



Government of Western Australia
Department of Mines and Petroleum

12 GA – T1 Seismic Line

What we have learnt and where to now?

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Outline



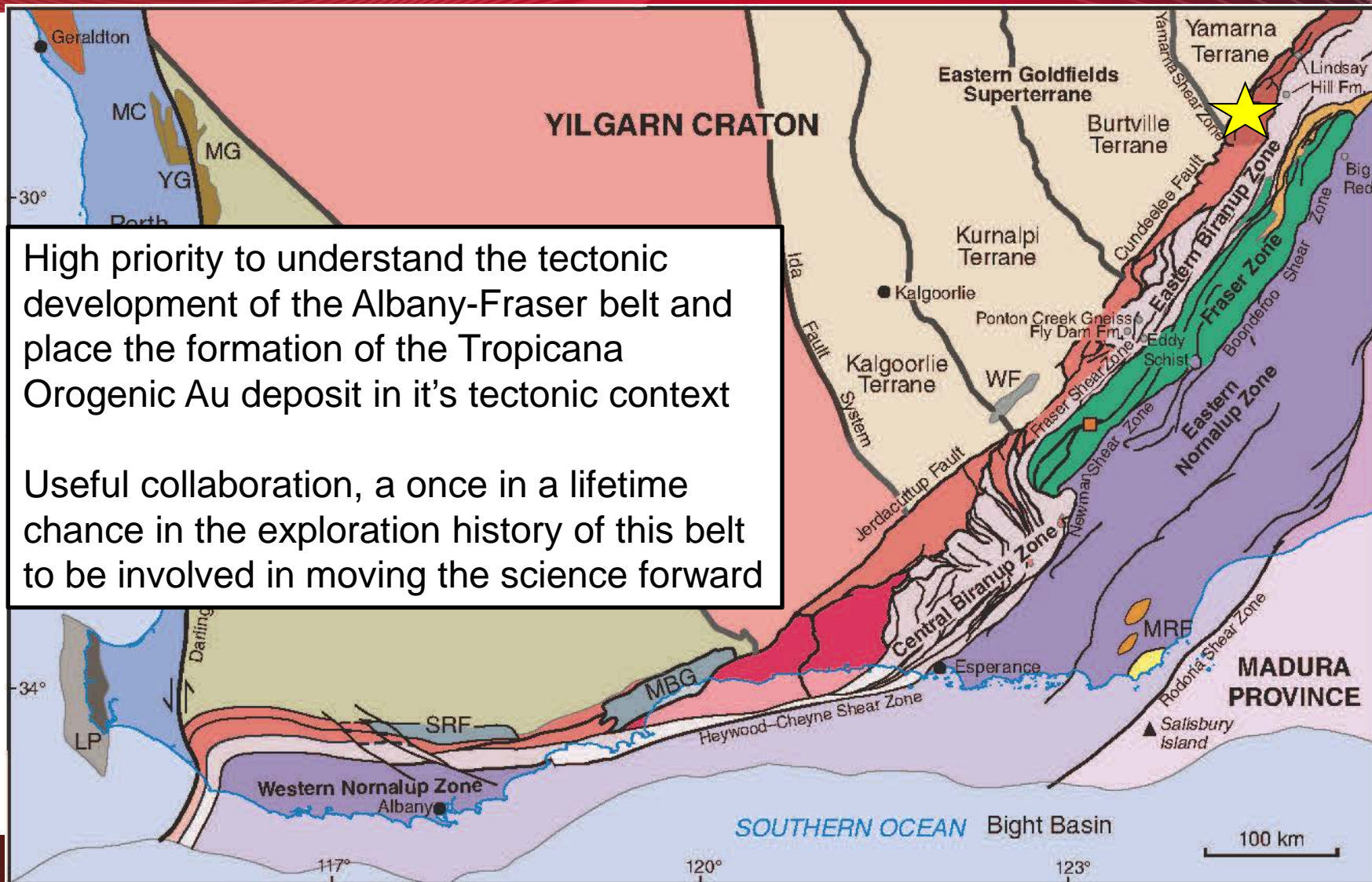
Approach:

The region is very complex with over 2 billion years of tectonic history to unravel. As such I will approach this talk using the traditional oldest to youngest timeline to help to delineate the tectonic history of the area.

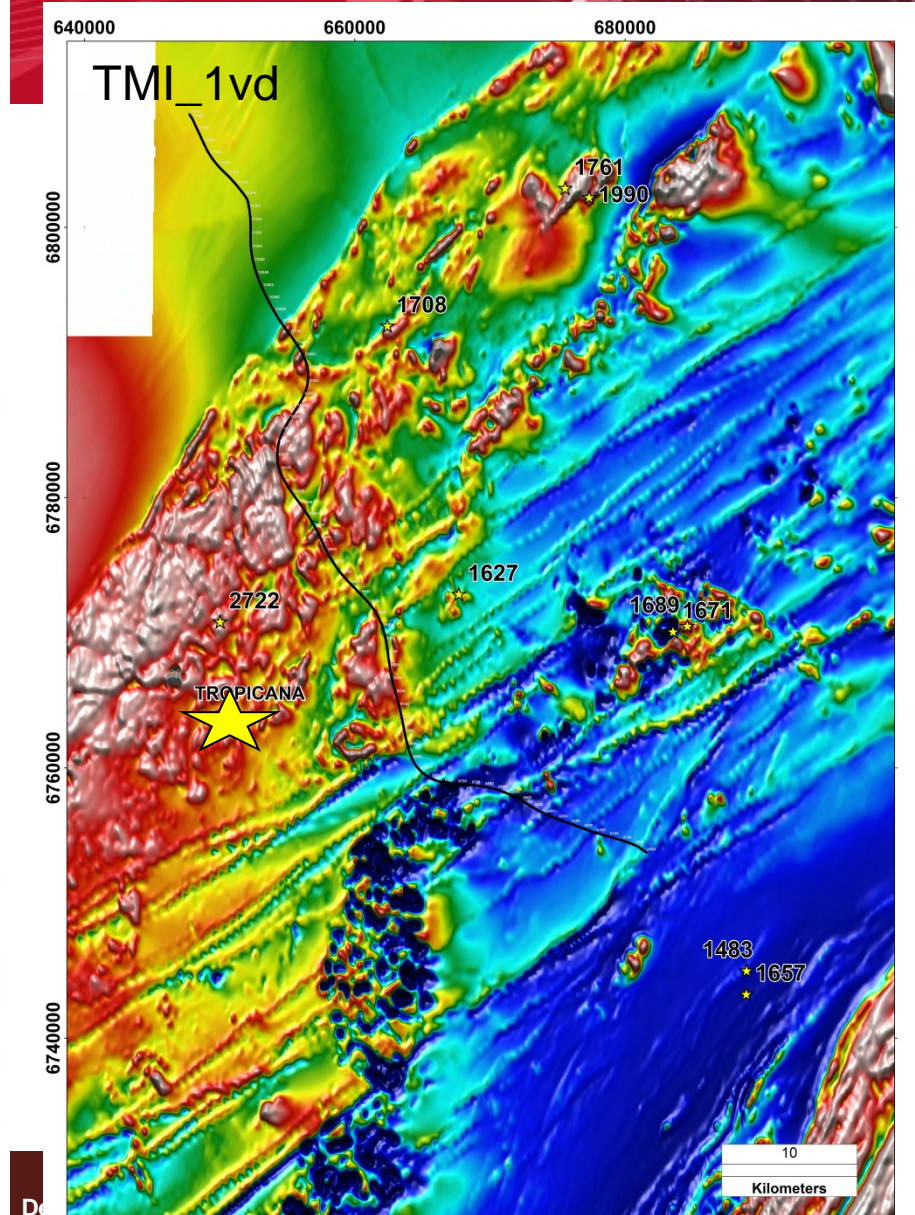
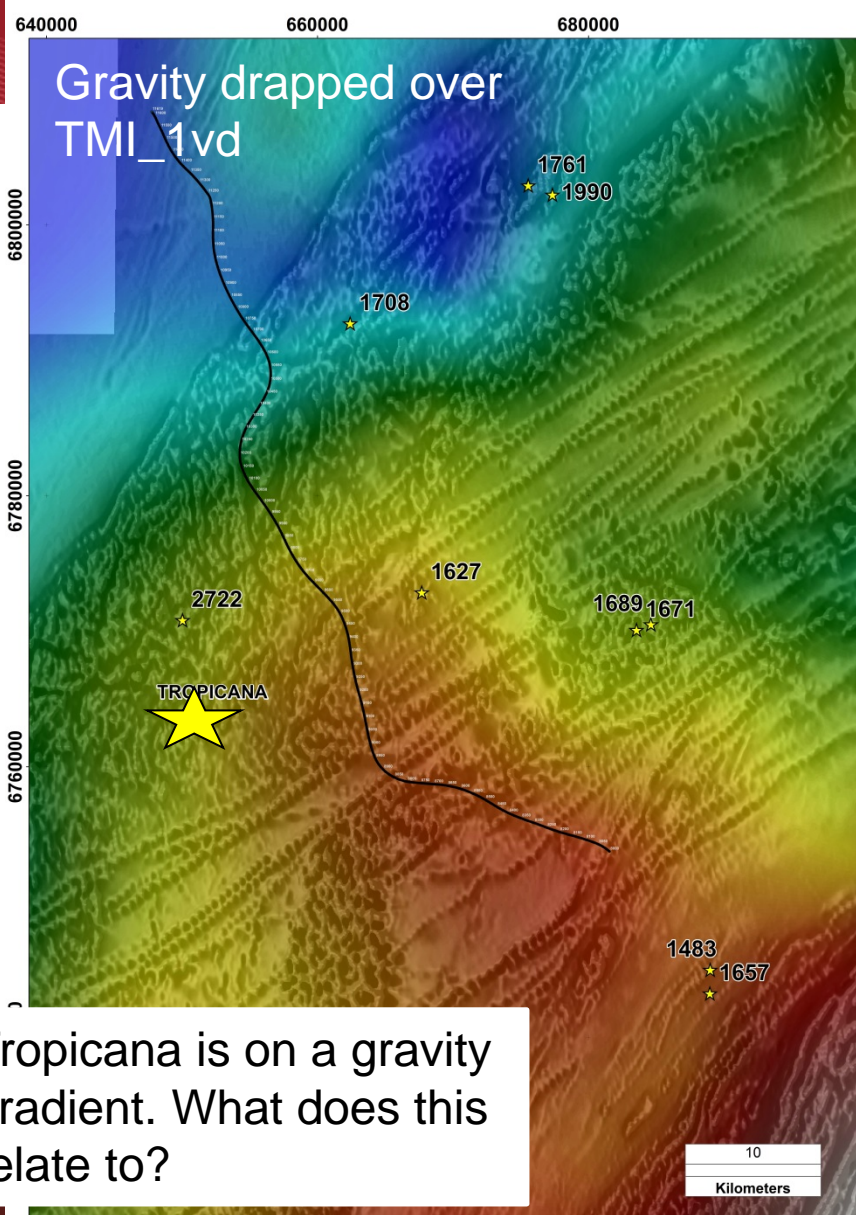
In doing so I will go through:

1. What has influenced our understanding of the region?
2. What kind of evidence do we have that there is an Archean component and influence on the zone?
3. Is the Tropicana Zone part of the Yilgarn Craton?
4. What's so special about the Tropicana Zone?
5. What happened in the Paleoproterozoic?
6. What influence did the Albany-Fraser orogenesis have on this part of the Orogen.

AngloGold Ashanti's and the Independence Group's involvement in the GA-GSWA seismic acquisition program: We wanted to improve our understanding of the region



The Tropicana Zone contains very little outcrop – so geological maps have been compiled using geophysical datasets



Tropicana is on a gravity gradient. What does this relate to?

Plate 1: Geological Interpretation map of the region

Yilgarn Craton

Gunbarrel Basin

This is largely an interpretation of 3D volumes of magnetic data with some field observations, geochemistry, and geochronology

