Integrating seamless geological mapping with geophysics: a profile across (and beyond) East Riverina

26 November 2020

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- The future – EFTF seismic, and more sections

The East Riverina mapping project

East Riverina mapping project

5-year project

- Mapping 2014 to 2018
- Finalisation of line work, data and reports in 2019
- Synthesis map 2020

Update geological knowledge

- Previous maps mostly from 1960–70s at 1:250 000
- Increasing land use pressures

Multi-disciplinary approach

- ‘Boots on the ground’ mapping with specialist input

Applied research projects

- e.g. Uni of Newcastle, Lachlan Orogen ARC.

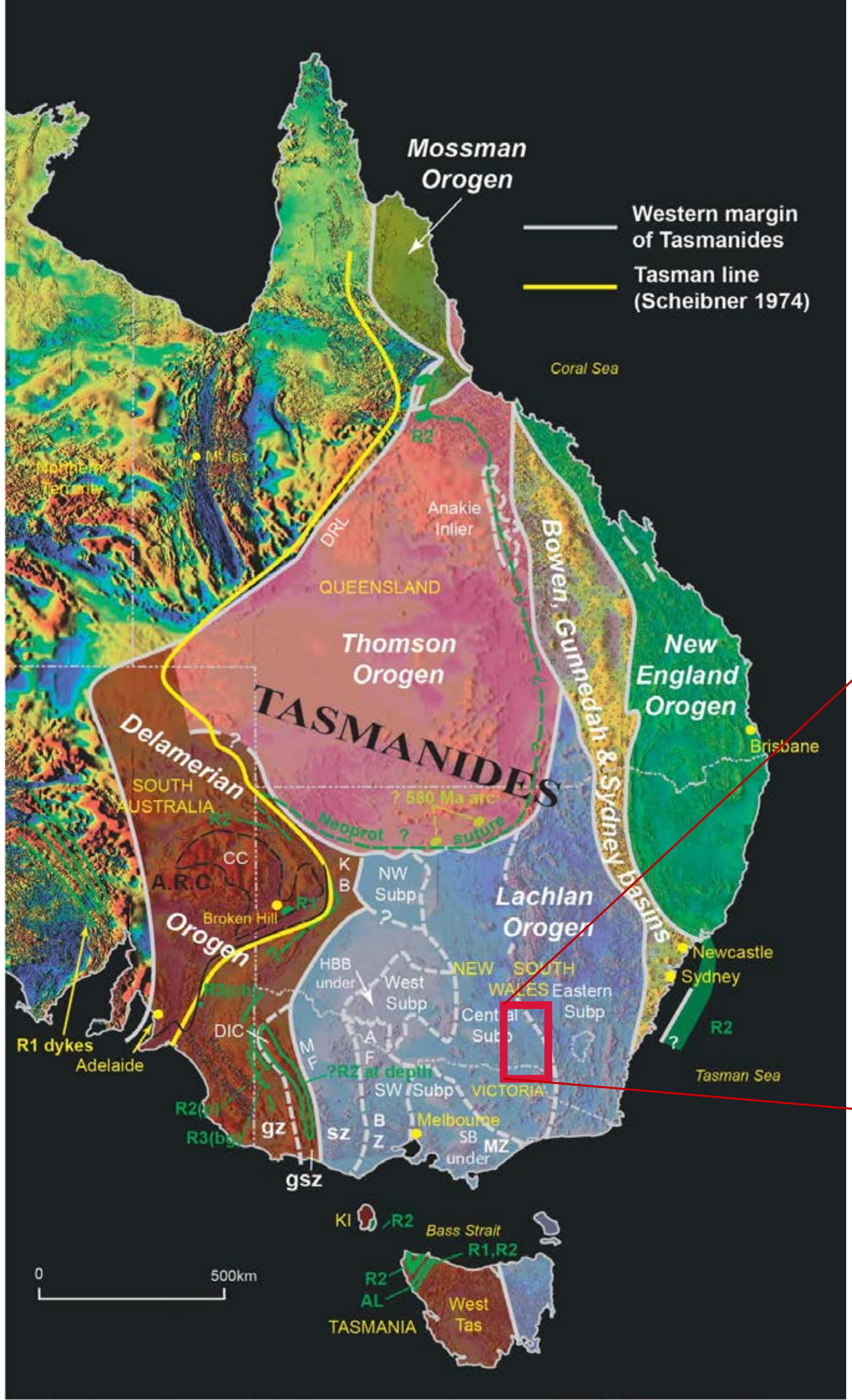
Local engagement

- Professionals and community

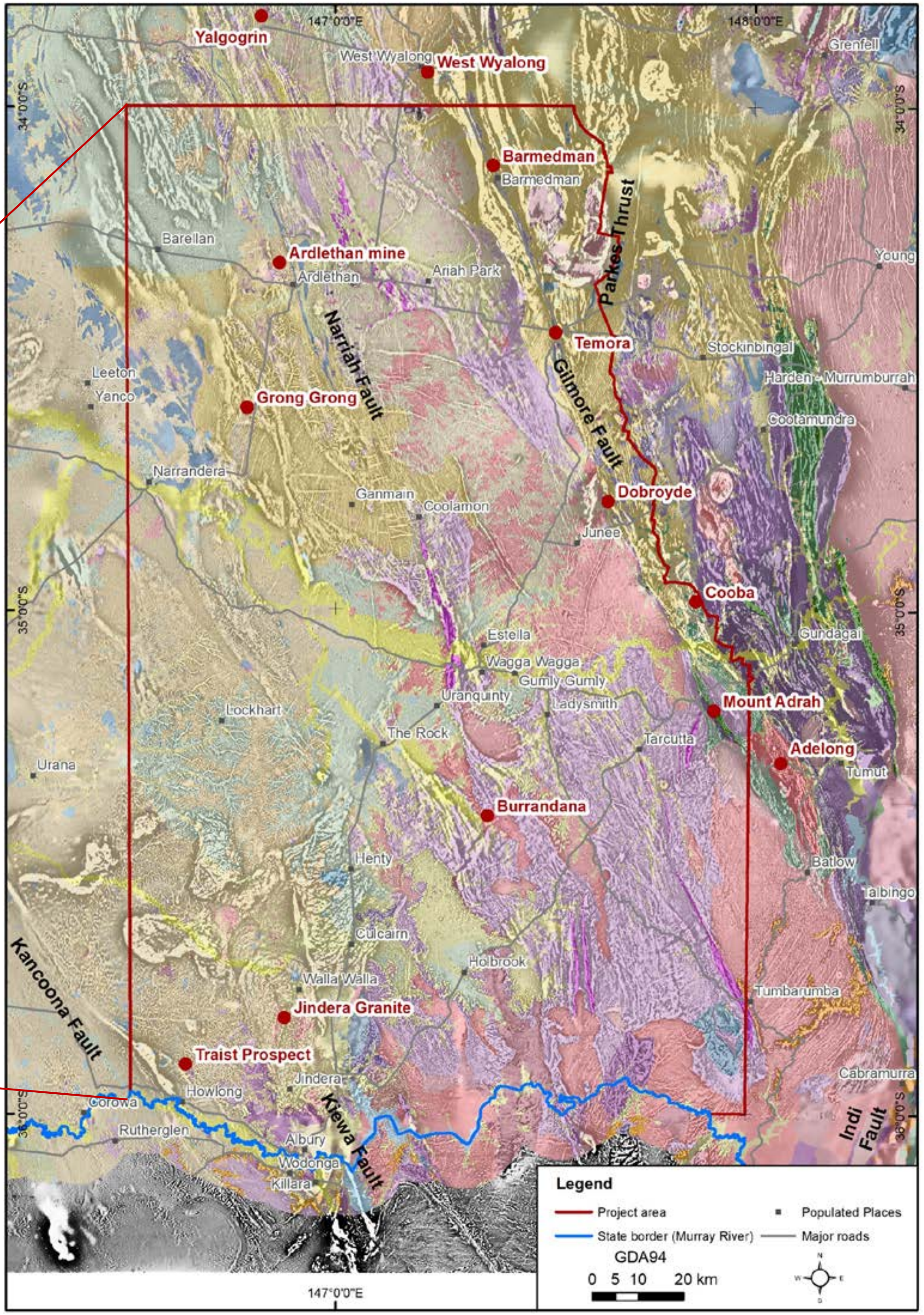
GOAL 1

A growing and diverse economy

Direction 12: Sustainably manage mineral resources



Surface geology from NSW Seamless Geology over 1vd TMI



Source: Glen 2013

New data, new mapping

>7250 new observations & measurements (FieldObs)

- Available in MinView
- Include photos, sample and analytical information

~200 new age determinations

- >100 new isotopic (SHRIMP, Ar–Ar)
- >90 new palaeo (conodonts, graptolites, fish and invertebrates)

New linework

- Into Seamless Geology – layers representing four provinces
- New Lachlan Orogen basement geology + metallogenic map:
    - in preparation
    - cross-section refined by **potential-field modelling.**

