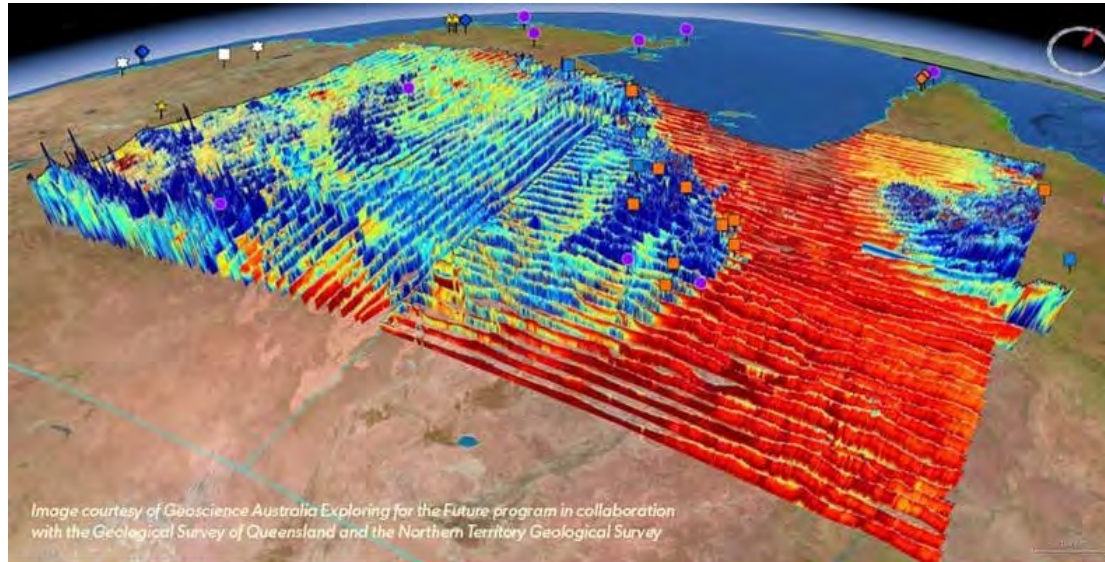


# ***Science in the Surveys 2019***

**Tuesday 26 March 2019**



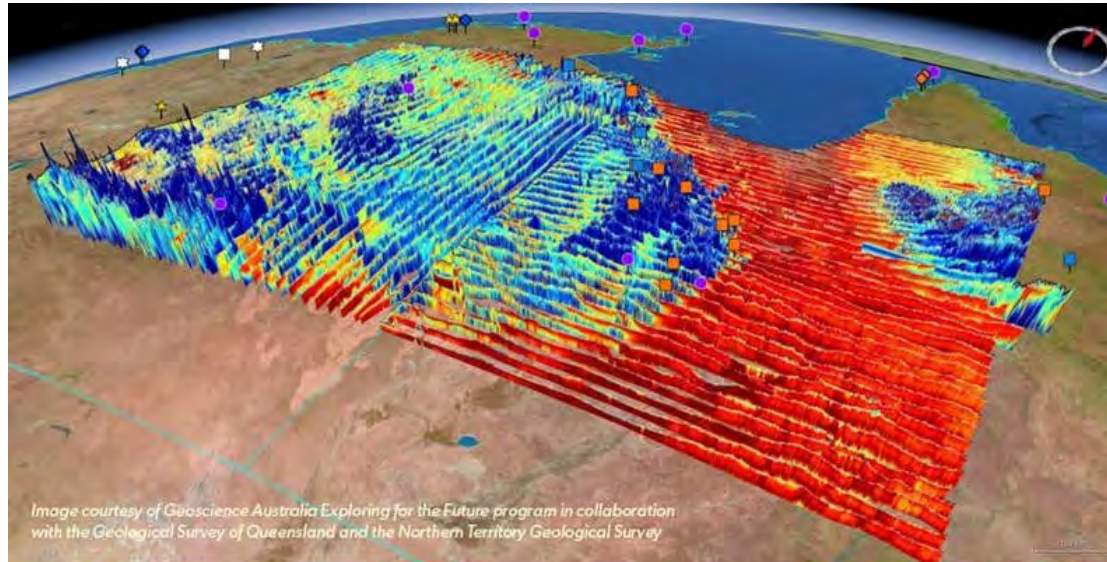
# Session One

Chair: **Chris Yeats**

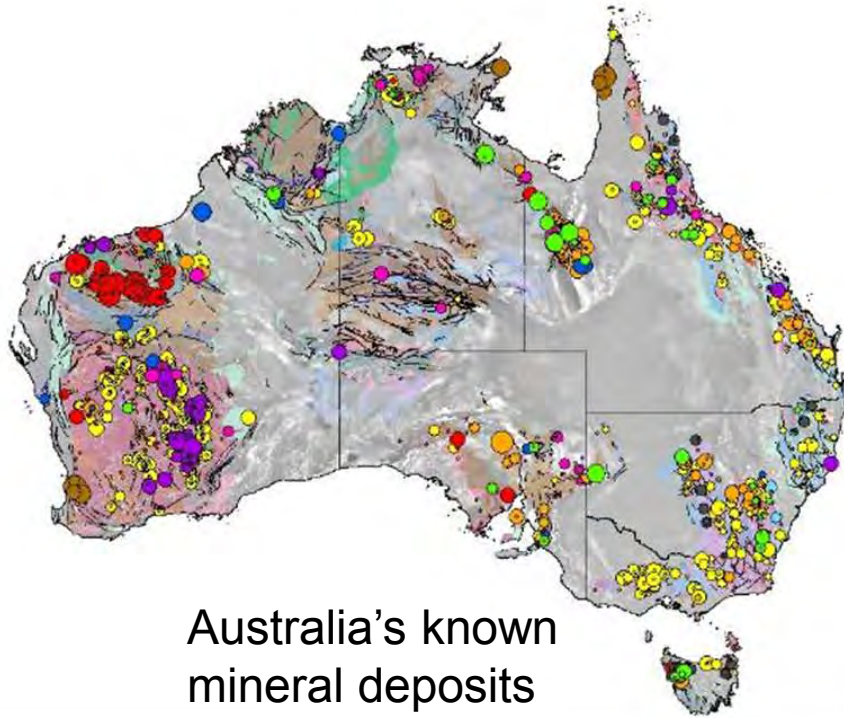
- 9:00** Welcome and Opening Address  
***Chris Yeats**, Geological Survey of NSW*
- 9:15** National datasets to guide resource exploration: Exploring for the Future  
***Alison Kirkby**, Geoscience Australia*
- 9:40** GSNSW – delivering tools for mineral exploration in the 21st Century  
***John Greenfield**, Geological Survey of NSW*
- 10:05** The Southeast Lachlan Crustal Scale Transect  
***Ross Cayley**, Geological Survey of Victoria*
- 10:30** Morning Tea

# ***Science in the Surveys 2019***

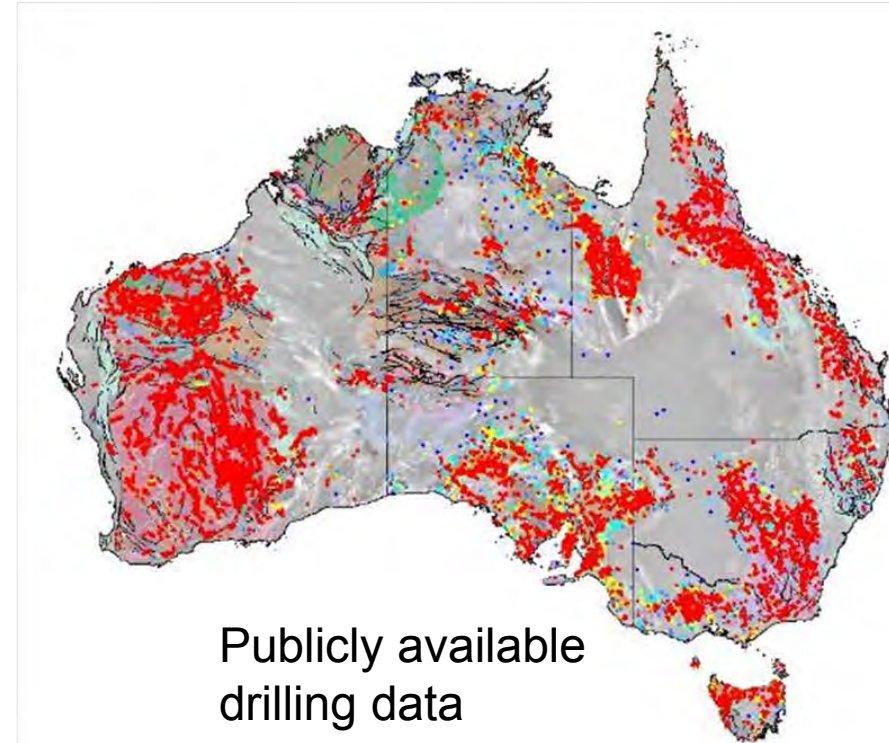
## **Opening Address**



# The exploration challenge



Australia's known  
mineral deposits



Publicly available  
drilling data

Courtesy Geoscience Australia





# National datasets to guide resource exploration: Exploring for the Future

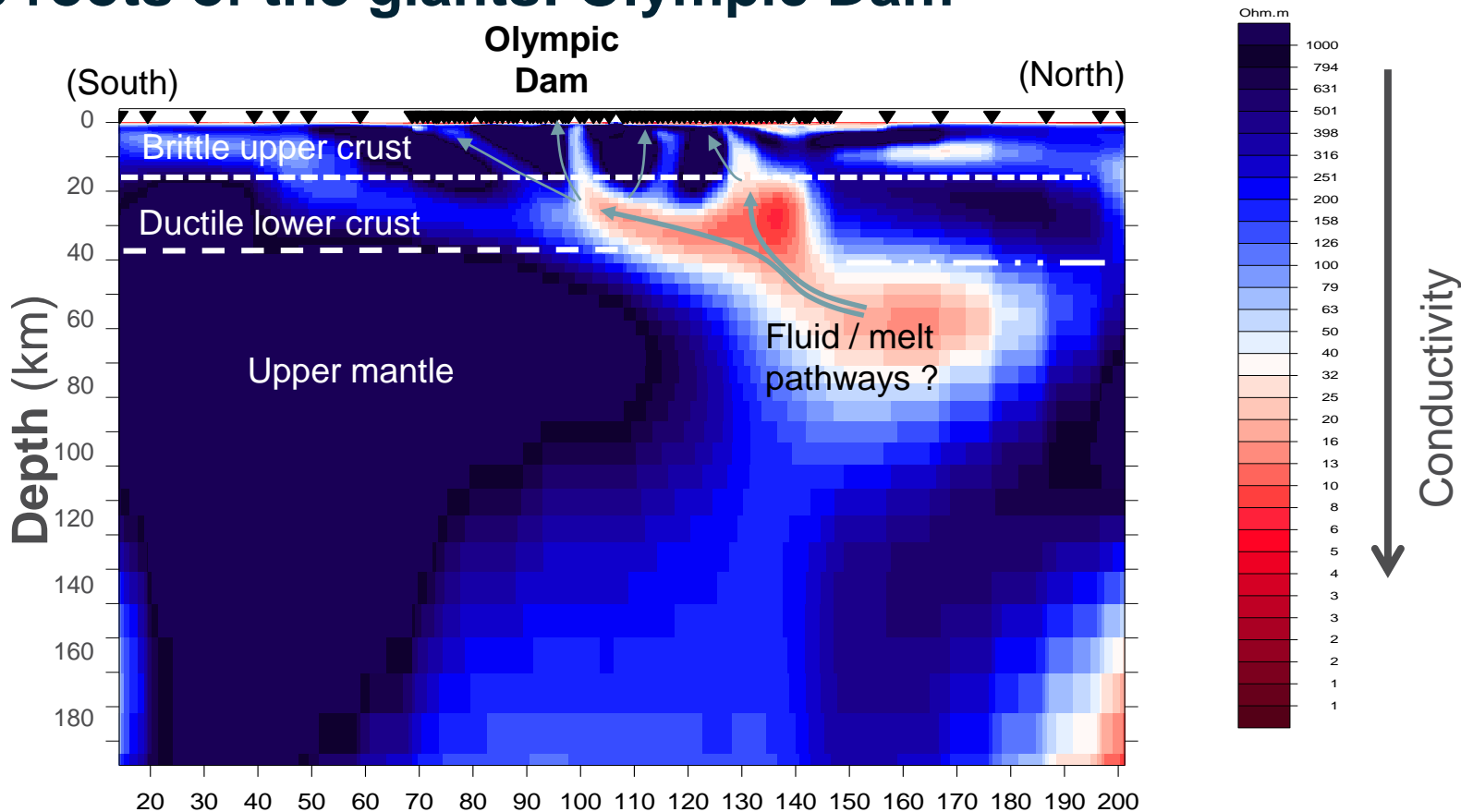
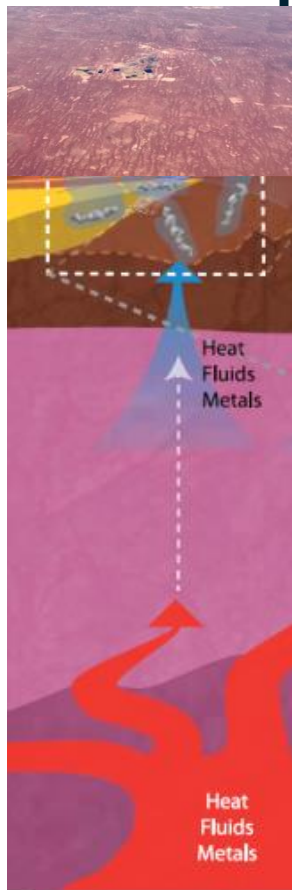
Dr Alison Kirkby

On behalf of the Mineral Systems Branch (+ others),  
Geoscience Australia

Alison.Kirkby@ga.gov.au

Science in the Surveys, Maitland, 26 March 2019

# Deep roots of the giants: Olympic Dam



Heinson et al. 2018 Scientific Reports

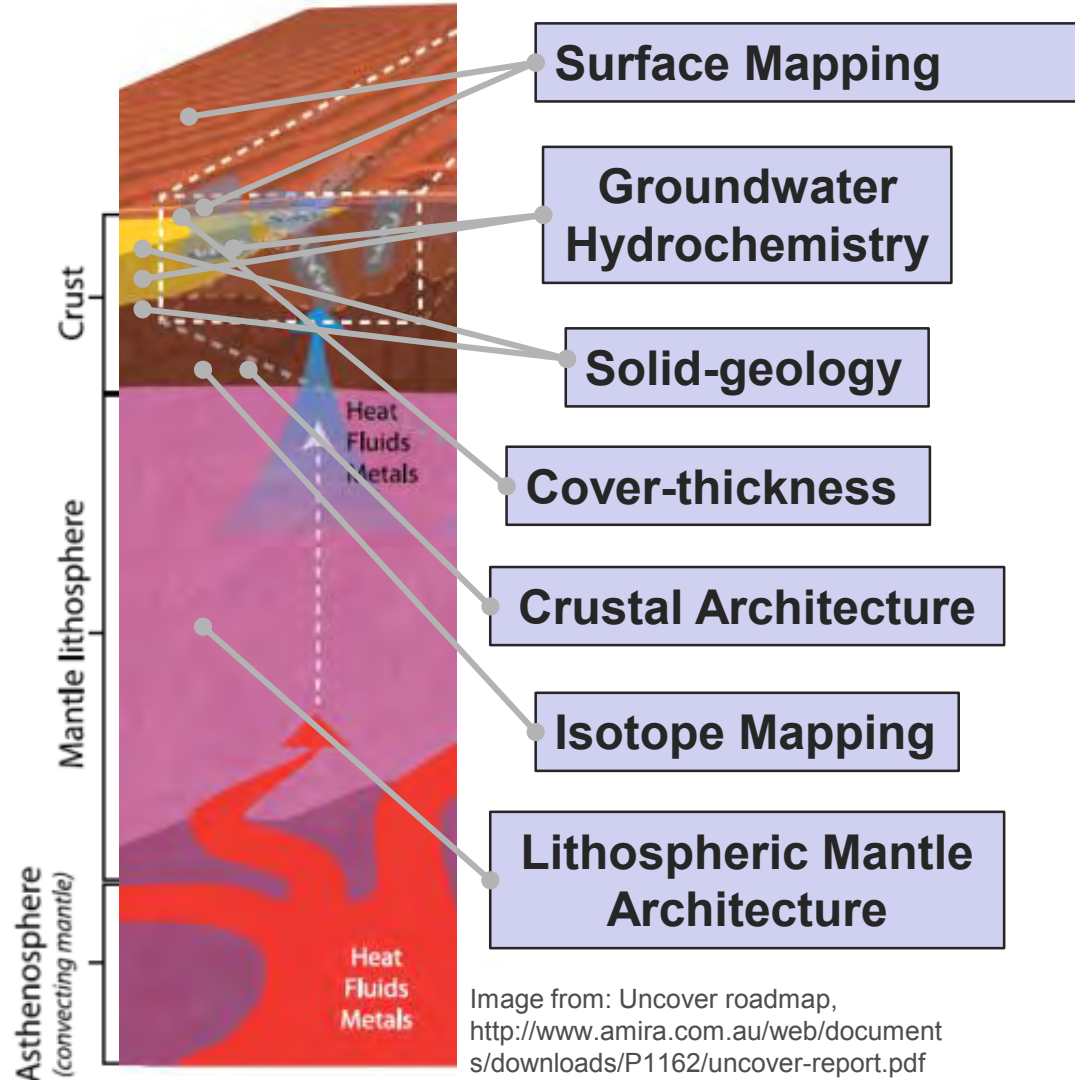
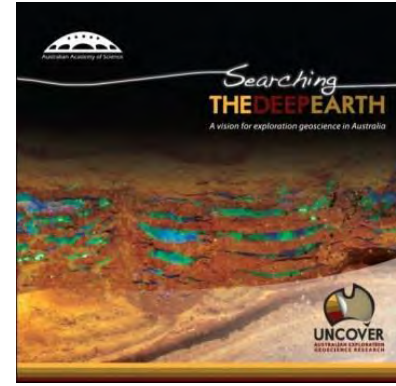


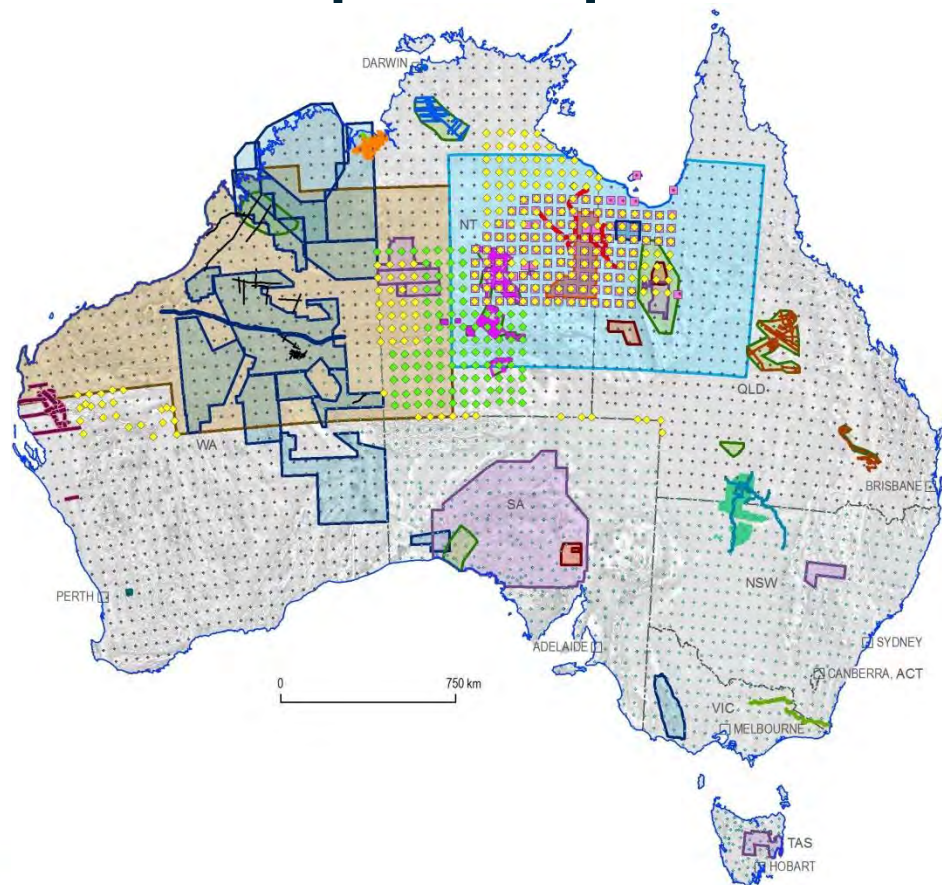
Image from: Uncover roadmap,  
<http://www.amira.com.au/web/document/s/downloads/P1162/uncover-report.pdf>



**Mineral  
Systems  
Potential**

**Economic  
Fairways**  
 decision support

# National pre-competitive databases: team effort



## Exploring for the Future, February 2019

- AusAEM 2017–2018 completed survey
- AusAEM 2019 proposed survey
- Gravity survey, South Nicholson Basin, released October 2017
- Seismic reflection survey, South Nicholson Basin, released March 2018
- AEM survey, Surat and Galilee basins
- AEM survey, East Kimberley
- AEM survey, Northern Stuart Corridor
- AEM survey, Southern Stuart Corridor
- Seismic reflection survey, Kidson Sub-basin
- Reprocessed seismic reflection survey, Canning Basin
- Reprocessed seismic reflection survey, Carnarvon Basin
- Reprocessed seismic reflection data, East Kimberley
- AusARRAY survey, Mount Isa to Tennant Creek
- ♦ EFTF AusLAMP survey, completed
- ♦ EFTF AusLAMP survey, southwest Alice Springs, in progress

## Geophysical Acquisition Programs, current activities

- Airborne magnetic and radiometric survey
- Gravity survey
- Airborne electromagnetic survey
- Magnetotelluric survey
- Airborne test site
- AEM survey, Thomson
- Gravity survey, Thomson
- Seismic reflection survey, Lachlan
- ♦ AusLAMP survey, completed and in progress
- ♦ AusLAMP survey, planned

NOTE: The greyscale background represents aeromagnetic data (0.5 first vertical derivative of total magnetic intensity).



Australian Government  
Geoscience Australia

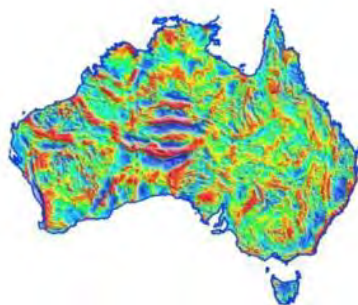




# National pre-competitive databases: team effort



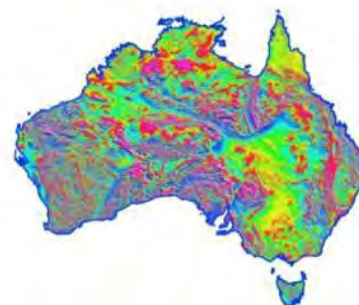
1:1M Surface Geology



Gravity



Radiometrics



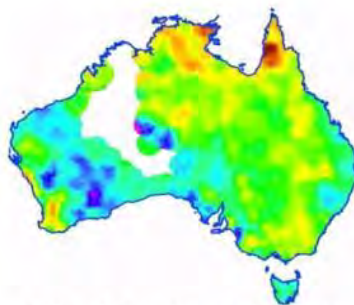
Magnetics



Onshore Seismic Lines



Nd Two-stage  
Depleted Mantle Model



National Geochemical Survey



Water bores

Data from Geoscience Australia and State/NT geological surveys

14-8099-5



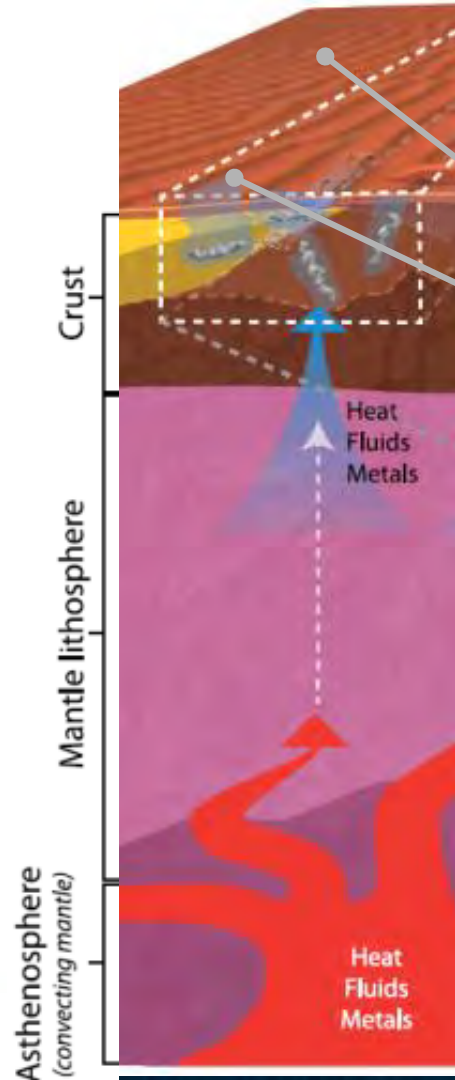
Australian Government

Geoscience Australia



Tasmanian  
Government



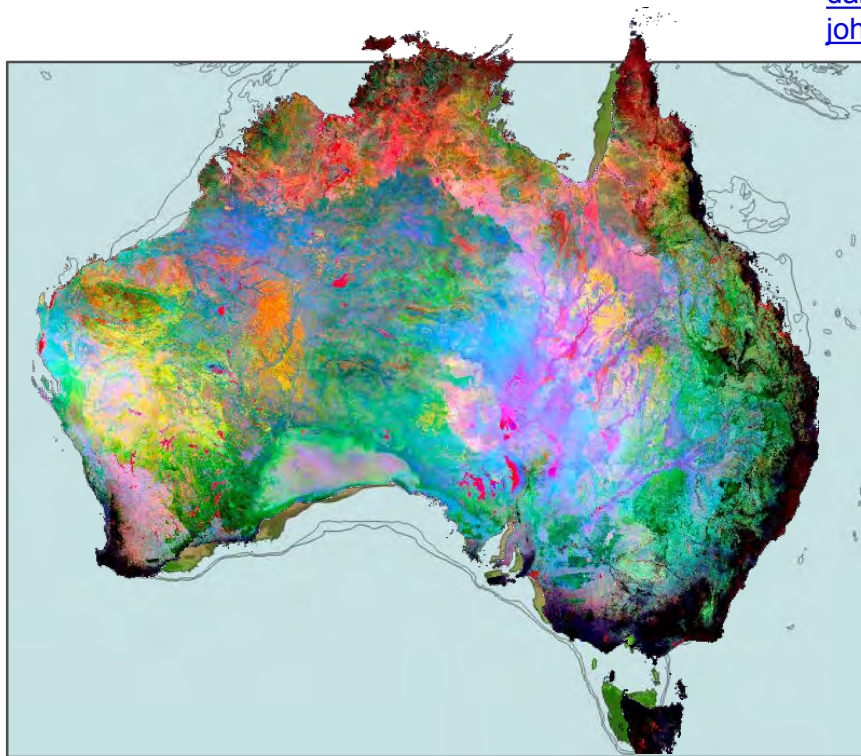
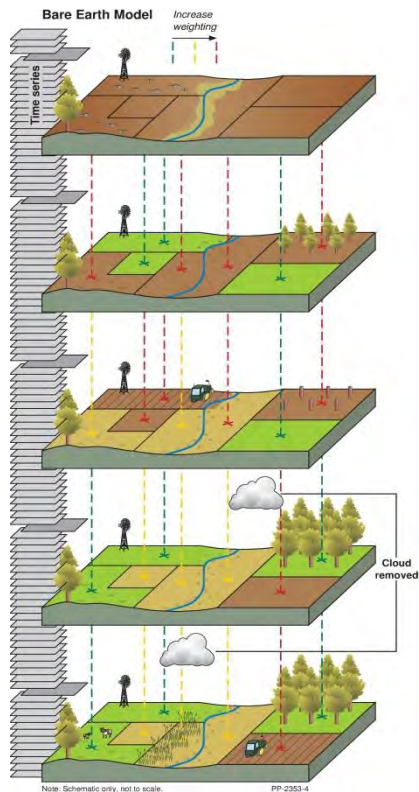


**Map the surface**

# Bare(st) earth satellite imagery to enhance geology

[dale.roberts@anu.edu.au](mailto:dale.roberts@anu.edu.au)

[john.wilford@ga.gov.au](mailto:john.wilford@ga.gov.au)

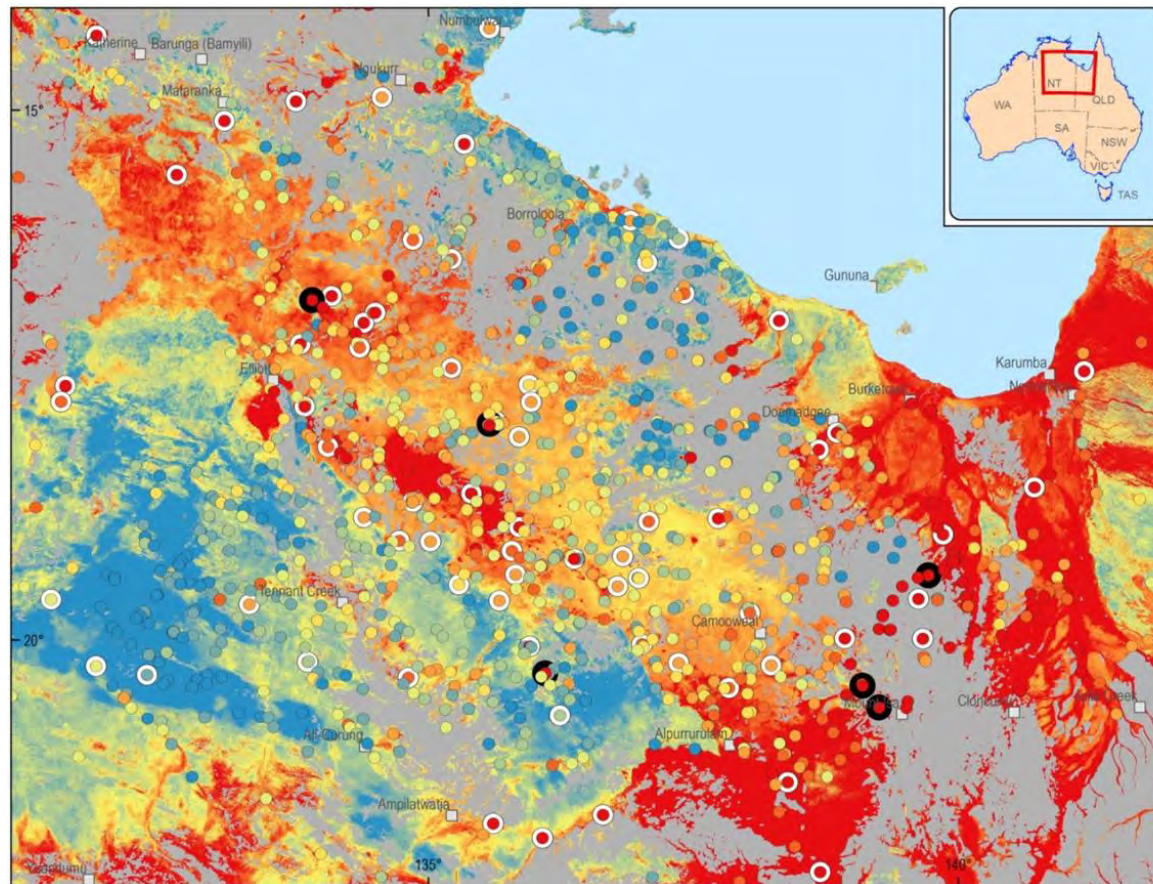


Landsat-8 Barest Earth mosaic, shown in False Colour  
Sentinel 2: Red = clays, Green = Fe, Blue = silica

[www.ga.gov.au/dea](http://www.ga.gov.au/dea)



# Soil Geochemistry and Big Data Analytics



## Tennant—Isa study area: Northern Australia Geochemical Survey

Machine-learning:  
**MMI Results**

### Legend

Cu mg/kg

- 0.04-0.38
- 0.38-0.54
- 0.54-0.68
- 0.68-0.8
- 0.81-0.97
- 0.97-1.20
- 1.2-1.70
- 1.70-19.2

**Cu predicted**  
1.38 mg/kg  
0.29 mg/kg

**1 Sigma**

○ 0 - 0.46

**2 Sigma**

● 0 - 0.21

0 250 km

<http://www.ga.gov.au/efft/minerals/fis/nags>

**Method:**

Wilford et al. 2016  
Applied  
Geochemistry

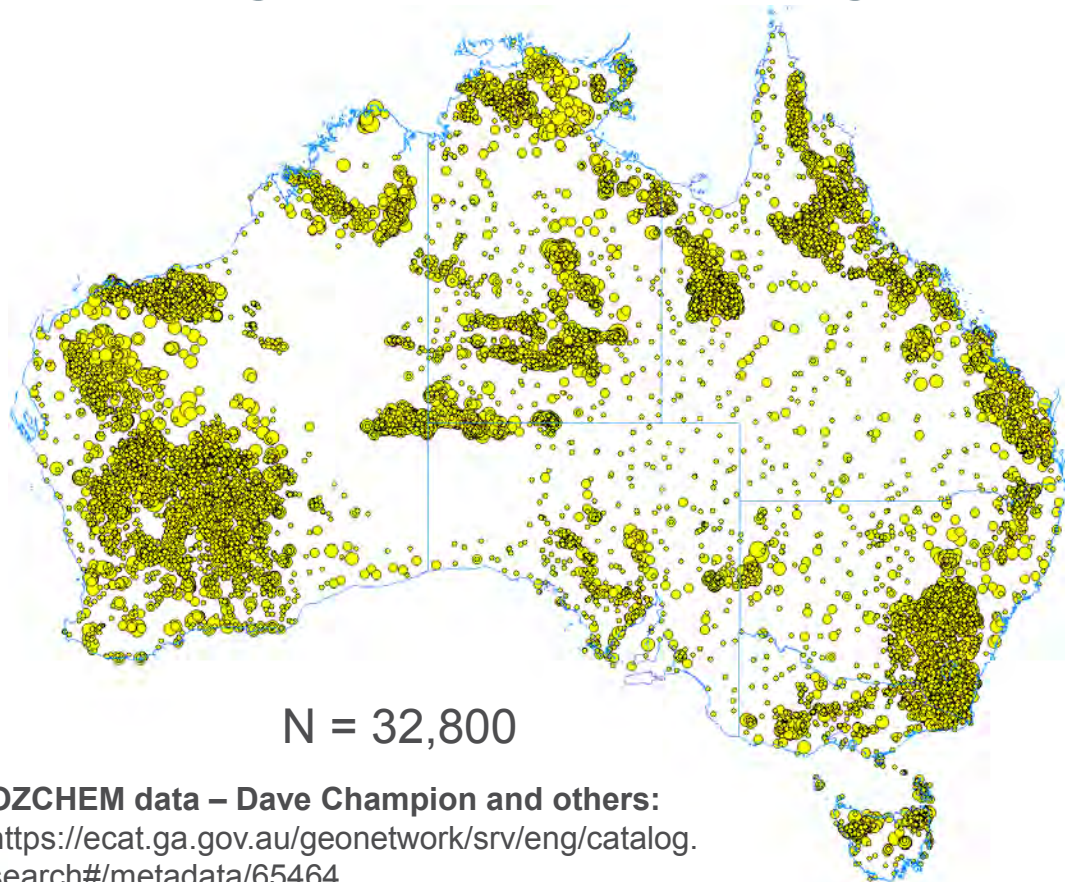
**NAGS:**

Phil Main

<http://www.ga.gov.au/efft/minerals/fis/nags>



# Mapping Australia: mapping Fe from chemistry points



**OZCHEM data – Dave Champion and others:**  
[https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.  
search#/metadata/65464](https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/65464)

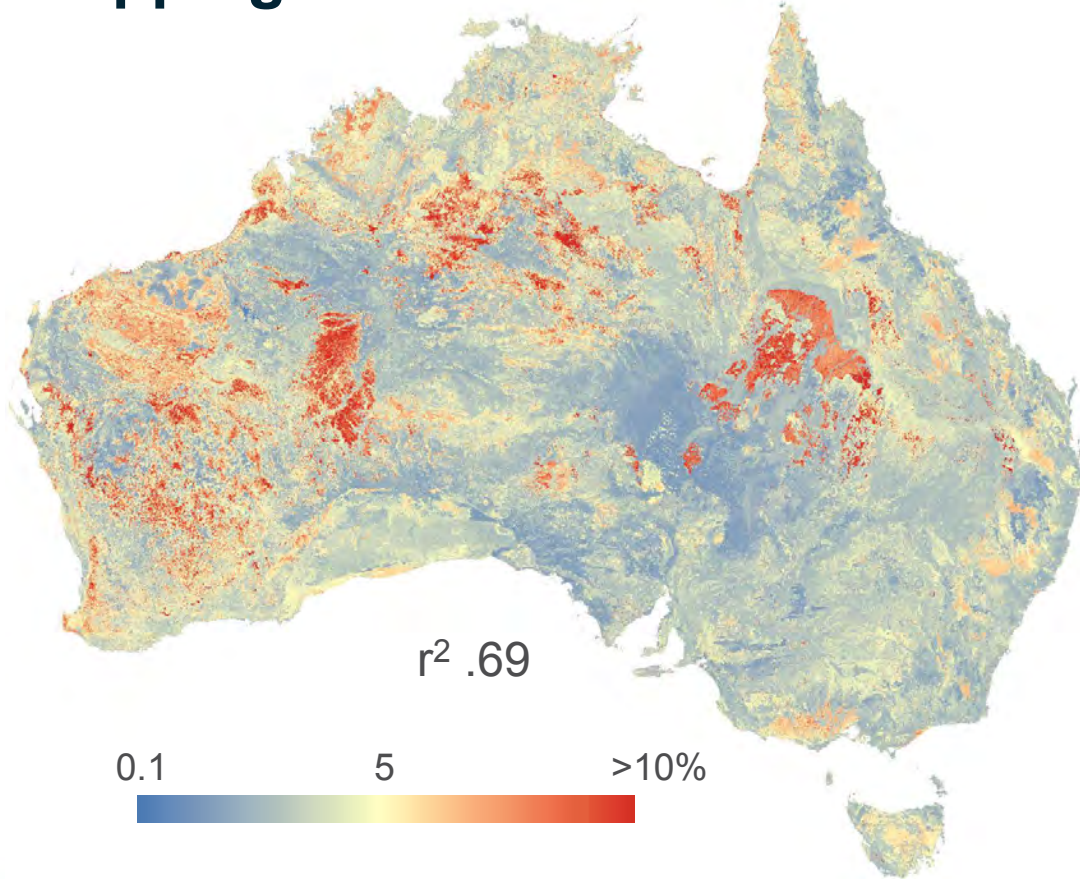
National OZCHEM  
database  
(soils, regolith and rock  
samples at the surface)

## Fe (%)

- 0.0 - 3.3
- 3.4 - 7.9
- 8.0 - 22.8
- 22.9 - 48.5
- 48.6 - 69.8

**Method:**  
Wilford et al. 2016 Applied Geochemistry

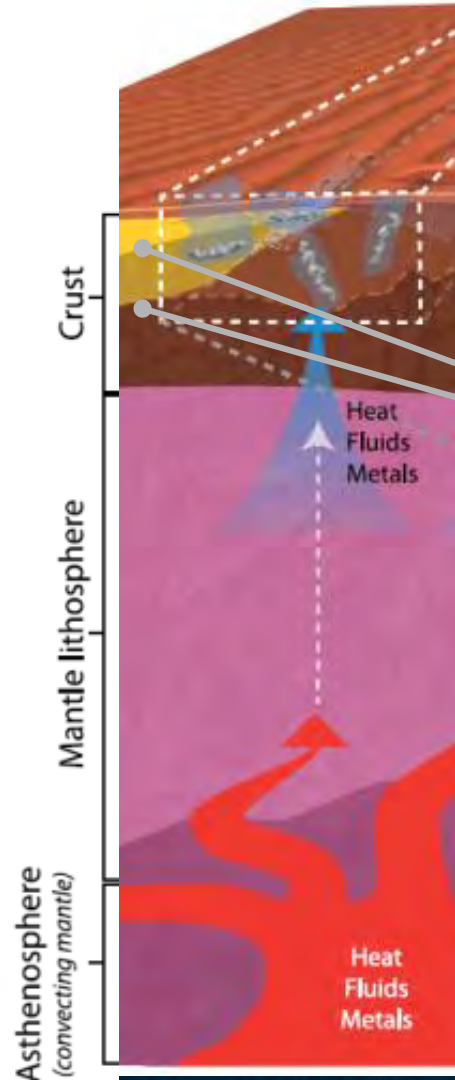
# Mapping Australia: Fe surface model prediction



- Fe model of Australian surface
- UncoverML
- All major elements being mapped

**Method:**

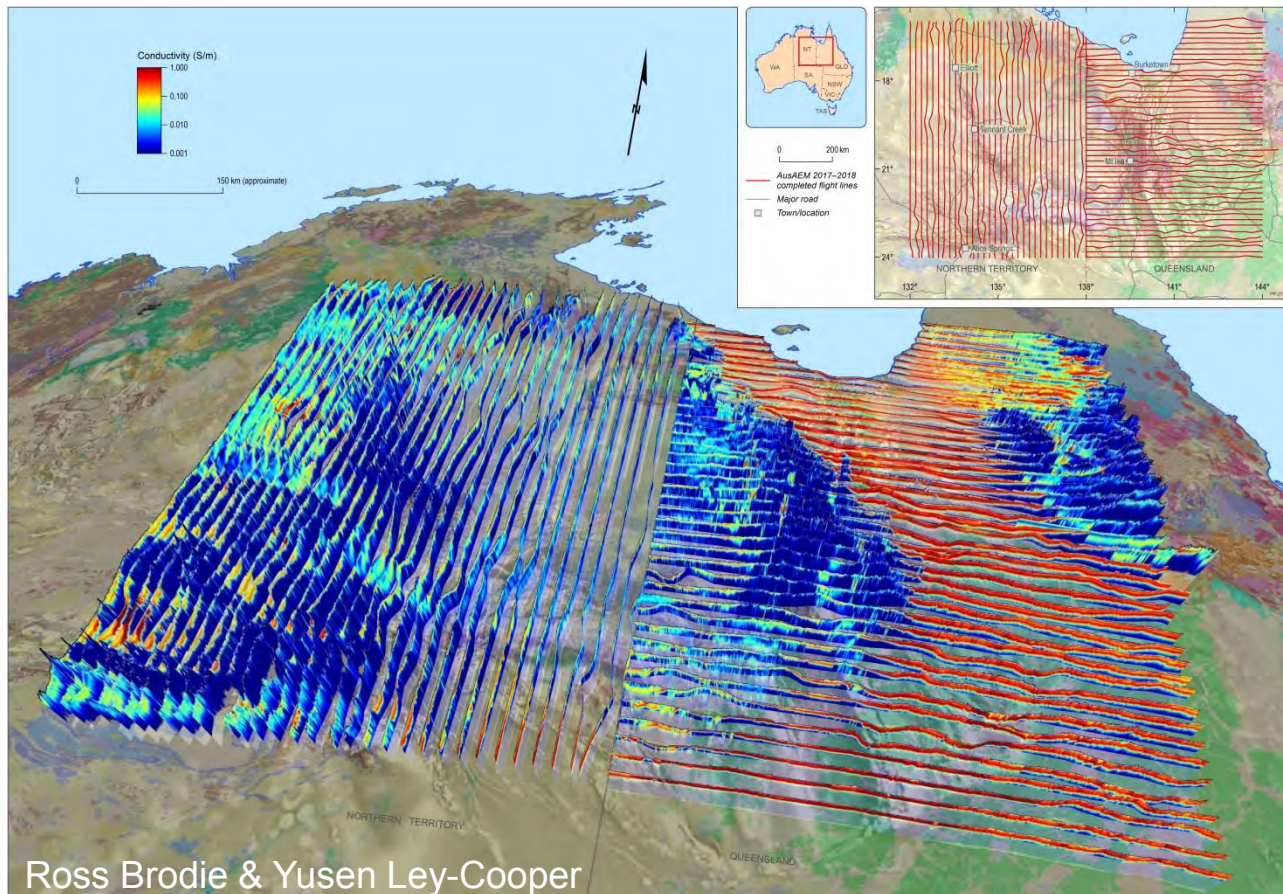
Wilford et al. 2016 Applied Geochemistry



**Cover-  
thickness and character**



# National Airborne Electromagnetic Survey: AusAEM



Provide a 20 km spaced national framework for AEM surveys

Map:

- cover-thickness
- cover-character
- hydrogeology
- direct-detection

Reduce exploration risk  
& stimulate investment

<http://www.ga.gov.au/efft/minerals/nawa/ausaem>

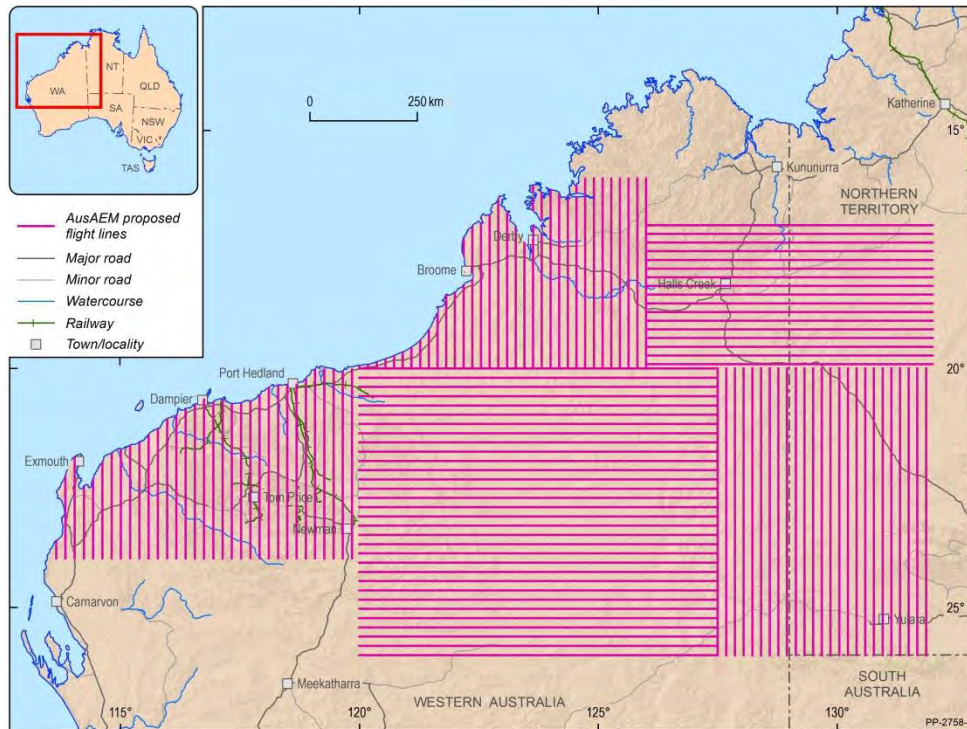
Ross Brodie & Yusen Ley-Cooper





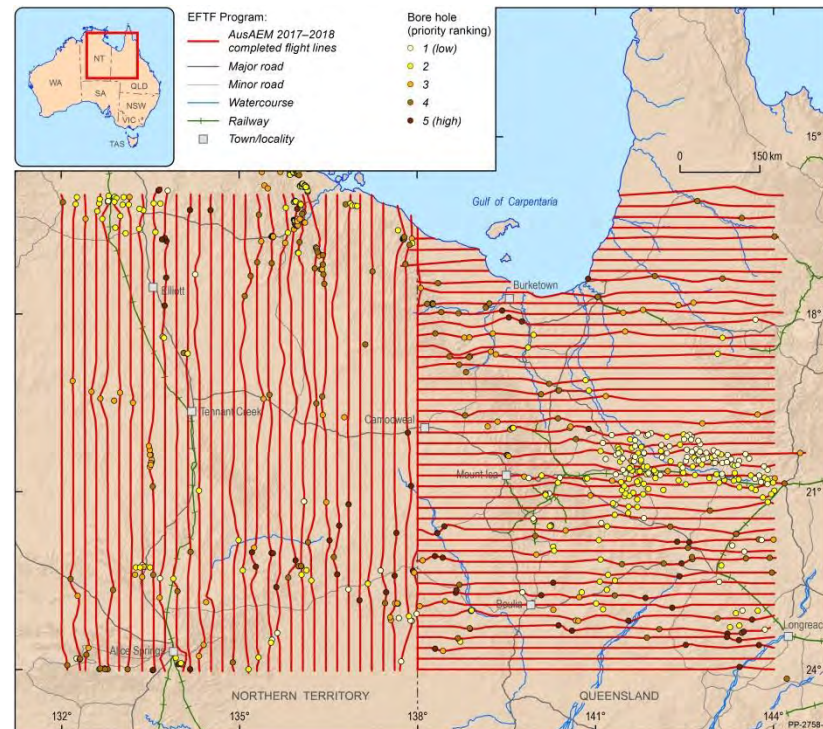
# National Airborne Electromagnetic Survey: AusAEM

Stage 2 in progress: over 1 million km<sup>2</sup>



72,500 line km PLUS **64,000** line km of company infill

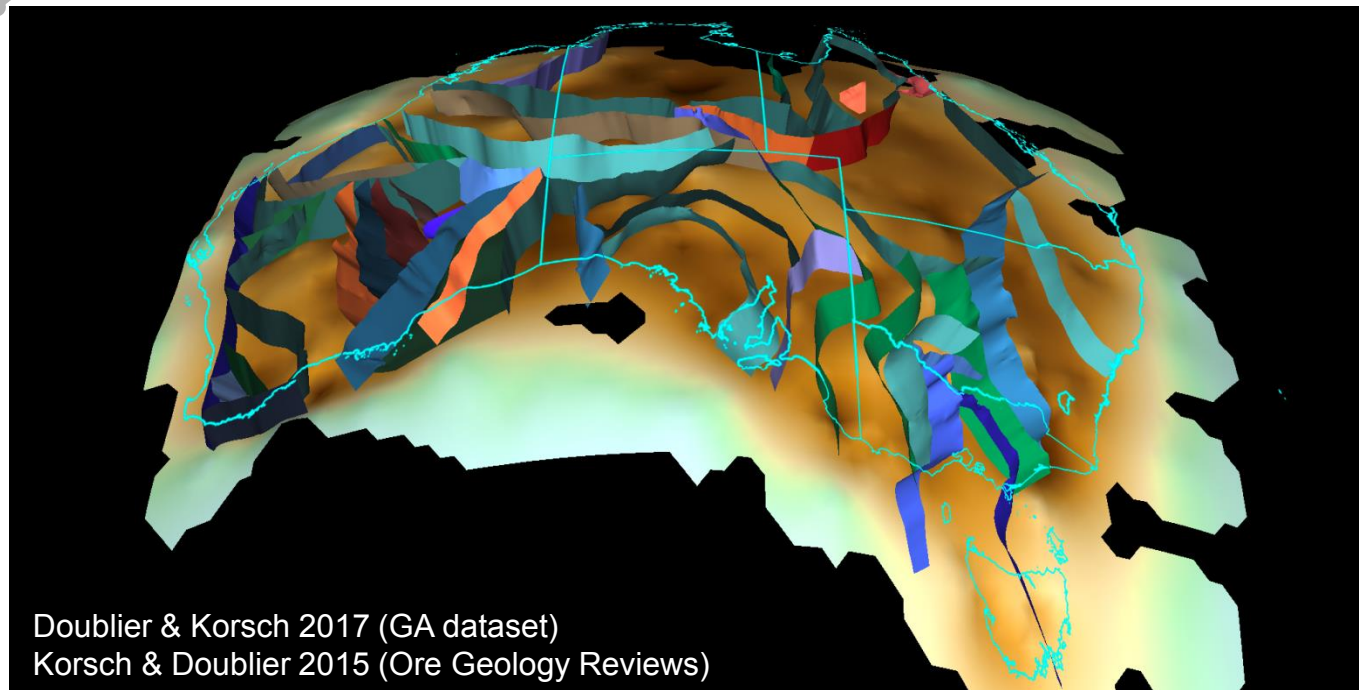
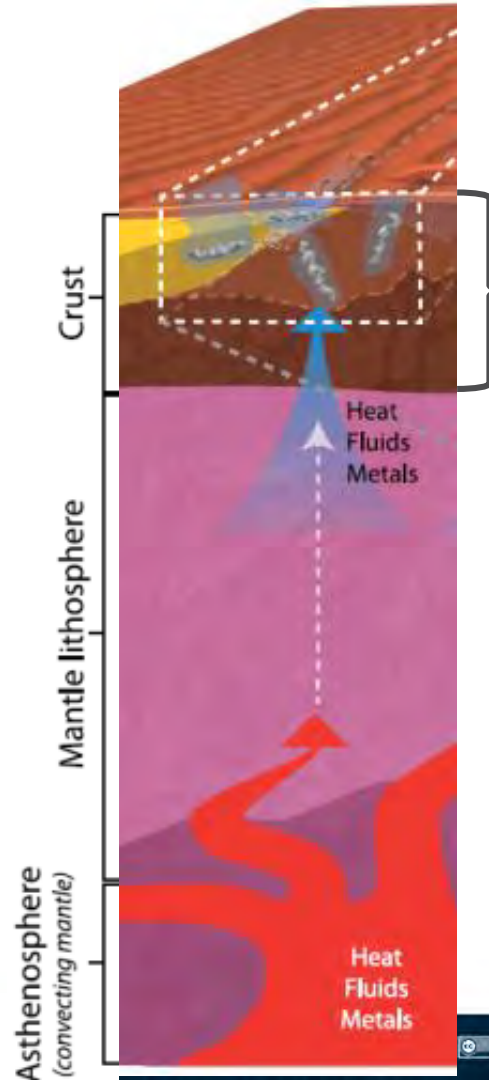
Stage 1 Delivered: 1 million km<sup>2</sup>



