# The SLaCT deep reflection seismic transect of SE Australia – spectacular data that constrains a spectacular Lachlan Orocline geological narrative

Ross Cayley, Geological Survey of Victoria.

on behalf of the SLaCT GSV, GA, GSNSW and Auscope collaborative research team

Australian Earth Sciences Convention
3 February 2025

RESOURCES VICTORIA

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it.

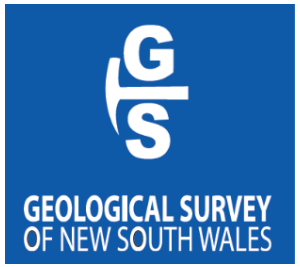
We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

Resources Victoria is committed to genuinely partnering with Victorian Traditional Owners and Victoria's Aboriginal community to progress their aspirations.

# GEOLOGY IS A COLLABORATIVE SCIENCE!




Australian Government
Geoscience Australia





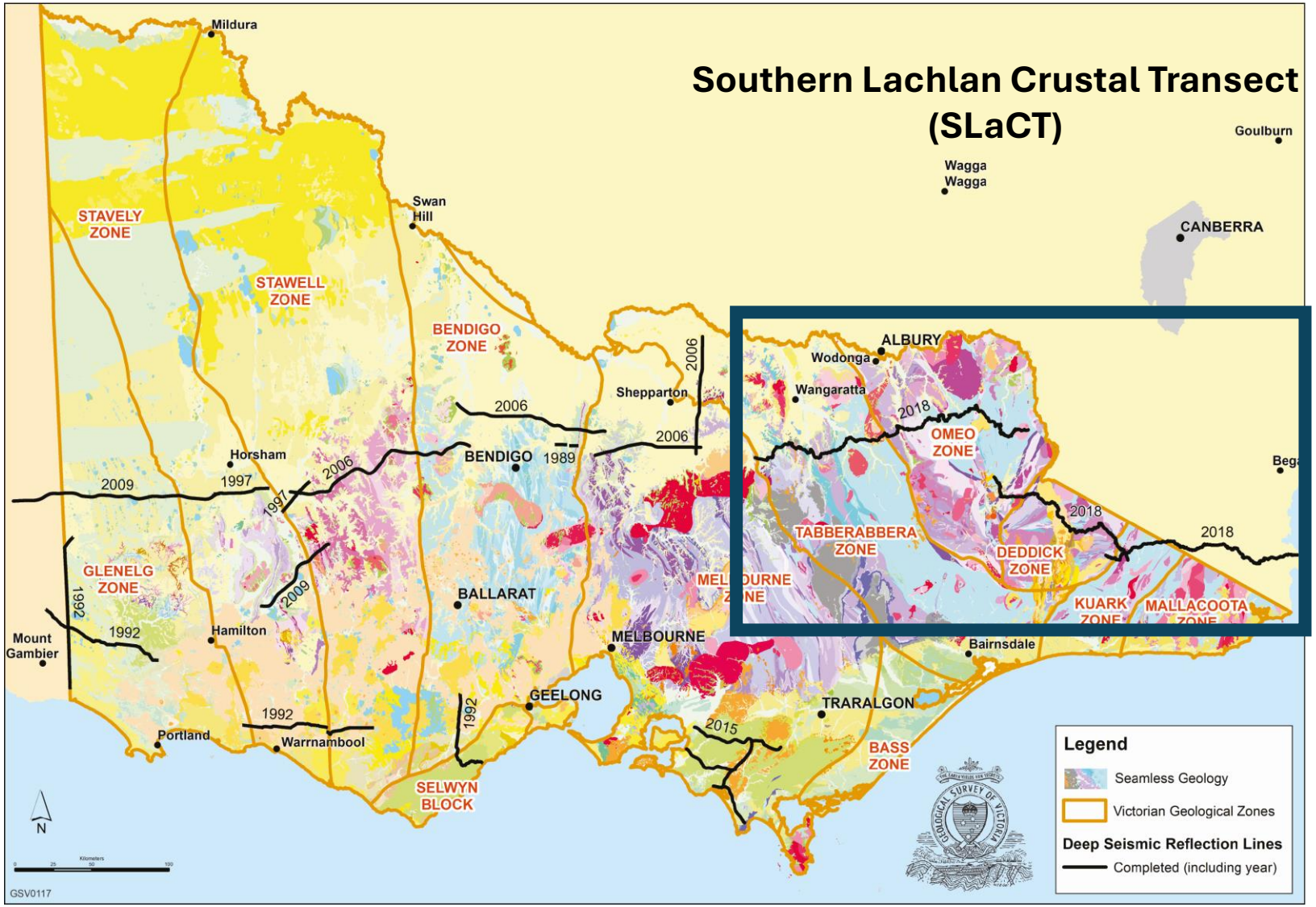




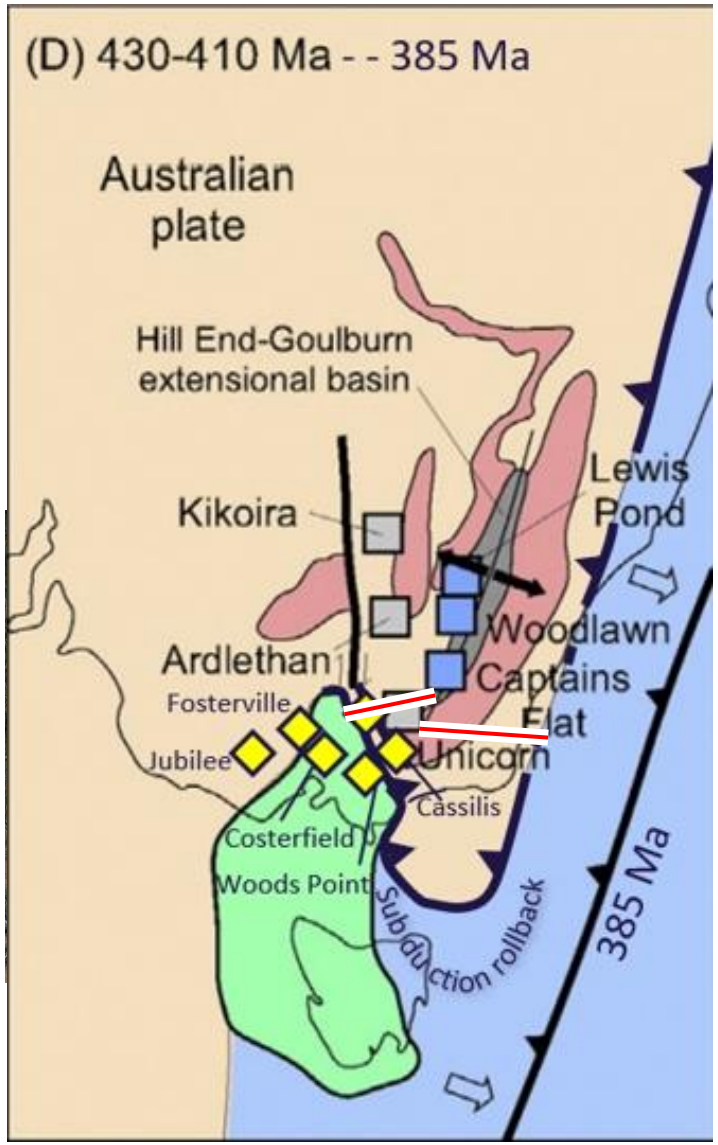
# Talk Outline

- **Objectives: deep seismic reflection+ data spanning Palaeozoic Victoria; test the Lachlan Orocline hypothesis**
- Oceanic Lachlan Fold Belt versus the Selwyn Block continental collider that's embedded within it.
- The Lachlan Orocline hypothesis – a quick review
- Deep Seismic Reflection Survey design, acquisition, processing. Complementary geophysics.
- Results of the survey – interpretation methodology, forward modelling
- Governor Fault – building understanding of the Melbourne Zone/Tabberabbera Zone interface
- Governor Fault Zone revealed as a lithospheric-scale mega-thrust – a Silurian east-dipping subduction zone congested by a thick continental fragment (the Selwyn Block east flank)

# Deep Seismic Reflection




Modified from: Huston et al., 2016



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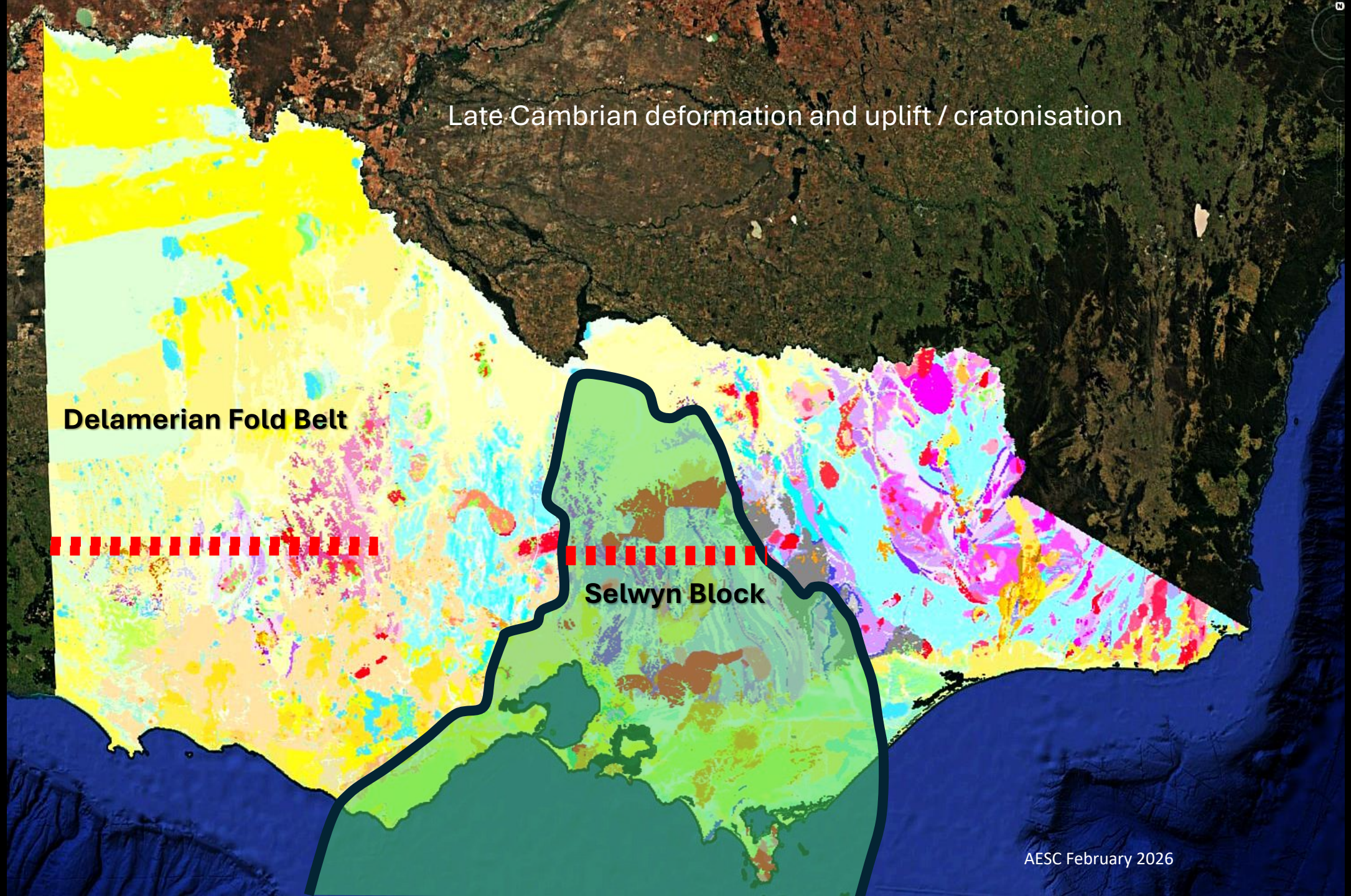
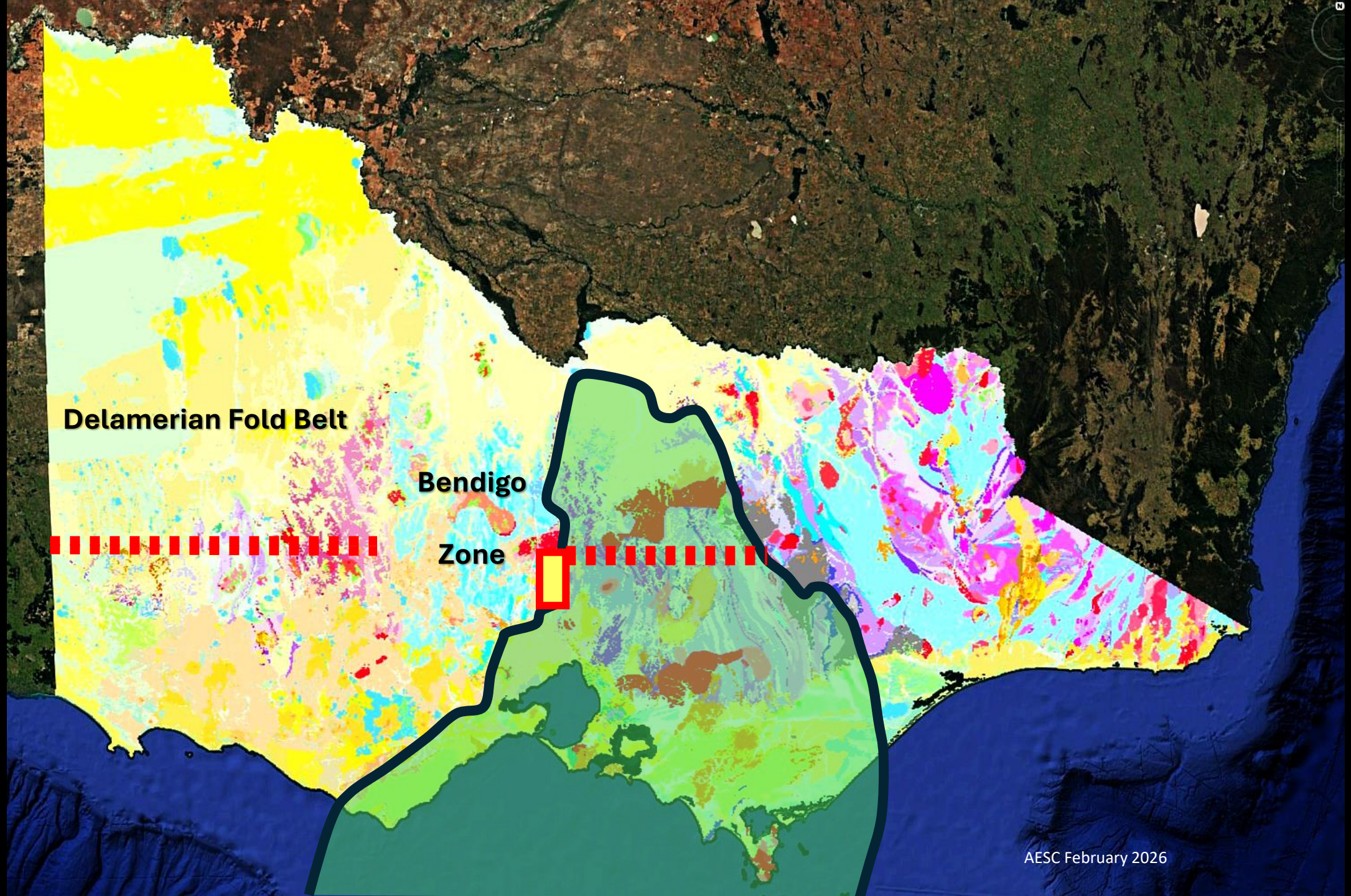
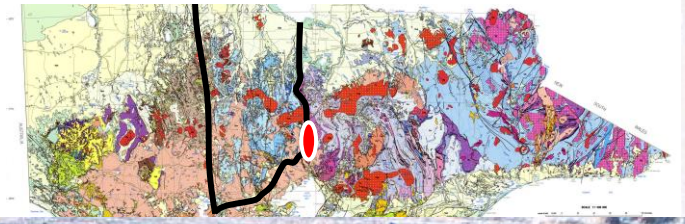

Late Cambrian deformation and uplift / cratonisation
Delamerian Fold Belt
Selwyn Block
AESC February 2026

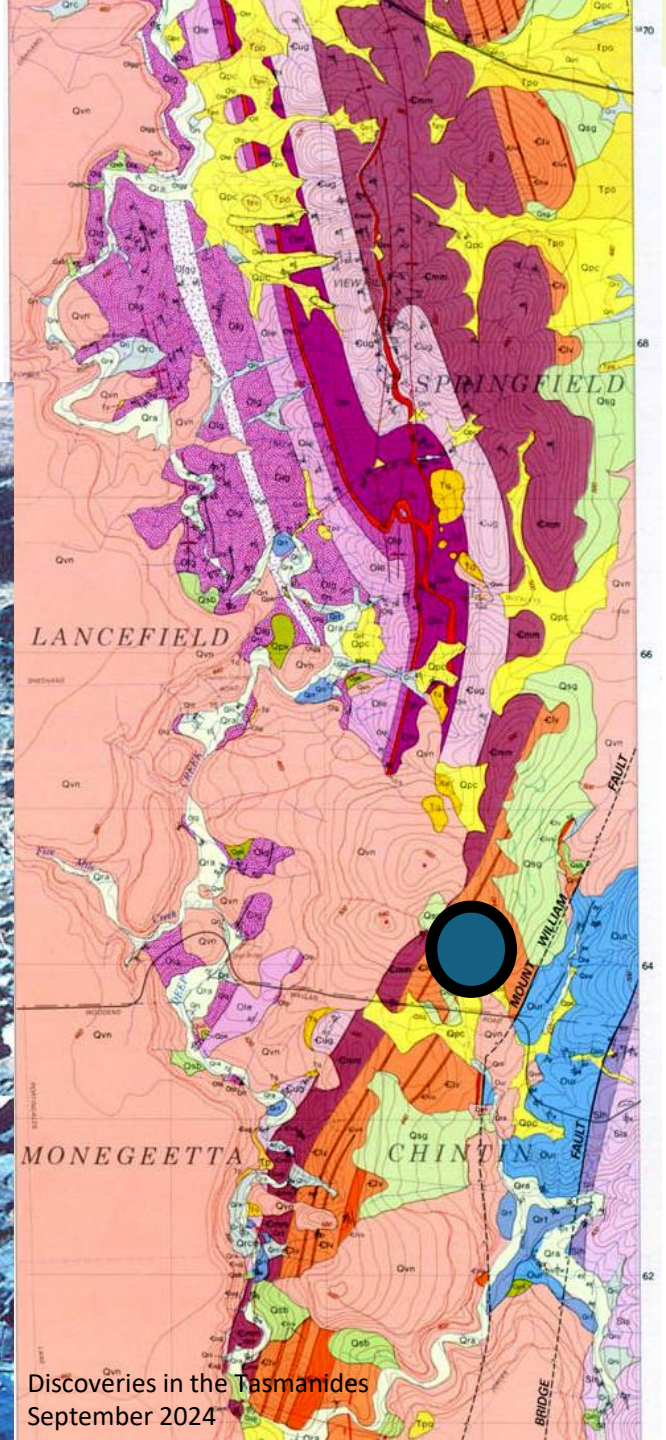

Delamerian Fold Belt
Bendigo
Zone
AESC February 2026

# Kilmore / Heathcote

**Bendigo Zone:**
**plenty of Cambrian rocks,**
**NO Delamerian Orogeny!**

VandenBerg, 1991





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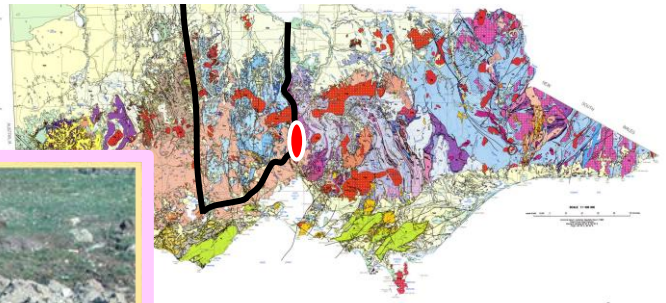

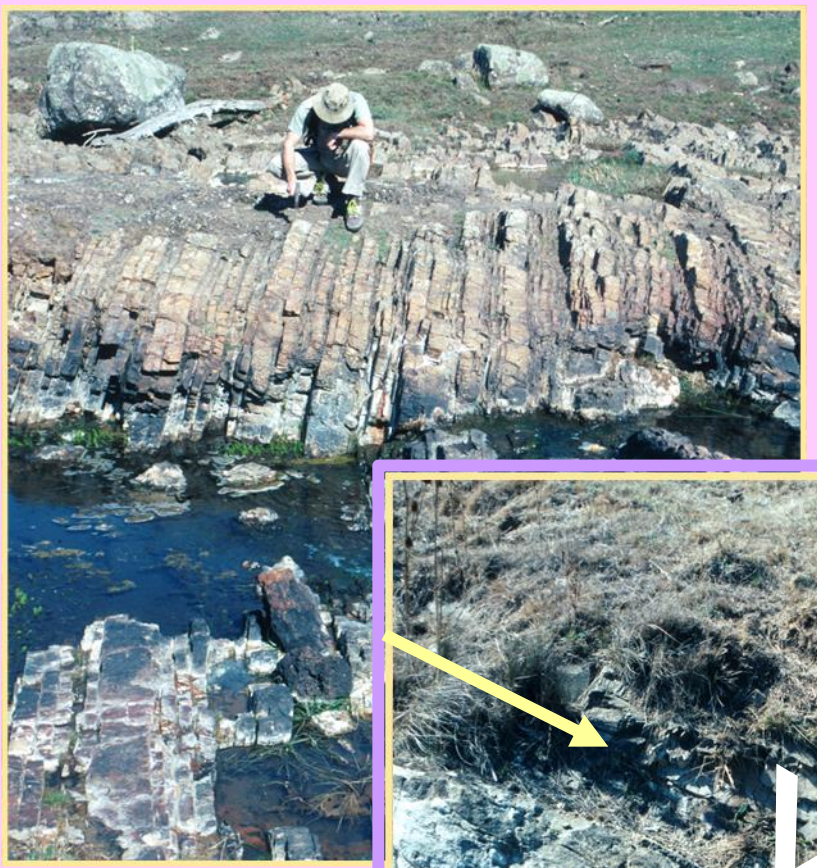

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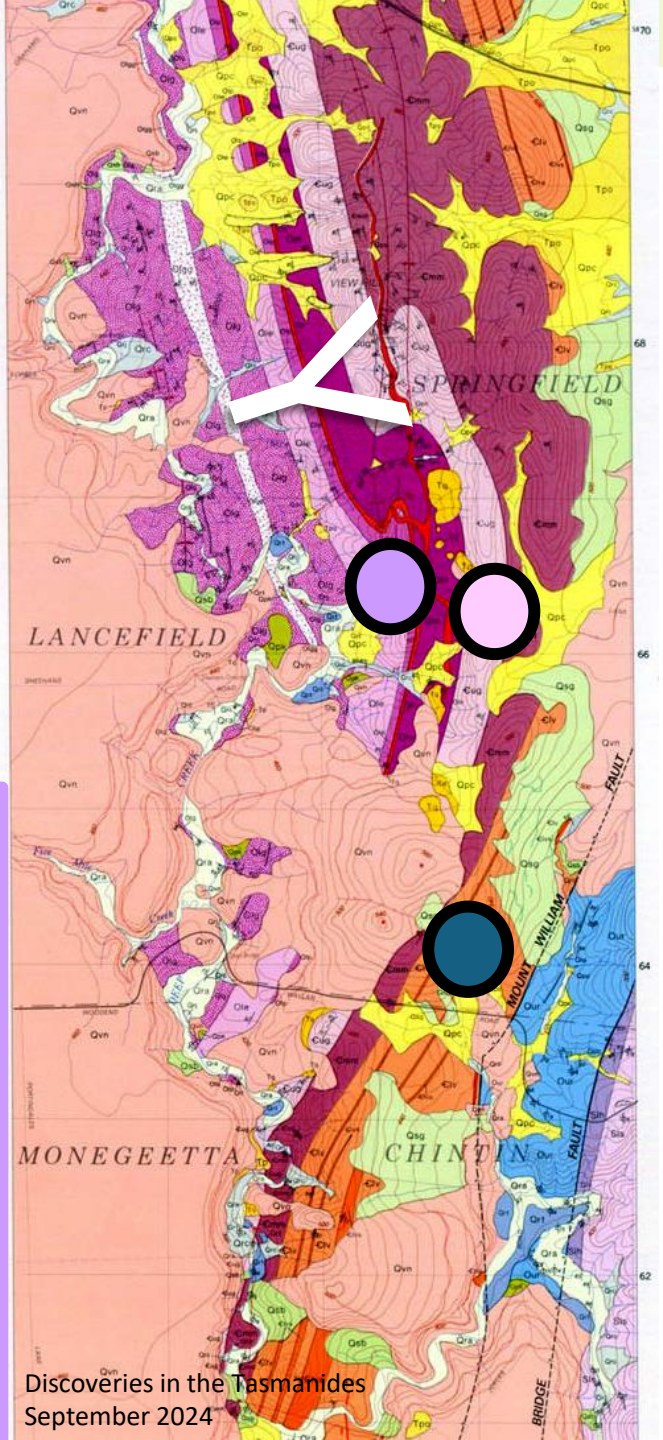
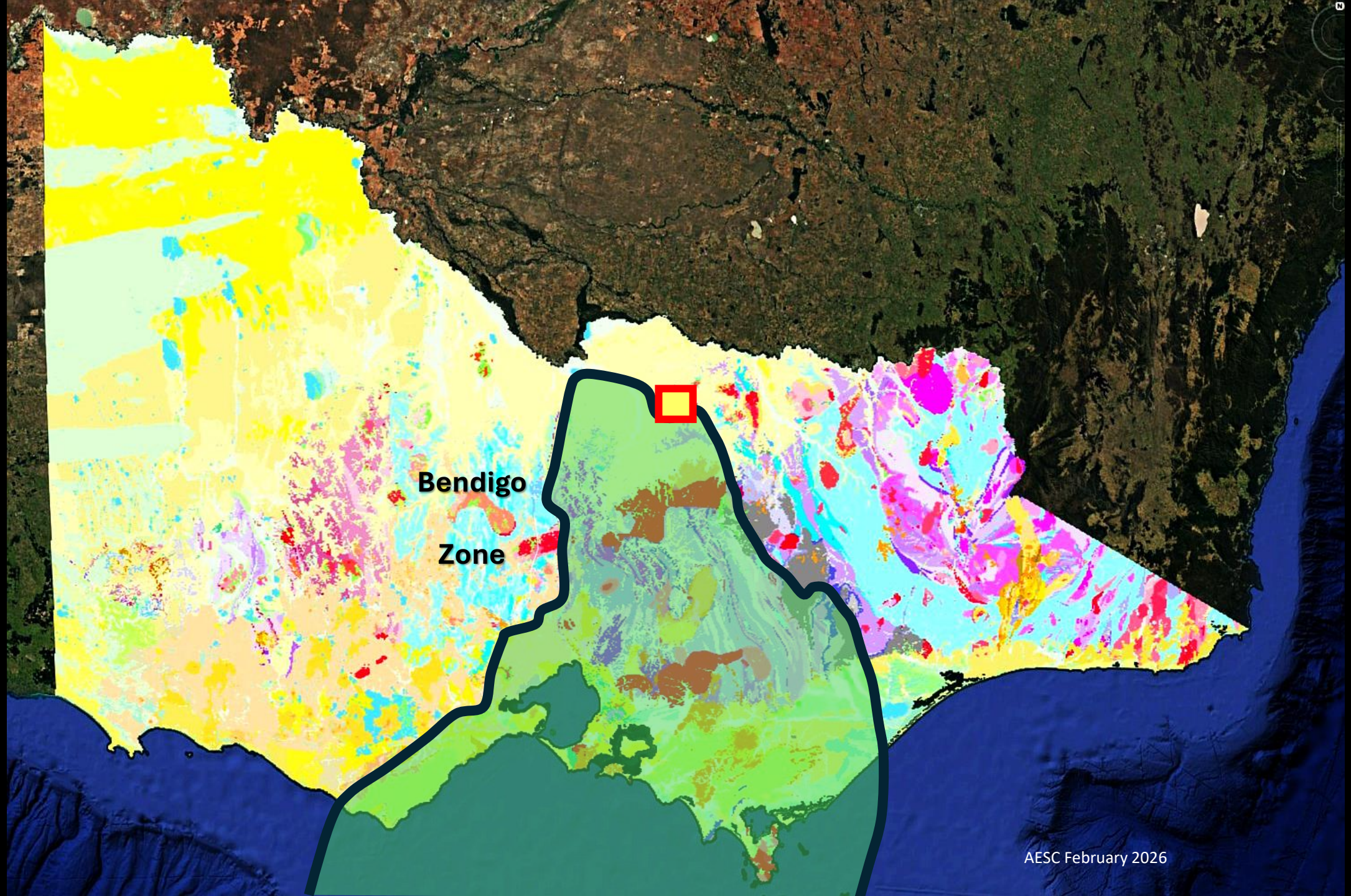
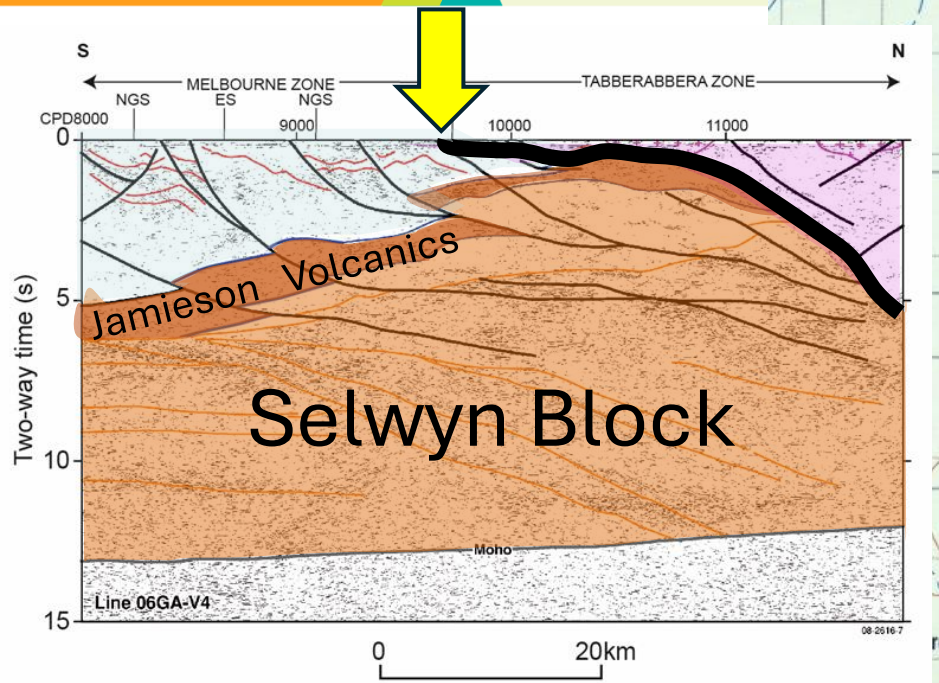





Discoveries in the Tasmanides
September 2024


Bendigo
Zone
AESC February 2026

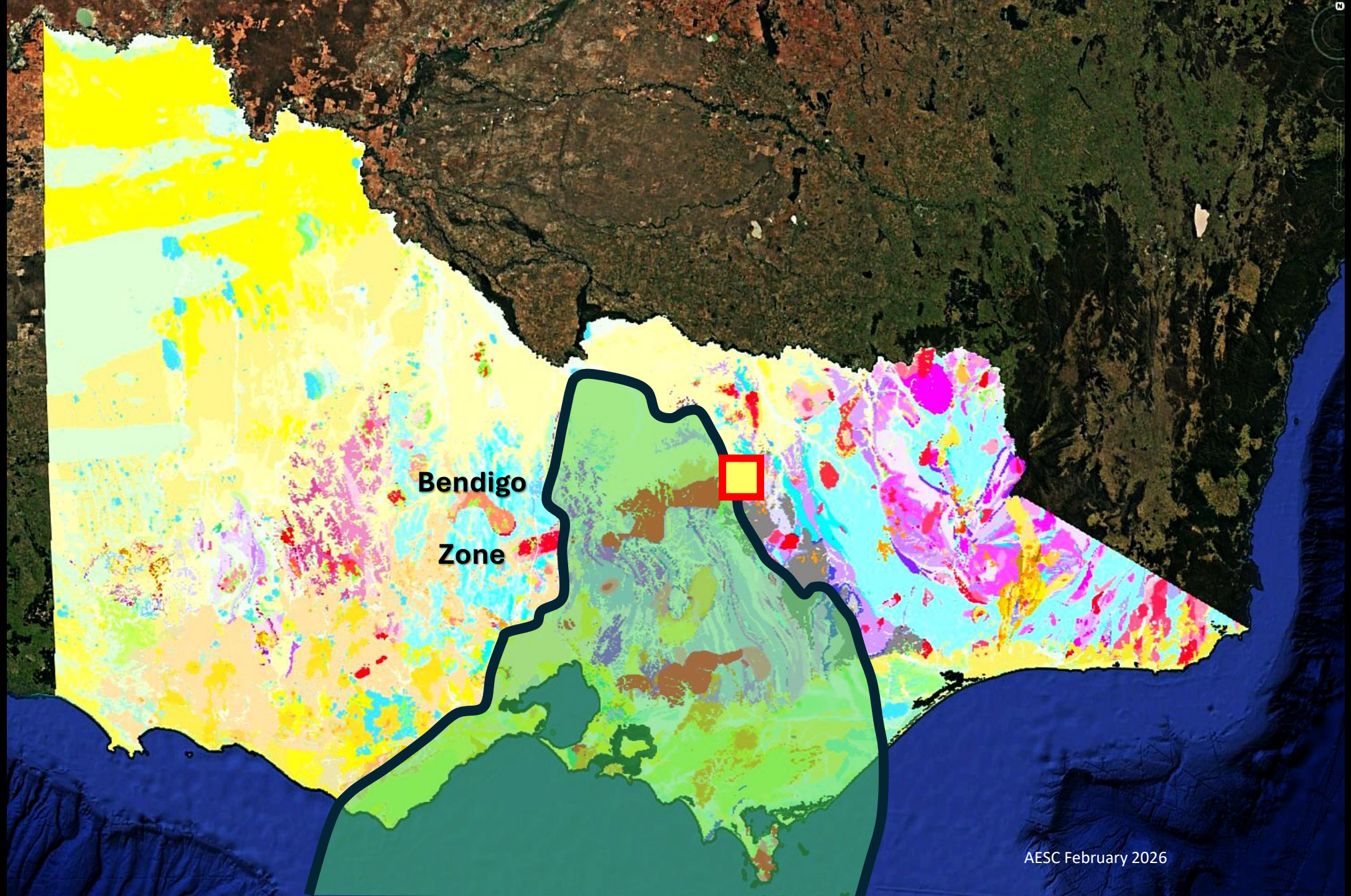



Cayley et al, 2011

# Dookie

- ?conformable Cambrian-Ordovician
- Sediment starved until Ordovician
- Deep marine Cambrian - Silurian

Tickell, 1986


Bendigo
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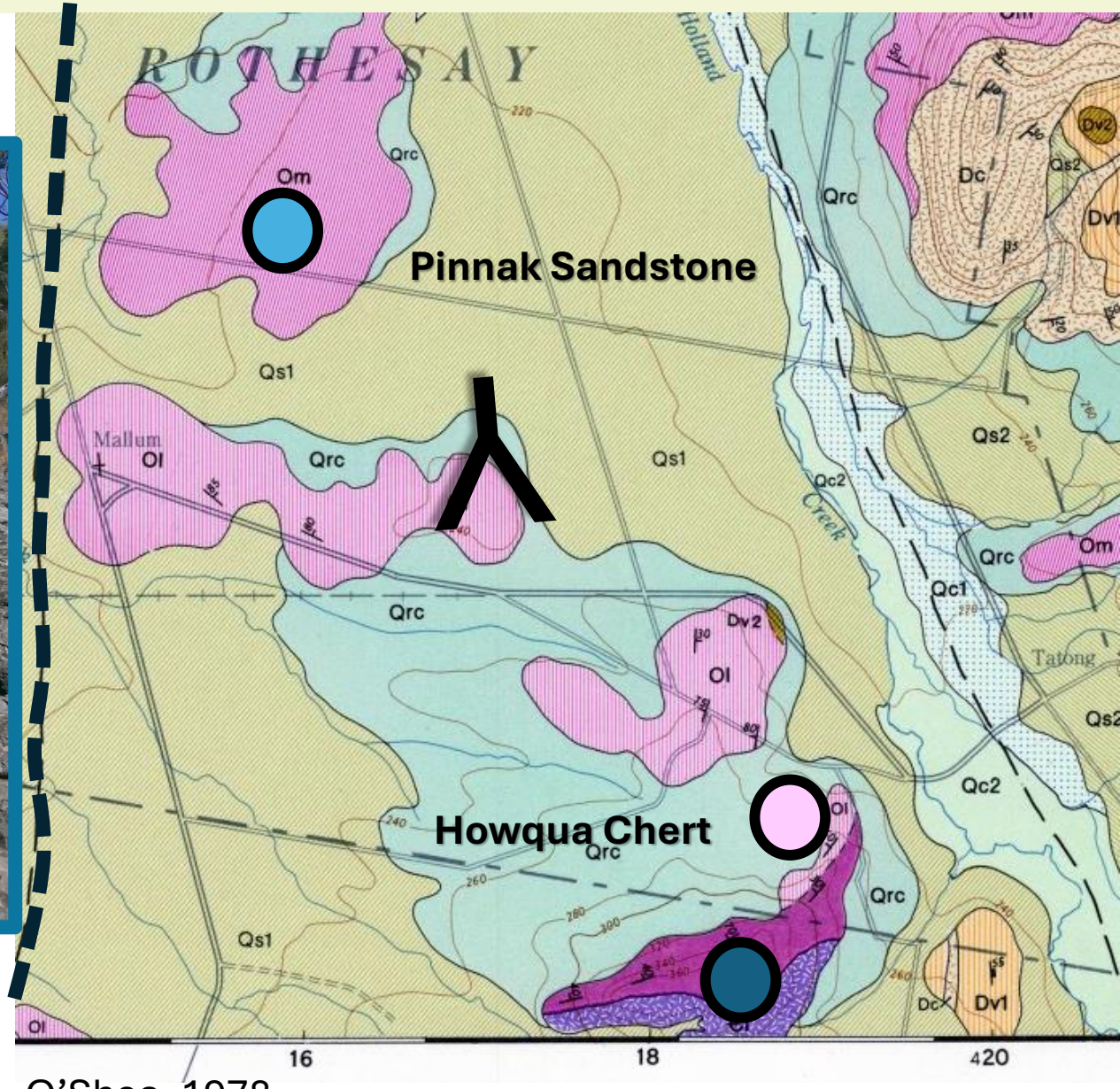
AESC February 2026

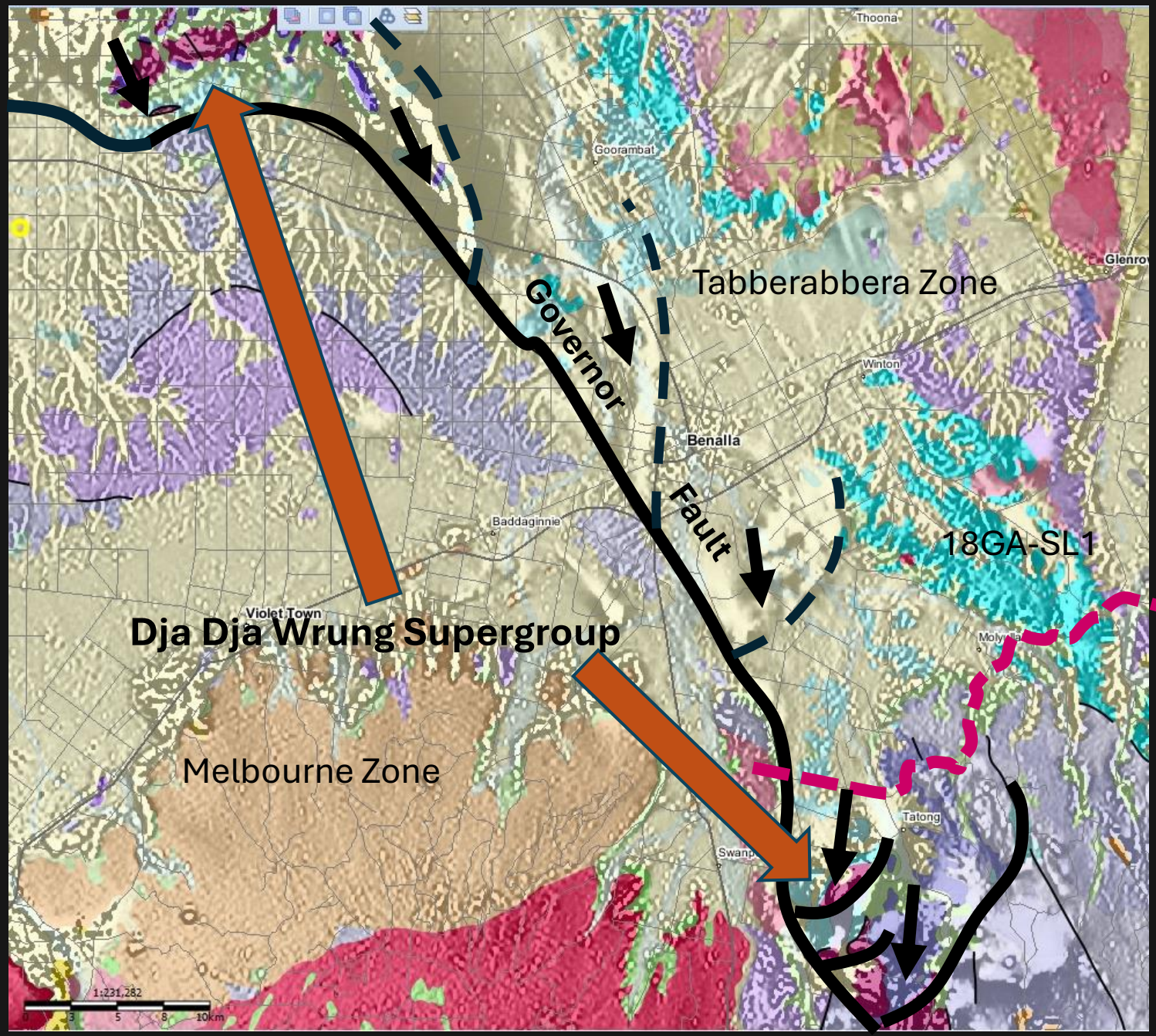
# Tatong


O'Shea, 1978

- Conformable Cambrian-Ordovician.
- Sediment starved until Ordovician
- Deep marine Cambrian - Silurian