Tropicana Zone

Tropicana gold mine

Tropicana Gneiss

Hercules Gneiss

Hercules

Atlantis

Black Dragon Gneiss

Biranup Zone

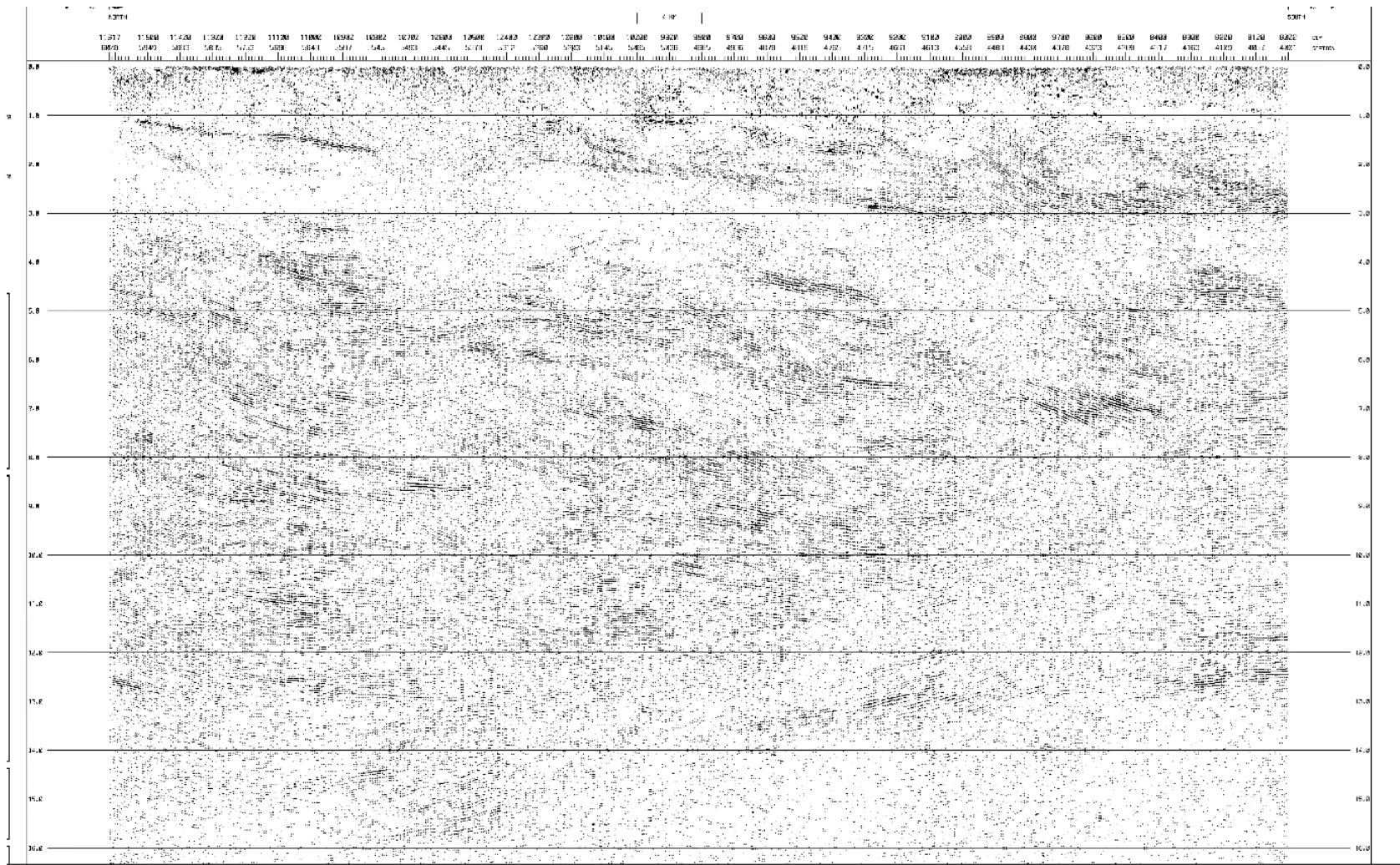
Gwynne Creek Gneiss

Fraser Zone

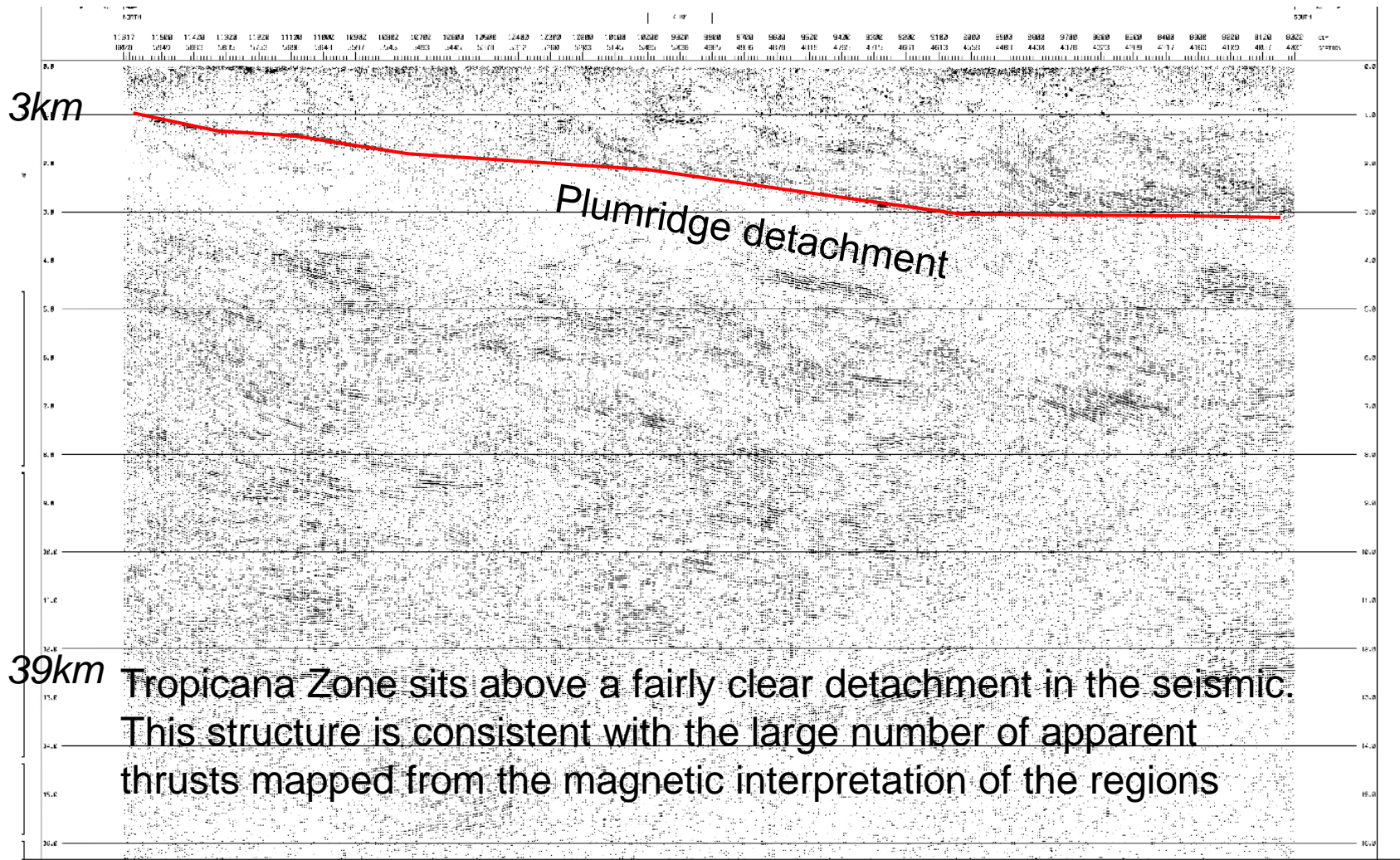
Nornalup Zone

Spaggiari, 2014

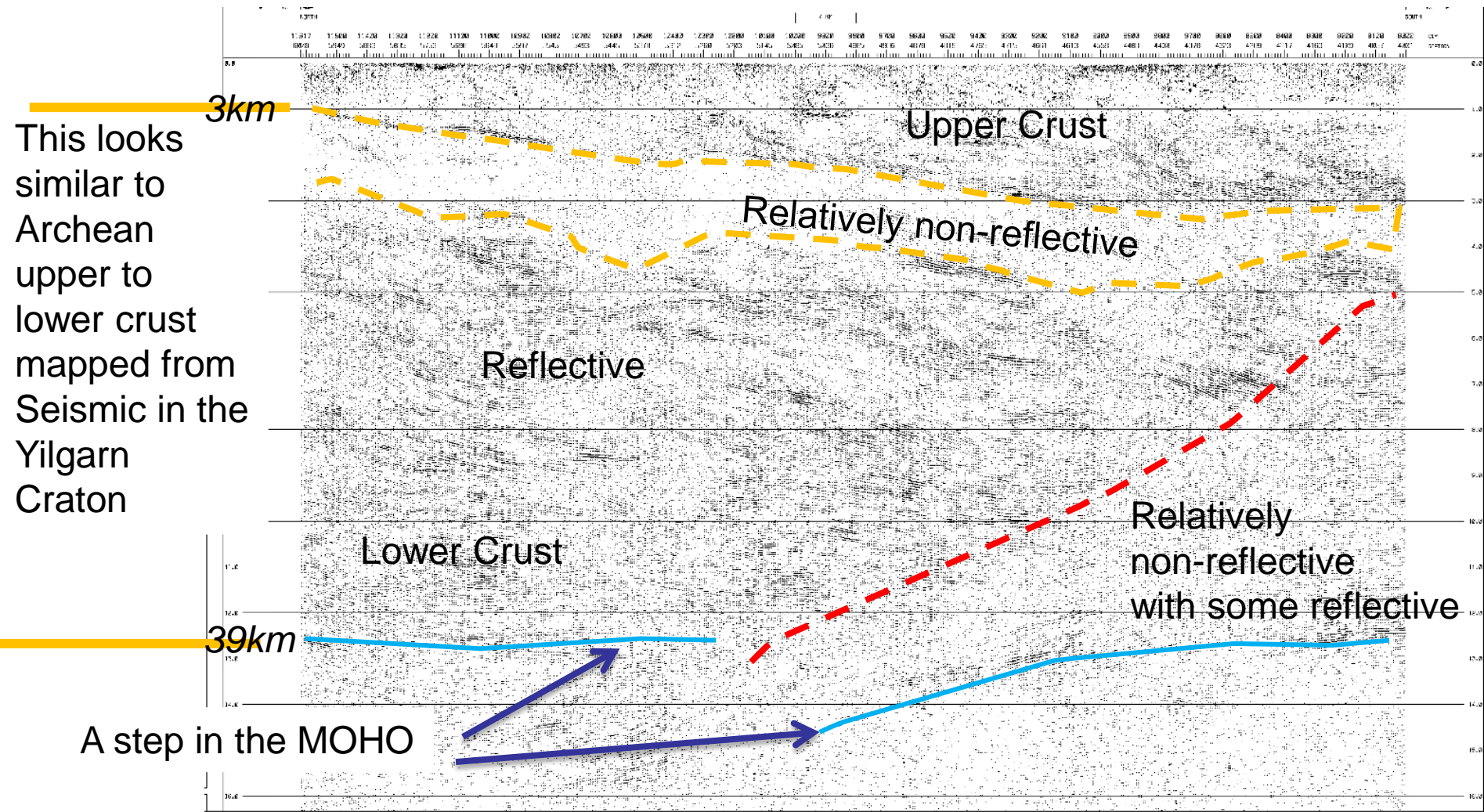
Seismic Line 12GA-T1 what does it show us?



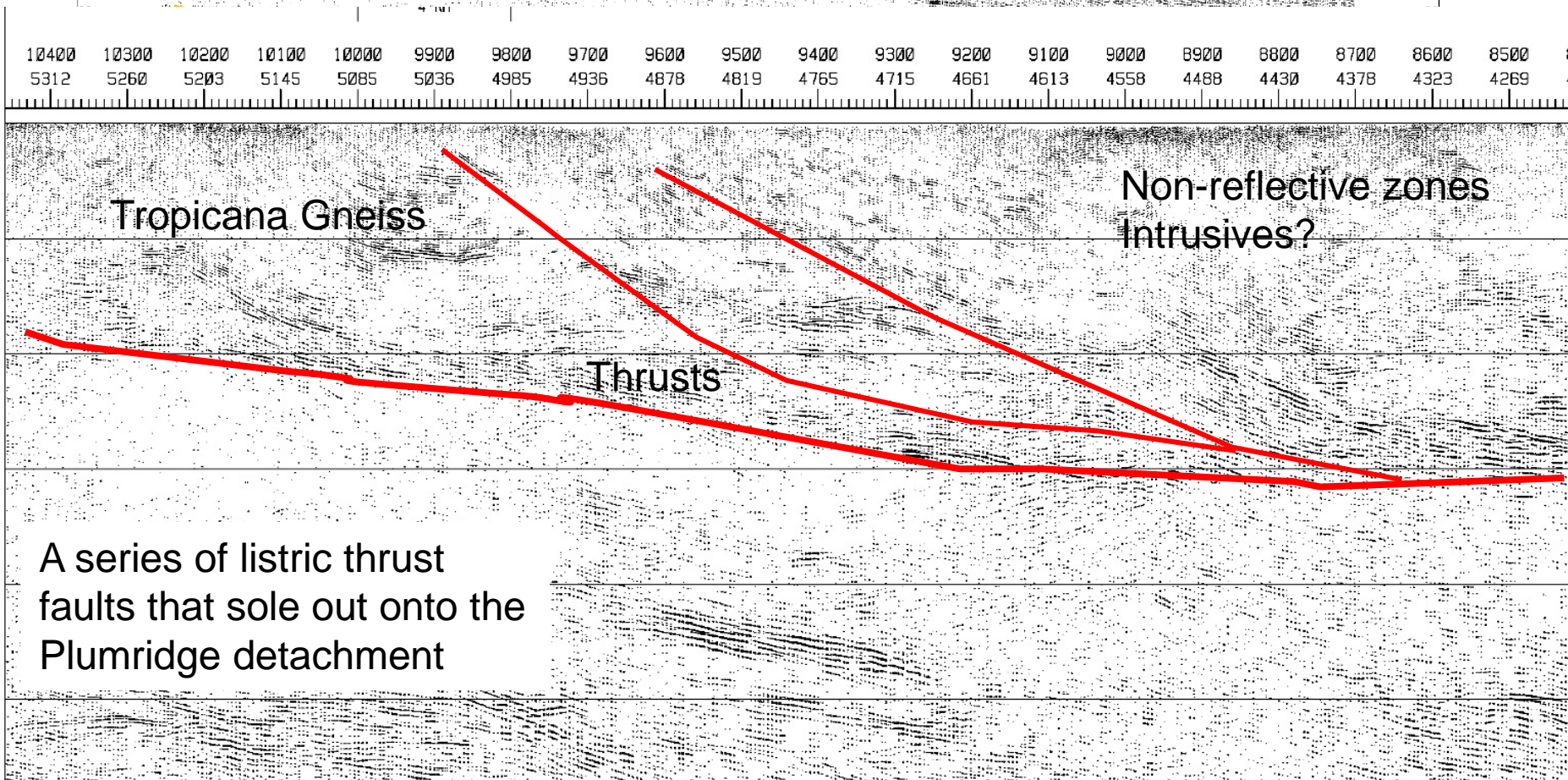
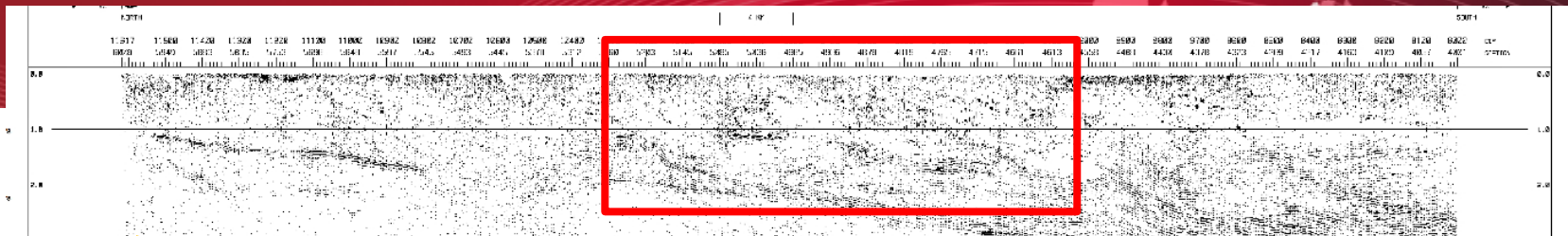
Seismic Line 12GA-T1Plumridge detachment



Seismic Line 12GA-T1Plumridge detachment – What's below it?



12GA-T1Above the Plumridge detachment



Northwest

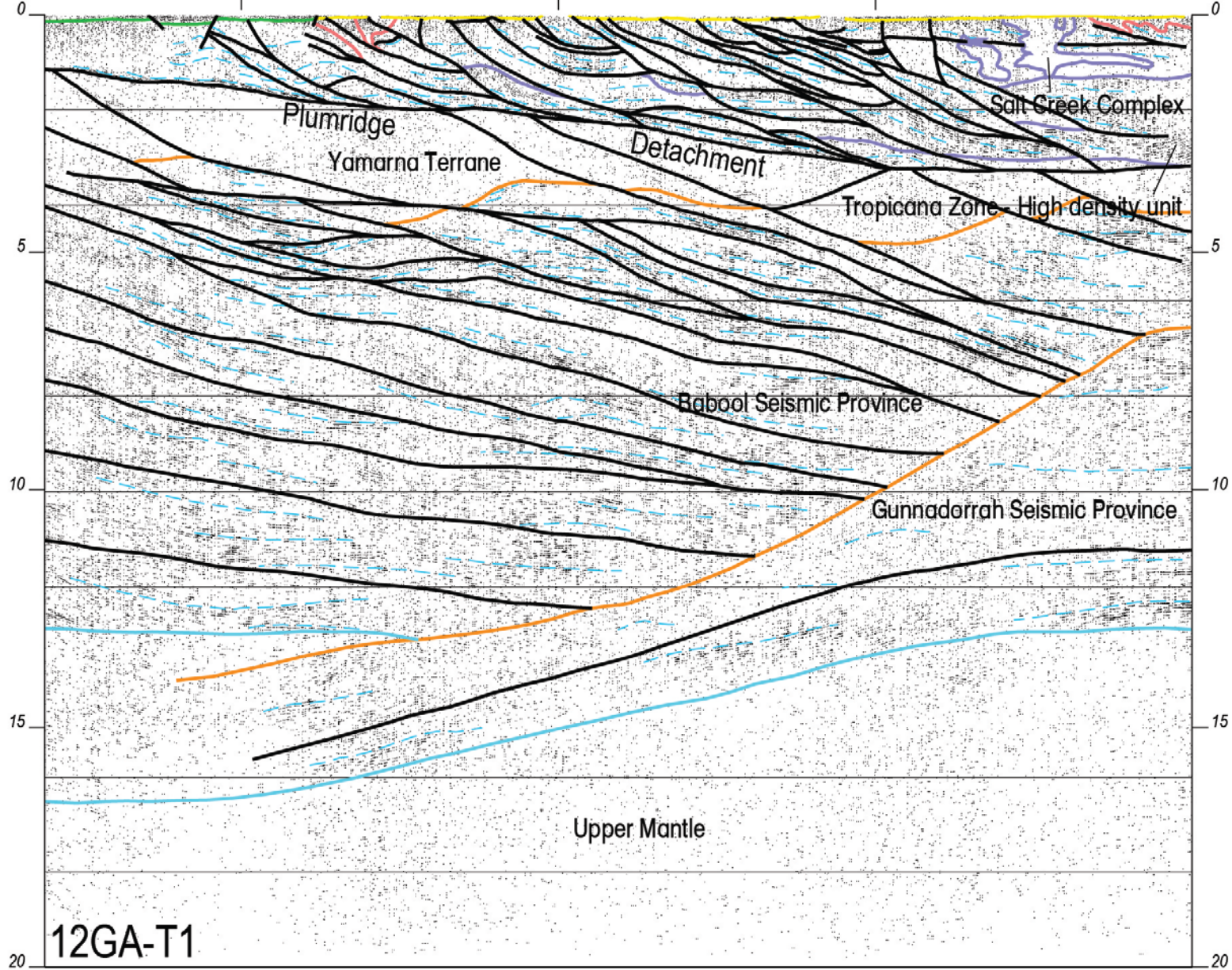
Southeast

CDP

11000

10000

9000



Two-way travel time (seconds)

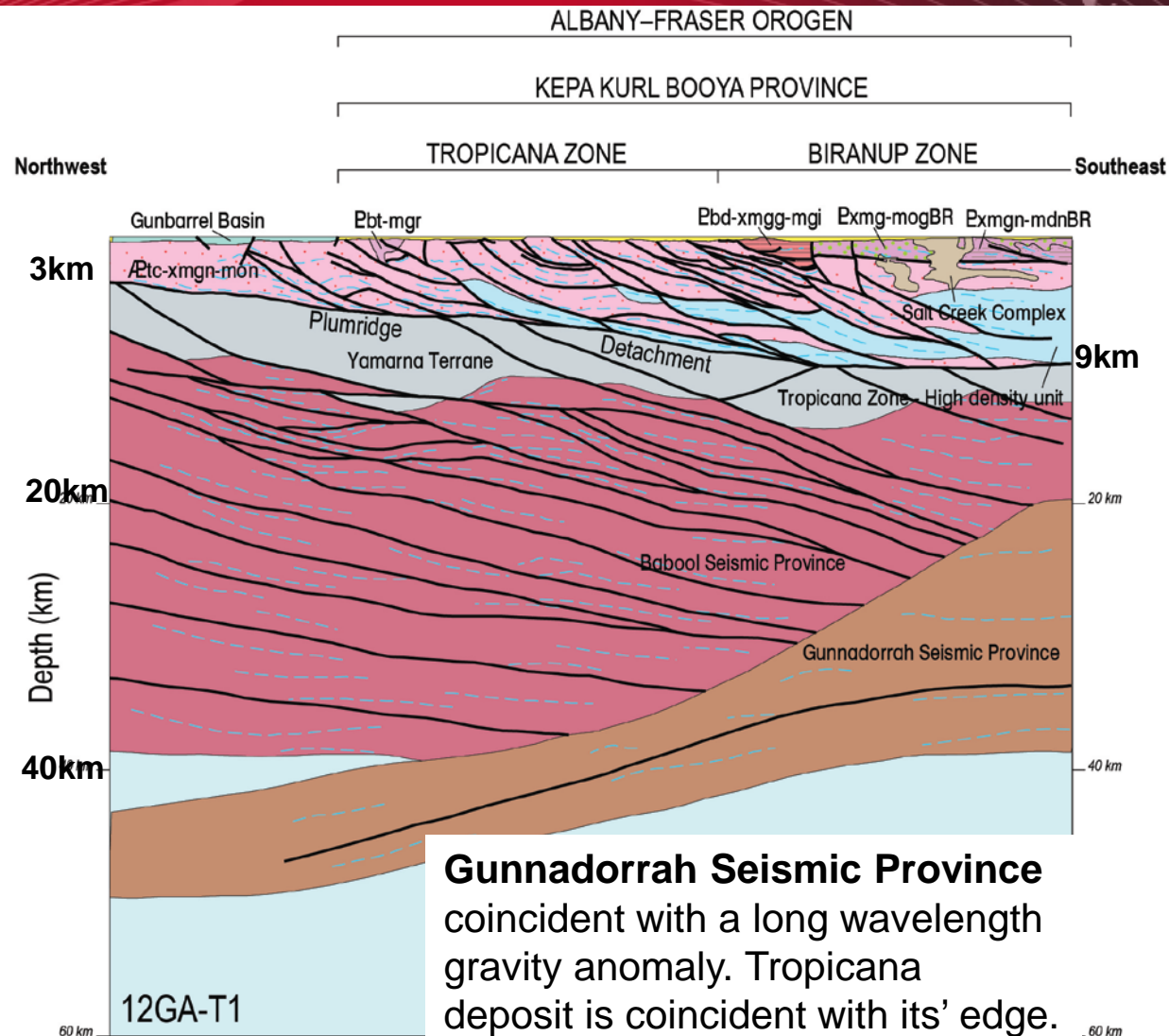


Seismic Line 12GA-T1

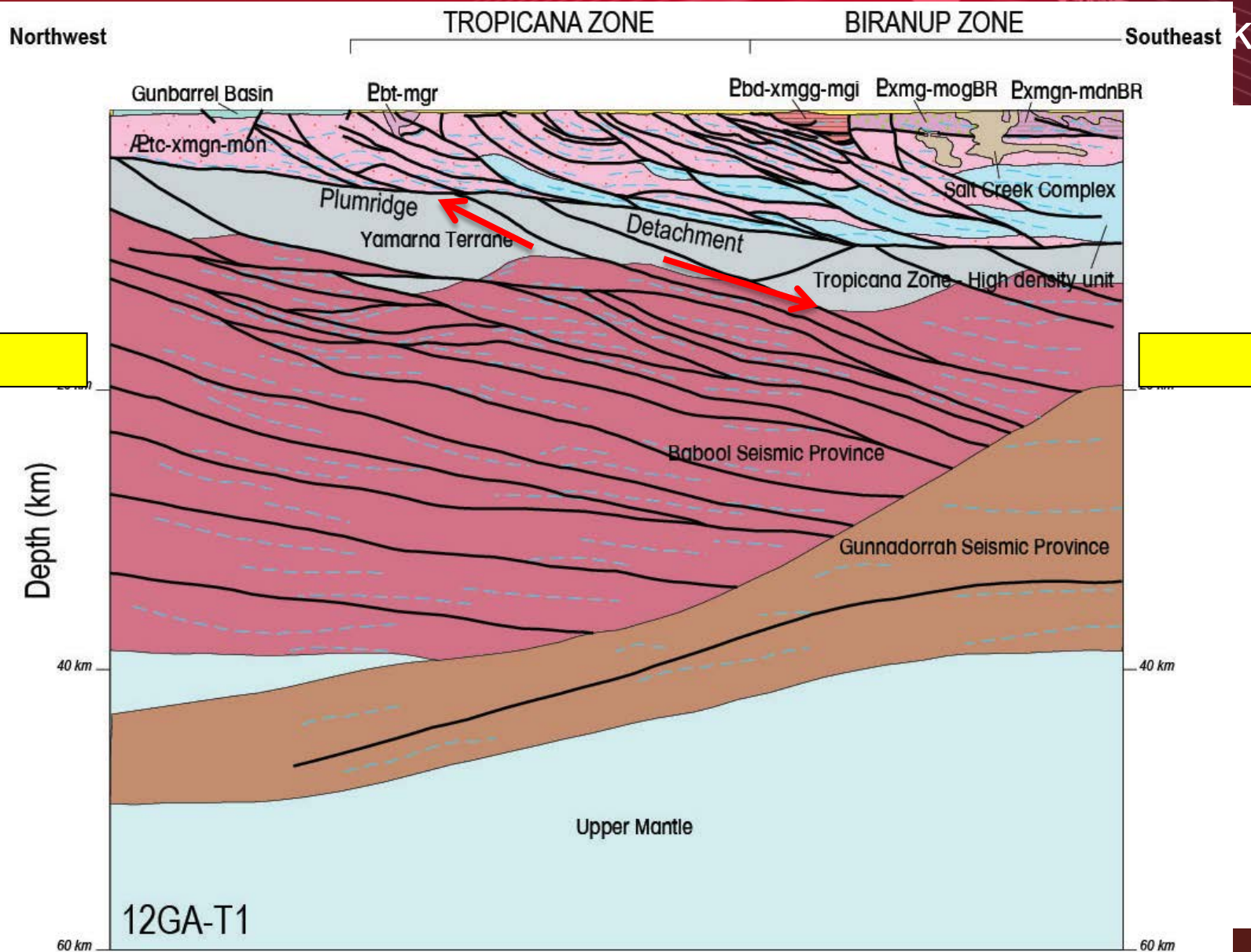
A cross-section through the Tropicana Zone

