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

Proterozoic Intrusives

Youanmi Seismic Workshop

Photo: Giovanni Capponi

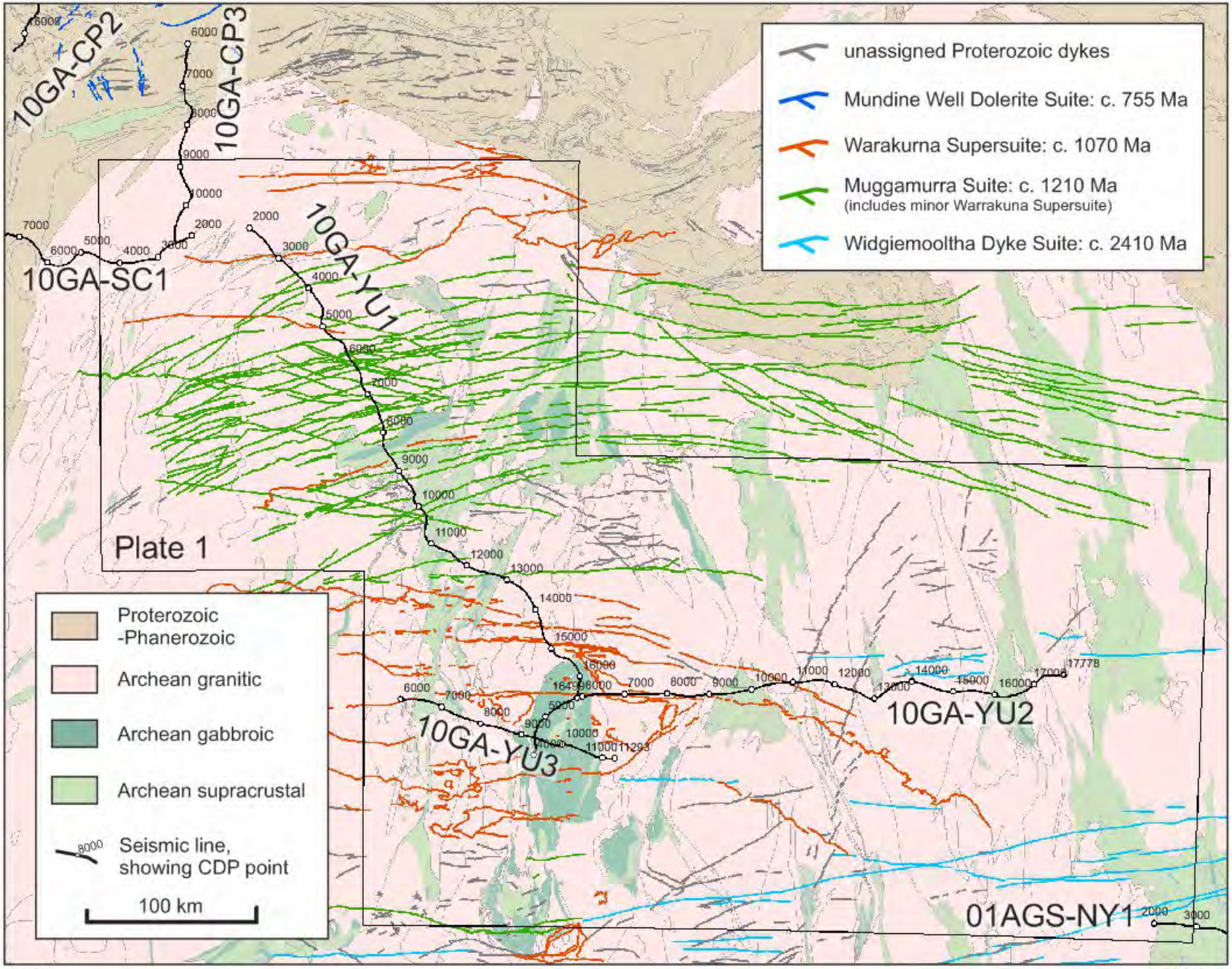
Geological Survey of Western Australia

ROYALTIES FOR REGIONS

Australian Government
Geoscience Australia

Tim Ivanic

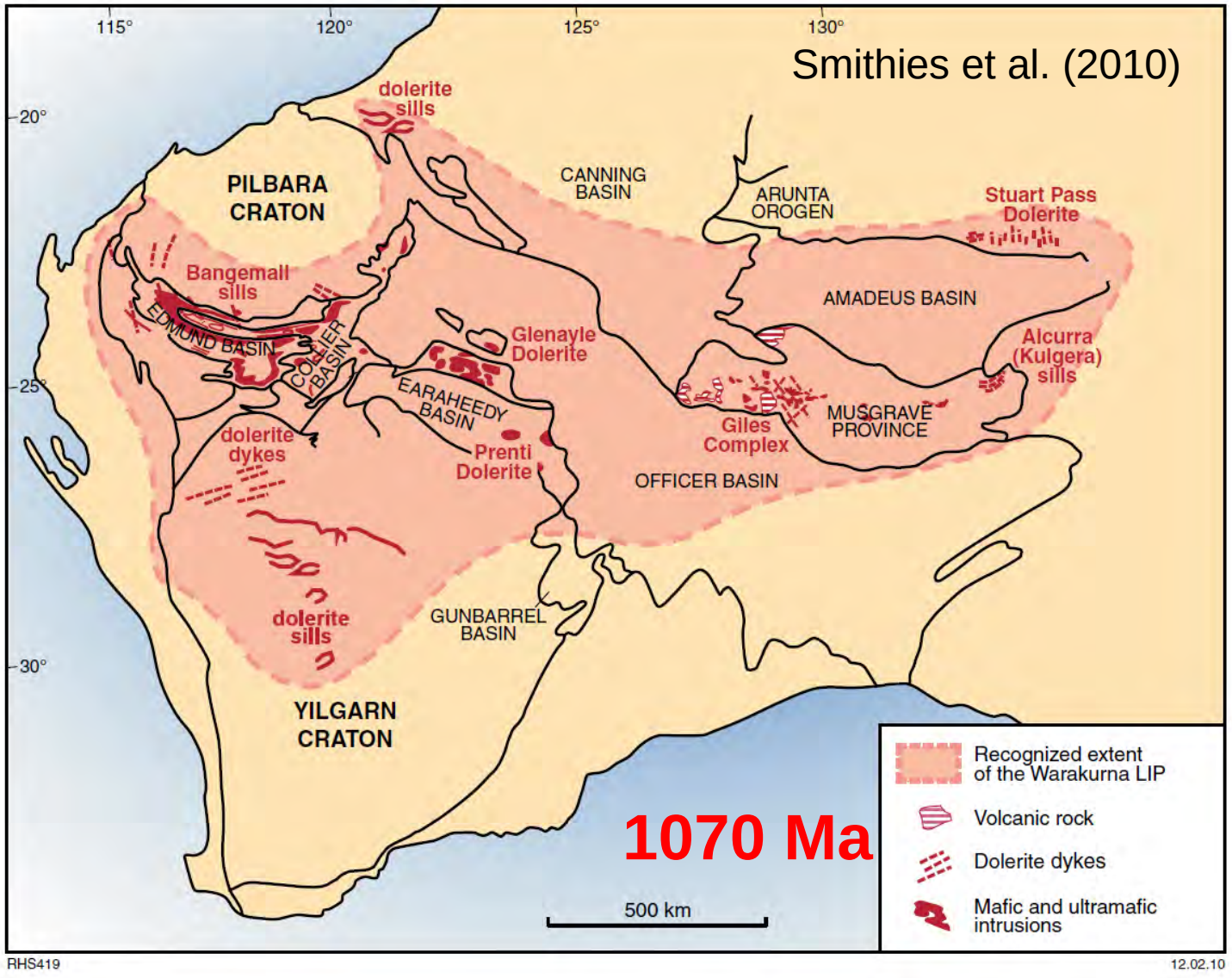
27th Feb 2013


unassigned Proterozoic dykes
Mundine Well Dolerite Suite: c. 755 Ma
Warakurna Supersuite: c. 1070 Ma
Muggamurra Suite: c. 1210 Ma
(includes minor Warrakuna Supersuite)
Widgiemooltha Dyke Suite: c. 2410 Ma
10GA-CP2
10GA-CP3
10GA-SC1
10GA-YU1
10GA-YU2
10GA-YU3
01AGS-NY1
Plate 1
Proterozoic
-Phanerozoic
Archean granitic
Archean gabbroic
Archean supracrustal
Seismic line,
showing CDP point
100 km