60,000 line km PLUS **6,000** line km of company infill

<http://www.ga.gov.au/eftf/minerals/nawa/ausaem>

# Crustal architecture



# Still improving the potential fields and radiometrics

## Gawler Craton Airborne Survey

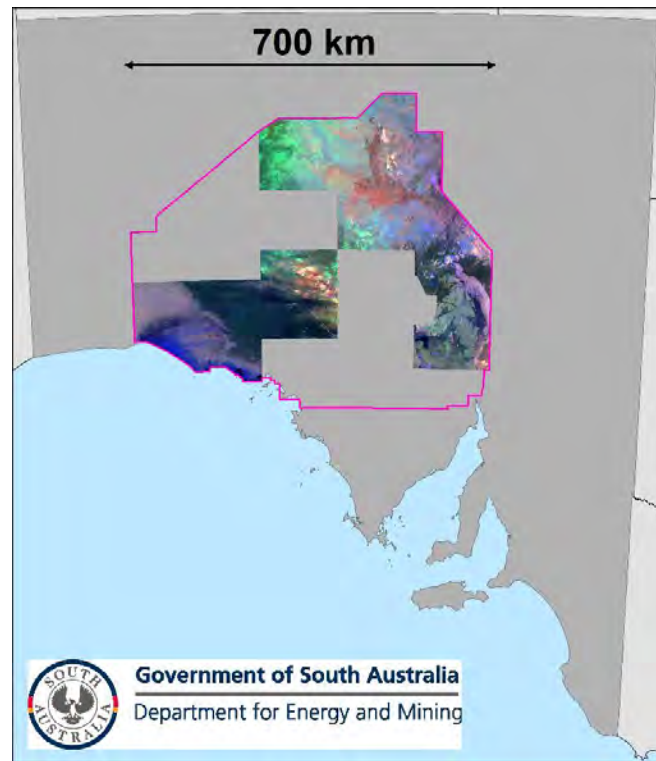
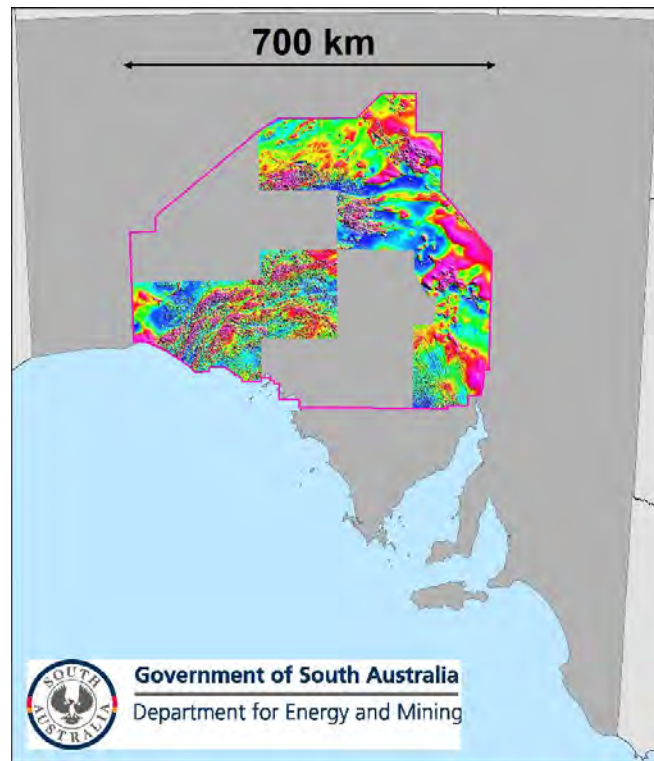
Magnetics &  
radiometrics

1.66M Line km

295,000 km<sup>2</sup>

200m Line Spacing

60m Ground Clearance



[http://www.energymining.sa.gov.au/minerals/geoscience/pace\\_copper/gawler\\_craton\\_airborne\\_survey\\_community\\_information](http://www.energymining.sa.gov.au/minerals/geoscience/pace_copper/gawler_craton_airborne_survey_community_information)



# New seismic

**South Nicholson 1102 km**  
**GA and NTGS, GSQ**  
Completed Aug 2017  
Released

**Kidson sub-basin 872 km**  
**GA and GSWA**  
Completed Aug 2018

**Southeast Lachlan 629 km**  
**GA and GSV, GSNSW, AuScope**  
Completed 2018

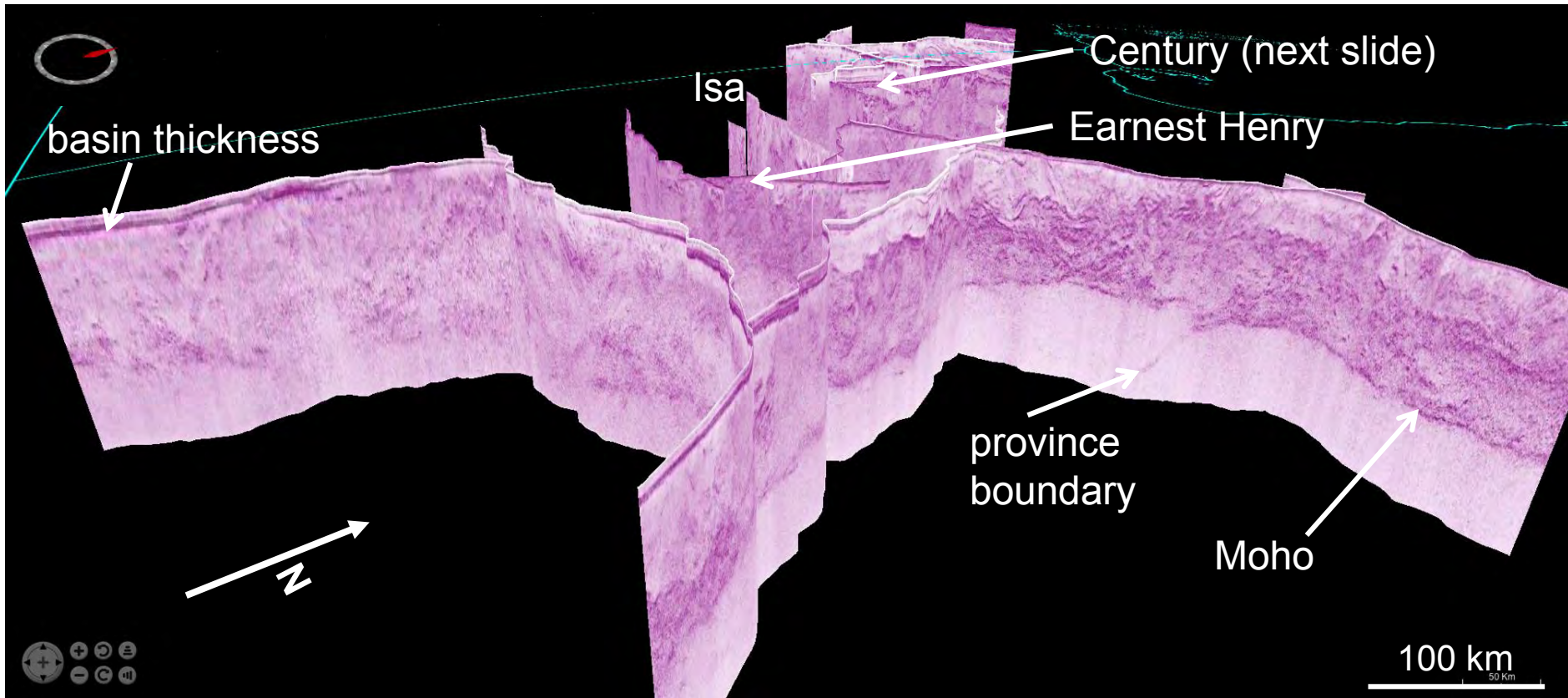
Tanya Fomin / Ross Costelloe

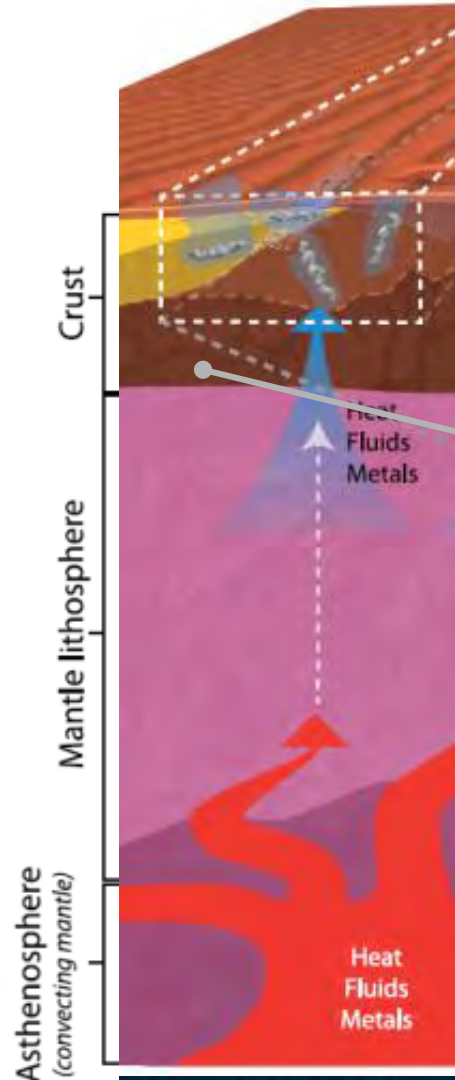
For more information: <http://www.ga.gov.au/about/projects/resources/seismic>





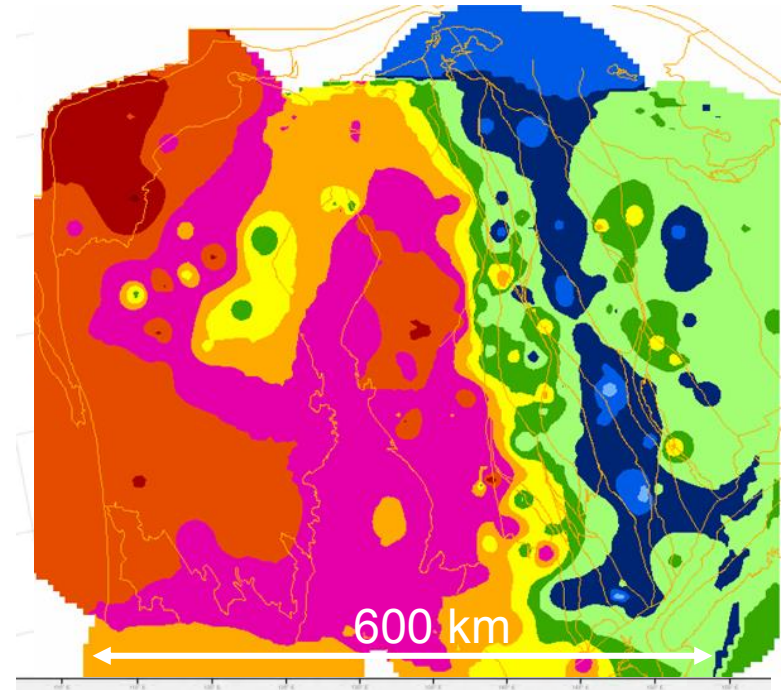
# Seismic 3D fence around Mt Isa





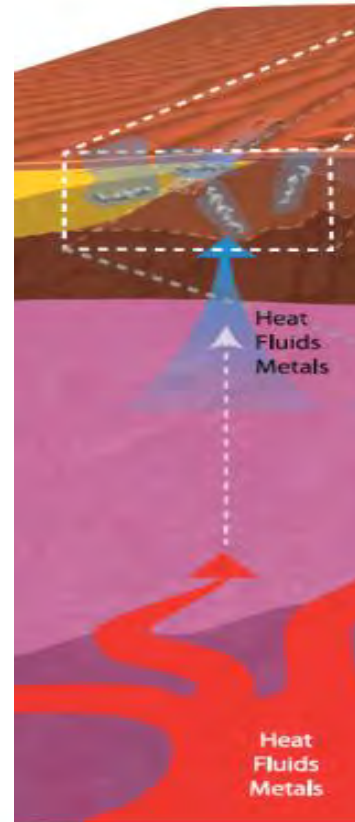
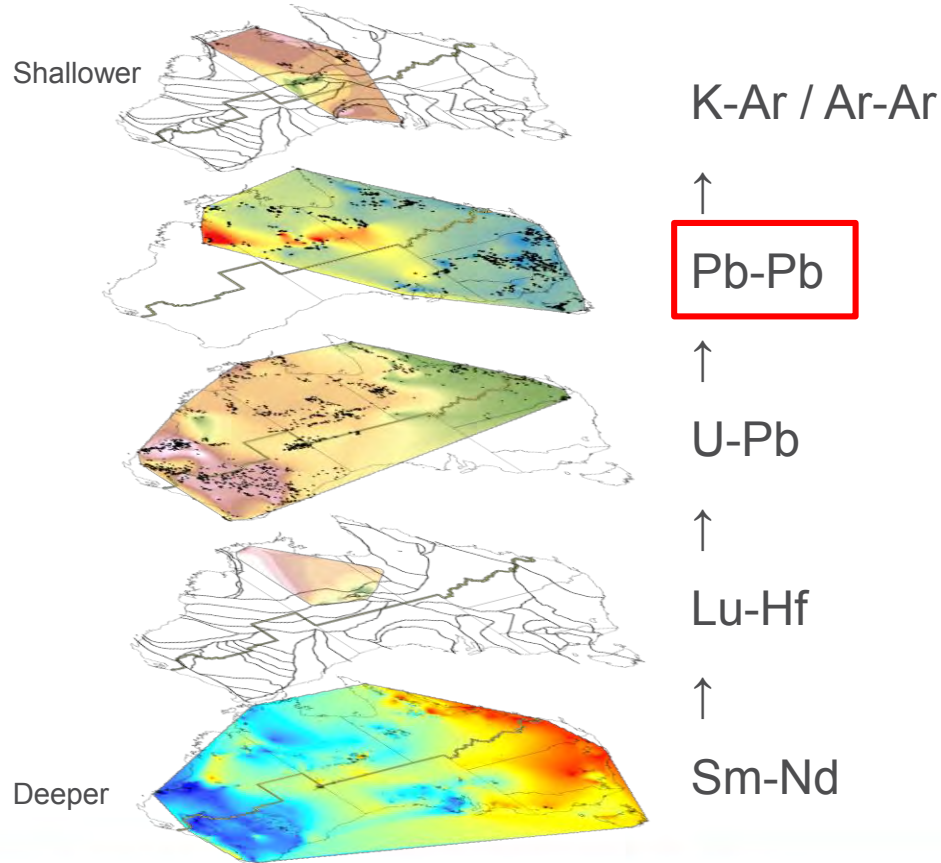
**Isotopic  
mapping**

Nd map of the Yilgarn

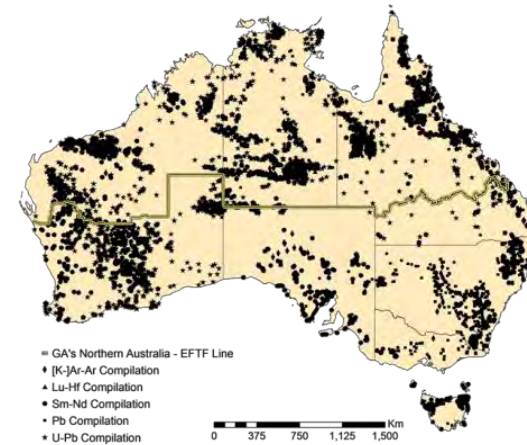


Champion 2013

# Isotopic architecture: a new national atlas



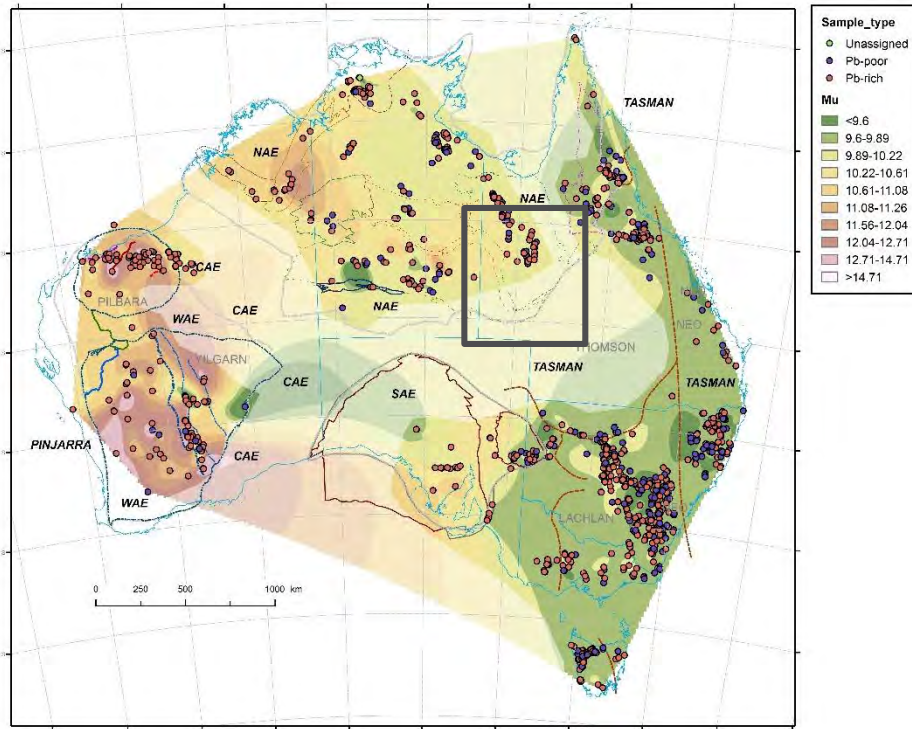
## National geochronology coverage



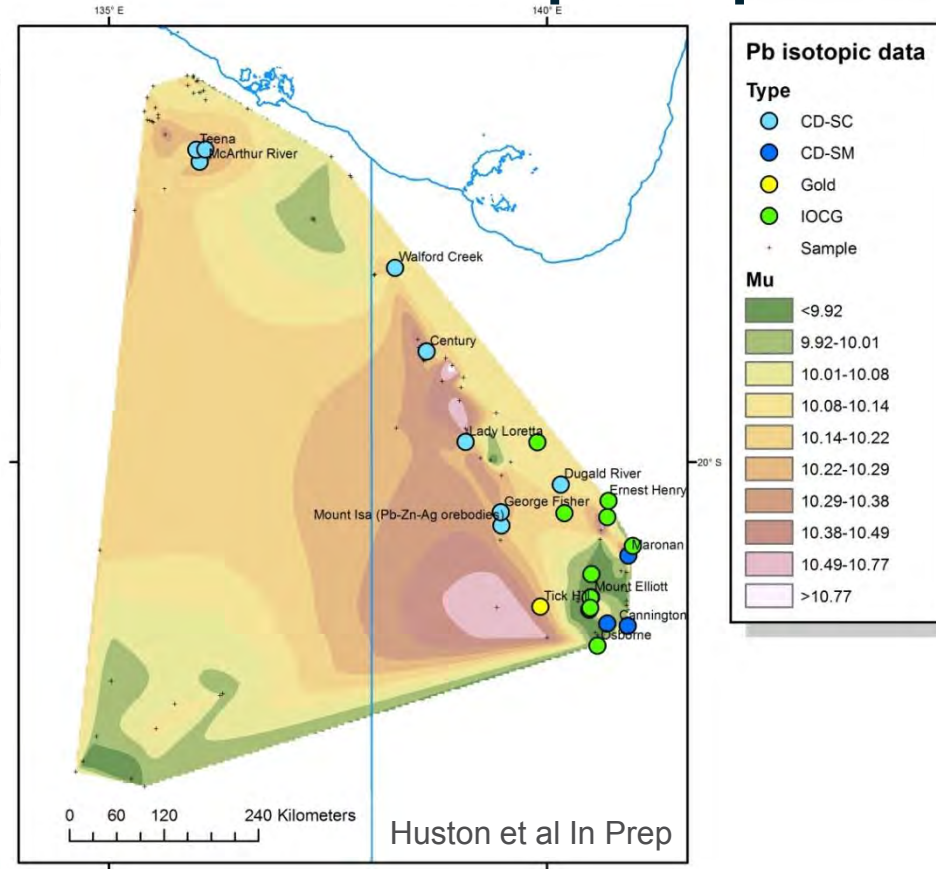
<http://www.ga.gov.au/eftf/minerals/naw/a/geochronology-and-isotopic-mapping>



# Isotopic architecture: a new national Pb isotope map



Huston et al 2019, GA record 2019/001



Huston et al In Prep

# Mantle architecture and metal fertility

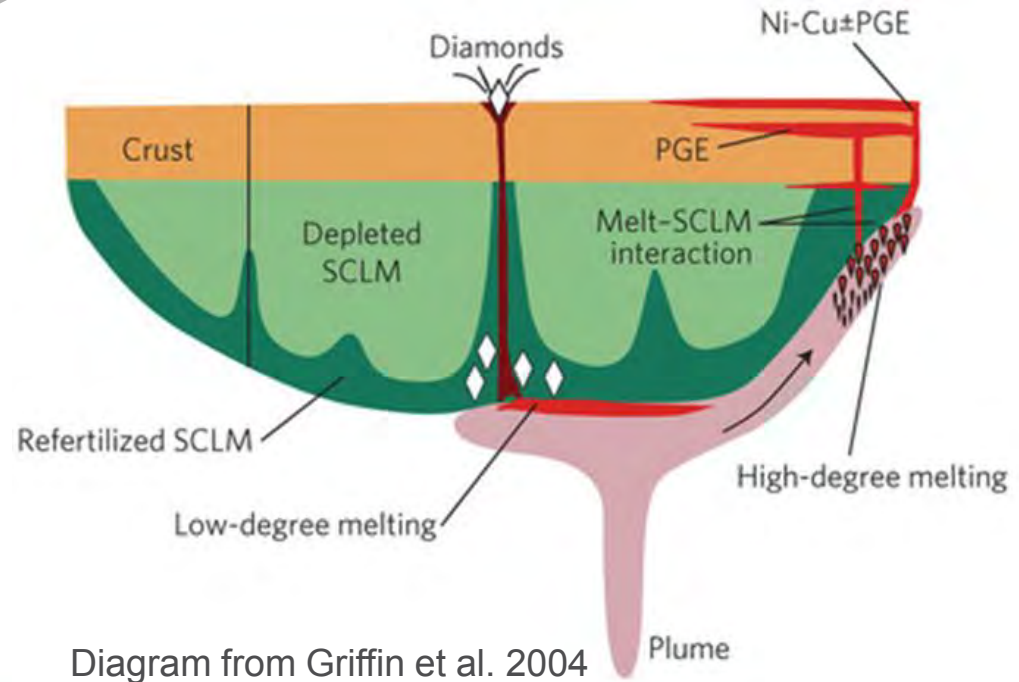
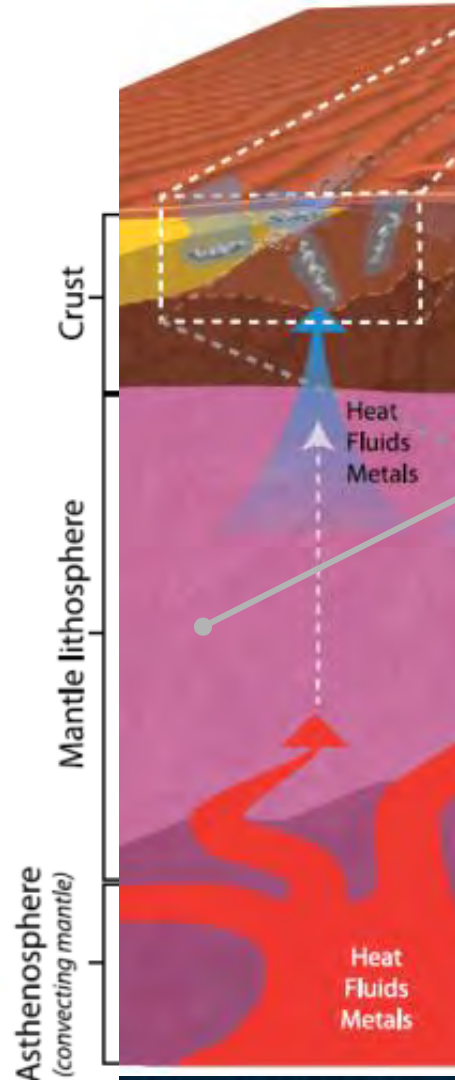
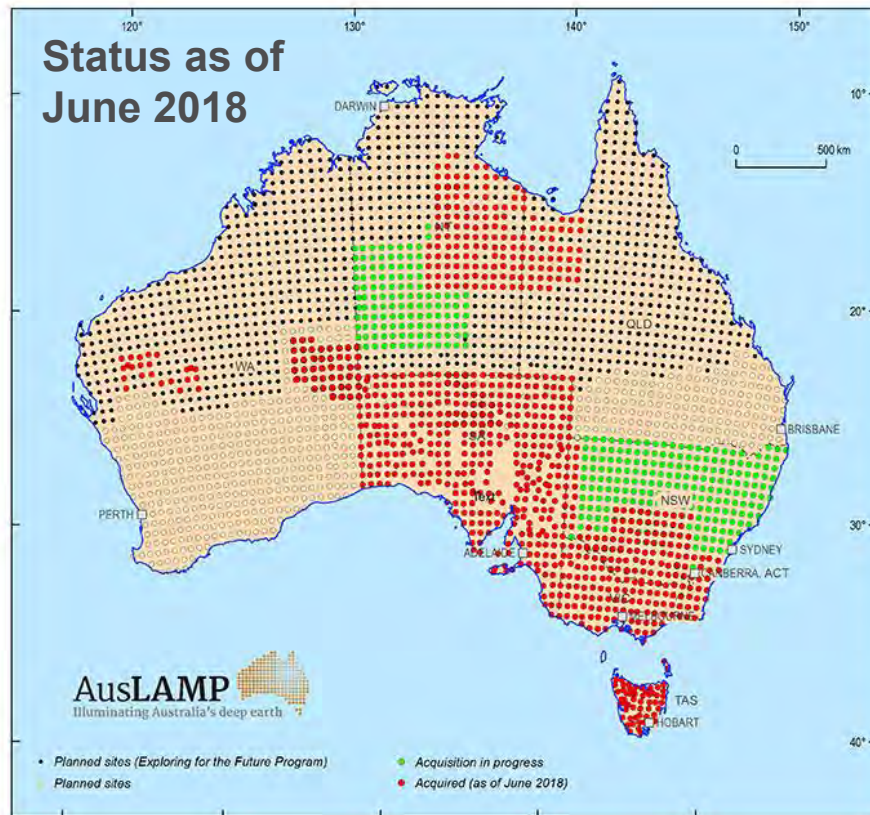


Diagram from Griffin et al. 2004

# AusLAMP: a national-scale survey in progress



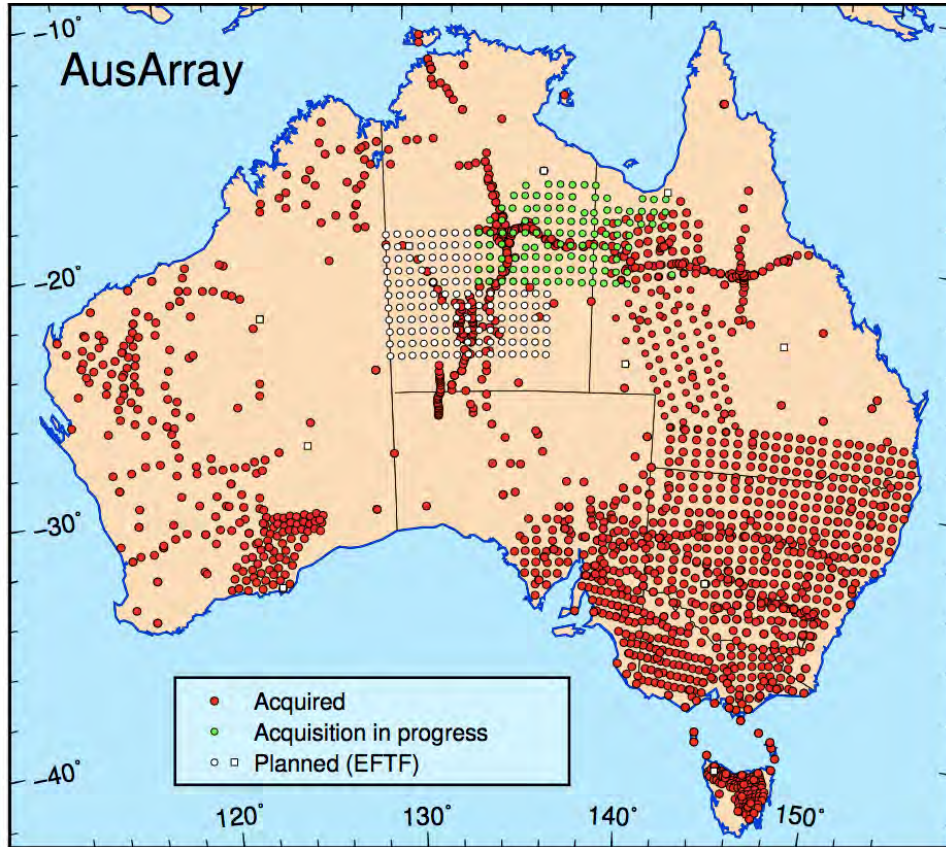
- Commenced late 2013; collaborative project with universities/State surveys
- Completed ~1000 of ~3000 sites, ~ 55 km station spacing
- Broad-scale; highlight areas for infill

GA acquisition programs:

- **Northern Australia (EFTF)**
- **New South Wales (GA + GSNSW)** fieldwork ongoing since 2016
- **Victoria (GA + GSVic)** – data released:  
<https://data.gov.au/dataset/australian-lithospheric-architecture-magnetotelluric-project-auslamp-victoria-data-release-repo>



# AusArray: passive seismic



- Collaborative program between government and academia
- Improve national 3D velocity models
- High resolution in areas covered by transportable array

GA contribution:

- Northern Australia under EFTF

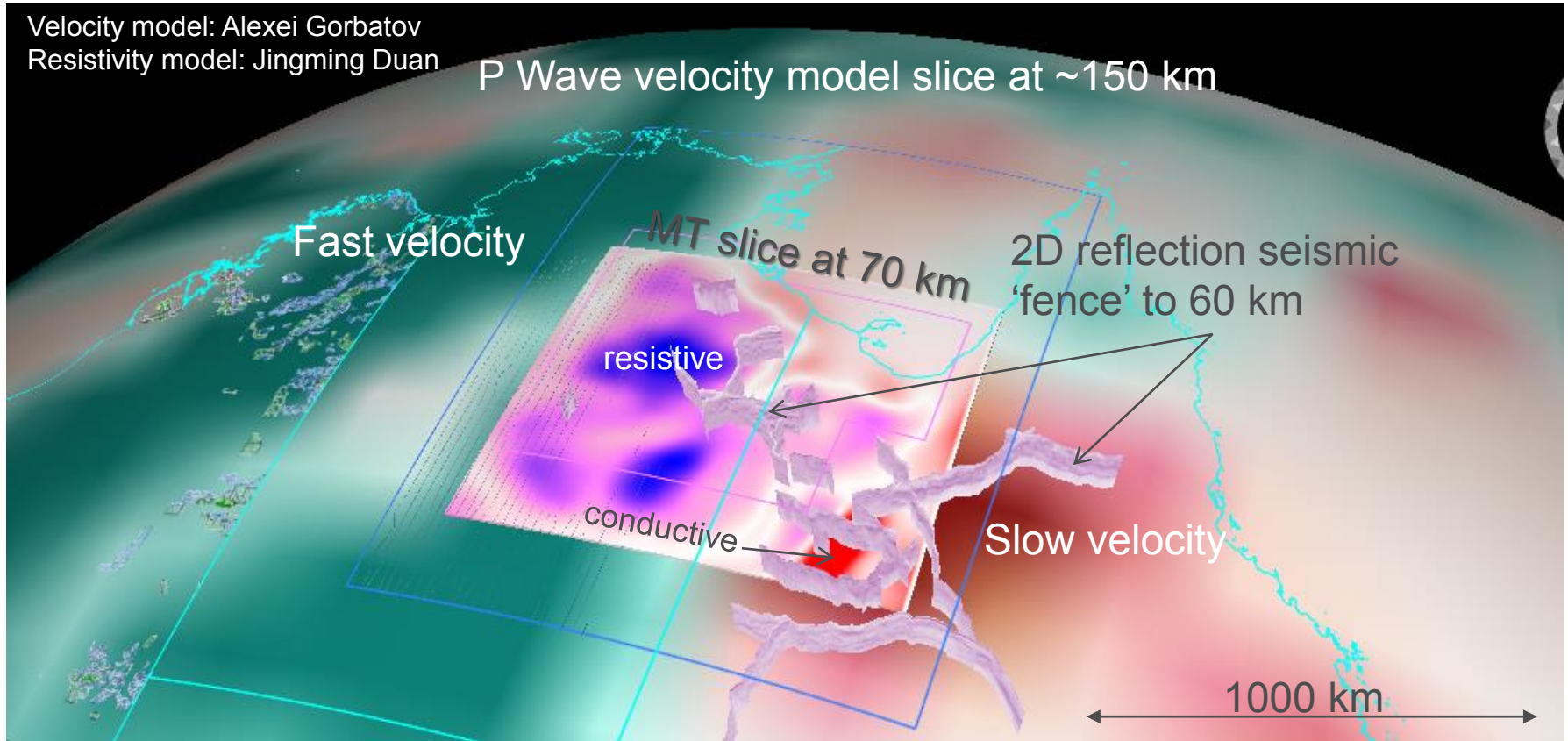
Alexei Gorbatov

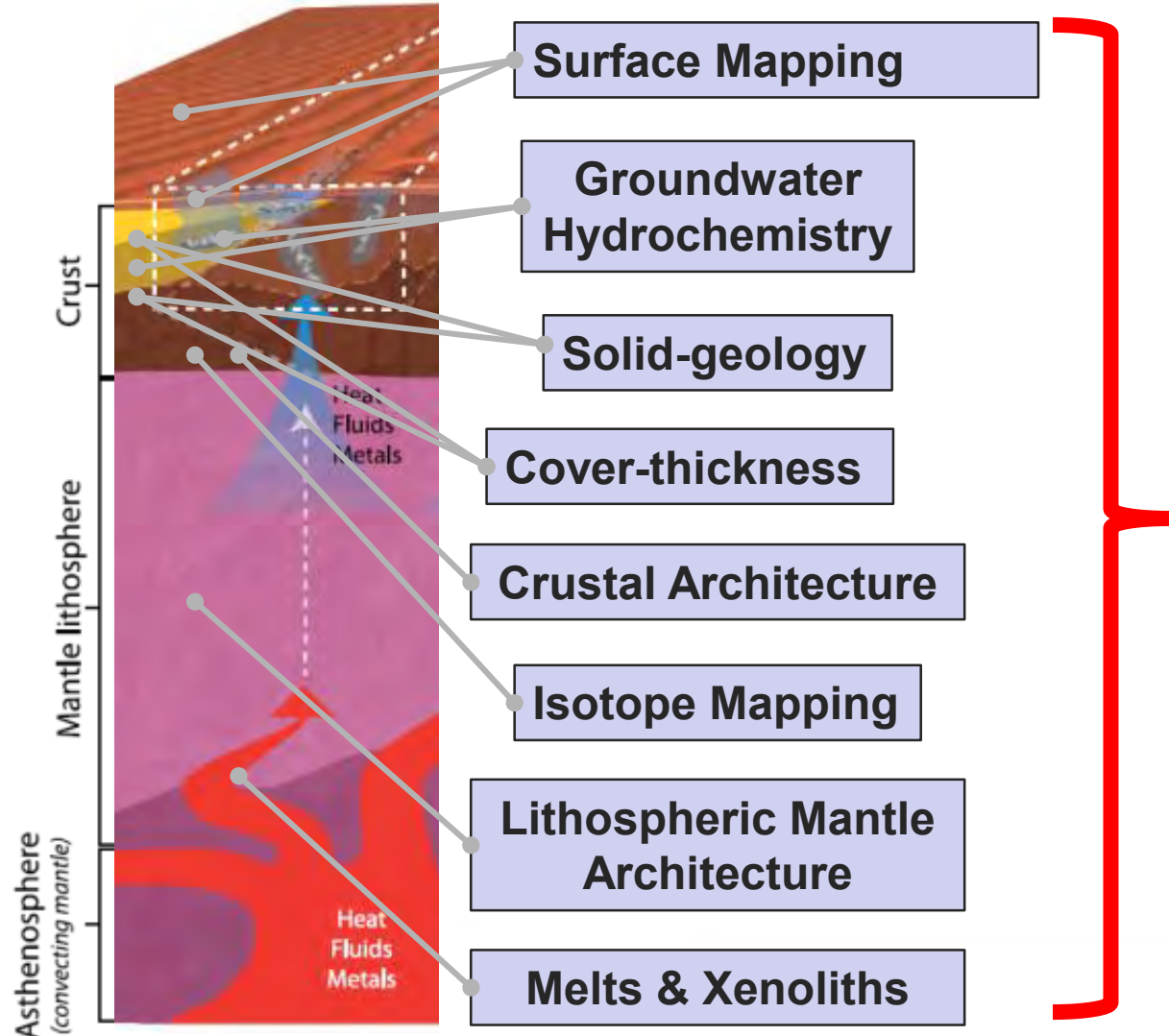
# Integrating seismic reflection, MT and velocity

Velocity model: Alexei Gorbatov

Resistivity model: Jingming Duan

P Wave velocity model slice at ~150 km

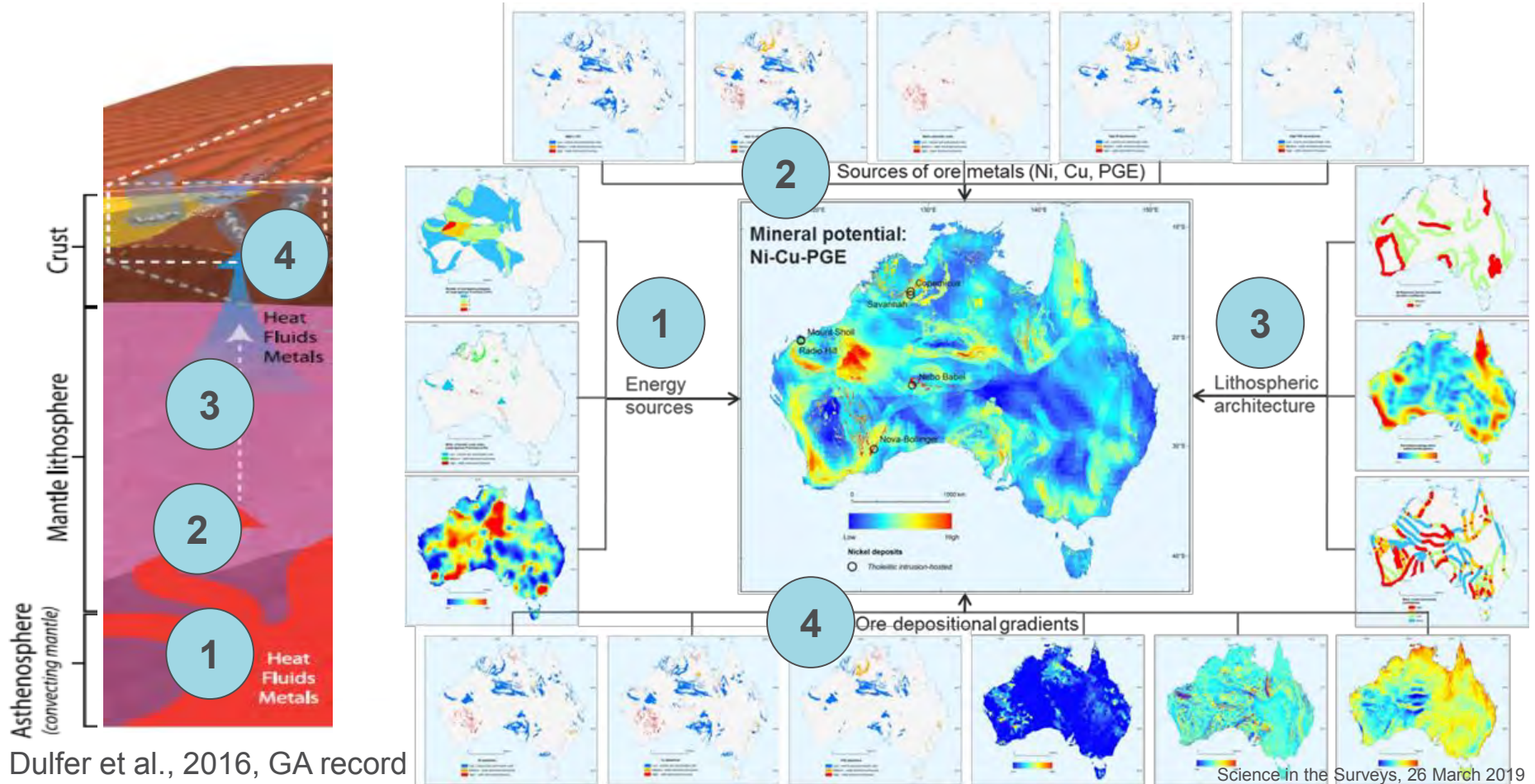




# Mineral Potential Mapping



# Bringing all together: national mineral potential mapping

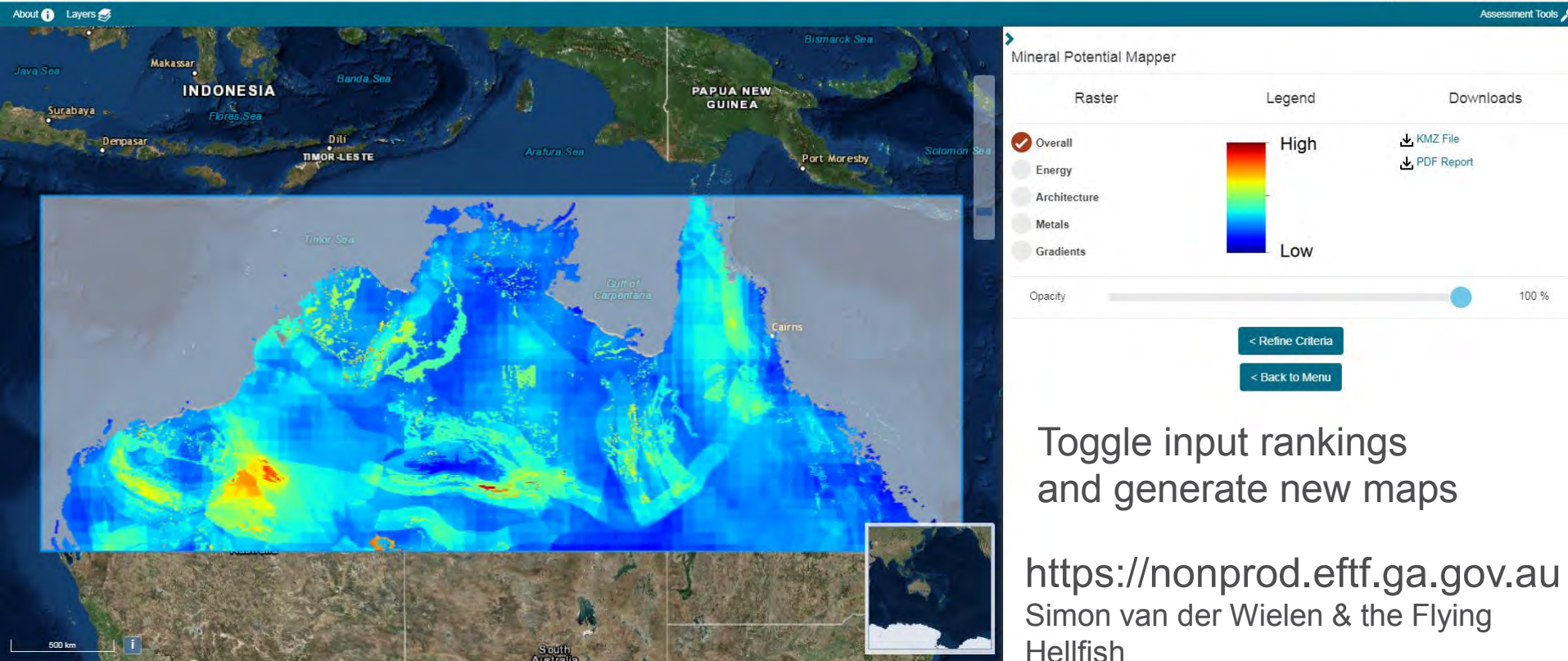


# New tools: mineral potential mapping on the fly



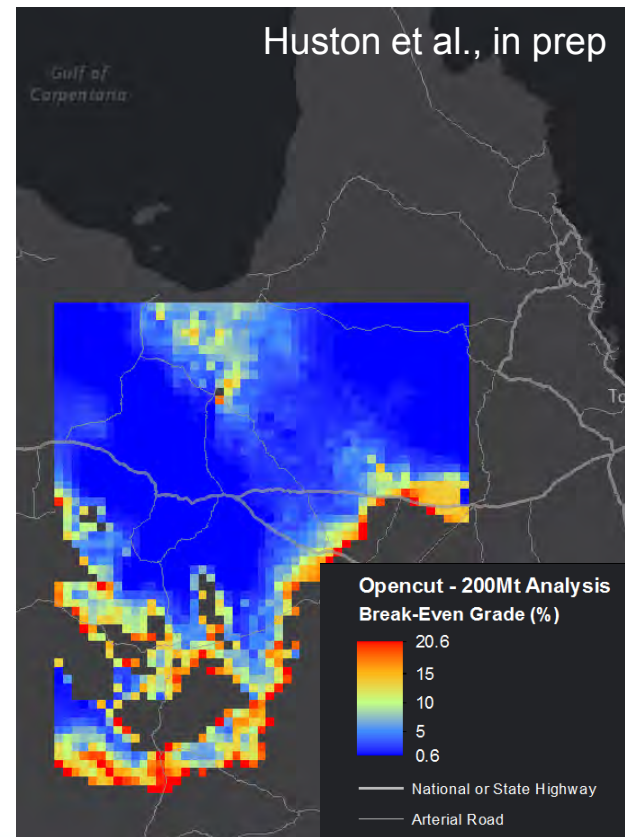
Australian Government  
Geoscience Australia

Exploring for the Future (Nonprod)



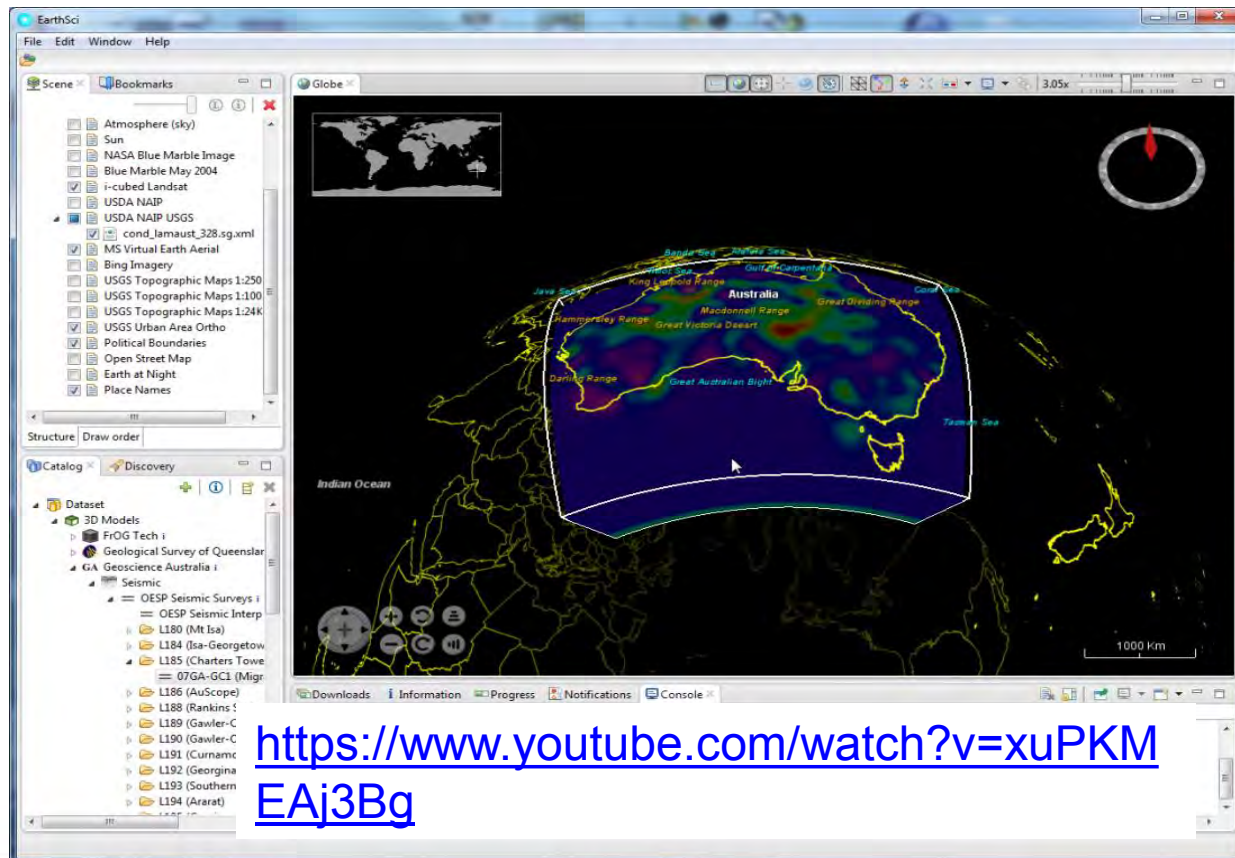


# New tools: economic and social impact decision support





# New tool: EarthSci to visualise, integrate and deliver



- GA-developed 2D and 3D visualisation tool
- supports integration & visualisation wide range data types
- runs on normal PCs & Macs with reasonable graphics card

<https://www.youtube.com/watch?v=xuPKMEAj3Bg>

[malcolm.nicoll@ga.gov.au](mailto:malcolm.nicoll@ga.gov.au)

# Take home message

- GA supports resource exploration through collection of national datasets in collaboration with state/territory surveys
- EFTF aims to unlock completely new areas for exploration
- Use a diverse set of geoscience datasets that sample a large range of lithospheric depths
- Integration using a mineral systems approach



# Acknowledgement





# Questions?





# GSNSW — delivering tools for mineral exploration in the 21st century

*John Greenfield*

*Science in the Surveys, Rutherford NSW, March 2019*

# ○ *Contents*

- 1. Unveiling the most powerful exploration tool for the 21st century*
- 2. What will change in the 21st century?*
- 3. What is the GSNSW solution?*
- 4. MinEx CRC in NSW*
- 5. Summary*



*Unveiling the most powerful  
exploration tool for the 21st century*

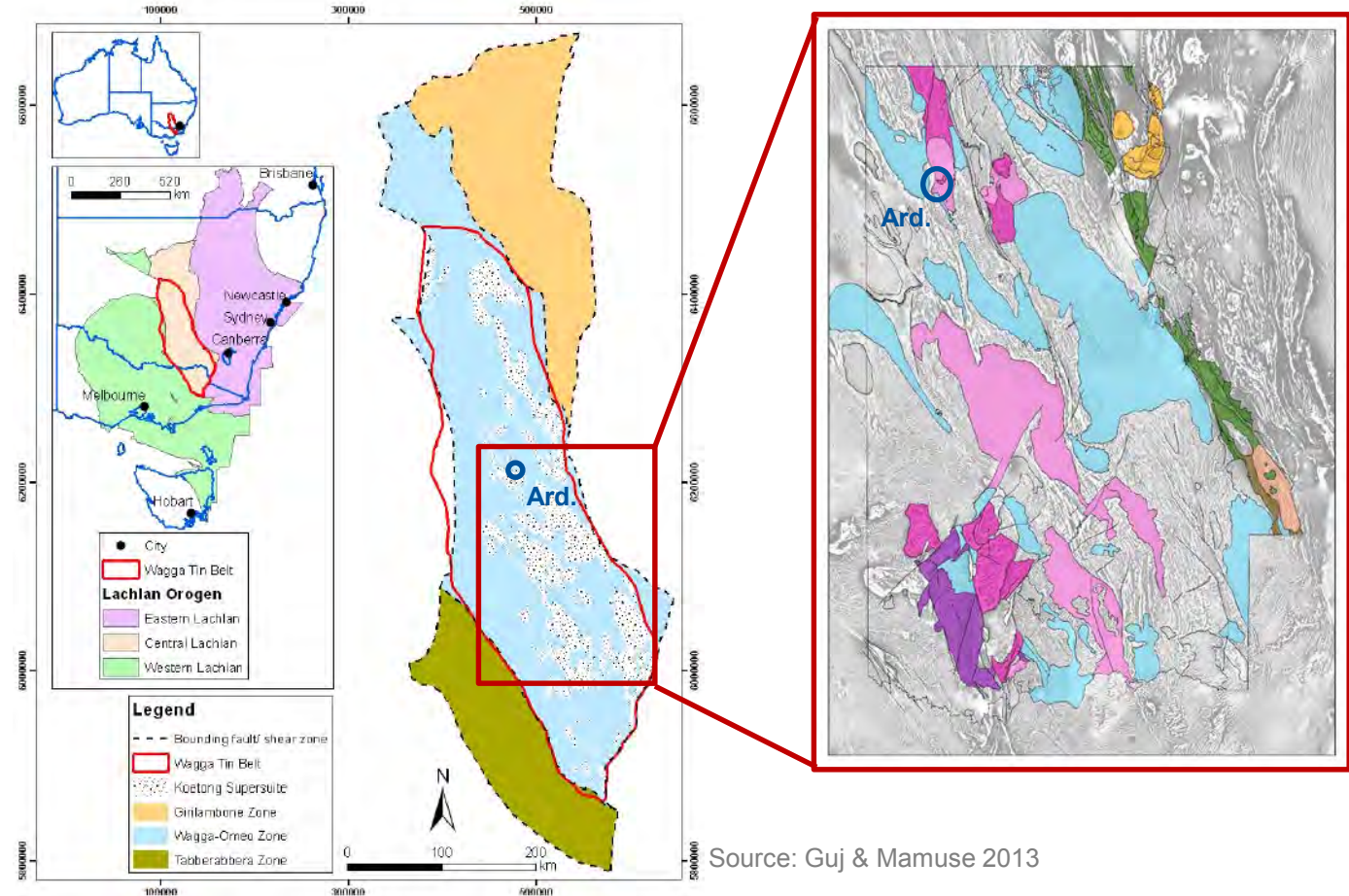
## • *'Boots on the ground' fieldwork*

- Basic geological field mapping and sampling will continue to be the foundation of GSNSW projects.
- Access to the field is getting more difficult.
- Therefore fieldwork must 'build on the shoulders of giants'.
- NSW Seamless Geology creates a 'land of the giants' that new fieldwork can build on.
- But: ensure geologists immerse themselves long enough in projects to make true insights and advance our knowledge.



