Sr/Y and Dy/Yb still much lower than expected for a true adakite and reflect lower-pressure (mid-crustal) melting of a mafic source.

This source can't be similar to known c. 1610 Ma mafic crust – which is too K-rich.

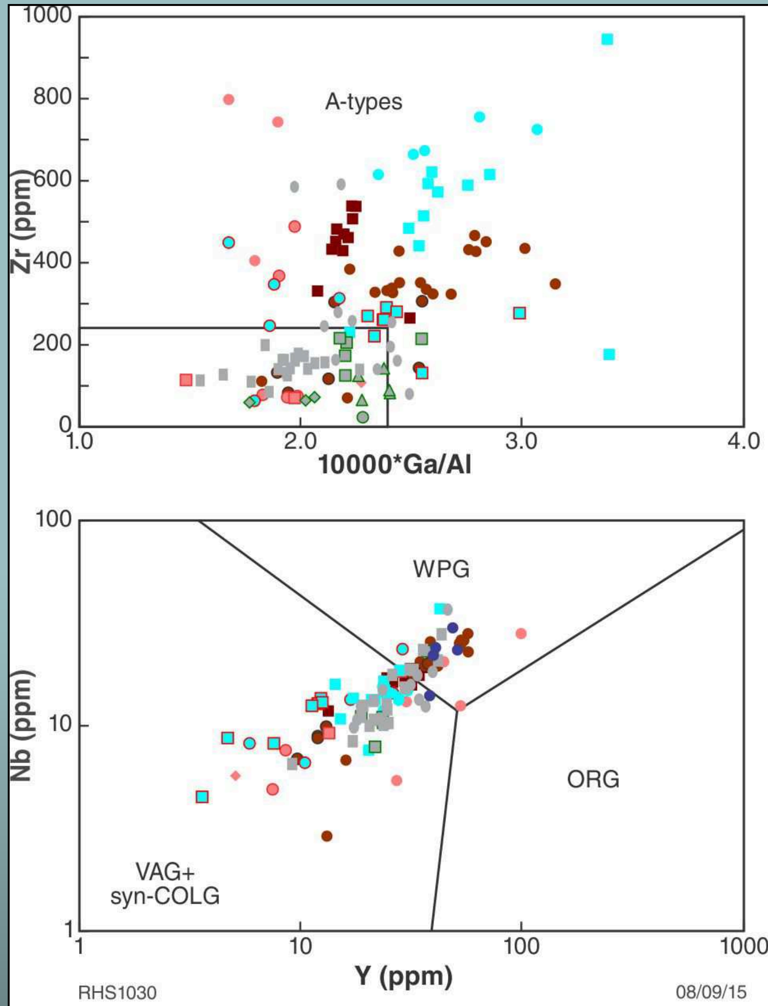


Undawidgi Supersuite



High-K group

Show enrichments in TiO_2, P_2O_5, HFSE, Ga, Zn typical of A-type magmas but are distinct in that they remain magnesian until quite high SiO_2.

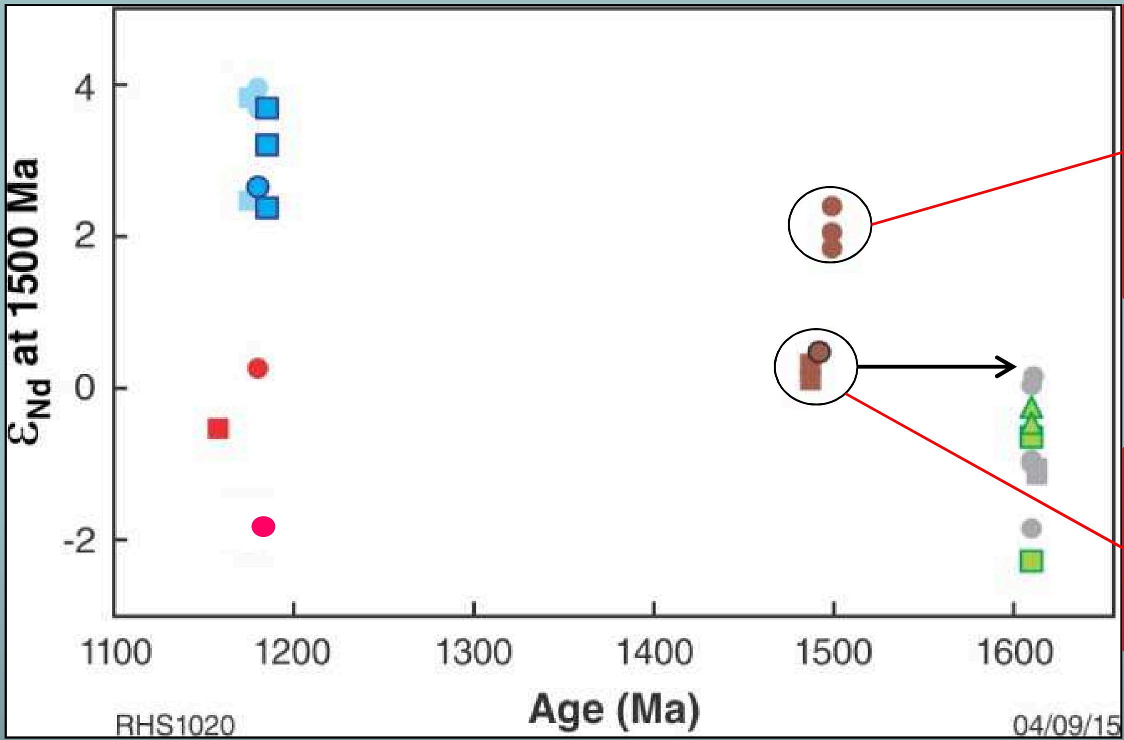


A-type pertrogenesis might explain the lack of inherited zircon – or the source was simply mafic!

