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

Regional geology and seismic interpretation of 11GA-YO1: Musgrave Province

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NGAANYATJARRA COUNCIL (Aboriginal Corporation)
Australian Government Geoscience Australia
ROYALTIES FOR REGIONS EXPLORATION INCENTIVE SCHEME
Geological Survey of Western Australia

Collaborators

Ngaanyatjarra Council

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University of Western Australia (Centre for Exploration Targeting)

Monash University

Geoscience Australia

Wolfgang Maier (University of Oulu)

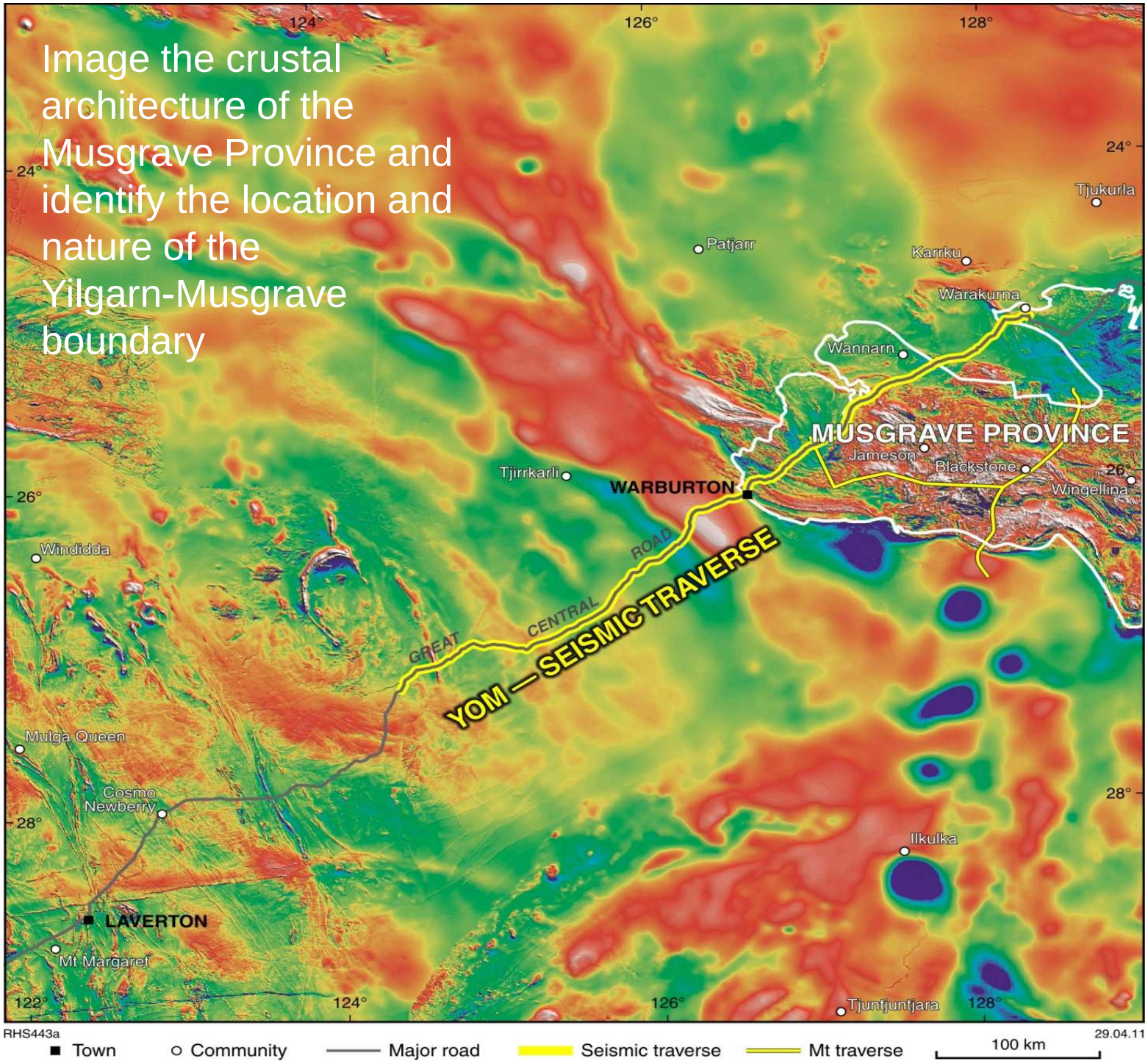
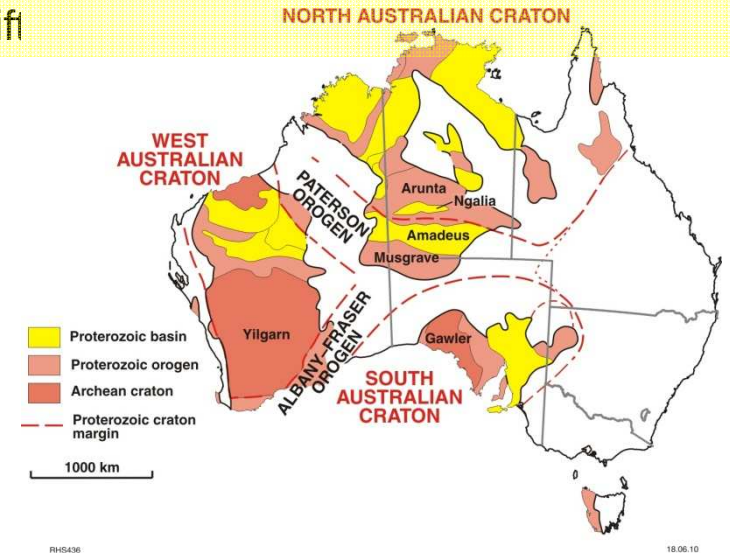


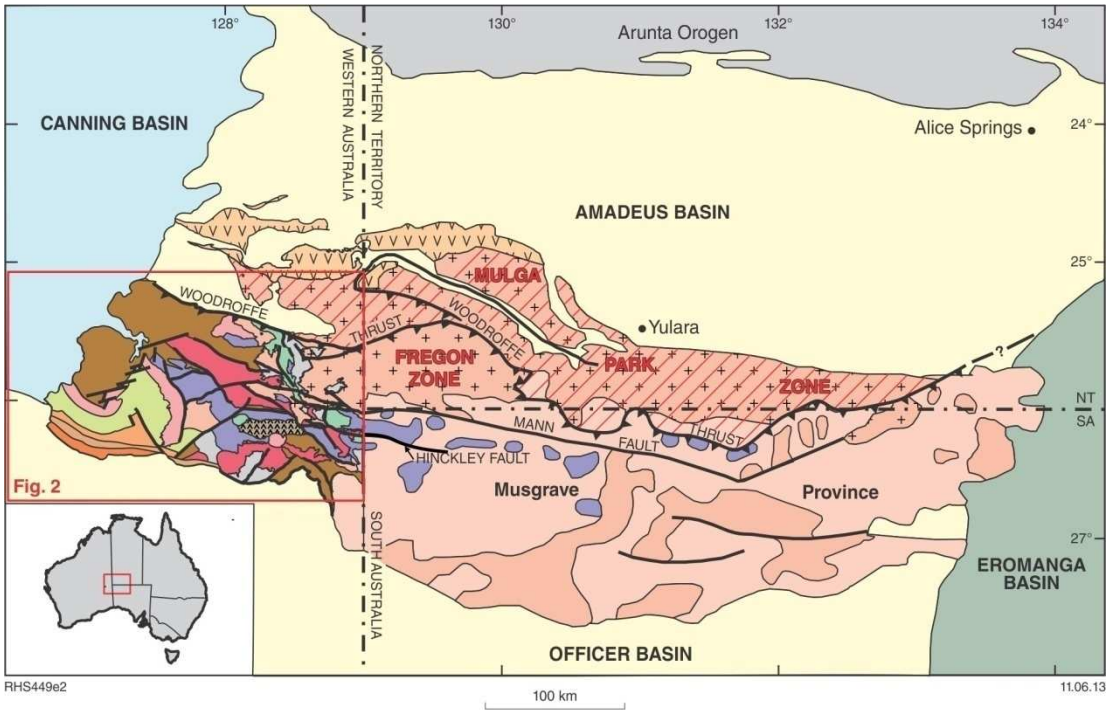
Image the crustal architecture of the Musgrave Province and identify the location and nature of the Yilgarn-Musgrave boundary
124°
126°
128°
24°
26°
28°
Tjukurla
Patjarr
Karrku
Warakurna
Wannarn
MUSGRAVE PROVINCE
Jameson
Blackstone
Wingellina
Tjirrkarli
WARBURTON
Windidda
GREAT CENTRAL ROAD
YOM — SEISMIC TRAVERSE
Mulga Queen
Cosmo Newberry
LAVERTON
Mt Margaret
Ilkulka
Tjuntjuntjara
122°
RHS443a
29.04.11
Town
Community
Major road
Seismic traverse
Mt traverse
100 km

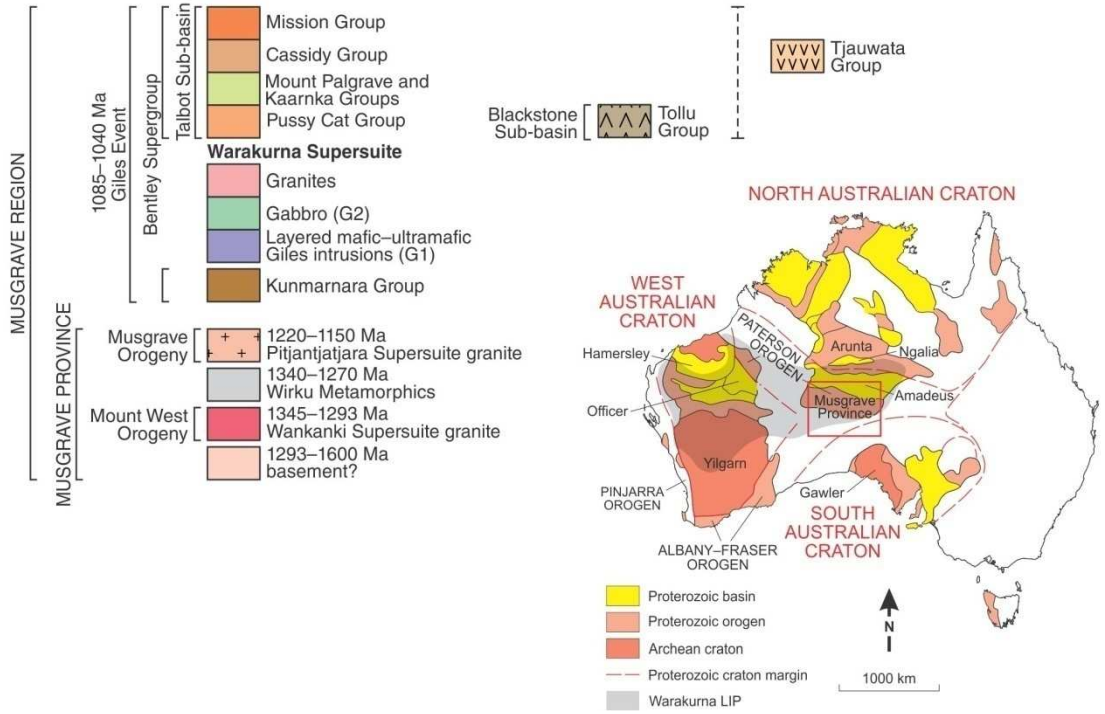
What is the Musgrave Province

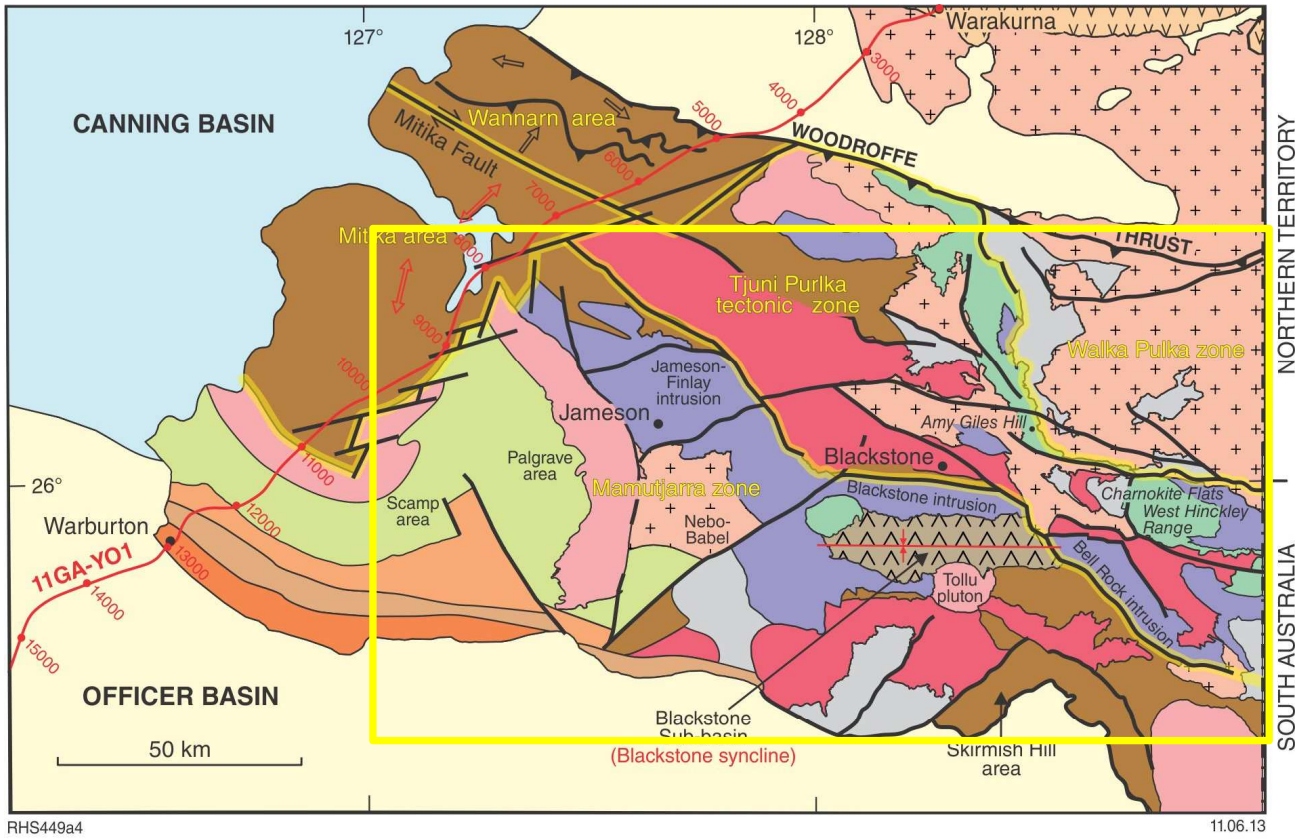
An east-trending Proterozoic belt, lying at the junction of central Australia's main Proterozoic structural trends, that has undergone several periods of Mesoproterozoic deformation, metamorphism and Magmatism. Main components/events include;

- cryptic basement (at least in the west)
- c. 1400 Ma (unnamed event) – calc-alkaline magmatism
- regional deformation (?accretion)
- 1345 – 1293 Ma (**Mount West Orogeny**) – calc-alkaline magmatism
- regional deformation (?accretion)
- 1220 – 1120 Ma (**Musgrave Orogeny**) - UHT metamorphism, intracontinental? magmatism
- 1085 (1120?) – 1040 Ma (**Giles Event**) – extension/rift
- c. 1000 Ma – regional dolerite dyke swarm
- c. 825 Ma – regional dolerite dyke swarm
- c. 720 Ma – uplift
- c. 620 Ma – uplift, minor crustal melting
- c. 550 Ma **Petermann Orogeny**
-
-
-




128°
130°
132°
134°
Arunta Orogen
CANNING BASIN
WESTERN AUSTRALIA
NORTHERN TERRITORY
Alice Springs
24°
AMADEUS BASIN
25°
MULGA
WOODROFFE
THRUST
WOODROFFE
Yulara
FREGON ZONE
PARK
ZONE
NT
SA
MANN
FAULT
THRUST
HINCKLEY FAULT
Fig. 2
Musgrave
Province
27°
EROMANGA BASIN
SOUTH AUSTRALIA
OFFICER BASIN
RHS449e2
100 km
11.06.13


MUSGRAVE REGION
MUSGRAVE PROVINCE
1085–1040 Ma Giles Event
Bentley Supergroup
Talbot Sub-basin
Mission Group
Cassidy Group
Mount Palgrave and Kaarnka Groups
Pussy Cat Group
Warakurna Supersuite
Granites
Gabbro (G2)
Layered mafic–ultramafic Giles intrusions (G1)
Kunmarnara Group
Musgrave Orogeny
1220–1150 Ma Pitjantjatjara Supersuite granite
1340–1270 Ma Wirku Metamorphics
Mount West Orogeny
1345–1293 Ma Wankanki Supersuite granite
1293–1600 Ma basement?
Blackstone Sub-basin
Tollu Group
Tjauwata Group
NORTH AUSTRALIAN CRATON
WEST AUSTRALIAN CRATON
PATERSON OROGEN
Hamersley
Arunta
Ngalia
Amadeus
Officer
Musgrave Province
Yilgarn
PINJARRA OROGEN
Gawler
SOUTH AUSTRALIAN CRATON
ALBANY–FRASER OROGEN
Proterozoic basin
Proterozoic orogen
Archean craton
Proterozoic craton margin
Warakurna LIP
N
1000 km



1085–1040 Ma Giles Event

Bentley Supergroup

Talbot Sub-basin

- Mission Group
- Cassidy Group
- Mount Palgrave and Kaarnka Groups
- Pussy Cat Group

Warakurna Supersuite

- Granites
- Gabbro (G2)
- Layered mafic–ultramafic Giles intrusions (G1)

- Kunmarnara Group

Blackstone Sub-basin

- Tollu Group

- Tjauwata Group

Musgrave Province

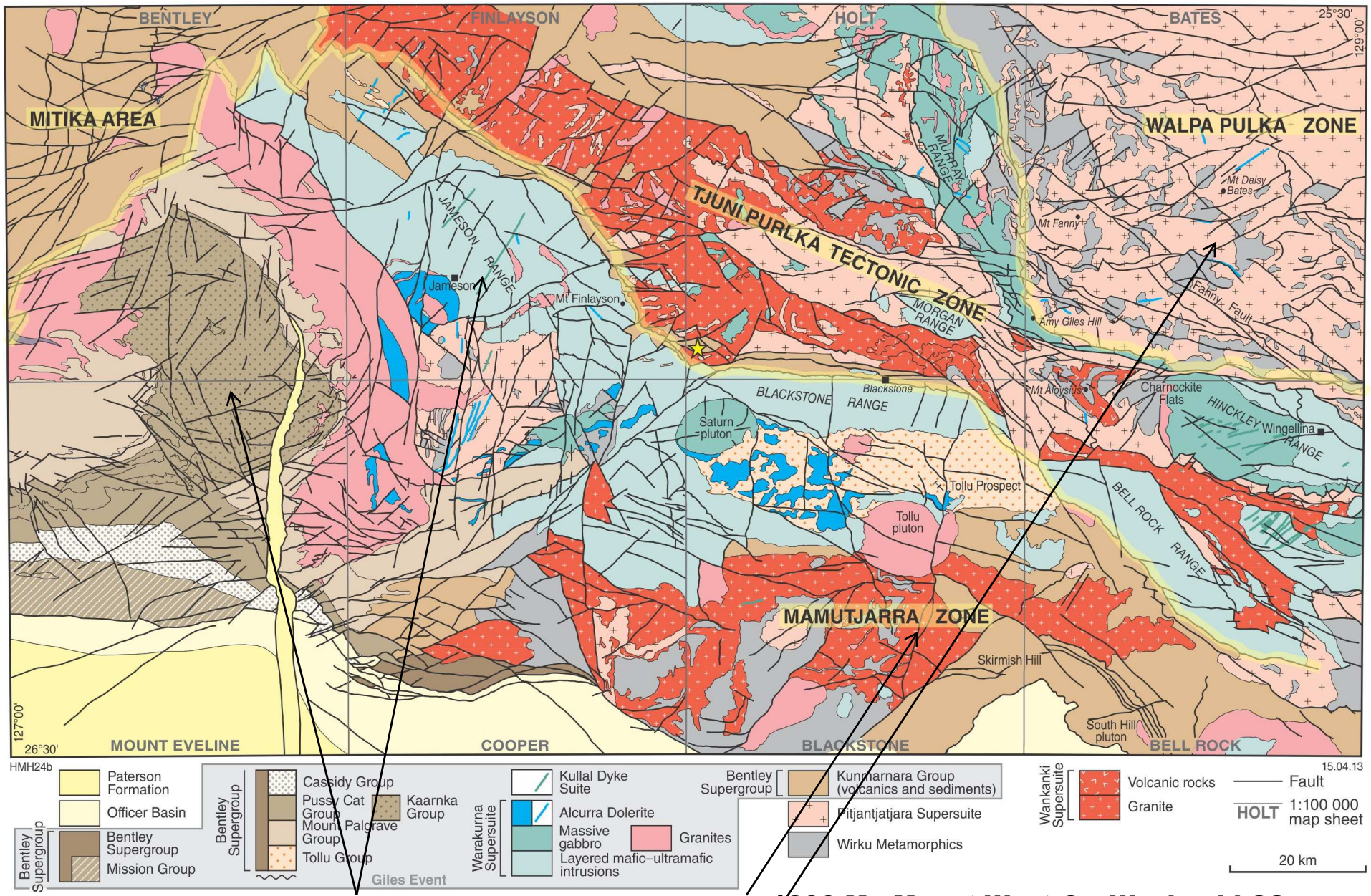
Musgrave Orogeny

- 1220–1150 Ma Pitjantjatjara Supersuite granite
- 1340–1270 Ma Wirku Metamorphics

Mount West Orogeny

- 1345–1293 Ma Wankanki Supersuite granite

- Transport direction
- Main folding direction
- Seismic line, with CDP



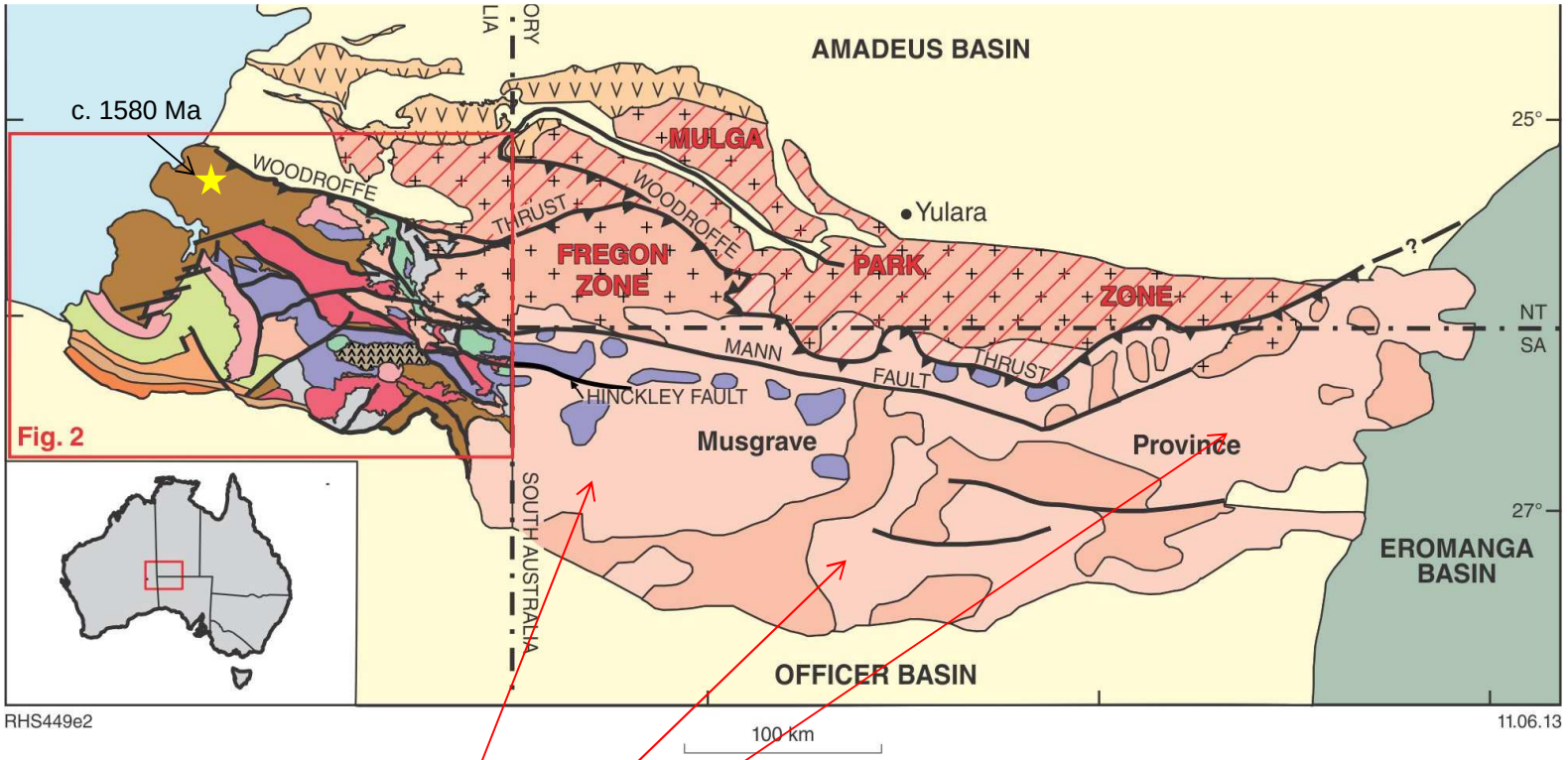
c. 1070 Ma Giles Event – Warakurna SS, Bentley Supergroup

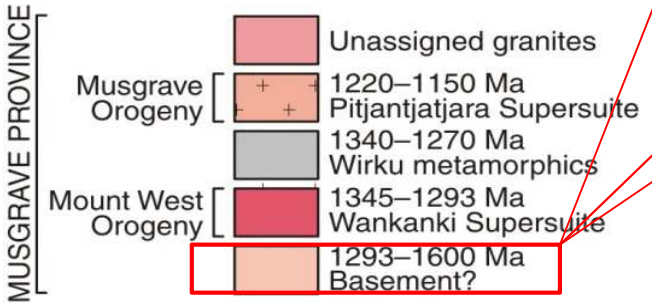
c. 1300 Ma Mount West O – Wankanki SS
c. 1200 Ma Musgrave O – Pitjantjatjara SS

Basement

Prevailing view (Wade et. al.)