# Dookie




# Tatong

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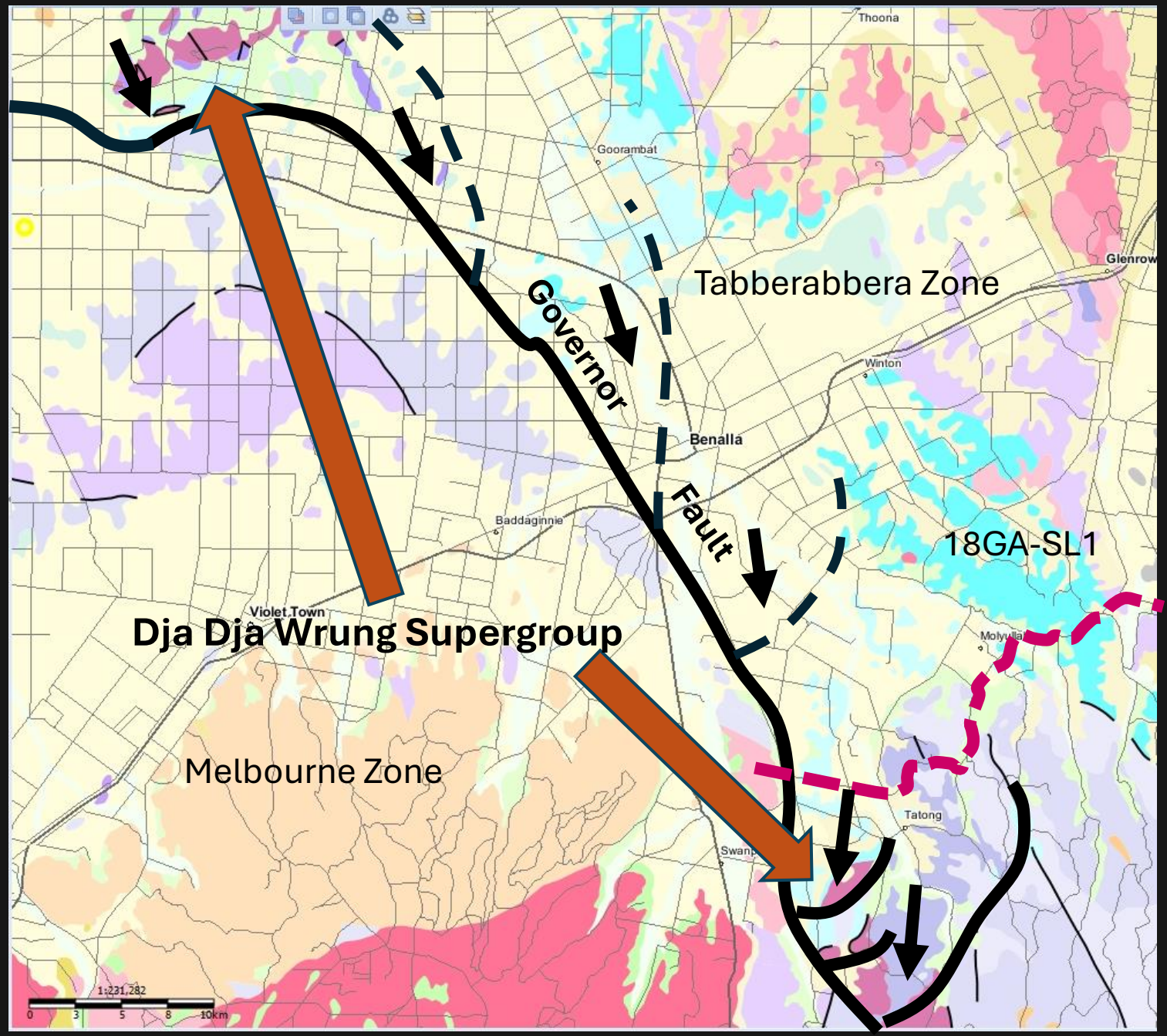


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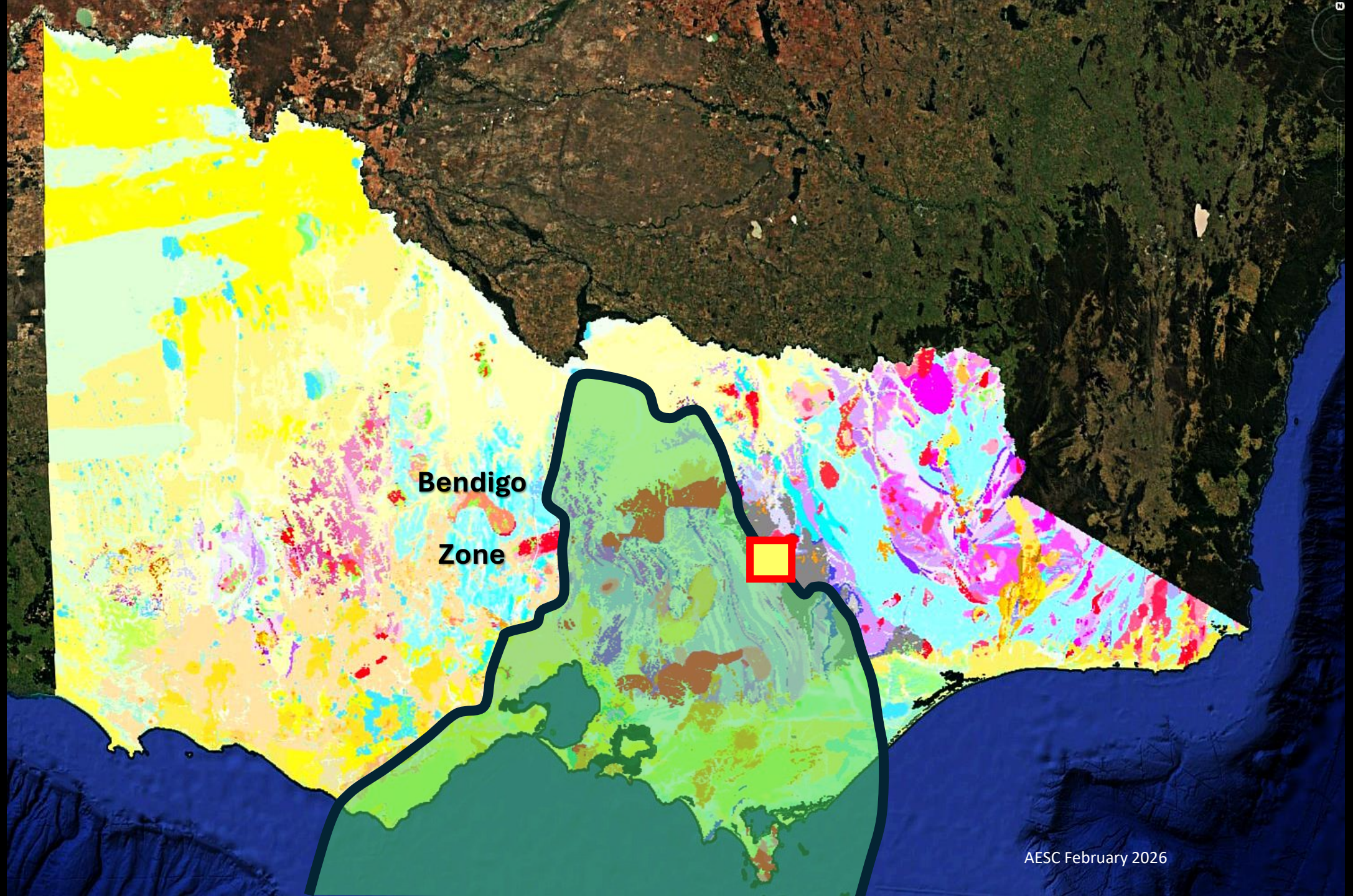
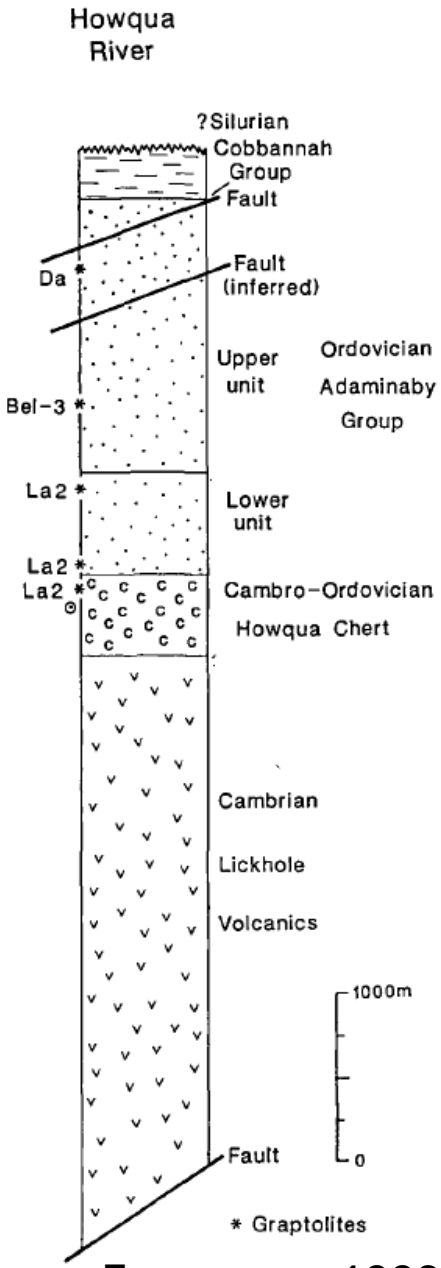
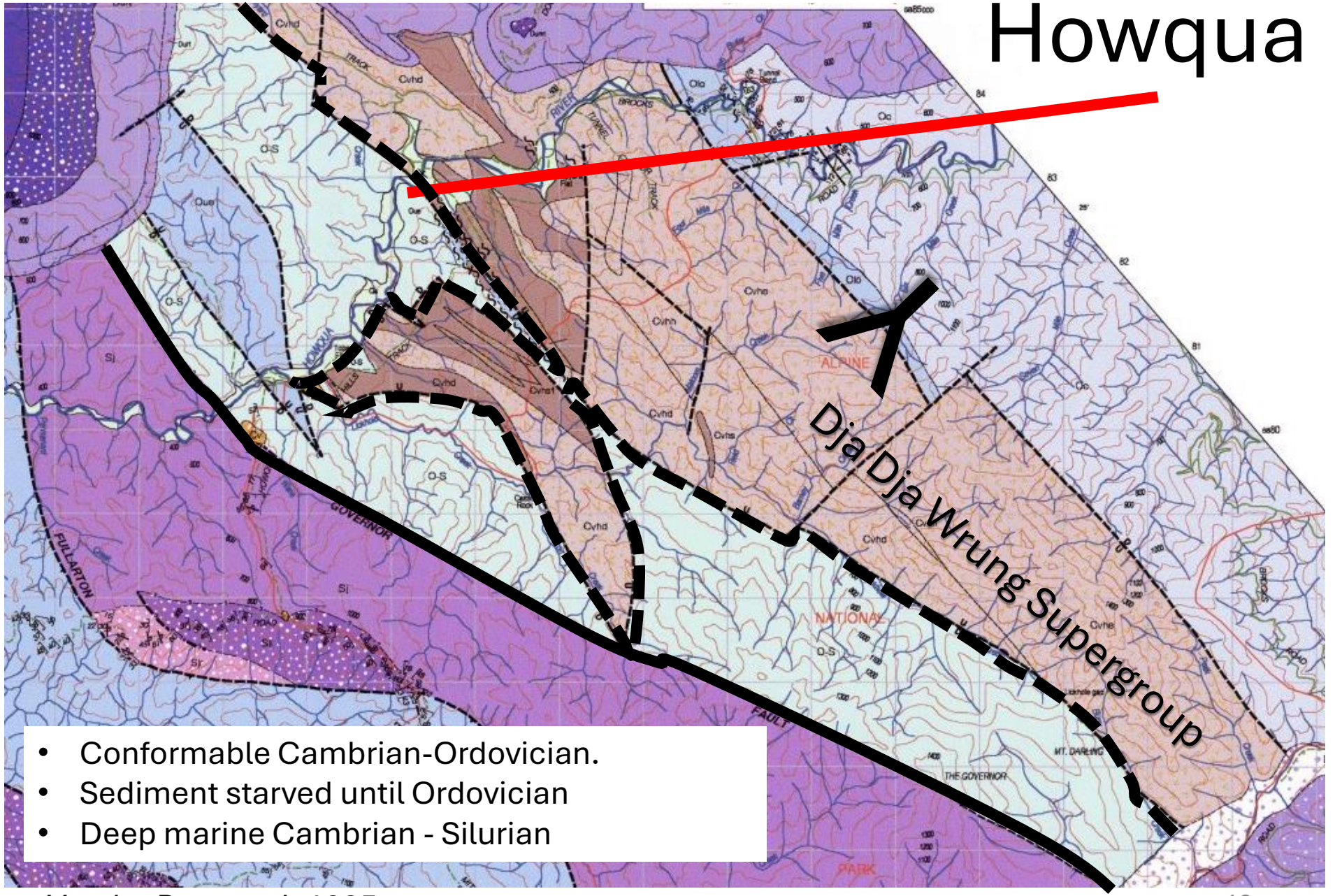

Bendigo
Zone
AESC February 2026

# Howqua




Fergusson, 1998

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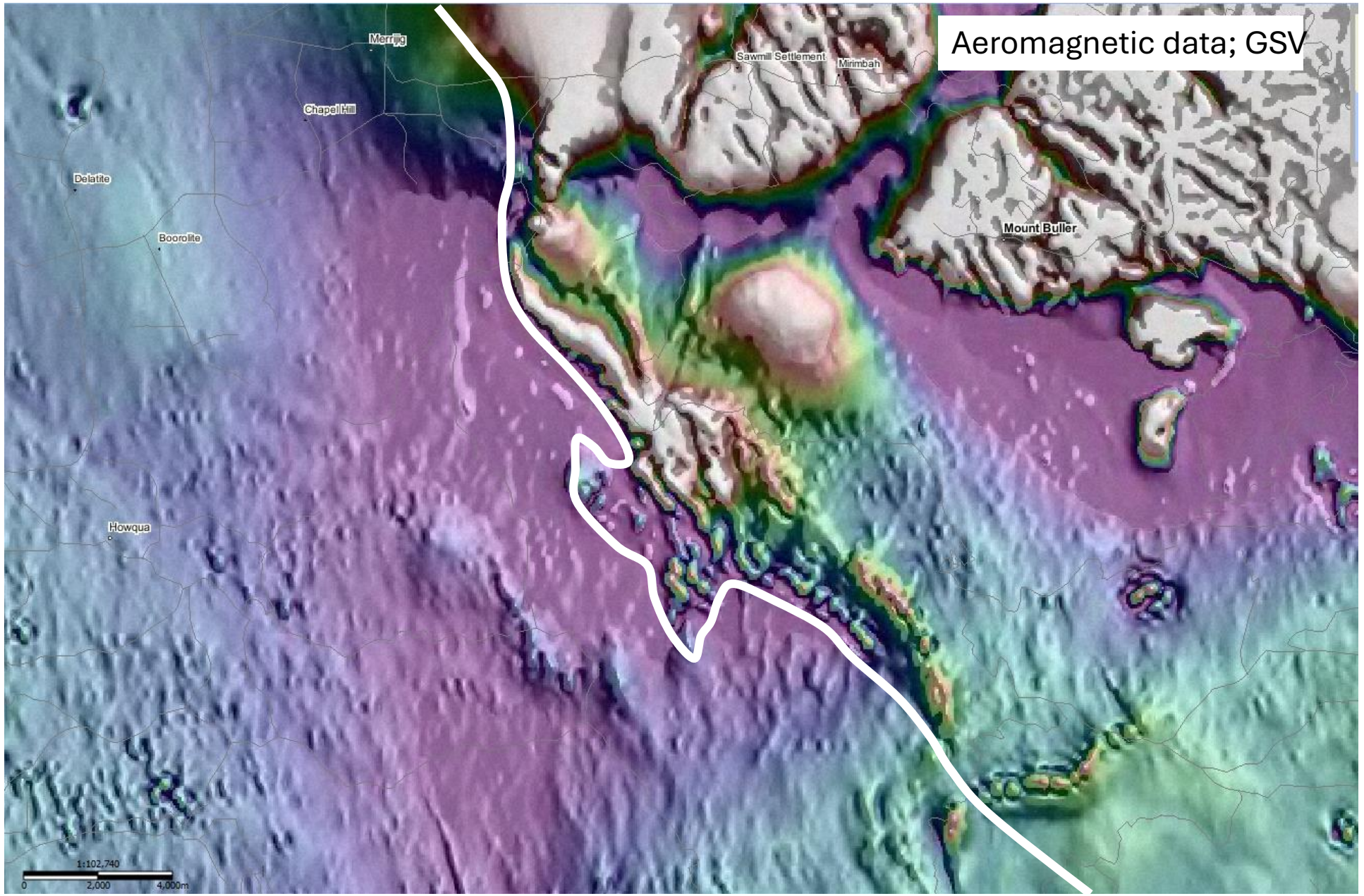
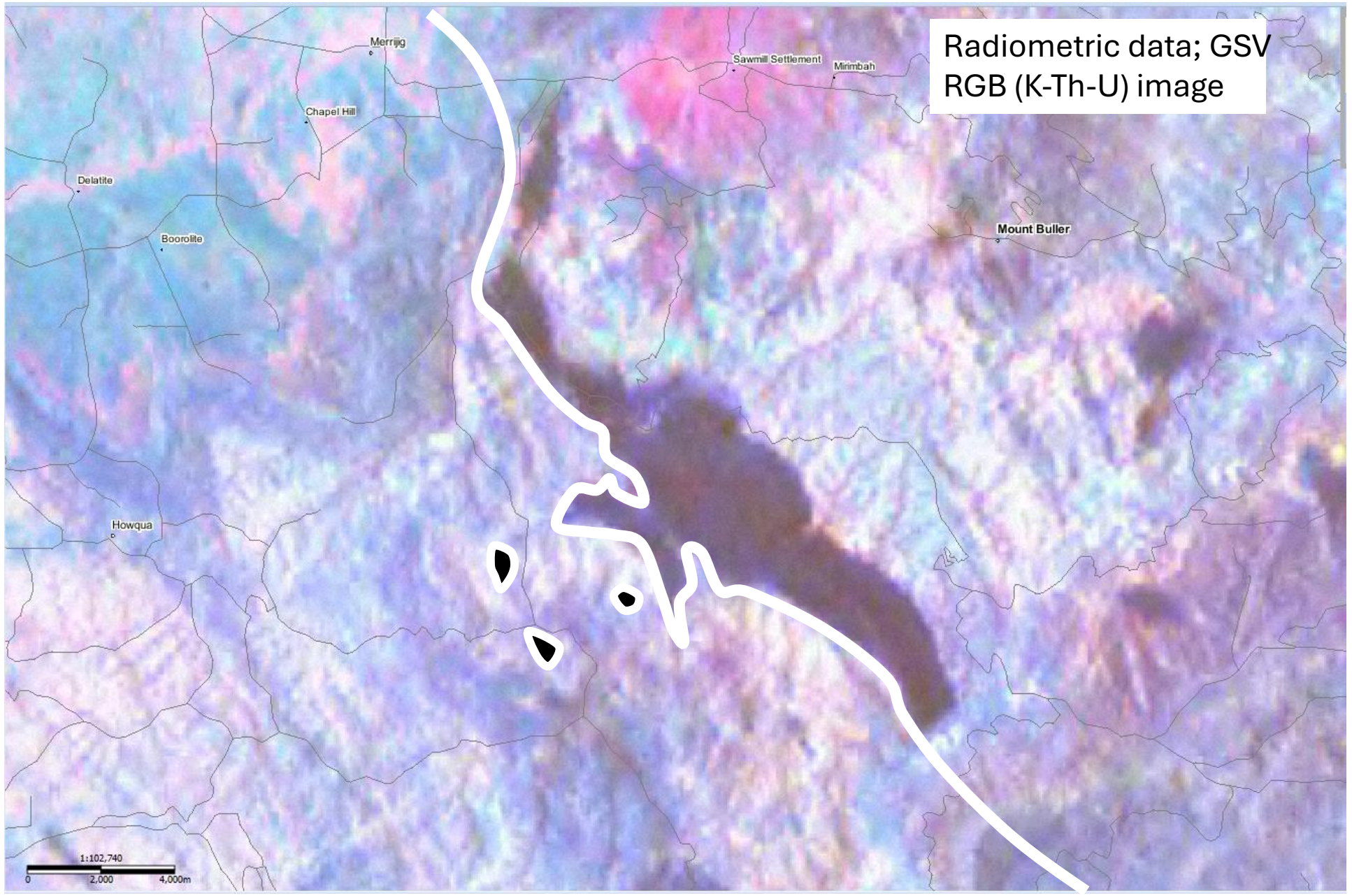
VandenBerg et al, 1995


Aeromagnetic data; GSV
Merrijig
Chapel Hill
Delatite
Boorolite
Howqua
Sawmill Settlement
Mirimbah
Mount Buller
1:102,740
0
2,000
4,000m


Radiometric data; GSV RGB (K-Th-U) image
Merrijig
Chapel Hill
Sawmill Settlement
Mirimbah
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1:102,740
0
2,000
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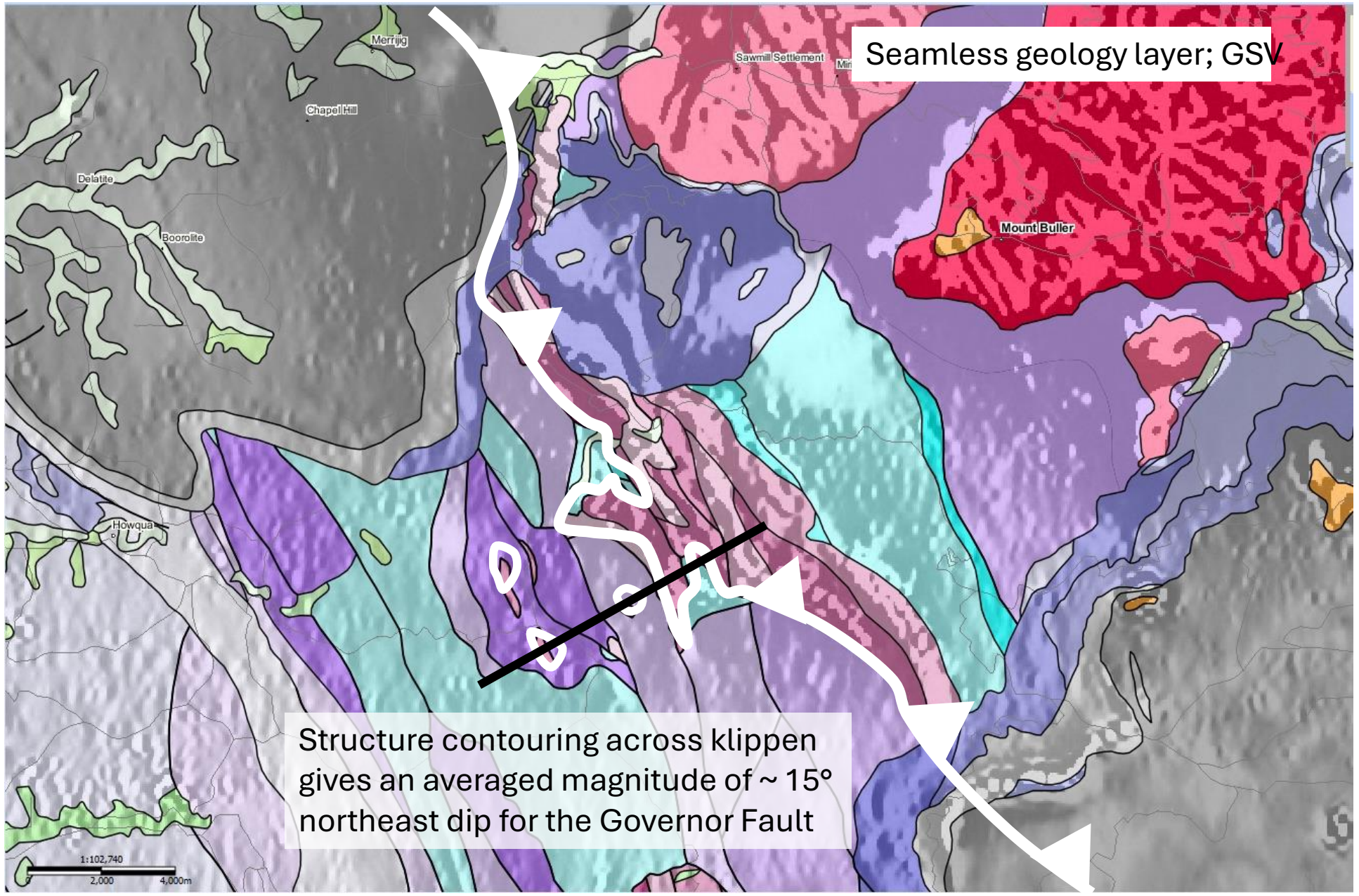
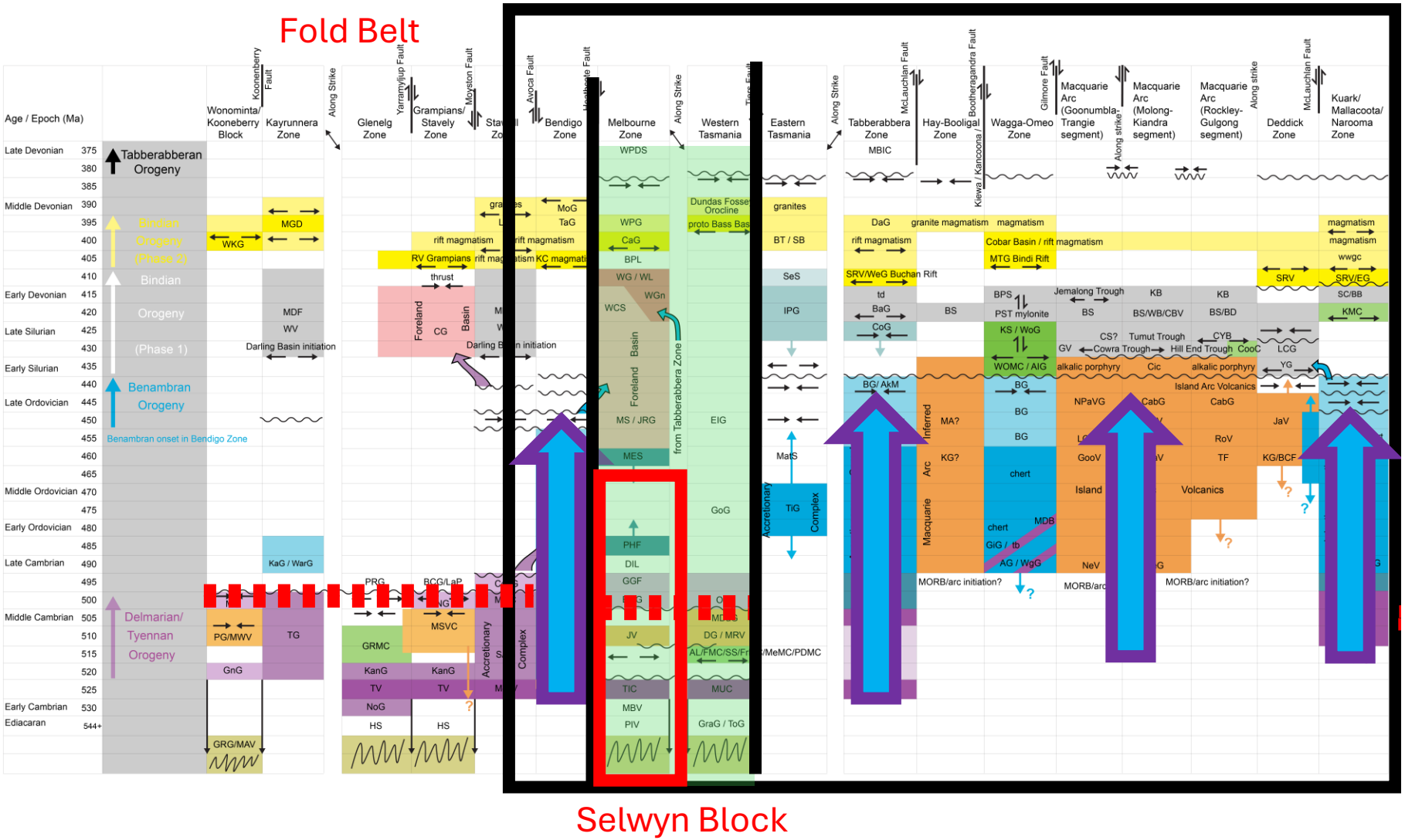

Seamless geology layer; GSV
Merrijig
Chapel Hill
Sawmill Settlement
Delatite
Boorolite
Mount Buller
Howqua
Structure contouring across klippen gives an averaged magnitude of ~ 15° northeast dip for the Governor Fault
1:102,740
2,000
4,000m

Delamerian Fold Belt

Lachlan Fold Belt




# Time-space plot : Eastern Australia

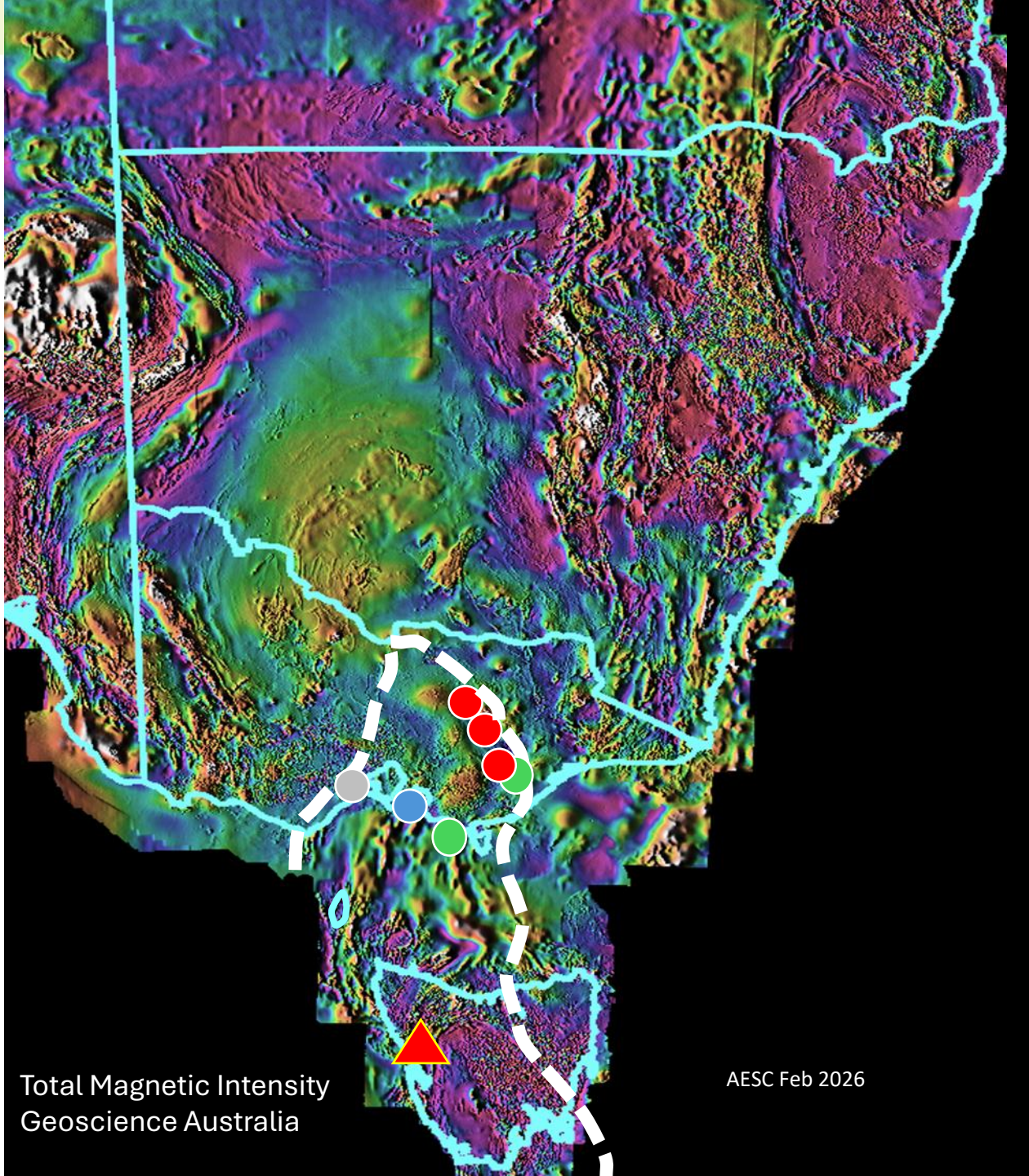
Cayley & Musgrave, in prep

Western Tasmania and its northern extension…the Selwyn Block. (Cayley et al., 2002)

The Vandieland microcontinent – deformed and uplifted Proterozoic - Cambrian continental crust beneath central Victoria (Cayley, 2011)

Cambrian calc-alkaline
Jamieson Volcanics (Vic)

coeval with (and along strike from)
Mount Read Volcanics ▲
Dundas ‘Trough’ (Tas)



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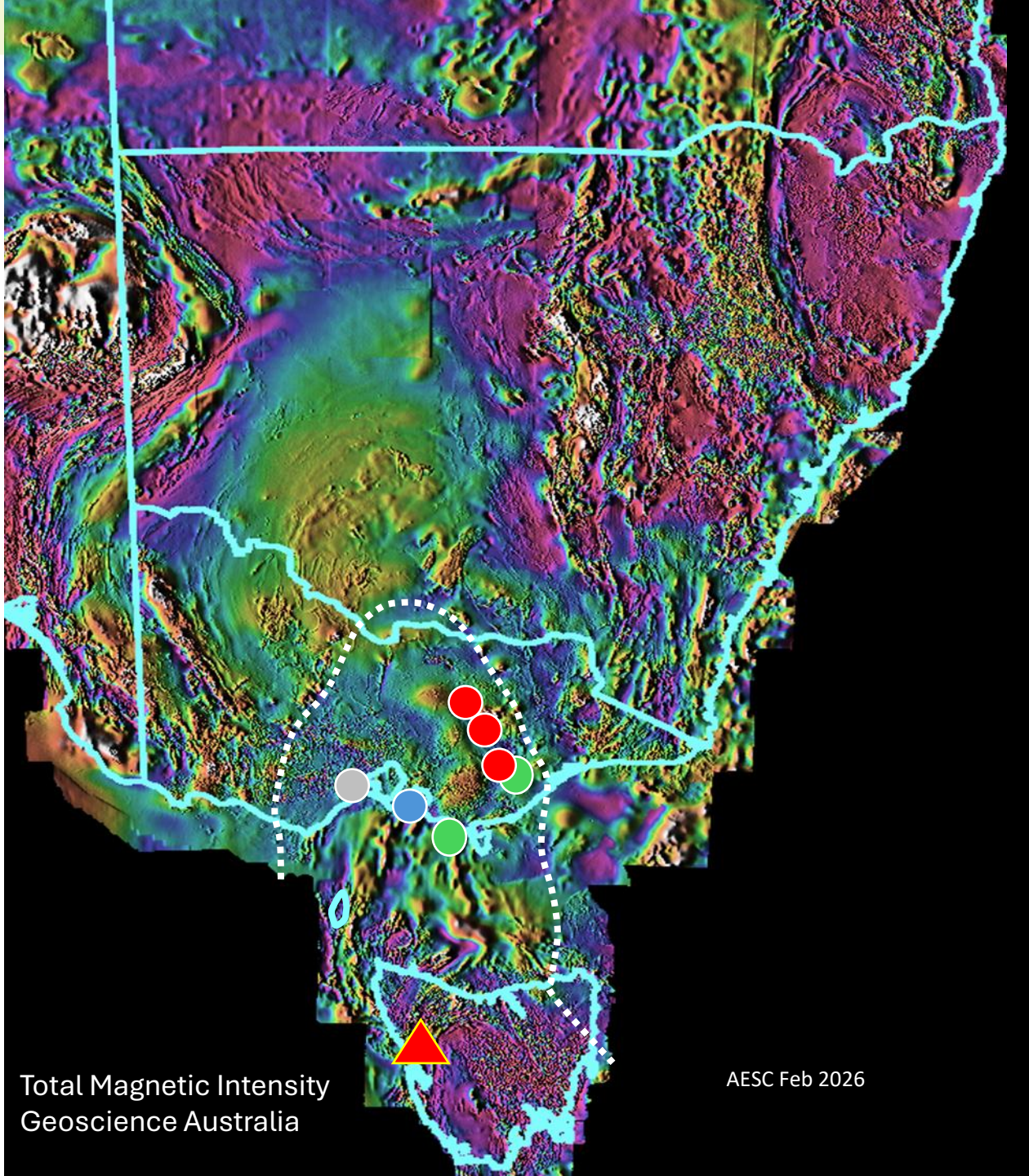
Extent in lower crust where Selwyn Block influence is expressed in a lateral change in granite chemistry (and age)



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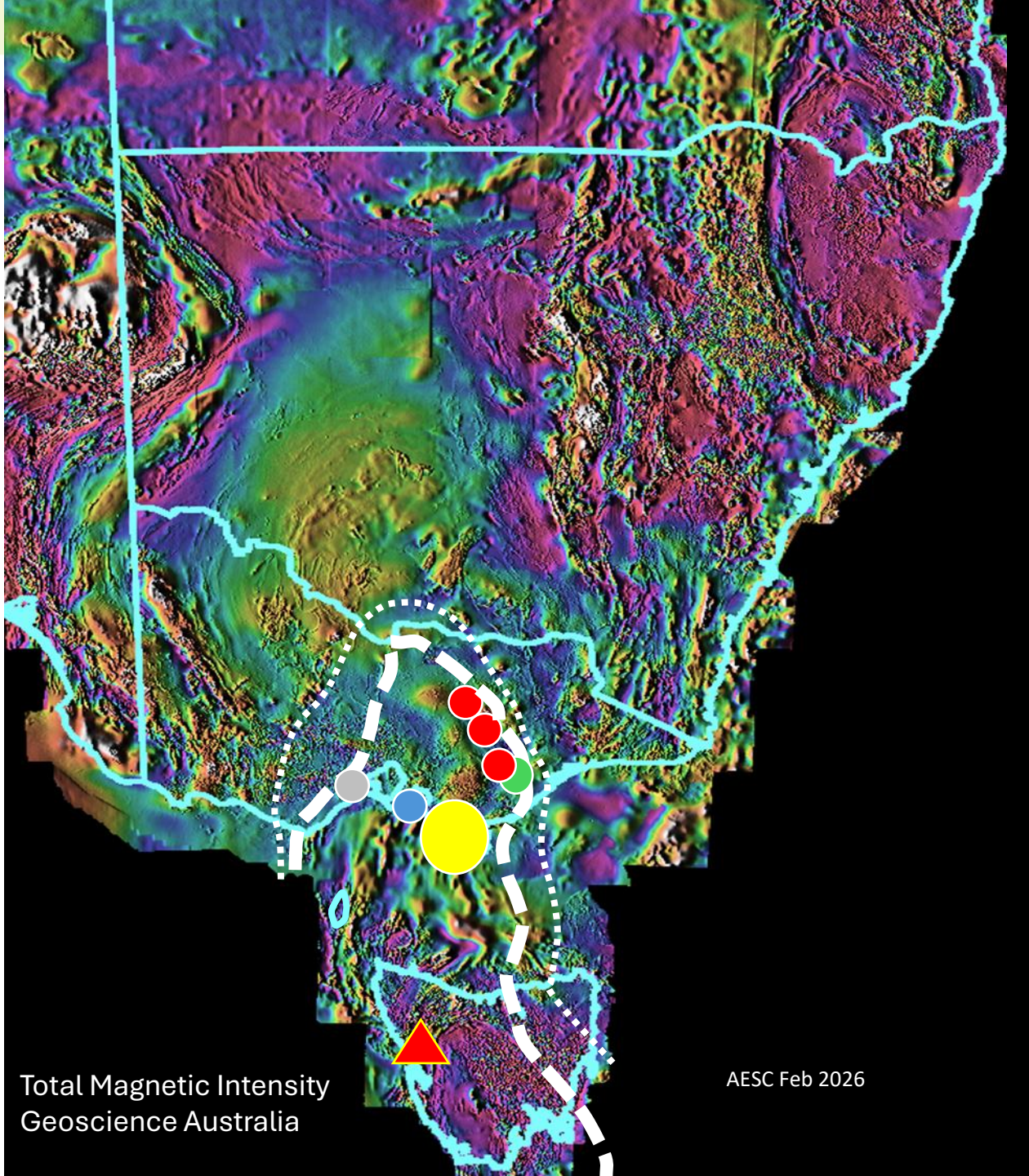
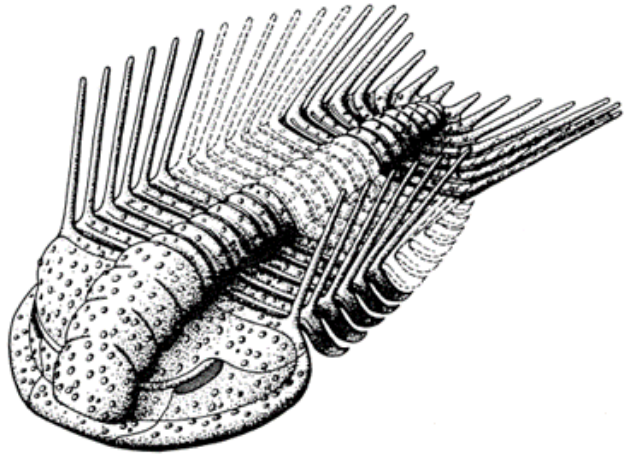
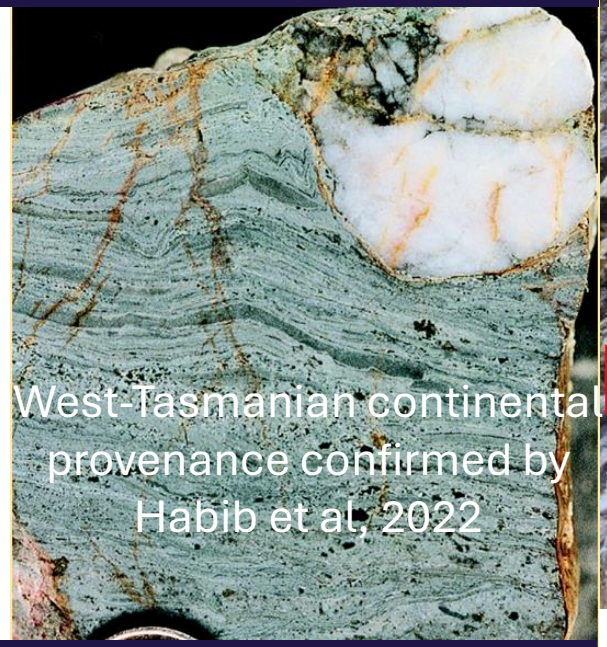
Extent in lower crust where influence is expressed in granite chemistry

