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Electrical resistivity distribution from magnetotelluric data in the region of YOM survey

Jingming Duan, Tanya Fomin, Peter Milligan, Tristan Kemp,
Josef Holzschuh, Ross Costelloe, Jingbao Wang

Onshore Seismic and Magnetotelluric Section
Minerals and Natural Hazards Division

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Geological Survey of Western Australia

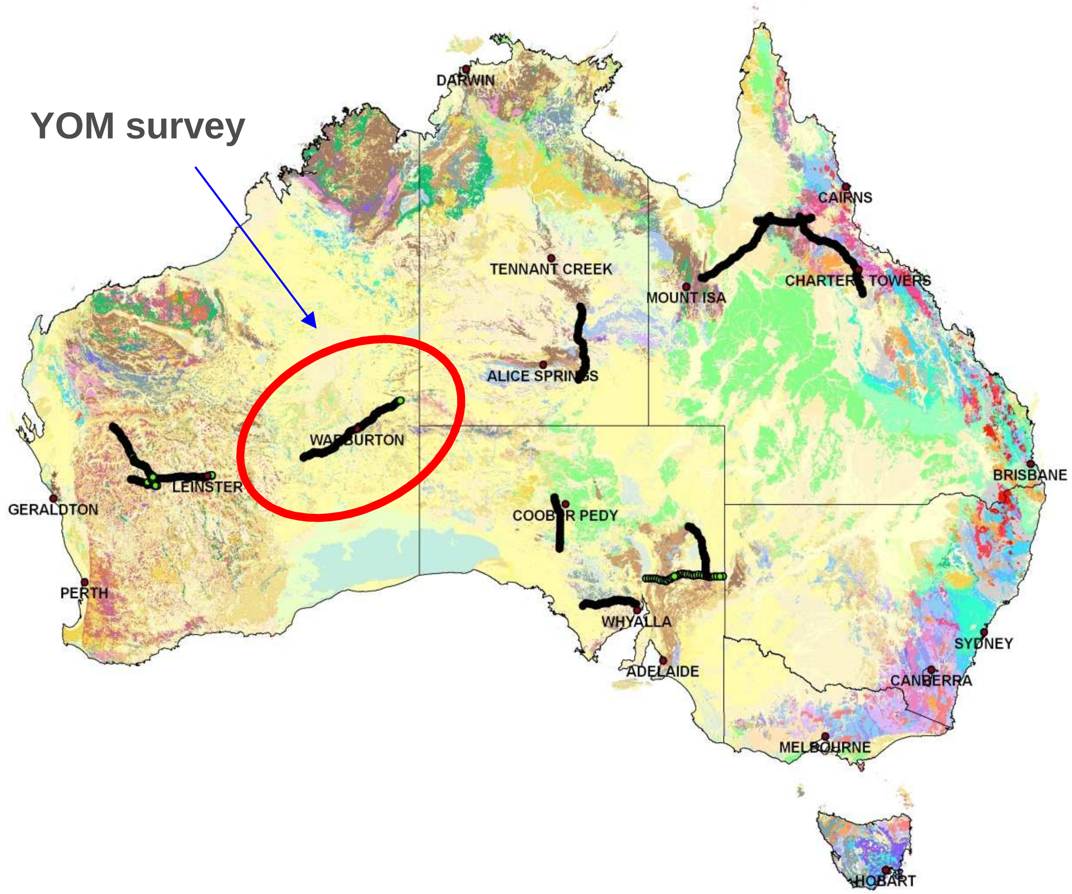
ANSIR/AuScope for MT equipment

Magnetotelluric acquisition overview

- Magnetotelluric (MT) data were acquired along 12 deep seismic reflection transects from July 2007 to June 2011

- Near 700 sites along 12 profiles, which are covering more than 3700 km in distance

- YOM MT survey includes 73 broadband (BB) and 31 long-period (LP) sites



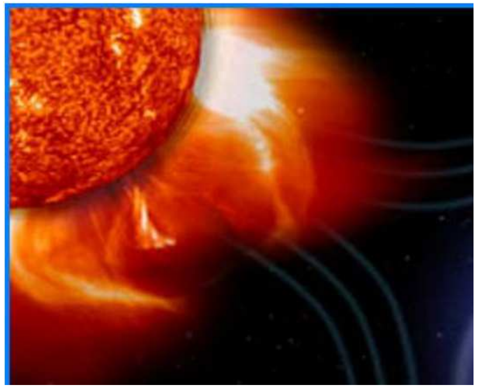
Data available at:
http://www.ga.gov.au/minerals/projects/current-projects/seismic-acquisition-processing.html

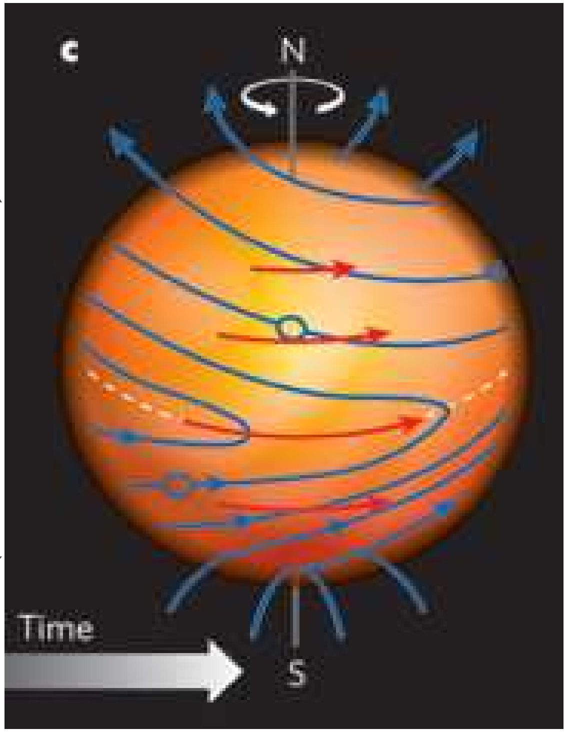
Source fields for the magnetotelluric method

THE INPUT

1. Lightning

2. Solar wind





F > 1Hz

F < 1Hz

Black box - Earth

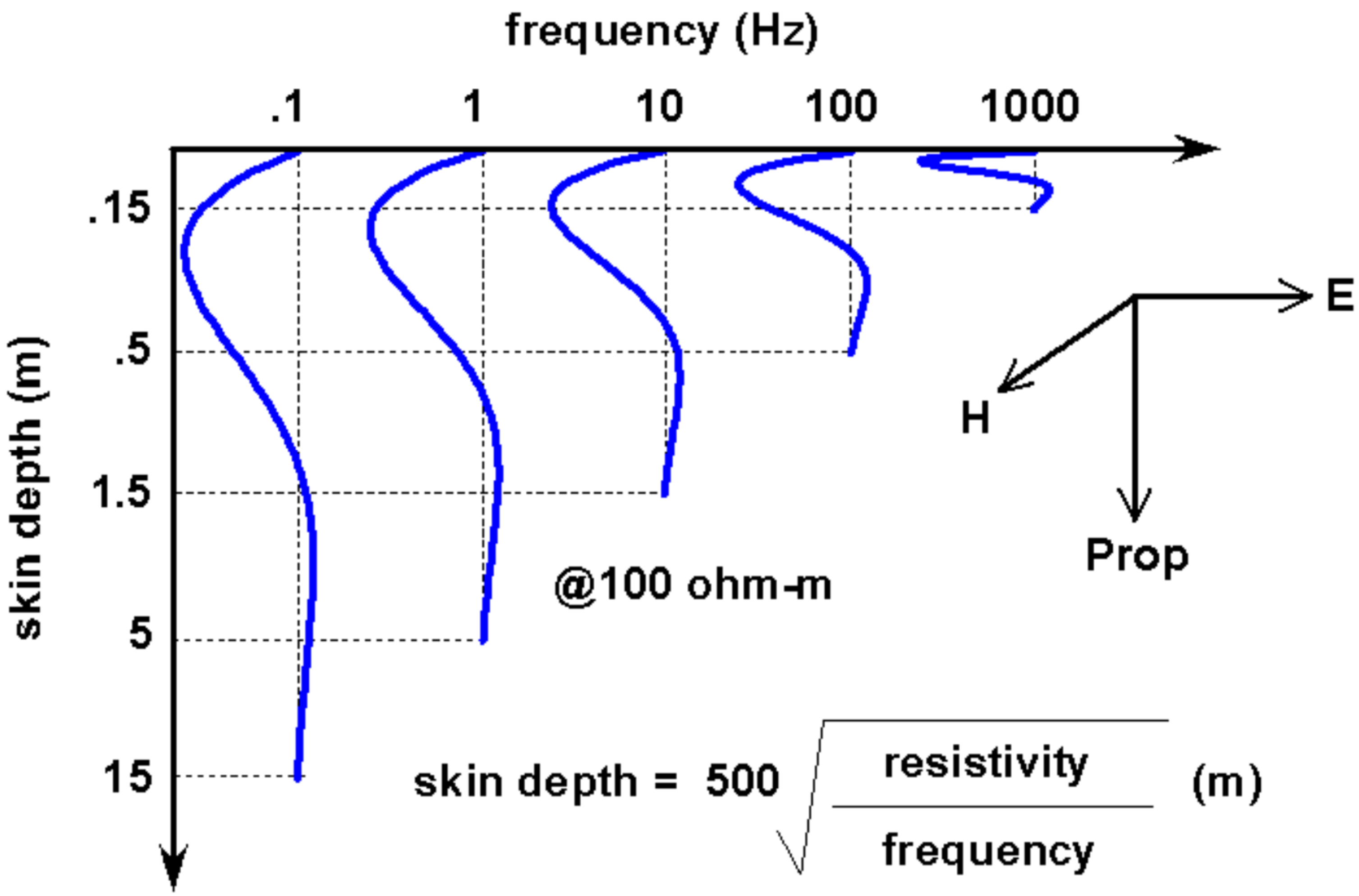
THE OUTPUT

Measure time variations of electric (E) and magnetic (H) fields at the Earth's surface.

