Geophysical Detection of Mineral Systems: The Importance of Deep Penetrating Geophysical Methods

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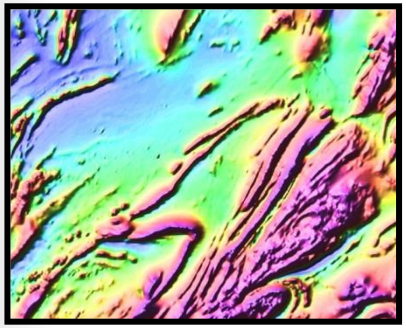
MINERAL SYSTEMS

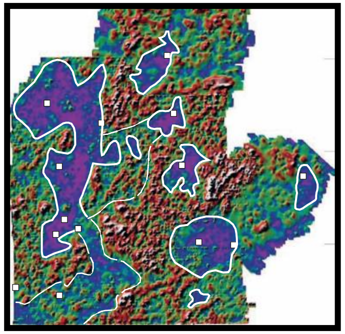
Geophysical exploration strategy at the terrain to prospect scale

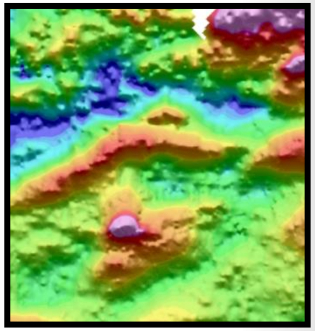
Mapping | Direct Detection

'The Map' | 'The Bump'

Stratigraphic Contacts	Structure	Host Lithotype	Alteration Zone	Gangue Minerals	Ore Minerals
Komatiite-hosted NiS	Orogenic Au	Primary Diamonds	Epithermal Au	VMS	Graphite/U



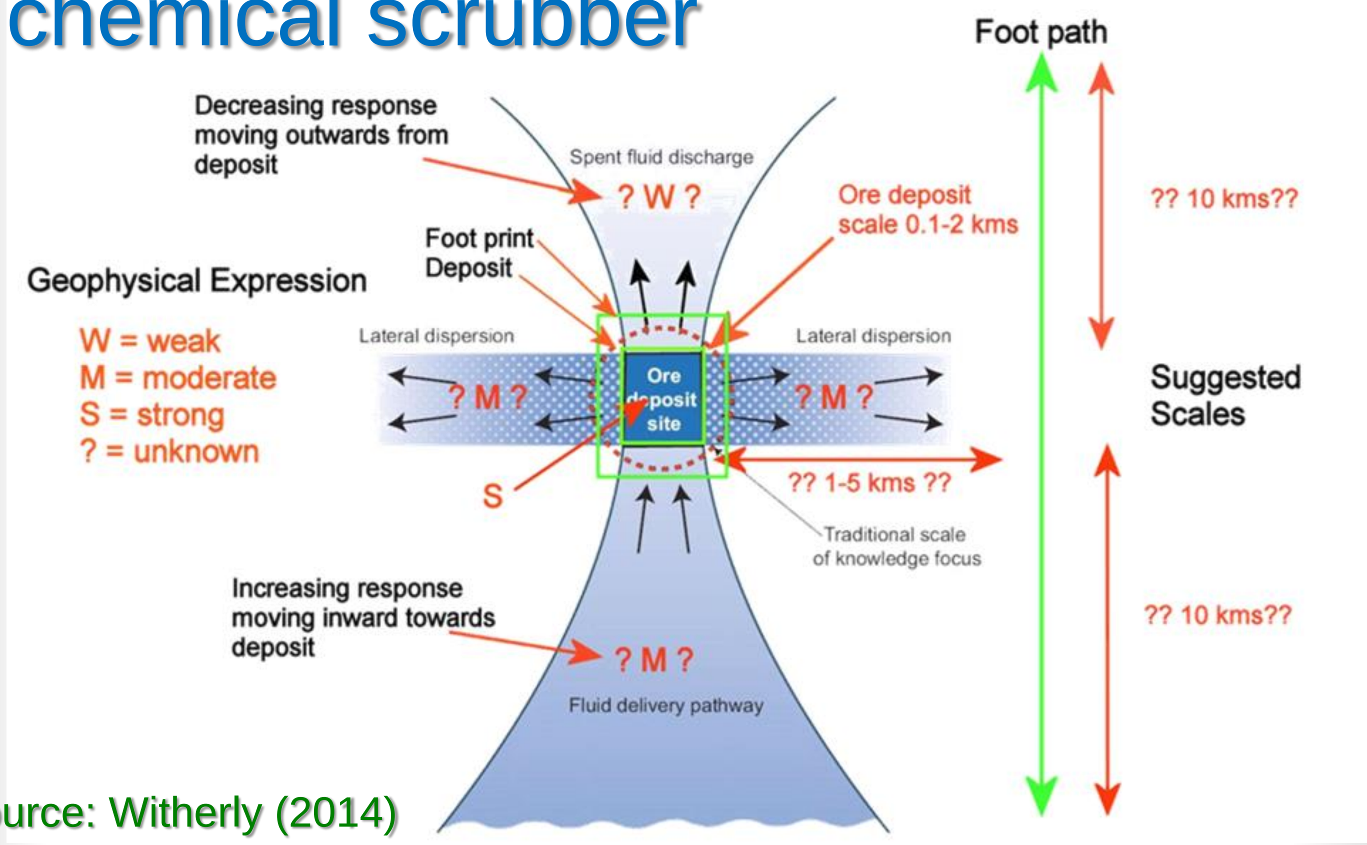




MINERAL SYSTEMS

A mineral system suggests a whole new set of targets!

- Source-pathway-physical throttle-chemical scrubber



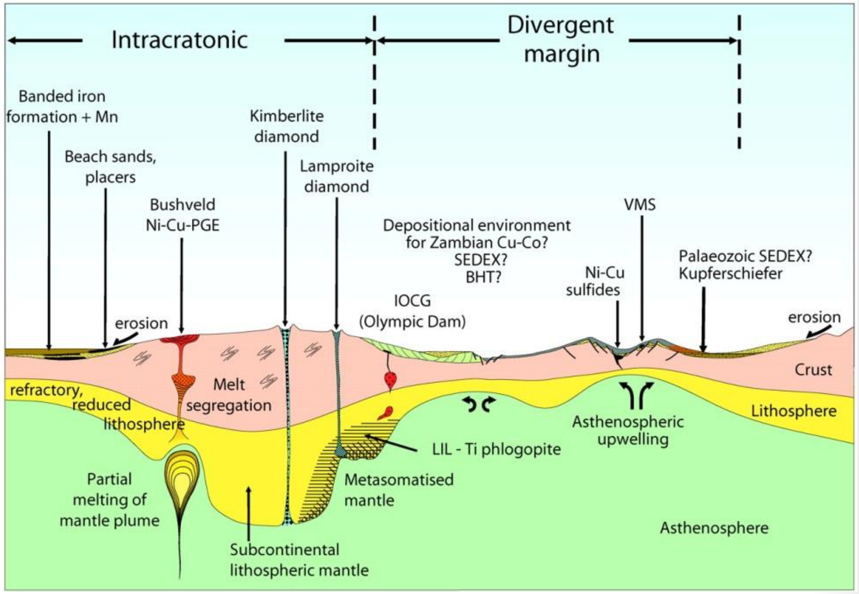
Source: Witherly (2014)