Undawidgi Supersuite

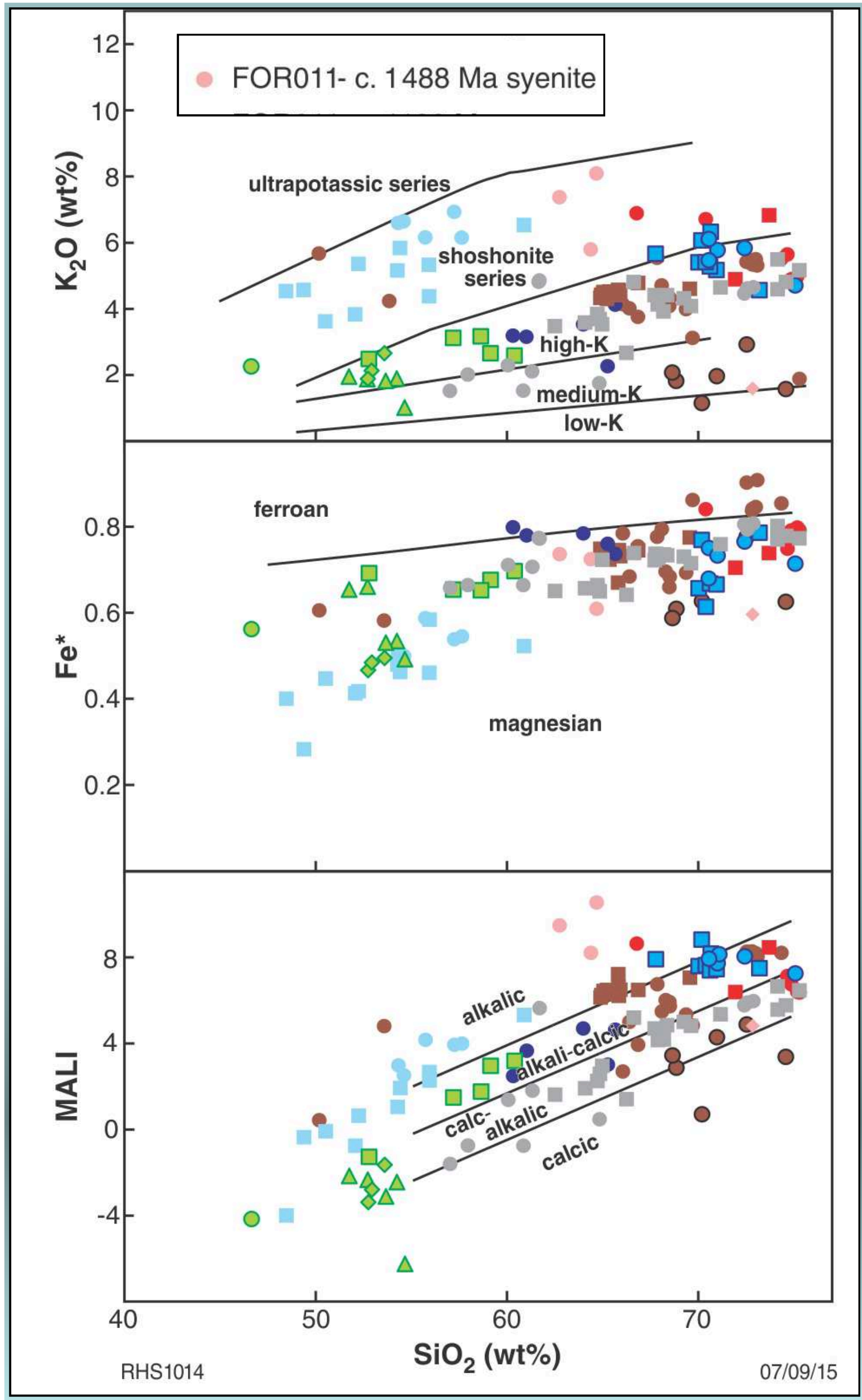
The Nd isotopic composition of the sodic group and some of the high-K group are similar and are equivalent to the radiogenic end of the range of c. 1610 Ma crust at c. 1500 Ma.

The high-K group from FOR012, however, requires an additional radiogenic component in the bulk source



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

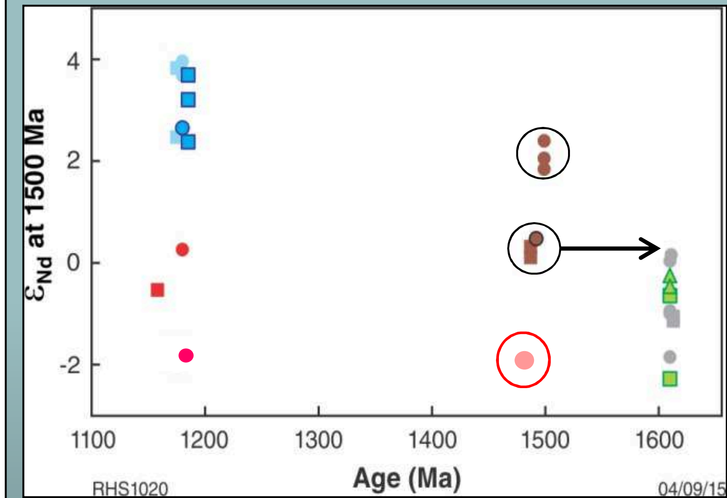
? remelting c. 1610 Ma crust (unsampled low-K basalt component in the case of the sodic group) + small mantle addition



Undawidgi Supersuite

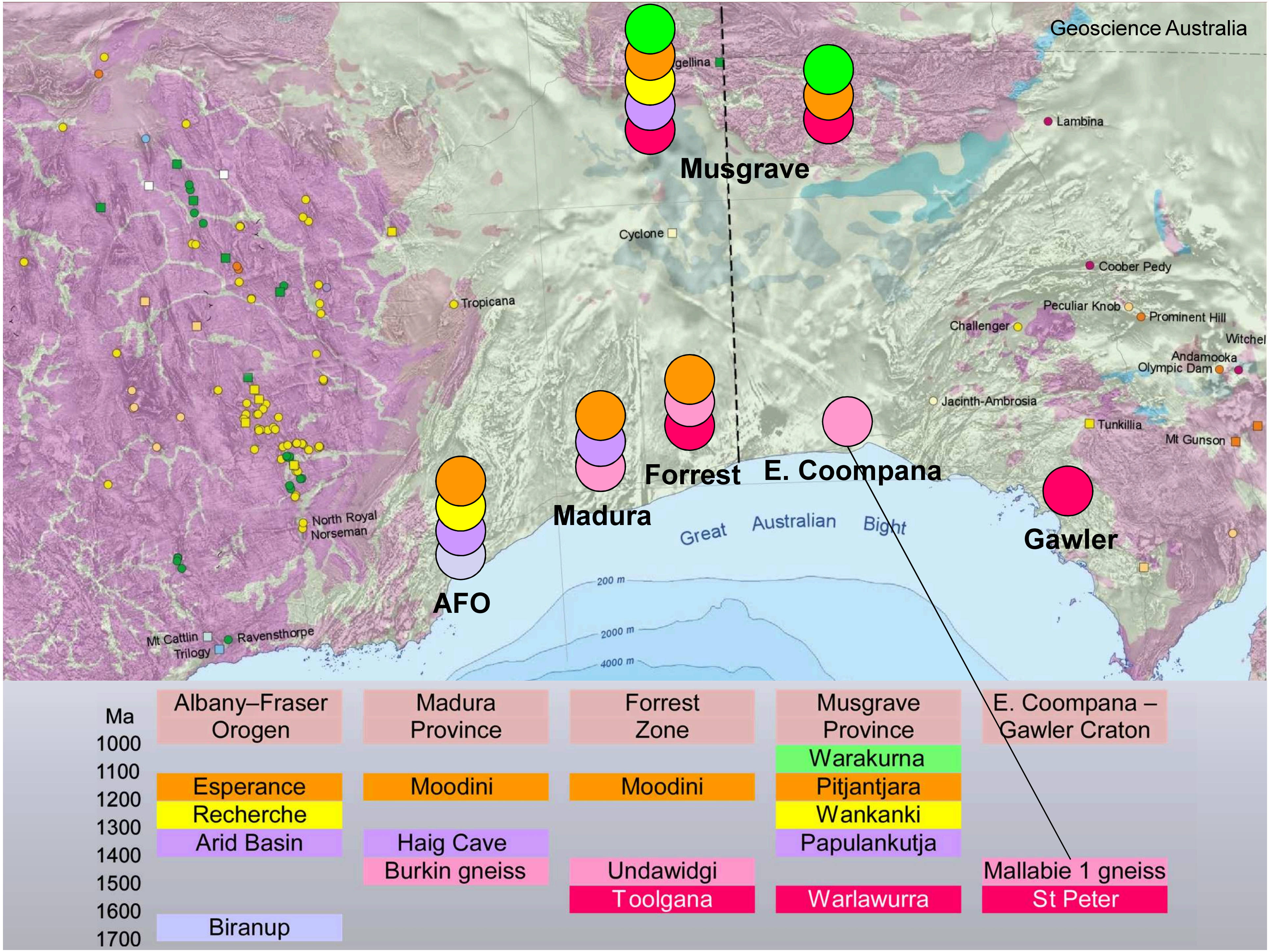
c. 1488 Ma syenites (FOR011)