## East Riverina mapping: zooming-in on tin mineralisation

- Project 2014–19 to improve 50 yr old mapping.
- Old theory was that tin-bearing granites were all Koetong Supersuite crystallising @ **~430 Ma**.
- New mapping and dating showed that mineralising granites @ **~412 Ma**.
- This has dramatically refined the exploration 'search-space' in the Wagga Tin Belt.





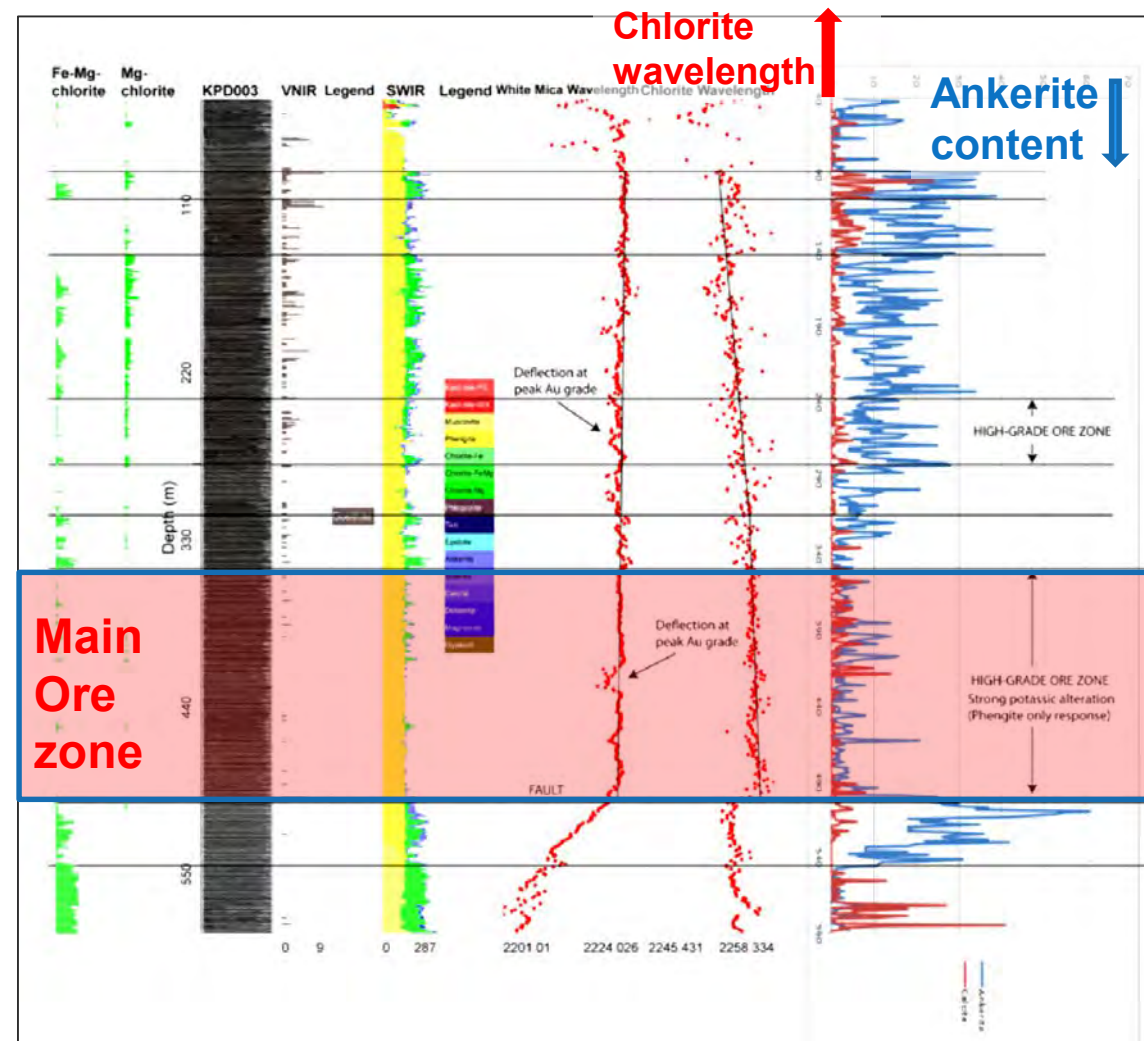
## Not just fieldwork: McPhillamys gold deposit

- Collaborative work with Regis Resources on the 2 Moz McPhillamys gold deposit near Orange.
- Core logging and petrographic work shows mineralisation to be clearly pre-deformational involving high heat flow.
- Alteration halo potassic>sericitic.
- Compares very well with HyLogger™ data.



## Not just fieldwork: hyperspectral mineralogy

- HyLogger™ data for >330 drillholes available free-of-charge.
- Accuracy of mineralogical interpretation constantly being refined.
- Corescan™ now owns the technology and is developing the next generation scanners.
- In this McPhillamy's example you can see chlorite wavelength and ankerite content as vectors to mineralisation.
- Industry can submit core for scanning at competitive rates.



*What will change in the 21st century?* ○



## • *Another turning point in the digital age?*

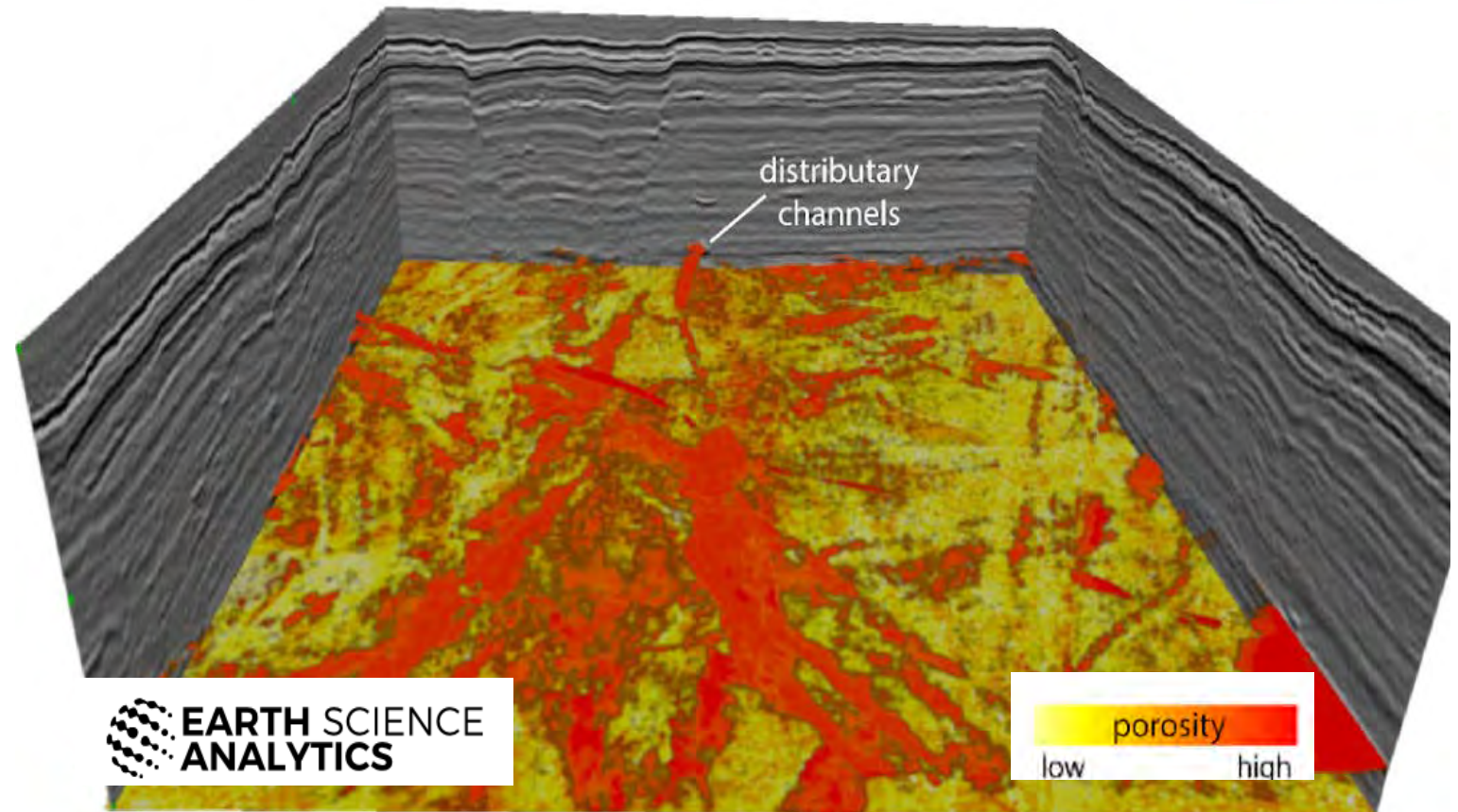
- It took Google's AI algorithm **AlphaZero** only four hours to 'learn' chess after being given the rules and playing itself.
- Looks at only 80,000 positions/second, compared to Stockfish's 70 million positions/second.
- 100-game match with 28 wins, 72 draws, and zero losses.



**Machines figuring out  
rules that humans can't  
detect.**

# • *The future is already here: AI-based exploration companies*

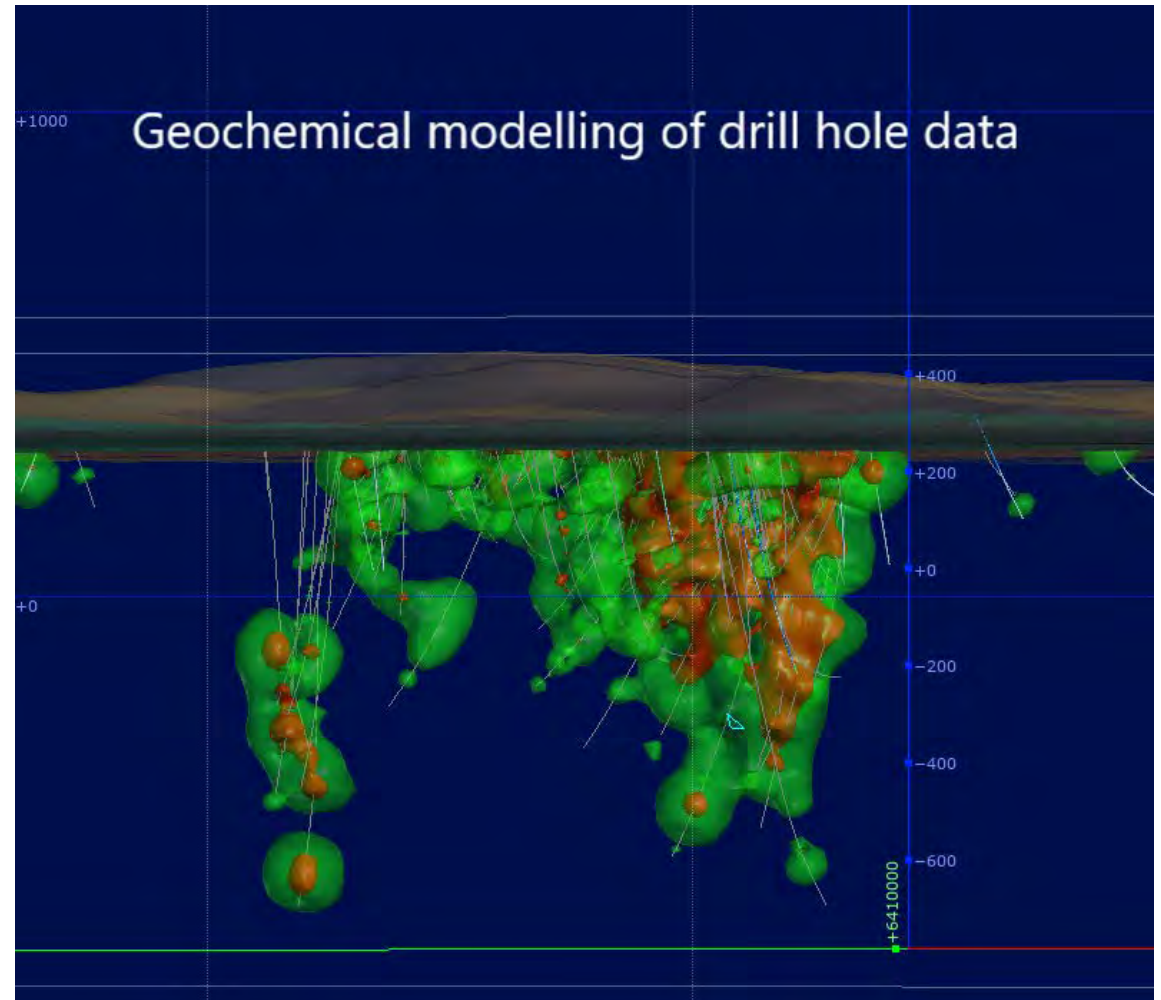
- Earth AI
- Earth Science Analytics



**Machines figuring out rules that humans can't detect.**

# Mineral exploration is an undercover operation

- Exploration is not chess.
- Mineral systems are complex, multivariate problems, with many of the variables impossible to directly measure, or even reliably estimate.
- There is not enough undercover data collected in most areas for AI to make a real difference YET.
- For the next 20–30 years, exploration will still require new data to be acquired and organised into relational databases.
- After that – it's data lakes, AI, and all bets are off!

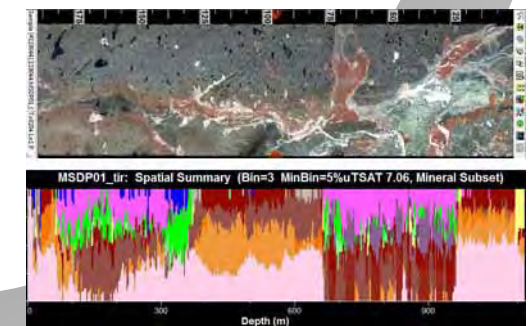
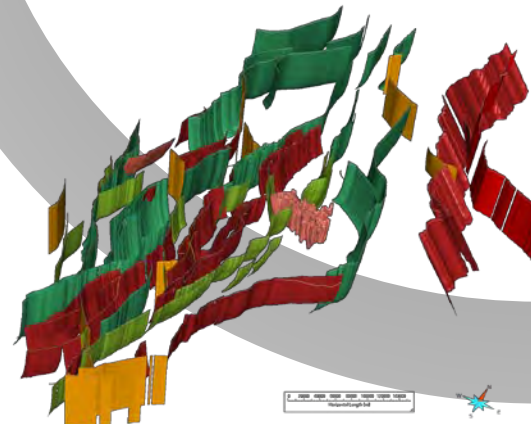
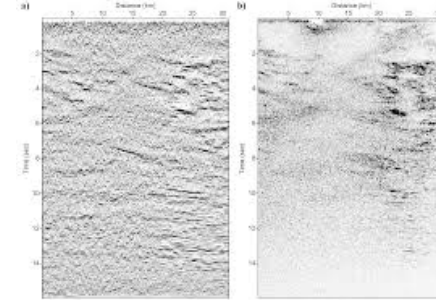
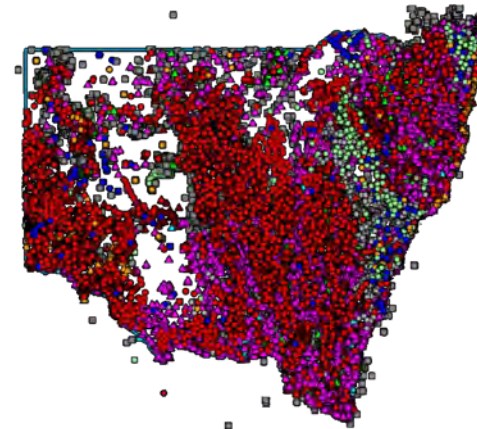
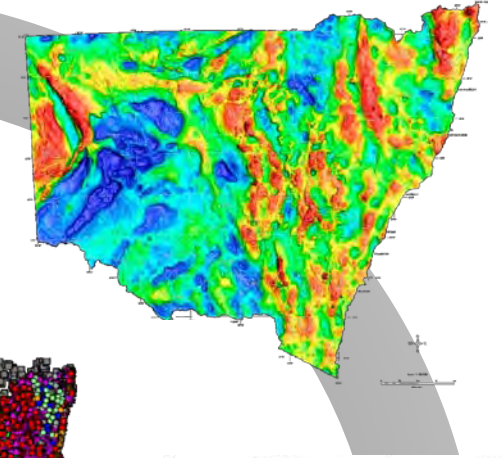
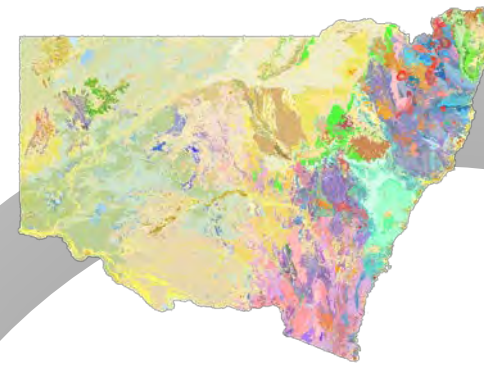




# *What is the GSNSW solution?*

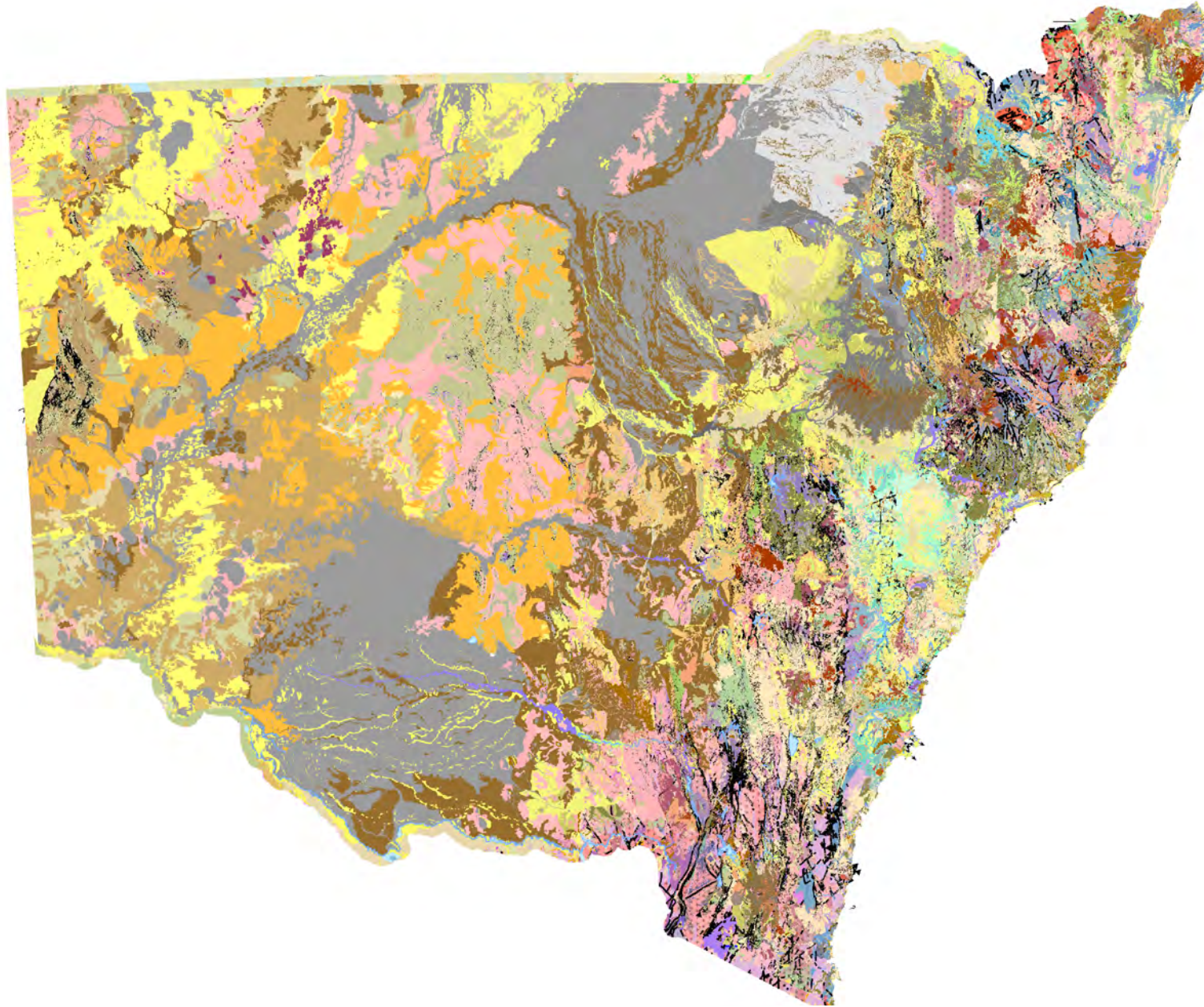
# GSNSW – one geology model

- All geological data consistent, reliable and best-available.
- Maps, point data, geophysics, 3D models, mineral potential models.
- Explanatory notes, GS reports.
- Exploration data: drillholes, logs, assays, HyLogger™ scans.
- By 2021, users will access a single data framework that will be continually updated.





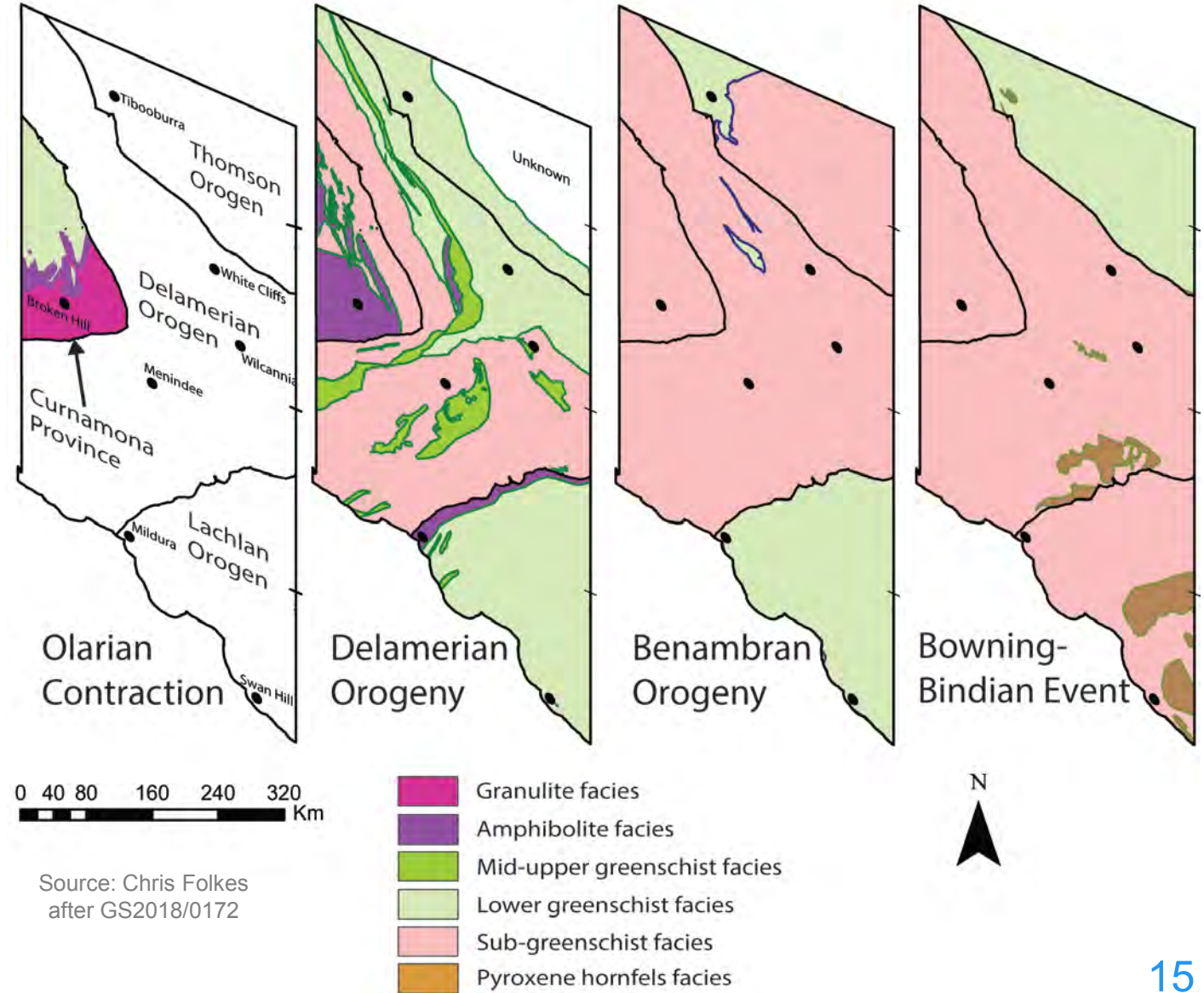
# *Seamless Geology: most complex digital map ever released*

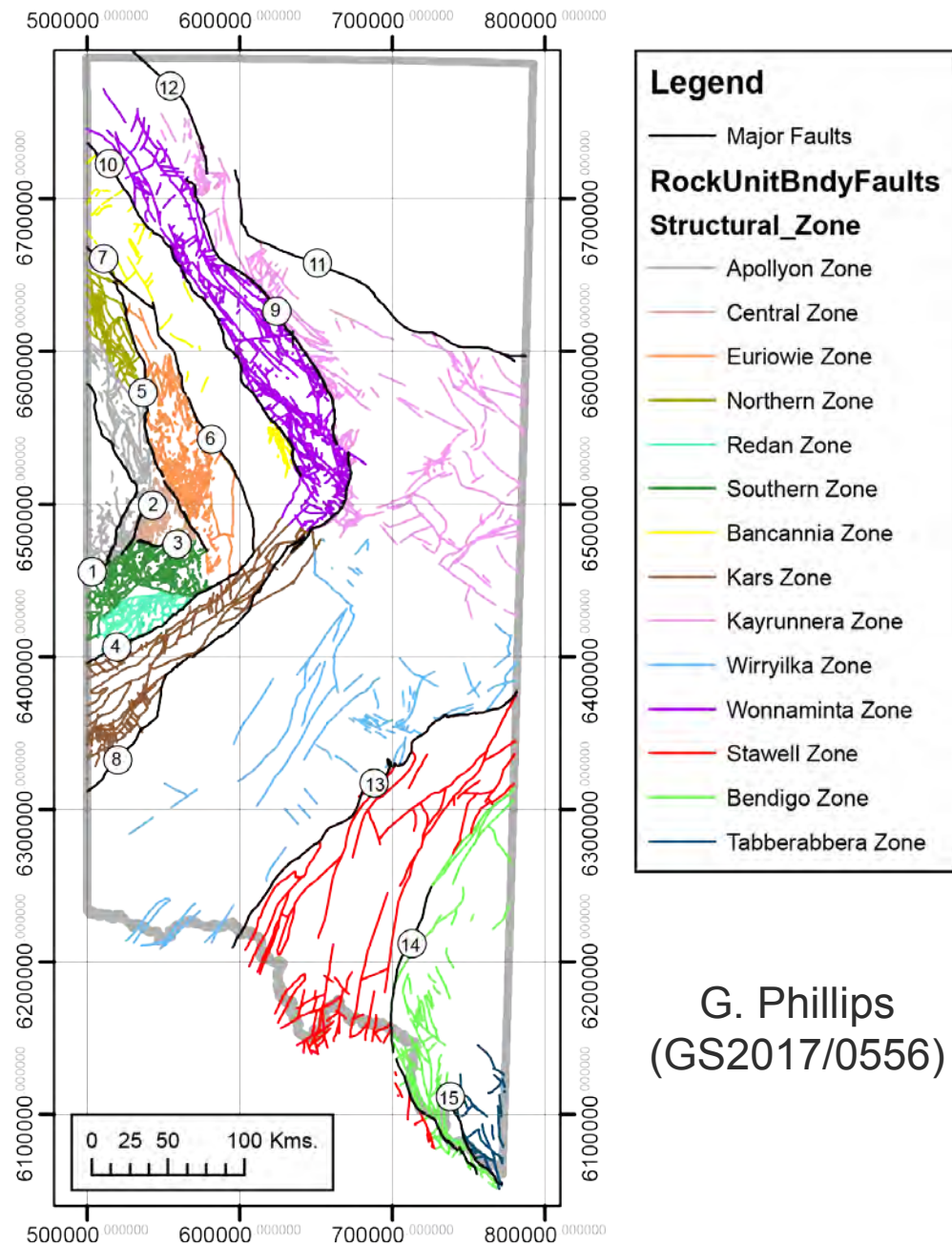




## Metamorphic maps

- Metamorphic facies and isograds mapped by geodynamic event.
- Zones 54, 56 complete and preliminary Zone 55E complete.



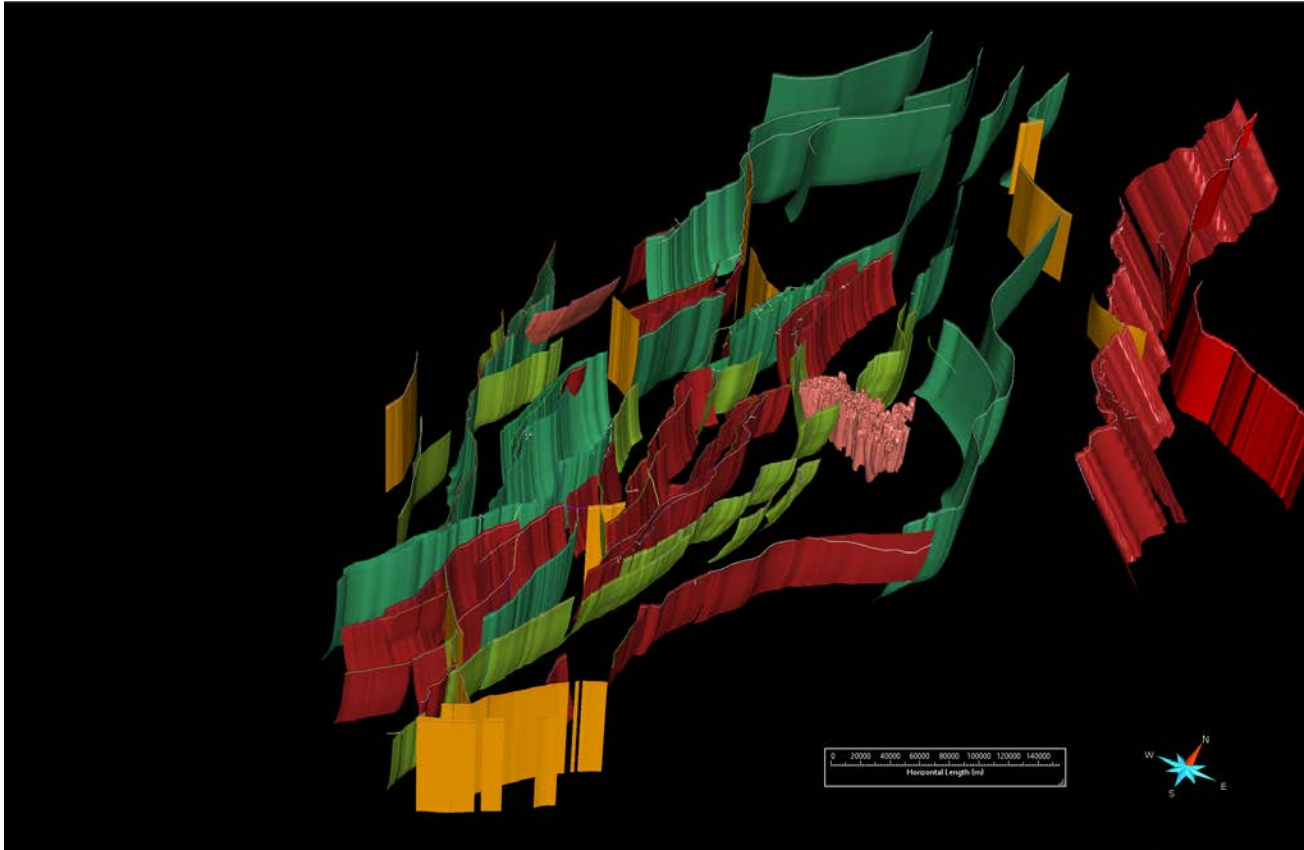


## Fault attribution

- Every fault attributed with:
  - geometry
  - order
  - parent
  - kinematics by geodynamic event.
- Zones 54, 56 and preliminary Zone 55E complete.

Sub System	Province	Structural features	Relevance for mineral prospectivity
Olary Detachment	Curnamona	Faults located at the contact between the Broken Hill and Sundown groups.	Extensional detachment between the Broken Hill and Sundown Group is also a major redox boundary and potential site for Pb-Zn-Ag mineralisation (Gibson & Nutman, 2004).
Cobham Kink Zone	Curnamona & Delamerian	NE-SW striking faults located in the Cobham Kink Zone.	NE-SW striking zone of crustal weakness that may have favoured repeated igneous intrusions (Gilmore et al., 2007).
Arrowsmith	Delamerian	Dominantly NW-SE striking faults spatially associated with the Mt. Arrowsmith Volcanics.	Faults that are spatially related to the Neoproterozoic (c. 585 Ma) mafic igneous Mount Arrowsmith Volcanics. These igneous rocks and associated faults may host magmatic nickel-sulfide and remobilised copper (Gilmore et al., 2007).
Larapintine	Delamerian	Basin bounding faults associated with the formation of post Delamerian basins.	Post-Delamerian basins including the Nuntherungie and Kayrunnera basins may contain orogenic gold.
Grasmere Knee Zone	Delamerian	Faults located in the Grasmere Knee Zone.	Zone of higher-strain that may host structurally modified and remobilised VMS/Besshi Cu, Pb, Au and Ag deposits.

# Integration of seamless and 3D geology

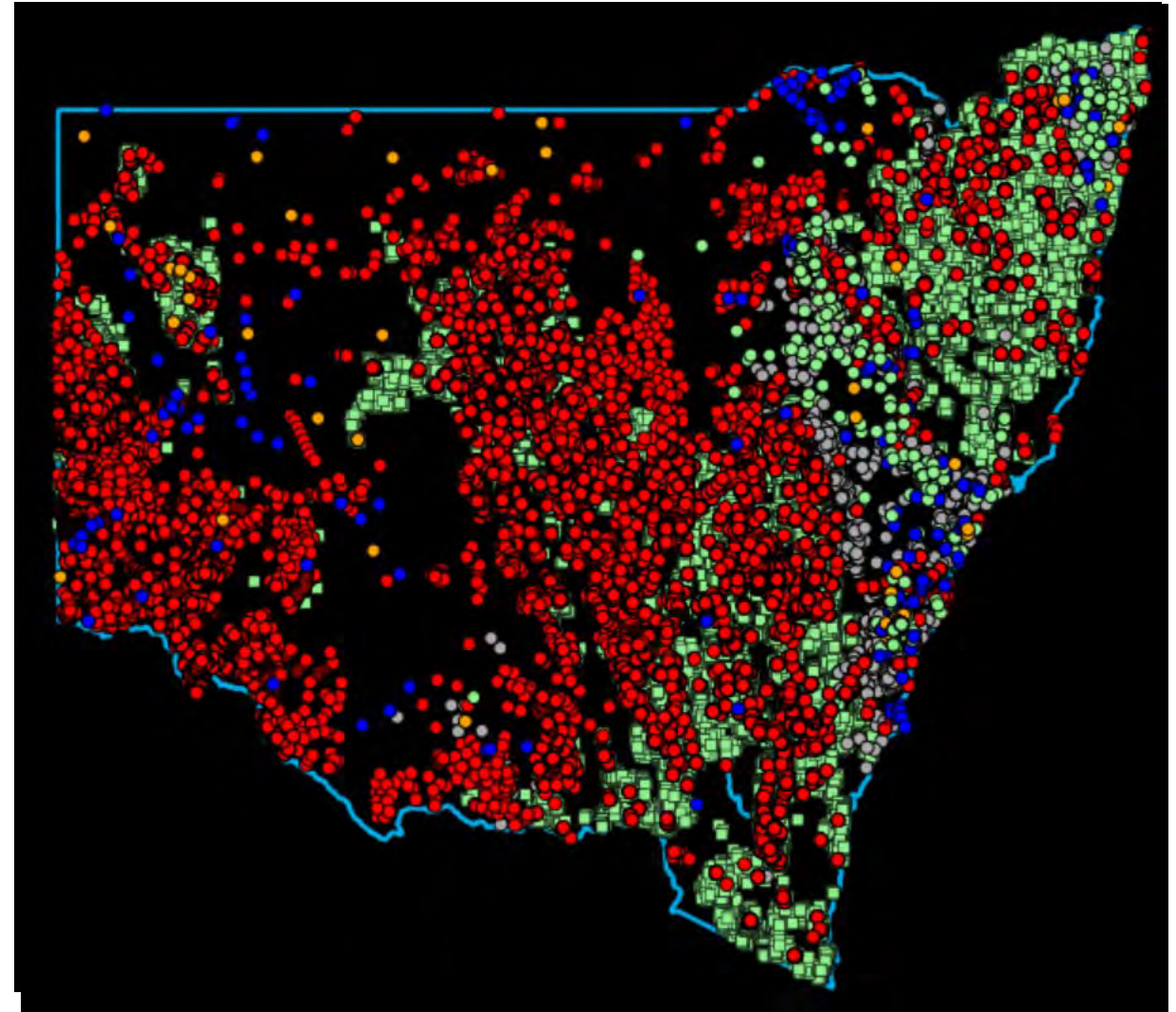


- Surface mapping, drillhole information, 2D cross-sections and seamless interpretation used to constrain 3D models.
- 3D models are then integrated with the Seamless Geology to improve it.
- This ensures a single geological model of NSW that is internally consistent in 2D and 3D.



## • *Sunset Clause on Company Data*

- GSNSW stores a vast collection of drillhole logs, geochemistry, and geophysical data extracted from reports.
- In June 2021 confidential company reports and data that were submitted  $\geq 5$  years before June 2016 will be released.
- By release date, data will have undergone QA/QC and be relatable to GSNSW coding.



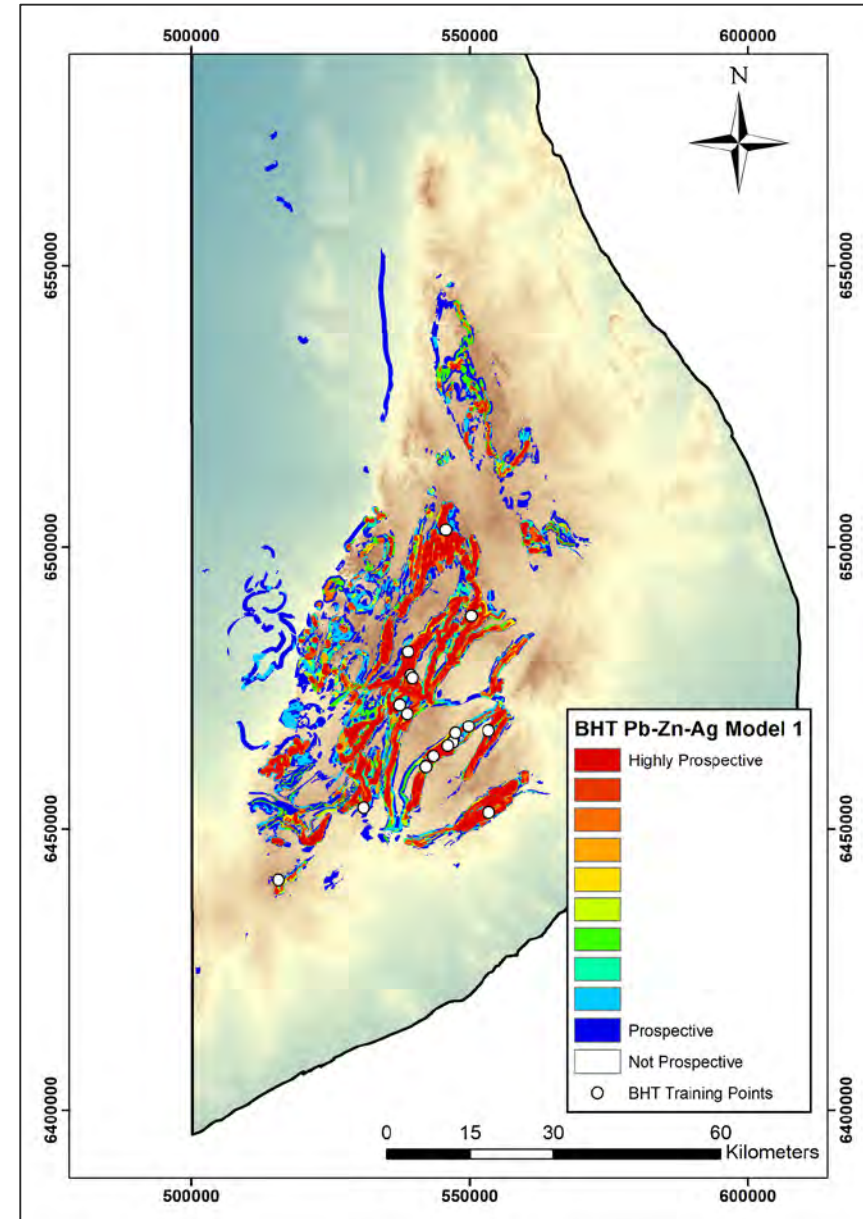
## Broken Hill-type mineral potential

- With Kenex Pty Ltd, GSNSW creating mineral potential maps for all major mineral systems in NSW.
- Mostly using weights of evidence technique.
- For land use planning purposes.

### Broken Hill-type:

- efficiency of classification = 99.1%
- all training points are in prospective area
- 15 of 17 training points fall in highly prospective area.

**However – not useful for undercover exploration!**



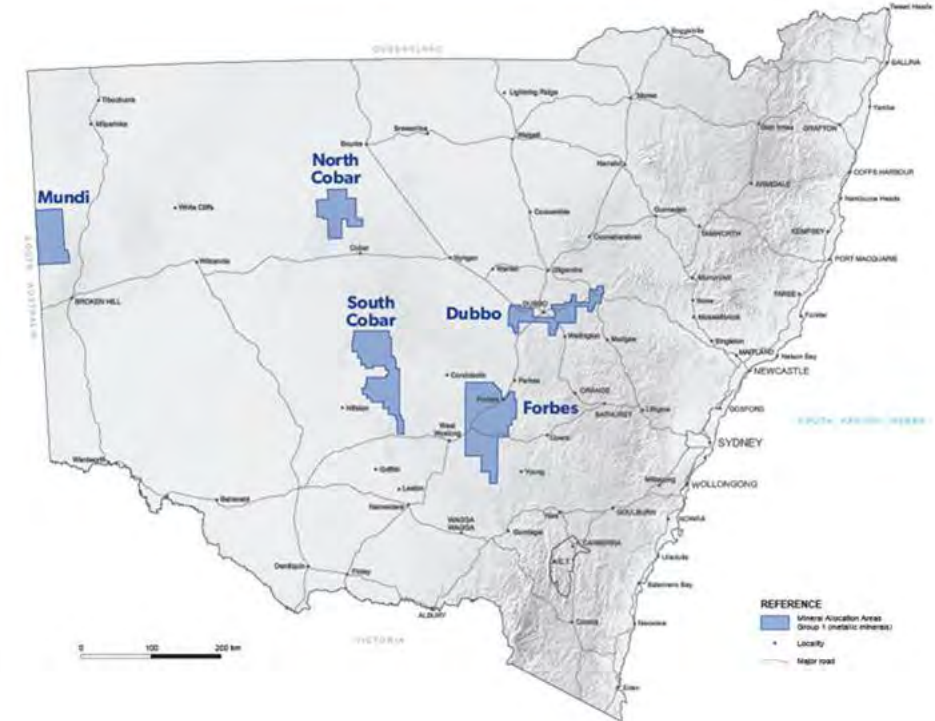
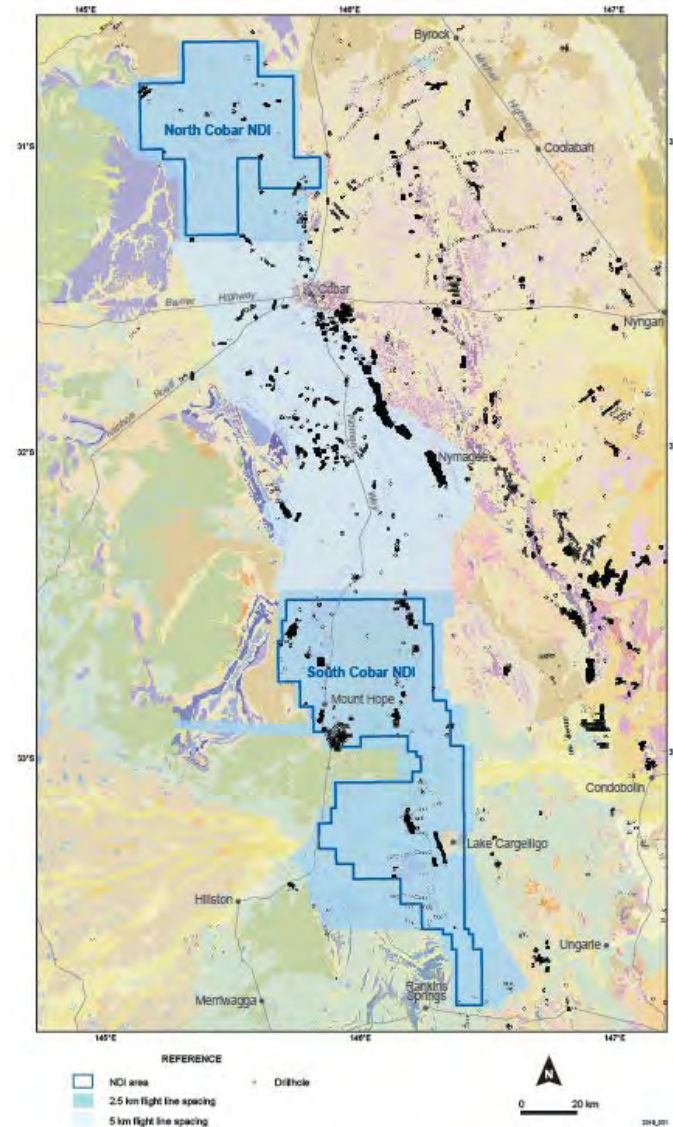
# *MinEx CRC in NSW*



# MinEx CRC: improving our undercover knowledge

## The world's largest mineral exploration collaboration

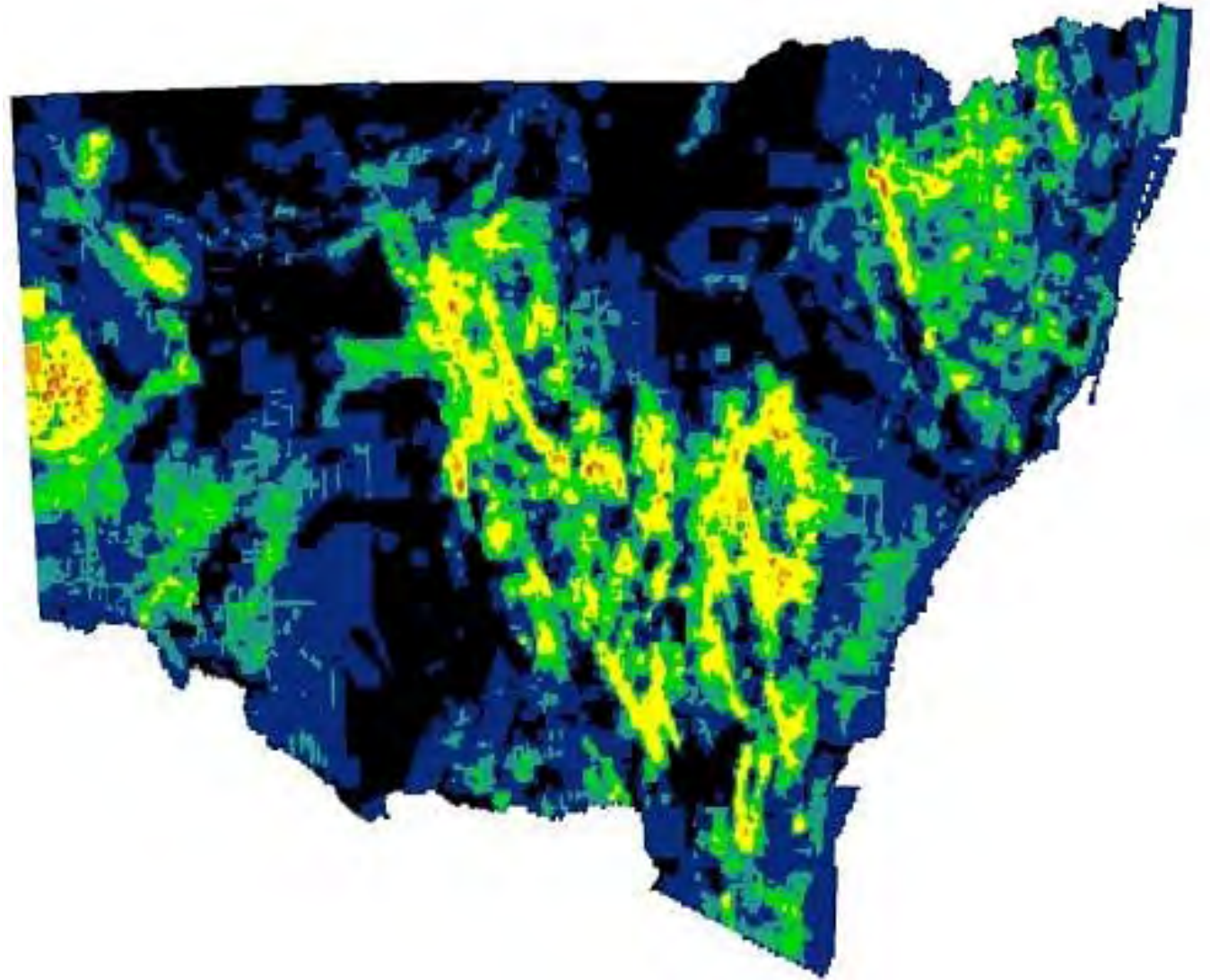
- \$218m over 10 years (1 July 2018 to 30 June 2028).
- \$16m investment by GSNSW into five uncover extensions of known mineralised terranes.
- Geophysics, geochemistry, drilling, 3D modelling, mineral potential undercover.
- Baseline data undercover.