Juvenile arc material formed during collision of the NAC and SAC at ~1550-1650 Ma.





Nevertheless, most units previously thought to be dominated by ~1550-1650 Ma ‘basement’ components were probably formed (intruded or deposited) ~ 1300 Ma. (Evins et al., 2010 – GSWA Record 2010/6)

Basement

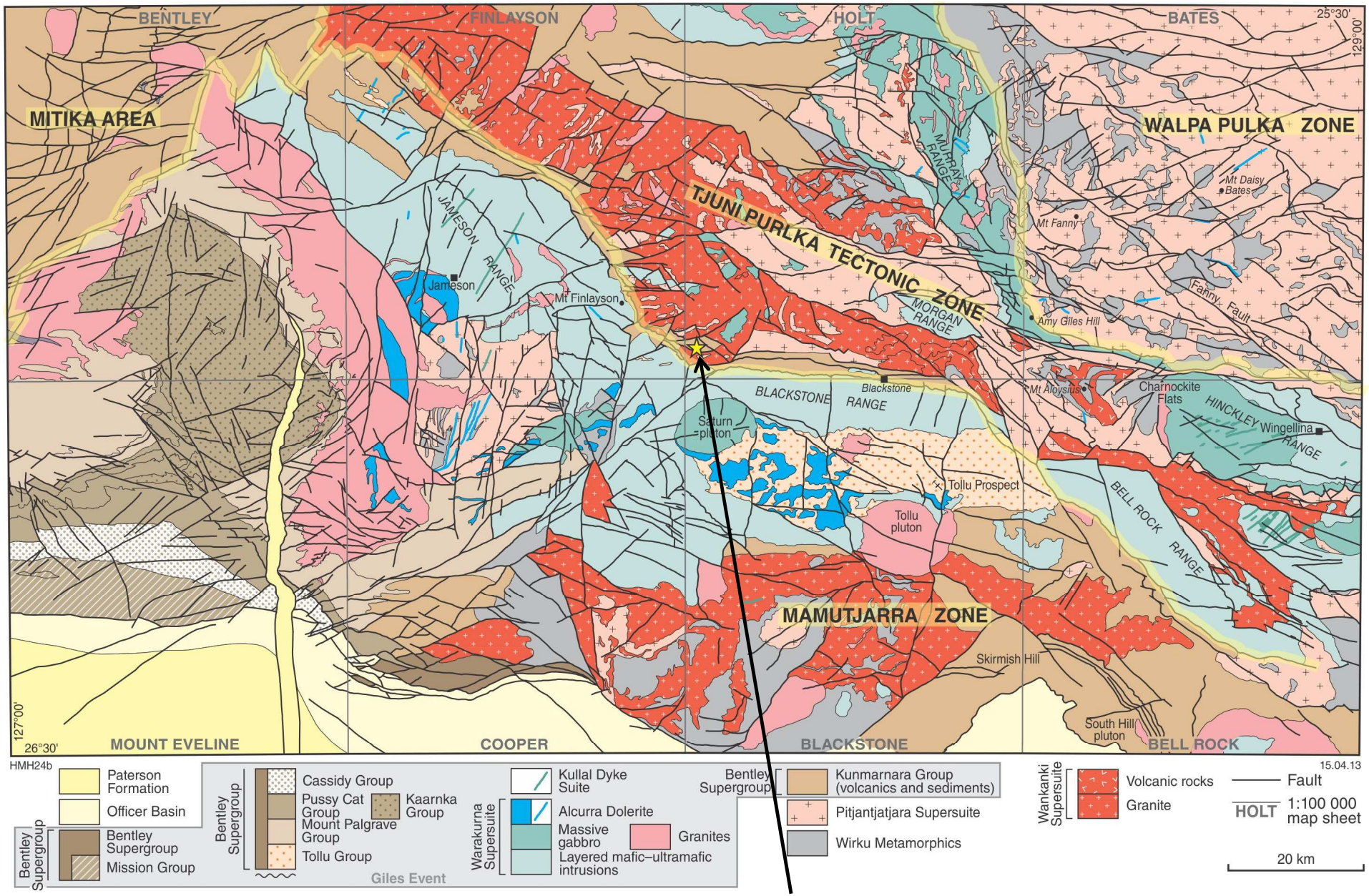
Prevailing view (Wade et. al.)

Juvenile arc material formed during collision of the NAC and SAC at ~1550-1650 Ma.

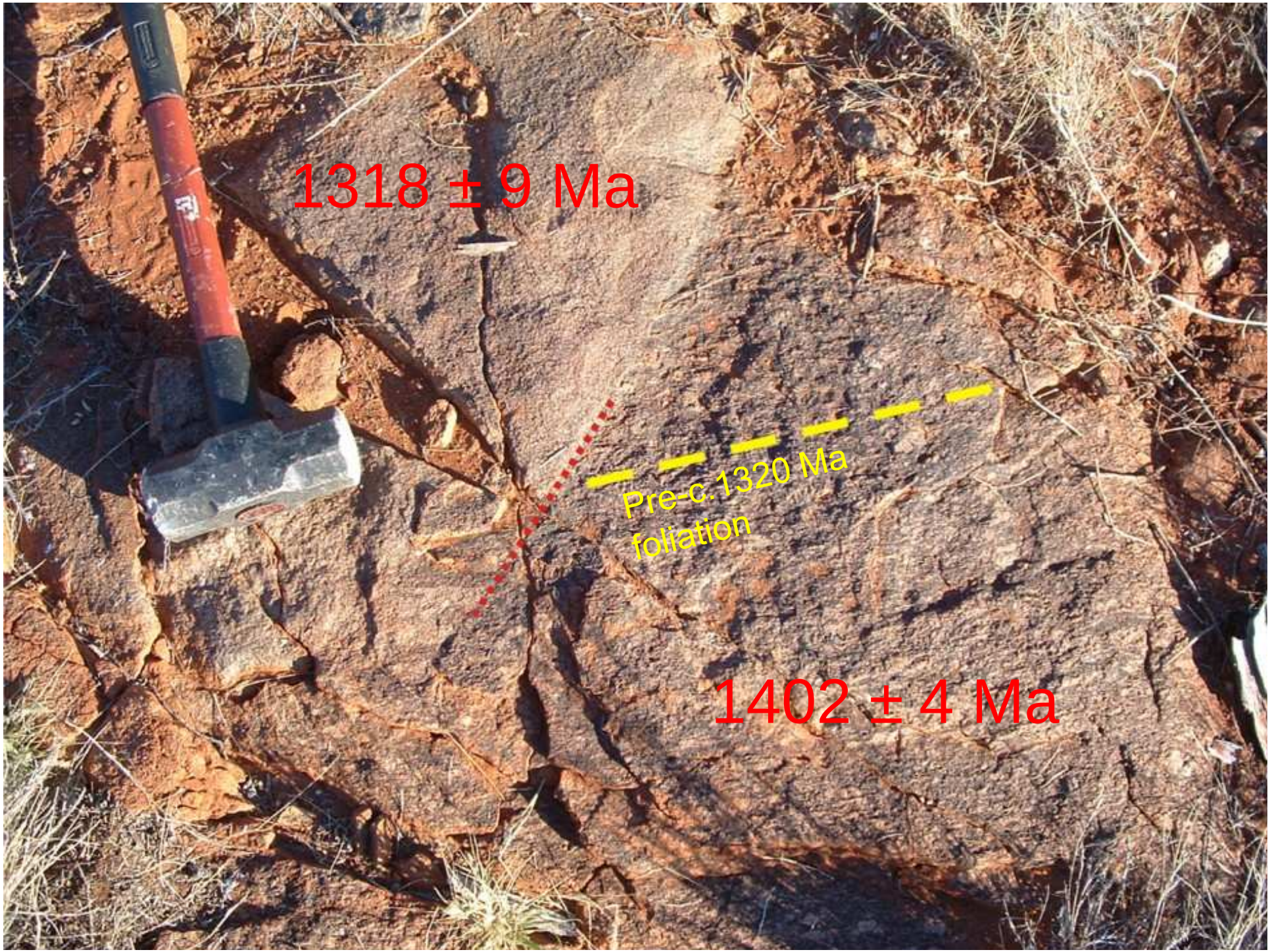
GSWA

Hf- and Nd-isotopic evidence for juvenile mafic-intermediate material dated at ~1950 Ma and ~1550-1650 Ma. ~1550-1650 Ma material is isotopically distinct from equivalent aged Arunta material.

BUT – this basement has been removed (at least from the west) at the ~ 1220 Ma beginning of the Musgrave Orogeny – and thick lithosphere was not re-established until at least the end of the Giles Event.



c. 1400 Ma Papulankutja Supersuite – our oldest rocks (up to two weeks ago!!)

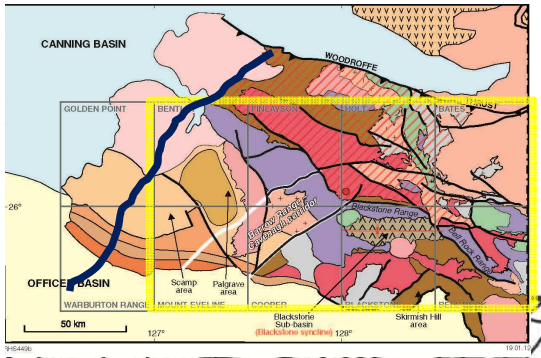

1318 ± 9 Ma
Pre-c.1320 Ma
foliation
1402 ± 4 Ma

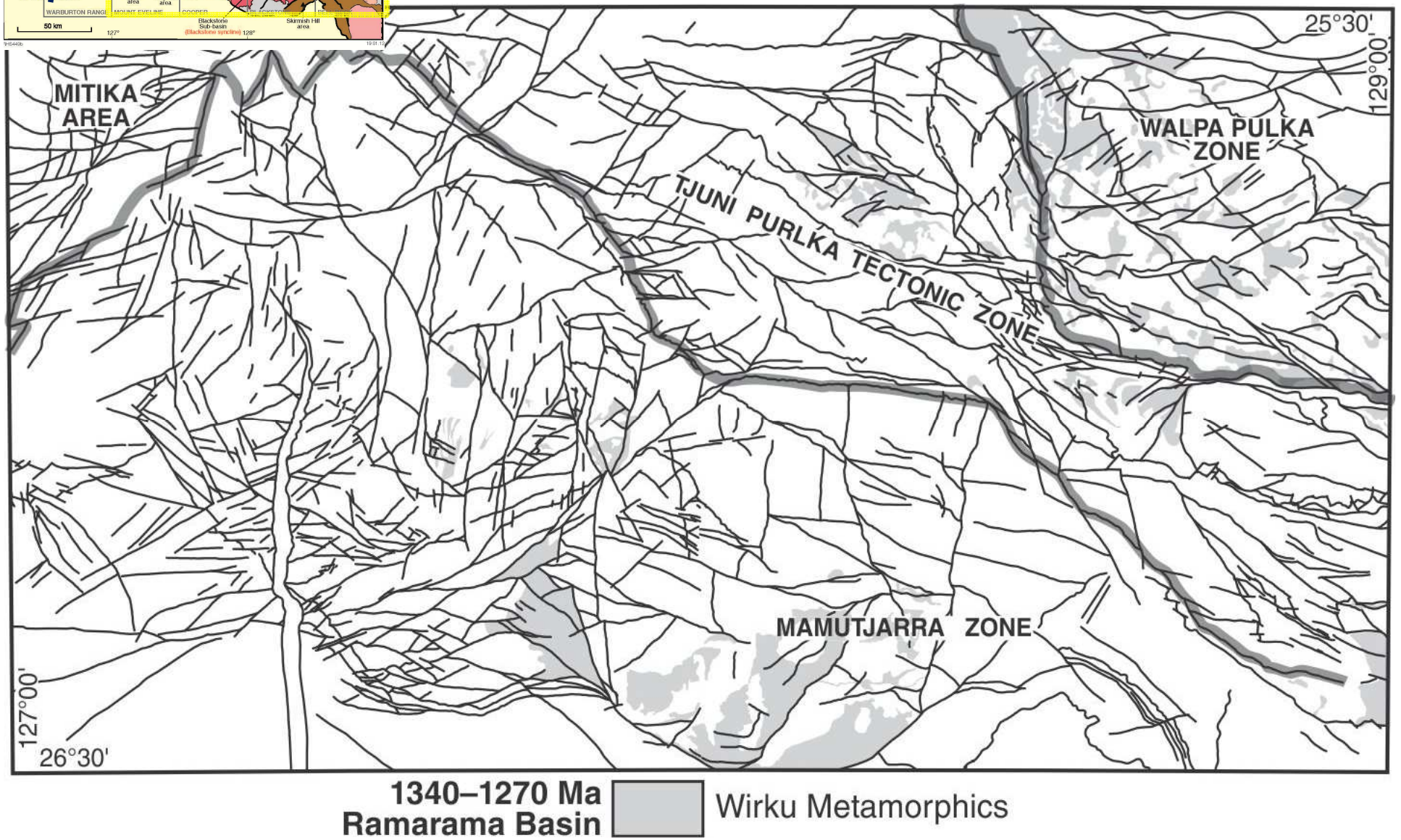
Mount West Orogeny - 1345 – 1295 Ma

• *Wirku Metamorphics* – paragneiss (metamorphosed during the Musgrave Orogeny) – psammite > pelite > volcanic rocks related to Wankanki Supersuite.

• *Wankanki Supersuite* – calc-alkaline intrusions

Wirku Metamorphics (Ramarama Basin)
Max depositional age ~ 1300 Ma





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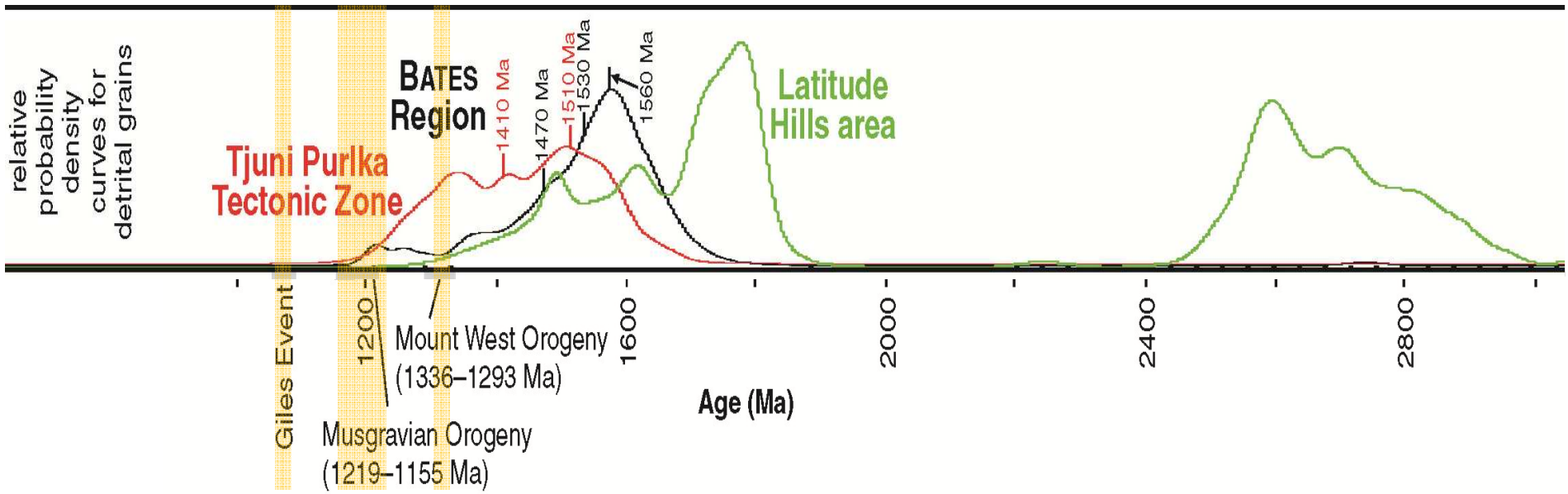
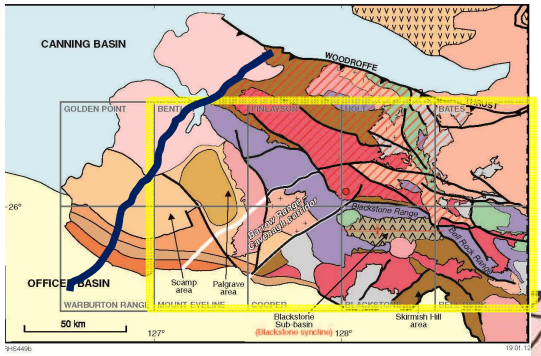
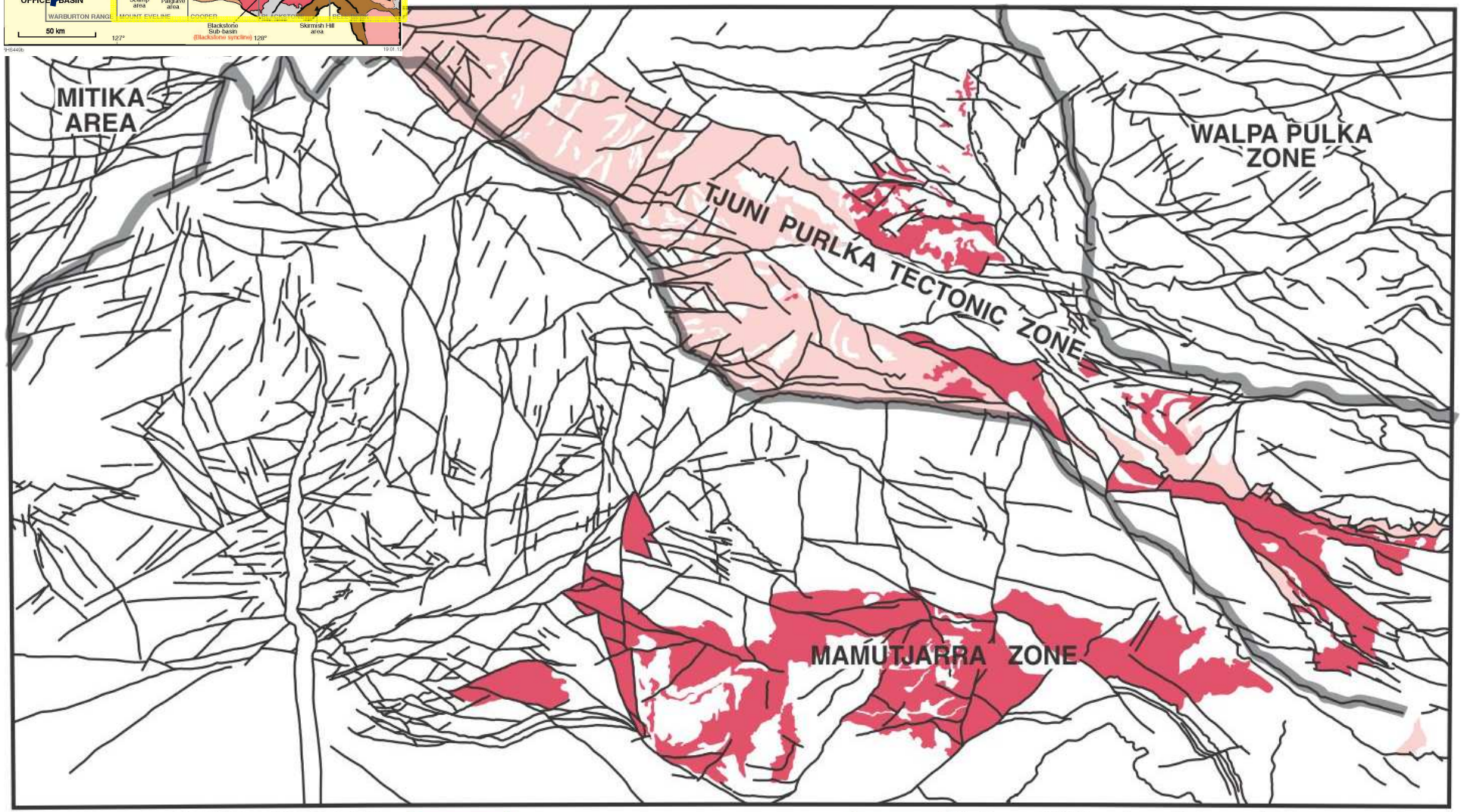
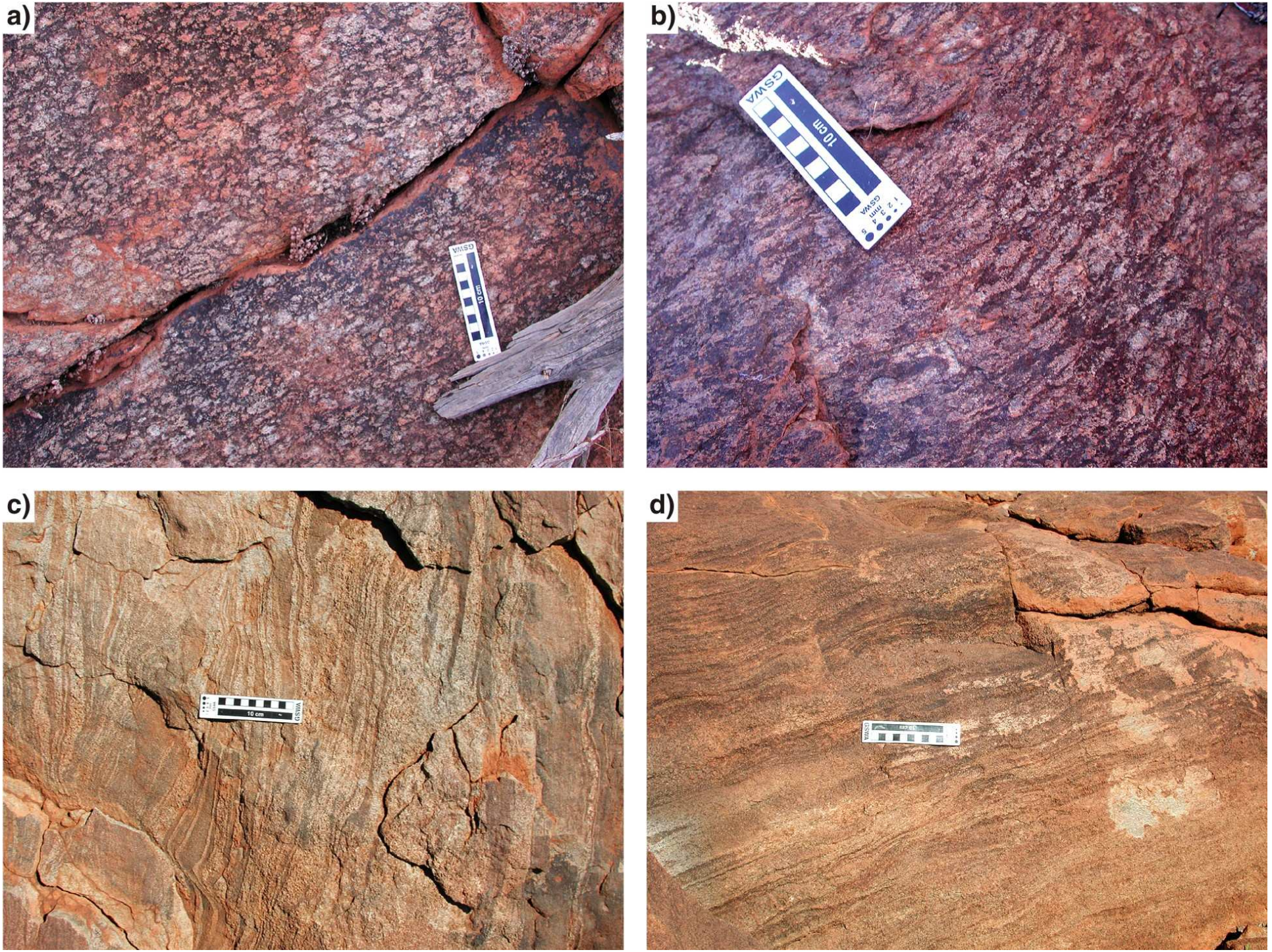

relative probability density curves for detrital grains
BATES Region
Tjuni Purlka Tectonic Zone
1410 Ma
1470 Ma
1510 Ma
1530 Ma
1560 Ma
Latitude Hills area
Giles Event
1200
Mount West Orogeny (1336–1293 Ma)
Musgravian Orogeny (1219–1155 Ma)
1600
2000
2400
2800
Age (Ma)



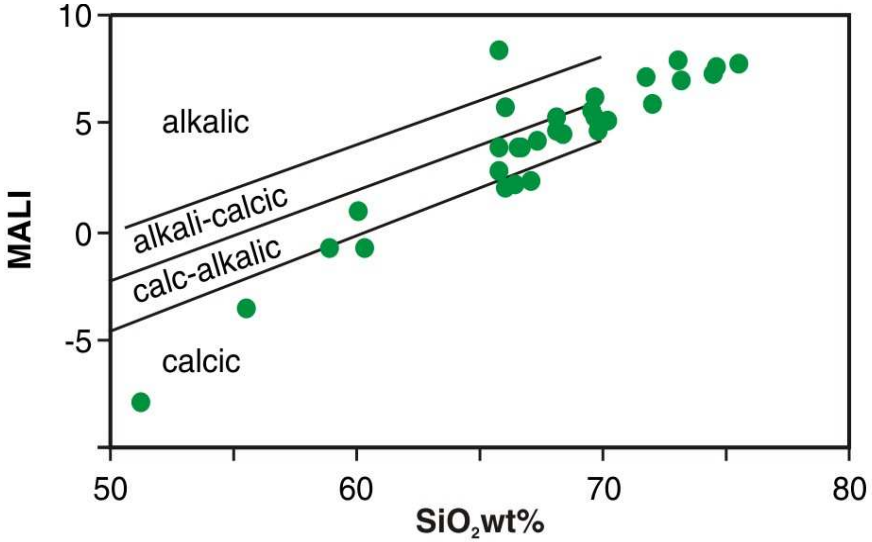
Wankanki Supersuite

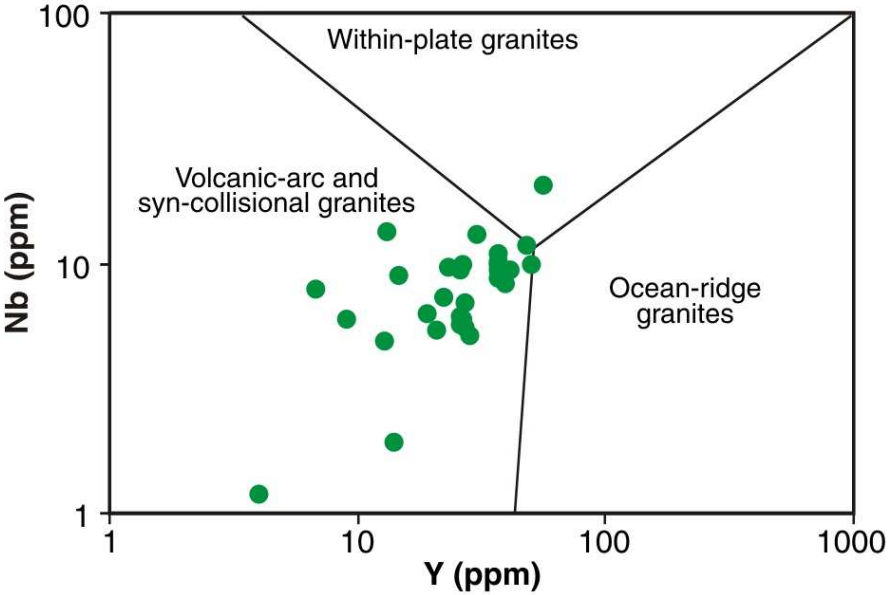
Mainly hbl-biot (+cpx) metamonzogranite, gneiss and migmatite