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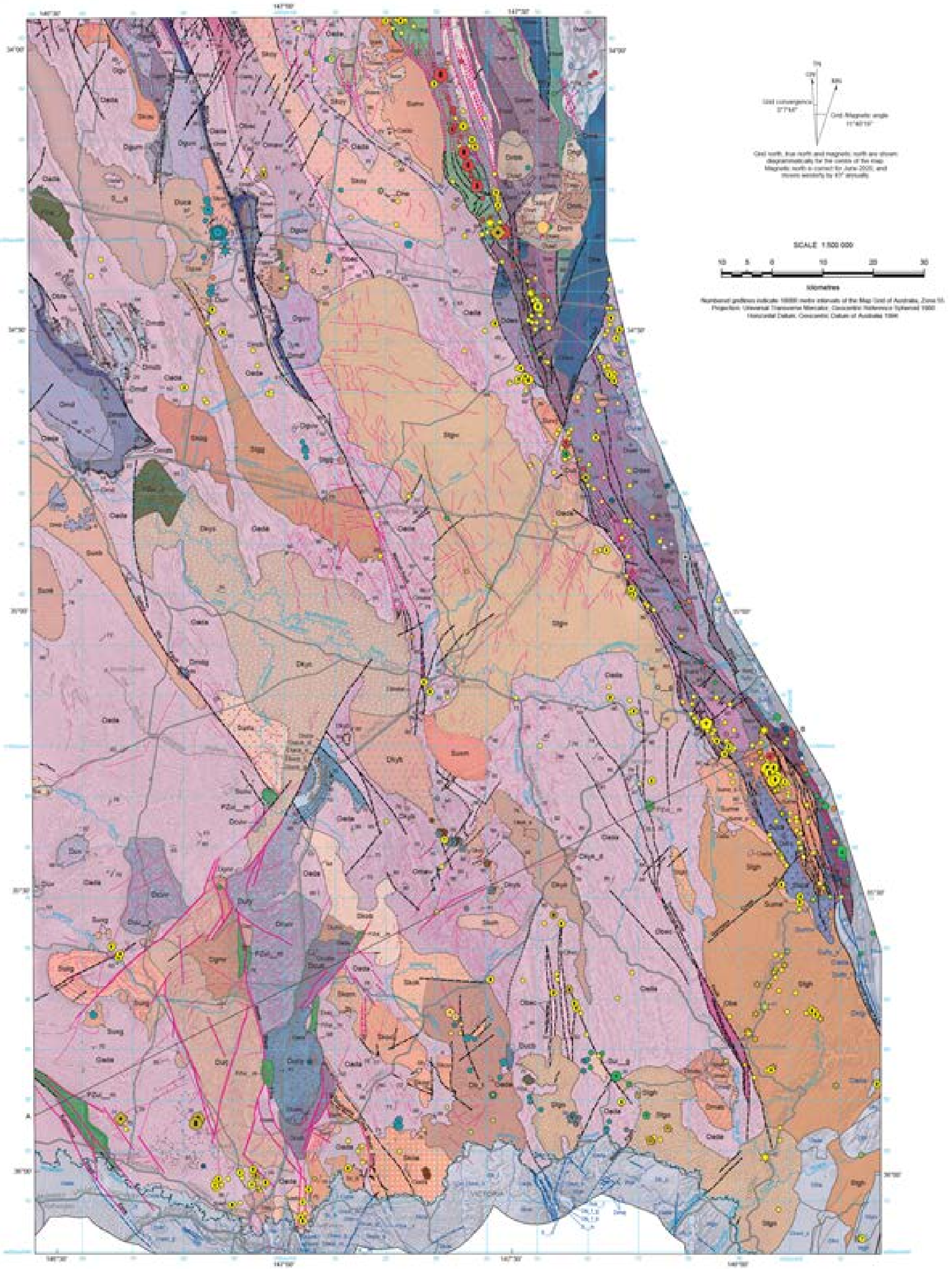

FieldObs with surface geology
(NSW Seamless Geology over 1VD TMI).

Geologically constrained potential field inversion – more than just a ‘forward model’

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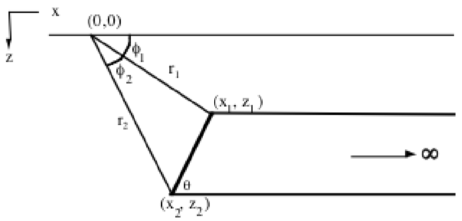
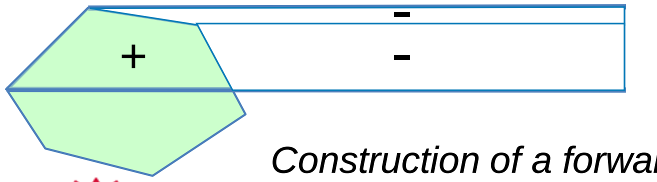
Forward and inverse potential-field modelling

Forward modelling

- Calculation of anomaly resulting from known or postulated geology
- Simplified representation of geology
- Determinate



$$\Delta g_z = 2G\Delta\rho\left[-\{x_1\sin\theta+z_1\cos\theta\}\left\{\sin\theta\ln\left(\frac{r_2}{r_1}\right)+\cos\theta(\phi_2-\phi_1)\right\}+z_2\phi_2-z_1\phi_1\right]$$



Construction of a forward model by addition of simple geometric elements – the Talwani slab

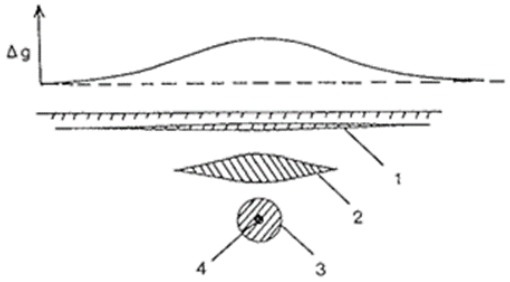
Inverse modelling

- Prediction of geology from known anomaly
- Often highly simplified
- Indeterminate: ambiguity of potential fields

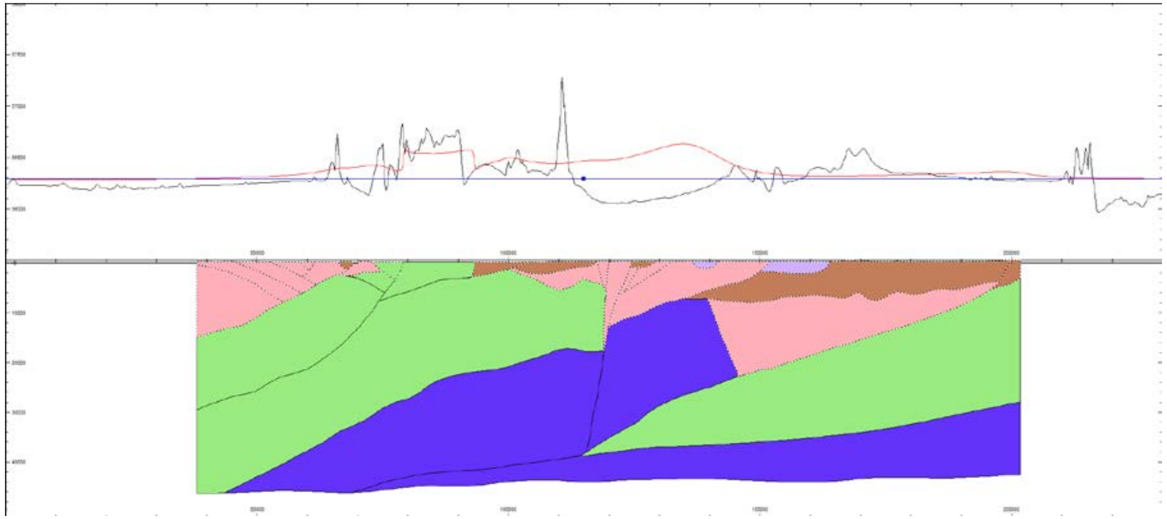
Most ‘inversion’ is achieved by iterative forward modelling.

- Assess misfit
- Alter model, and recalculate misfit
- Iterations can be random, guided by algorithms, or under human control

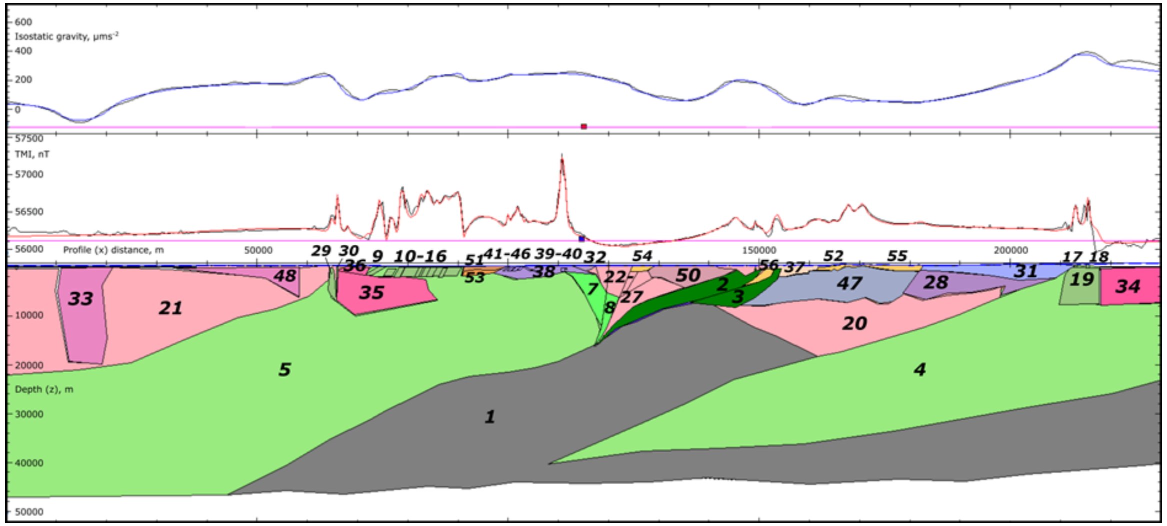
Inverse modelling ambiguity: all the sources produce the same anomaly



Inversion by iterative forward modelling



Forward model of a profile extracted from a 3D geological model of the Forbes–Bathurst district.



Inversion of the profile by iterative forward modelling for both gravity and aeromagnetics (TMI).

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Forward modelling and testing geological models

- A philosophical point: what are we trying to achieve by inversion?
- In well-constrained settings, we are trying to improve and/or extend our known geology.
  - Automated, stochastic or algorithm-driven methods are efficient.
- But in regional settings, we should think of inversion as an investigative tool.
- Principal purpose is to test geological concepts.
  - Admissibility of the geological model.
  - To the geologist, “westward vergence” may be more important than the precise dip on a fault.
  - Challenging problem for the geophysicist – difficult to quantify.
- Effective regional-scale modelling requires:
  - close, and reciprocal, interaction needed between geologist and geophysicist
  - ability to cope with clustered, discontinuous geologic constraints
  - operation within the conceptual framework of the geologist.