The Tropicana Zone is:

- One of the domains within the Kepa Kurl Booya Province, that is defined as 'the crystalline basement of the Albany-Fraser Orogen'
- In faulted/sheared contact with the underlying Yamarna Terrane
- Unconformably overlain by Proterozoic siliciclastic rocks
- Intruded by Proterozoic granitic and mafic igneous rocks
- Overlain by the 320 – 270Ma Gunbarrel Basin



Extended Yilgarn (Yamarna Terrane)



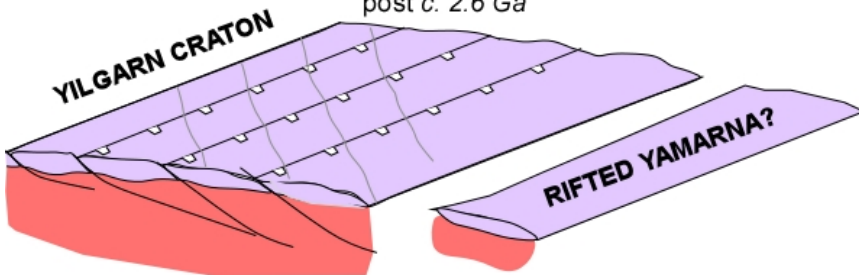
The region's formation through time: Yamarna Terrane and Babool Province

Neo-Archean

Westerly

Upper crust
Yamarna Terrane
post c. 2.6 Ga

Easterly

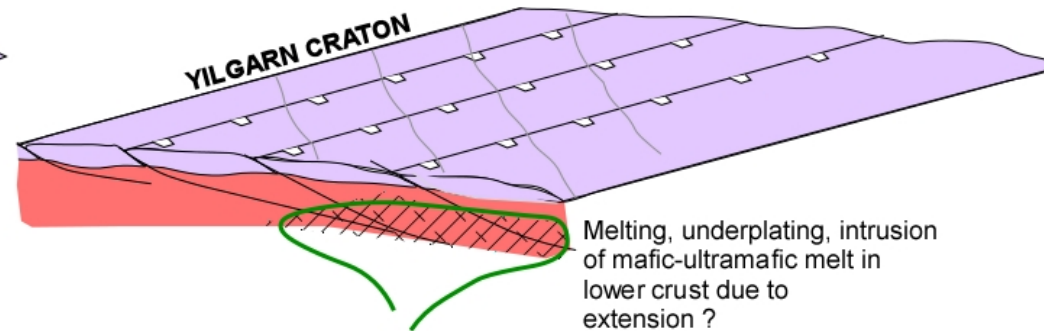


OR

Westerly

Upper crust
Yamarna Terrane
post c. 2.6 Ga

Easterly



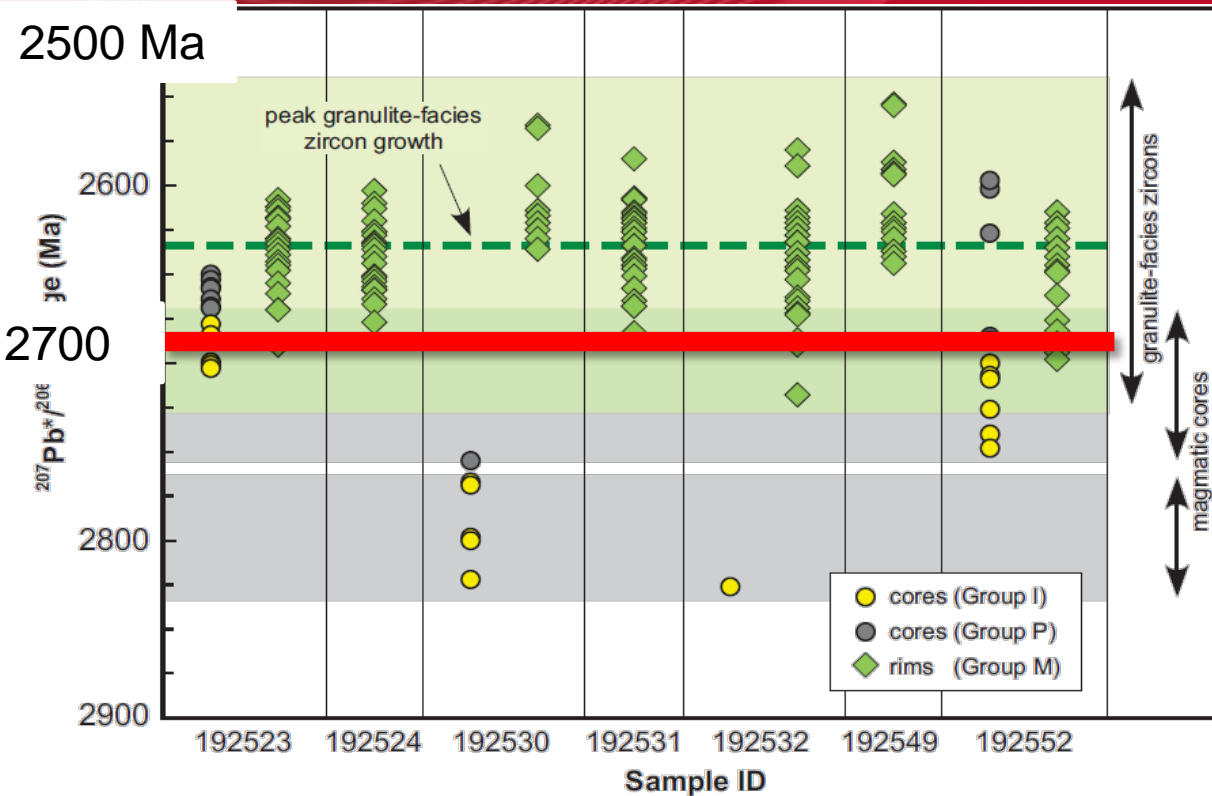
Melting, underplating, intrusion
of mafic-ultramafic melt in
lower crust due to
extension ?

***Yamarna Terrane** is the eastern most terrane of the Eastern Goldfields. It is poorly studied due to lack of outcrop and Permian cover.*

Extensional shears are present in the Yamarna Terrane, beneath the Tropicana Zone so:

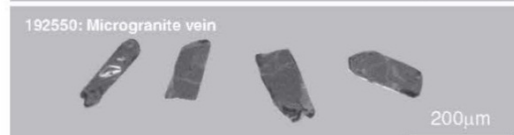
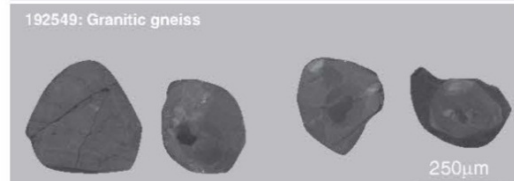
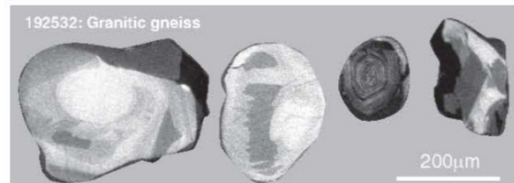
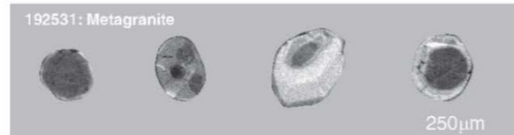
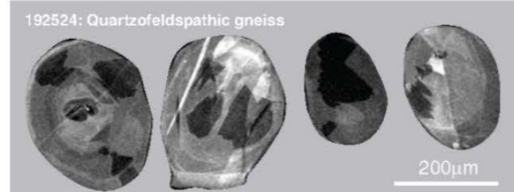
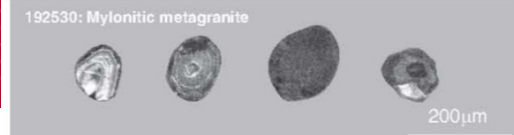
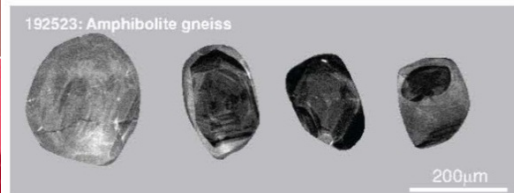
1. **Rifting** of the Yamarna Terrane **around c. 2.6 Ga** (after cratonisation of the Yilgarn) but **before c. 2.5 Ga**
2. Formation of **Gunnadorrah Seismic Province** – it could be **reworked Yilgarn Craton material** (addition of mafic/ultramafic magma leading to higher density domain?)

In the Tropicana Zone protoliths are NeoArchean but lower crustal rocks remained in the lower crust for 100 m.y. – Hercules Gneiss



Protoliths to granite gneisses are dated around c. 2700 Ma (in this example).

Rounded 'football-style' grains form under granulite facies Conditions (c. 2690 to 2560 Ma). These are metamorphic zircons (Kirkland, 2014)



But how about the Tropicana Zone – how did the Archean rocks form and where? Hercules Gneiss

Luckily clues are held in the rocks and a little forensic geochemistry and geochronology is putting helping to solve the mystery.

Geochemistry:

Granitic rocks in the region have been found to include – Sanukitoids

Sanukitoids – cousins to the TTG family:

- Form by re-melting of mantle peridotite previously metasomatised via the addition of slab melts
- Dioritic rocks containing high MgO, high Cr, high Ni, and high large-iron lithophile elements (LILE)
- Only formed in the Archean

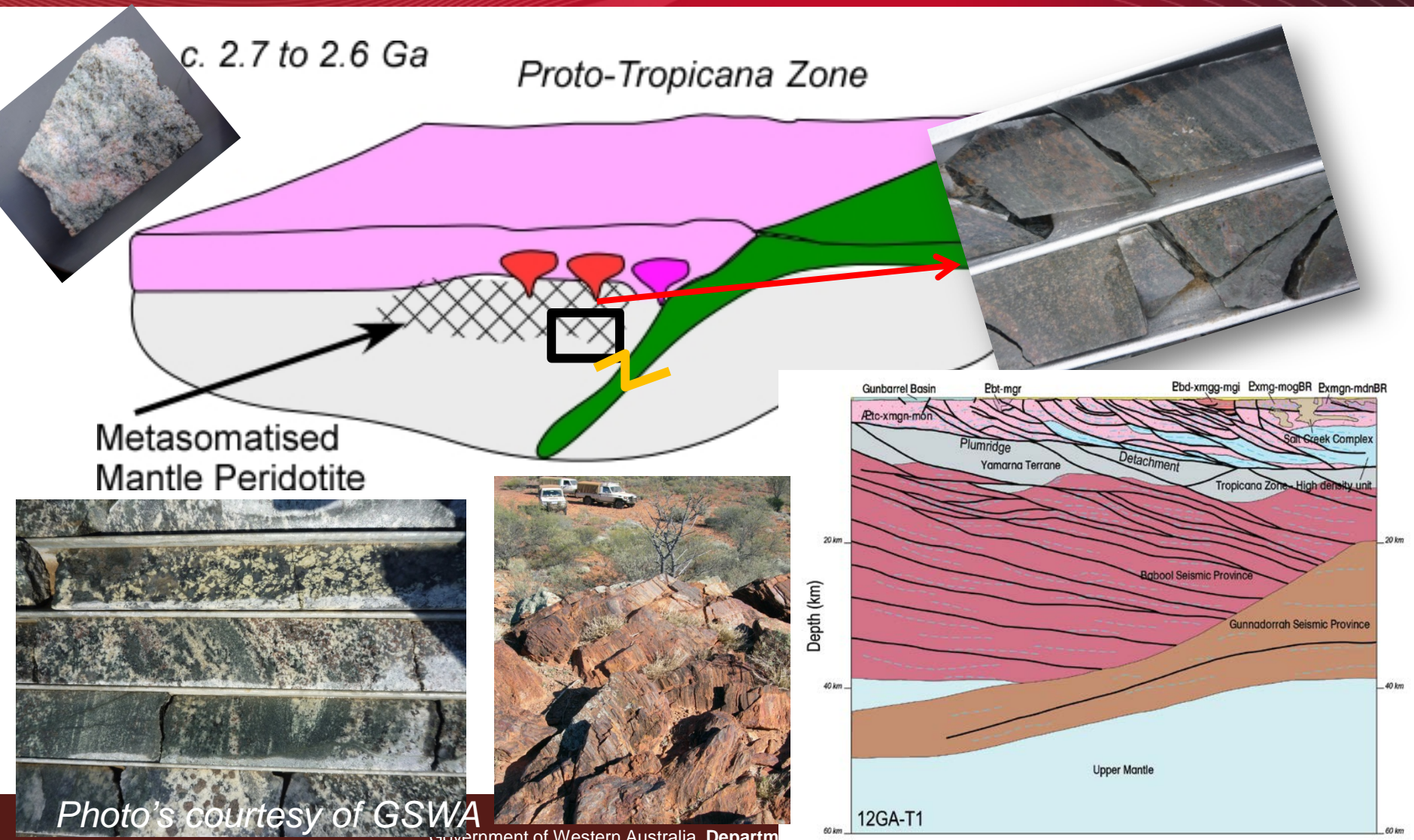
Sanukitoids are rare and are vectors to fossil subduction zones

(Smithies, 2014)



From Kirkland,
2014

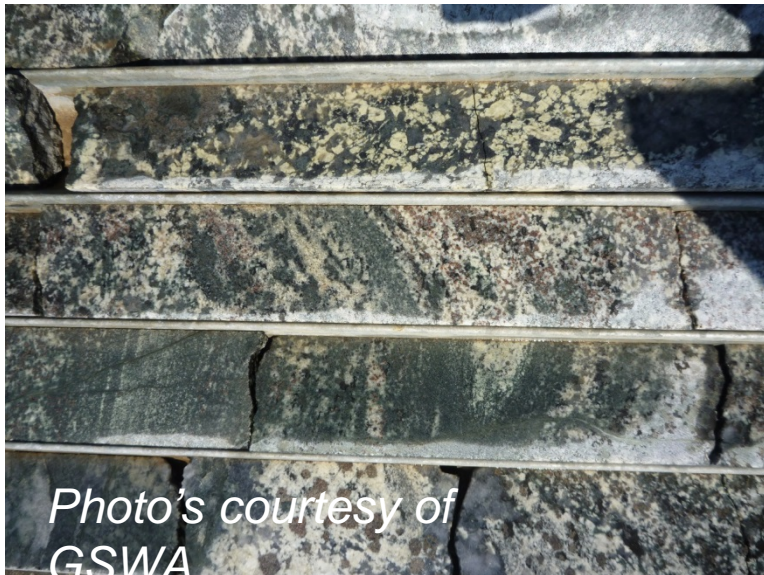
But how about the Tropicana Zone – how did the Archean rocks form and where?



Medium to high-grade metamorphism recorded in the rocks

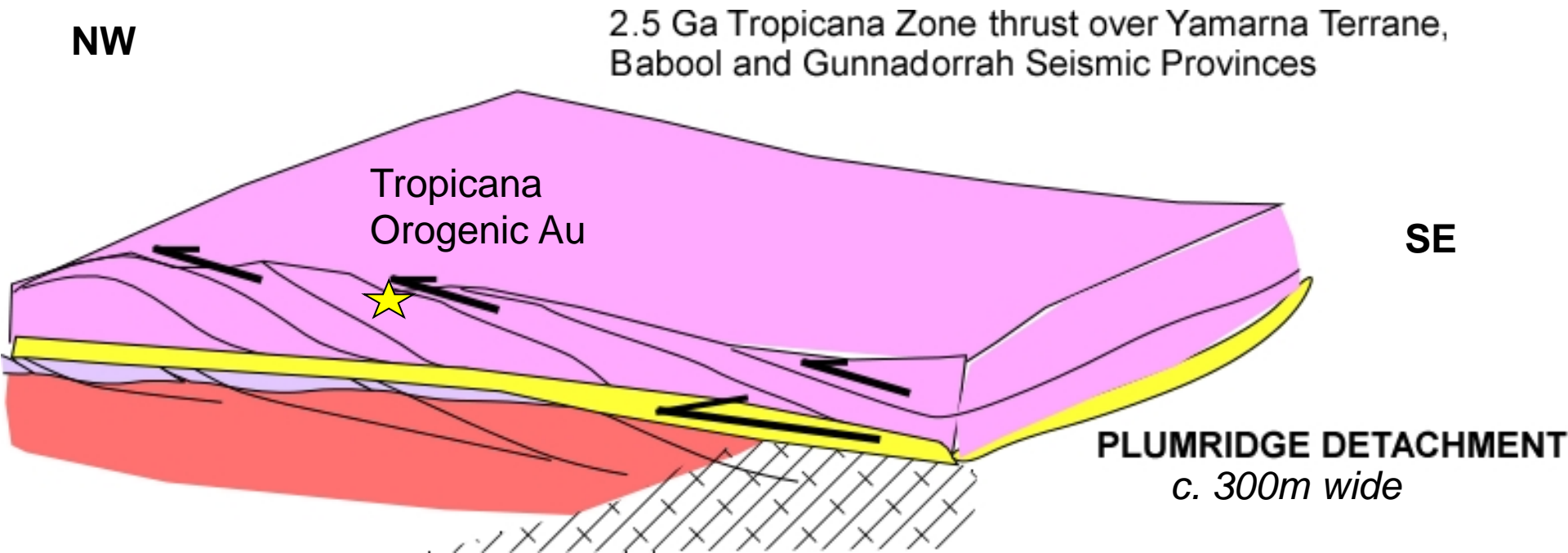
Summary:

- *Protoliths to the Tropicana and Hercules gneisses are dated around 2.7 Ga.*
- *100 Ma of time in the lower crust – up to granulite facies*
- *Gneisses are tectonically interleaved (eg. BIF and orthogneiss)*



*Photo's courtesy of
GSWA*

Gold mineralisation at Tropicana took place at c. 2.5 Ga – *how?*



Gunnadorrah Seismic Province underthrust the Babool Seismic Province during this convergence

K-metasomatism
Uplift to greenschist facies
Gold mineralisation
(pyrite+biotite)