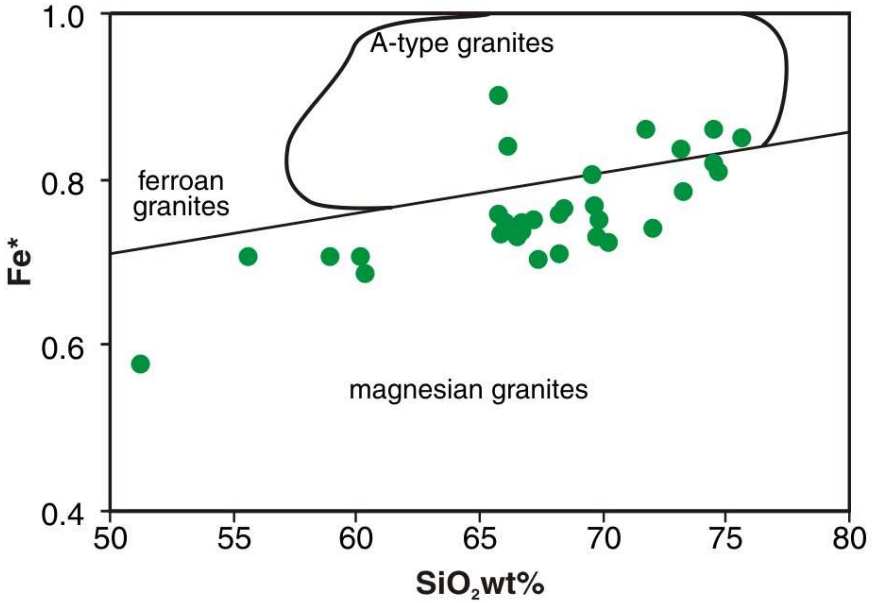



a)
b)
c)
d)
10 cm
GSWA

Wankanki Supersuite



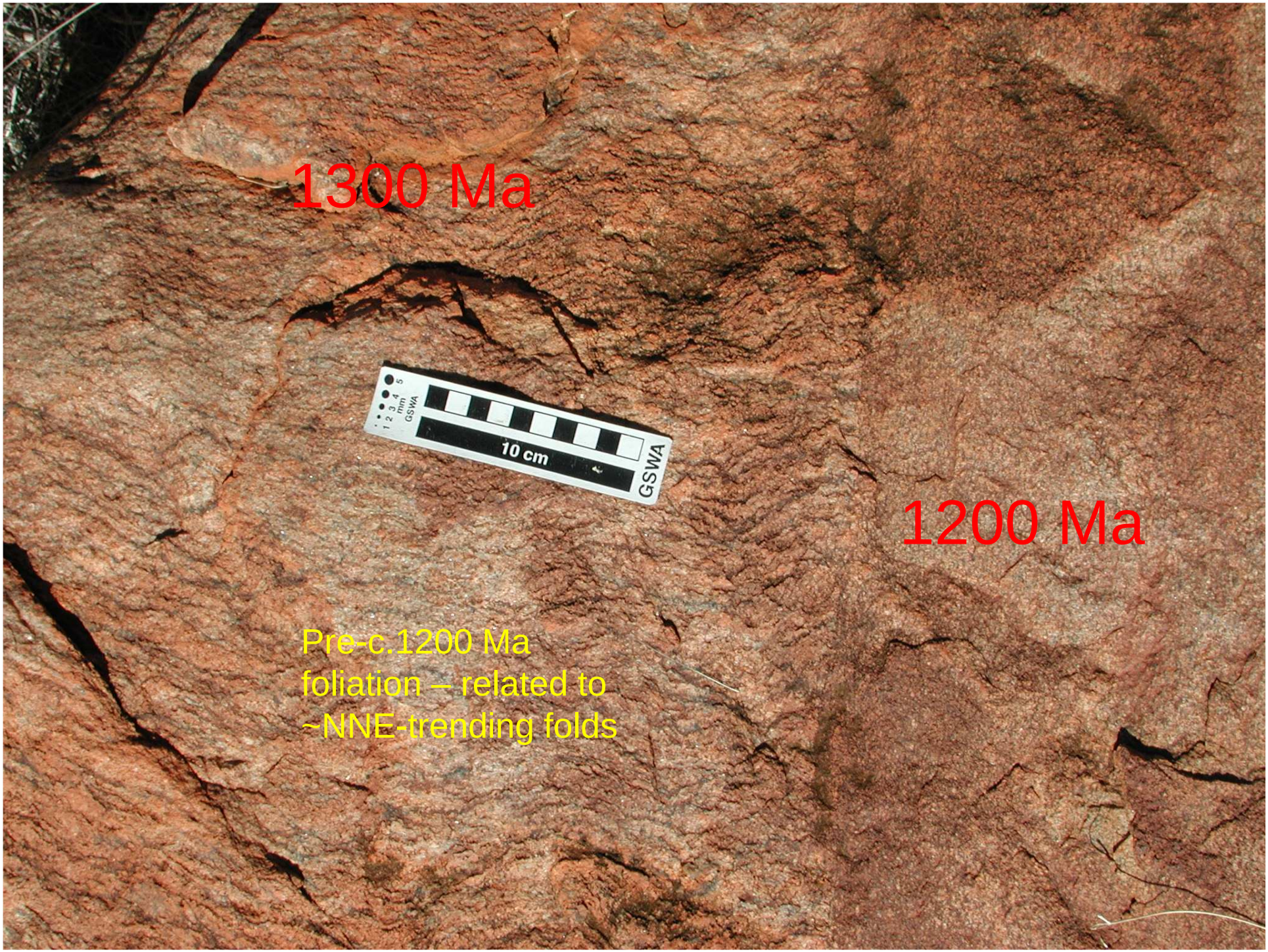




Continental arc major and trace-element chemistry

RHS436

21.06.10

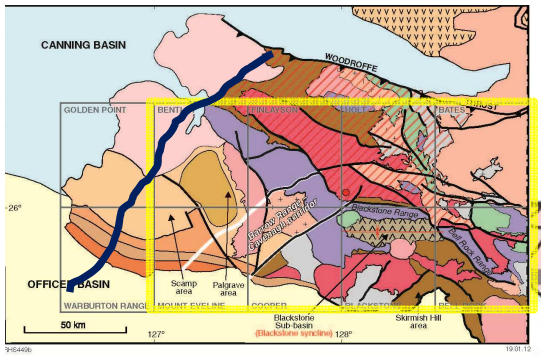

1300 Ma
10 cm
GSWA
1200 Ma
Pre-c.1200 Ma
foliation – related to
~NNE-trending folds

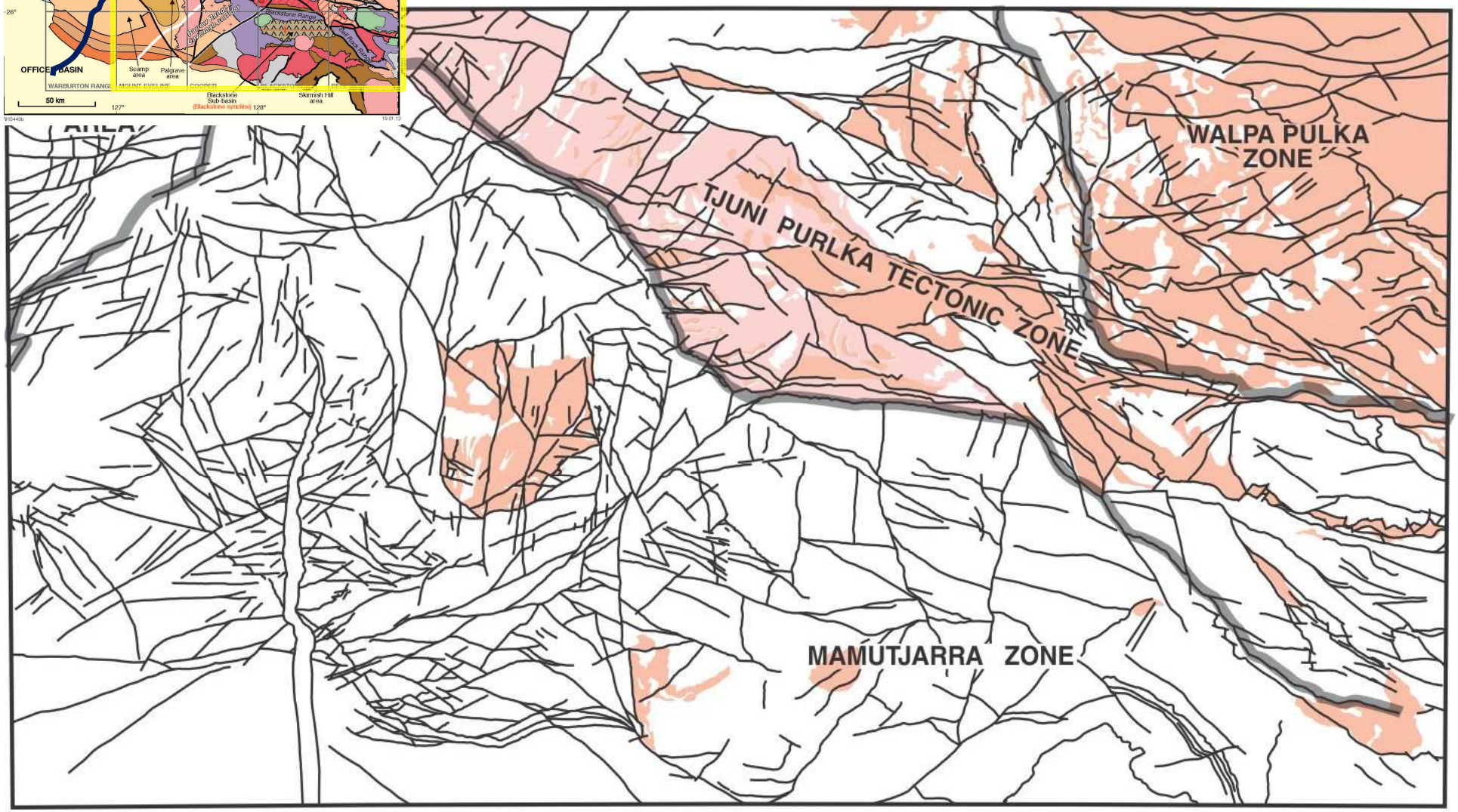
Musgrave Orogeny - 1220 – 1150 (1120) Ma

• *Pitjantjatjara Supersuite* – ferroan, alkali-calcic, dry intrusions

• Widespread UHT crustal reworking – but style of deformation is not clear

Pitjantjatjara Supersuite





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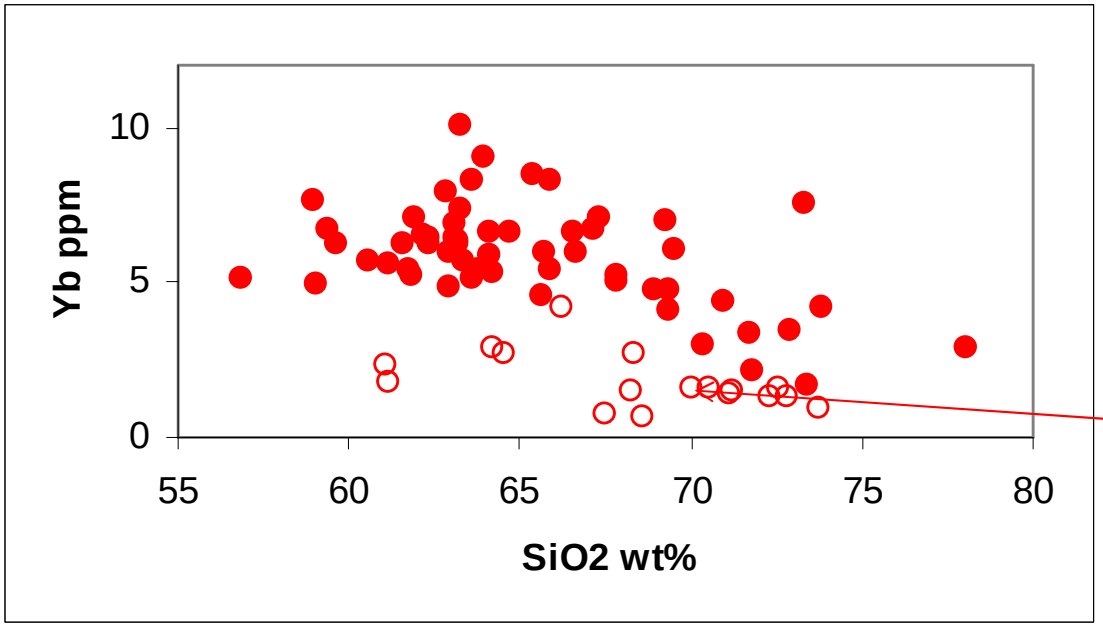
1220–1150 Ma
Musgrave Orogeny

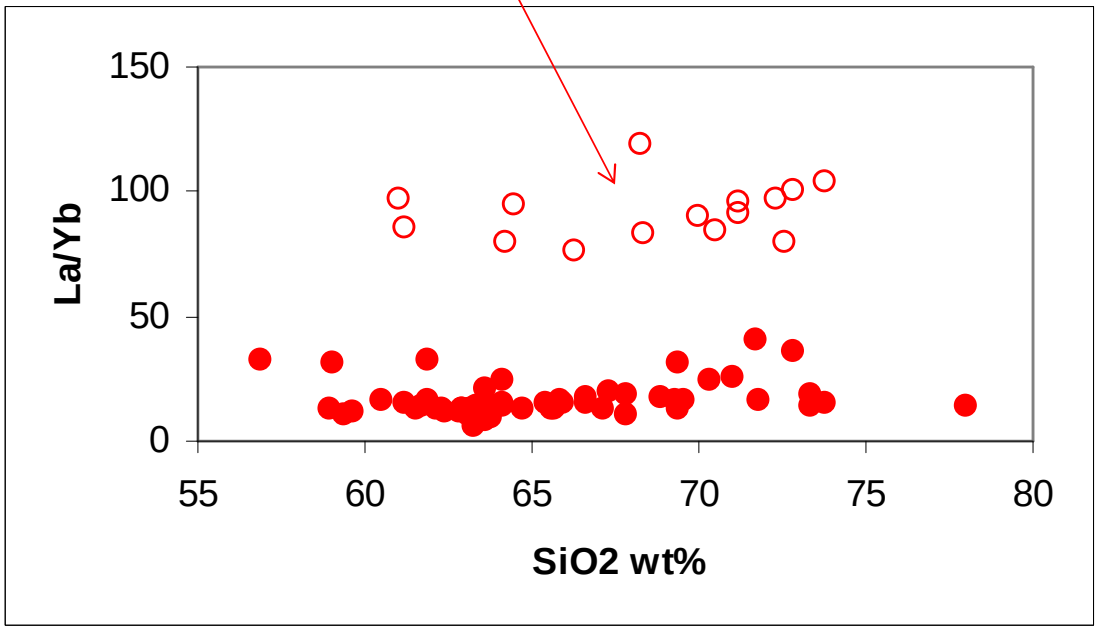
Pitjantjatjara Supersuite

Mixed Wankanki and Pitjantjatjara Supersuites

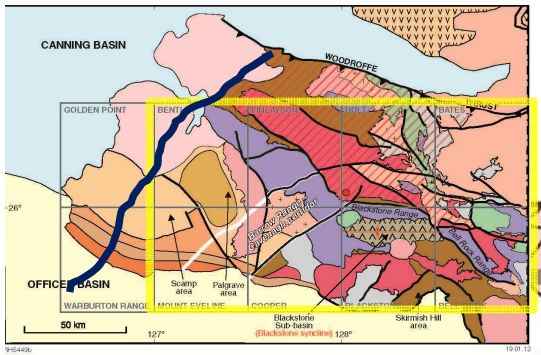
Earliest Pitjantjatjara granites



Mamut suite



Pitjantjatjara Supersuite



~1220 Ma

TJUNI PURLKA TECTONIC ZONE

MAMUTJARRA ZONE

~1200 Ma

RHS446a2

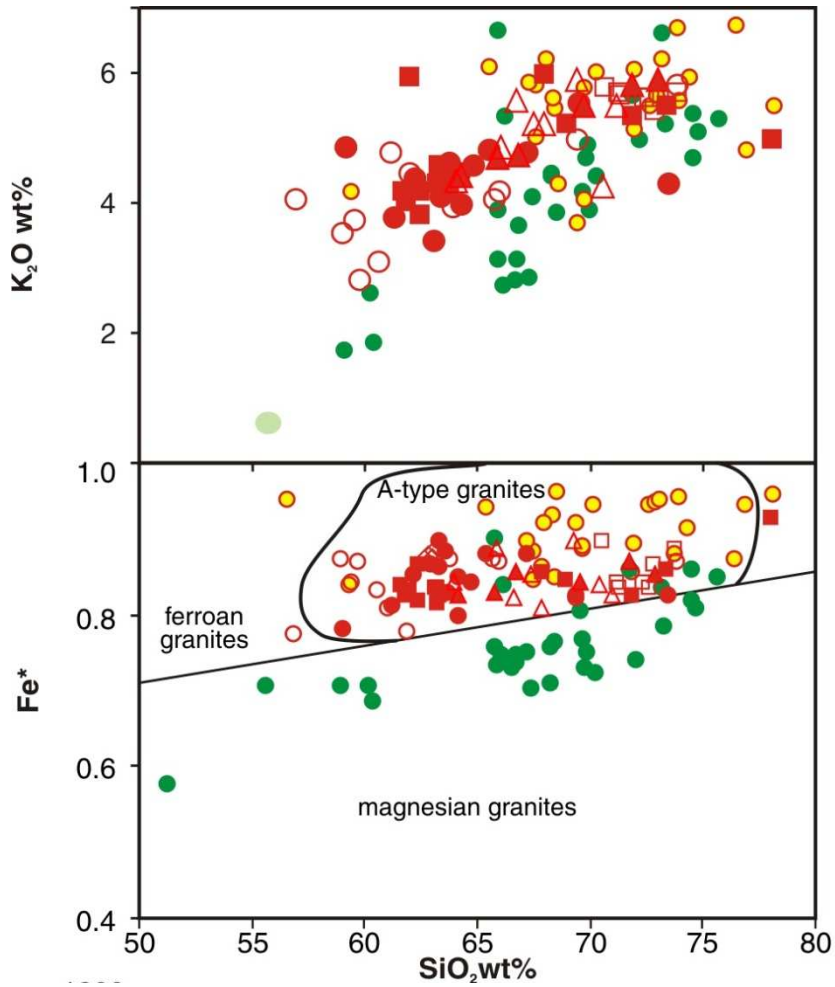
1220–1150 Ma
Musgrave Orogeny

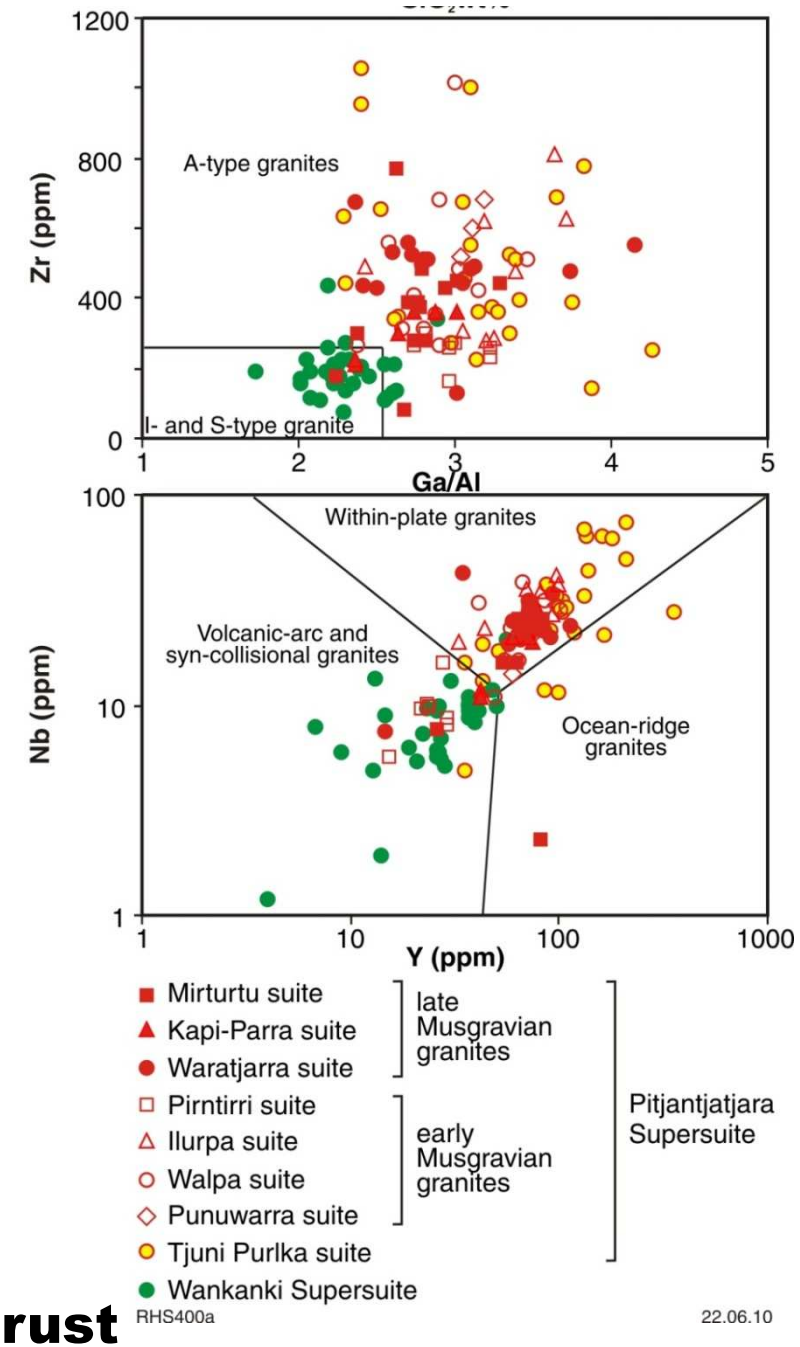
Pitjantjatjara Supersuite

Mixed Wankanki and Pitjantjatjara Supersuites

RHS417

12.11.09

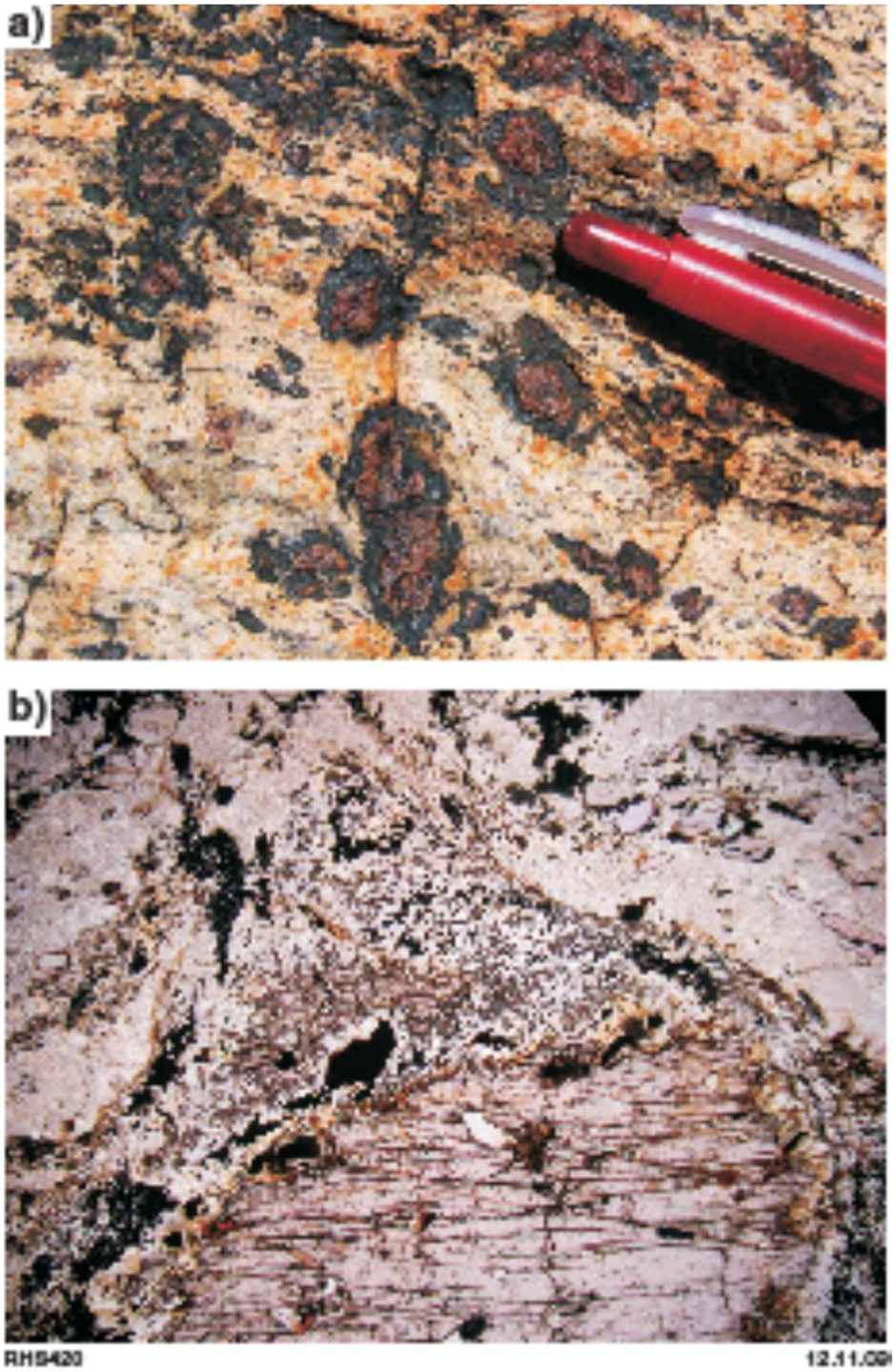




Pitjantjatjara Supersuite

A-type (whatever this means!!)