# *Summary* ○

## Summary

- Field-based knowledge is still the heart and soul of GSNSW service.
- By 2021 all GSNSW data will be delivered through a single 3D geological framework that will be updated continually.
- GSNSW will leverage MinEx CRC research and technologies to fast-track our knowledge of the subsurface geology in five key areas of the state as a springboard into statewide mapping of basement under cover.
- By 2050 we'll all be using AI assistants for exploration so the subsurface data better be good!







**Dr John Greenfield**

[john.greenfield@planning.nsw.gov.au](mailto:john.greenfield@planning.nsw.gov.au)



DISCOVER EARTH'S SECRETS

**HUNTER VALLEY, NSW**

26 March 2019  
9:00–17:15

Club Maitland City  
Diamond Room  
14 Arthur St  
Rutherford NSW 2320

**AUSTRALIA MINERALS**  
REALISE THE OPPORTUNITY



**SCIENCE IN THE SURVEYS 2019**

# The Southeast Lachlan Crustal Transect –

New deep seismic reflection data acquisition  
in eastern Victoria and SE NSW

Ross Cayley.  
Senior Geologist

**GEOLOGICAL  
SURVEY OF VICTORIA**

**March 2019**

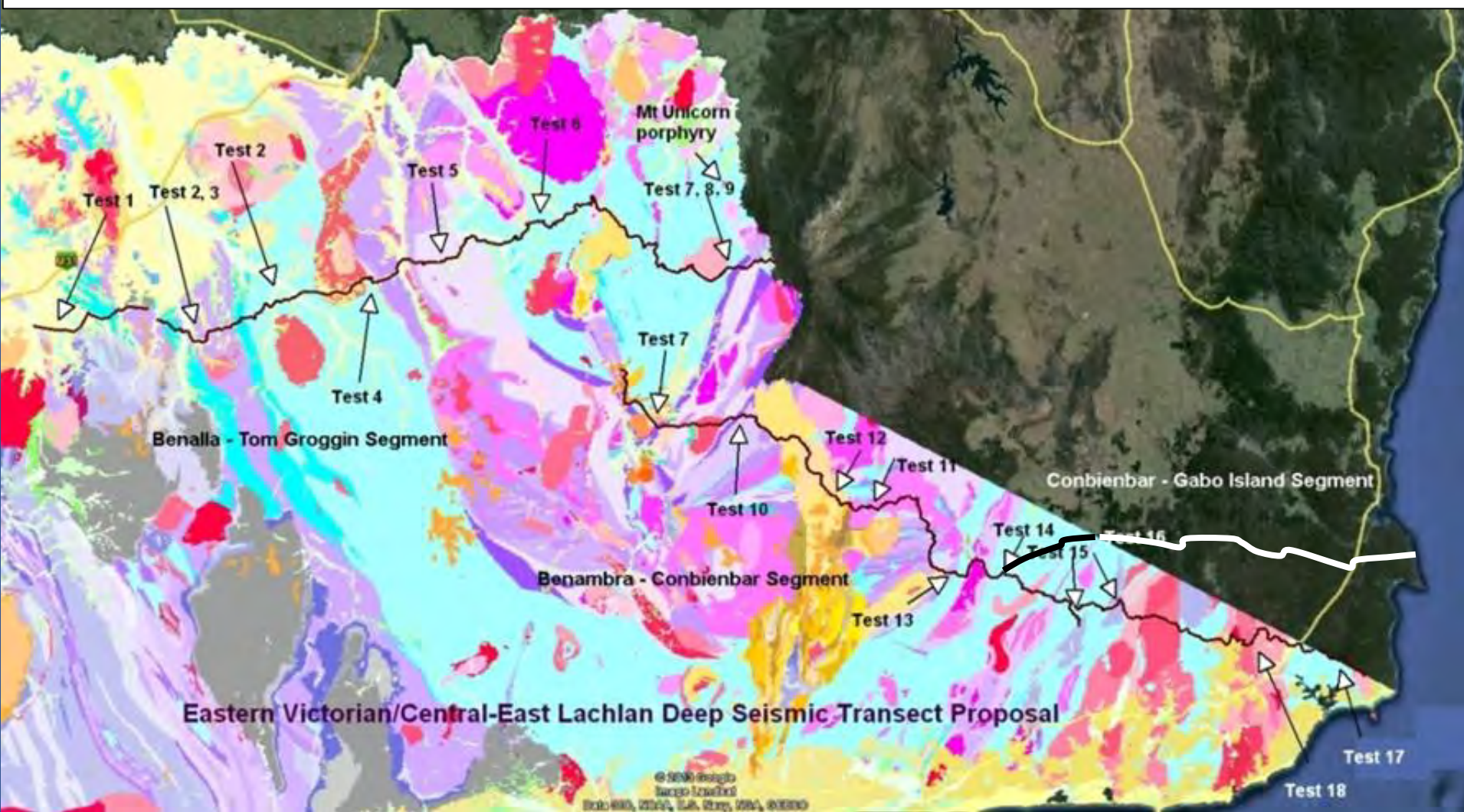
Edited version for optimal .pdf presentation

# Talk Outline

- A deep seismic reflection transect in eastern Victoria.
- Why?
- Where?
- Logistics
- Acquisition
- Next steps



The original project proposal in 2013 – 18 science questions to test a new geodynamic model (still!) in development – the Lachlan Orocline model.. Originally confined to Victoria, NSW joined as a project partner in 2017....



# Its a team effort.....



**Australian Government**  
**Geoscience Australia**



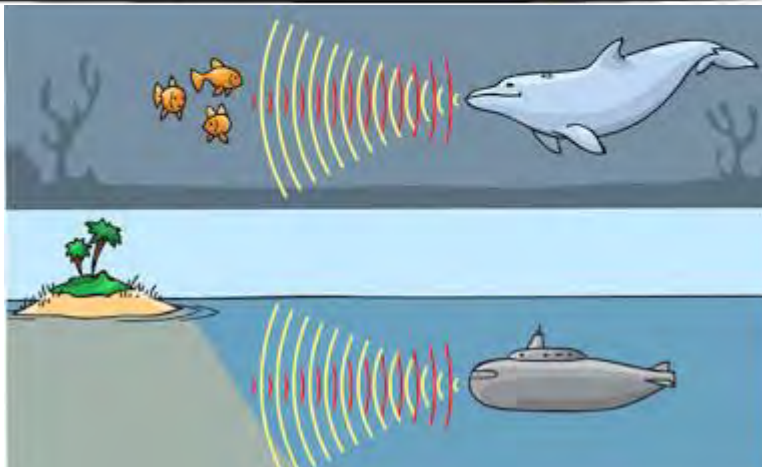
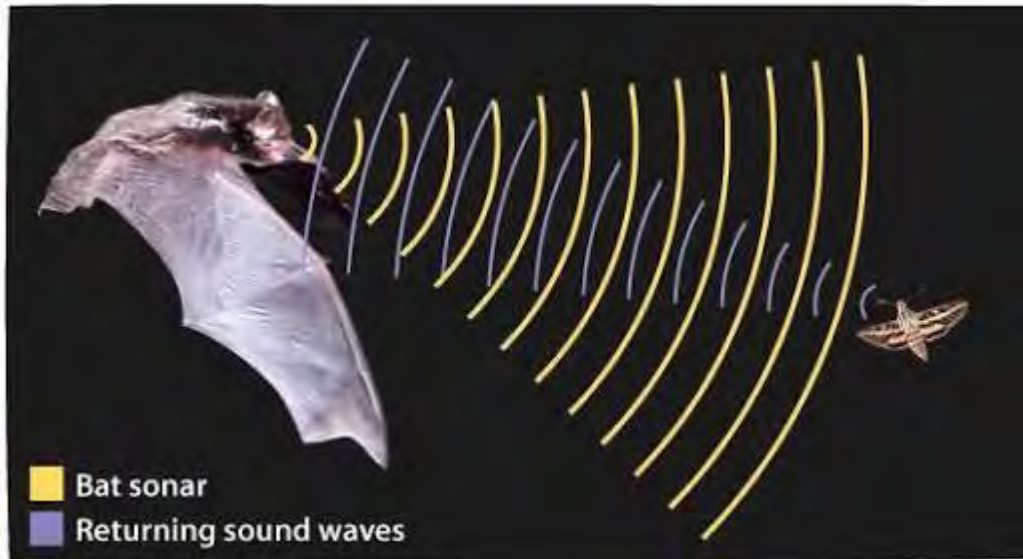
**AuScope**

# Talk Outline

- A deep seismic reflection transect in eastern Victoria.
- **Why?**
- Where?
- Logistics
- Acquisition
- Next steps



# Seismic reflection – some basics



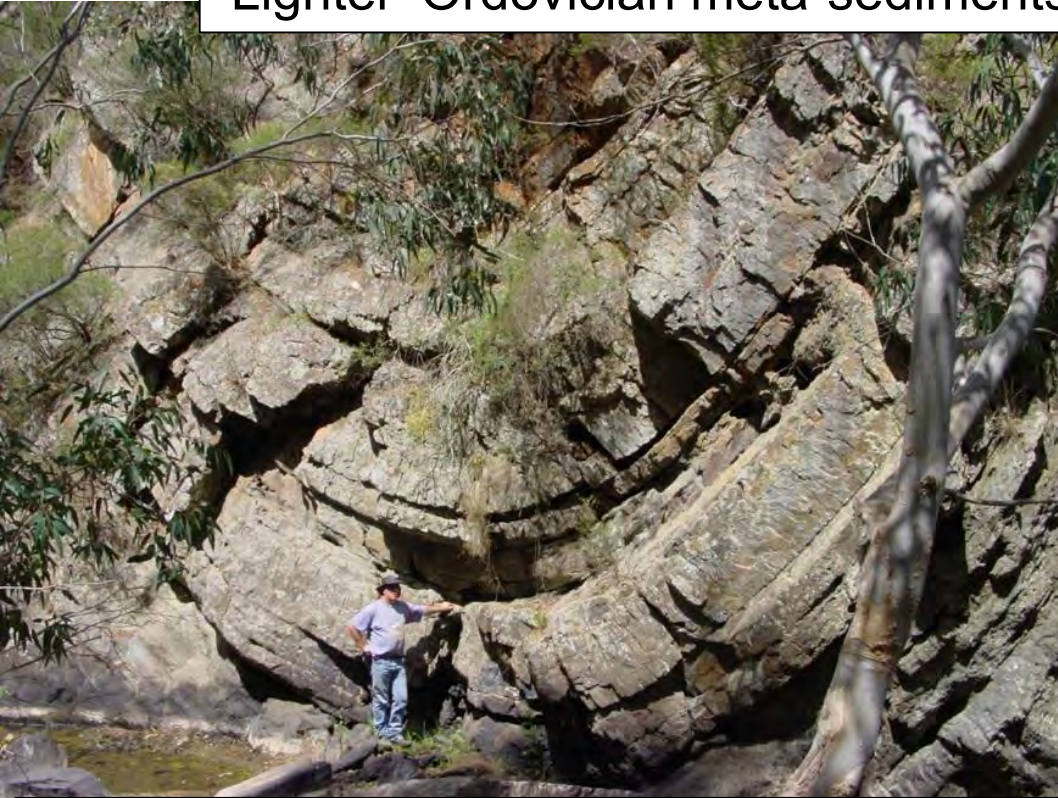
Acoustic sounding to gain an understanding of the surrounds is a very widely used technique.. in nature, and in science



# Why does seismic work for rocks?

**Because there are lots of different kinds...**

Dense Cambrian metabasalt north of Heathcote at right.  
'Lighter' Ordovician meta-sediments south of Redesdale at left



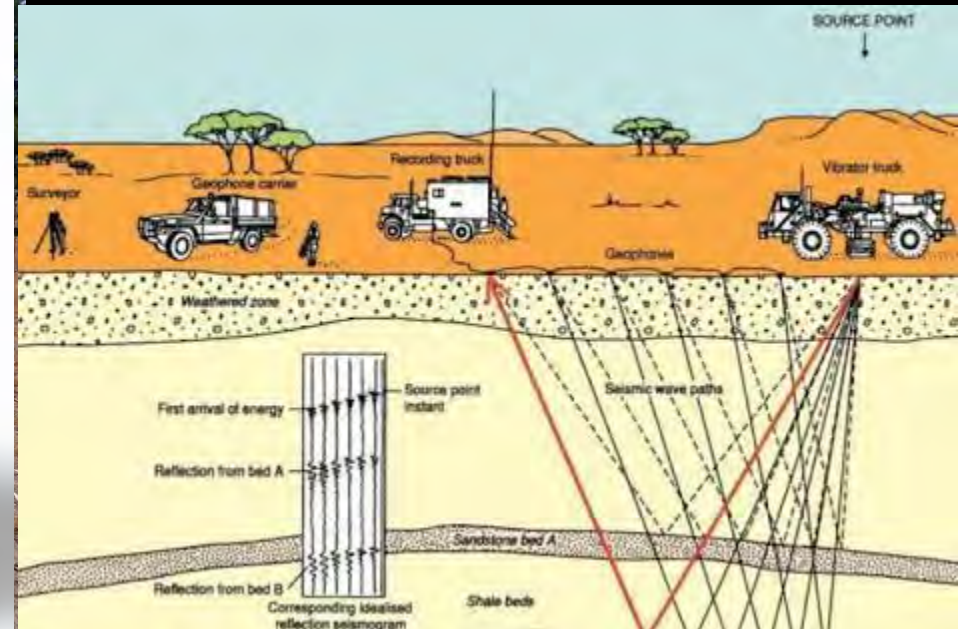
Denser rocks transmit sound energy faster than less-dense rocks.  
Reflections and refractions of sound energy occur at rock-interfaces



The process can be scaled to investigate different depths. We are interested in whole-of-crust (ie 40-50km deep), so use three big (30 tonne) trucks operating in concert to deliver as much energy as possible.



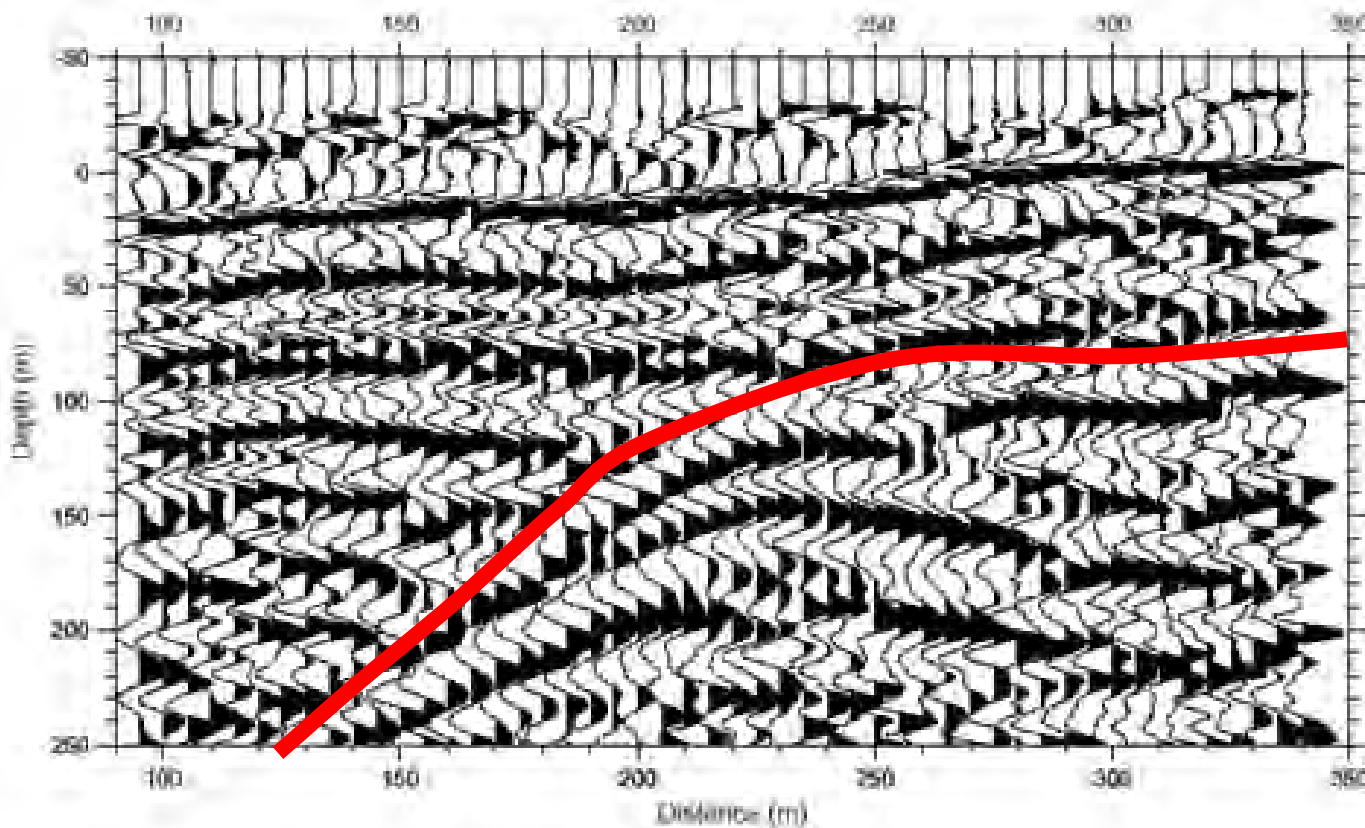
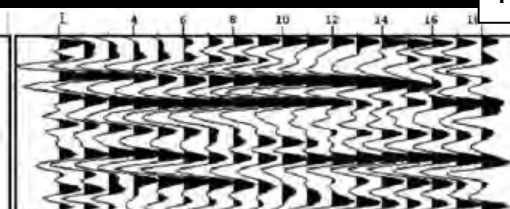
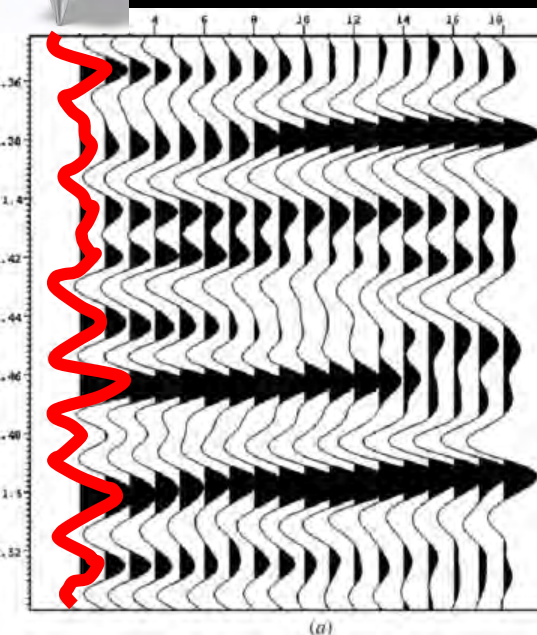
A nodal geophone



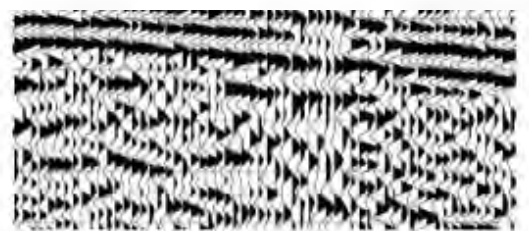
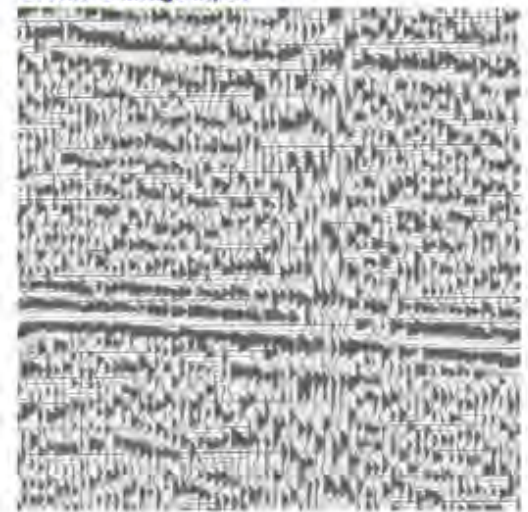




Interpretation theory – stacking the sound traces of multiple geophones along a transect can reveal patterns in the reflectivity of underlying rocks



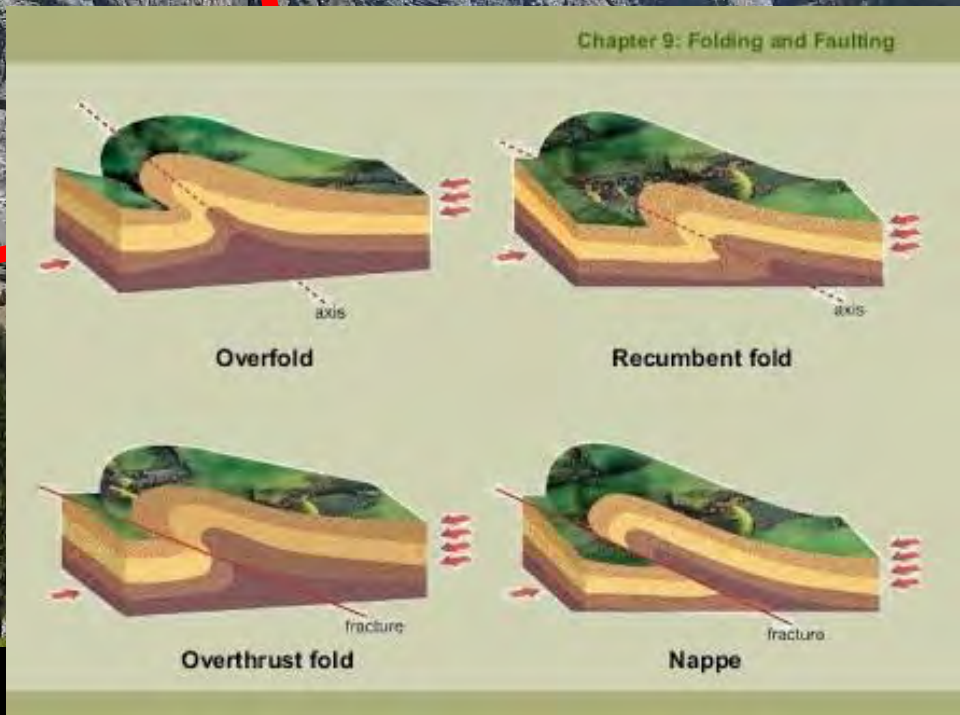
Scanned Image Input





In places of good outcrop (eg. European Alps),  
The patterns imaged by seismic reflection  
can be compared directly to reality.

The patterns can also be compared to theory.





...It is harder to understand complex geology in most places in Australia – its pretty low-relief, rock exposure very limited over most of the continent. In these cases, Seismic Reflection can be a critical 'tool of last resort', the only way to image some key aspects (eg structure) of completely concealed older geology... BUT...seismic reflection data interpretation with concealed geology can be very ambiguous.....



.....Victoria and SE NSW is a bit of an exception.

There is some great exposure in the Great Dividing Range which, in Victoria alone, crosses the Early Palaeozoic geology strike at right-angles, giving a unique opportunity to compare seismic reflection data results directly with exposed geology across the full width of the Lachlan Fold Belt.

Having direct knowledge of the rocks greatly reduces the ambiguity of geological interpretations of Seismic Reflection data imagery enormously - this, in turn, results in better constrained crustal-scale geological interpretations, and these form the fundamental basis for robust geological (+mineral) systems analyses.

The unique opportunity afforded by the geography of Victoria has been the motivation to progressively build a crustal-scale deep seismic reflection transect across the full width of the State.

The data and knowledge gained here will test, and has potential to validate, the Lachlan Orocline model, with implications that cascade south to Tasmania, north to include NSW and Queensland and parts of the Northern Territory, and west into South Australia.....

The project area cuts right through the heart of the most mountainous part of the whole continent, passing within sight of Mt Kosciuszko and Mt Bogong, nearly reaching the alpine summit of Mt Pinnibar, and crossing the iconic Snowy River in the remote heart of the Alpine and Snowy River National Parks.





Victoria, in particular, has a proud recent history of detailed new-generation geological mapping across the Australian Alps. The Geological Survey of Victoria has developed geological theories that can be tested by the deep seismic reflection method....







...and this is what the new Southeast Lachlan Crustal Transect project has achieved – regional-scale data acquisition in places where the rocks are exposed for direct study, also at regional scale (such as the south-dipping Ordovician-age (from graptolite fossils) deep marine turbidites of the Adaminaby Group exposed in this road cutting – photo from the 2018 SLaCT survey)

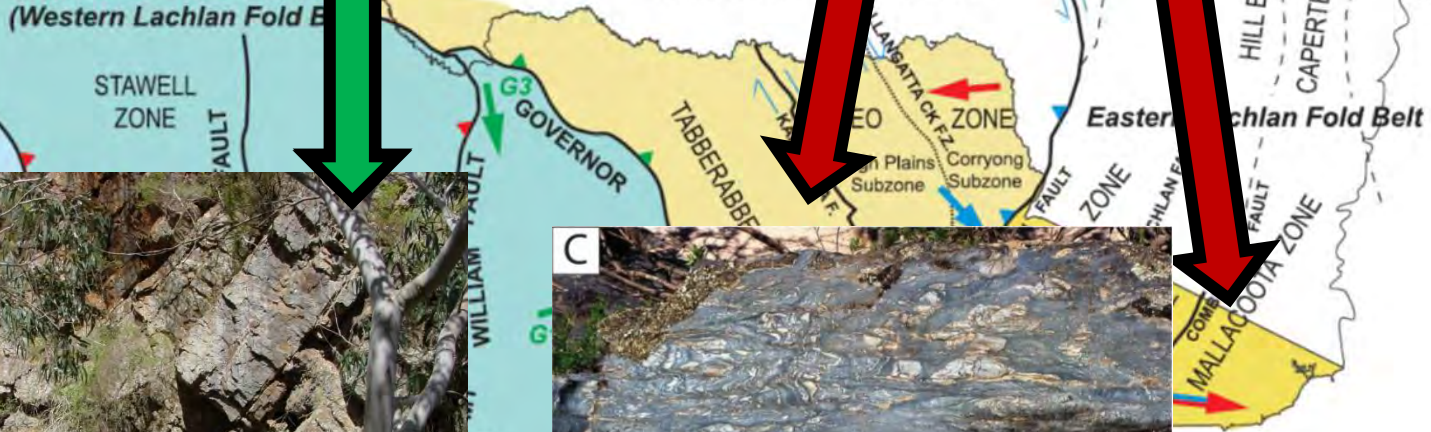
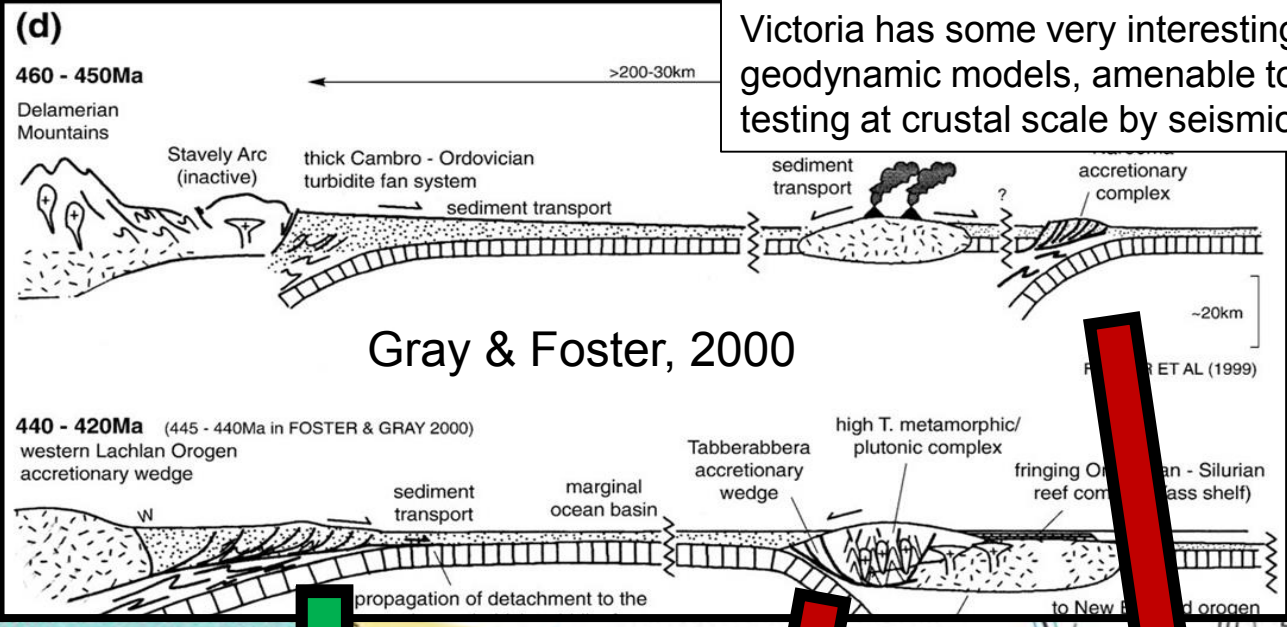


The project completes a transect across the full-width of the continent in the south, in the region of best geological control





Victoria has some very interesting and competing geodynamic models, amenable to testing at crustal scale by seismic reflection



Benambran deformation – Late Ordovician

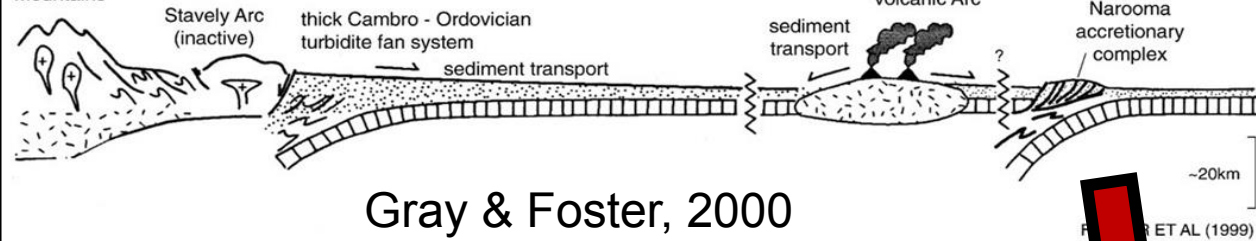
142° Models that honour structural vergence, accretionary character.....



(d)

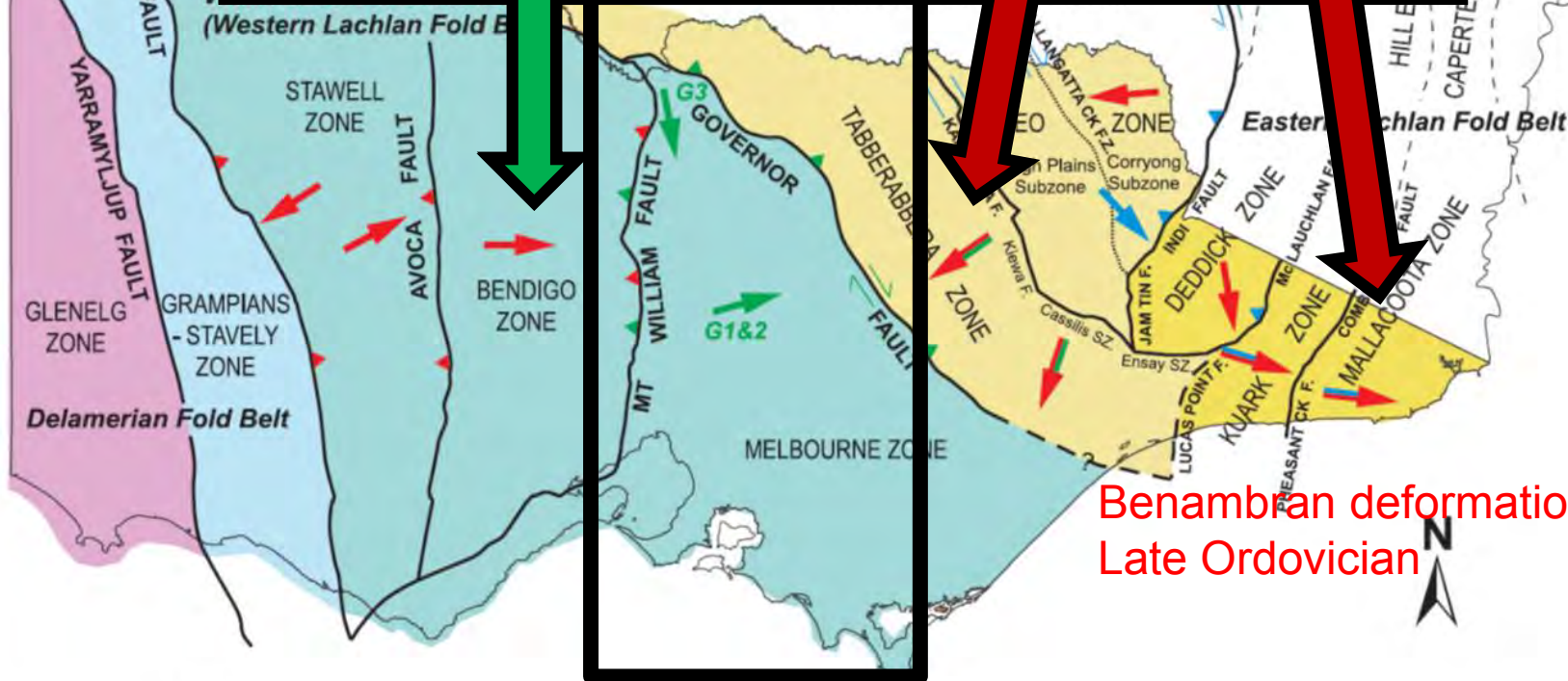
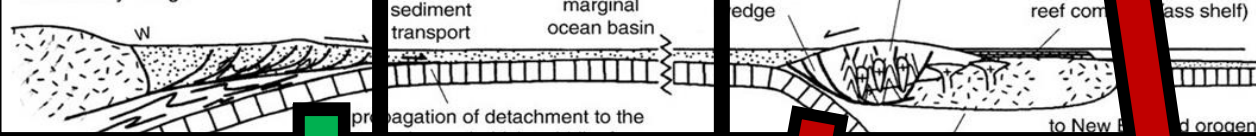
460 - 450Ma

Delamerian  
Mountains



440 - 420Ma

(445 - 440Ma in FOSTER & GRAY 2000)  
western Lachlan Orogen  
accretionary wedge



Models that honour structural vergence, accretionary character.....

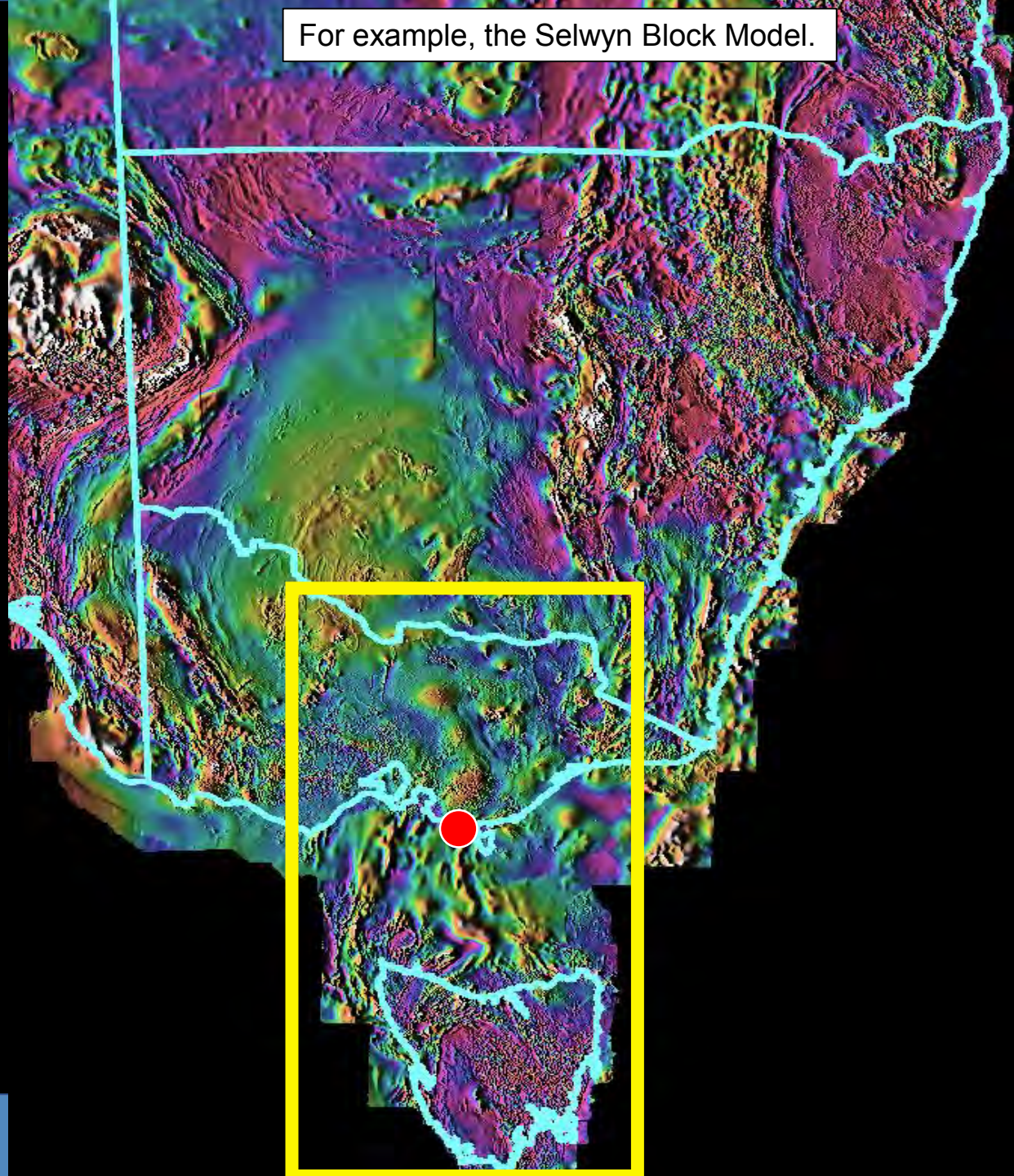


For example, the Selwyn Block Model.

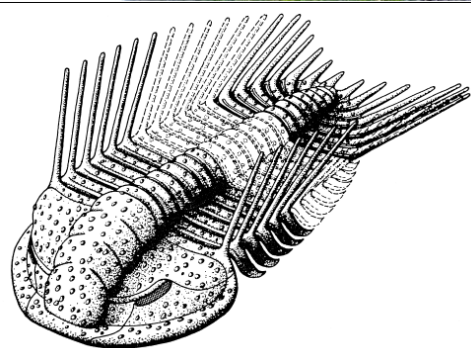
TMI data in Bass Strait  
pointed us towards...

the Selwyn Block model....

Proterozoic continental  
crust of west-Tasmania  
affinity beneath central Vic.





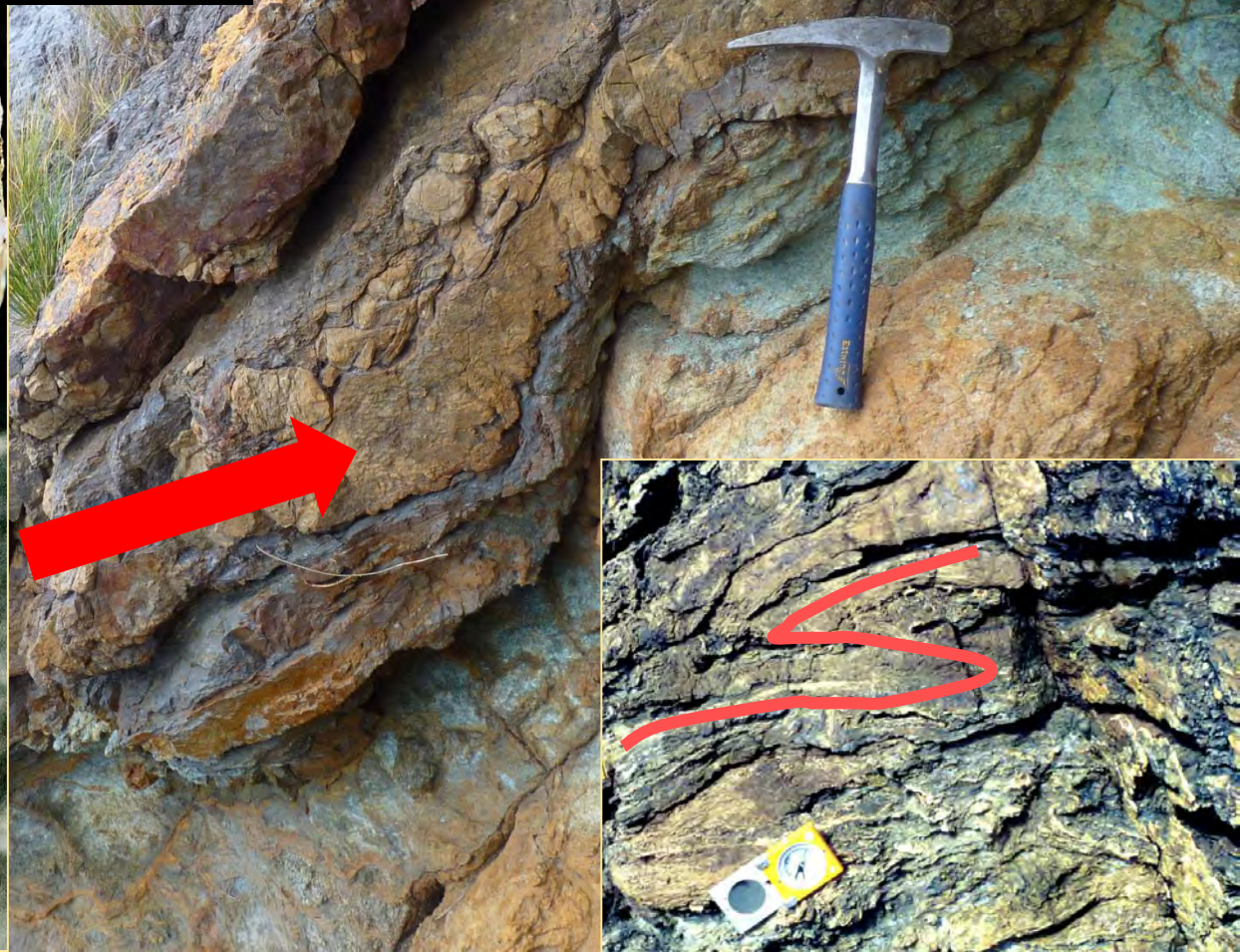


Early Lancefieldian –  
~490Ma+

Outcrops prove the existence of a Late Cambrian unconformity beneath the Melbourne Zone in central Victoria – this is the Tyennan Unconformity of Western Tasmania. Stratigraphy and structural history is directly comparable to Western Tasmania. (eg. Cayley et al, 2002)

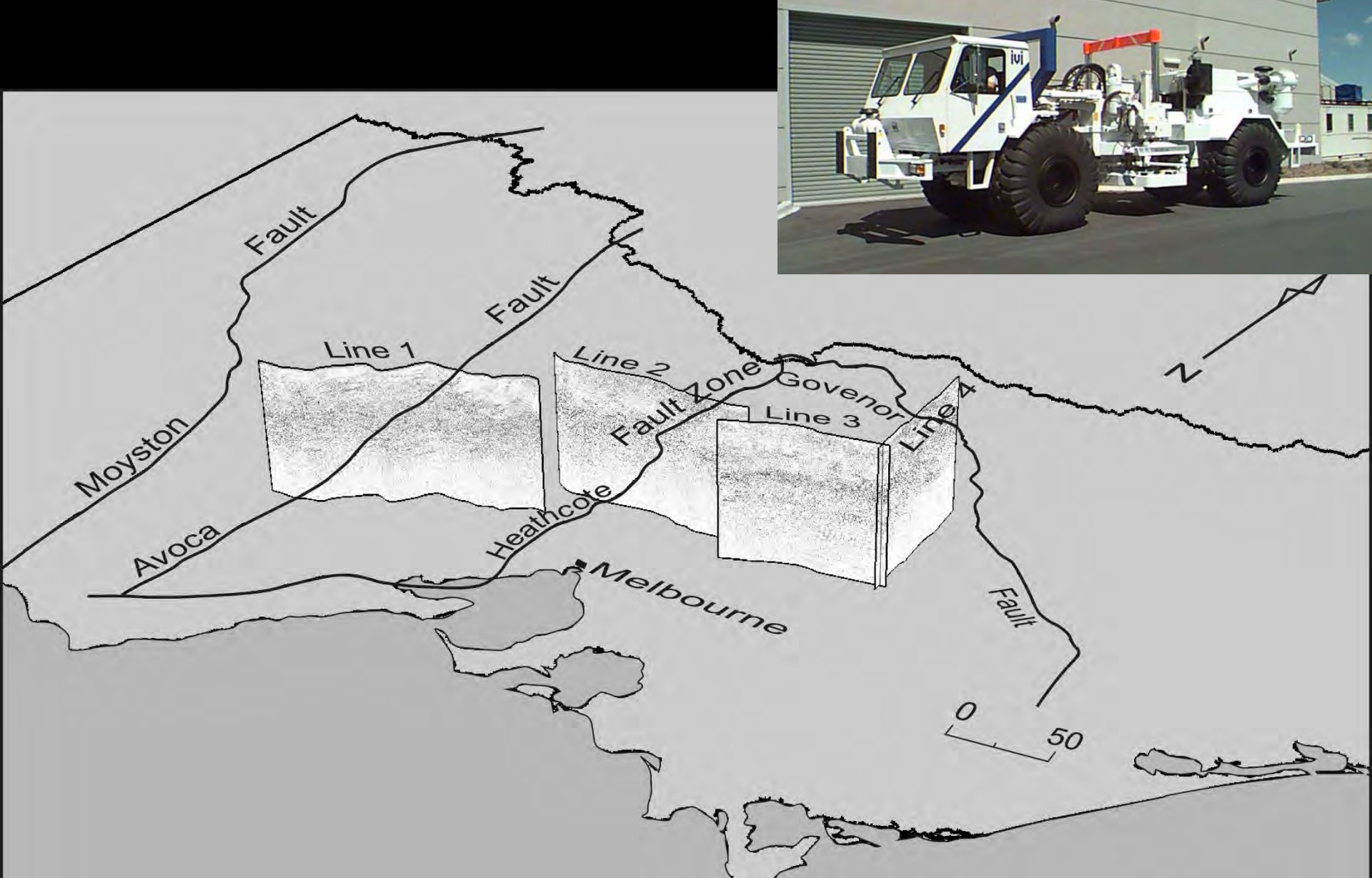


**Bear Gully Gritstone**







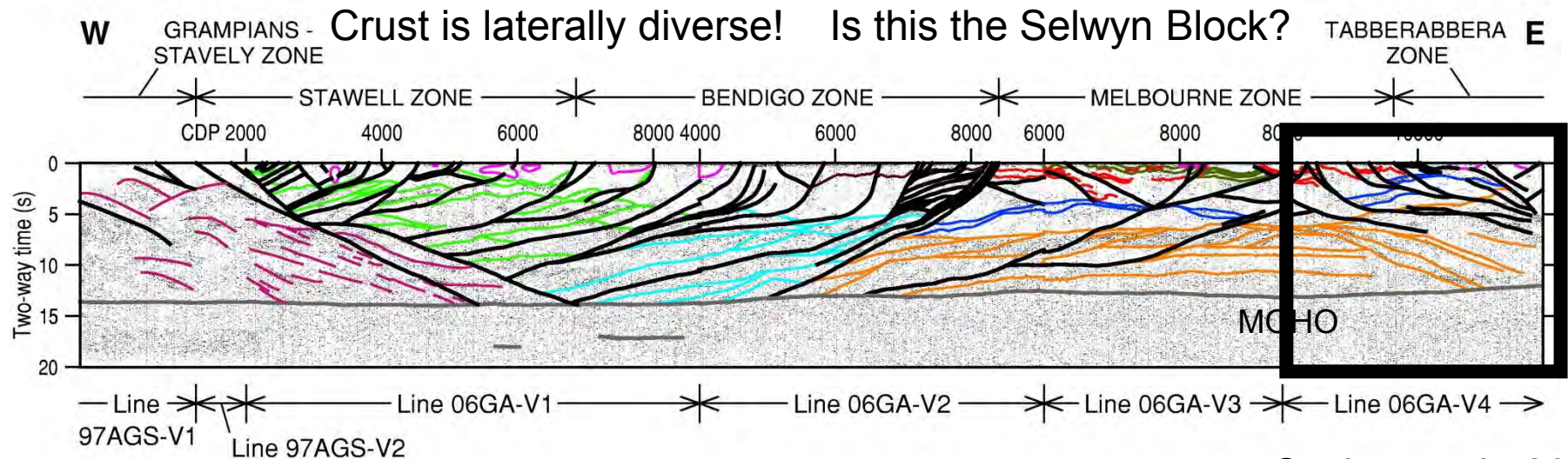
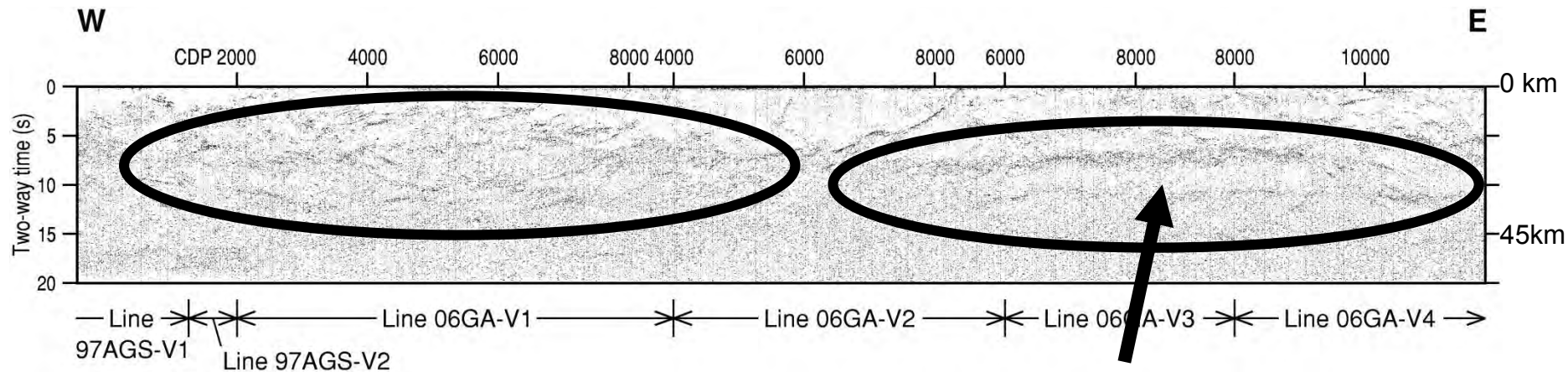


The 2006 deep seismic transect (Cayley et al., 2011) was designed to test ideas like this.