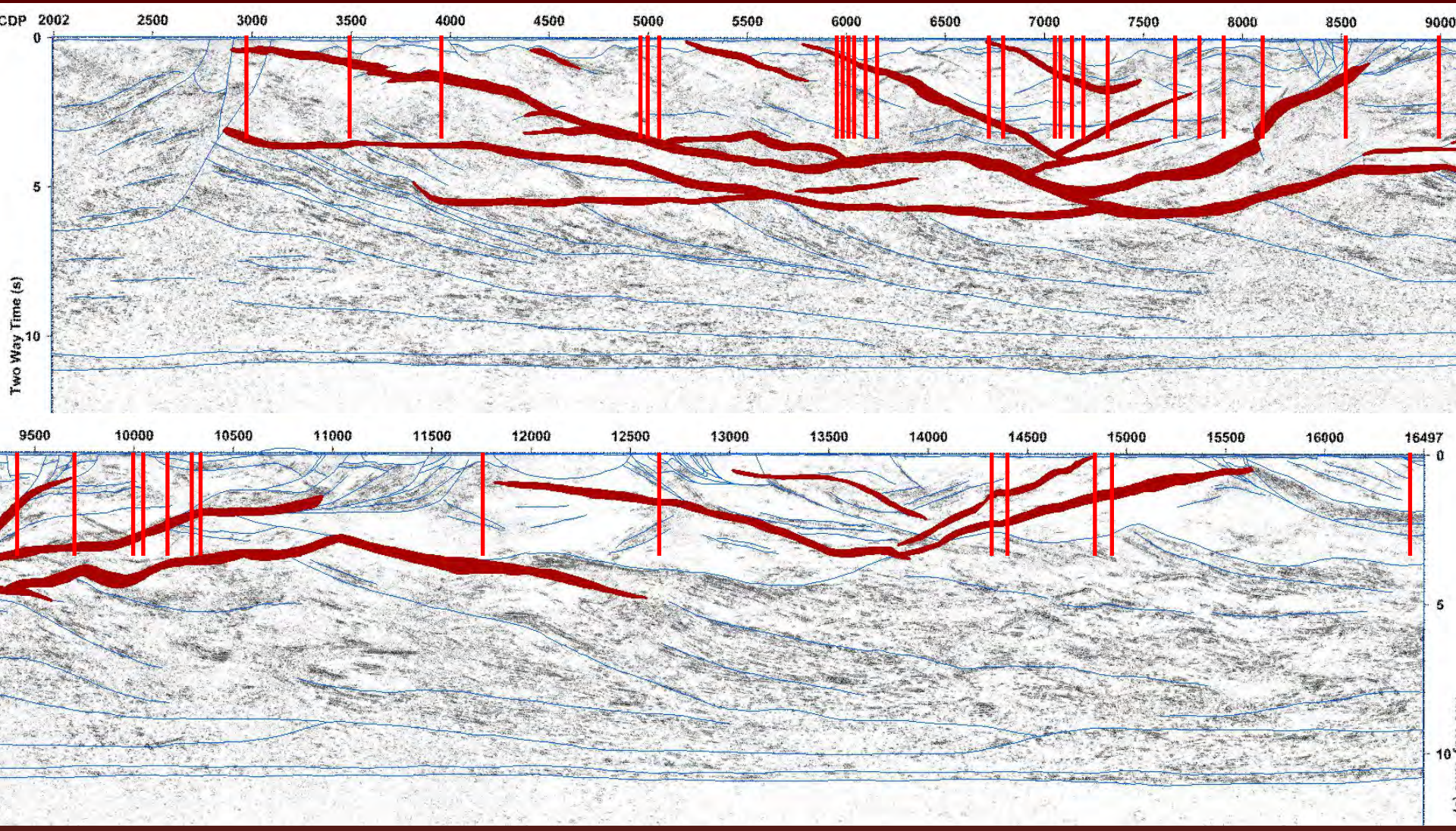
TJI46

3.12.12

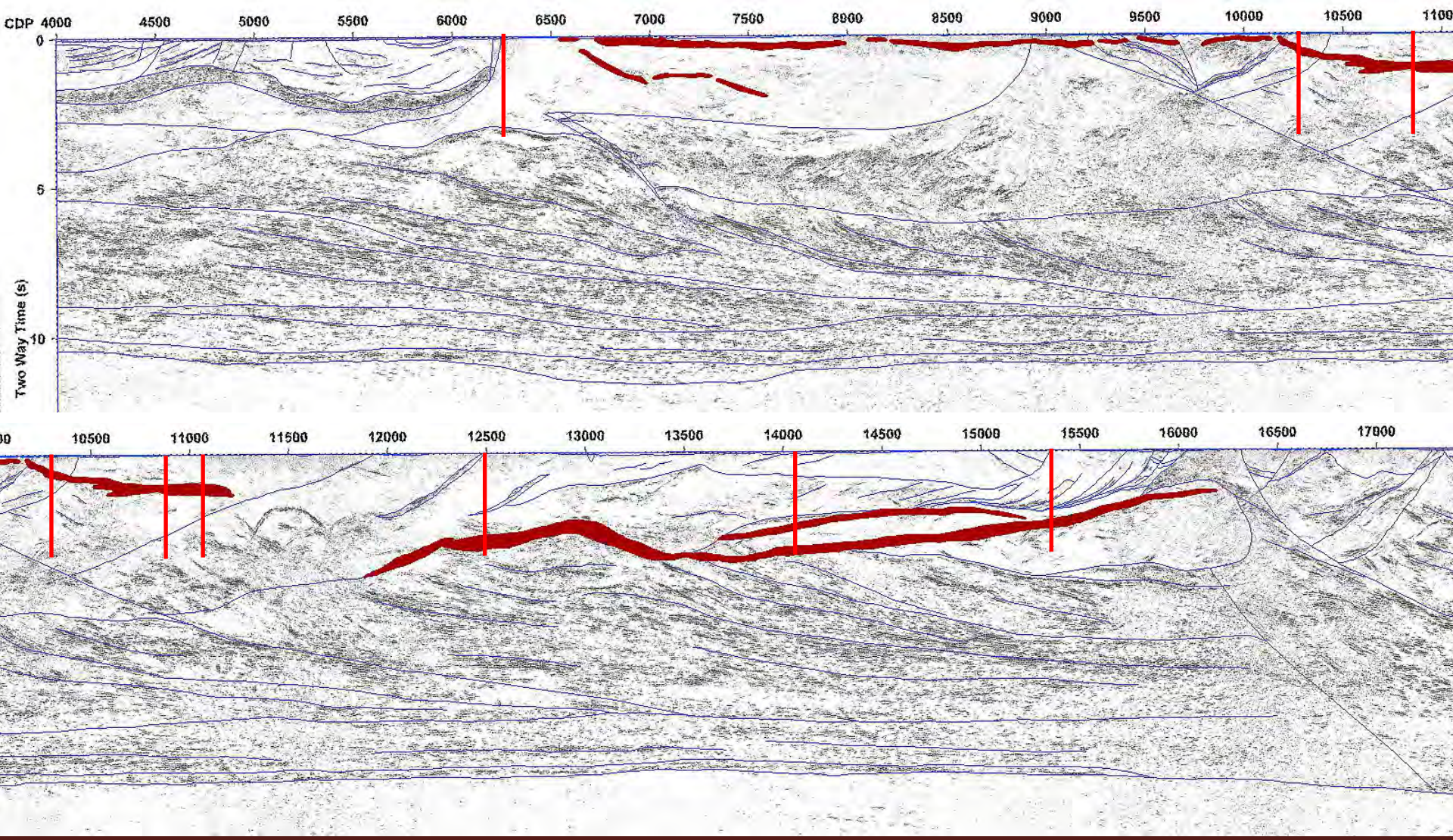
Warakurna Large Igneous Province



10GA-YU1 – Proterozoic intrusives



10GA-YU2 – Proterozoic intrusives



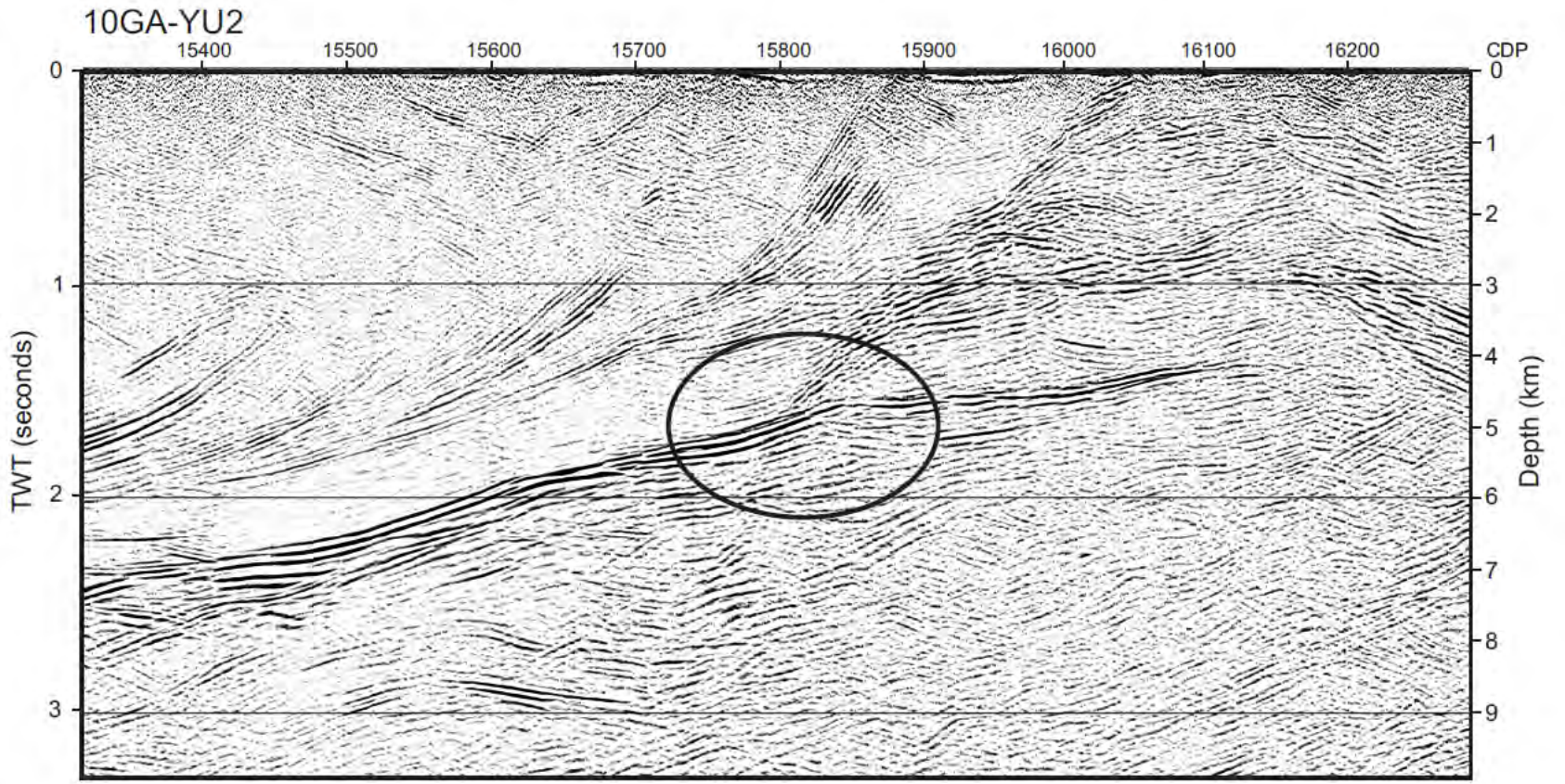


Figure 5. Detail from seismic line 10GA-YU2 showing the truncation of Archean features adjacent to the listric Waroonga Shear Zone by a Proterozoic sill.

Modelling seismic response of a mafic sill

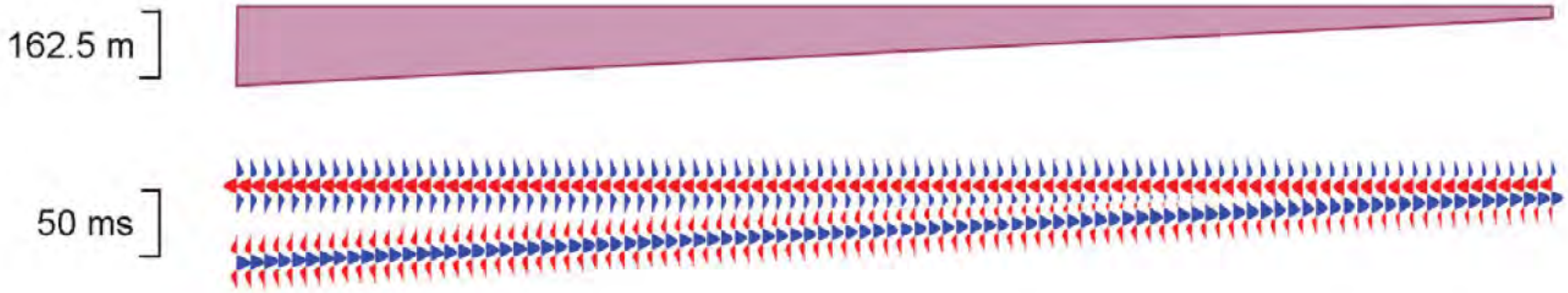


Figure 2. Modelled seismic response of a mafic sill, using a 40 Hz peak frequency zero phase Ricker wavelet. The polarity convention is that the acoustic impedance increase at the top of the sill corresponds to a trough (red). It is assumed that the impedance decreases by the same amount at the bottom of the sill, so the two reflected wavelets are equal in amplitude but opposite in polarity. The time-depth relationship uses an interval of 6500 ms-1 for the sill. The thickness of the sill decreases from 180 m to 25 m.

Analysis of real data

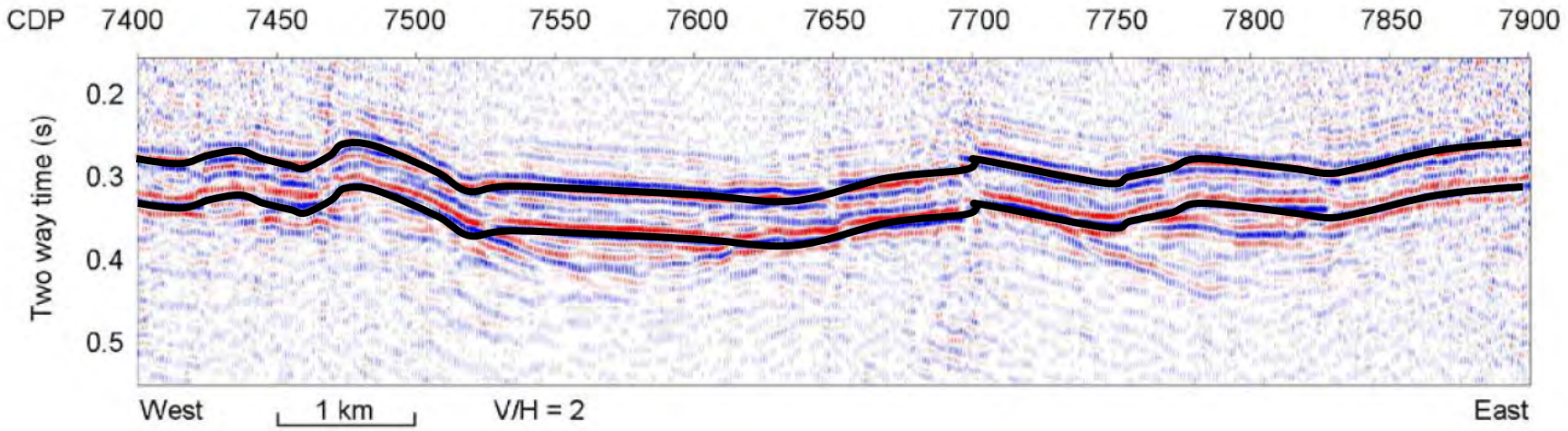
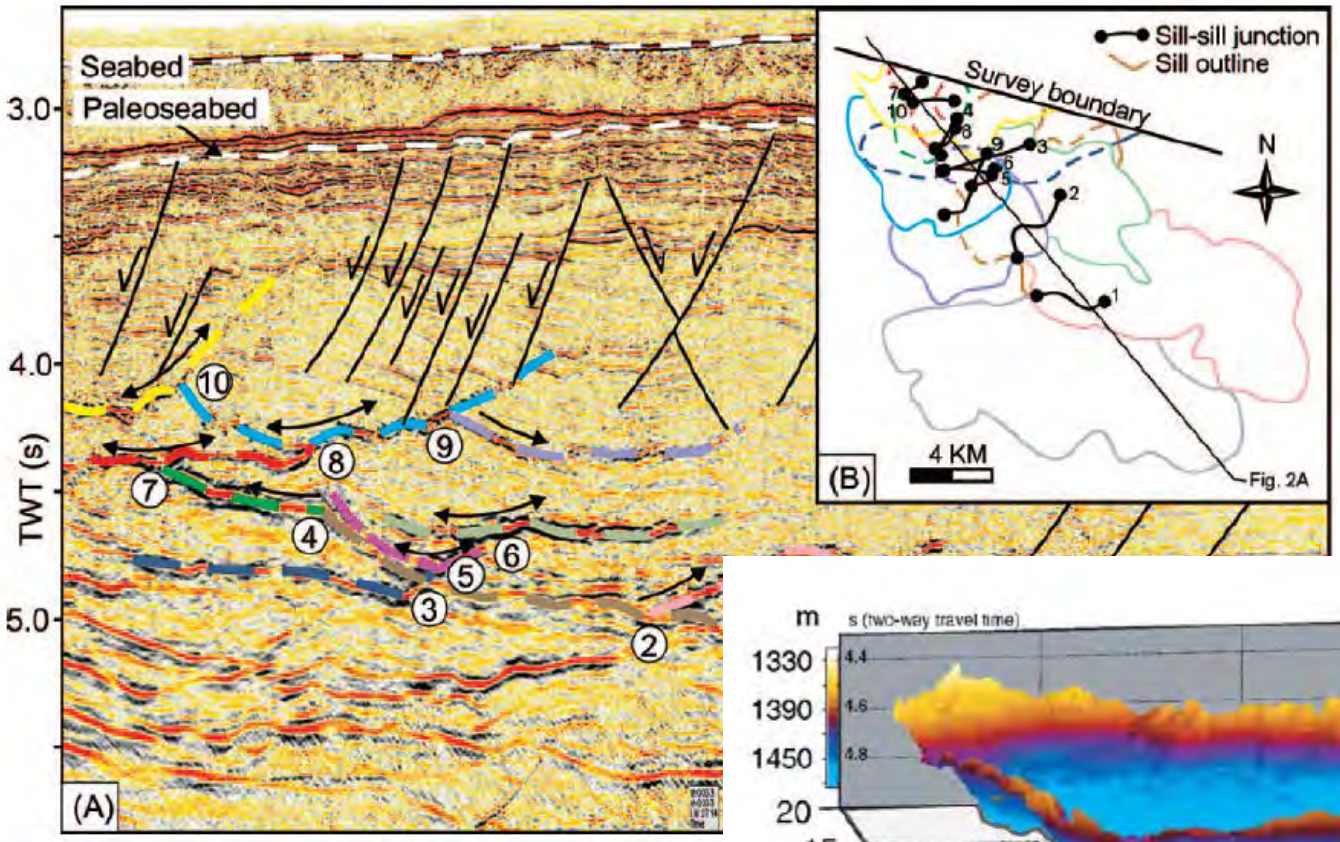


Figure 3. **Detailed image of a shallow sill on line 10GA-YU2. The vertical exaggeration is x2, assuming an average crustal velocity of 6000 ms-1. Note the reversal in polarity of the bottom reflection compared with top, as in the model in Fig. 1. The two-way travel time thickness varies from about 56 ms in the west to about 52 ms in the east. Additional stacking velocity analyses picking the top and bottom of the sill lead to an estimate of approximately 6500 ms-1 for the interval velocity.**

180m thick

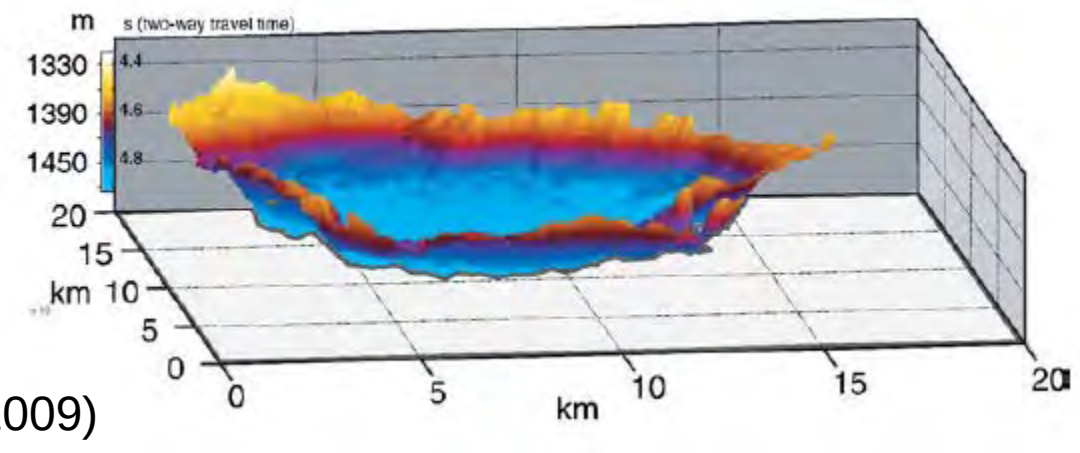
Close to // top and lower contact

Stacked Sills = efficient vertical magma transport



Cartwright and Hansen (2006)

Saucer-shaped lopoliths in 3D



Galland et al. (2009)

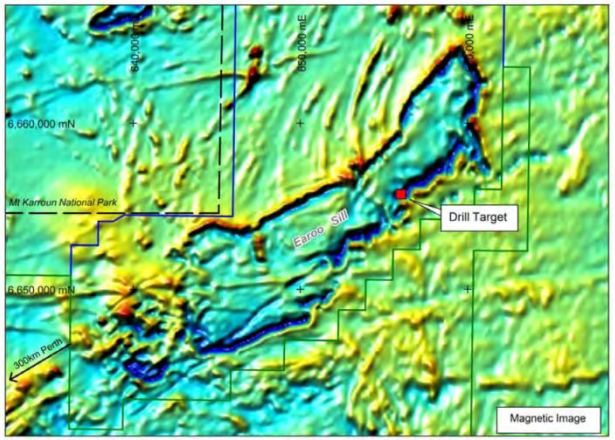
Summary

- **Age:** 1070 Ma LIP intruded N Yilgarn Craton down to 15 km
- **3D Geometry:** Interconnected lopoliths
- **Magnitude:** up to at least
  - c. 200 m thick
  - c. 200 km across

Implications — Mineralization

- 100m thick sill (S Yilgarn) with **NiS**s
- **Cu-Ni-Cr-PGE** potential at base of thicker sills
- **Ti-V** potential in fractionated rocks
- Marginal remobilization

  (**F** possible)



Regional Magnetic Image showing Earoo Sill and Location of Drill Prospect

AusQuest (2013), Earoo Project

Acknowledgements

- Leonie Jones (+modelling), Ross Costelloe
  (GA geophysical processing)
- Stephen Wyche, Ivan Zibra
  (GSWA Murchison Mapping Section)
- Mike Wingate
  (GSWA Geochronology)

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

The Geometry of the Windimurra Igneous Complex

Youanmi Seismic Workshop

Geological Survey of Western Australia

ROYALTIES FOR REGIONS

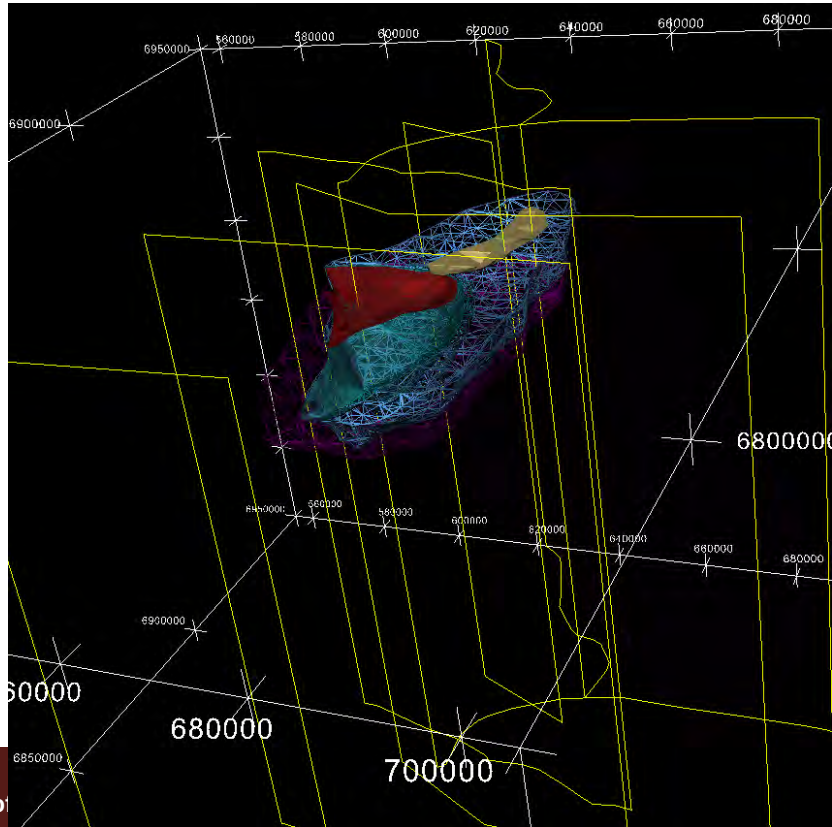
Australian Government
Geoscience Australia