High T°C melts at lease involving crust



King (2008), Kelsey et al (2009)

Gnt-sill-spin-qtz

≥1000ºC at 7-8 kbars

1211 ± 13 Ma	Latitude Hills
1150 ± 8 Ma	
1177 ± 8 Ma	Cohn Hill
1211 ± 7 Ma	
1223 ± 9 Ma	
1232 ± 8 Ma	
1177 ± 11 Ma	Mt West

*Youngest UHT date = c. 1120 Ma

Metamorphic T℃ = granite T℃
Metamorphic age range = granite age range
= 100 Myr

Musgrave Province zircon ages

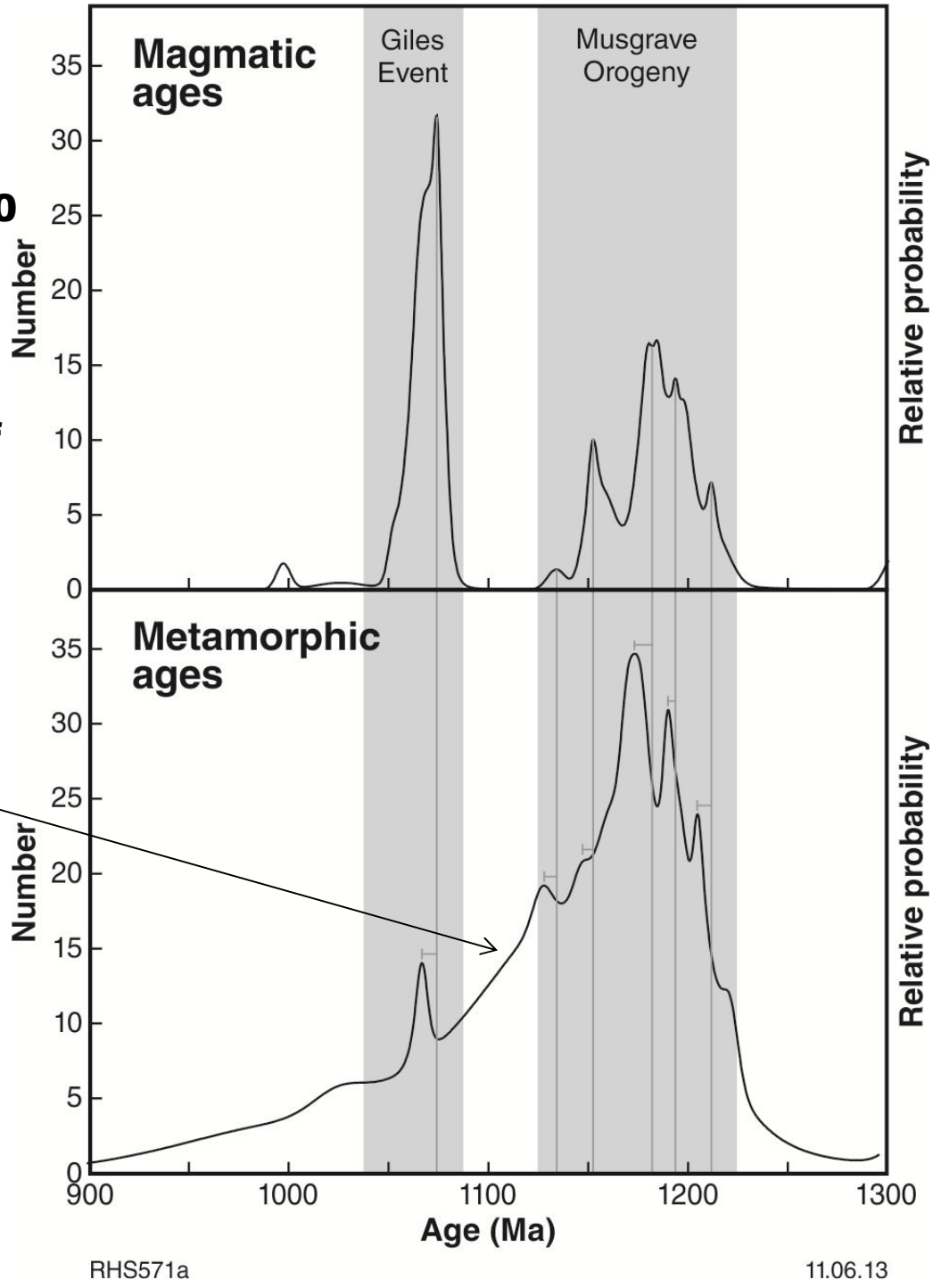
Metamorphic peak consistently ~ 10 Ma younger than magmatic peak.

This suggests that while UHT metamorphism is related to magmatism, it was not the *result* of magmatism.

Curve proxies for mid-crustal thermal evolution – never < 700ºC.

Very long-term thermal anomaly – at least partly related to lower crustal accumulation of Pitjantjatjara Granites (~40 ppm Th, 4 ppm U).

Retards re-establishment of lithosphere



- **≥1000°C and 7–8 kbars = geothermal gradient of up to 40 °C km^{-1} and this persisted for ~ 100 Ma (maybe longer).**

- **Granite source at P<10 kbar (i.e. no garnet) & very little crust existed below that because extrapolation of the geotherm to depth gives geologically unreasonable T °C.**

- Crust was very thin (maximum of ~35km) throughout the Musgrave Orogeny (lost the basement).

- Available crustal source column for the granites is not enough. This and Nd-isotopic evidence indicate a significant mantle contribution to the Pitjantjatjara Supersuite

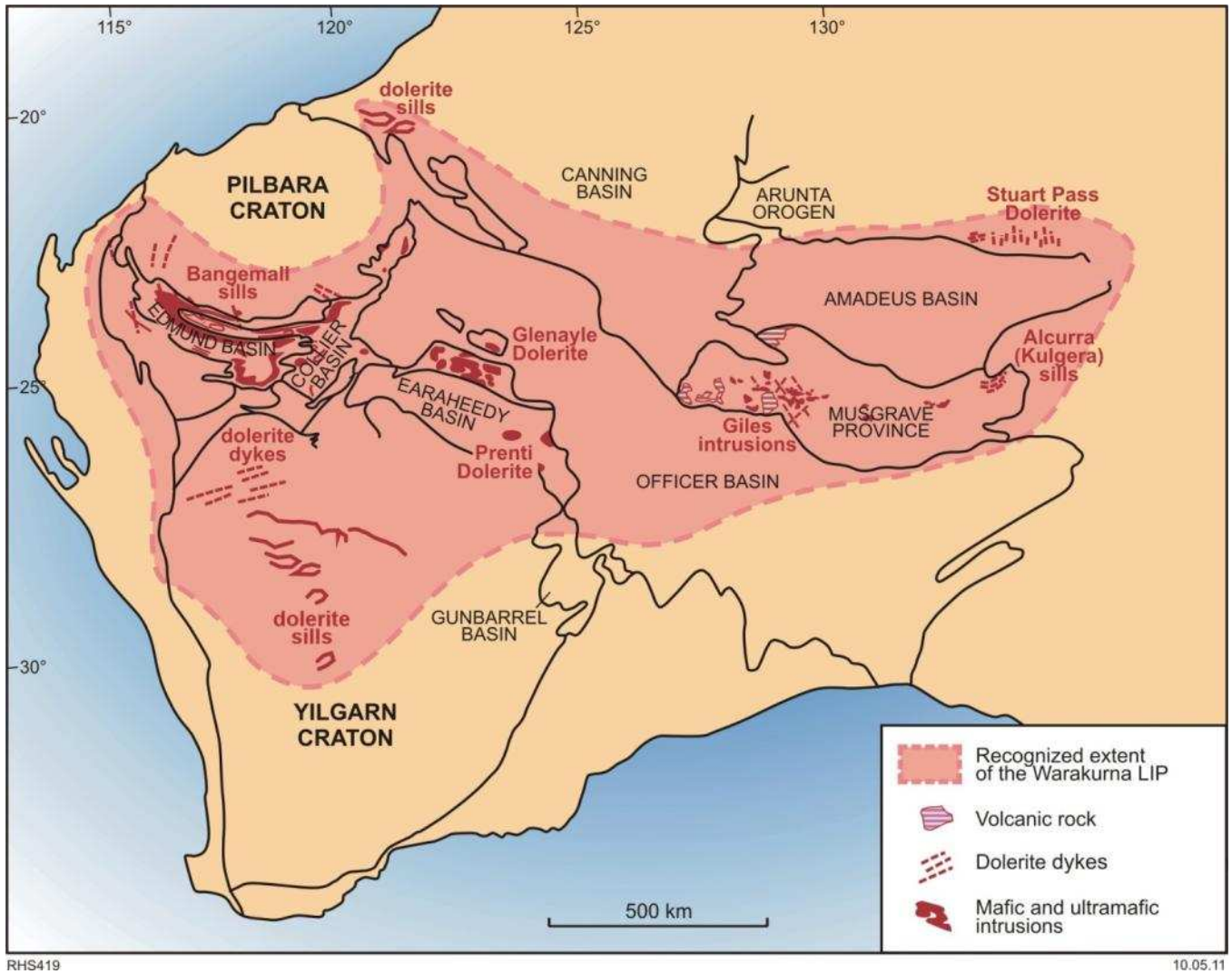
- **Intracontinental (maybe!!). Alternatively - an ultra-hot orogen born from a back-arc related to the Mount West Orogeny**

Giles Event – 1085 (1120?) – 1040 Ma

- ***Warakurna Supersuite –*** magmatic component
- ***Bentley Supergroup –*** depositional component

Main expression of this event is the Warakurna LIP

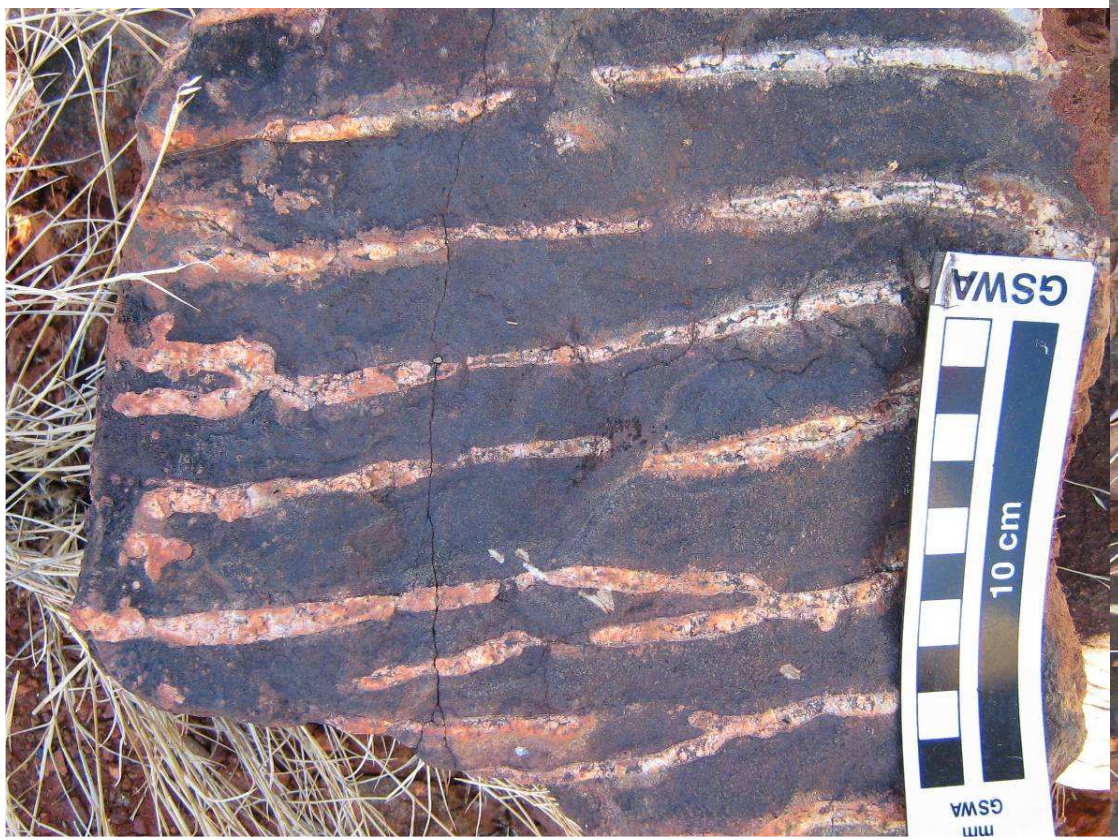
- **short-lived (c. 1078-1073 Ma) and in a temporal sense only a minor magmatic component of the Giles Event.**



Kunmarnara Group
(base of Bentley Supergroup)

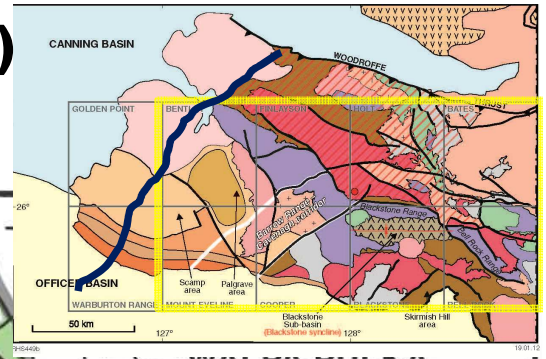
- MacDougall Fm (coarse clastics) & Mummawarrawarra Basalt
- > c. 1078 Ma

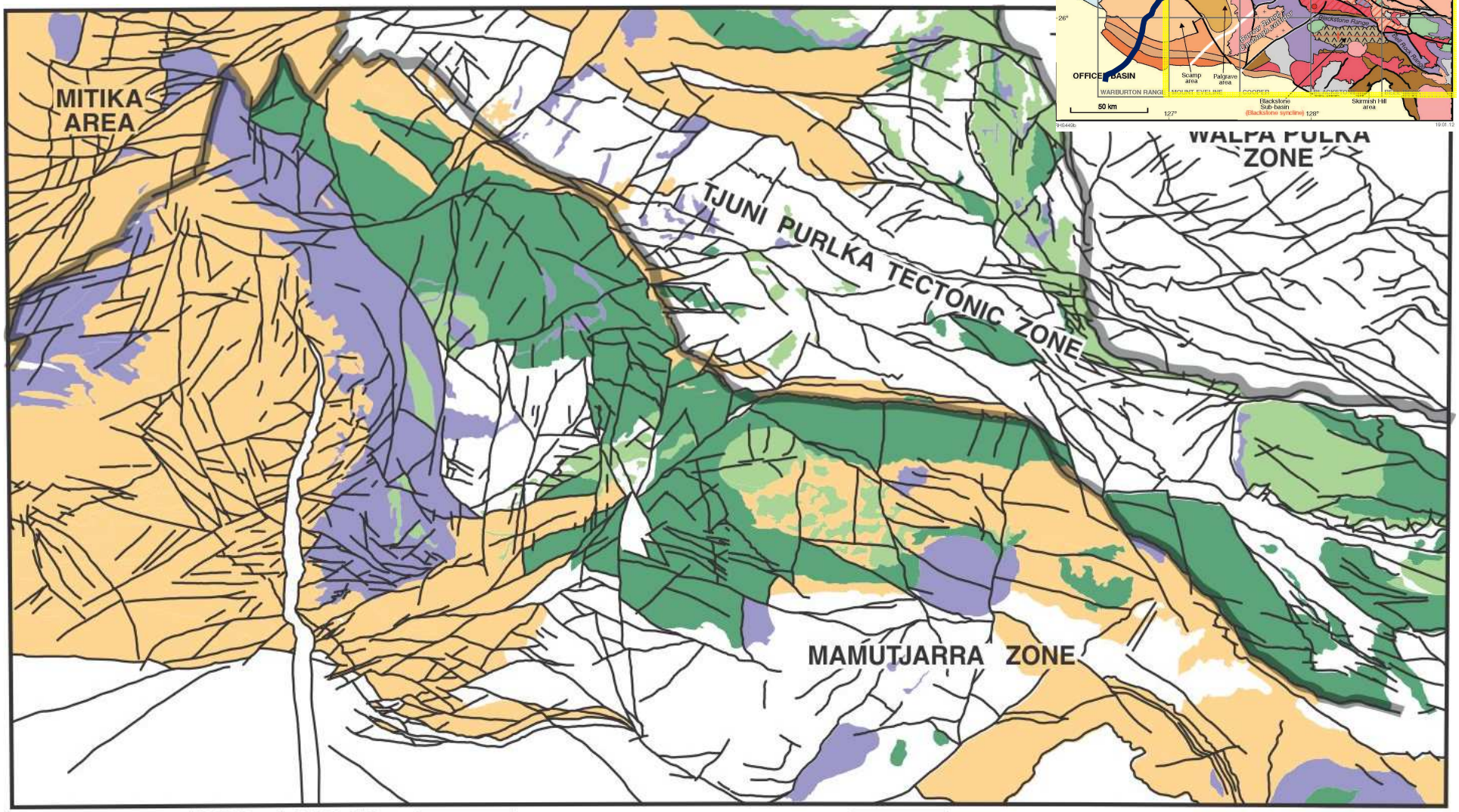
(important unit in the seismic interp)



Layered mafic/ultramafic ‘Giles’ intrusions (G1)

~1078 -1075 Ma – intruded INTO Kunmarnara Gp.





1085–1040 Ma
Giles Event
Warakurna Supersuite

Granites

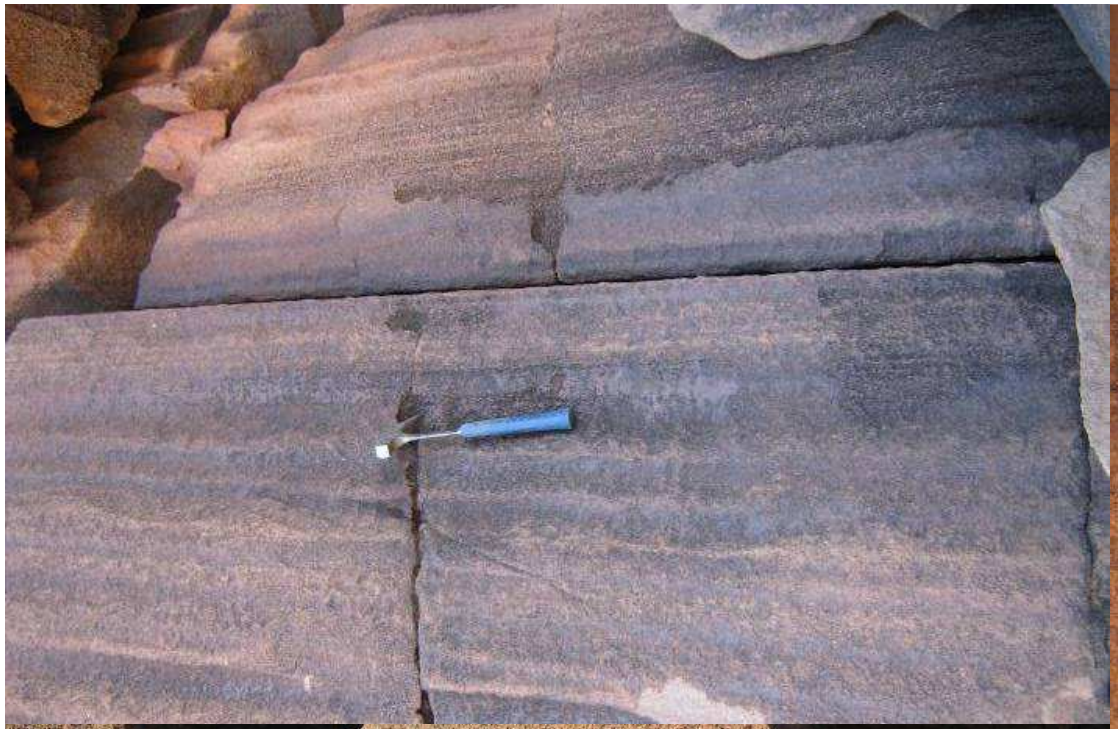
Bentley Basin
Bentley Supergroup

Gabbro

Layered ‘Giles intrusions’

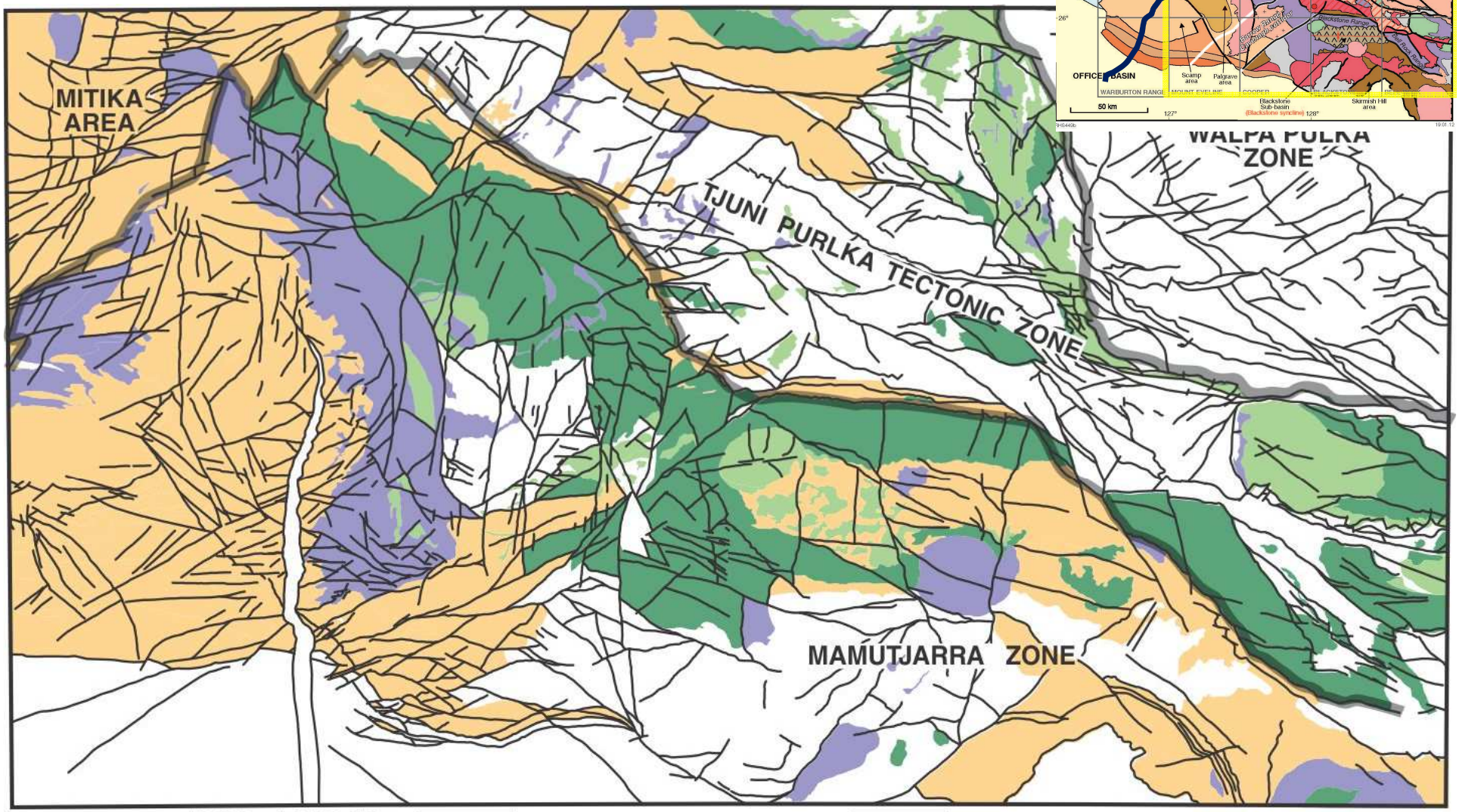
16.04.13

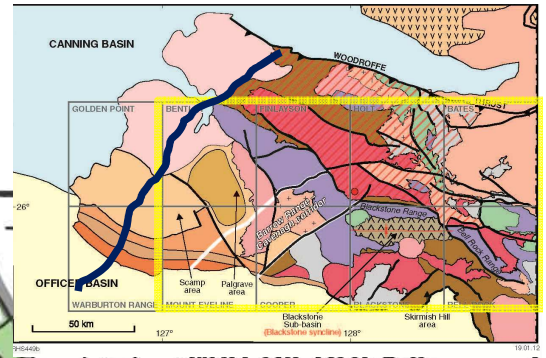
20 km



Layered mafic/ultramafic ‘Giles’ intrusions (G1)

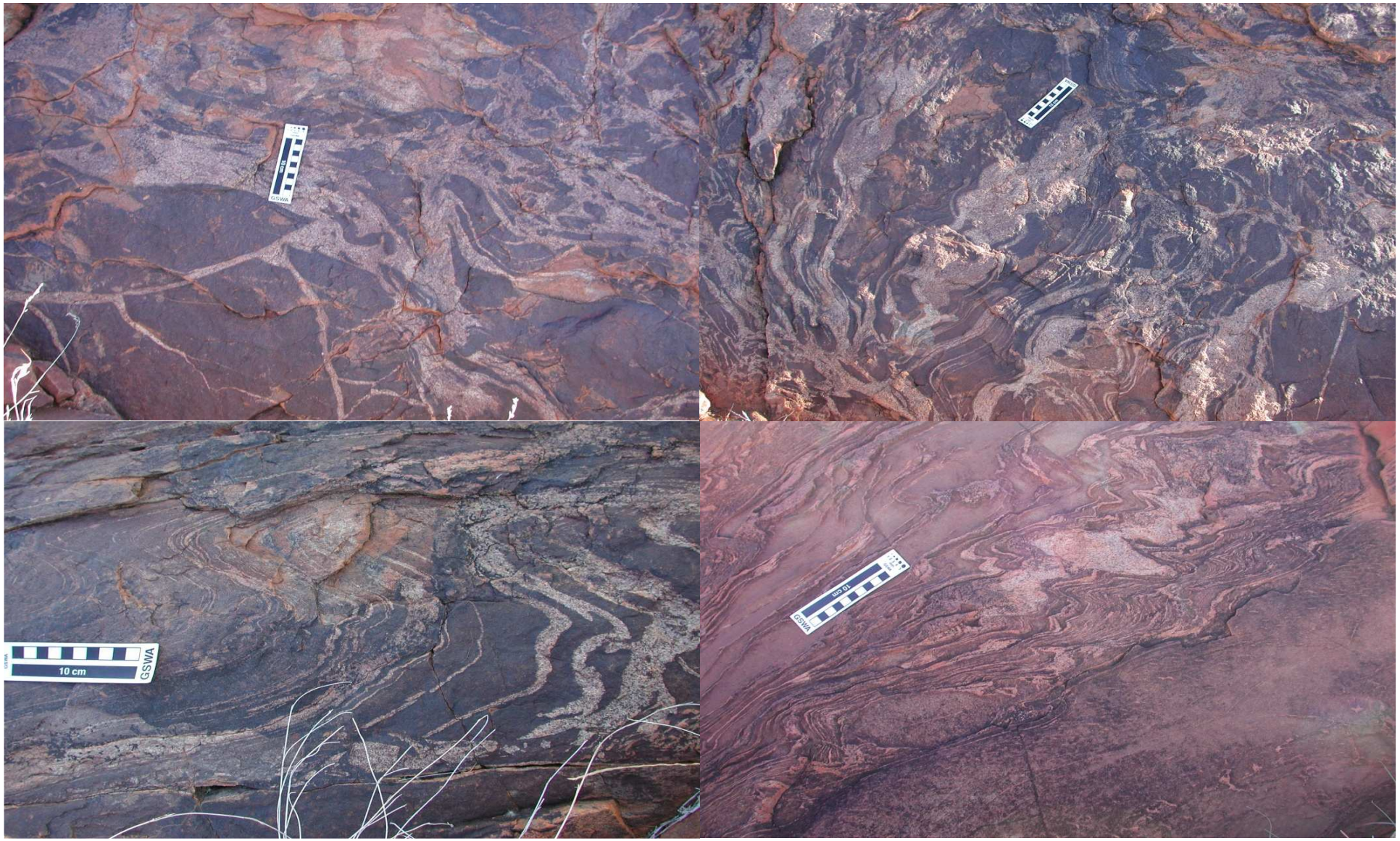
‘Massive gabbros’ (G2) ~1078 -1074 Ma





‘Massive’ gabbros (G2) ~ 1078 - 1074 Ma but always younger than associated G1 intrusions.

