The Youanmi Magnetotelluric (MT) transects

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Acknowledgements

Geoscience Australia – Onshore Seismic & Magnetotelluric Section (OSMT)

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Aki Nakamura, Tim Jones, Emilio Extremera

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- Terrex Seismic for logistic support.

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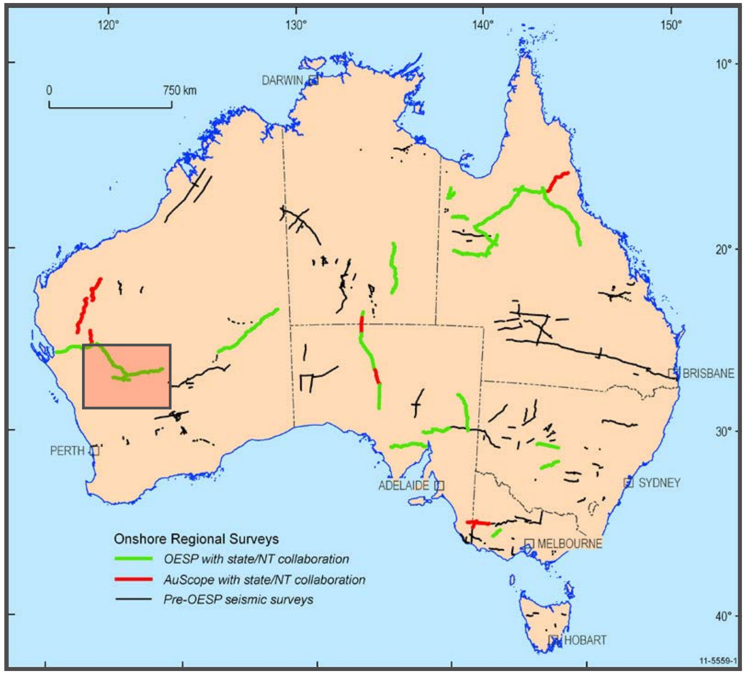
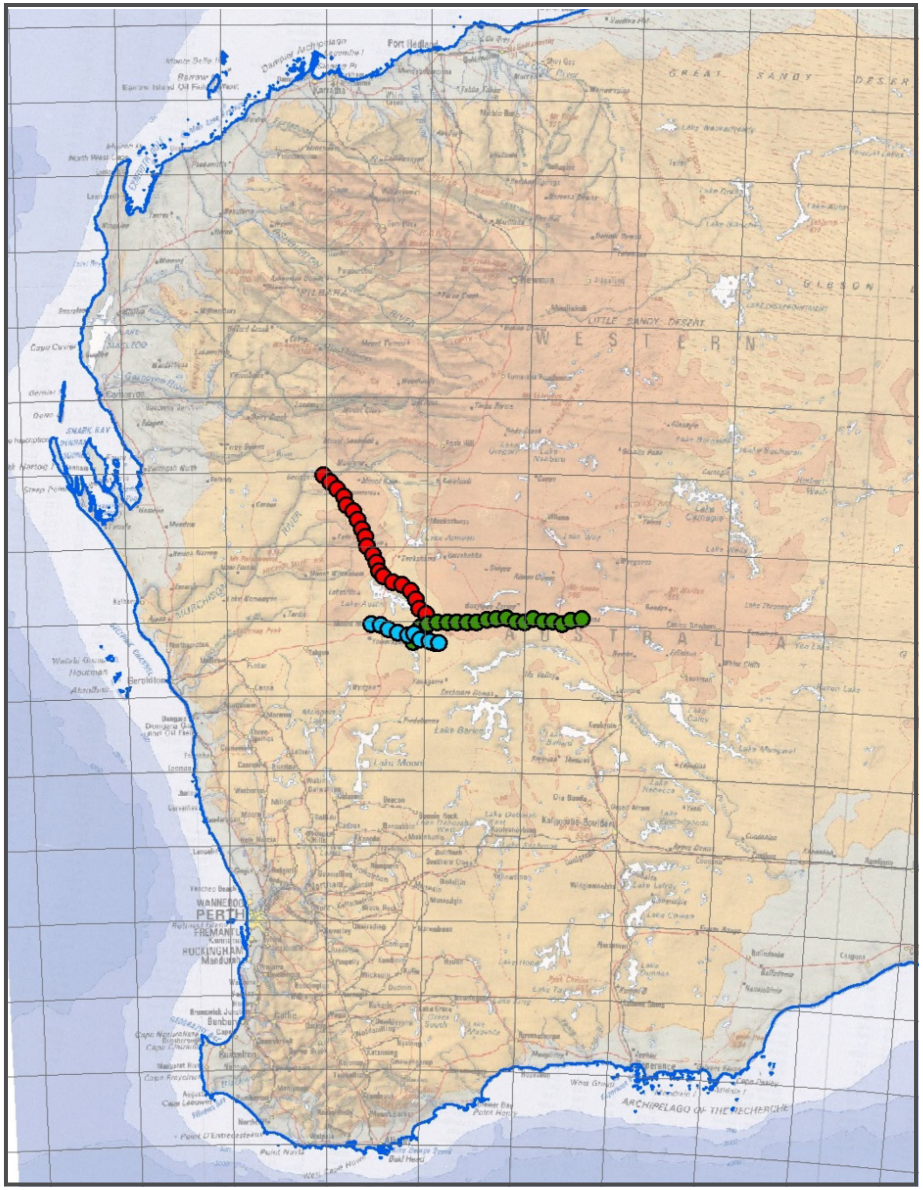
Introduction





Youanmi MT survey is a collaborative project along three seismic transects in the NW Yilgarn of WA

YU1 – red

YU2 – green

YU3 - blue

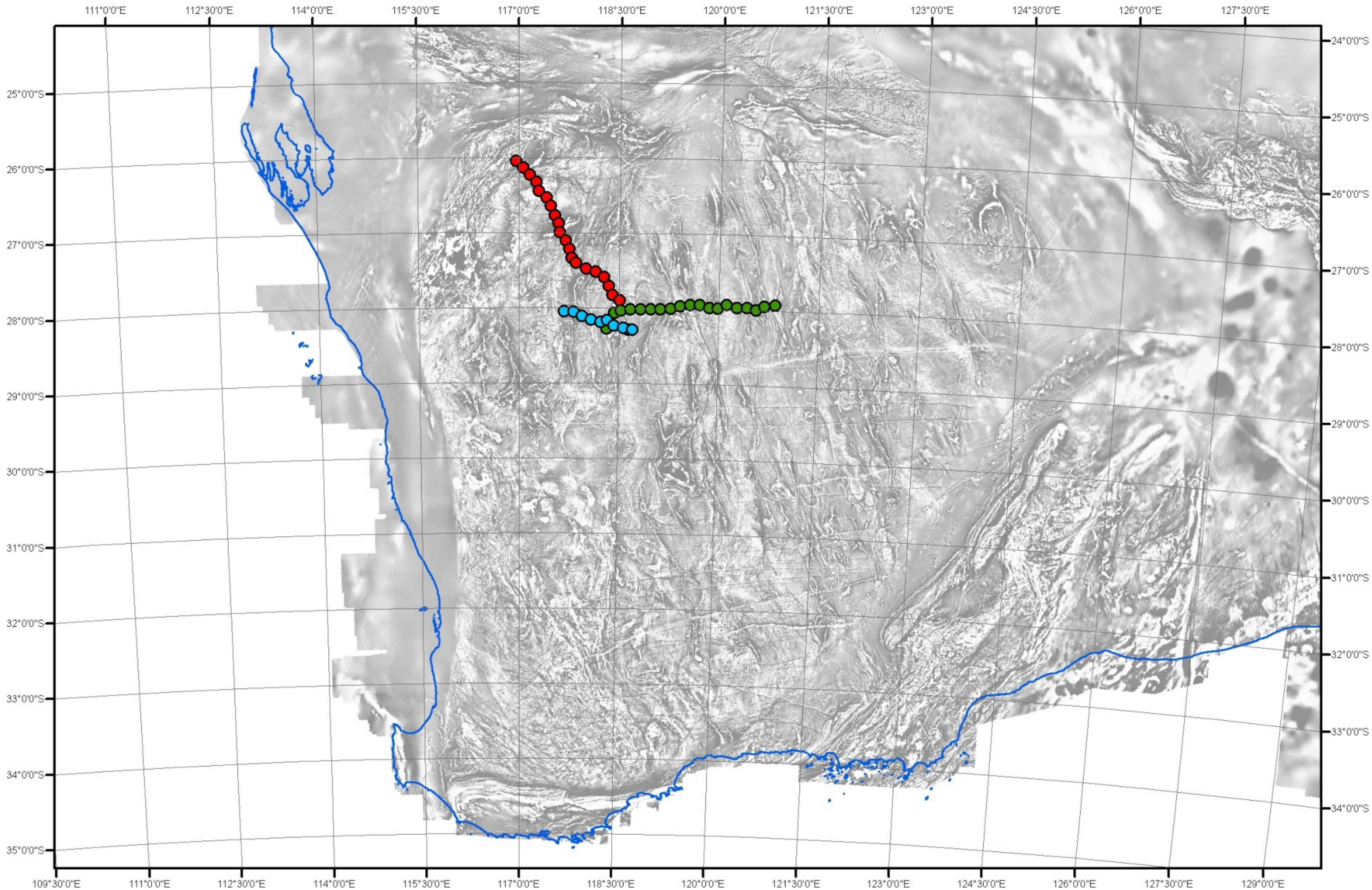
690 km total traverse

51 long-period sites, 15 km spacing

141 broad-band sites, 5 km spacing

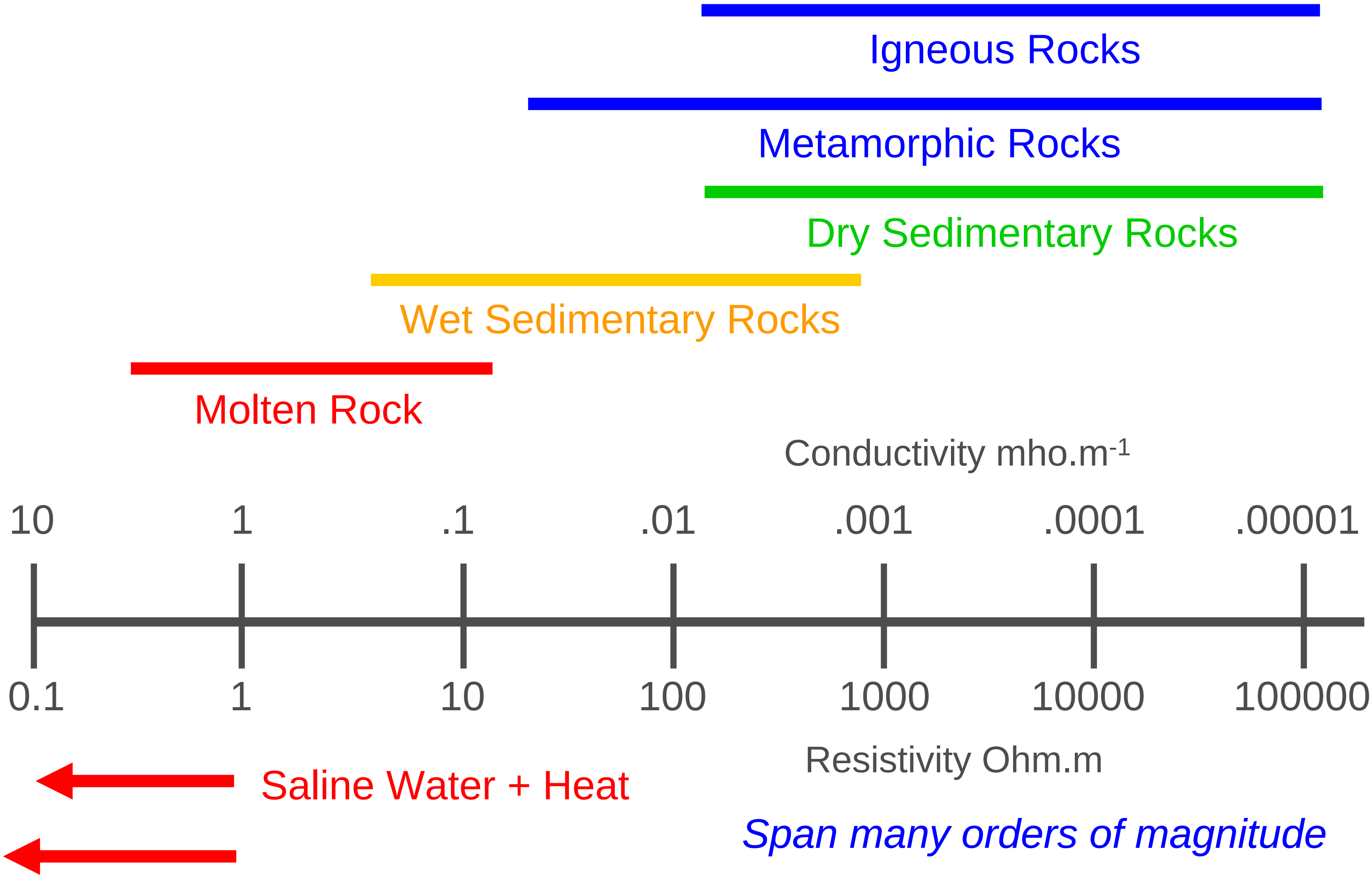
Introduction

Half vertical derivative of total magnetic intensity of Yilgarn (derived from the Magnetic Anomaly Map of Australia, 2010)



Introduction

Why measure resistivity (conductivity)?