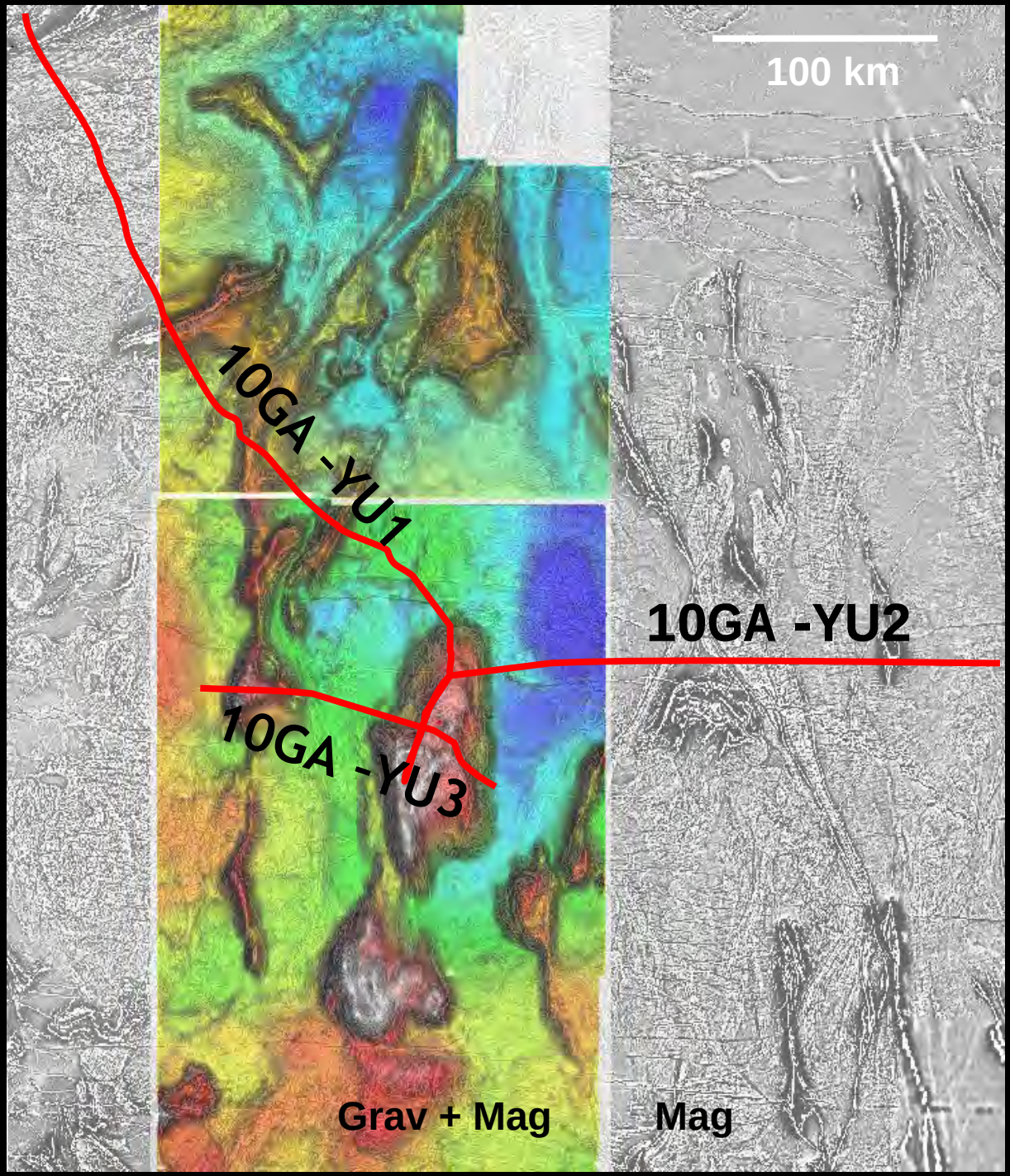
Tim Ivanic

27th Feb 2013

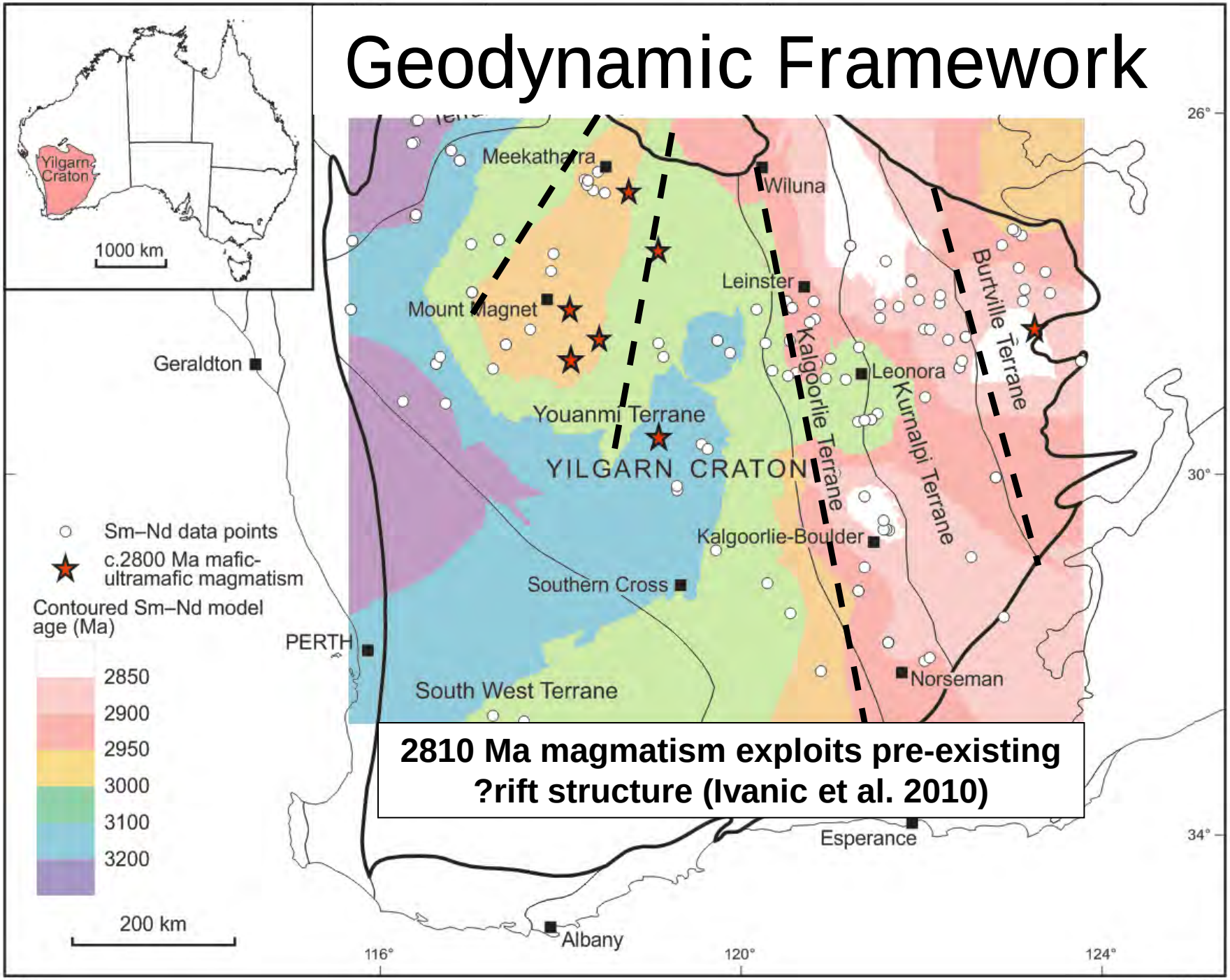
Objectives

- **Outline** current state of knowledge on the complex
- **Results** — information added by seismic data
- Towards a **3D model** ➔
- **Implications**
  - igneous processes
  - mineralisation




100 km
10GA -YU1
10GA -YU2
10GA -YU3
Grav + Mag
Mag

Geodynamic Framework



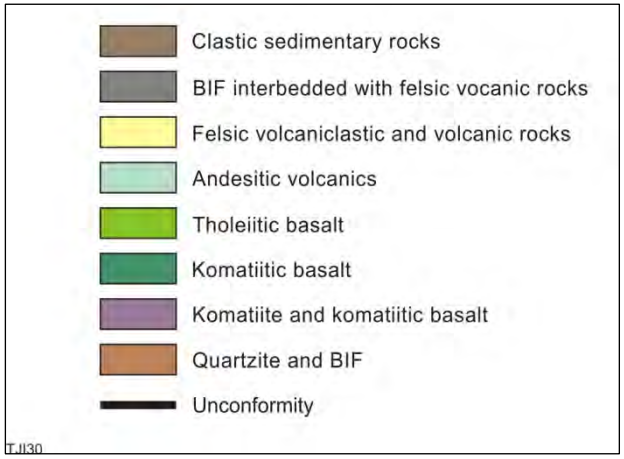
2810 Ma magmatism exploits pre-existing ?rift structure (Ivanic et al. 2010)

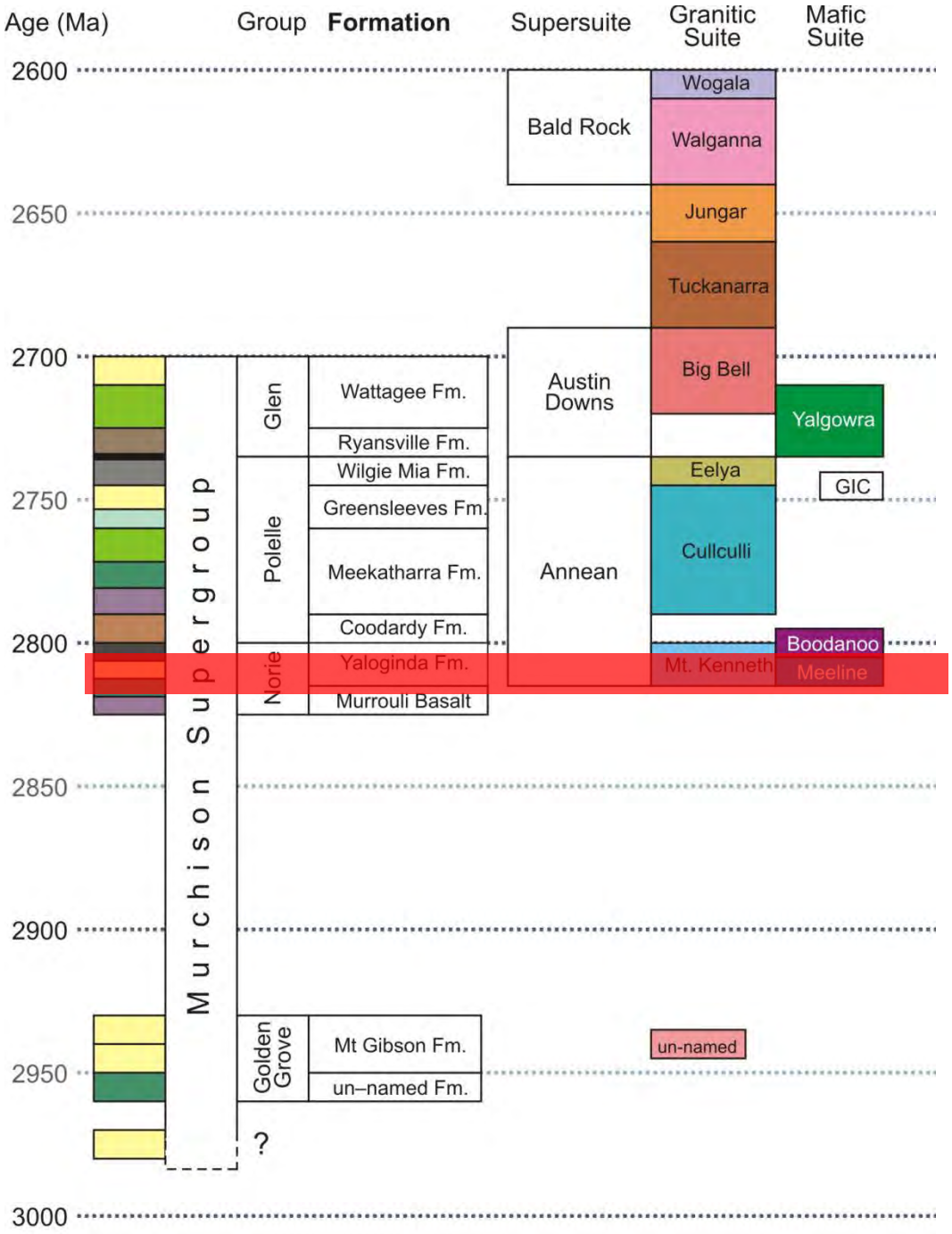
TJI3a

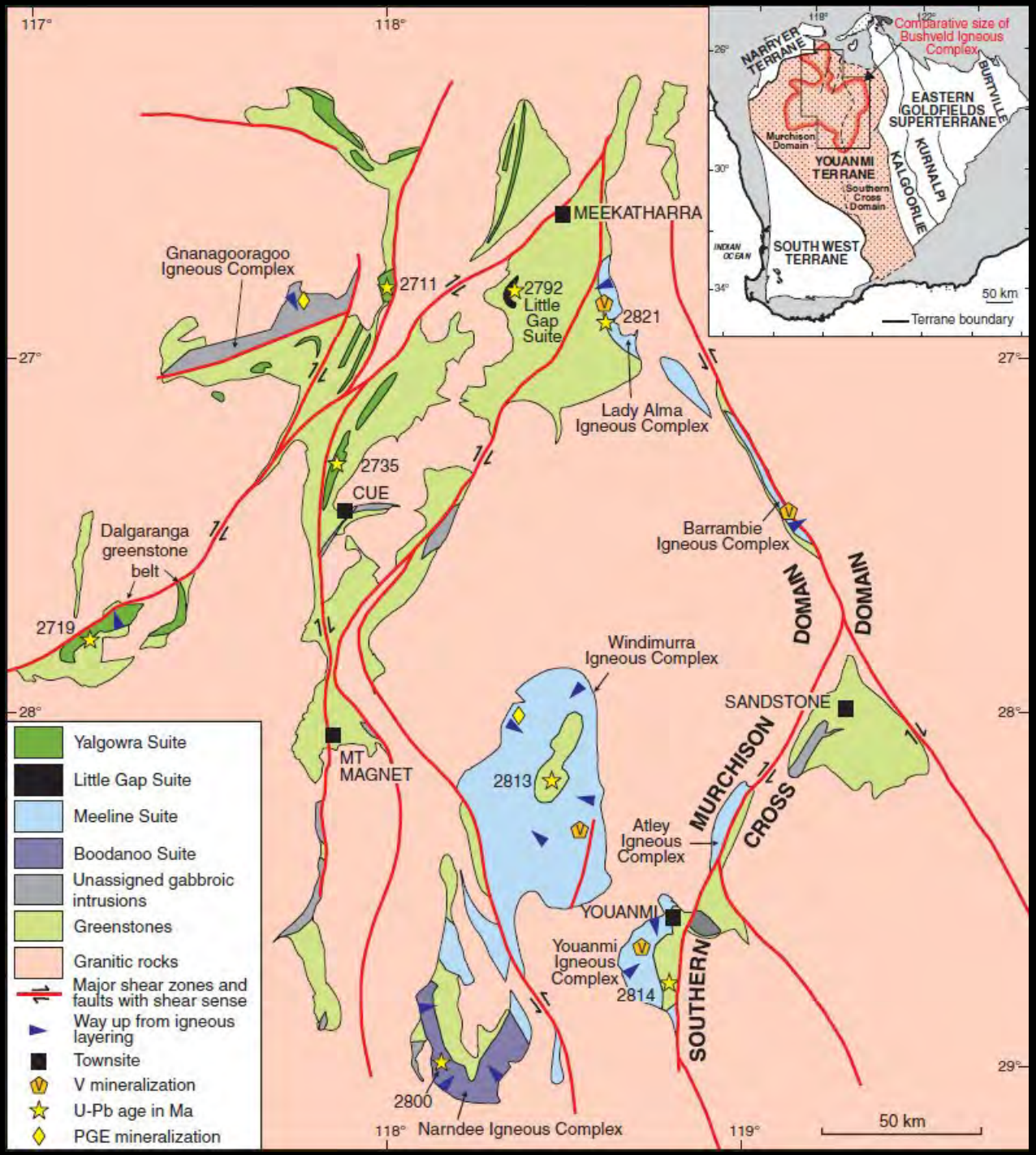
19.08.10

Stratigraphic Framework

Meeline LIP (Ivanic et al. 2012a) **2.81 Ga**
Norie Plume (Wyman et al 2012; Van Kranendonk et al. 2013)