Co-magmatic granite – compositional equivalent of Smoke Hill Volcanics.



Alcurra Dolerite suite (G3)

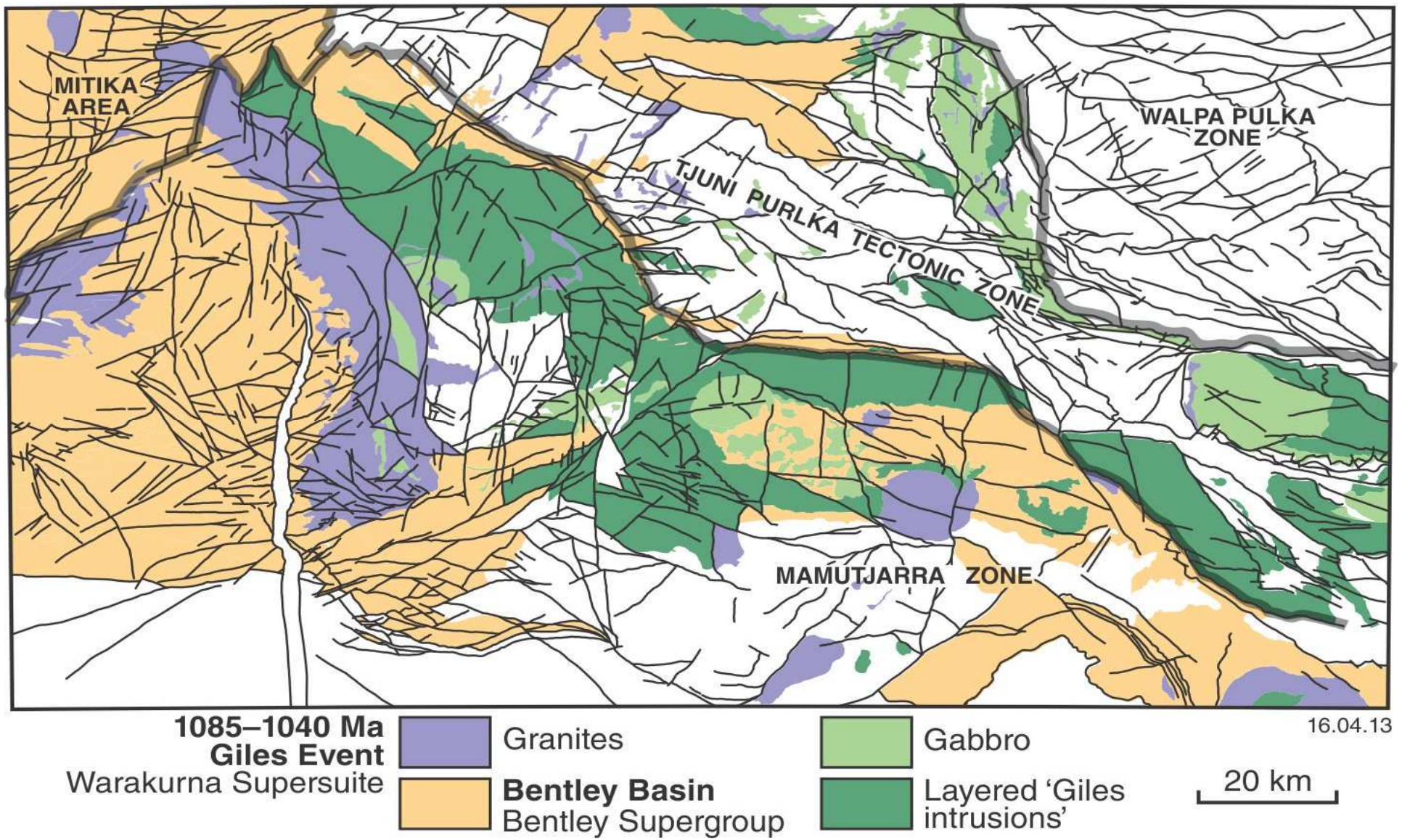
-Warakuran LIP (1078 – 1073 Ma)

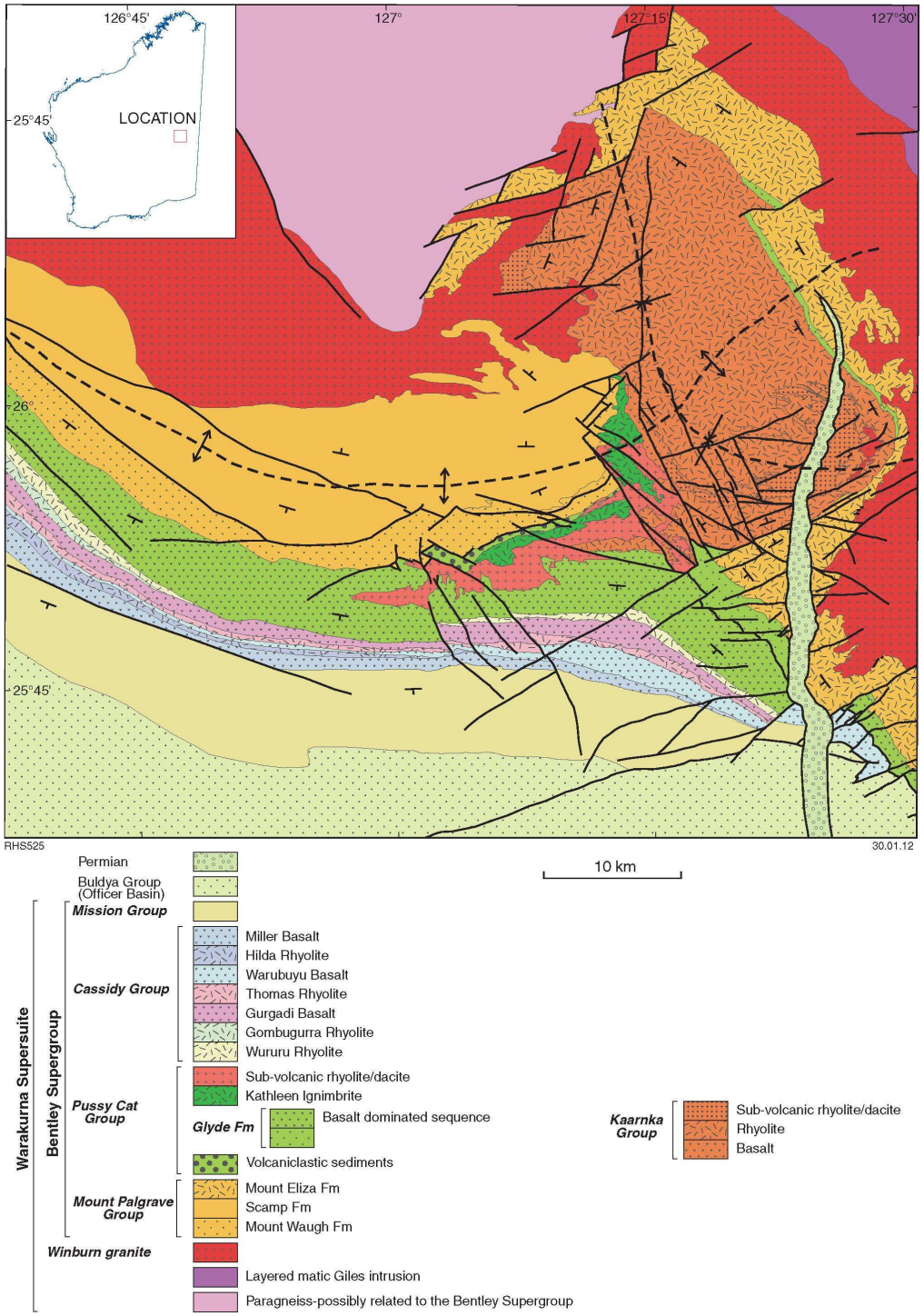
-Series of Fe-gabbro to Fe-gabbronorite intrusions including the **Nebo-Babel** gabbro and other Cu-mineralized gabbros (~ 1067 Ma)

-Majority of basalt Fm in the Bentley Supergroup (1078 to < 1040 Ma)

Bentley Supergroup ~1078 to 1040 Ma

At least three sub-basins dominated by bi-modal volcanic rocks





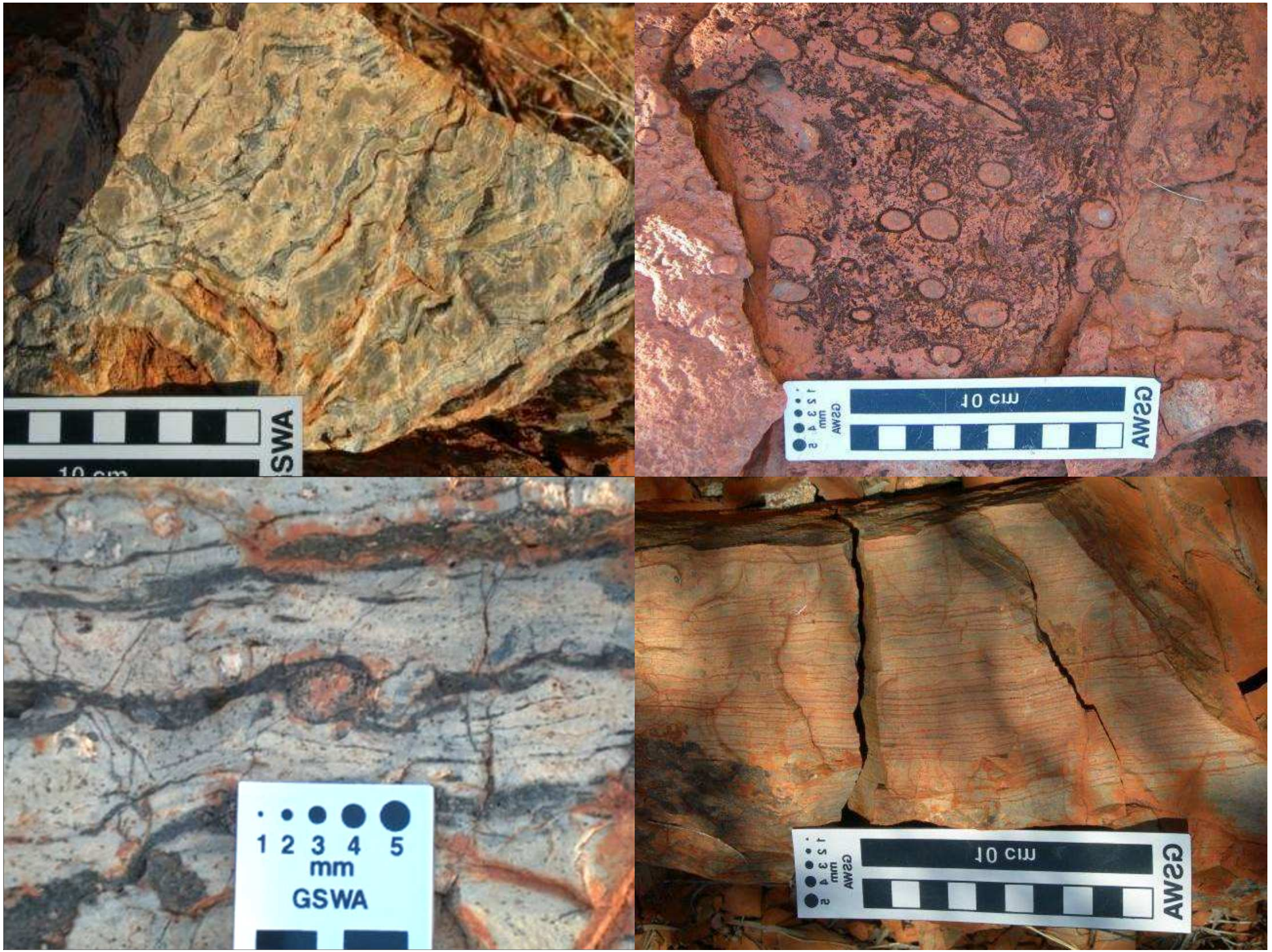
Talbot Sub-basin

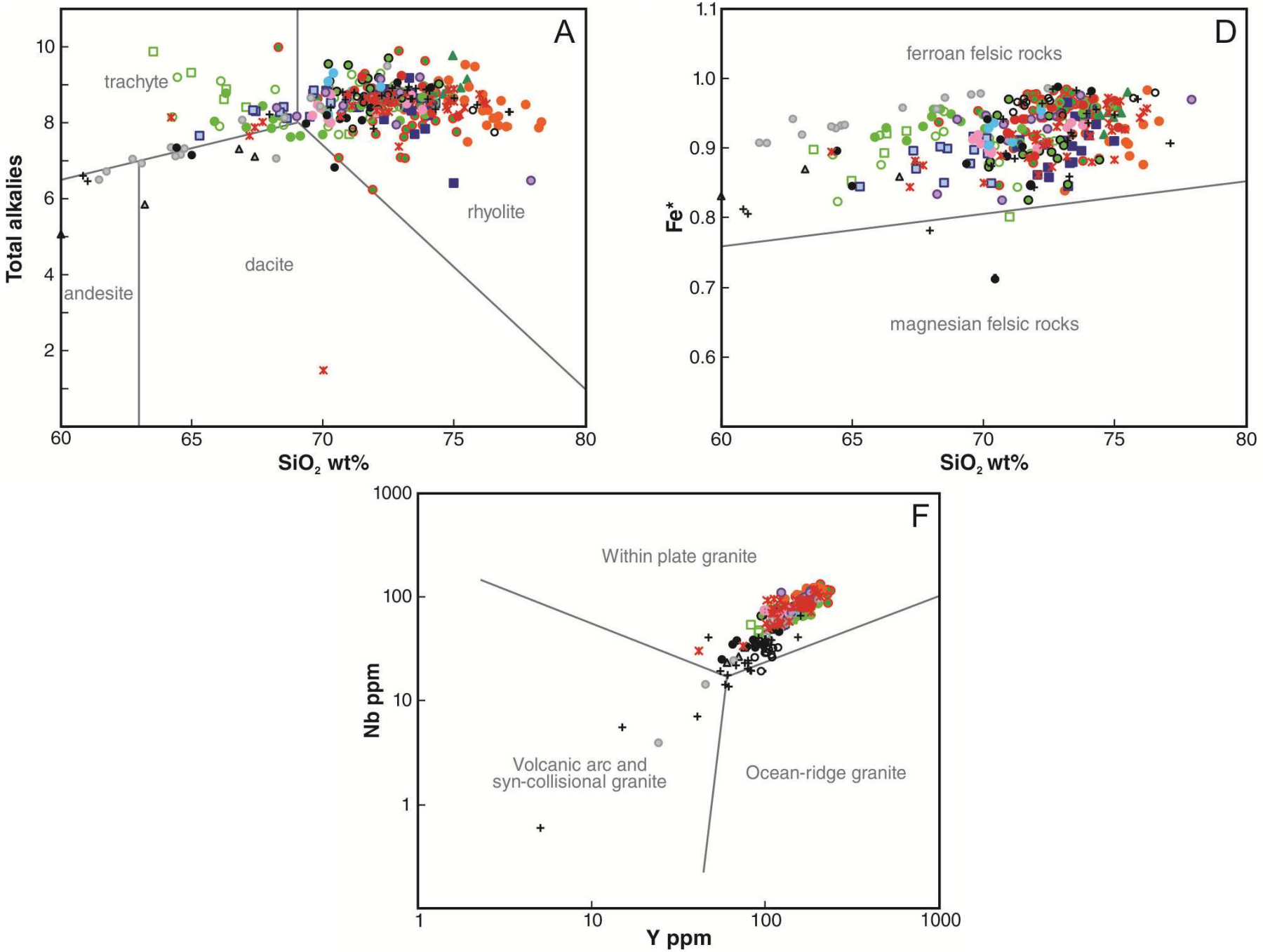
>1075 Ma to < 1040 Ma

Bi-modal volcanic succession dominated by rhyolites, with many deposits reflecting ‘super-eruptions’ and surrounded by exposed chamber (Winburn granite)

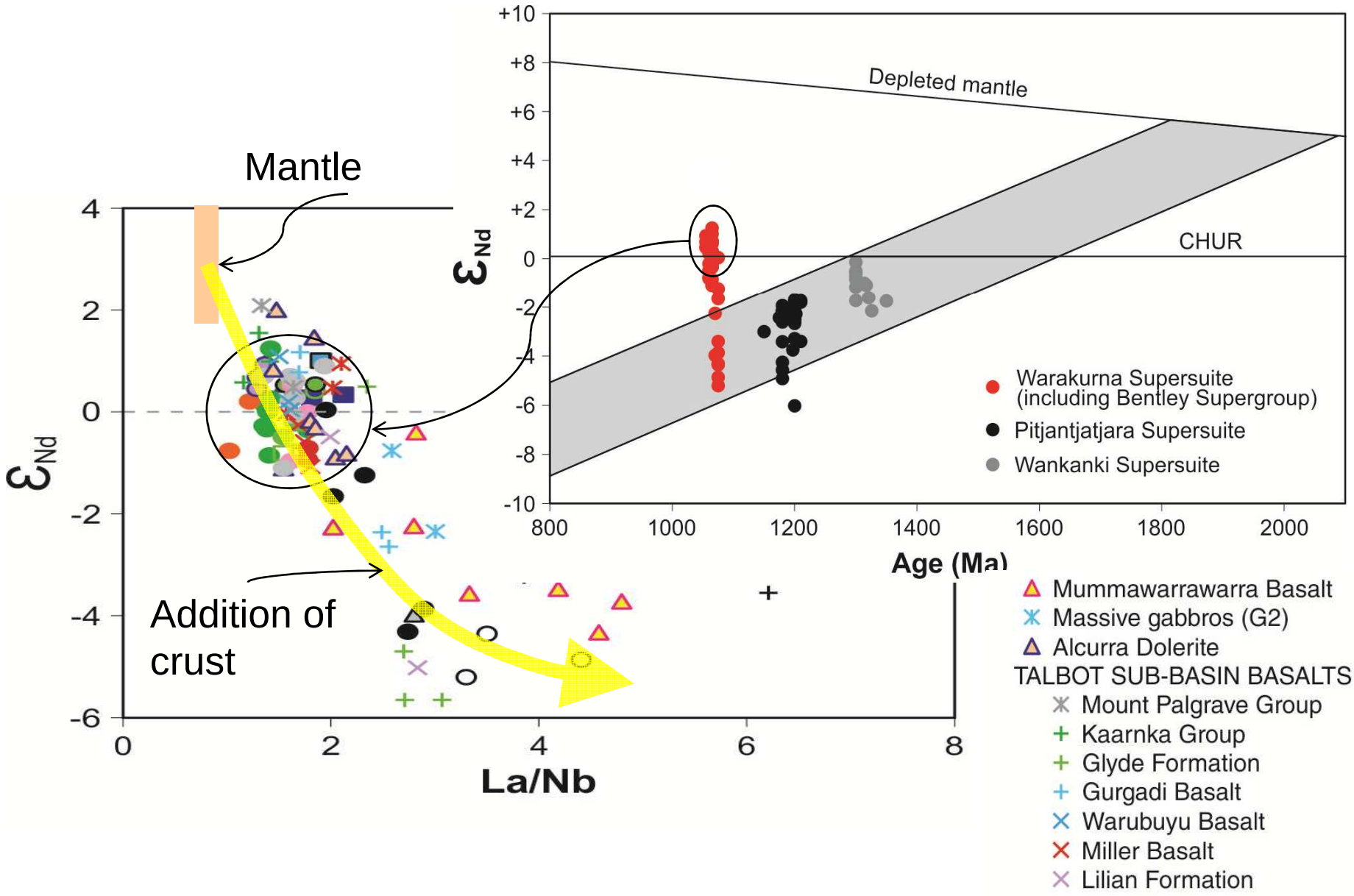
Talbot Supervolcano

Crustal-scale chamber (feeder) system incorporating up to 30% basalts (eruption triggers).


10 cm
GSWA
1 2 3 4 5
mm
GSWA


A
trachyte
rhyolite
dacite
andesite
Total alkalies
SiO2 wt%
D
ferroan felsic rocks
magnesian felsic rocks
Fe*
SiO2 wt%
F
Within plate granite
Volcanic arc and
syn-collisional granite
Ocean-ridge granite
Nb ppm
Y ppm

Source - crustal or mantle?



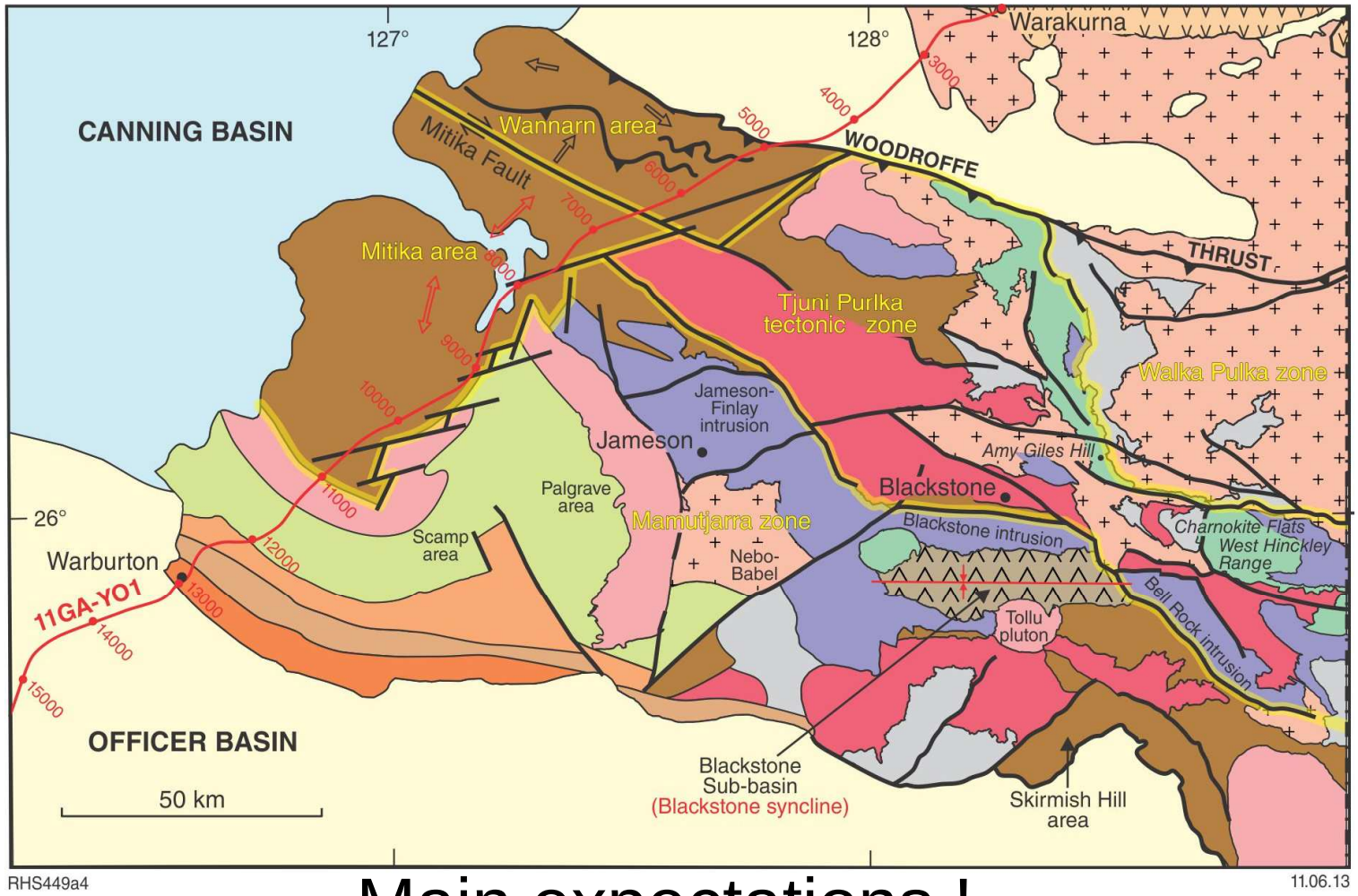
Some magma volumes

- Talbot Sub-basin - average stratigraphic thickness ~ 6 km and 70% rhyolitic.
- Preserved (minimum) extent ~ 5 200 km^2.
- Represents ~ 9 400 and 22 000 km^3 of basalt and rhyolite respectively.
- Represents > 230 000 km^3 of parental mantle-derived magma added to the crust (enough for 2 LIPs)

Supervolcano.