MT Method

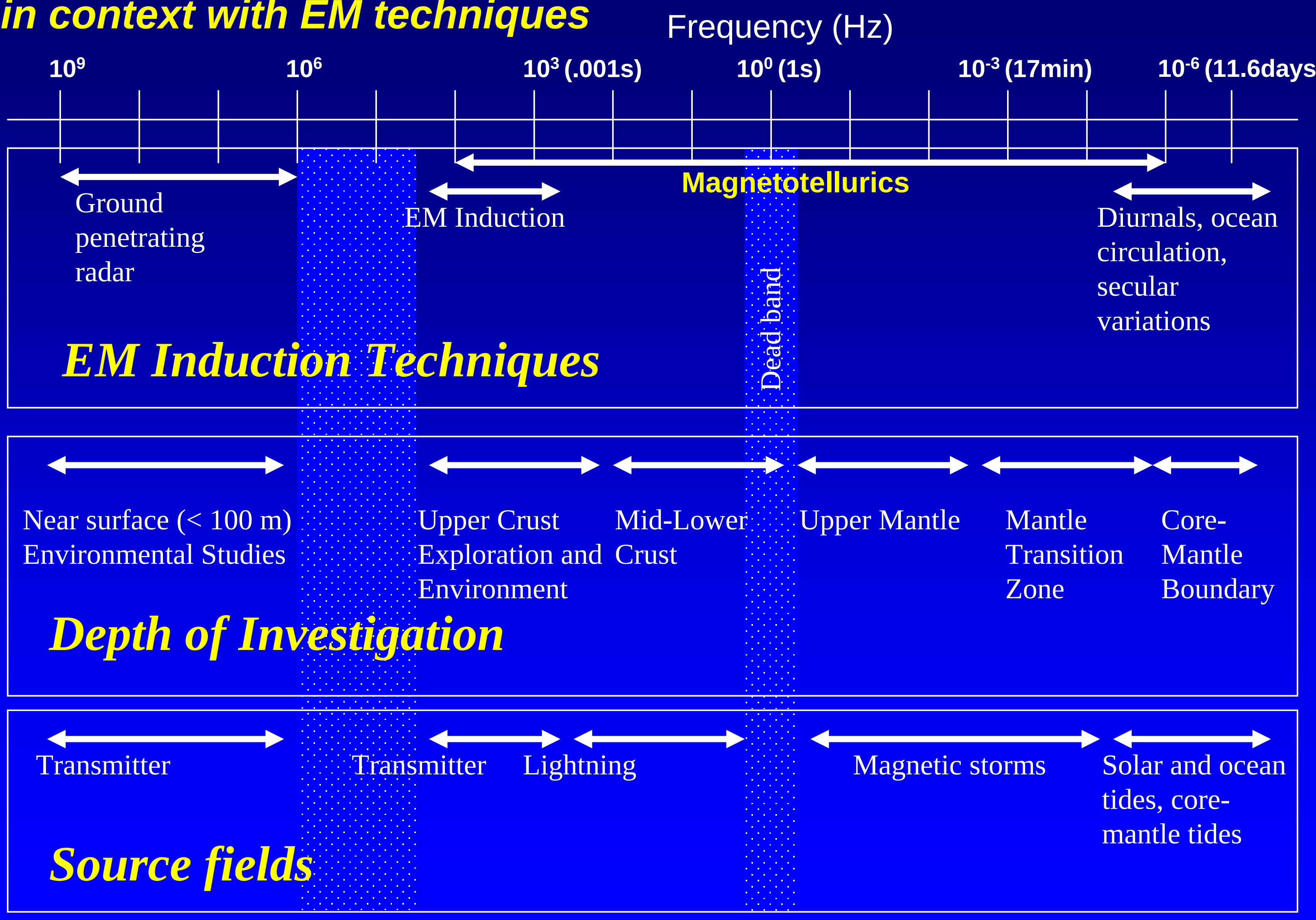
The Magnetotelluric Method (MT) records time variations of Earth's magnetic and electric fields over a wide frequency range at arrays of ground sites to measure Earth electrical resistivity (conductivity) structure with depth (near-surface to core/mantle boundary)

- Magnetic field variations are the source signals
- Electric field variations are the response signals
- Ratio of Electric to Magnetic provides resistivity measurement

- Complementary Earth physical property measurement to deep seismic imaging

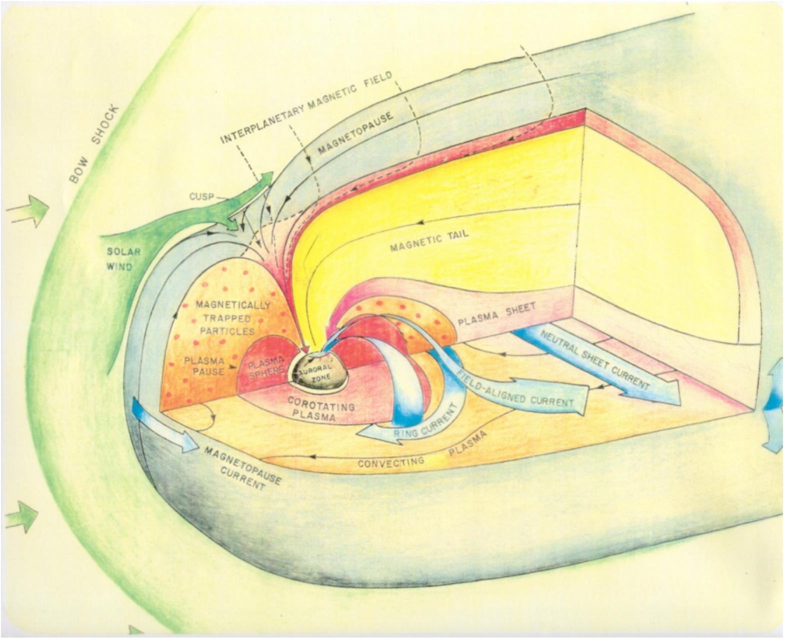
MT Method

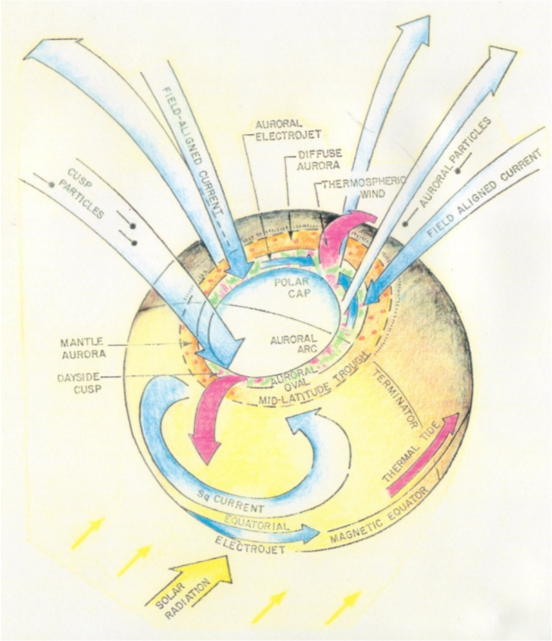
MT in context with EM techniques



MT Method

- Passive surface measurement of the Earth's natural electric (E) and magnetic (H) fields
- Assume planar horizontal magnetic source field (reasonable assumption in mid-latitudes, far from external source regions)
- This is a diffusive process, the physics based on Maxwell's equations of electromagnetic induction
- Measure time changes of E and H at arrays of sites
- Frequency range 10 KHz to .0001 Hz (0.0001 s to 10000 s) – broadband to long period
- Ratio of E / H used to derive resistivity structure of sub-surface





MT Method

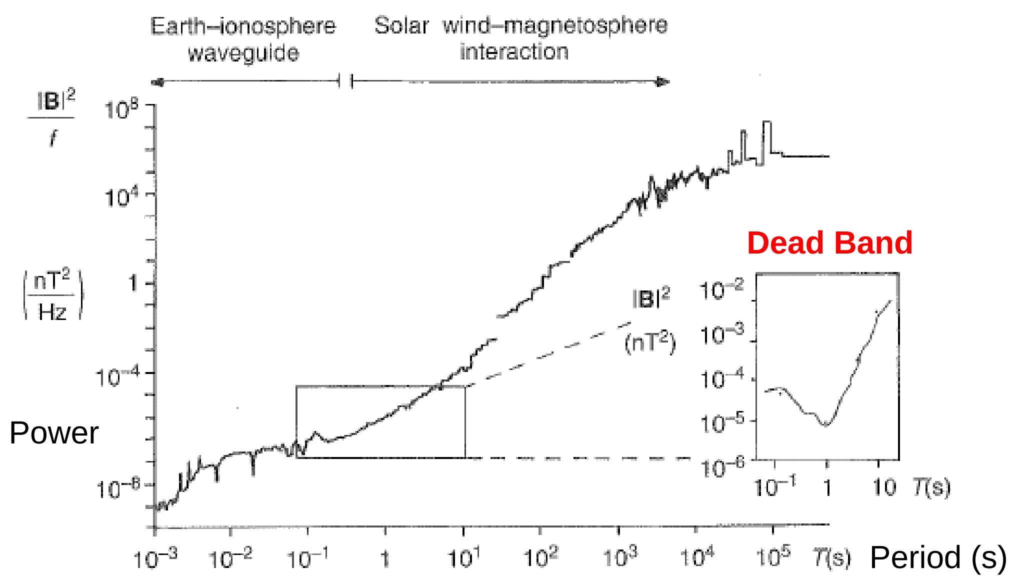
Source fields

High frequencies >1 Hz from Spherics, generated by world-wide thunderstorms

Low frequencies <1 Hz from Earth's magnetic field variations

- solar wind interactions

- variations with periods from seconds, minutes, hours, days to yearly cycles (eg. micropulsations, bays, storms)



Dead Band

10^1 to 10^{-1} Hz

0.1 to 10 s

Little energy

Skin depths 1.5 to 15 km, upper-middle crust

MT Method

Impedance tensor

Measure two orthogonal components of electric field and two orthogonal components of magnetic field (usually north, x and east, y).

Apparent resistivity is determined from their ratios.

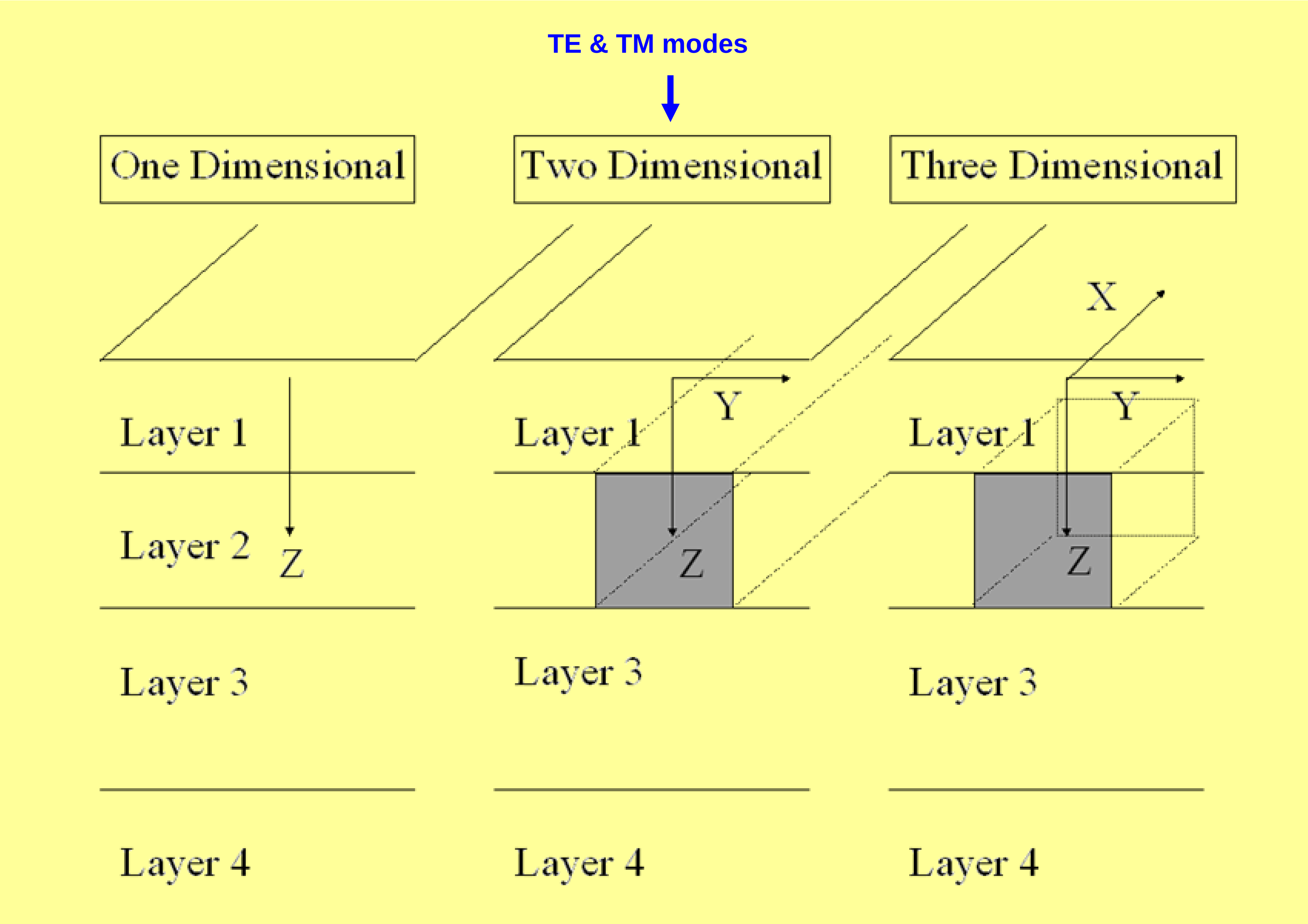
The magnetotelluric impedance tensor is defined as:

$$\begin{pmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{pmatrix} \begin{pmatrix} B_x \\ B_y \end{pmatrix} = \begin{pmatrix} E_x \\ E_y \end{pmatrix}$$

The impedance tensor transfer function values Z are complex values of frequency.