Gold mineralisation at Tropicana – c. 2500 Ma

NW

2.5 Ga Tropicana Zone thrust over Yamarna Terrane,
Babool and Gunnadorrah Seismic Provinces

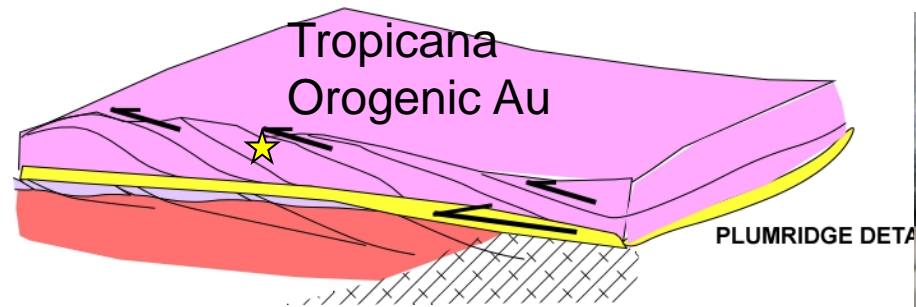


Photo courtesy of B. Hobbs

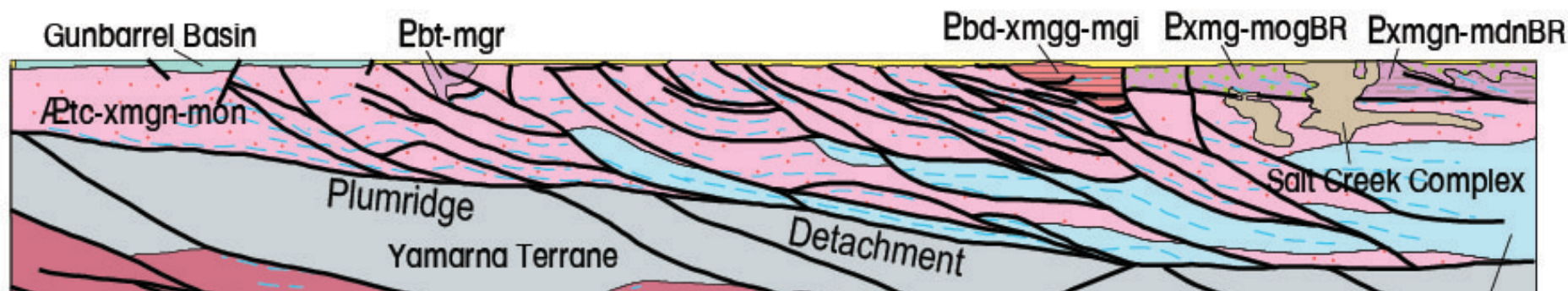
K metasomatism during...
uplift to greenschist facies

Gold mineralisation (pyrite+biotite)

Archean summary



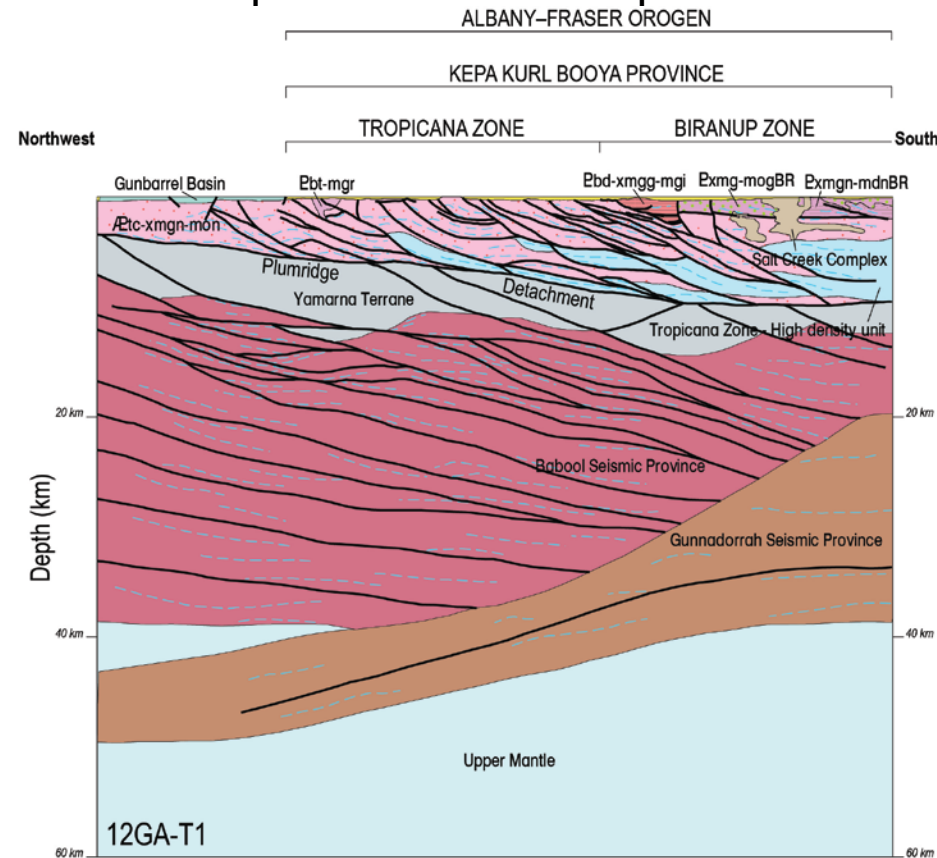
- The Hercules and Tropicana gneisses have been dated as Neoproterozoic
- They contain Neoproterozoic TTG's and Sanukitoids
- High-grade granulite and amphibolite facies metamorphism illustrate the Tropicana Zone formed in the middle to lower crust. The *age data* suggest that they could be deep crustal equivalents of Yilgarn Craton components...but they are para-autochthonous (they moved upstairs and from a long way outboard.....)
- Exhumation from the the mid to lower crust to greenschist facies, was locally concomitant with the gold mineralisation at c. 2500 Ma
- Thinning of the Tropicana Zone from southeast to northwest is consistent with thrusting along the Plumridge Detachment



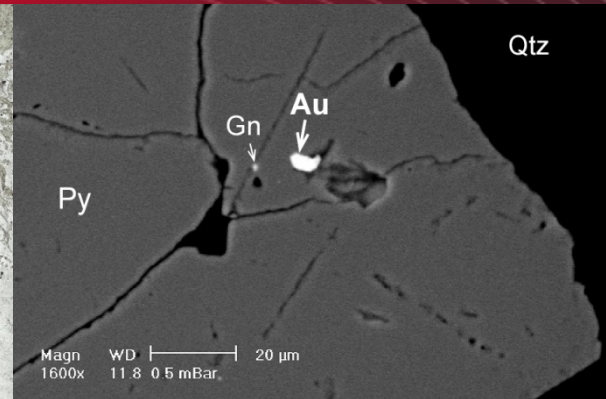
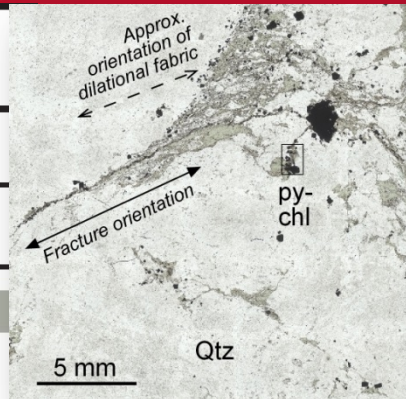
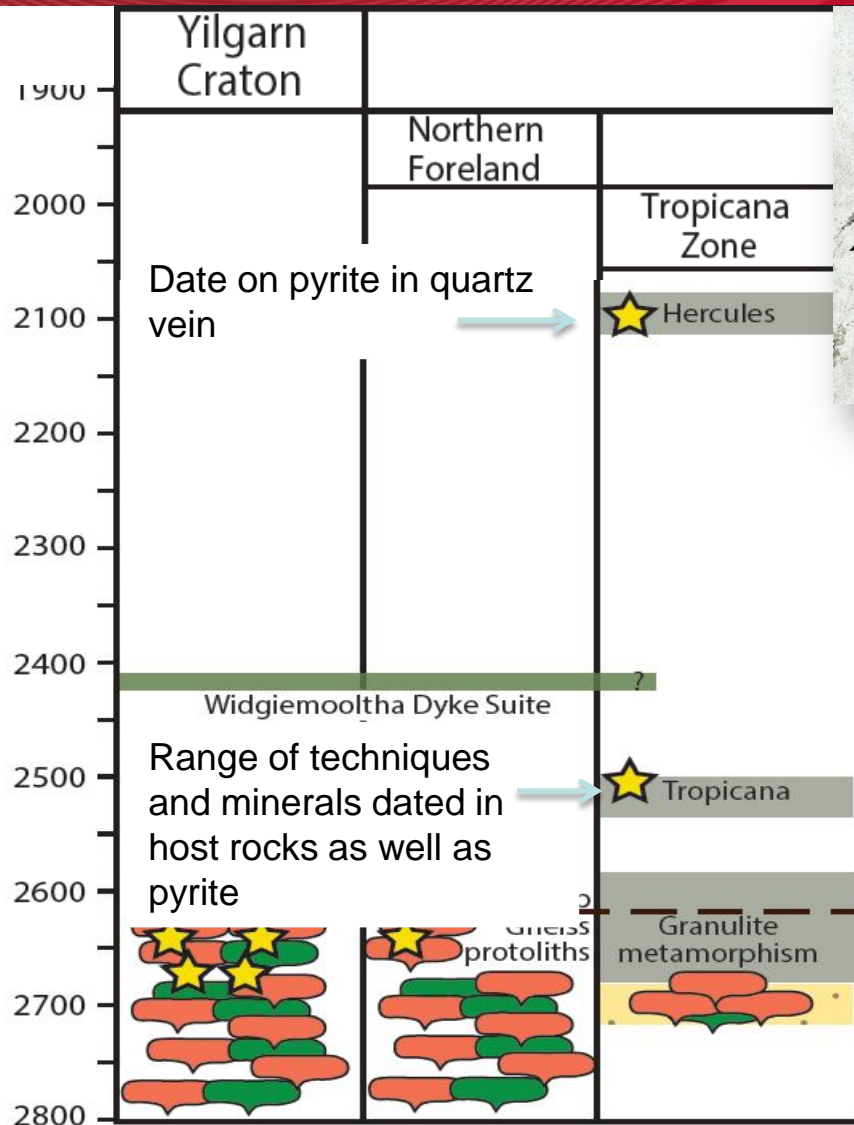
Paleoproterozoic History



- A hiatus of c. 400 Ma between the known c. 2500 Ma event and anything that can be recorded from the Paleoproterozoic
- There is a long Paleoproterozoic history within the Tropicana and Biranup Zones of the Kupa Kurl Booya Province
- What happened in the Paleoproterozoic?



2.1 Ga gold mineralisation dated at Hercules....



An age of c. 2.1 Ga from Re-Os dating of pyrite that is associated with gold mineralisation

Pyrite dated from within quartz vein. Disseminated pyrite in host rock not dated

Archean sanukitoid magmas may be a source of gold in the quartz vein

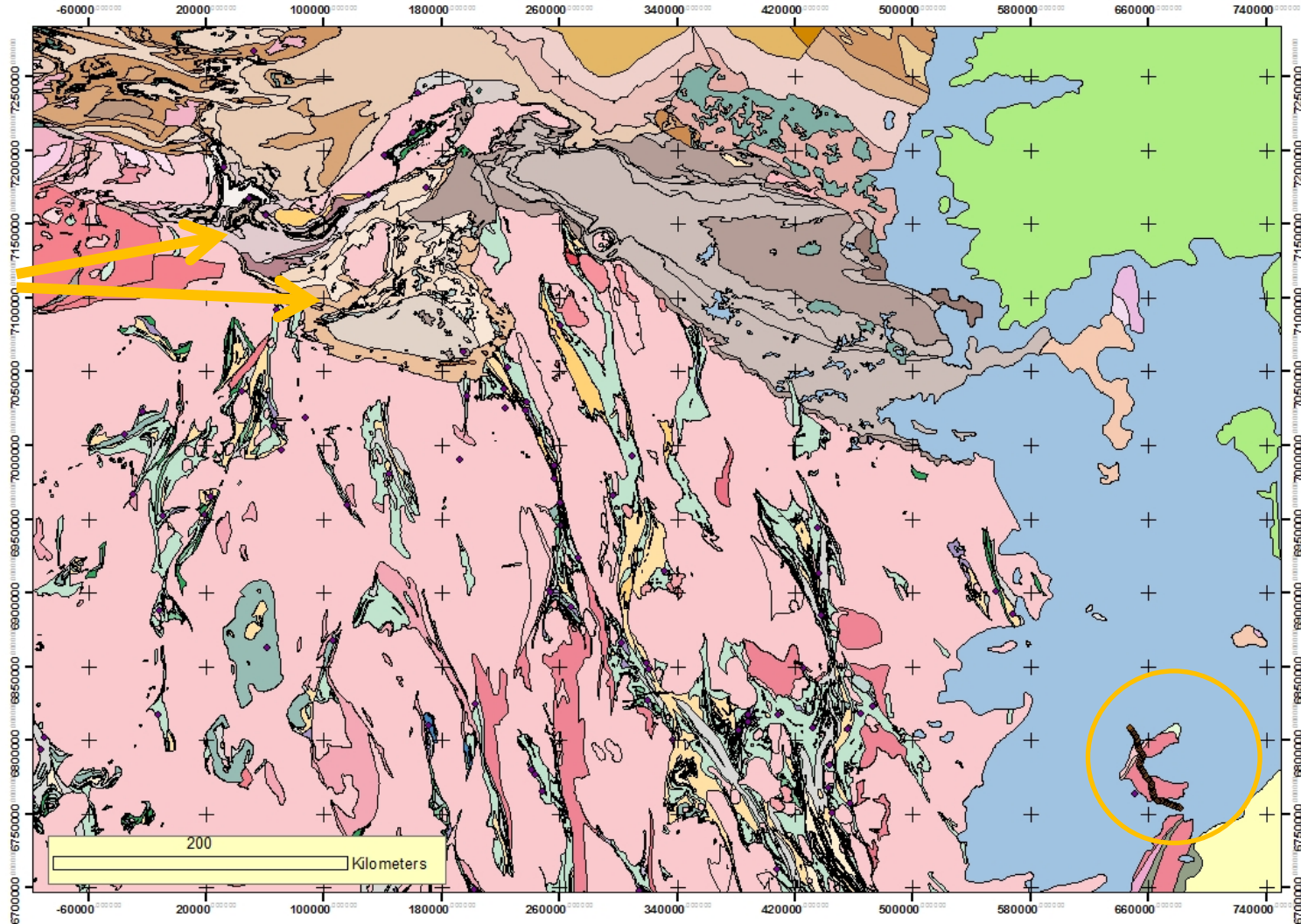
Sweetapple, M (CSIRO)

What is the 2.1 Ga event related to?



Sedimentary and volcano-sedimentary basins in the Capricorn Orogen could overlap in age

Extensional processes ?

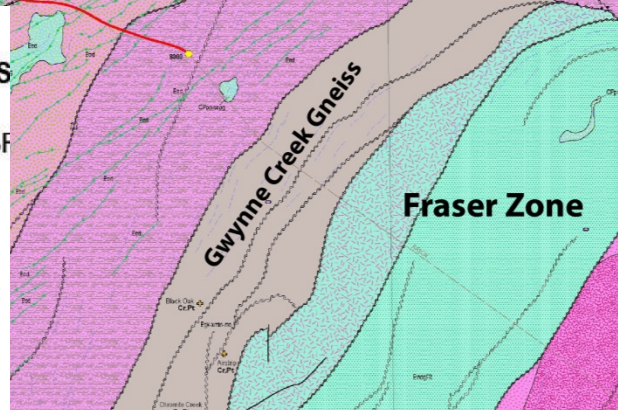
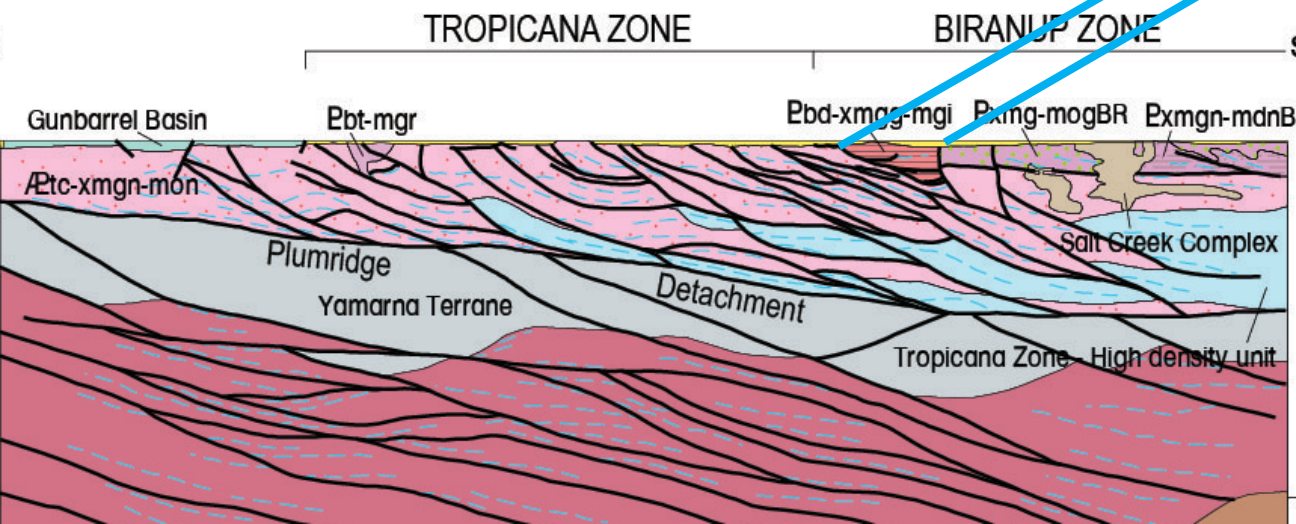
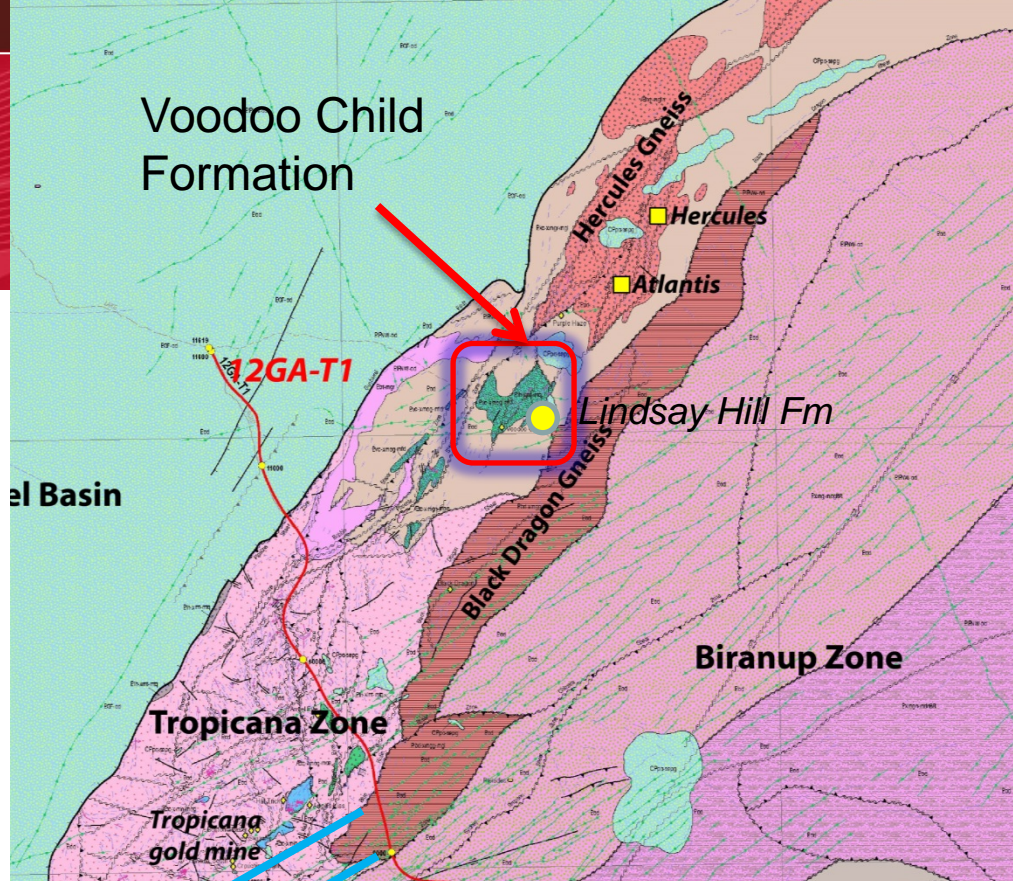