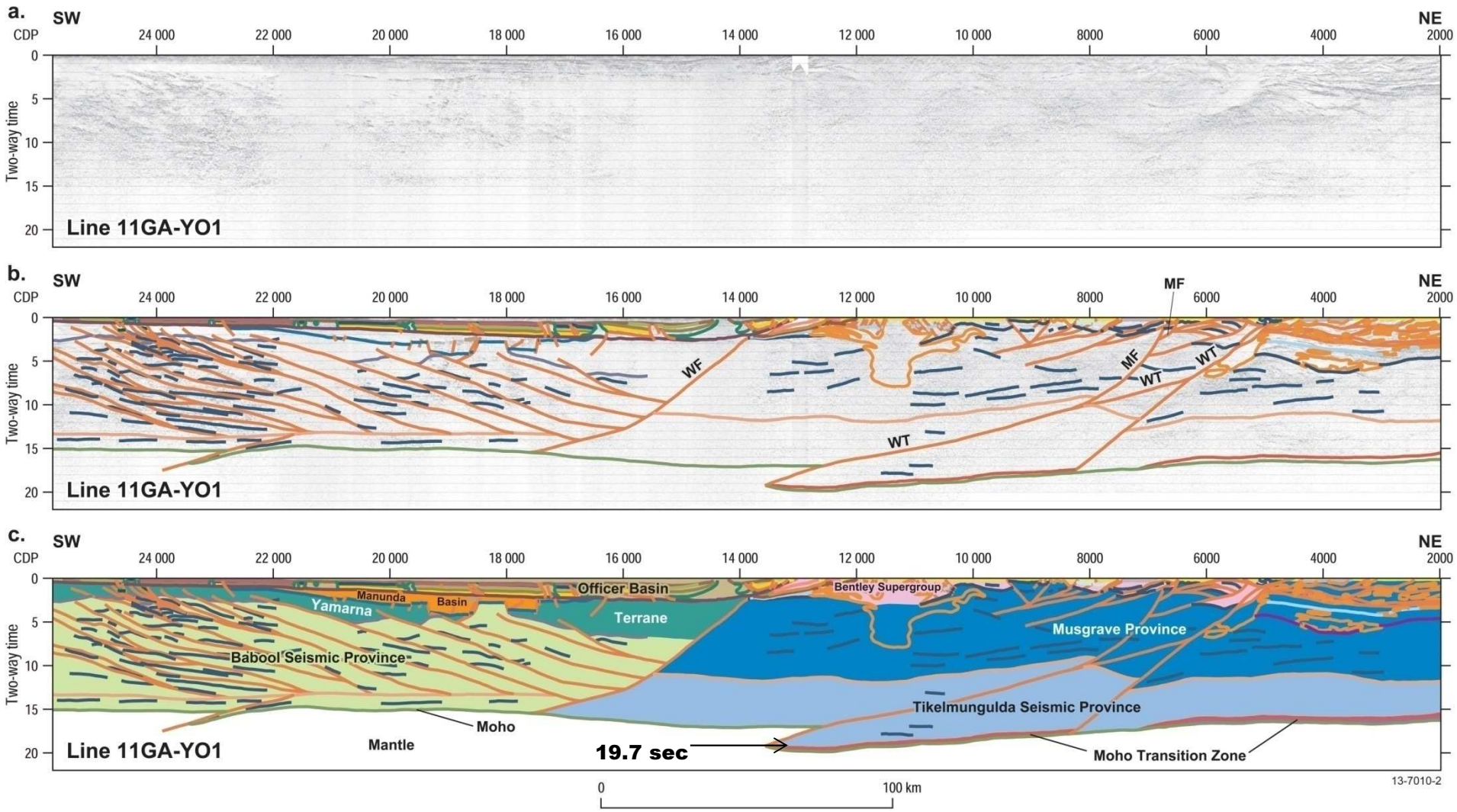
- Extended over outcrop extent of the Bentley basin in WA = > 2.2 x 10^6 km^3 of parental mantle-derived magma added to the crust (enough for 22 LIPs).

* This ignores: G1 (world's big 5) and G2 intrusions Mummawarrawarra Basalt and the Warakurna LIP



Main expectations !

1) Thin layer of Bentley volcanics, perhaps evidence of layered intrusions.
2) Musgrave Province (i.e. pre-Giles) crust ~35 km thick.
3) Any underlying crustal material is younger than, and related to the magmatic development of the mid- and upper-crust.



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- Base Wahlgu Formation
- Base Steptoe Formation
- Base Kanpa Formation
- Base Hussar Formation
- Intra Browne Formation 2
- Intra Browne Formation 1
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- Salt
- Base Mesoproterozoic metasedimentary rocks

Musgrave Province

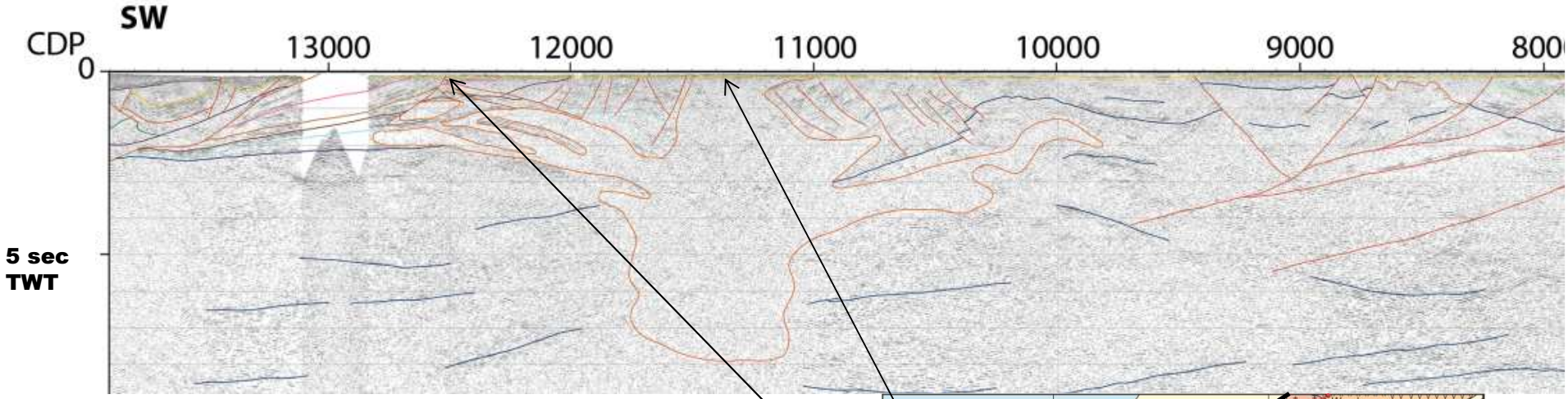
- Base Permian or Cambrian sedimentary rocks
- Base Mission Group
- Base Cassidy Group
- Base Pussy Cat Group
- Base Palgrave Group and equivalents
- Base Bentley Supergroup
- Layered intrusion

Fault

- **WF** Windularra Fault
- **MF** Mitika Fault
- **WT** Woodroffe Thrust

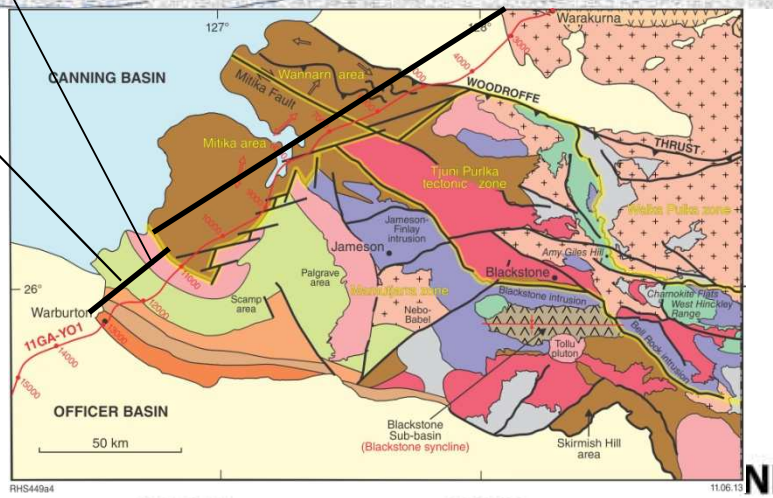
General

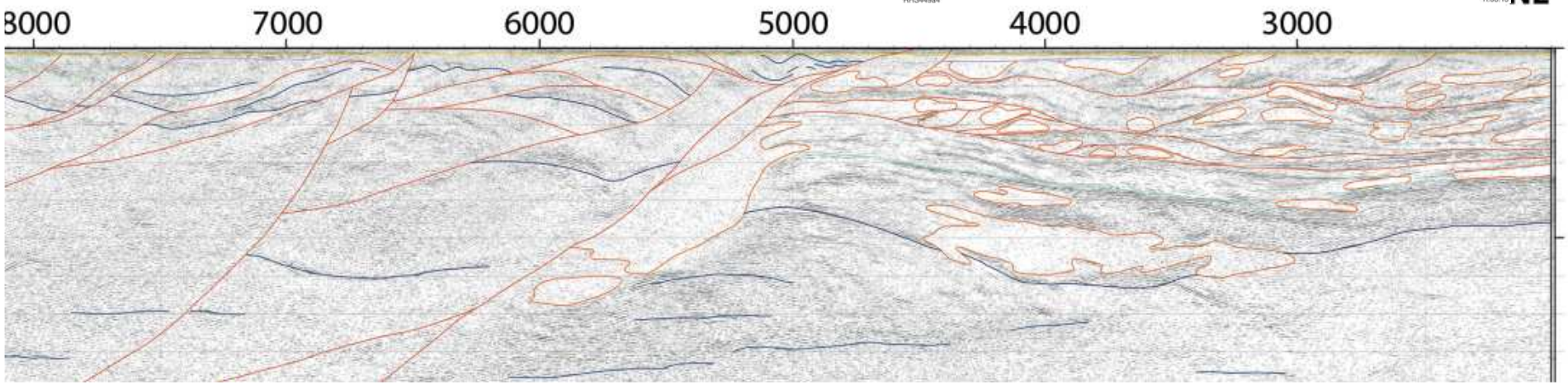
- Base Cenozoic/regolith
- Base mafic rocks
- Base nonreflective upper crust in Yilgarn Craton
- Base upper crust
- Base middle crust
- Top moho transition zone
- Moho
- Fault
- Granite
- Dyke/sill
- Form line

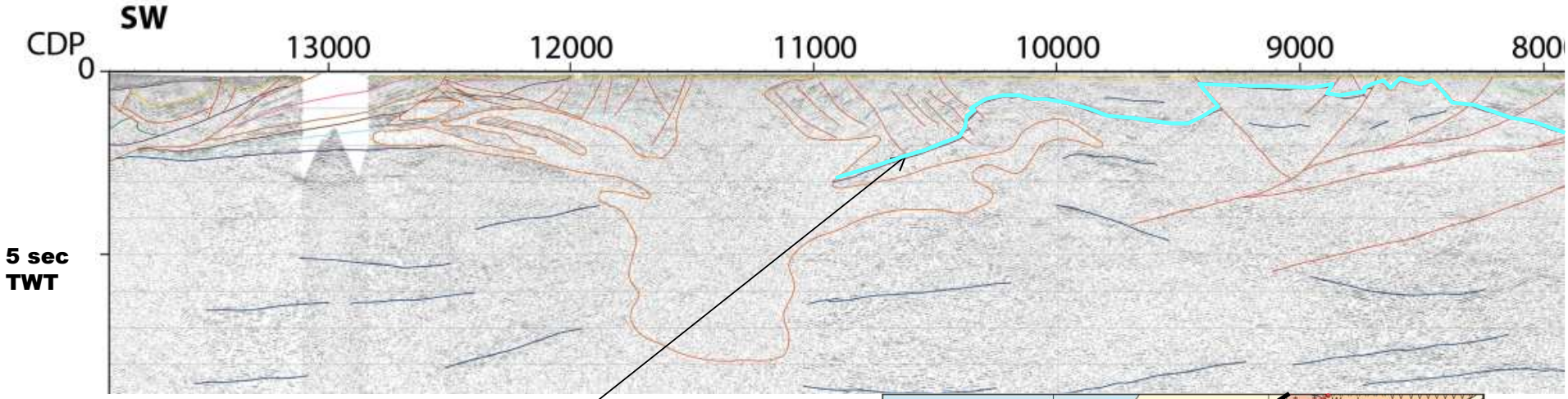


Upper crust

Thin (typically < 3 sec TWT) veneer.
-Bi-modal Talbot Sub-basin in the SW
-Kunmarnara Group in the mid NE
-Far NE ? Amphibolite-facies Pit SS?







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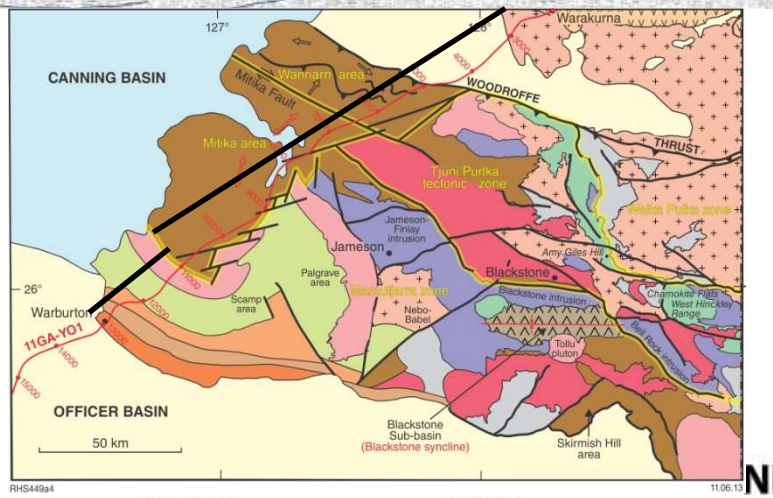

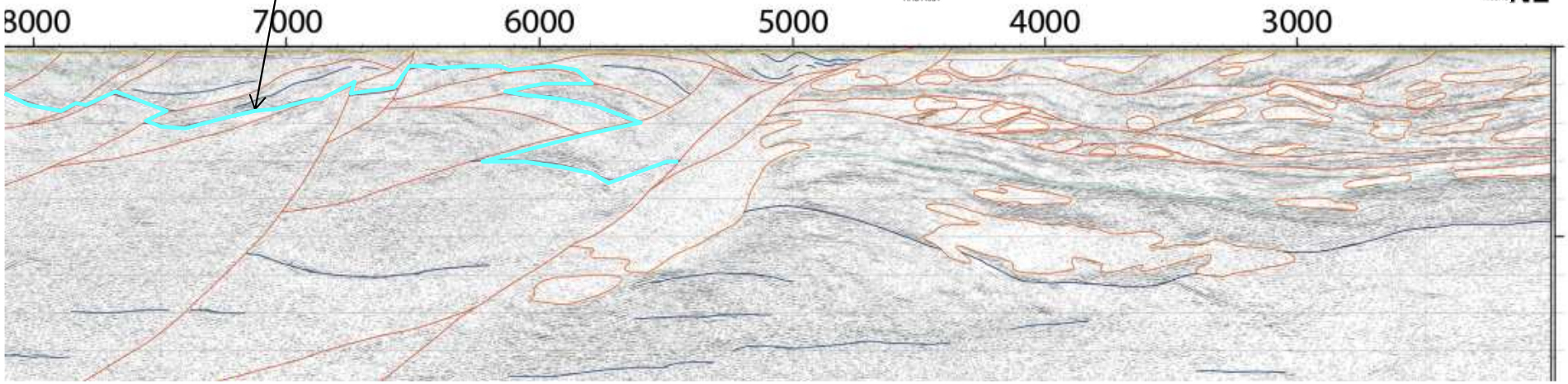

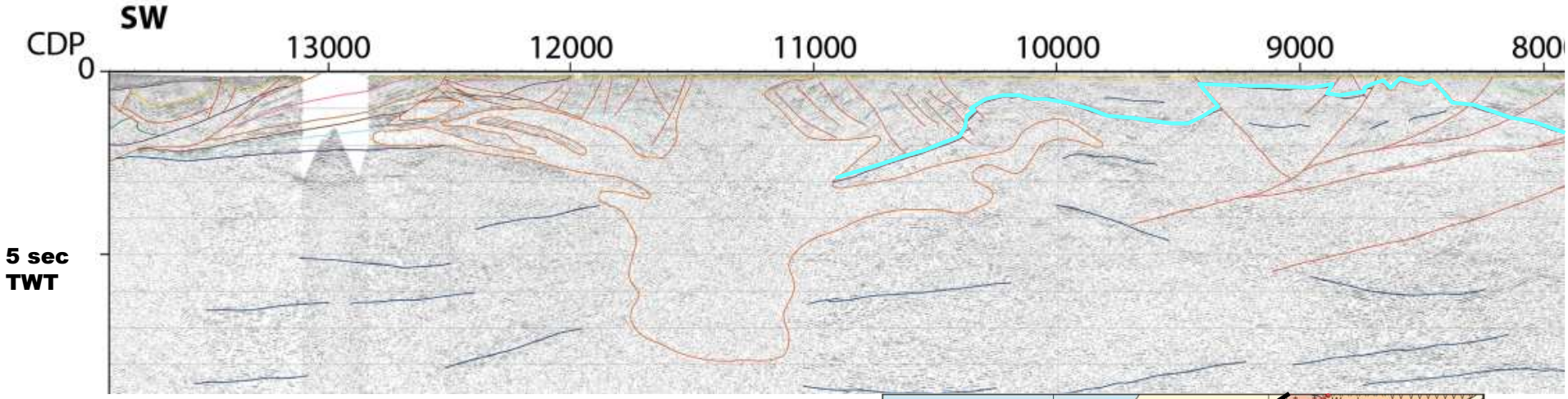

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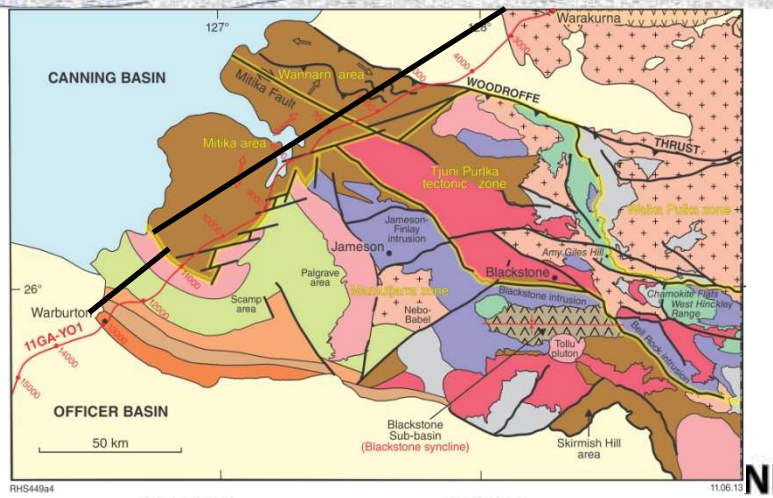
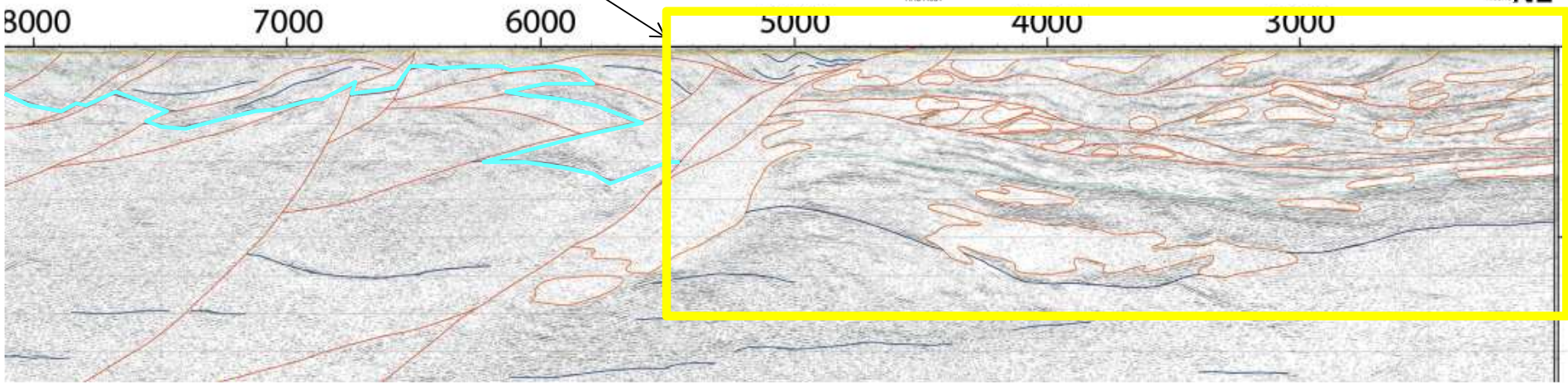
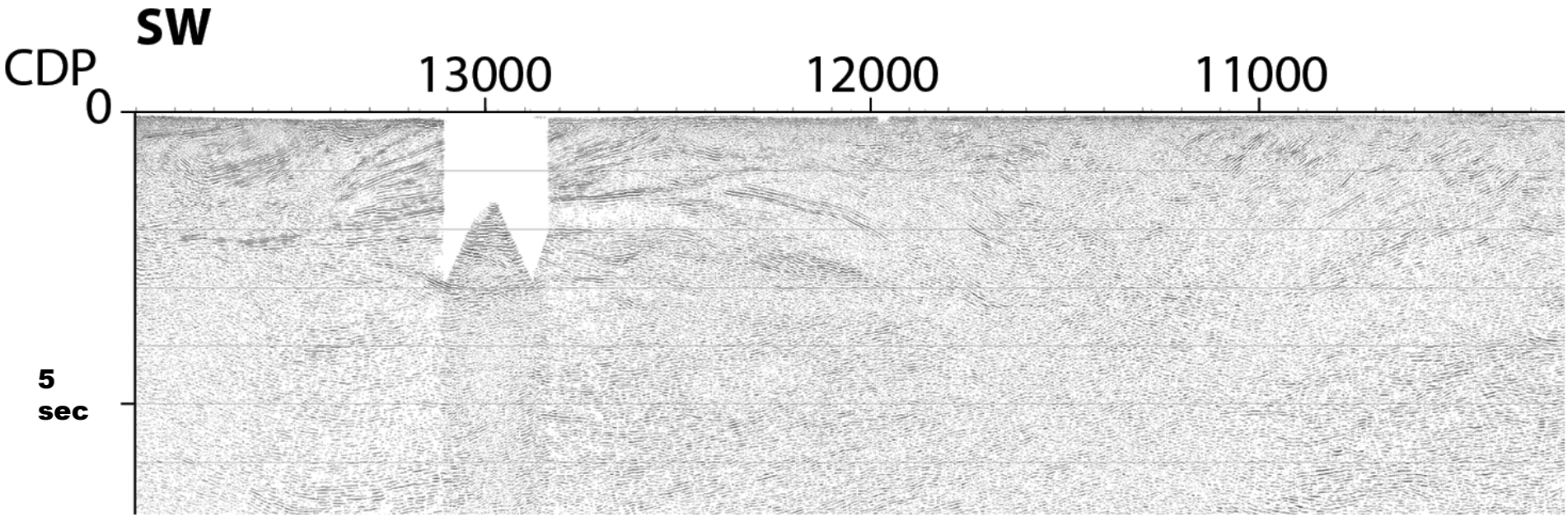
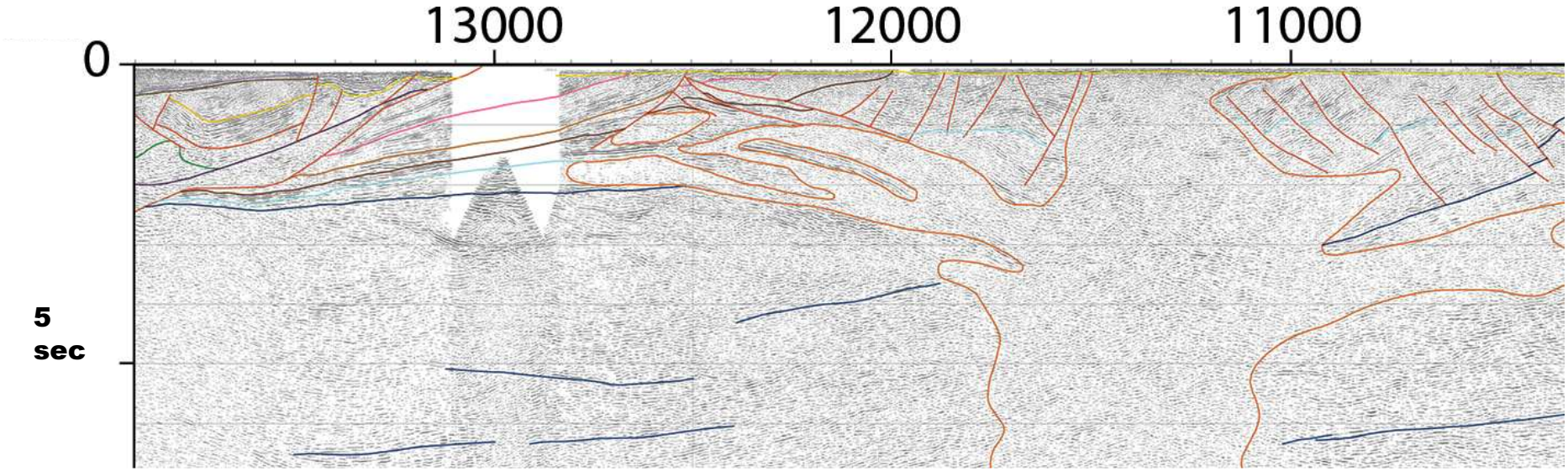
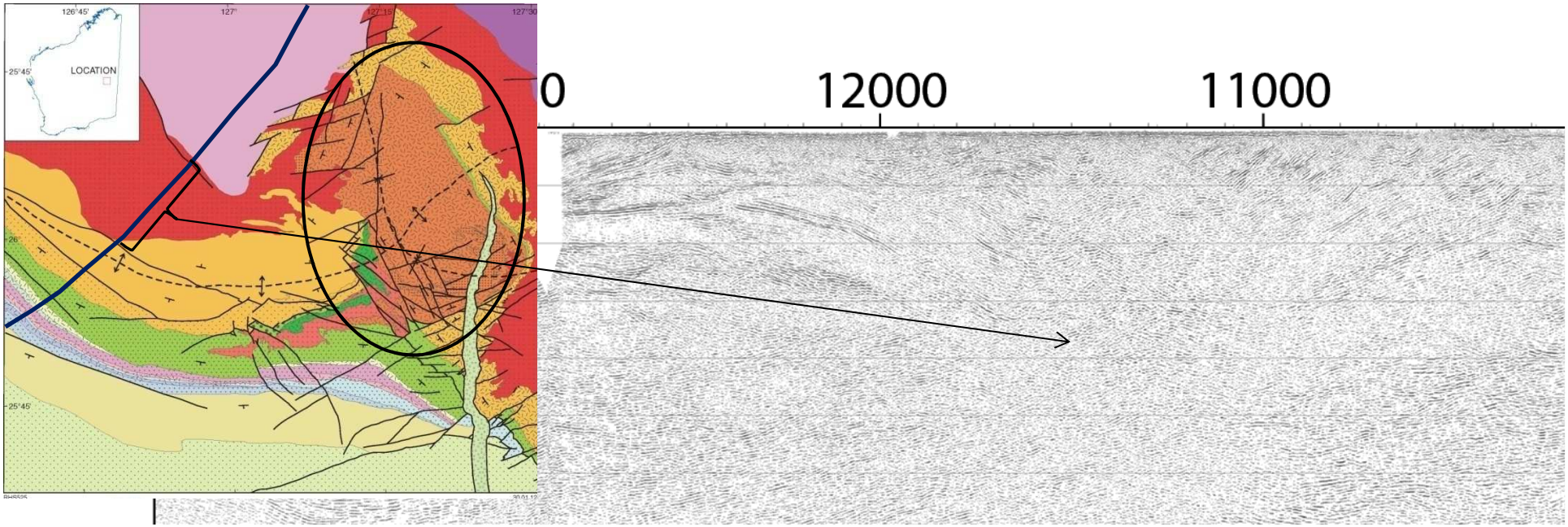