MT Method

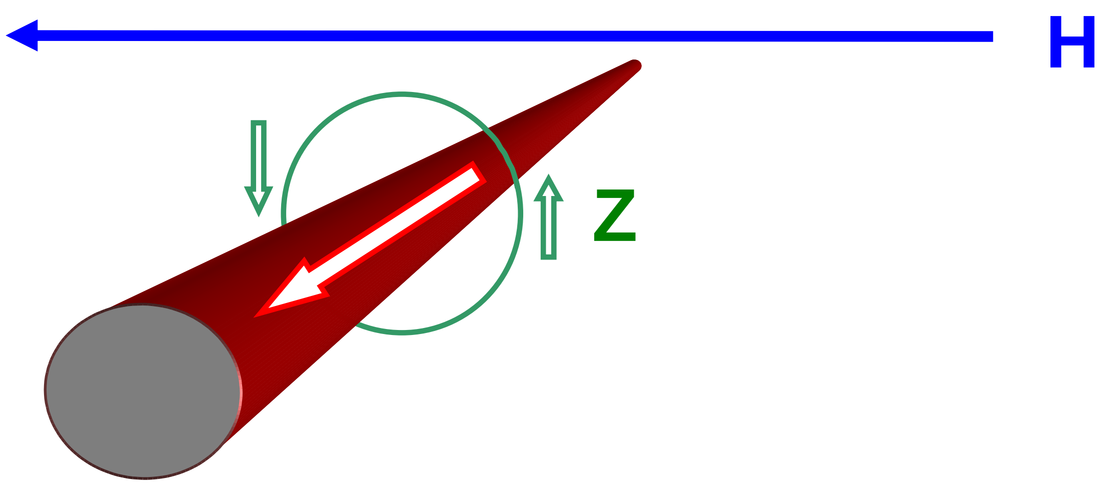
Dimensionality



MT Method

Geomagnetic Depth Sounding – Parkinson Arrows

- Geomagnetic depth sounding relates vertical magnetic field variations to horizontal magnetic field variations
- Ratios of Z to H are complex functions of period
- Ratio is always zero for a 1D Earth, so ratio senses 2D & 3D structure
- Parkinson Arrows "point" to subsurface electric currents – provide lateral information

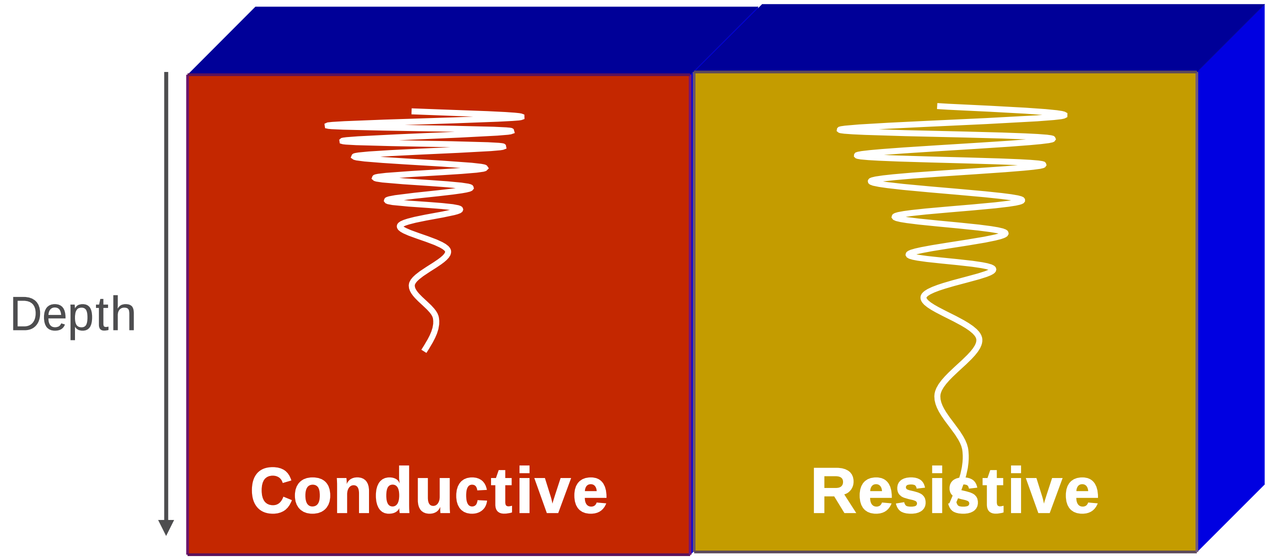


MT Method

Depth of Investigation – Skin Depth

4 concepts:

1. Low frequencies penetrate deeper than high frequencies
2. High frequencies image the near-surface
3. Signals penetrate further in resistive material
4. Diffusive signal senses greater volume with depth



Data acquisition

Survey specifications

AuScope equipment (based at the University of Adelaide):

Long-period (LP) (3-component Fluxgate, sampling at 10 Hz, bandwidth .1 to .0001 Hz)

Broadband (BB) (2-component Lemi induction coils, sampling at 500 Hz, bandwidth 100 to .001 Hz)

Data acquired in 2010. Long-period sites spaced 15 km apart, and Broadband sites spaced 5 km apart

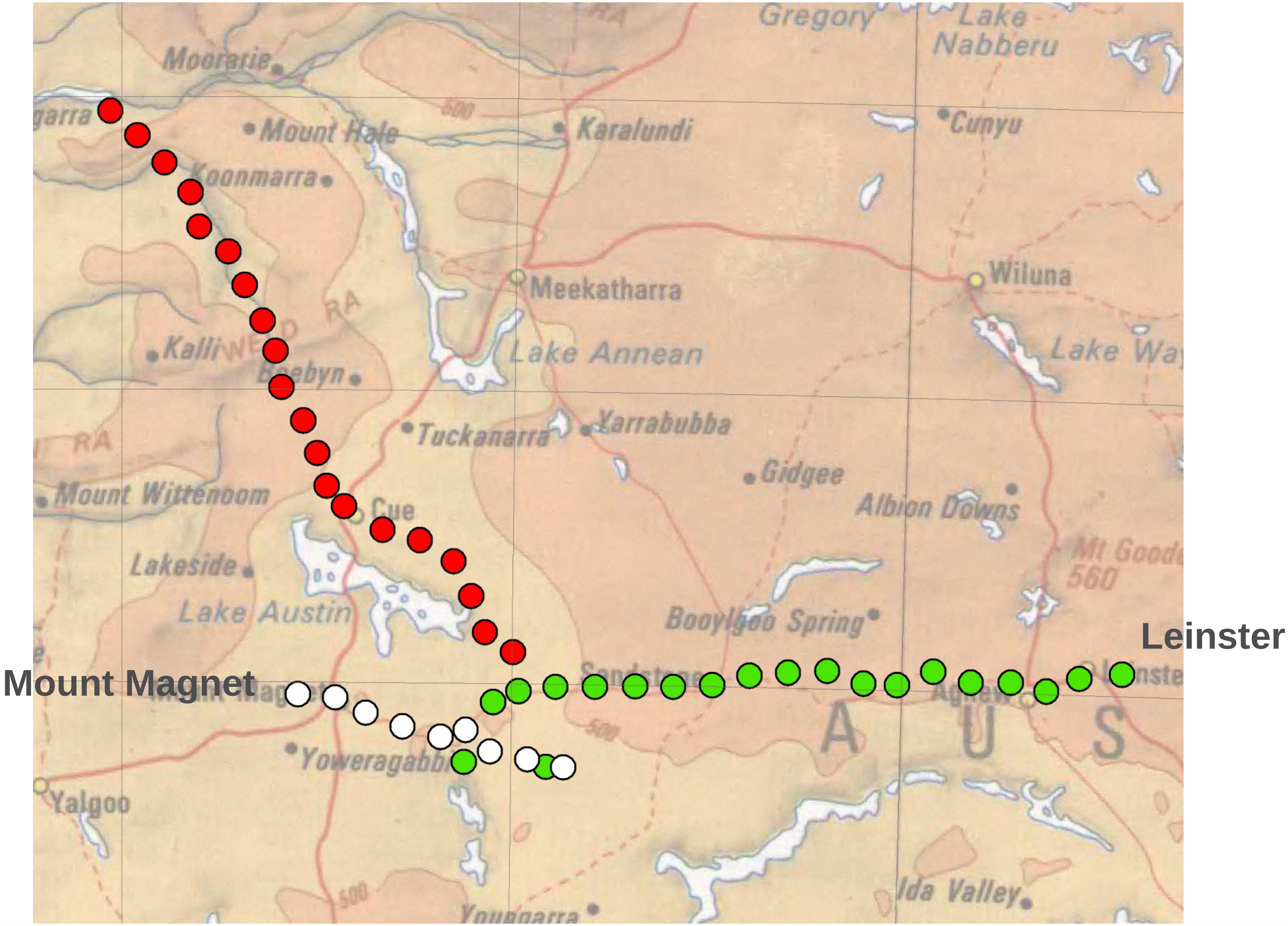
Line 1 21 Long-period sites & 60 Broadband sites

Line 2 16 Long-period sites & 54 Broadband sites

Line 3 9 Long-period sites & 22 Broadband sites

Data acquisition

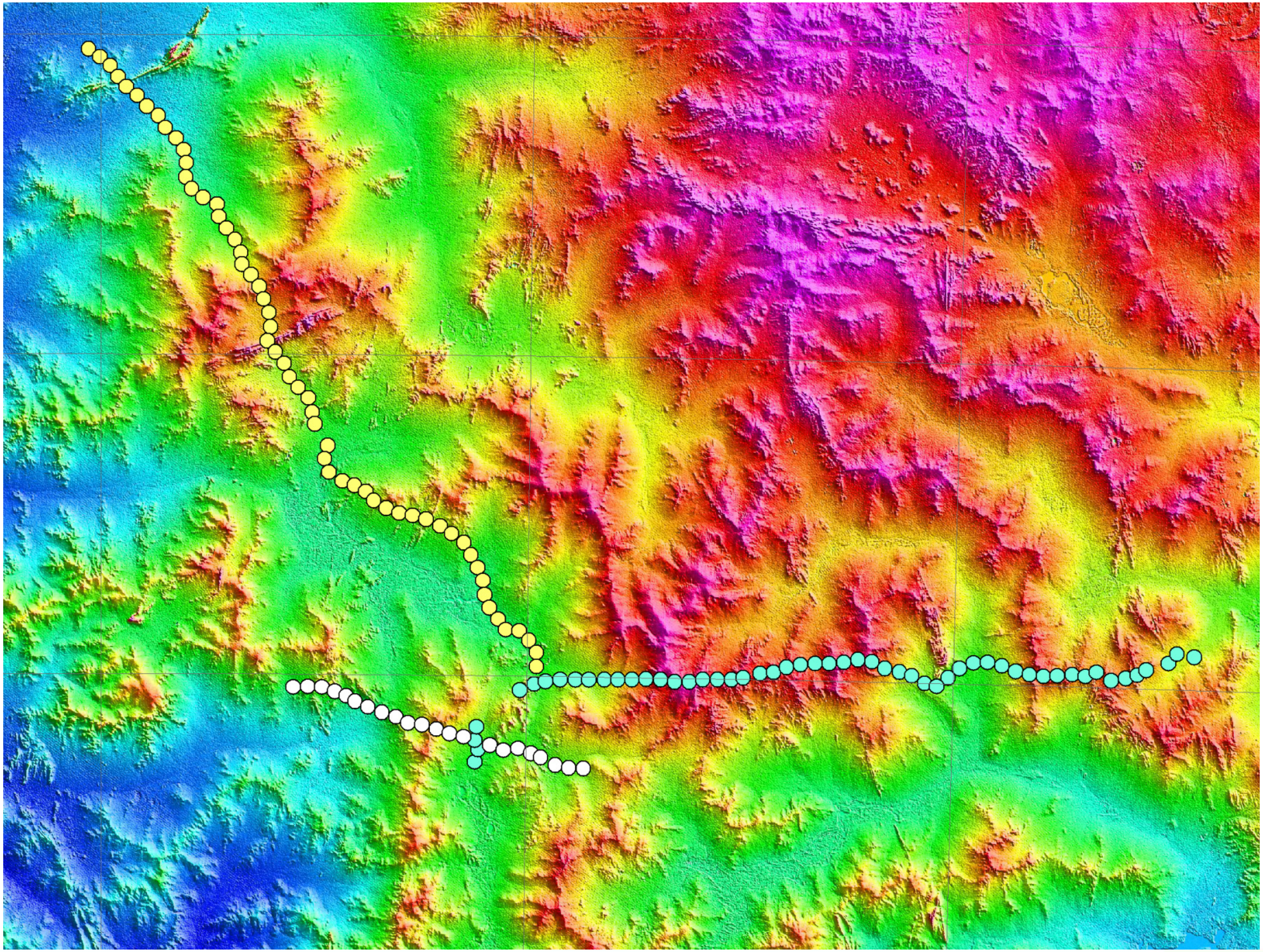
Location of long-period sites, 15 km spacing