Black Dragon Gneiss: c. 1800 Ma

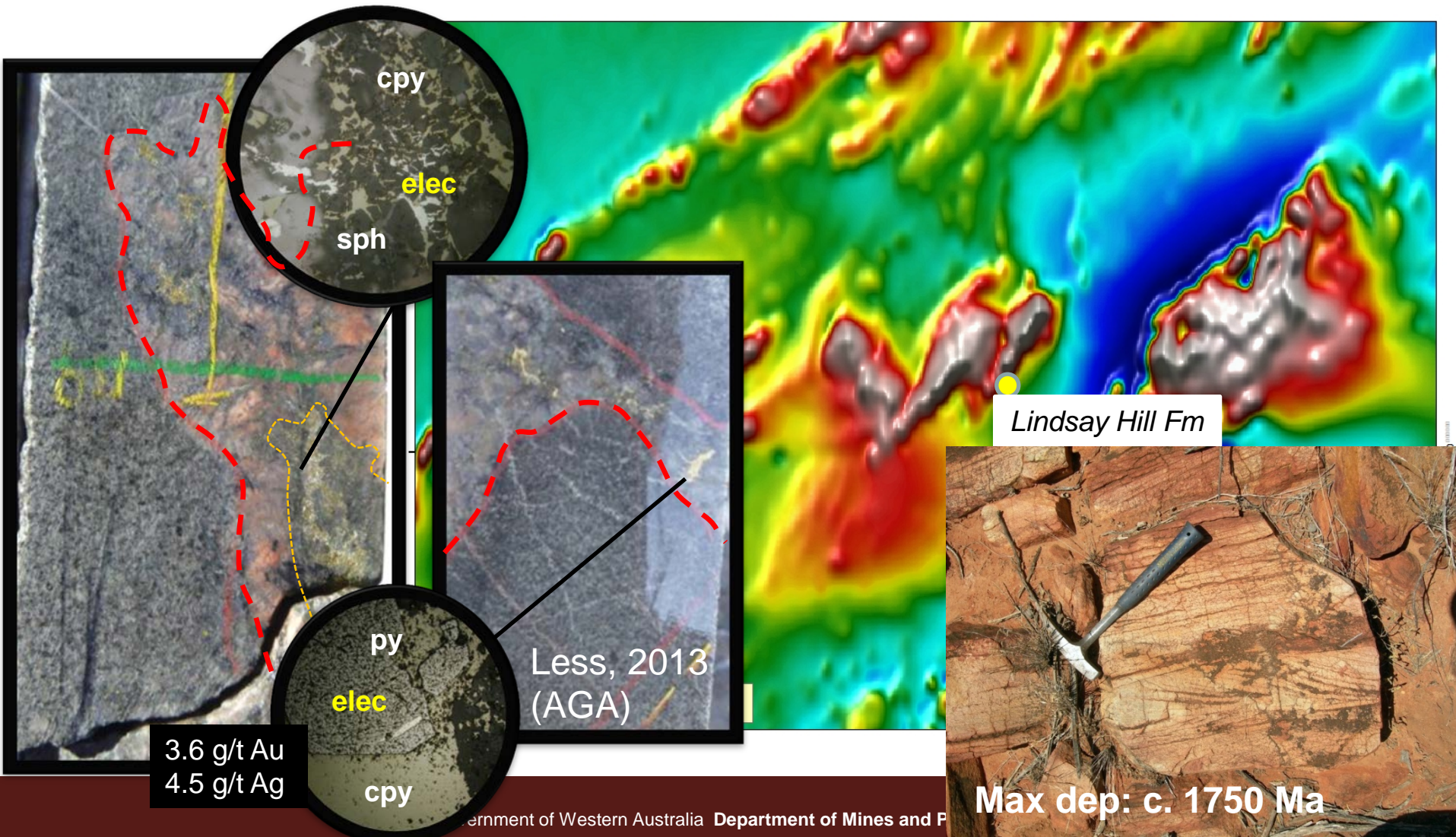
SALMON GUMS EVENT:

Granodiorite, quartz diorite, and diorite from the Black Dragon Gneiss

Above and below the Blue Robin Shear Zone) dated at c. 1800 Ma (Blenkinsop and Doyle, 2014)



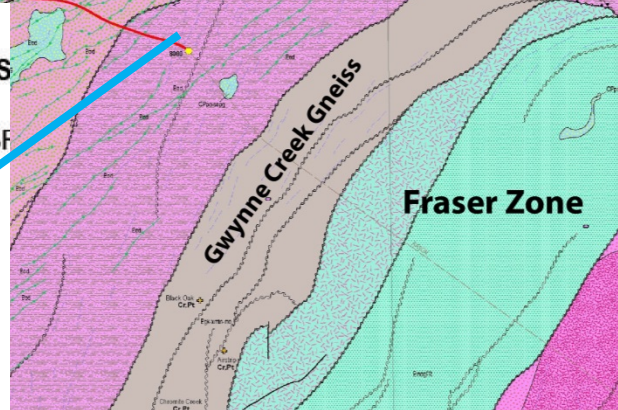
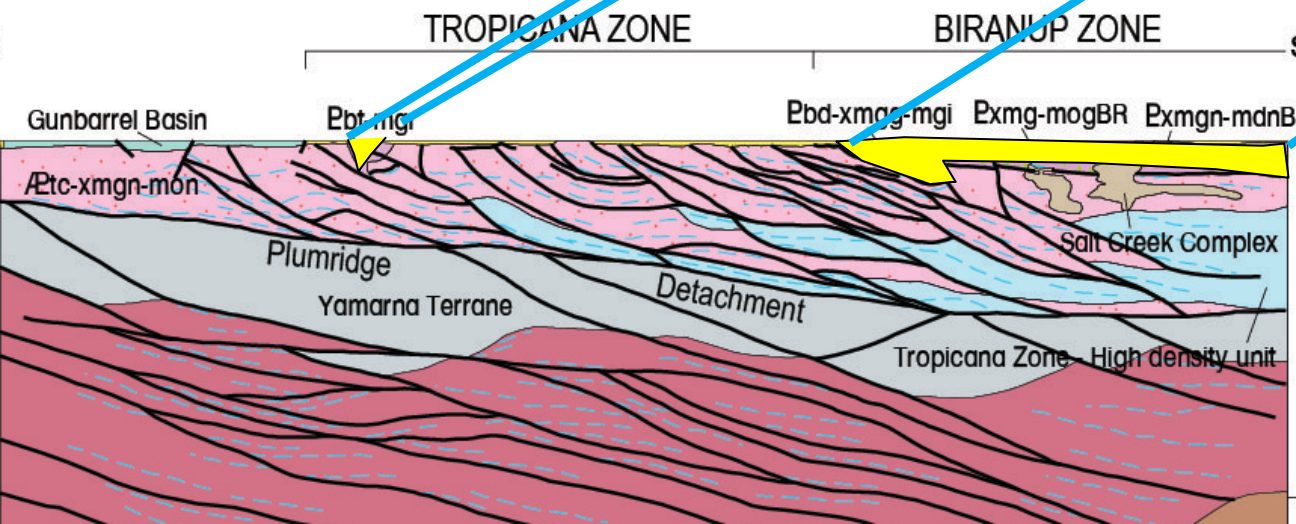
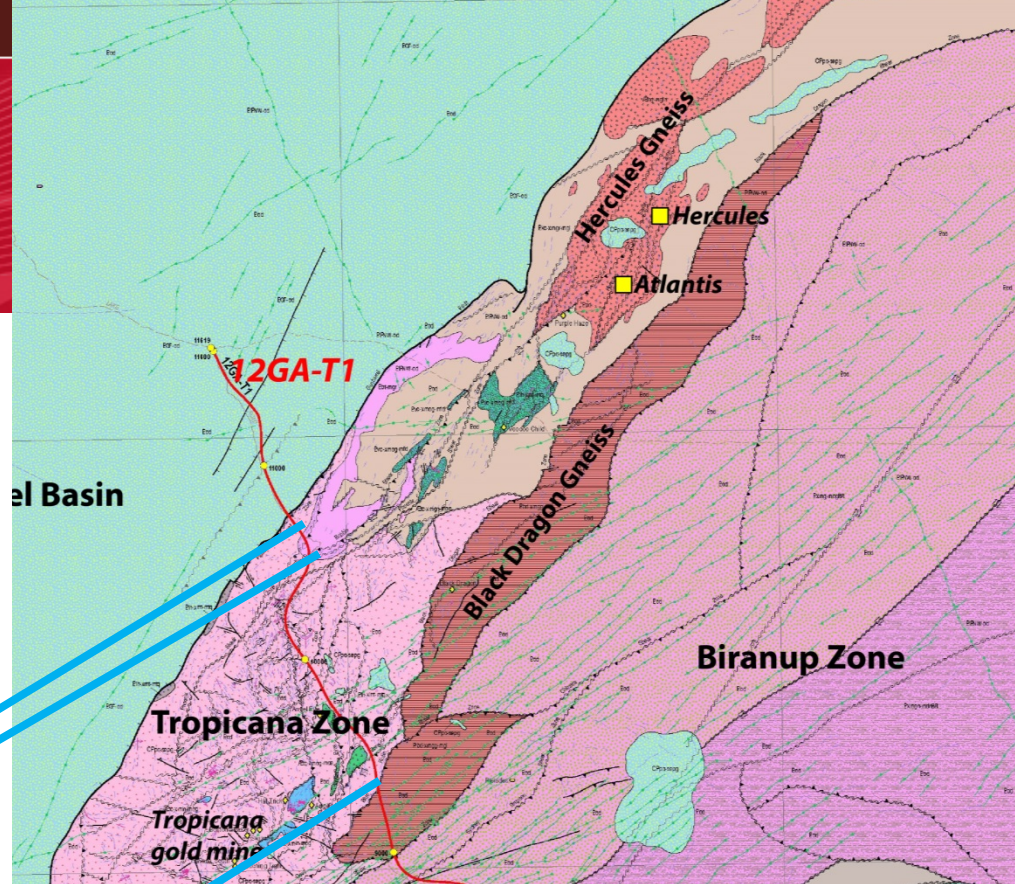
Voodoo Child Formation: 1780 to 1760 Ma – Magnetism (Ngadju Event)



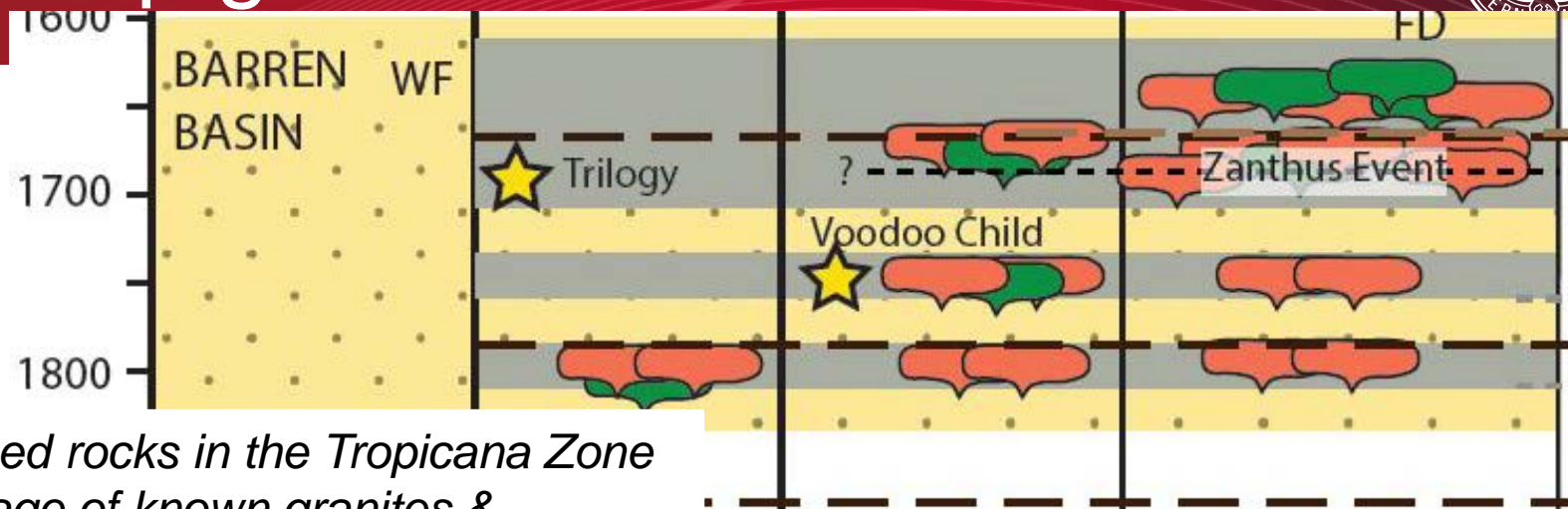
Biranup granites: c. 1710 to 1670 Ma

Biranup Orogeny

Just magmatism in the Tropicana and Biranup Zones ?

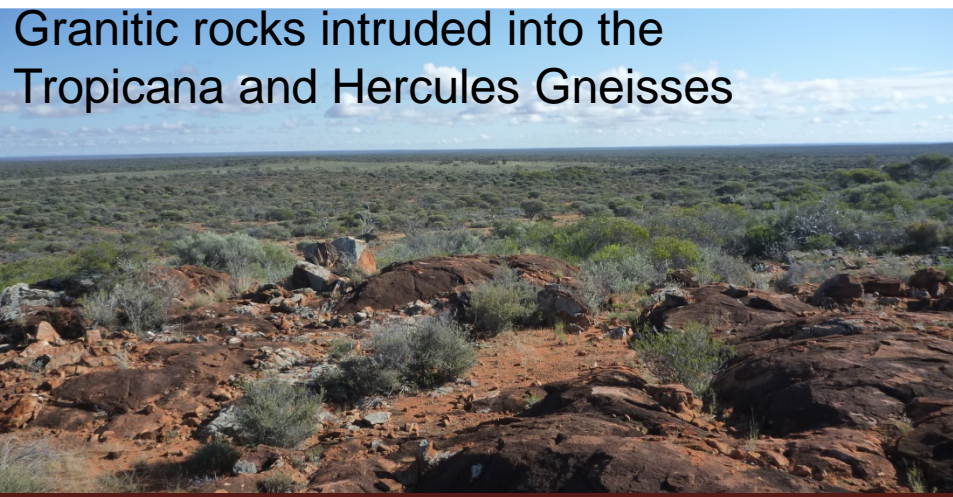


Biranup granites: c. 1710 to 1670 Ma



Biranup-aged rocks in the Tropicana Zone overlap in age of known granites & sedimentary rocks to the south supporting that the Tropicana Zone was emplaced pre-Paleoproterozoic

Granitic rocks intruded into the Tropicana and Hercules Gneisses



Massive to locally Foliated greenschist facies discrete shear zones

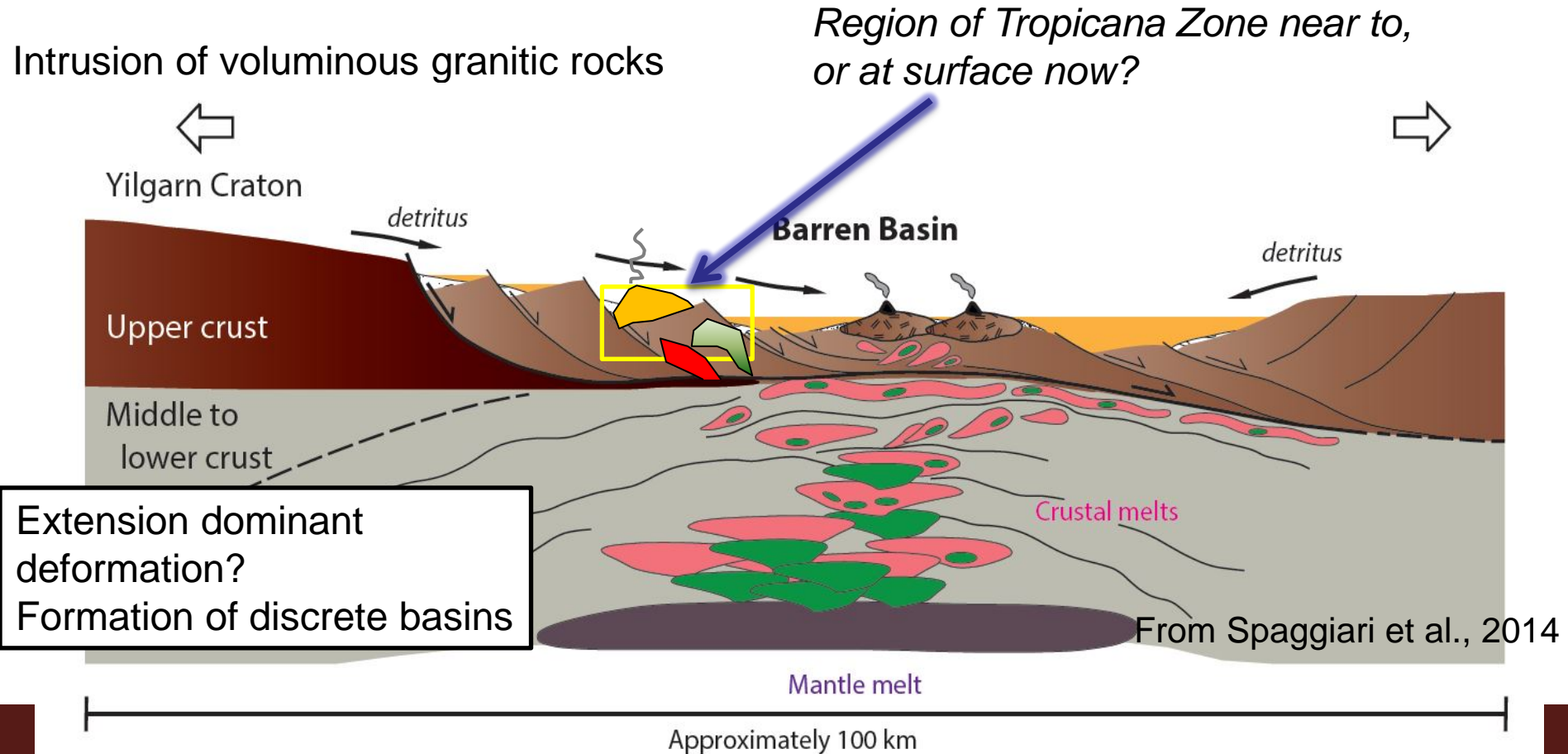
Dextral strike-slip and SE over NW reverse faults

(but could be AFO deformation and metamorphism)



What happened during the Paleoproterozoic over the Tropicana Zone?

Formation of basins over the Tropicana Zone – **Extensional Setting** – Biranup Orogeny
Siliciclastics and the discrete Voodoo Child Formation mafic-felsic igneous association
Possibly a **distal backarc to a west-vergent subduction zone** ?