Regional deep seismic transects: pmd\*crc, AUSCOPE

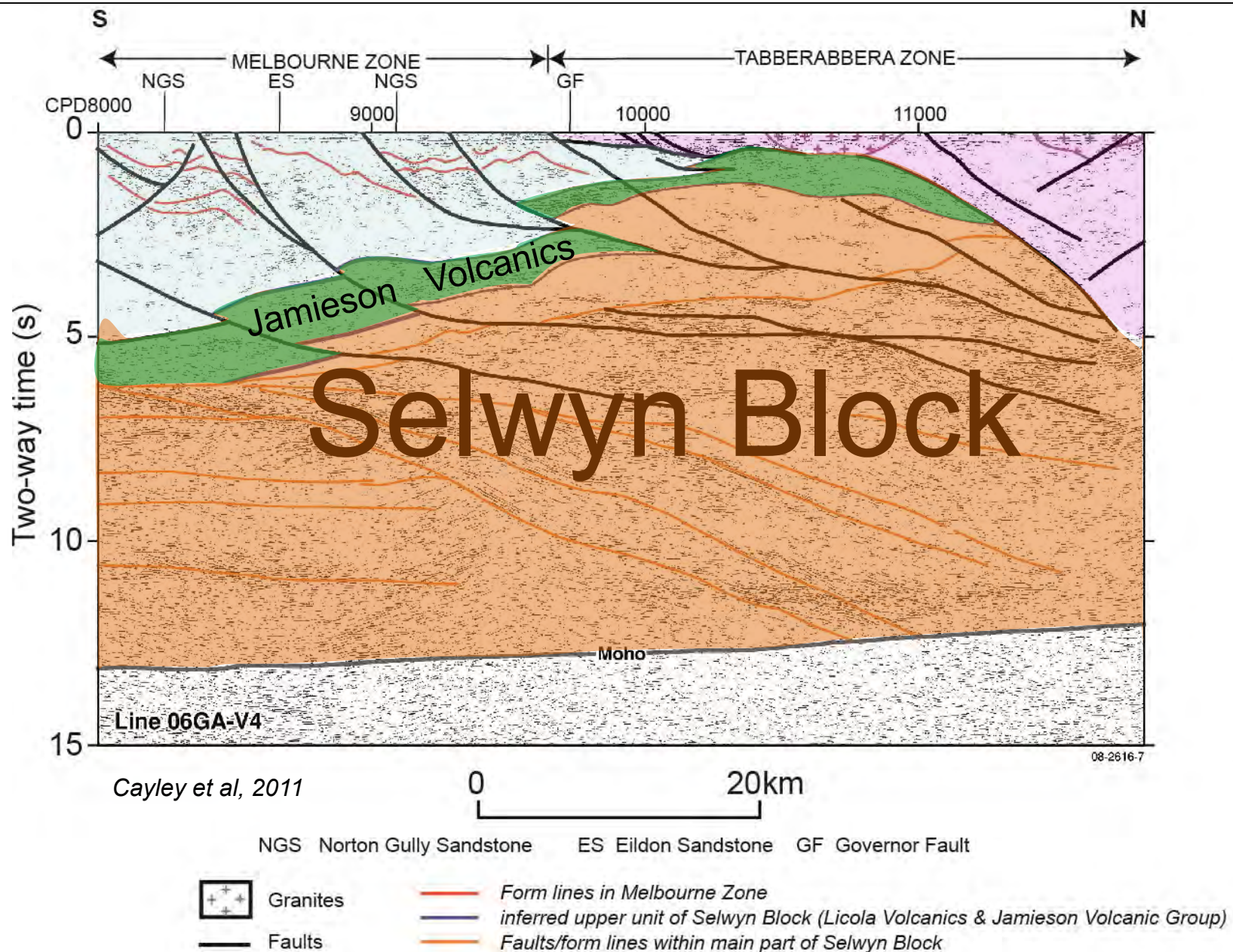


Is the mid-lower crust laterally uniform or laterally diverse?





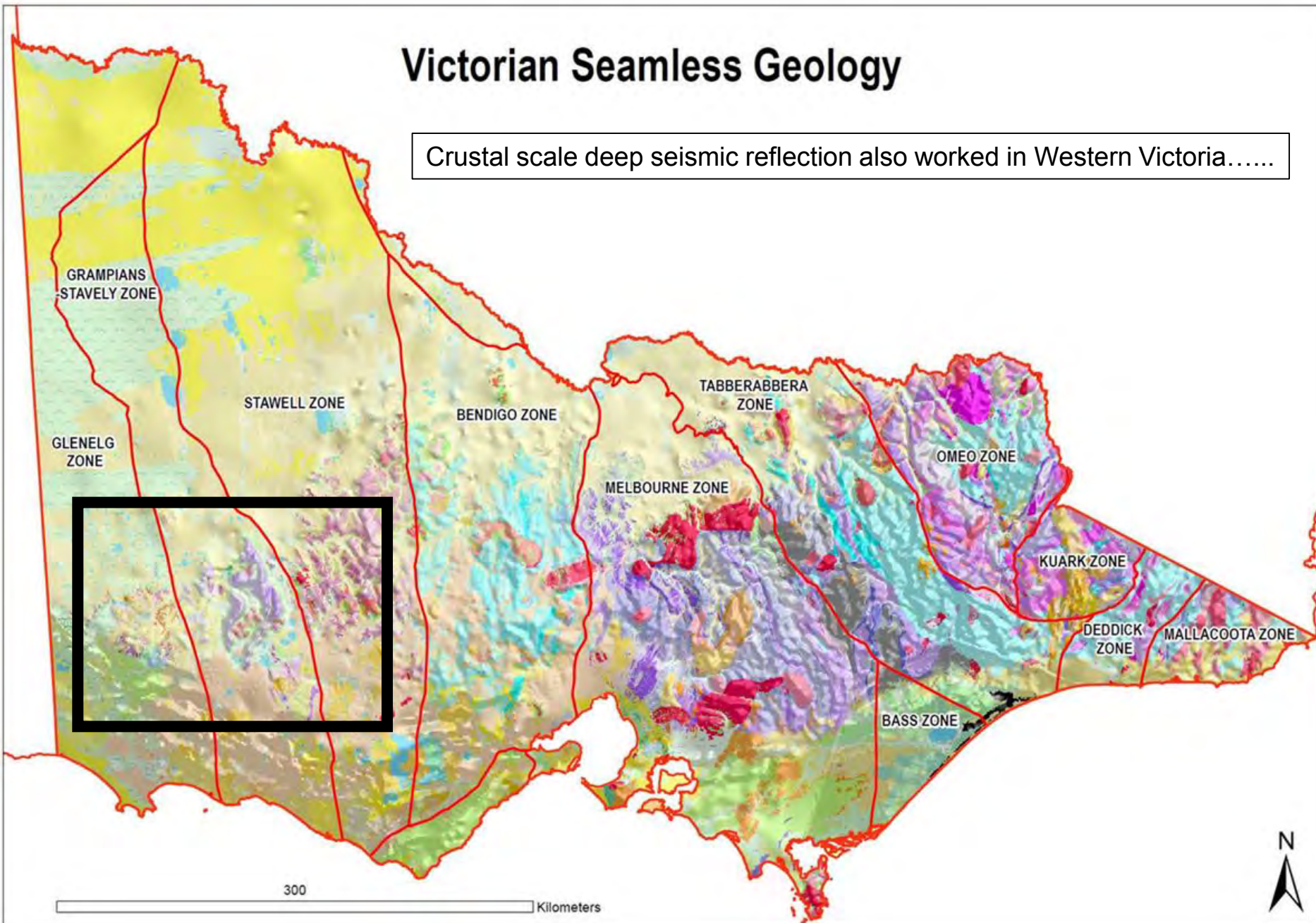
Because we have outcrops of Selwyn Block rocks nearby, we can attribute seismic domains with confidence. eg. the Mid-Cambrian Jamieson Volcanics, a direct along-strike correlate of the Tasmanian Mt Read Volcanics.





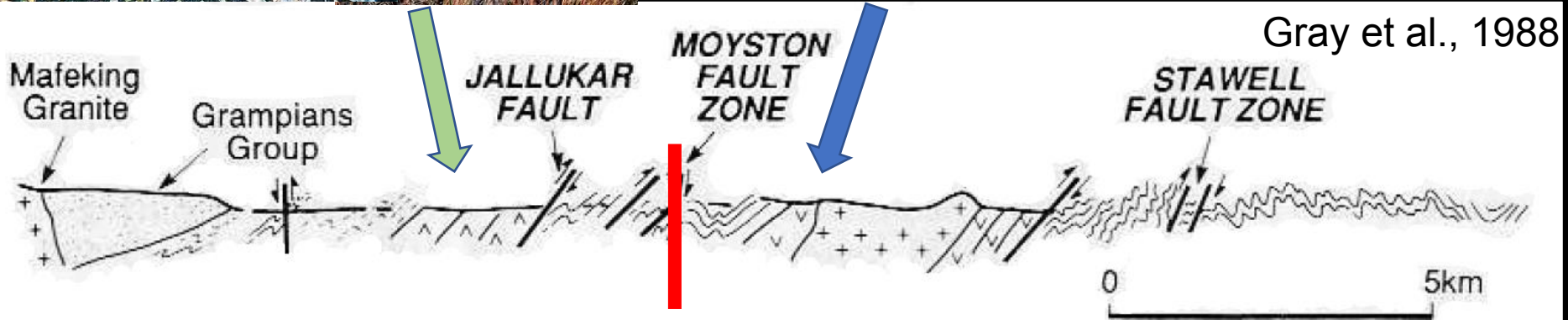
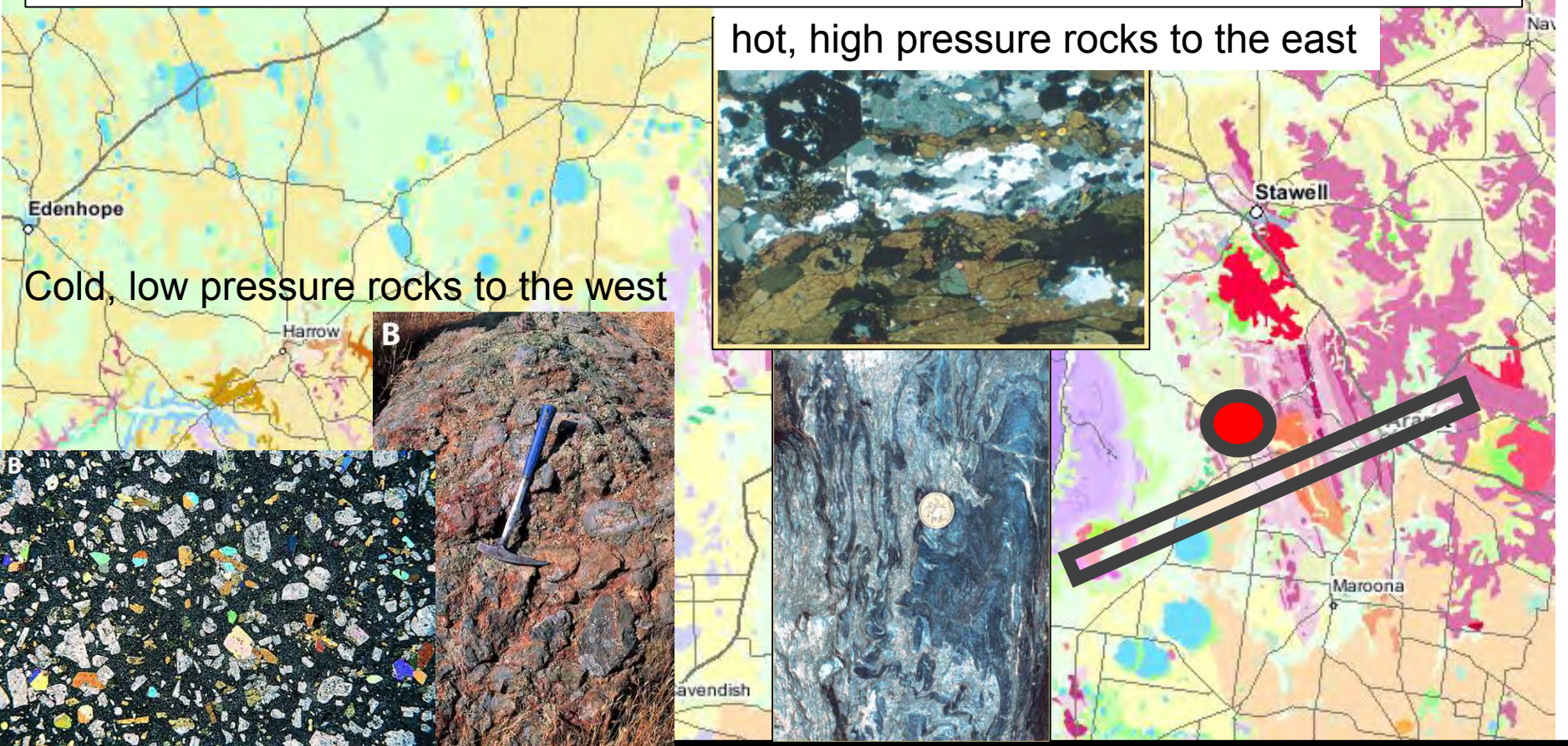
# Victorian Seamless Geology

Crustal scale deep seismic reflection also worked in Western Victoria.....





...for example, using seismic reflection data to test the crustal-scale geometry of the major Moyston Fault, and associated structures and a metamorphic complex (Moornambool Metamorphic Complex).....





Garnet

Hornblende

Stawell Zone

Moyston

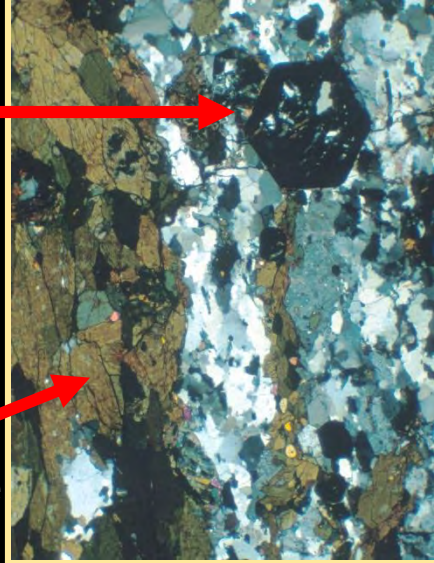
East

Fault

Grampians-Stavely  
Zone

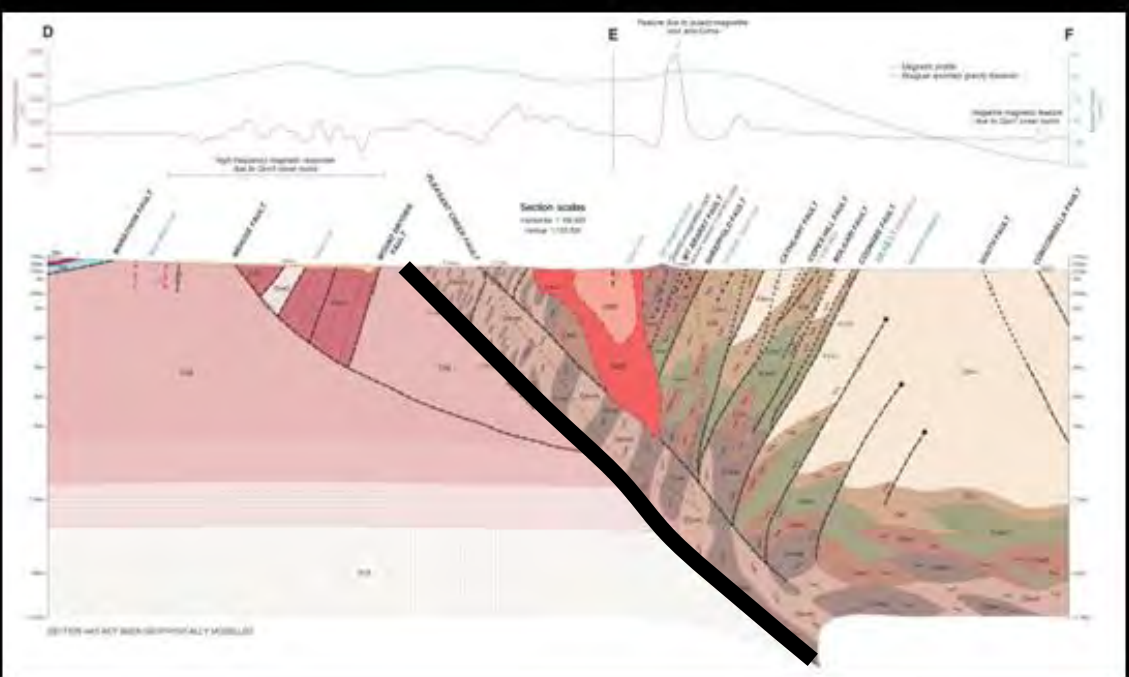
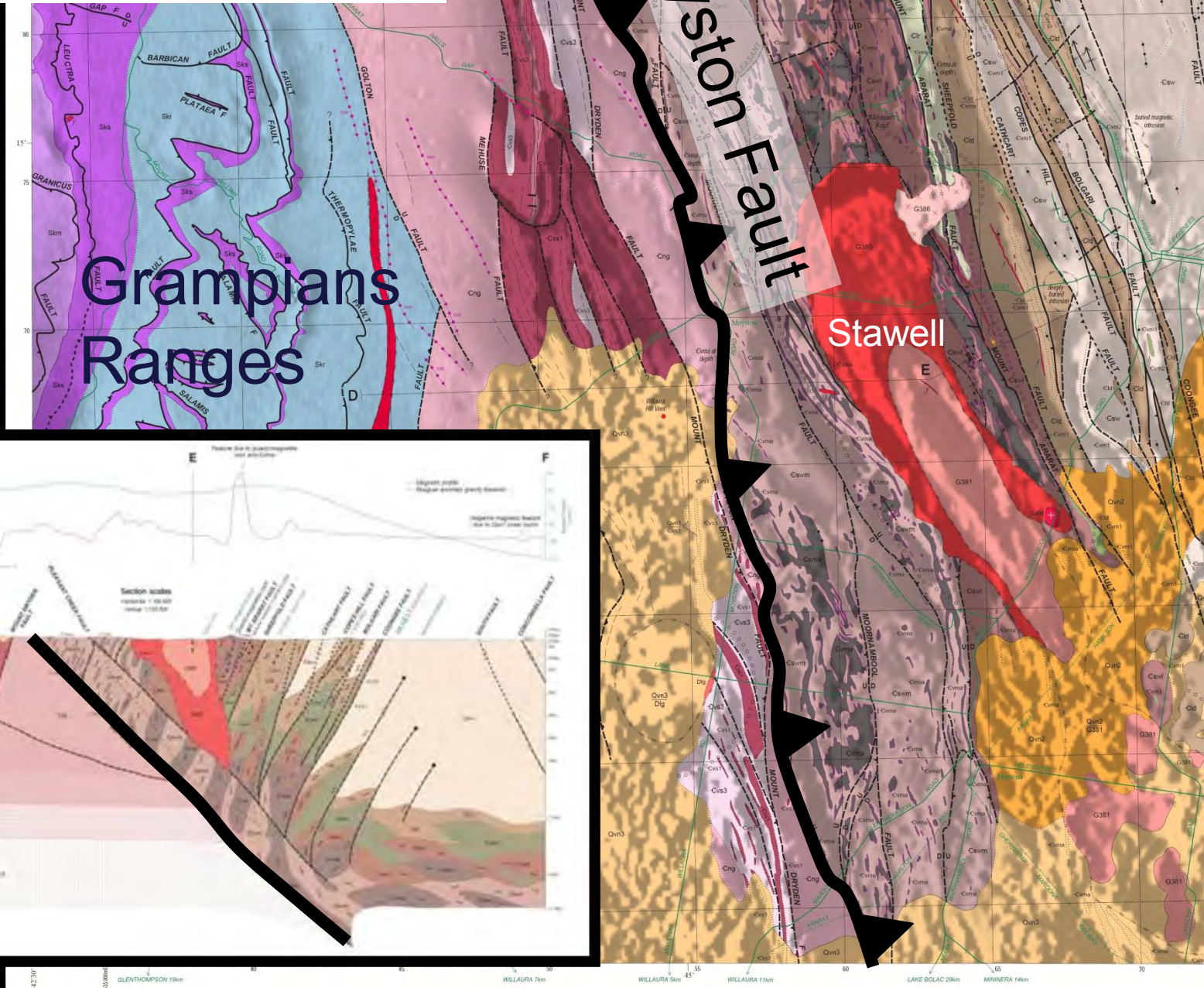
West

Moyston Fault is exposed, and is east-dipping to steeply-dipping near-surface

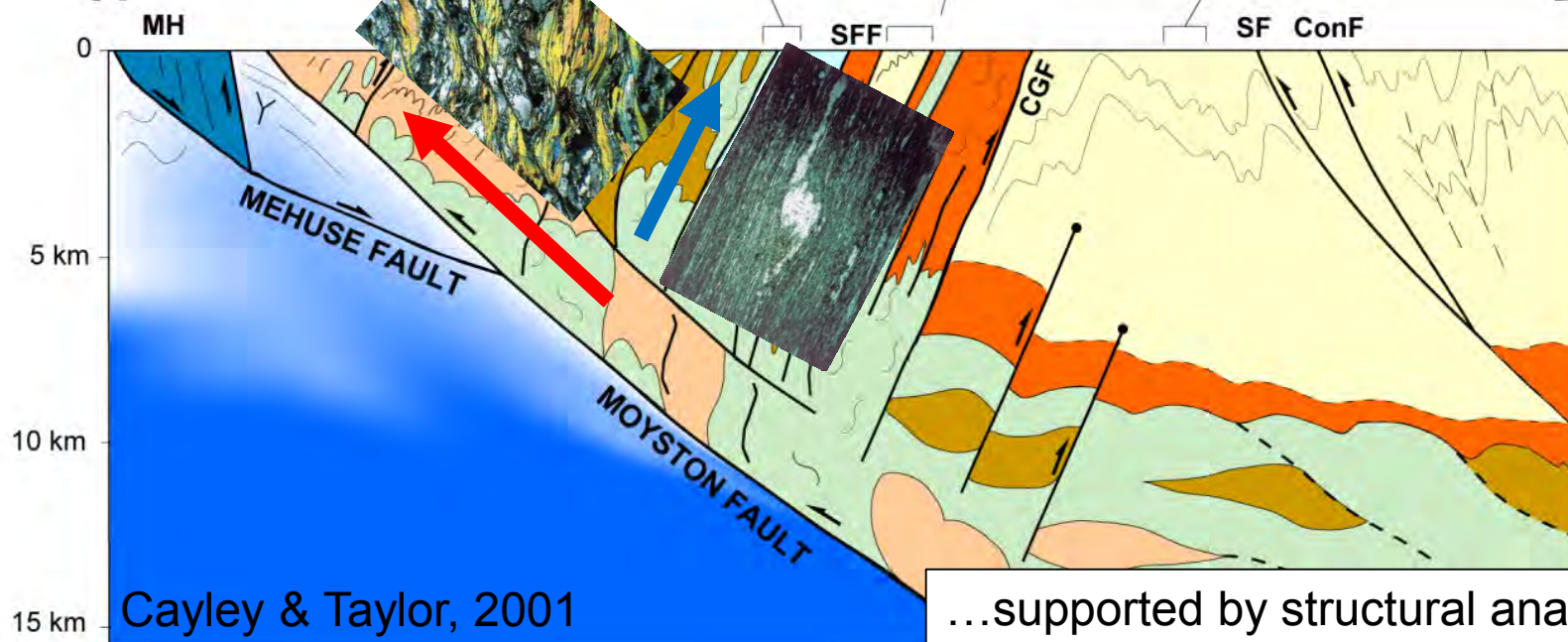




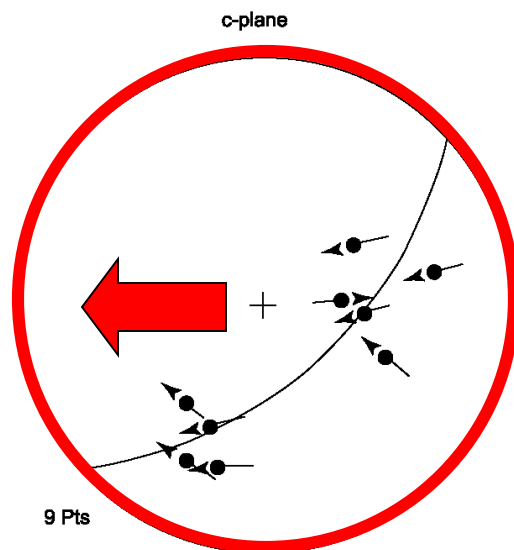
This is the geometry at crustal scale, suggested by the mapping, supported by magnetic, gravity data (Cayley & Taylor, 2001).....



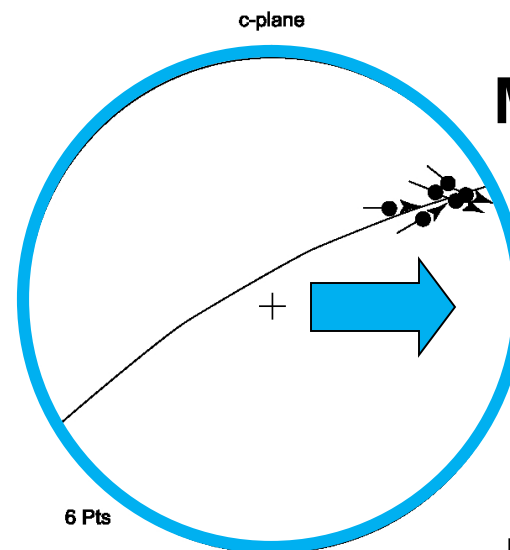




...supported by structural analysis..



Spherical Mean=27-032  
Spherical Variance=0.23  
Calculated girdle: 64-139  
Calculated beta axis: 26-319



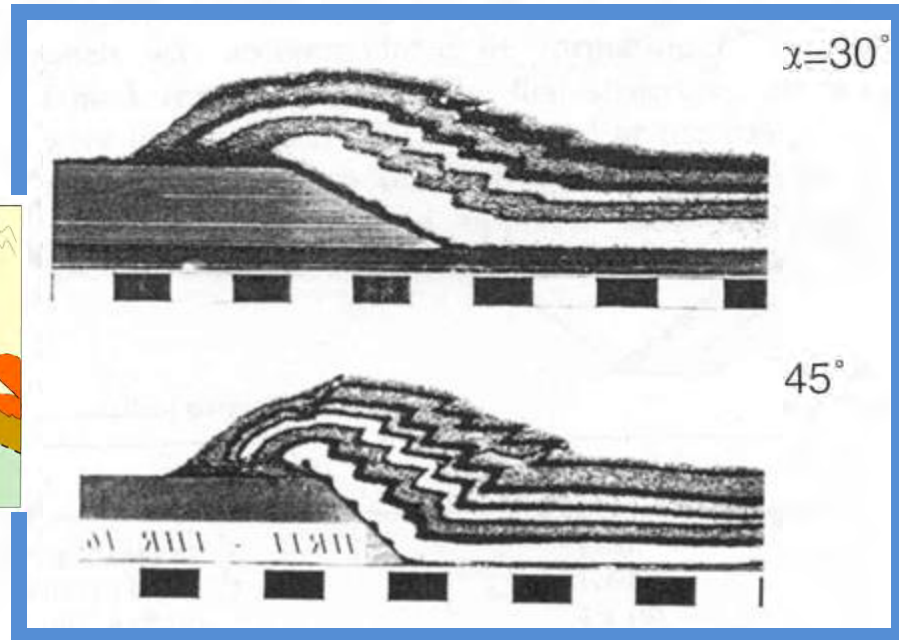
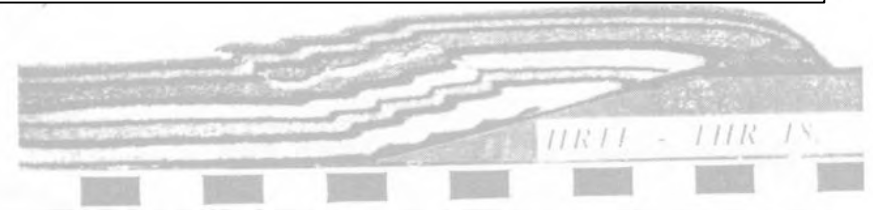
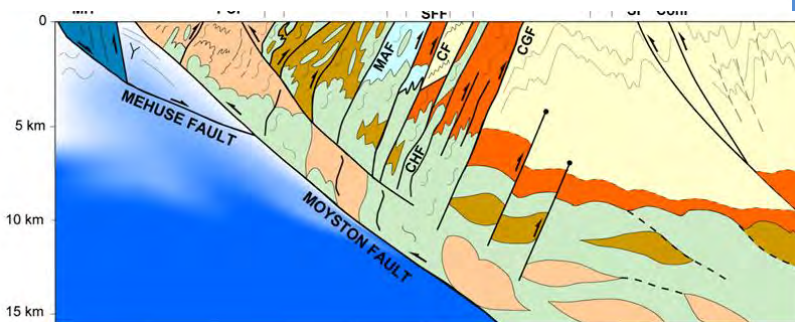
Spherical Mean=69-123  
Spherical Variance=0.02  
Calculated girdle: 80-331

**Moyston Fault,  
Moornambool  
Metamorphic  
Complex –**

**crustal scale,  
doubly-vergent  
'pop-up'?**

...and by comparison to structural theory.... 5°

Analogue:  
small-scale (sand-box)  
modelling



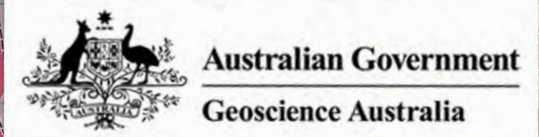
Bonini et al., 1999  
J.S.J.

Fig. 2. Cross-sections of experiments with frictional hanging wall (Type 1) at 40% bulk shortening. Frontal ramp angle ranges from 15° up to 60° by steps of 15°. The ruler at the base of all models is in centimetres.



...in 2009 we tested it with seismic reflection....

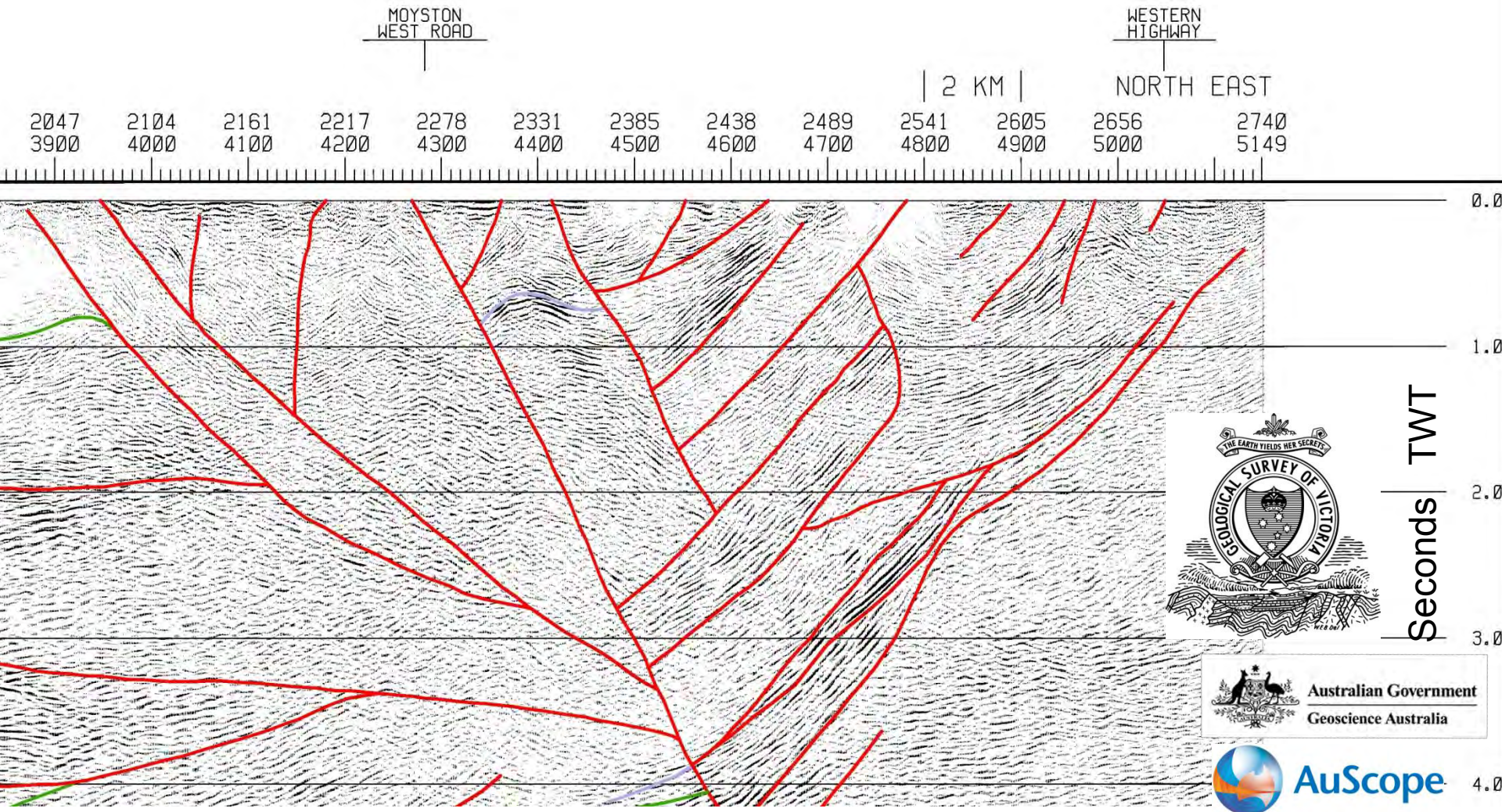
09GA-AR1



Cayley & Taylor, 2000

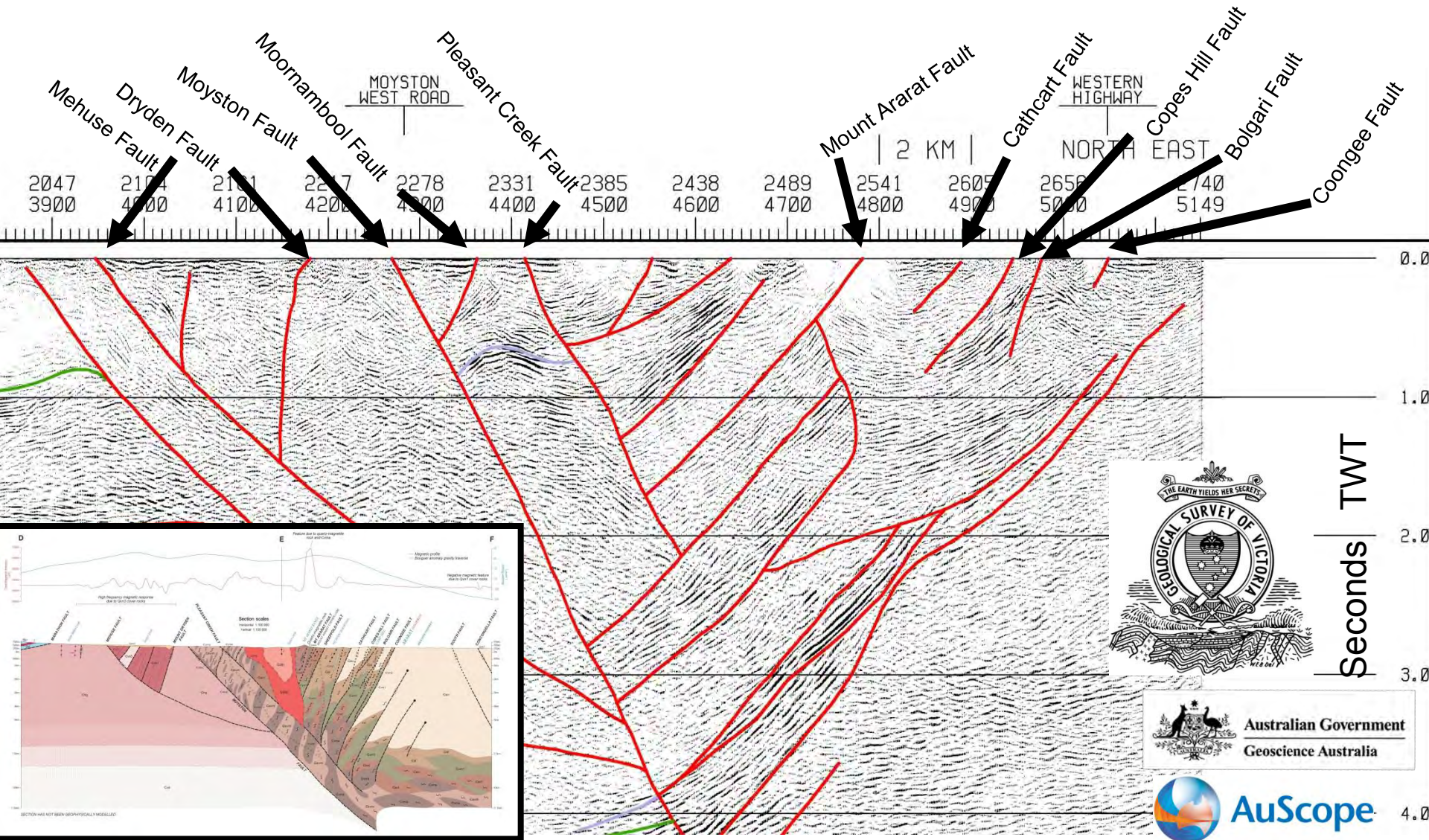


...and got a result that is constrained by geology exposed at surface, and shows a similar wedge-style geometry at depth to that inferred from mapping, and at the same scale....

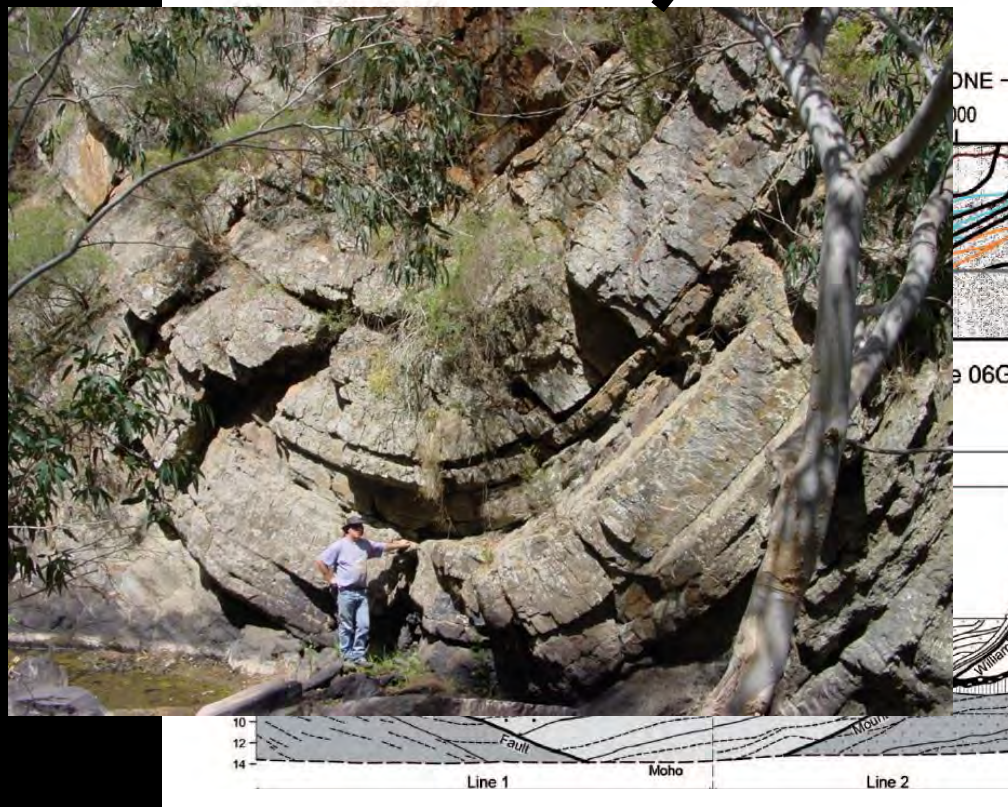
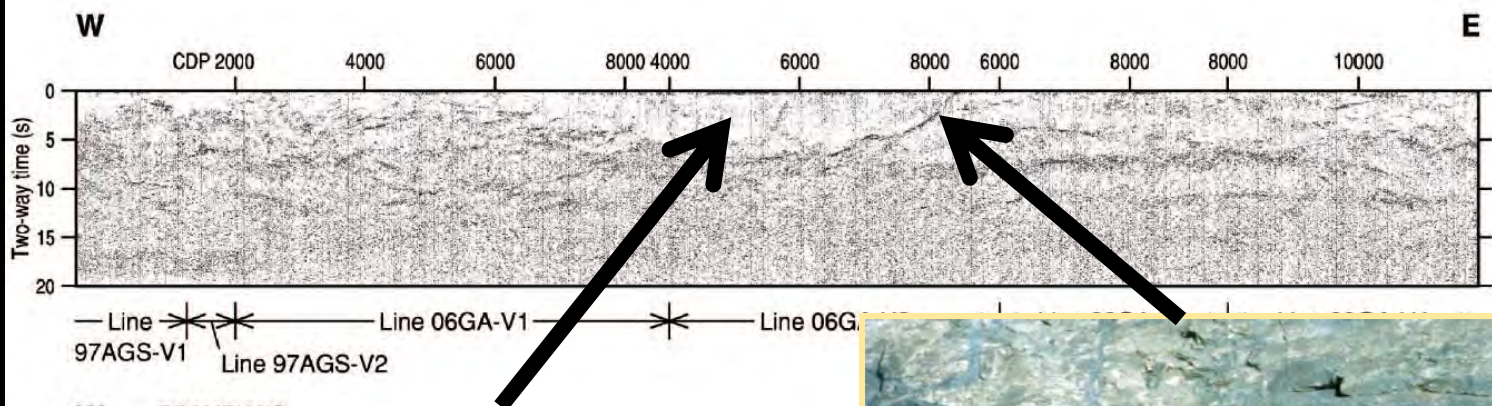




This reaffirmed our faith that deep seismic reflection works in Early Palaeozoic terranes in Victoria, and can deliver additional constraints to geometry at crustal scale

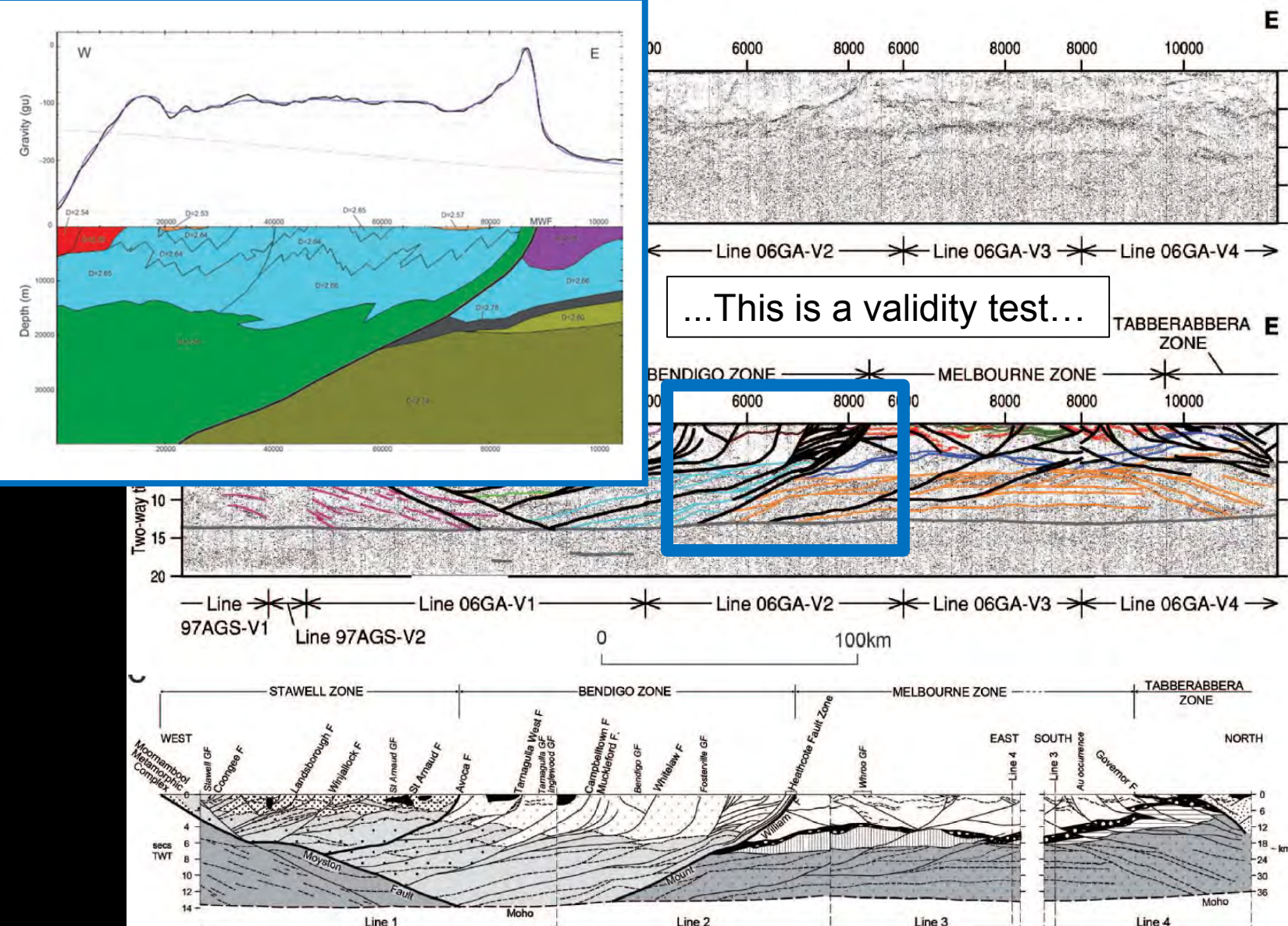






We can use the geometrical constraints to build models that we can test back against reality – using directly measured densities of different rocks to model gravity response, for example....

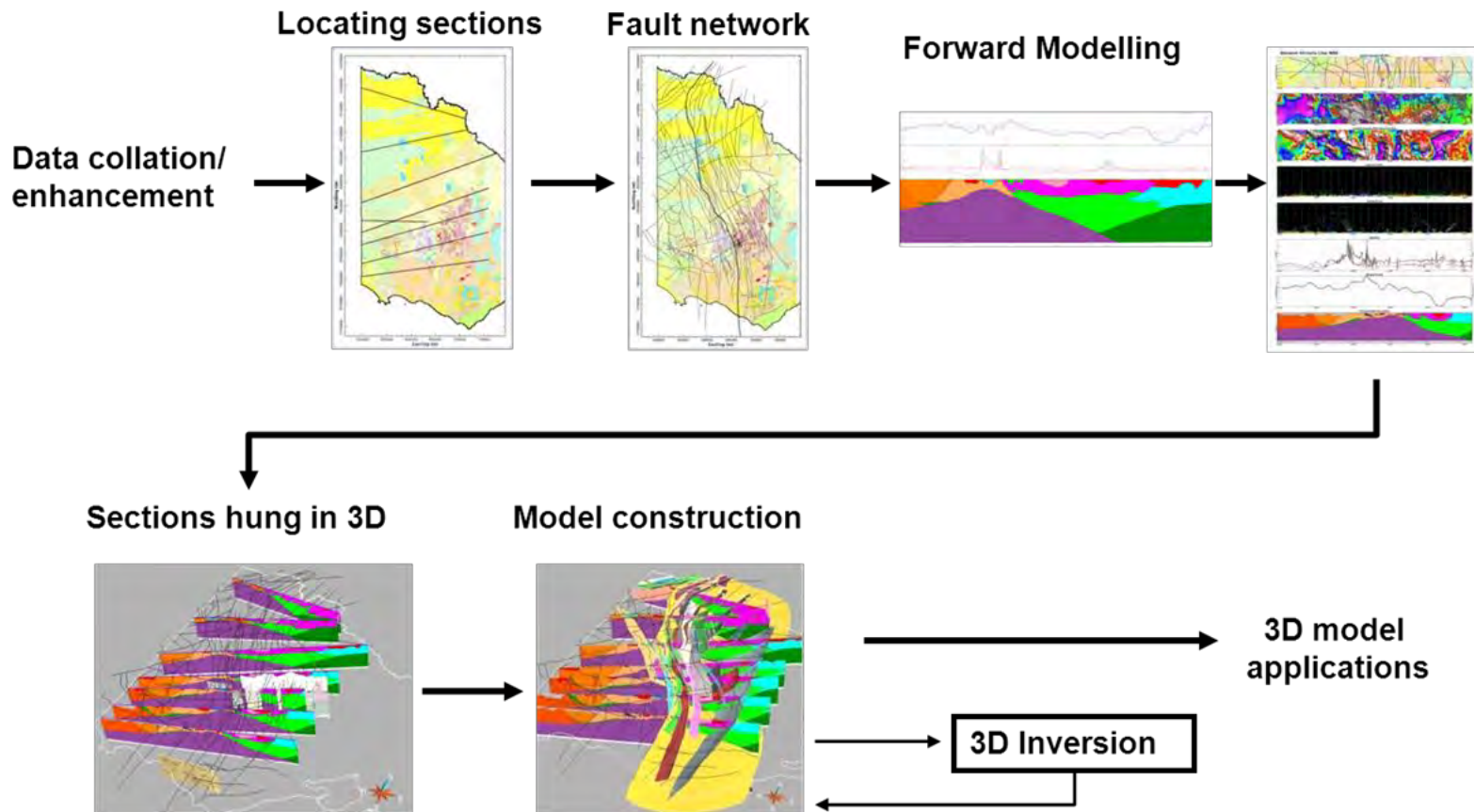




Aeromagnetic data + seismic reflection + modern geological mapping  
= integrated crustal-scale geological interpretations

# Put all this together, and you can start to build.....

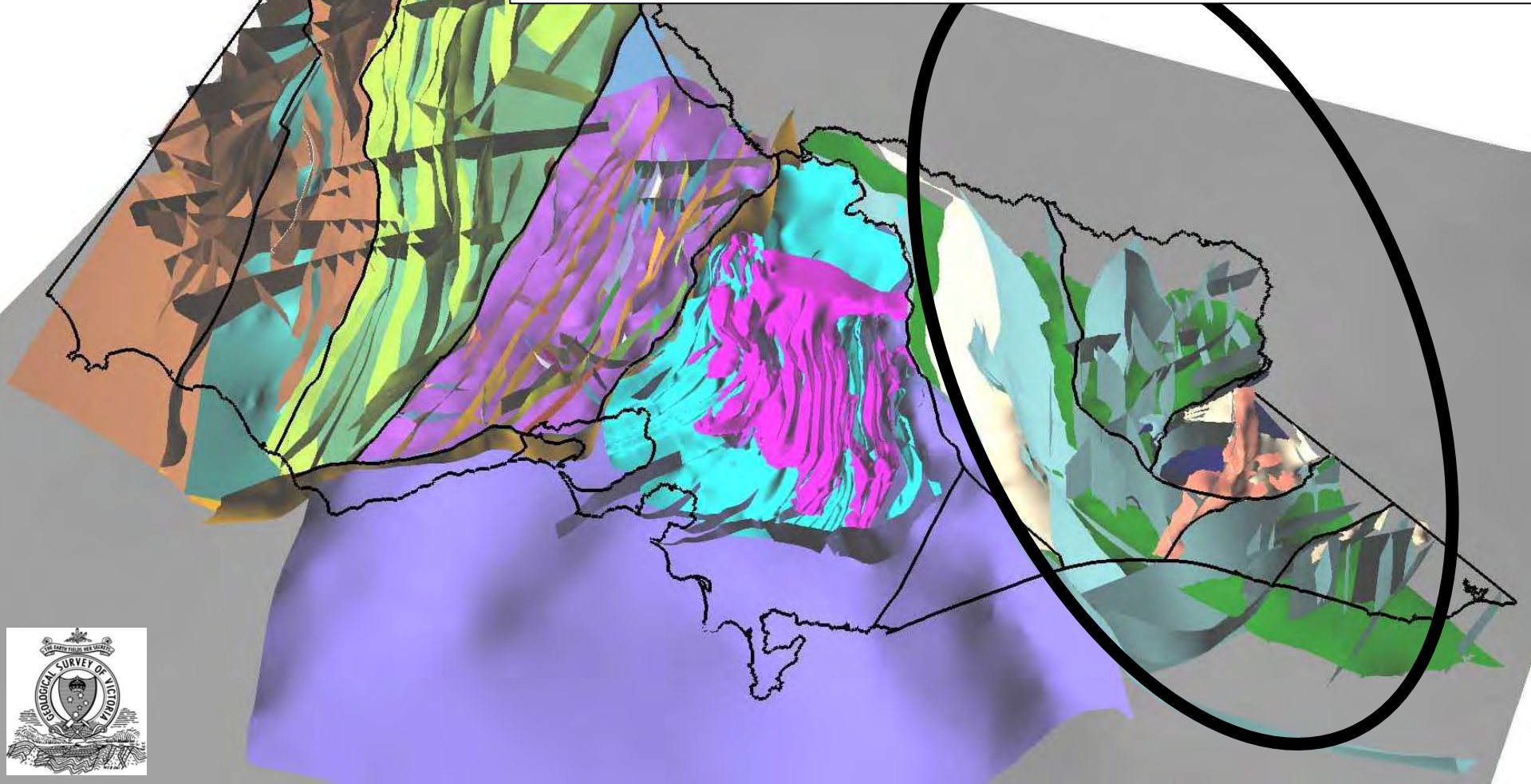
## The 3D model building process



...to give additional constraints and confidence to the 3D models we are building for Victorian geology

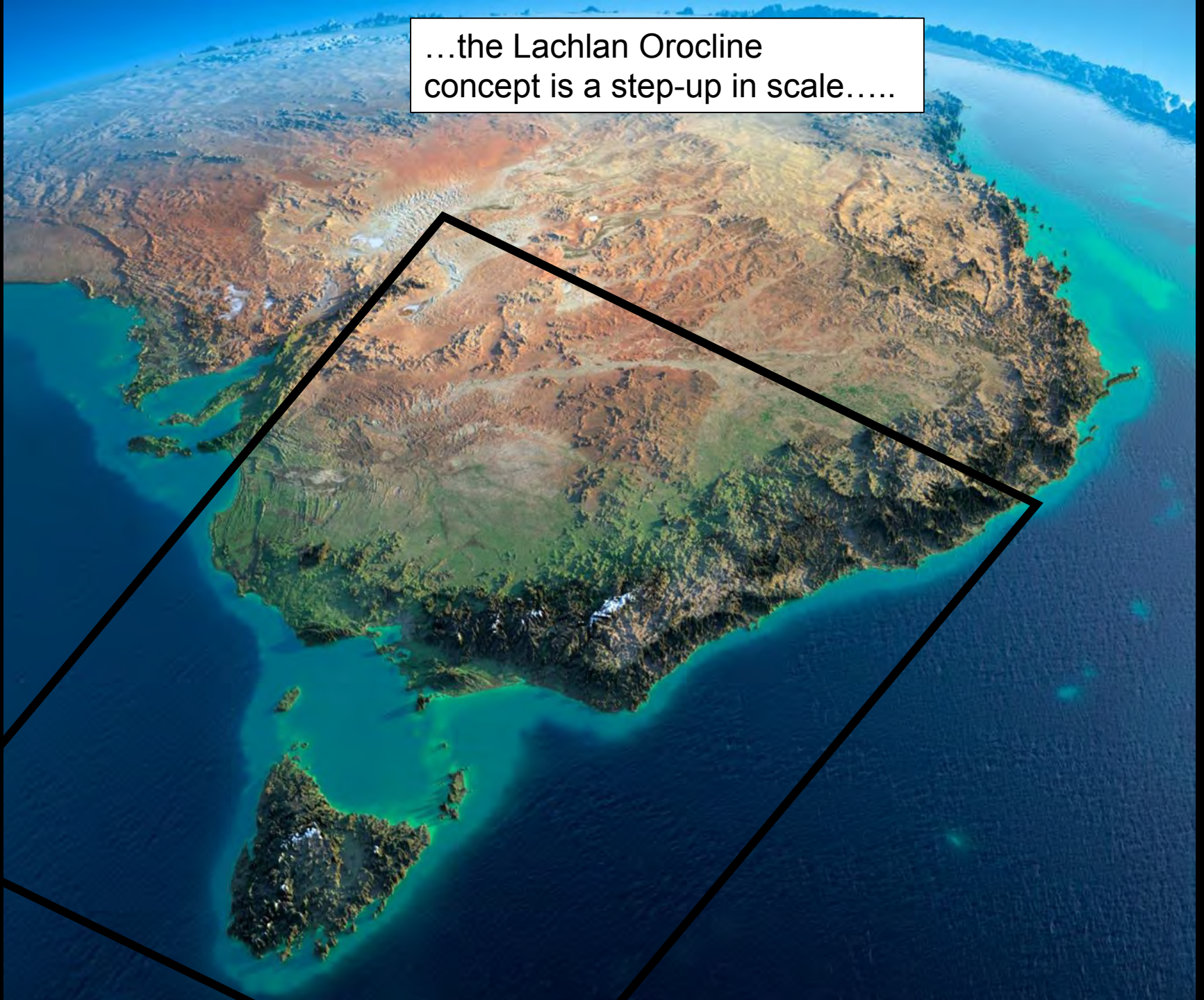


...but we do not have seismic reflection data for eastern Victoria – this bit of the Victorian 3D model was built using surface geology, and inferences from regional-scale geodynamic models – for example the Lachlan Orocline concept.