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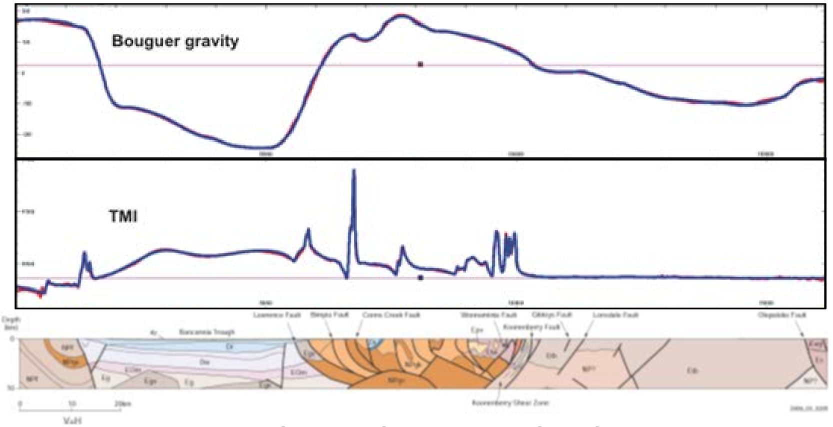
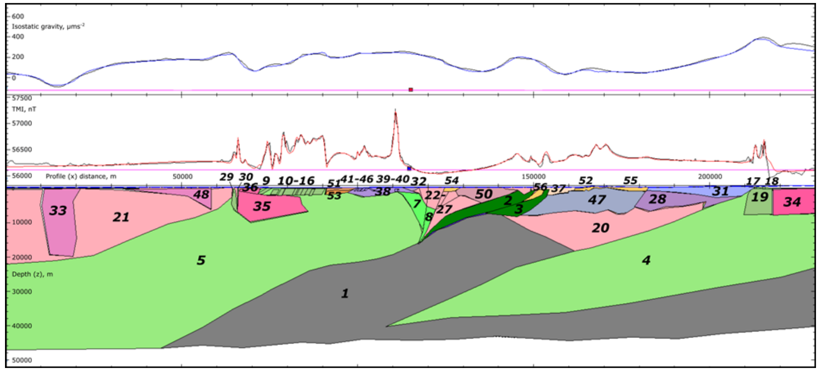
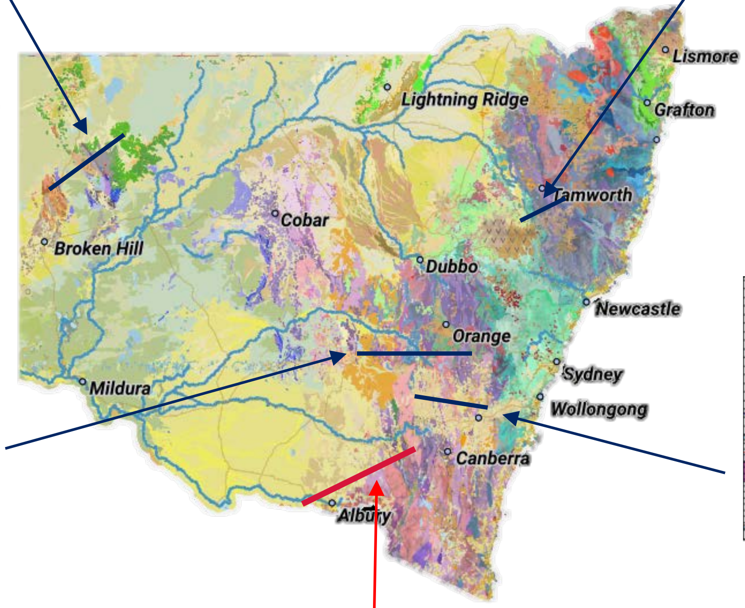
Some I prepared earlier…



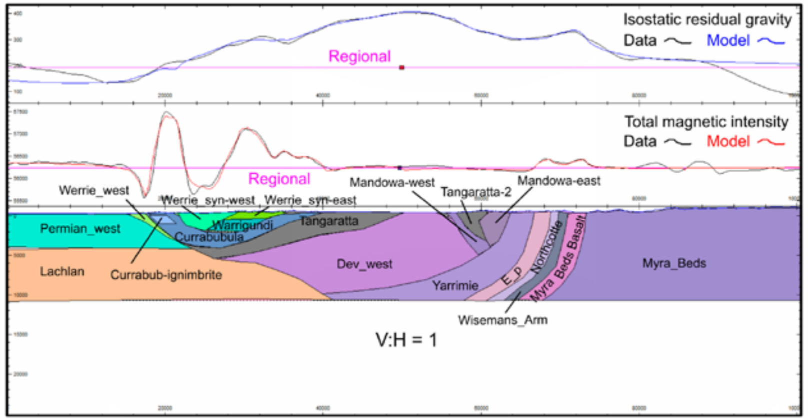
Koonenberry (Wonnaminta), 2007



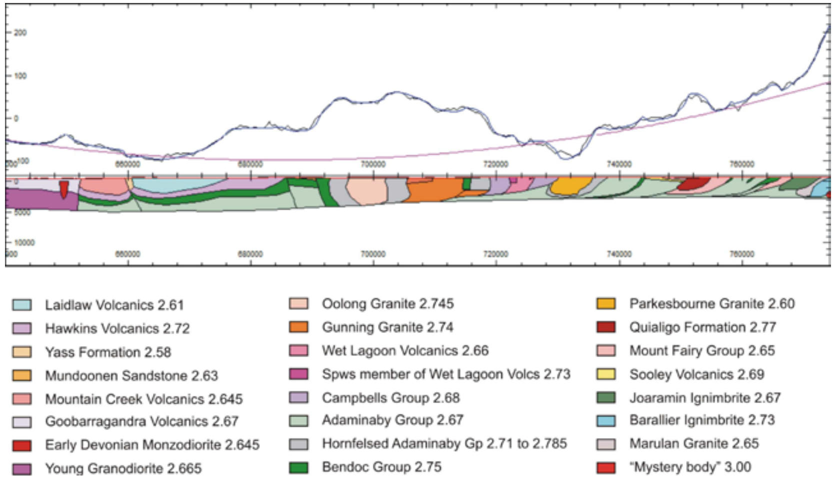
Forbes, 2018



East Riverina, 2020



Currabubula, 2016



Goulburn, 2006

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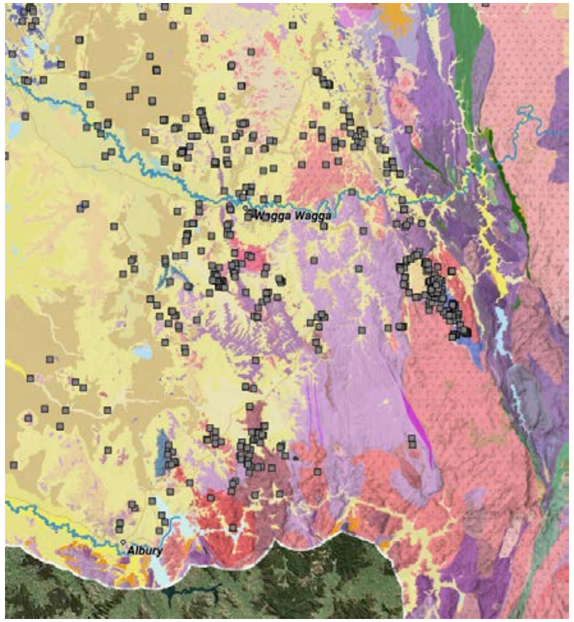
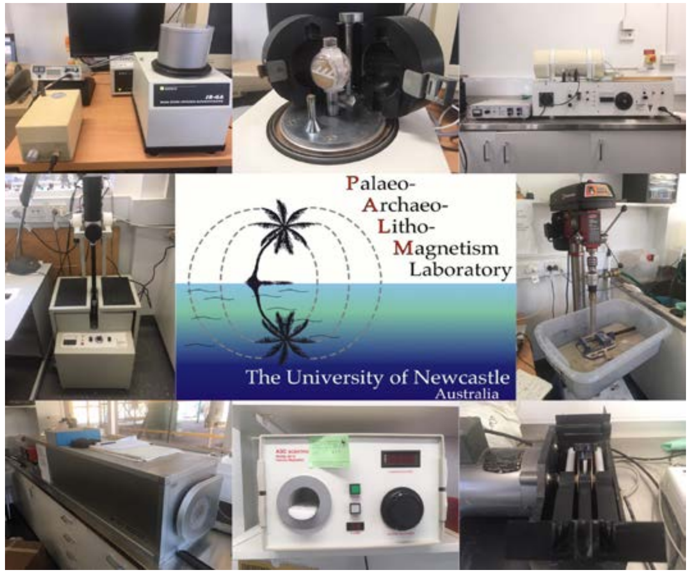
Petrophysical constraints

The PALM Lab

- Joint gravity and magnetic model needs density and magnetic susceptibility constraints.
  - o And remanence (Koenigsberger ratio)?
- Over 500 field observations of magnetic susceptibility collected during East Riverina project.
  - o But only 2 density measurements.
  - o And no remanence.
- Now building a database of a complete magnetic and density suite of collected hand samples.
- Standardised cylinder samples used in all measurements.
- Archived for future measurements of other properties.
  - o Conductivity, chargeability, seismic velocity…



Magnetic susceptibility observations



PALM Lab instruments

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The input (reference) cross-section