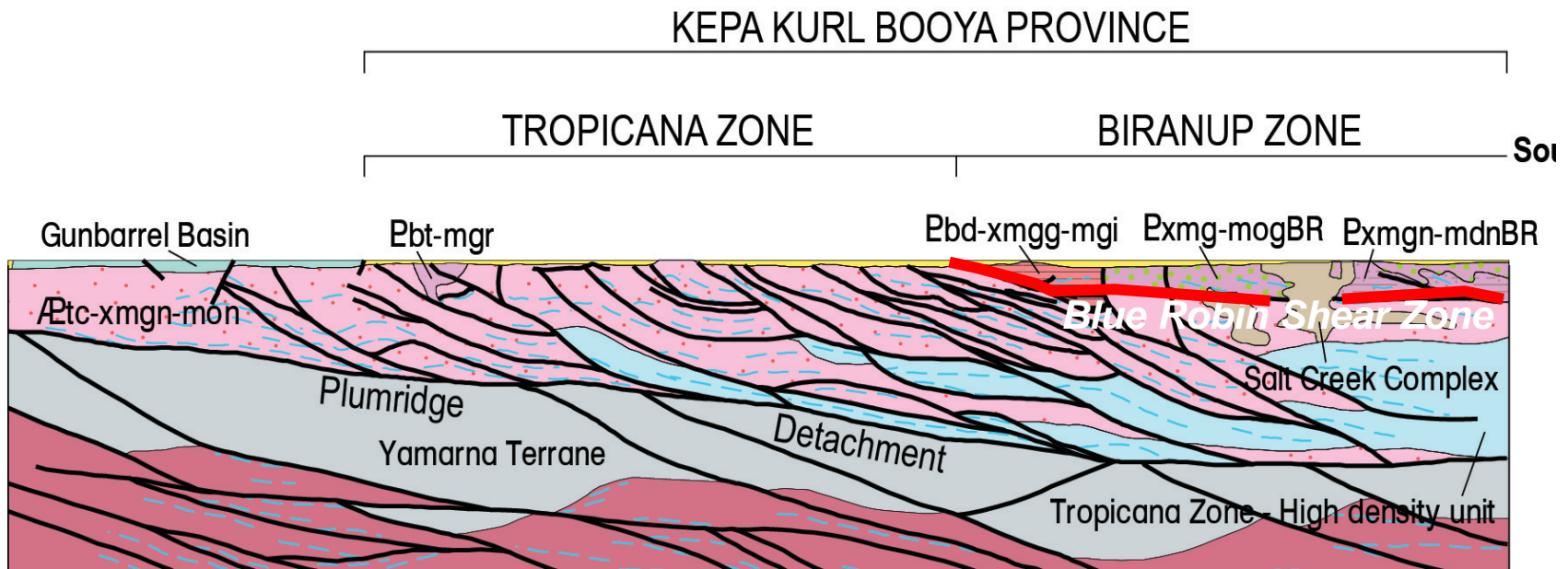


Biranup Zone....

Paleoproterozoic rocks in the region:

- Intrude into both the Tropicana and Biranup zones of the Kupa Kurl Booya Province

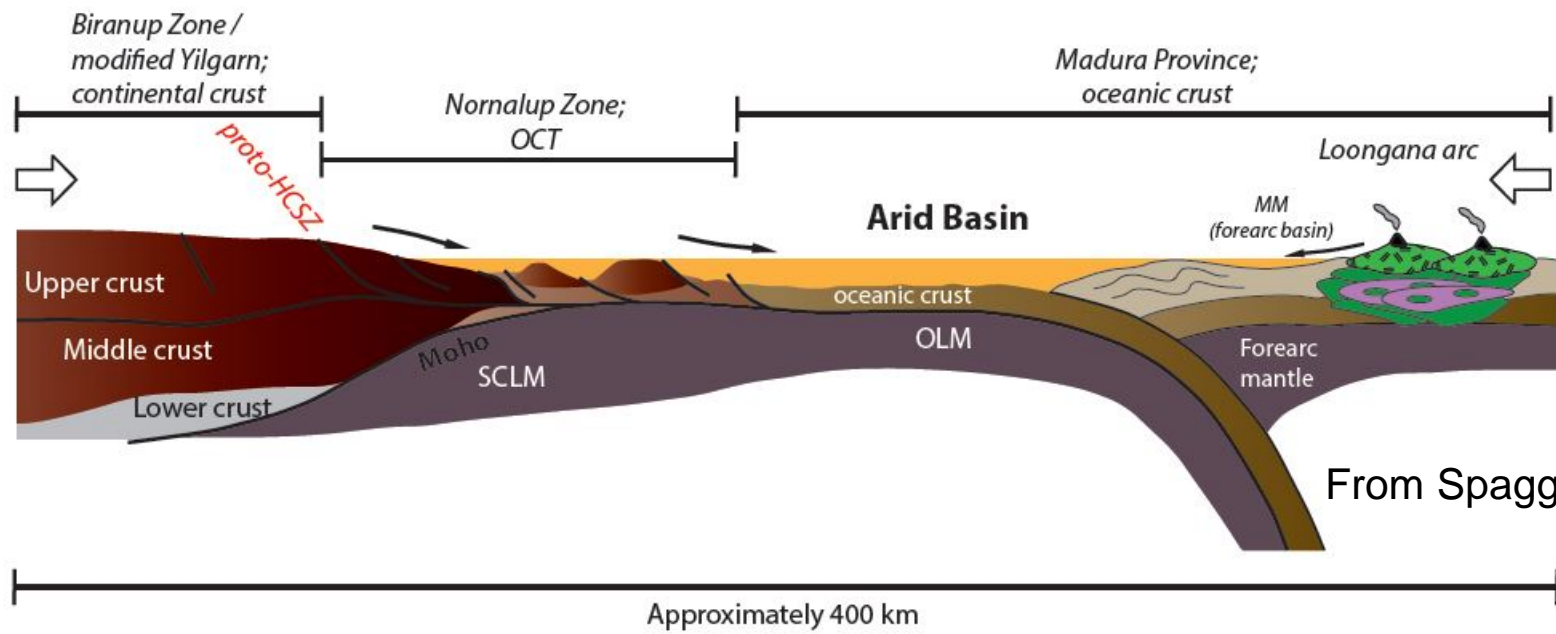
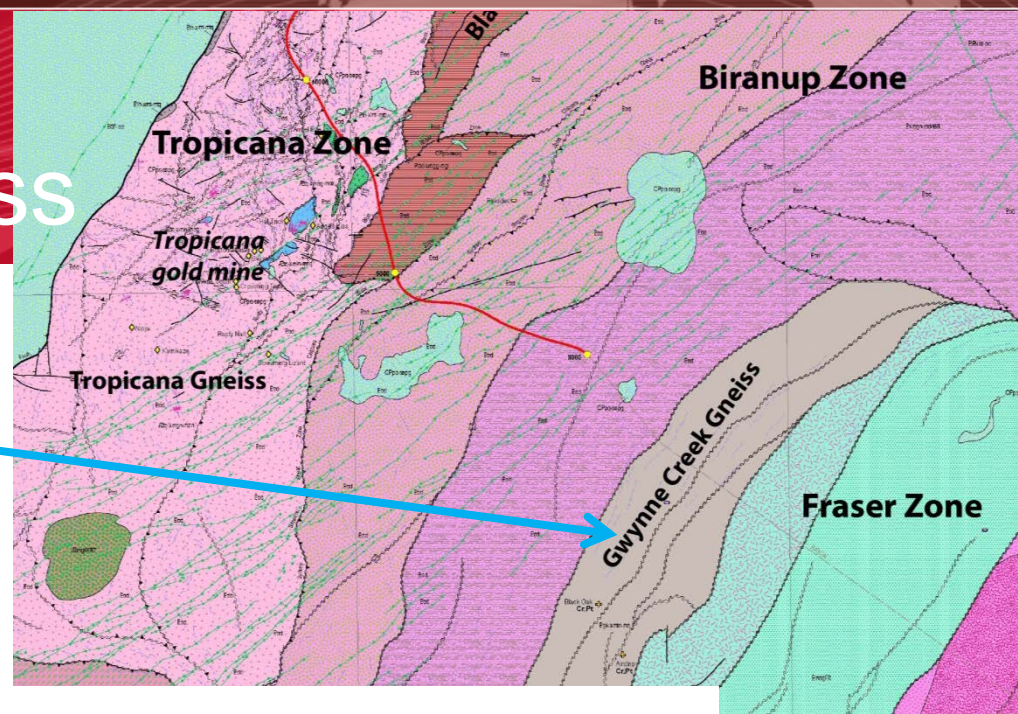
The Tropicana and Hercules gneisses form the basement to the Paleoproterozoic rocks in the region



Arid Basin Gwynne Creek Gneiss

Gwynne Creek Gneiss:
Maximum depositional age
c. 1483 Ma (Arid Basin)

Formed over Kepa Kurla Booya
Province

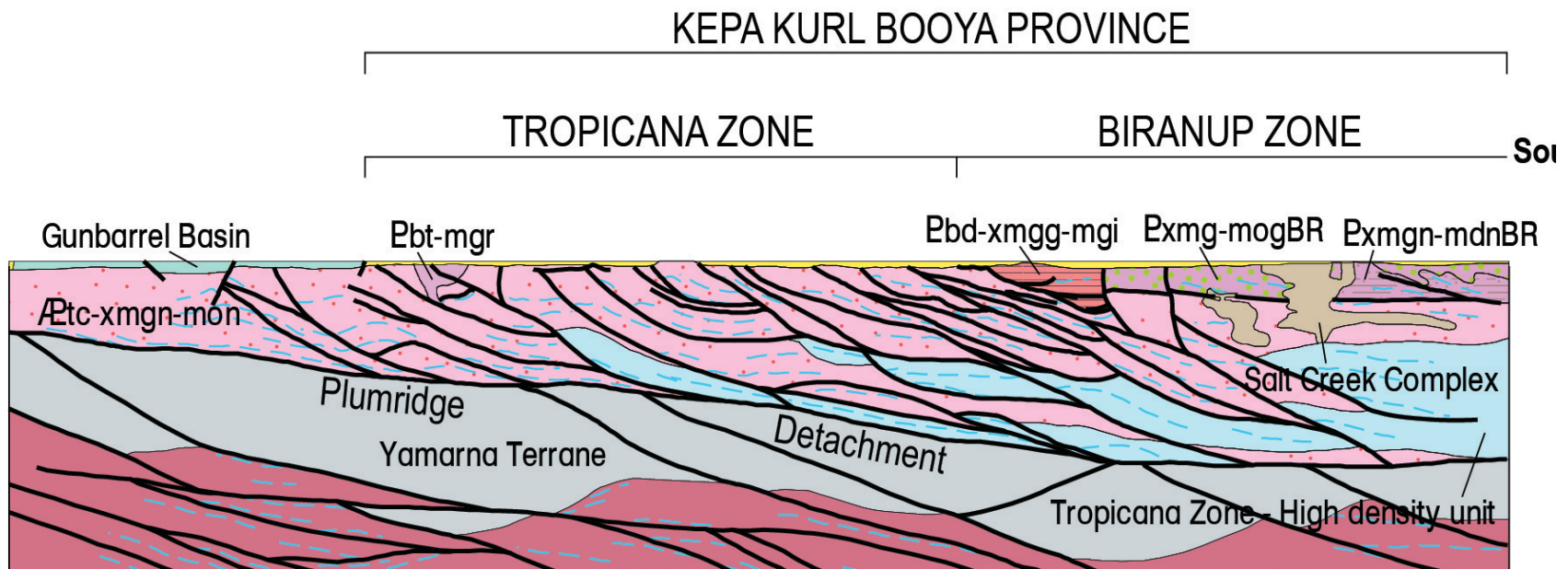


From Spaggiari et al., 2014

Hiatus of c. 300 million years then....

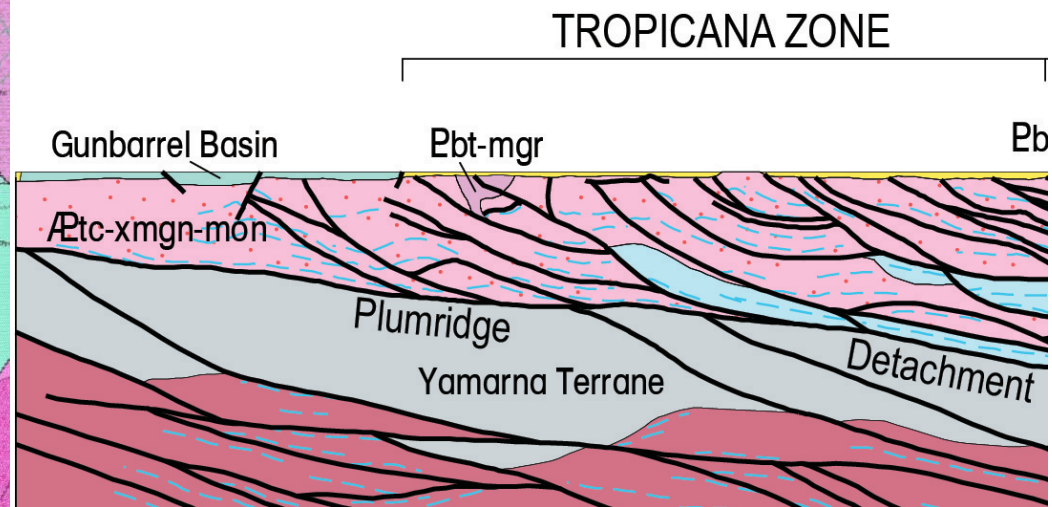
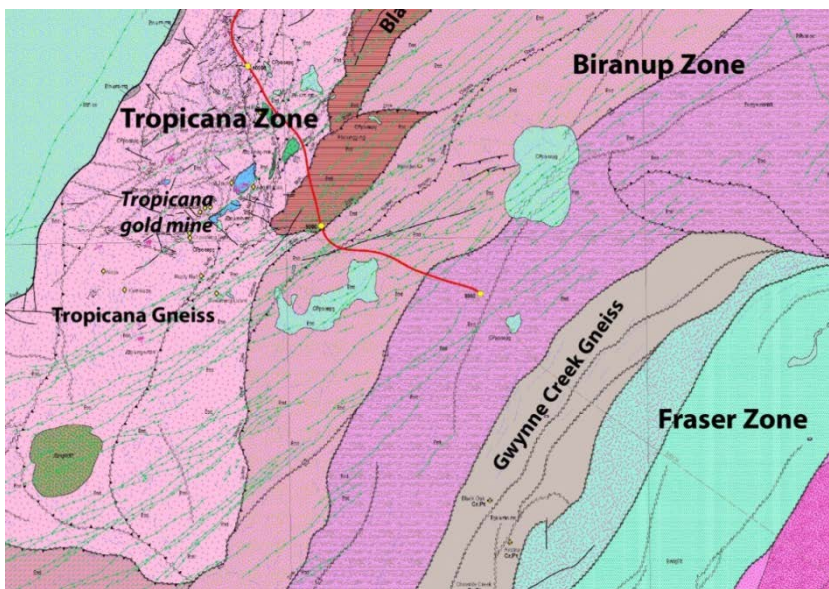
Albany Fraser Stages 1 and 2 – What influence did these Orogenic events have on the **Kepa Kurl Booya Province in the northern Albany Fraser Province**
Likely that some NE trending discrete greenschist facies oblique dextral reverse or thrust shears formed during the AFO.

BUT



AFO the Tropicana Zone

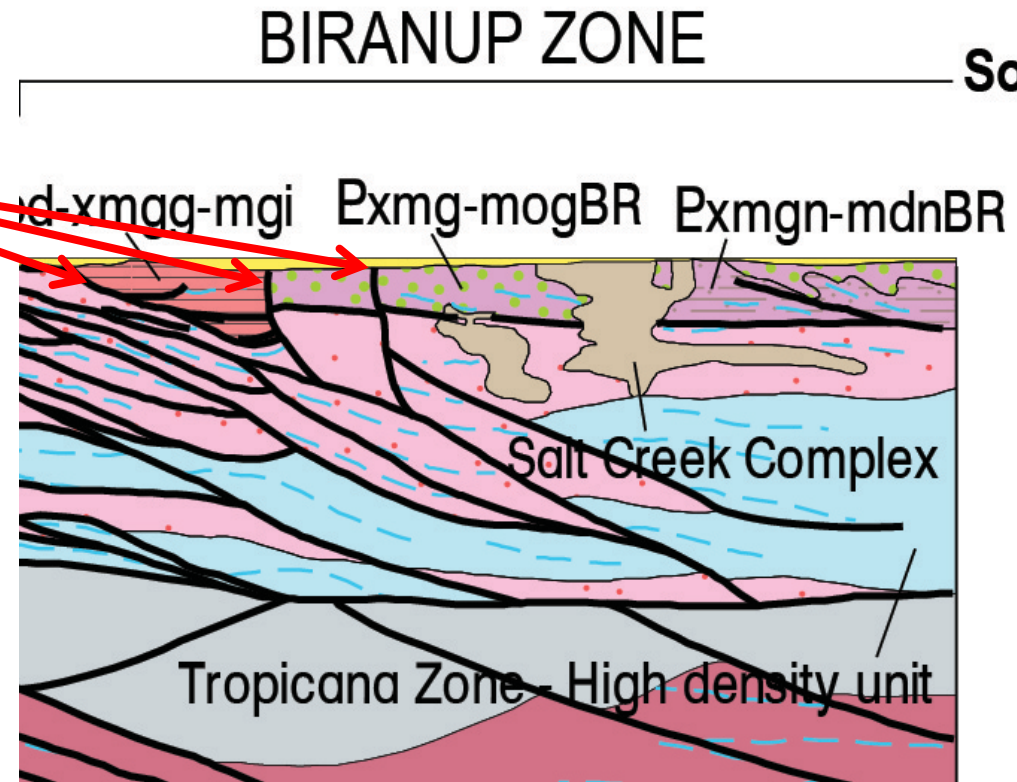
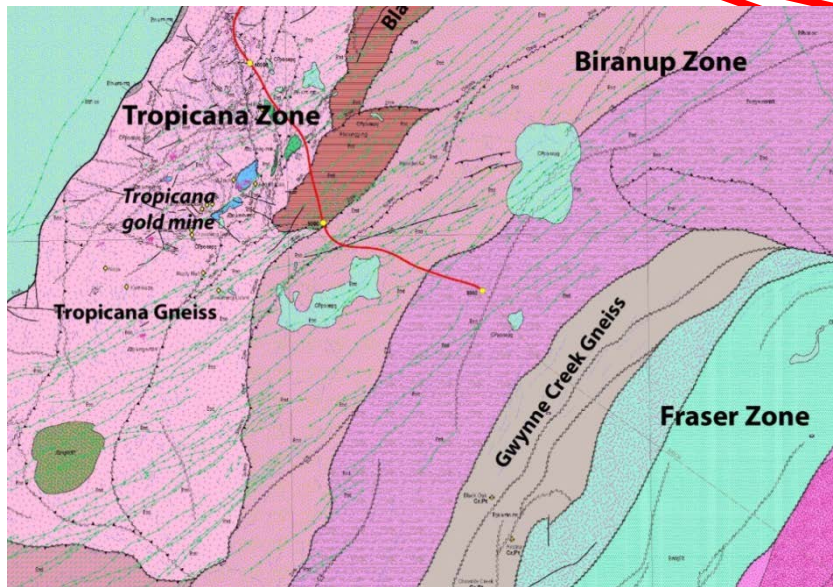
- Currently no dated evidence of either Stages 1 or 2 of the AFO
- Discrete NE greenschist facies dextral reverse or thrust faults may be either AFO 1 or 2 or they could be older
- These NE trending shear zones are cut by the apparently c. 1210 Ma Gnowangerup–Fraser dykes
- Thus in the seismic section 12GA–T1 the major shear zones mapped are all assigned to Paleoproterozoic or older



AFO in the Biranup Zone

Faults/shears can be demonstrated to cut the Paleoproterozoic granites in the region.....so must be younger

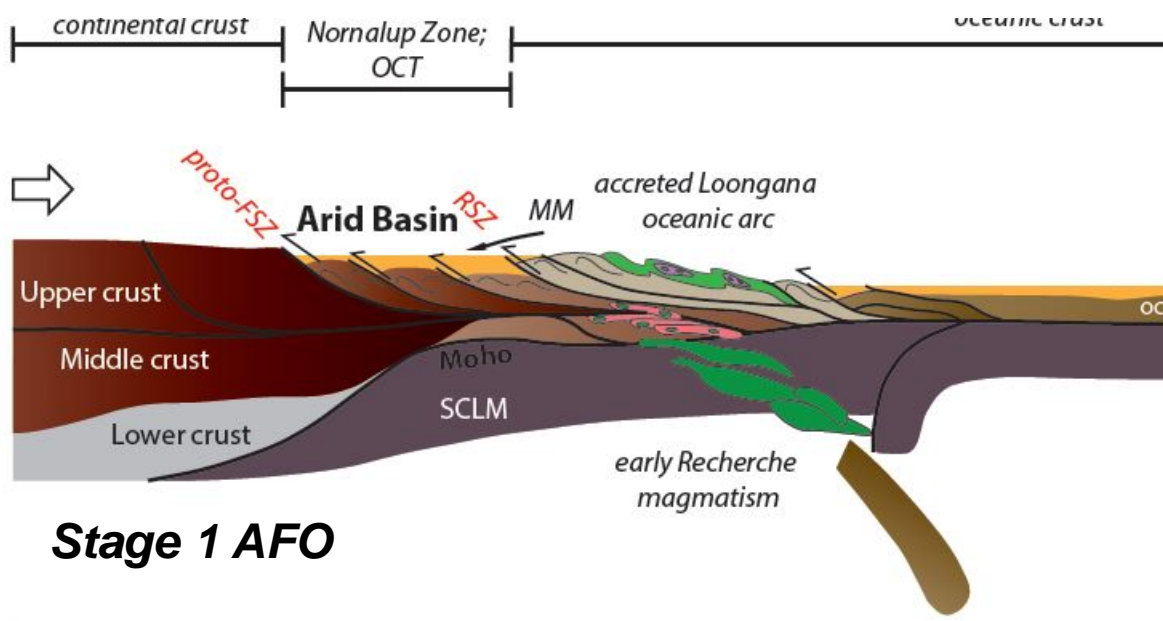
Did these form during AFO Stage 1 or 2?



