Australian Government

Geoscience Australia

Magnetotelluric survey in Gawler Craton – Musgrave

Seismic Acquisition & Processing team

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Outline

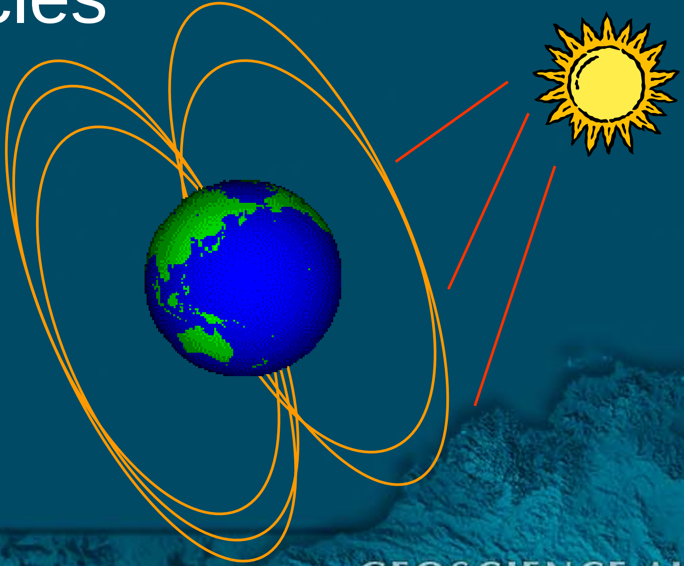
- Magnetotelluric (MT) method
- GOMA MT survey overview
- Acquisition system and parameters
- Data processing and analysis
- MT survey preliminary results

MT Definition

- Magnetotelluric (MT) is a passive electromagnetic (EM) sounding technique
- Measure variation in Earth's natural electrical (E) and magnetic (B) fields in time series
- Ratio of E / B use to derive resistivity distribution of Earth's crust and upper mantle
- Frequency range 10 kHz to 0.0001 Hz (0.0001 s to 10000 s)
- Investigation depths of tens of metres to hundreds of kilometre

MT Source Field

- High frequencies >1 Hz from Spherics
  - Lightning (thunderstorm) activity world-wide
- Low frequencies <1 Hz from
  - Interaction between solar wind and magnetosphere
- Vary with periods on seconds, minutes, hourly, daily, yearly cycles



Depth of Investigation

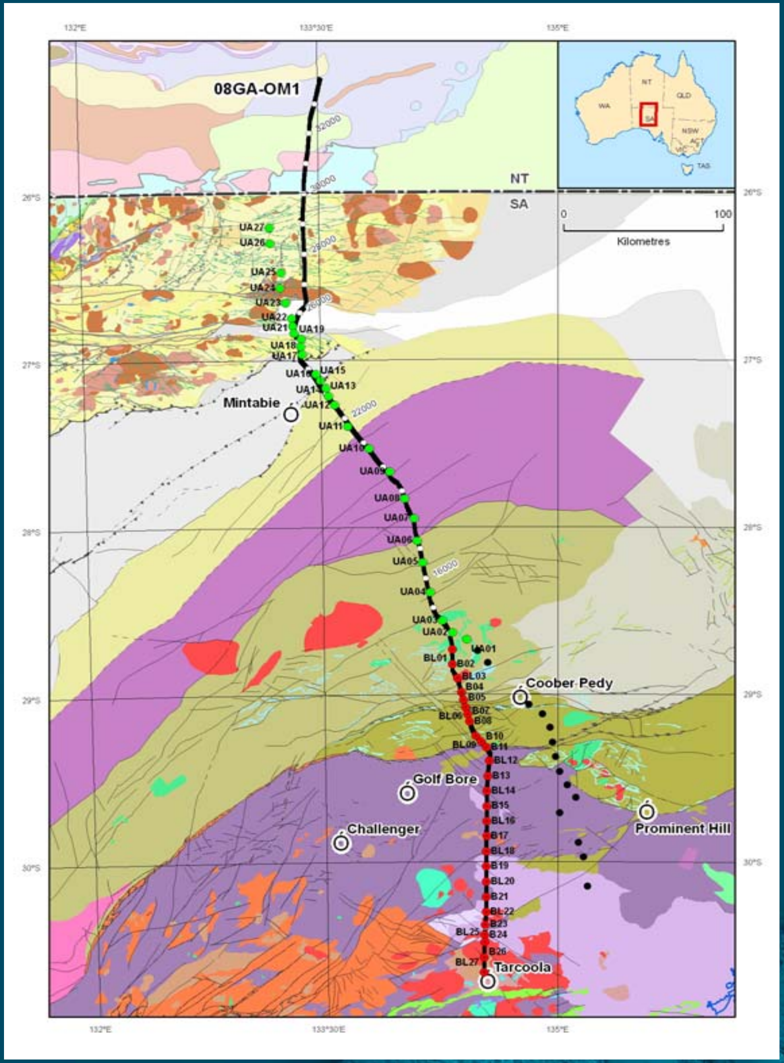
- The depth of investigation depends upon frequency and resistivity of the subsurface
  - High frequencies image the near-surface
  - Lower frequency penetrate to greater depths
  - Higher resistivity means deeper penetration
- Skin depth (in metres):

$$\delta = \frac{1}{\sqrt{\pi \mu_o}} \sqrt{\frac{\rho}{\mu_r f}} \approx 503 \sqrt{\frac{\rho}{\mu_r f}}$$