DEEP GEOPHYSICS

Mineral systems processes occur on a scale of 100s to 1000s of km^3

- Need geographically widespread datasets
- Scale is such that these are likely to come from Government

Need to image source/pathways at kms to mantle depths

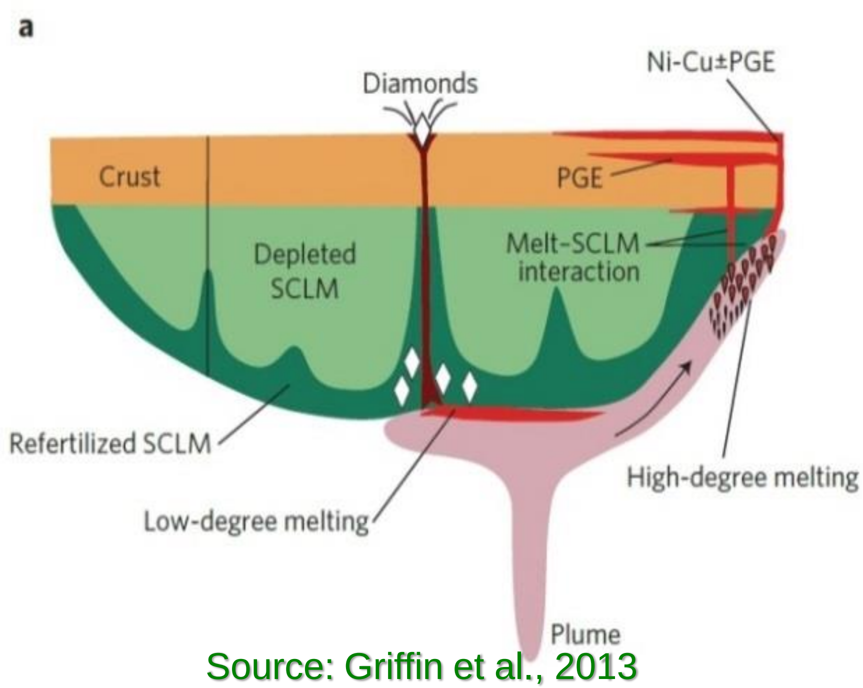


(Source: Groves and Bierlein (2007))

DEEP GEOPHYSICS

Potential mineral system ‘targets’ in the crust and mantle - sources

- Metasomatised mantle
  - Depleted, re-fertilized etc
- Major magma chambers or fluid reservoirs
- Zones of crustal underplating
  - Rifting related
  - Mafic intrusions



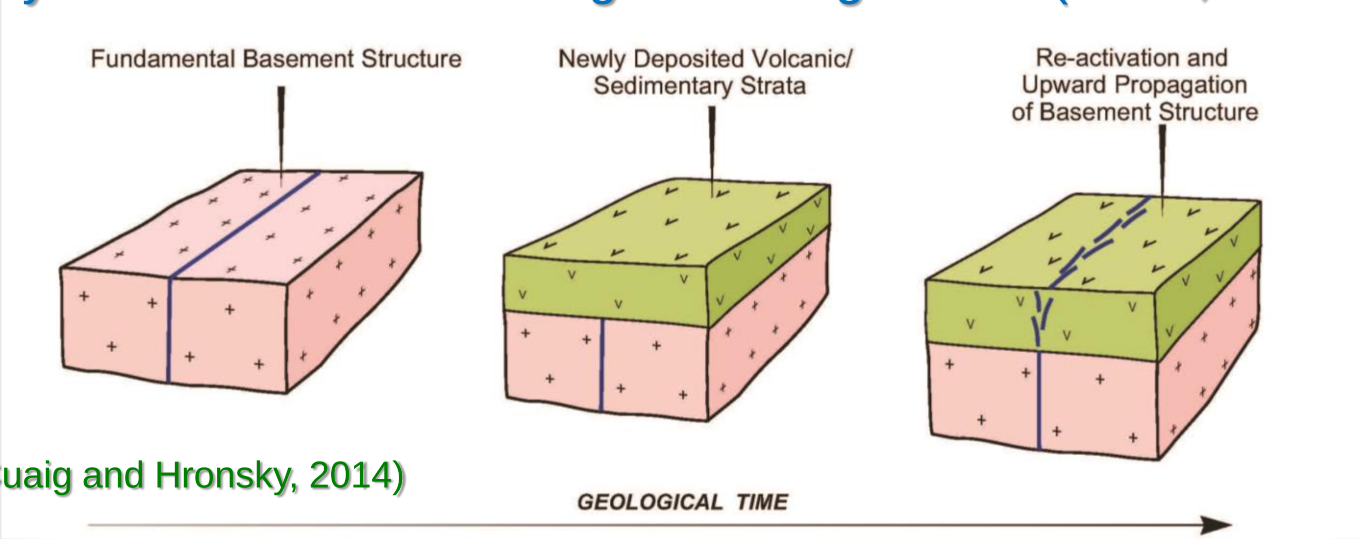
Source: Griffin et al., 2013

DEEP GEOPHYSICS

Potential mineral system 'targets' in the crust and mantle - pathways

Characteristics of major deposit controlling structures

- 100s km in strike length
- 'Early' basement structures that are repeatedly reactivated
- Often lack an obvious surface expression
- Associated structures propagate upwards in to the younger cover
    - May be fault arrays
    - Individual faults with small individual displacements
- May be associated with long-lived magmatism (mafic, alkaline)



Source: McCuaig and Hronsky, 2014)

DEEP GEOPHYSICS

Pathways

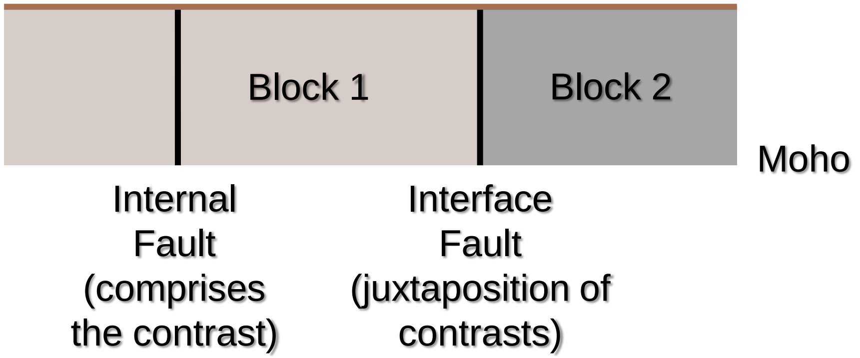
- Major structures seen as linears in regional datasets

  Need depth data to determine how structures link and which reach the mantle

Useful to define two classes

The response is controlled by a combination of physical property contrast and the volume of the material representing the contrast (most cases)