Key Outcrop at Waratah Bay proves western Tasmanian structural history (Tyennan Orogeny) and provenance:





Early Lancefieldian – ~490Ma+



West-Tasmanian continental provenance confirmed by Habib et al, 2022

**Bear Gully Gritstone**

GEOLOGICAL SURVEY OF VICTORIA

# Walkerville / Waratah Bay



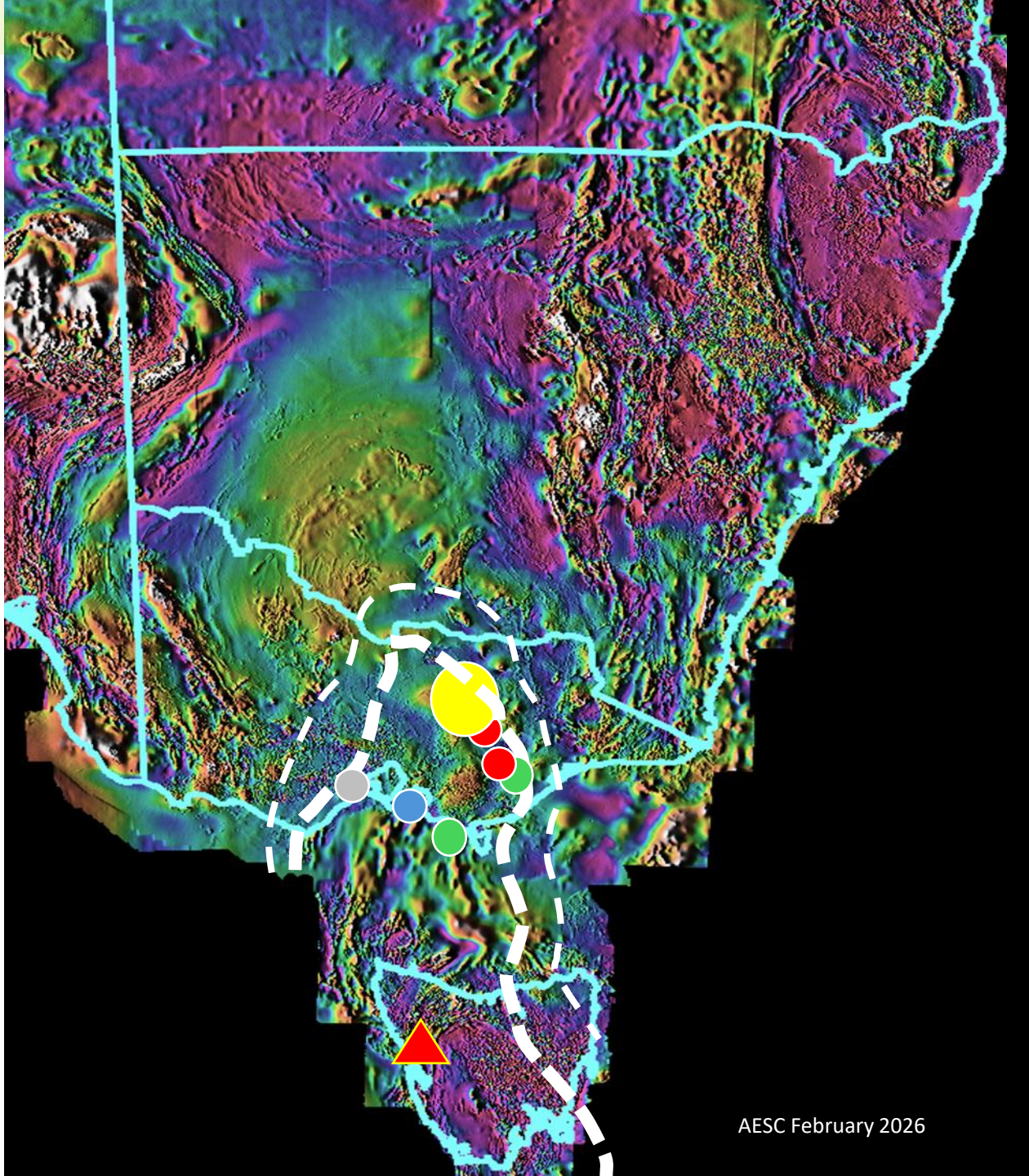
- **Prominent Late Cambrian unconformity – ‘Tyennan Orogeny’**
- Coarse continentally-derived sediment pulse in latest Cambrian
- Shallow marine post-Cambrian (limestones, phosphatic shale) = Western Tasmania.

Western Tasmania and its northern extension…the Selwyn Block. (Cayley et al., 2002)

The Vandieland microcontinent – deformed and uplifted Proterozoic - Cambrian continental crust beneath central Victoria (Cayley, 2011)

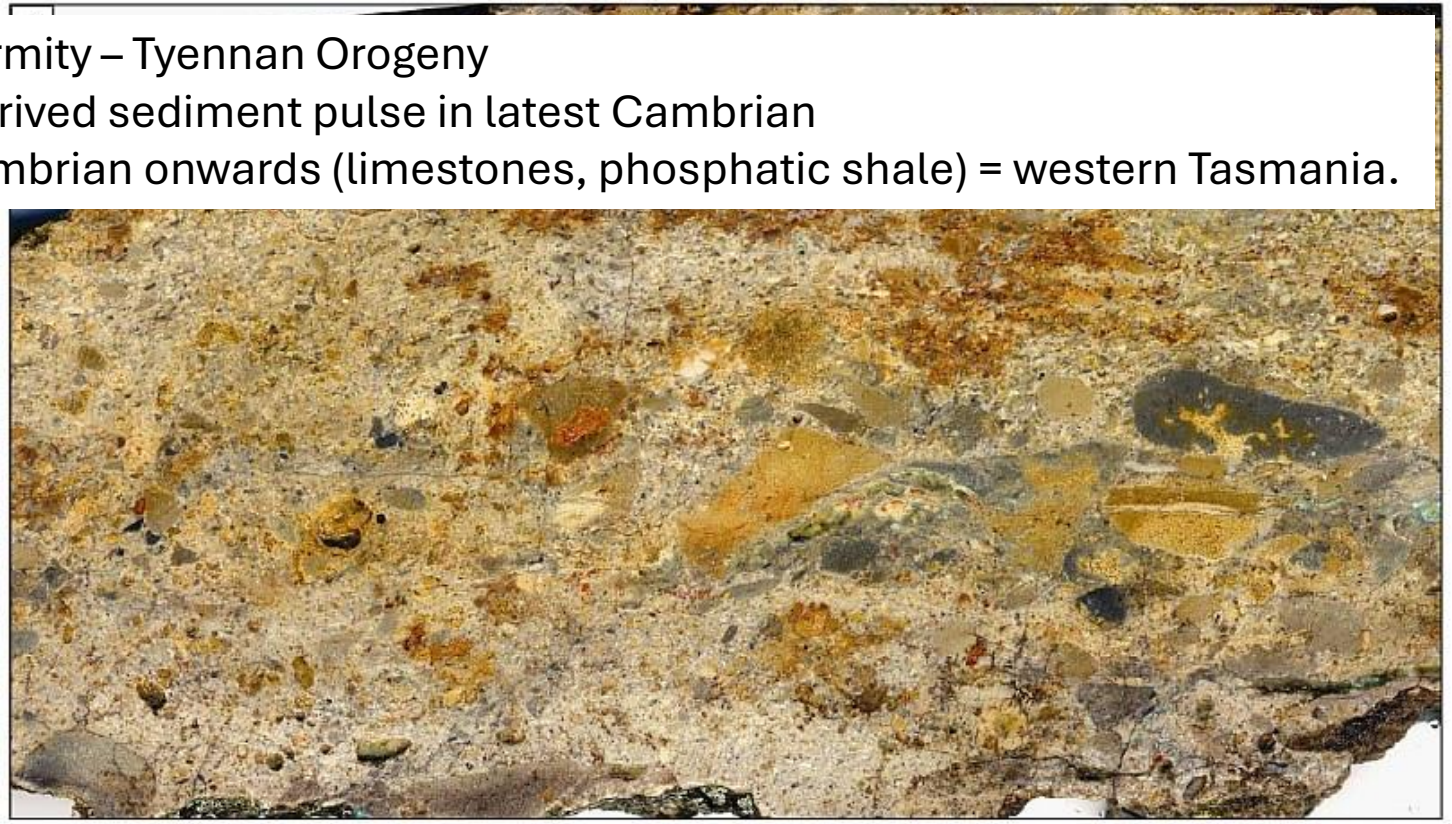
Extent in lower crust where influence is expressed in granite chemistry

Same relationships extend into north-central Victoria:



# Glen Creek

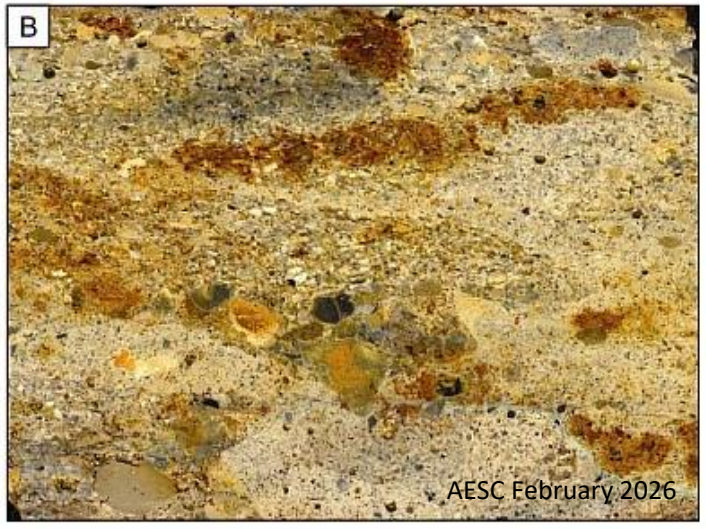
- Late Cambrian unconformity – Tyennan Orogeny
- Coarse continentally-derived sediment pulse in latest Cambrian
- Shallow marine Late Cambrian onwards (limestones, phosphatic shale) = western Tasmania.

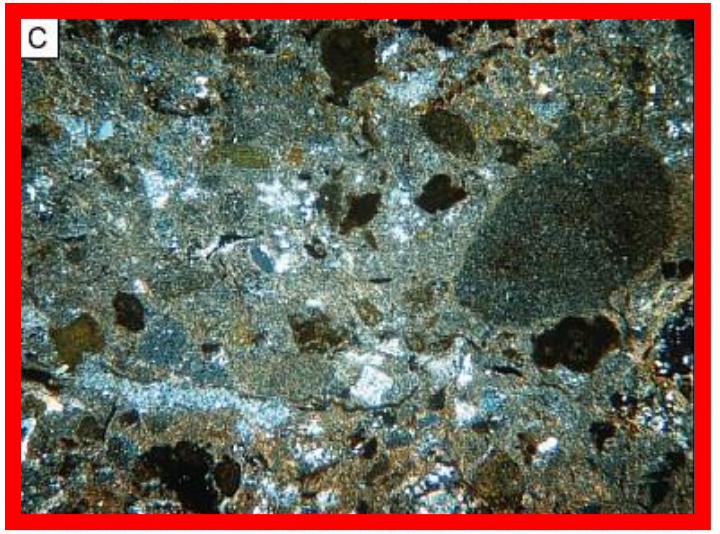


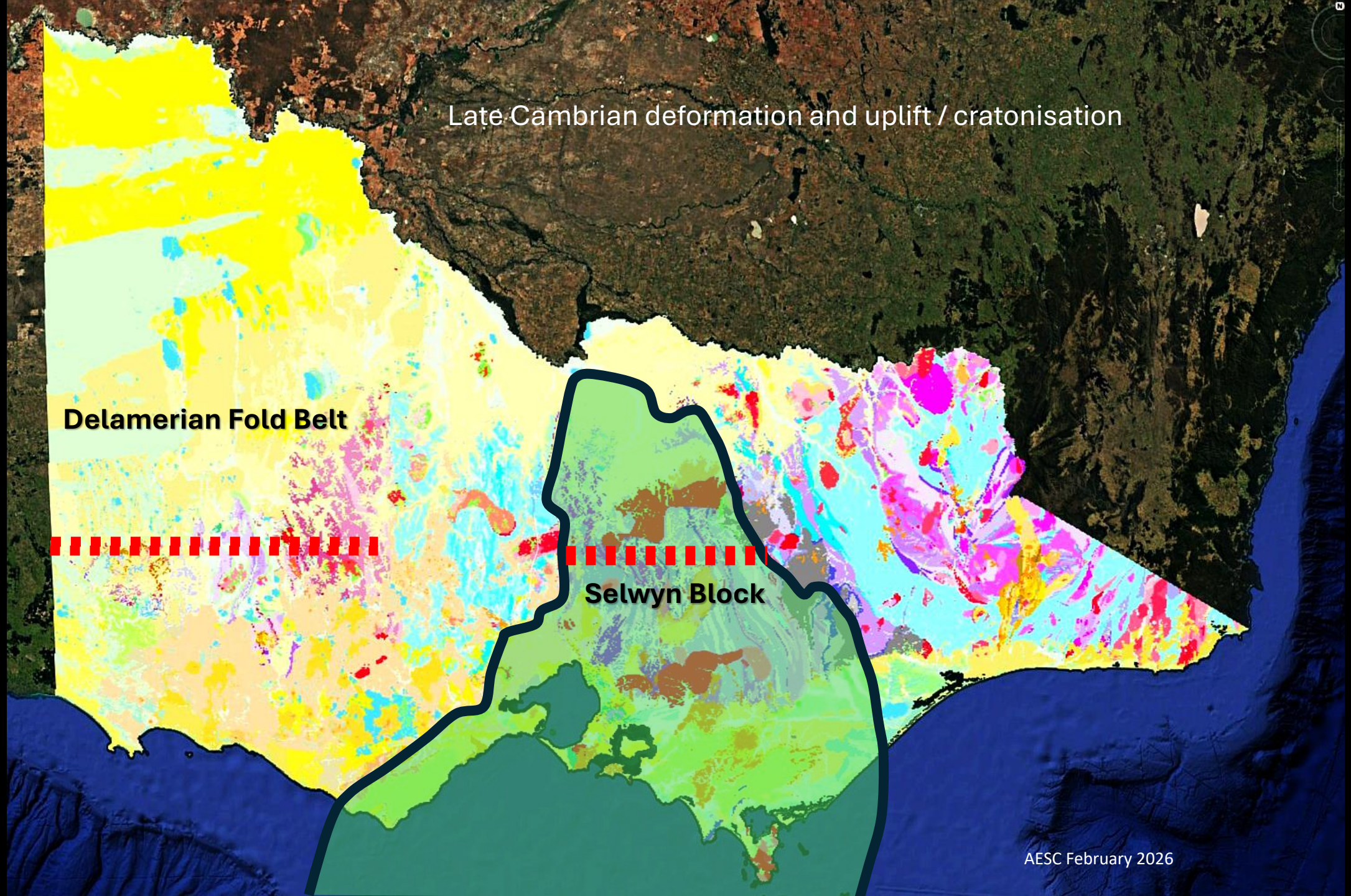
Bear Gully Gritstone and Digger Island Limestone correlates.

The <u>only</u> region capable supplying proximal metamorphic siliciclastics and shallow marine carbonates onto northern Selwyn Block rocks in the Late Cambrian / Earliest Ordovician: subaerial west-Tasmanian-style continental crust.

All other adjacent regions lay in persistent deep-marine sediment-starved oceanic settings at this time.



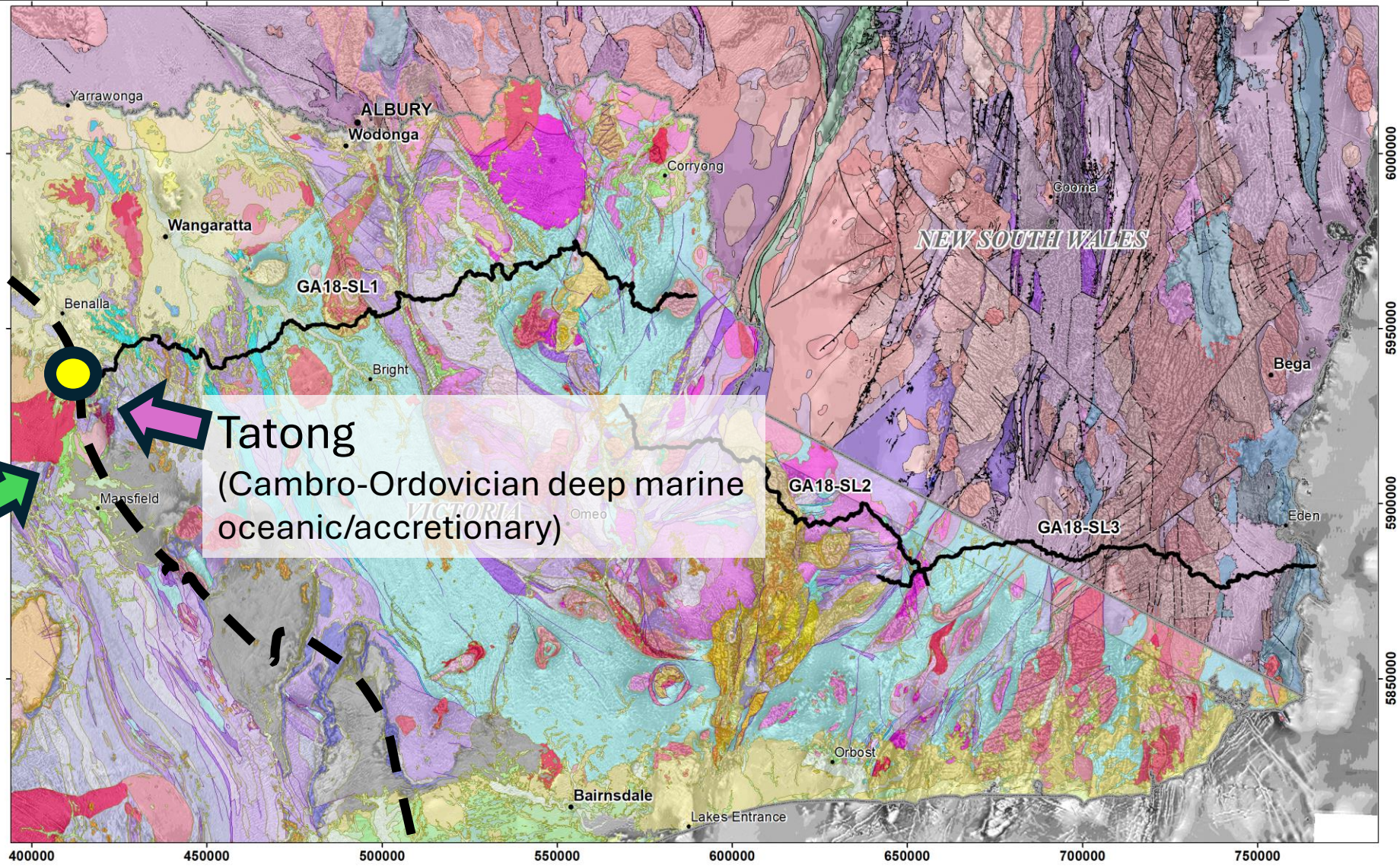




Late Cambrian deformation and uplift / cratonisation
Delamerian Fold Belt
Selwyn Block
AESC February 2026

With the NSWGS onboard in 2016, project redesigned to cross the full width of eastern LFB geology where best exposed and the best mapping and geological constraints already exist.

## Glen Creek

(Late Cambrian cratonic – shallow marine Selwyn Block)



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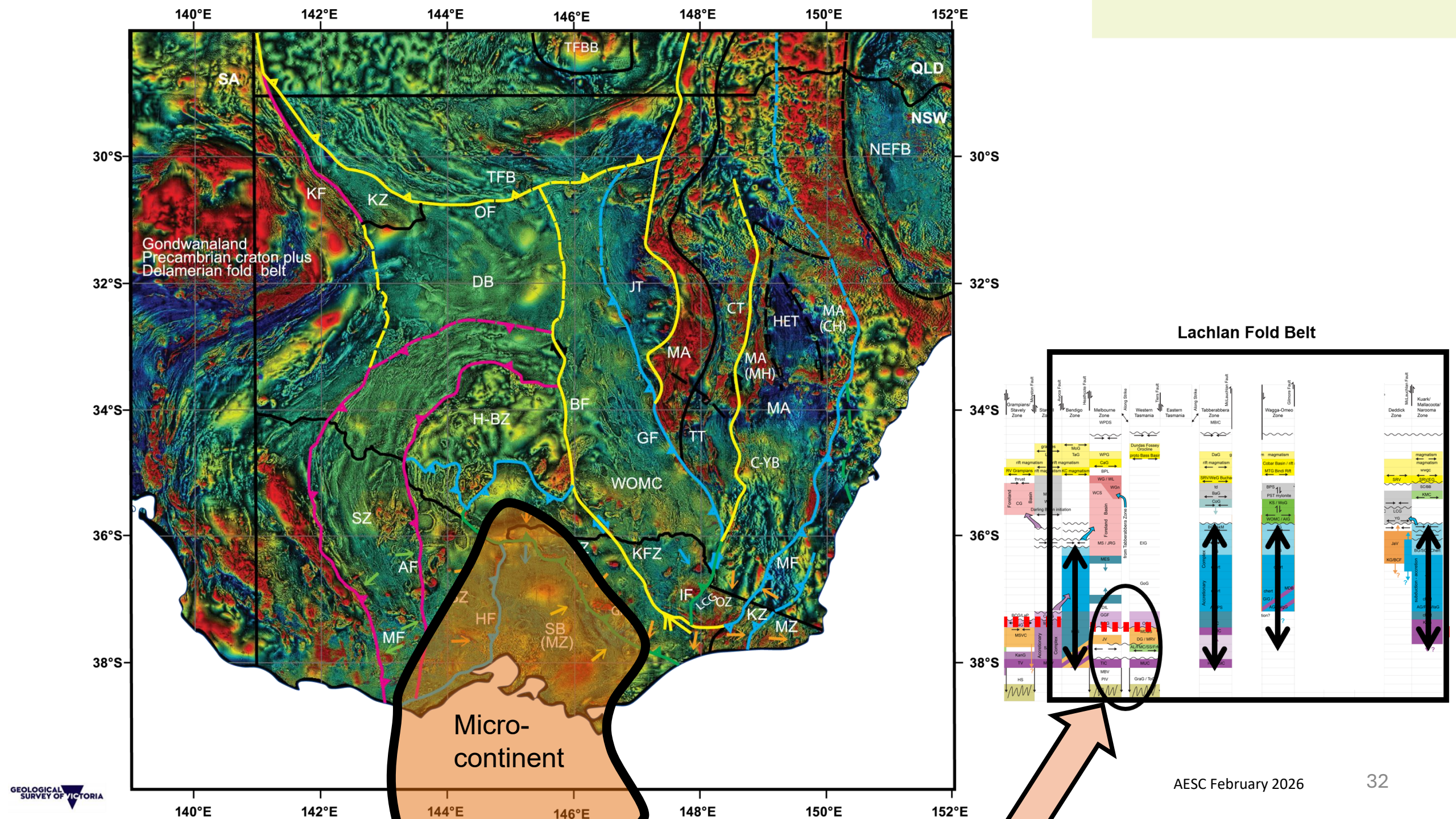
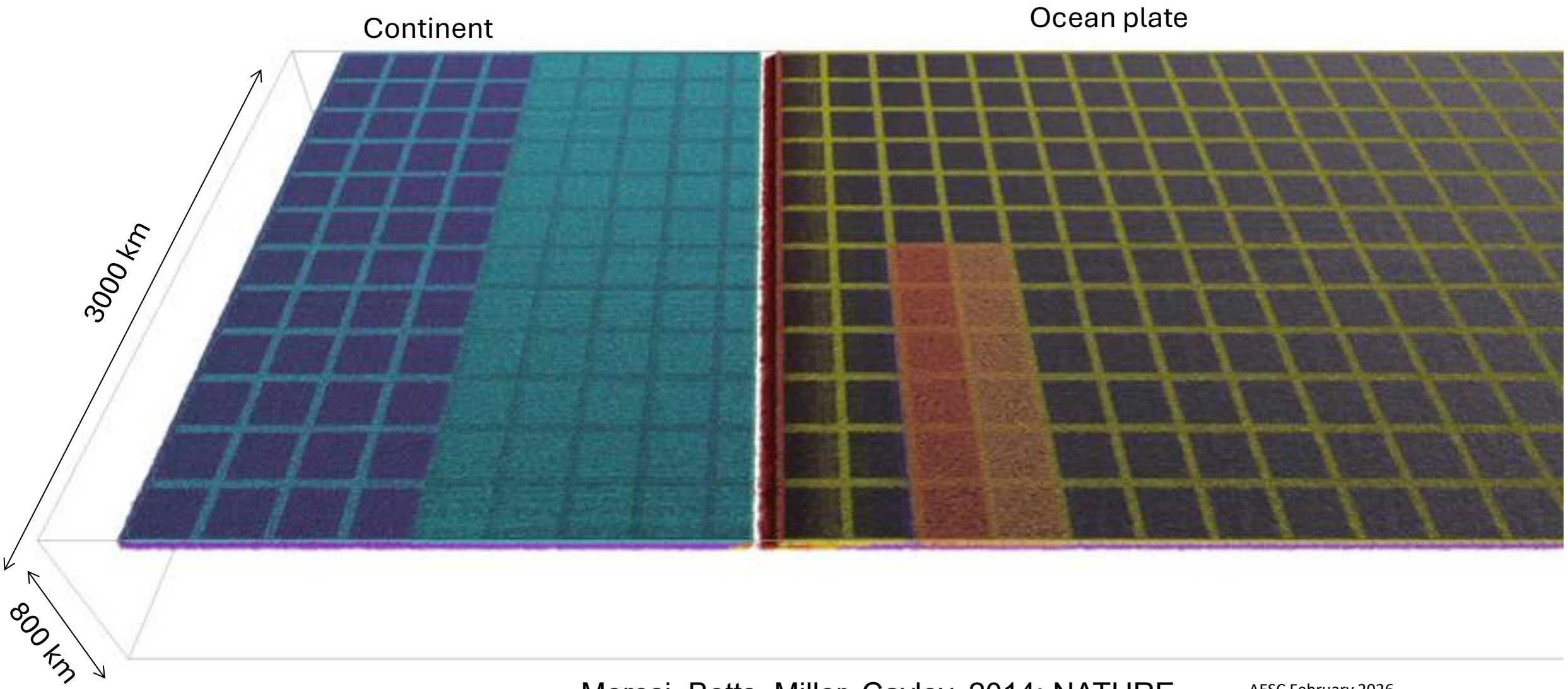
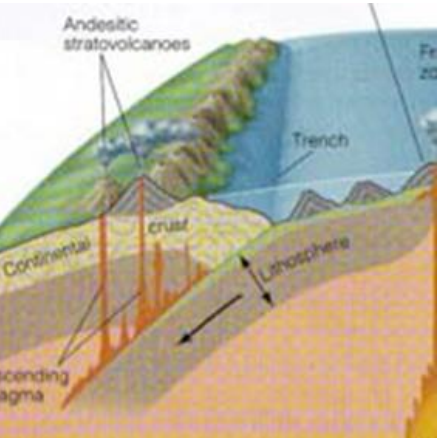

140°E
142°E
144°E
146°E
148°E
150°E
152°E
30°S
32°S
34°S
36°S
38°S
SA
QLD
NSW
NEFB
TFBB
TFB
OF
KF
KZ
Gondwanaland
Precambrian craton plus
Delamerian fold belt
DB
JT
CT
HET
MA
(CH)
MA
MA
(MH)
MA
BF
H-BZ
GF
TT
C-YB
WOMC
SZ
KFZ
AF
MF
IF
LCC
OZ
KZ
MZ
HF
SB
(MZ)
MF
Micro-
continent
Lachlan Fold Belt

# Geodynamics of congested subduction zones

Model run time = 60 Million years

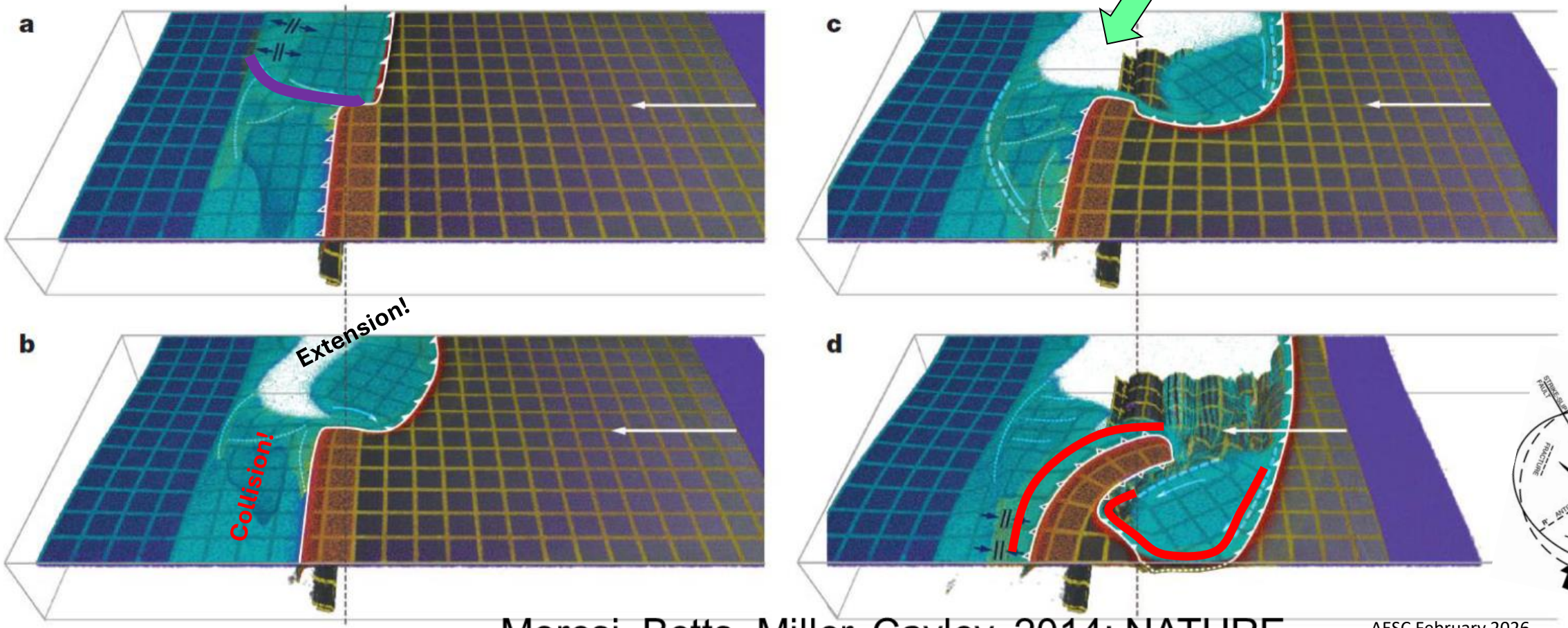


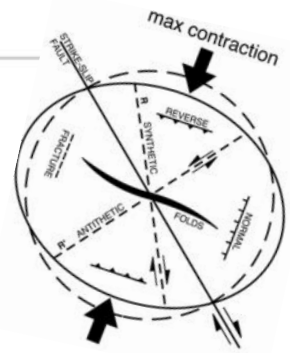

Moresi, Betts, Miller, Cayley, 2014: NATURE



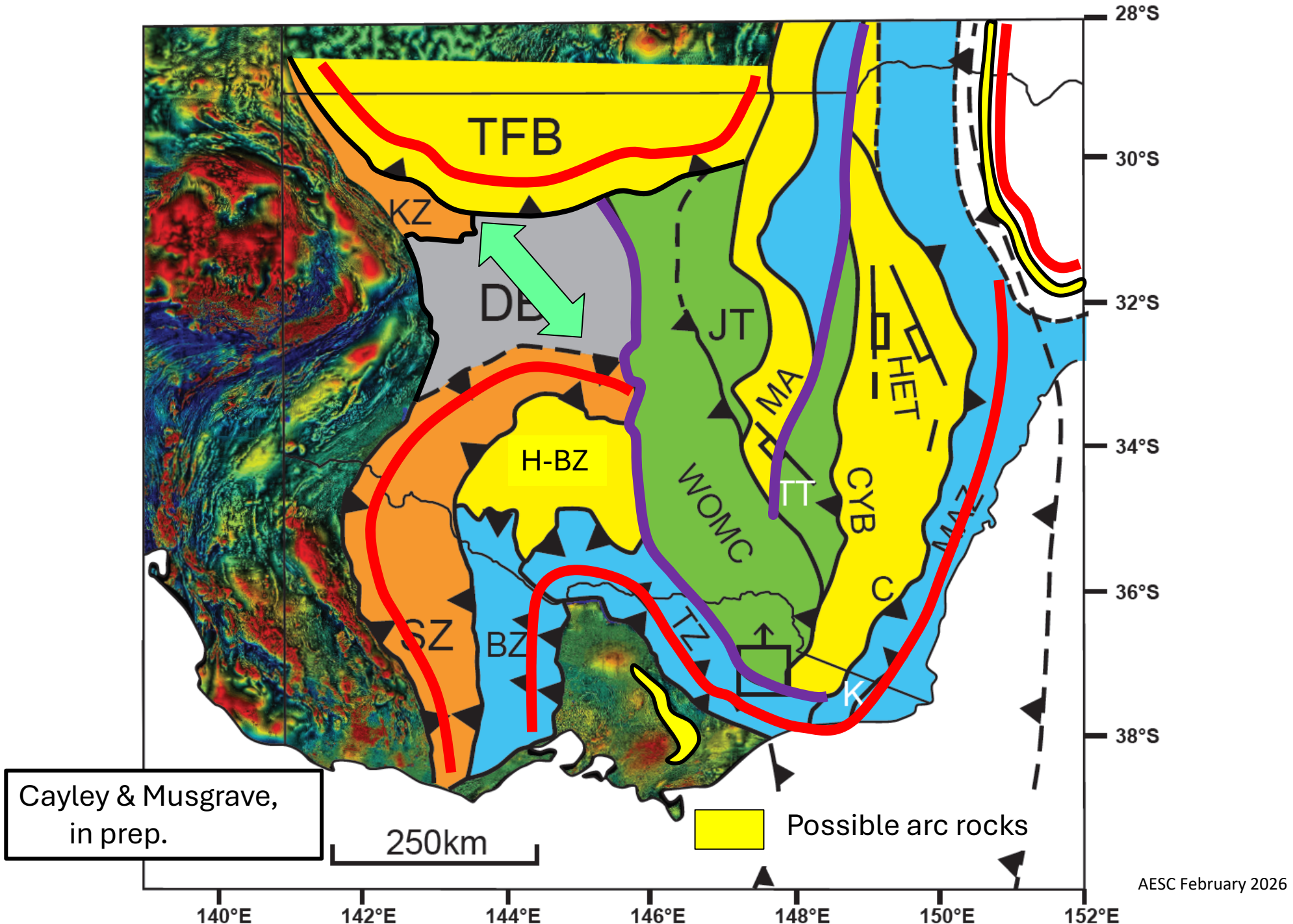

# Geodynamics of congested subduction zones

Rifting / basins




Moresi, Betts, Miller, Cayley, 2014: NATURE


TFB
KZ
DB
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MA
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WOMC
TT
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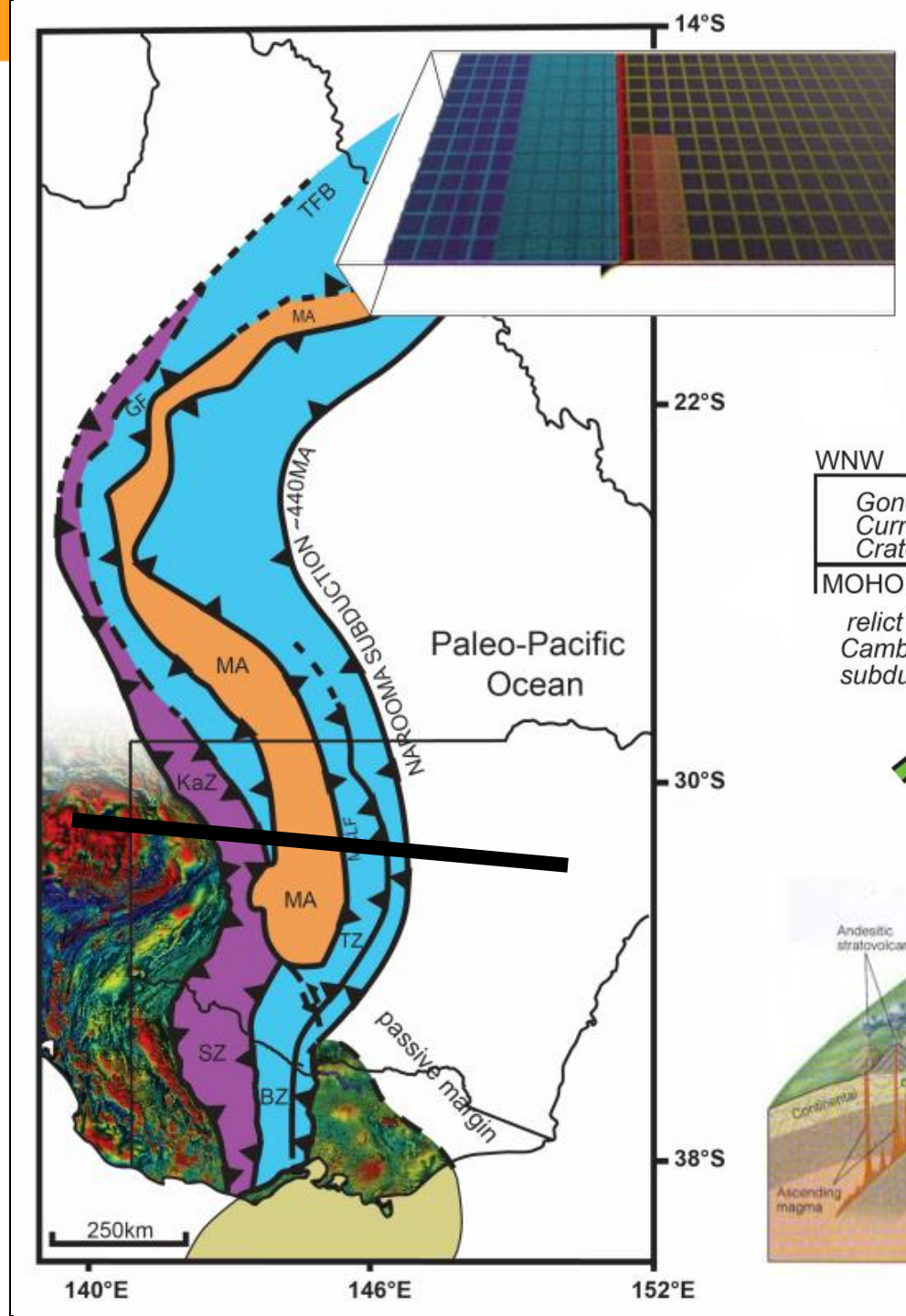
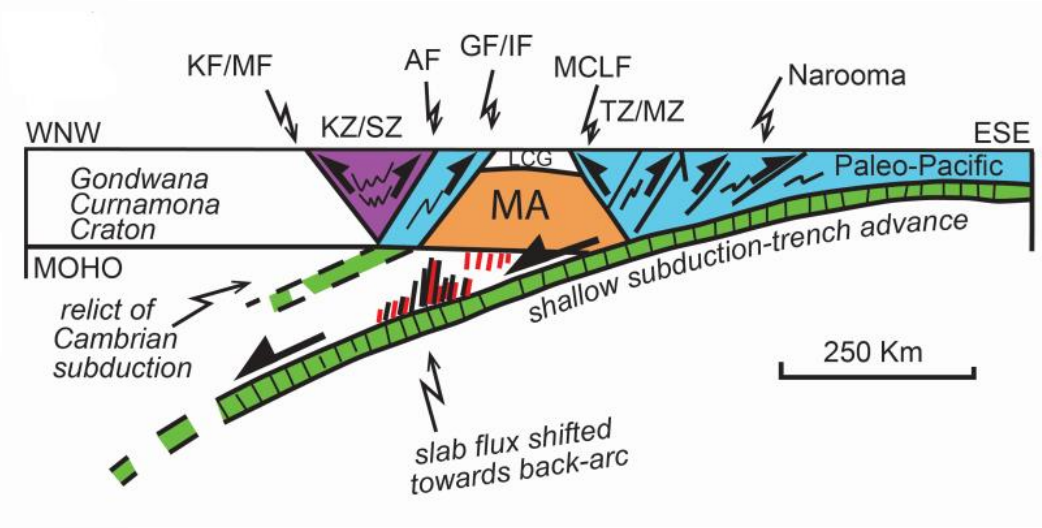
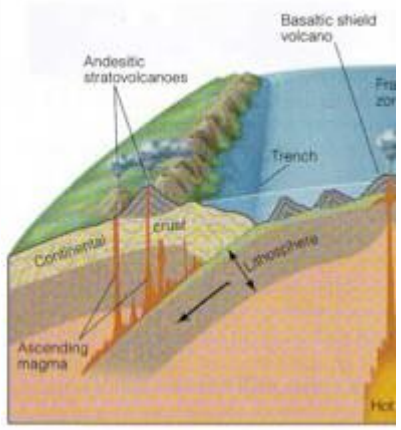
K
28°S
30°S
32°S
34°S
36°S
38°S
140°E
142°E
144°E
146°E
148°E
150°E
152°E
Cayley & Musgrave,
in prep.
250km
Possible arc rocks
AESC February 2026