μr is the relative permeability of the medium
$\mu 0$ is magnetic permeability of free space
ρ is the apparent resistivity
f is the frequency

GOMA MT survey

- 39 MT sites were acquired along 08GA_OM1 deep seismic reflection transect in Nov – Dec 2008.
- The profile is approximate 230 km
- 27 broadband MT sites and 12 long period MT sites
- Early study by Kate Selway, etc from The University of Adelaide (2006, 2010)



MT Acquisition System

- 9 broadband and 9 long period MT systems from ANSIR
- Portable data recorder with high dynamic range, 24 bits resolution and 30 GB storage.
- GPS clock synchronization
- Magnetic sensors (induction coils and fluxgate magnetometer)
- Electric sensors (copper/copper sulfate electrodes with dipole length 50 m)

Magnetic Sensors

Electric Sensors

MT Acquisition Parameters

Type of MT	Broadband	Long period
Recording channels	4	5
Sample rate	500	10
Recording time	30 - 60 hours	5 - 7 days
Site spacing	5 - 10 km	10 - 15 km
Deployment	3 or 4 sites at a time	4 or 5 sites at a time
Data format	MiniSeed	MiniSeed

MT System Set up

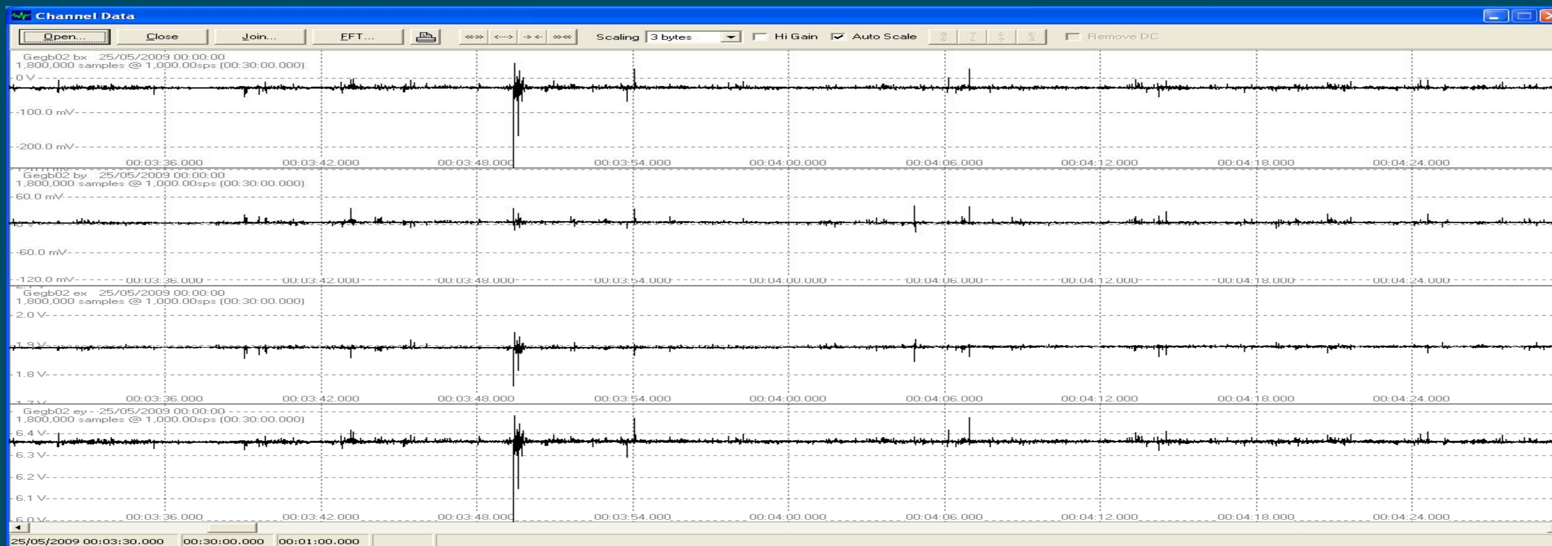
Example of Time Series Data

Magnetic N

Magnetic E

Electric N

Electric E



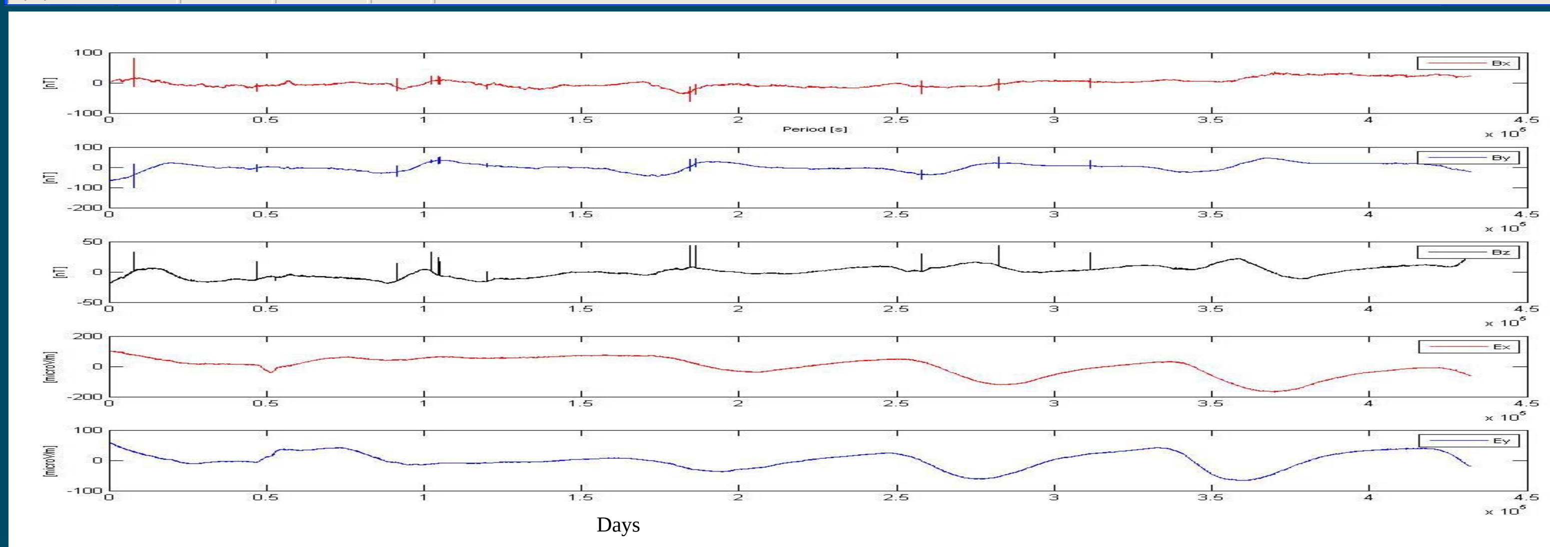
Magnetic N

Magnetic E

Magnetic Z

Electric N

Electric E



Data Processing

- Time series pre-processing (spikes and steps removal, editing, and filtering)
- Converted time series data into the frequency domain using the robust algorithm BIRRP (Spectral analysis, Statistical analysis, remote reference technique, etc)
- Calculate spectra and impedance tensor components

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

Data Processing

- Calculate apparent resistivity and phase from impedance tensor

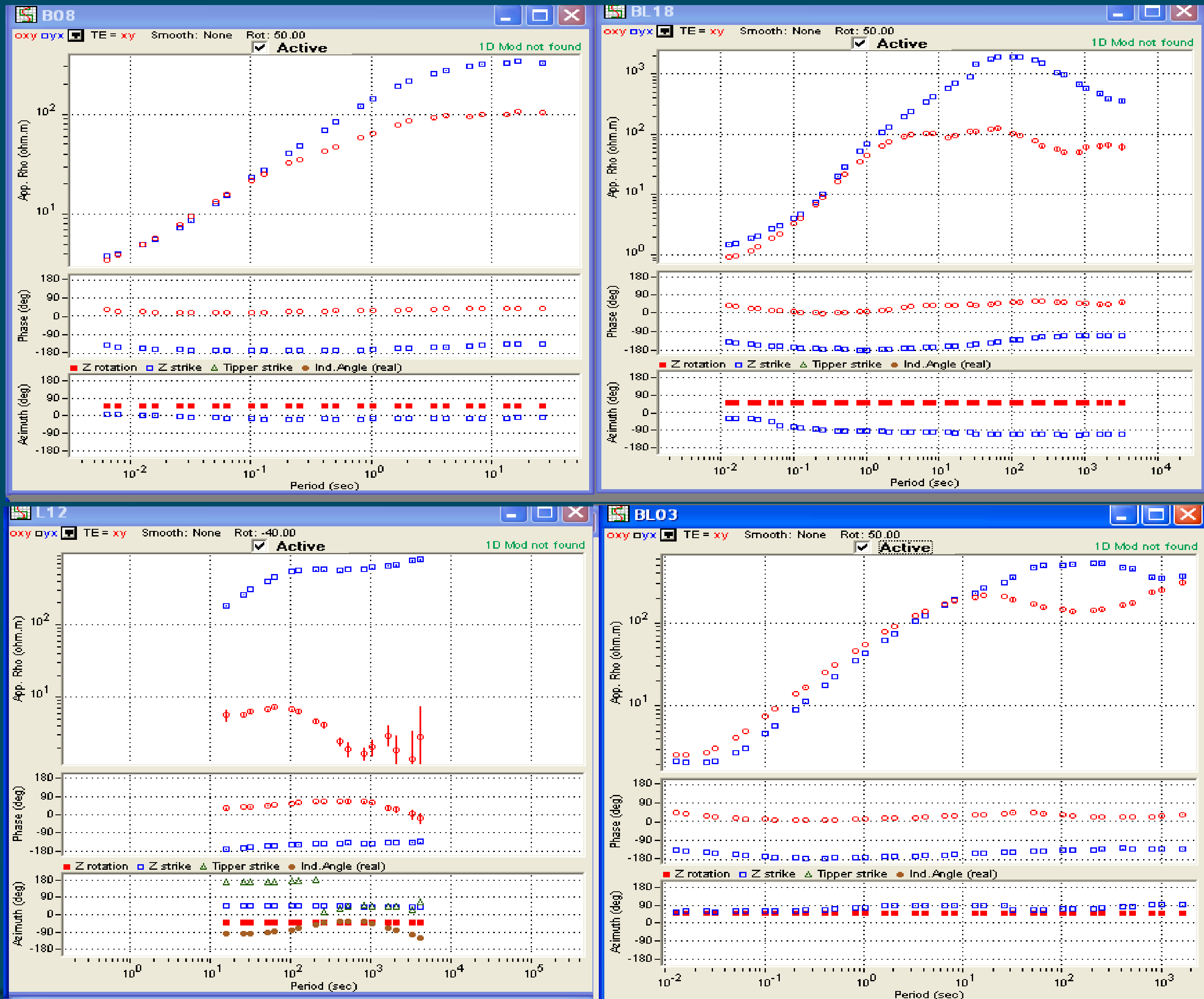
$$\rho = \frac{2\times 10^{-7}}{T}\left|\frac{E_x}{B_y}\right|^2 = \frac{2\times 10^{-7}}{T}\left|Z_{xy}\right|^2$$

