Magnetotelluric data for exploration

Janelle Simpson | Geophysicist
Geological Survey of Queensland
Dep. of Natural Resources, Mines and Energy
E: janelle.simpson@dnrme.qld.gov.au

Geological Survey of Queensland
Celebrating 150 Years
Exploring Queensland's Resources

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Workshop overview

12:50 pm Introduction to MT

1:10 pm Overview of data release products

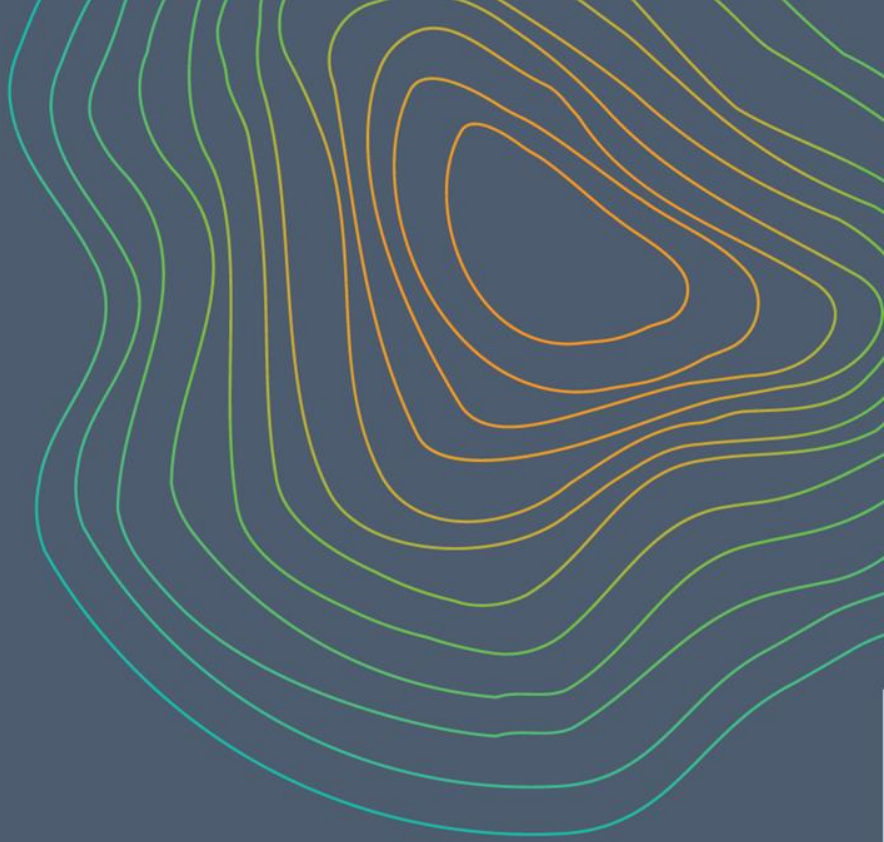
1:20 pm MT for targeting – exercise

1:50 pm Targeting discussion

2:00 pm General Q&A

- Sensitivity analysis

Introduction to MT



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Introduction to MT outline

- MT basics
- Regional survey design
- Examples
- MT limitations

What is MT?

Passive geophysical method

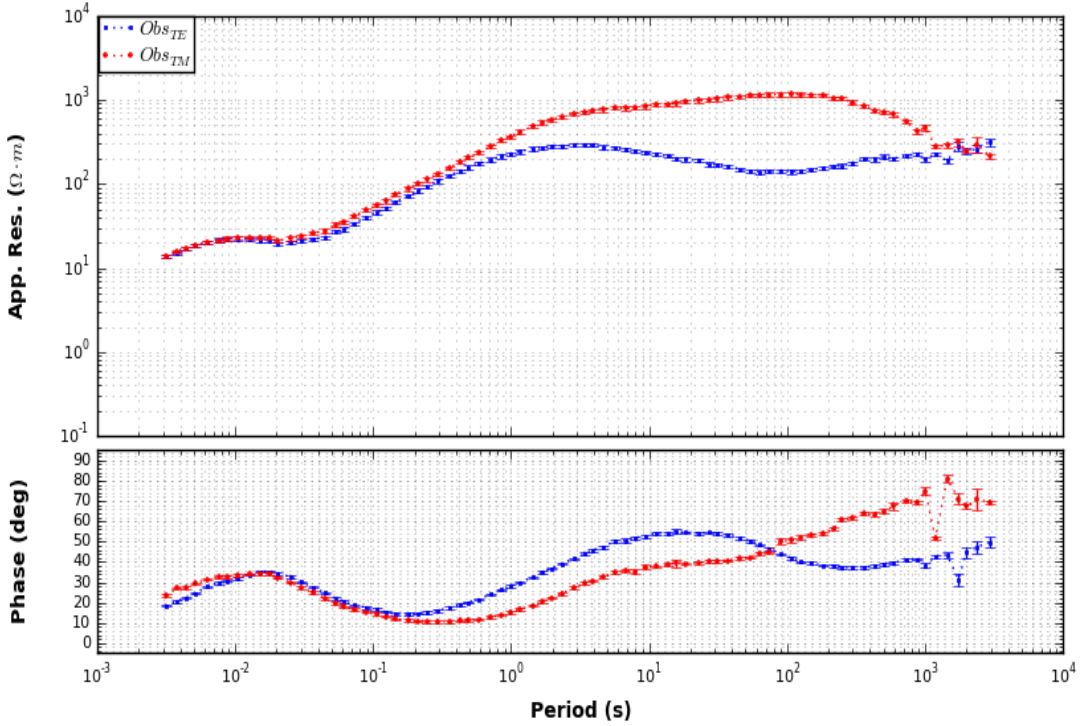
Characterisation of crustal resistivity

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

MT data

Electric field

Magnetic field



Note – High conductivity = low resistivity

Source field

High frequencies (>1 Hz)
= Spherics

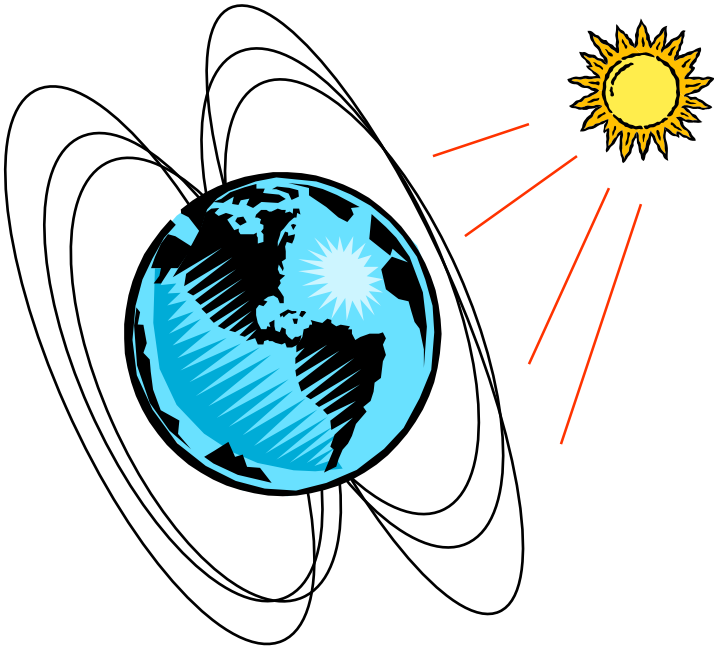
thunderstorm activity
world-wide

Low frequencies (<1 Hz)
= Micropulsations

Solar wind interacting w/
magnetic field

Vary on hourly, daily,
yearly cycles

High frequency = short period



Data types

Audiomagnetotelluric (AMT)