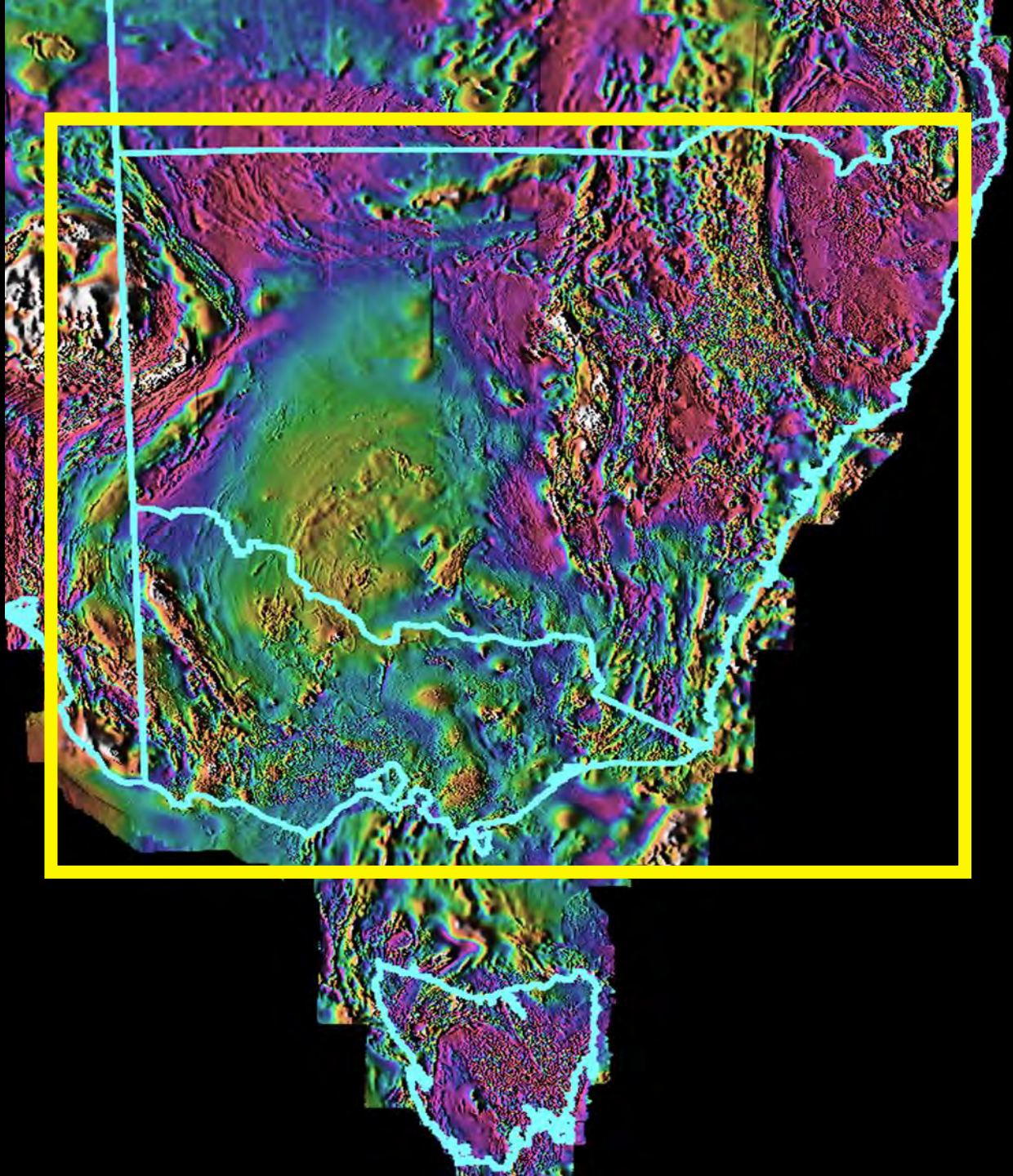
...the Lachlan Orocline  
concept is a step-up in scale.....





...and depended on.....

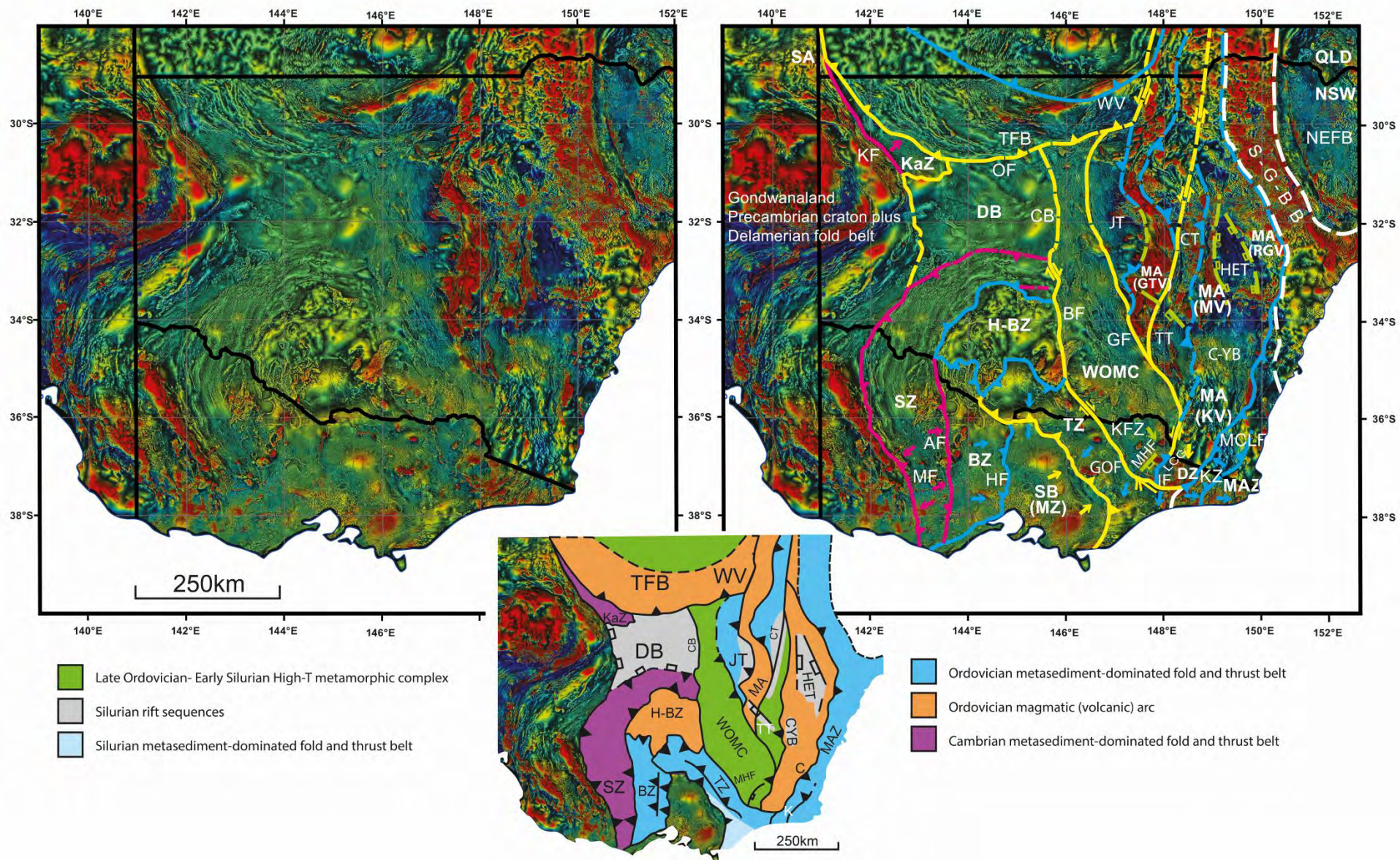
New, higher quality  
aeromagnetic data infill....











Ross Cayley (GSV) & Robert Musgrave (GSNSW) in prep.

# and.. on new ideas for LFB geodynamics...

Recognition of the critical role of roll-back in LFB evolution....

Tectonic switching and roll-back in the LFB

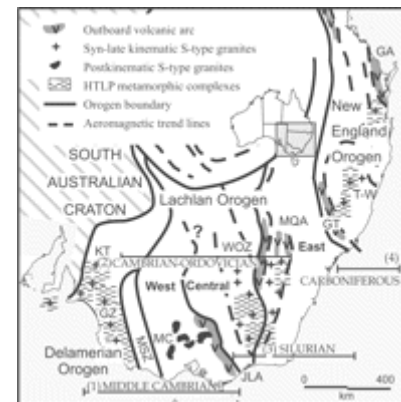
Collins, 2002 (Geology)



Extension and the tripartite association:

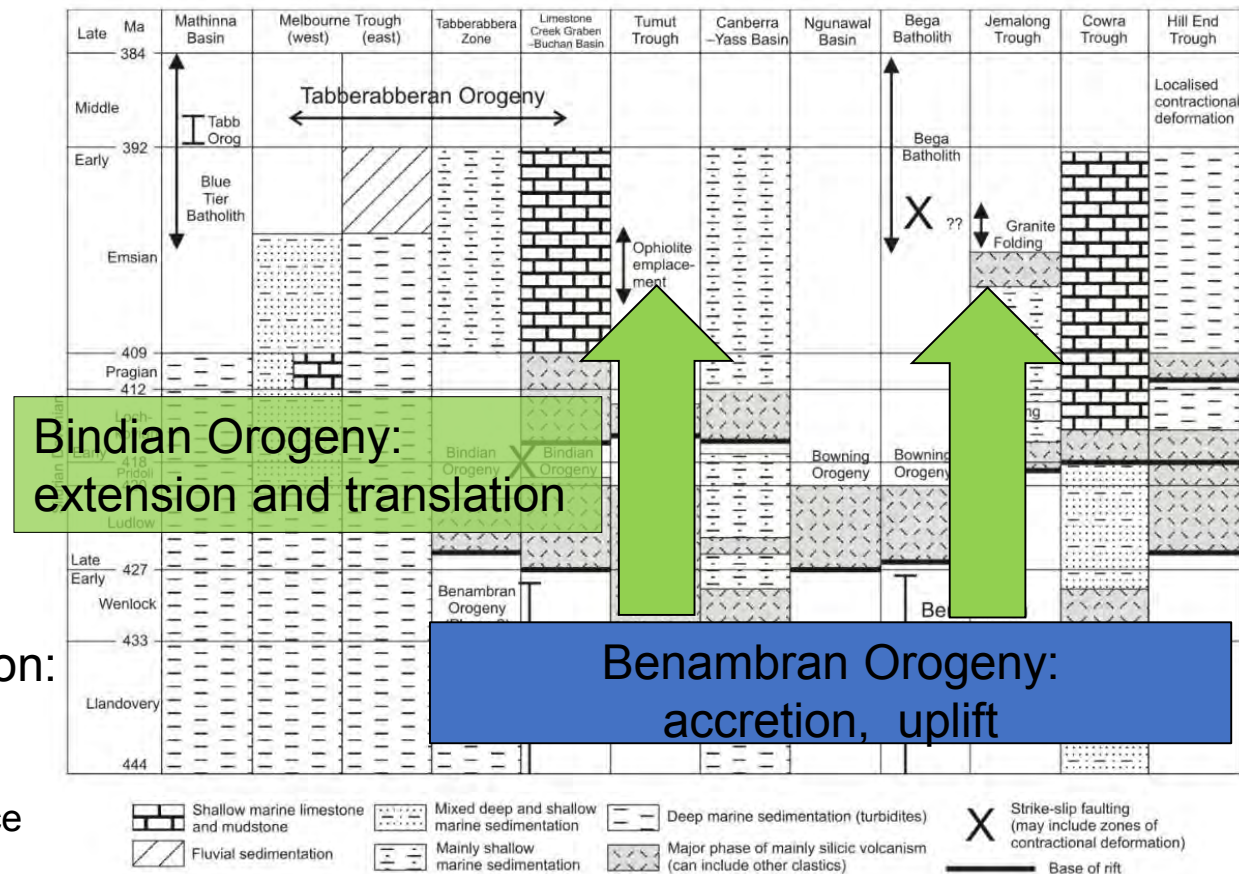
S-type granites, arcs and back-arc basins

Collins and Richards, 2008 (Geology)





# Models that link extension to sedimentation in the LFB:

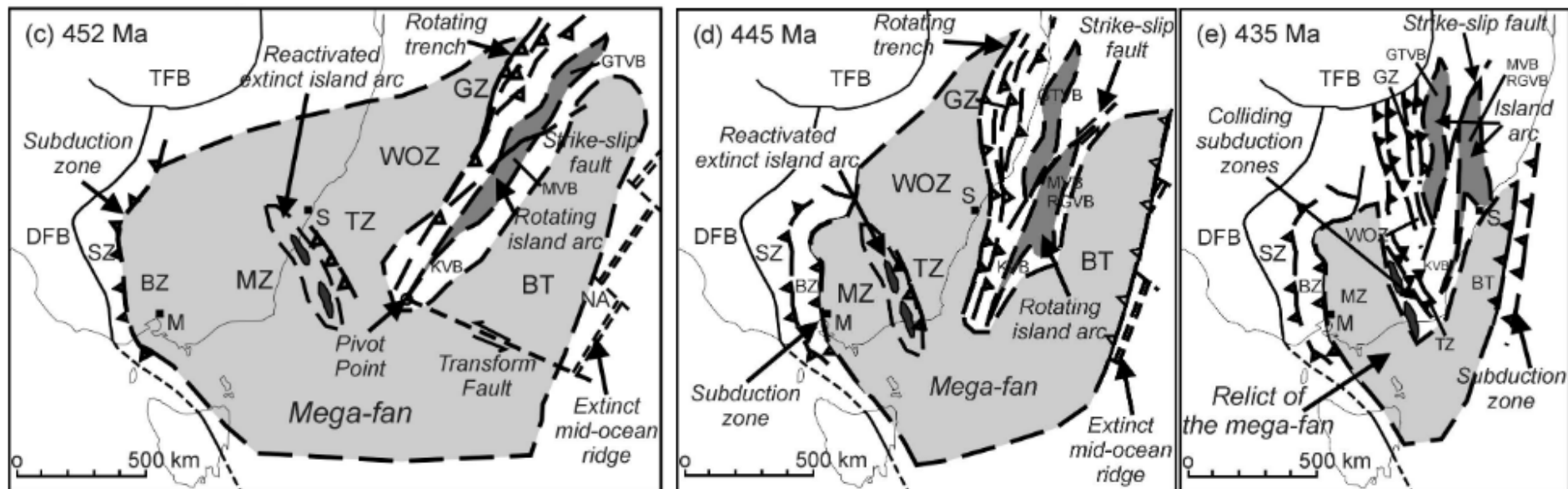


Fergusson, 2010: AJES:

Lachlan Fold Belt sedimentation:

Late Silurian-Middle Devonian  
plate-driven extension and convergence

# Models that suggest strike-slip repetition of Macquarie Arc segments:

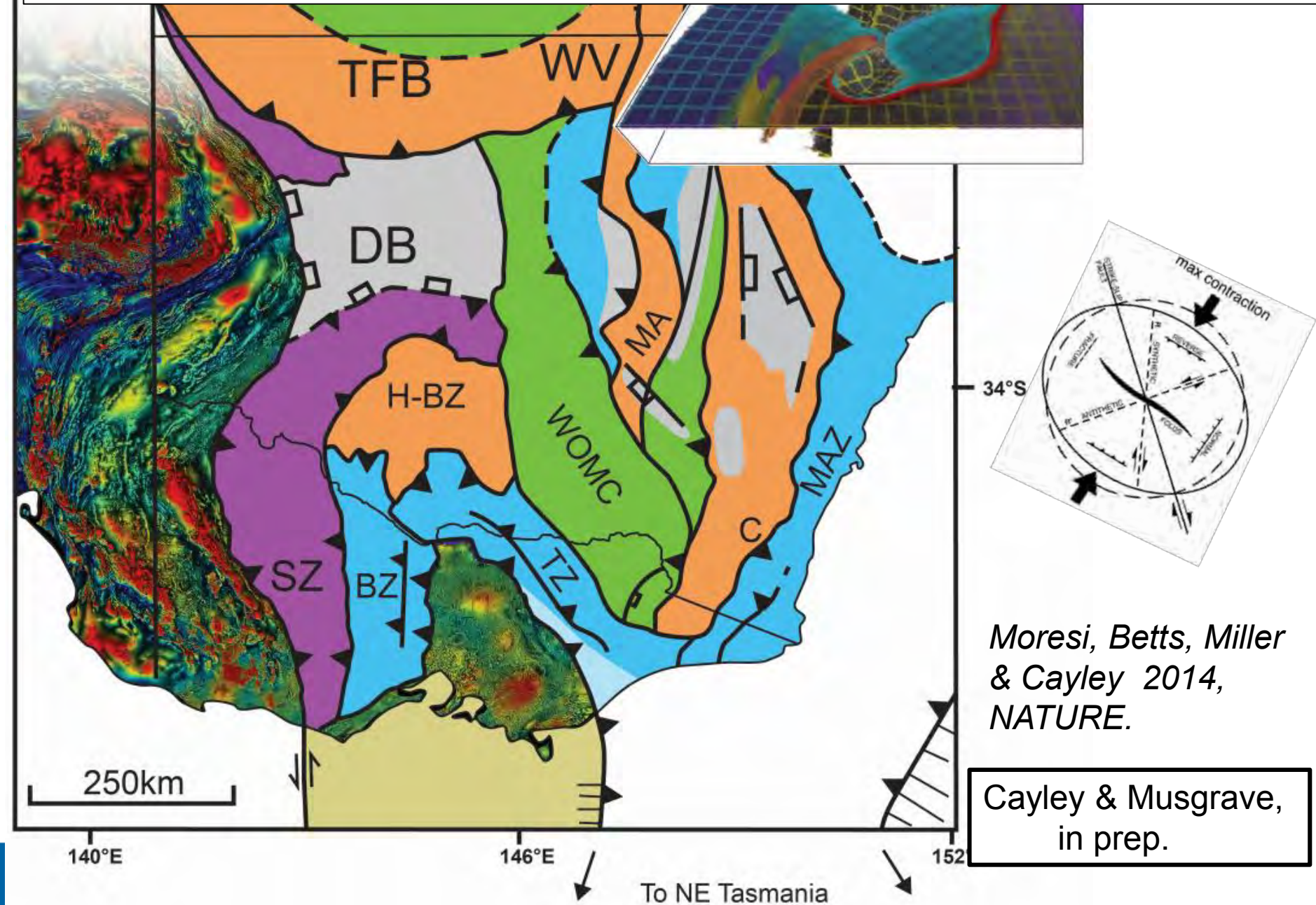


Packham, 1987 (AGU Geodynamics Series 19)

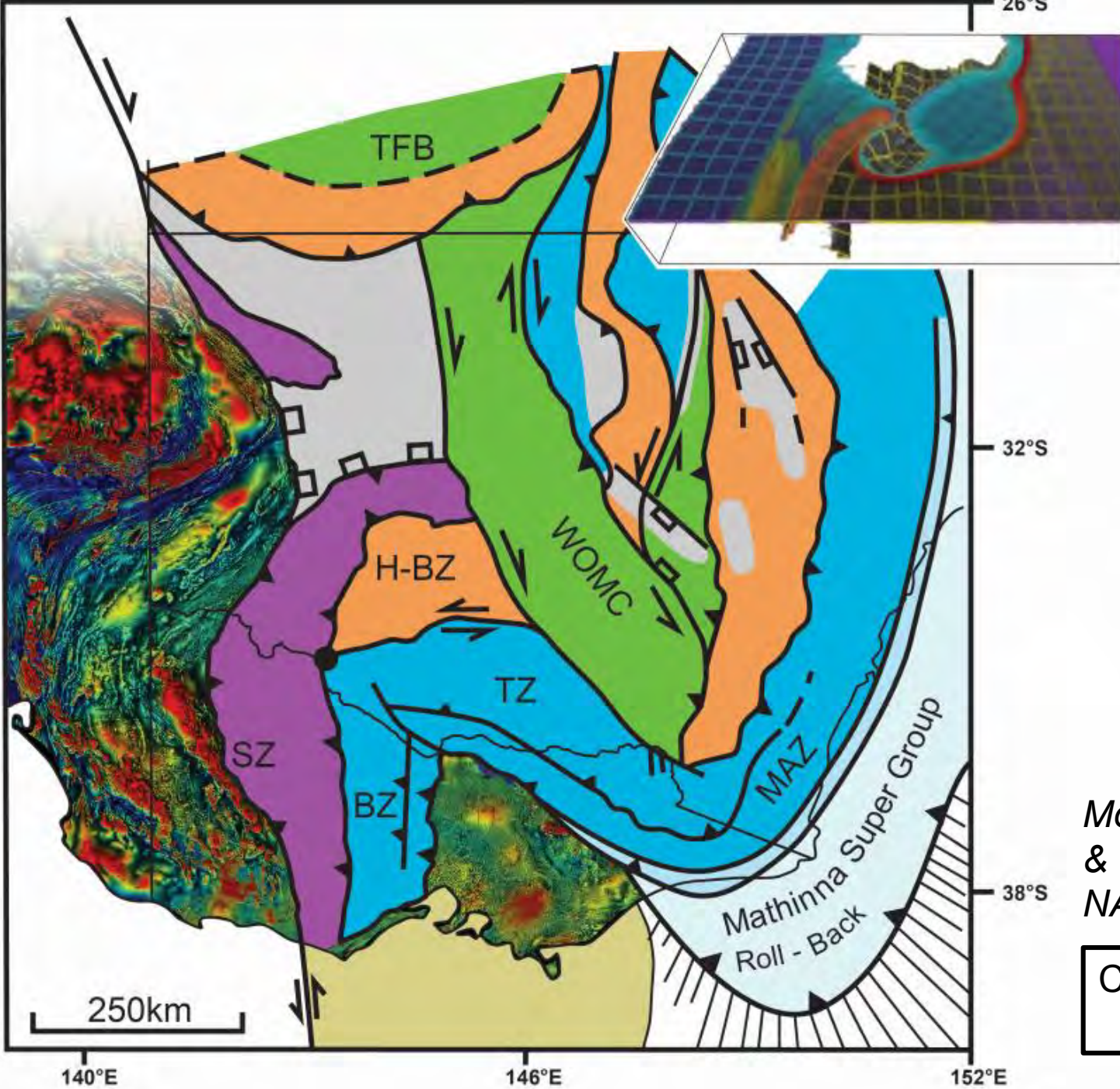
Fergusson, 2009 (AJES)



A summary of the Lachlan Orogen concept, stepped back through time (385-450 Ma), shows how the complexity of today's LFB may have evolved from simpler beginnings...



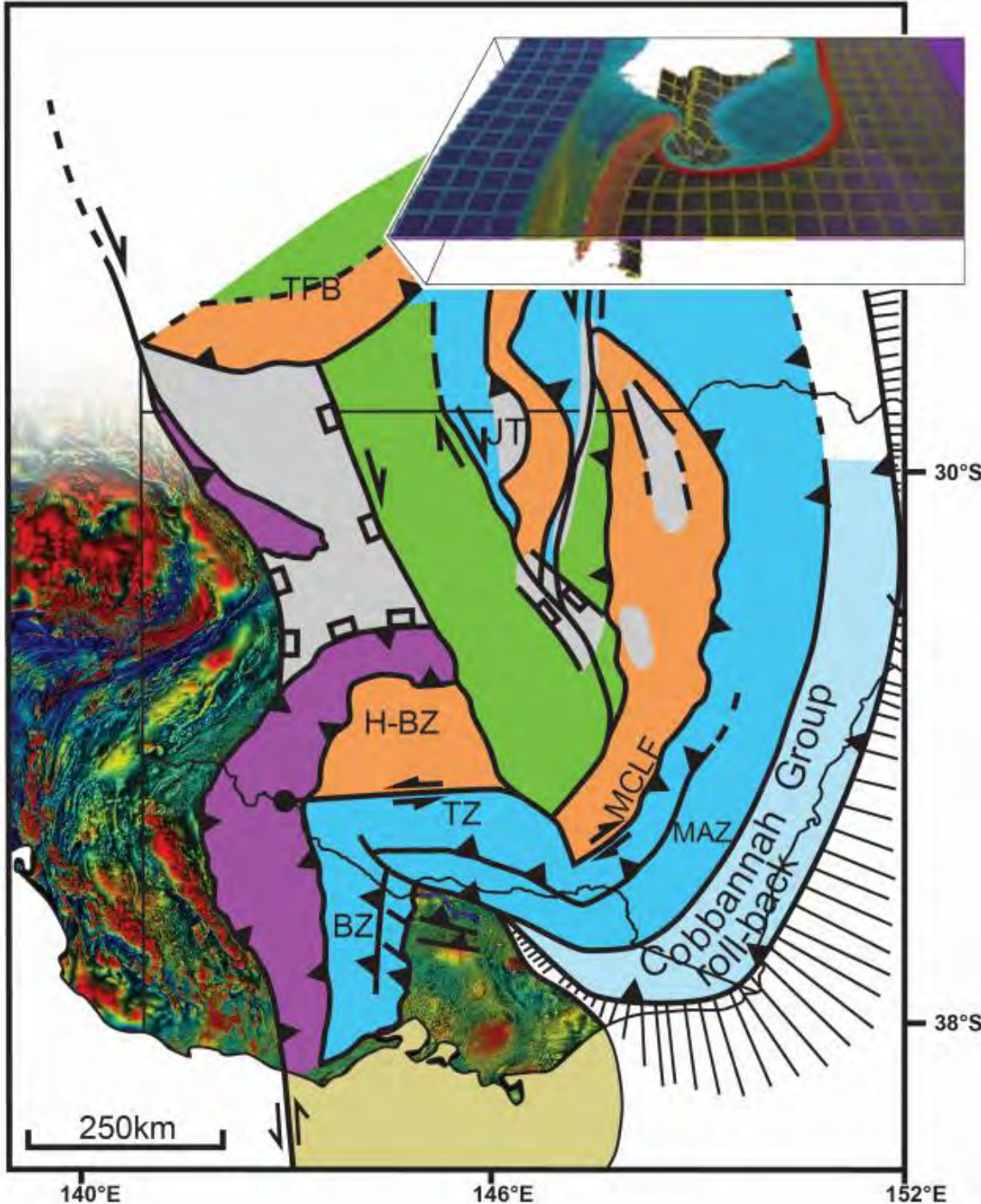




*Moresi, Betts, Miller  
& Cayley 2014,  
NATURE.*

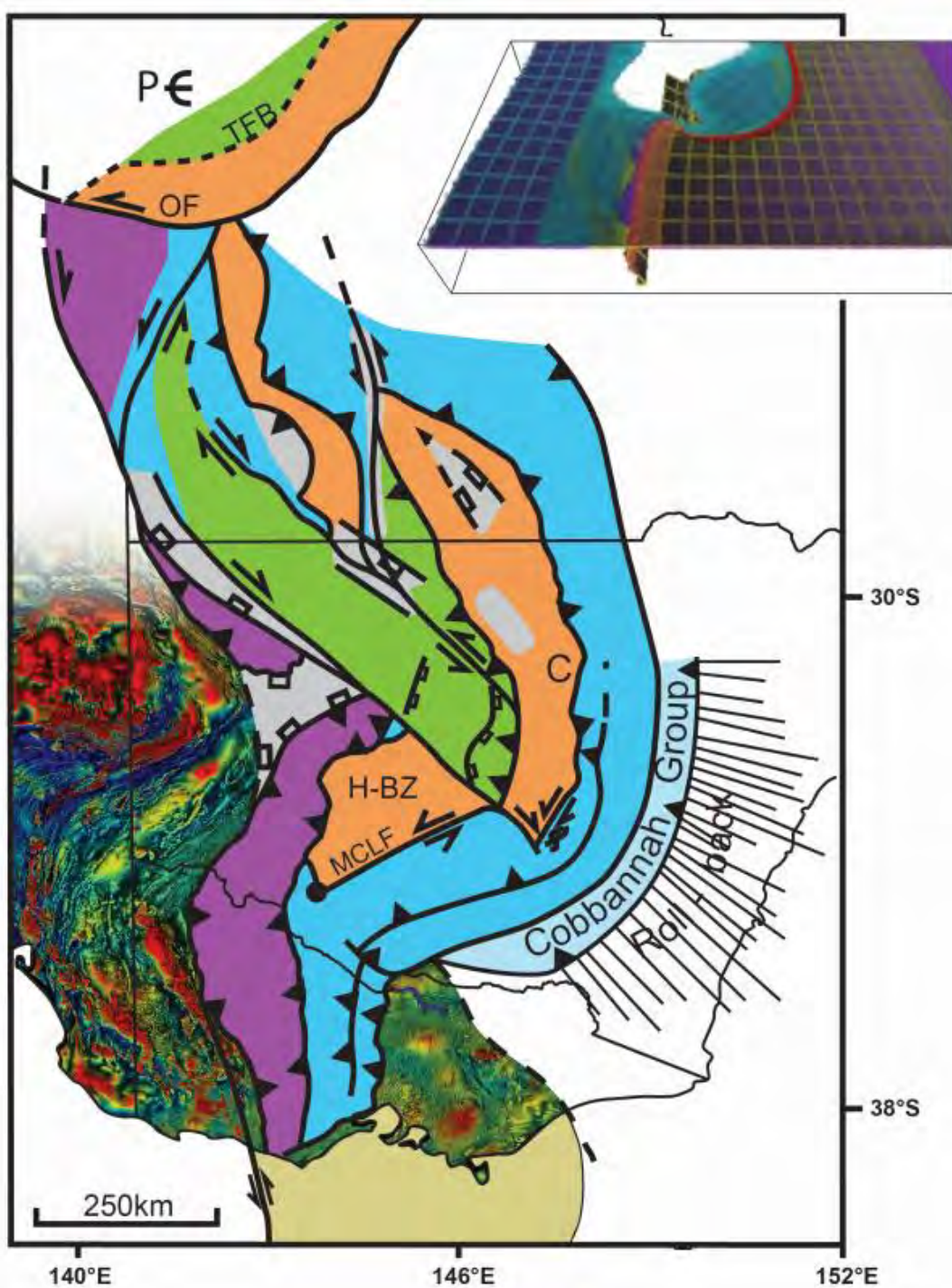
Cayley & Musgrave,  
in review





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

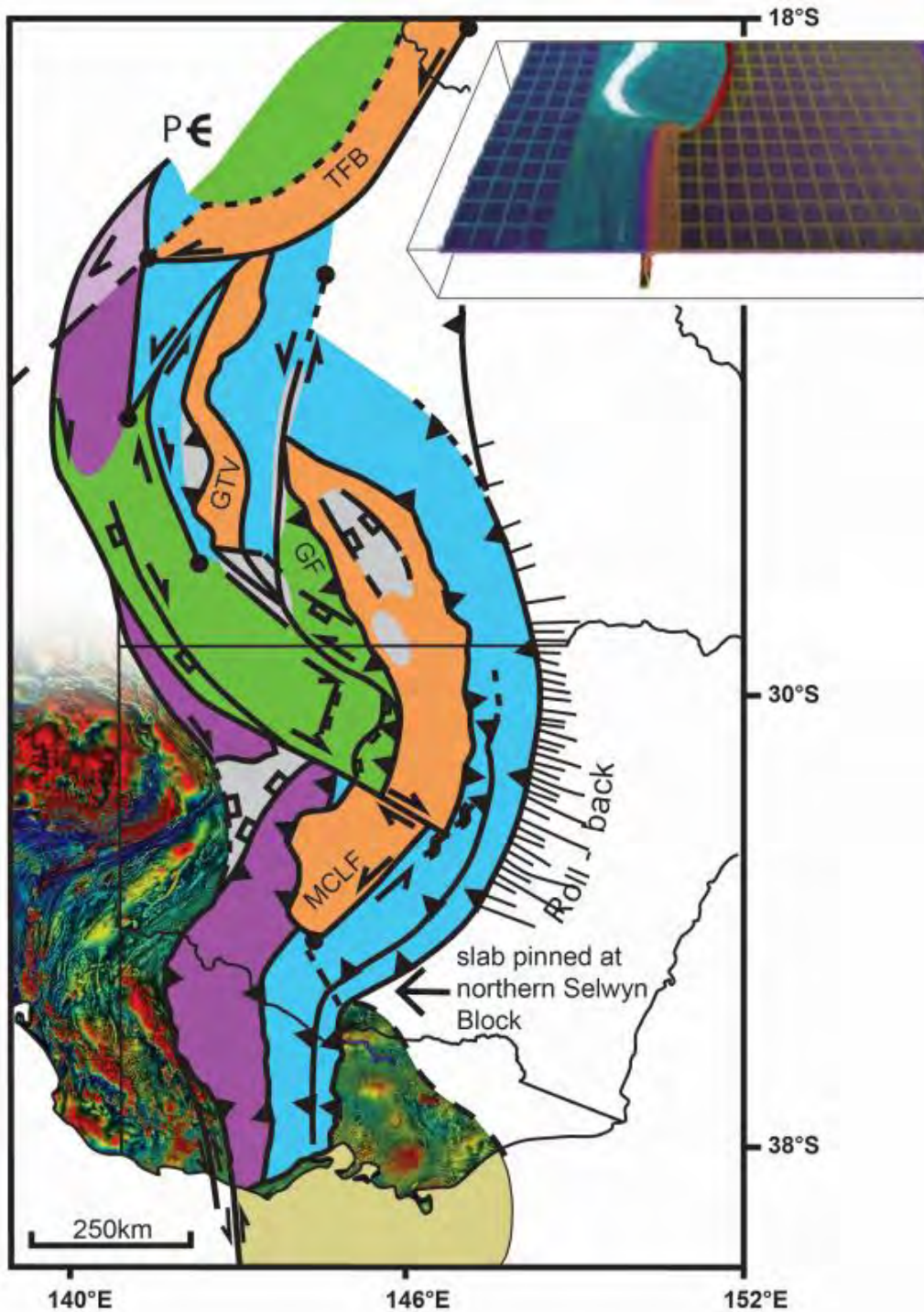
Cayley & Musgrave,  
in review



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

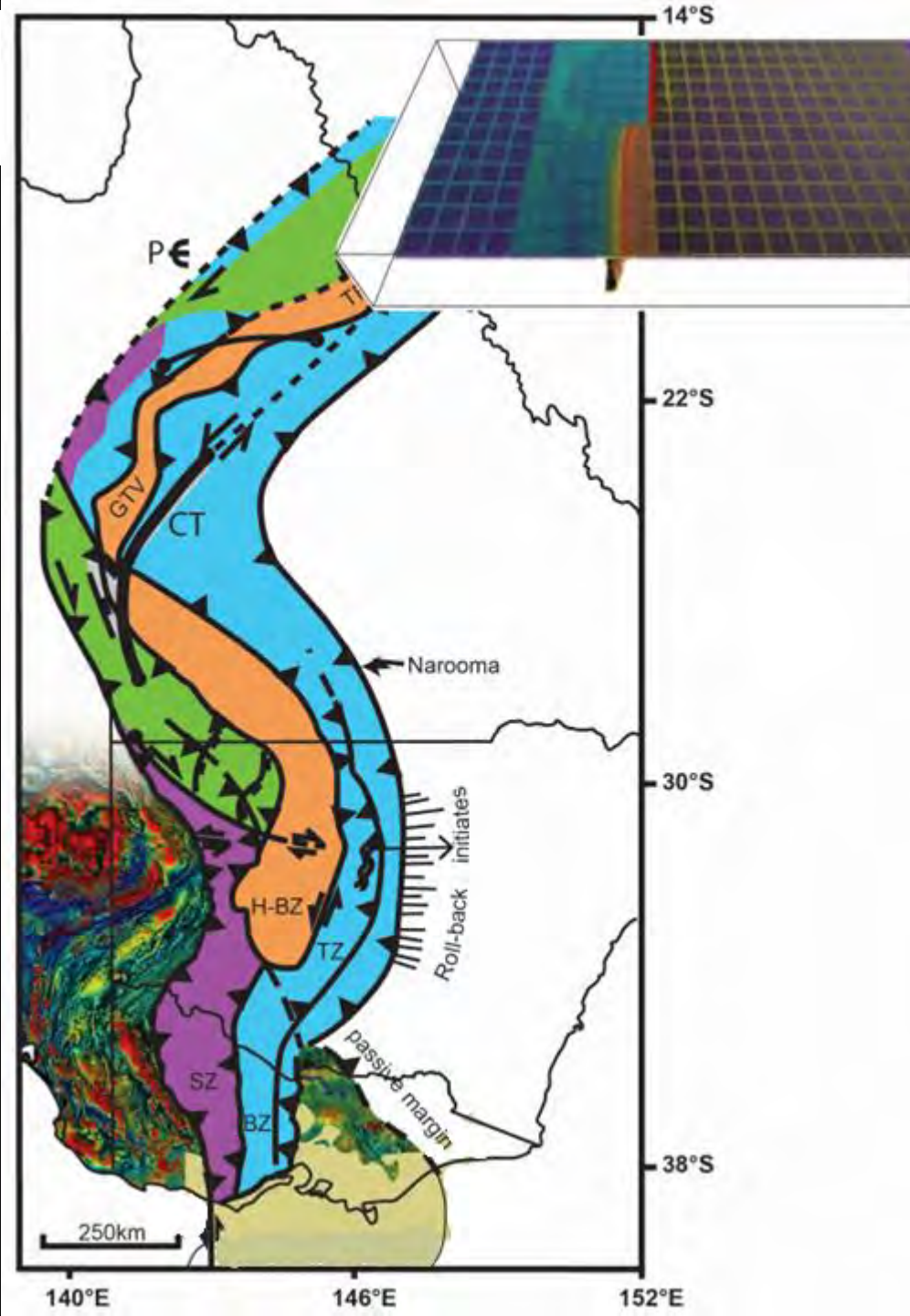
Cayley & Musgrave,  
in review





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

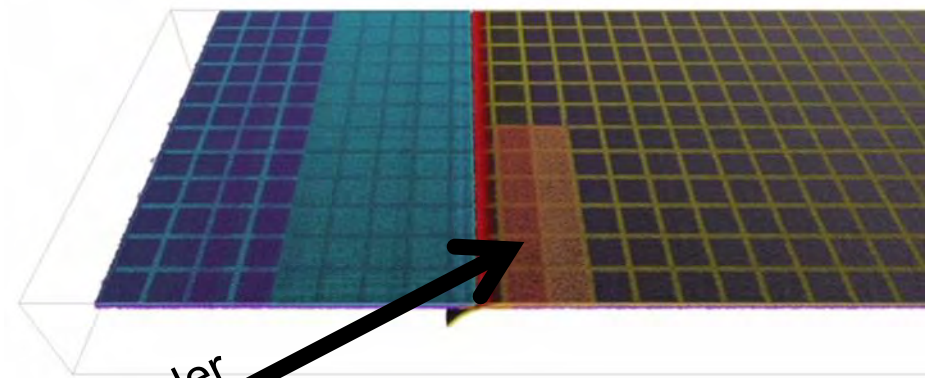
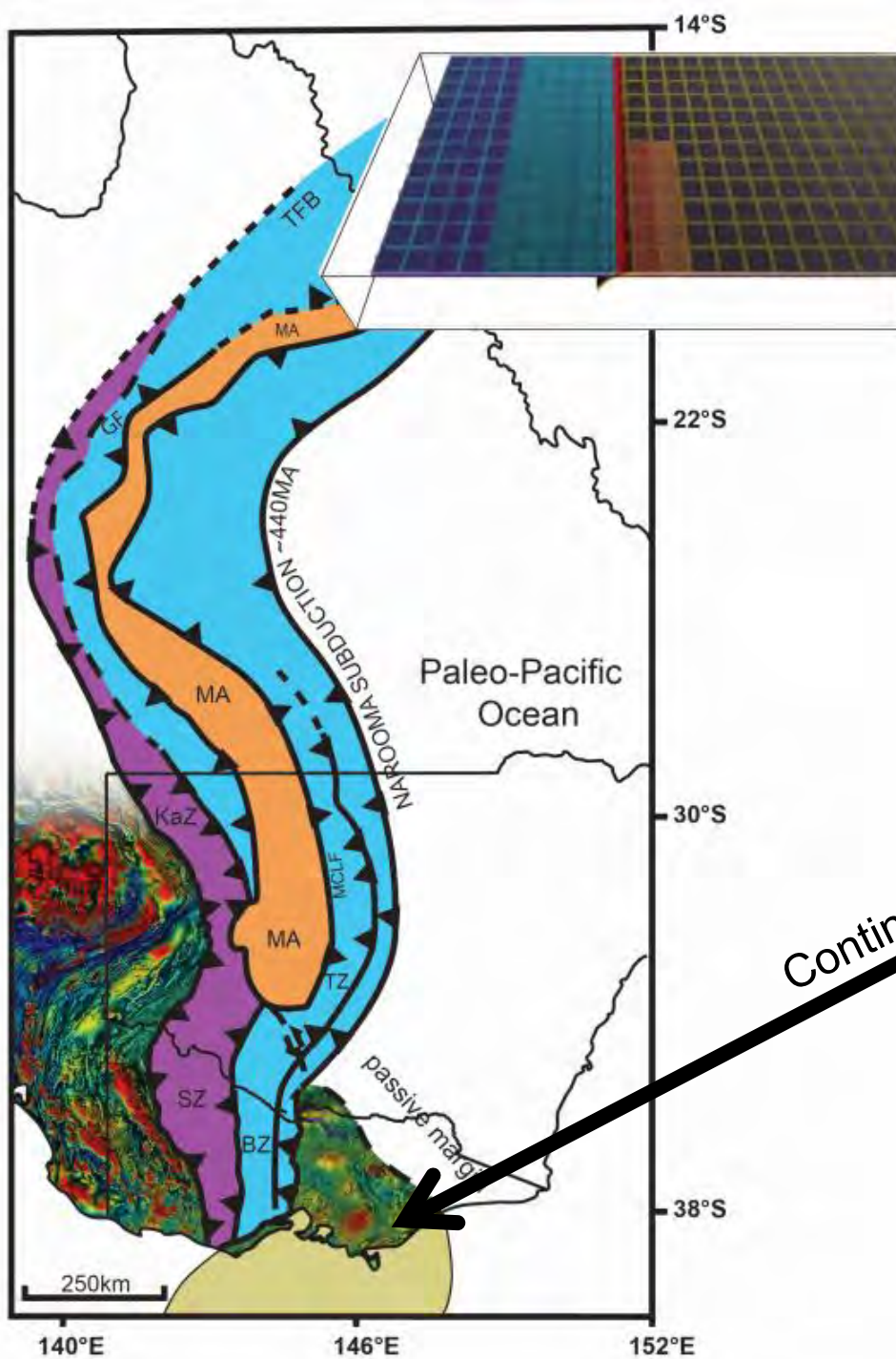
Cayley & Musgrave,  
in review



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

Cayley & Musgrave,  
in review

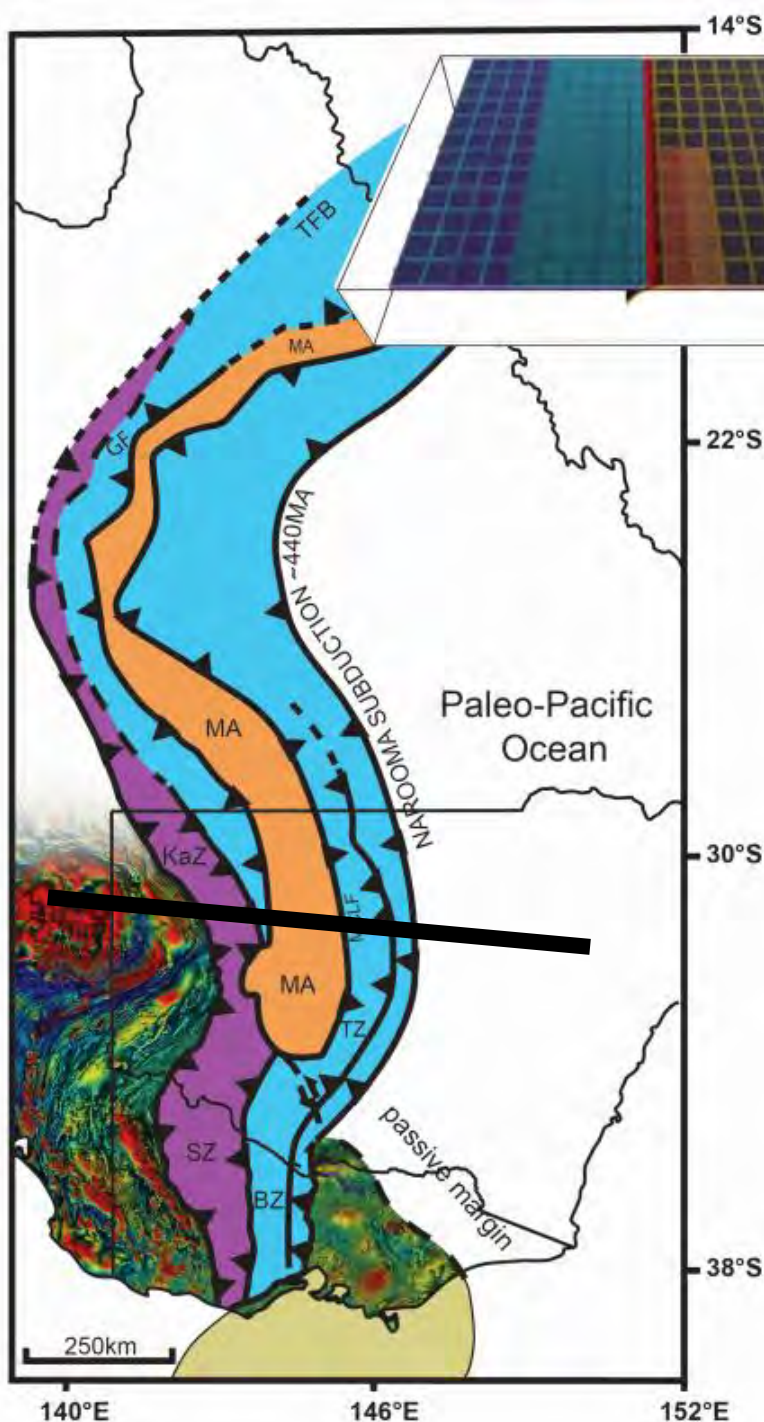




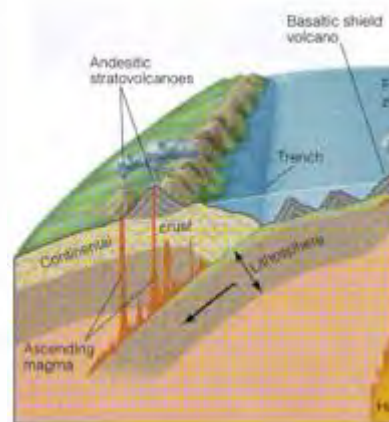
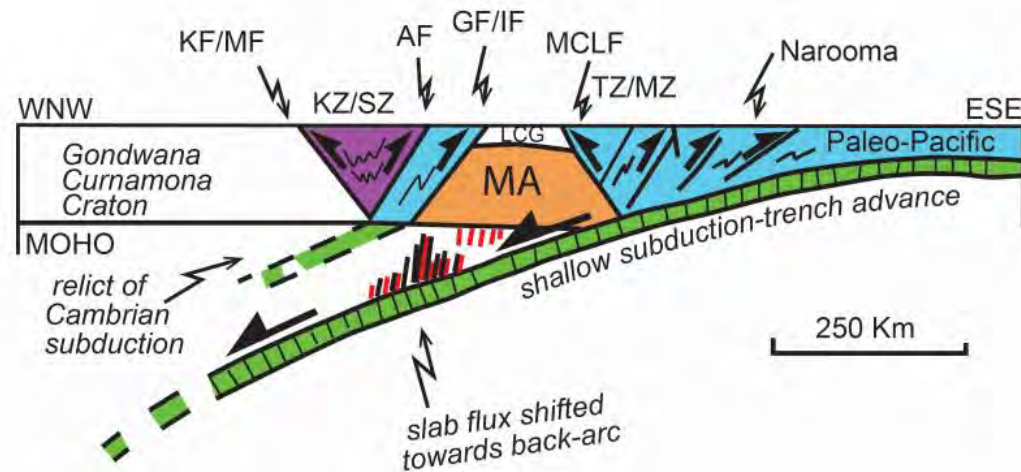
Continental Collider

Moresi, Betts, Miller  
& Cayley 2014,  
NATURE.

Cayley & Musgrave,  
in review



...When the Lachlan Orocline is unfolded, A simple, linear Macquarie Arc and Lachlan Fold Belt is revealed...