MT DATA

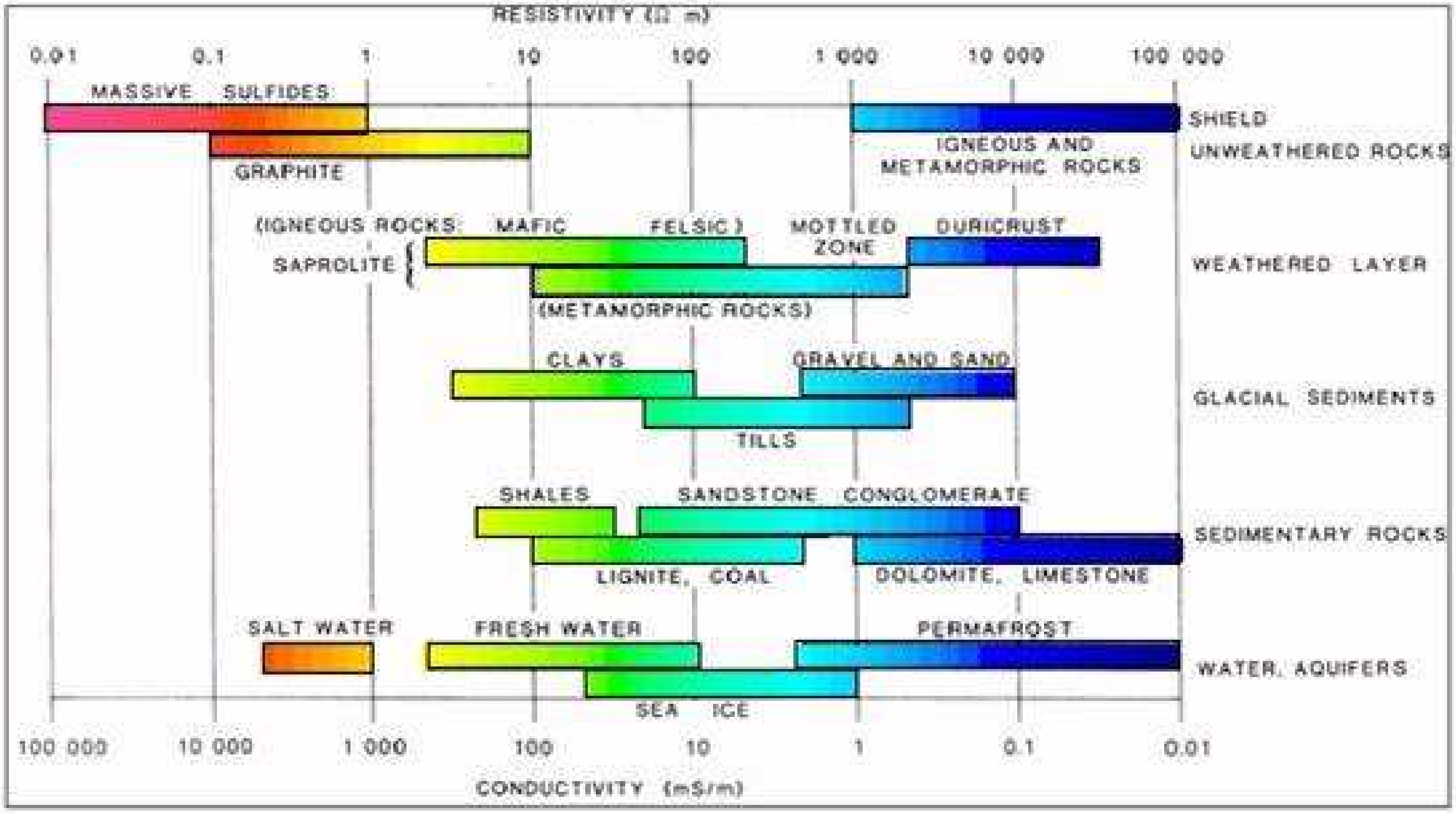
Objective: derive the geoelectric structure and relate it to geological structure and tectonics

Diffusive propagation and depth of signal penetration



$$\text{skin depth} = 500\sqrt{\frac{\text{resistivity}}{\text{frequency}}}\ (\text{m})$$

Resistivity Values of Earth Materials



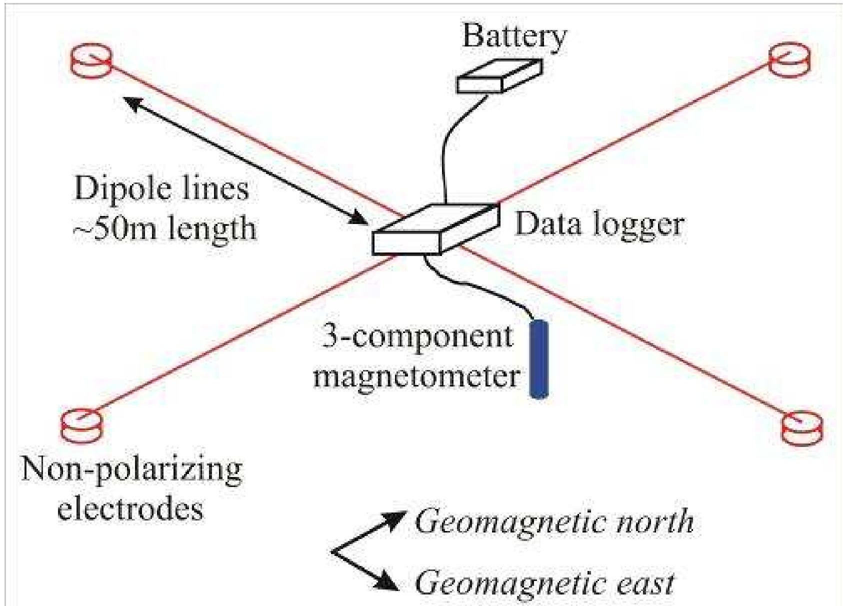
From Palacky, 1988

YOM MT acquisition

MT acquisition system:

- **Portable data recorder**
- **GPS clock synchronization**
- **Magnetic sensors**
  - induction coils & fluxgate magnetometer
- **Electric sensors**
  - electrodes configured as NS & EW dipoles

MT acquisition layout:



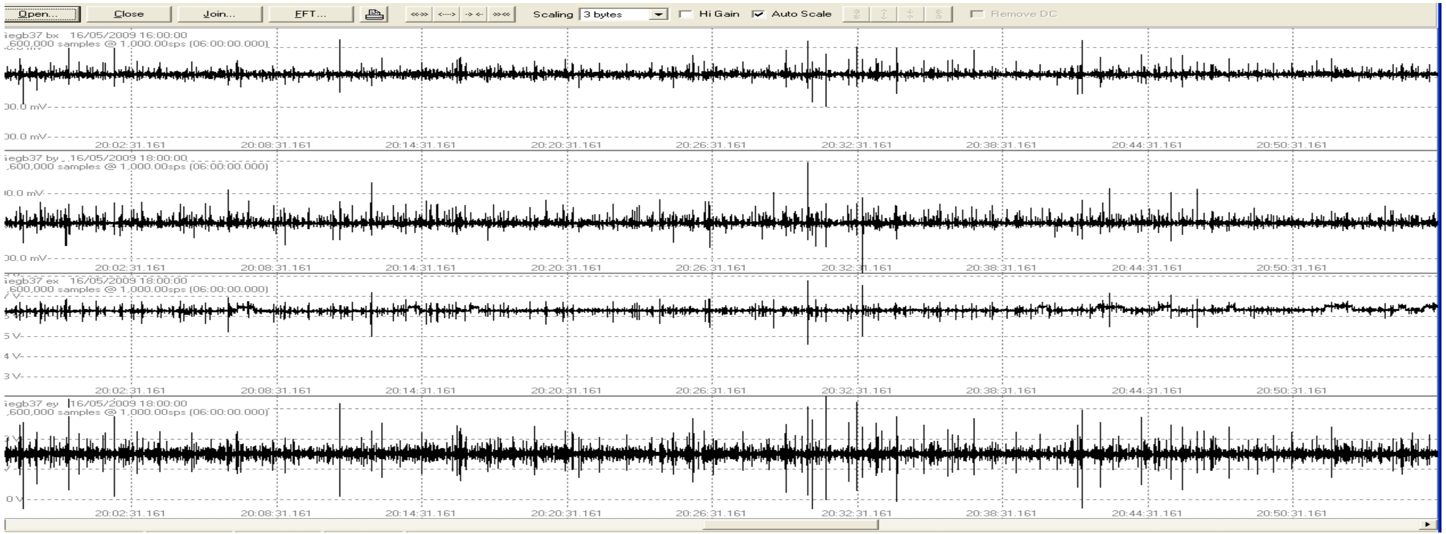
Example of time series data

Magnetic N

Magnetic E

Electric N

Electric E



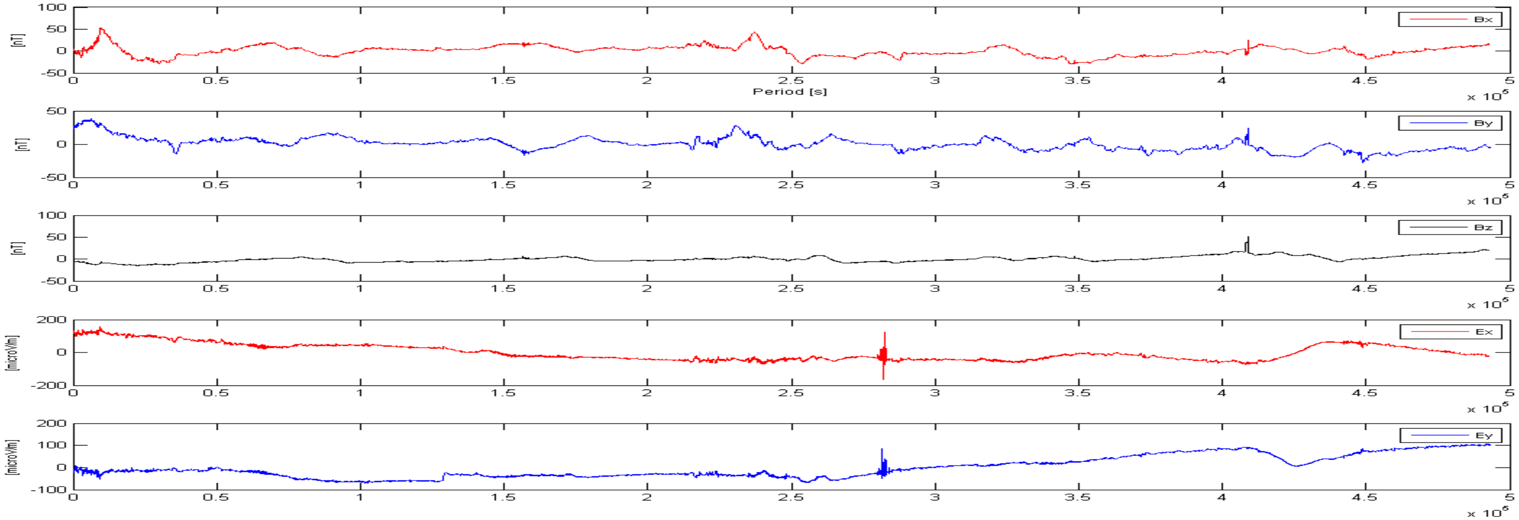
Magnetic N

Magnetic E

Magnetic Z

Electric N

Electric E



MT processing sequence

Time series data pre-processing

↓

Transform data into frequency domain

↓

Derive impedance tensor and spectra

↓

Calculate apparent resistivity and phase
Calculate tipper function for long period data

↓

Convert MT response into EDI file

↓

Data analysis

↓

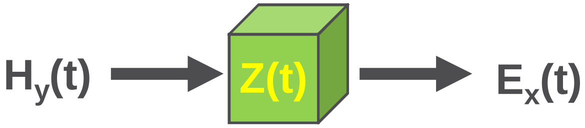
Modelling and inversion

MT data response

MT impedance tensor:

- Define by the relationship between horizontal components of the E field (Ex, Ey) with the horizontal components of the H field (Hx,Hy),

- Filtering operation



In frequency domain:

$$\mathbf{Z}(\omega)=\frac{\mathbf{E_x}(\omega)}{\mathbf{H_y}(\omega)}$$

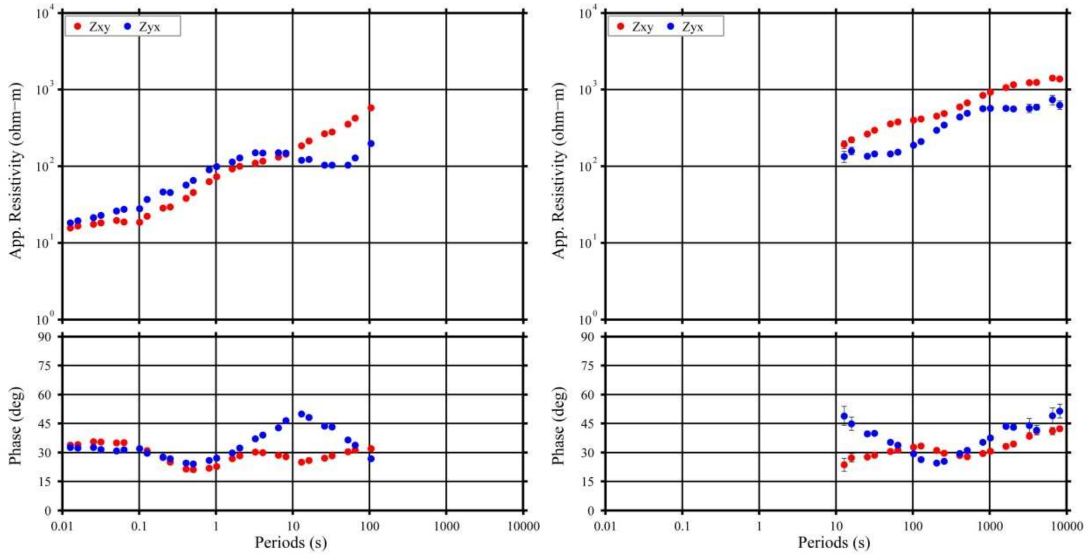
$$\mathbf{E}(\omega)=\mathbf{Z}(\omega)\bullet\mathbf{H}(\omega)$$

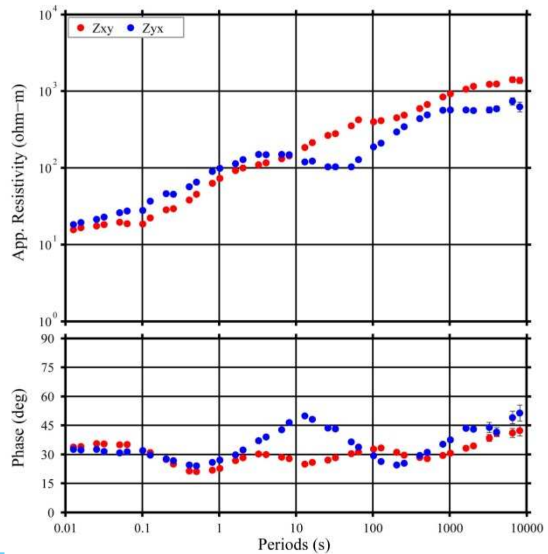
$$\begin{pmatrix} E_x(\omega) \\ E_x(\omega) \end{pmatrix} = \begin{pmatrix} Z_{xx}(\omega) & Z_{xy}(\omega) \\ Z_{yx}(\omega) & Z_{yy}(\omega) \end{pmatrix} \bullet \begin{pmatrix} H_x(\omega) \\ E_x(\omega) \end{pmatrix}$$

Apparent resistivity is average resistivity of a homogeneous, isotropic half-space.

$$\rho_a(\omega)=\frac{1}{\mu\omega}\left\|Z(\omega)\right\|^2$$

$$\phi(\omega)=Arg\left[Z(\omega)\right]$$





Dimensionality of MT impedance tensors

1D

$$\mathbf{Z}_{\text{obs}} = \mathbf{Z}_{\text{1D}} = \begin{bmatrix} 0 & Z_{xy} \\ -Z_{xy} & 0 \end{bmatrix}$$

Assumptions: Earth is isotropic, the resistivity property varies only in depth, and the lateral variation is small in a geological region.

2D

$$\mathbf{Z}_{\text{obs}} = \mathbf{R}\,\mathbf{Z}_{\text{2D}}\,\mathbf{R}^{\text{T}} = \mathbf{R}\begin{bmatrix} 0 & Z_{xy} \\ Z_{yx} & 0 \end{bmatrix}\mathbf{R}^{\text{T}}$$

Assumptions: the resistivity is constant along one horizontal direction while changing both along the vertical and the other horizontal directions.

3D

$$\mathbf{Z}_{\text{obs}} = \mathbf{R}\,\mathbf{Z}_{\text{3D}}\,\mathbf{R}^{\text{T}} = \mathbf{R}\begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{bmatrix}\mathbf{R}^{\text{T}}$$

Assumptions: the resistivity varies in all horizontal and vertical directions. plane wave approximation

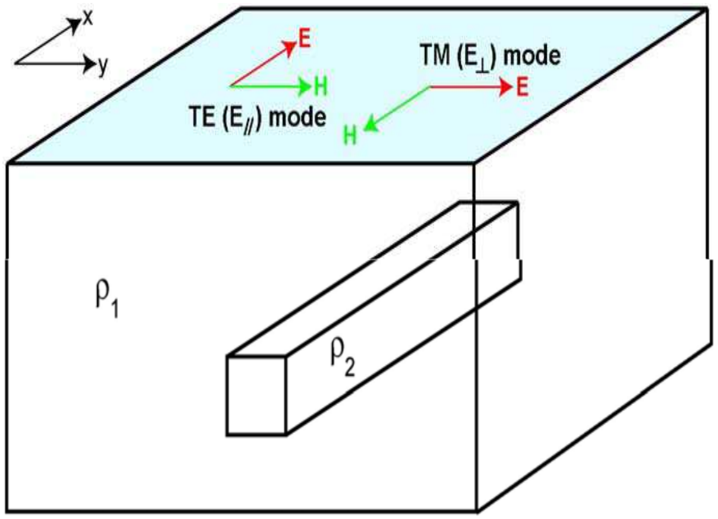
3D/2D

$$\mathbf{Z}_{\text{obs}} = \mathbf{R}\,\mathbf{T}\,\mathbf{S}\,\mathbf{Z}'_{\text{2D}}\,\mathbf{R}^{\text{T}}$$

$$= \mathbf{R}\begin{bmatrix} 1 & -t \\ t & 1 \end{bmatrix}\begin{bmatrix} 1 & s \\ s & 1 \end{bmatrix}\begin{bmatrix} 0 & Z_{xy} \\ Z_{y} & 0 \end{bmatrix}\mathbf{R}^{\text{T}}$$

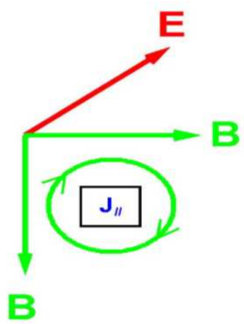
2D Earth structure

$$\mathbf{Z}_{obs}(\theta) = \mathbf{R}(\theta)\,\mathbf{Z}_{2D}\,\mathbf{R}^{T}(\theta)$$
$$= \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} 0 & Z_{xy} \\ Z_{yx} & 0 \end{pmatrix} \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$

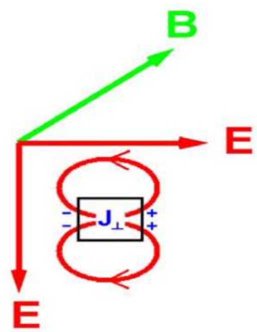


- By convention, the x-direction is along the strike of the structure, and the y-direction is across it.
- The strike angle θ is the angle between geographic north and the strike direction of the 2D structure.
- This tensor is very dependent on the angle observed.