'Internal' fault zones are <u>harder</u> to see than 'interface' faults

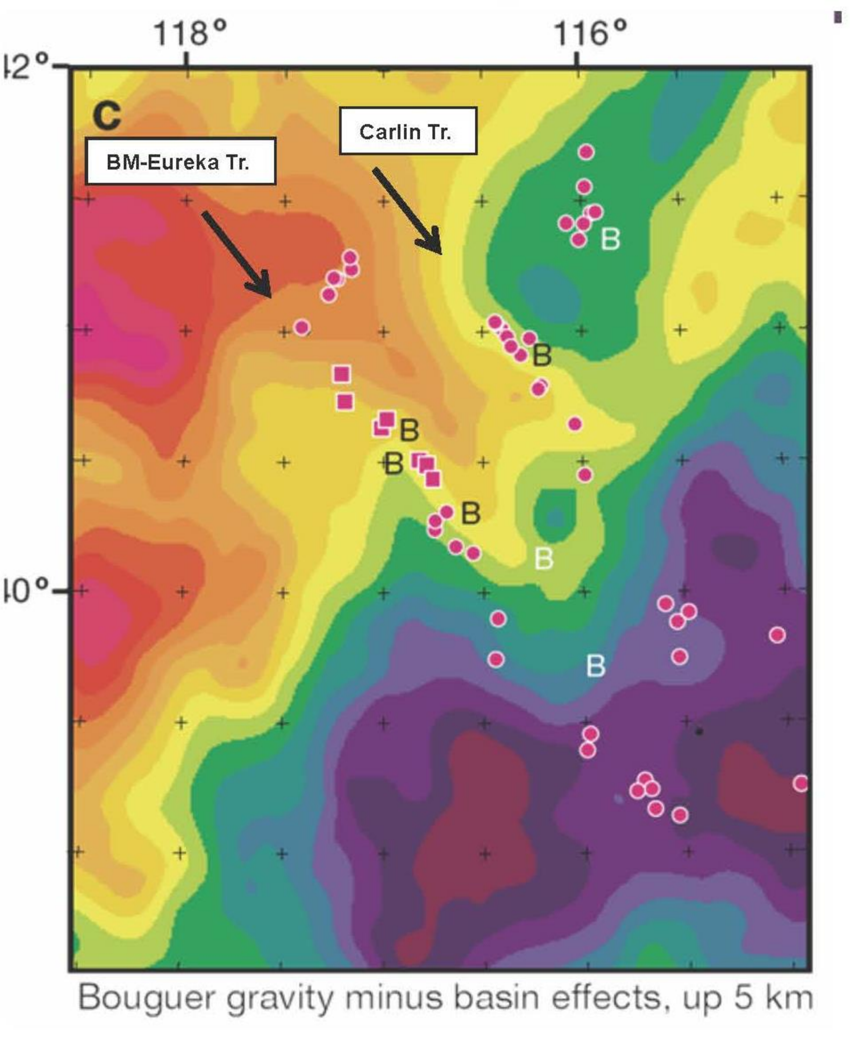


DEEP GEOPHYSICS

Geophysical options?

- Magnetotellurics (MT)
- Active seismic methods
- Passive seismic methods
- (Gravity and magnetics)
- (Heatflow, DEMS/satellite remote sensing)

How can these 'academic' tools be best utilised in exploration?



Source: Grauch et al, 2003

MAGNETOTELLURICS

Deep penetrating frequency-domain EM technique

- Developed in 1940s
- Can penetrate well in to the mantle

Passive source

- Cheap

Well established 'academic' geophysics tool

MAGNETOTELLURICS

Major problem is the lack of understanding of causes of conductivity variations in deep Earth – conductive lower crust

- Sulphide and oxide phases, graphite, saline fluids (upper crust)
- Temperature (younger regions)
- Hydration (mantle)

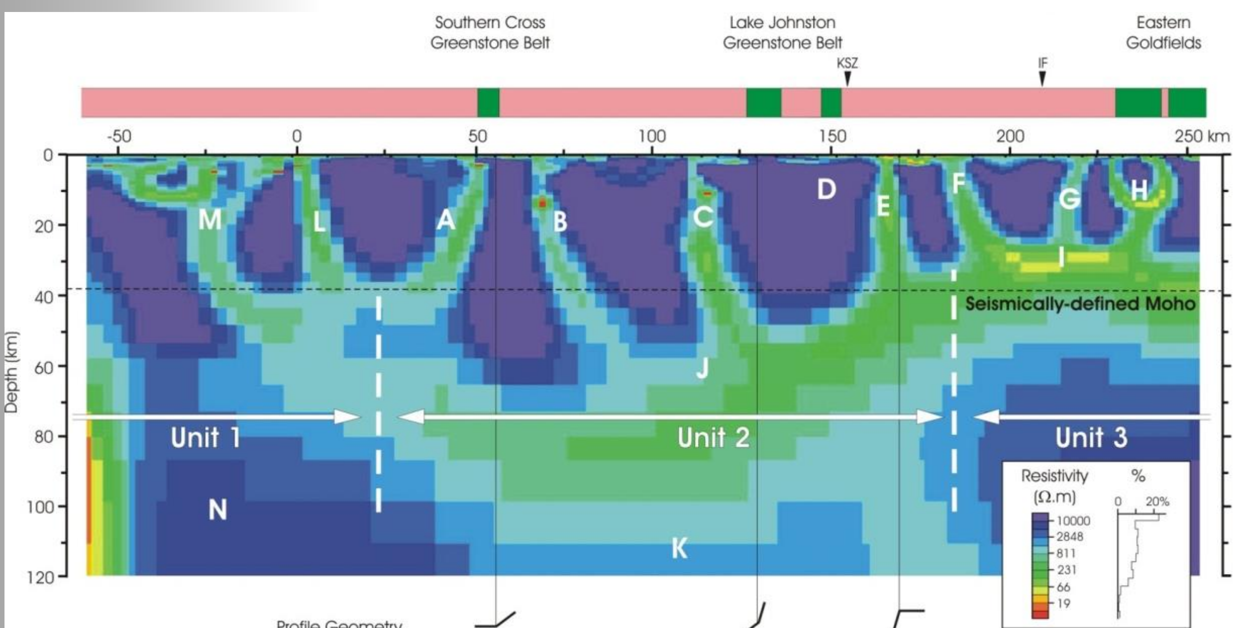
Indicative of mantle melting etc, i.e. source areas

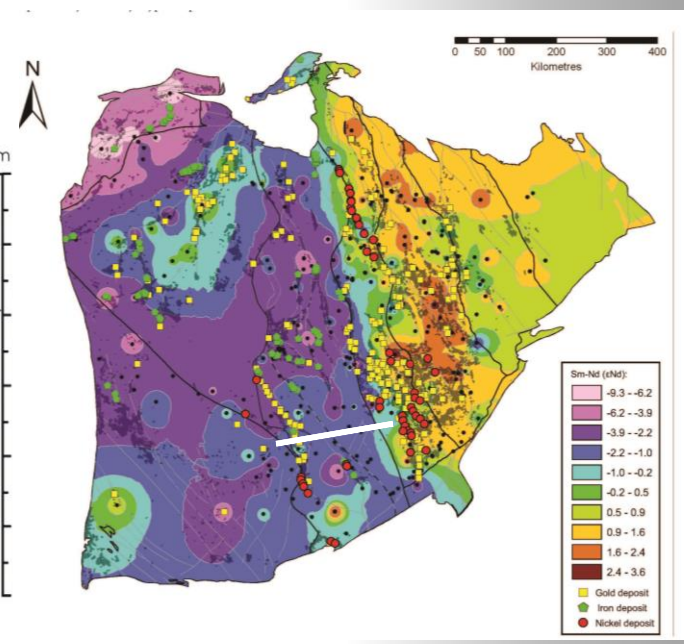
Interpretation is exercise in geological pattern recognition

MAGNETOTELLURICS

When it works can provide apparently very useful results – southern Yilgarn Craton, Western Australia

- Major faults – both interface and internal
- Mantle source zone?