Almost perakaline; high Ba, LREE, HFSE – but not typical of A-types



Non-radiogenic Nd requires a dominantly 'crustal' source similar to c. 1600 Ma crust.

? Remelting of strongly alkali-metasomatised subduction-related crust.

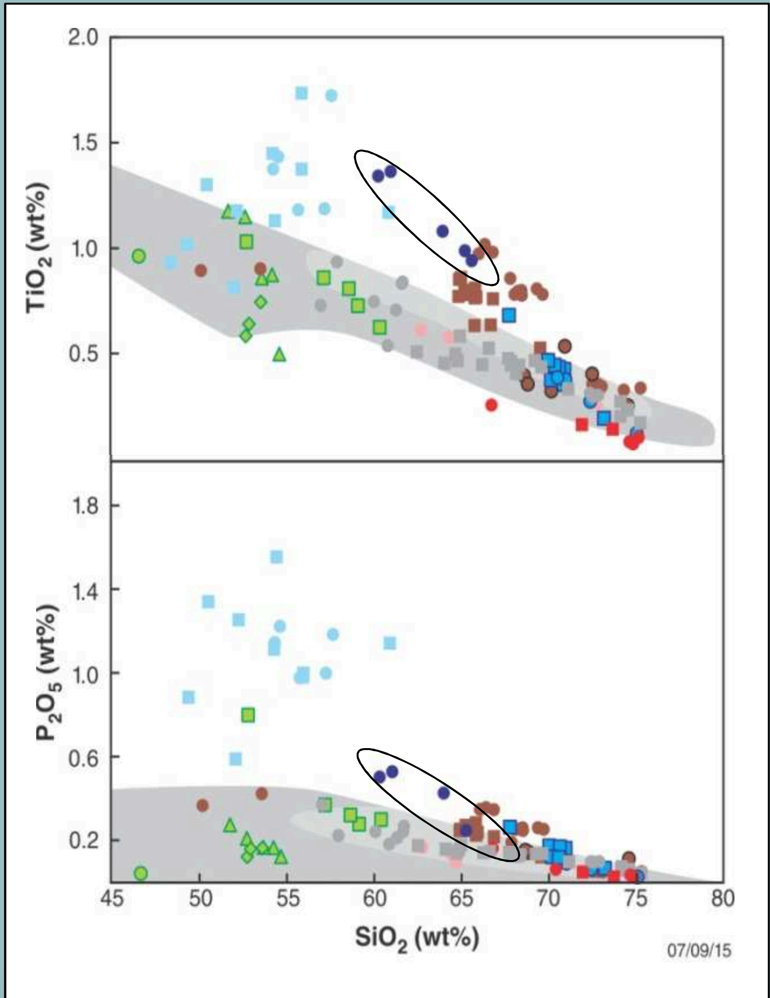

Geoscience Australia
Musgrave
Madura
Forrest
E. Coompana
Gawler
AFO
Great Australian Bight
200 m
2000 m
4000 m
Tropicana
Cyclone
Lambina
Coober Pedy
Peculiar Knob
Prominent Hill
Challenger
Witchel
Andamooka
Olympic Dam
Jacinth-Ambrosia
Tunkillia
Mt Gunson
North Royal
Norseman
Mt Cattlin
Ravensthorpe
Trilogy
Ma
1000
1100
1200
1300
1400
1500
1600
1700
Albany–Fraser Orogen
Madura Province
Forrest Zone
Musgrave Province
E. Coompana – Gawler Craton
Warakurna
Esperance
Moodini
Moodini
Pitjantjara
Recherche
Wankanki
Arid Basin
Haig Cave
Papulankutja
Burkin gneiss
Undawidgi
Mallabie 1 gneiss
Toolgana
Warlawurra
St Peter
Biranup