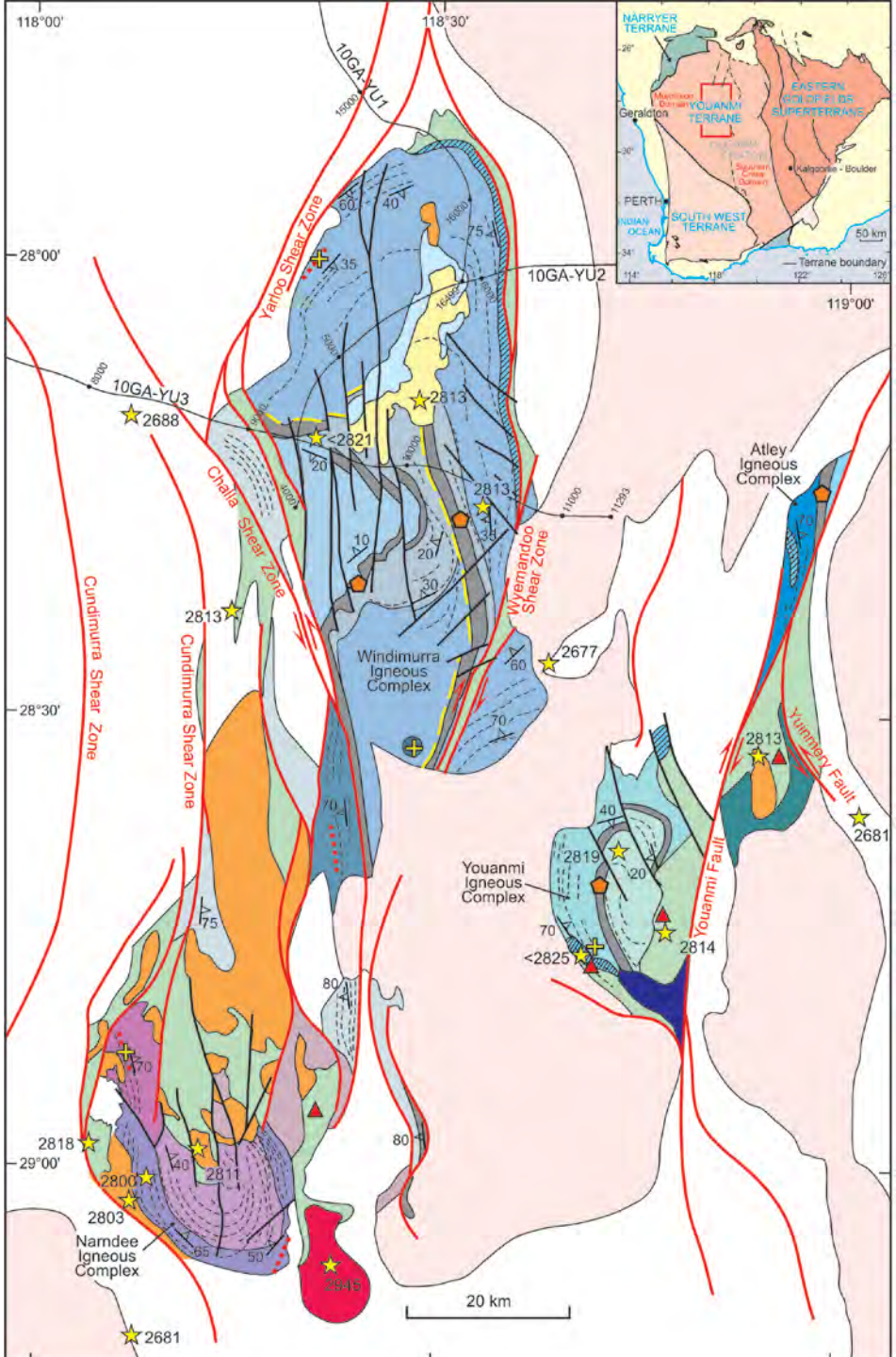
Mafic Suites

Dismembered greenstones; 2980-2710 Ma

Large layered mafic-ultramafic igneous complexes and sills;

Pulses @ c.2810 and c. 2720 Ma

"Sea" of granites; 2750-2600 Ma, isolated older occurrences



2640–2600 Ma — Bald Rock Supersuite: post-tectonic granites

2710–2640 Ma — metamonzogranites

c. 2800 Ma — Mt. Kenneth Suite: metagranitic rocks

unassigned gabbroic rocks

c. 2800 Ma Boodanoo Suite — Narndee Igneous Complex 2800 Ma:
- other gabbros
- middle zone
- lower zone
- ultramafic zone

c. 2813 Ma — Kantie Murdanna Volcanics Member

c.2810 Ma Meeline Suite:
- Atley Igneous Complex: upper zone, middle zone
- Youanmi Igneous Complex 2819 Ma: upper zone, middle zone, lower zone
- Windimurra Igneous Complex 2813 Ma: other gabbros, roof zone, upper zone, middle zone, lower zone, ultramafic zone, Corner Well Gabbro, border group dolerites, magnetitite-bearing rocks

c. 2820 – 2810 Ma — greenstone supracrustal lithologies

c. 2950 Ma — granite gneiss

Geochronology sample site showing age in Ma

V mineralization

Cu-Zn mineralization

PGE (Ni, Cu, Cr) mineralization

20 Igneous layering (right way up)

Chromitite seam

Fault

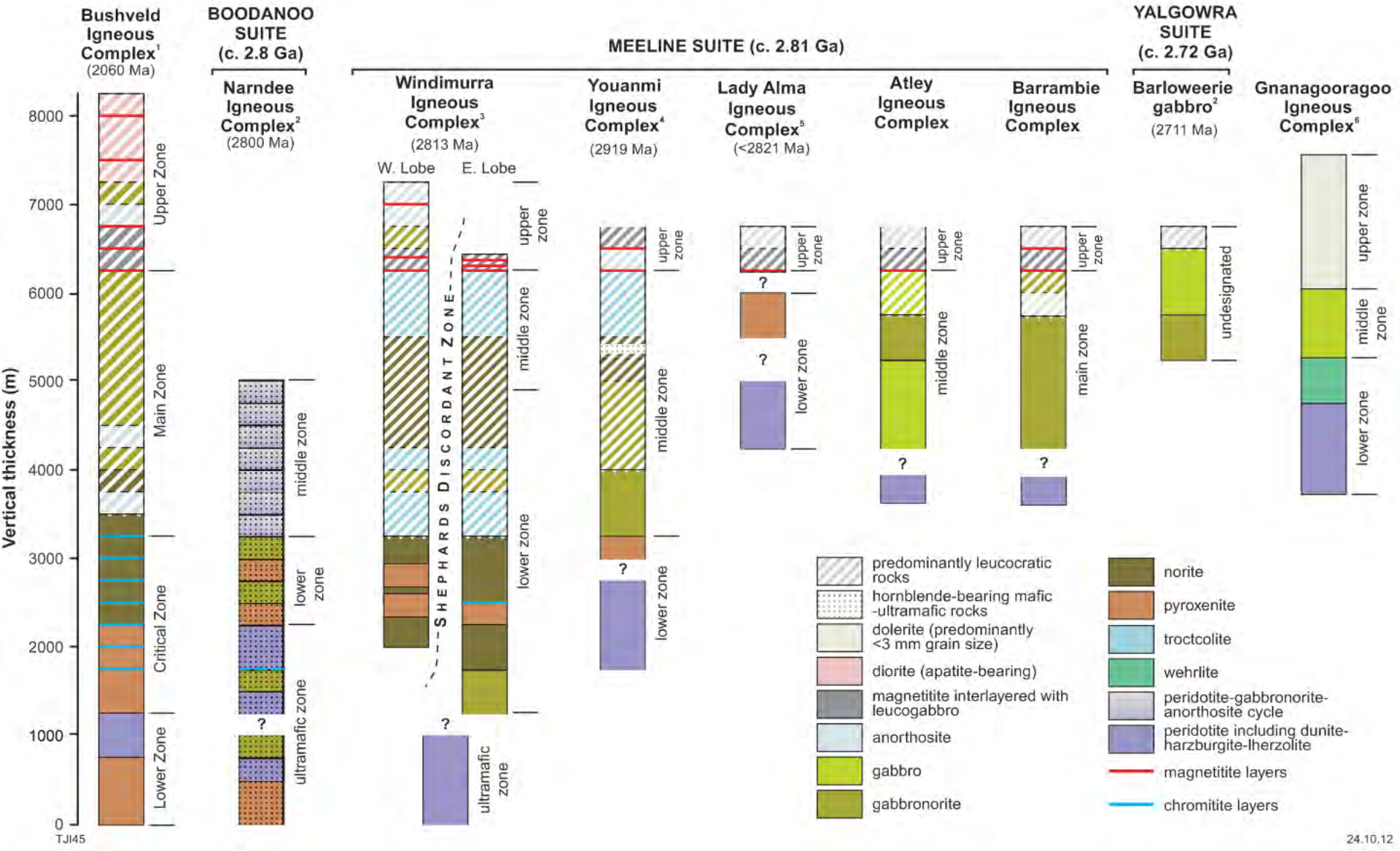
Shear zone showing sense of movement

Trend of igneous layering

Magmatic discordant zone (Shephards Discordant Zone)

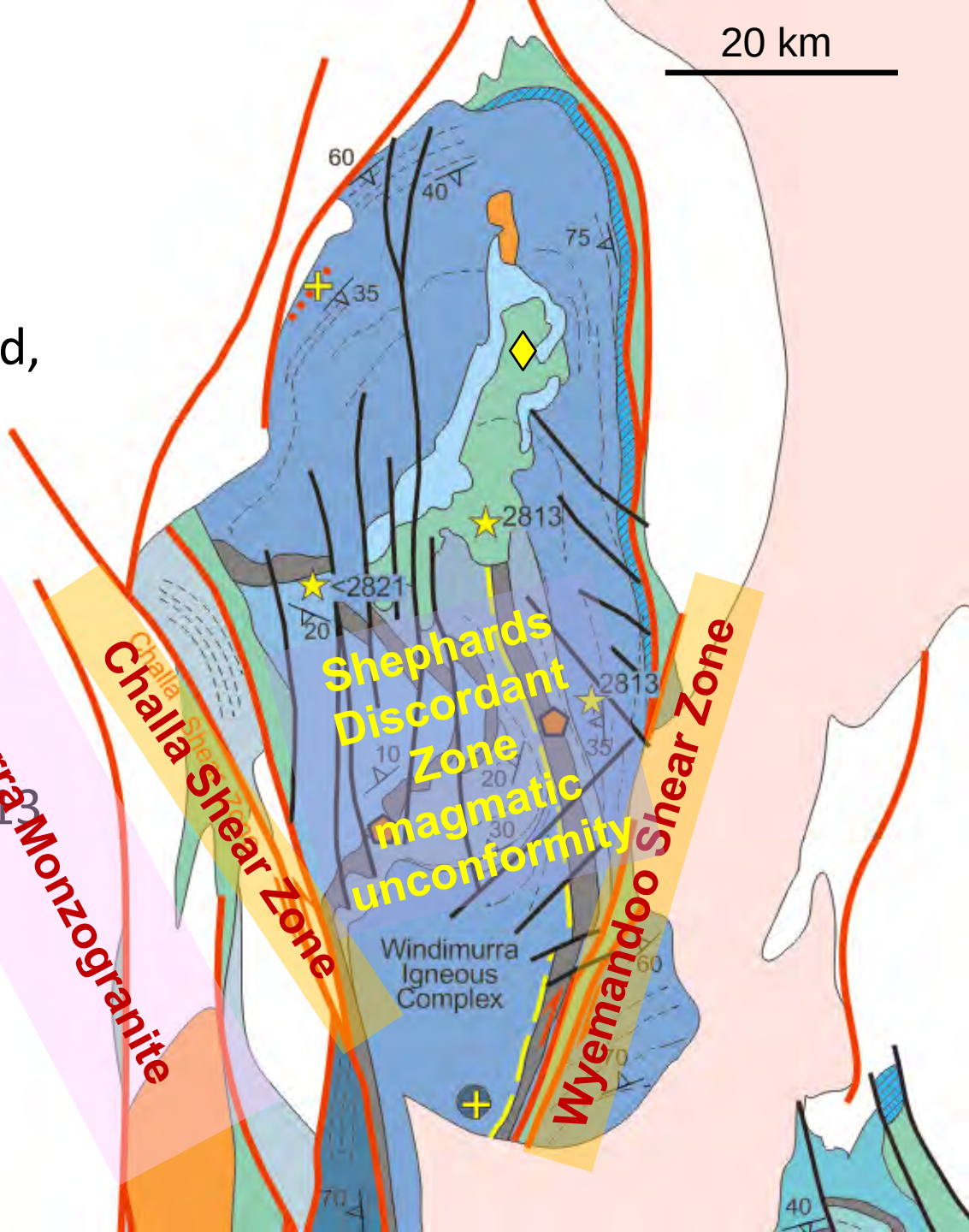
Seismic line, with CDP points

TJ/04 04.1.12

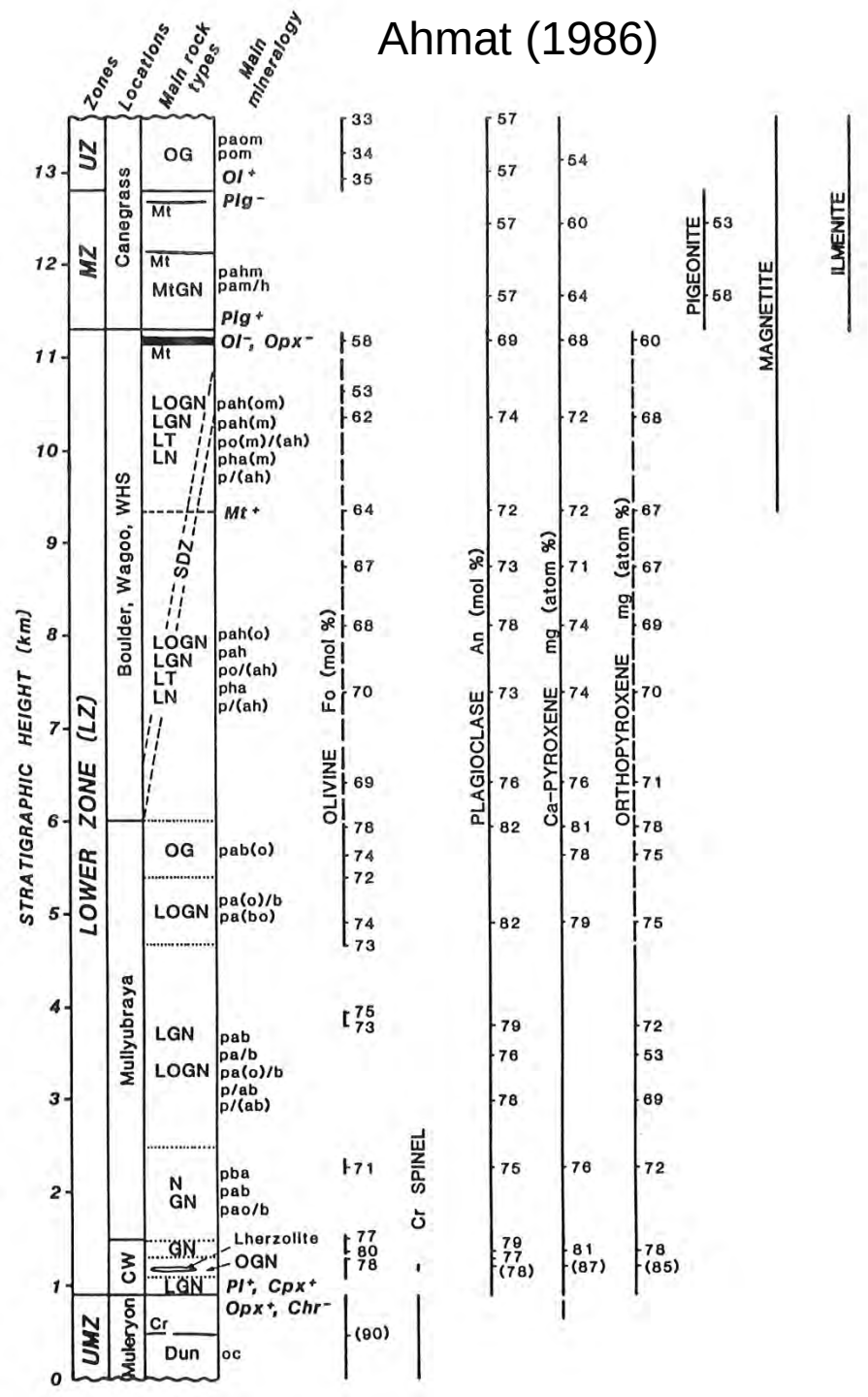


After Ivanic et al. (2010)