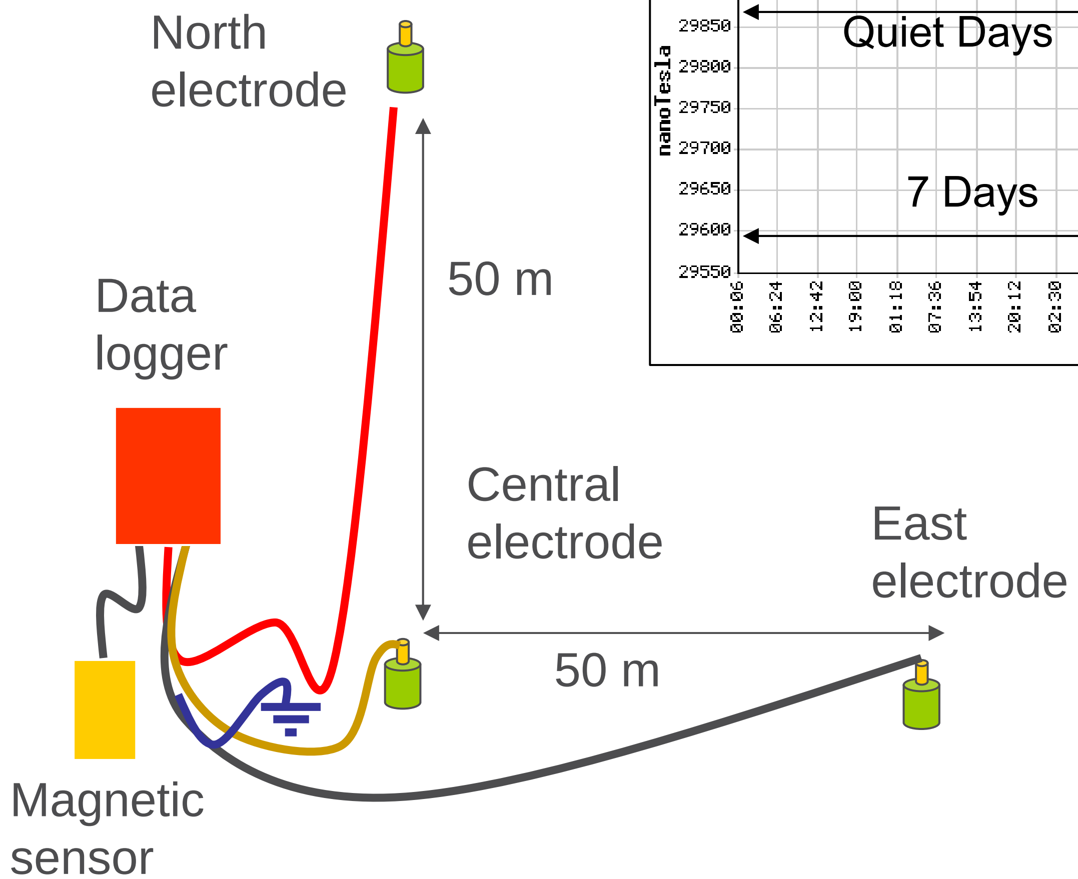
Data acquisition

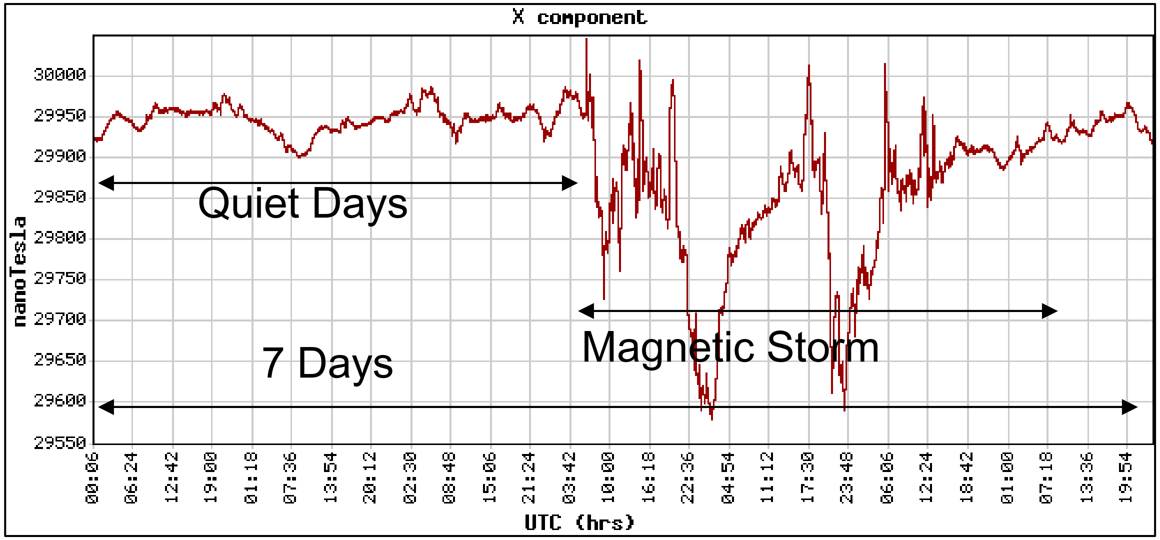
Location of broad-band sites, 5 km spacing

SRTM image



Data acquisition





Data acquisition

Induction coils for broadband acquisition

Data acquisition

Fluxgate sensors for long-period acquisition

Data acquisition

Copper/copper sulphate electrodes

Data acquisition

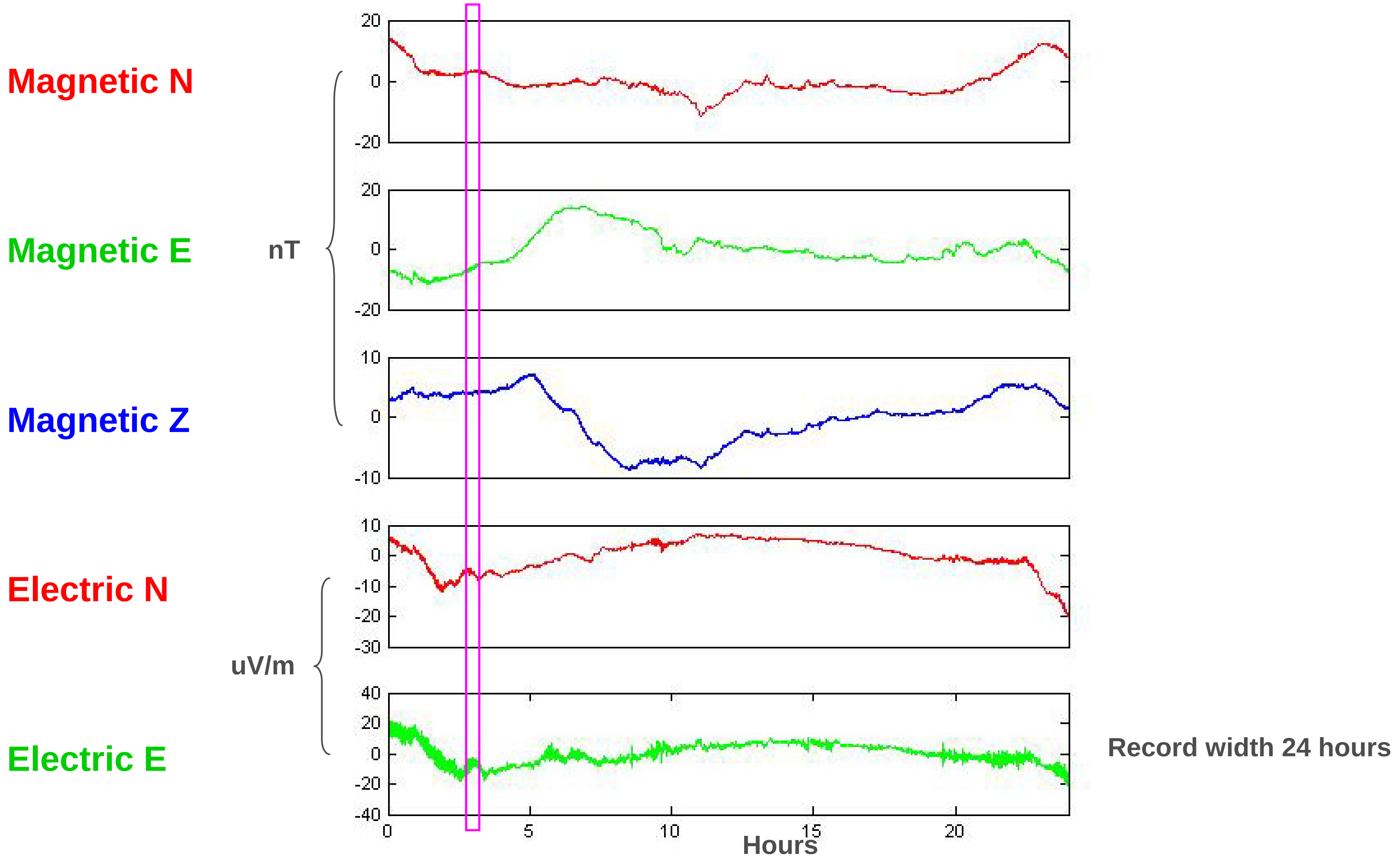
Earth Data logger

Data acquisition

Typical field locations

Data acquisition

Example long-period time-series as recorded in the field



Data acquisition

Example broad-band time-series as recorded in the field

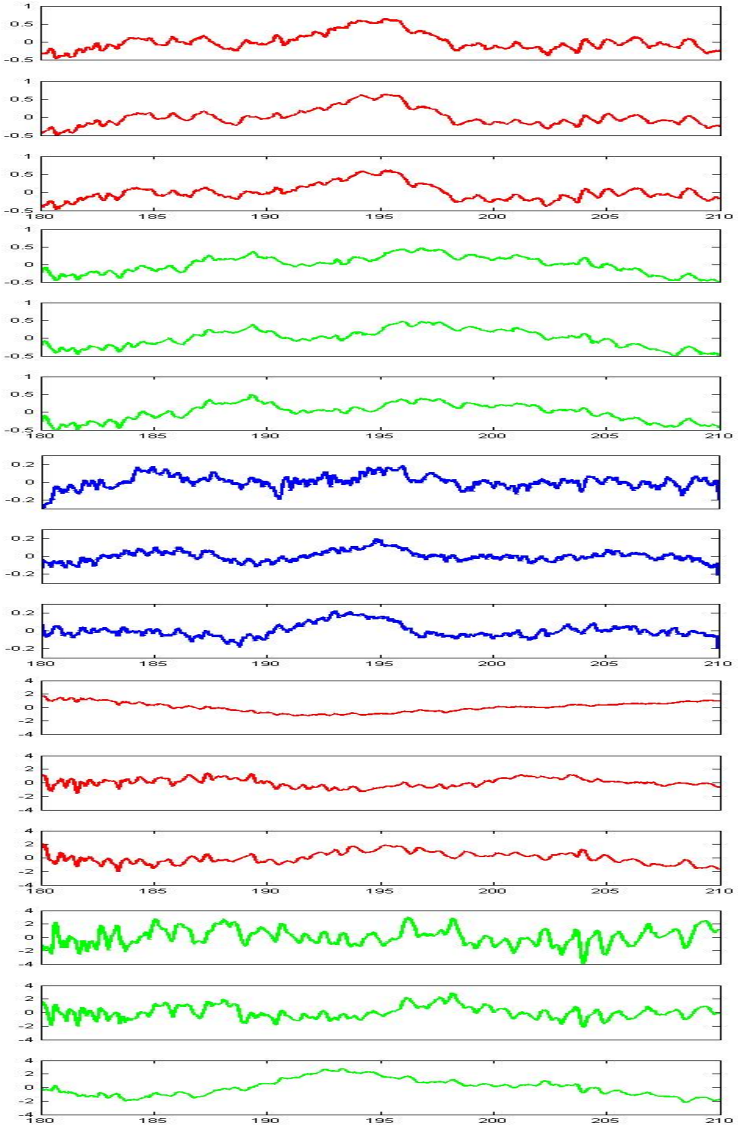
Magnetic N

Magnetic E

Magnetic Z

Electric N

Electric E



Record width 30 minutes

Processing

Processing steps

- Read data
- Calibrate
- Rotate to geographic coords.
- Edit
- Calculate spectra & impedance tensor components
- Store in EDI files
- Calculate apparent resistivity (δ) & phase (θ) from impedance tensor
- Display δ and θ graphically and as pseudosections
- Display induction arrows (Parkinson arrows)

Processing

Calculation of impedance tensor values (AuScope processing)

- Time series data are converted to the frequency domain
- Program BIRRP5 of Alan Chave is publicly available for non-commercial use (*Bounded Influence Remote Reference Processing*)
- Remote referencing with other sites (or observatory data) to remove uncorrelated noise
- For each frequency, the impedance equation is solved for Z with noise in E and B

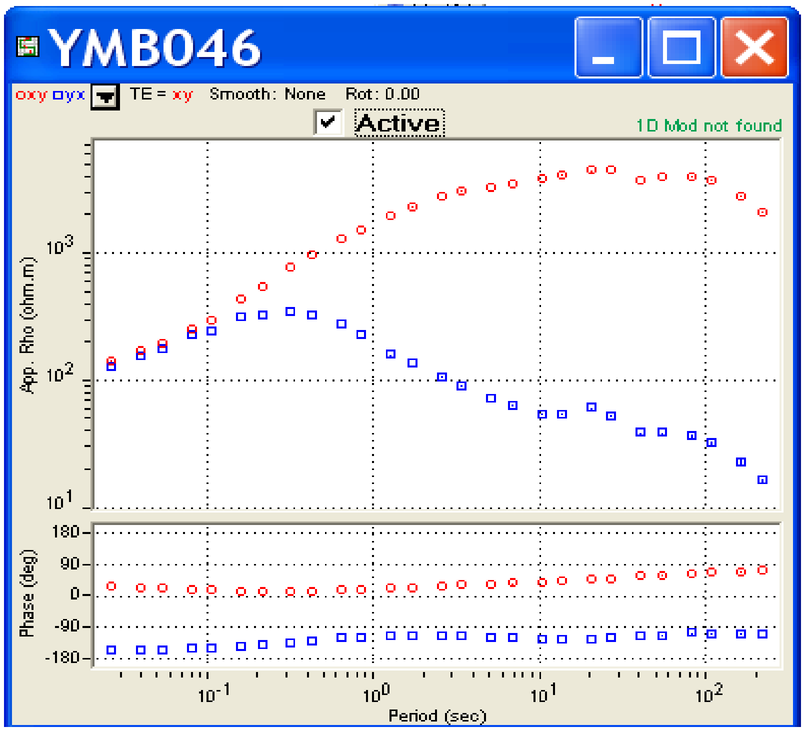
$$\begin{pmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{pmatrix} \begin{pmatrix} B_x \\ B_y \end{pmatrix} = \begin{pmatrix} E_x \\ E_y \end{pmatrix}$$

Processing

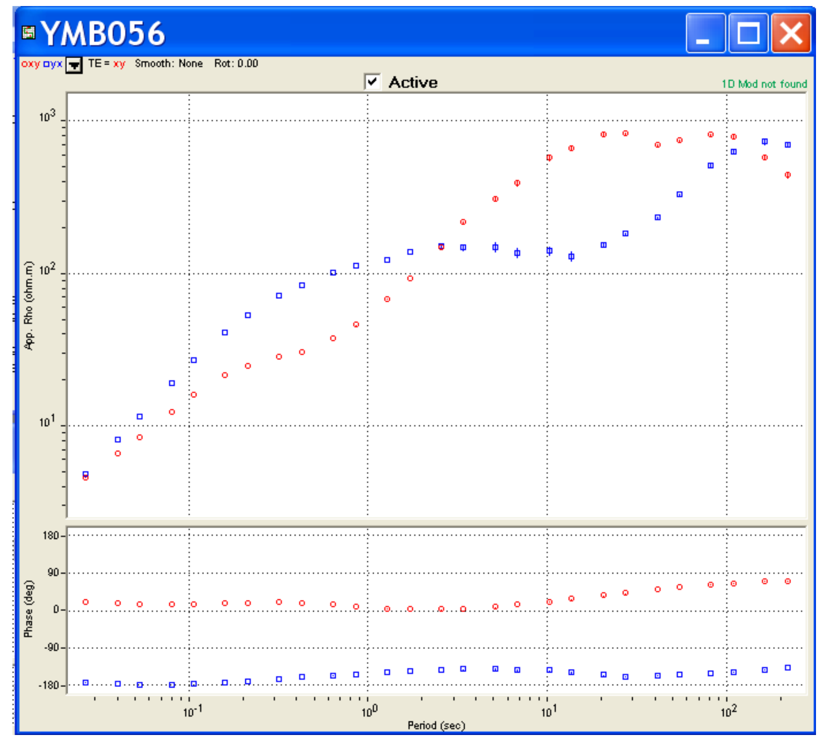
Examples of apparent resistivity (δ) & phase (θ), calculated from the impedance tensor values.