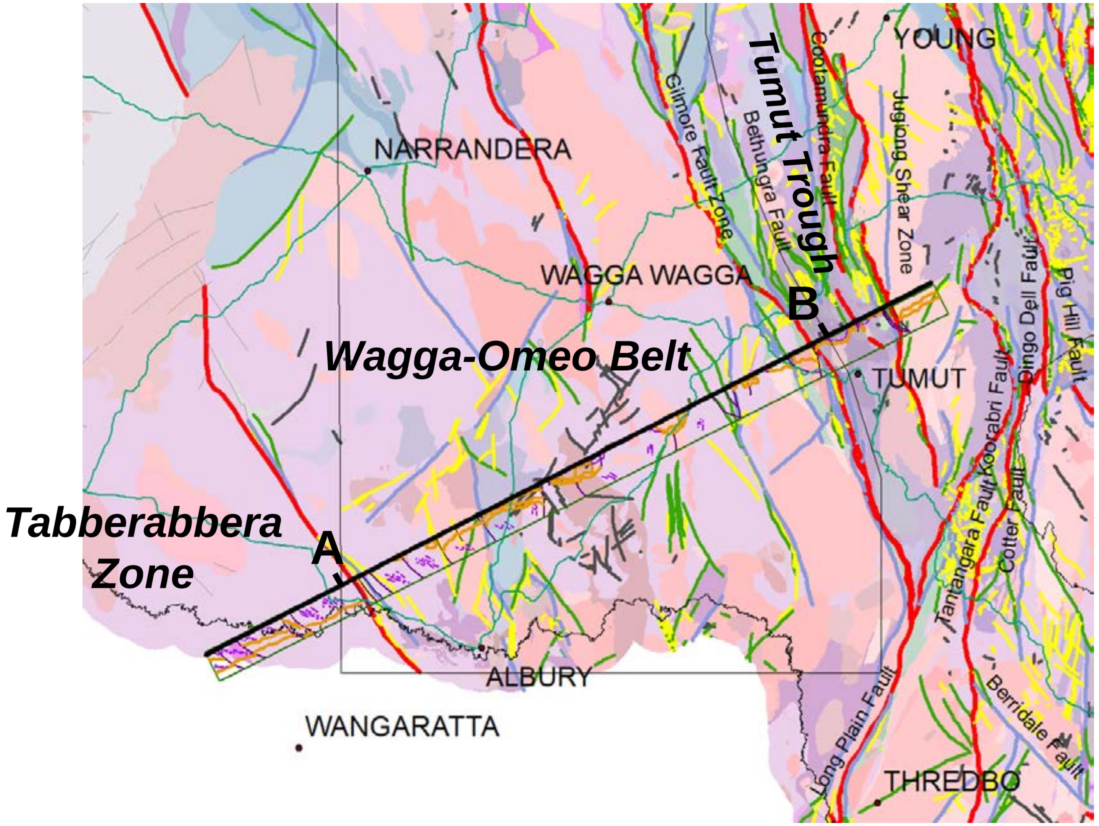
Geological setting

Map cross-section spans Wagga-Omeo Belt

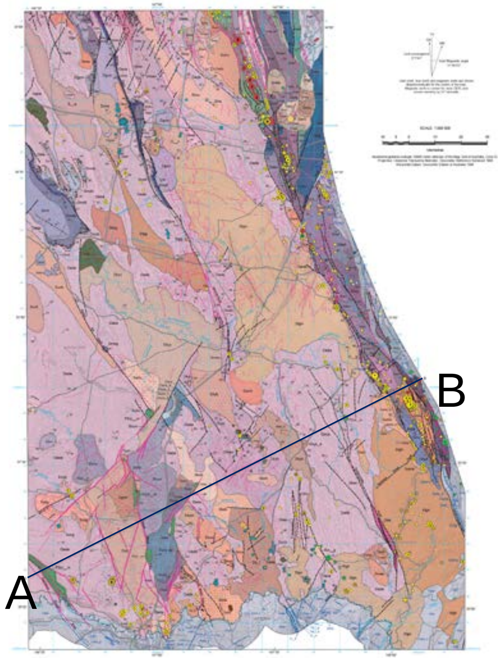
- From **A**, west of Kancoona Fault, to **B**, east of Gilmore Fault Zone
- 10 km vertical extent

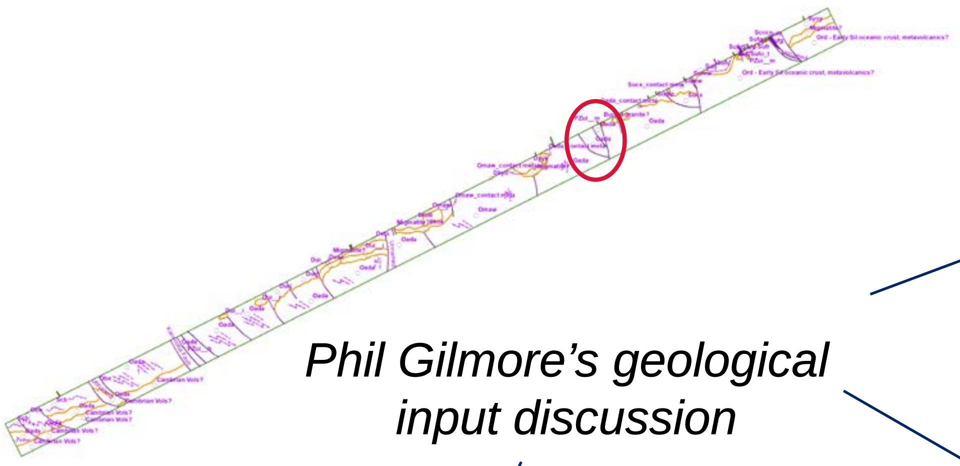
Extended potential-field profile

- West (and across the Murray) into the Tabberabbera Zone
    - o Very little map control
- East across the Tumut Trough to the Young Granodiorite
- Vertical extent to base of crust