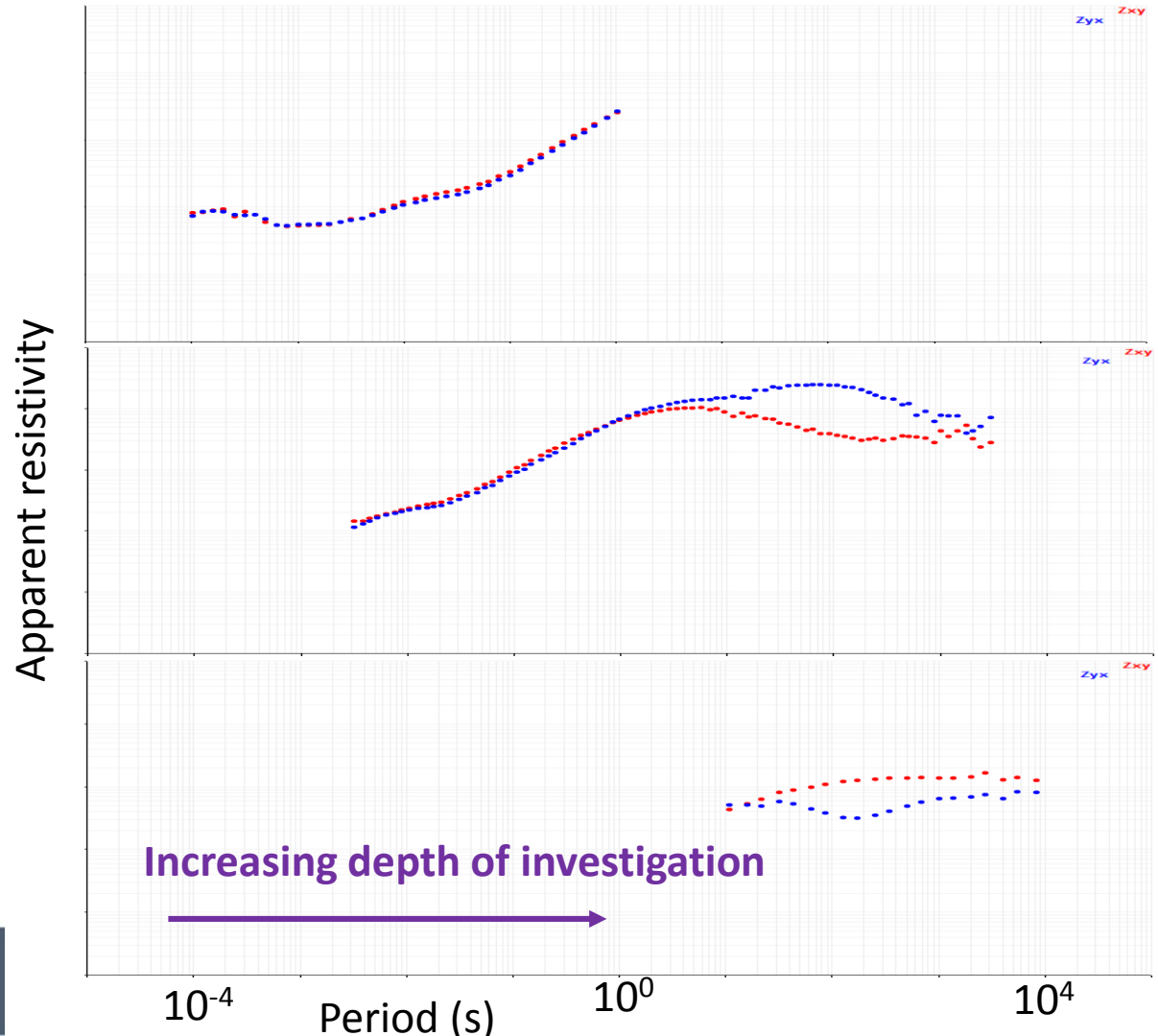
- 10^{-4} – 10^{0} s
- Record time 2 hrs

Broadband (BBMT)

- 10^{-2} – 10^{3} s
- Record time 16 hrs

Long Period MT

- Record time 3 weeks
- 10^{1} – 10^{4} s



Depth of investigation

Skin depth characterises effective depth of penetration for MT

Skin depth $\approx 503\sqrt{\rho T}$

ρ – resistivity (Ωm)
T – period (seconds)