(δ)

(θ)



Period



Period

Red – XY – north (TE) mode

Blue – YX – east (TM) mode

Analysis

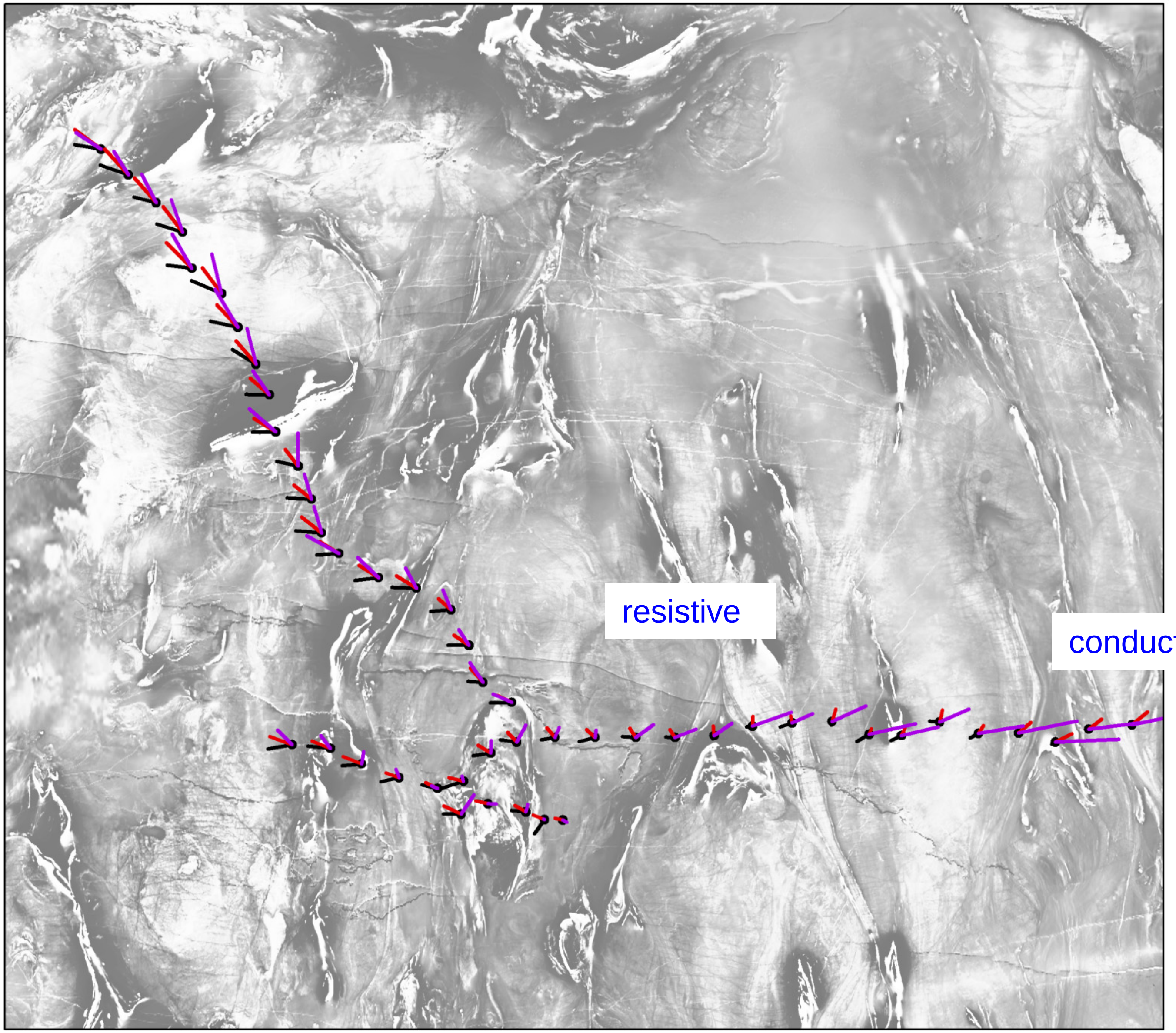
conductive

Induction arrows

3,276 s black

819 s red

68 s purple



Analysis

Analysis of MT impedance tensor

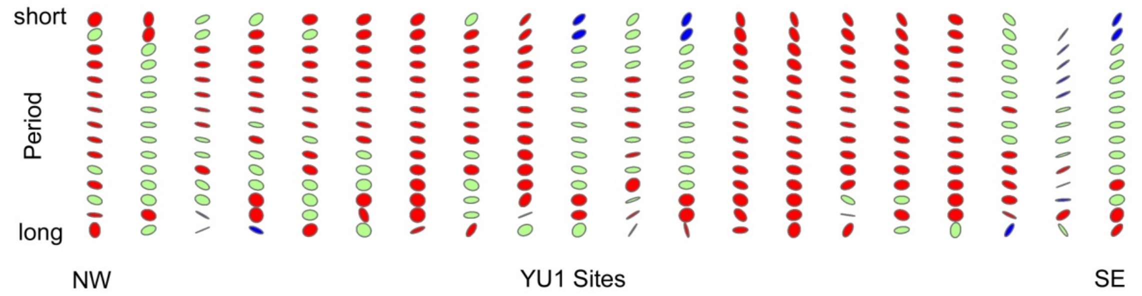
The impedance tensor is the Earth filter, relating E response to H source

However, there are complicating factors:

- Dimensionality of Earth (1D, 2D state of art, 3D in development)
- Strike direction (from impedance tensor and phase tensor if 2D)
- Electric field distortion (eg. current channelling)
- Magnetic field distortion (eg. uniform source field assumption not true)
- Noise (from various sources, both natural & cultural)

Analysis

Long-period

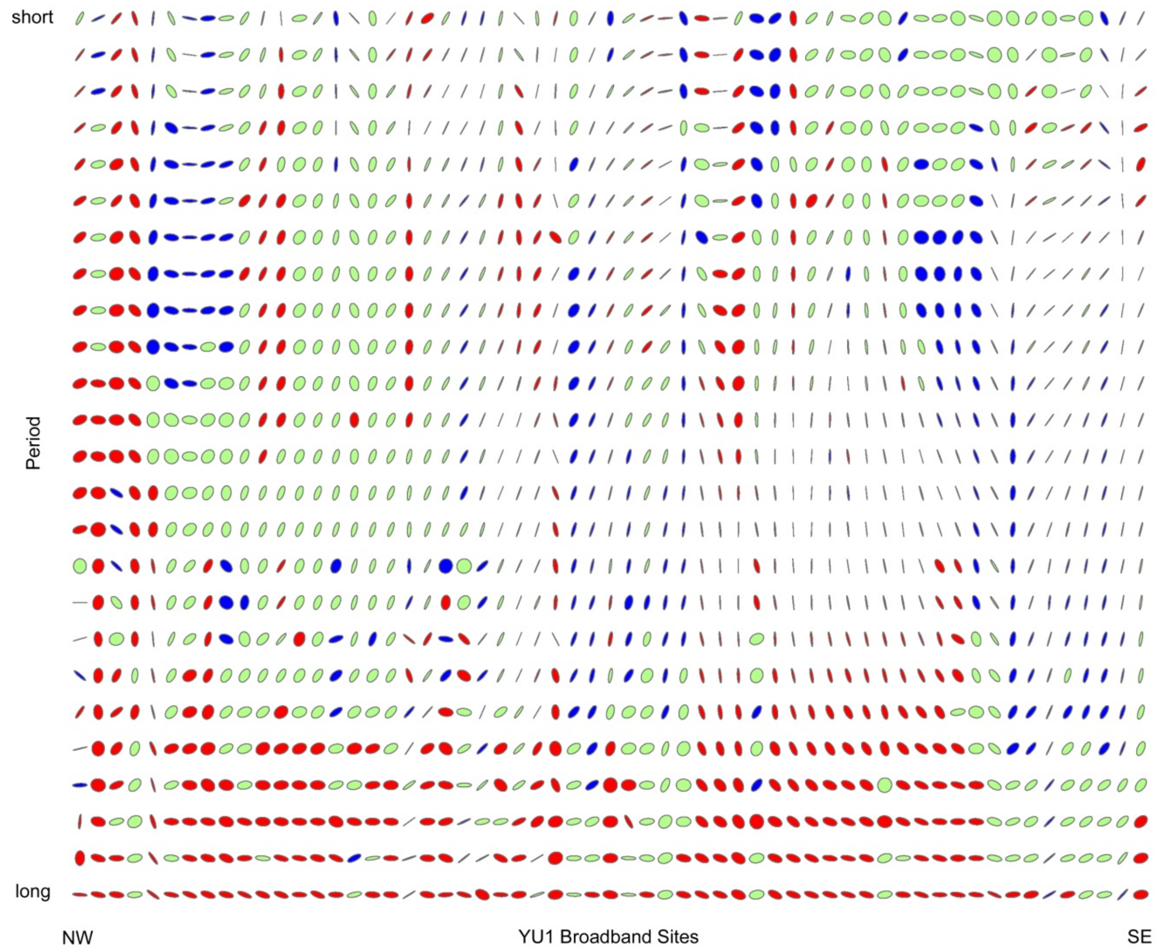


Phase Ellipses

Circular 1D

Elliptical green 2D

Broad-band

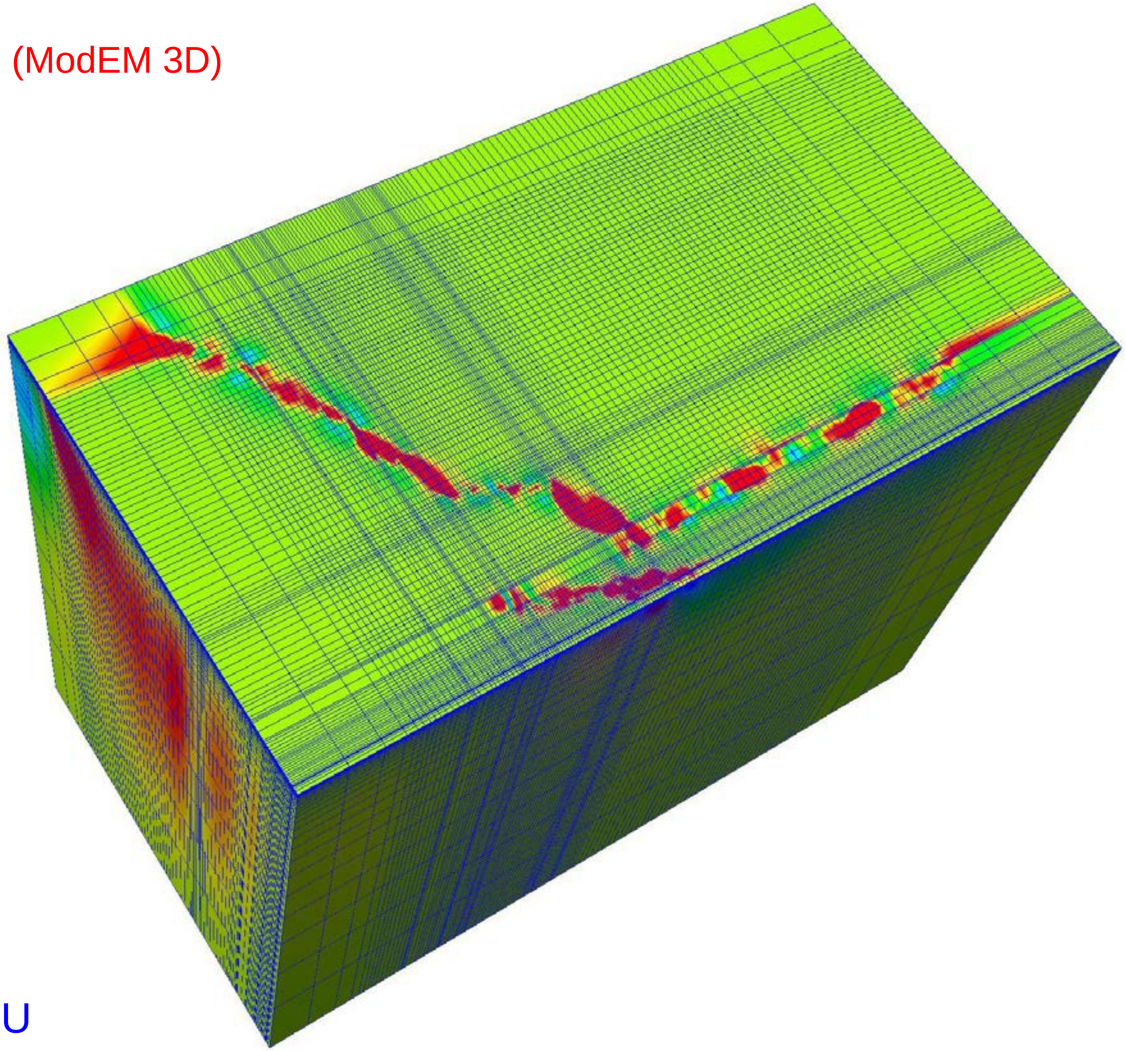


Modelling

1D & 2D modelling not appropriate for 3D data

Modular Electromagnetic Inversion Software (ModEM 3D)