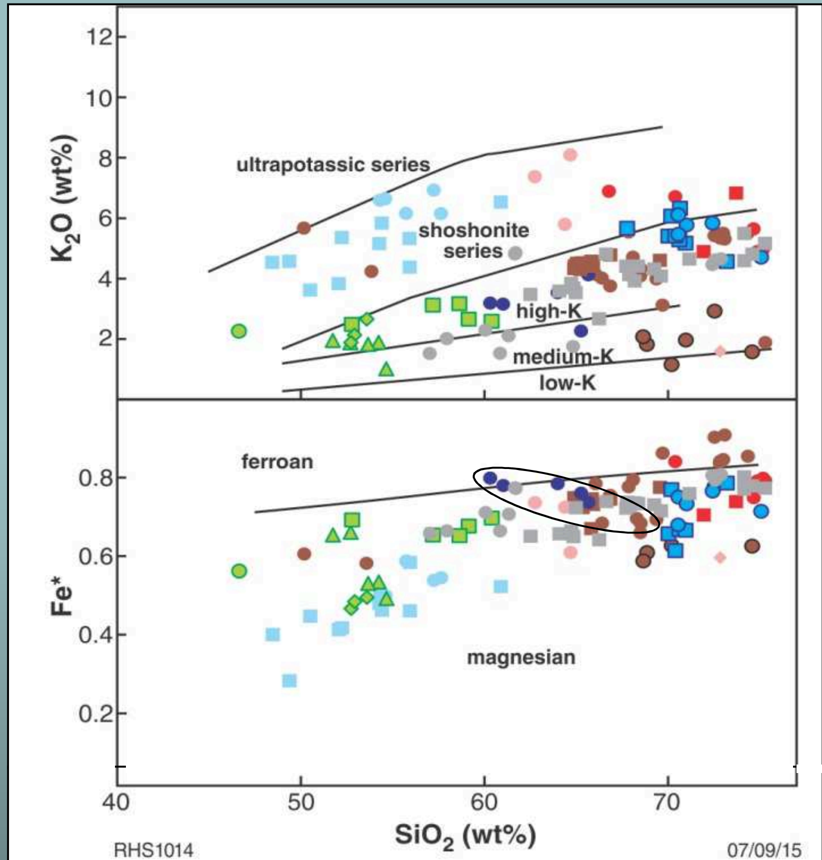
Undawidgi Supersuite

Mallabie 1

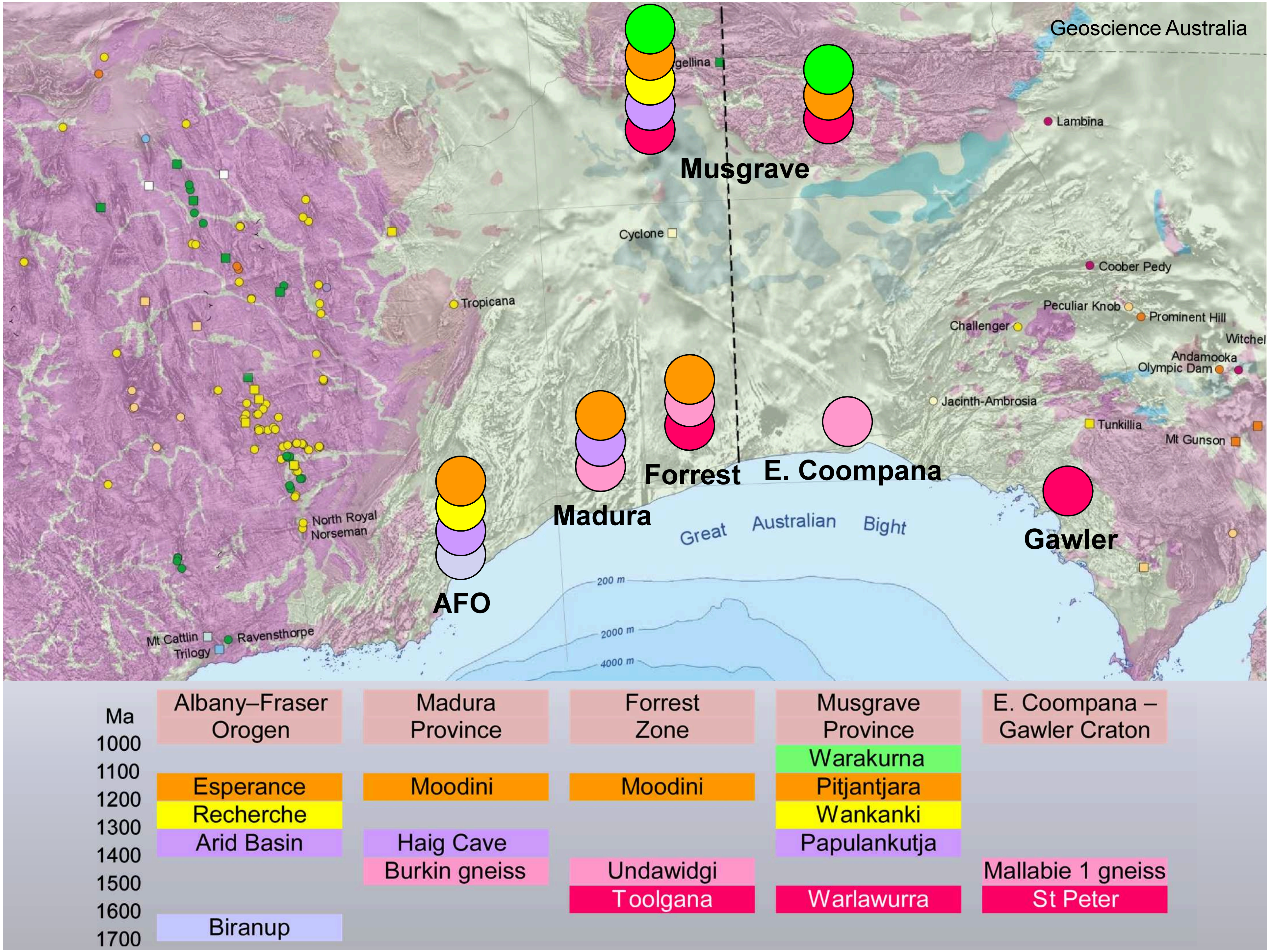
High-K c. 1500 Ma granites drill from the Coompana Province in South Australia

Compositionally and isotopically identical with high-K c. 1500 Ma granites from the Forrest Zone





(Mallabie 1 data from Wade et al., 2007)



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Moodini
Undawidgi
Toolgana
Musgrave Province
Warakurna
Pitjantjara
Wankanki
Papulankutja
Warlawurra
E. Coompana – Gawler Craton
Mallabie 1 gneiss
St Peter