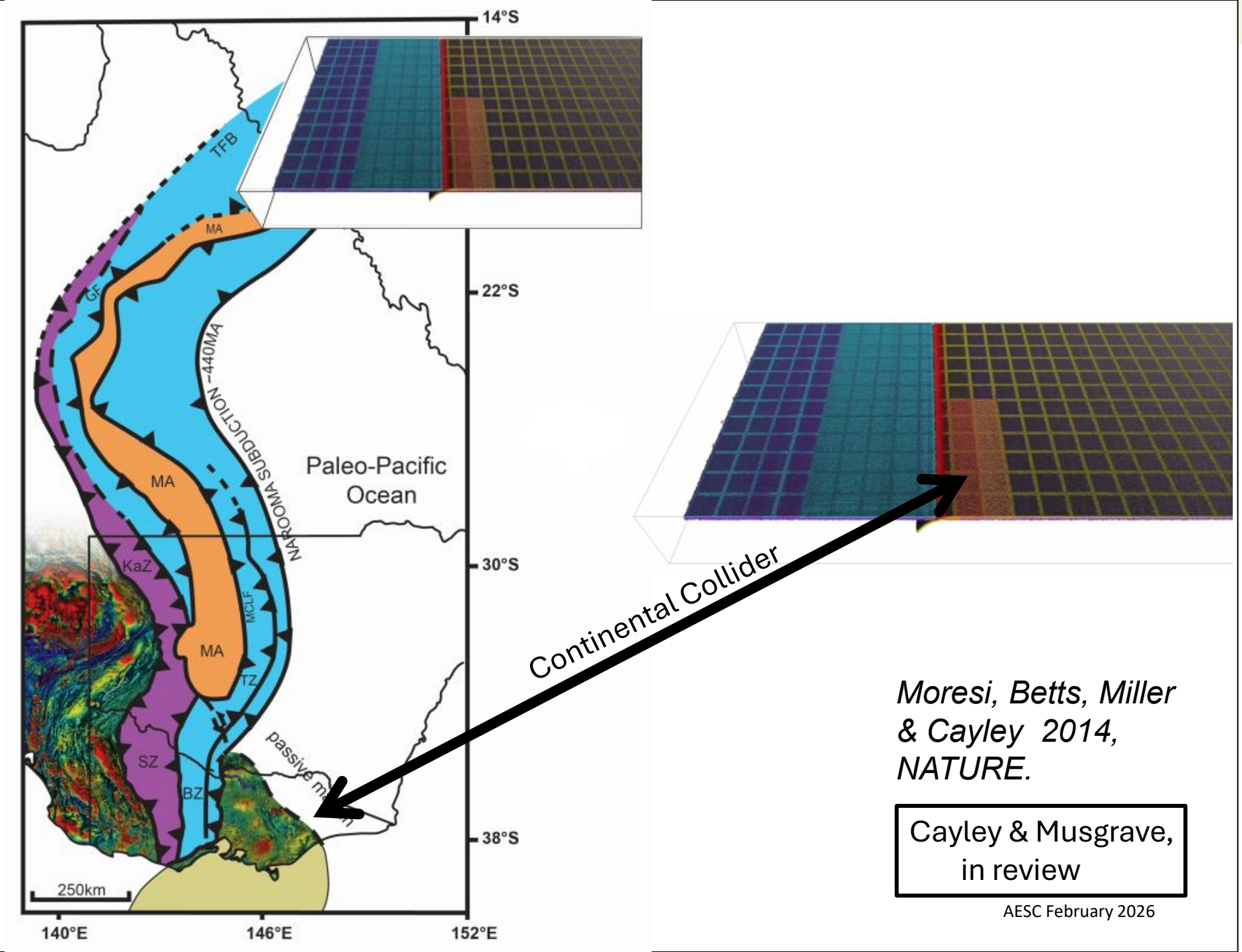



*Moresi, Betts, Miller & Cayley 2014, NATURE.*

Cayley & Musgrave, in review

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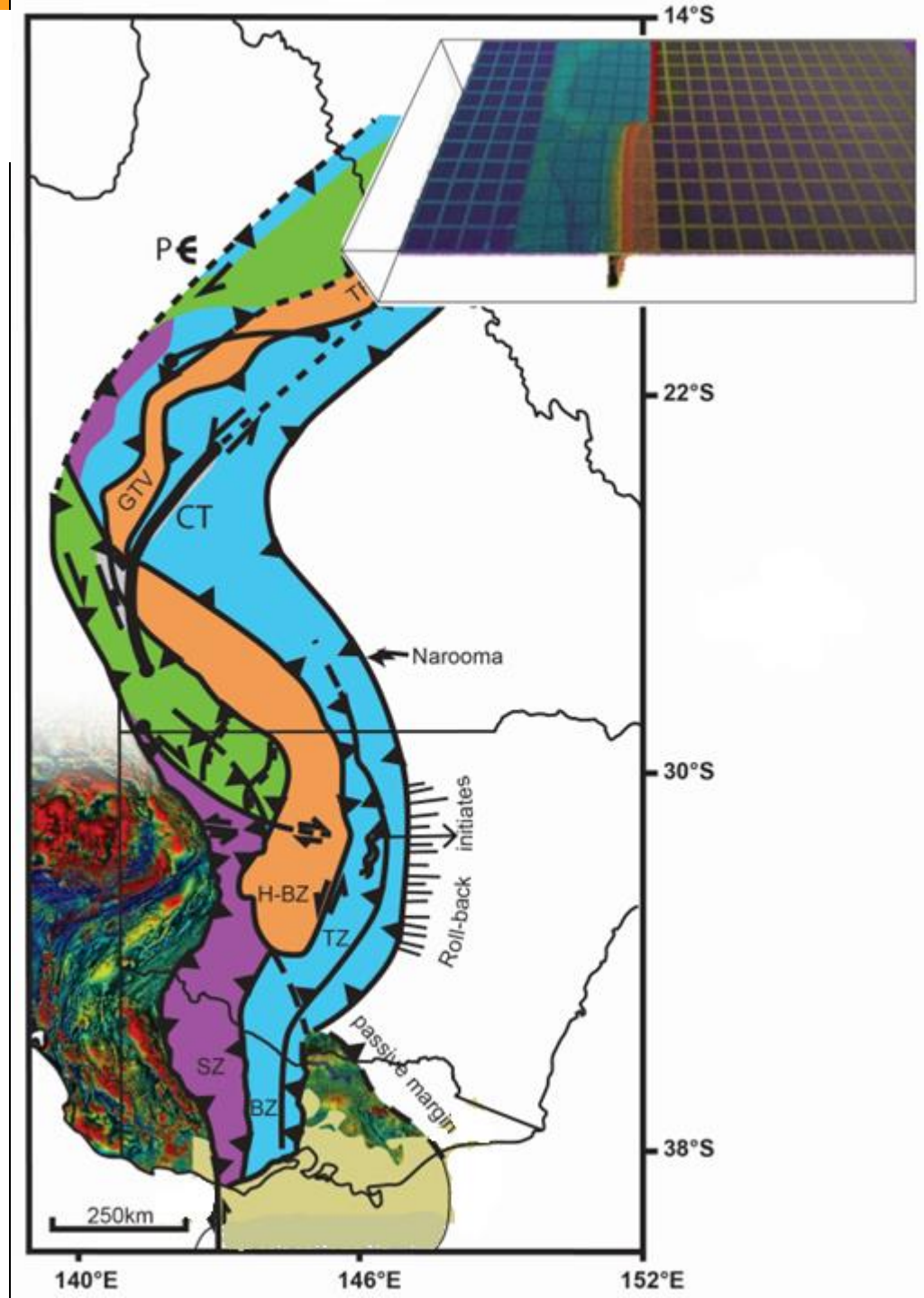


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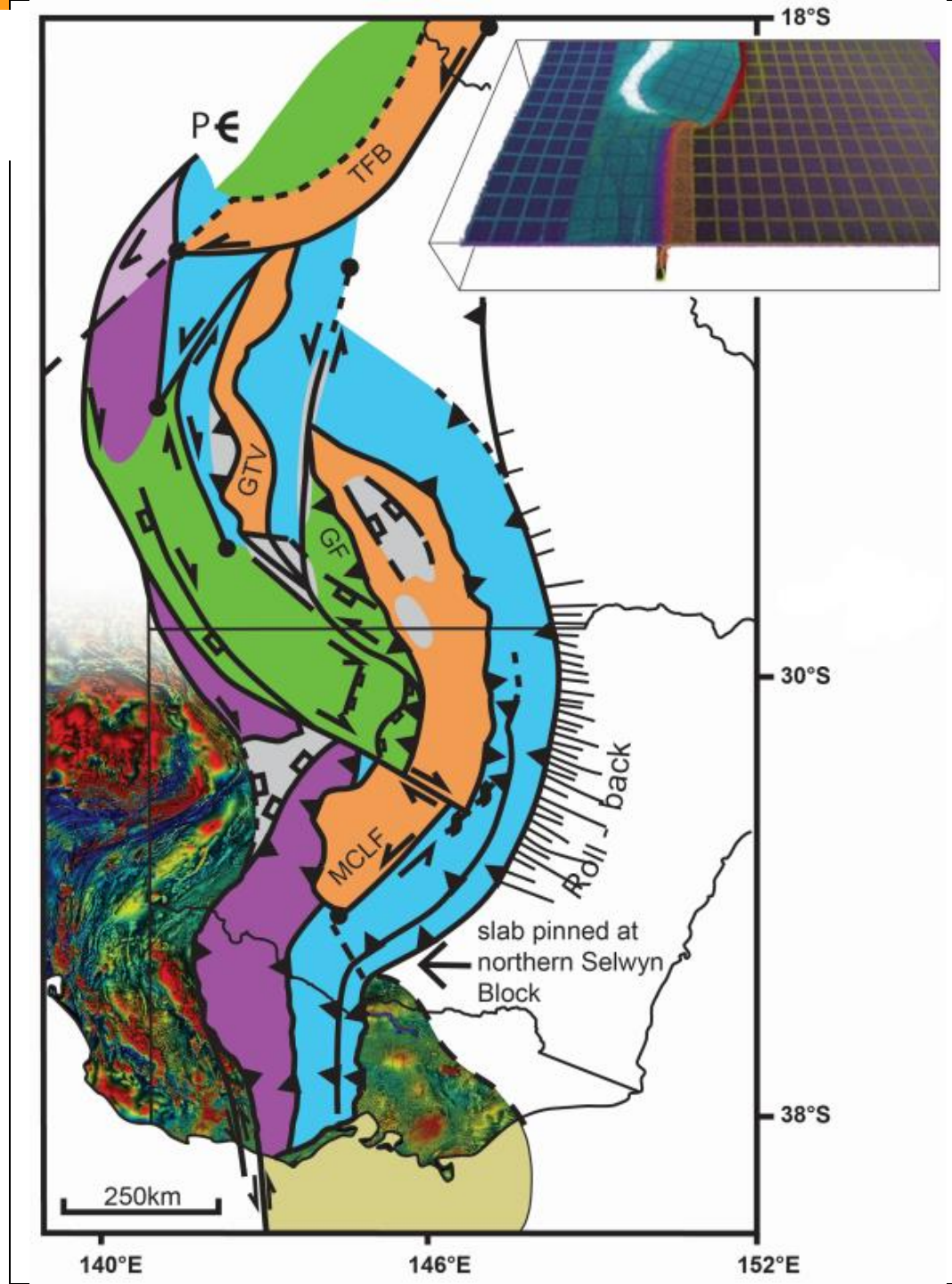


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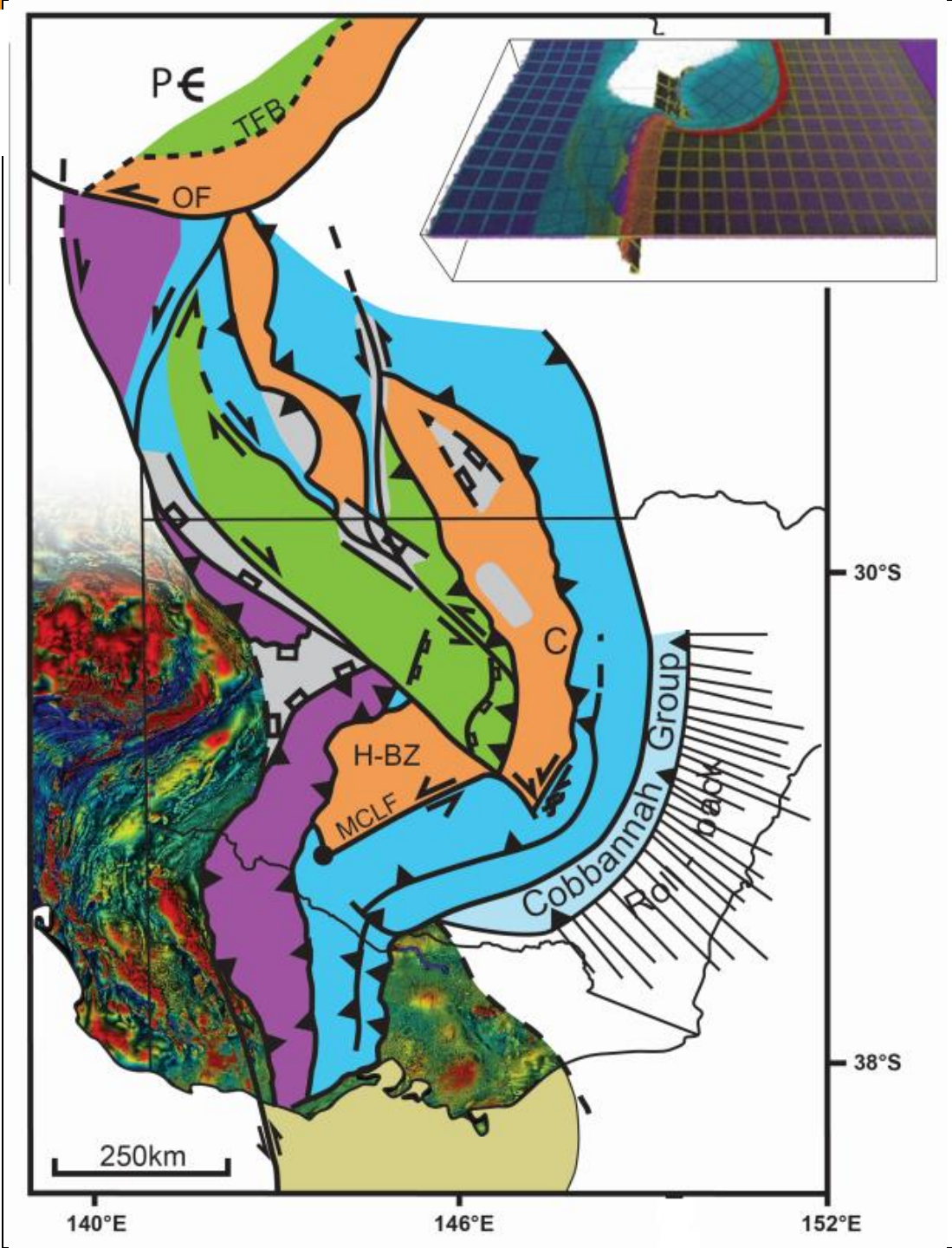


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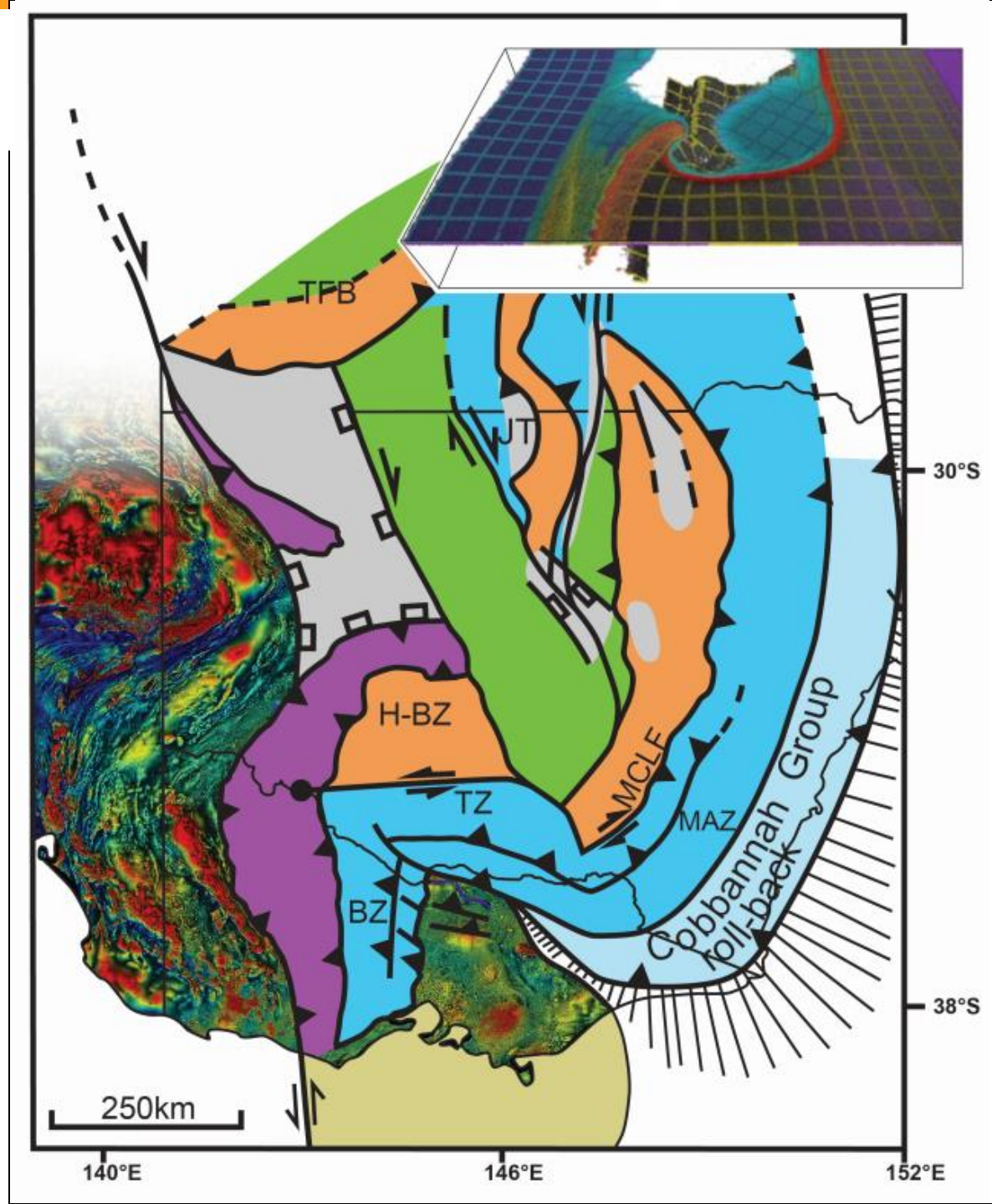


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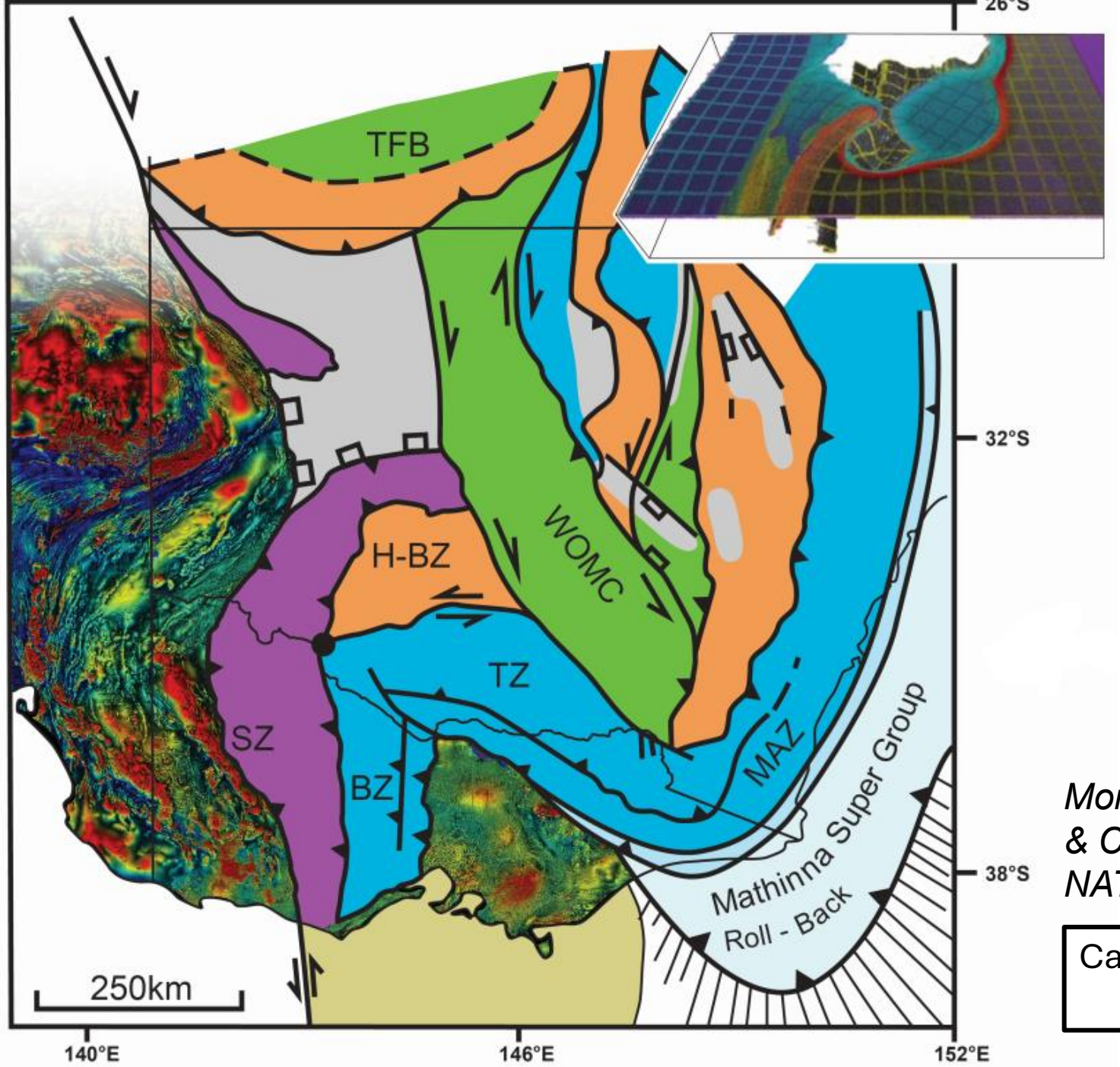


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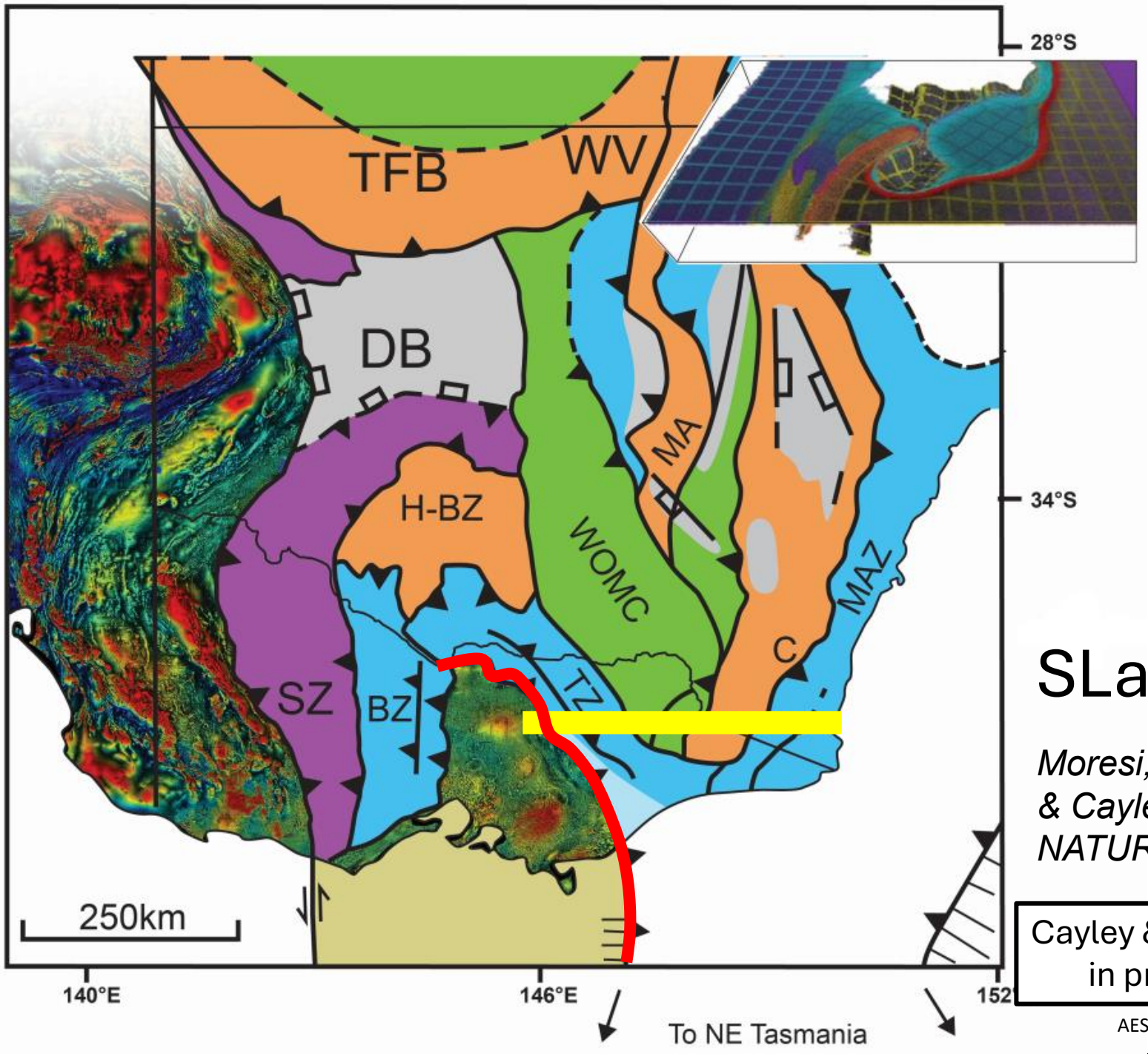
Cayley & Musgrave, in review




# SLaCT

*Moresi, Betts, Miller & Cayley 2014, NATURE.*

Cayley & Musgrave, in prep.

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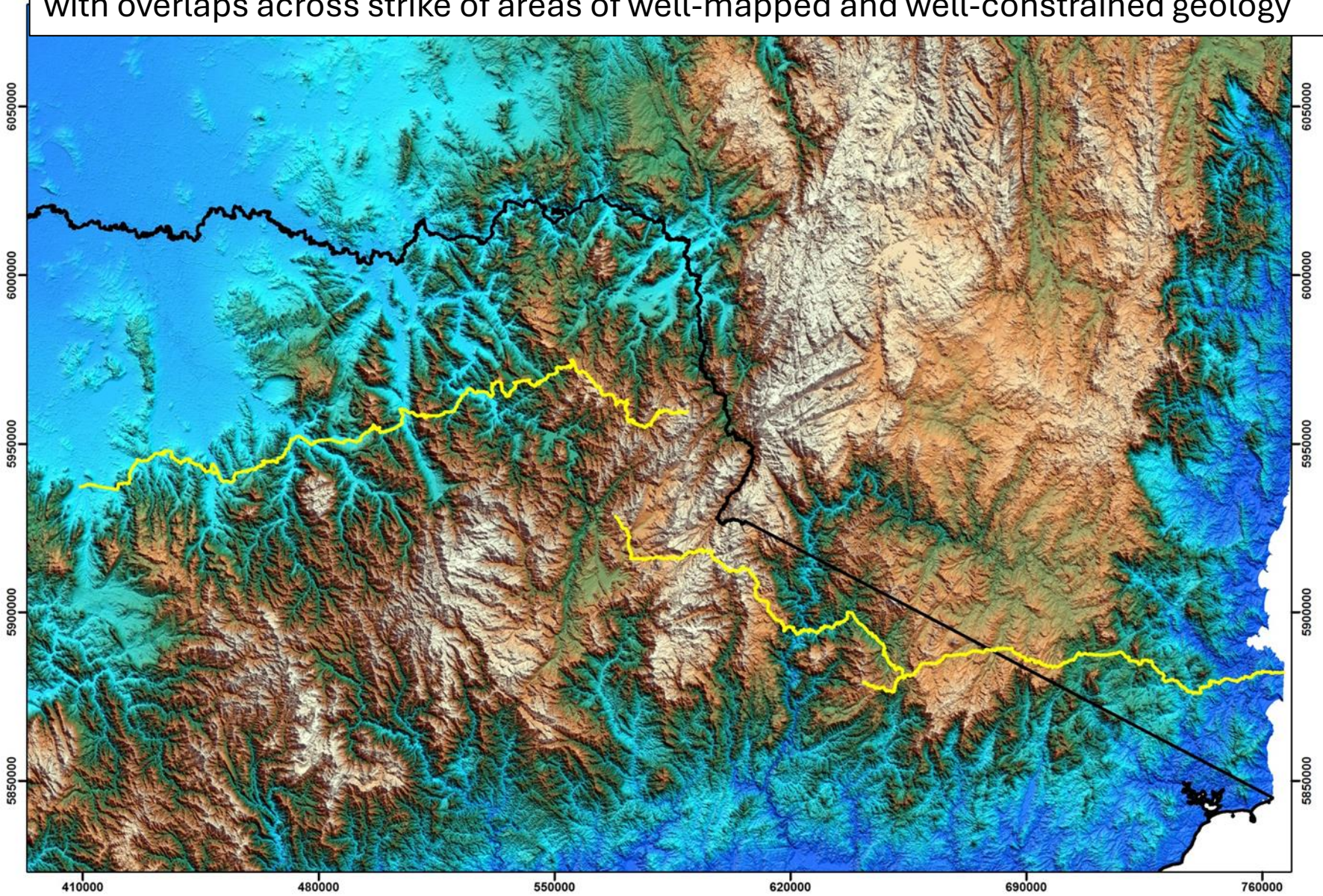
...in places where access for the deep seismic reflection acquisition infrastructure is possible, given it is the highest topographic relief in the whole continent. The lines were designed to be as straight as possible with overlaps across strike of areas of well-mapped and well-constrained geology



**And now…a little something for the geophysicists……**

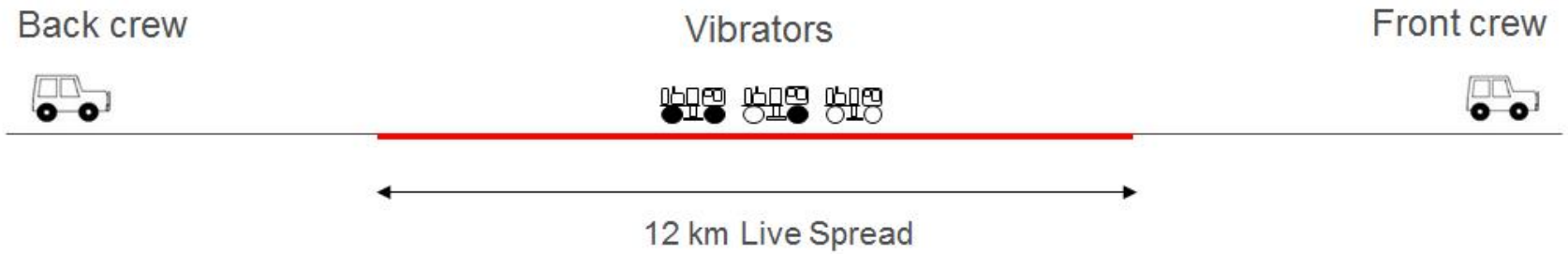
## Seismic data acquisition parameters

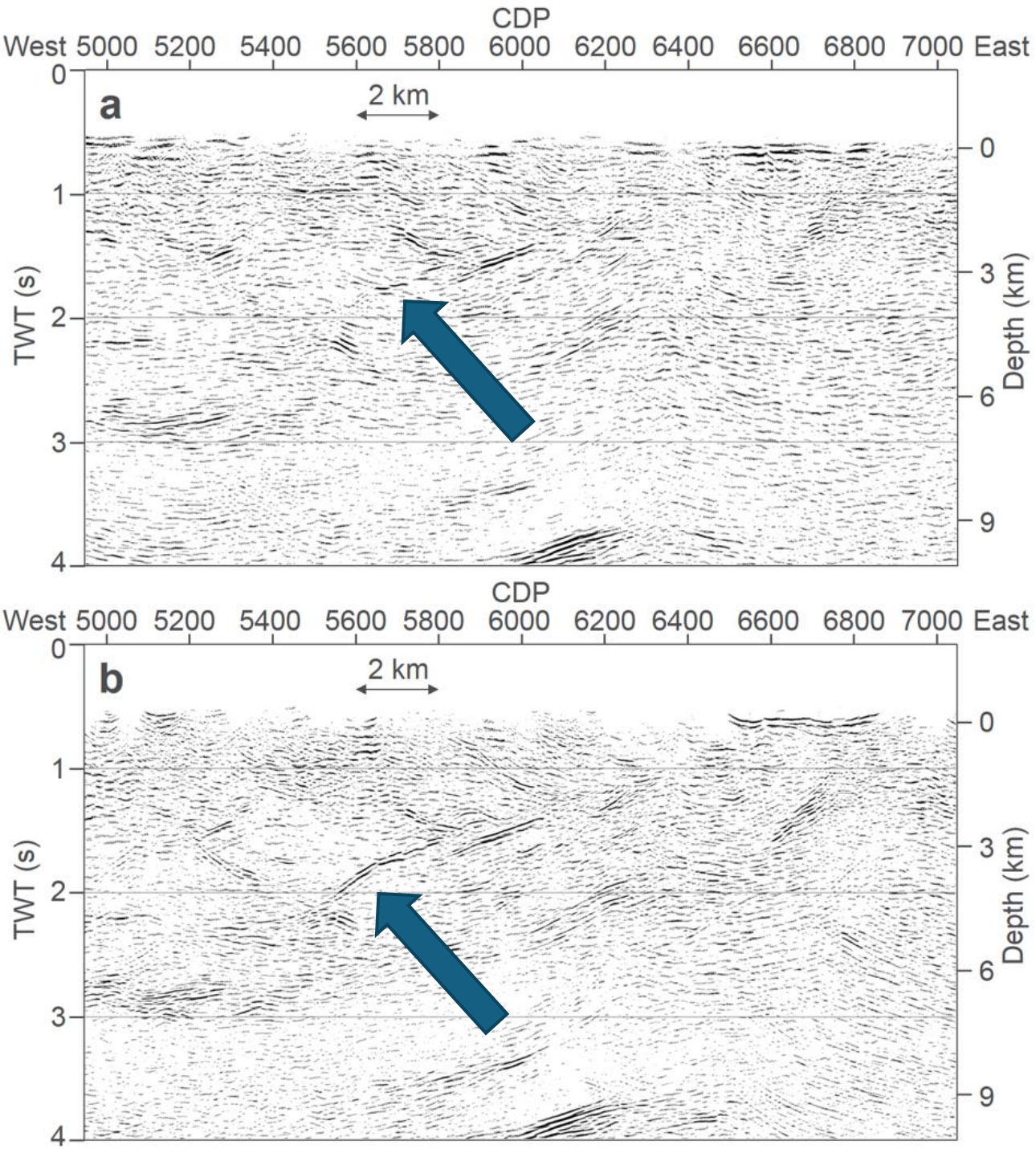
Symmetrical split spread, offset: minimum 20 m, maximum 6 km

300 channels at 40 m intervals, 75 nominal fold data

80 m VP interval

Used a nodal system (SmartSolo) : geophones recorded until collected




**Oh, all right…**

**something else for the geophysicists……**

Crooked Line
data processing

2-D vs hybrid 3-D
data processing

Differences between results of processing the upper few seconds of data using 2-D and hybrid 3D methods reveal off-line reflectors….

Costelloe et al, 2019

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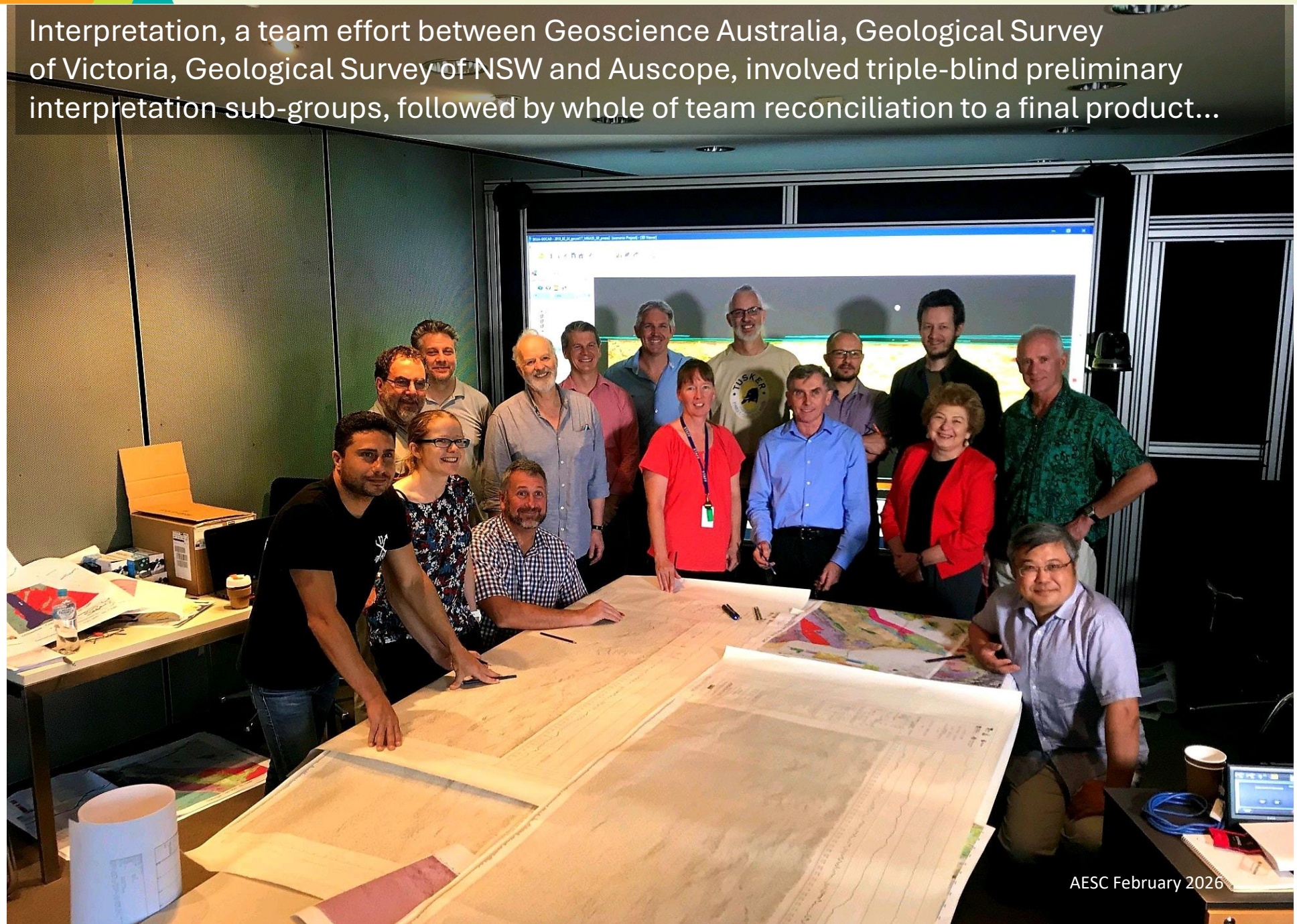
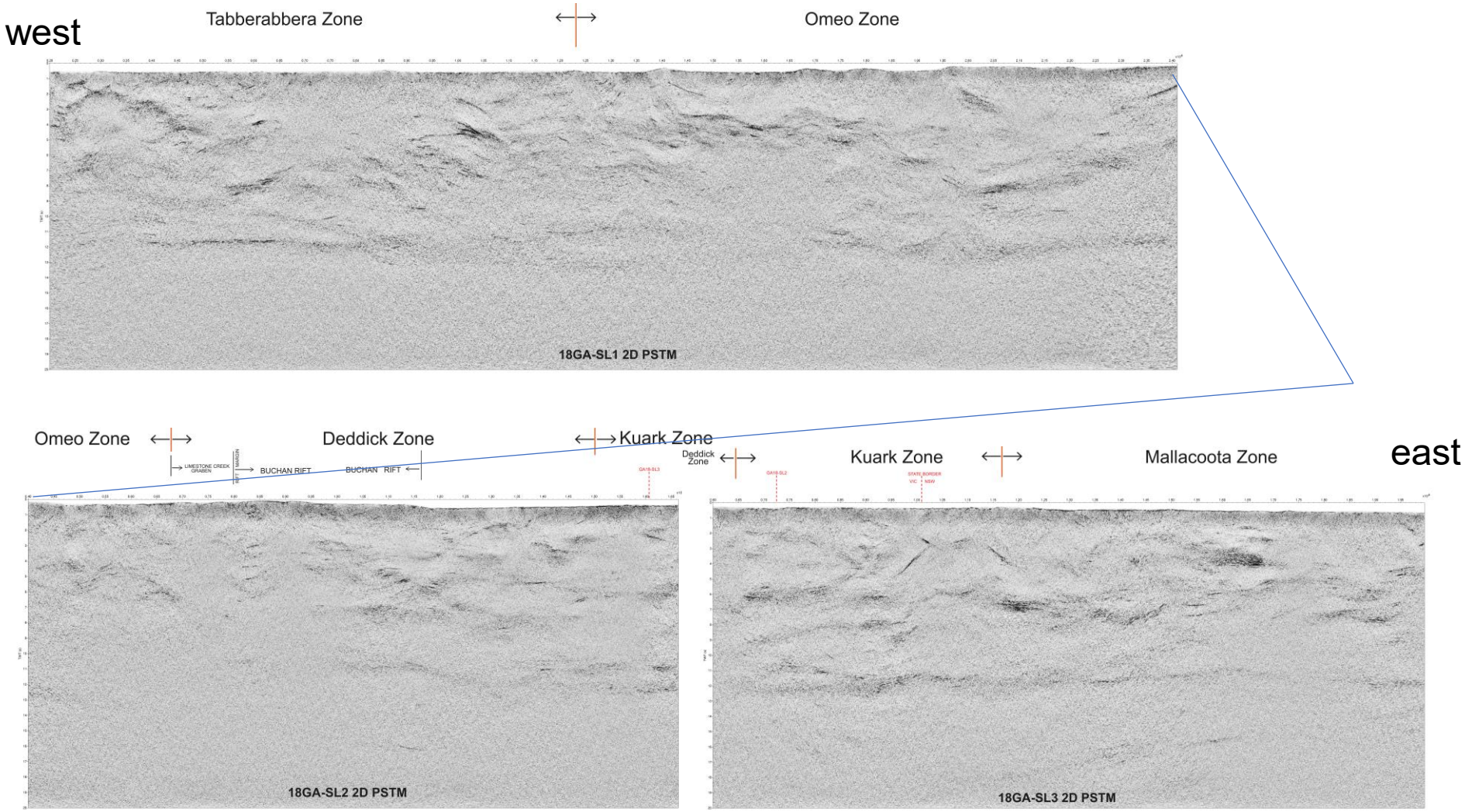
Interpretation, a team effort between Geoscience Australia, Geological Survey of Victoria, Geological Survey of NSW and Auscope, involved triple-blind preliminary interpretation sub-groups, followed by whole of team reconciliation to a final product...