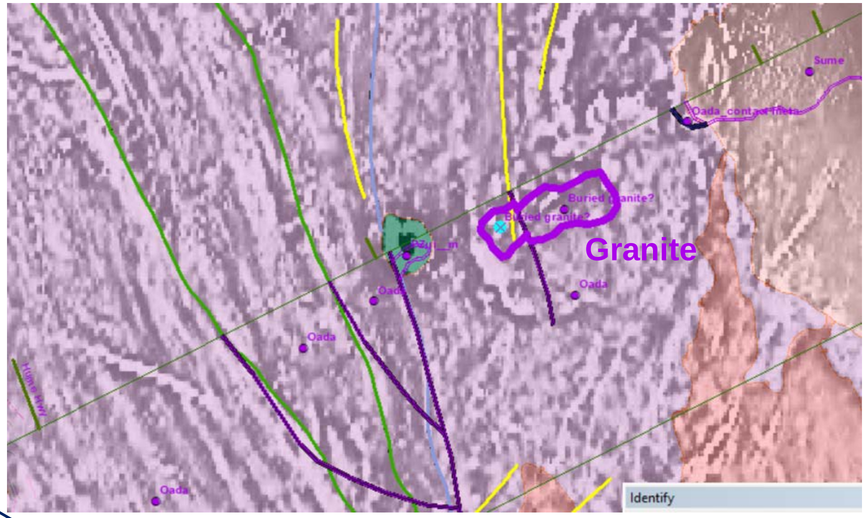


Input section and geological discussion



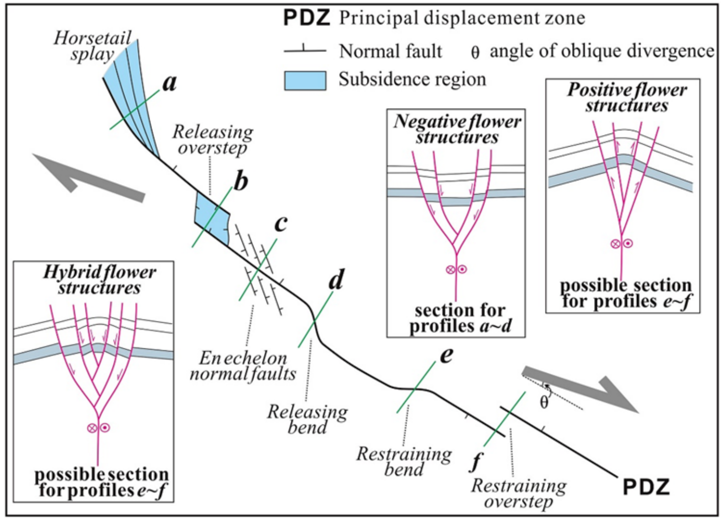


Phil Gilmore’s geological input discussion

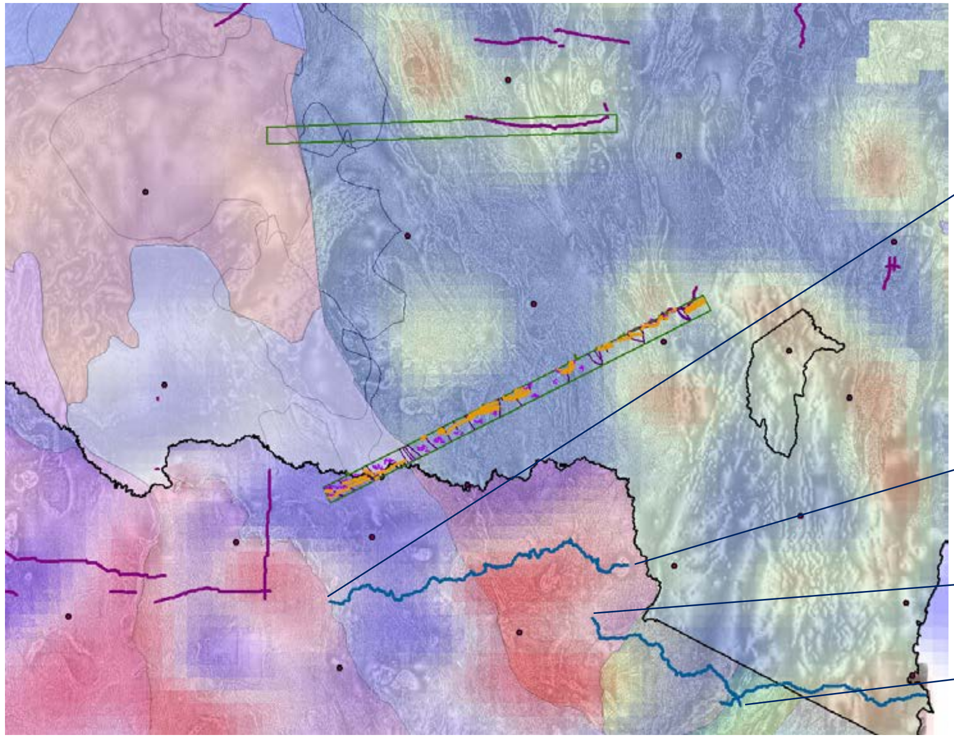


Fault splays

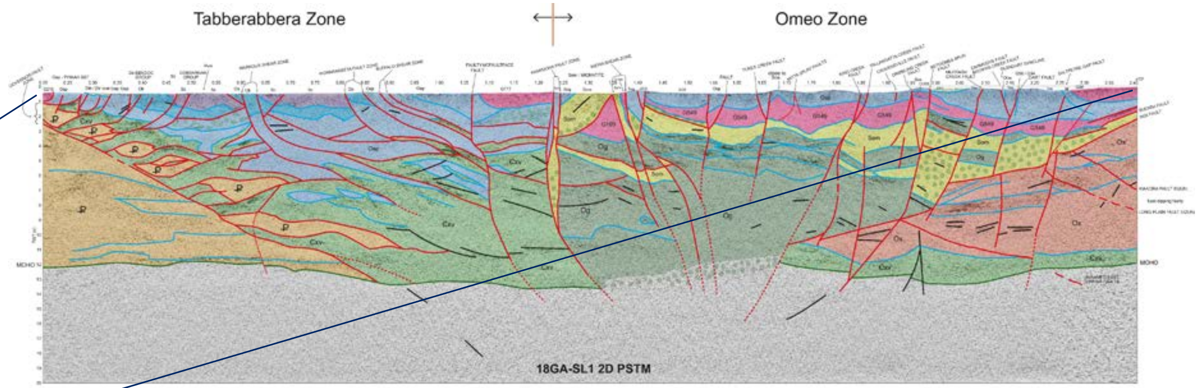
- Looks like horsetail splays off the eastern fault (it is higher order in fault attribution).
- As likely strike-slip movement, have drawn as a negative flower …
- Have made the eastern fault to be a steep west dipper – to be consistent with other faults in area and SLACT – but could also be steep east dip …
- The magnetic doughnut is not at surface – but can’t be deep. Have probably made too thick. We have said Palaeozoic – could be Tertiary basalt? Appears to sit on HW of fault?
- The buried granite is interpreted from the TMI IVD.

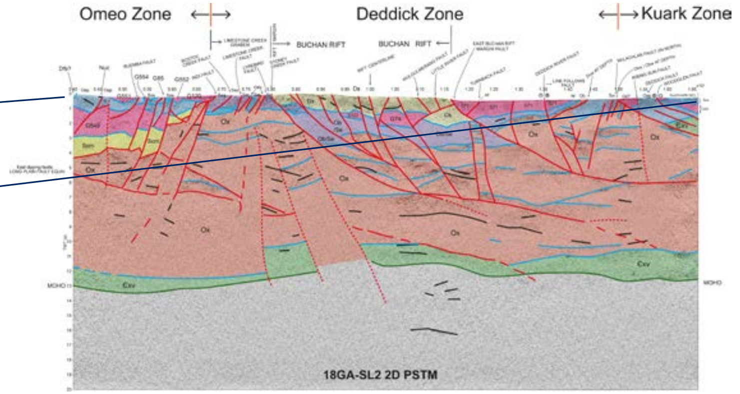


Seismic and other constraints



Deep seismic reflection lines: tilt-filtered aeromagnetic grid, AusLAMP MT conductivity model at 20 km.





SE Lachlan Crustal Transect lines 1 & 2

The process – iterative refinement

Modelling procedure

1. Set up data: input magnetic and gravity grids, geology map rasters, reference profile raster.
2. Set magnetic and gravity “regionals”, assuming constant regional.
3. Proceed through series of models (major changes) and iterations (refinement).
   - x#y, starting 0#0.
4. Model Moho, taking into account other models. Establish Curie depth: within crust?
5. Initially focus on magnetic response.
6. Block model deep sources for long-wavelength magnetics.
7. Move to increasingly shallow magnetic sources. Start with anticipated magnetic sources in reference model.
   - Iteratively refine: modify vertices, magnetic susceptibility.
   - Add/eliminate bodies where required by data.
   - Require consistency with major features of reference section unless invalid.
   - Test for “geological reasonability” and consistence with tectonic and stratigraphic evidence.
8. Shift to gravity response.
   - Adjust body densities, within bounds.
   - Add bodies to match gravity features where necessary. Most often deep S-type granites.
9. Final iterations to simultaneously reconcile magnetics and gravity.
10. Return to geologist for review. Modify as required, returning through step 7.

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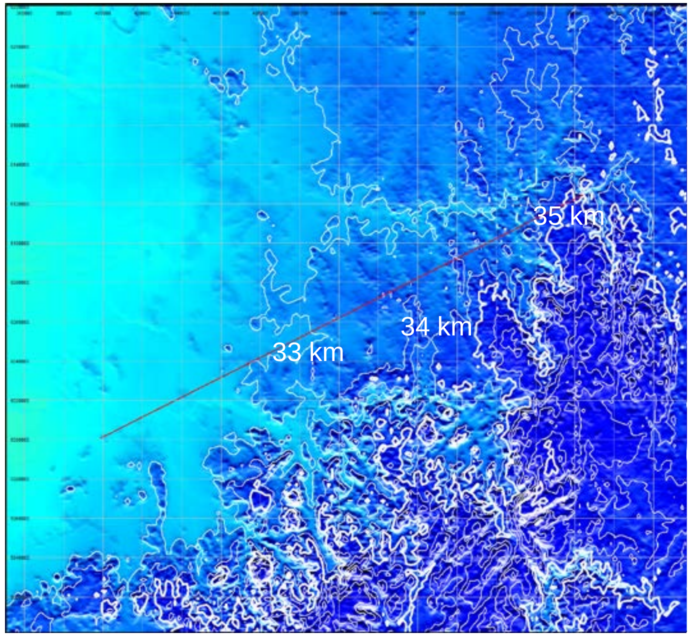
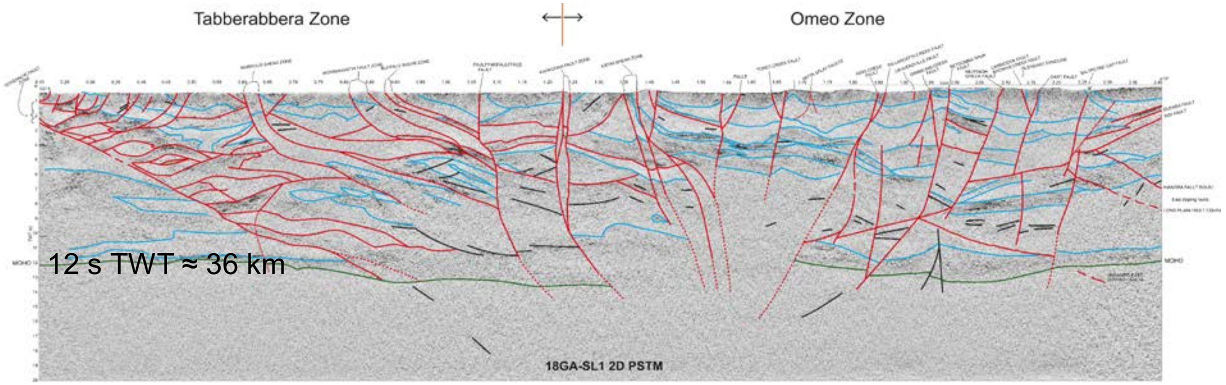
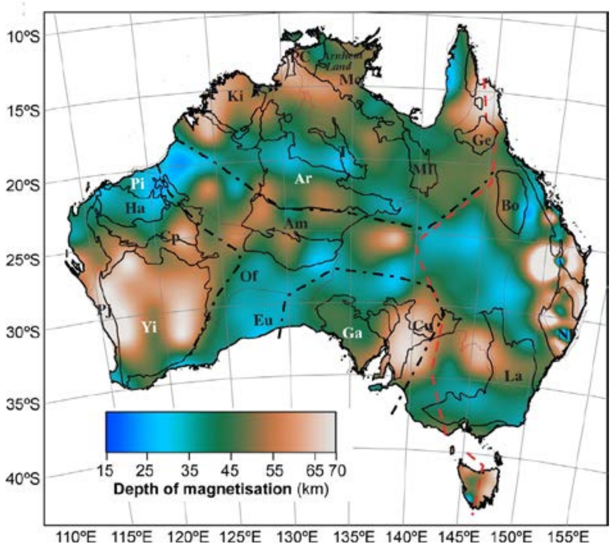
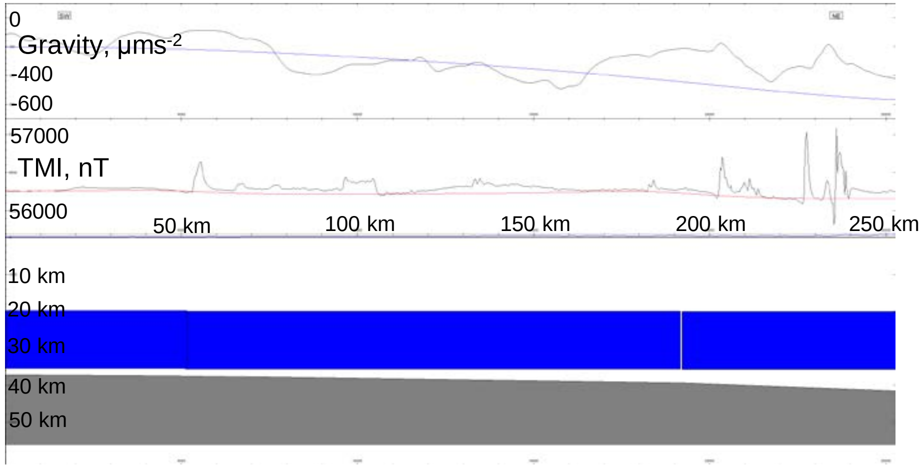
Moho, Curie depth (step 4)