- Calculated tipper function if the data has got vertical magnetic field (long period MT)

$$B_z = T_{zx}\,B_x + T_{zy}\,B_y$$

- Store MT response into standard EDI file
- Display apparent resistivity and phase graphically

MT Data Response



Data Analysis

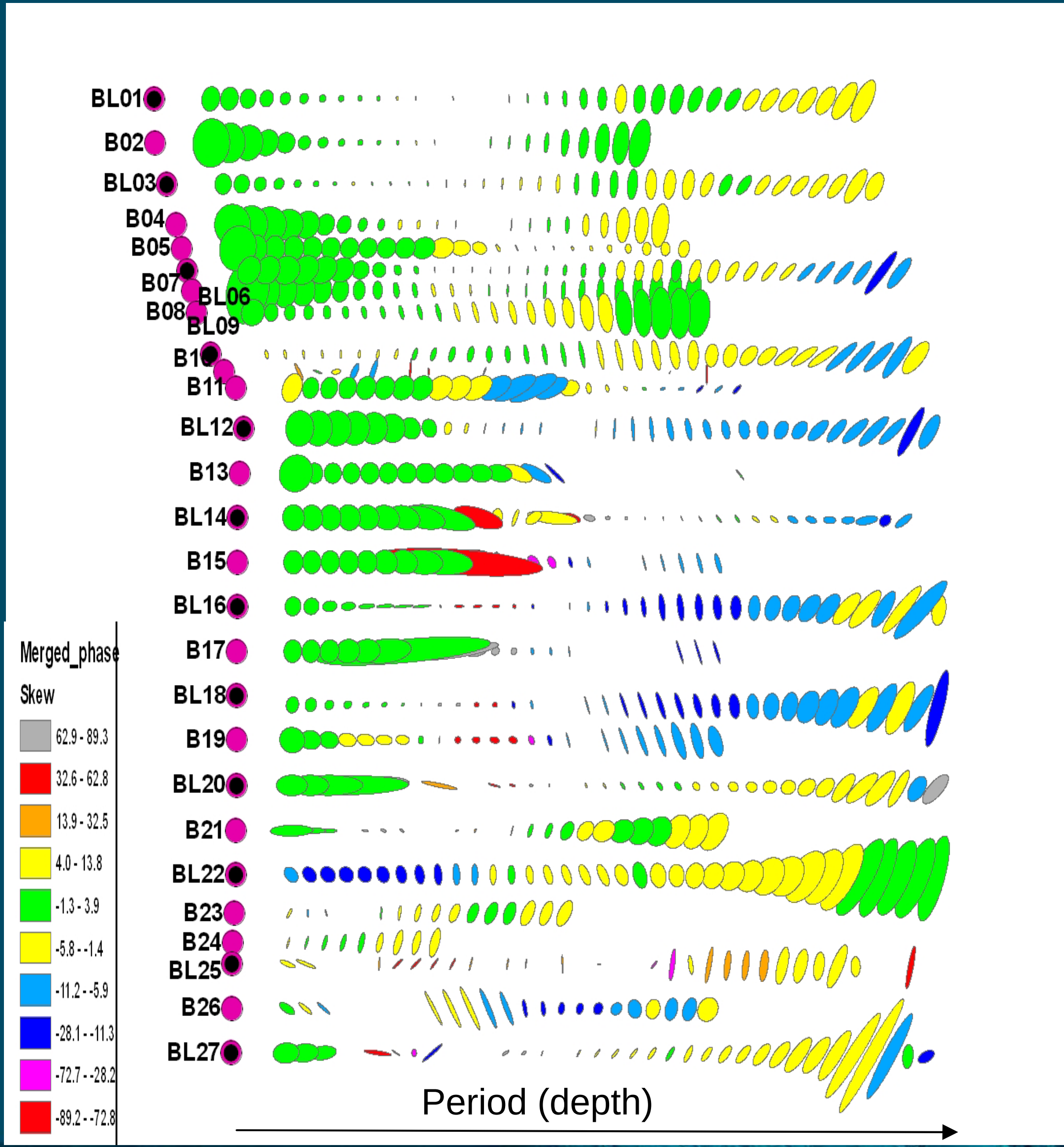
Type of MT response	Broadband data	Long period data	Merged data	UA's LP data
No of period	30 periods	22 periods	40 periods	10 - 20 periods
Range of period	0.005 s to 100 s	10 s up to 10000 s	0.005 s up to 10000 s	10 s up to 5000 s

Data Analysis

- Define the dimensionality and electric strike angle of the data set.
- Several techniques have been used, such as, phase tensor decomposition, Mohr circle technique, vertical induction vector (arrow), WALDIM, etc.
- PseudoSection of data set gives a qualitative impression of resistivity variations with depth and distance
- Complicating factors need to be considered