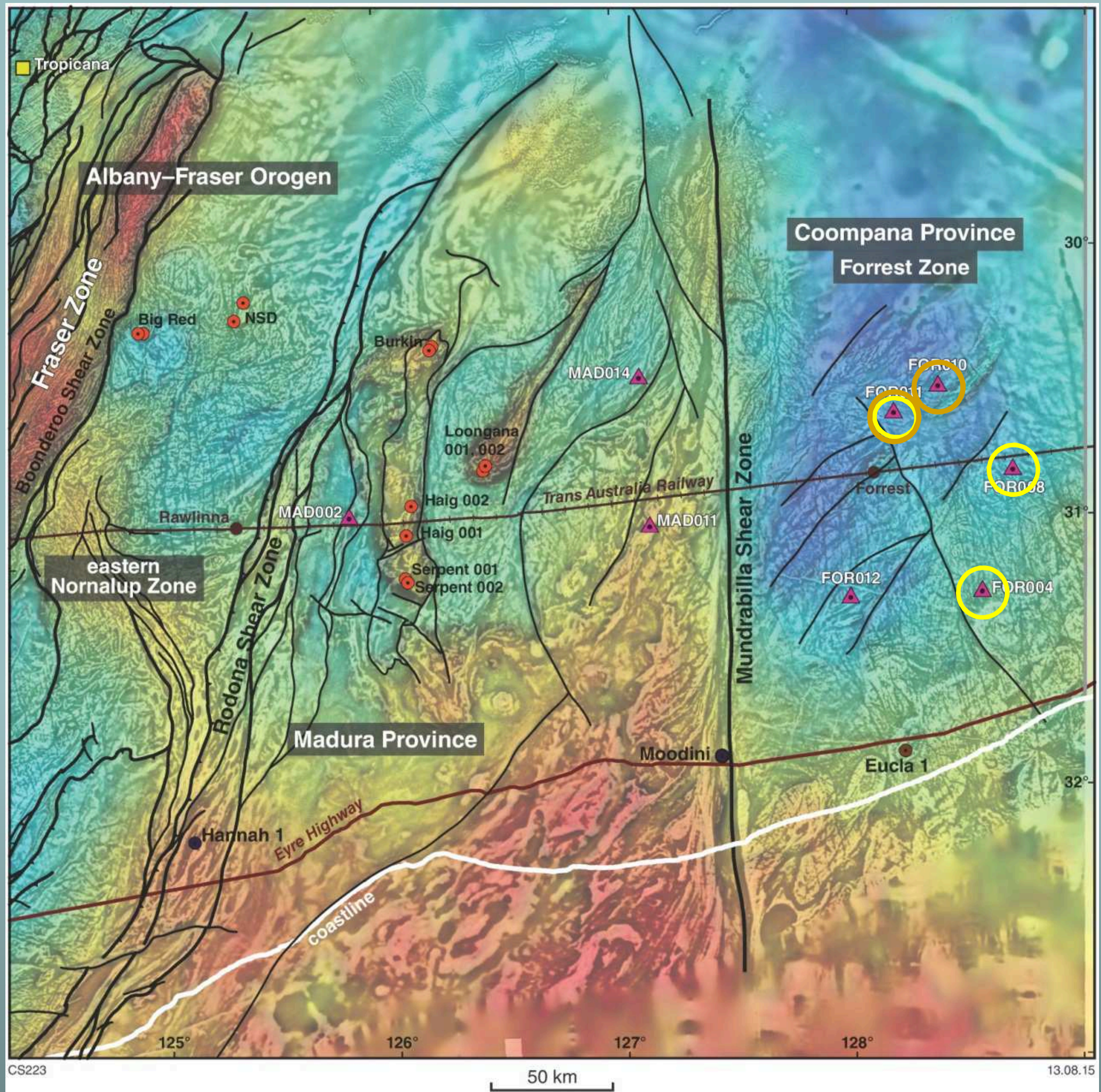
Undawidgi Supersuite c. 1500 Ma

We have three instances of similarly aged rocks with similar compositional features that distinguish them from other magma compositions including typical subduction compositions. In many respects these resemble post-collisional granites, with the more magnesian compositions perhaps correlating with their more ‘crustal’ isotopic compositions.

It is inviting to suggest that these rocks formed through high temperature melting of juvenile arc-related crust (the c. 1600 Ma to < 1950 Ma arc complex) during extension.

Forrest Zone c. 1185 – 1150 Ma

Regional high-temperature re-melting



Mooooodini Supersuite

~*in-situ* anatectic melts

FOR008

FOR004

FOR011

Shoshonitic magmas

FOR011

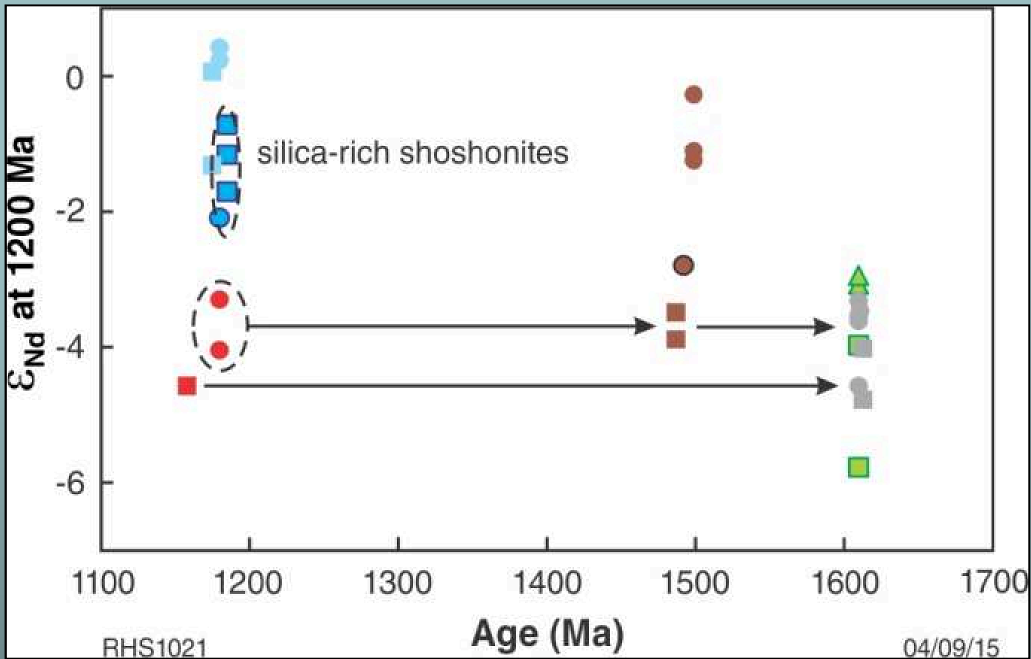
FOR010

Moodini Supersuite

Two types, local anatectic partial melts (not really Moodini Supersuite) and shoshonitic magmas.

Shoshonites include mafic and high silica groups

Major element compositions of high silica shononites difficult to distinguish from the anatectic melts (which are of K-rich crust!), but the shoshonites are clearly distinguished based on their trace element compositions (e.g. high Ba, Sr, Zr, LREE) and on their much more radiogenic Nd isotopic compositions.