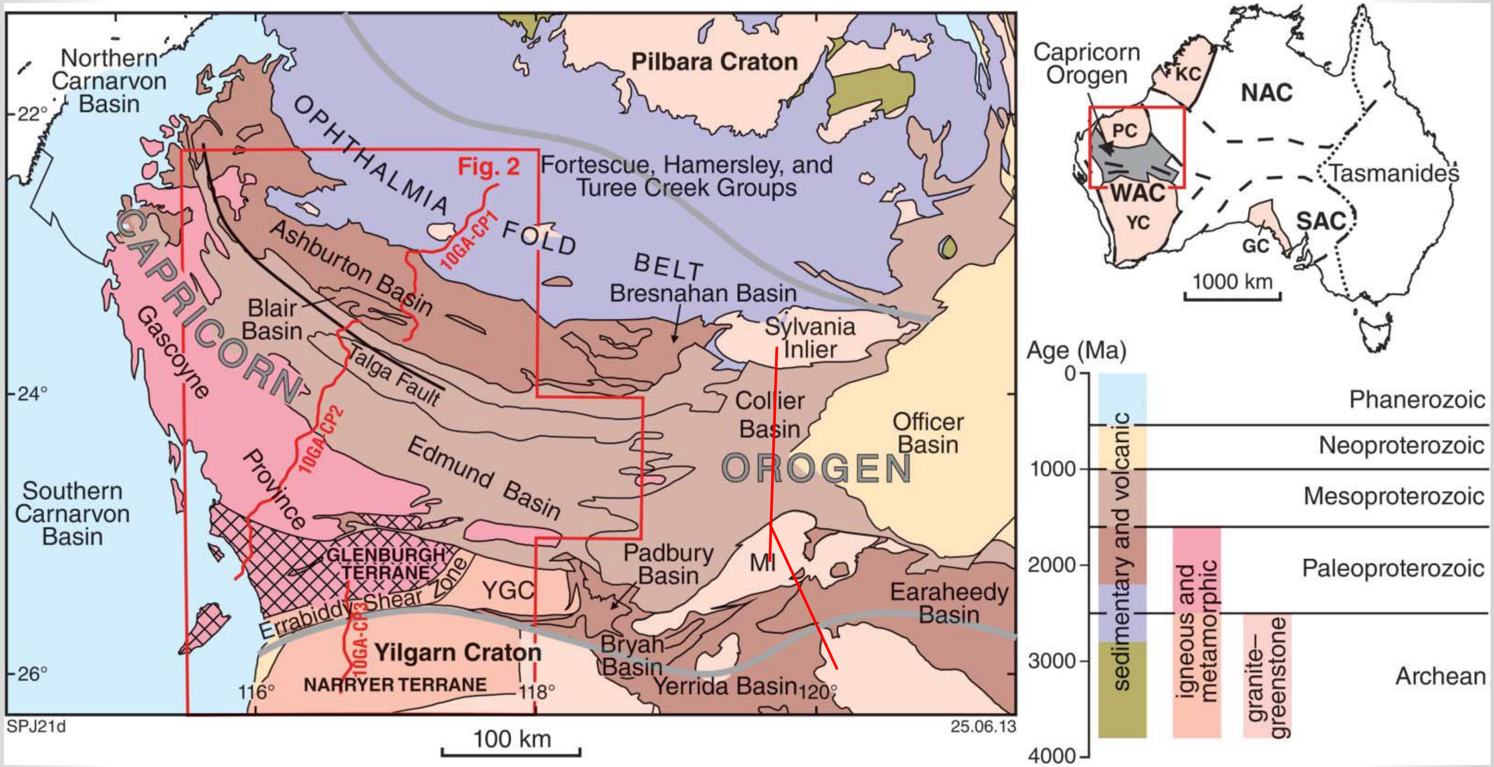




MAGNETOTELLURICS

When it works can provide apparently very useful results – Capricorn Orogen, Western Australia

- Cratonic margins beneath younger cover



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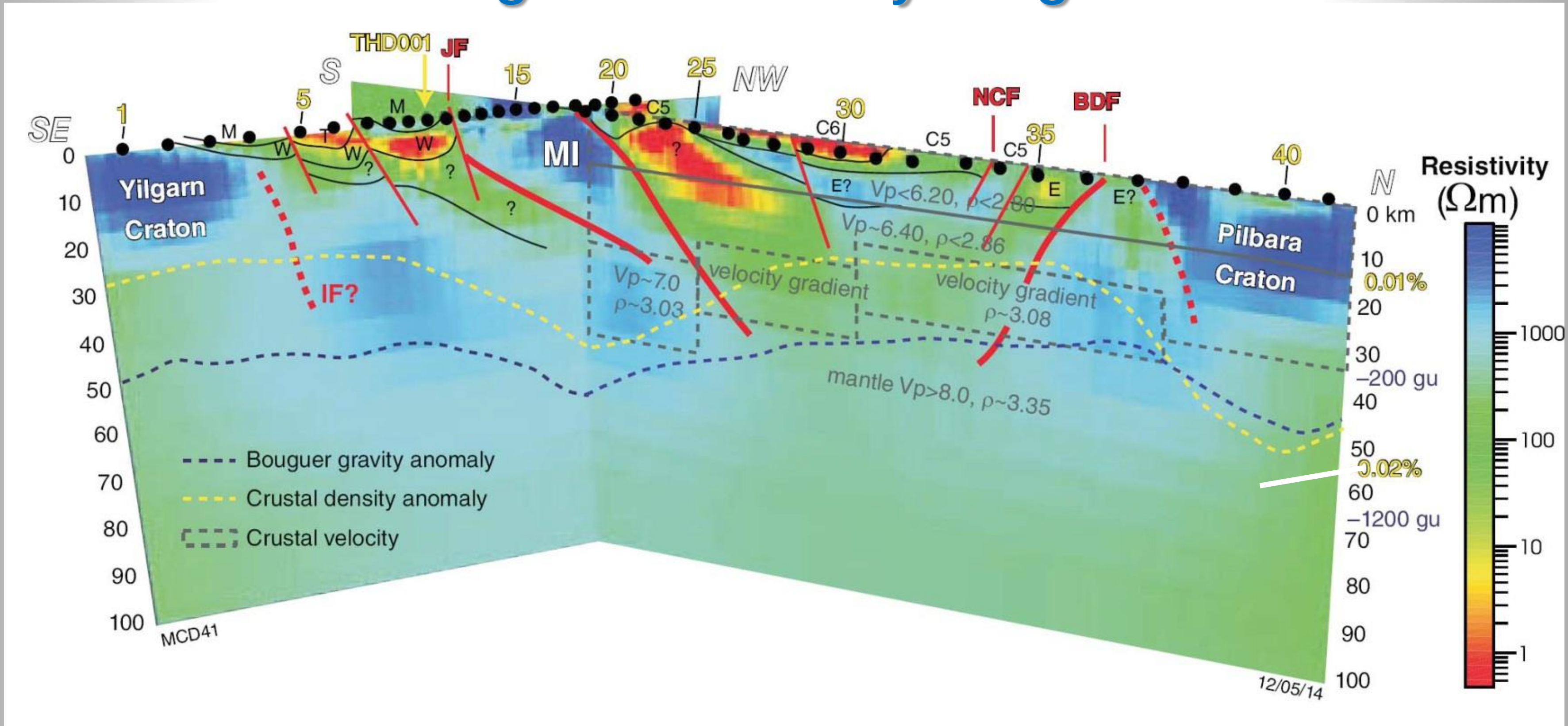
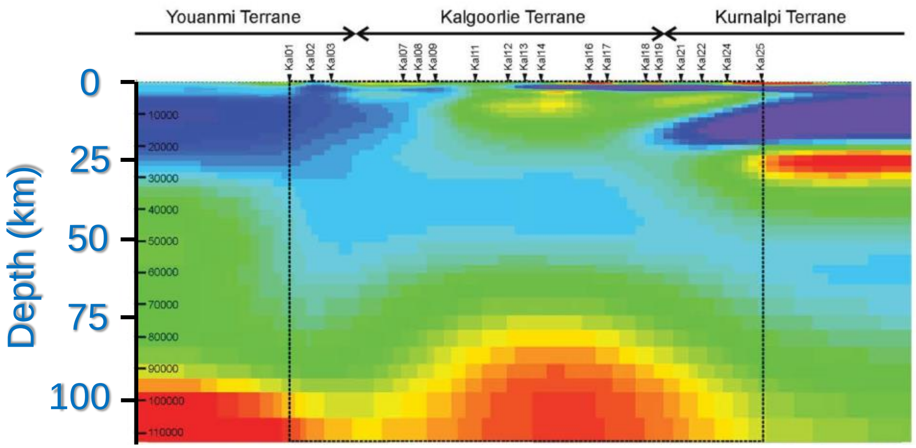