<u>Conductive basin sediments reduce DOI</u>

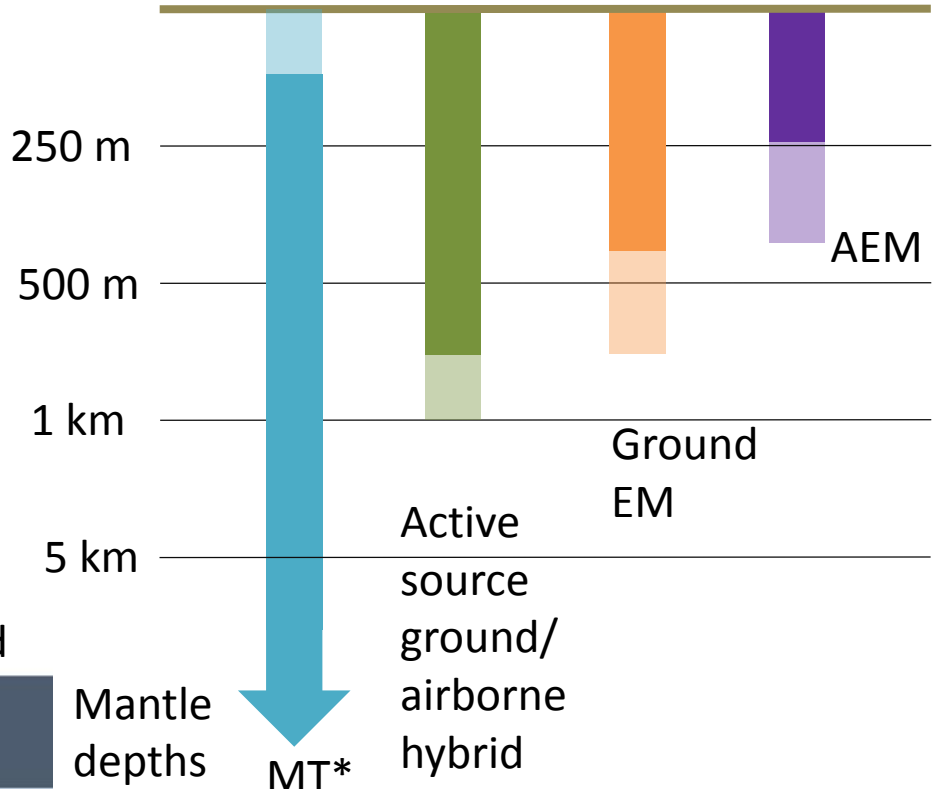
AMT
Approx. 50 m to 5 km

BBMT
Approx. 300 m to 150 km

Long Period
Approx. 15 km to 500 km

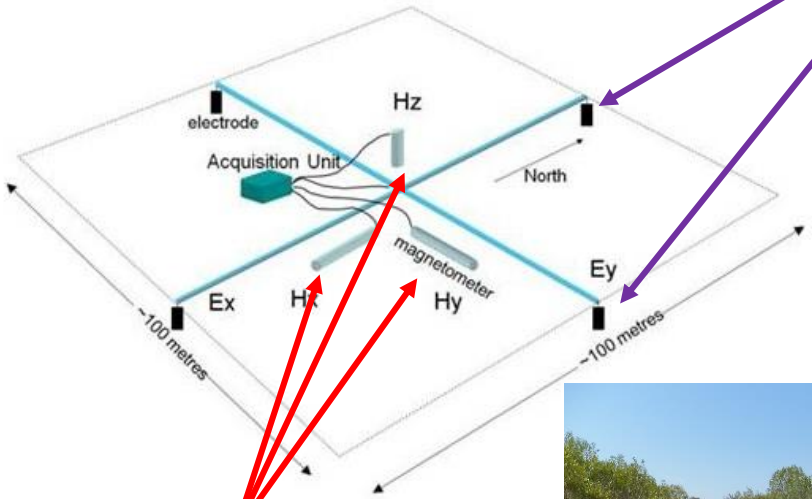
Depth of investigation

Where does MT sit in the electric methods toolkit?



* Dependent on frequencies acquired

Field setup



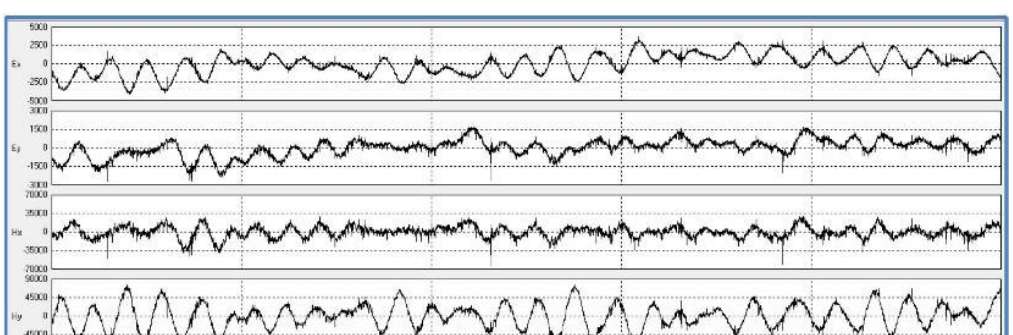
Electric field

Magnetic field

Data formats

Raw Data (time series)