AusMOHO
AiryRoot







Model 2, iteration 1: 11th overall iteration

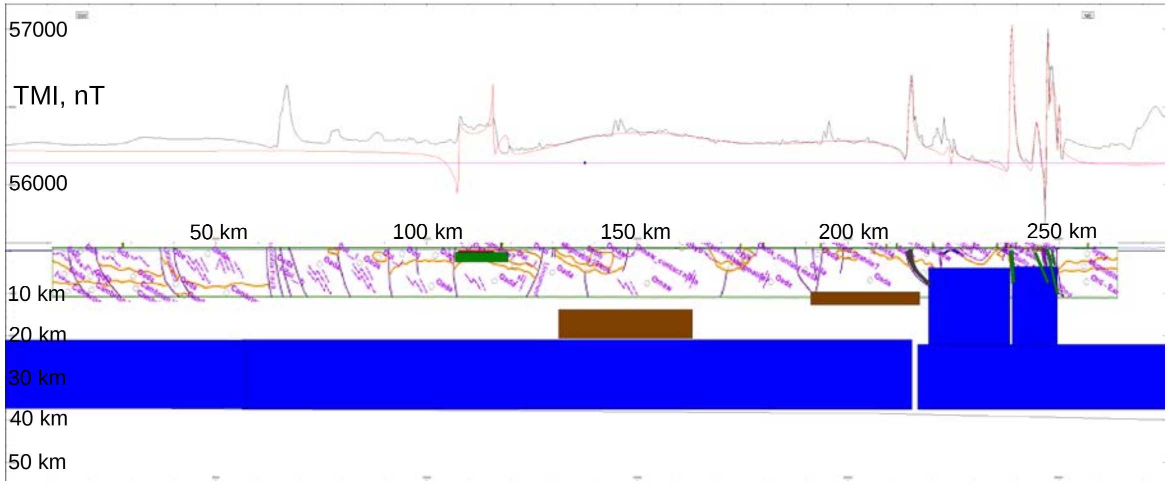
Long-wavelength magnetics (step 6)

Deep magnetic sources with TMI wavelengths >10 km.

- Wavelength implies middle or lower crust source.
- Mostly below map cross-section extent.
    - But tectonically significant.
- Often ‘aliased’ by overly complex ‘regional’ field.
- Block prism at this stage.

Easier to separate deep and shallow contributions in magnetics than gravity.

- Shallow “pancake” granite imitates deep gravity source.



Model 5, iteration 1: 25th overall iteration

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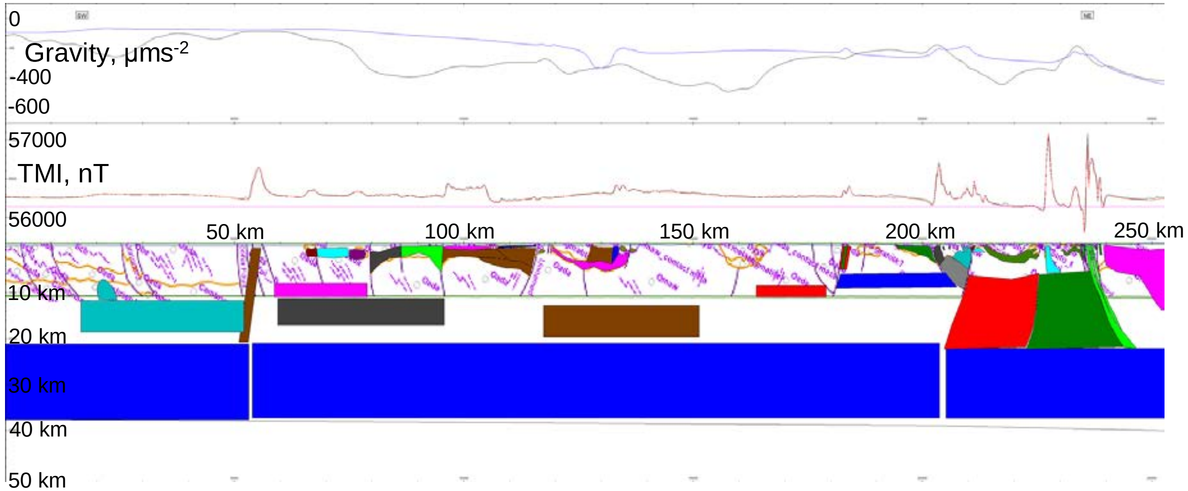
Short-wavelength magnetics (step 7)

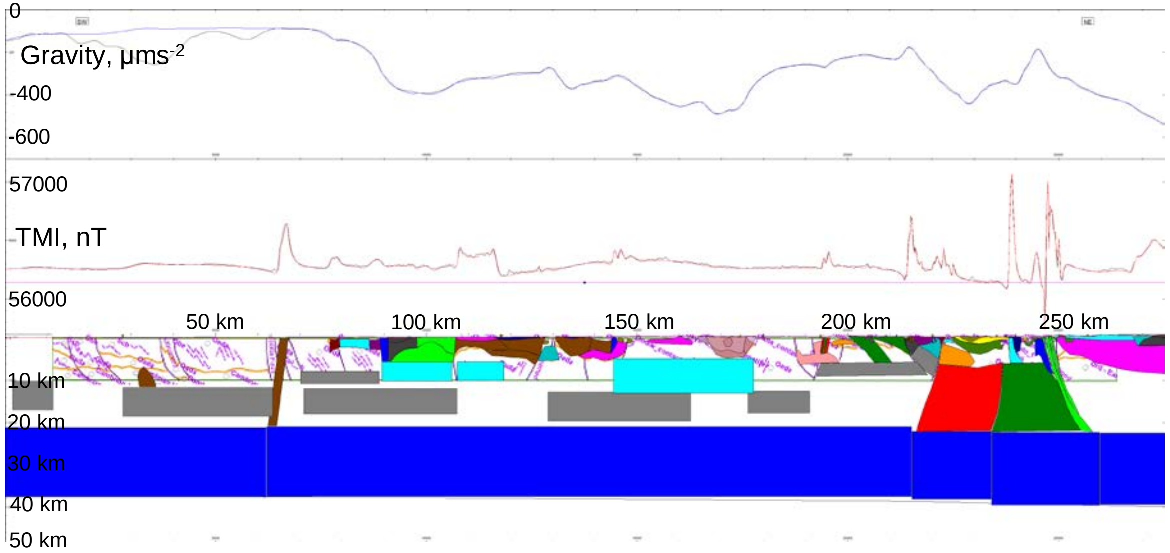
- Shallower sources, largely corresponding to features on reference cross-section (i.e., < 10 km).
- Assign magnetic susceptibility according to stratigraphic unit/lithology.
- Modify and add features as needed.
  - Aim for geologically reasonable and consistent geometry at this stage.
- Note multiple magnetic sources in 10–20 km depth range.
- No attempt to model gravity at this stage.



Model 12, iteration 5: 58th overall iteration

Introducing gravity (step 8)

- Assign density according to stratigraphic unit/lithology.
- Model density from deepest sources (longest wavelength) up.
- Identify new gravity anomaly sources.
    - o Most significant are buried granites.
- Test modifications against magnetic anomaly.
    - o Play-off magnetic vs gravity misfits.
- Continue until both fields closely matched.



Model 26, iteration 3: 122nd overall iteration

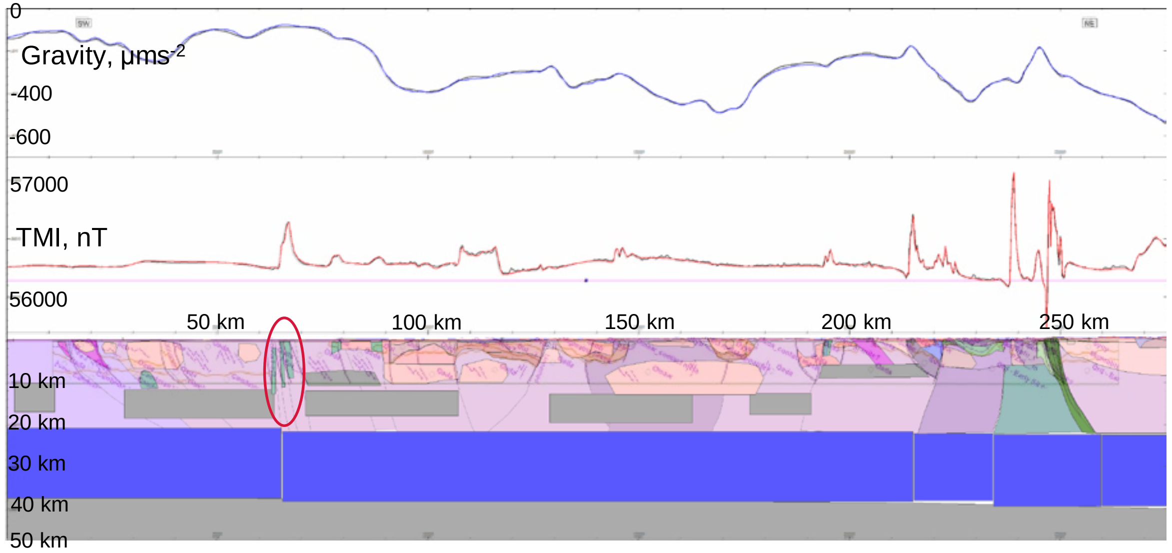
Final refinement (step 9)

Fill in the “white areas” – bodies with no magnetic or density contrast

- Magnetic susceptibility ~0, density ~2.67 g/cm^3
- Matches Ordovician metaturbidites
  - o Dominant Wagga-Omeo Zone lithology
  - o Abercrombie Formation and Willandra Sandstone