Gary Egbert, Anna Kelbert & Naser Meqbel
College of Atmospheric and Oceanic Sciences
104 COAS Admin. Bldg.
Oregon State University, Corvallis



Example 3D finite difference mesh model result visualised in GoCad

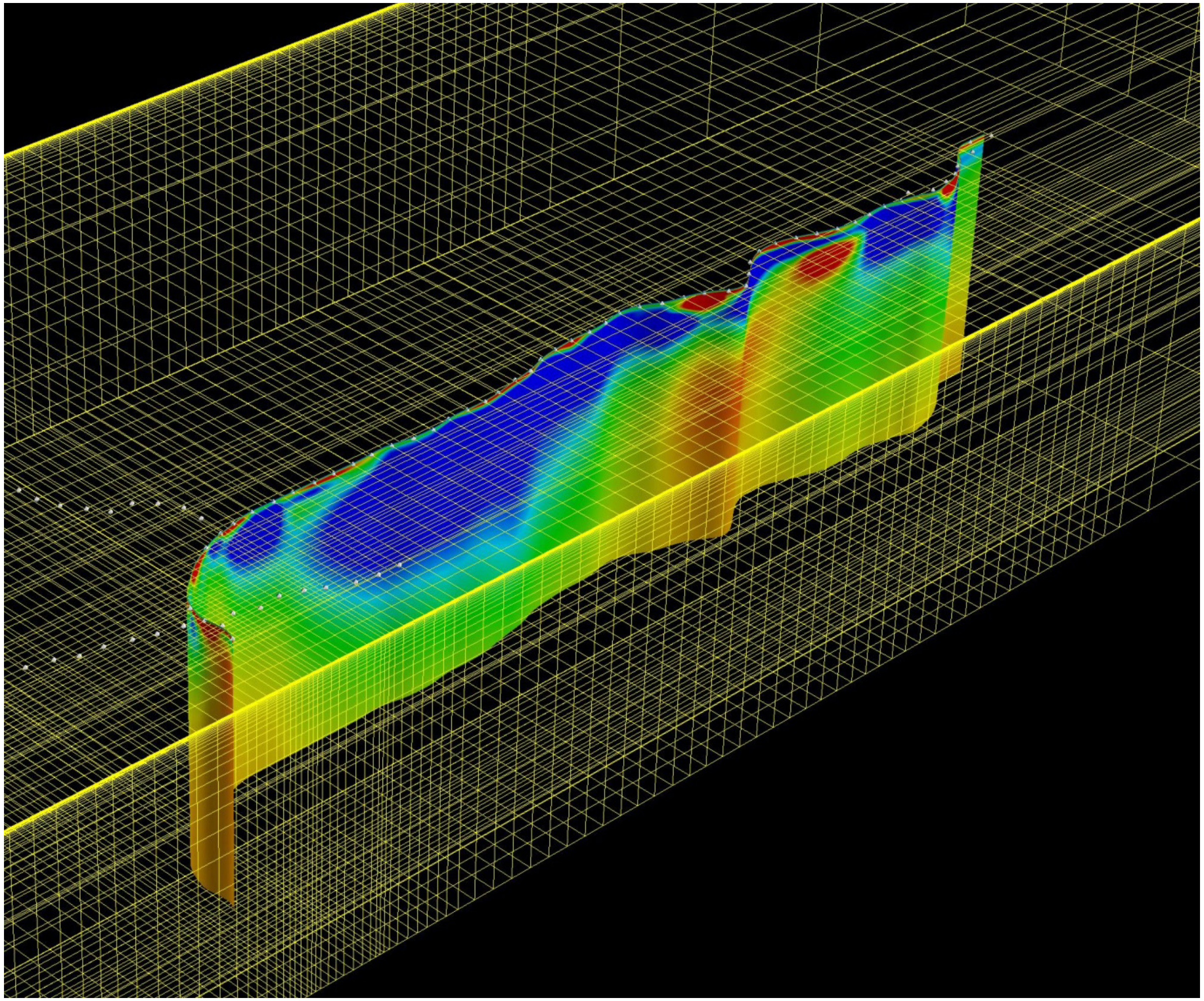
ModEM is written in

Fortran95, MPI parallelised

Execute on NCI National Facility at ANU

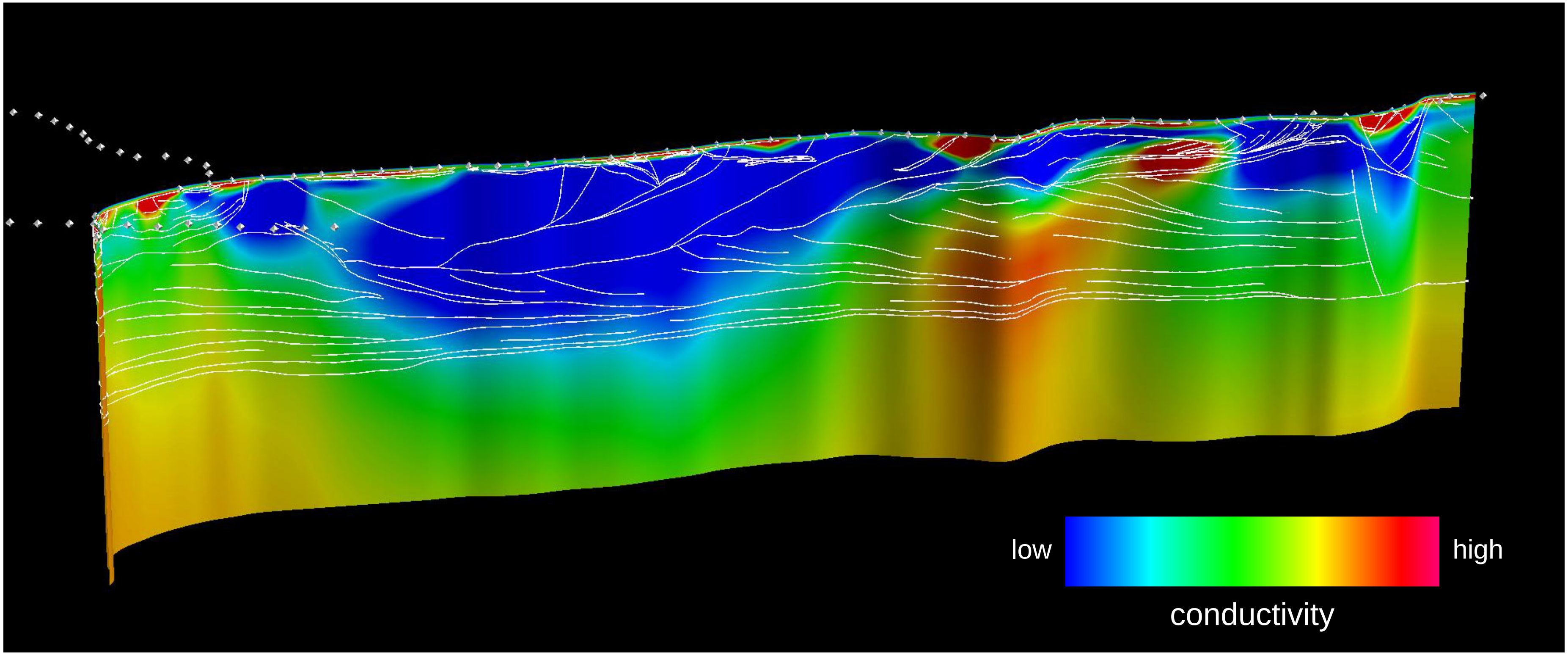
Modelling

3D Model resistivity values interpolated onto 2D vertical surface formed from CDPs of YU2 seismic line.



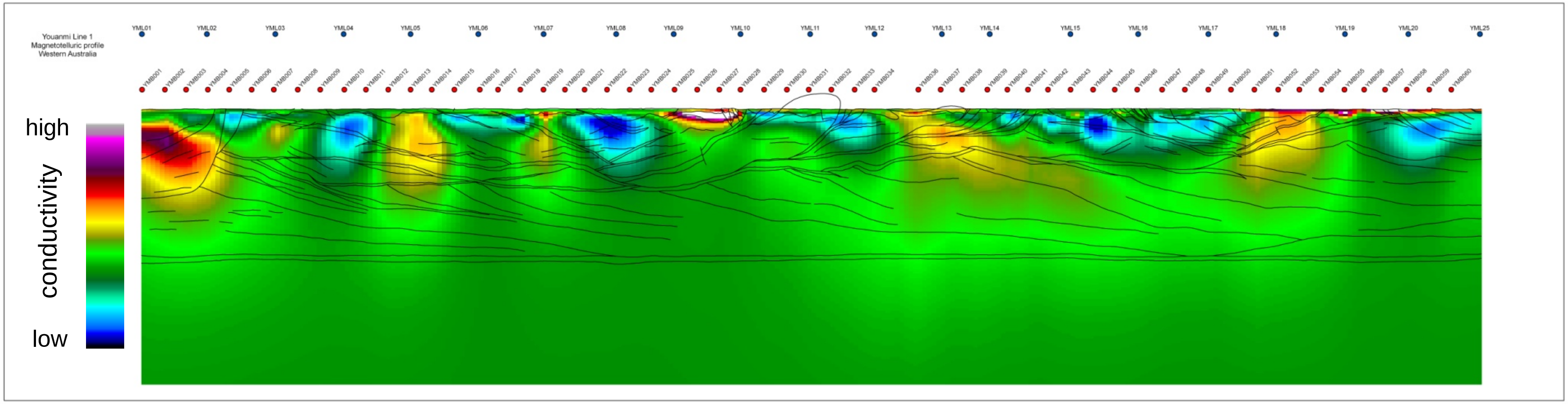
Modelling

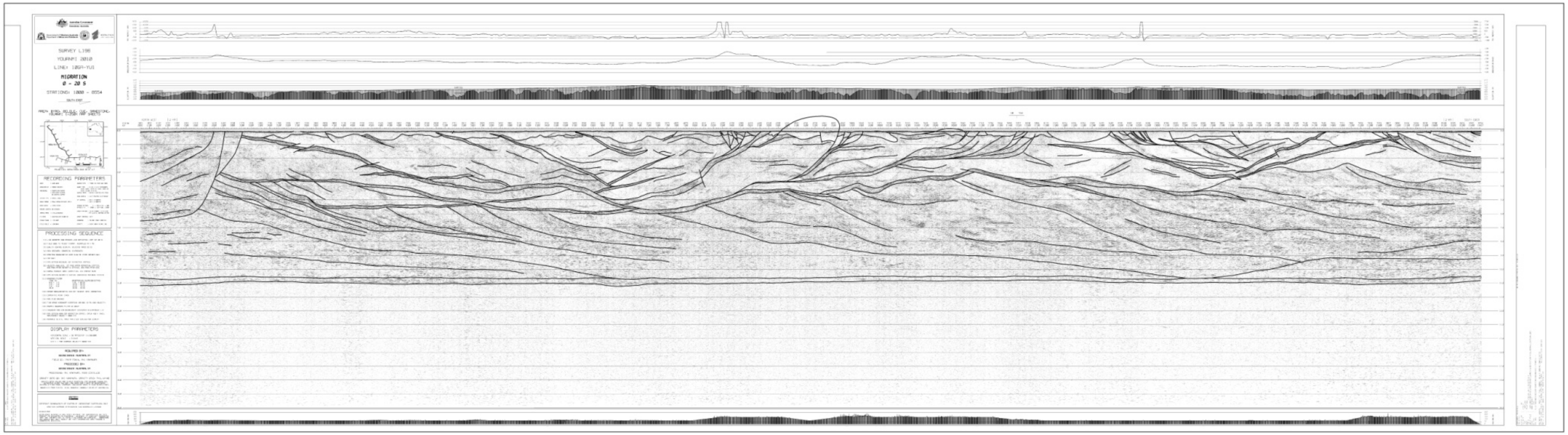
YU2 vertical surface image with seismic interpretation linework.



Modelling

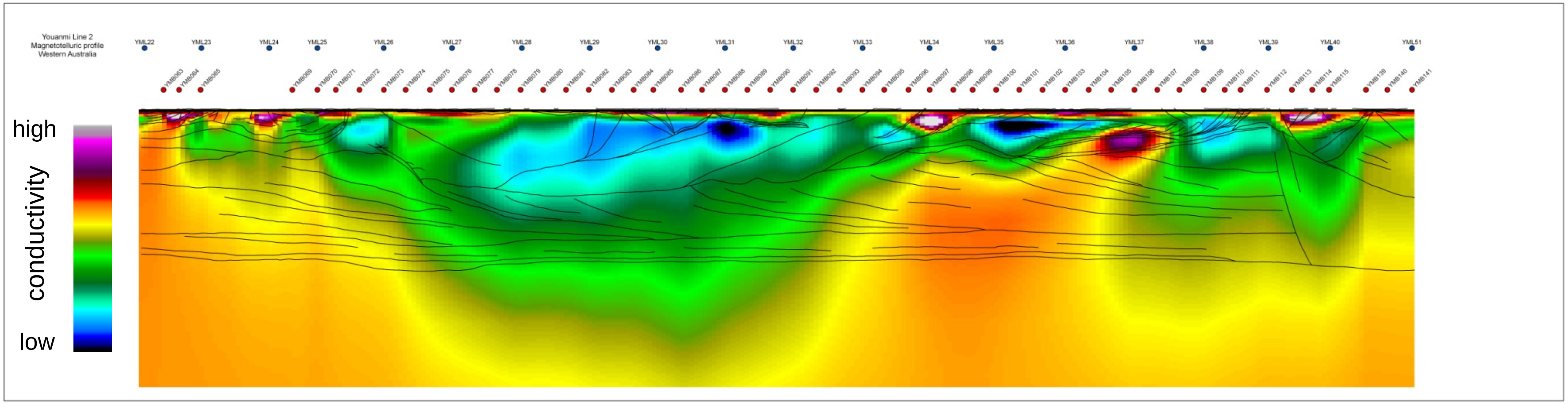
YU1 vertical surface image with seismic interpretation linework and seismic image.