- ascii
- proprietary



Processed Data

- .edi files
  - Spectra
  - Impedance

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CLIENT CO:Geoscience Australia
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 0.000000e+00  0.000000e+00
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-1.713725e+00 -1.748177e+00 -1.799323e+00 -1.620809e+00 -1.490893e+00 -1.587525
-1.492978e+00 -1.279888e+00 -1.394814e+00 -1.353692e+00 -1.168710e+00 -1.162154
-1.072702e+00 -1.140643e+00 -1.136824e+00 -1.170496e+00 -1.255756e+00 -1.347977
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-2.129100e+00 -2.265891e+00 -2.253600e+00 -2.275087e+00 -2.300035e+00 -2.211318
-2.109168e+00 -1.960465e+00 -1.800172e+00 -1.534238e+00 -1.654158e+00 -1.395742
-1.394662e+00 -1.307700e+00 -1.247171e+00 -1.077193e+00 -9.359311e-01 -7.835566
-6.629366e-01 -4.202279e-01 -3.699847e-01 -2.376280e-01 -8.872528e-02  1.391929
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-1.072550e-01  6.435659e-02
>ZXXI ROT=ZROT //80
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-9.868164e-01 -8.703715e-01 -8.051529e-01 -8.303933e-01 -7.216777e-01 -6.284543
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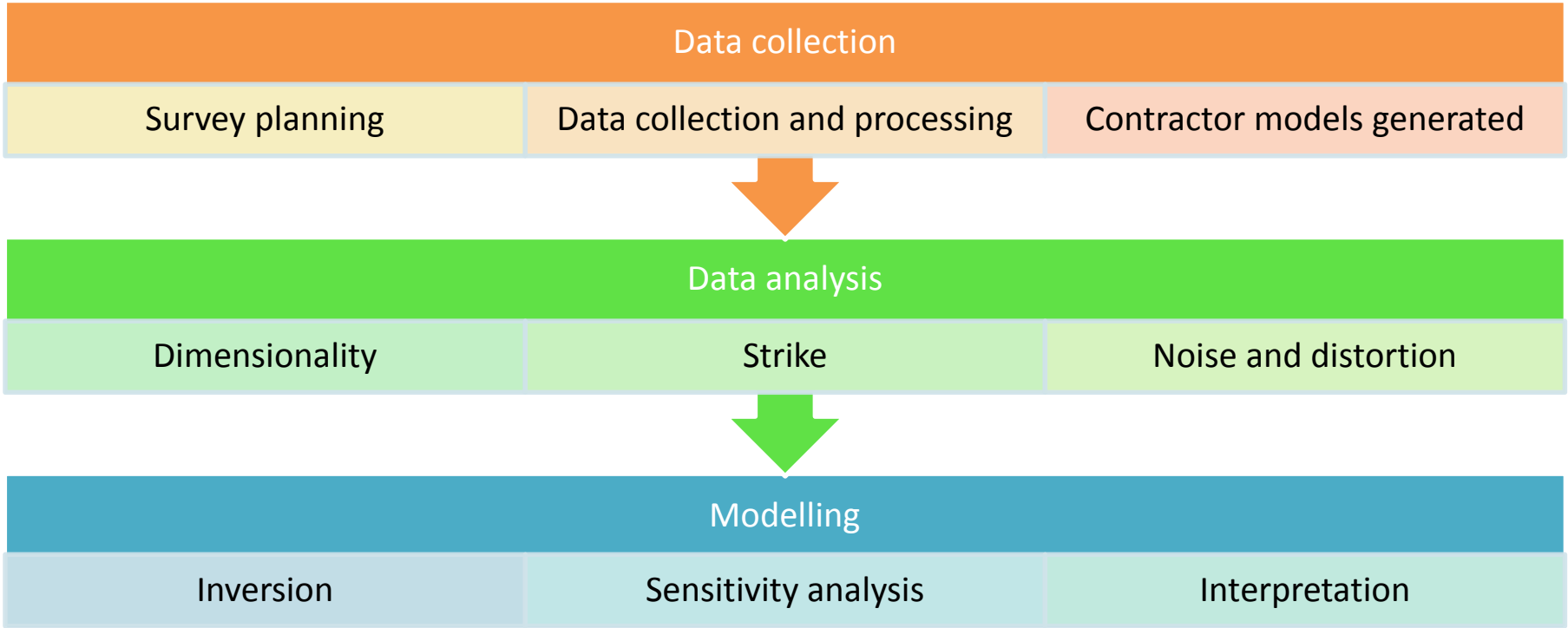
```

MT workflow overview



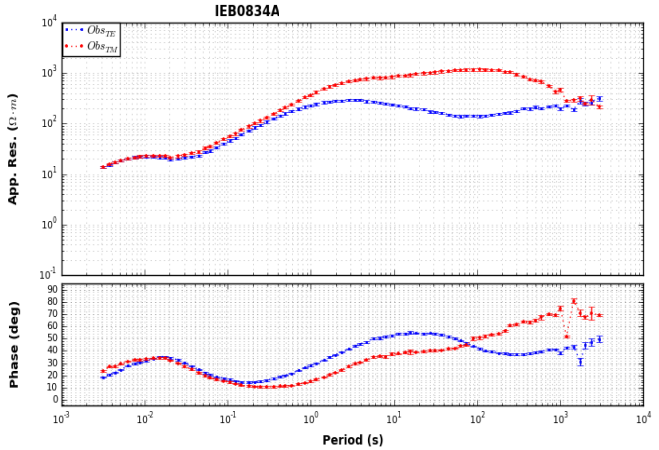