Moresi, Betts, Miller & Cayley 2014, NATURE.

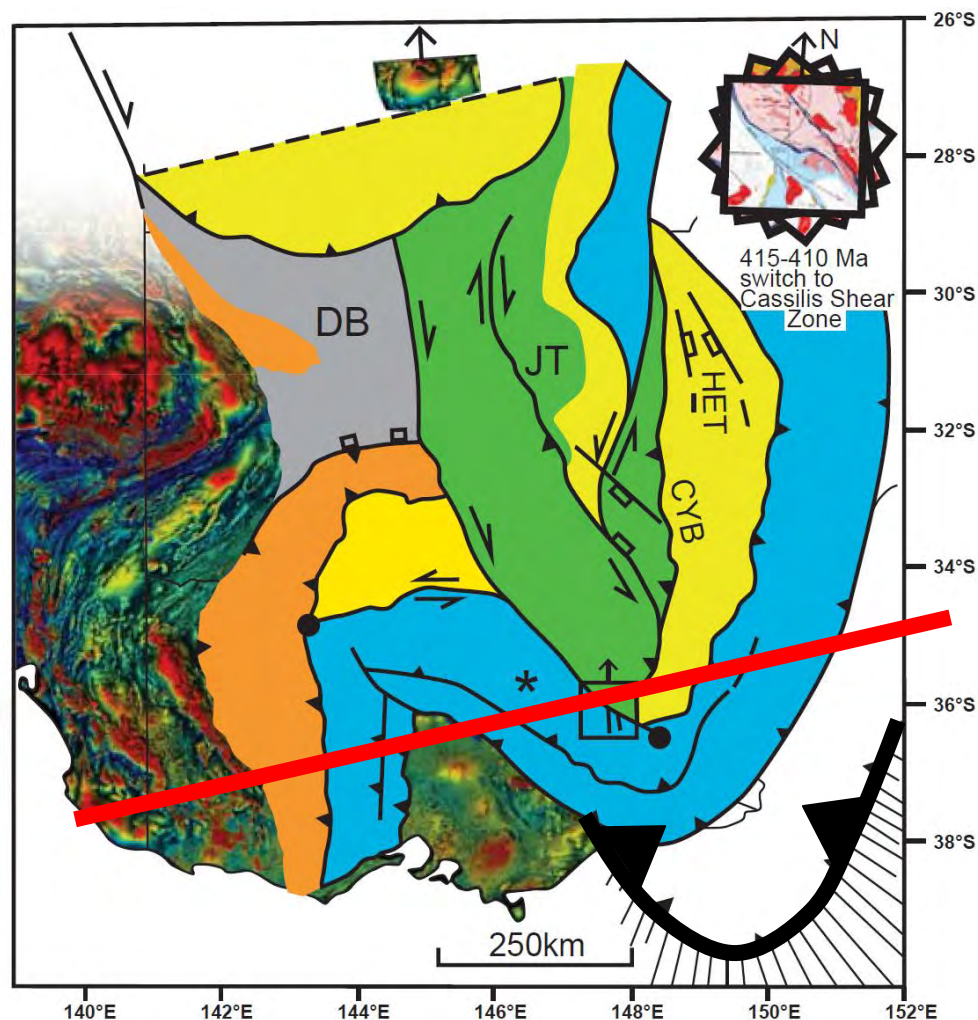
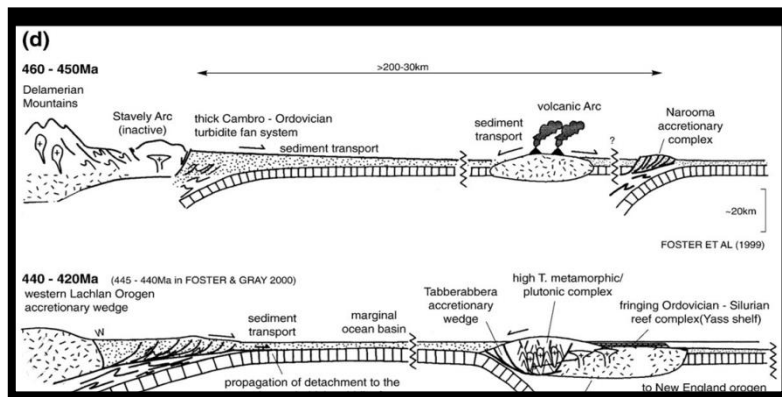
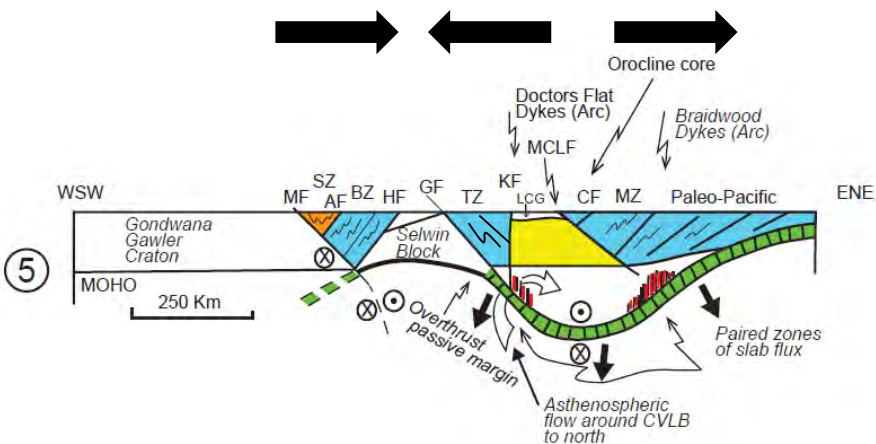
Cayley & Musgrave, in review



....It is an alternative geodynamic scenario to previous multiple subduction and/or strike-slip duplication models proposed for southeastern Australia – with its own unique geometrical characteristics that should be testable using seismic reflection

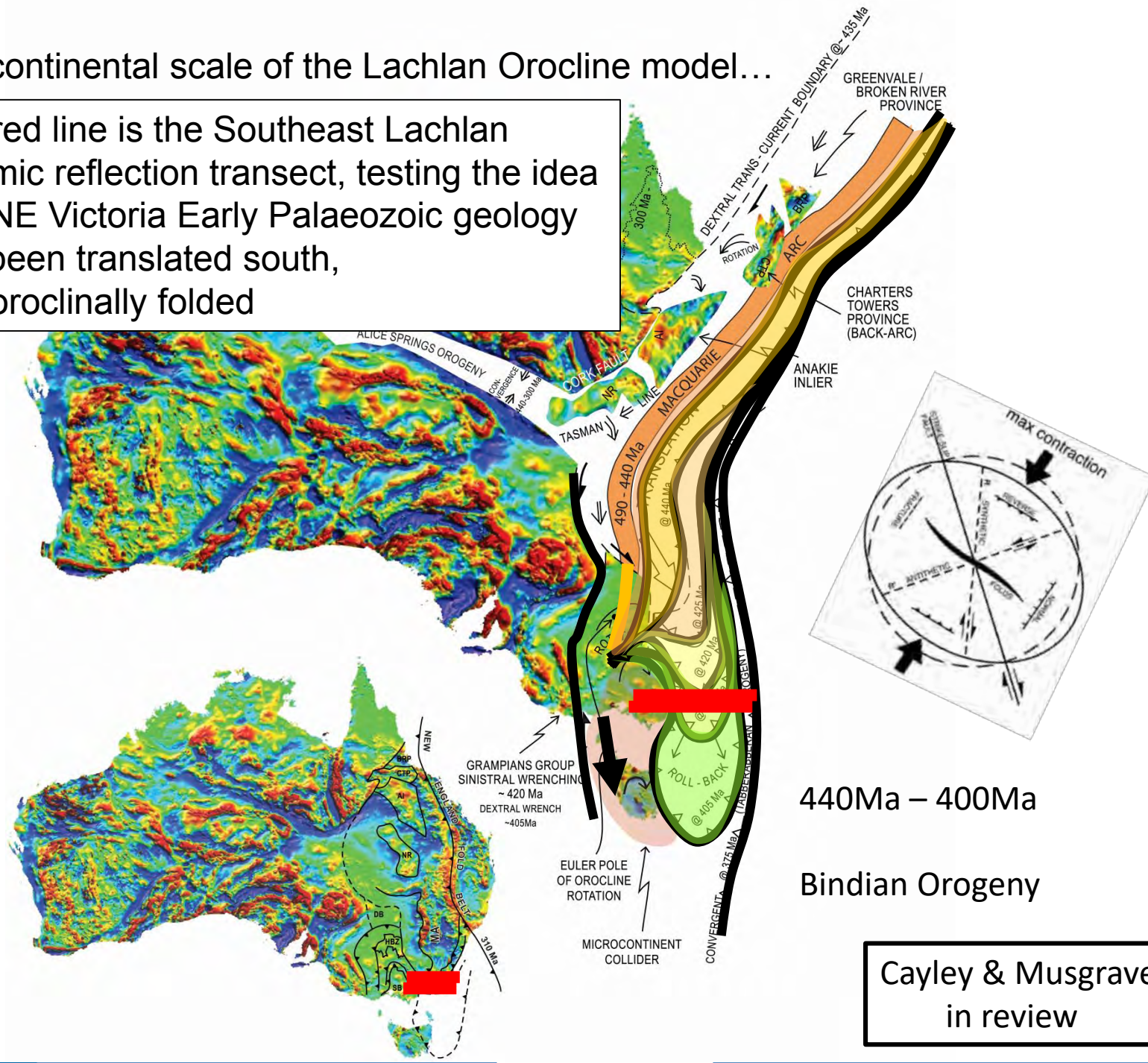
## The Lachlan Orocline:

an alternative explanation of apparent vergence reversals in Ordovician LFB:



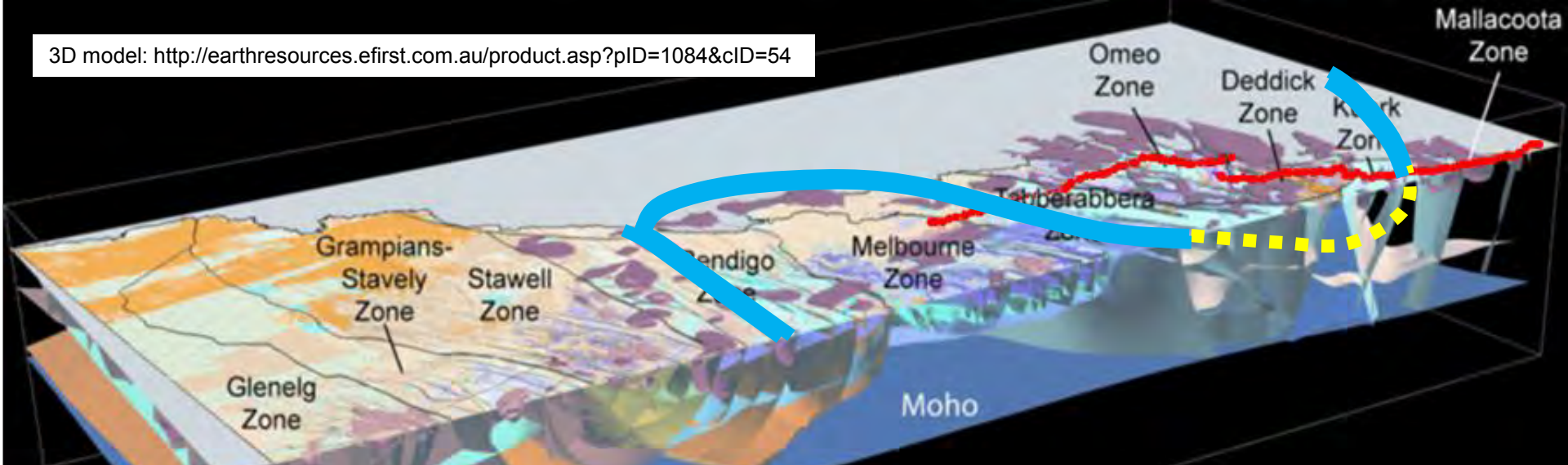
## The continental scale of the Lachlan Orocline model...

The red line is the Southeast Lachlan Seismic reflection transect, testing the idea that NE Victoria Early Palaeozoic geology has been translated south, and oroclinally folded

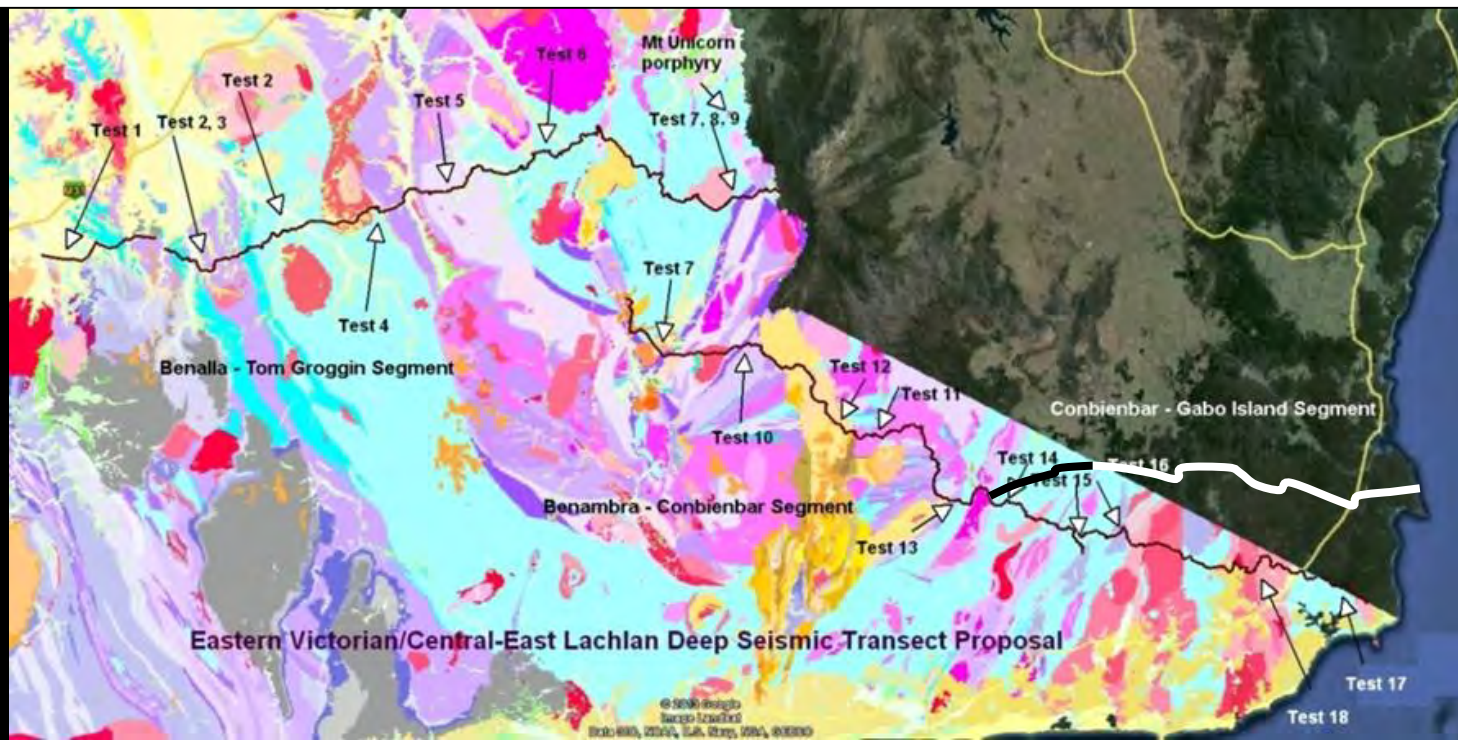




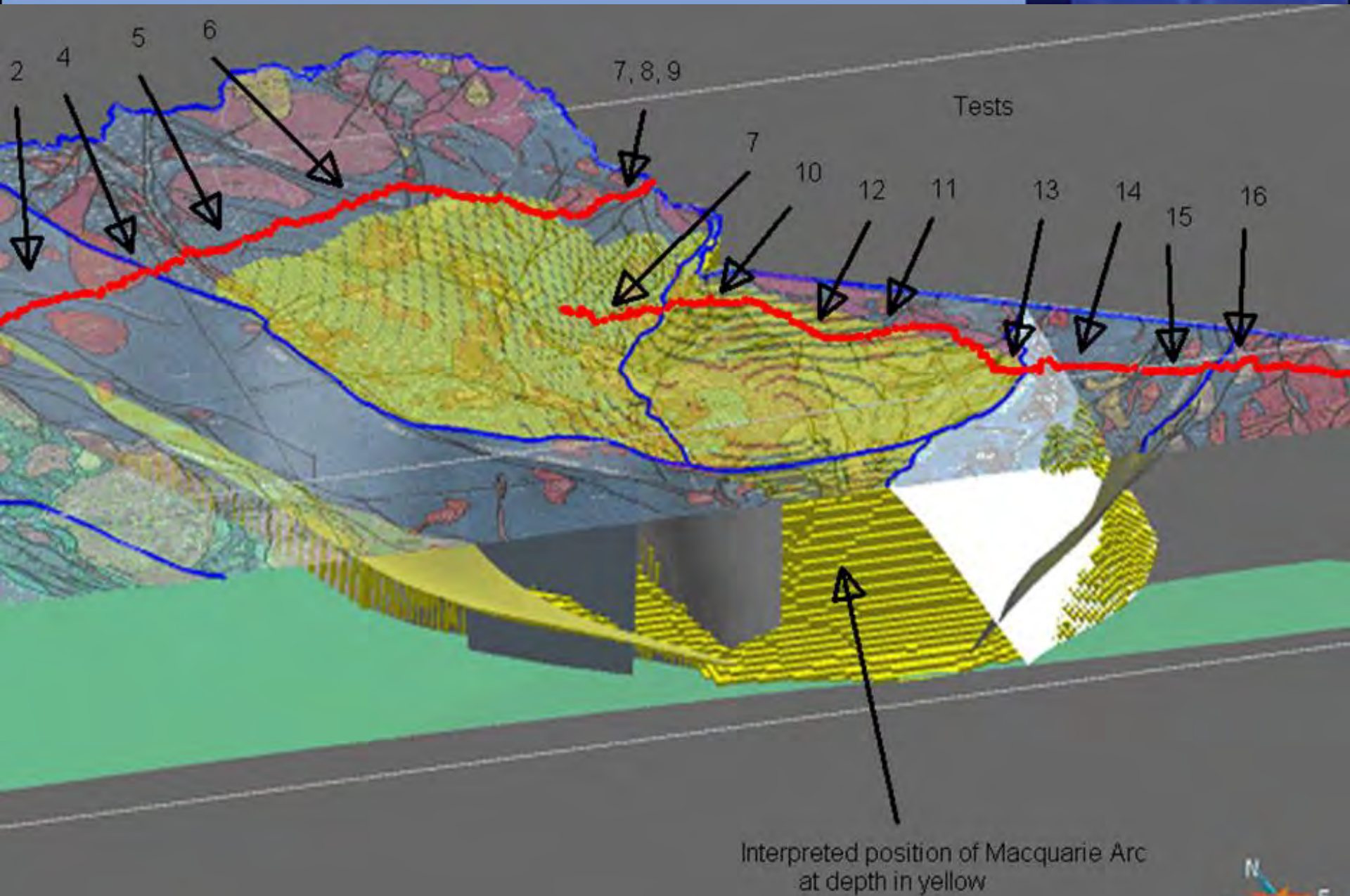
3D model: <http://earthresources.efirst.com.au/product.asp?plD=1084&cID=54>



...the Lachlan Orocline concept, and the regional-scale Victorian 3D model were both tested with the Southeast Lachlan Crustal Transect....

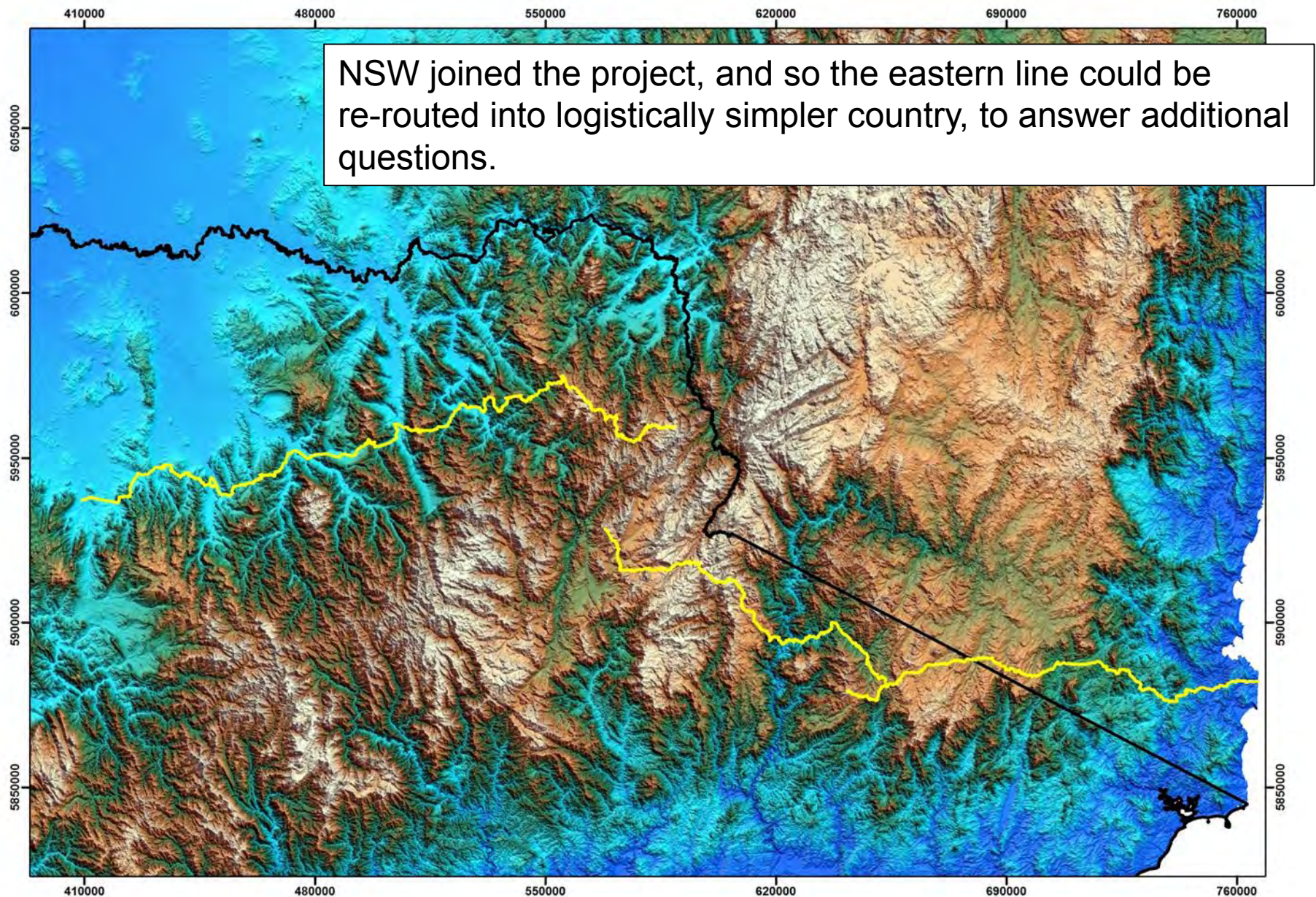






....including the prediction that Macquarie Arc material may underlie, at shallow depth, parts of north-eastern Victoria....

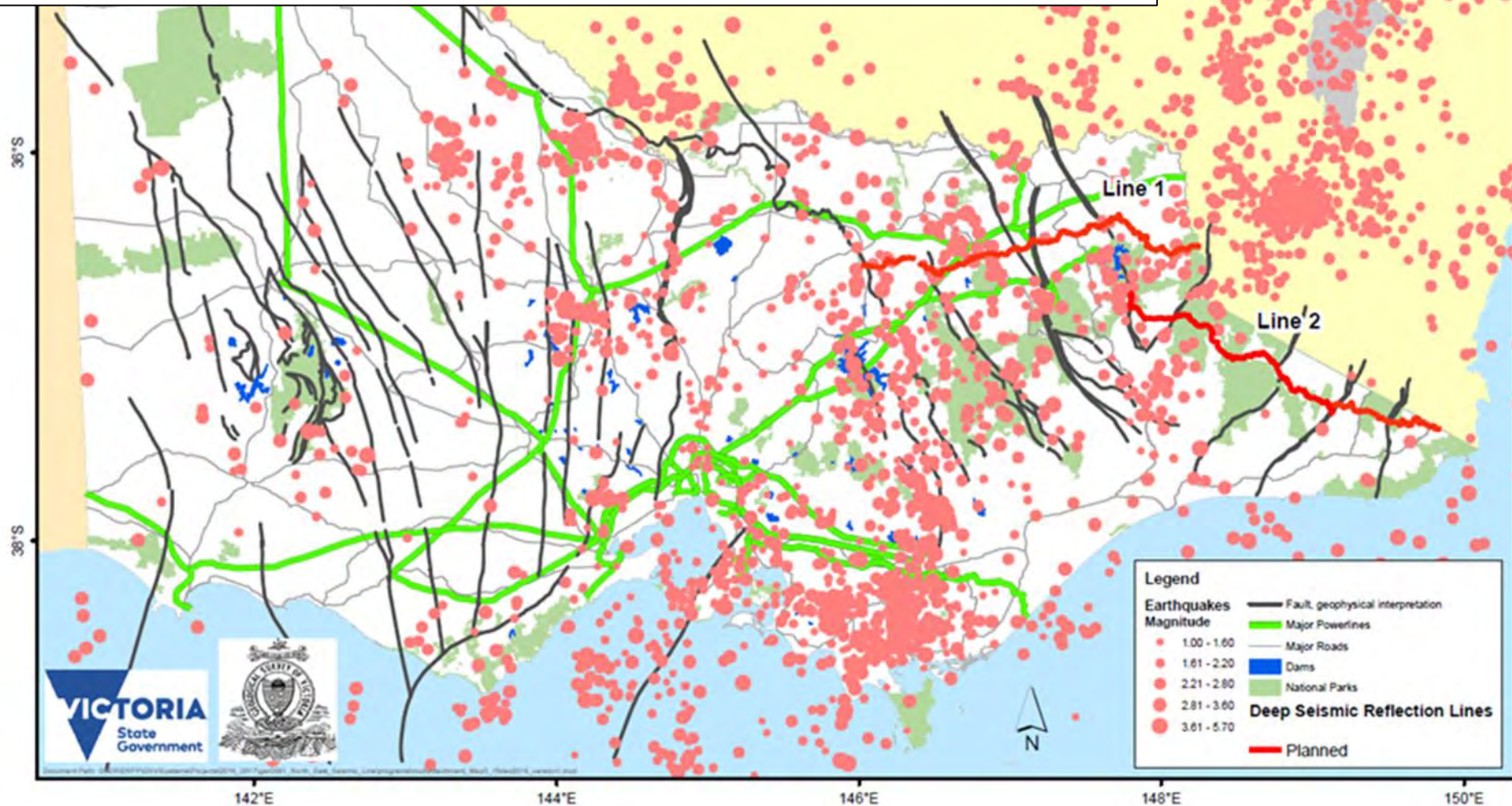






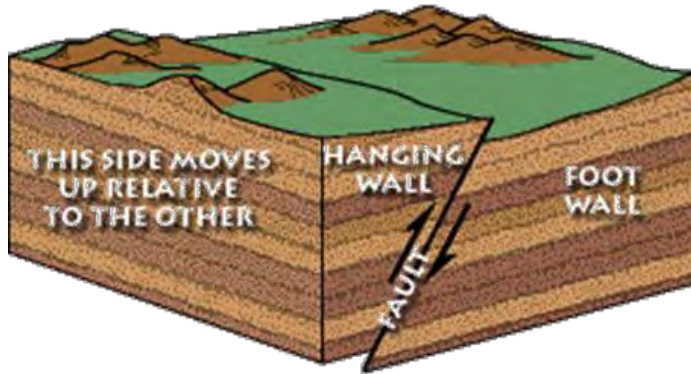
Community safety and planning was also an important objective of the project – NE Victoria and SE NSW is one of the most seismically active regions of Australia - the topographic relief of the area is obvious evidence of that.

**Rejuvenated Alpine uplift: possibly since Eocene,**  
**intensifying in Neogene-Quaternary (last 5-10 million years).**





# Seismic hazard mapping



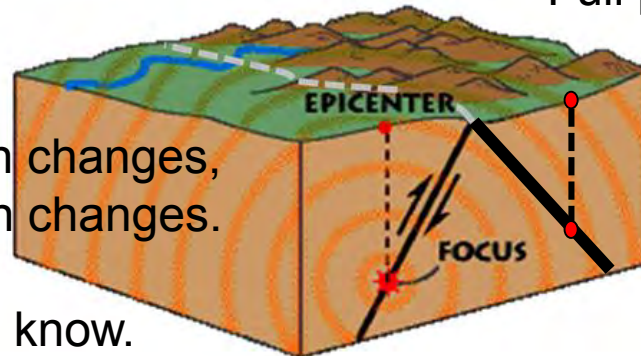
Eastern Victoria:

Recent fault movements – eg. Tawonga Fault  
landslide activity: eg. Lake Tali Karng  
ongoing seismic activity up to ~M6.0

Relatively high horizontal compressive stress =  
tends towards shallow level (<5km) earthquakes  
= most destructive for any given magnitude.

Full pattern of seismicity not established

eg. Sandiford, 2003; Sandiford et al., 2004



If the fault dip direction changes,  
the epicentre location changes.

This would be good to know.

Seismic reflection can better determine fault dip directions.

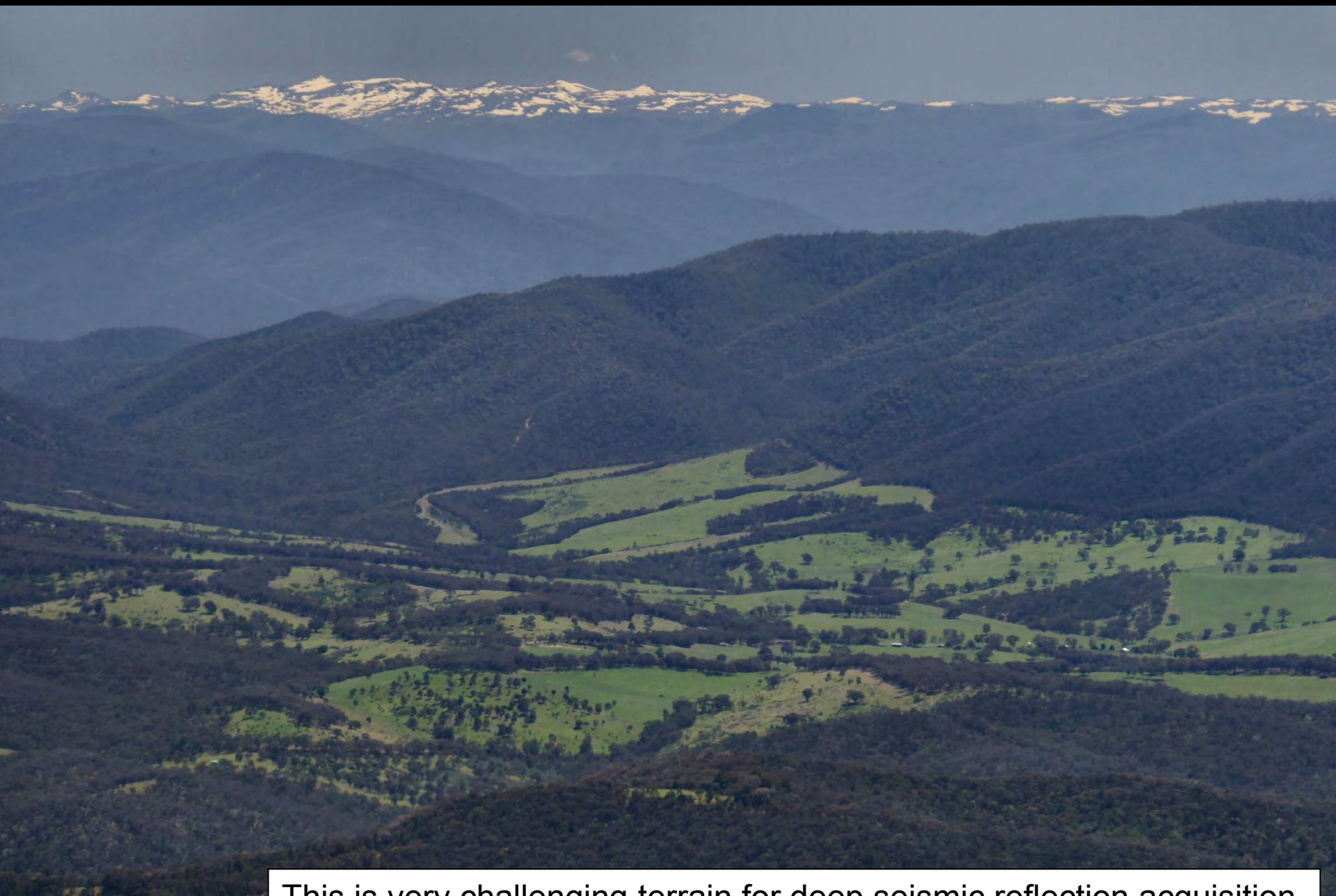
Seismic hazard mapping can better estimate

local seismic (shaking) hazard – a duty of care

# Talk Outline

- A deep seismic reflection transect in eastern Victoria.
- Why?
- **Where?**
- Logistics
- Acquisition
- Next steps

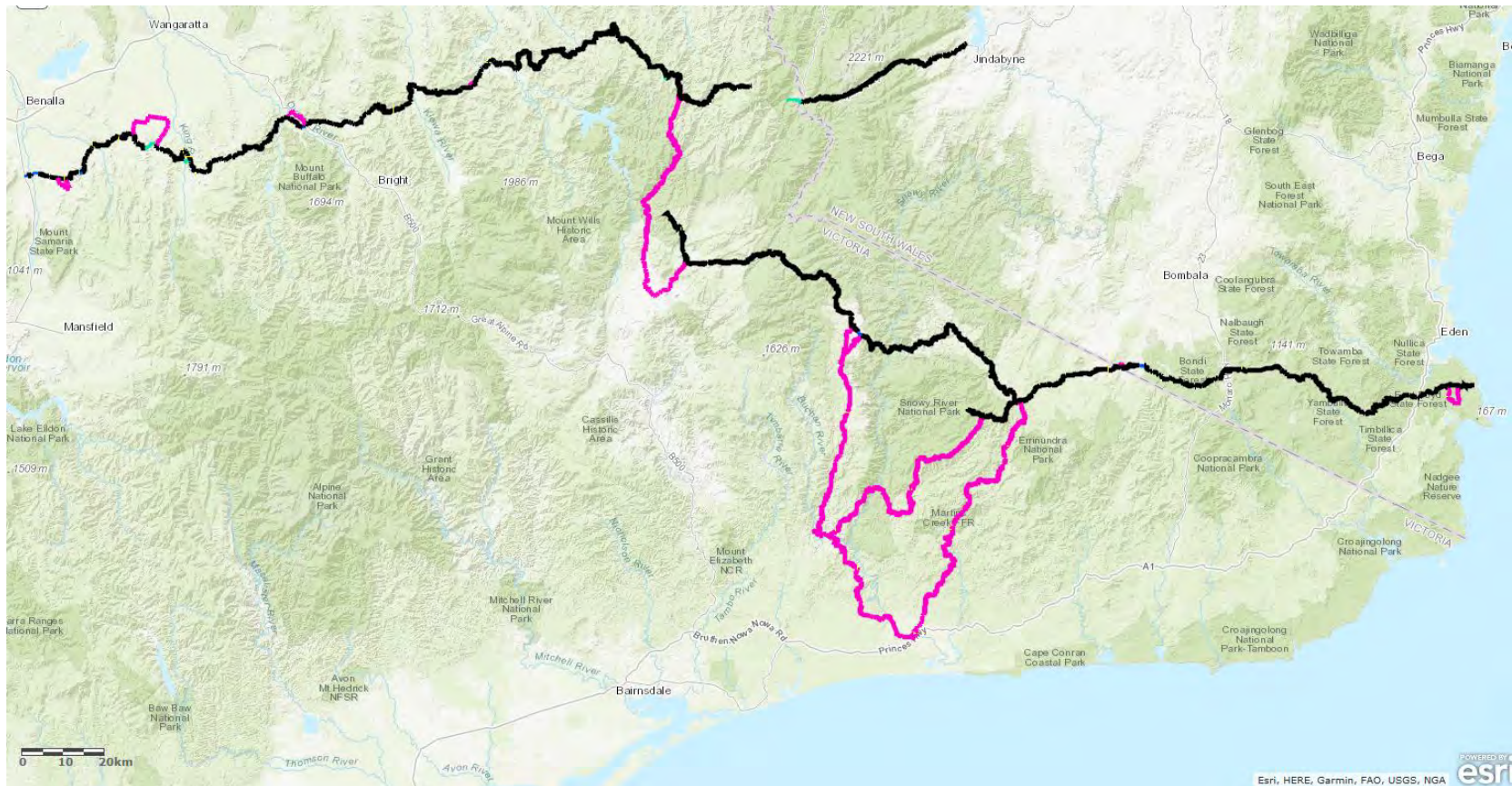




This is very challenging terrain for deep seismic reflection acquisition



# EASTERN VICTORIA GEOPHYSICAL SURVEY ROUTES



Line 1 North East Victoria from Benalla to the junction of Link Trak and Mt Boeuck Trak in Alpine NP.

Line 2 East Gippsland from Benambra through to east of Bendoc on the NSW border.

Line 2 continue into New South Wales east of Wonboyn North. The NSW part of the survey will be managed by Geological Survey NSW

Detours (in pink) will be used for support vehicles and where bridge limits are not suitable for the vibroseis trucks



# Talk Outline

- A deep seismic reflection transect in eastern Victoria.
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Route planning, line scoping in late 2017





Some routes worked, others didn't. This one didn't.





...once we had a possible route, it was time to engage with landowners/managers.....bring on the paperwork!!



Mr Paul McDonald  
Director Geological Survey of Victoria  
Department of Economic Development, Jobs, Transport and Resources  
Level 17, 1 Spring Street, Melbourne VIC 3000

Dear Mr McDonald,

**Eastern Victoria Geoscience Initiative, February – June 2018**  
I refer to your application, requesting approval to conduct Research ('Event') on a freeway or arterial road on between February – June 2018.

Under section 99B(1) of the *Road Safety Act 1986*, I advise that Forest Fire Management Victoria (FFMV) permits you to conduct the Event on the designated freeway(s) or arterial road(s) managed by FFMV, subject to the following:

- compliance with your submitted Traffic Management Plan and Risk Management Plan; and
- the conditions of the attached Permit.

I also advise that FFMV authorises, for the purposes of the *Road Safety (Traffic Management) Regulations 2009*, any event signage or traffic control devices outlined in your Traffic Management Plan.

The Permit is given to Geological Survey of Victoria and Geoscience Australia. It is given on the understanding that the activities referred to in the Permit will occur under the direction and control of, and will be the responsibility of Geological Survey of Victoria and Geoscience Australia. By applying for this Permit, you have consented to the disclosure of your contact details to any member of the public inquiring about the Event. FFMV reserves the right to amend the Permit at any time.

At least one official who is on location at the Event must carry a signed copy of the Permit, together with any Gazette notice being relied on for exemption from the law, and must be able to produce them on request to any member of Victoria Police, or to any person who is an authorised officer under *Section 71 of the Road Management Act 2004*.

In conjunction with the Event, the route in the attached Permit have been approved subject to all other requirements being met. No additional road use or road closures may be implemented without permission from VicRoads (in the case of freeways or arterial roads) or the relevant municipal council (in the case of local roads).

**FFMV and the Department of Environment, Land, Water and Planning (DELWP) do not accept any responsibility for accidents, damage or injury to property, participants or**

**Privacy Statement**  
Any personal information about you or a third party in your correspondence will be protected under the provisions of the Privacy and Data Protection Act 2014. It will only be used in accordance with appropriate administrative, statutory authority, or departmental staff in regard to the purpose for which it was provided, unless required or authorised by law. Enquiries about access to information about you held by the Department should be directed to the Privacy Coordinator, Department of Environment, Land, Water and Planning, 80 Swanston Street Melbourne, Victoria 3000.



# Landholder / manager Engagements, permitting

Permit No: 10008658  
File No: FF383578

## NATIONAL PARKS ACT 1975, CROWN LAND (RESERVES) ACT 1978 AND FORESTS ACT 1958 RESEARCH PERMIT

Pursuant to provisions §20 National Parks Act 1975, Crown Land (Reserves) Act 1978 and §52 of Forests Act 1958 permission is hereby granted to:

Mr Paul McDonald  
Director Geological Survey of Victoria  
Earth Resources Policy and Programs  
DEDJTR  
Level 17, 1 Spring St  
Melbourne VIC 2000

Ms Tanya Fomin  
Senior Research Scientist  
Onshore Seismic and Magnetotellurics  
Geoscience Australia  
101 Jerrabomberra Ave  
Symonston ACT 2609

and Mr Cameron Calms, Ms Roisin Langrell, Mr Ross Cayley and Mr Ed Gerner, Geological Survey of Victoria and Geoscience Australia and the contractor, Tarrux Seismic Ltd, and staff under the direction of either permit holder to –

Conduct a seismic survey using deep seismic reflection profiling to gain regional-scale information on the nature of the earths crust in Eastern Victoria.

The objective of the project is to use deep seismic reflection profiling to gain regional-scale information on the nature of the Earth's crust along a line that extends east from central Victoria (near Bevalia) to the southeast coast of Australia, completing an east-west transect of seismic reflection data across the bedrock geology of the State. Seismic data acquisition will be supported by gravity measurements along two lines with a total length of more than 400km. The seismic survey will allow correlation between surface features and deeply buried crustal features. This will enhance understanding of the geologic makeup of the State, constrain regional-scale three-dimensional models of the crust, and test recent hypotheses regarding tectonic evolution of the region. The new data will help determine the geometry of major faults subject to recent and ongoing reactivation to uplift the Victorian Alps, thereby improving earthquake hazard mapping, infrastructure planning and community safety in this region.

Permission is given subject to the following particular conditions:

1. Arrangements for access and authorisation to conduct research on land managed by Parks Victoria must be made at least FIVE WORKING DAYS in advance with the Parks Victoria District Manager on 13 19 63 who must be advised of any activity proposed in connection with the provisions of this permit. The permit holder will advise the District Manager of current operations at least every 3 days whilst working on Parks Victoria managed land. The permit holder must abide by any decisions of the Parks Victoria District Manager or delegate.
2. The researchers are required to notify the relevant DELWP representatives listed below of their proposed activities at least FIVE WORKING DAYS in advance of working on land managed by DELWP. The permit holder will advise the relevant district contact below of current operations at least every 3 days whilst working on DELWP land. The permit holder must abide by any decisions of the DELWP representatives listed below or delegate.

### DELWP representatives

District	Name	Role	Phone	Email
Goulburn, Ovens and Upper Murray	Shawn Lawlor	Regional Manager: Forest and Fire Operations	(03) 57611609 0427 303 854	<a href="mailto:Shawn.P.Lawlor@delwp.vic.gov.au">Shawn.P.Lawlor@delwp.vic.gov.au</a>
Snowy	Neil Wait	Senior Forest Management and Rousling Officer	(03) 5161 1335 0429 177 974	<a href="mailto:Neil.Wait@delwp.vic.gov.au">Neil.Wait@delwp.vic.gov.au</a>
Tambo	Brad Fisher	District Manager	(03) 5157 0495 0429 103584	<a href="mailto:Brad.Fisher@delwp.vic.gov.au">Brad.Fisher@delwp.vic.gov.au</a>

3. The permit holder should contact the Forest Fire Management Victoria (FFMVic) District Duty Officer regularly throughout the survey to ascertain the current bushfire situation and details of planned burns that may impact on the survey.

Note: The DELWP representatives listed in clause 2 will provide the survey team with the District Duty Officer's contact details and the District Duty Officer with the survey team's contact details as required.



## Tender process: A week of line scoping with shortlisted applicants



Because of the unique terrain/logistical challenges presented by this project, project tenders were shortlisted, and the shortlisted applicants were shown the entire route so that they could prepare detailed project quotes.







Bush infrastructure had to be able to cope with 15 tonne axle loadings, and 30+ tonne gross vehicle weights and minimum 2.5m+ widths....or alternatives (drive arounds) were needed...





With a 20T gross load limit, Mckillops Bridge across the iconic Snowy River was a potential show-stopper....





...there is no easy way to drive around this bad-boy.....



## 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

Back crew



Vibrators



Front crew



12 km Live Spread





# Talk Outline

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- Why?
- Where?
- Logistics
- **Acquisition**
- Next steps

This was a massive, mobile operation with complex logistics – dozens of staff, dozens of vehicles, camp accommodation, data processing infrastructure, etc.

Swanpool footy oval, south of Benalla









The project team took over the Swanpool footy oval for the first quarter of the operation.





## Project kick-off meeting in Swanpool





First vibe point on the line



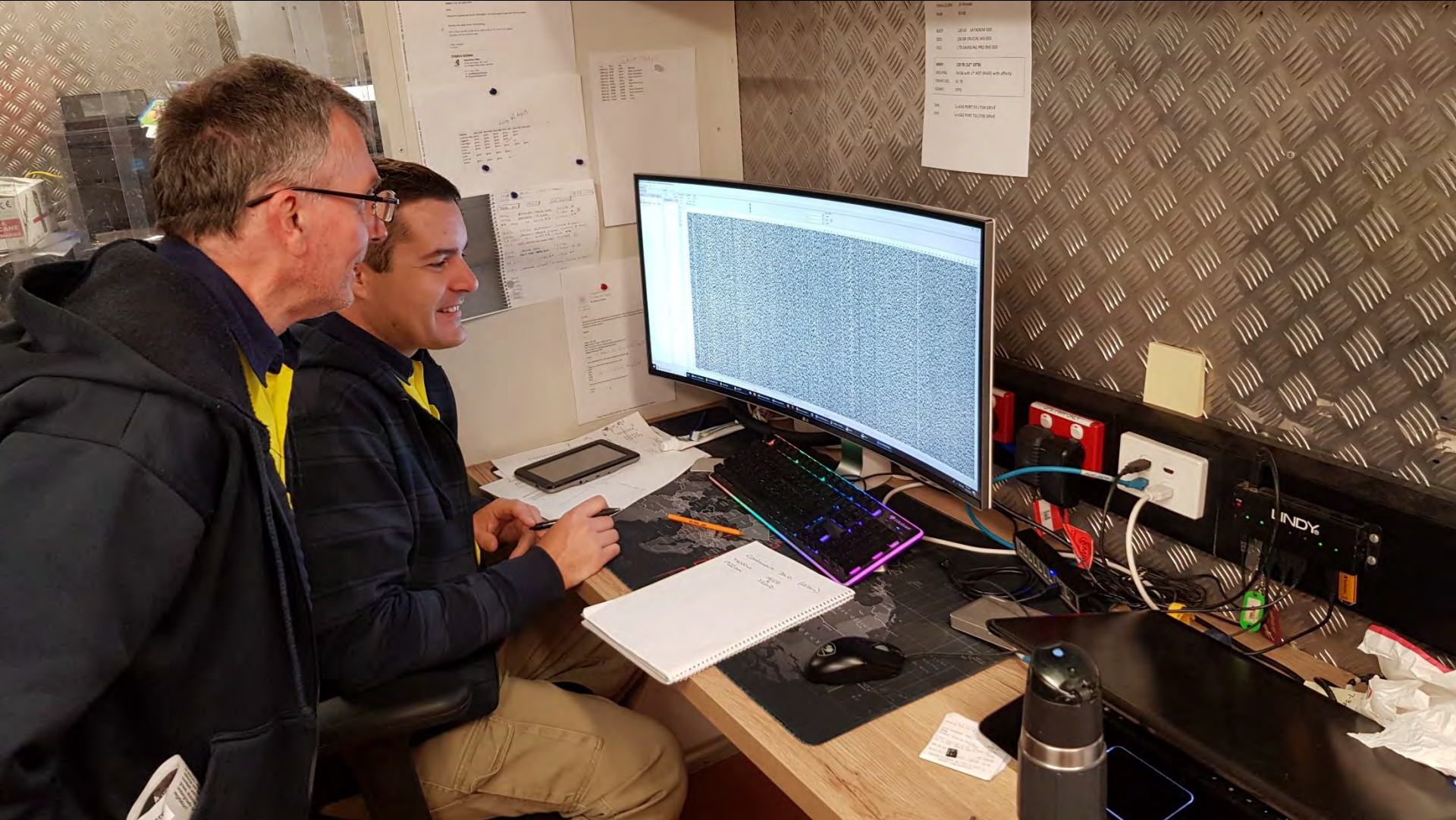


Inside the vibe control truck – real-time control on the vibrator plates





## First look at the raw data back in the data-processing office at Swanpool



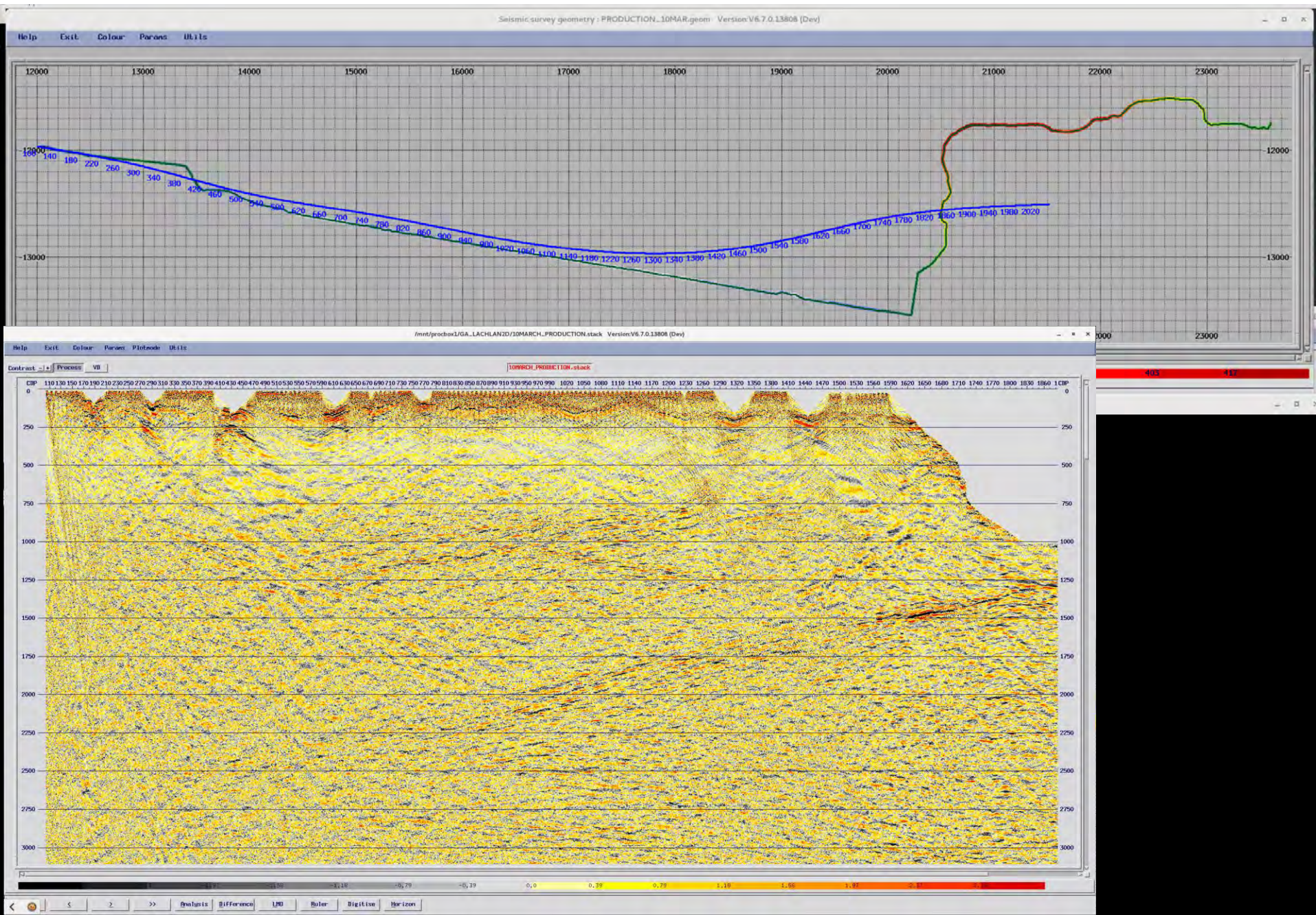




The vibe trucks head east, into the Alps



# NE Victoria data starts to flow....







With suitable adaptation (rubber coverings on the vibe-plates to distribute load), it is possible to acquire data along bitumen roads even with the big trucks, with absolutely no damage to the road surface – traffic management is more involved.