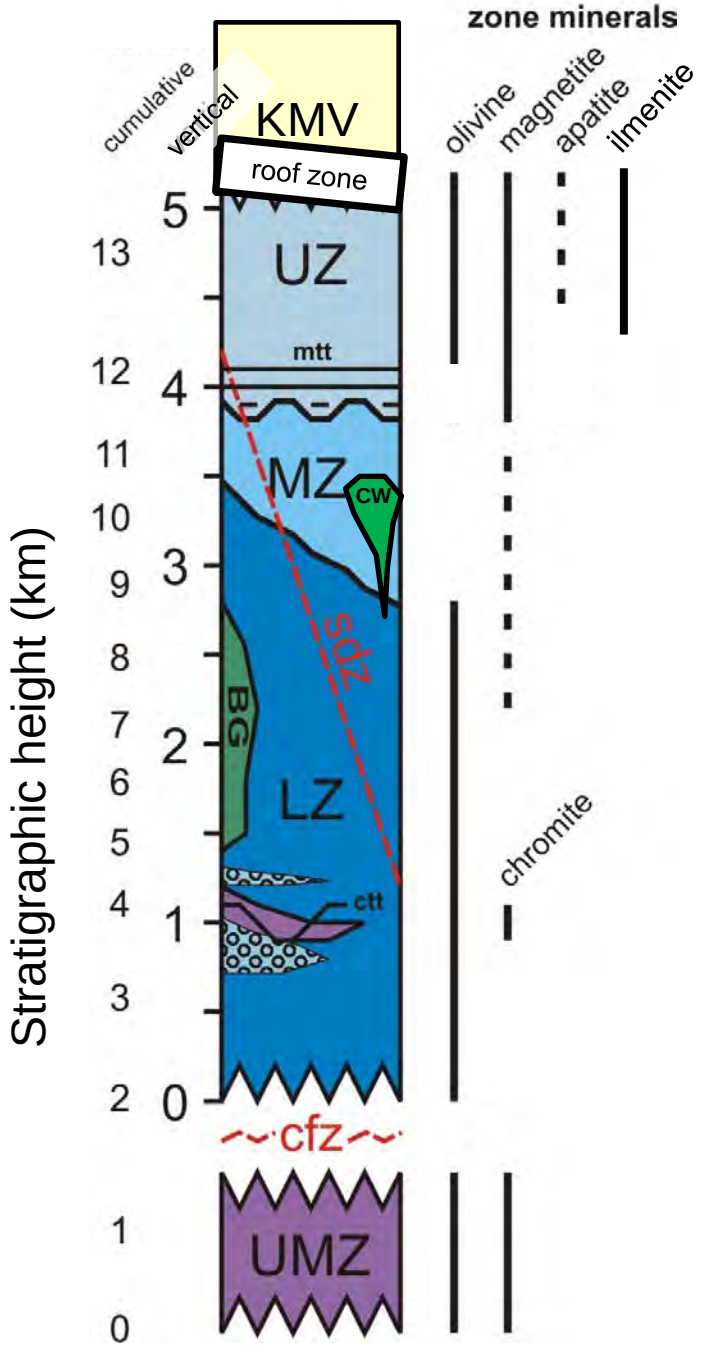
- Cumulate layering
  - Modal, rhythmic, graded, cryptic
  - Megacyclic units
- Discordant features
  - Estimated vertical thickness ~7 km
  - Cumulative thickness ~13 km
- Structural complexity



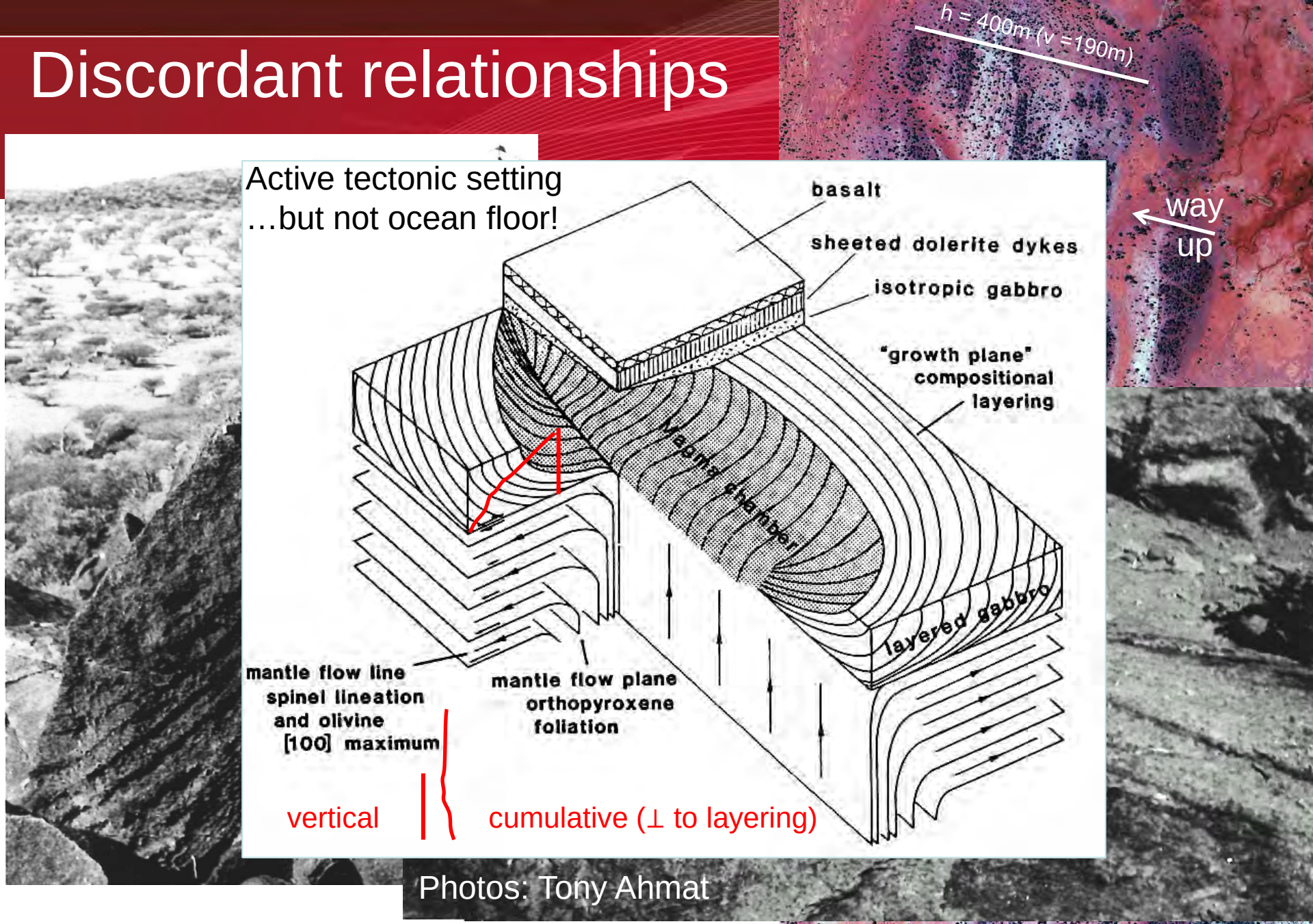
Ahmat (1986)



Ivanic (in prep.)

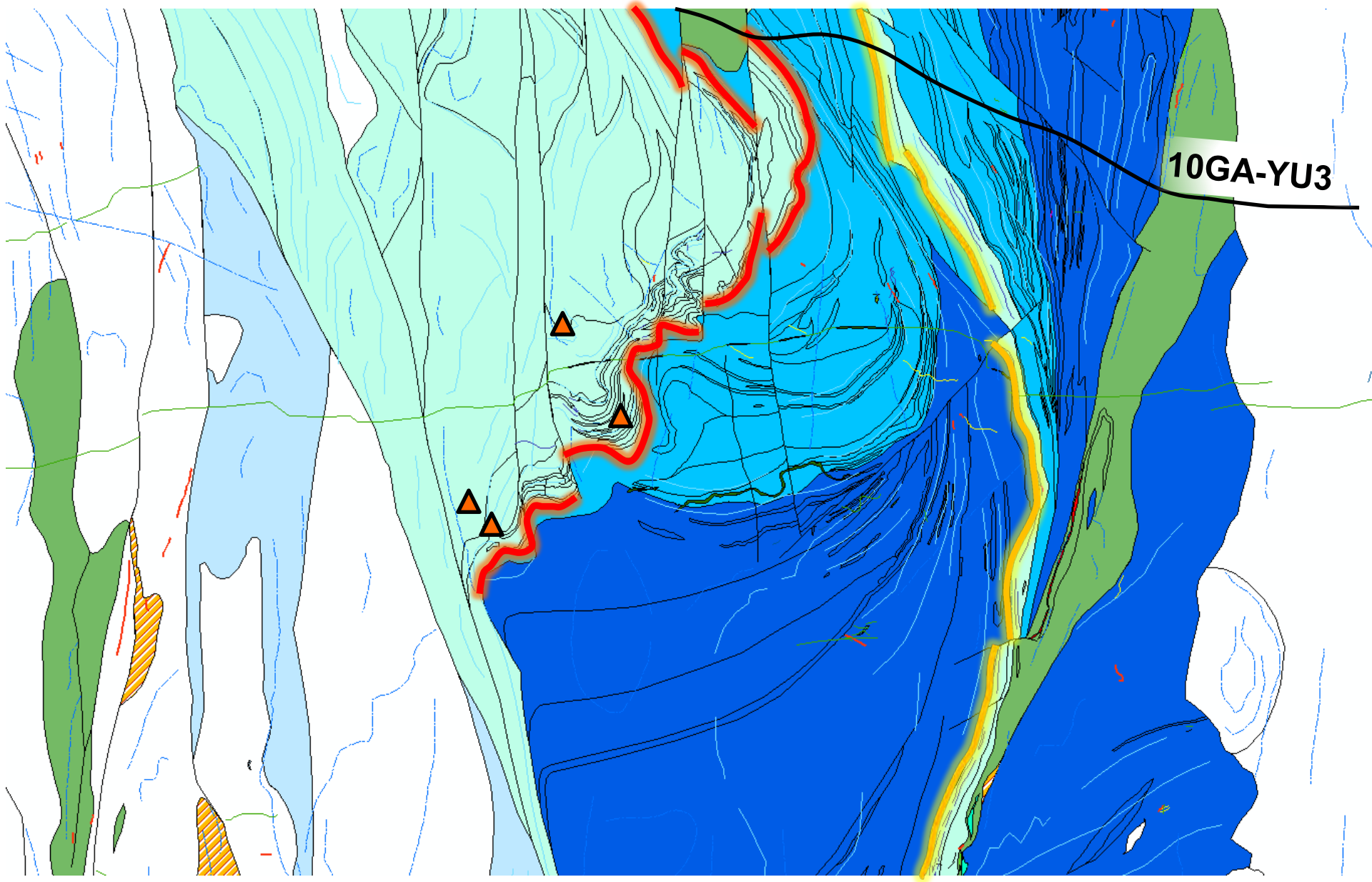


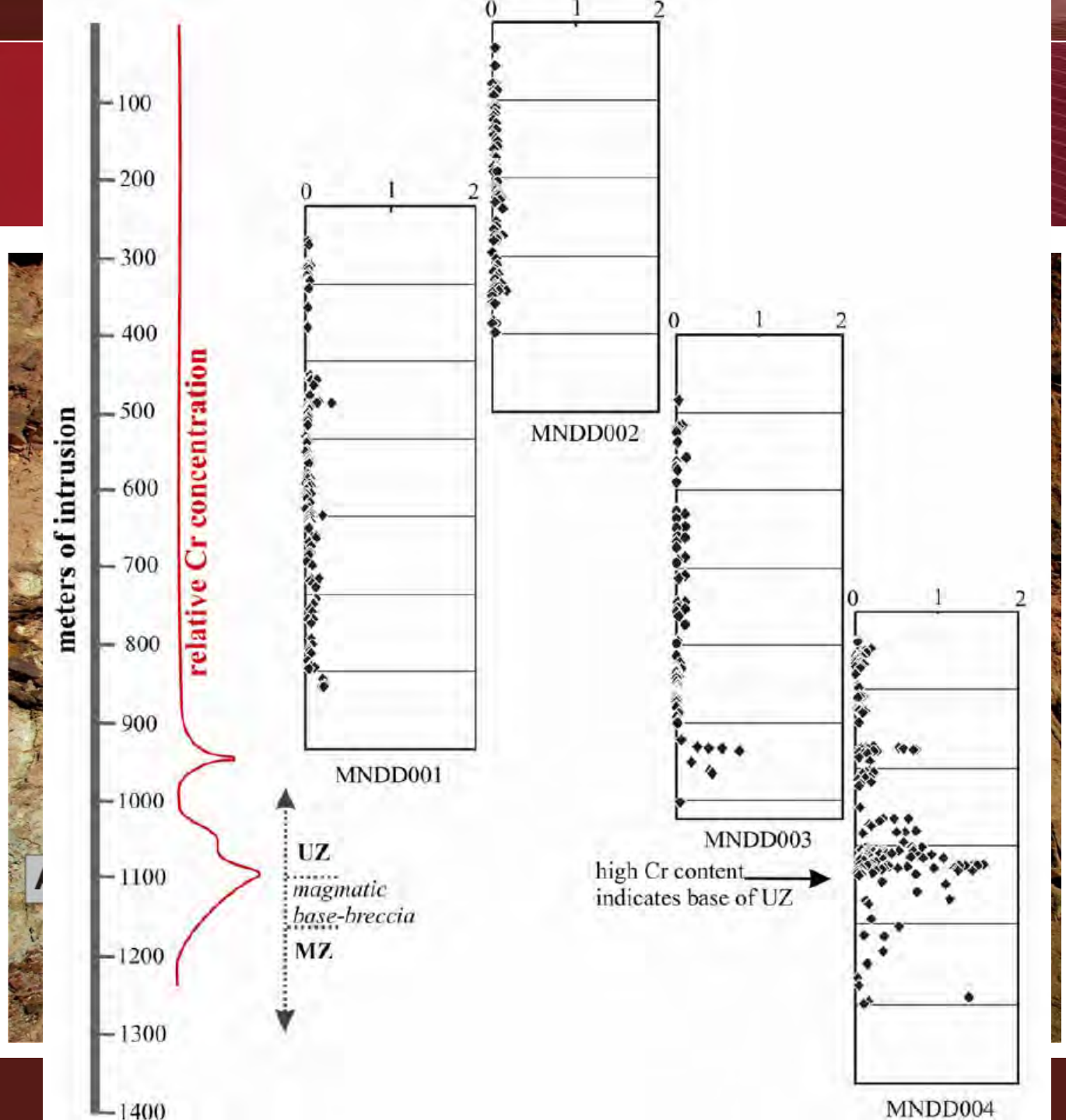
Discordant relationships



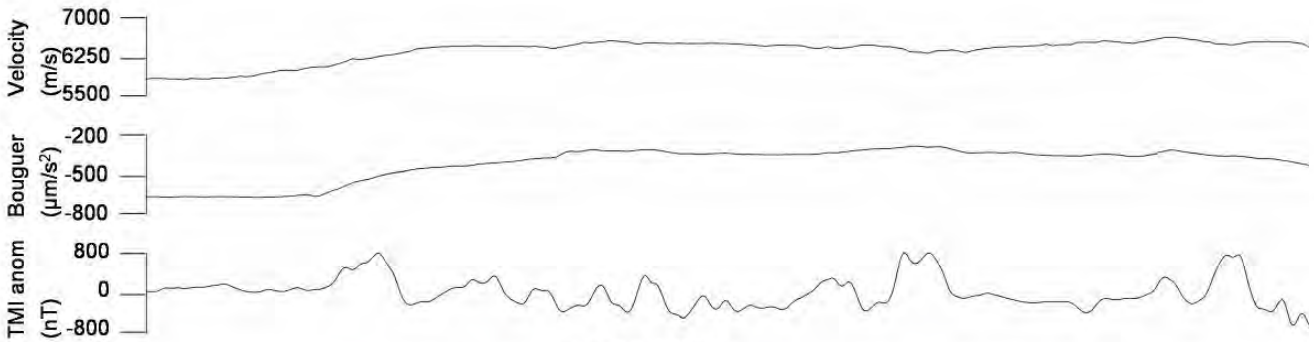
Photos: Tony Ahmat

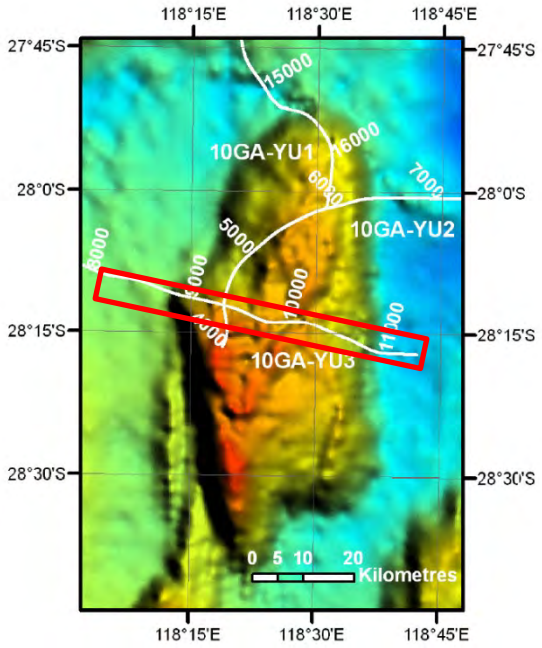
Windimurra Hills section

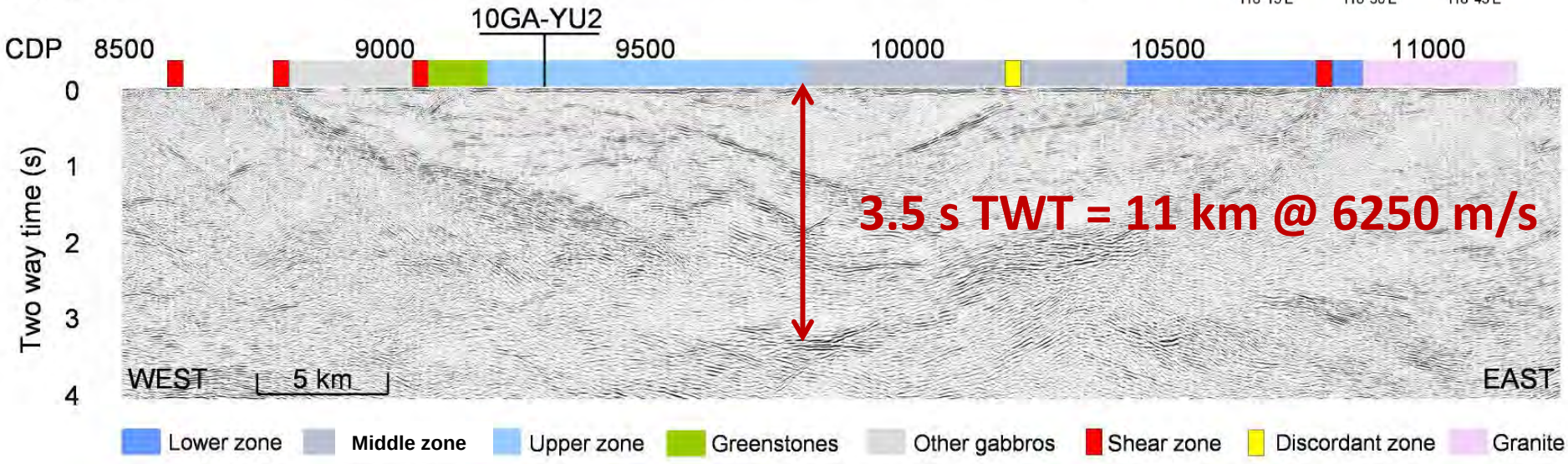

10GA-YU3
Maximus Resources diamond drill core
10 km


meters of intrusion
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
relative Cr concentration
0
1
2
MNDD001
MNDD002
MNDD003
MNDD004
UZ
magmatic
base-breccia
MZ
high Cr content
indicates base of UZ