# SLaCT transects – migrated and stacked 20s TWT profiles




Cayley et al., in prep.

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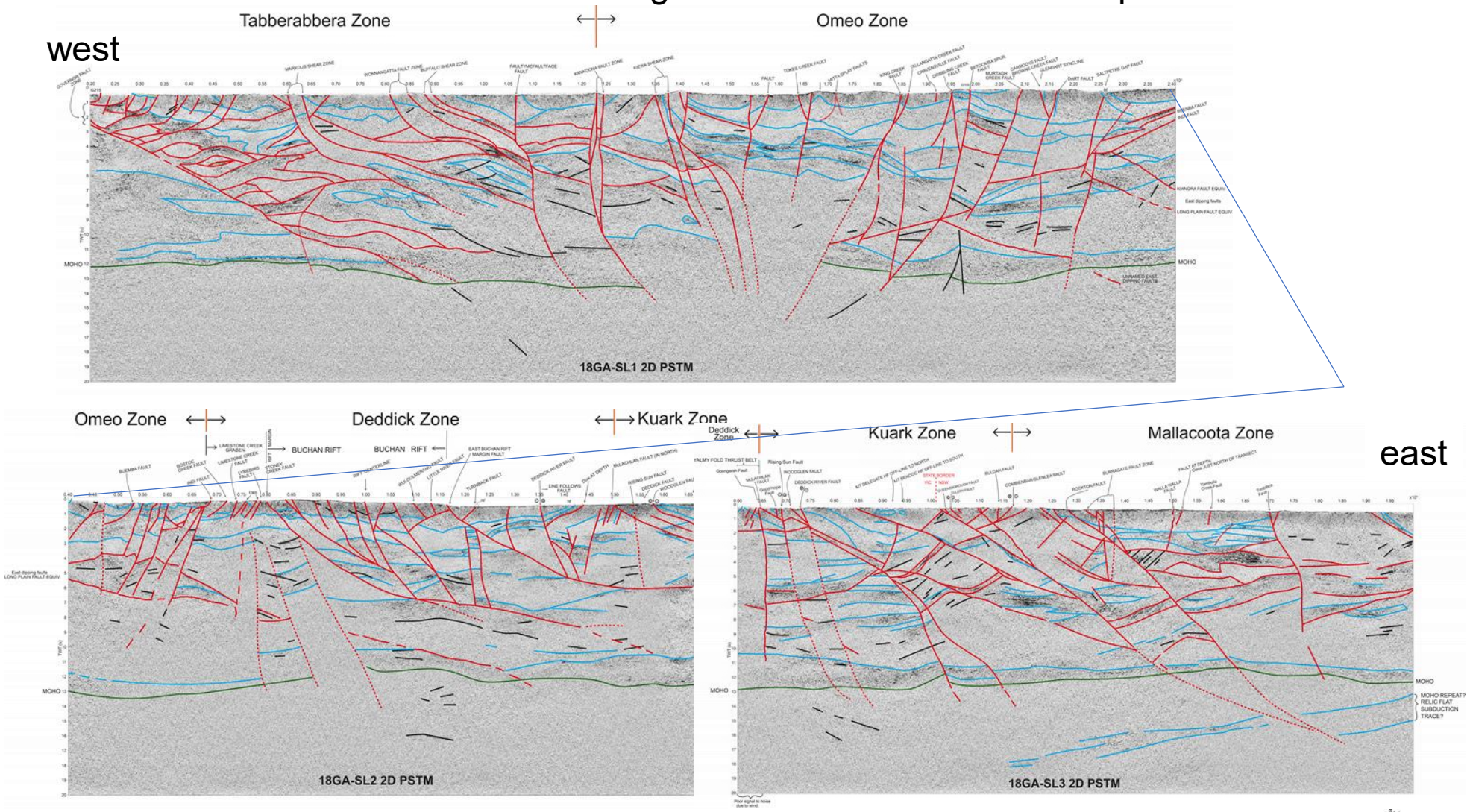


Cayley et al., in prep.

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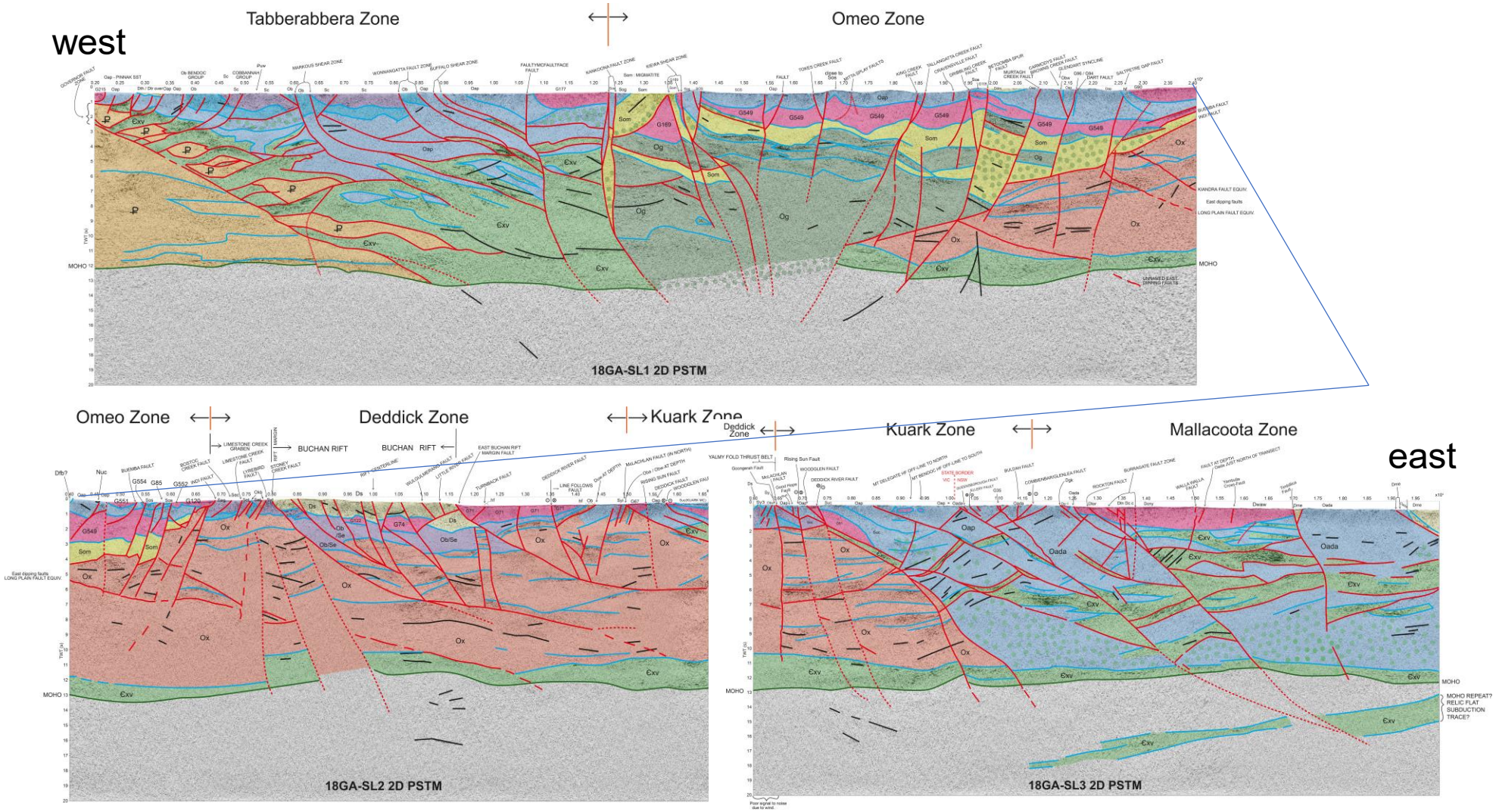
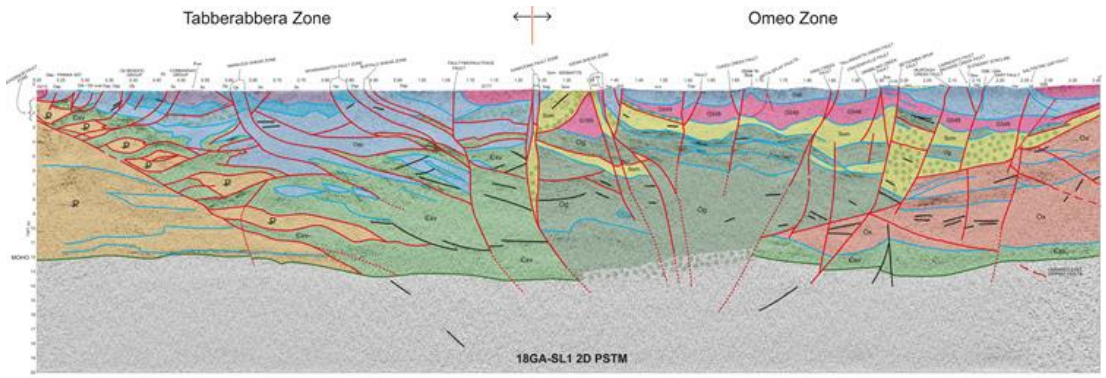
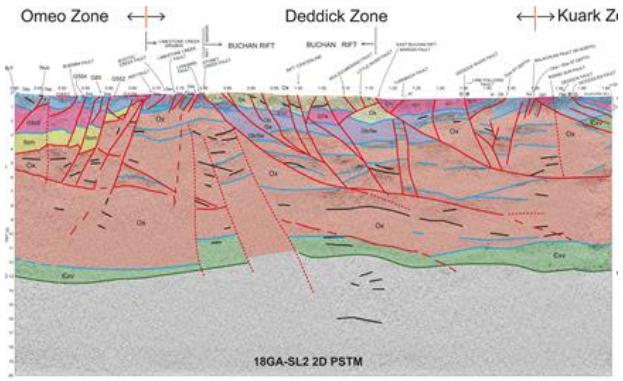
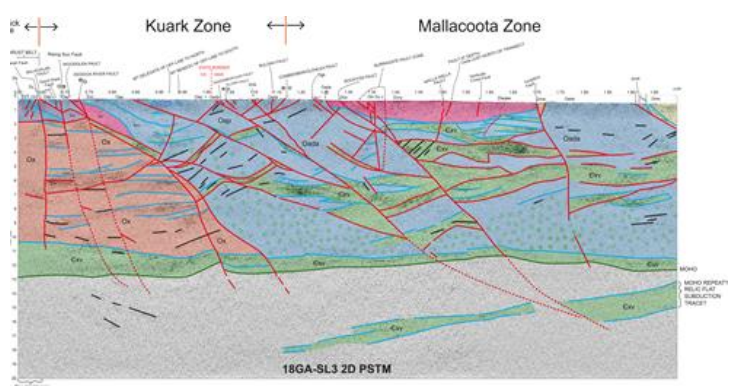


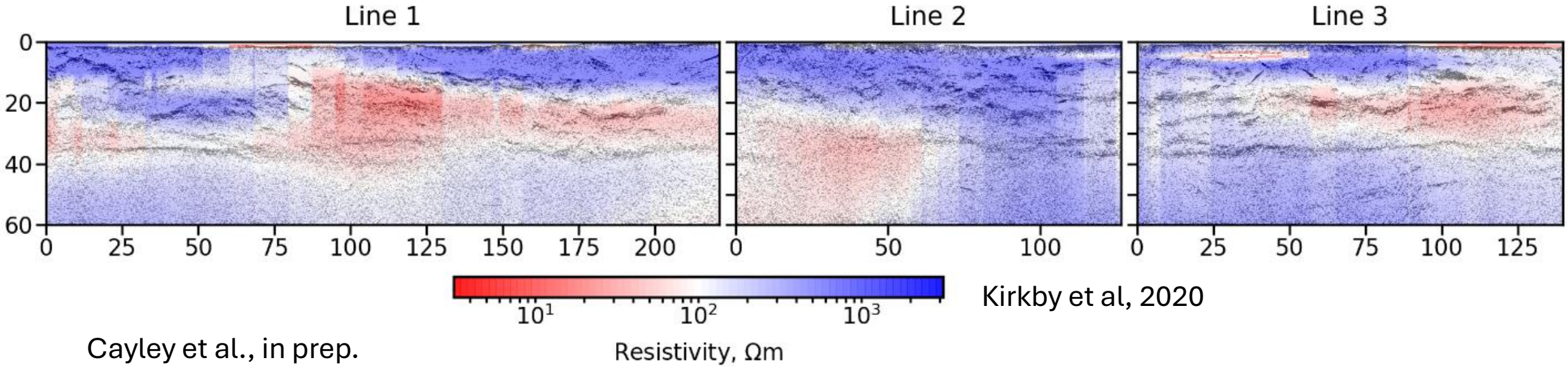

Cayley et al., in prep.



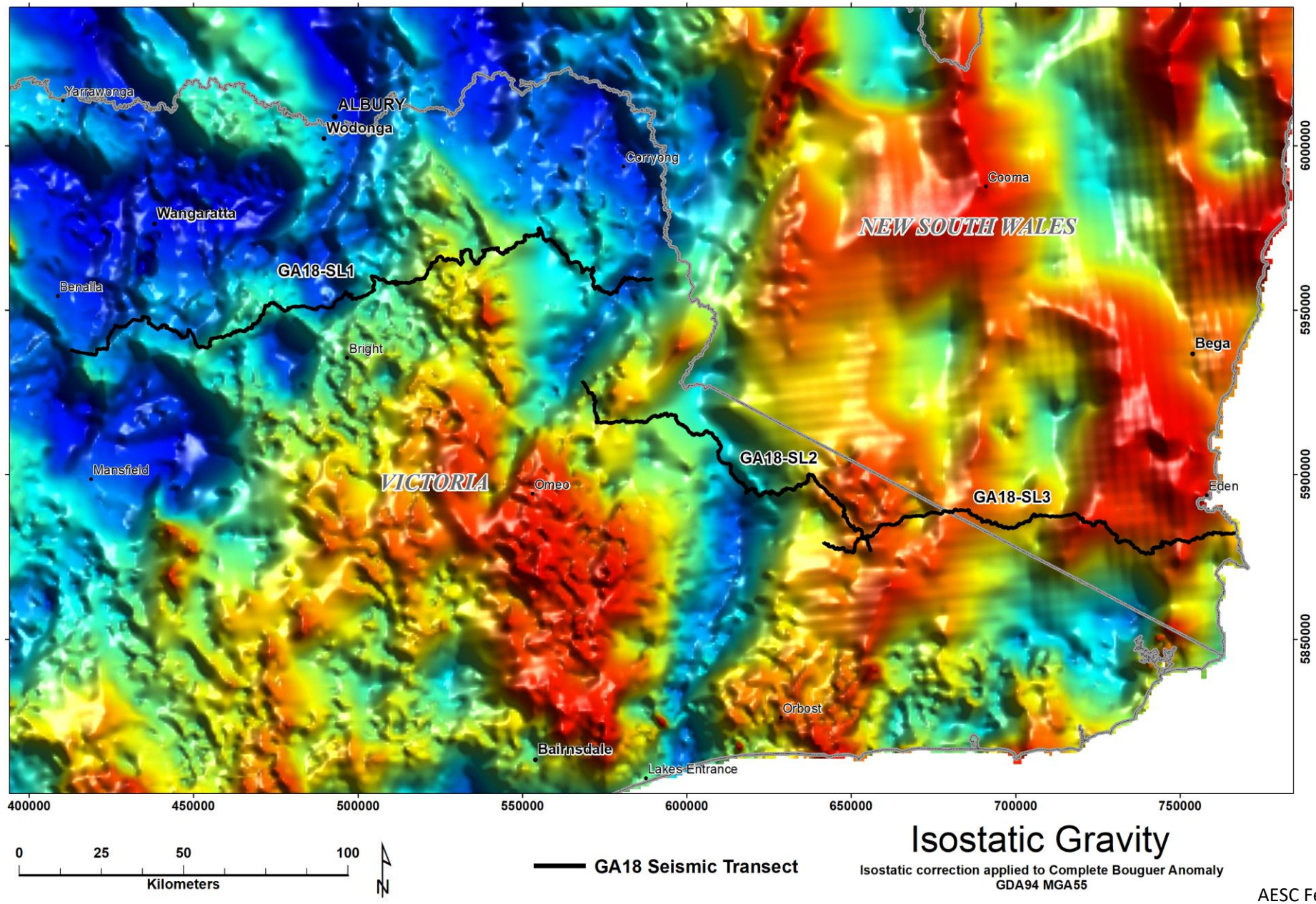



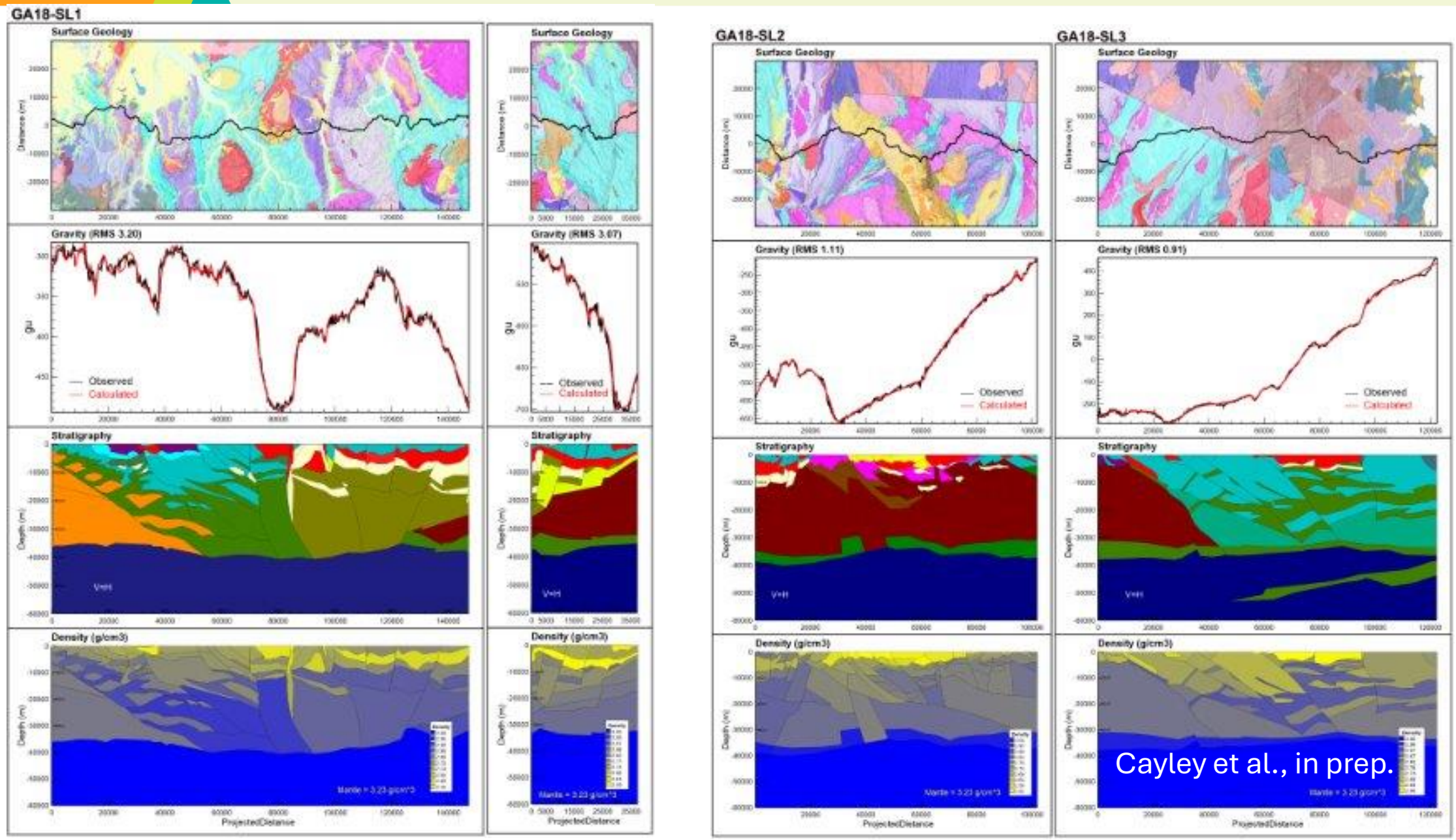

- Regional scale magnetotellurics:



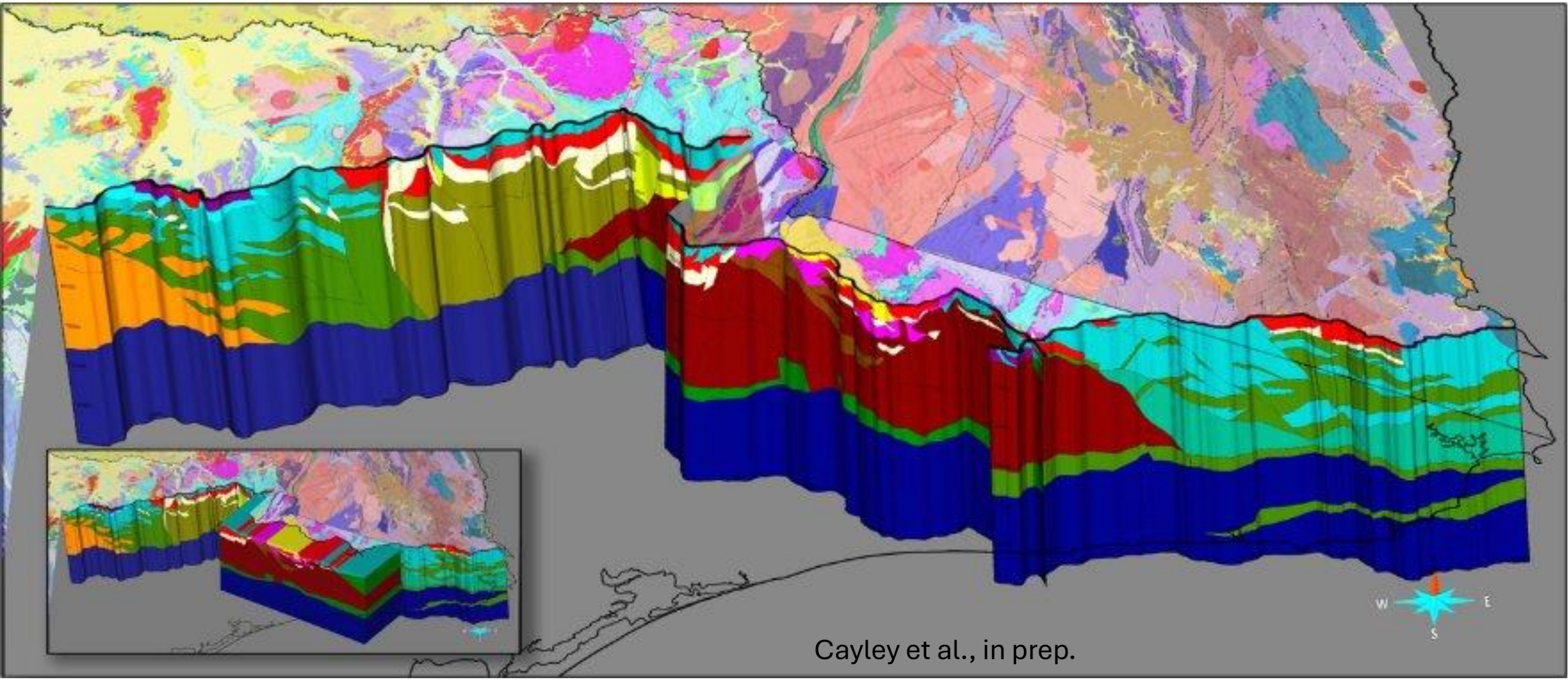

Cayley et al., in prep.

Kirkby et al, 2020

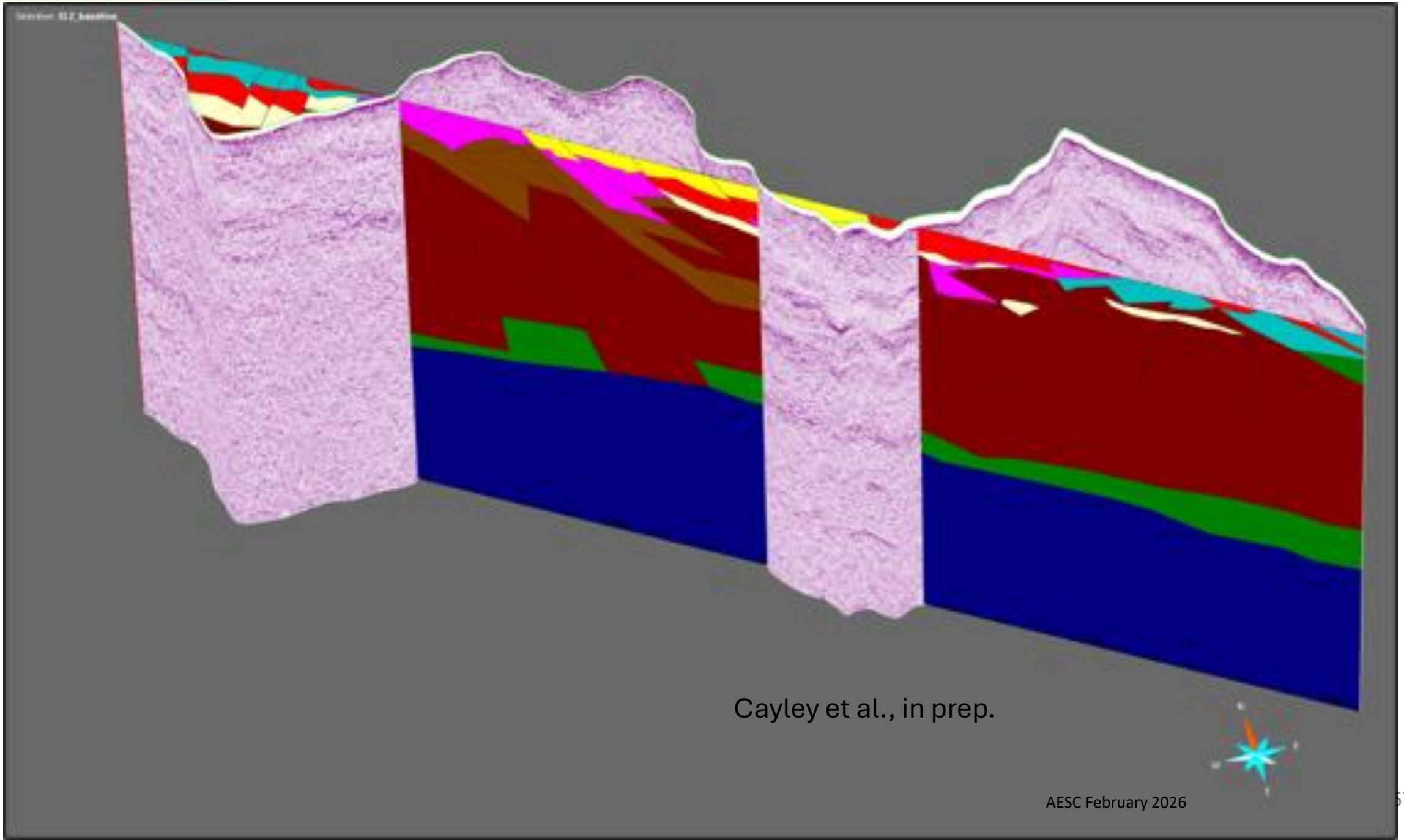

Yarrawonga
ALBURY
Wodonga
Corryong
Cooma
Wangaratta
NEW SOUTH WALES
GA18-SL1
Benalla
Bright
Bega
GA18-SL2
Mansfield
VICTORIA
Omeo
GA18-SL3
Eden
Orbost
Bairnsdale
Lakes Entrance
6000000
5950000
5900000
5850000
400000
450000
500000
550000
600000
650000
700000
750000
0
25
50
100
Kilometers
N
GA18 Seismic Transect
Isostatic Gravity
Isostatic correction applied to Complete Bouguer Anomaly
GDA94 MGA55




Forward modelling of gravity data by Phil Skladzien to test interpretation



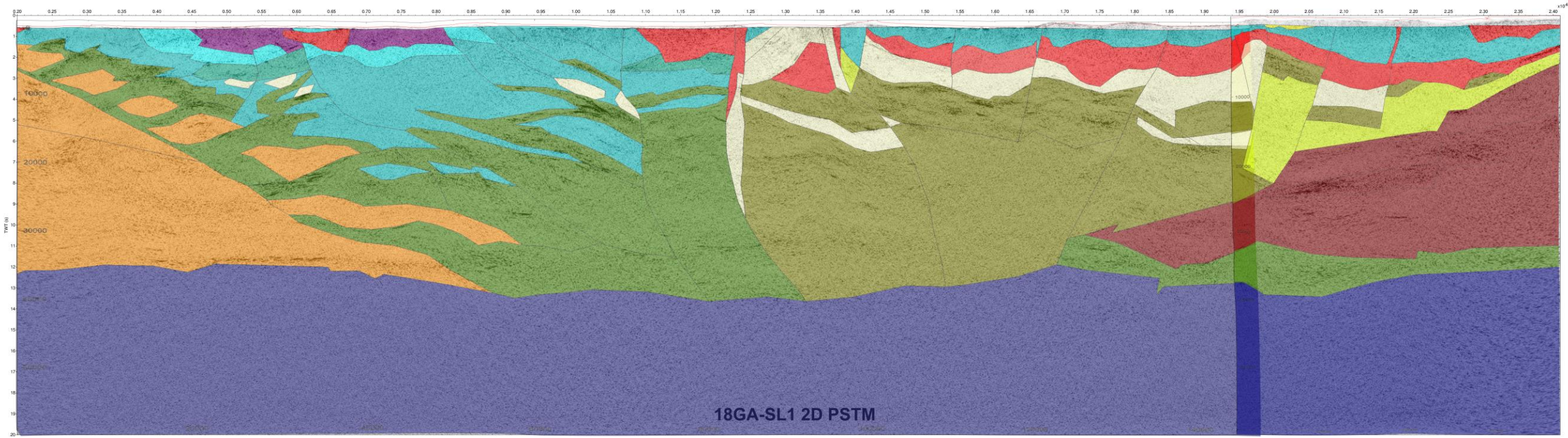

Cayley et al., in prep.



Cayley et al., in prep.

Tabberabbera Zone

Omeo Zone

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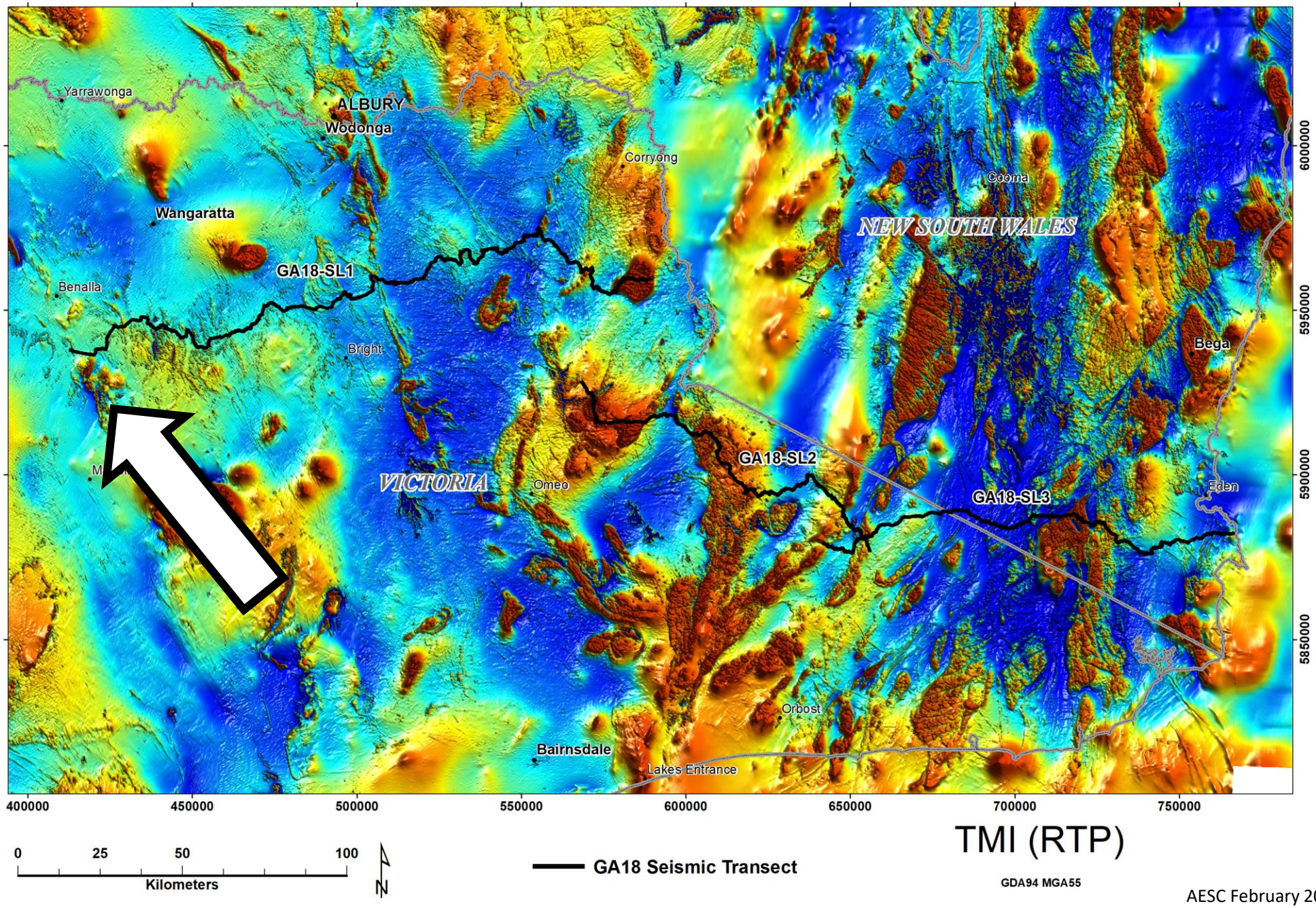
Yarrawonga
ALBURY
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Eden
GA18-SL3
Orbost
Bairnsdale
Lakes Entrance
6000000
5950000
5900000
5850000
400000
450000
500000
550000
600000
650000
700000
750000
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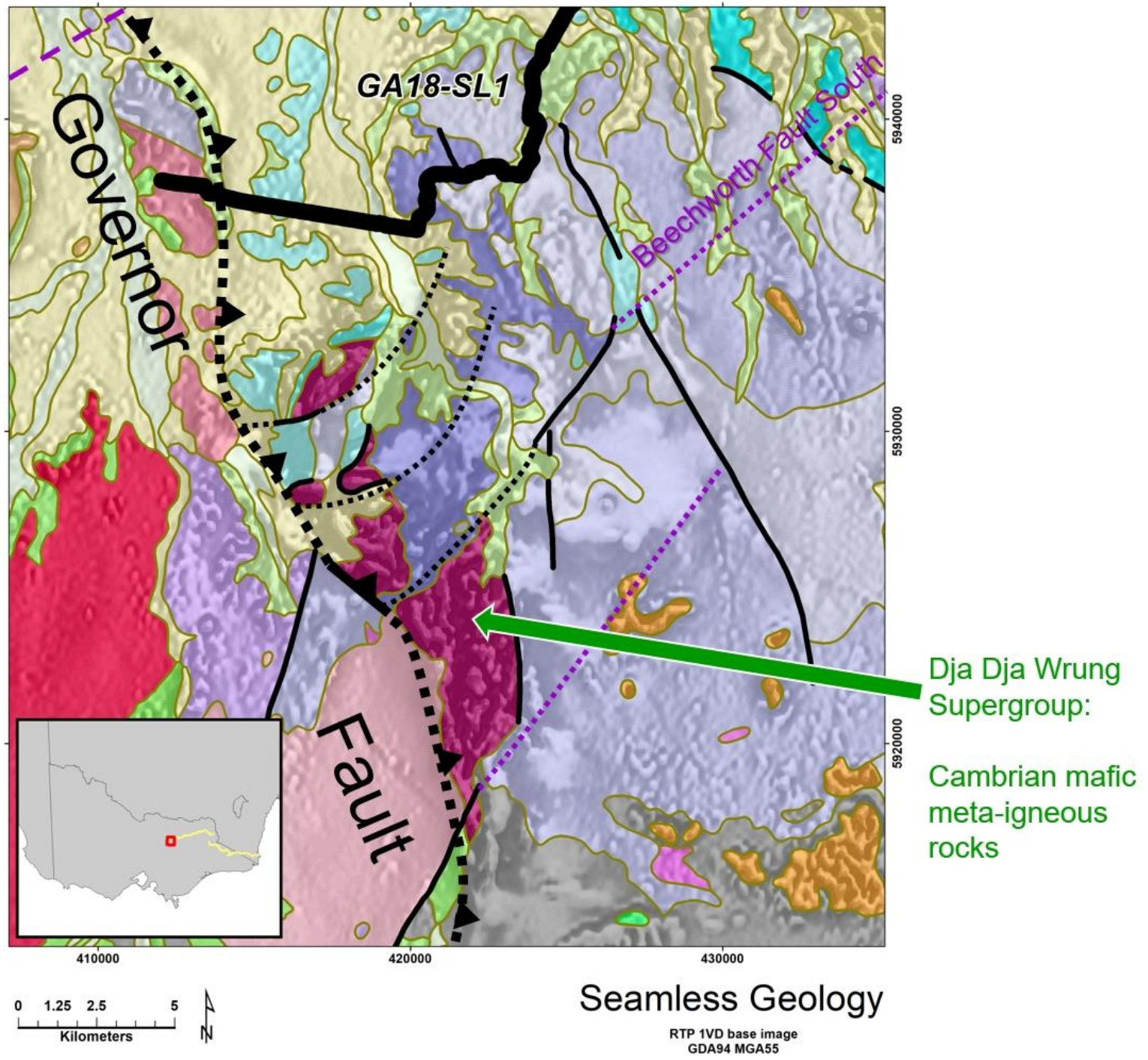
25
50
100
Kilometers
N
GA18 Seismic Transect
TMI (RTP)
GDA94 MGA55