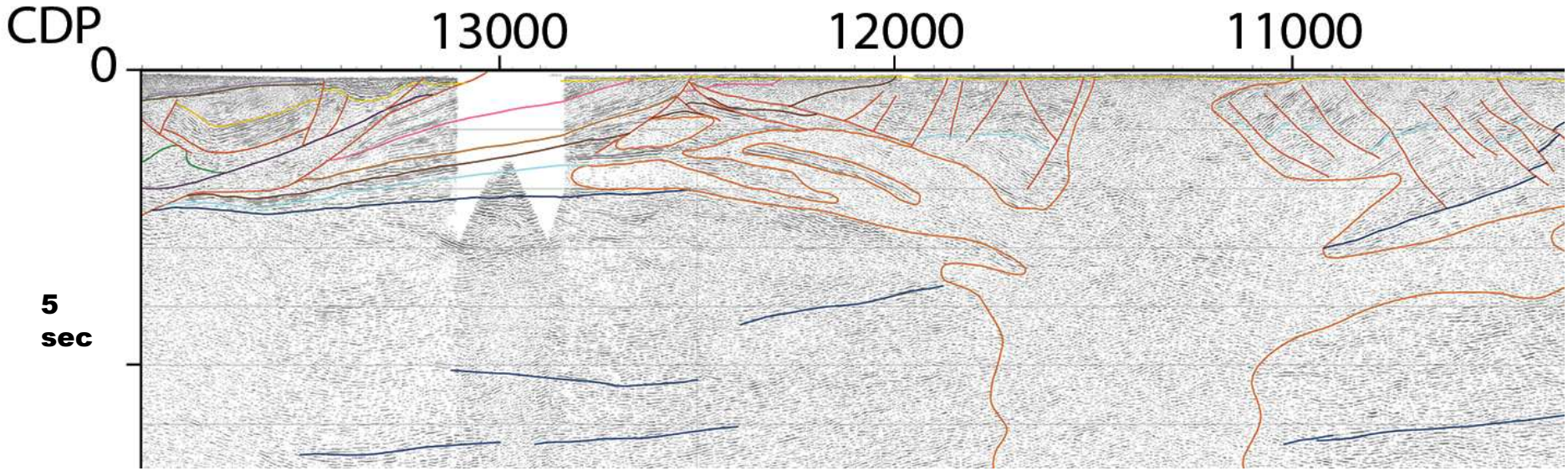


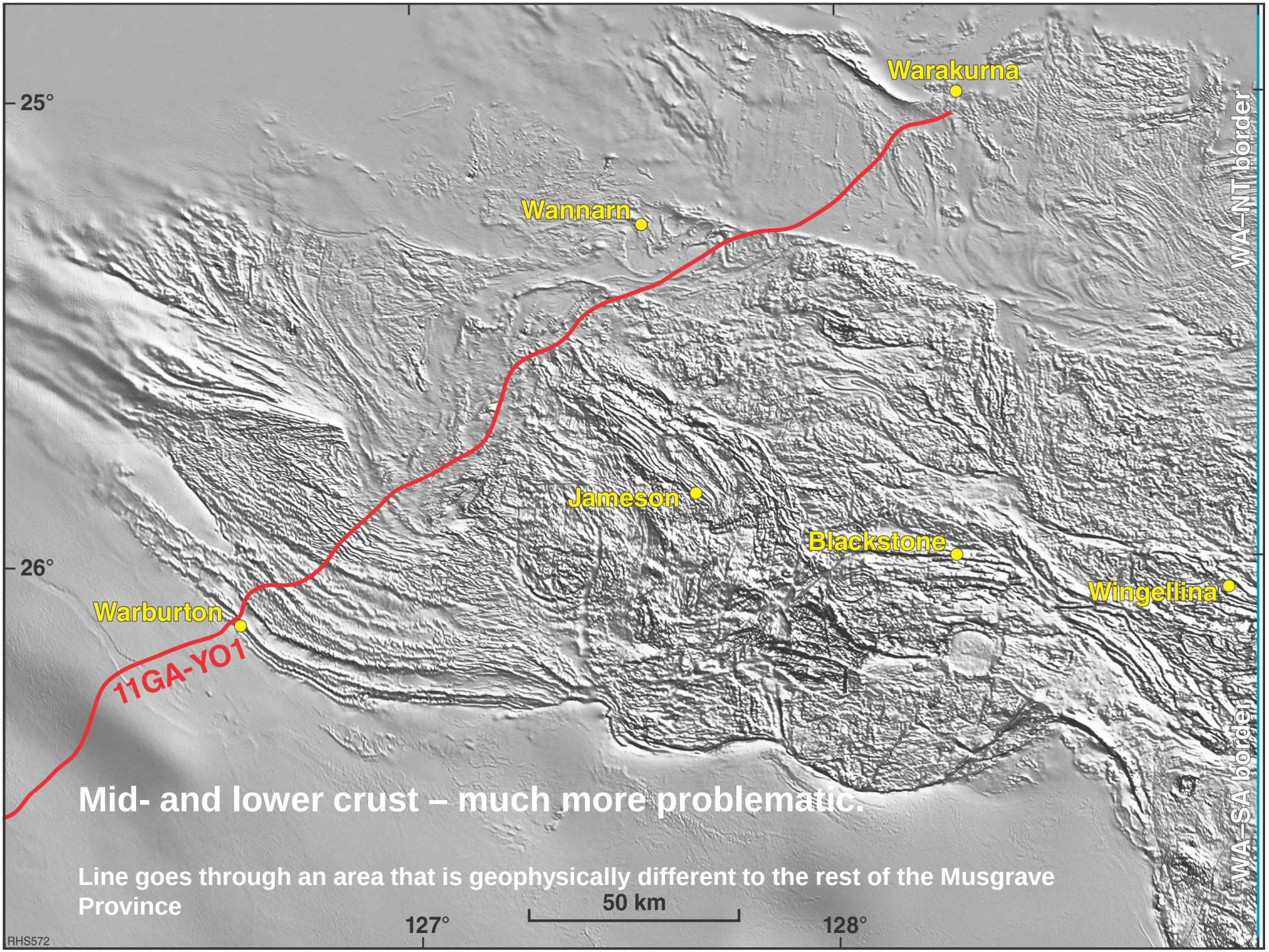
Talbot Sub-basin – gentle dips to S, syn-volcanic faulting, ~ 6 km stratigraphic thickness. Possibly underlying Kunmarnara Gp. Well imaged unconformity with basement.

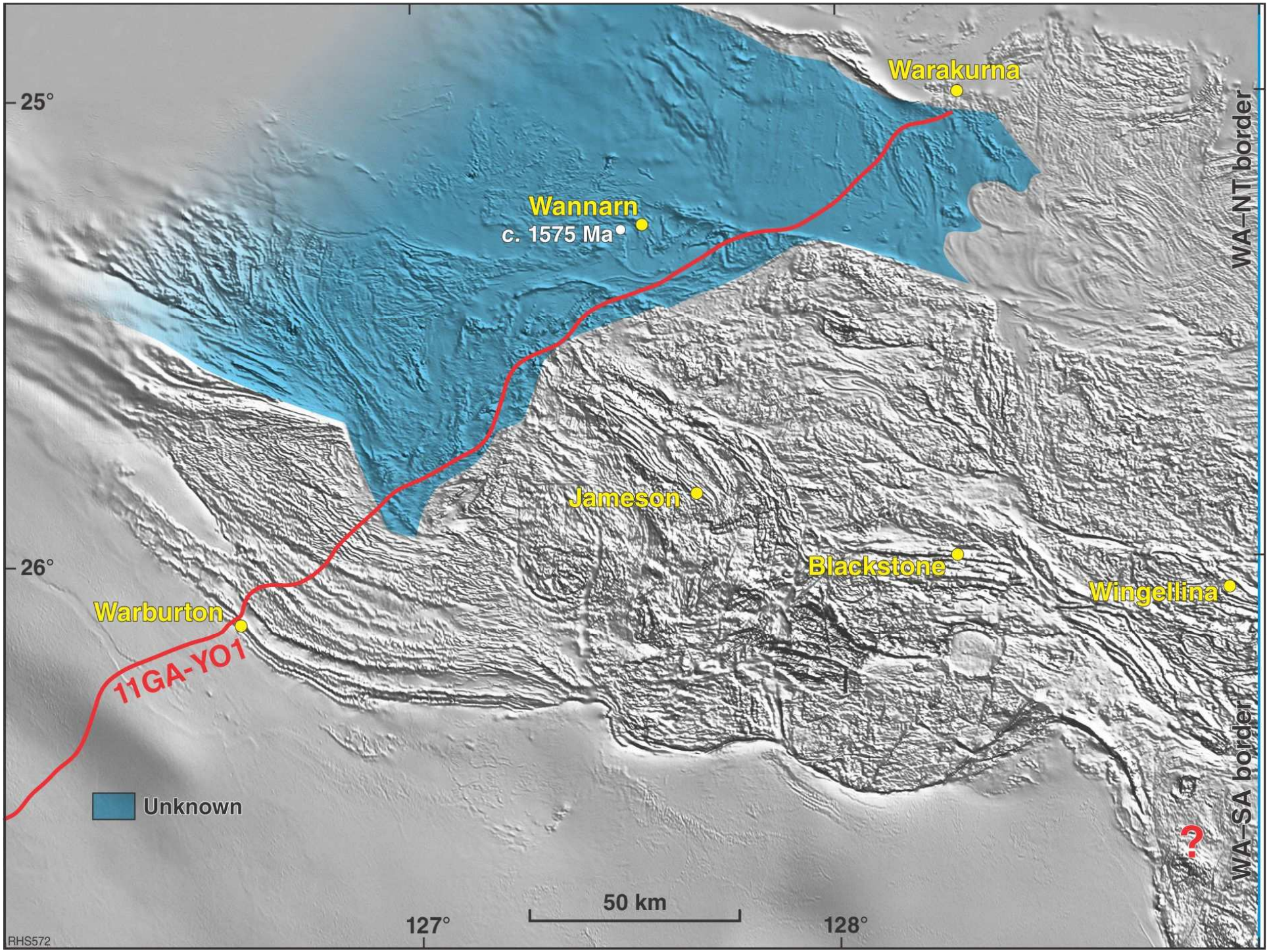


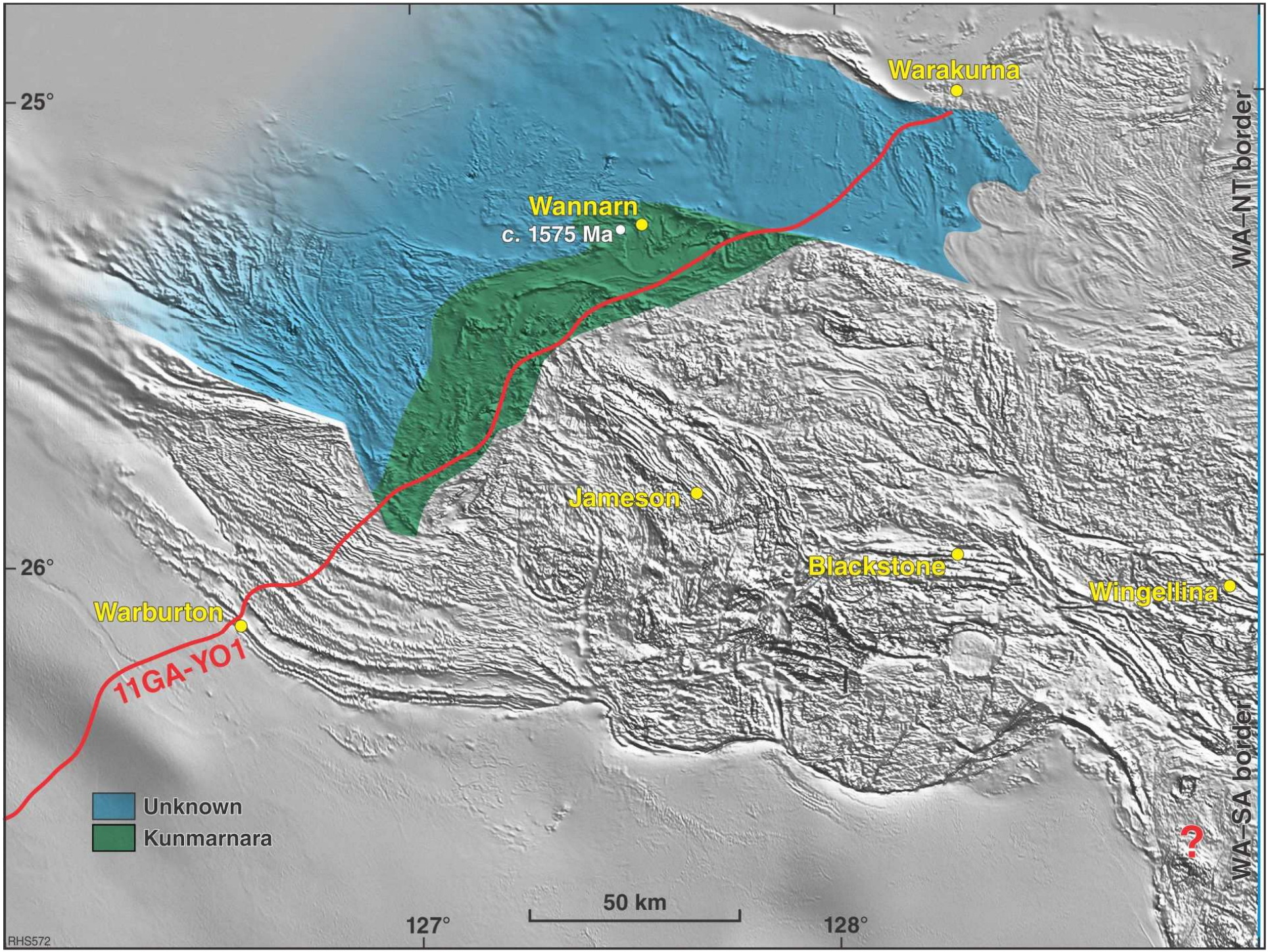


Winburn granite – part of the magma chamber system for the world longest-lived supervolcano system and one of the worlds most voluminous juvenile felsic additions to the crust. Locally contains up to 30% basalt (thermal triggers and source of basalt flows)




Warakurna
Wannarn
Jameson
Blackstone
Wingellina
Warburton
11GA-YO1
25°
26°
127°
128°
50 km
WA–NT border
WA–SA border
Mid- and lower crust – much more problematic.
Line goes through an area that is geophysically different to the rest of the Musgrave Province
RHS572


Warakurna
25°
Wannarn
c. 1575 Ma
WA–NT border
Jameson
26°
Blackstone
Wingellina
Warburton
11GA-YO1
Unknown
?
WA–SA border
50 km
127°
128°
RHS572


Warakurna
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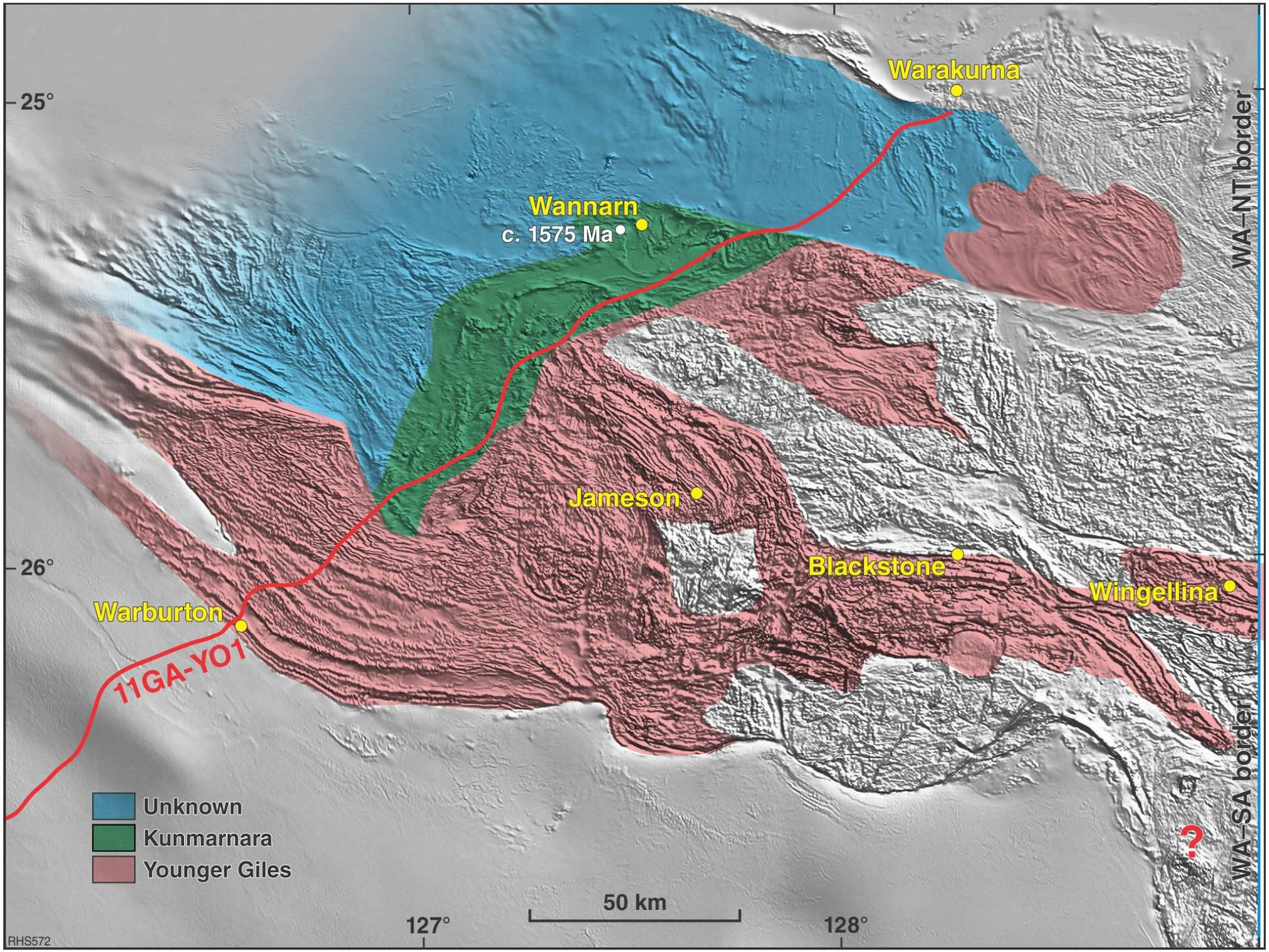
RHS572


Warakurna
25°
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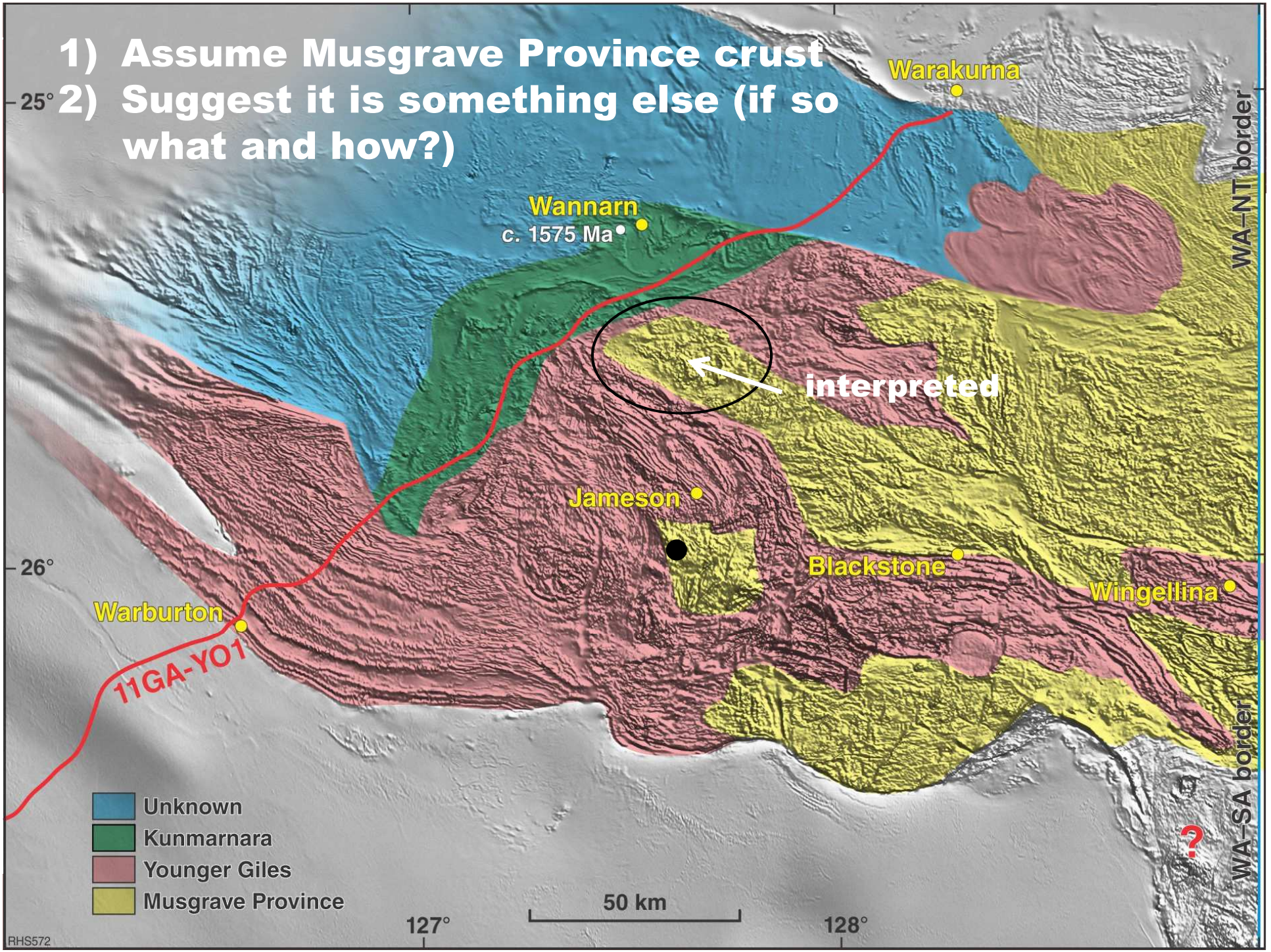
11GA-YO1
WA–SA border
?
Unknown
Kunmarnara
Younger Giles
50 km
127°
128°
RHS572


1) Assume Musgrave Province crust
2) Suggest it is something else (if so what and how?)
25°
26°
127°
128°
Warakurna
Wannarn
c. 1575 Ma
interpreted
Jameson
Blackstone
Wingellina
Warburton
11GA-YO1
WA–NT border
WA–SA border
?
Unknown
Kunmarnara
Younger Giles
Musgrave Province
50 km
RHS572

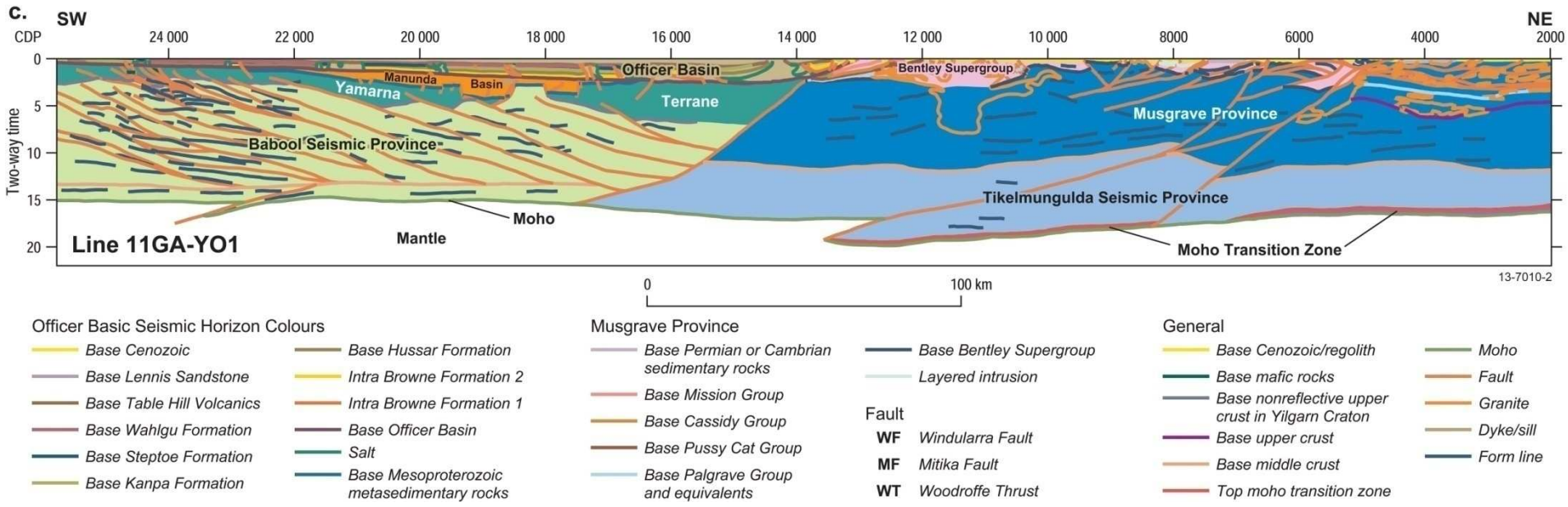
Safe option – Musgrave Province crust

-Thickness is about what we would expect

-Outcrop relationship between the Wankanki and Pitjantjatjara Supersuites would suggest that this crust was dominantly Wankanki Supersuite.