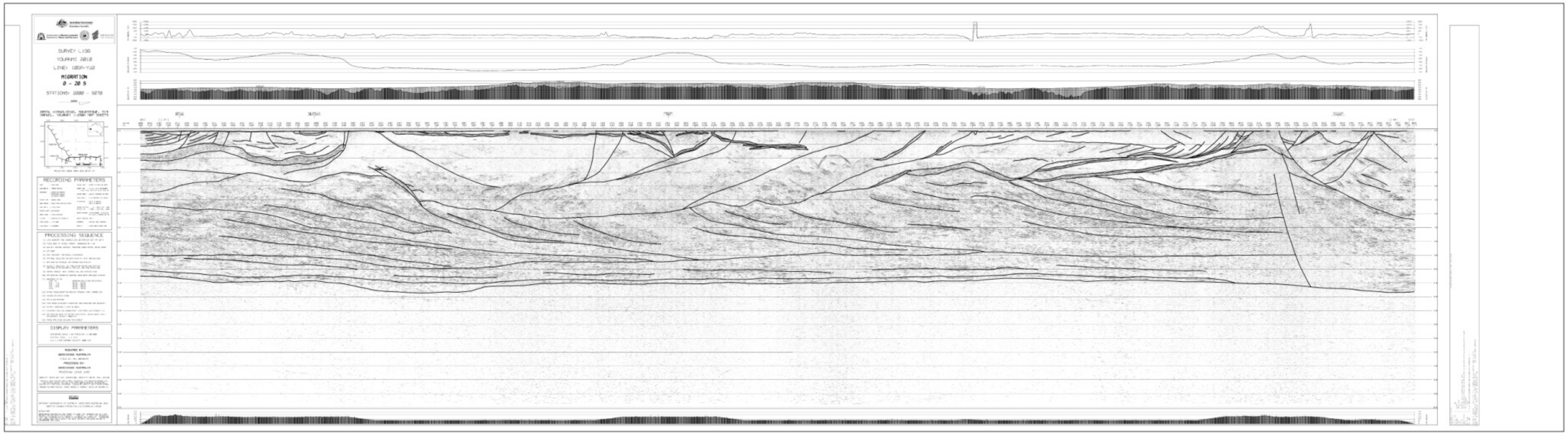




Modelling

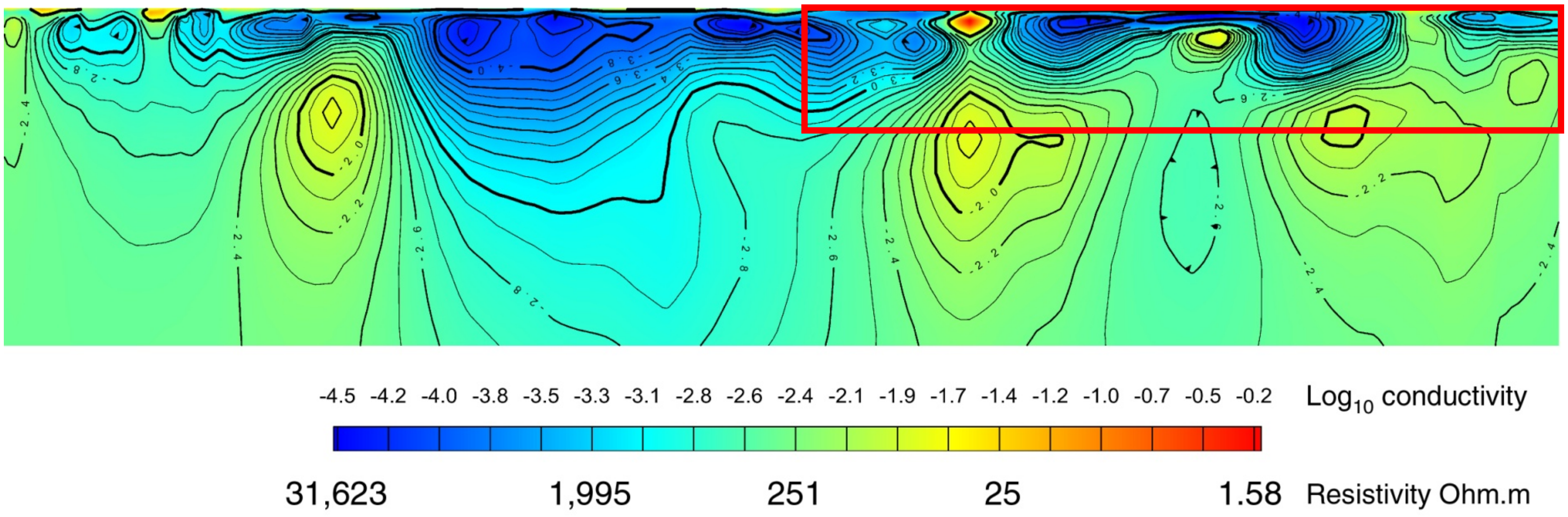
YU2 vertical surface image with seismic interpretation linework and seismic image.

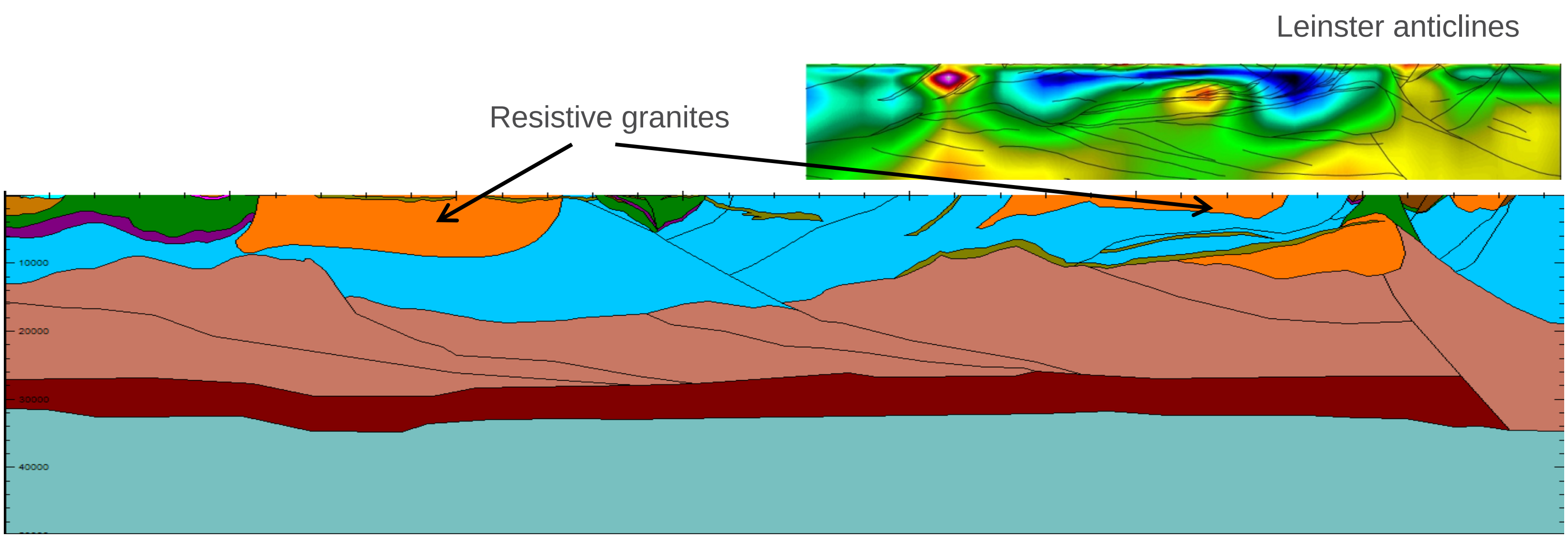




Modelling

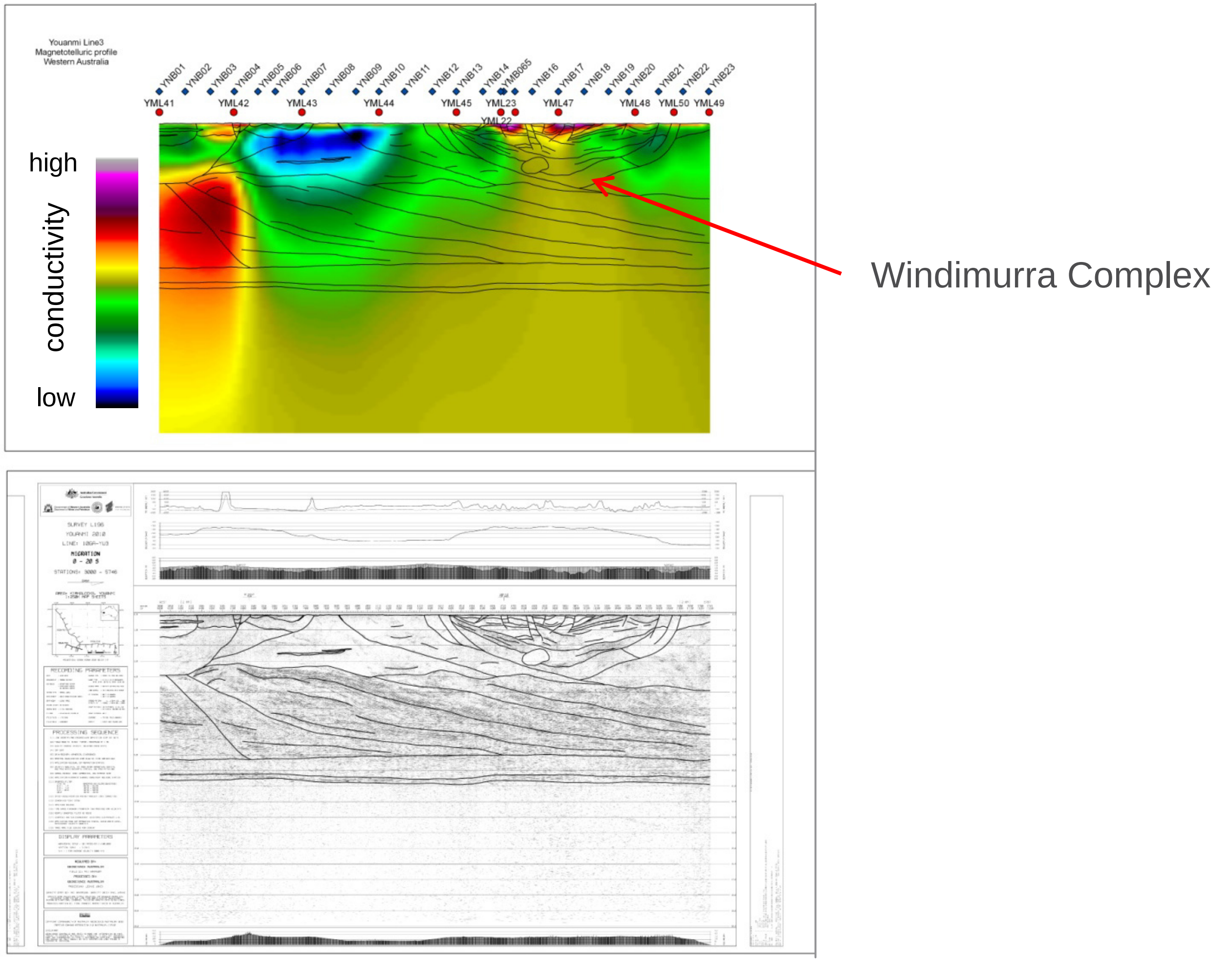
YU2 vertical surface image with seismic interpretation linework and seismic image.





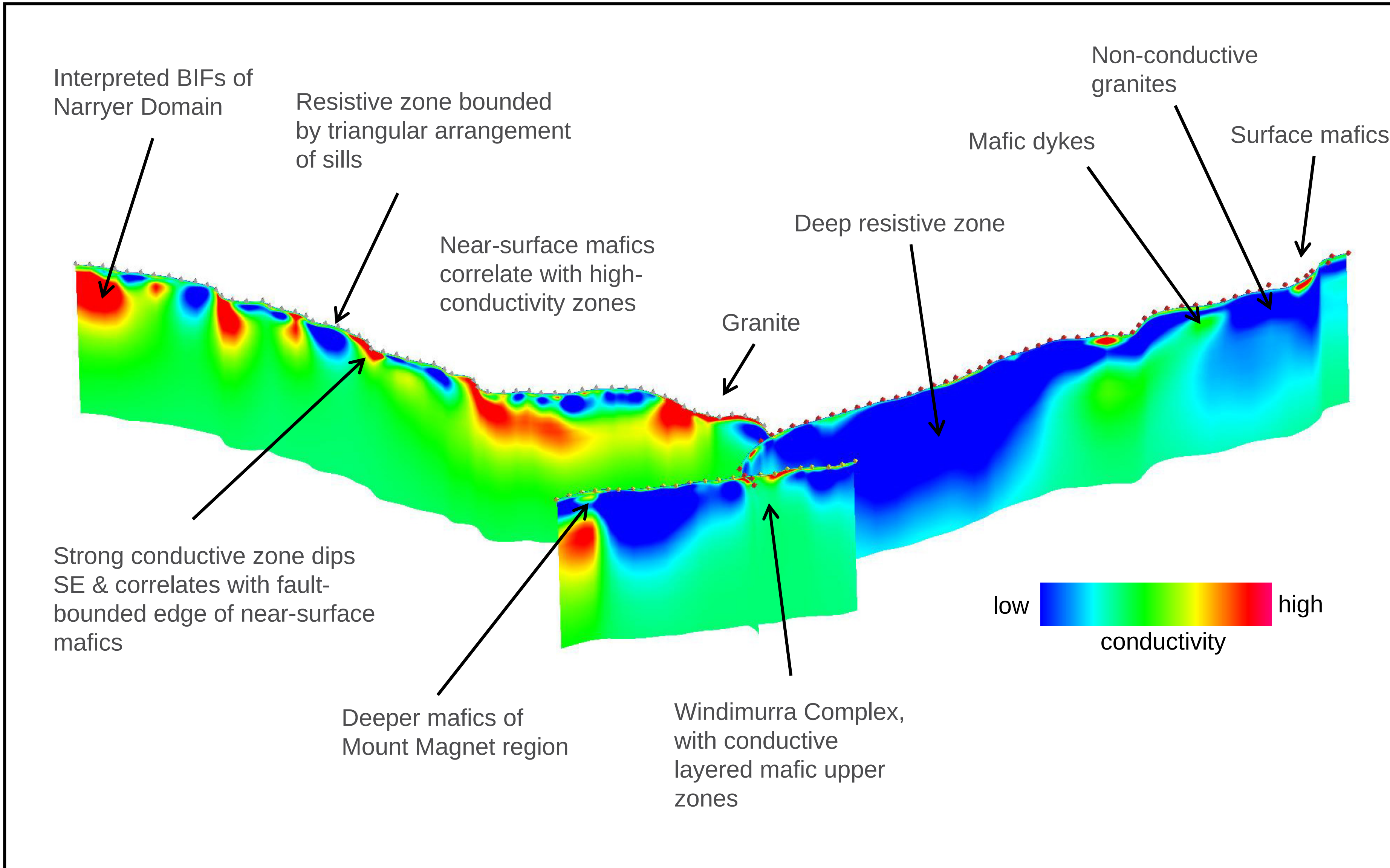
Modelling

YU3 vertical surface image with seismic interpretation linework and seismic image.