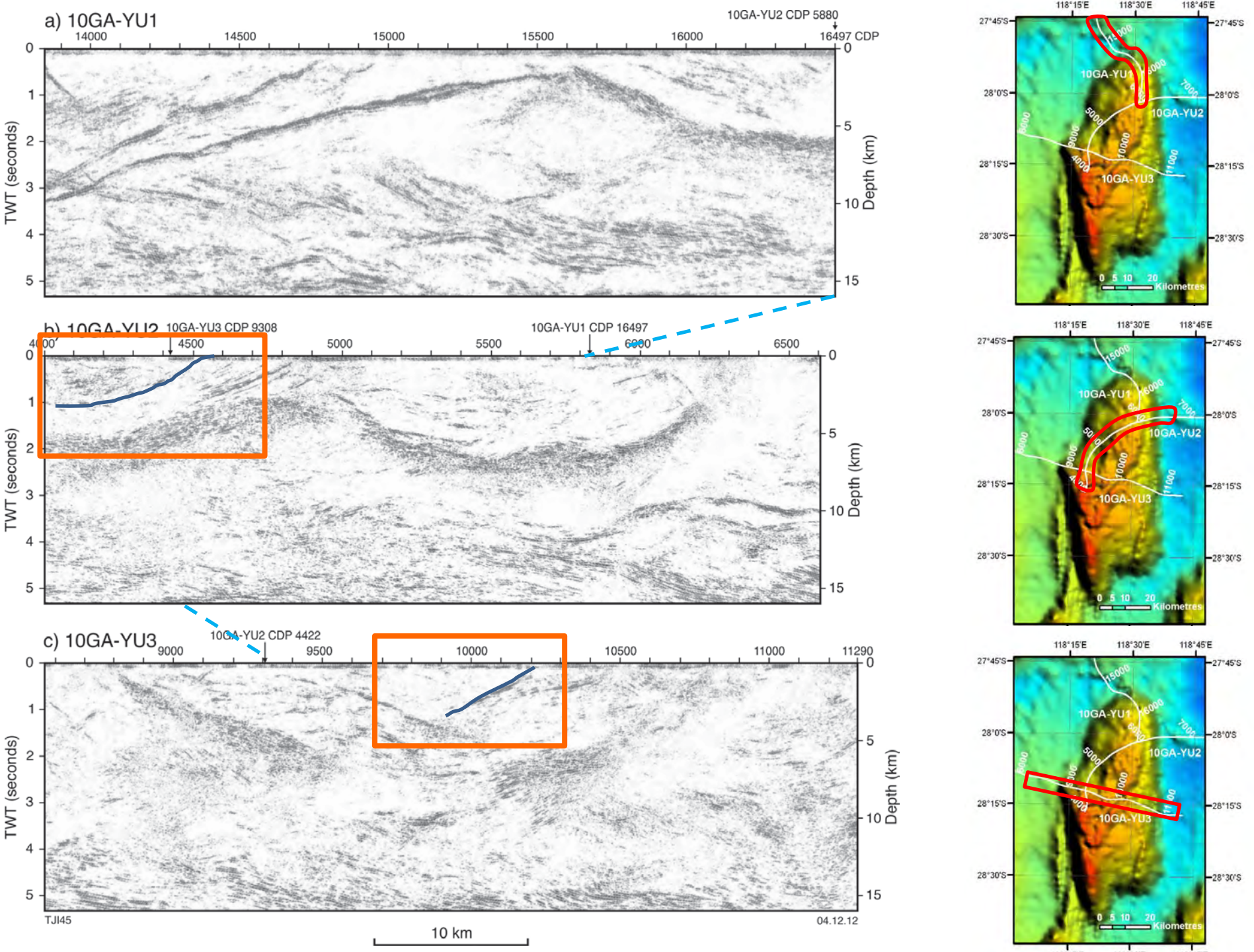
Seismic observations



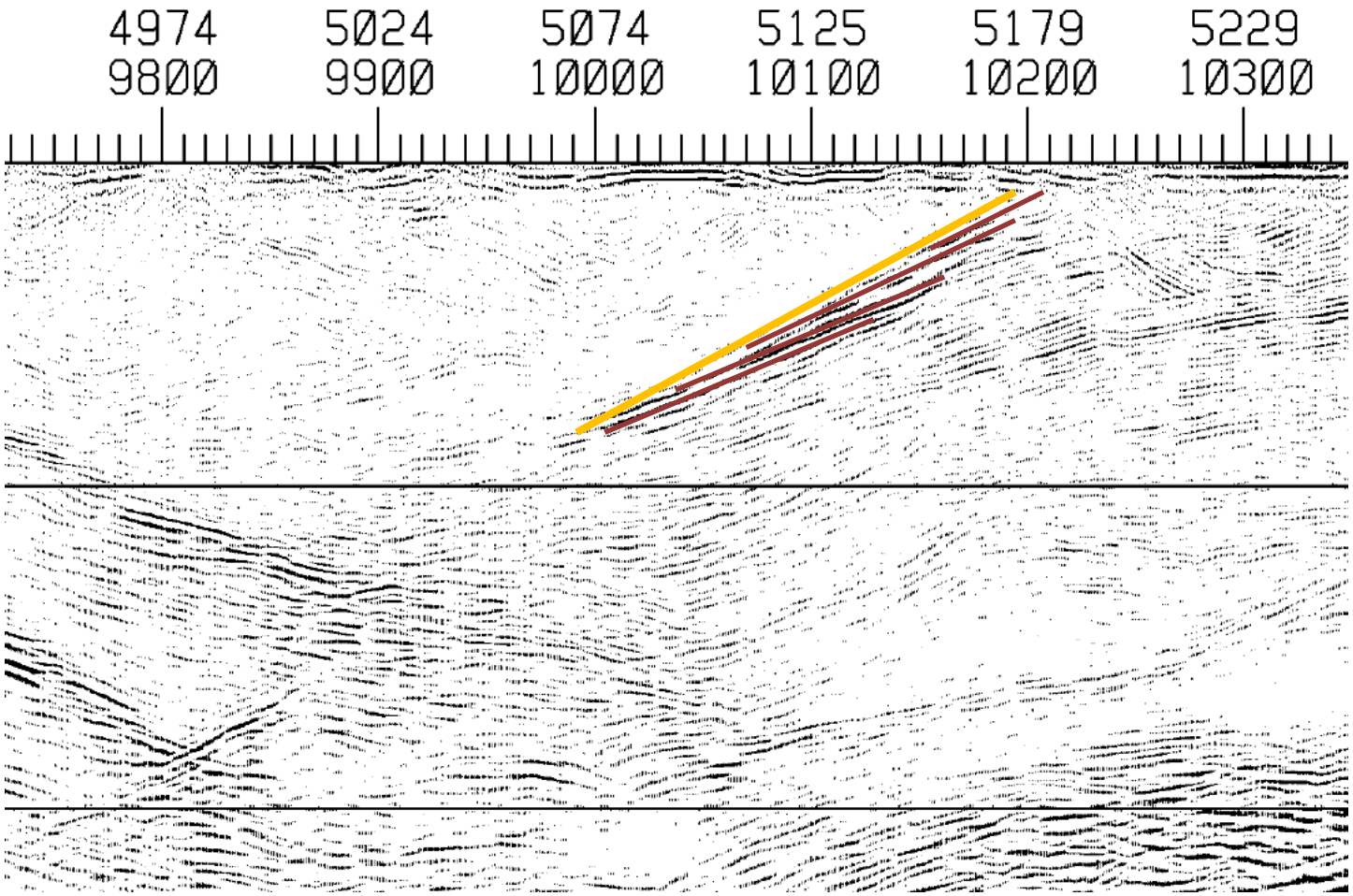




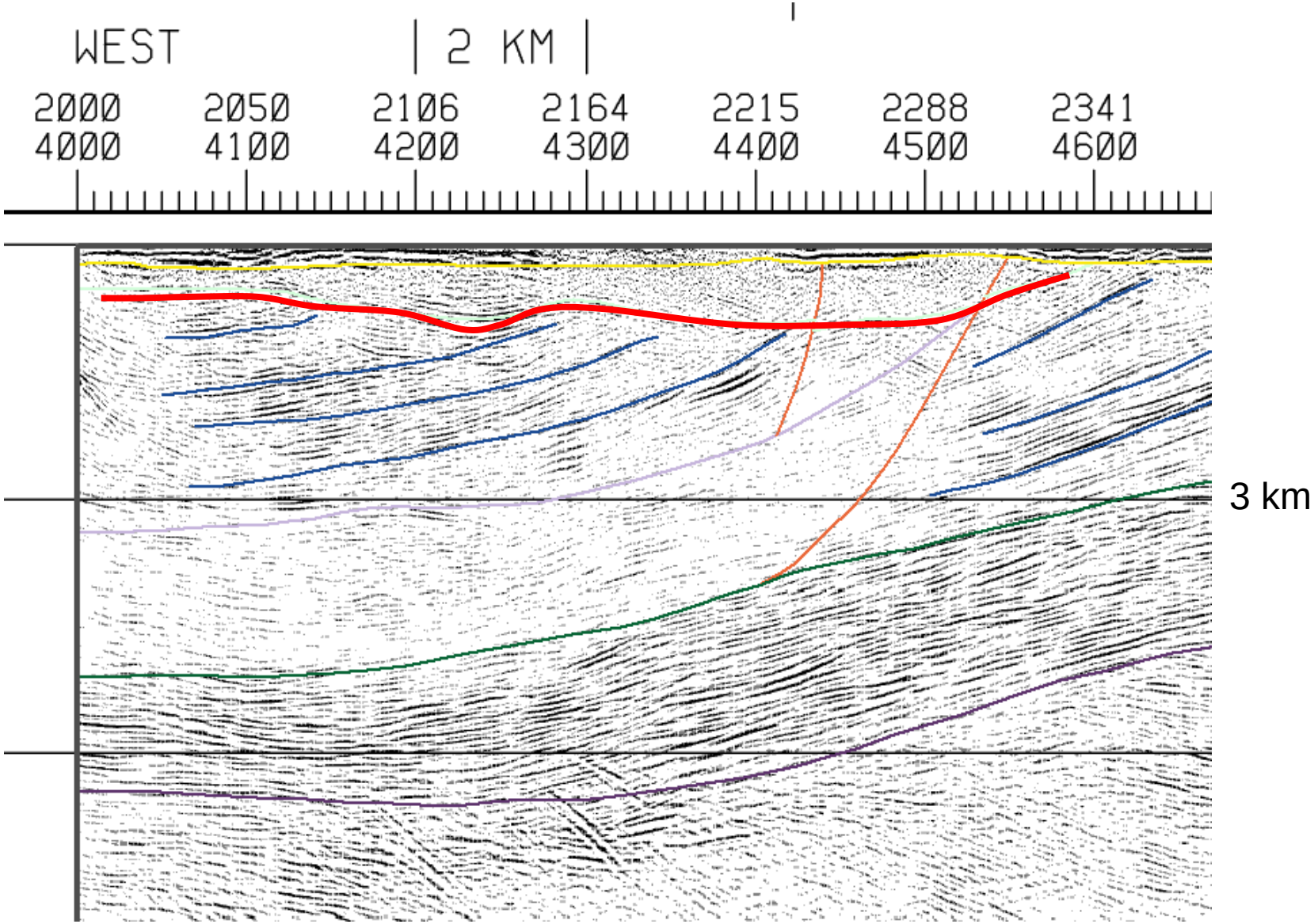
Jones, Ivanic, Costelloe (2012)

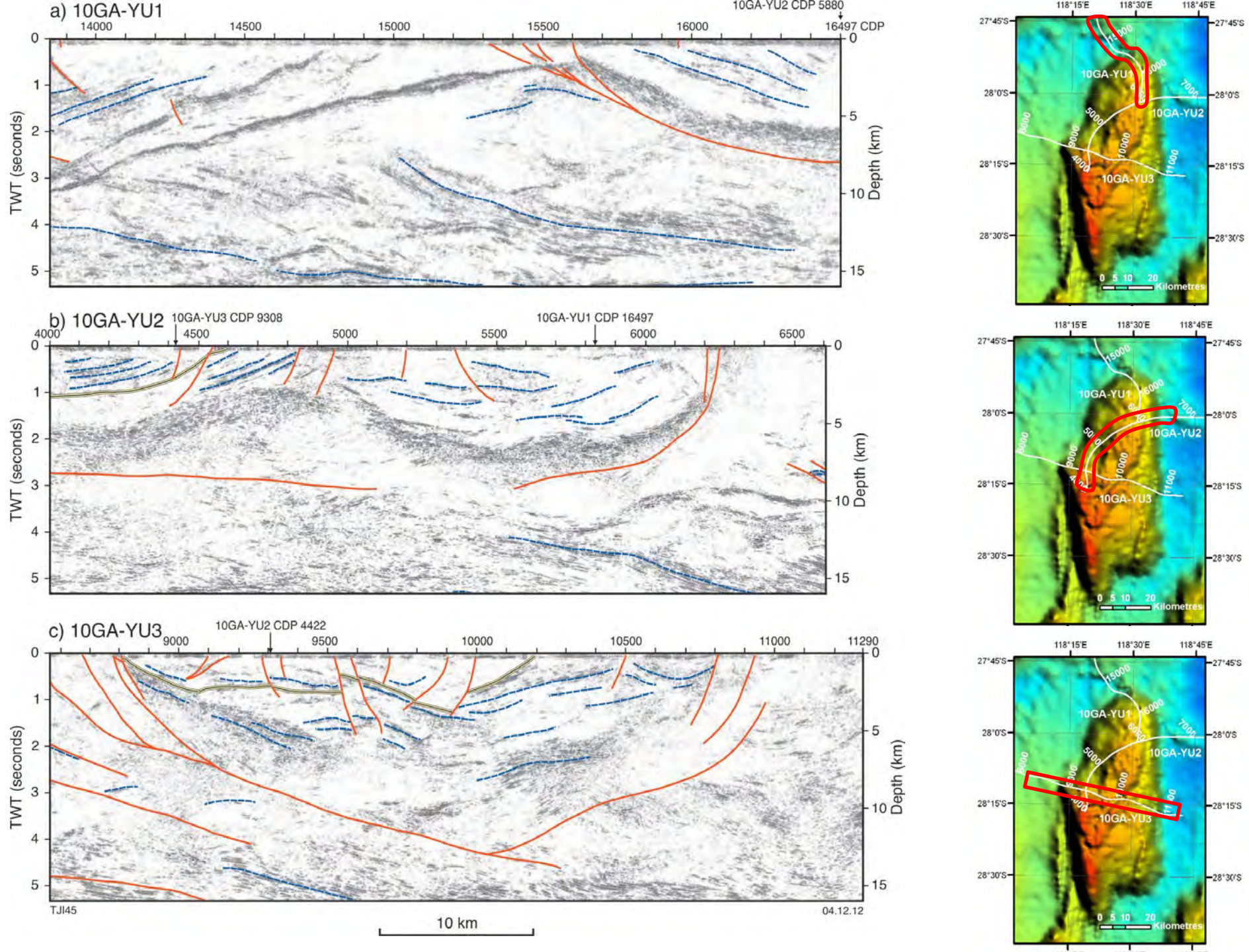

a) 10GA-YU1
10GA-YU2 CDP 5880
16497 CDP
14000
14500
15000
15500
16000
TWT (seconds)
Depth (km)
b) 10GA-YU2
10GA-YU3 CDP 9308
10GA-YU1 CDP 16497
4500
5000
5500
6000
6500
c) 10GA-YU3
10GA-YU2 CDP 4422
9000
9500
10000
10500
11000
11290
TJI45
04.12.12
10 km
118°15'E
118°30'E
118°45'E
27°45'S
28°0'S
28°15'S
28°30'S
10GA-YU1
10GA-YU2
10GA-YU3
0 5 10 20
Kilometres