MAGNETOTELLURICS

A comparatively cheap method of imaging very deep

- Unsure of sources of conductivity variations
- Images major faults and other tectonic features – fluid pathways
- Evidence that it can help identify fluid source and reservoir zones too



Source: Blewitt et al. (2011)

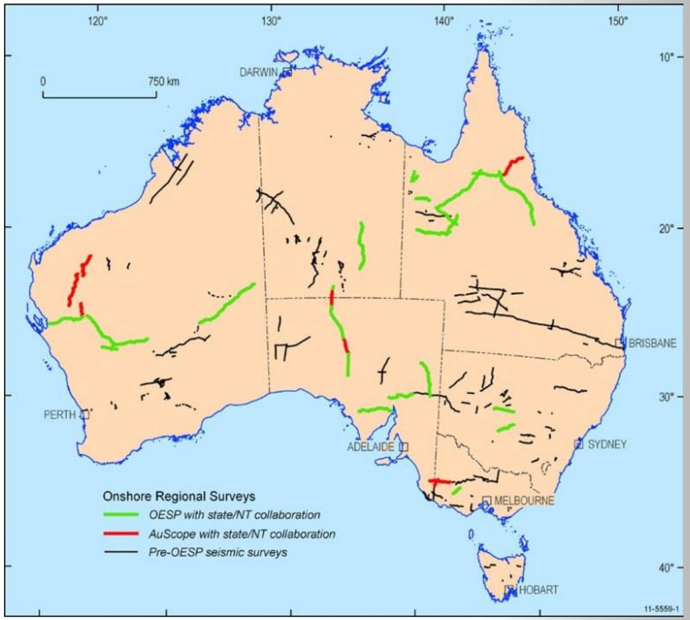
SEISMIC REFLECTION

Deep (whole crust) seismic reflection data

- Deeper, lower frequency version of petroleum seismic surveys
- Several countries have significant amounts of data

Advantages

- Highest resolution type of geophysics
- Map structure and stratigraphy in crust and upper mantle



Source: http://www.ga.gov.au/about/what-we-do/projects/minerals/current/seismic

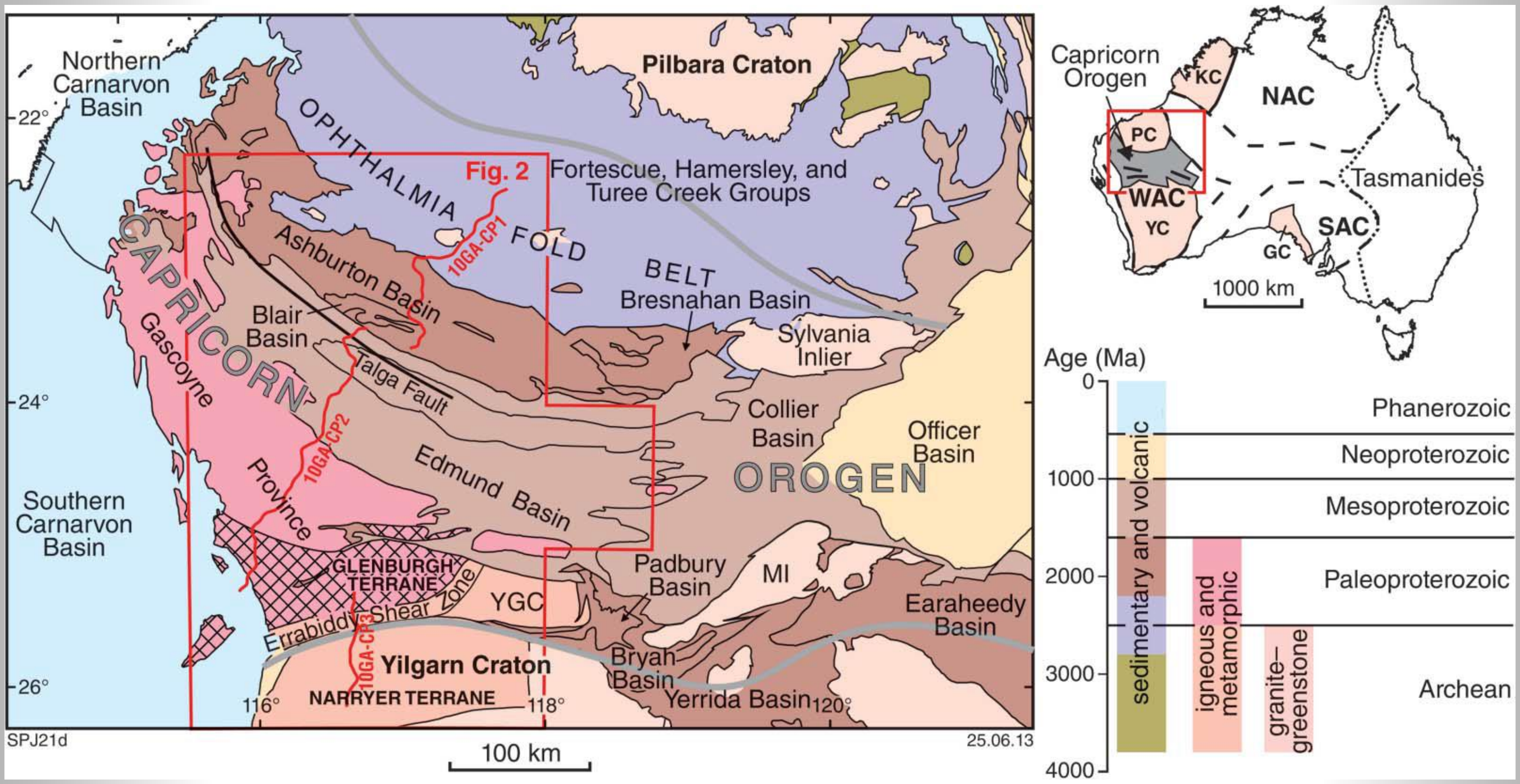
SEISMIC REFLECTION

Disadvantages

- Very expensive
- Only practical to record in 2D
  - Sideswipe
  - Crooked lines
- Poor velocity information
  - High velocities
- Hard to migrate
  - Affects geometric relationships
- ¼ wavelength and Fresnel zones are large in lower crust
  - Wavelengths are hundreds of metres