The project garnered some media interest







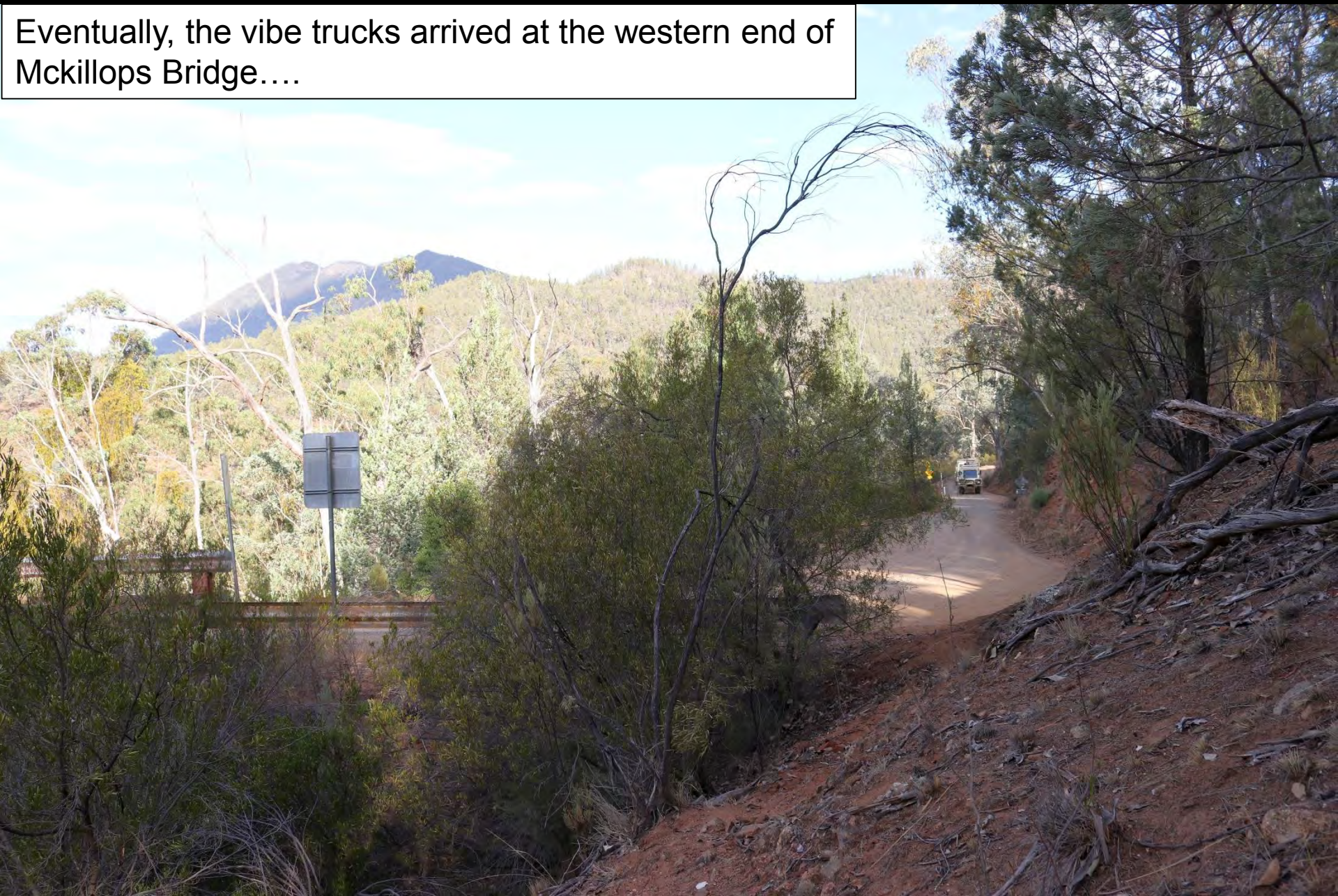
## Start of line 2



Full-on Alpine 4x4 and old logging tracks formed significant parts of the line. Success in terrain like this is a breakthrough for deep seismic reflection acquisition in Australia and elsewhere.



Eventually, the vibe trucks arrived at the western end of Mckillops Bridge....





The recording truck and the mechanics truck could drive on over.  
But the vibe trucks couldn't. Far too heavy. They had to find another way.....







Image © 2018 CNES / Airbus  
© 2018 Google

Google Earth



The vibe trucks had to do a u-turn, and head back west along the line....

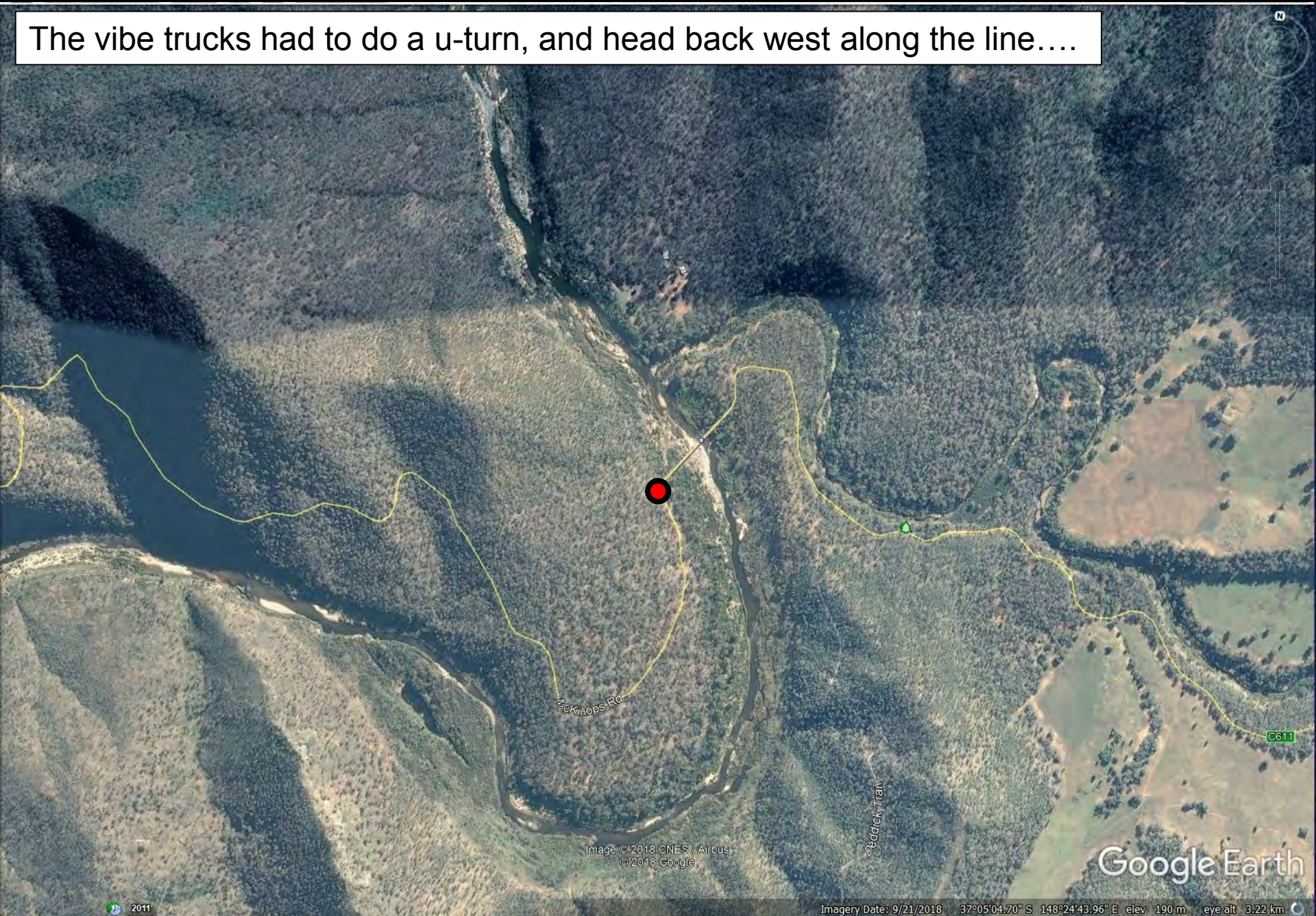






Image © 2018 CNES / Airbus  
© 2018 Google

Google

Google Earth

2011

Imagery Date: 9/21/2018 37°05'06.68" S 148°24'46.22" E elev 186 m eye alt 4.07 km



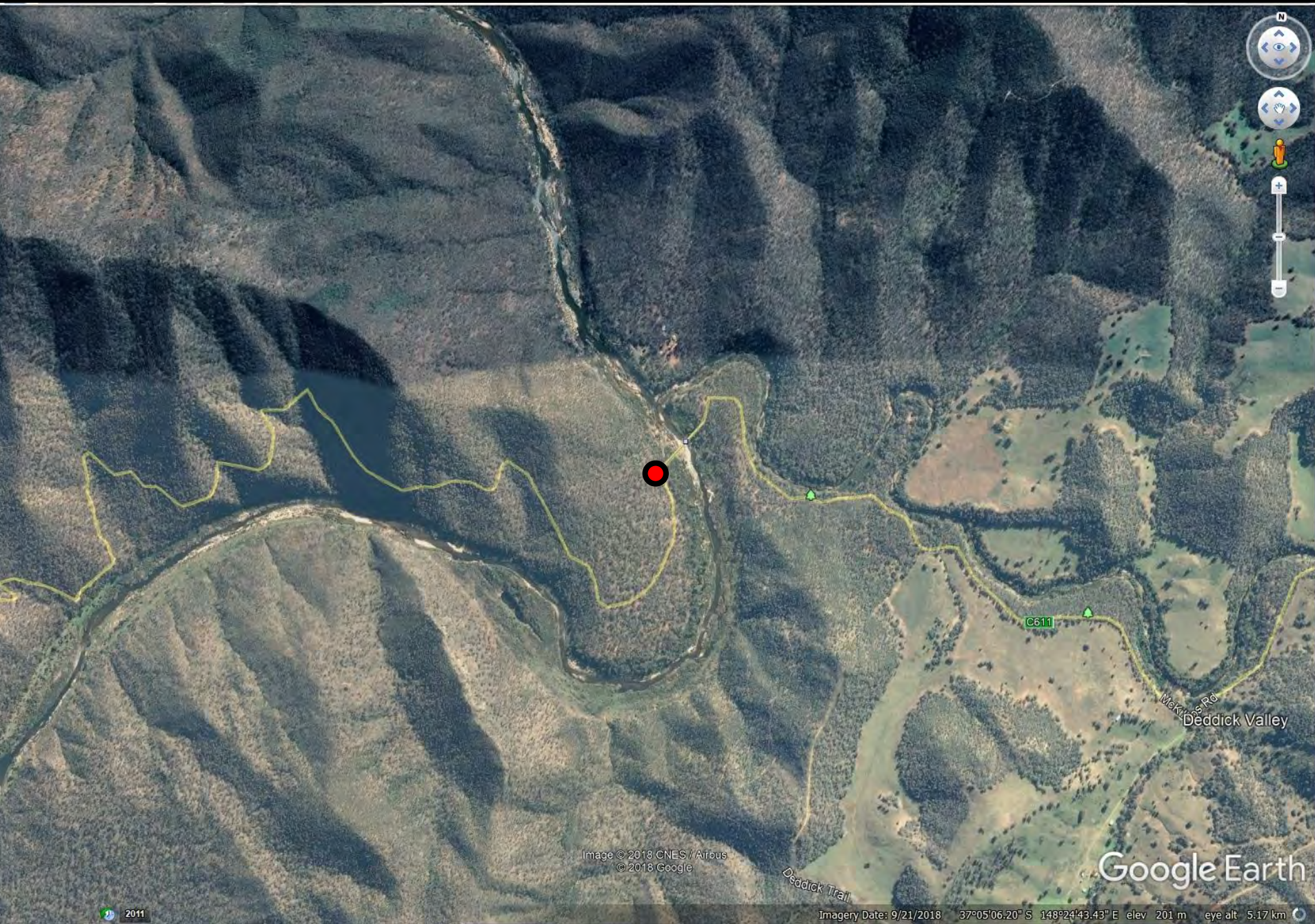


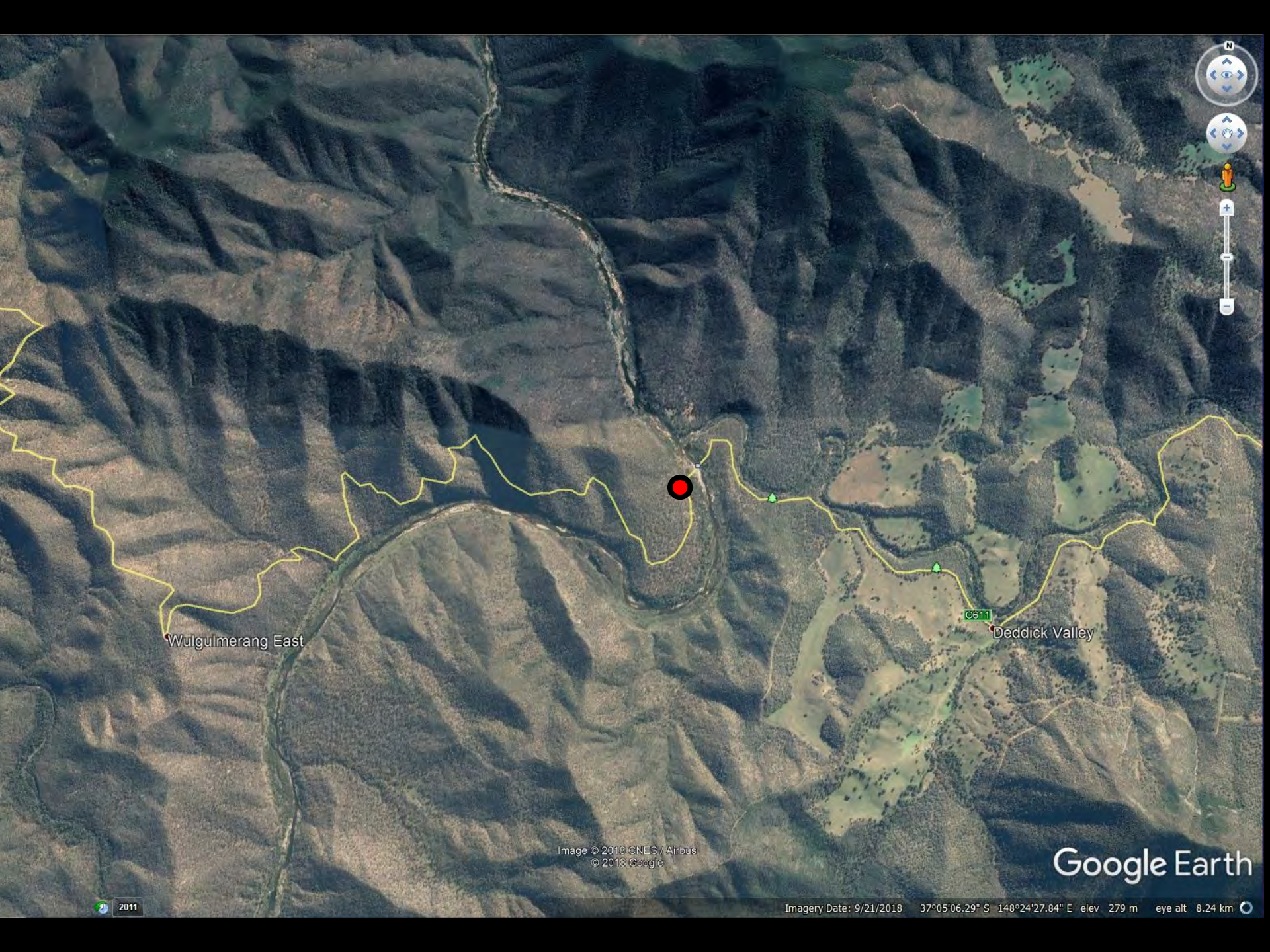
Image © 2018 CNES / Airbus  
© 2018 Google

Google Earth

2011

Imagery Date: 9/21/2018 37°05'06.20" S 148°24'43.43" E elev 201 m eye alt 5.17 km





Wulgulmerang East

C611

Deddick Valley

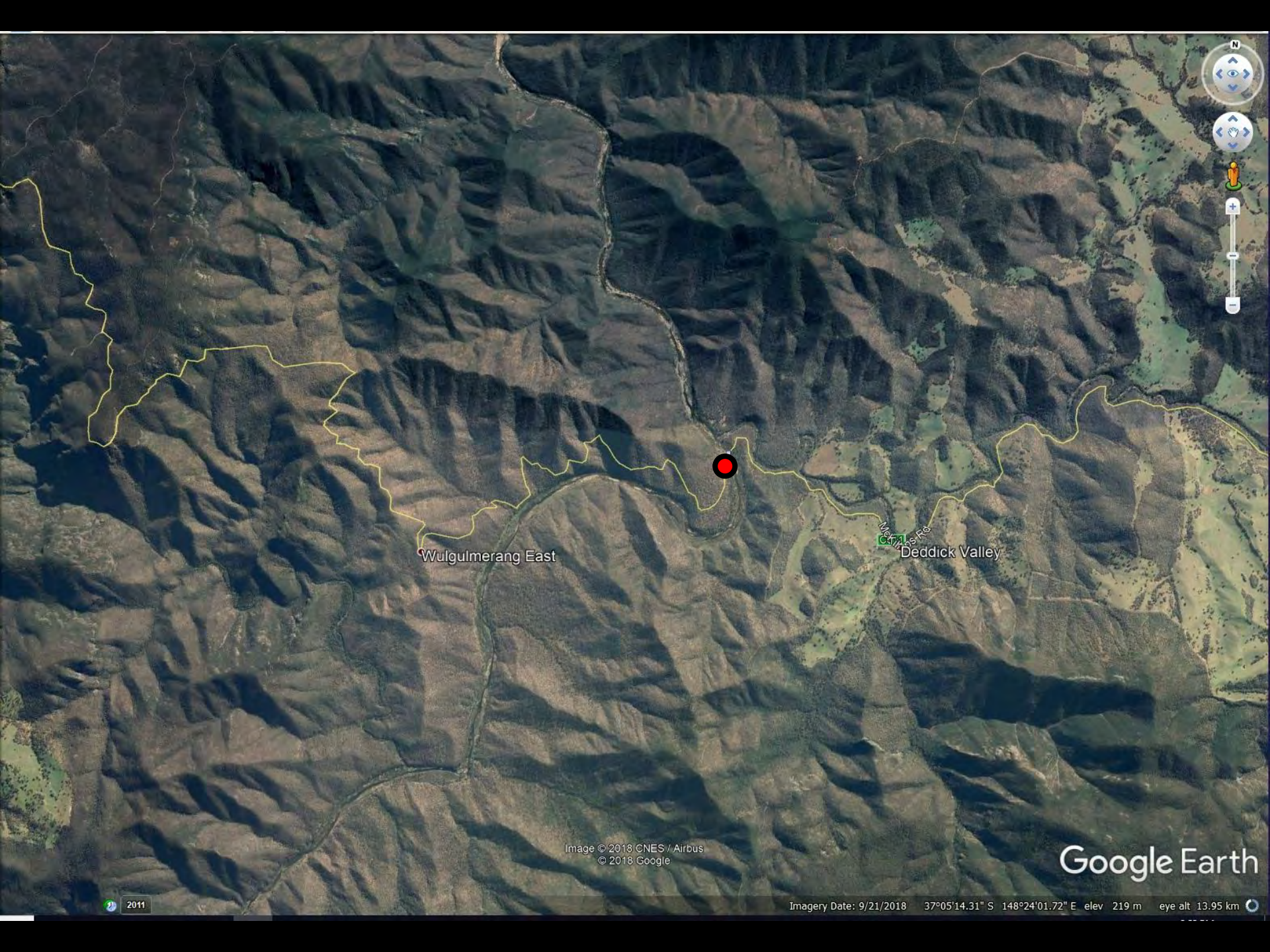
Image © 2018 CNES / Airbus  
© 2018 Google

Google Earth

2011

Imagery Date: 9/21/2018 37°05'06.29" S 148°24'27.84" E elev 279 m eye alt 8.24 km





Wulgulmerang East

Wulgulmerang Rd  
Deddick Valley

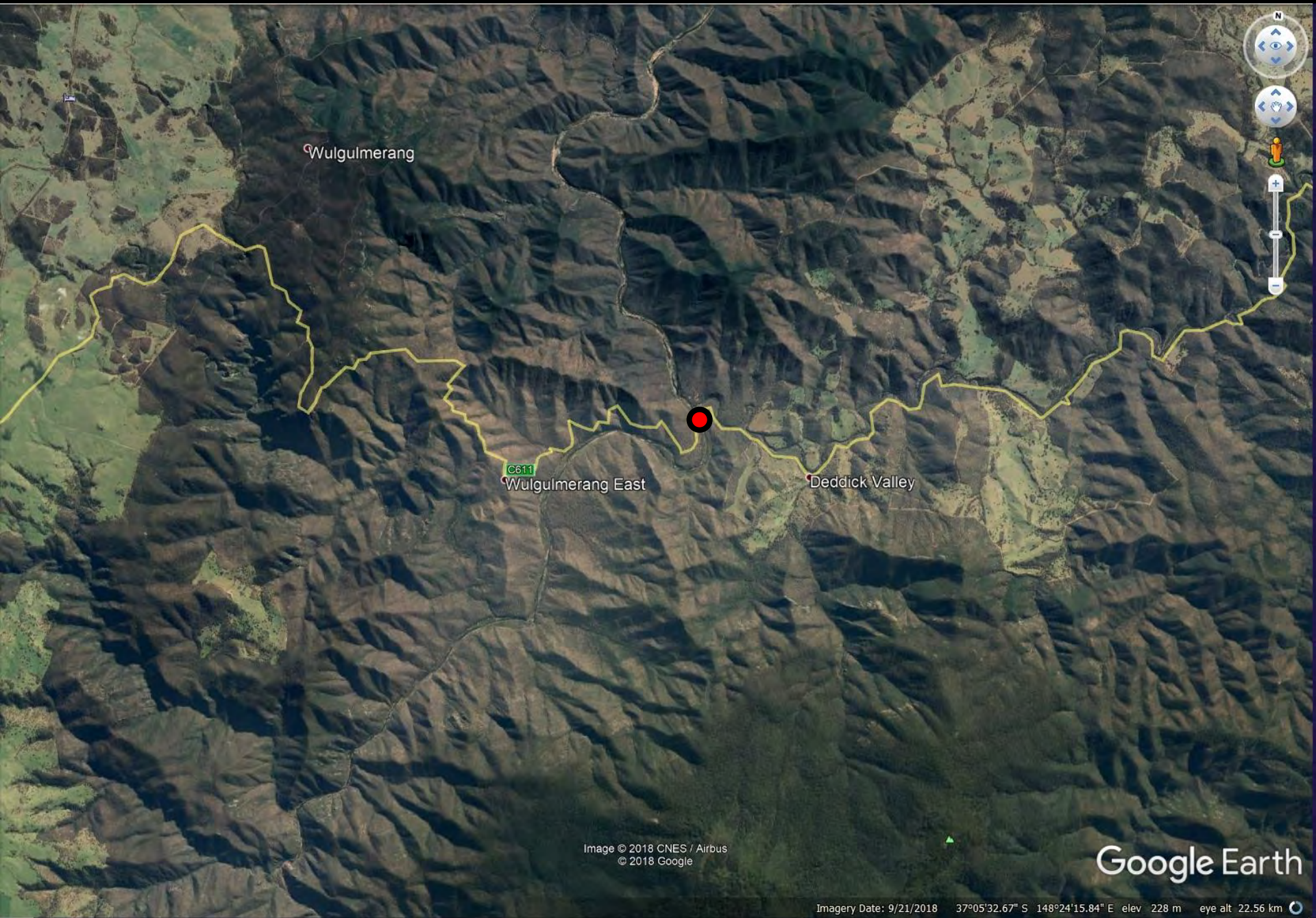
Image © 2018 CNES / Airbus  
© 2018 Google

Google Earth

2011

Imagery Date: 9/21/2018 37°05'14.31" S 148°24'01.72" E elev 219 m eye alt 13.95 km





Wulgulmerang

C611  
Wulgulmerang East

Deddick Valley

Image © 2018 CNES / Airbus  
© 2018 Google

Google Earth

Imagery Date: 9/21/2018 37°05'32.67" S 148°24'15.84" E elev 228 m eye alt 22.56 km



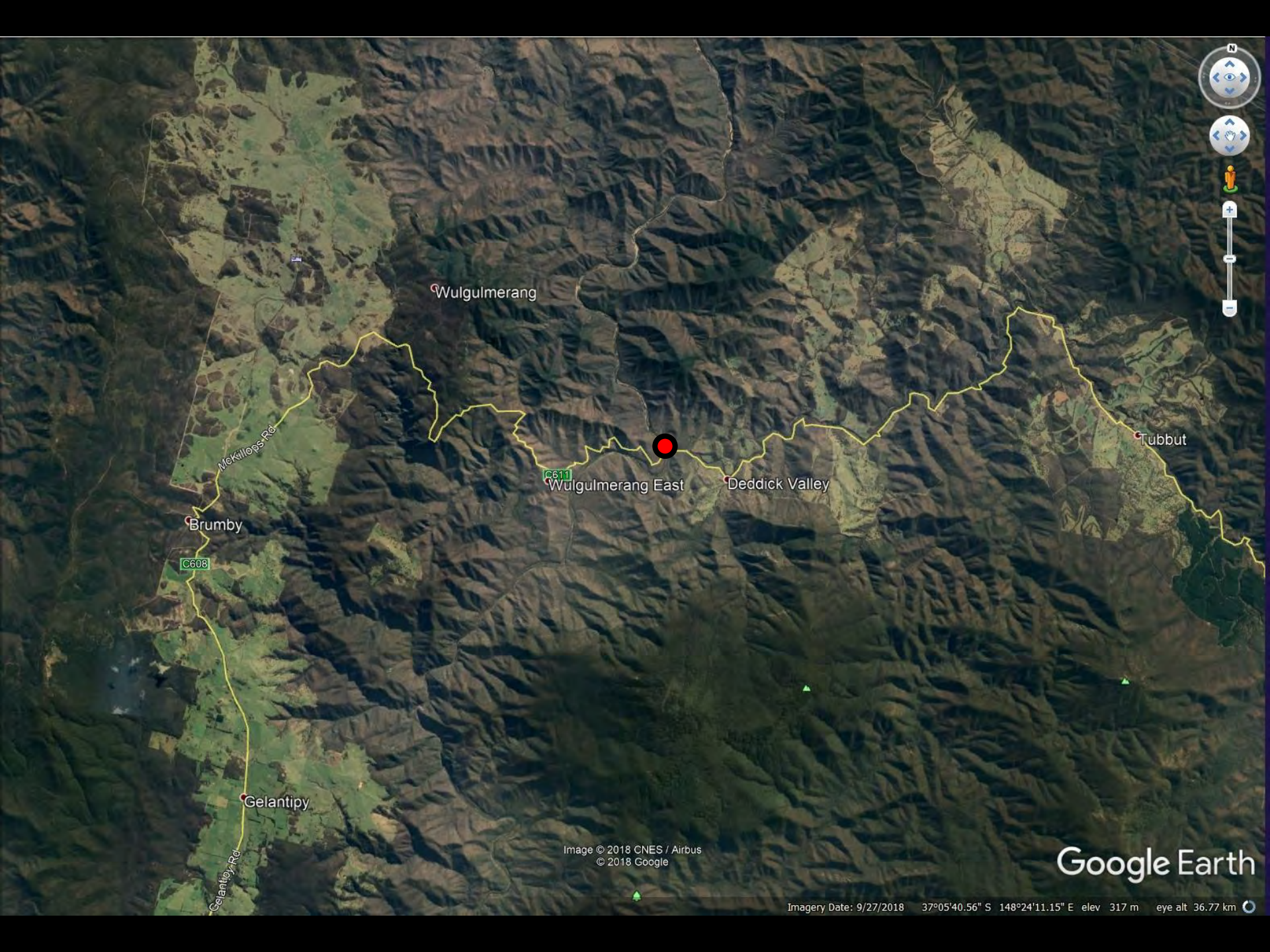
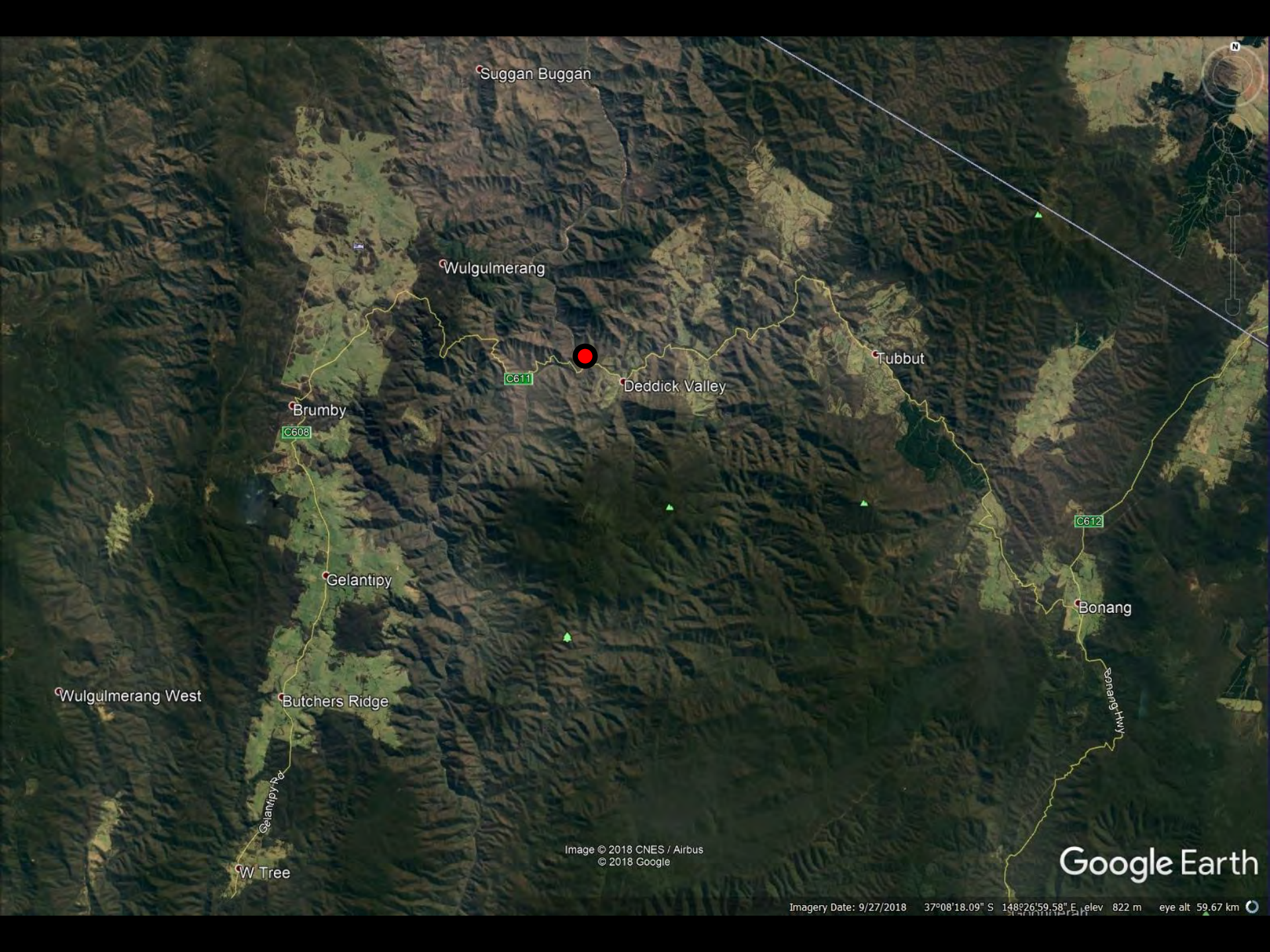


Image © 2018 CNES / Airbus  
© 2018 Google

Google Earth

Imagery Date: 9/27/2018 37°05'40.56" S 148°24'11.15" E elev 317 m eye alt 36.77 km





Suggan Buggan

Wulgulmerang

Deddick Valley

Tubbut

Brumby

C608

Gelantipy

C612

Bonang

Wulgulmerang West

Butchers Ridge

W Tree

Image © 2018 CNES / Airbus  
© 2018 Google

Google Earth

Imagery Date: 9/27/2018 37°08'18.09" S 148°26'59.58" E elev 822 m eye alt 59.67 km





Image © 2018 CNES / Airbus  
© 2018 Google  
Image Landsat / Copernicus  
Image © 2018 DigitalGlobe

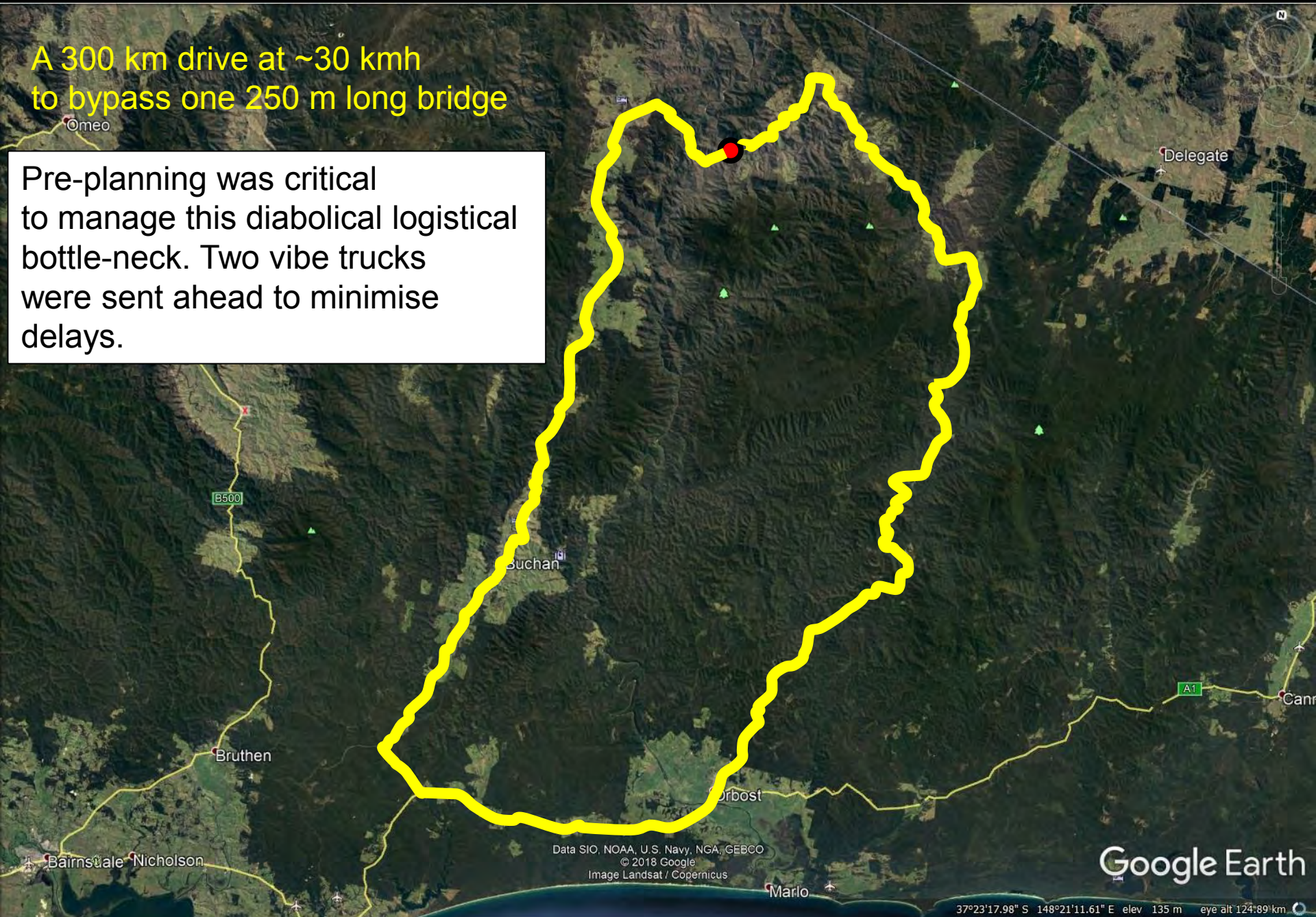
Google Earth

Imagery Date: 9/27/2018 37°15'10.13" S 148°25'38.55" E elev 320 m eye alt 97.59 km



A 300 km drive at ~30 kmh  
to bypass one 250 m long bridge

Pre-planning was critical  
to manage this diabolical logistical  
bottle-neck. Two vibe trucks  
were sent ahead to minimise  
delays.





Last nodes...  
on the beach  
at Saltwater Creek







Vibe trucks parked up at the eastern end of the line, at Saltwater Creek campground.

















# Talk Outline

- A deep seismic reflection transect in eastern Victoria.
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# Processing

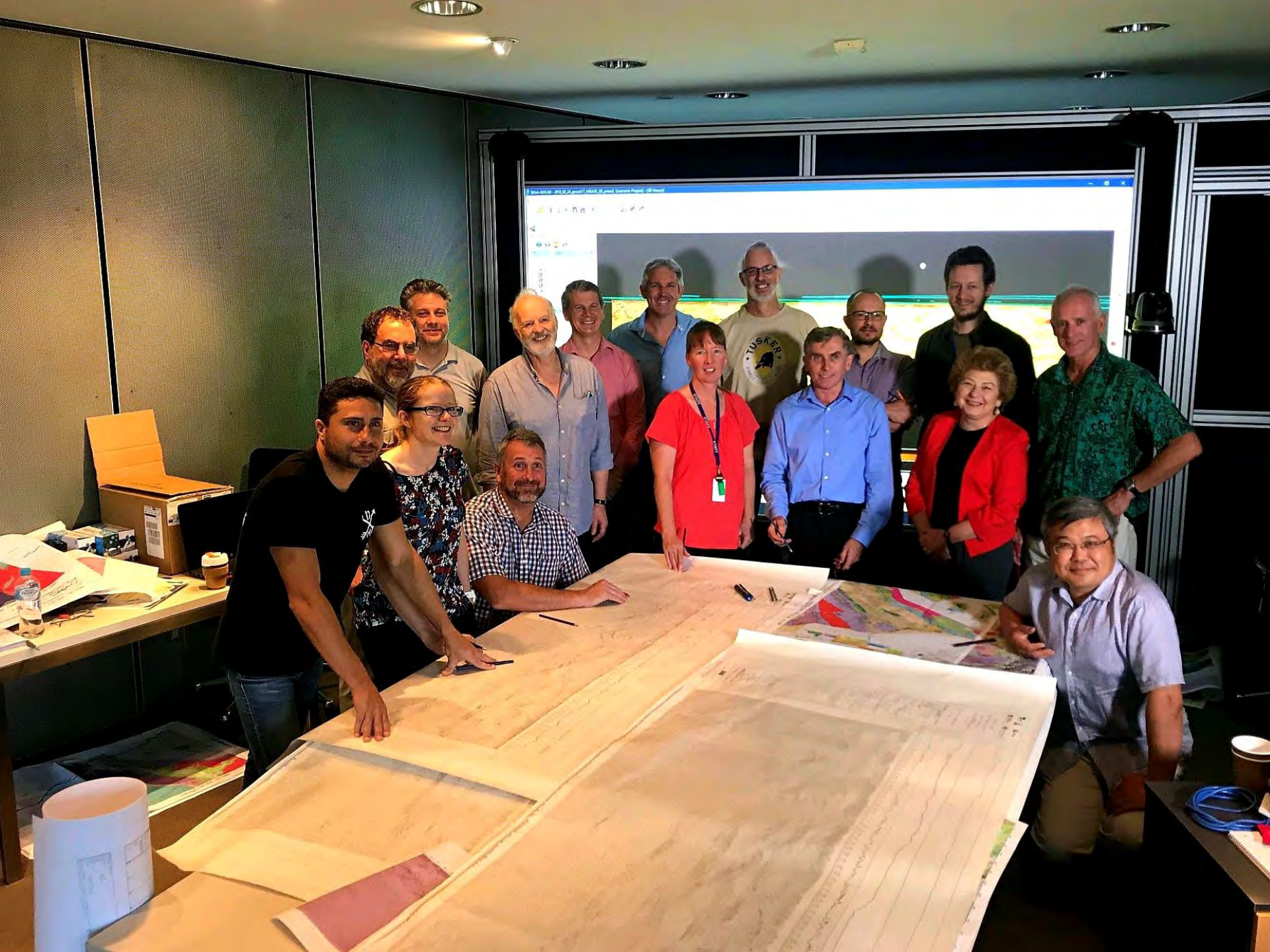
- Data quality is good, enough to answer the major science questions that inspired the project.
- Crooked line processing issues – inspired development of a new processing methodology by Geoscience Australia and the processing contractor
- 2-D and 3-D processing methods adopted for migrating and stacking top 8-seconds TWT – appears to work well.
- 2-D processing methods for 20 sec TWT data

# Geological interpretation

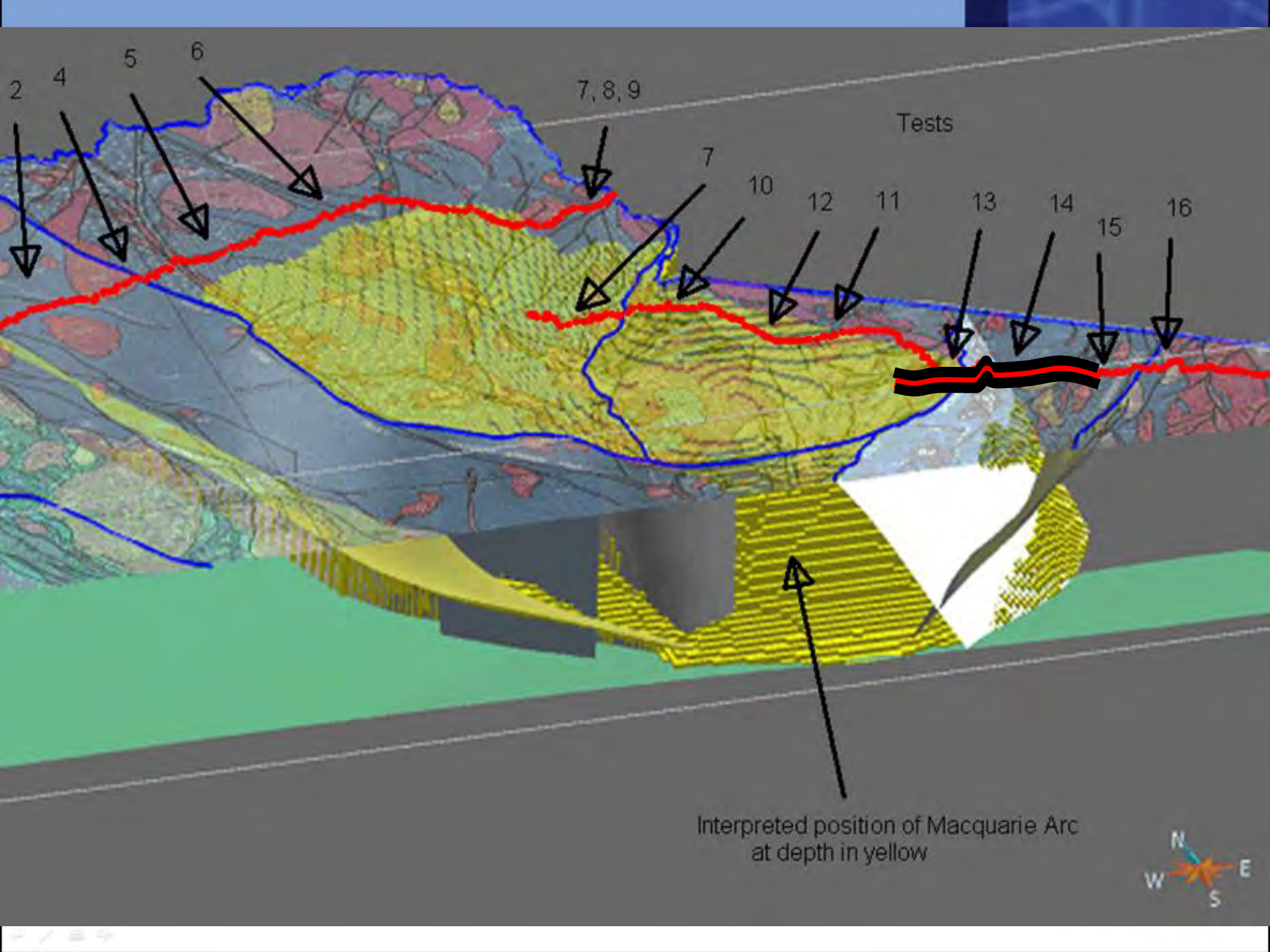


The data we need to test our ideas is now 'in the can'. And it looks great! Interpretation is underway... Expected release date – late 2019







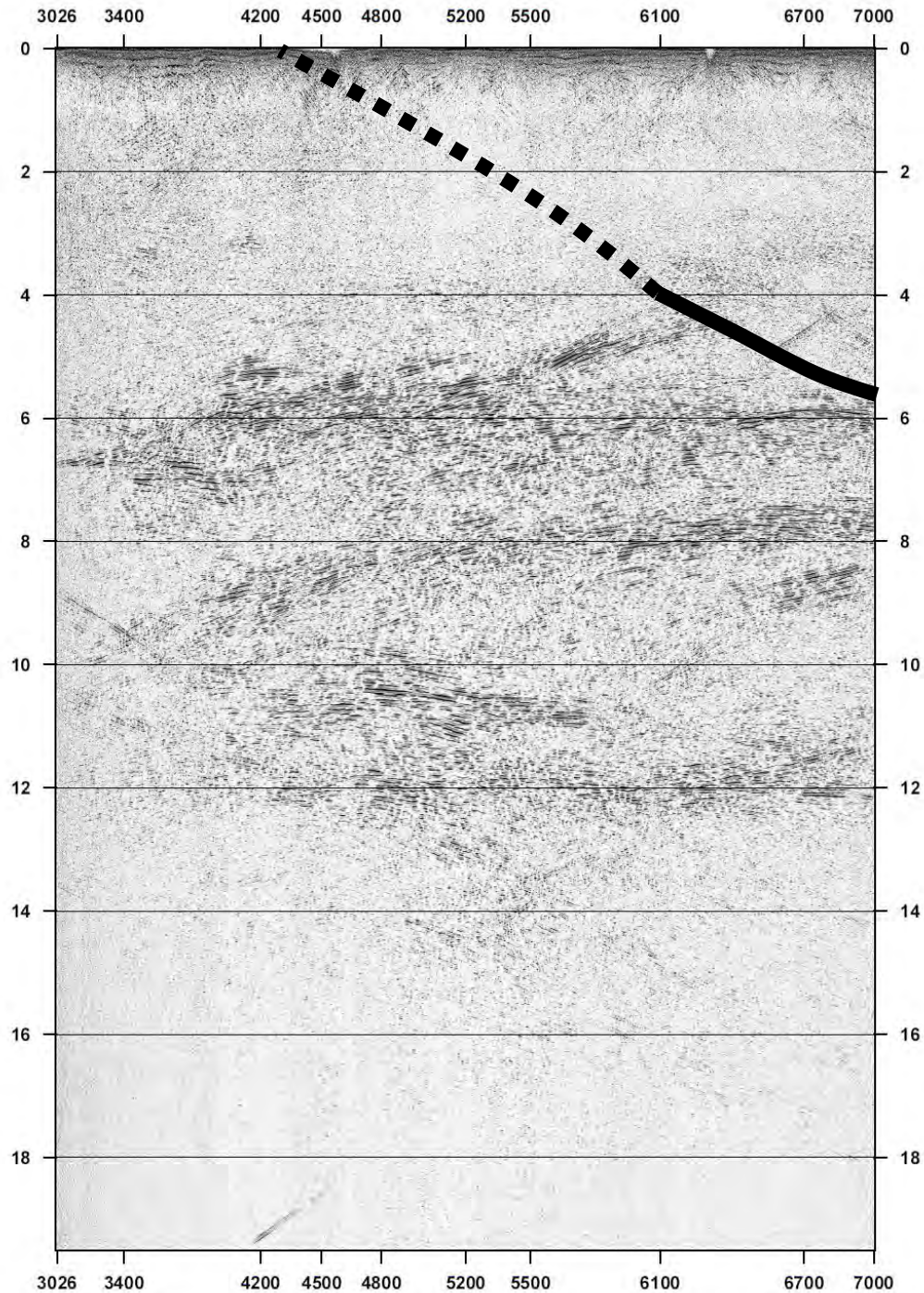




Deddick Zone  
(Yalmy fold-thrust belt)

Igneous basement  
(Macquarie Arc?  
Cambrian MORB?  
both?)

18GA-SL 3  
segment



Kuark Zone

moho

# Conclusions

- Quality deep seismic reflection acquisition is possible in hilly, crooked alpine terrane (and can be done safely)
- Quick win: acquisition pumped \$250k+ directly into regional communities (+ Survey crew spend)
- Data processing tricky (crooked line issues) but possible – new migration/stacking process (GA, contractors) success is exciting for future surveys!
- Data interpretation: underway, completed during 2019
- Technical write-up: after that.
- Close-spaced ground gravity along transect: 2019?
- Magneto-tellurics? Feasibility study underway.

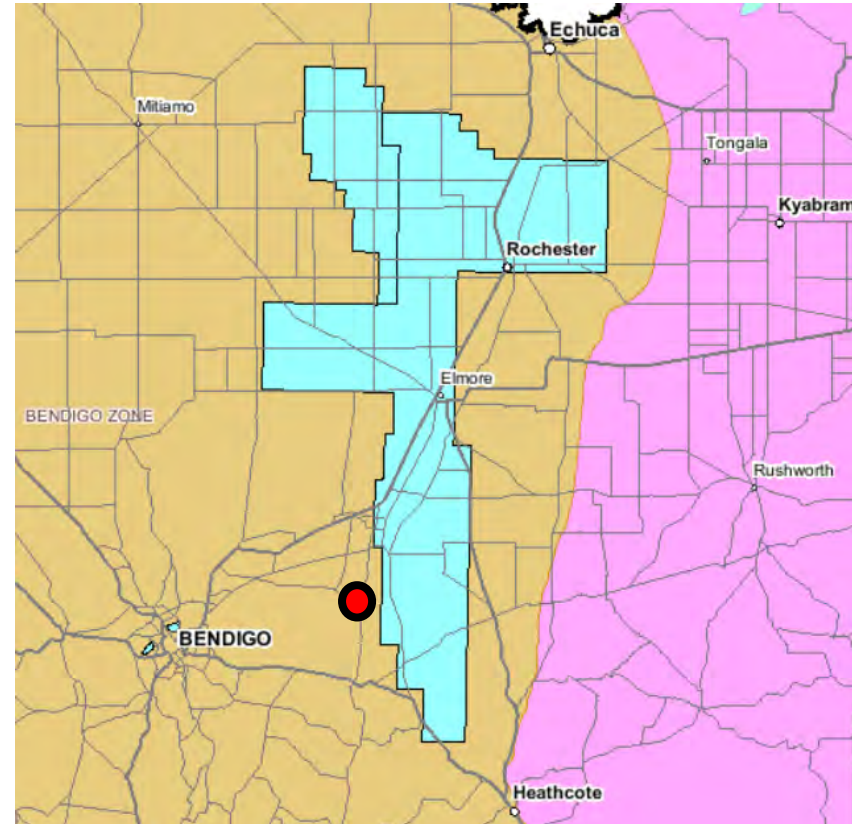


# And another thing.....

## An opportunity – Lockington

- North Bendigo Zone (1,128 km<sup>2</sup>)
- Ordovician (turbidite) host-rocks
- Demonstrated vein-hosted orogenic gold
  - Under cover (40-100m)
  - 10km x 5km footprint
  - Surface geochemistry, gravity, drilling
- Fosterville to immediate west
  - Coincident regional structures
- Low population density, regional/rural setting
- Very active exploration environment

**Ground release planned for 2019**



# The prize- Fosterville: 8.7Moz and growing

## Production 2018

356,230oz @ 24.9g/t Au

Recovery: 97.3%

Operating: \$200/oz

AISC: \$442/oz

## Current reserves (February 2019)

2.7Moz @ 31.0g/t Au

+60% on 2018

Swan Zone: 2.34Moz @ 49.6g/t Au

## Guidance

2019: 550,000-610,000k (\$170-\$190/oz)

2020: 550,000-610,000k

2021: 570,000-610,000k



Fosterville: Lower Phoenix Fault - Eagle ore body, drill hole UDH1501: 12.5m @ 500.7 g/t Au (4.5m ETW)