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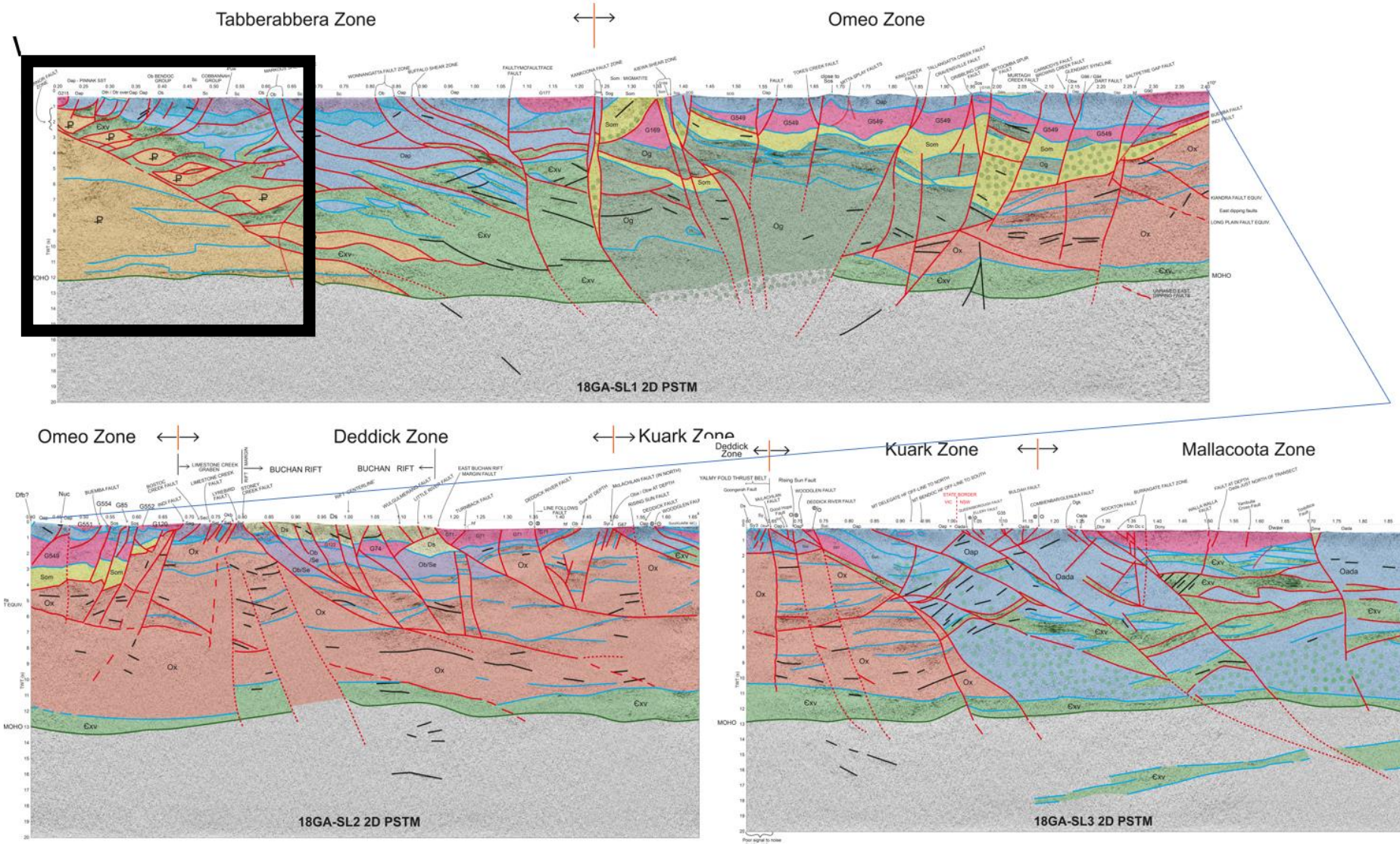
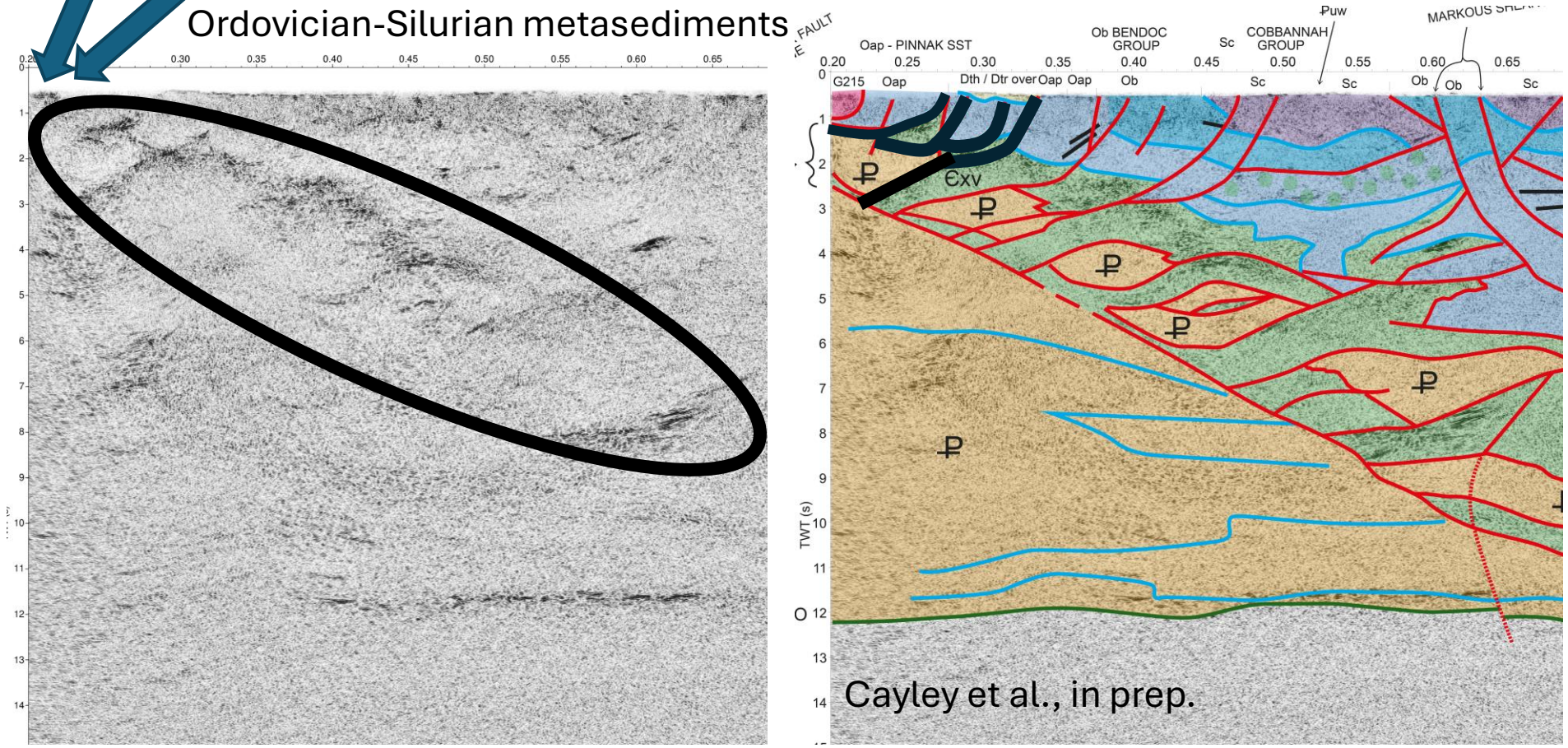



Cayley et al., in prep.

Governor Fault position at surface

Cambrian-age MORB metavolcanics (DDW Supergroup) and shale at surface

Ordovician-Silurian metasediments

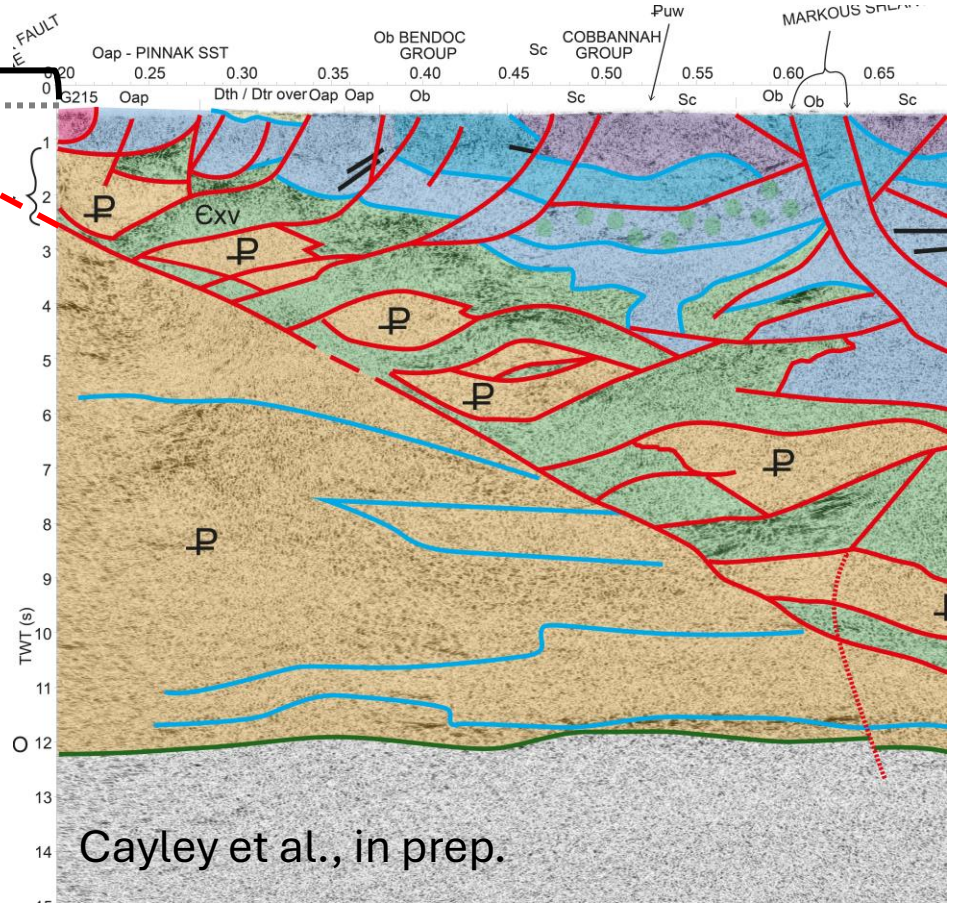



- Governor Fault – overthrusts east flank of Selwyn Block, dips east overall (consistent with mapping and 2011 results)
- Tabberabbera Zone – mid-upper crust dominated by low reflectivity Palaeozoic metasediments (Adaminaby, Bendoc, Cobbannah groups).
- Reflectors at depth, rising to surface along western margin – Cambrian Dja Dja Wrung SuperGroup.
- But: with crazy alternating reflectivity arranged en-echelon along the fault-plane into the lower crust.
- Unreflective ‘eyes’ too coherent and extend too deep to be Palaeozoic metasediments or equivalent.

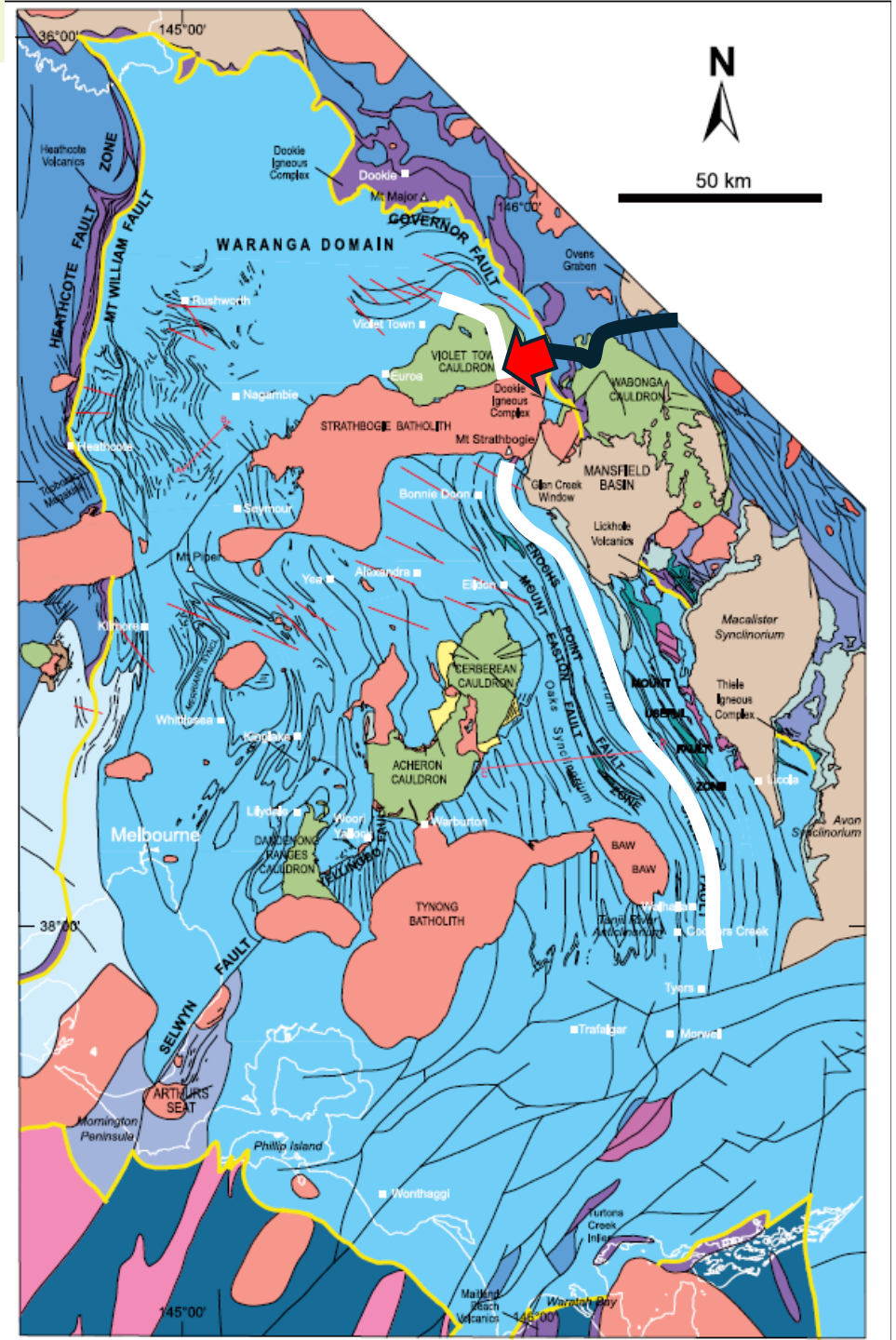
# Governor Fault Zone footwall projects to surface 12 to 15 km west across strike within Melbourne Zone

Average Fault Zone dip to base of crust: 26°

Average FZ dip from ~ 4 to 2.5 s TWT: 23°




- Seismic data reveals the Governor Fault Zone as 1.5 – 2 s TWT thick (= ~4.5 - 6 km)
- Only the upper part of the fault zone is exposed.





***Upper Devonian***
- *Mansfield Group and fluvial sedimentary rocks*
- *Wellington Volcanics, Delatite Group*
- *Cauldron complexes*

***Middle and Upper Devonian***
- *Granite*

***Lower and Middle Devonian***
- *Cathedral Group*

***Lower Devonian***
- *Granite*

***Silurian to Lower Devonian***
- *Murrindindi Supergroup*
- *Cobbannah Group*

***Upper Ordovician***
- *Mount Easton Shale*
- *Sunbury Group*

***Lower to Upper Ordovician***
- *Castlemaine Group and Mount Easton Shale*

***Lower and Middle Ordovician***
- *Castlemaine and Adaminaby Groups*

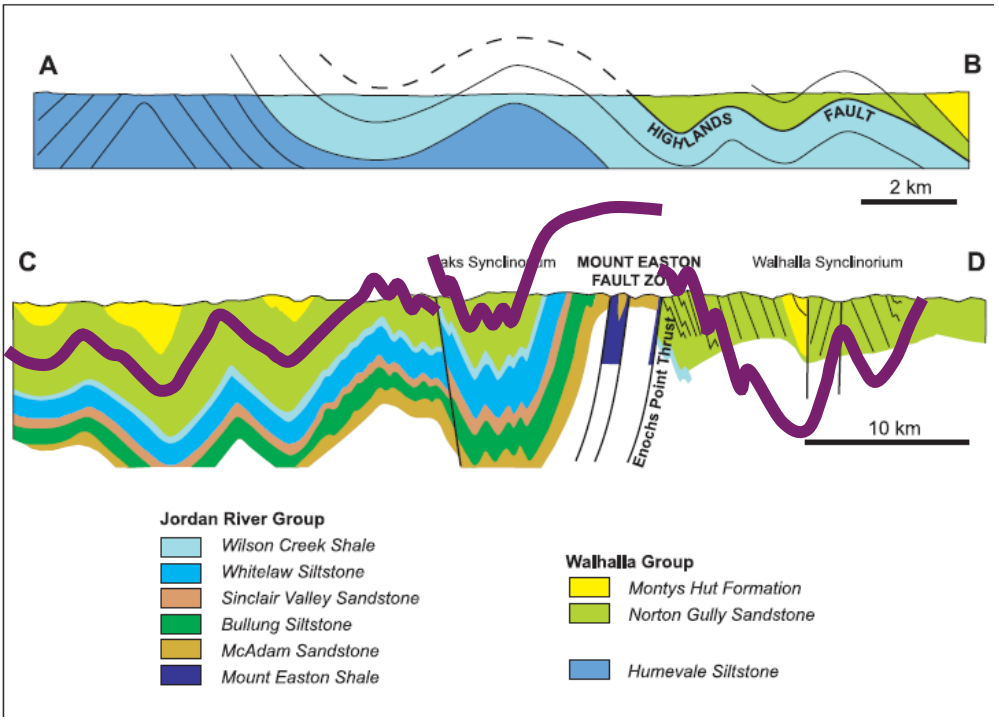
***Cambrian***
- *Tholeiitic and boninitic igneous and overlying sedimentary rocks*
- *Calc-alkaline volcanic and overlying sedimentary rocks*

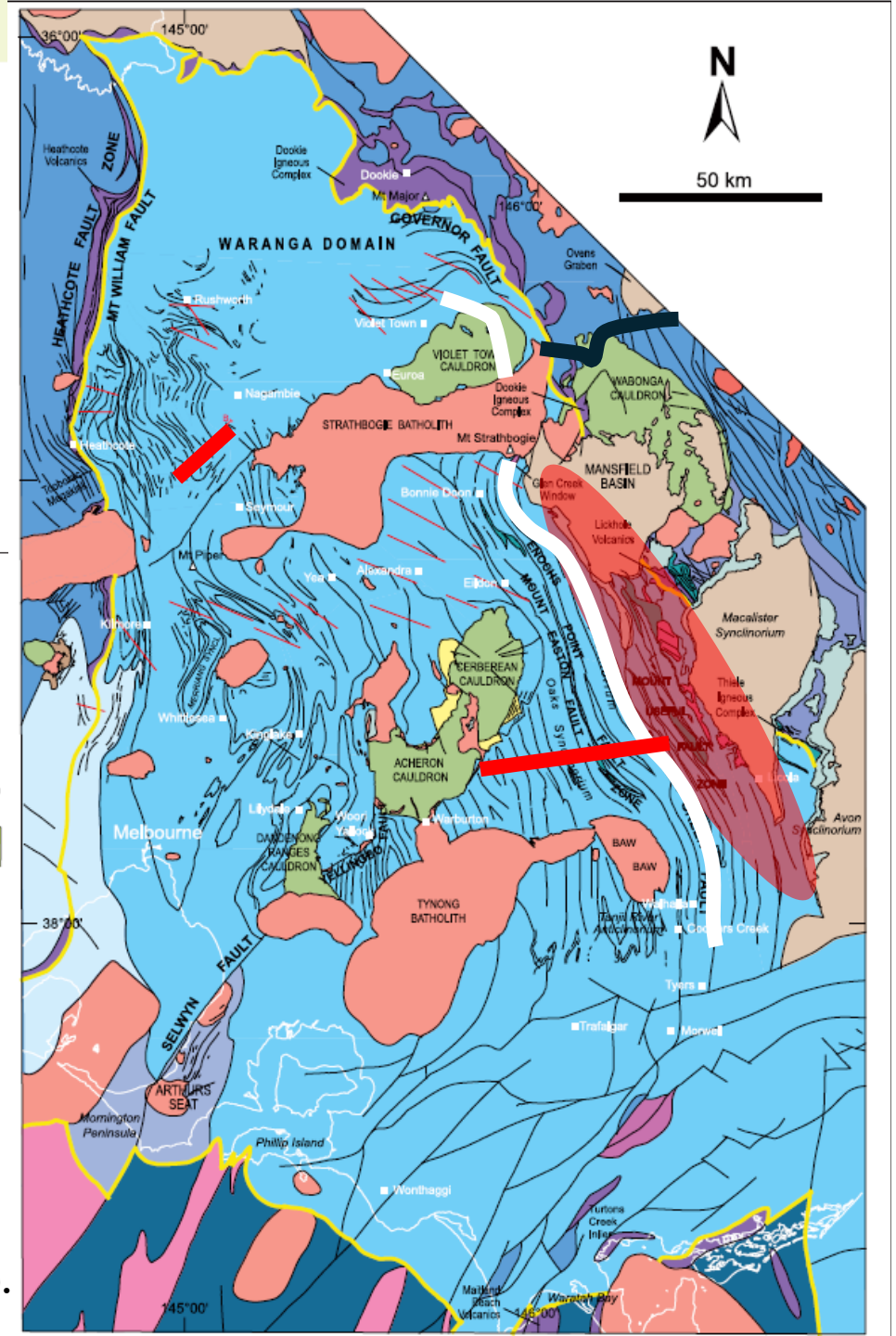
***Neoproterozoic***
- *Sedimentary rocks*
- *Volcanics*

- *Fault*
- *Geological boundary*
- *Zone boundary*
- *Bedding trend*
- *Melbourne Zone northwest trending cleavage*

Cayley et al., in prep.

AESC February 2026





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- *Cathederal Group*

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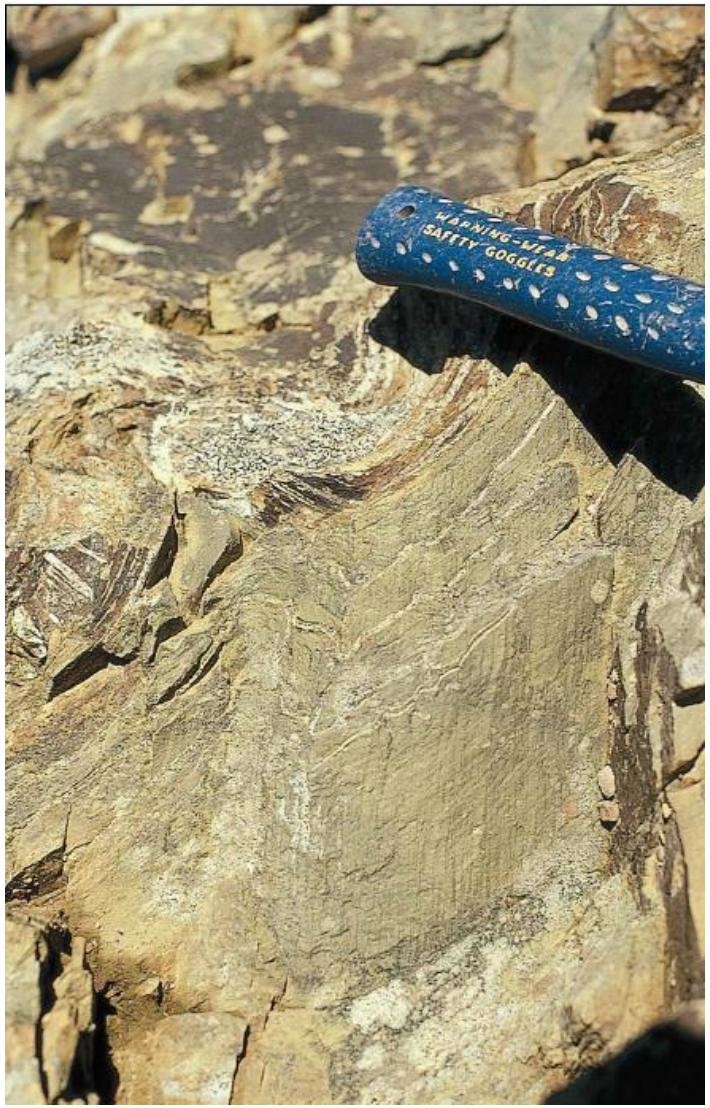
VandenBerg et al., 2000-; Cayley et al., in prep.

# Mount Useful ‘Slate Belt’ – atypical Melbourne Zone - polydeformed

Donnellys Creek, Walhalla; VandenBerg et al, 2006

Deep Creek, Walhalla; VandenBerg et al, 2006




Jamieson-Licola Road; VandenBerg et al, 2006



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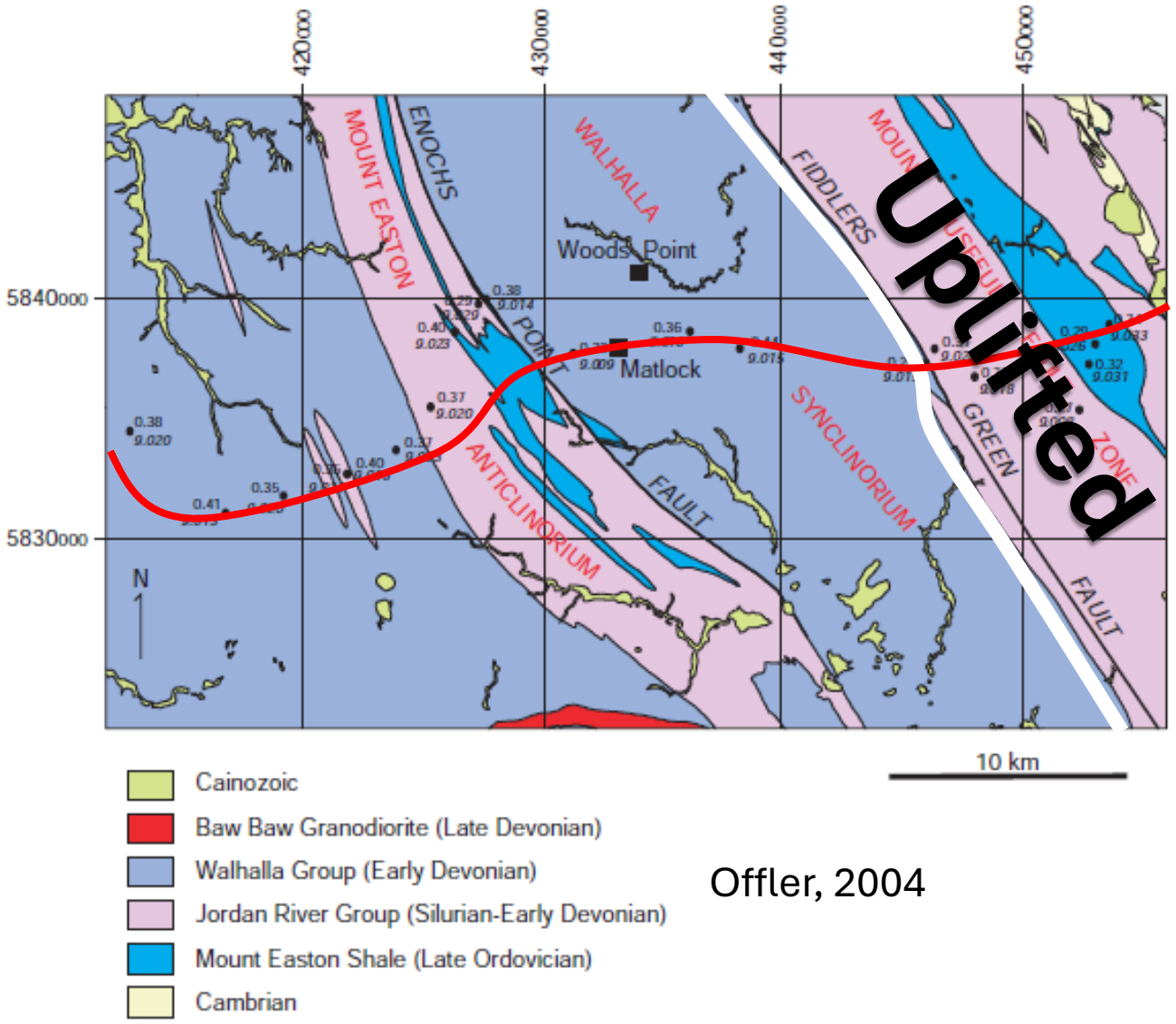
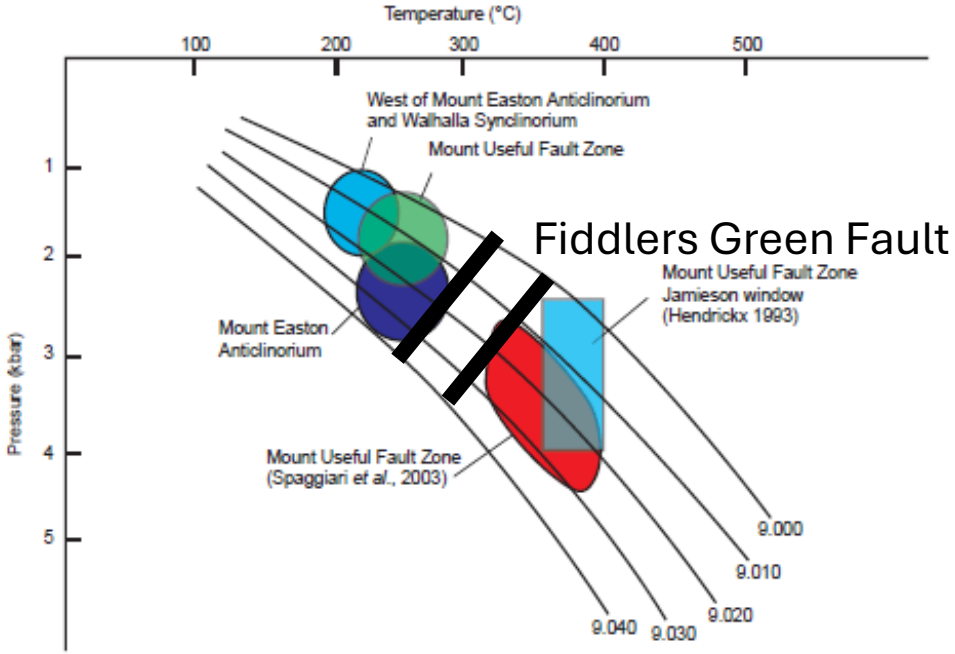
# Illite Crystallinity transect

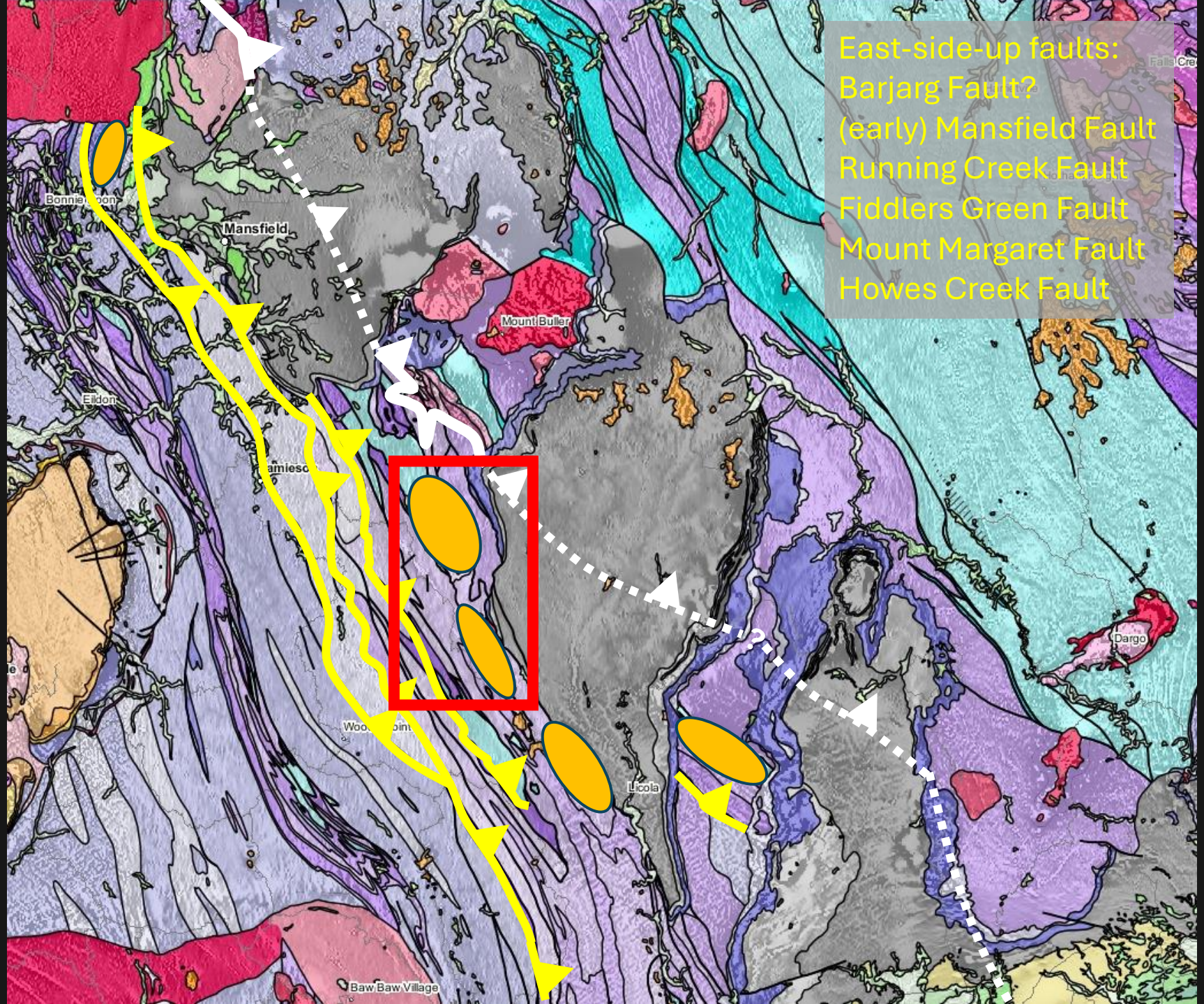



Offler, 2004

Values less than 0.25: epizone (greenschist facies (T > 300 °C)
Values between 0.25 and 0.42: anchizone conditions
(prehnite-pumpellyite / zeolite facies (T 200–300 °C, Frey *et al.*, 1991).
Values greater than 0.42: diagenetic zone
(T < 200 °C ;Warr & Rice, 1994; Merriman & Frey, 1999).




Hendrickx, 1993; Spaggiari et al., 2003; VandenBerg et al., 2006




Cayley et al., in prep.

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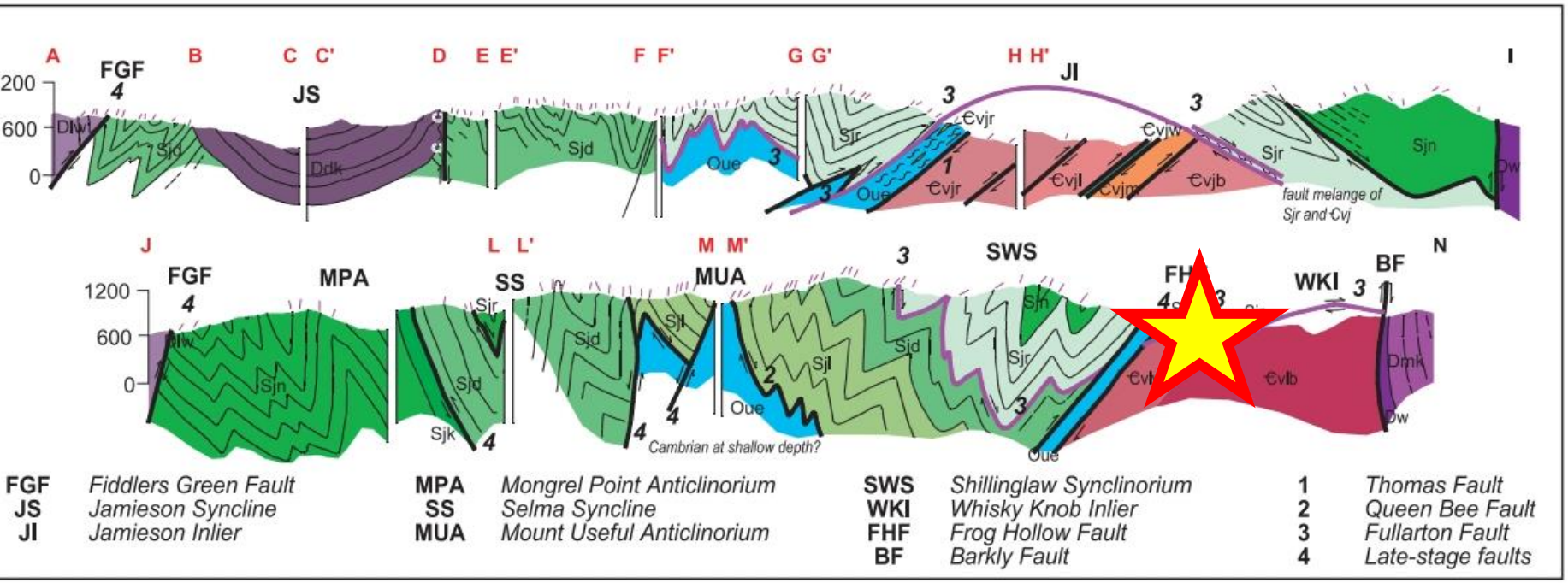
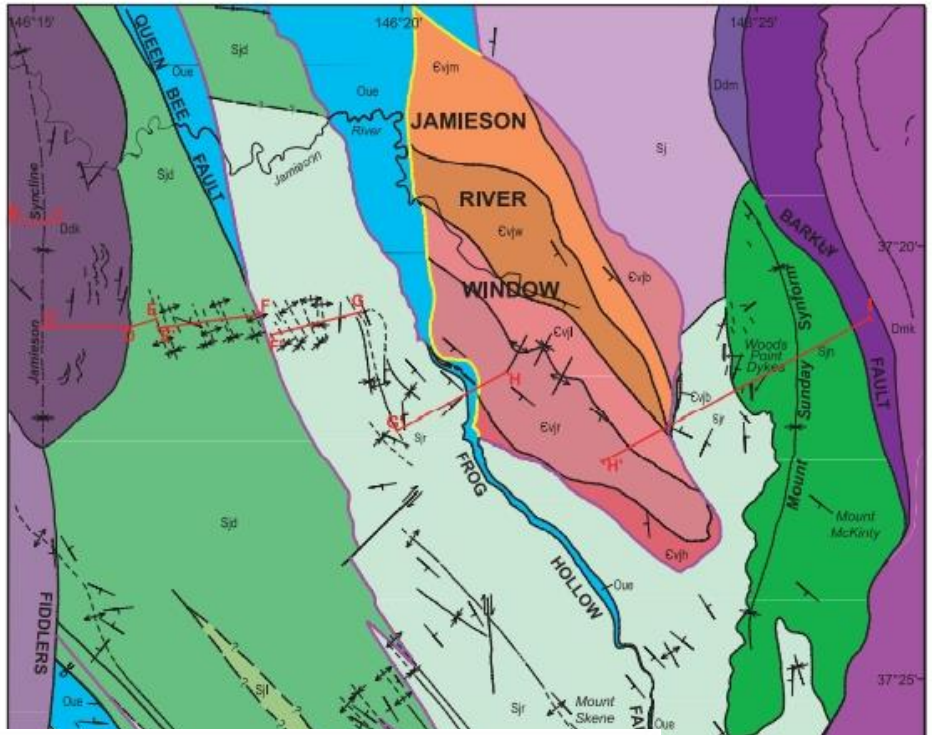
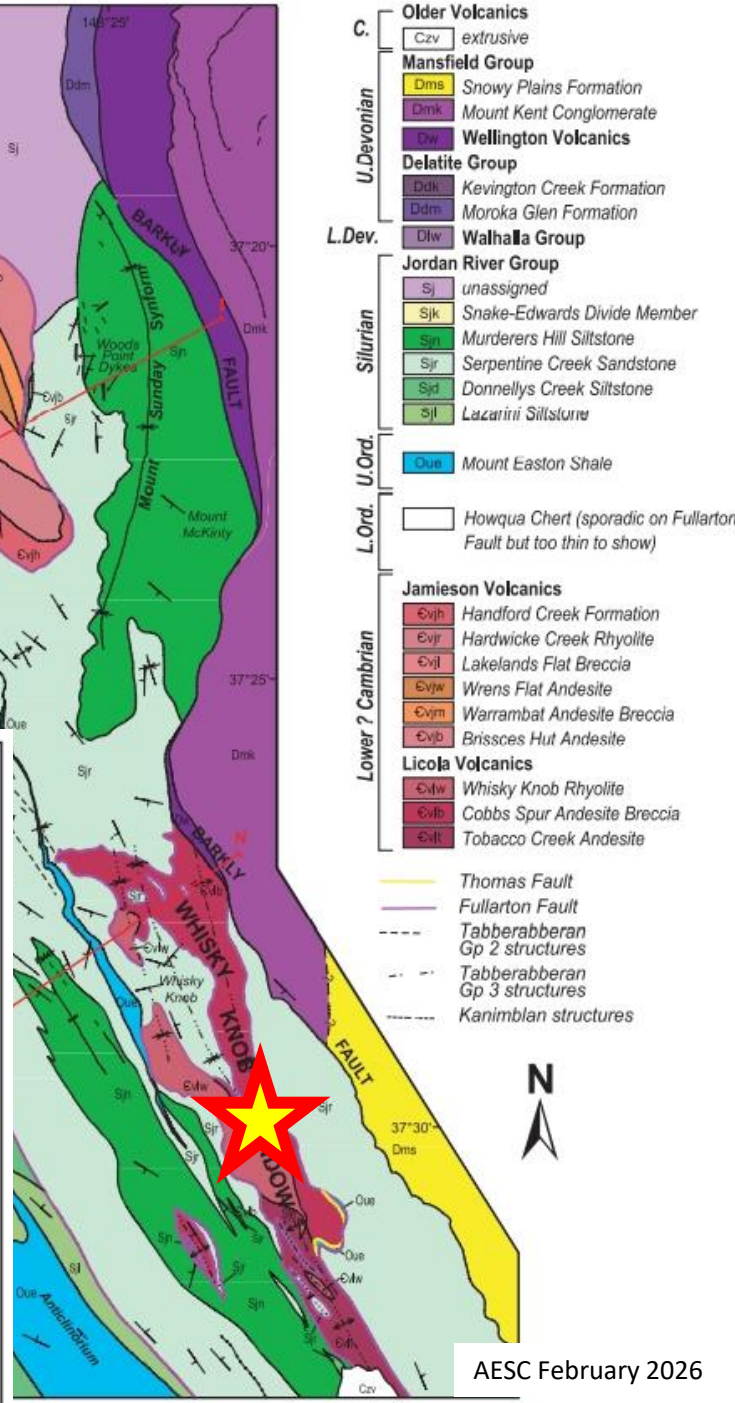
VandenBerg et al., 2000