Transverse electric (TE) mode: current parallel to strike and does not cross boundaries. no divergent E and no boundary charges.



Transverse magnetic (TM) mode: current perpendicular to strike and crosses boundaries. divergent E and boundary charges.
divergent E effects (e.g., static shifts).



Objectives of data analysis

- Determine the **dimensionality** and **directionality** (strike direction) within the MT impedance tensor, and their variation with frequency

- Determine response functions fully consistent with assumptions about the dimensionality

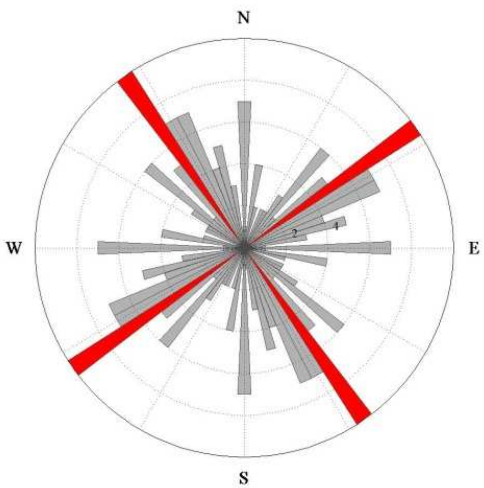
- Determine whether MT tensor estimates are internally consistent

- Determine extent of **static shifts** and **distortion**

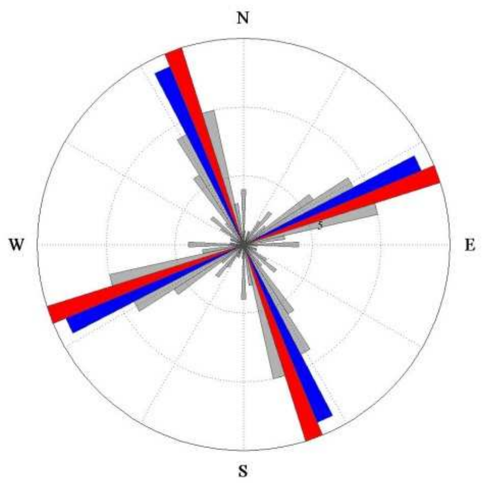
- Analysis techniques: phase tensor decomposition, Mohr circle technique, WALDIM method, induction arrows, etc

Data Analysis - dimensionality and directionality

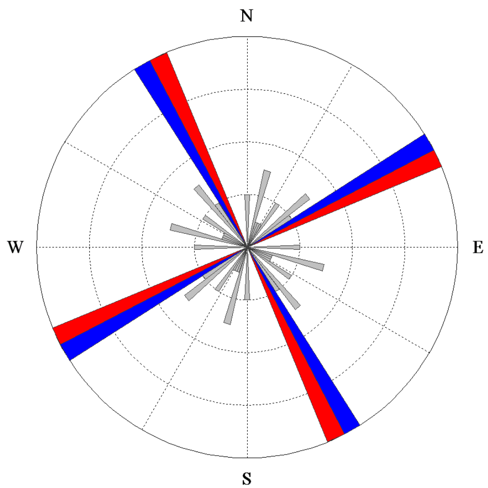
- Assume a 2D regional structure with local 3D distortion and no electromagnetic induction occurs in the distorter
- Regional electric fields = measured electric fields - distortion
- Compute electric strike angle and distortion (twist and shear angles)
- Inherent ambiguity of 90 degrees in strike direction
- Static shift still unknown



Regional strike 0.003 - 1 s



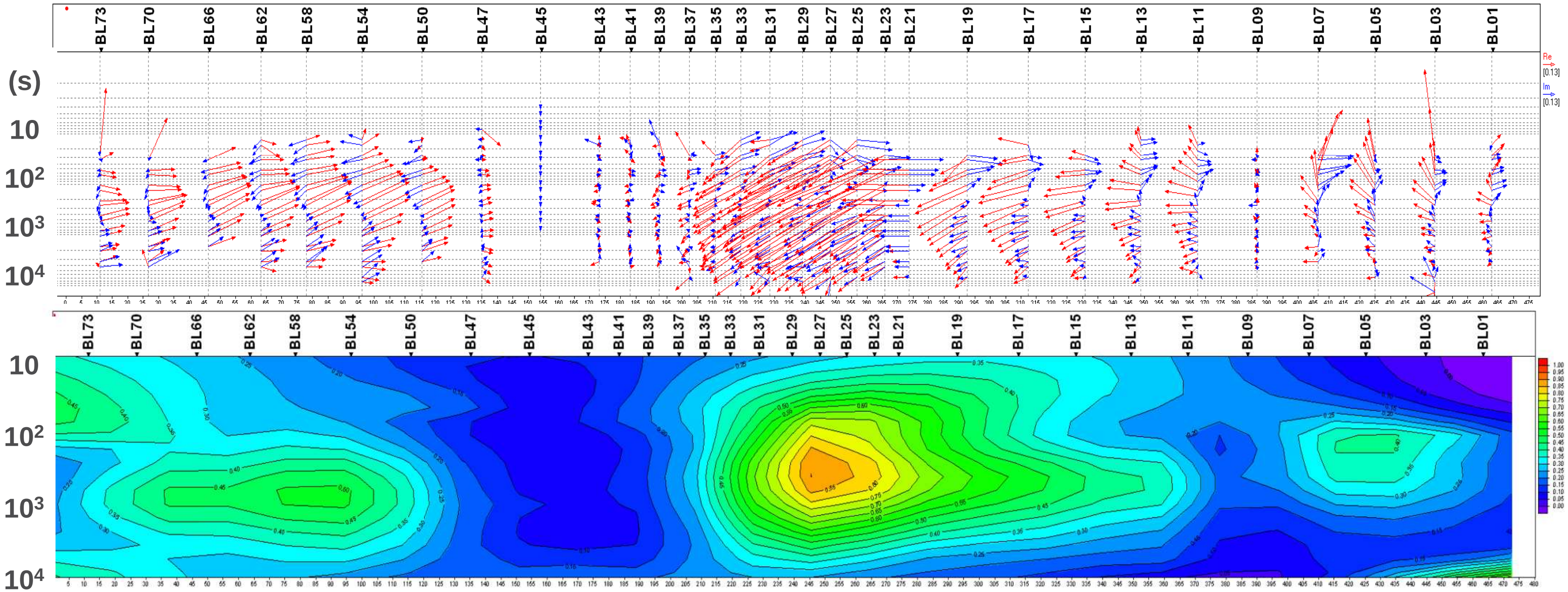
Regional strike 1 - 100 s



Regional strike 100 - 10000 s

Dimensionality – induction vectors

- Induction vector (arrows, Tipper, Tz) is the transfer function of the horizontal and vertical magnetic fields
- In the Parkinson convention, these vectors point at conductors.
- More sensitive than apparent resistivity data to structures
- Higher values of magnitude can be diagnostic of 3D effects



PseudoSection of apparent resistivity and phase

TM mode:

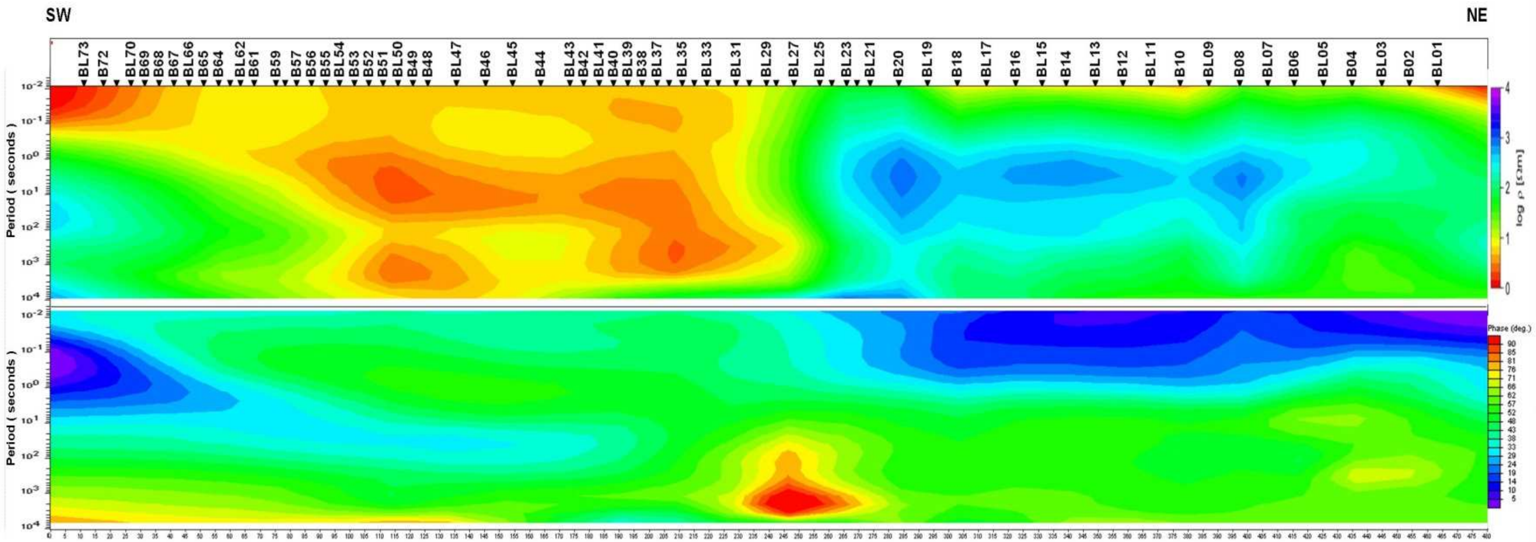
short

Apparent resistivity

period

Phase

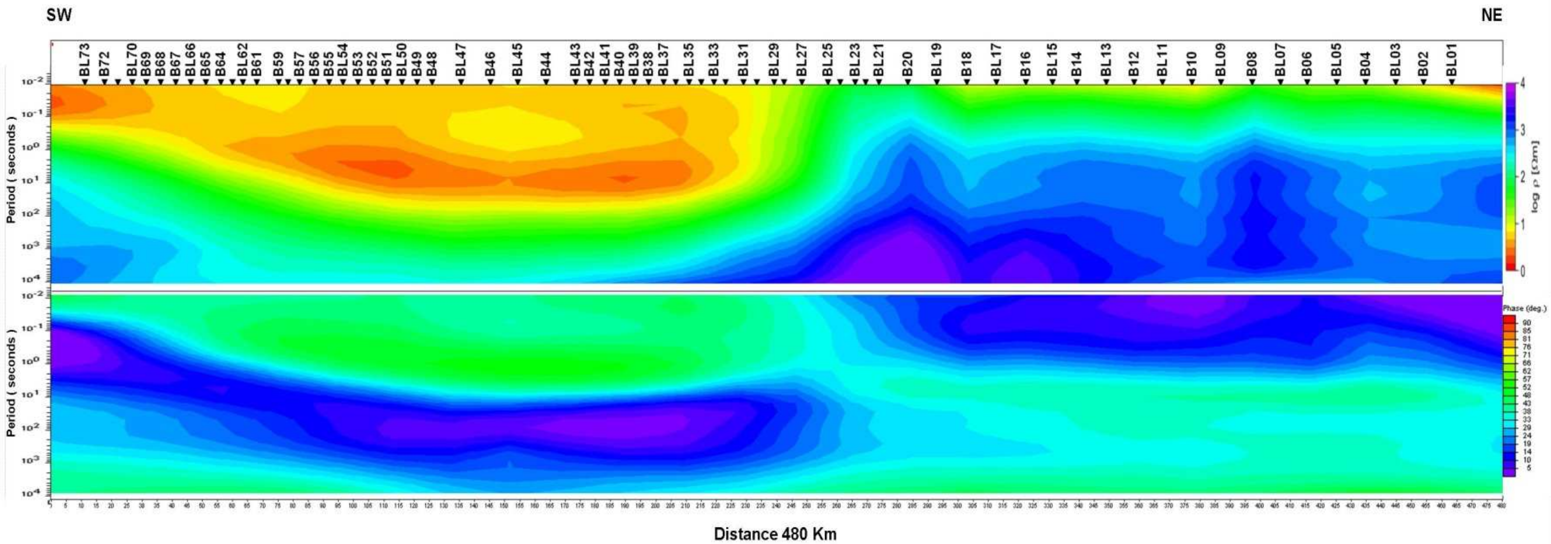
longer



TE mode:

Apparent resistivity

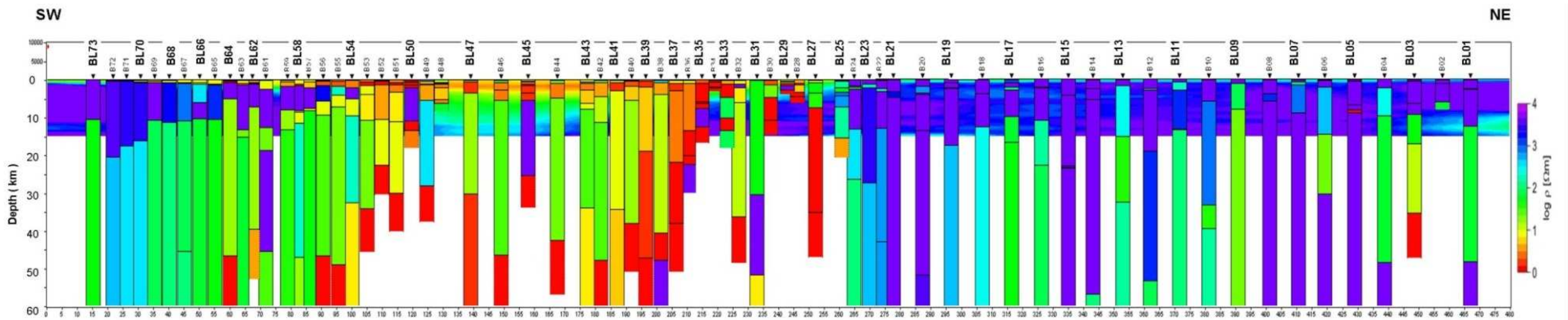
Phase



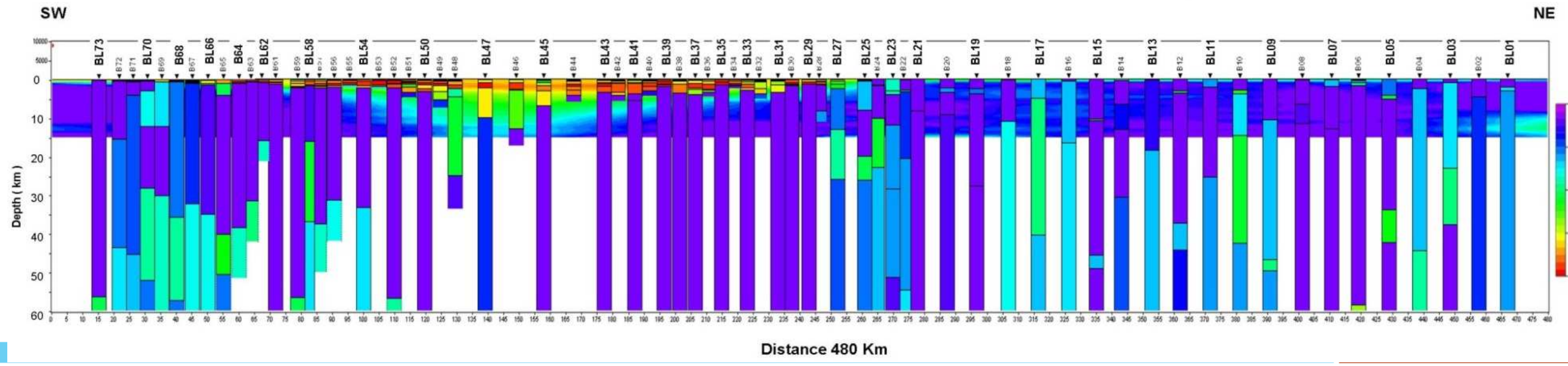
1D MT inverse problem

- 1D models have been done by Occam inversion and Bostick inversion
- Given MT data (impedance, ρ, φ) as a function of period, find a reasonable (smoothest) conductivity-depth model fitting the data.
- Screen effects exist due to the higher conductive structure above these sites .
- 1D assumption is not appropriate since major lateral changes

TE:

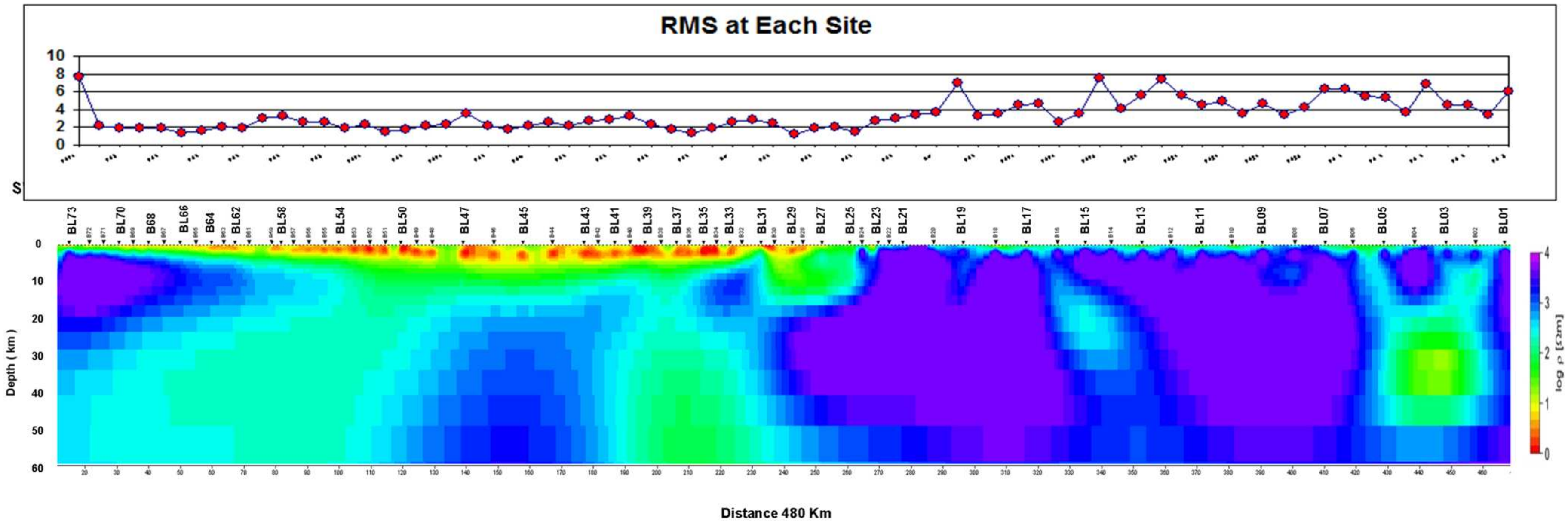


TM:

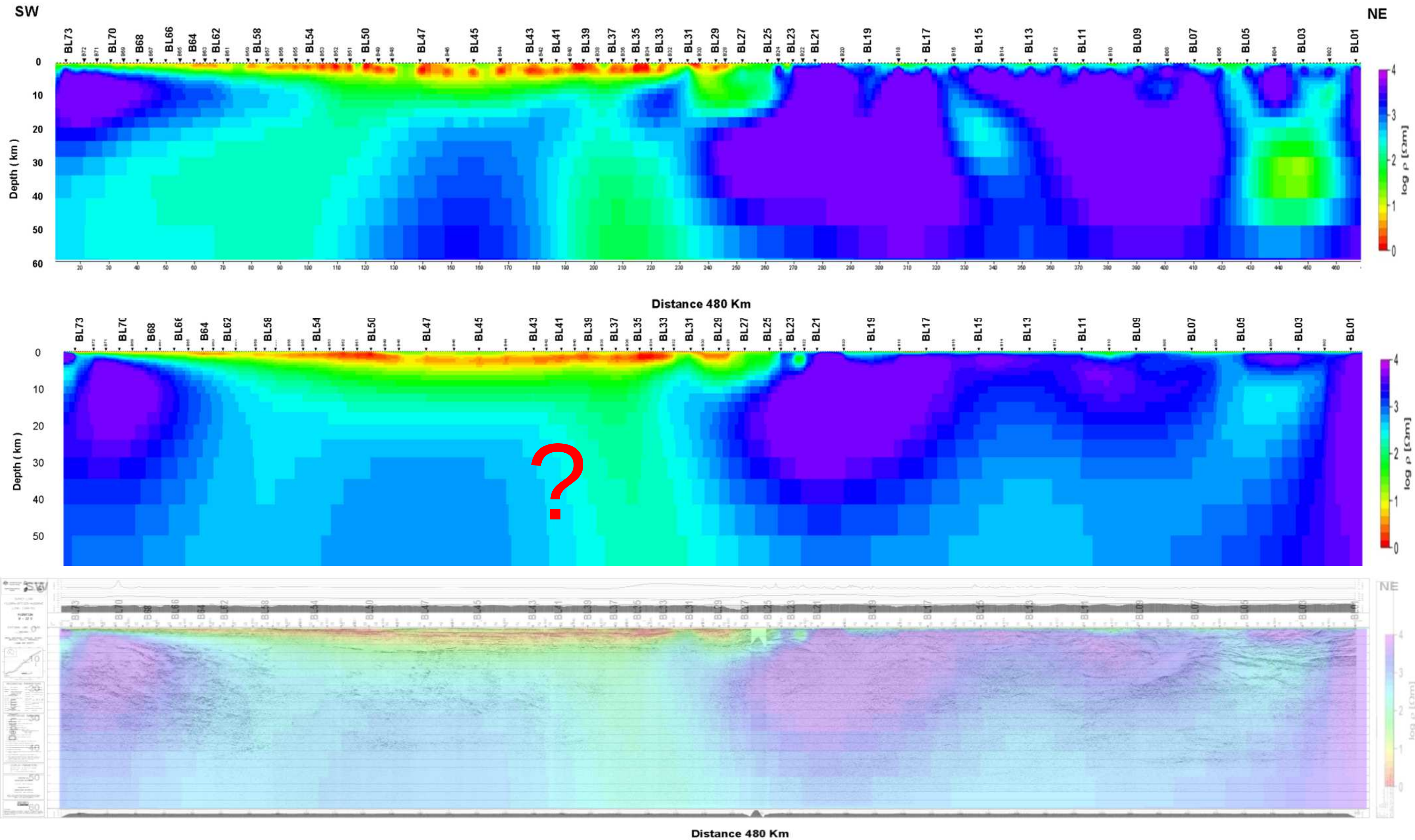


2D inversion model

- Inverted with NLCG algorithm developed by Rodi and Mackie.
- Wide range of inversion and regularization parameters were tested. eg, use data TE, TM, TE+TM, and TE+TM+Tz together and respectively for different inversions.
- RMS (root mean square) misfit show how well the assumptions are satisfied at each MT site, large misfit values can be diagnostic of 3D effects
- MT inverse problem is inherently non-unique. A trade-off exists between data misfit and model roughness. Require extra constraints on solution (e.g. known seismic)