Return to geologist for review

- Further refinement, e.g. Kancoona fault zone

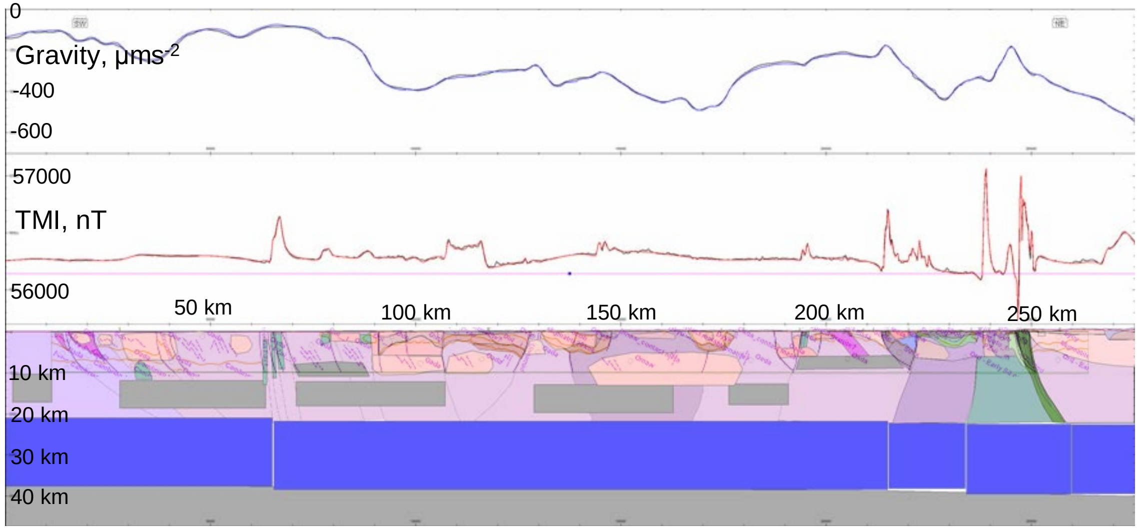


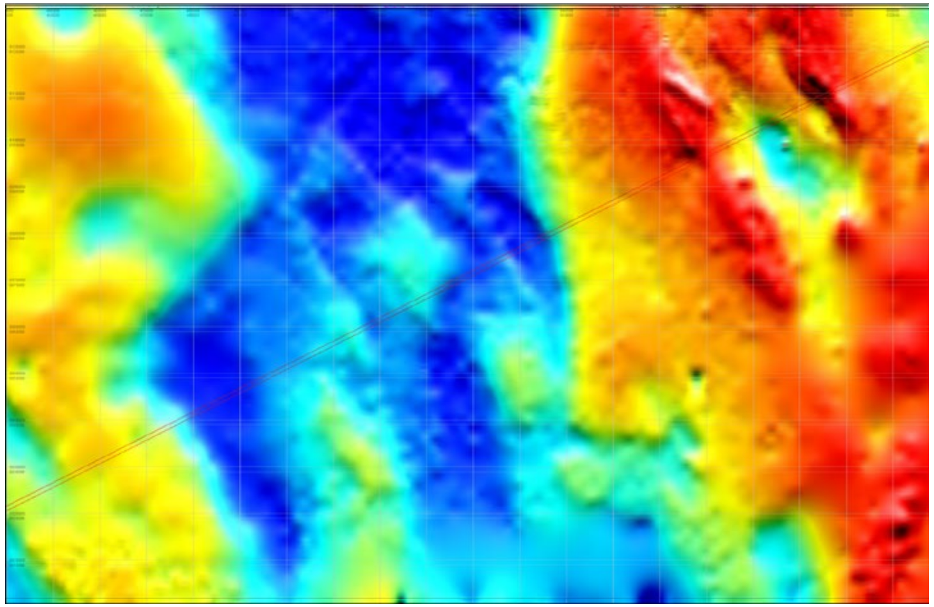
Model 30, iteration 1: 130th overall iteration

The output – magmatic and tectonic implications

Upper crust: faults and granites

- Model confirms location and dip of most mapped and inferred faults.
  - Minor revision of location of some inferred faults
- Most upper crust granite units are associated with major faults.
  - Stitching plutons or in hanging wall, thickening towards fault
- S-type granite more abundant than reference cross-section indicated.
  - In several places the Abercrombie Formation is a thin screen, <1 km thick
  - Large S-type granite units down to about 12 km
  - I-types with ignimbrite veneer





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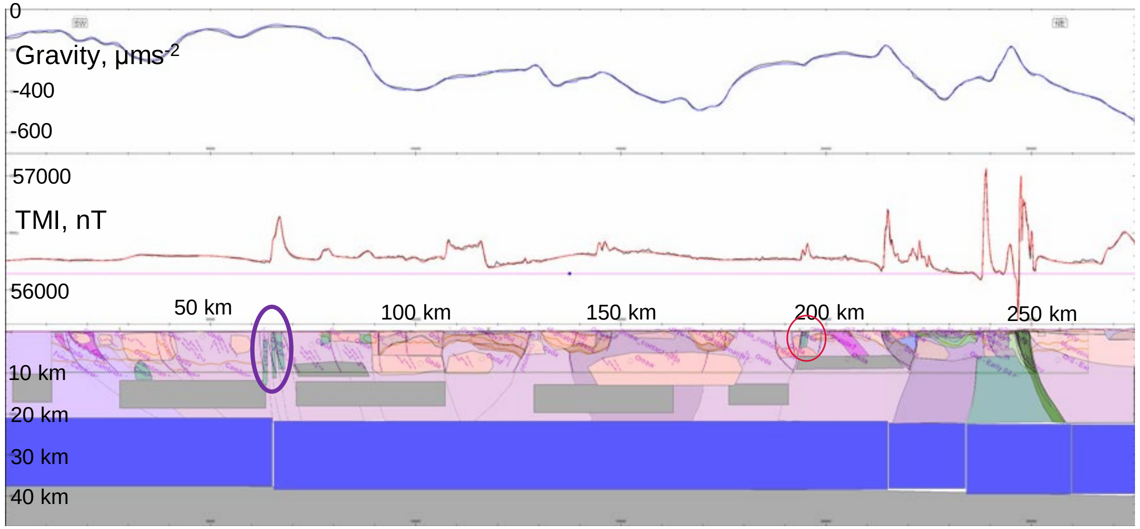
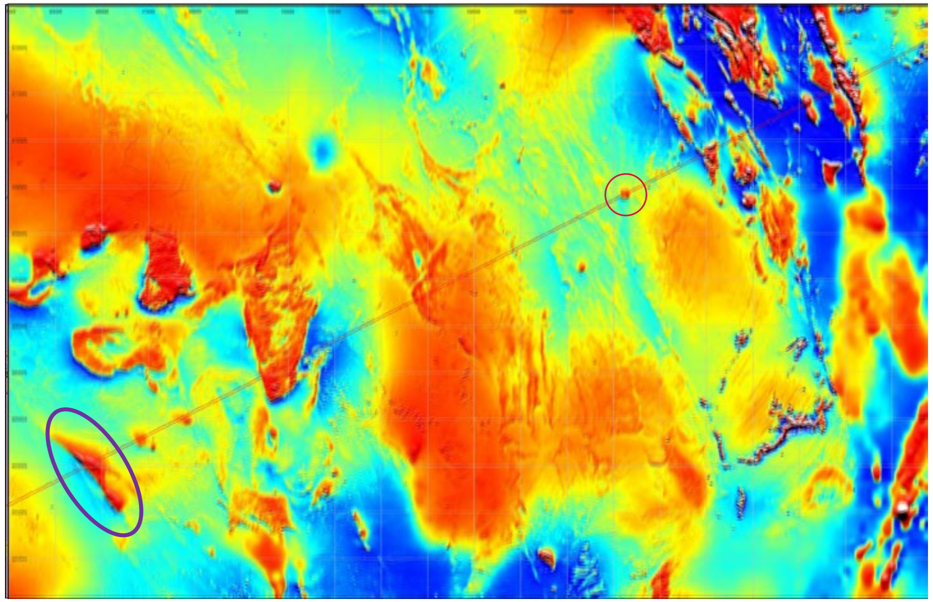
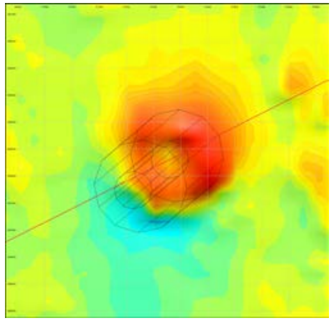
Upper crust: ?Early Devonian intrusions

- Highly magnetic intrusions
  - Multiple inferred locations from magnetic images
  - Very limited outcrop
  - Possibly equivalent of Middledale gabbroic diorite
    - – Early Devonian?
- Modelling shows these are deeply rooted.
  - Appear to connect to mid-crust magnetic intrusions
  - Most follow faults
    - – including major strike-slip faults
    - – Kancoona and Kiewa fault zones
  - Some appear to have significant remanence
- Nested pipe intrusion about 200 km NE on line (near Tarcutta)
  - Inner pipe reversed-polarity remanence