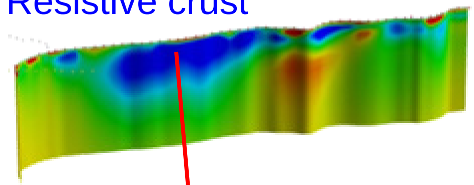
Modelling

Conductivity image of all sections



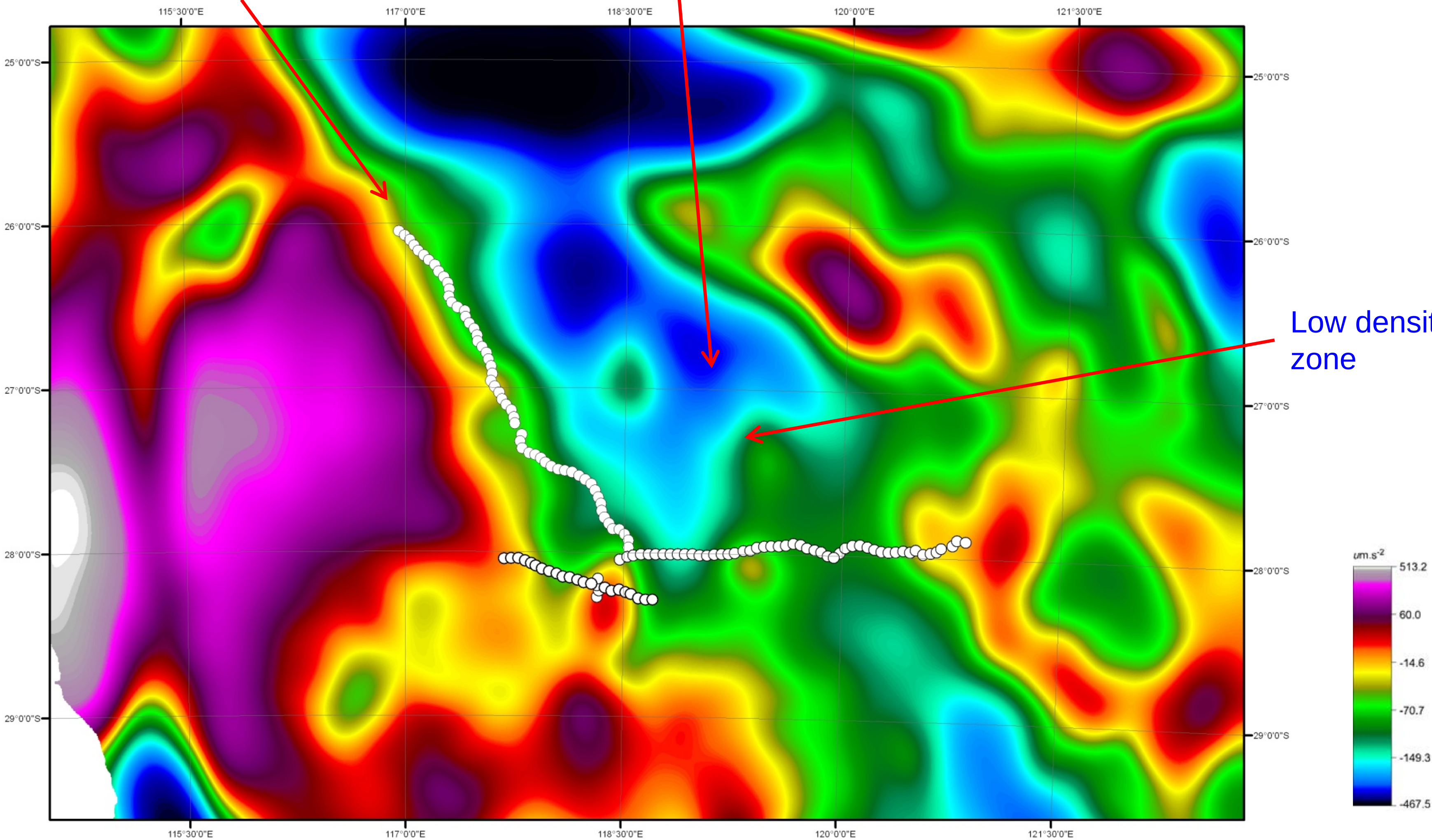
Comparisons with other data

Resistive crust



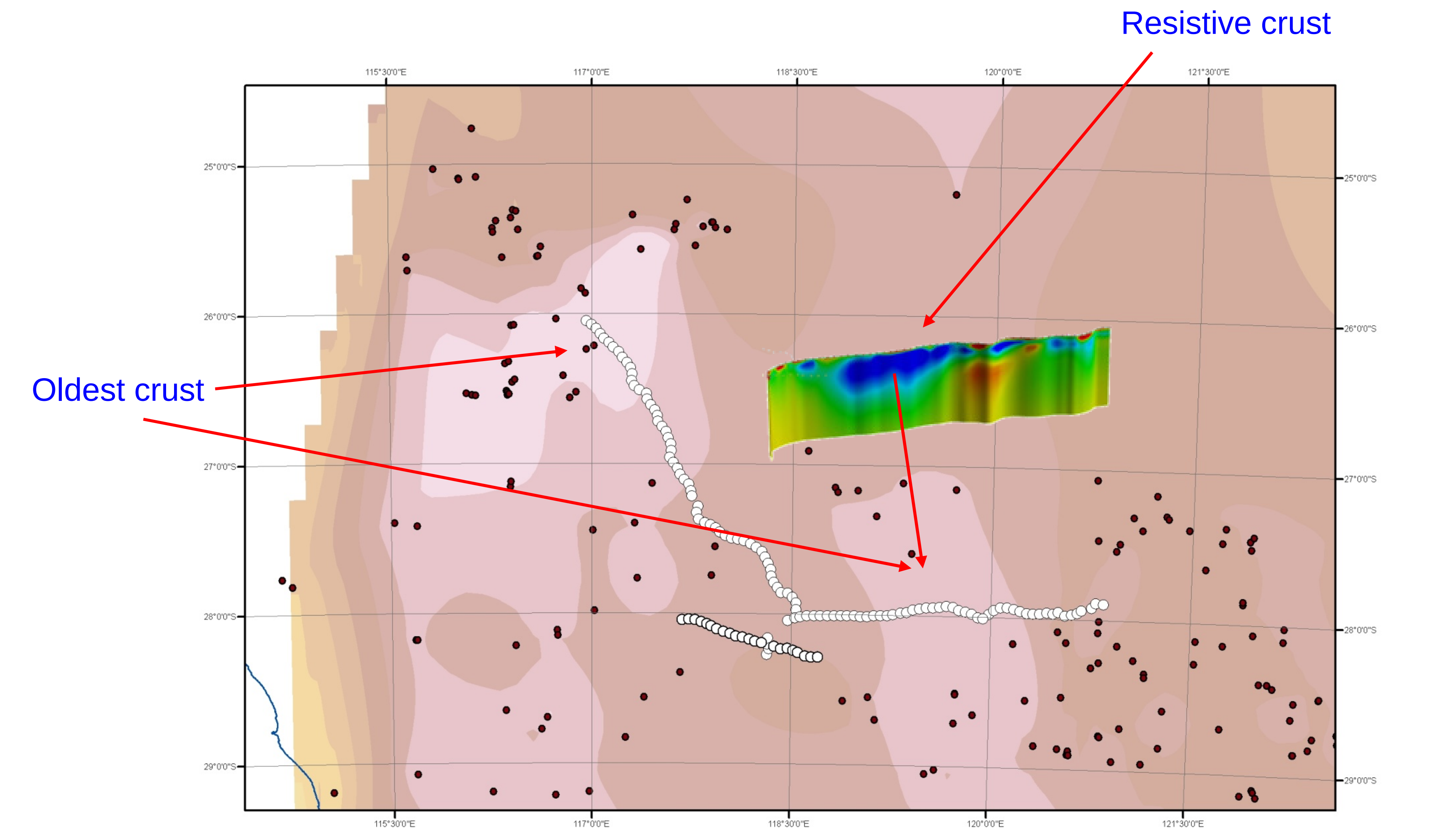
Bouguer gravity of Australia, upward-continued 20 km

YU1 along gravity gradient



Comparisons with other data

Radiogenic isotopes of Sm-Nd, good for deciphering crustal histories, from David Champion.

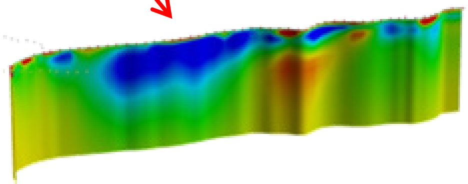


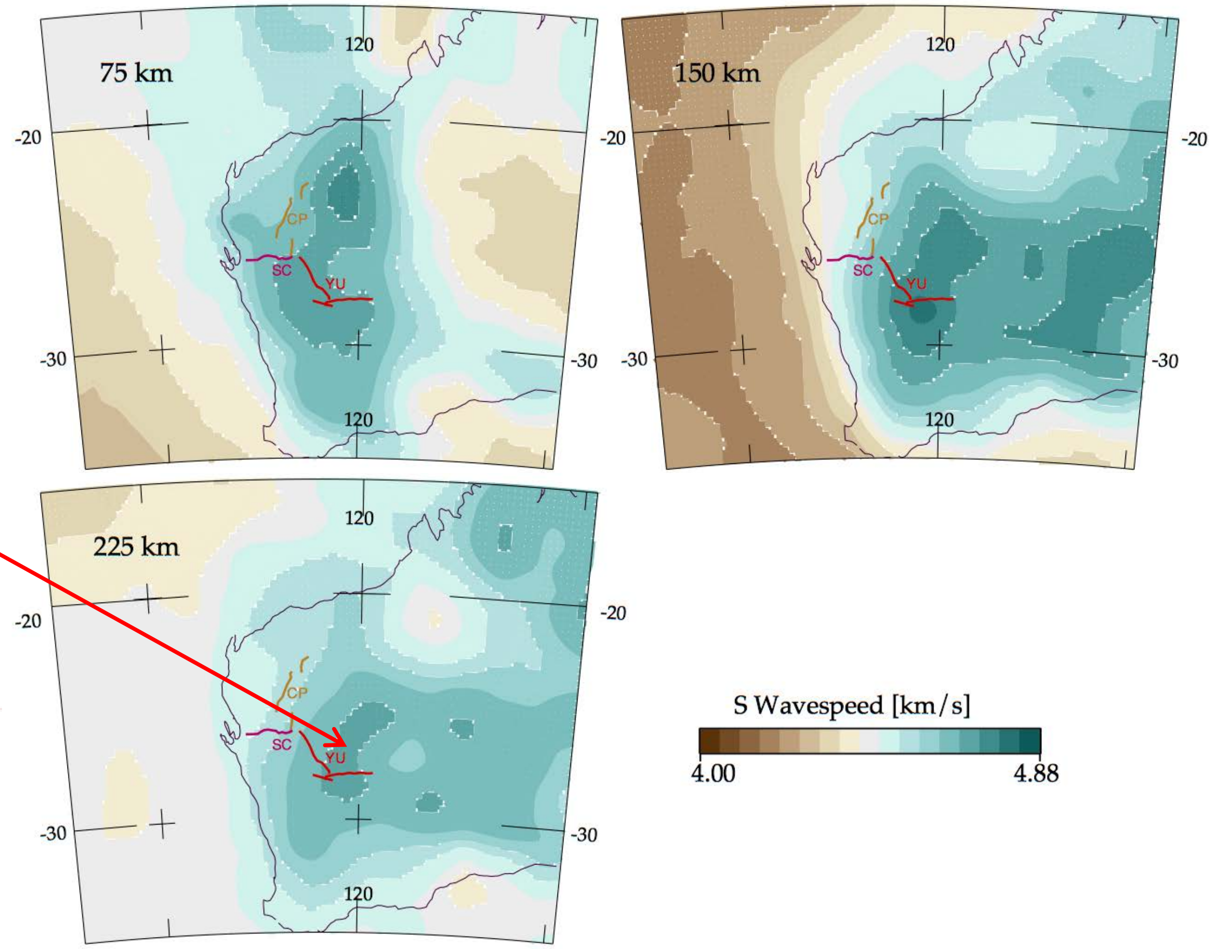
Comparisons with other data

Seismic shear-wavespeed structure from AuSRem mantle model (Brian Kennett, this workshop).

Fastest crust

Resistive crust





Conclusions

- MT data acquired along 3 seismic transects in Yilgarn in collaboration with the Geological Survey of WA
- Earth conductivity is complimentary to information from the seismic method, and the MT method has been briefly described
- Examples of display, analysis of data show its 3D character dominates
- New 3D modelling of data images features which correlate with seismic interpretations
- Features to mid-crust are well imaged
- The crust in the center of YU2 is resistive to the mantle: this correlates with other data
- Processing and modelling of all three sets of data are on-going – results presented here are preliminary
- Further work required to image long-period data for deep conductivity contrasts well into the lithosphere

Australian Government

Geoscience Australia

Thank you

Youanmi Seismic/MT Workshop 27 February 2013

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