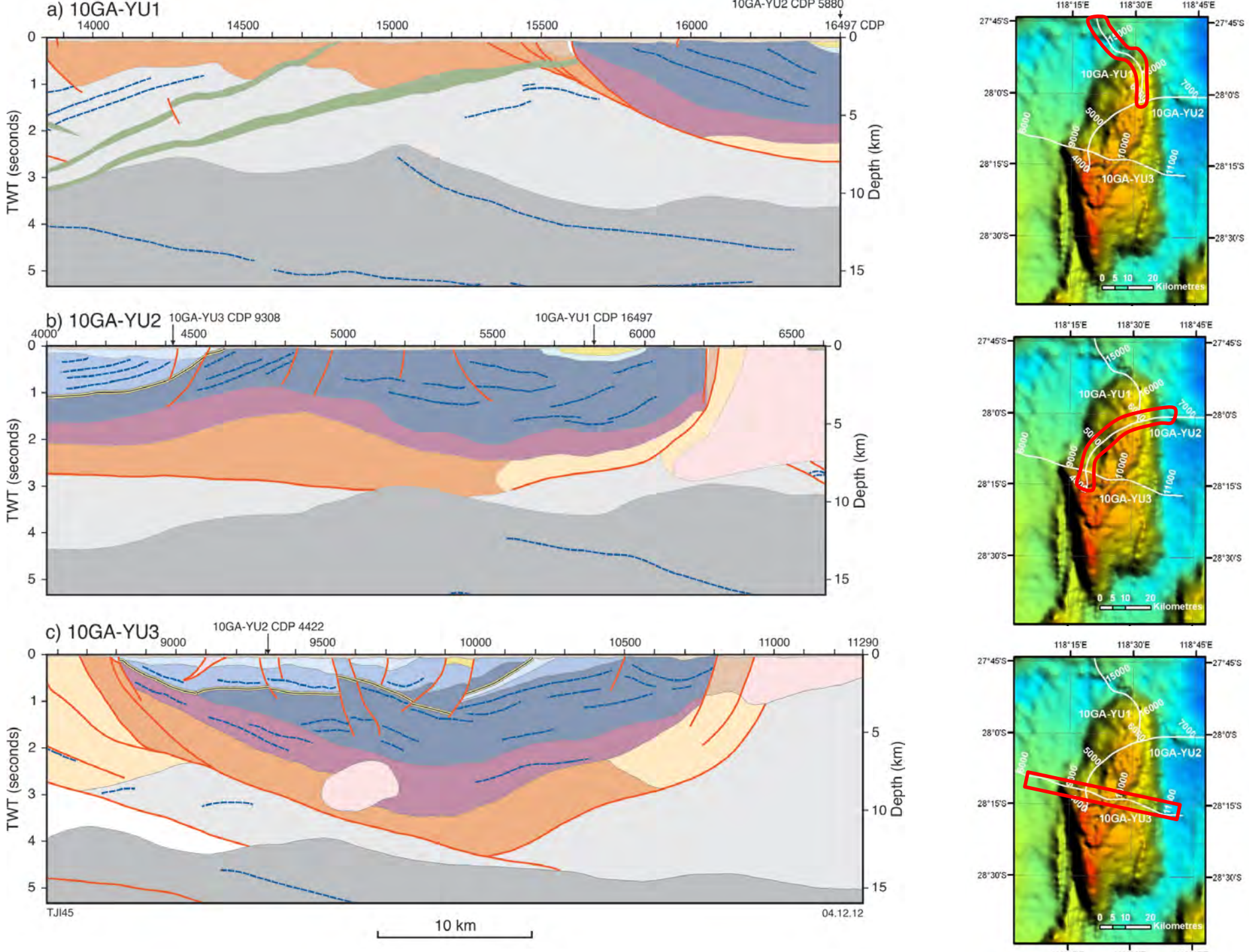
Detail top 2 s TWT, 10GA-YU3

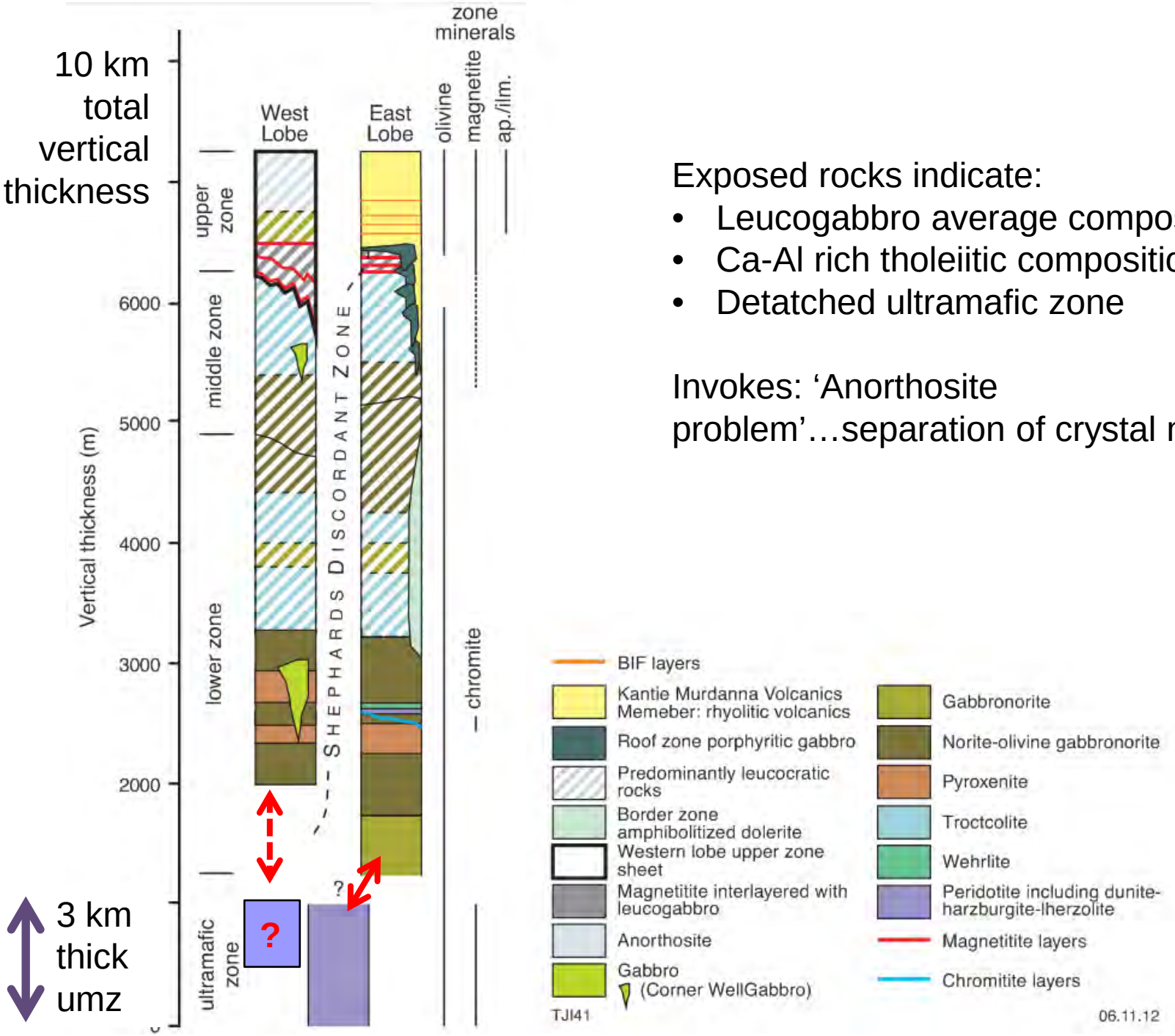


Detail top 2 s TWT, 10GA-YU2




a) 10GA-YU1
10GA-YU2 CDP 5880
14000
14500
15000
15500
16000
16497 CDP
TWT (seconds)
Depth (km)
b) 10GA-YU2
10GA-YU3 CDP 9308
10GA-YU1 CDP 16497
4000
4500
5000
5500
6000
6500
c) 10GA-YU3
10GA-YU2 CDP 4422
9000
9500
10000
10500
11000
11290
TJI45
04.12.12
10 km
118°15'E
118°30'E
118°45'E
27°45'S
28°0'S
28°15'S
28°30'S
10GA-YU1
10GA-YU2
10GA-YU3
0 5 10 20
Kilometres

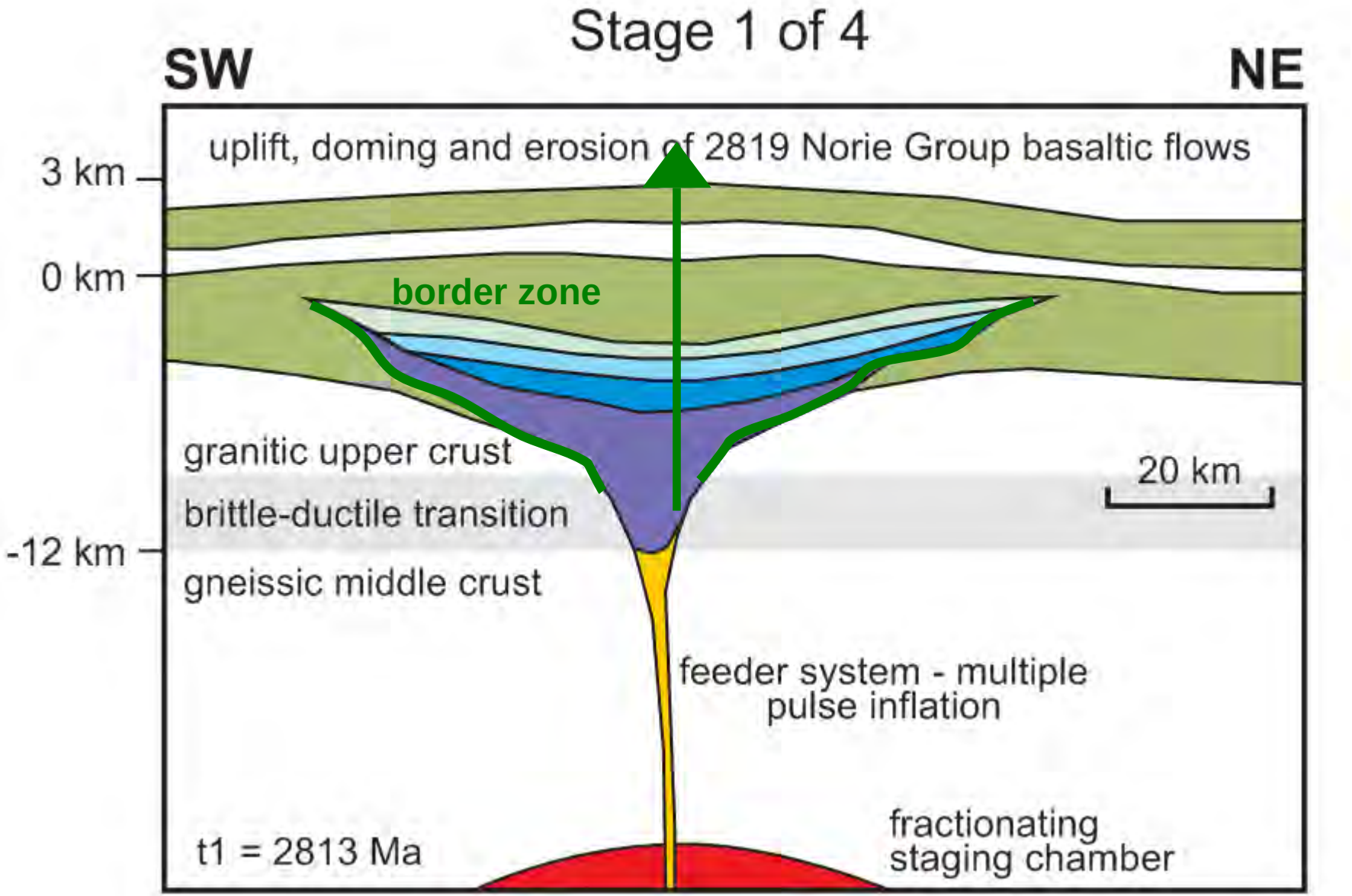

a) 10GA-YU1
10GA-YU2 CDP 5880
14000
14500
15000
15500
16000
16497 CDP
TWT (seconds)
Depth (km)
b) 10GA-YU2
10GA-YU3 CDP 9308
10GA-YU1 CDP 16497
4000
4500
5000
5500
6000
6500
c) 10GA-YU3
10GA-YU2 CDP 4422
9000
9500
10000
10500
11000
11290
TJI45
04.12.12
10 km
118°15'E
118°30'E
118°45'E
27°45'S
28°0'S
28°15'S
28°30'S
10GA-YU1
10GA-YU2
10GA-YU3
0 5 10 20
Kilometres



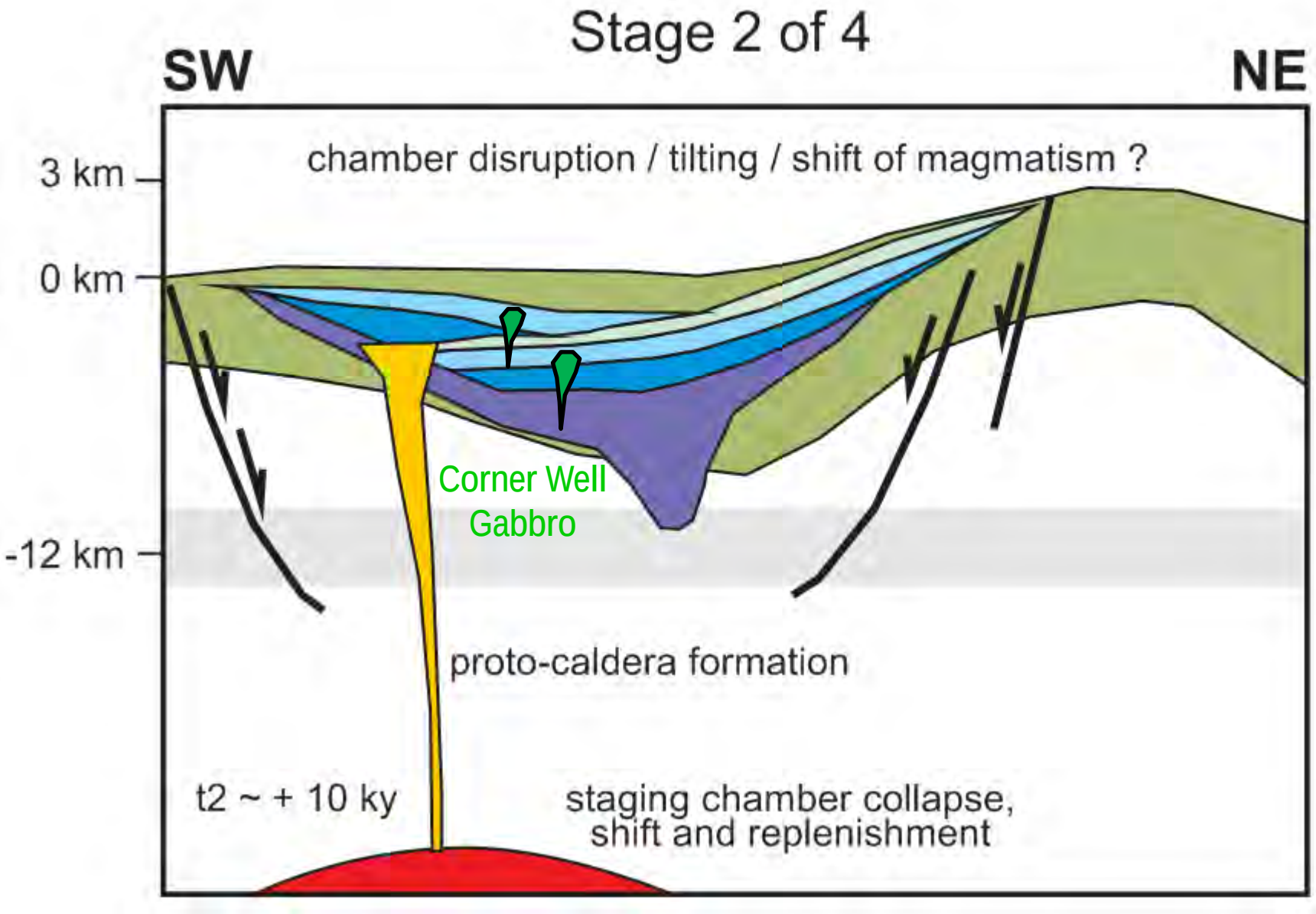
Exposed rocks indicate:

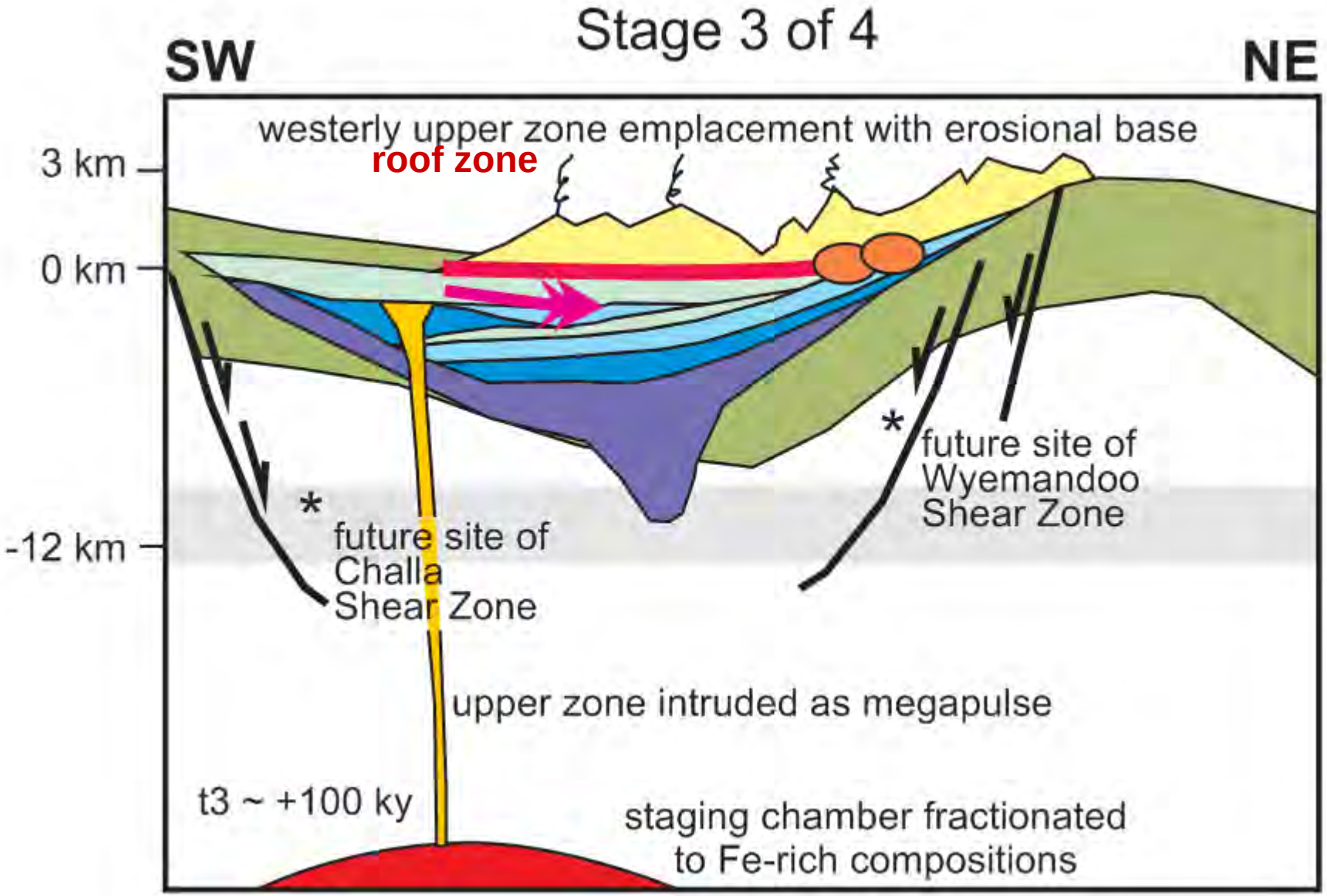
- Leucogabbro average composition
- Ca-Al rich tholeiitic composition
- Detatched ultramafic zone

Invokes: ‘Anorthosite problem’…separation of crystal mush

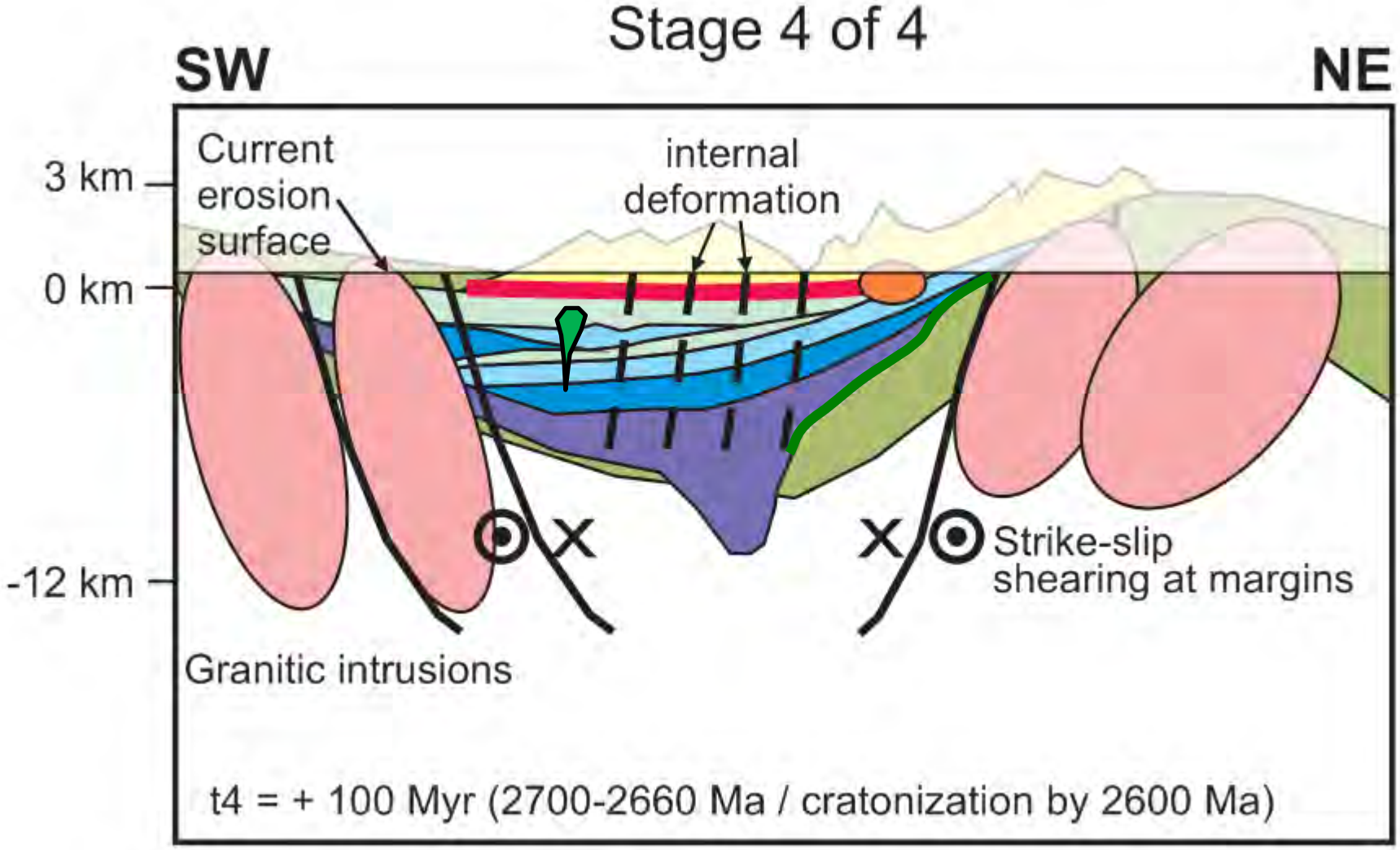

Stage 1 of 4
SW
NE
uplift, doming and erosion of 2819 Norie Group basaltic flows
3 km
0 km
-12 km
border zone
granitic upper crust
brittle-ductile transition
gneissic middle crust
20 km
feeder system - multiple
pulse inflation
fractionating
staging chamber
t1 = 2813 Ma

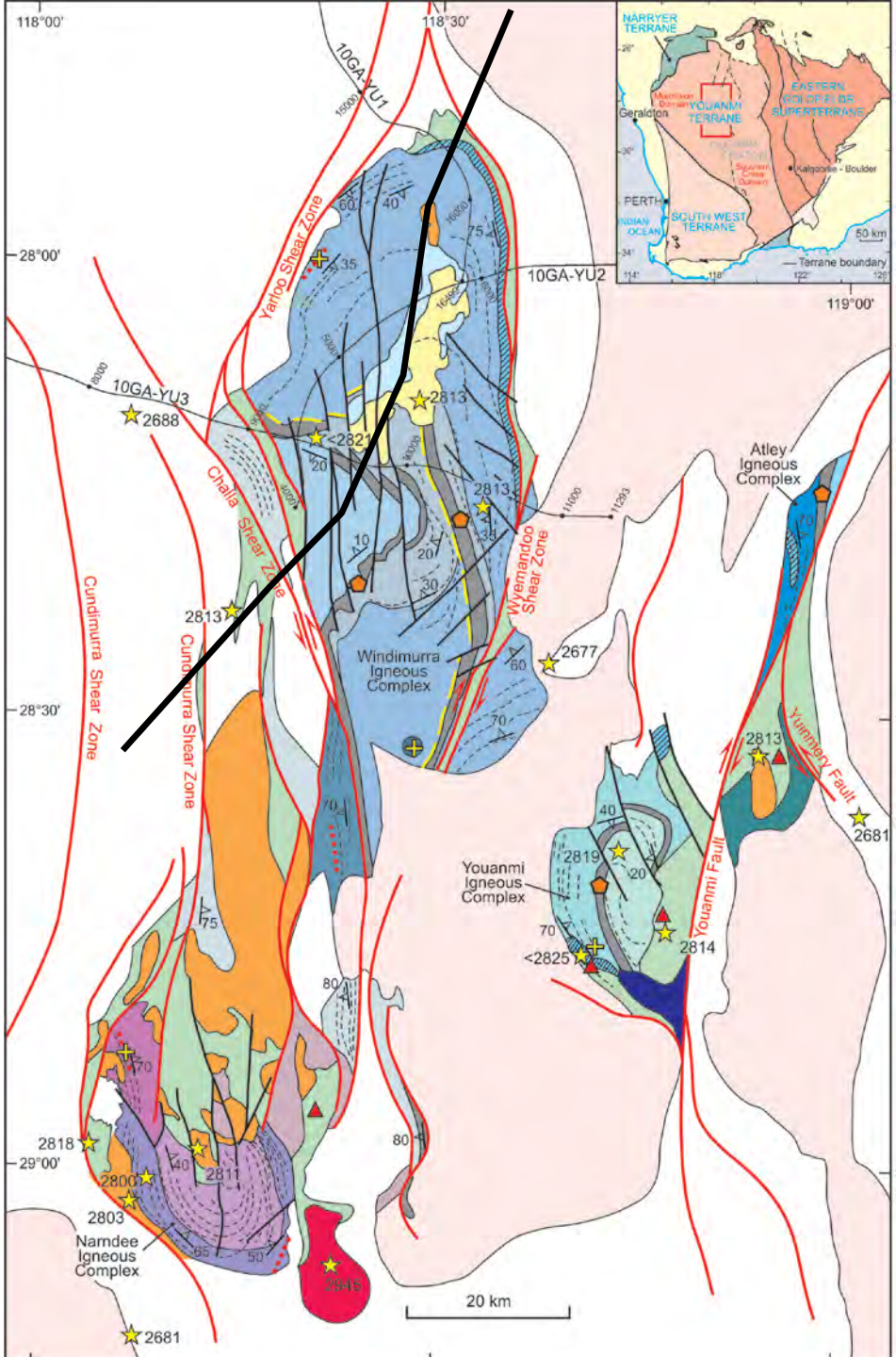
← E-W extensional setting →




Stage 3 of 4
SW
NE
westerly upper zone emplacement with erosional base
roof zone
3 km
0 km
-12 km
future site of
Challa
Shear Zone
future site of
Wyemandoo
Shear Zone
upper zone intruded as megapulse
t3 ~ +100 ky
staging chamber fractionated
to Fe-rich compositions

→ E-W shortening (f=0.75) and broad syncline formation ←





2640–2600 Ma — Bald Rock Supersuite: post-tectonic granites

2710–2640 Ma — metamonzogranites

c. 2800 Ma — Mt. Kenneth Suite: metagranitic rocks

unassigned gabbroic rocks

c. 2800 Ma Boodanoo Suite — Narndee Igneous Complex 2800 Ma:
- other gabbros
- middle zone
- lower zone
- ultramafic zone

c. 2813 Ma — Kantie Murdanna Volcanics Member

c.2810 Ma Meeline Suite:
- Atley Igneous Complex: upper zone, middle zone
- Youanmi Igneous Complex 2819 Ma: upper zone, middle zone, lower zone
- Windimurra Igneous Complex 2813 Ma: other gabbros, roof zone, upper zone, middle zone, lower zone, ultramafic zone, Corner Well Gabbro, border group dolerites, magnetitite-bearing rocks

c. 2820 – 2810 Ma — greenstone supracrustal lithologies

c. 2950 Ma — granite gneiss

Geochronology sample site showing age in Ma

V mineralization

Cu-Zn mineralization

PGE (Ni, Cu, Cr) mineralization

20 Igneous layering (right way up)

Chromitite seam

Fault

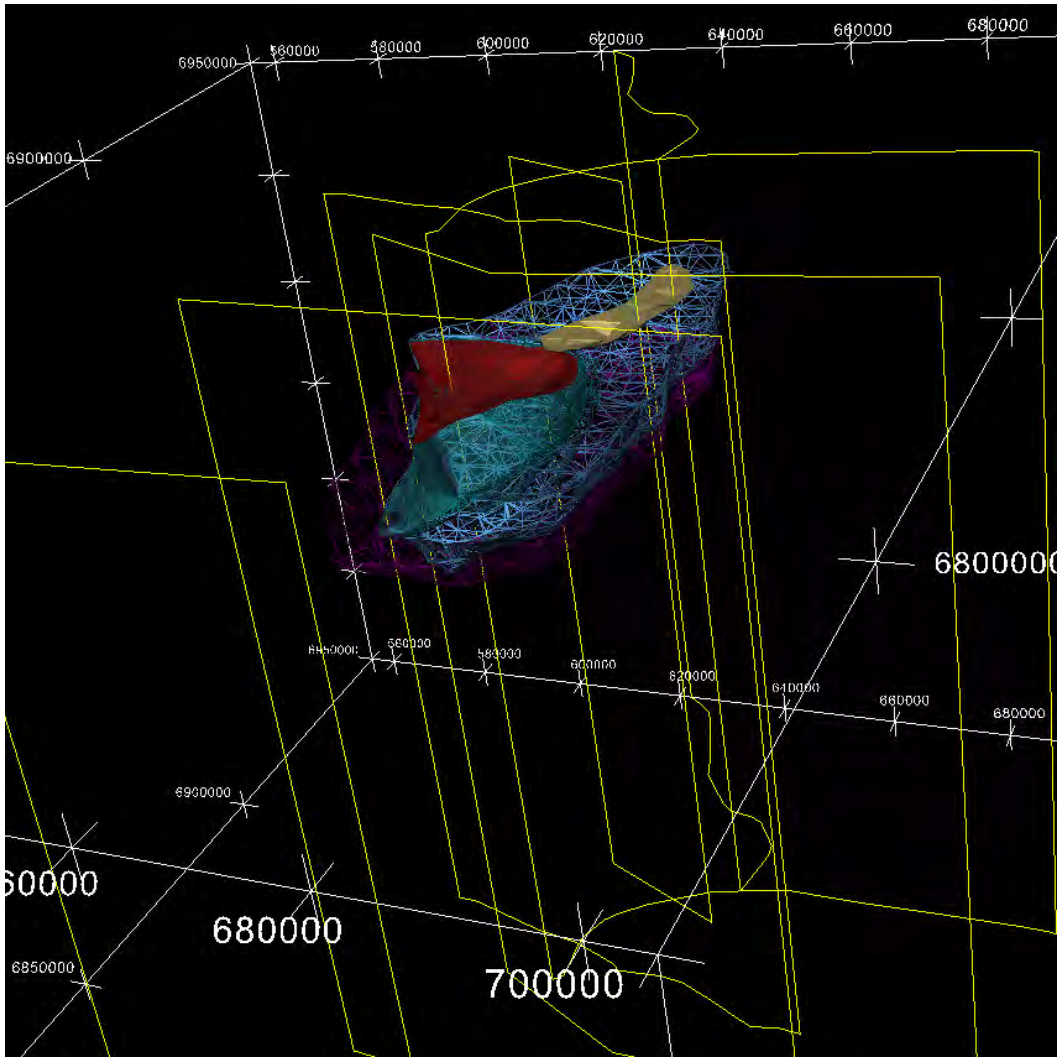
Shear zone showing sense of movement

Trend of igneous layering

Magmatic discordant zone (Shephards Discordant Zone)

Seismic line, with CDP points

3D Geomodeller



Summary of implications (I)

- Clarification of aspects of the **dynamic magmatic history**
- Bulk composition problem resolved by **identification of thick ultramafic zone**
- **First 3D model** complete, consistent with seismic, magnetic, gravity and surface observations
- **Revised igneous stratigraphy** makes the complex unique

Summary of implications (II)

- Ultramafic zone prospectivity revealed
- Upper zone of western lobe, confirmed as 1km thick single intrusive sheet, basal parts likely prospective (fertile magma interaction)
- Form of Shephard's Discordant Zone estimated
- Potential for umz at Youanmi

Acknowledgements

- Russell Korsch, Leonie Jones, Ross Costelloe
  (GA, Geophysics)
- John Brett, David Howard, Klaus Gessner
  (GSWA, Geophysics/3D)
- Stephen Wyche, Martin Van Kranendonk[1], Ivan Zibra
  (GSWA, Murchison Mapping Section, [1]Now at UNSW)
- Mike Wingate, Chris Kirkland
  (GSWA, Geochronology)
- Graham Kennedy, Richard Langford
  (ex. Flinders Mines), Nick Corlis (Flinders Mines)
- Oliver Nebel, John Mavrogenes,
  Richard Arculus (ANU)

ARC linkage project