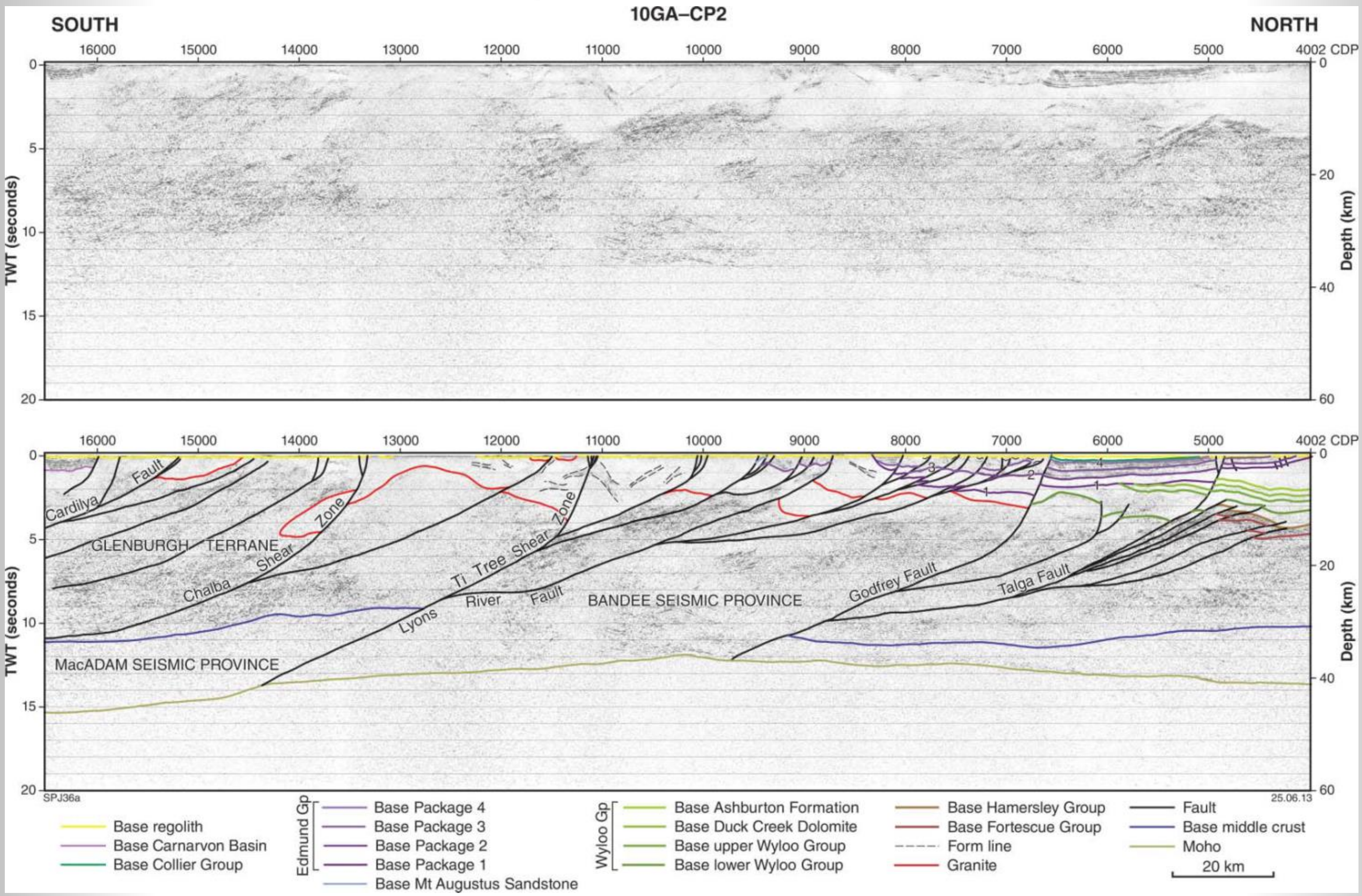
SEISMIC REFLECTION

Example – Capricorn Orogen, Western Australia



SEISMIC REFLECTION

Which of the major faults reach the mantle?
Where are the major ‘terrane’ boundaries?

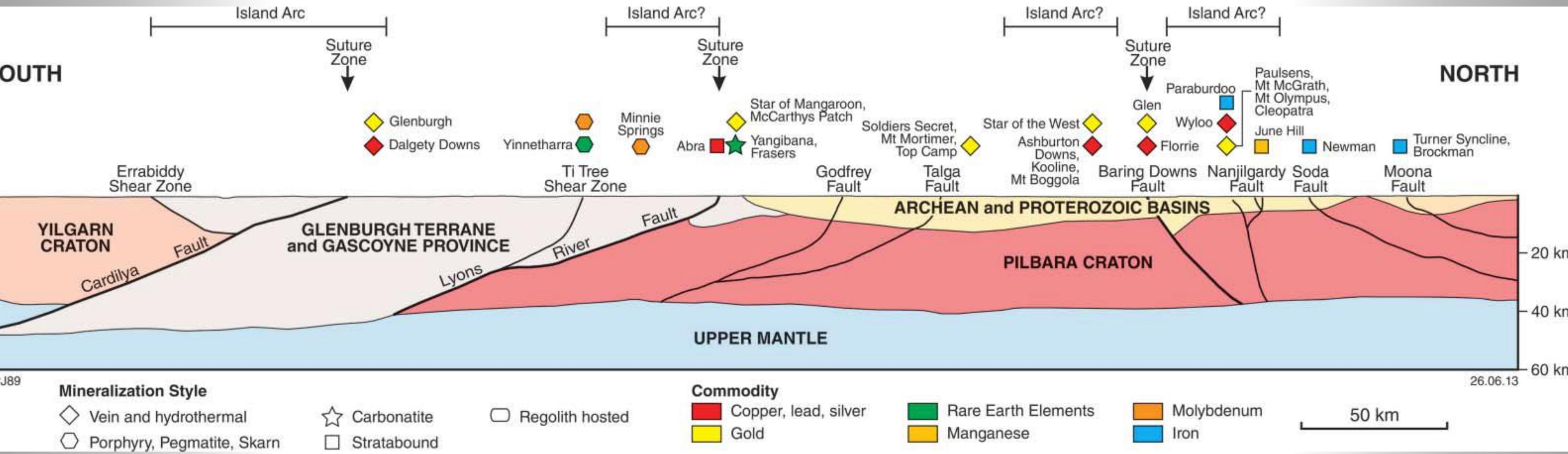


SEISMIC REFLECTION

Which of the major faults reach the mantle?

Where are the major 'terrane' boundaries?