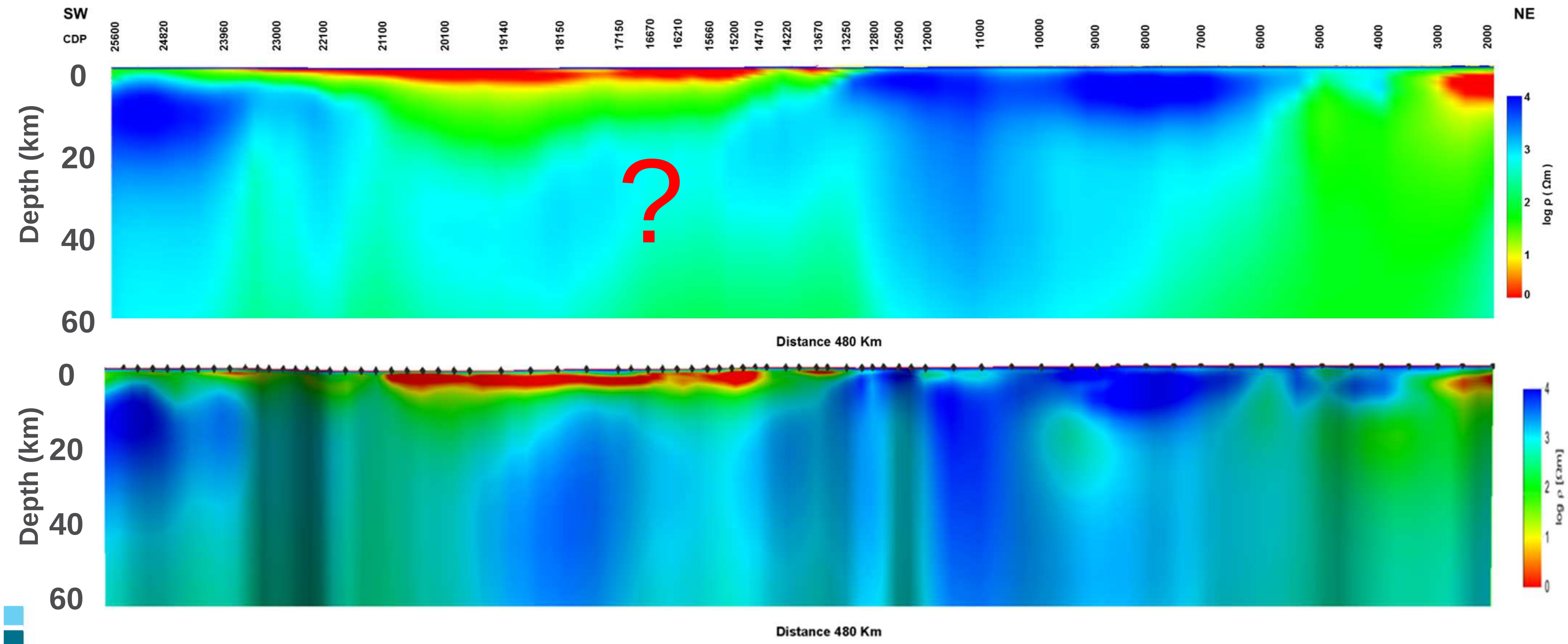


2D inversion model

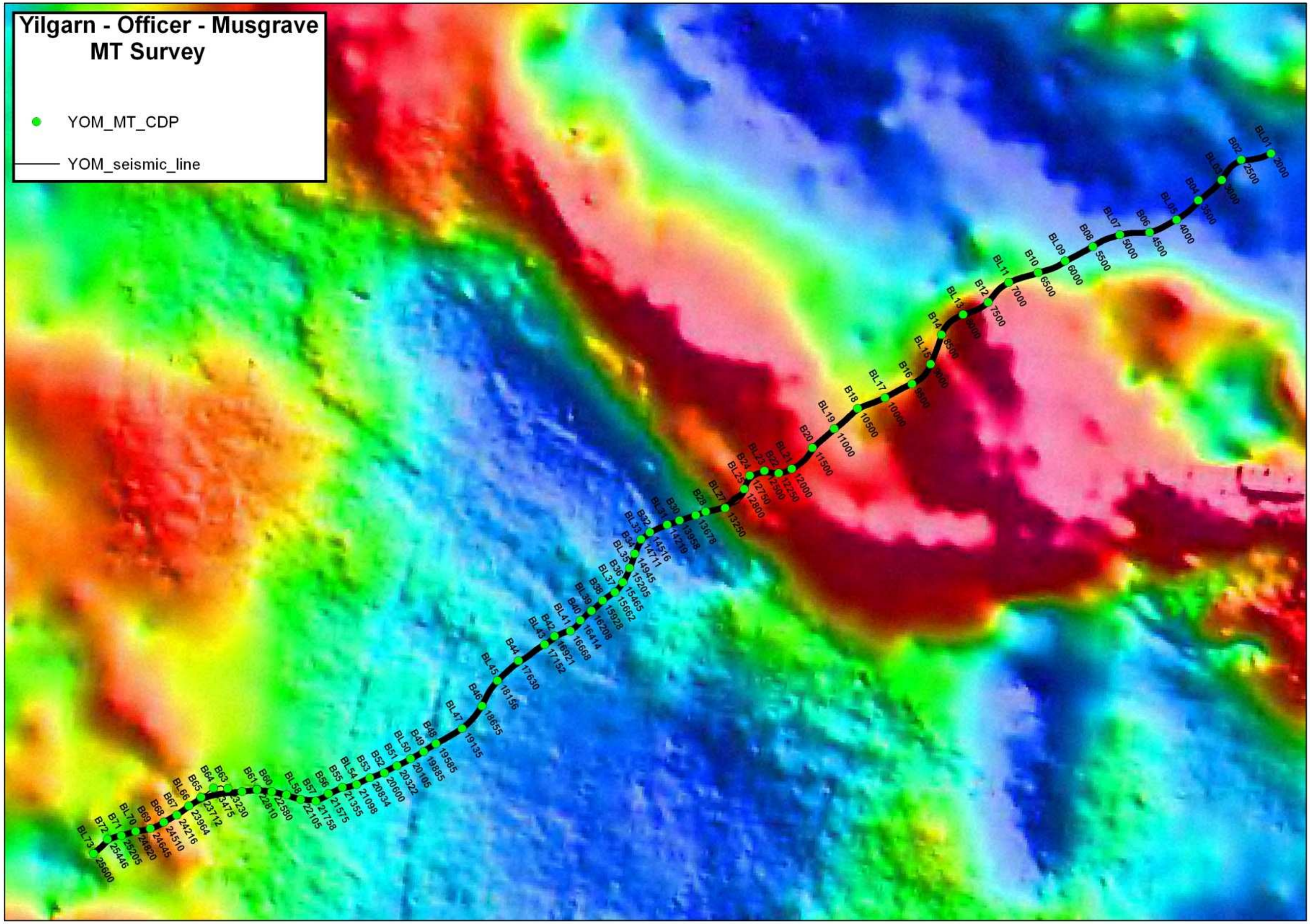


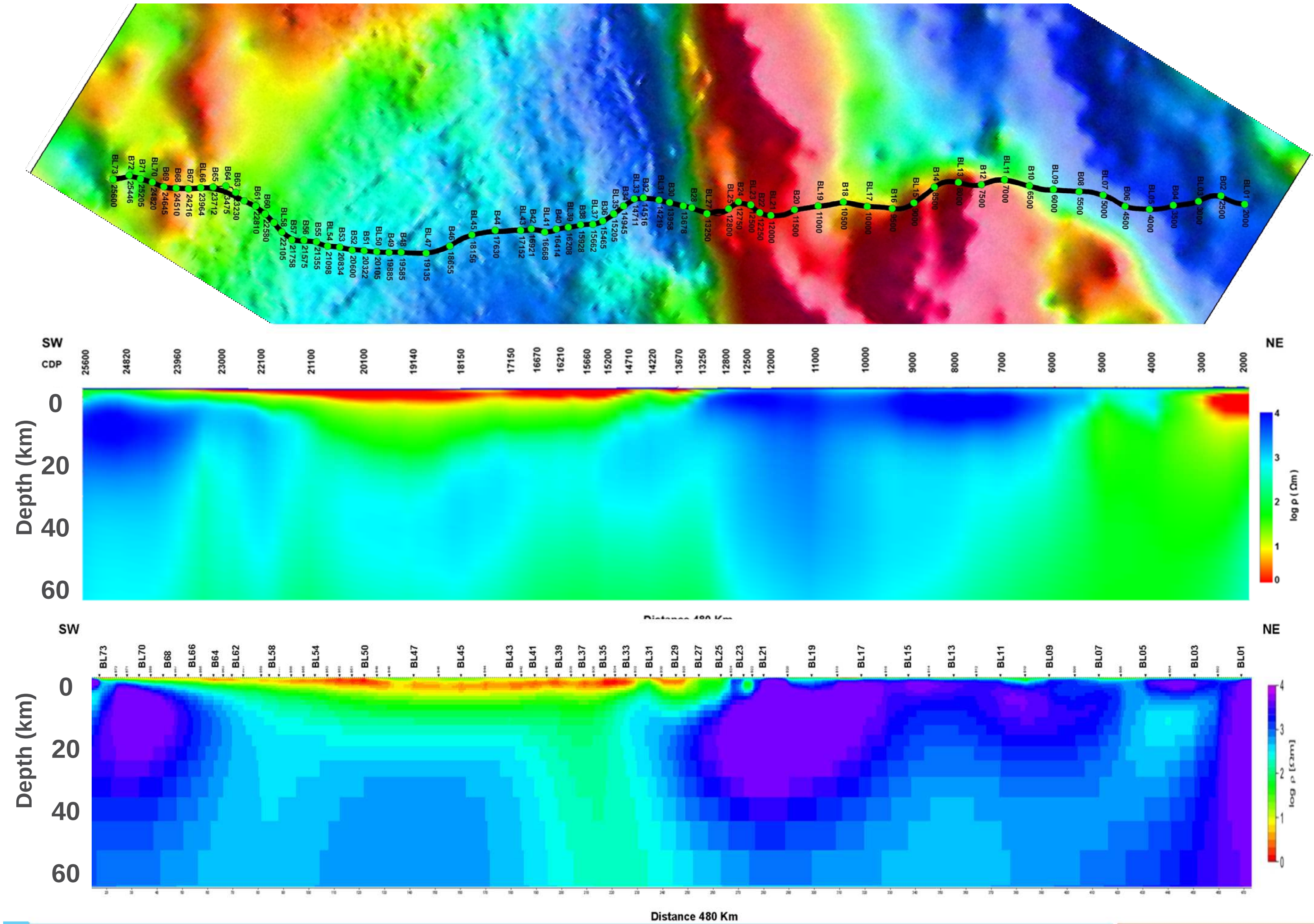
3D preliminary model

- 3D models produced by new ModEM code from Gary Egbert, Anna Kelbert and Naser Meqbel, Oregon State University
- Strike angle is not required, can treat as a quasi 2D structure since 3D structure usually has one length longer than the other.
- Non-unique still exist, require extra constraints on solution
- 3D inversion can validate 2D inversion