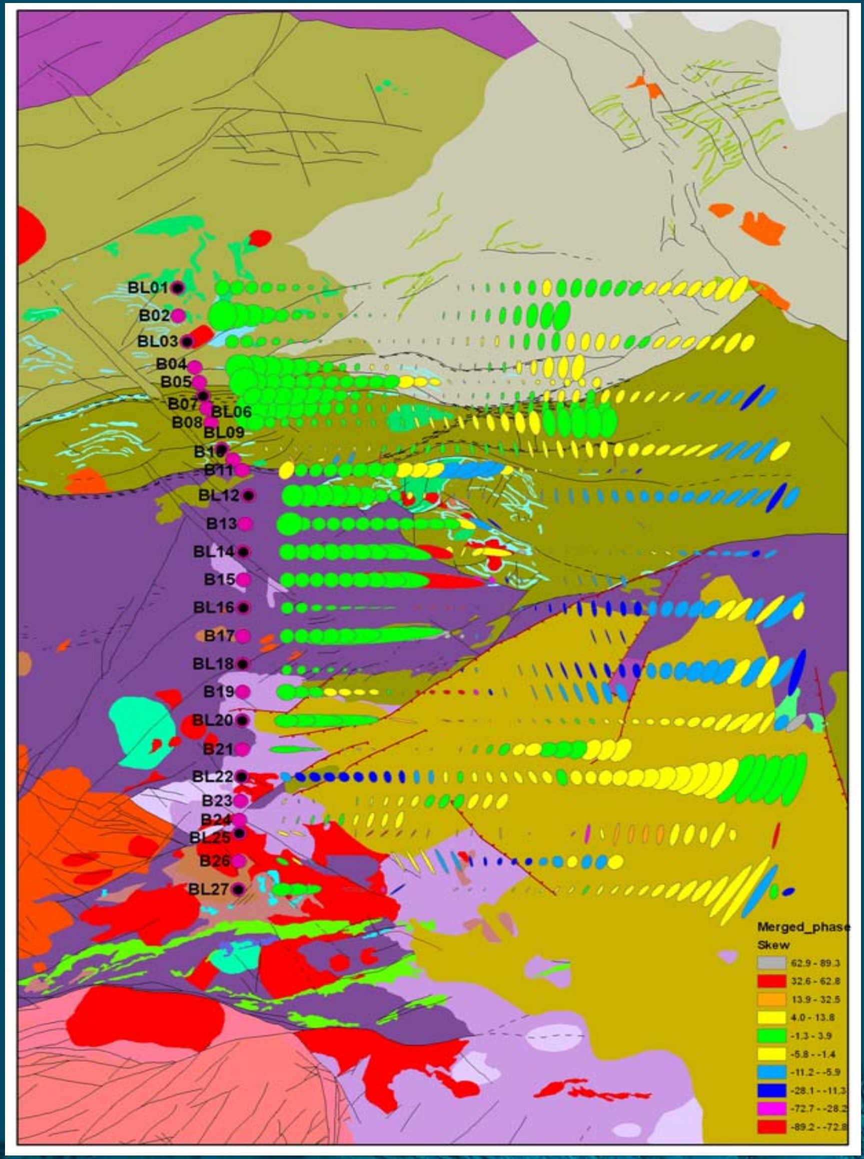
Phase Tensor Analysis

- Phase tensor is characterized by maximum, minimum phase values and skew angle. It represented as an ellipse
- Ellipses coloured by skew angle (3D if skew angle > few degrees)
- Long (principal) and short axes of the ellipse represent the maximum and minimum phase values