https://www.youtube.co

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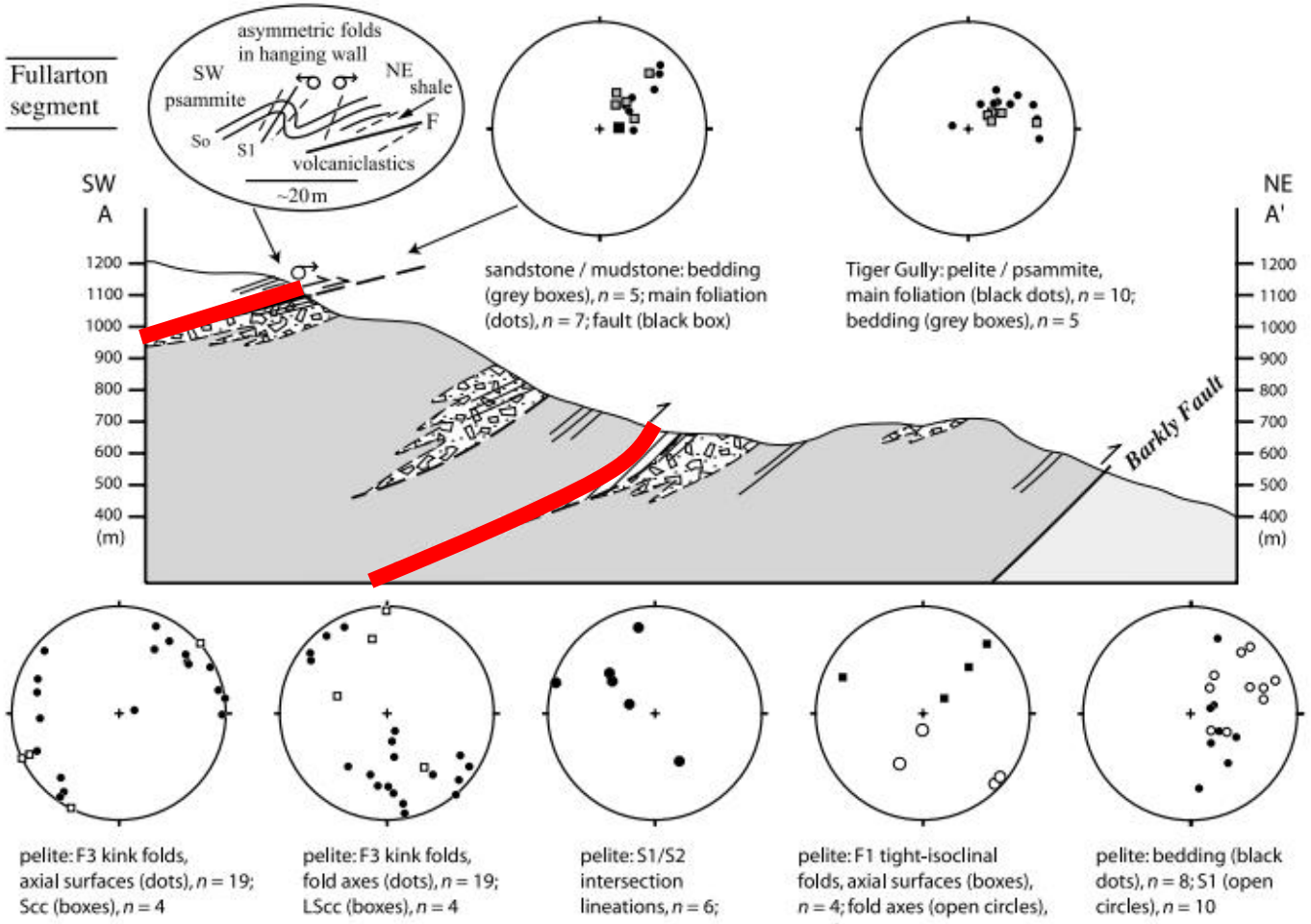
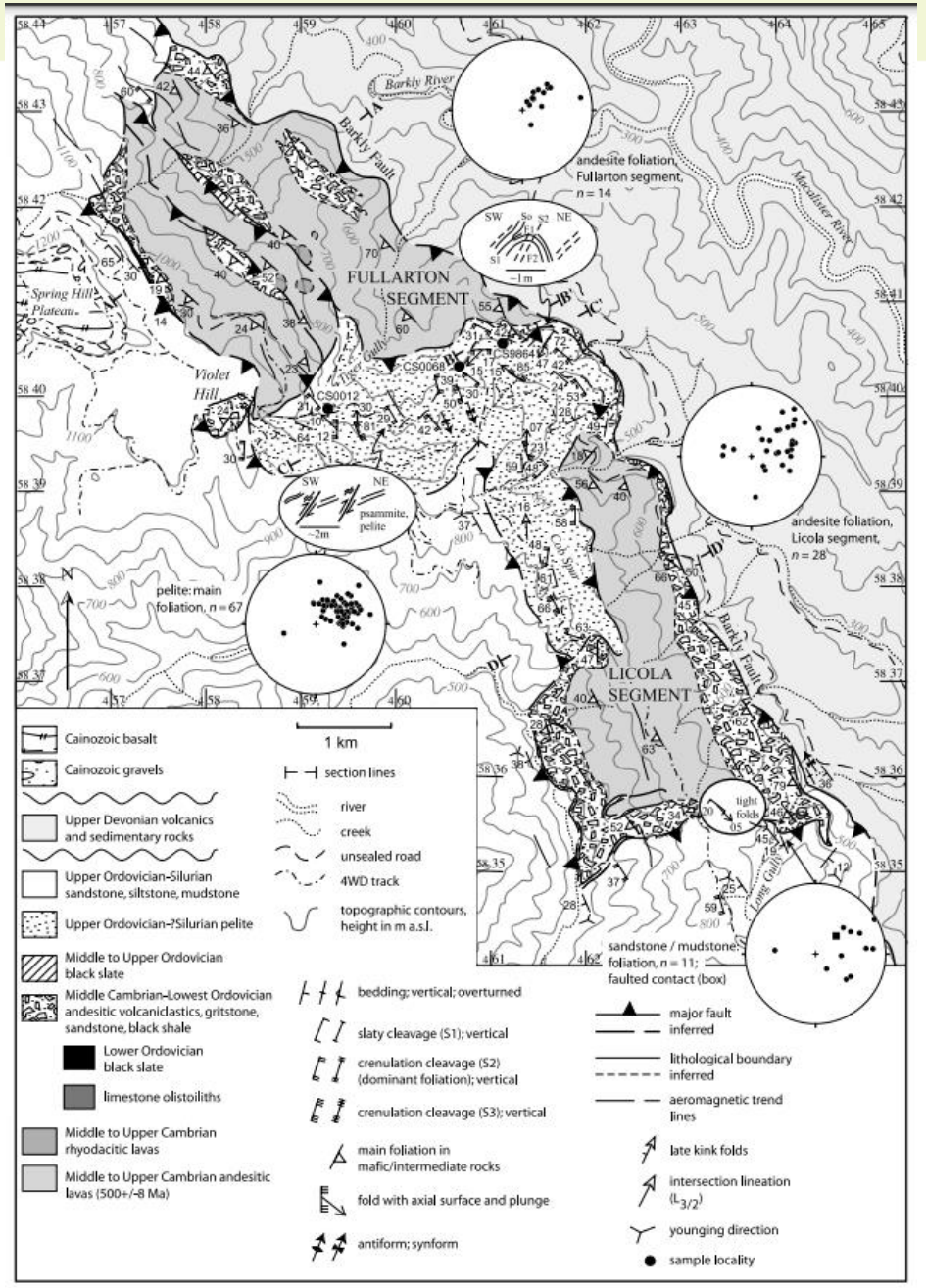
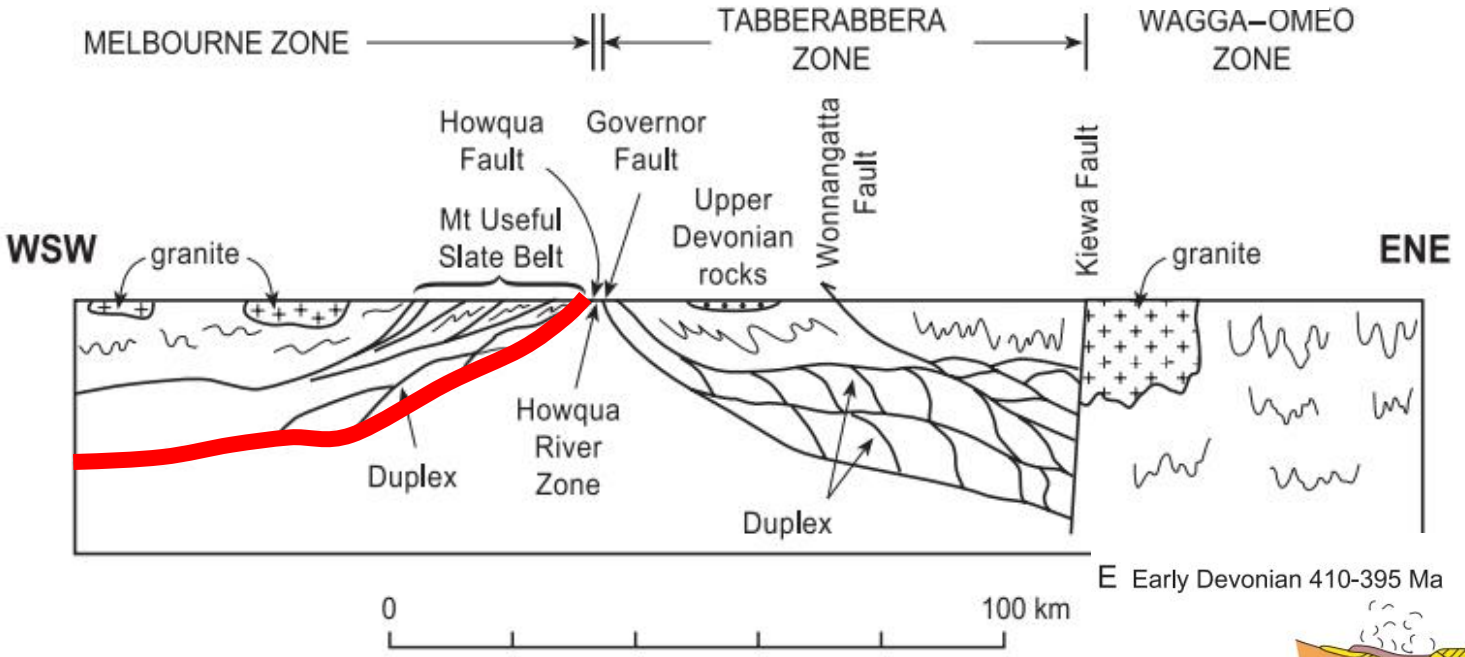



Spaggiari et al., 2004




Fergusson, 2003

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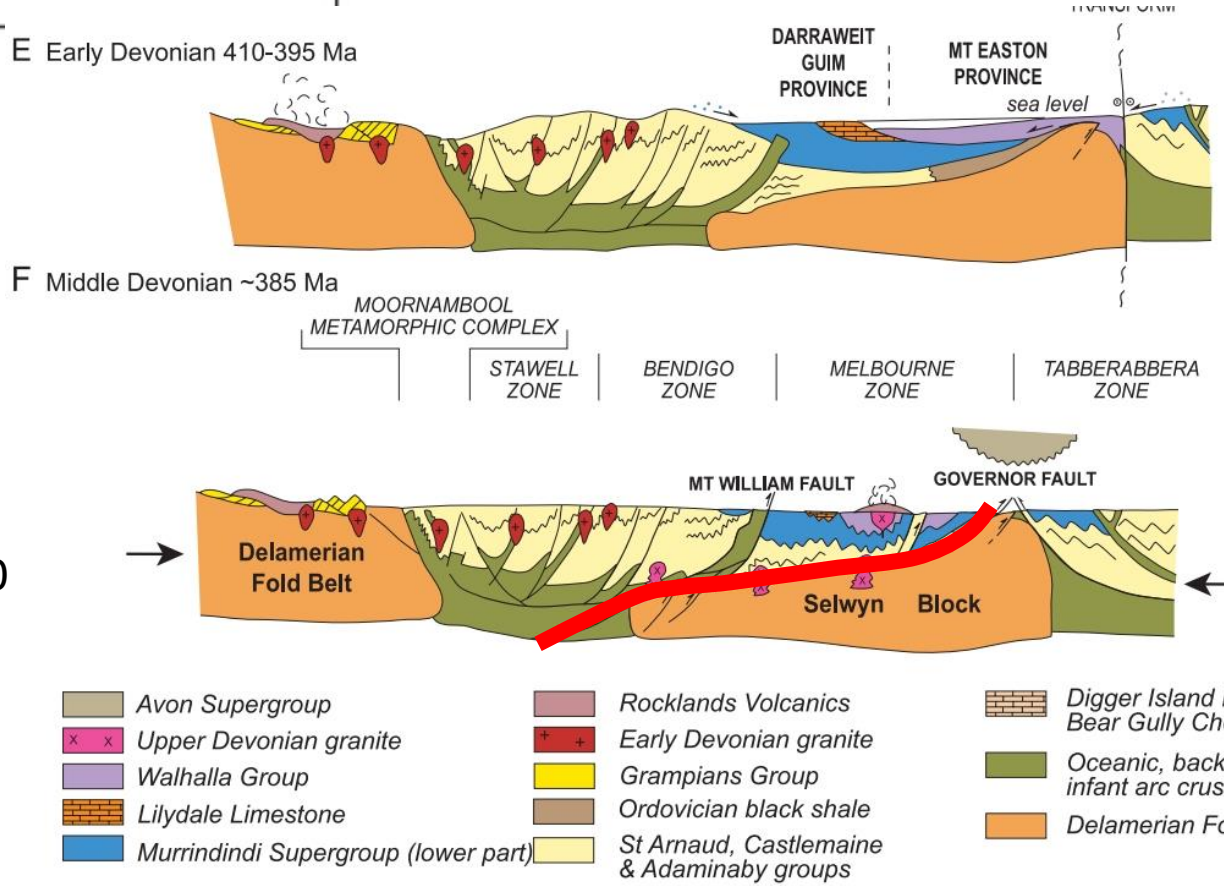
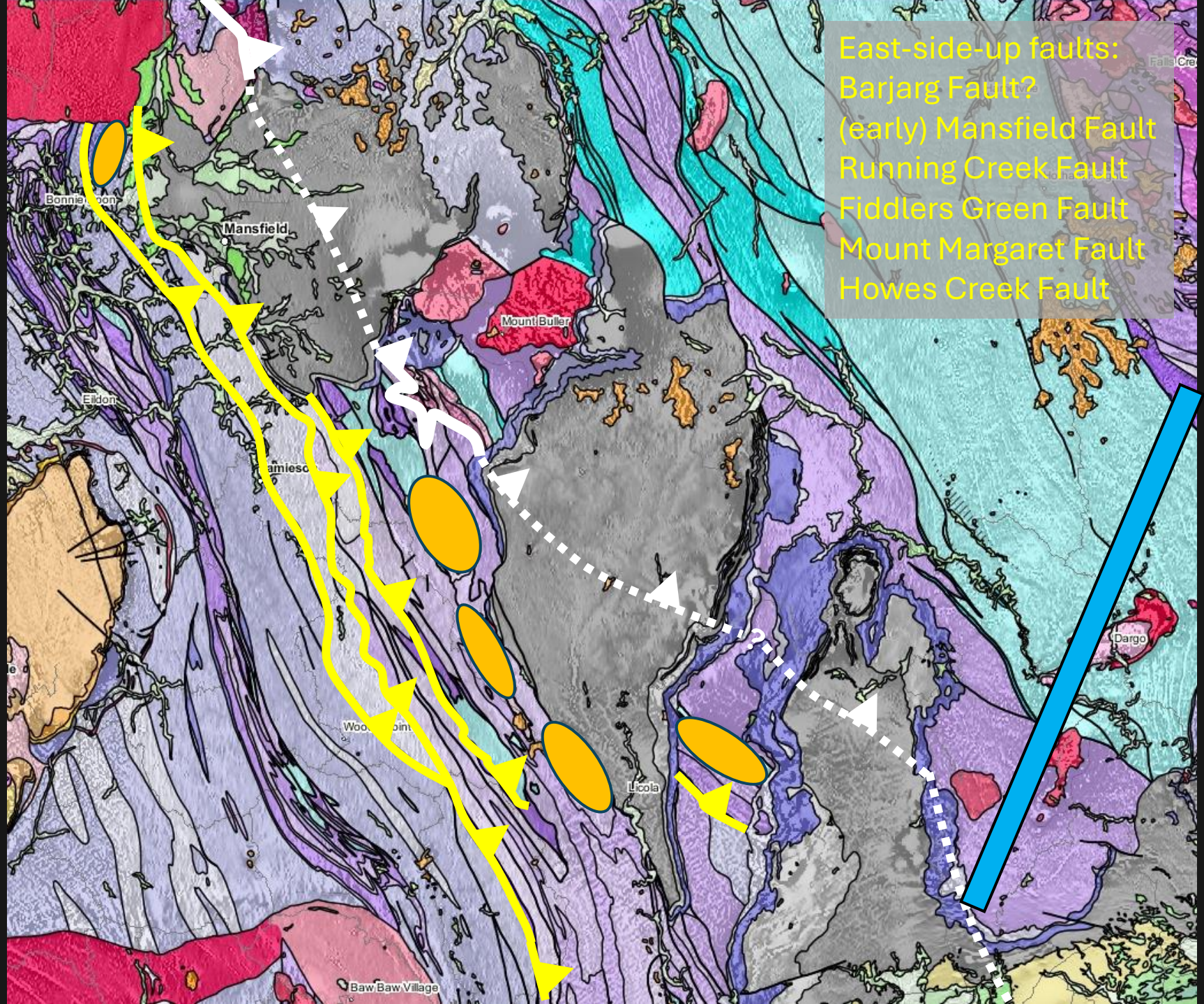



VandenBerg et al, 2000

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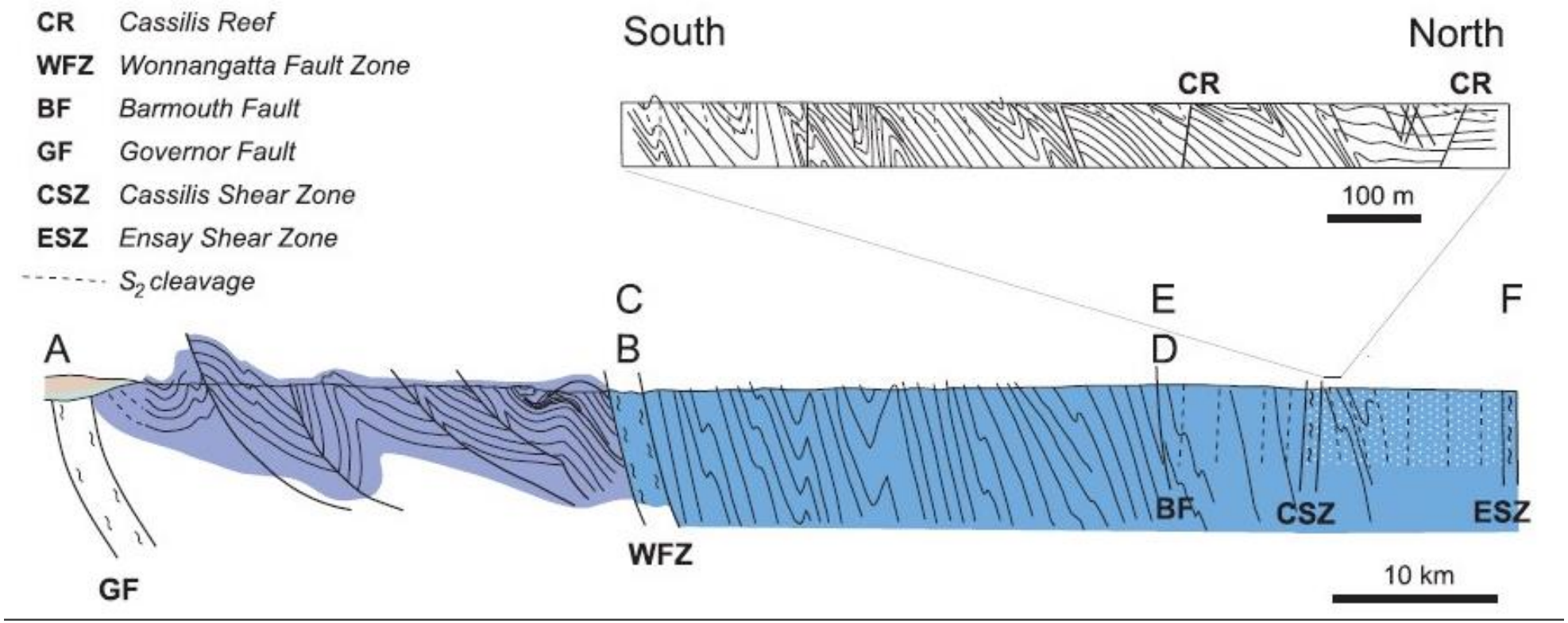
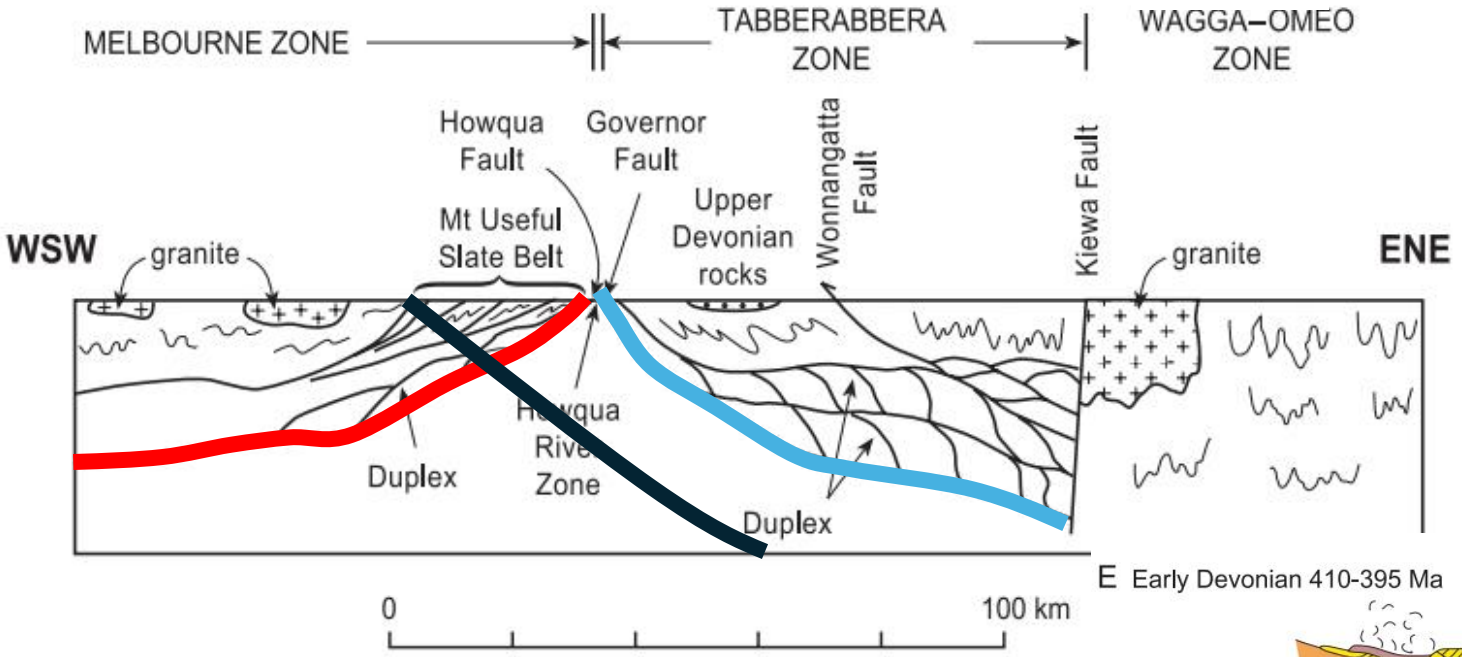
Tabberabbera Zone regional mapping.




VandenBerg et al., 2000




Fergusson, 2003

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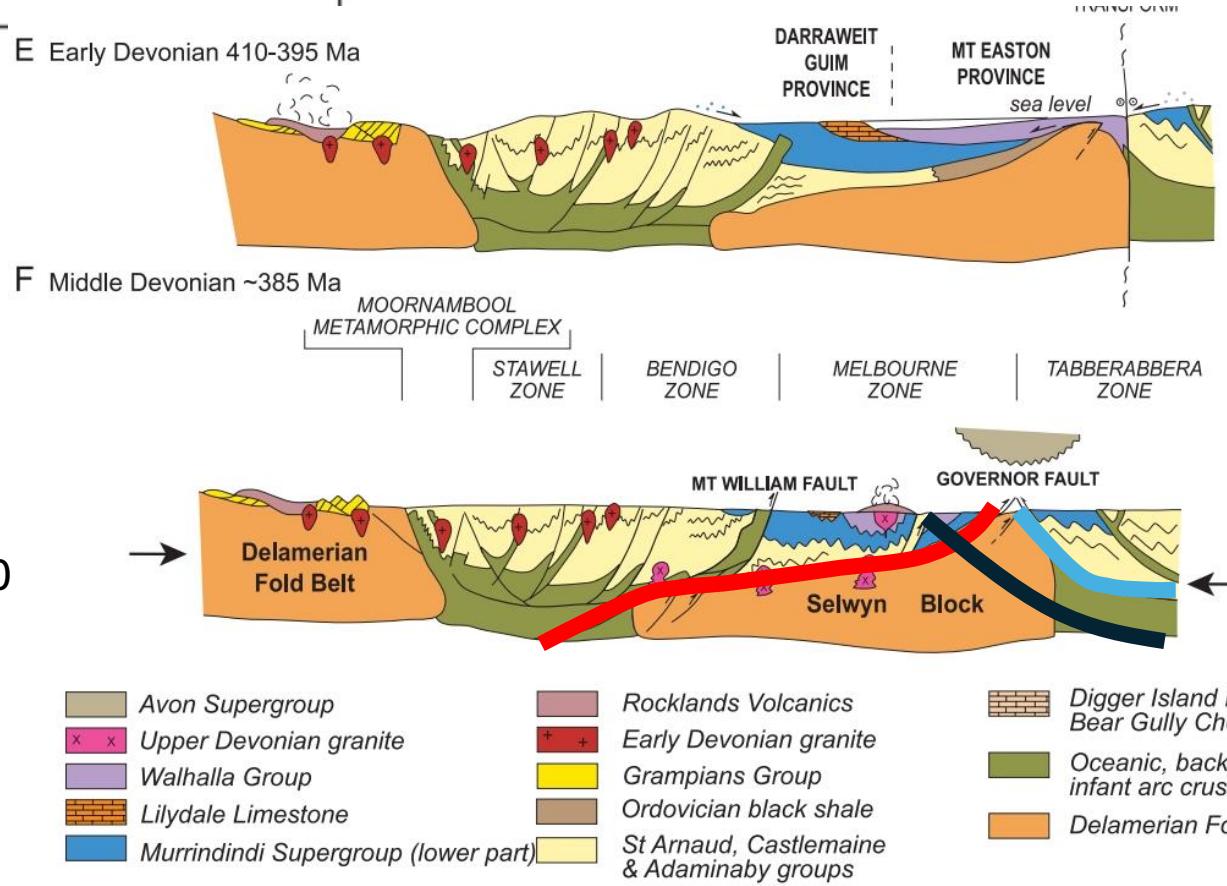
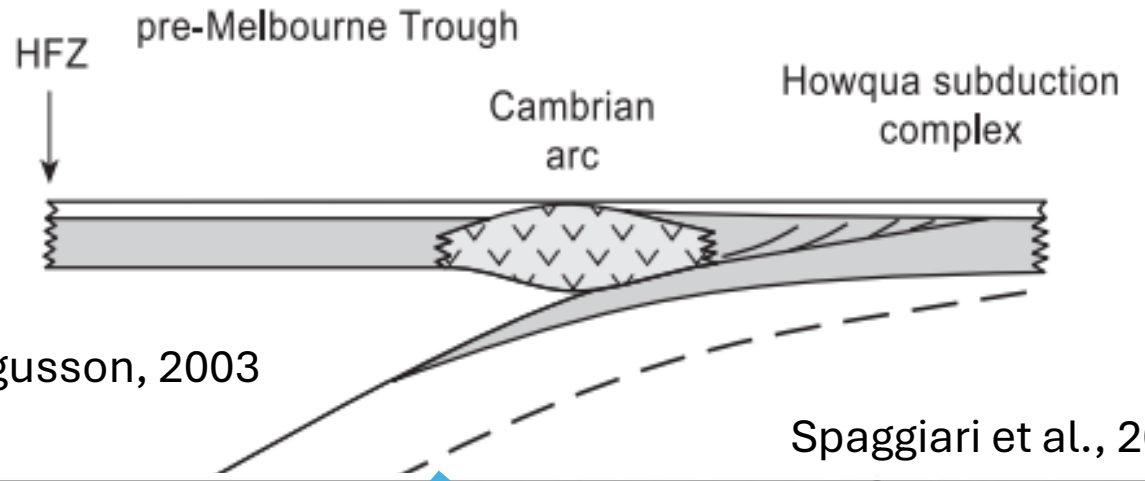


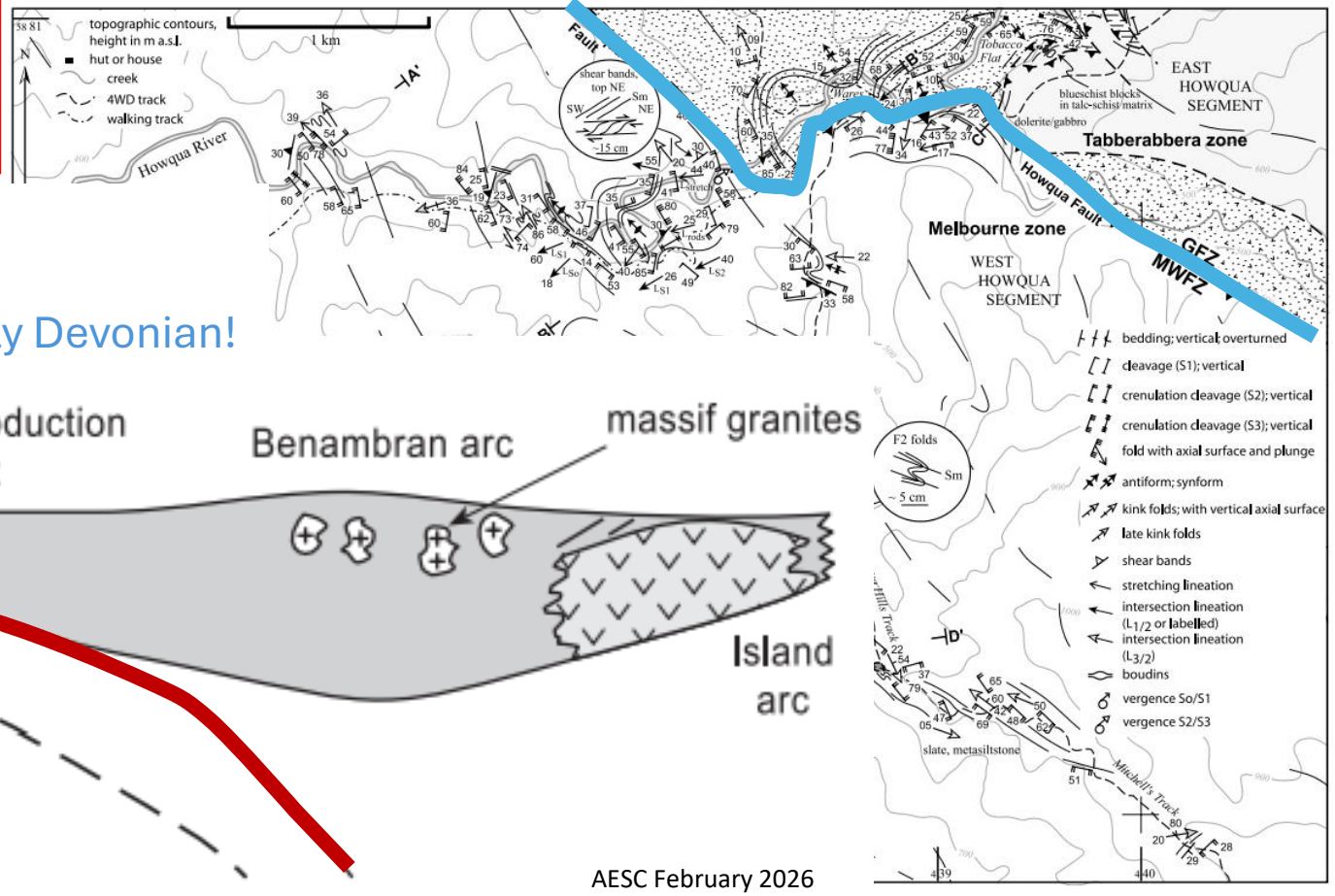

VandenBerg et al, 2000

The Howqua River Zone consists of highly disrupted Ordovician turbidites and blocks of Cambrian mafic volcanics, including blueschist fragments metamorphosed at temperatures of <450°C and at pressures of 700–900 MPa (Spaggiari *et al.* 2002a, b). Age constraints are based on local black shale containing Darriwilian–Gisbornian graptolites (Harris & Thomas 1938), reconnaissance SHRIMP ages of 450 ± 23 Ma on titanite in blueschist and Ar–Ar ages of 446 ± 2 Ma on slate that indicate Late Ordovician metamorphism (Spaggiari *et al.* 2002a).

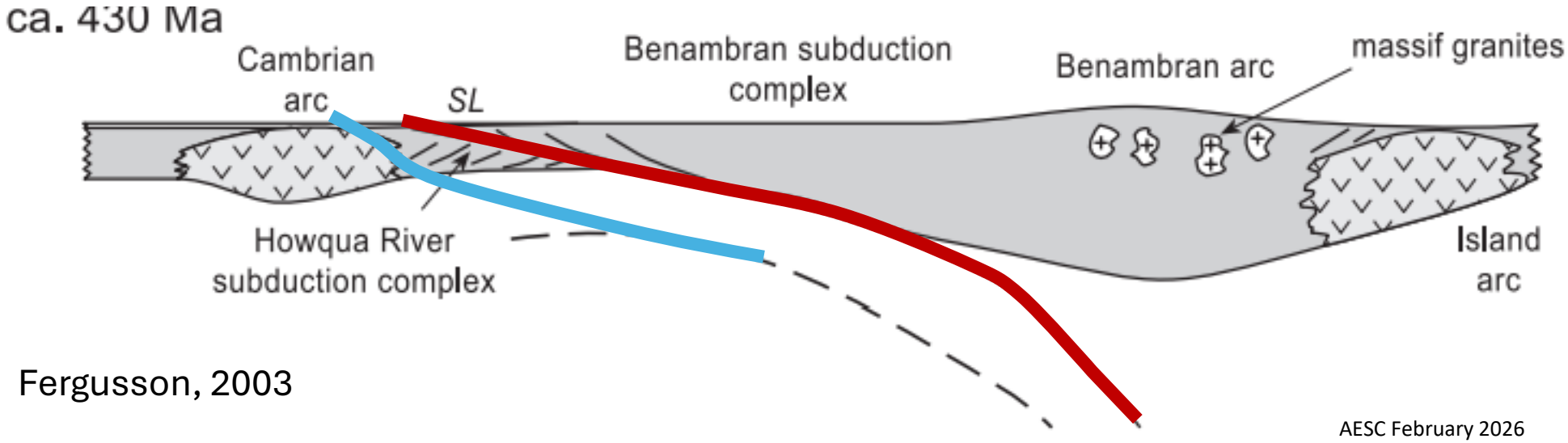



Fergusson, 2003

Spaggiari et al., 2002



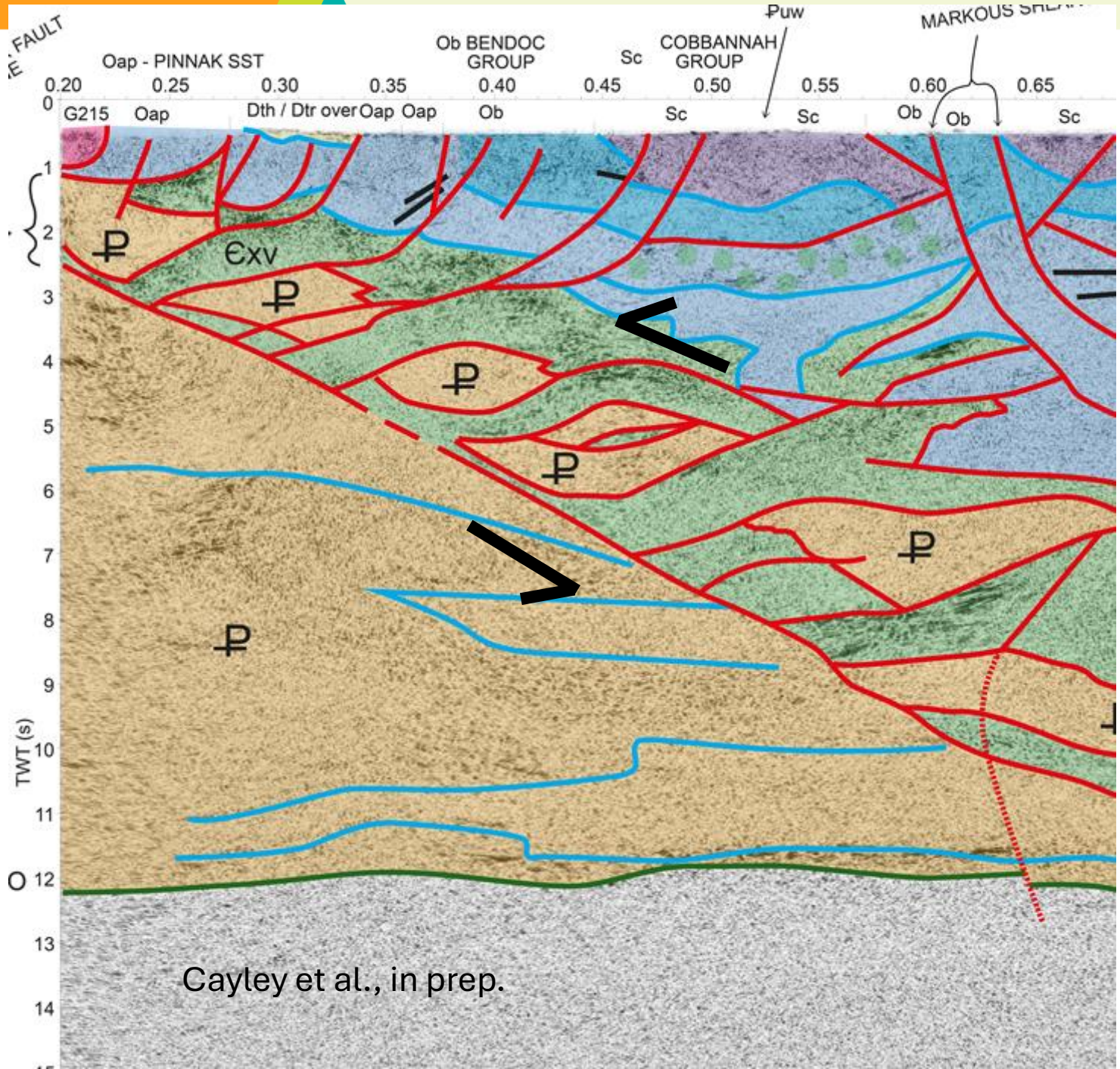

BUT: palaeogeography shows the Tabberabbera Zone and Melbourne Zone weren't together in the Ordovician – first arrival across Governor Fault was Early Devonian!