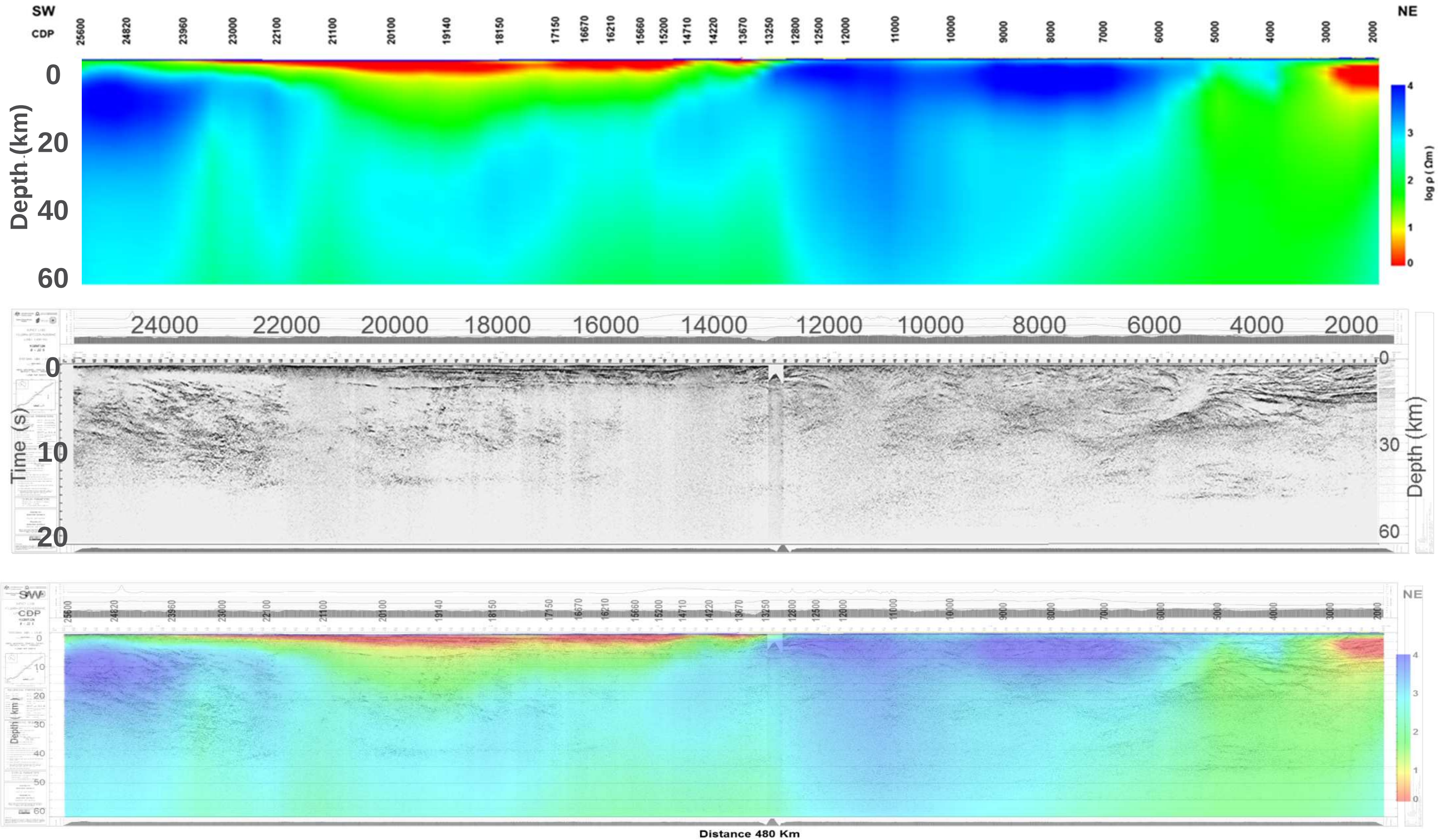


Comparison – MT and Gravity

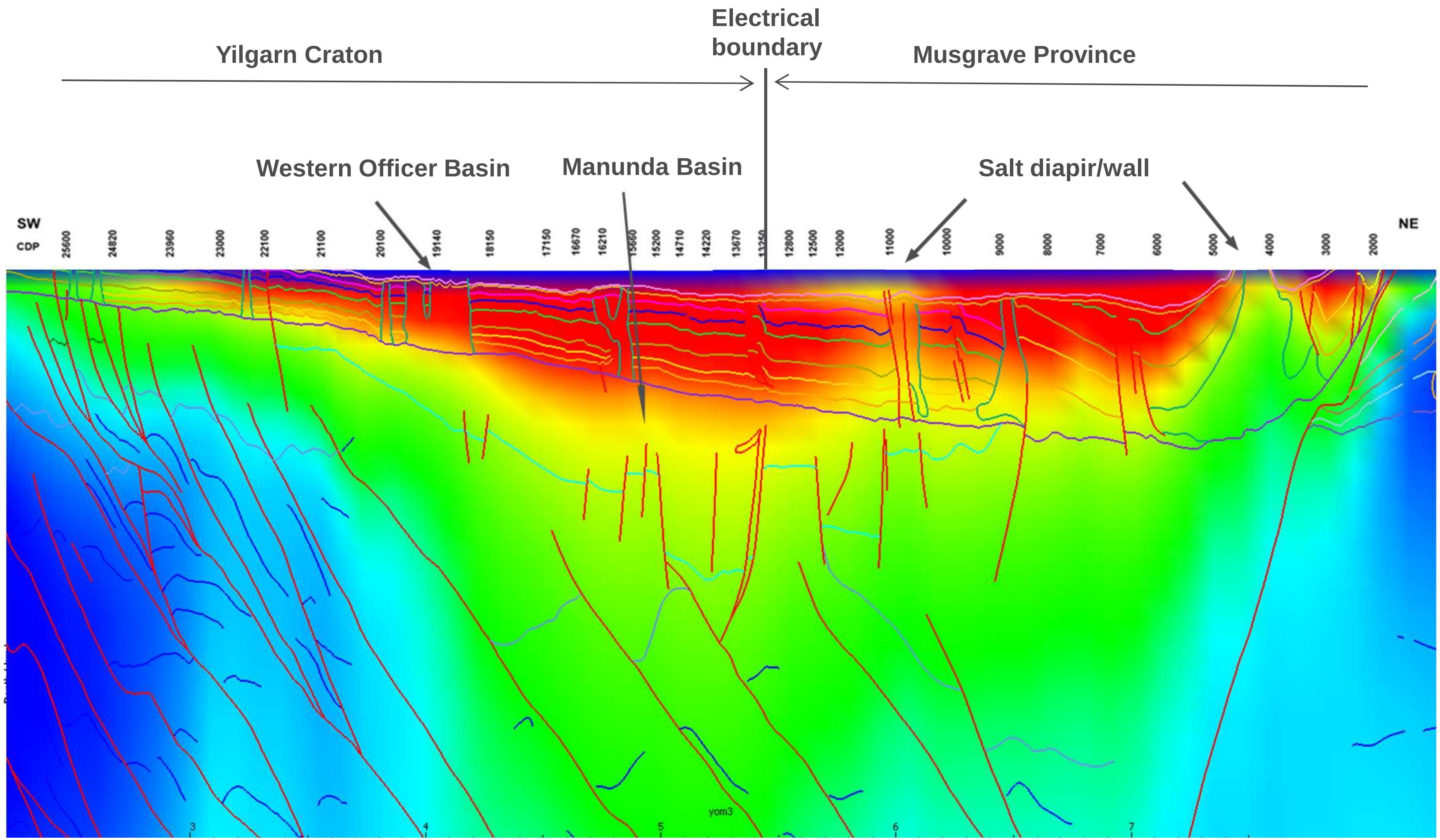



SW
CDP
25600 24820 23960 23000 22100 21100 20100 19140 18150 17150 16670 16210 15660 15200 14710 14220 13670 13250 12800 12500 12000 11000 10000 9000 8000 7000 6000 5000 4000 3000 2000
NE
Depth (km)
0
20
40
60
log ρ (Ωm)
SW
BL73 BL70 B68 BL66 B64 BL62 BL58 BL54 BL50 BL47 BL45 BL43 BL41 BL39 BL37 BL35 BL33 BL31 BL29 BL27 BL25 BL23 BL21 BL19 BL17 BL15 BL13 BL11 BL09 BL07 BL05 BL03 BL01
NE
Depth (km)
0
20
40
60
log ρ [Ωm]
Distance 480 Km

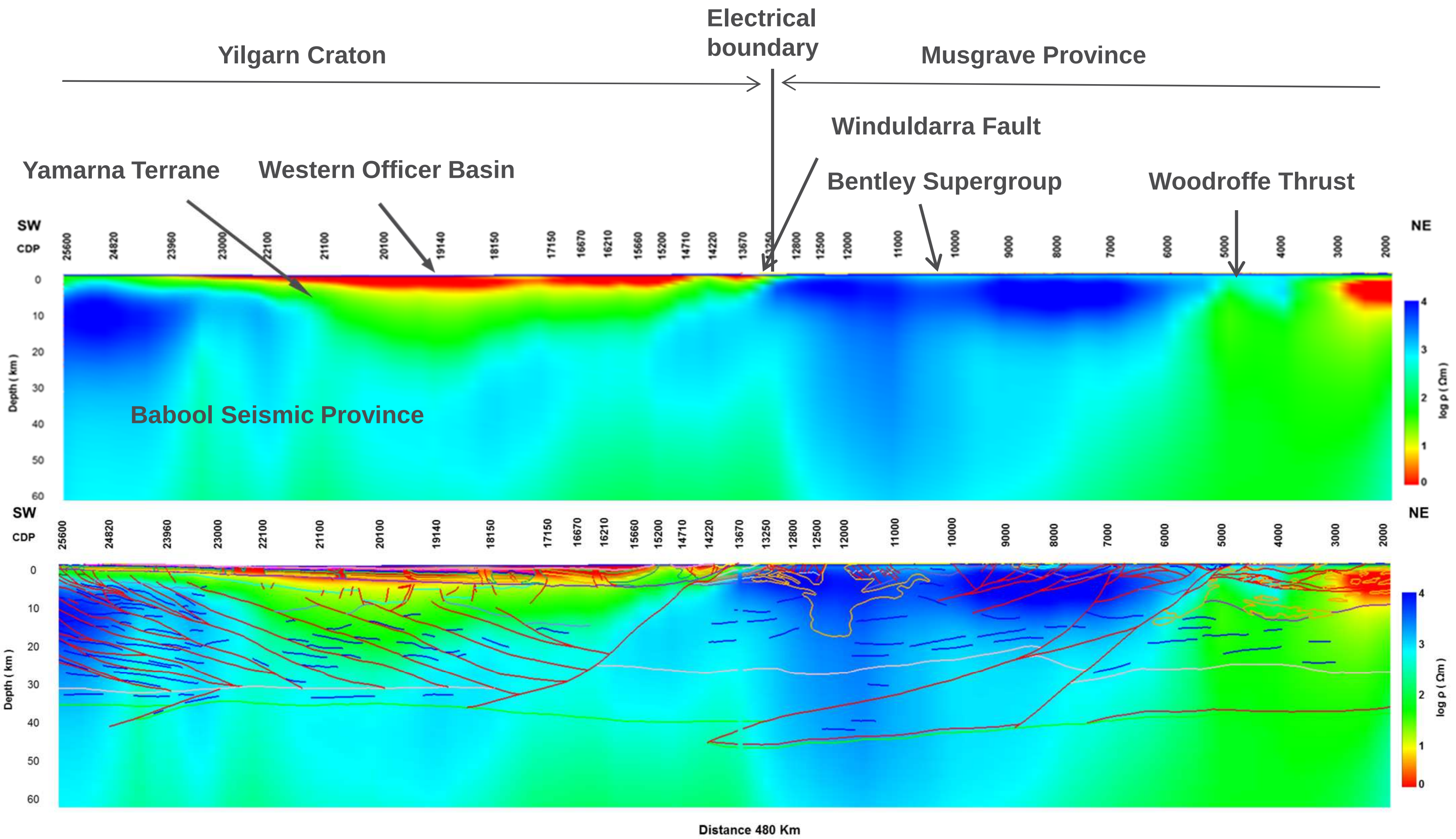
Comparison – MT and Seismic



What MT can tell ?



What MT can tell ?



Discussion and Conclusion

- The MT models show various correlation and difference with other geophysical data, such as, seismic, and gravity. The MT data provide additional constraints to complement multi-disciplinary geophysical and geological data.
- MT data provide evidence of electrical/geological structures in this region, for example, the near-surface sediments are well-resolved, some boundaries have been defined.
- MT inversion is non-linear, non-unique and unstable problem. It can be complex and impossible to accurately estimate physical properties due to large station spacing and complicating factors, such as, uncertainty of data, static shift, distortion, 3D effects.
- Prior geological and geophysical information should be applied to constrain the model.
- 2D approaches can be optimized, but growing recognition of fully 3D nature of the problem
- MT data interpretation is a difficult task, which is involving expert knowledge in multi-disciplinary.

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Thank You

Phone: +61 2 6249 9079

Web: www.ga.gov.au

Email: jingming.duan@ga.gov.au

Address: Cnr Jerrabomberra Avenue and Hindmarsh Drive, Symonston ACT 2609

Postal Address: GPO Box 378, Canberra ACT 2601