What is inversion?

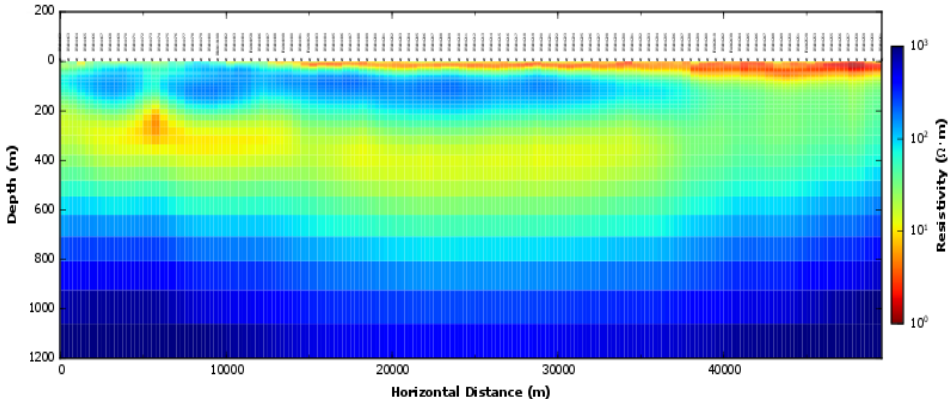
Inversion

Observed data → Resistivity model

Forward modelling

Resistivity model → Predicted data





Sources of conductivity

Composition

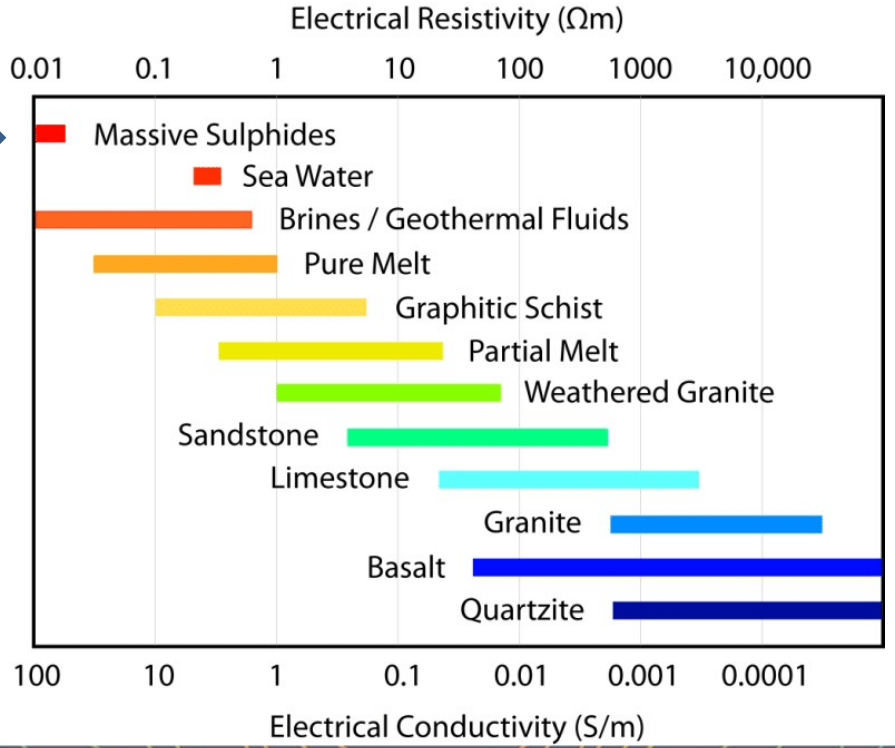
Temperature

Pressure

Fluids

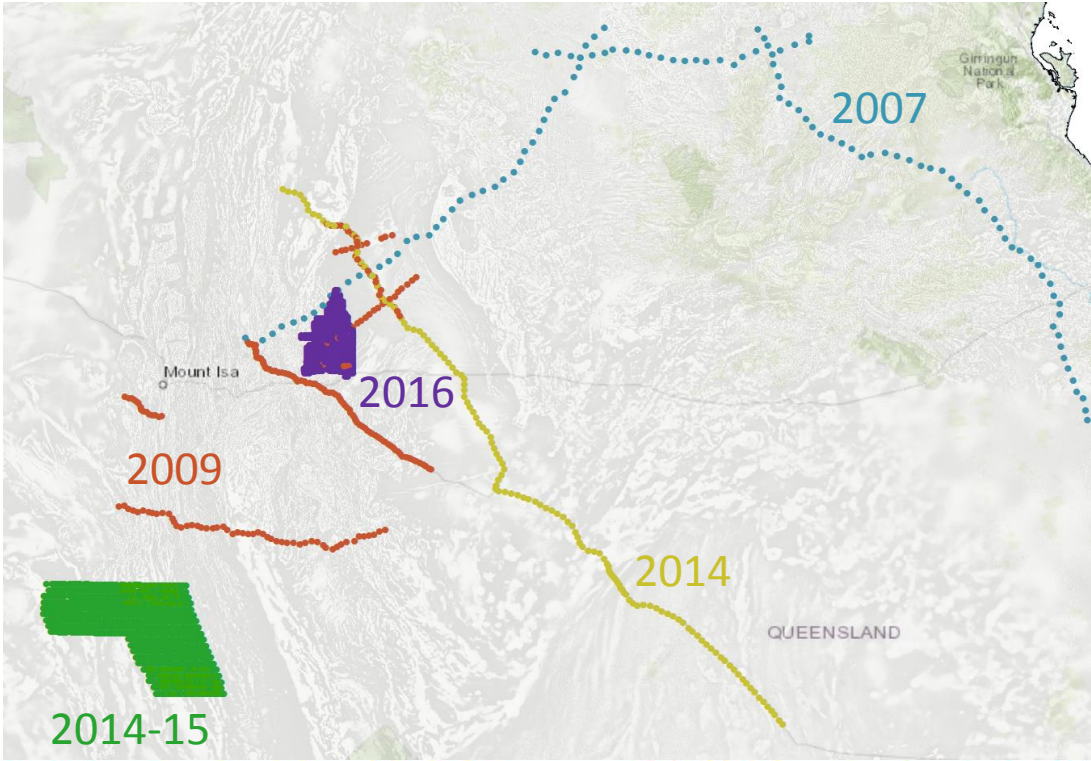
Hydrogen

Conductivity



Regional survey design

- 2-5 km station spacing
- BBMT / AMT
- Regional targeting

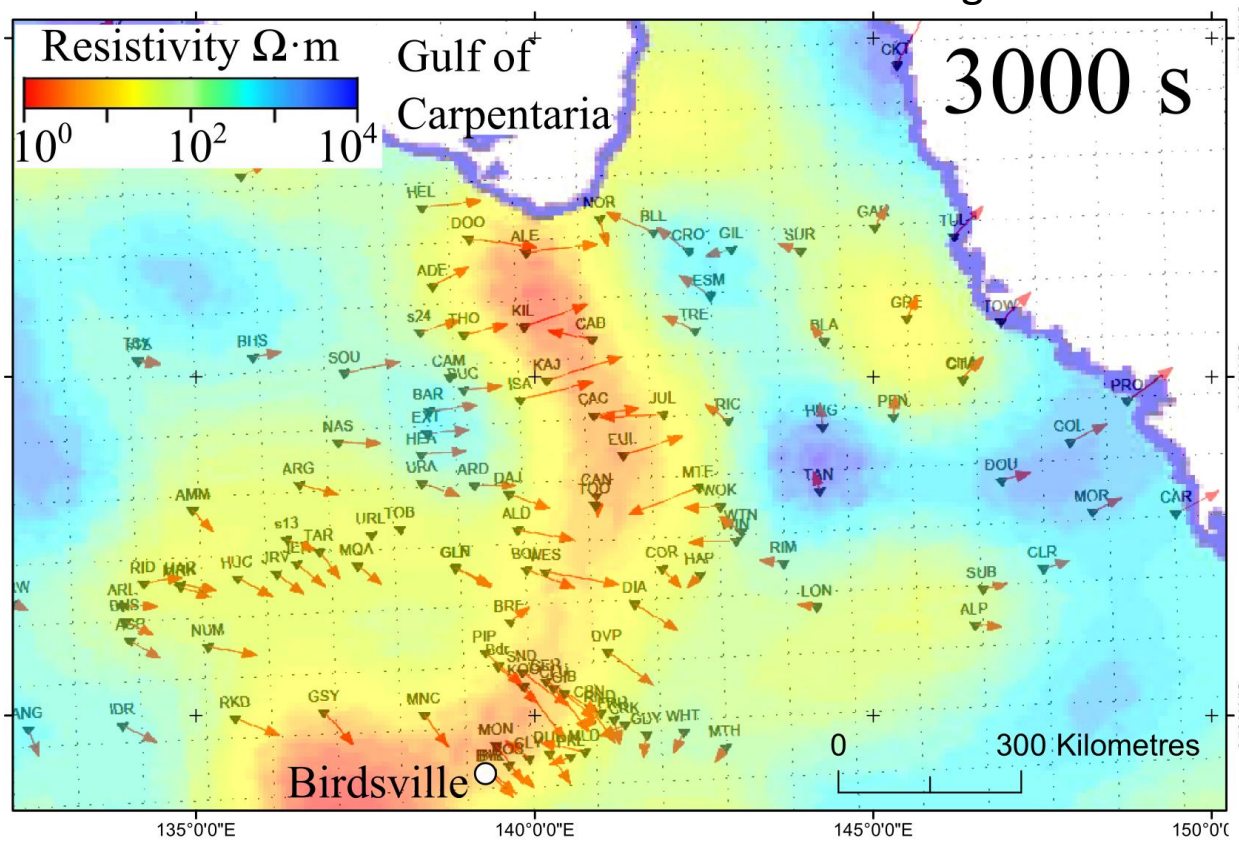


Long Period example

53 km depth slice

255 km spaced sites

Wang et al. 2014

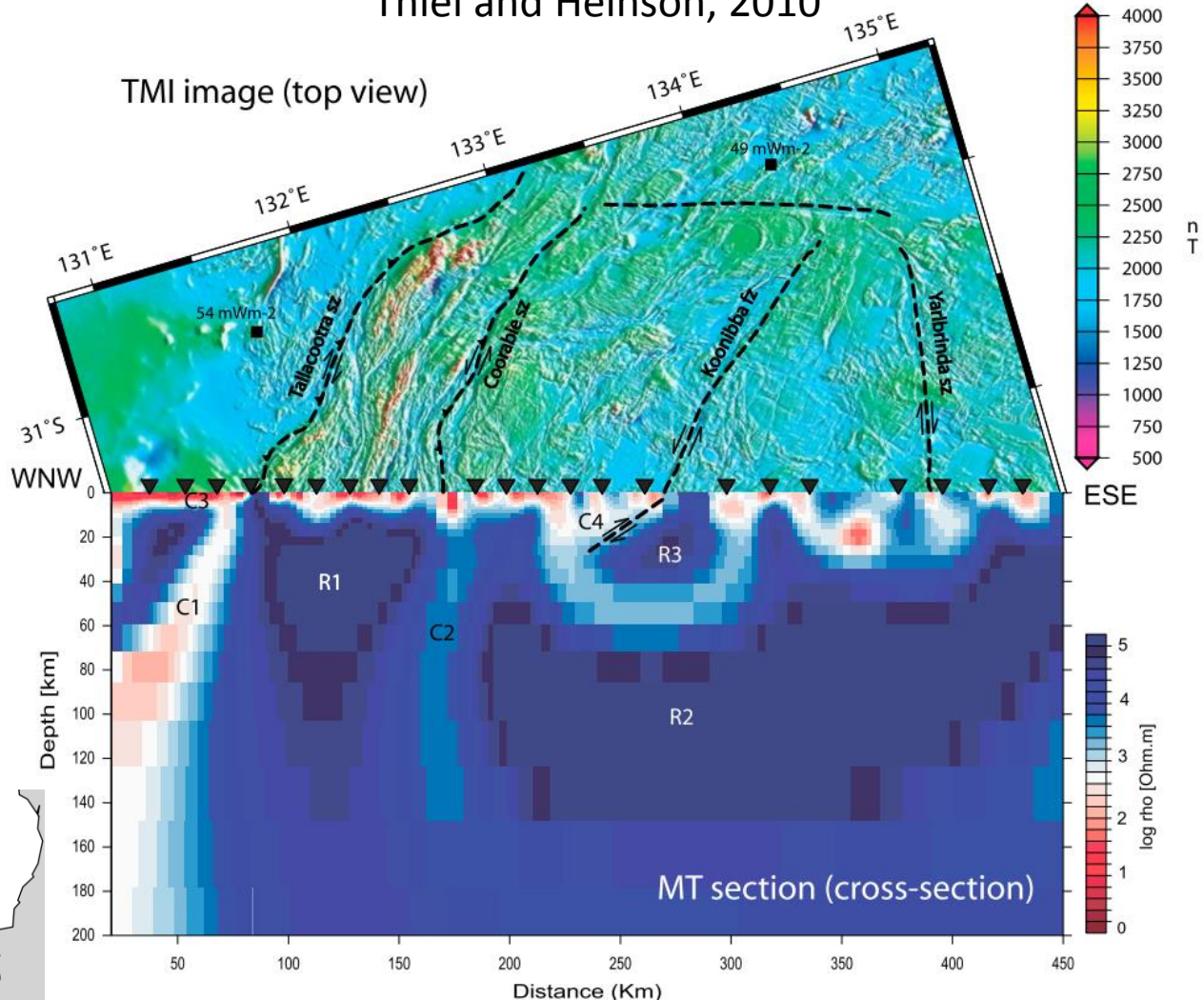


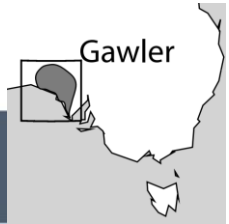
AusLAMP

Thiel and Heinson, 2010