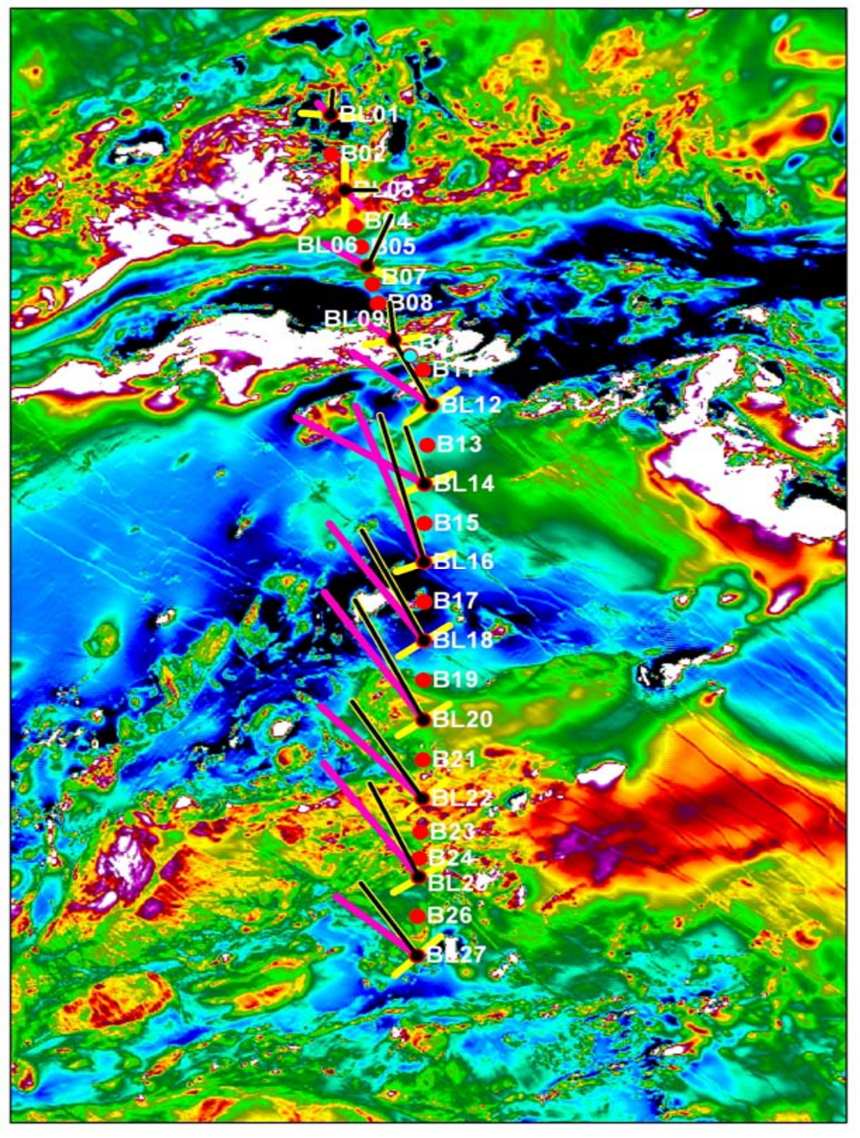
Phase Tensor Analysis

- Smaller ellipses represent higher resistivity and large ellipses represent lower resistivity
- The principal axes indicate the strike direction with 90 degree ambiguity

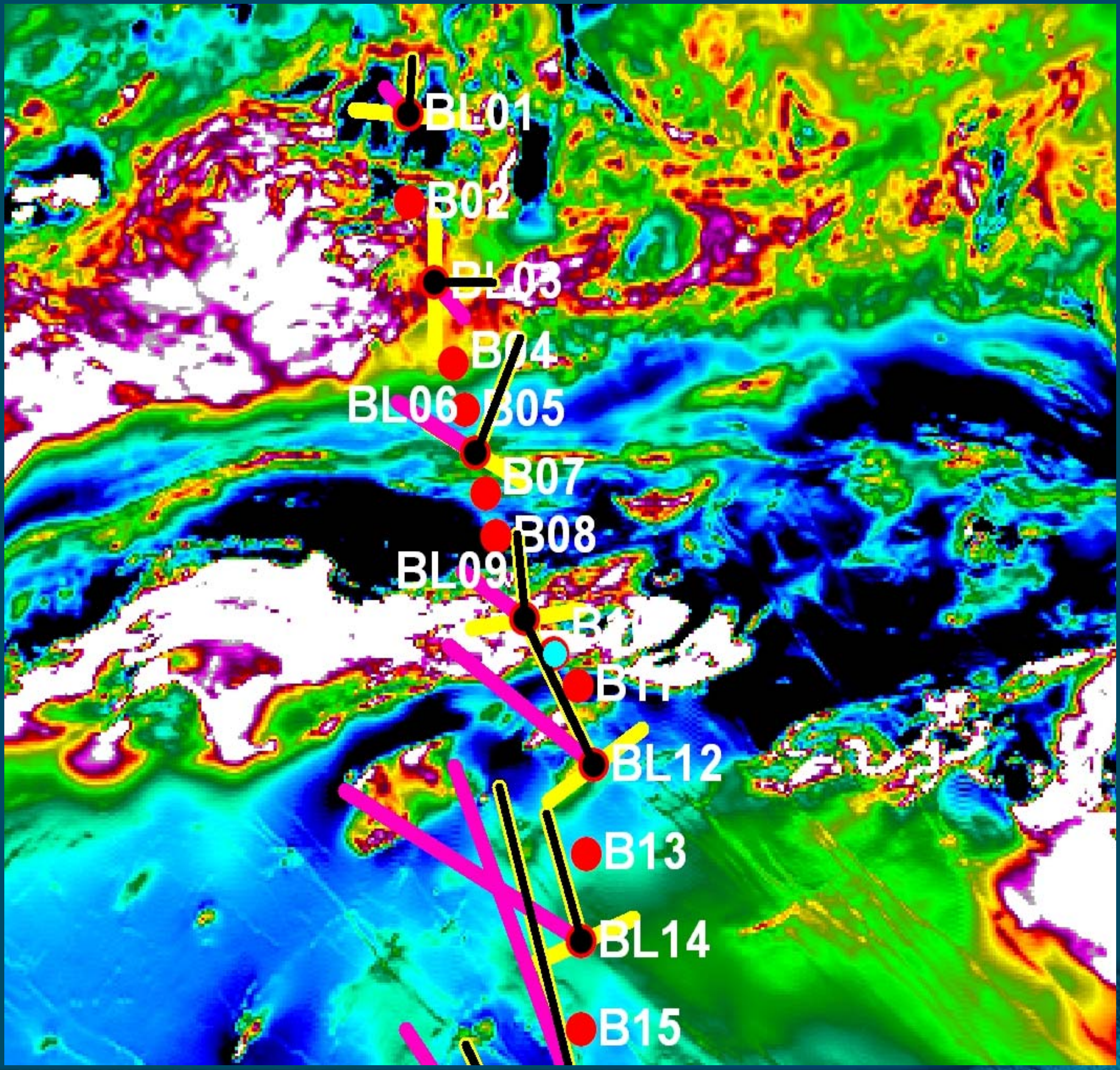


Induction Arrow

- Complex ratio of vertical to horizontal magnetic fields
- Induction arrows indicate surface electric current flow
- In Parkinson convention, induction arrow points toward conductive regions or away from high resistivity regions
- Induction arrow oriented perpendicular to the geoelectric strike