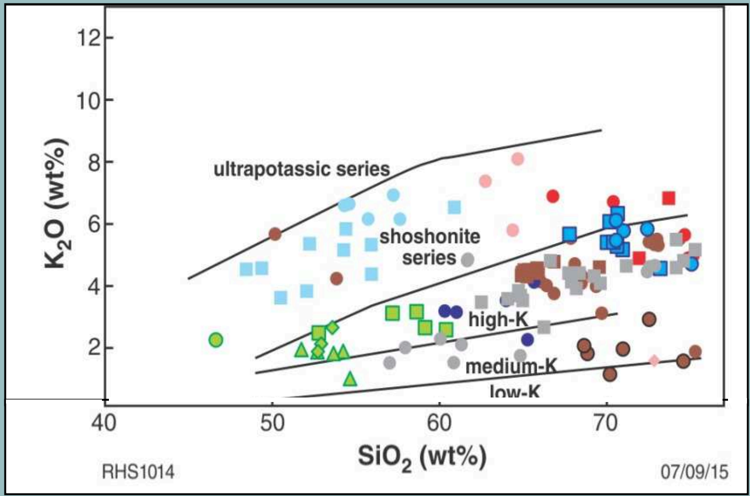


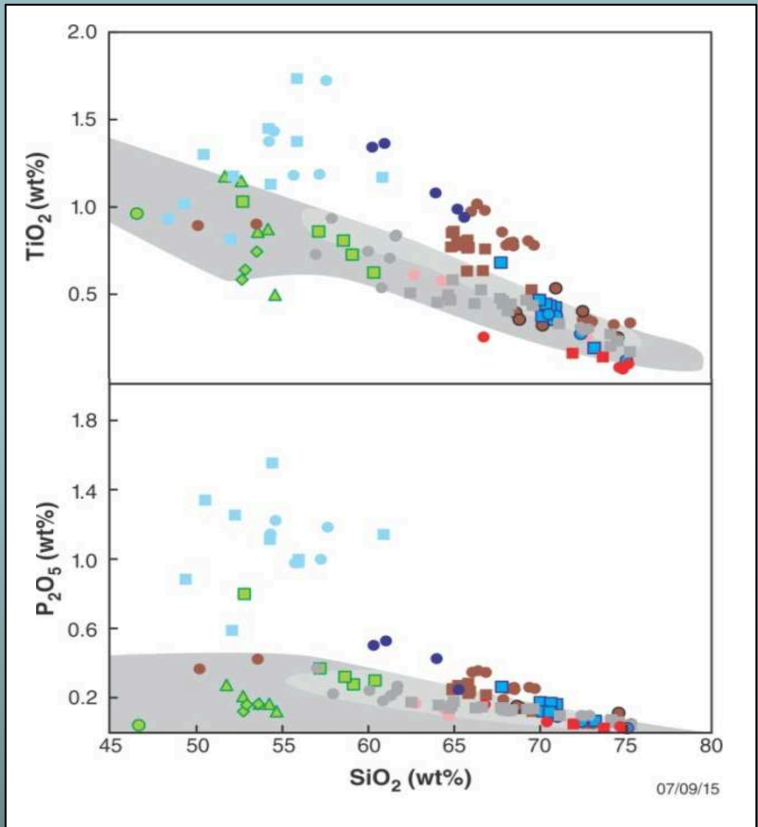
Moodini Supersuite

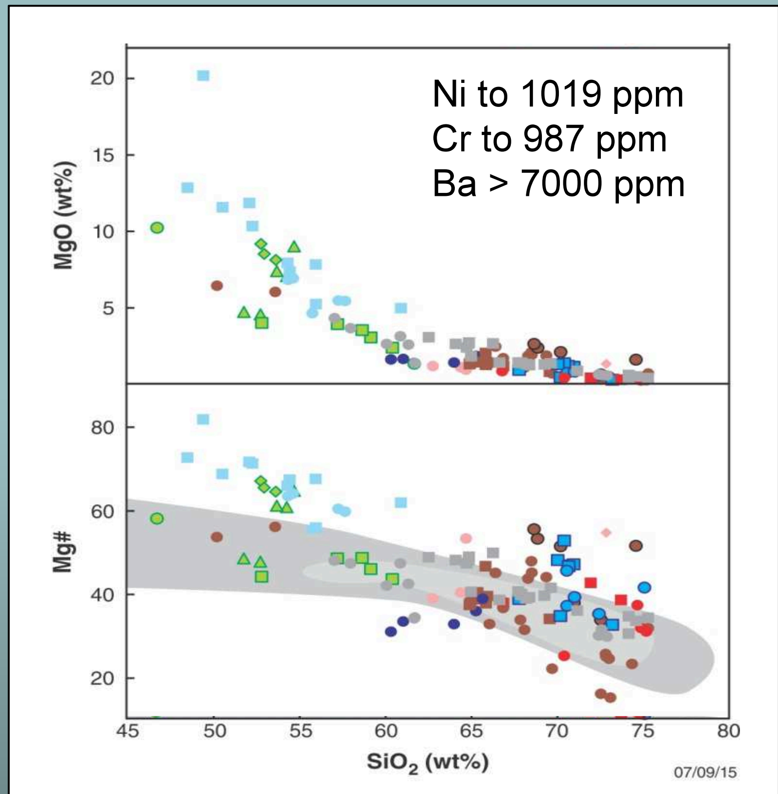
Shoshonites

Form a major component (up to 25%) of both FOR010 and FOR011

Include mafic (SiO_2 48.45 – 60.87 wt%) and felsic (SiO_2 67.78 – 75.08 wt%) groups each type occurring in both cores.