~55 km spaced sites

Large crustal and upper mantle features

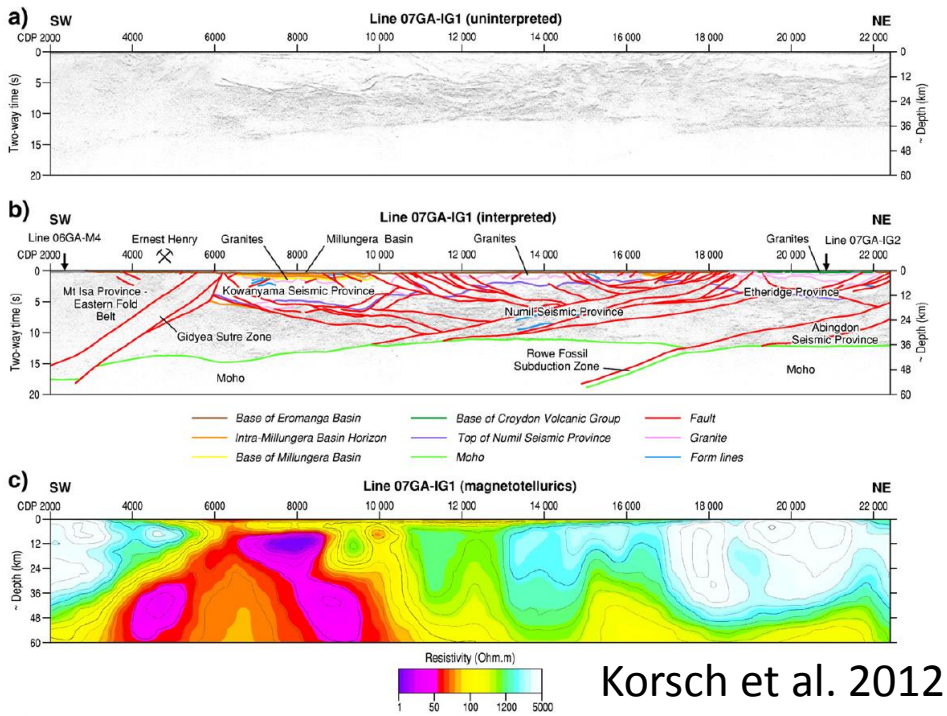




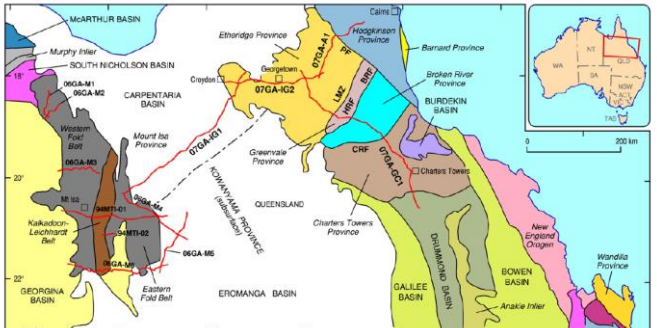
BBMT data

Crustal features

10 km station spacing



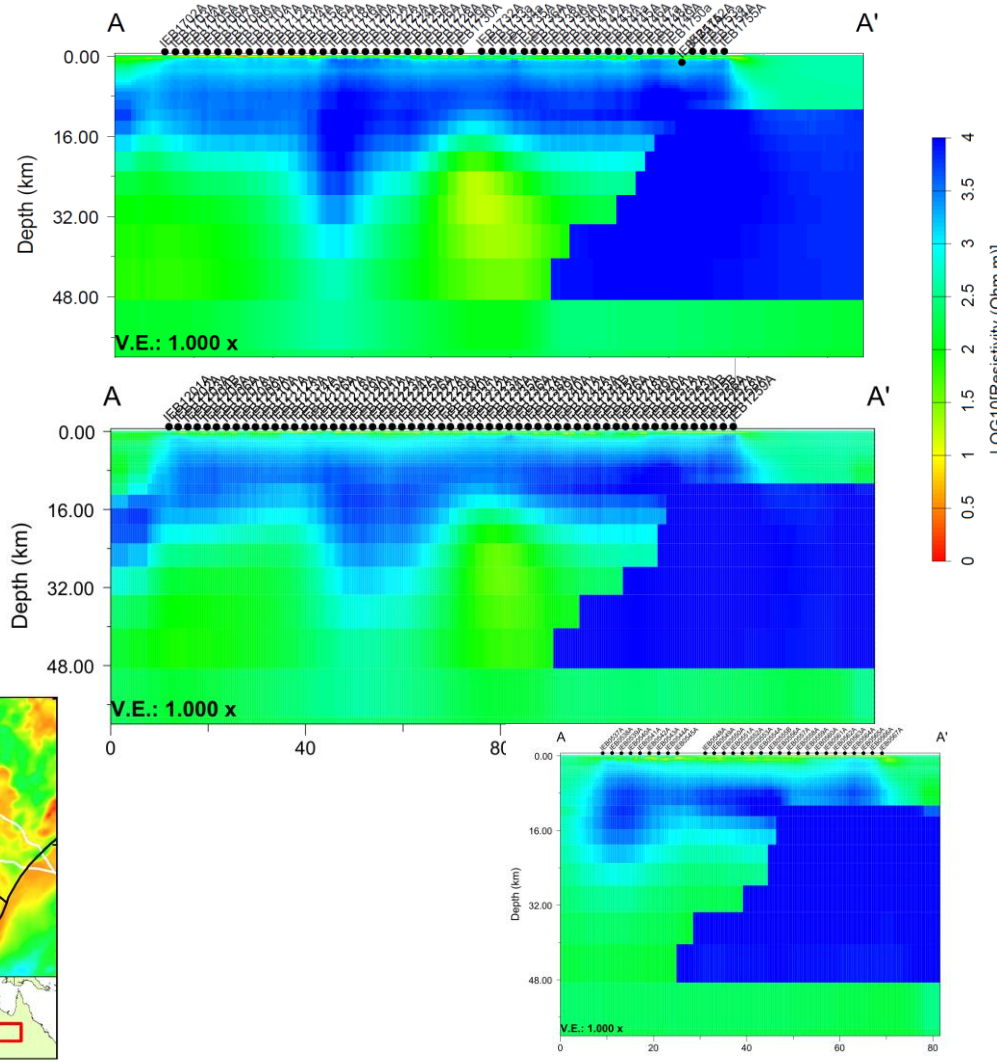
Korsch et al. 2012

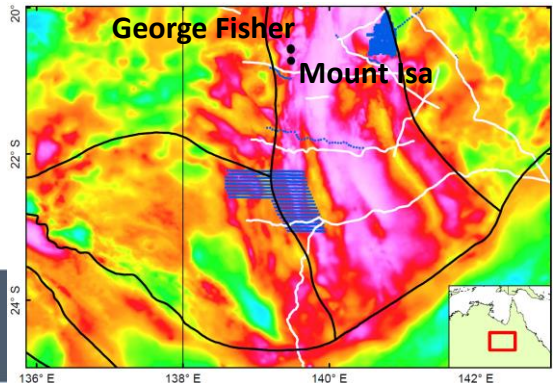


BBMT data

Crustal features

2 km station spacing

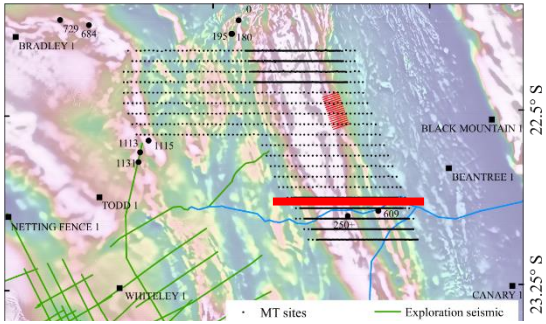


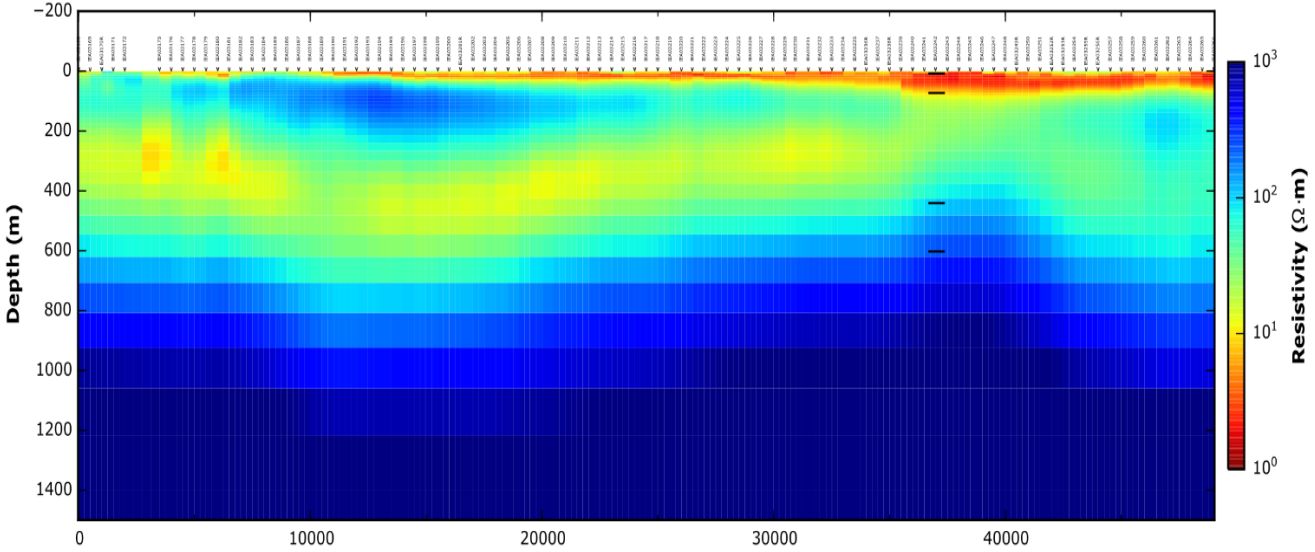


AMT data

Features to approx. 5 km

500 m station spacing

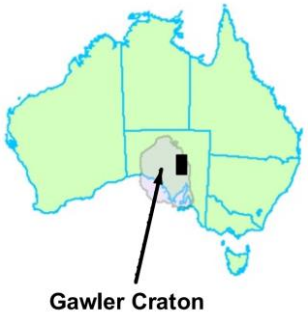


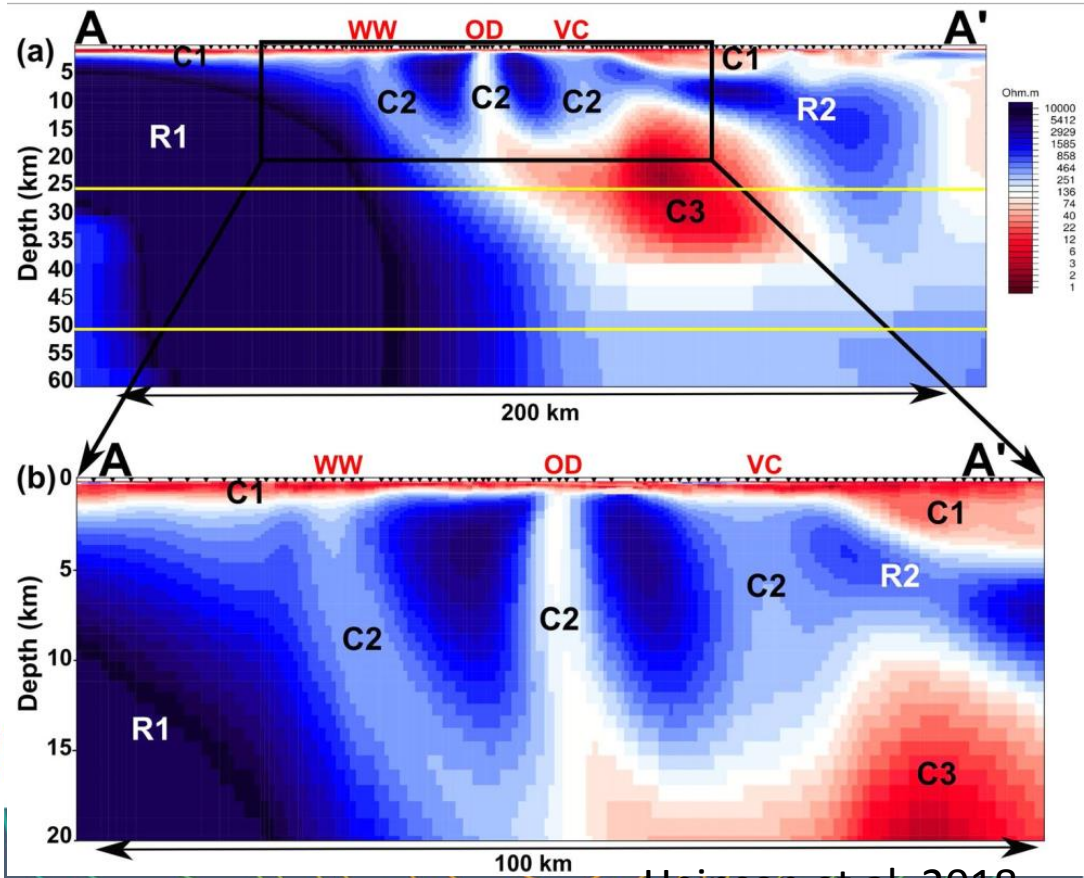


Relevance to exploration

- Conductivity anomalies associated with major deposits