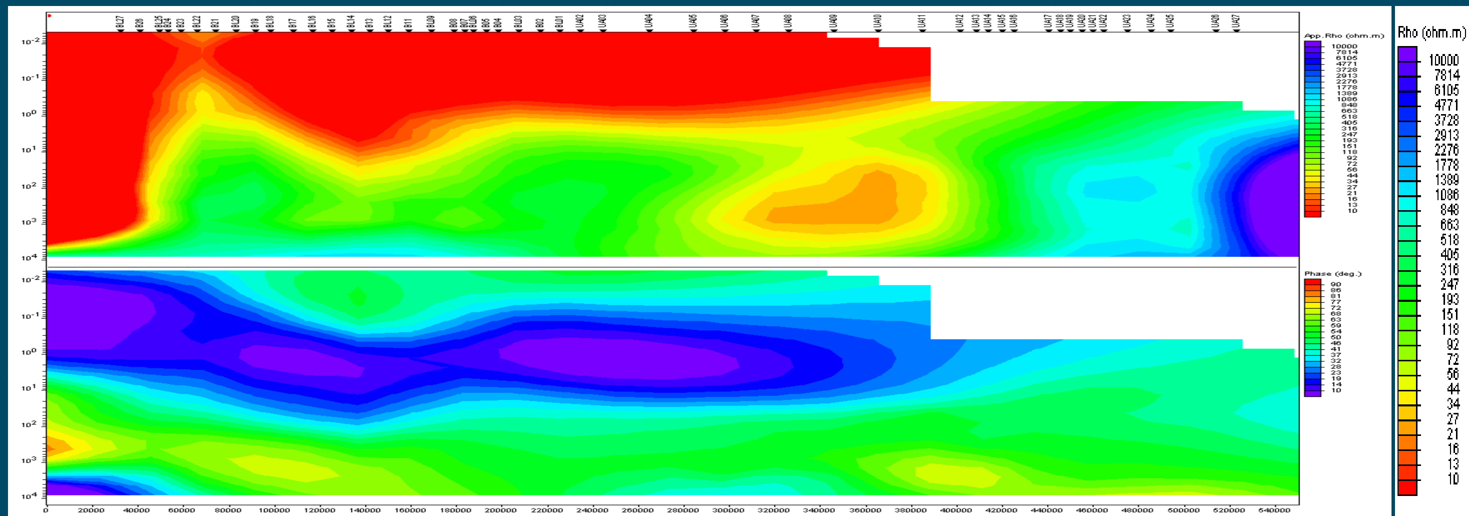
Induction Arrow



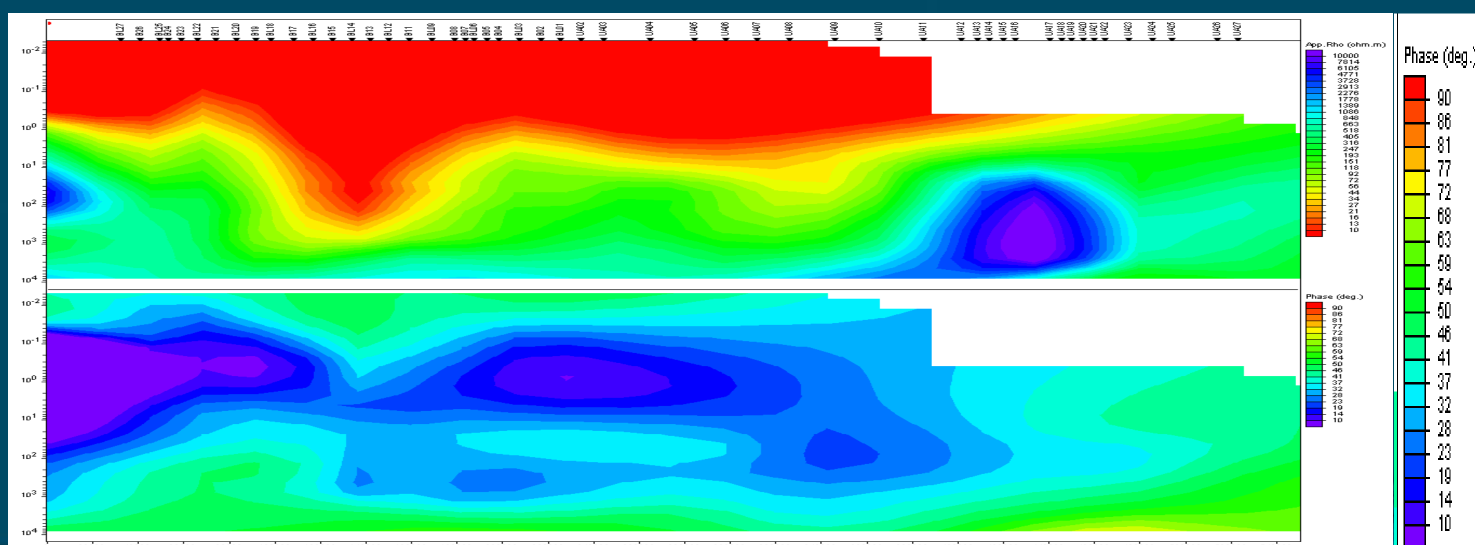
PseudoSection of Apparent Resistivity and Phase