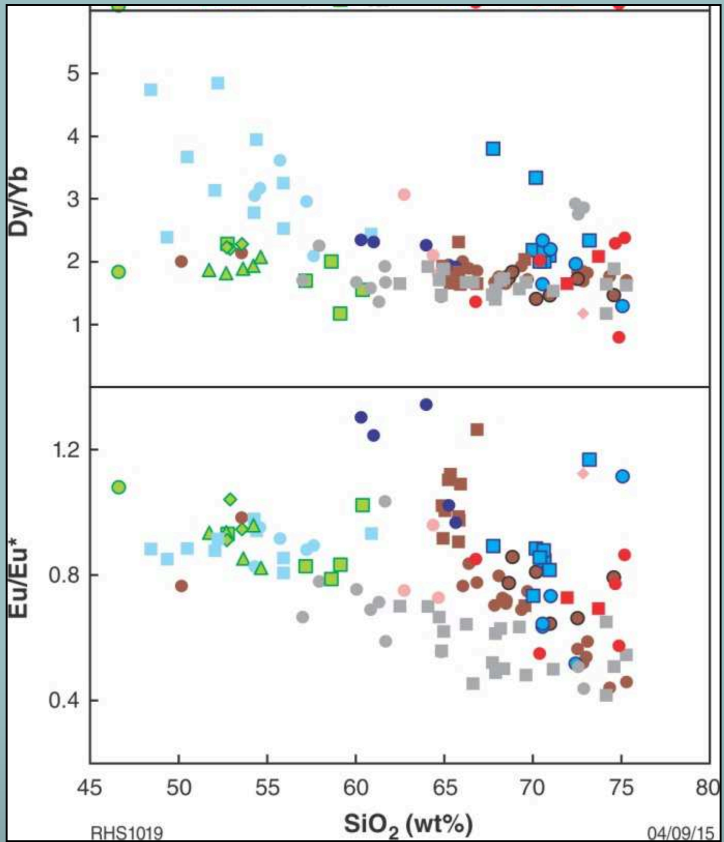


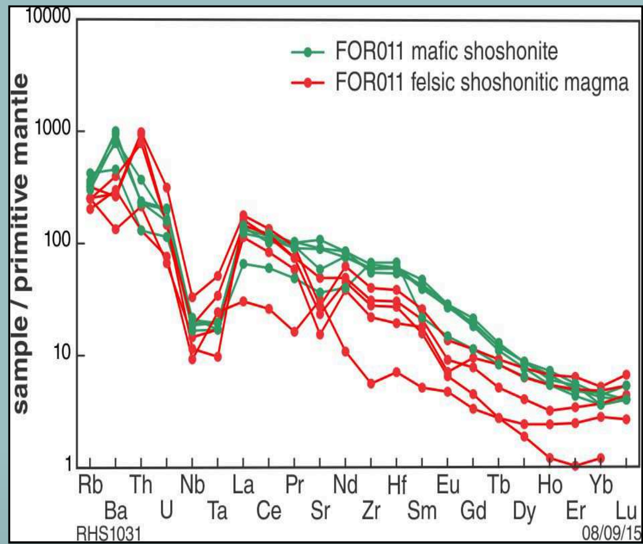




Moodini Supersuite *Shoshonites*

Dy/Yb ratios are high but decrease rapidly with increasing silica suggesting a strong role for hornblende fractionation, but Eu/Eu* remain constant at ~ 1.0 – 0.8, suggesting either relatively oxidized (and wet?) conditions or no feldspar fractionation — or all of these.





The high La/Yb and Sr/Yb ratios and low Yb support a deep melting source with residual garnet, but not plagioclase. The evidence for wet and oxidised magmatism favours a garnet amphibolite source.

Moodini Supersuite *Shoshonites*

The combination of extremely high $Mg^{\#}$ and strong enrichments in incompatible trace elements points clearly to a lithospheric mantle source.

Remelting of thick (deep) lithospheric mantle, hydrated and enriched during an earlier subduction event

Models for shoshonite petrogenesis typically emphasize post-orogenic extensional melting of subduction-modified lithosphere as a resulting of upwelling asthenosphere.

Toolgana Supersuite c. 1610 Ma magmas

Magmatism at c. 1610 Ma included co-genetic mafic to felsic suites

Mafic end-members are monzodiorite with compositions in equilibrium with mantle peridotite and with trace element enrichments most likely related to subduction processes.

Zircon inheritance suggests the age of the crust they intrude was c. 1724 –1671 Ma and was compositionally very similar

The crust was isotopically juvenile.

Isotopic and zircon-age data require that c. 1610 Ma basement occurs throughout the entire sampled portion of the Forrest Zone.

Geochemical and isotopic similarities with the St. Peter Suite, along the southern and western edge of the Gawler Craton, permit the interpretation of a much more regionally extensive primitive arc-related suite.

Undawidgi Supersuite c. 1500 Ma magmas

Most units dated at c. 1500 Ma, including rocks from Mallabie 1 in the Coompana Province of South Australia (Wade et al., 2007), are transitional A-type felsic rocks

Thier crustal source component that was primitive, MgO-rich, and likely hydrated and oxidized (potentially c. 1610 Ma monzodioritic crust).

Their mantle source component comprising upwelled asthenosphere.

These rocks formed in response to extension of the 1724–1610 Ma (to 1950 Ma) arc-complex.

Moodini Supersuite c. 1185 - 1150 Ma magmas

Magmatism during the 1192–1150 Ma period is diverse (anatectic melts and shoshonites)

Shoshonitic magmatism likely reflects extensional destabilization of the lithosphere that was significantly enriched during formation of the c. 1724–1610 Ma (or older) arc complex.

This thermally anomalous period relates directly with processes occurring in the Madura Province and in the Albany–Fraser Orogen and Musgrave Province.

MAD – FOR; same crustal origin, different crustal history

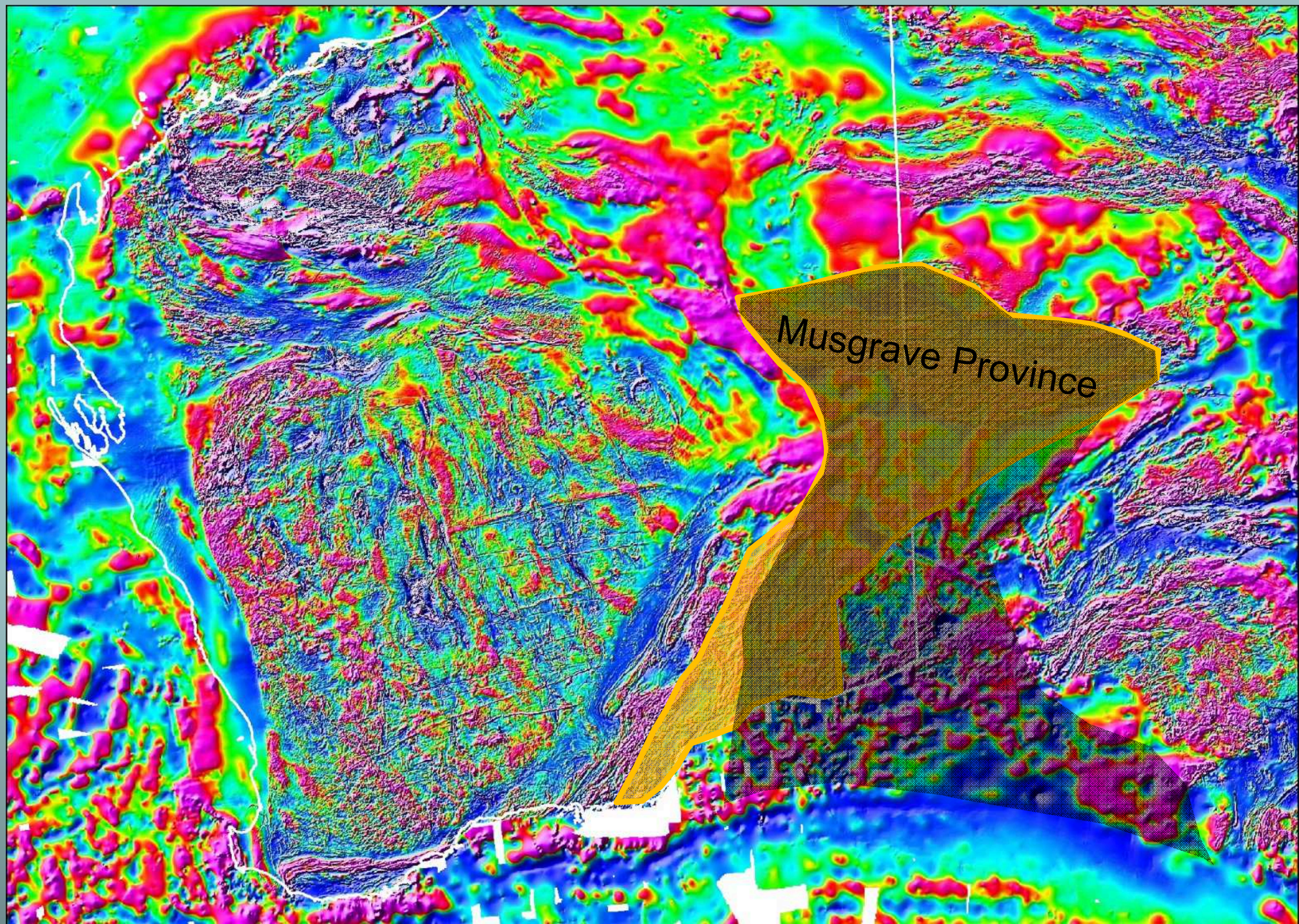
The Madura Province and the Forrest Zone are isotopically identical pieces of crust which, at c. 1.95 Ga were essentially entirely juvenile.