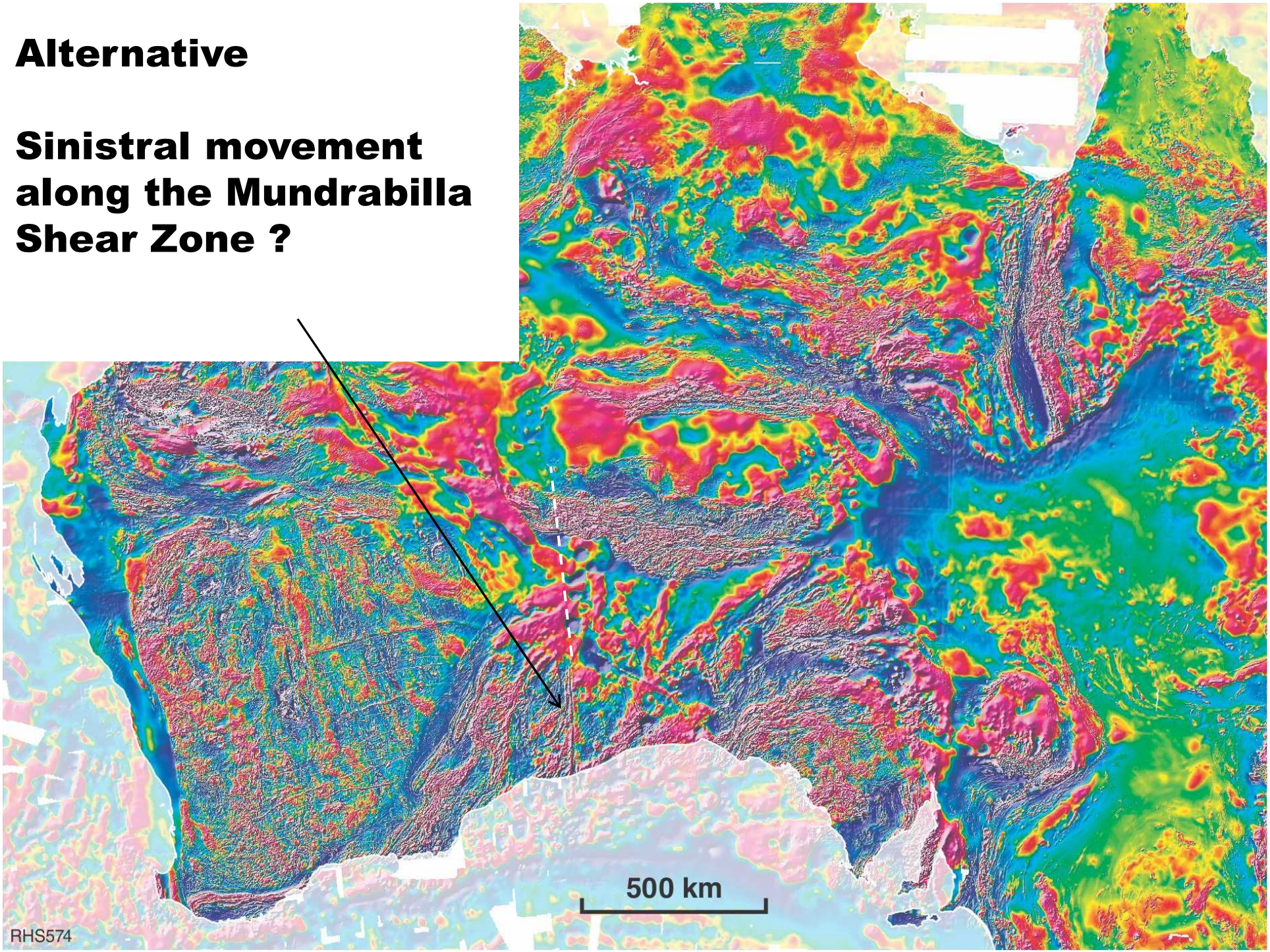
-In this case, some of the stronger reflectors might be rafts of Wirku Metamorphics

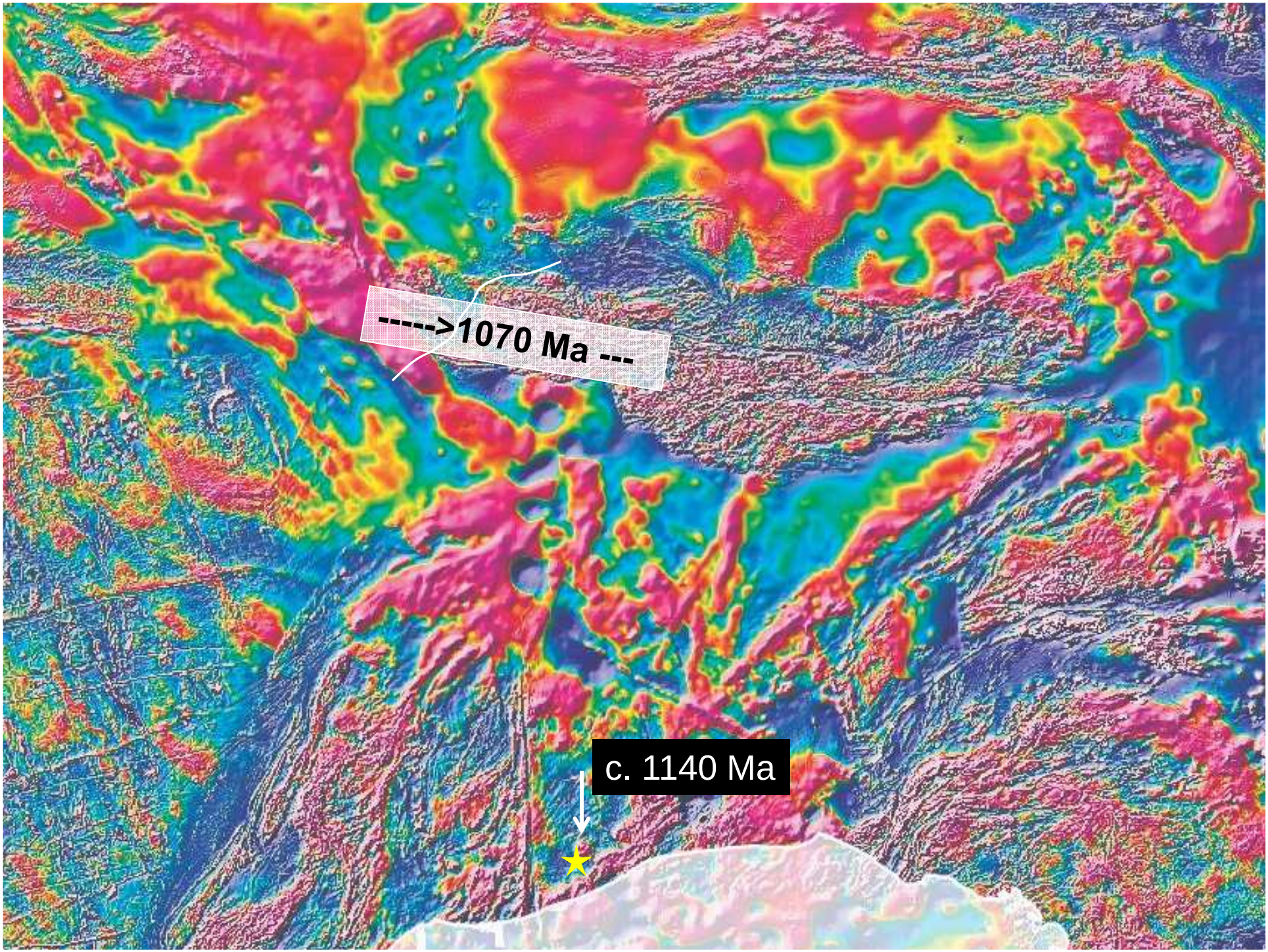
-Tikelmungulda Seismic Province needs to be younger – and dominantly mafic!!

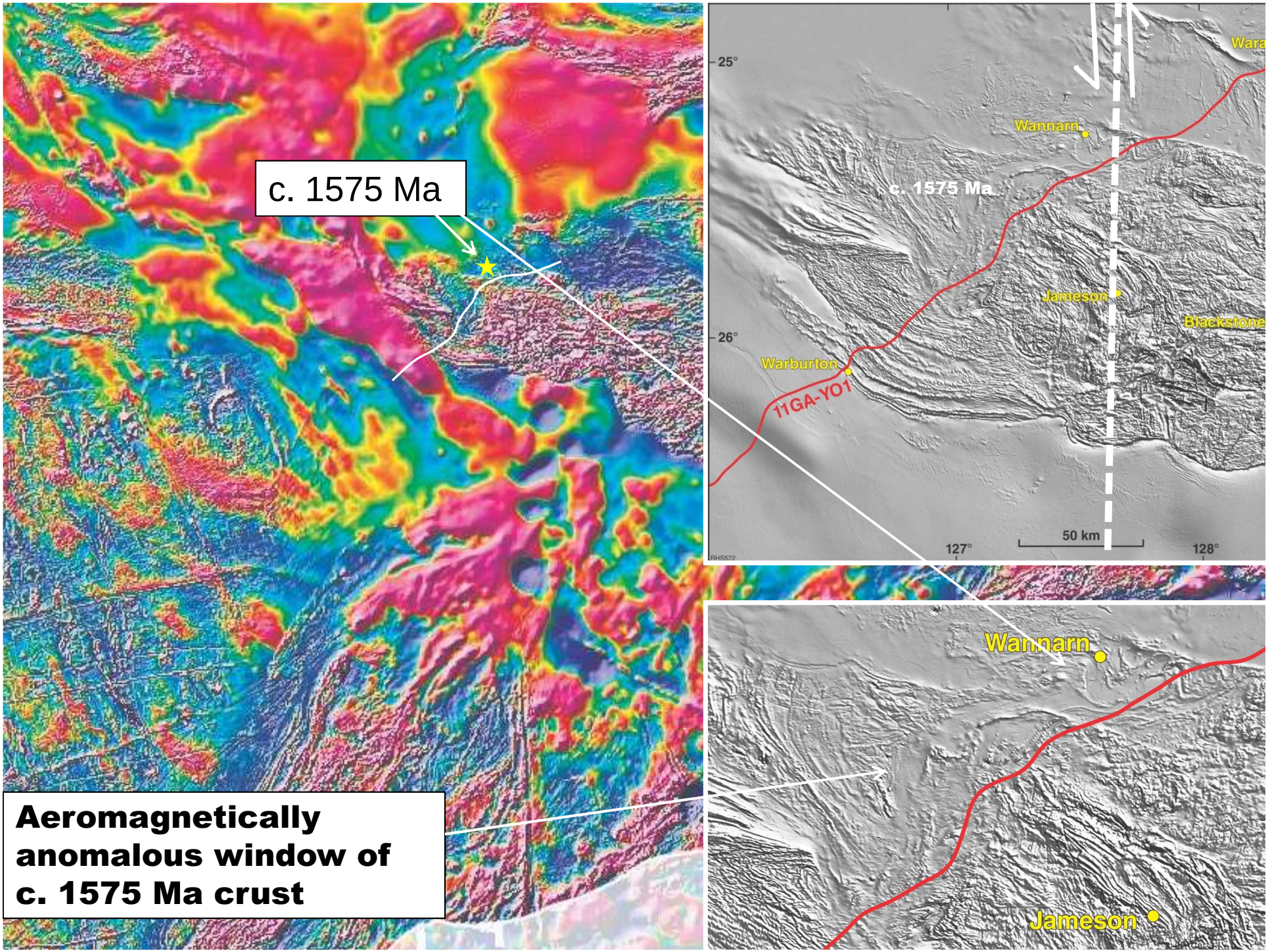


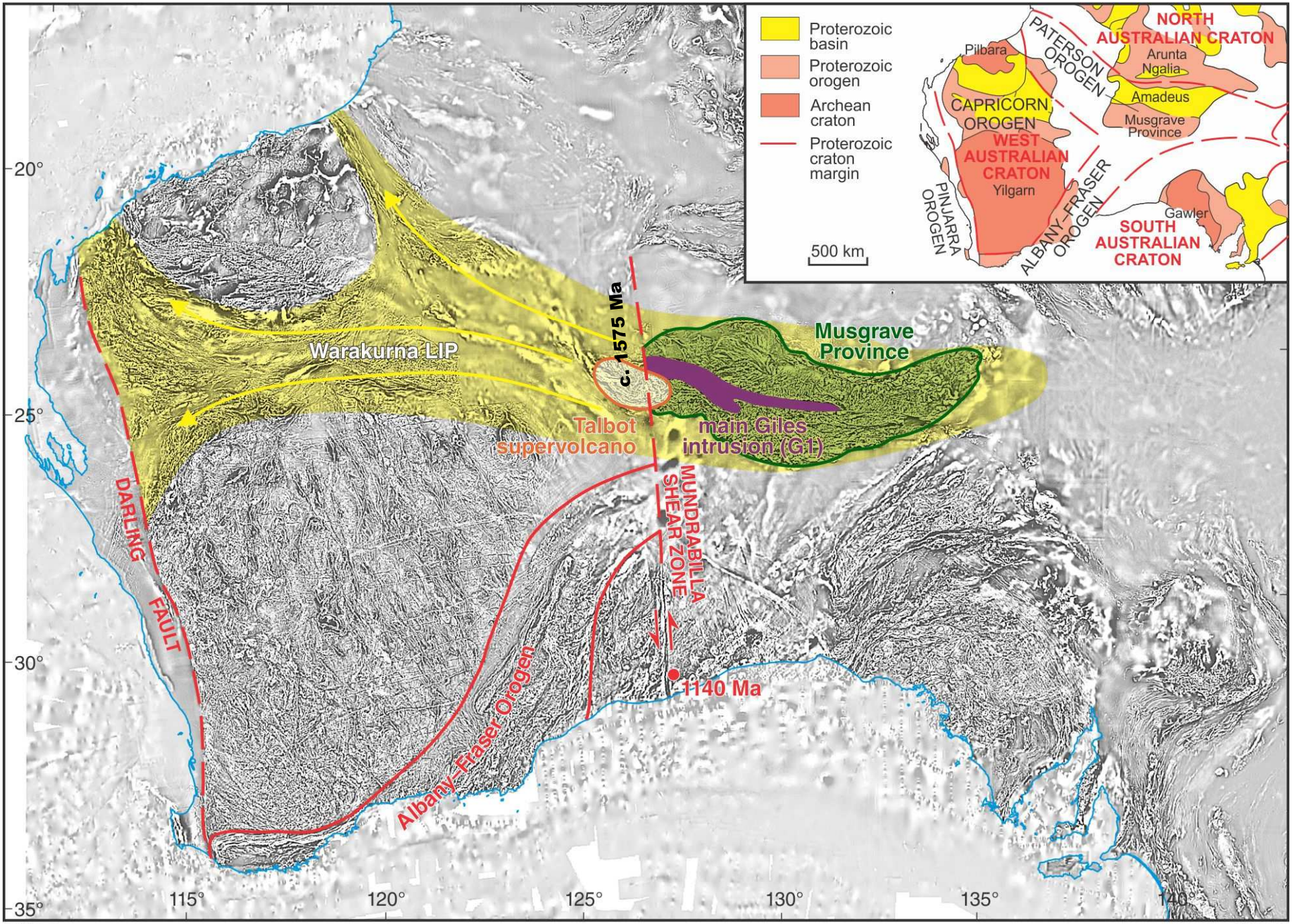
Alternative

Sinistral movement along the Mundrabilla Shear Zone ?




----->1070 Ma ---
c. 1140 Ma

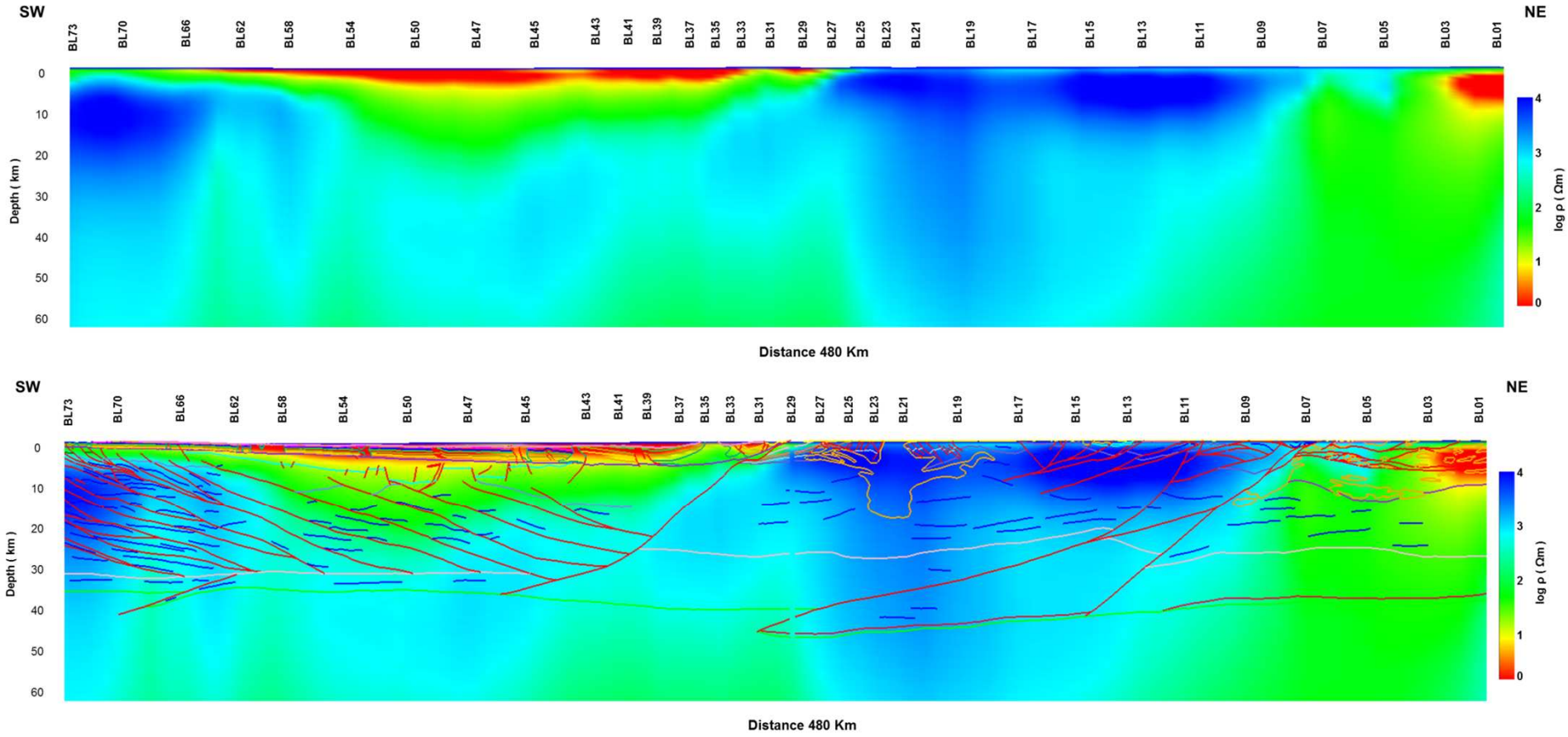

c. 1575 Ma
Aeromagnetically anomalous window of c. 1575 Ma crust
25°
26°
Wannarn
c. 1575 Ma
Jameson
Blackstone
Warburton
11GA-YO1
50 km
127°
128°
Wannarn
Jameson



RHS575

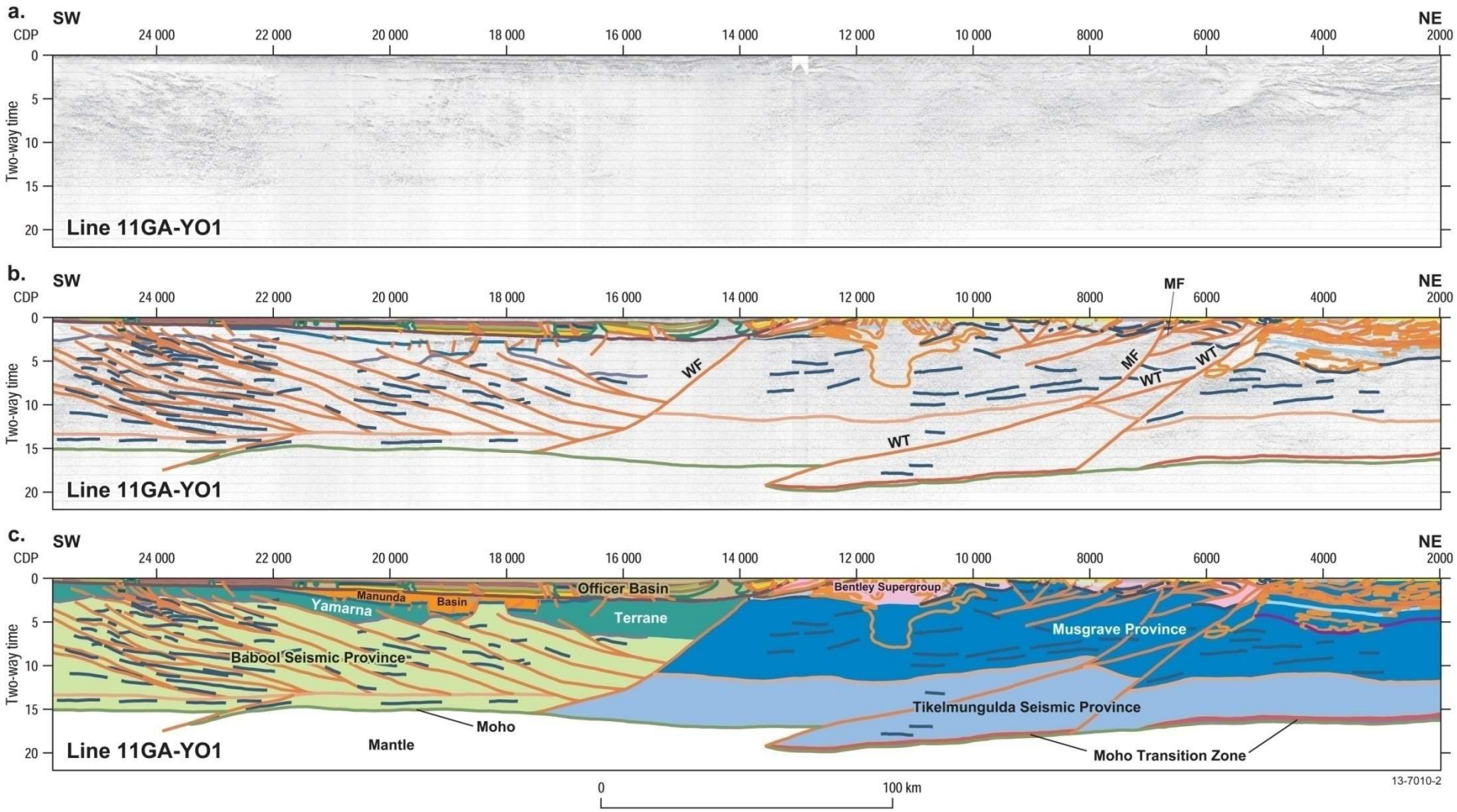
14.06.13

YOM crustal architecture – crustal provinces



Magnetotellurics confirms difference in crust between SW and NE parts
But, also shows two distinct MT regions within Musgrave Province

(Stolen from Russell)



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- *Base Wahlgu Formation*
- *Base Steptoe Formation*
- *Base Kanpa Formation*
- *Base Hussar Formation*
- *Intra Browne Formation 2*
- *Intra Browne Formation 1*
- *Base Officer Basin*
- *Salt*
- *Base Mesoproterozoic metasedimentary rocks*

Musgrave Province

- *Base Permian or Cambrian sedimentary rocks*
- *Base Mission Group*
- *Base Cassidy Group*
- *Base Pussy Cat Group*
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- *Form line*