South | Distance 550 km | North

TM mode



TE mode



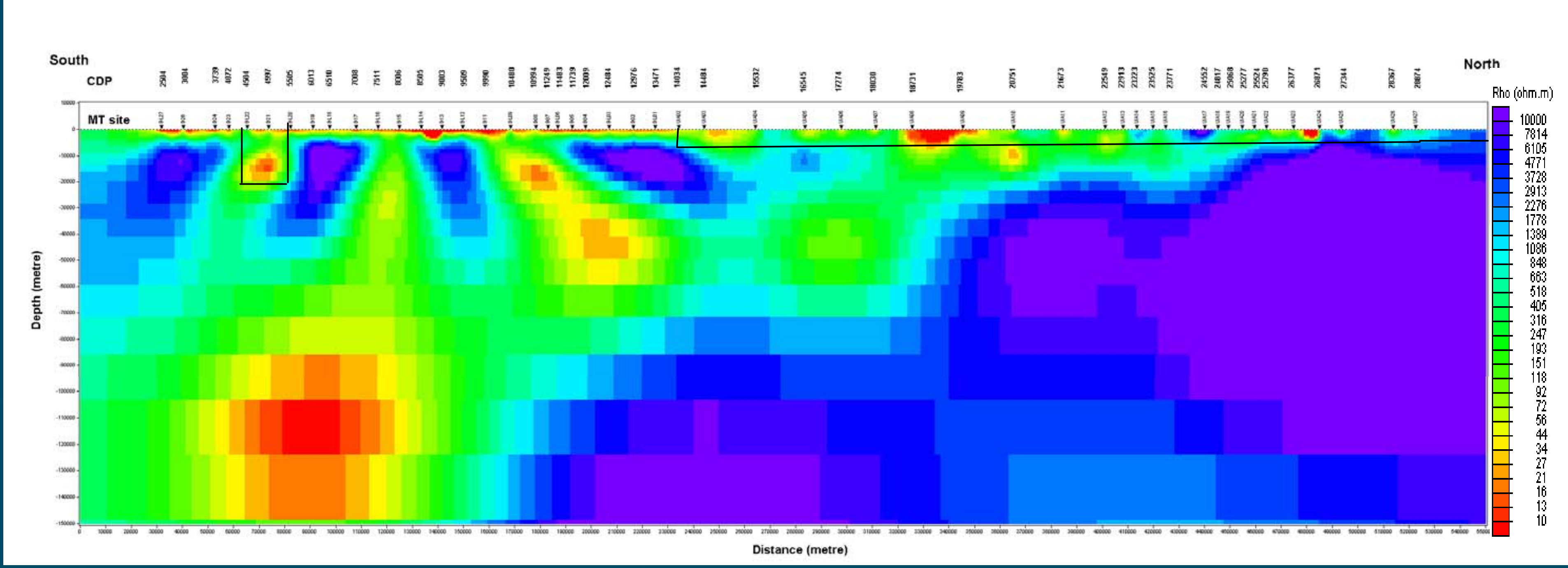
Inversion and Modelling

- 1D model carry out used different 1D codes
- A preliminary 2D model implemented by using the Non-Linear Conjugate Gradient (NLCG) algorithm of Rodie and Mackie (2001)
- Wide range of regularization parameters were tested for different 2D models
- Test robustness of the model (forward model, compare with other geophysics results)

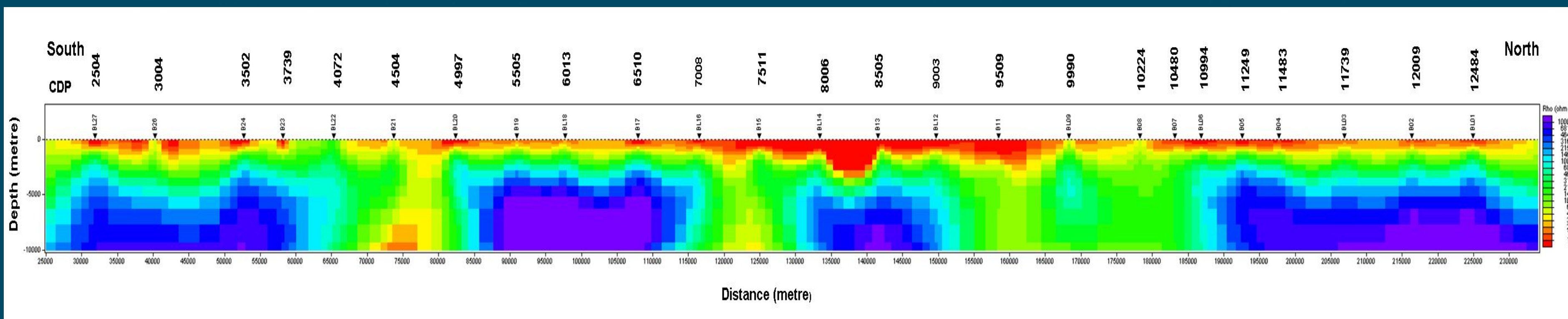
Inversion and Modelling

- Impossible to accurately estimate physical properties from a finite set of certain or uncertain data
- 2D MT inversion is non-linear, non-unique and unstable problem. If a solution can be found, then an infinite set of models may also be found.
- Regularization is generally required to find the better solution. Apply prior information, geological and geophysical.

Preliminary 2D model



Preliminary 2D model



Future work

- Apply geological and geophysical information to constrain the 2D model
- Better define the near surface anomalies
- Test different 2D inversion codes
- Test 3D inversion code
- Joint inversion with other geophysical method

Conclusion

- Broadband and long period MT data were acquired along 08GA-OM1seismic line
- Data presented and analysed as pseudosections, phase ellipses, induction arrows, etc
- A preliminary 2D model shows that near-surface conductive sediments are well-resolved, deeper conductive zones and geological structure have been suggested
- Further analysis and modelling is ongoing

Thank you !