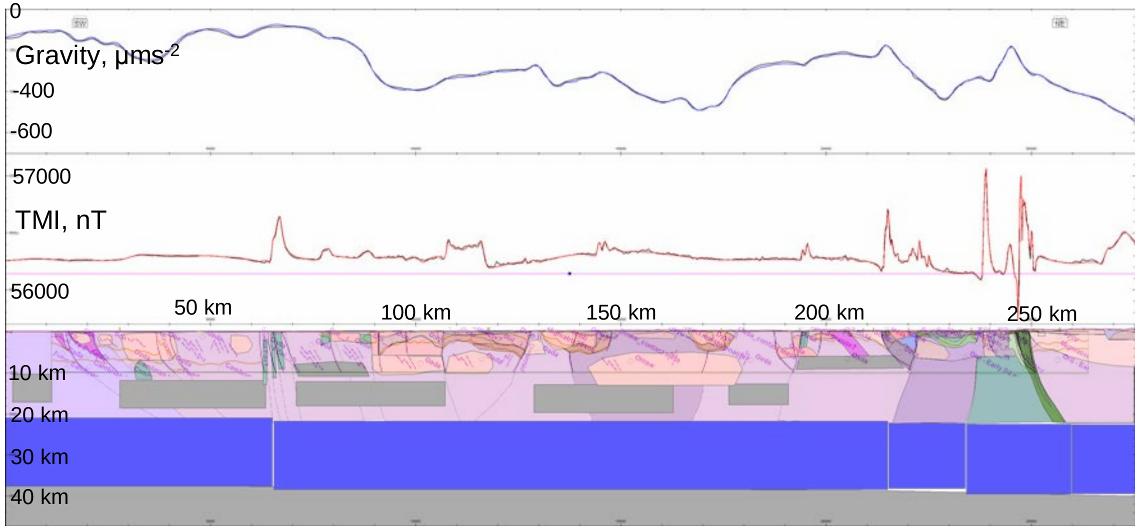


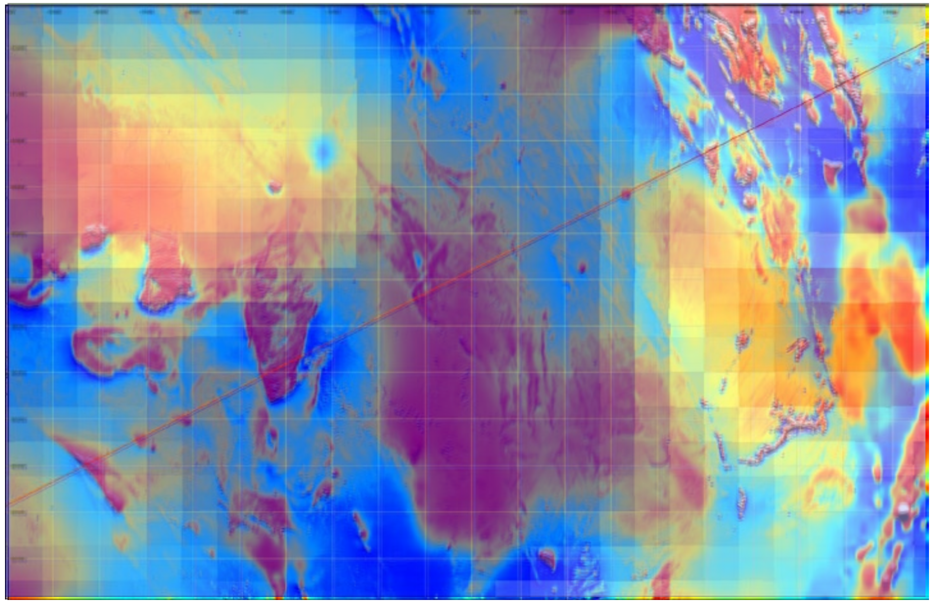




Middle crust: magnetic intrusions

- Magnetic susceptibility (k) > 600 x 10^{-5} SI
  - Most ≥ 1000 x 10^{-5} SI
- Density not certain
  - Models with intermediate density, ρ = 2.67 g/cm^3, but could be denser
  - Suggests intermediate to mafic chemistry
- Too deep to definitively model geometry
  - But magnetic image suggests fault-bounded
- Root of ?Early Devonian intrusions?
- Association with overlying S-type granites
  - Probable heat source
- At least one appears associated with MT conductivity high at 20 km.





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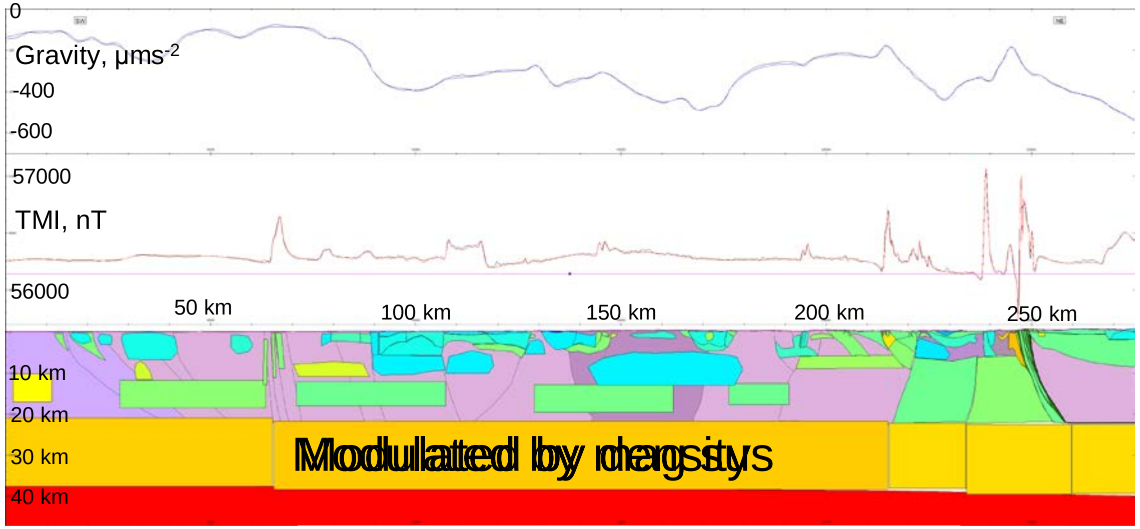
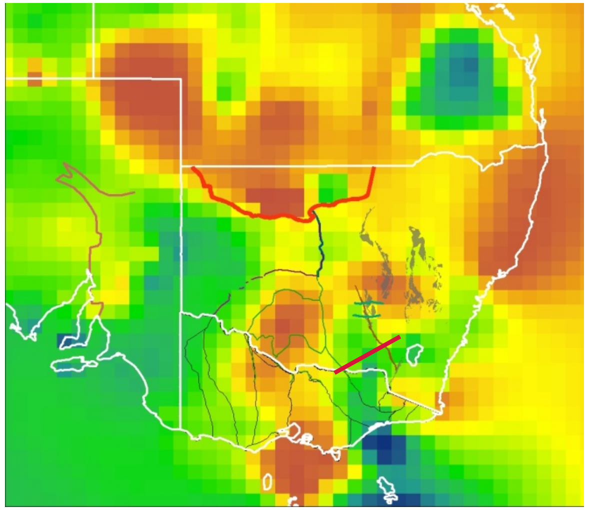
Lower crust: back-arc and arc basements

- Wagga–Omeo Belt and Tumut Trough have contrasting lower crust.
    - Wagga Omeo $k = 3000 \times 10^{-5}$ SI, $\rho = 2.87$ g/cm^3 Tabberabbera Zone similar
    - Tumut Trough $k = 200 \times 10^{-5}$ SI, $\rho = 2.85$ g/cm^3
- Wagga–Omeo Belt properties consistent with back-arc MORB
- Tumut Trough – probably more intermediate
    - Much of Macquarie Arc has similar substrate
    - Similar to ~tonalitic composition of lower crust under some modern mature oceanic arcs (e.g., Izu–Bonin)
- Seismic velocity of lower crust supports division into high-velocity MORB and lower velocity tonalite





The future – EFTF seismic, and more sections

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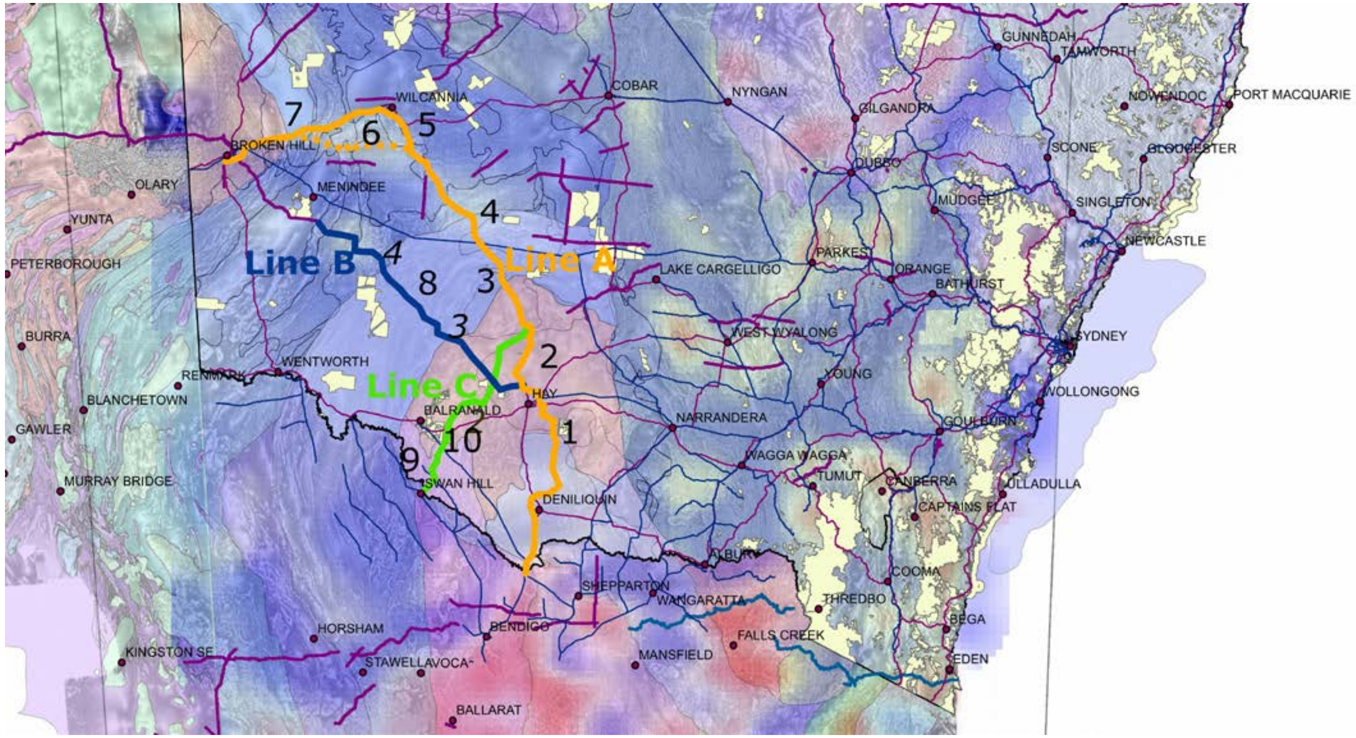
EFTF seismic proposal

- Modelling in East Riverina was possible because of an excellent reference cross-section.
- It's much more challenging under basin cover.
  - o Unresolved tectonic relationships between Curnamona, Delamerian Orogen, Lachlan Orogen and Hay–Booligal Zone.
- What we need is a long, continuous seismic reflection profile.
  - o Similar to the Victorian profile
- We are currently arguing the case for a slice of GA's Exploring for The Future initiative funding.
  - o Program 4: Curnamona–Delamerian–Stuart Shelf



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