Albany-Fraser deformation and metamorphism in the Gwynne Creek Gneiss (Arid Basin) is fairly well constrained

A quartzofeldspathic gneiss with c. 1650Ma protolith age was metamorphosed at c. 1270 Ma = AFO 1 *high-grade metamorphic and deformation event*

And suffered brittle deformation **between 1270 and 1190Ma**, constrained by hydrothermal zircon growth in brittle fractures in zircon grain = AFO 2 *low-grade metamorphic/deformation event*



Stage 1 AFO

From Spaggiari et al., 2014
Approximately 400 km

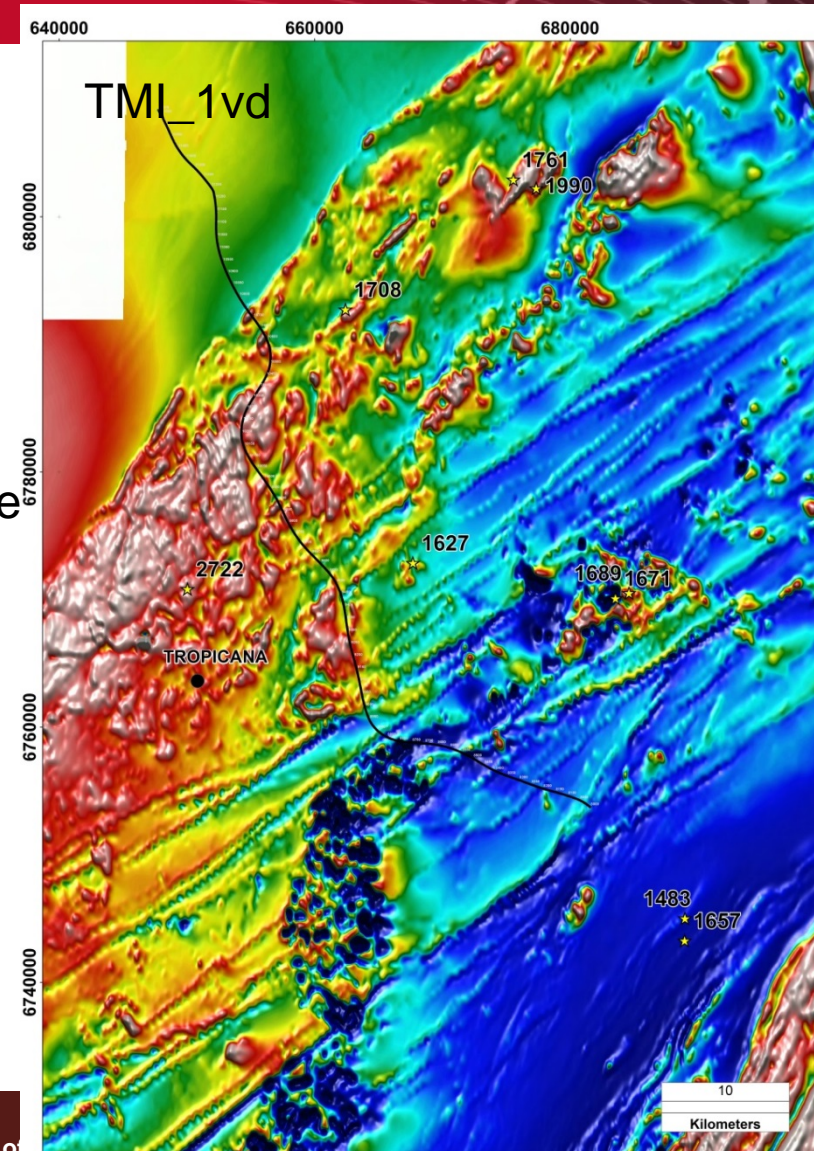
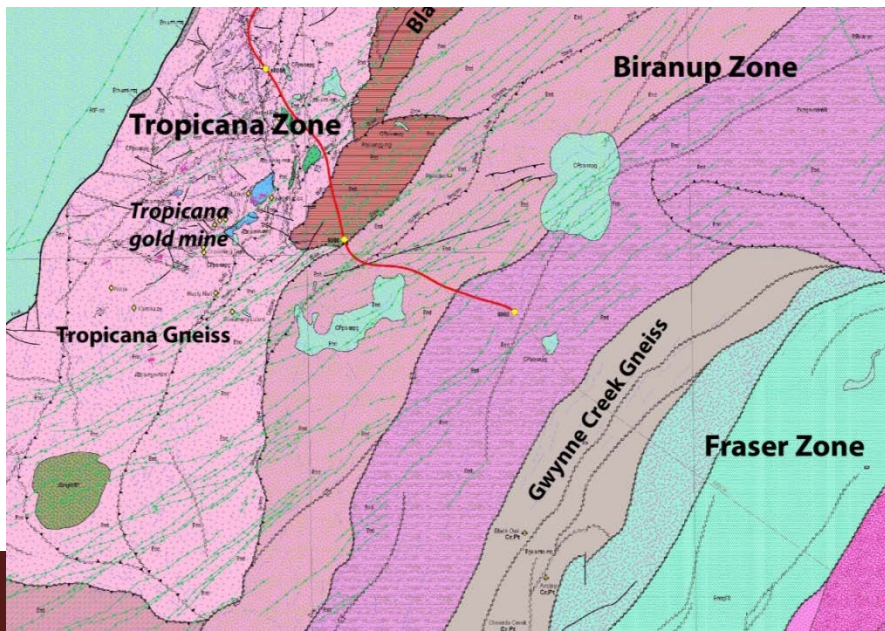


Courtesy of Catherine Spaggiari

Gnowangerup – Fraser dykes (Marda Moorn Large Igneous Province) and Salt Creek Complex – what are they?

Gnowangerup – Fraser gabbroic dykes:

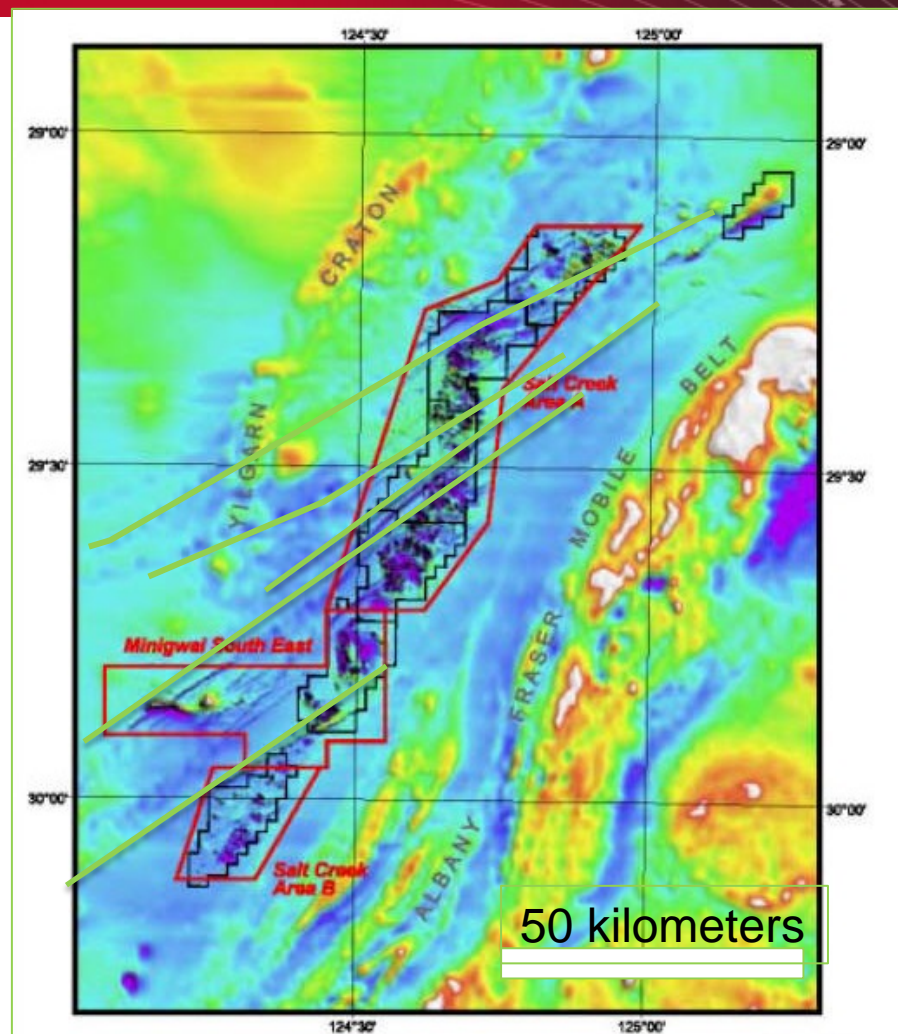
- Cut across the Kepa Kurl Booya Province
- Generally trend: ENE to NE
- Appear unmetamorphosed
- They must have intruded either in the very late stages of the AFO Stage 2 or sometime after it
- Herein - c. 1210 Ma, but in reality unknown age



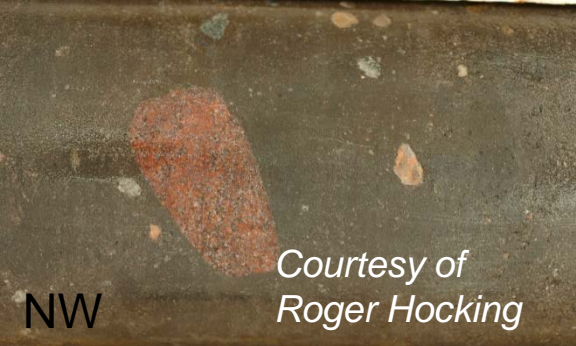
Salt Creek Complex – what is it ?

Salt Creek Complex – What is it ?

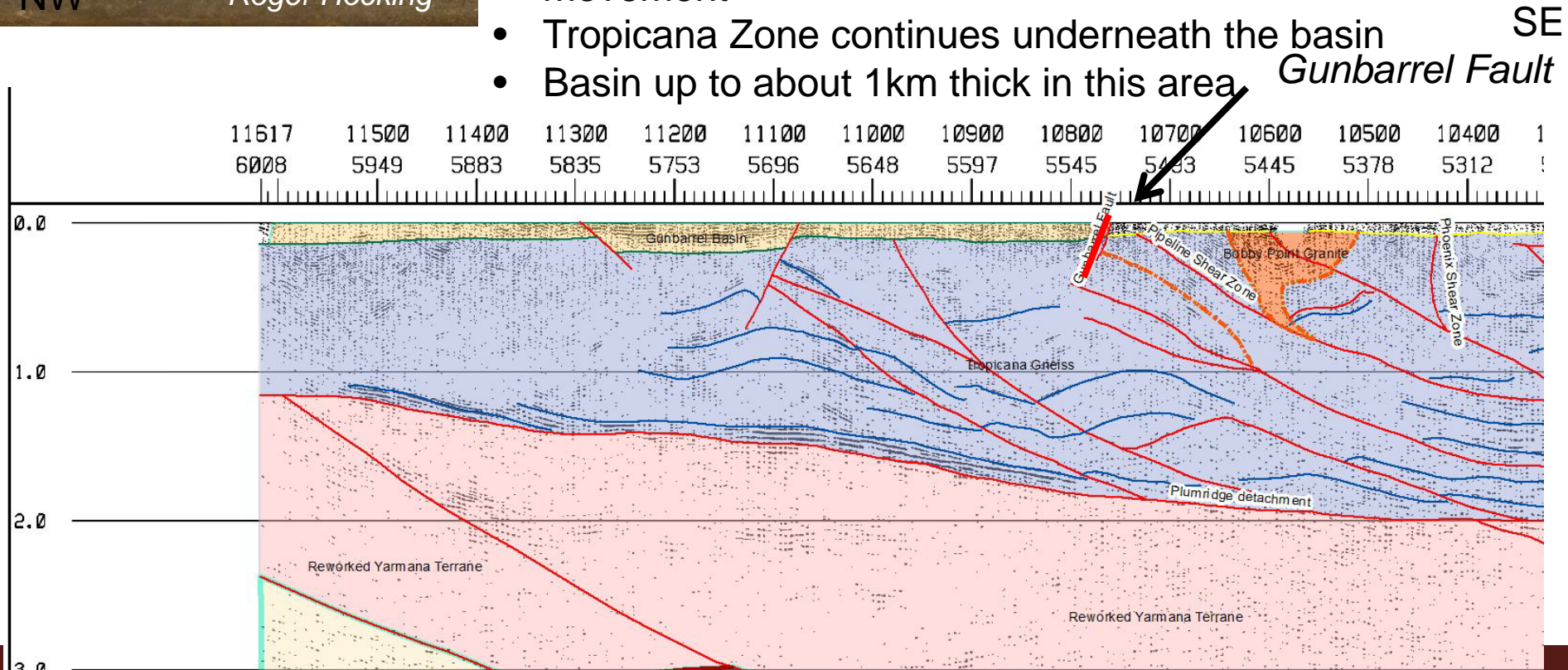
- Remanantly magnetised hypersthene gabbro's
 - Relatively unmetamorphosed Exploration for Ni, Cu, PGE by Mithral Resources in the late 1990's early 2000's (after a list of other explorers), little but variable success
 - Intrude across several different other units/domains in the belt that have been metamorphosed to varying degrees
 - Must be late in the sequence
- (Mithral, Mines Dpts Rpts, early 2000's)



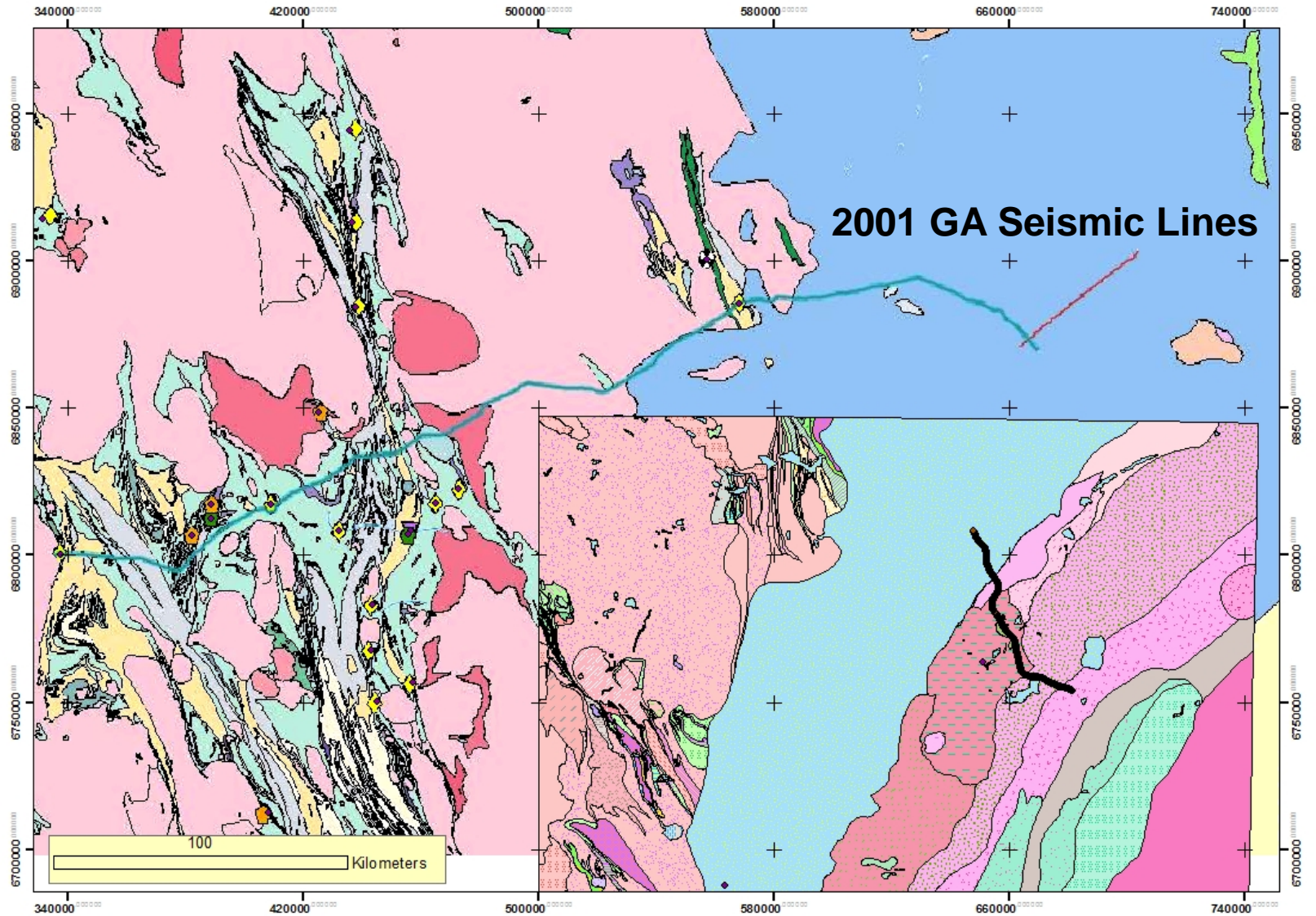
Late Carboniferous to Permian Gunbarrel Basin – siliciclastics/diamictite