Geochemical, and Hf- and Nd-isotopic data indicate that juvenile, depleted mantle material was periodically added (e.g. at c. 1600, 1500, 1400, 1200 Ma).

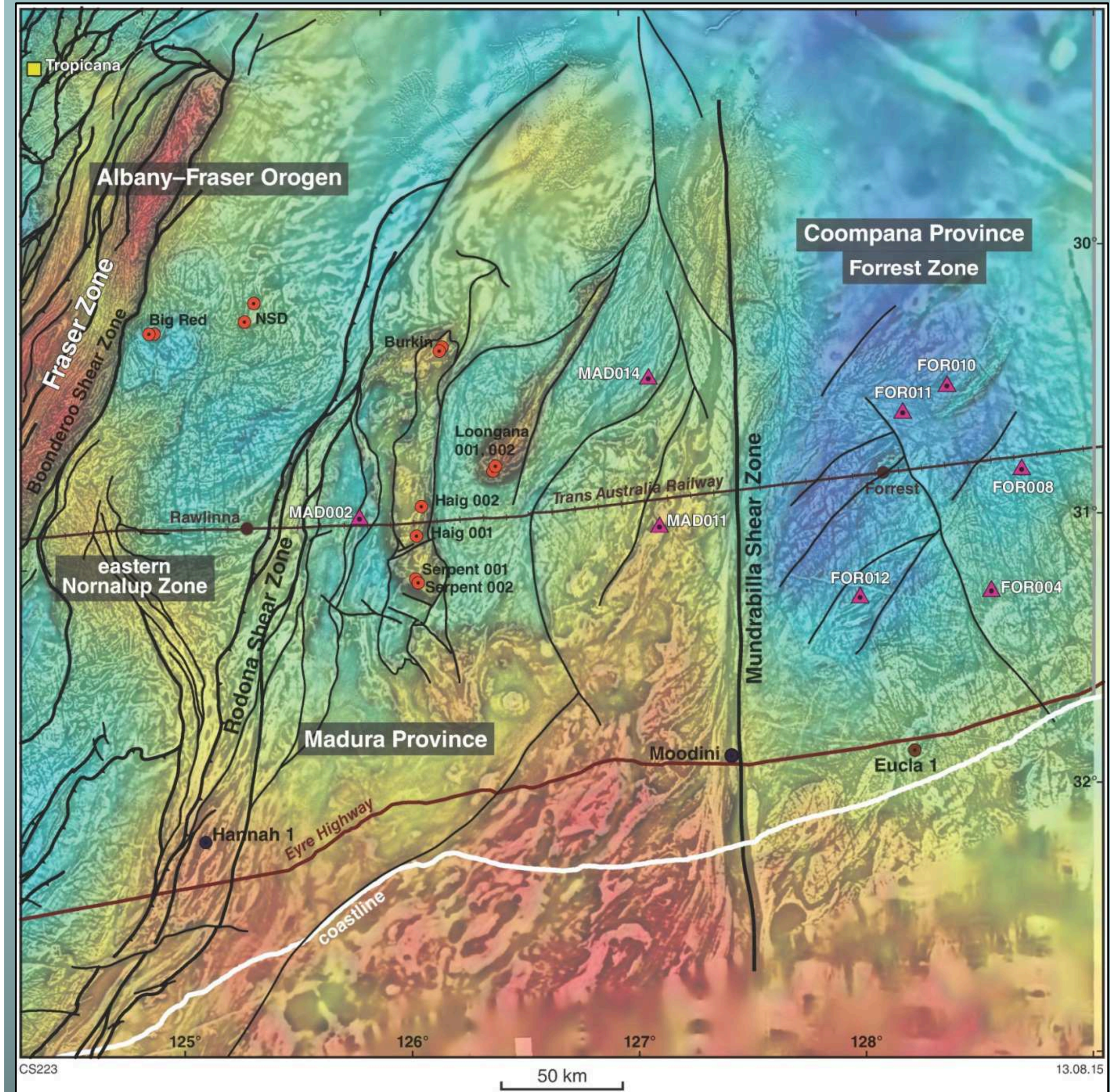
However, the compositional evolution does not require the addition or contribution from older, non-radiogenic sources, and the only physical evidence for such material is in the form of rare inherited zircons, mainly in samples from regions presently proximal to major tectonic boundaries (e.g. the Rodona Shear Zone).

In all of these regards, the Madura Province and the Forrest Zone are indistinguishable from the Musgrave Province, to the northeast.

FOR – MAD – Musgrave Province + geochronologically and isotopically the same piece of juvenile crust



But different regions show a different history.



FOR – Early, multi-phase subduction modification – a 'calc-alkaline' history

MAD – no evidence for subduction processes until c. 1400 Ma – more of a 'tholeiitic' history

The differences manifest themselves most dramatically during the c. 1220 – 1150 Ma regional 'big meltdown' in the contrast between FOR high-KMg magmatism related to deep re-melting in thick subduction-modified mantle, and MAD high-KFe magmatism reflecting crust-mantle interaction at the base of thin crust under dry and reduced conditions.