- Spatial association with hydrothermal deposit



SEISMIC REFLECTION

Too expensive to be a greenfields exploration method

Need to consider cheaper alternatives

- Wide-angle/refraction surveys
- Passive seismic methods
- Using these methods to produce ‘reflection’ equivalent products (key research objective)

Probably best used together

- Extrapolate away from the reflection profiles
- Also provide complementary information

PASSIVE SEISMIC METHODS

Advantages

- Do not require expensive artificial sources

  Drilling of shot holes

Disadvantages

- Lack resolution
- Long deployment times

  Weeks, months, years

Options

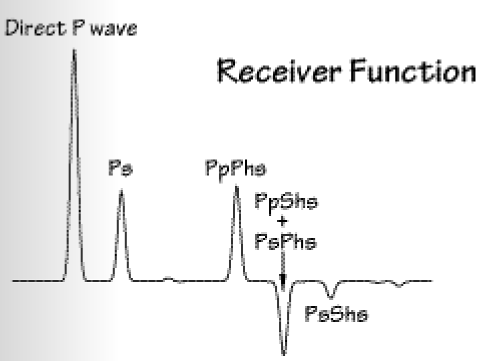
- Ambient noise methods
- Teleseismic methods

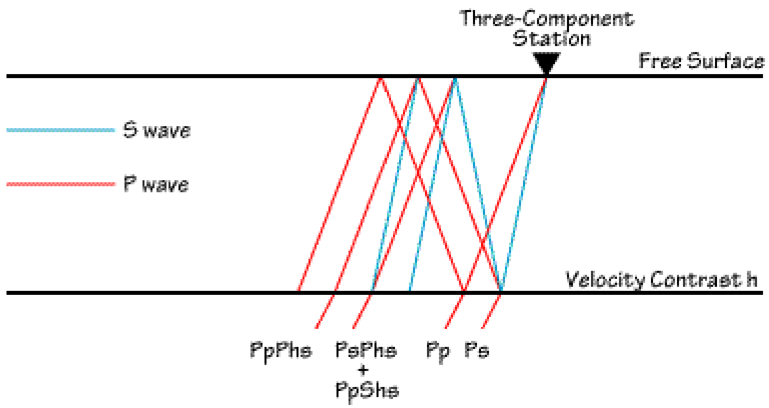
  Receiver functions, body wave tomography

TELESEISMIC METHODS

Receiver functions

- Based on the modification of the teleseismic wavefield as it passes through the crust (conversions, multiple reflections)
- Receiver function is the velocity structure beneath the recording station
- Produces 1D velocity-depth function

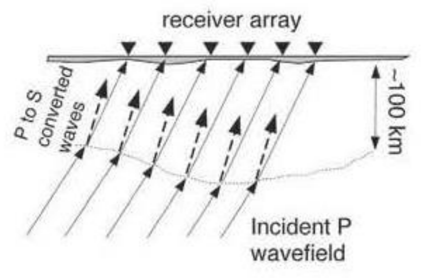




Source: http://eqseis.geosc.psu.edu/~cammon/HTML/RftnDocs/rftn01.html

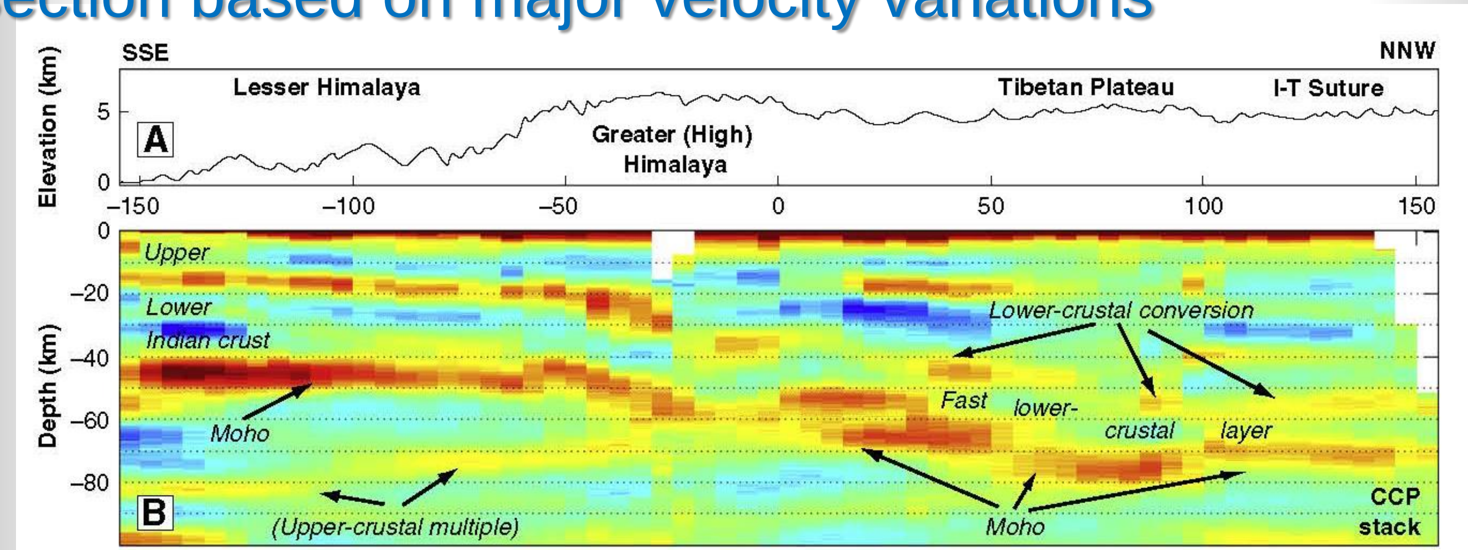
TELESEISMIC METHODS

Receiver functions



Teleseismic imaging
(forward scattered P to S)

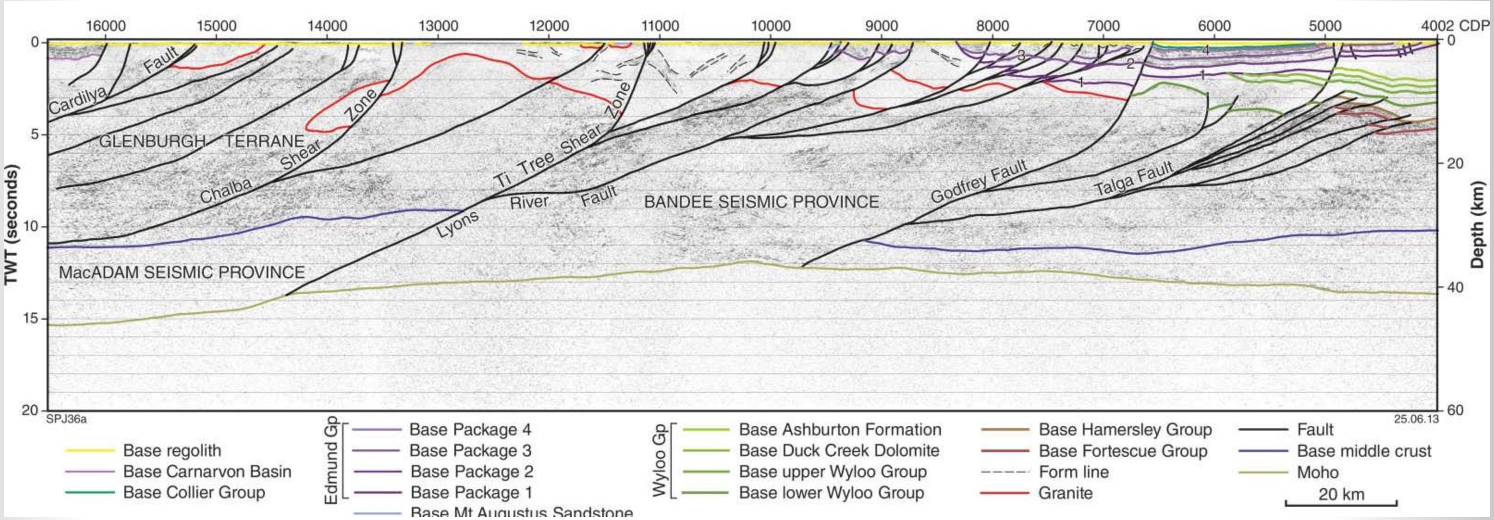
- Can be inverted to produce a 1D velocity function
- More recent work has concentrated on higher resolution arrays and common conversion point (CCP) processing
- Can produce a 'low resolution' seismic reflection-like section based on major velocity variations