Fergusson, 2003

# Talk Outline

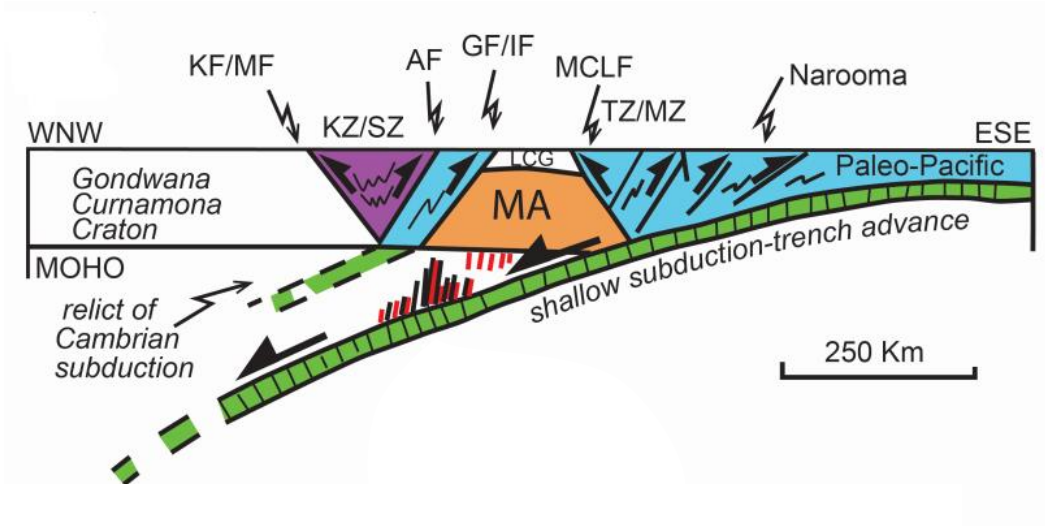
- Objectives: deep seismic reflection+ data spanning Palaeozoic Victoria; test the Lachlan Orocline hypothesis
- Oceanic Lachlan Fold Belt versus the Selwyn Block continental collider that's embedded within it.
- The Lachlan Orocline hypothesis – a quick review
- Deep Seismic Reflection Survey design, acquisition, processing. Complementary geophysics.
- Results of the survey – interpretation methodology, forward modelling
- Governor Fault – building understanding of the Melbourne Zone/Tabberabbera Zone interface
- **Governor Fault Zone revealed as a lithospheric-scale mega-thrust – a Silurian east-dipping subduction zone congested by a thick continental fragment (the Selwyn Block east flank)**

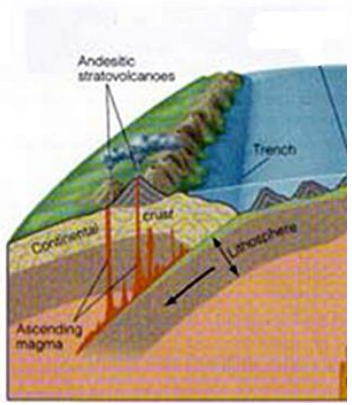



Cayley et al., in prep.

Working Hypothesis: Ordovician imbricated forearc / accretionary wedge reactivated in Silurian, progressively underthrust by Selwyn Block flank to congest subduction zone.....

Cayley et al., in prep.



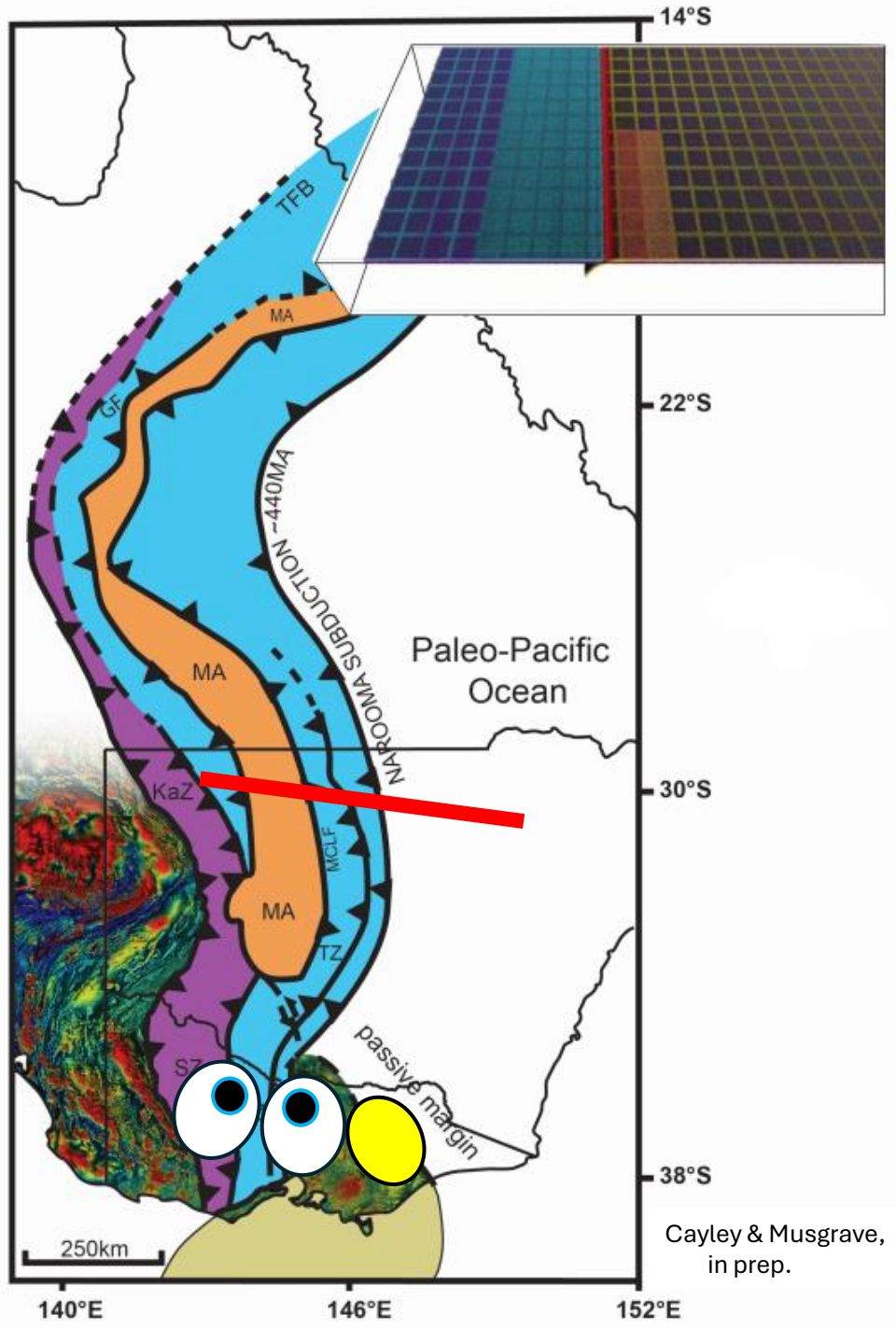

pre-Omeo Zone trough

Macquarie Arc

Howqua subduction complex

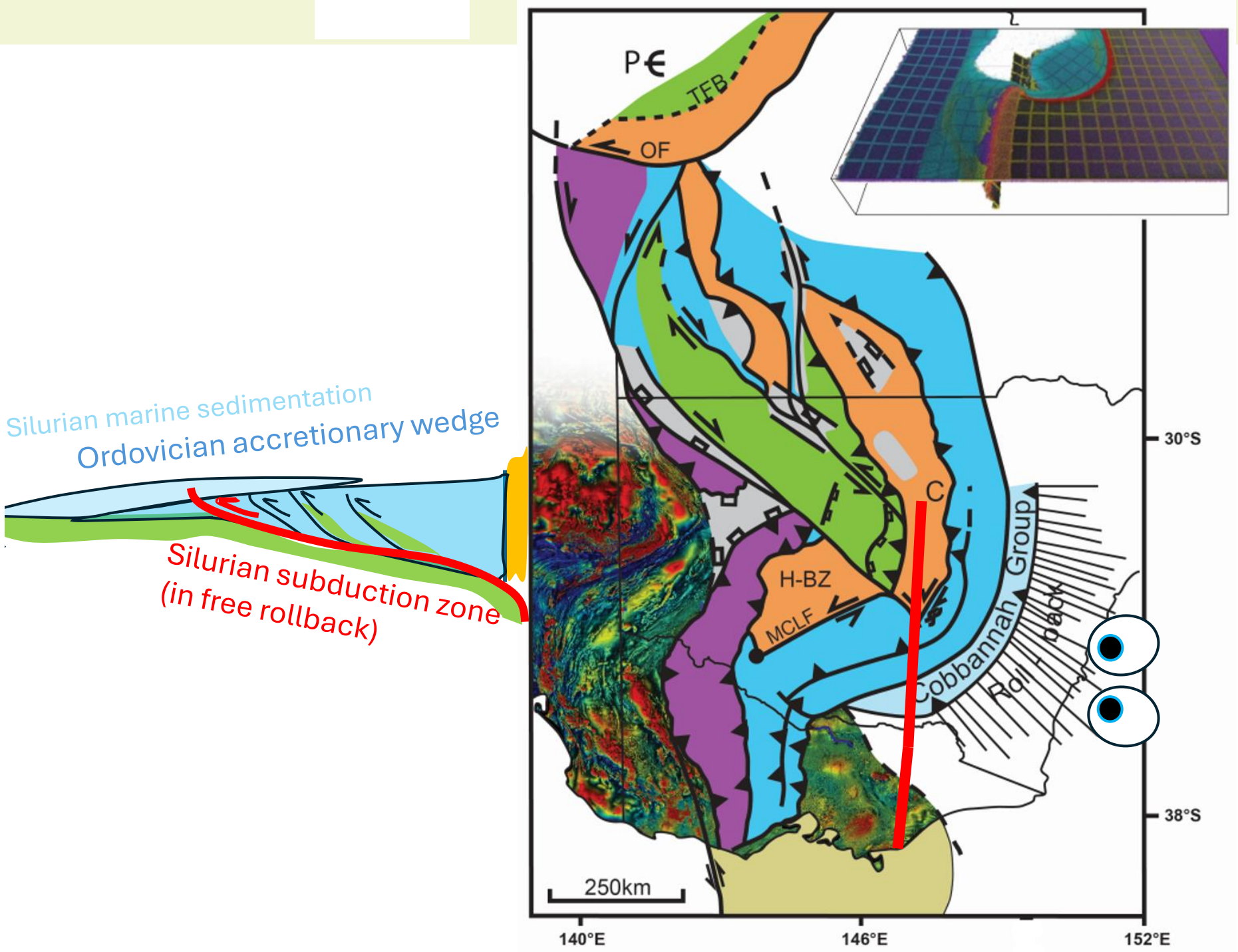
Fergusson, 2003

450-446 Ma – Spaggiari et al., 2002
This is the Benambran Orogeny

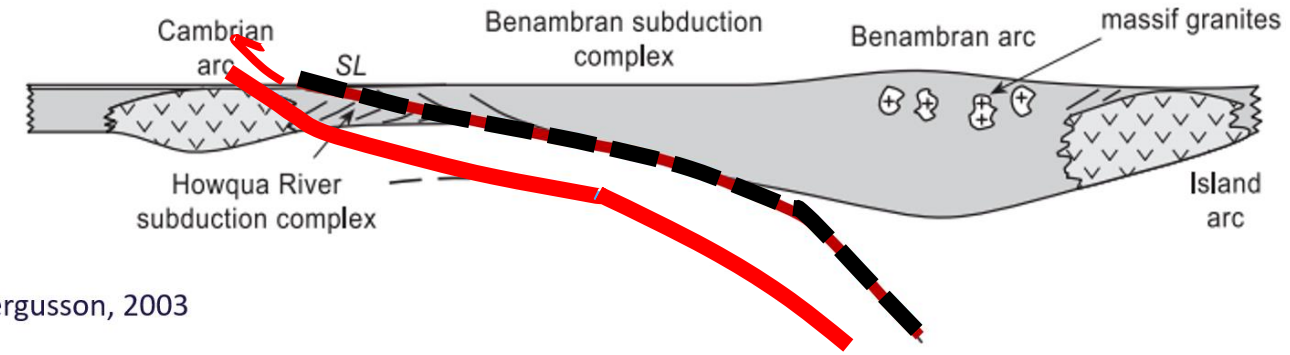



Cayley & Musgrave, in prep.

Cayley et al., in prep.

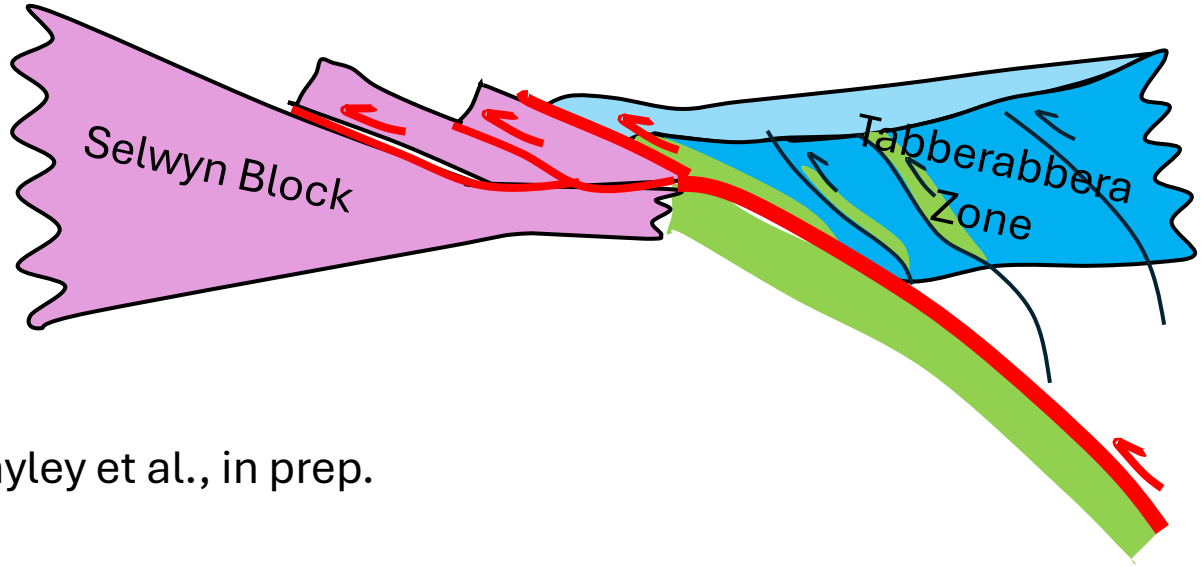


Age constraints on collision initiation from changes in Melbourne Zone sedimentation (Siluro-Devonian boundary)

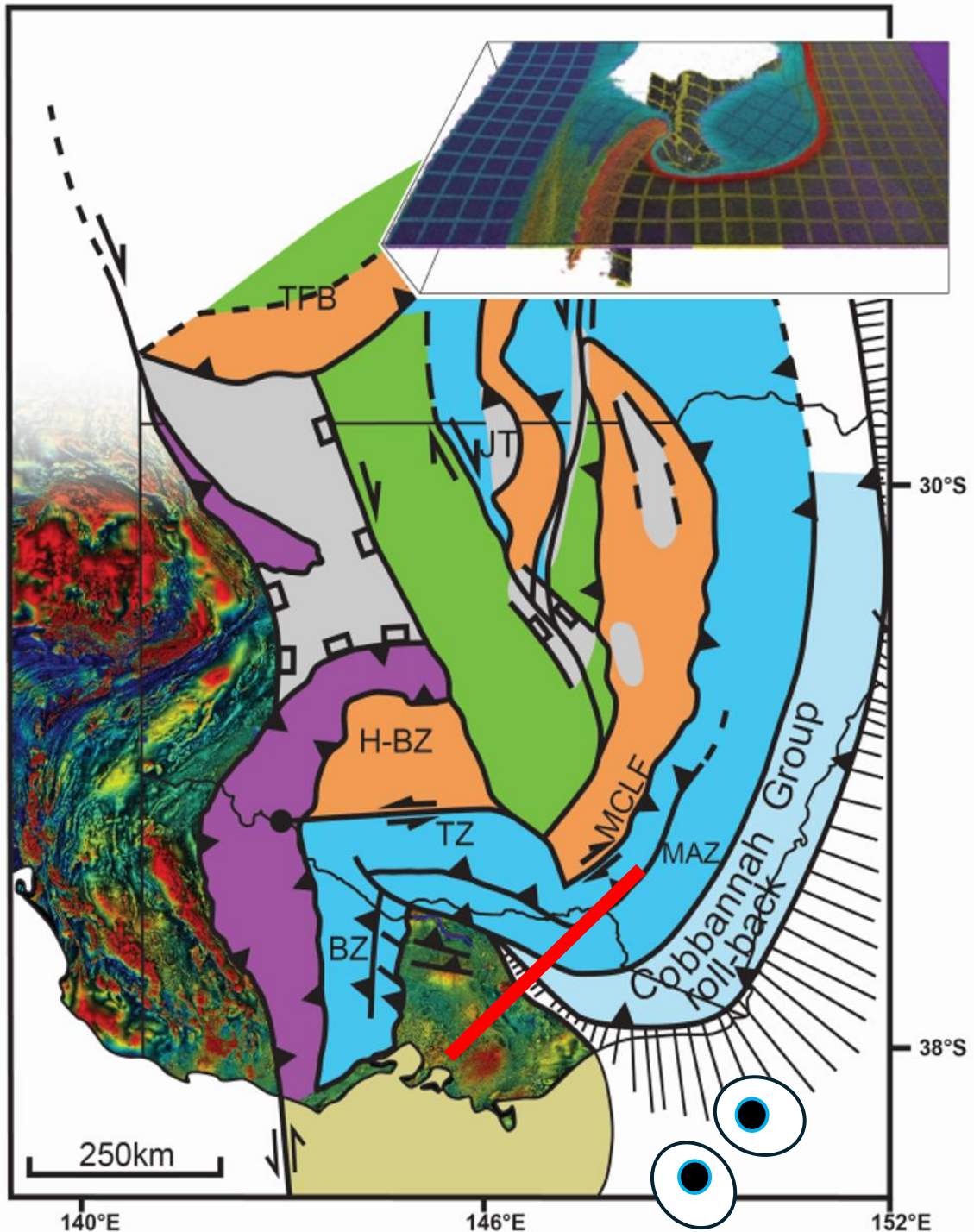



Fergusson, 2003

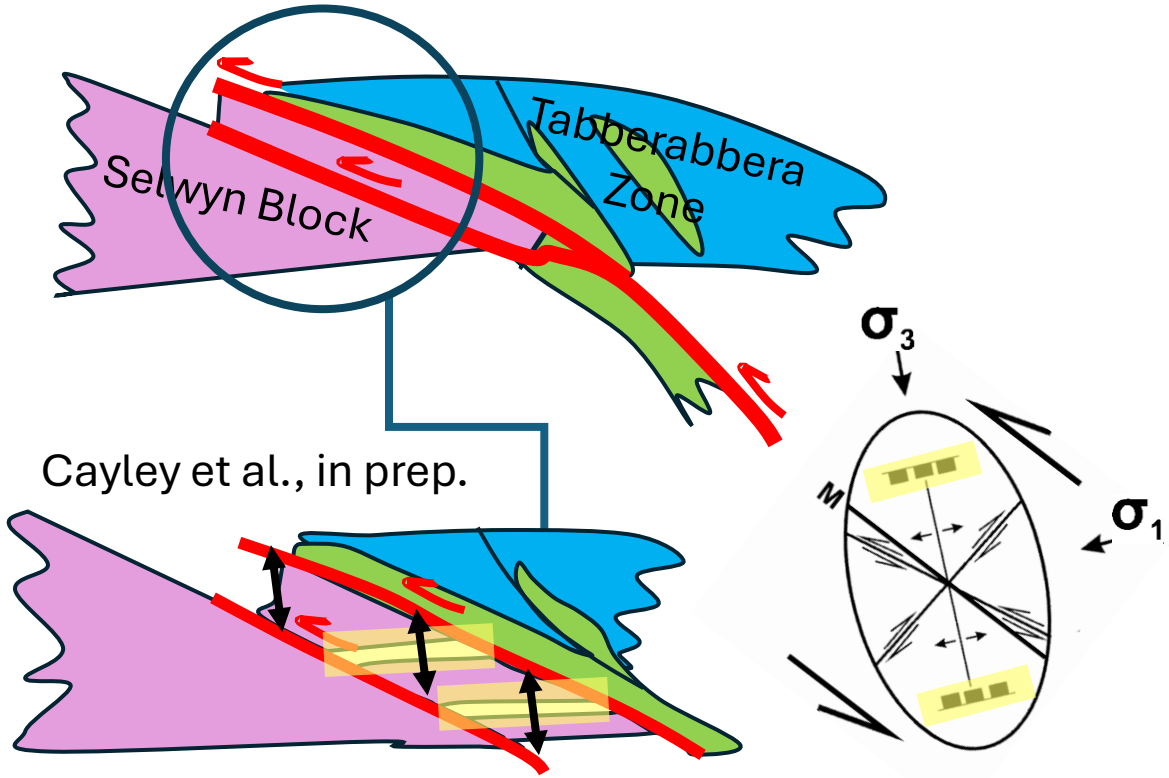
Passive margin drawn into Silurian subduction zone

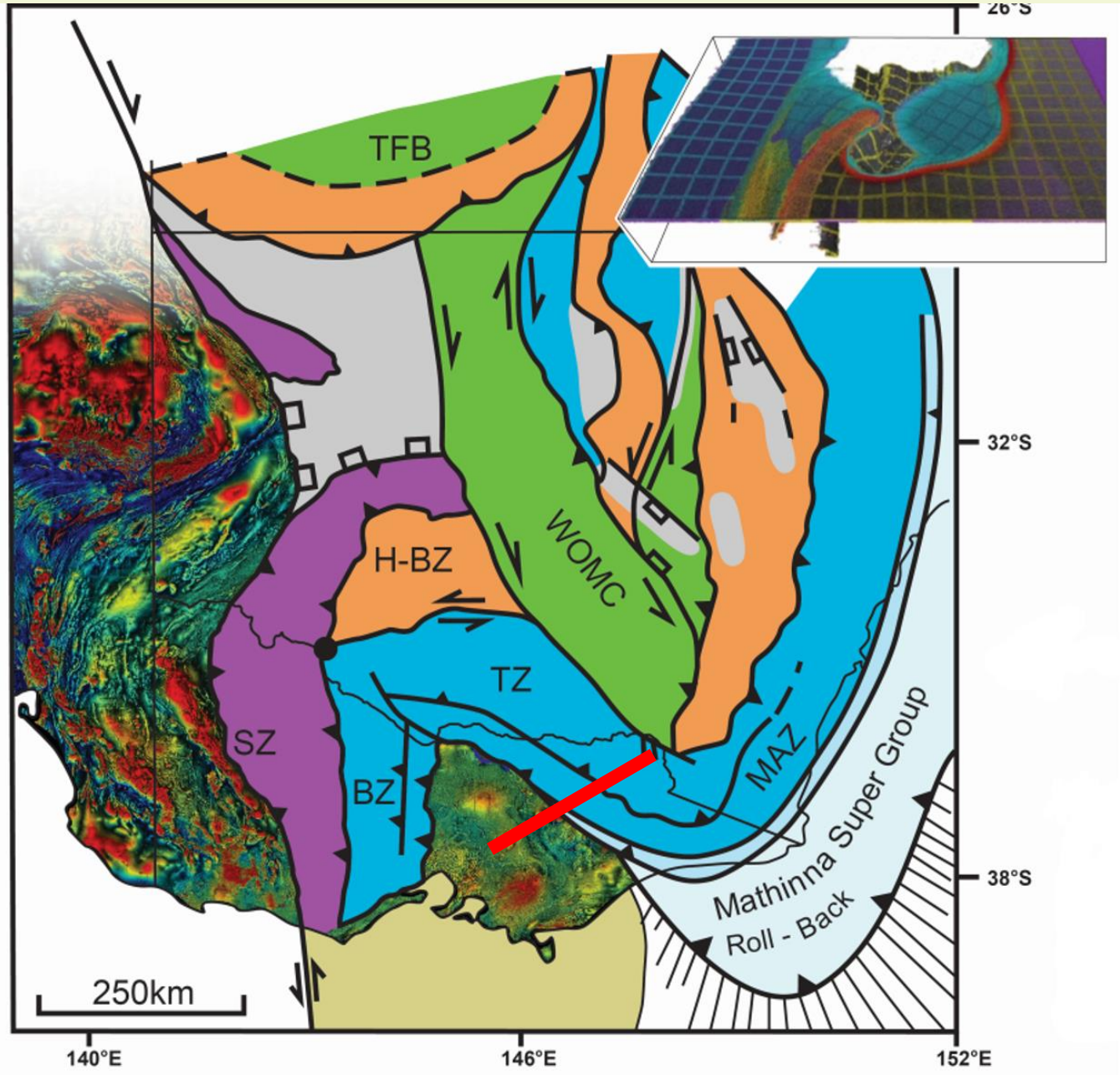



Cayley et al., in prep.



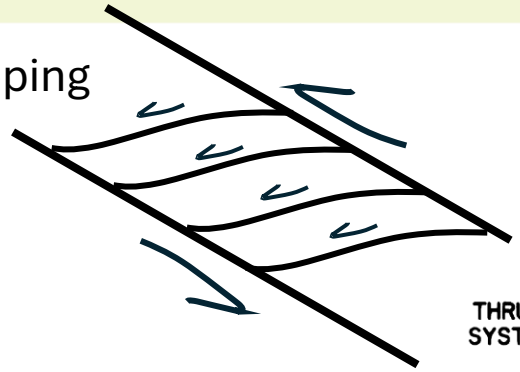
Accretionary wedge overthrusts Selwyn Block
Passive margin, inverts former rift faults / blocks

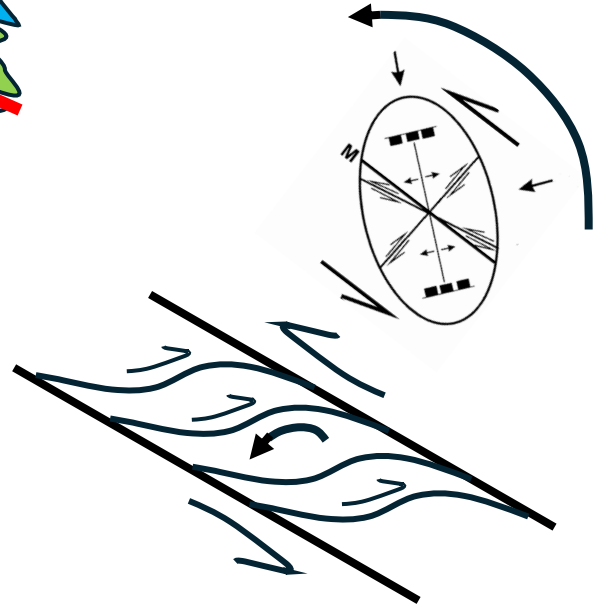


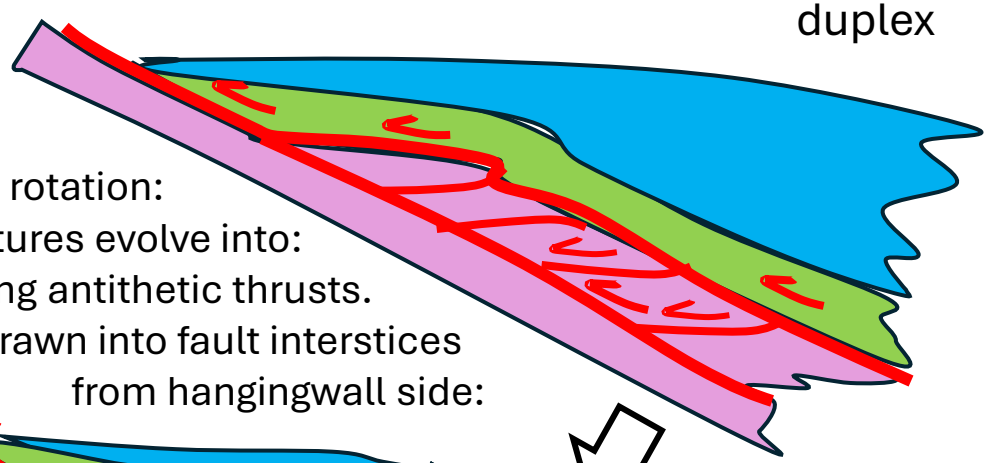

Subvertical extension field (sigma 3) for east-over-west thrusting – would be expected to drive systematic fragmentation of mobilised SB crust blocks

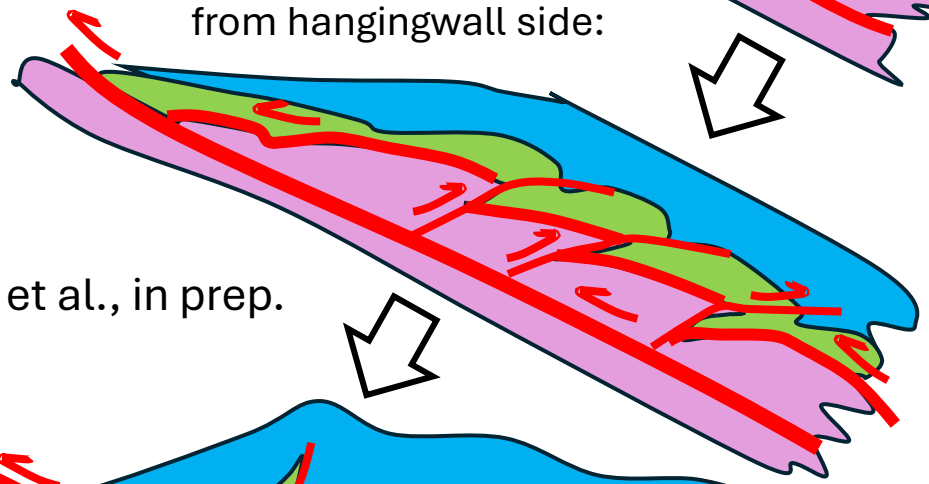
Foreland dipping duplex

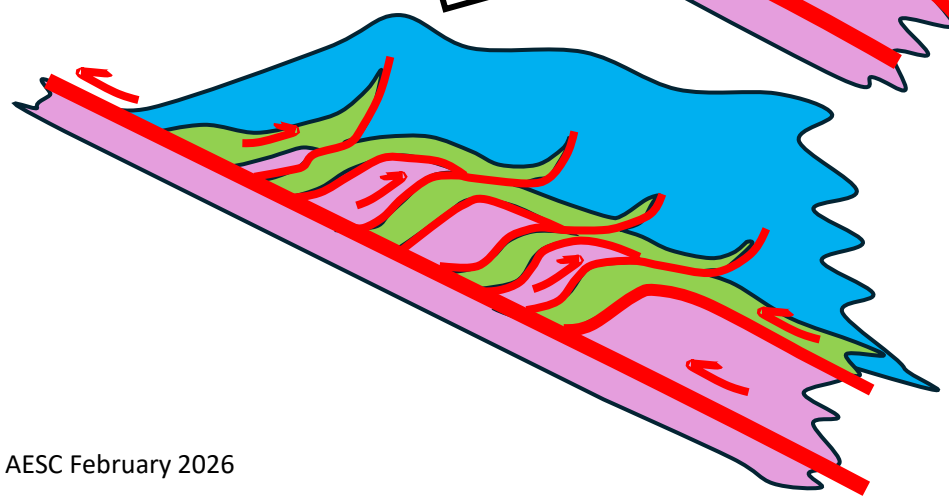




shear-induced rotation:
extension fractures evolve into:
foreland-dipping antithetic thrusts.
MORB slices drawn into fault interstices from hangingwall side:







Cayley et al., in prep.

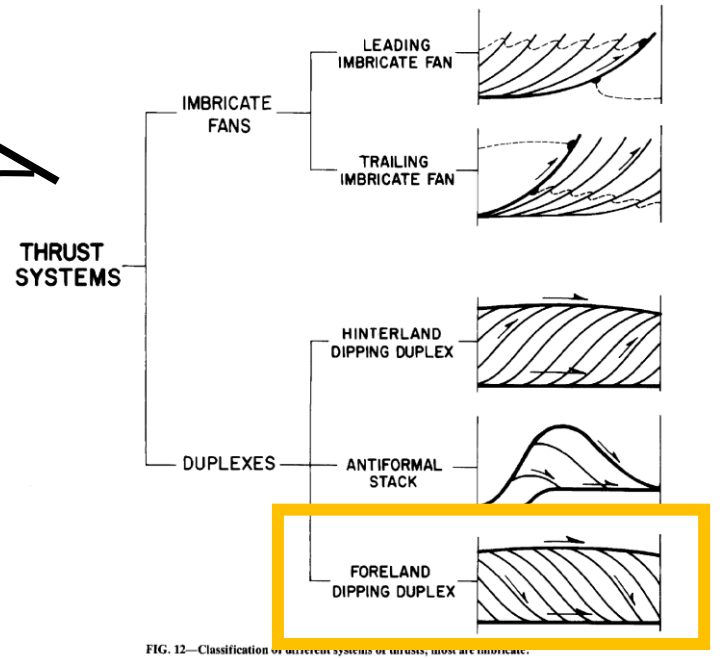



FIG. 12—Classification of different systems of thrusts; most are imbricate.

Boyer & Elliot, 1982

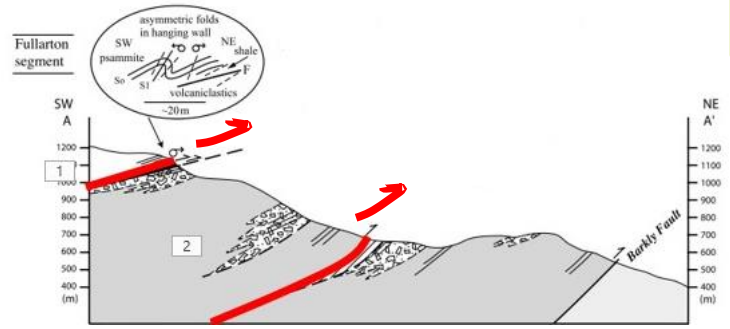
Shear-induced rotation progressively rotates duplex elements into westerly dips = explains ladder-array geometry of interlayered reflective and non reflective crust imaged in Governor Fault Zone. Explains west-dip of fabrics, folds and thrust faults within an overall east-dipping ‘Mount Useful Fault Zone’

Fiddlers Green / Howes Creek faults

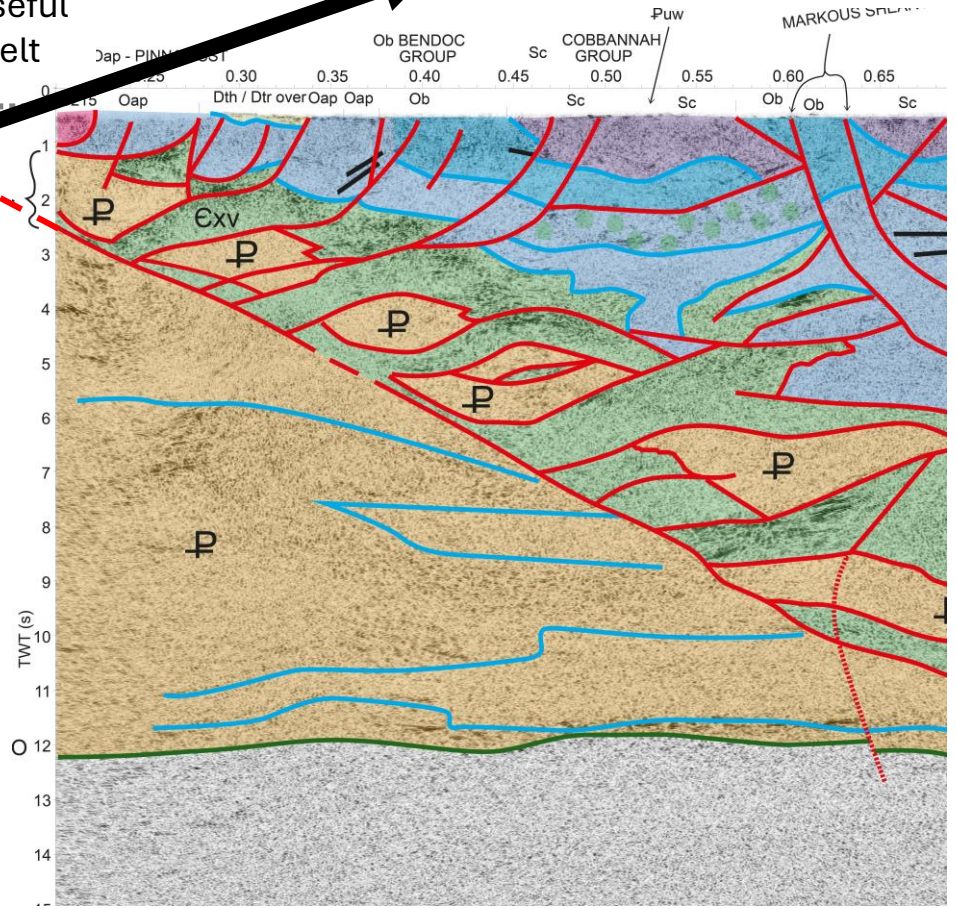
Walhalla Synclinorium

Mount Useful Slate Belt

Melbourne Zone

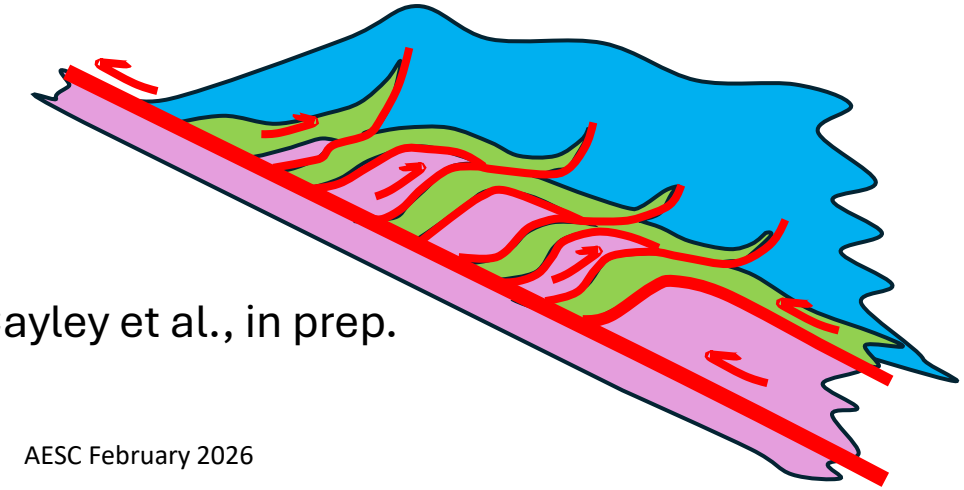



eg: Spaggiari et al., 2004

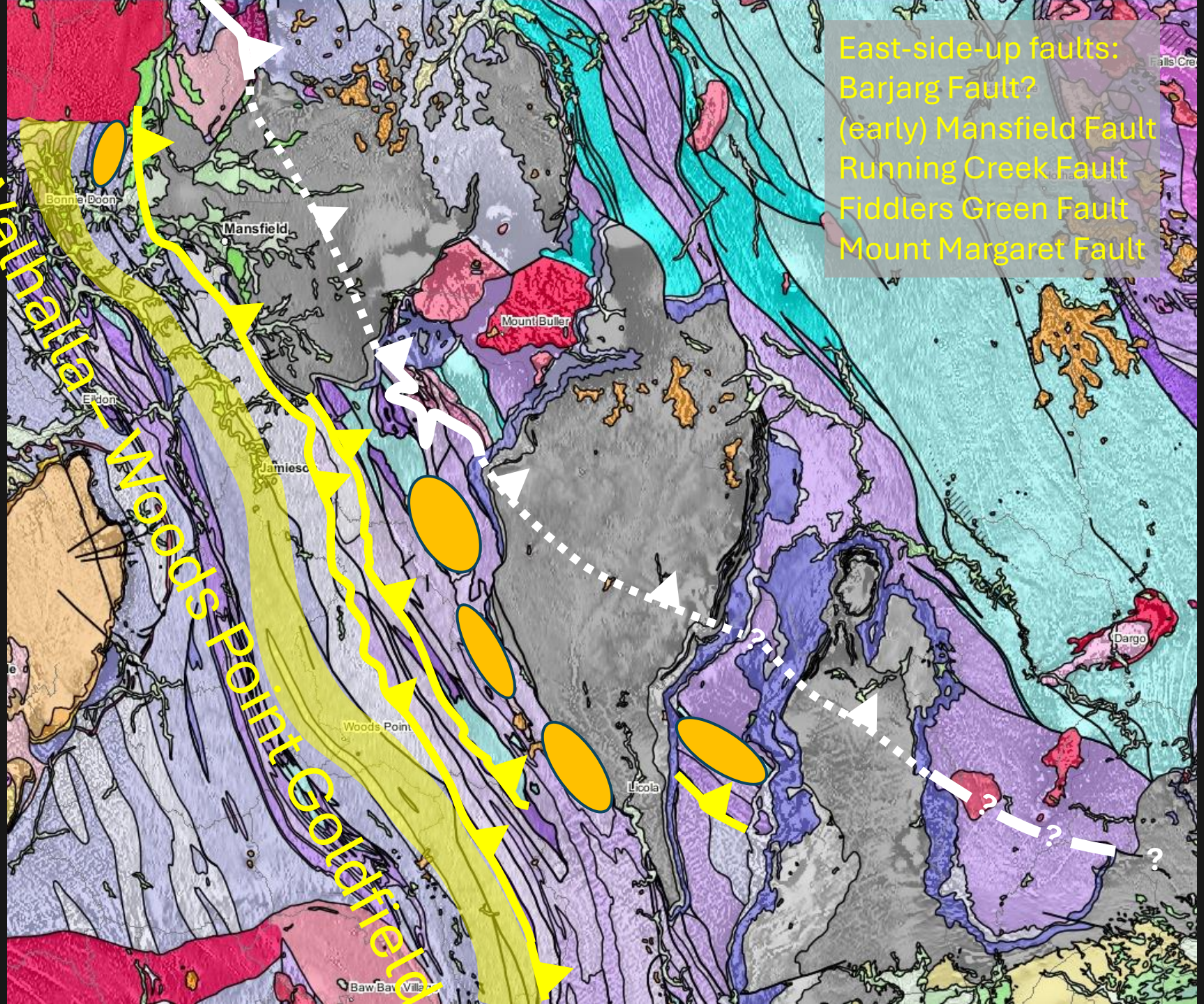



Seismic data reveals the Governor Fault Zone to be 1.5 – 2 s TWT thick (= ~4.5 - 6 km) with a simple planar base.
The fault zone is the 'Mount Useful Slate Belt'.
This model explains the reversal of structural vergence.

Wahalla Synclinorium is a thrust-footwall-propagated syncline.
'Governor Fault' sensu-stricto revealed as an upper fault zone-bounding structure which will have variable character along-strike



Cayley et al., in prep.




Cayley et al., in prep.

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