- Relatively steep normal north to northeast trending fault in 12GA–T1
- In map section normal fault appears to cut earlier faults/shears with reverse or thrust sense of movement
- Tropicana Zone continues underneath the basin
- Basin up to about 1km thick in this area

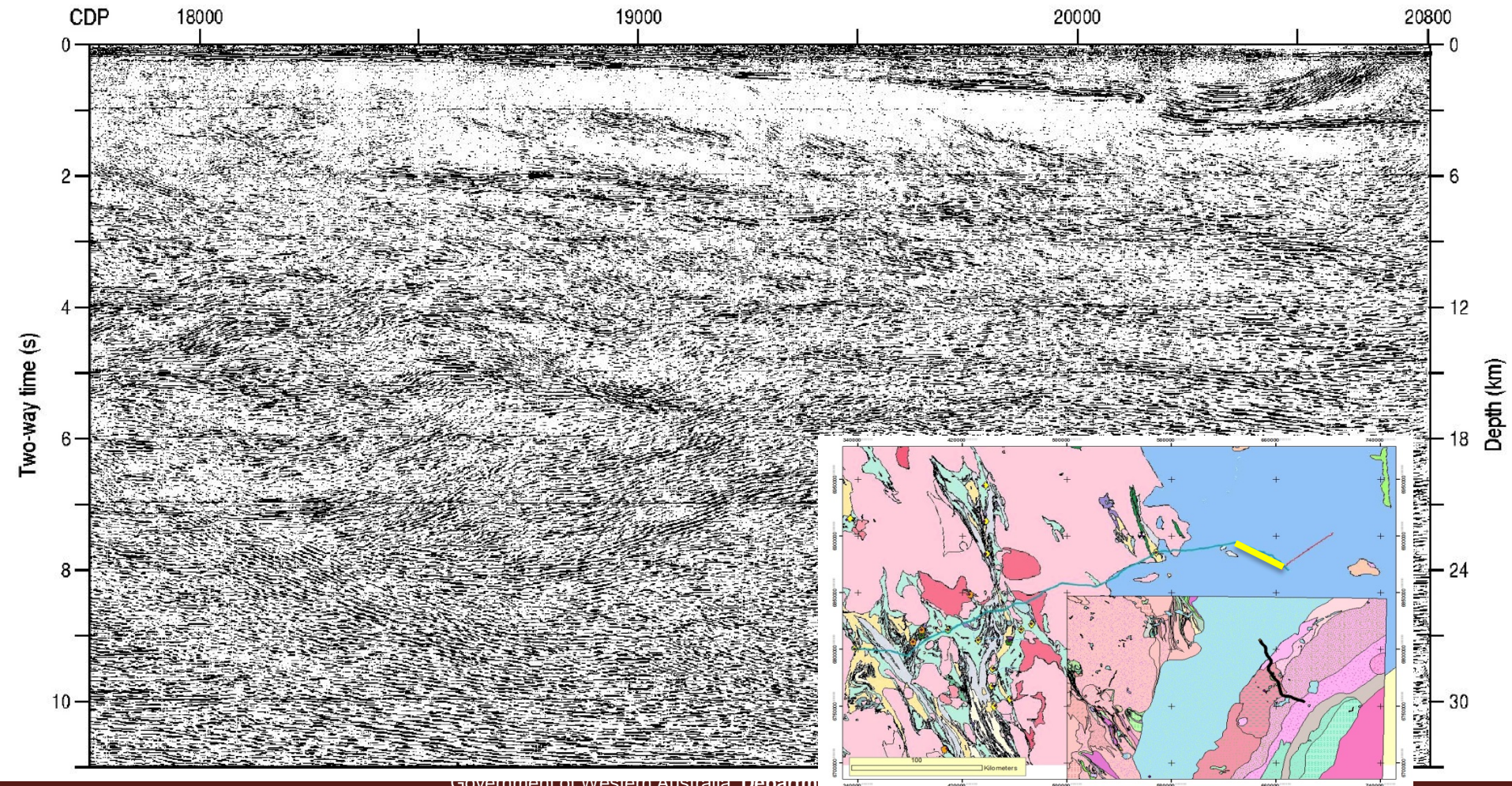


Where to next? What if the Tropicana Zone was thrust over the Yilgarn Craton, west of the Gunbarrel Basin ?

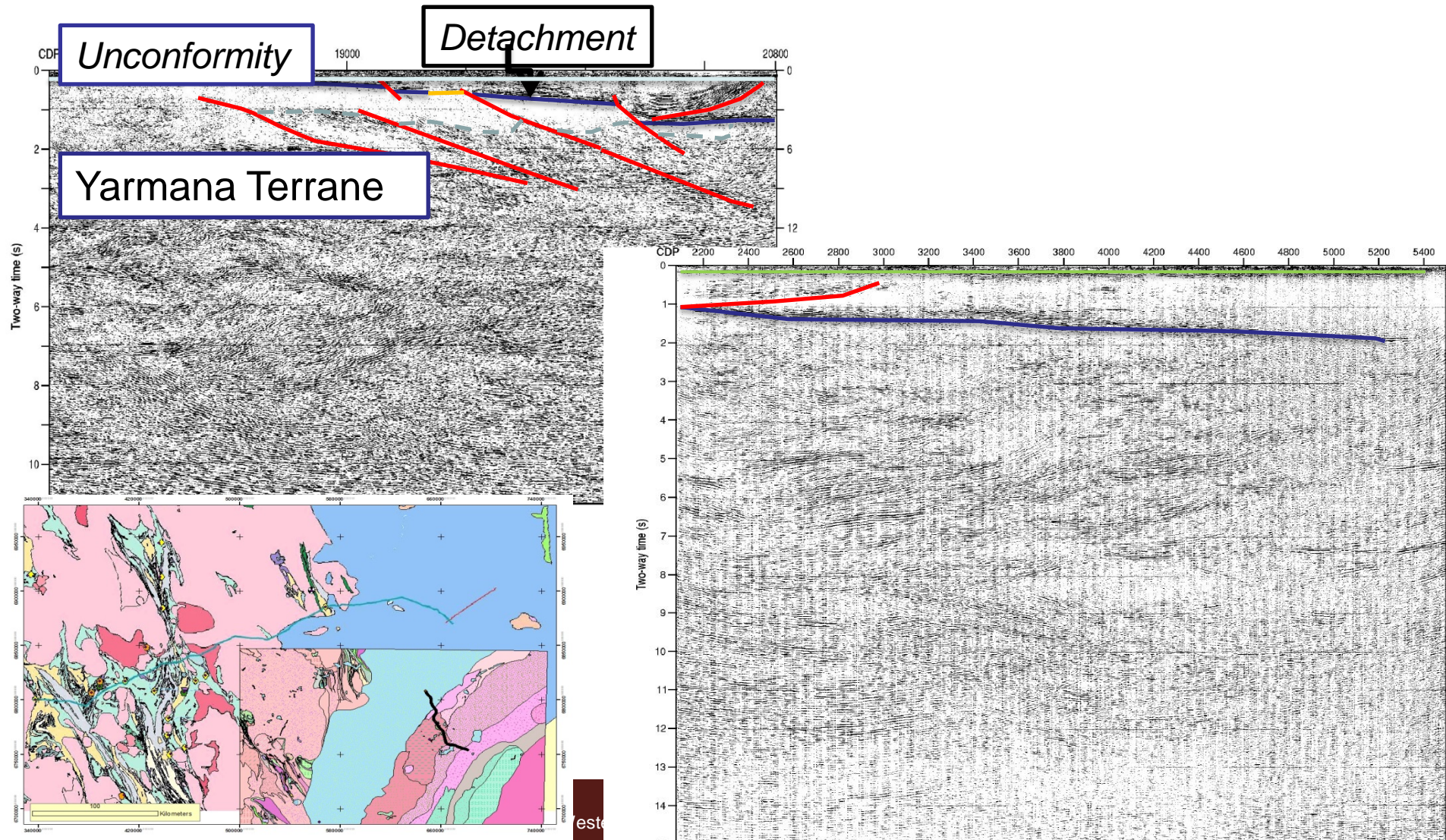


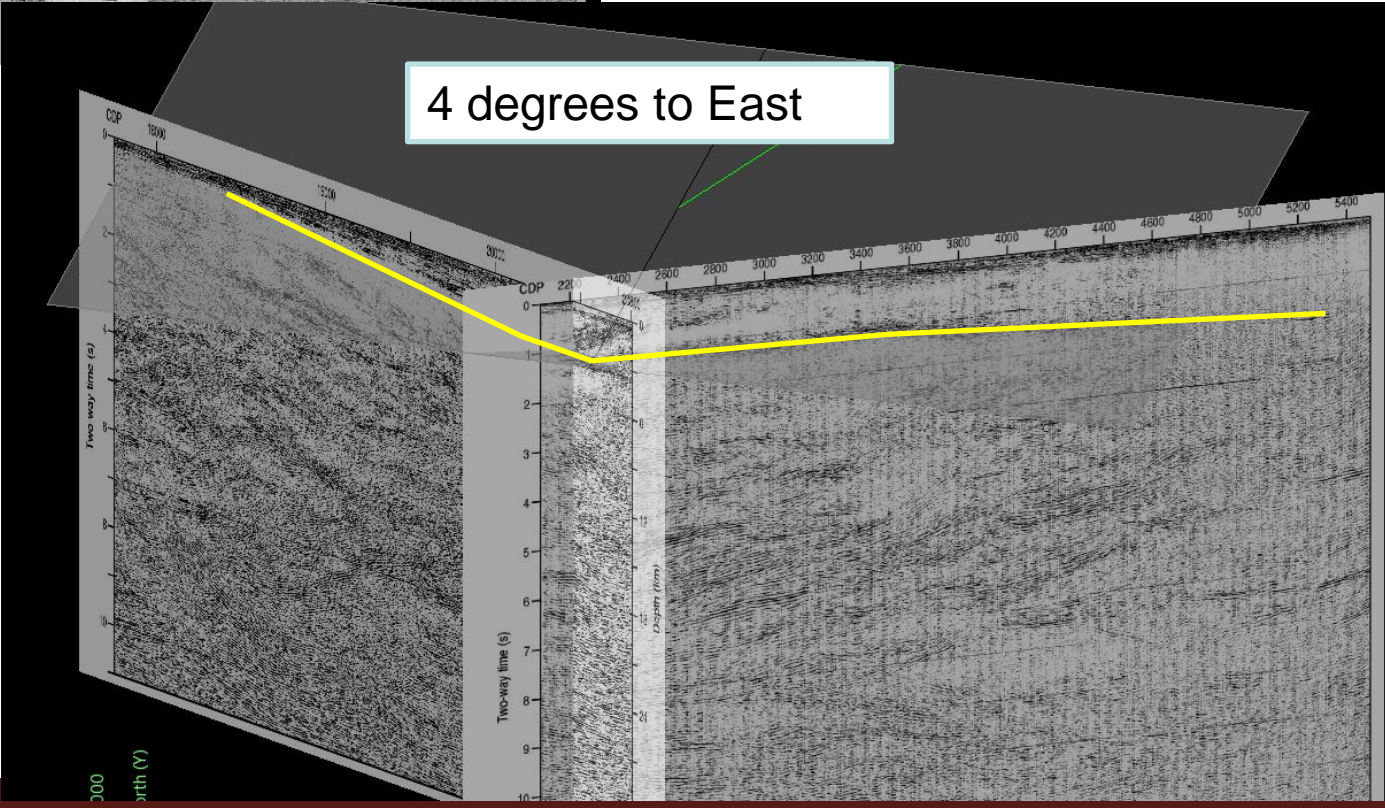
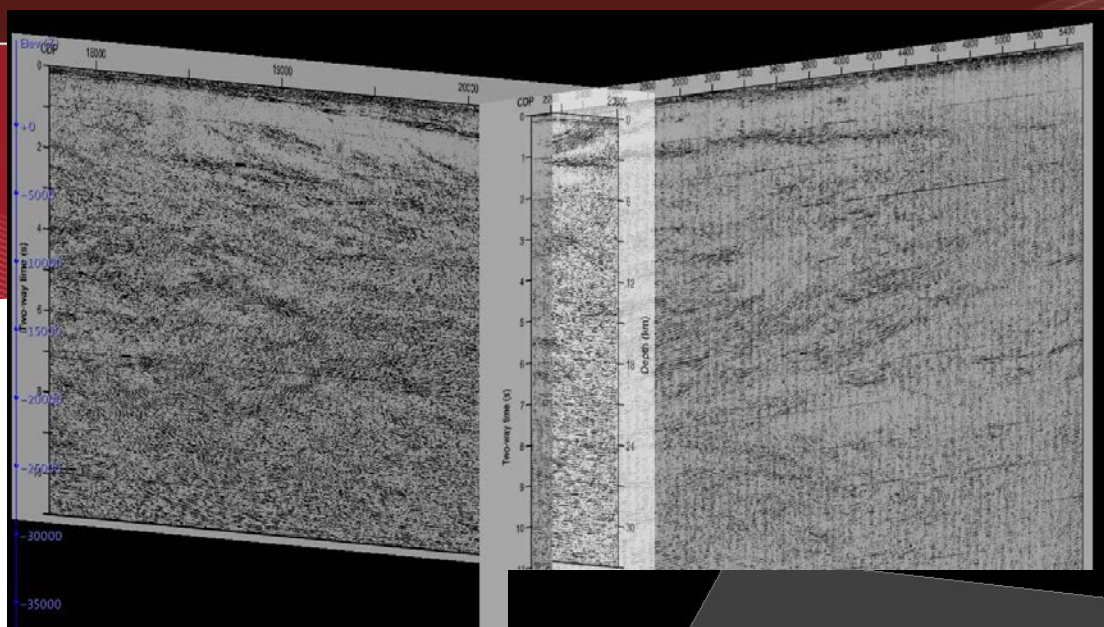
What if the Tropicana Zone was thrust over the Yilgarn Craton, west of the Gunbarrel Basin – NW trending line?

What would it look like?

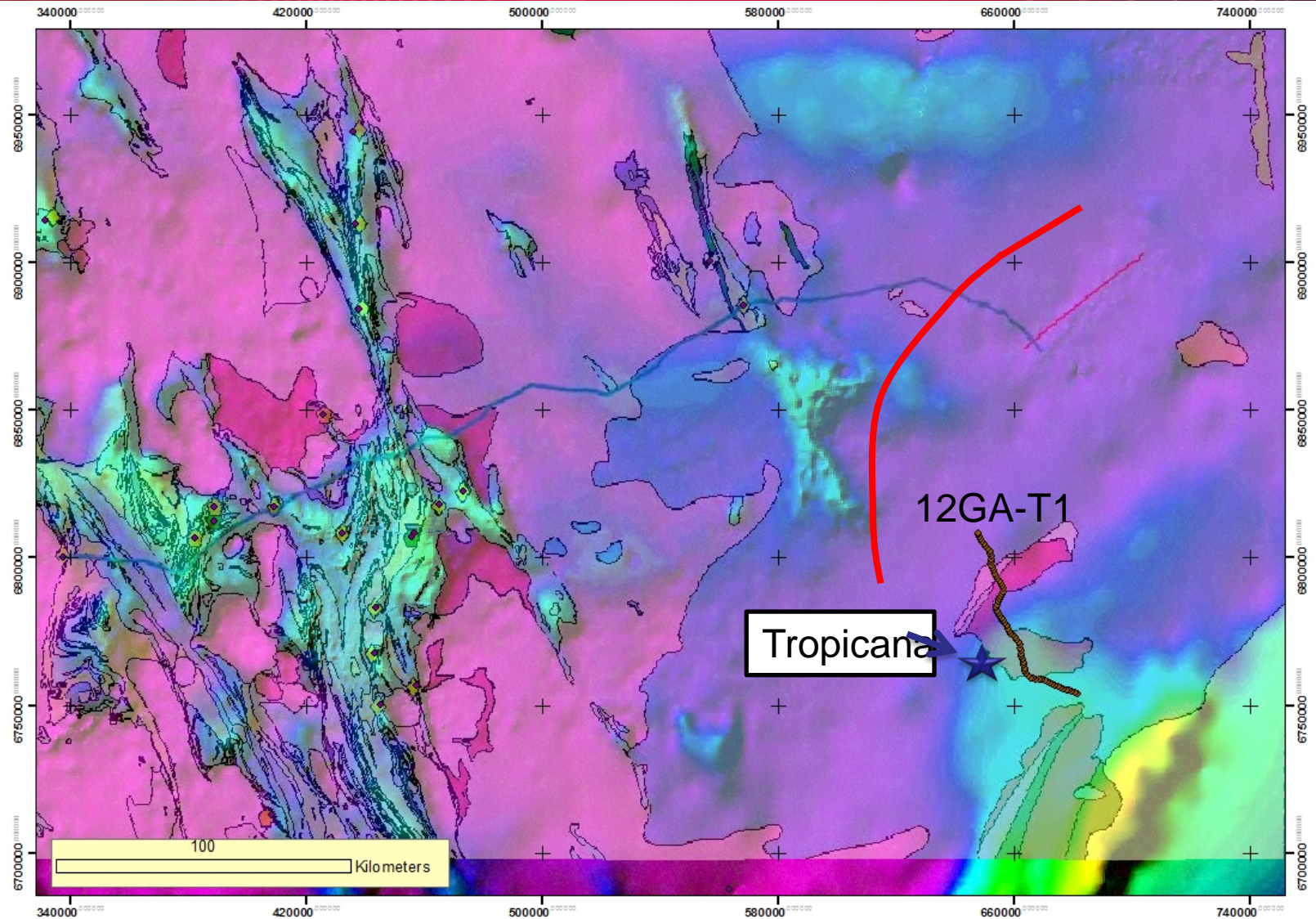


What if the Tropicana Zone was thrust over the Yilgarn Craton, west of the Gunbarrel Basin – NW and NE trending lines ?





Plumridge detachment - Gravity



What have we learnt?

- **Yamarna Terrane** underwent extension between 2.6 Ga and 2.5 Ga
- **Tropicana Zone** is the middle to lower crustal components of the Yilgarn Craton. Sanukitoids in the Tropicana Zone suggest the region was in the upperplate region of a fossil subduction zone between 2.7 and 2.6 Ga
- **Gunnadorrah Province** is likely to be reworked Yilgarn Craton
- **2.5 Ga gold mineralisation** coeval with a tectonic event that thrust the Tropicana Zone gneisses over the Yamarna T into the greenschist facies (upper crust), and underthrust the Gunnadorrah Province beneath the Babool Province
- **Extensional** processes prominent during the **Paleoproterozoic**.
- **Paleoproterozoic mineralisation** in the region could be a reflection of the presence of 'fertile' rocks in the source region
- **c. 1300 and 1200 Ma** Stage 1 and 2 AFO only affected the Tropicana Zone in discrete greenschist facies shear zones – but was pervasive and higher grade to the east in the Gwynne Creek Gneiss & Fraser Zone (reflecting metamorphic gradient?)
- **Salt Creek Complex** and **Gnowangerup-Fraser dykes** formed either after, or during the waning stages of the Stage 2 of the Albany-Fraser Orogeny