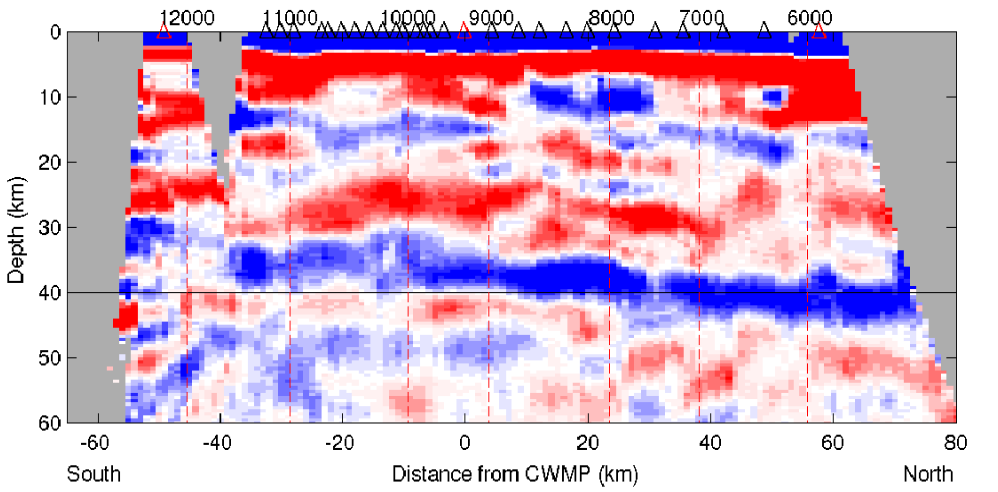


Source: Schulte-Pelkum et al. (2005)

TELESEISMIC METHODS

High resolution receiver function study in the Capricorn Orogen





PASSIVE SEISMIC METHODS

Potential role in mapping major geological boundaries

- Interface faults at craton margins
- Methods etc in existence

Emerging role for receiver function-based surveys

- Map major boundaries (interface faults)
- New methods map major structures (internal faults)
- Cheaper, lower resolution surveys to complement seismic reflection surveys

DEEP GEOPHYSICS & MINERAL SYSTEMS

There are plenty of useful and established deep geophysical tools available

And there are potentially some exciting new ones over the horizon

We need to combine ‘interface’ and ‘internal’ fault imaging methods

- Deep seismic reflection data can provide a reference point but need other methods to get good spatial coverage at realistic cost
- MT, receiver function, and ambient noise tomography?

DEEP GEOPHYSICS & MINERAL SYSTEMS

Implications for mineral system analysis

- Mapping lithospheric architecture/pathways is achievable with existing ‘solid earth’ geophysical methods
- There is inadequate understanding of causes of variations in petrophysical properties

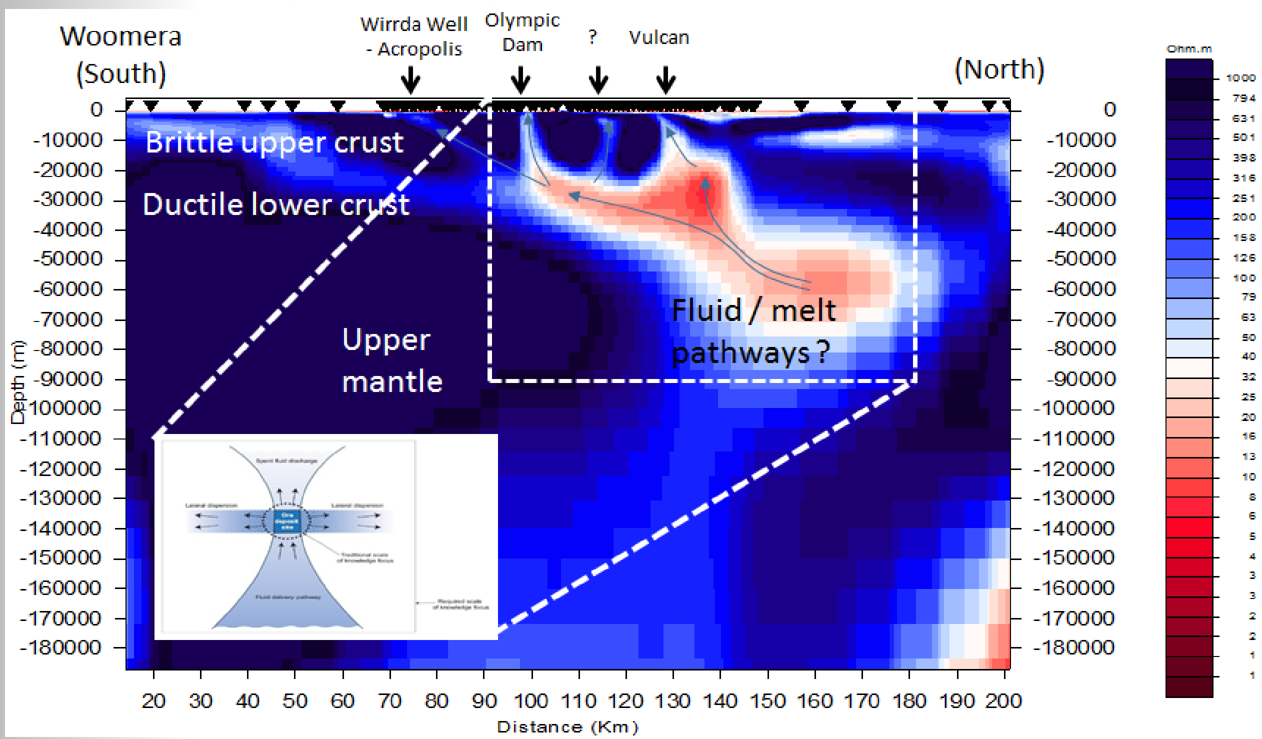
  Alteration associated with fluid flow and reservoirs

  Particular problem with understanding electrical properties

DEEP GEOPHYSICS & MINERAL SYSTEMS

Implications for mineral system analysis

- Governments should think about collecting deep geophysical datasets



Olympic Dam Cu-U-Au-Ag-REE Iron Oxide Copper Gold Deposit