- Profile data only

OD – Olympic Dam
WW – Wirrda Well
VC – Vulcan

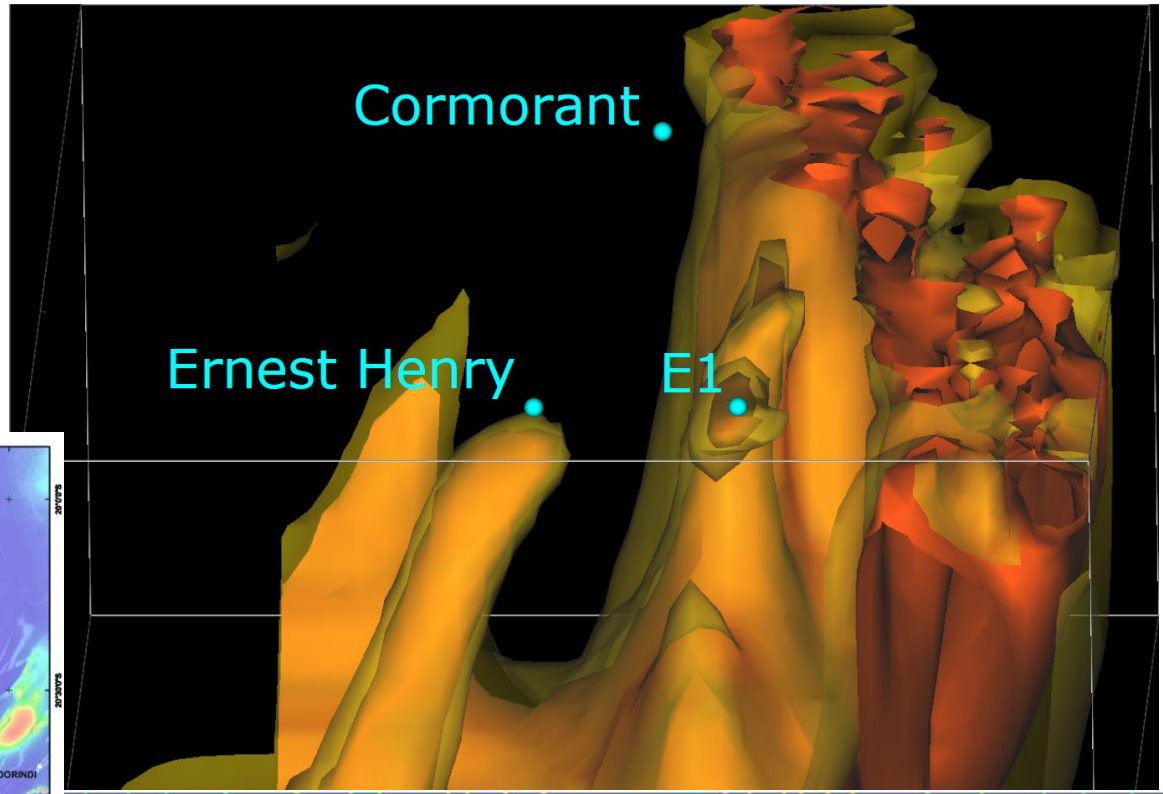


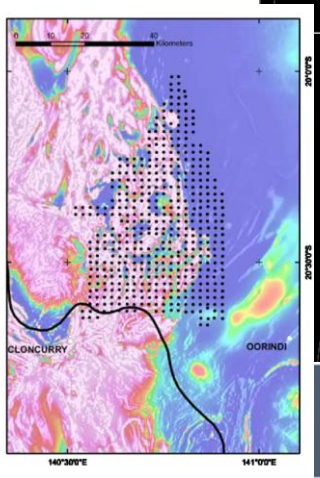


Heinson et al. 2018

Relevance to exploration

- Conductivity anomalies associated with major deposits
- First example with a grid survey





Wang et al. 2018

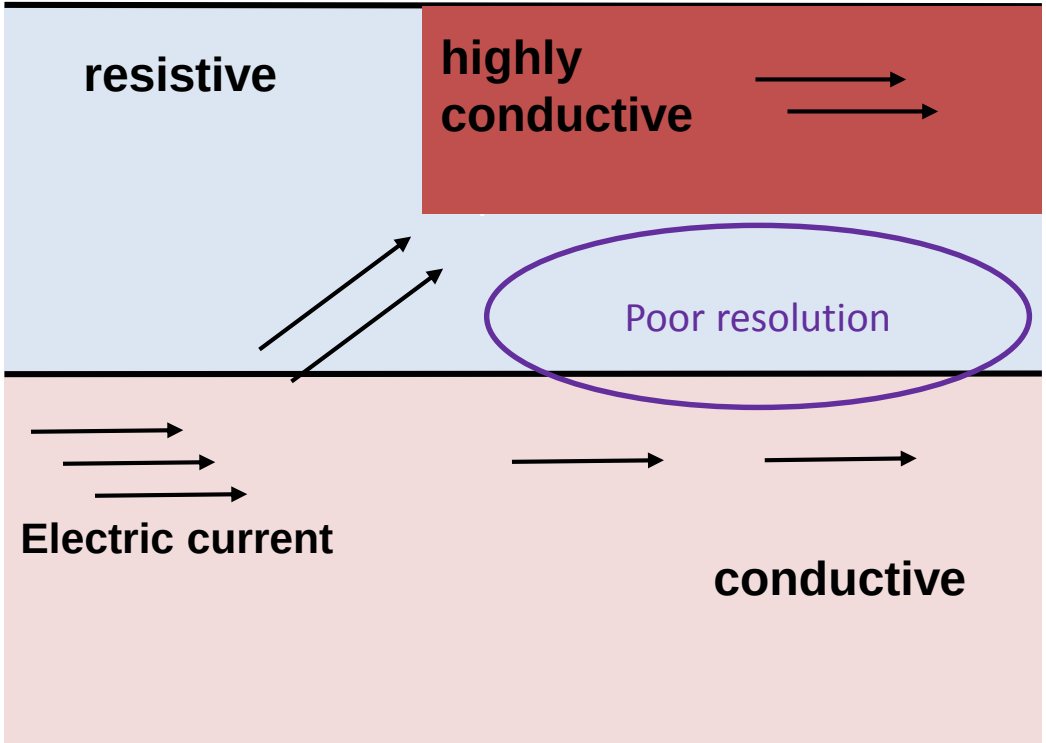
Introduction to MT outline

- MT basics
- Regional survey design
- Examples
- Limitations

MT limitations - vertical current gathering

Current flows through conductive bodies

Areas beneath conductors have low current density



MT limitations - vertical current gathering

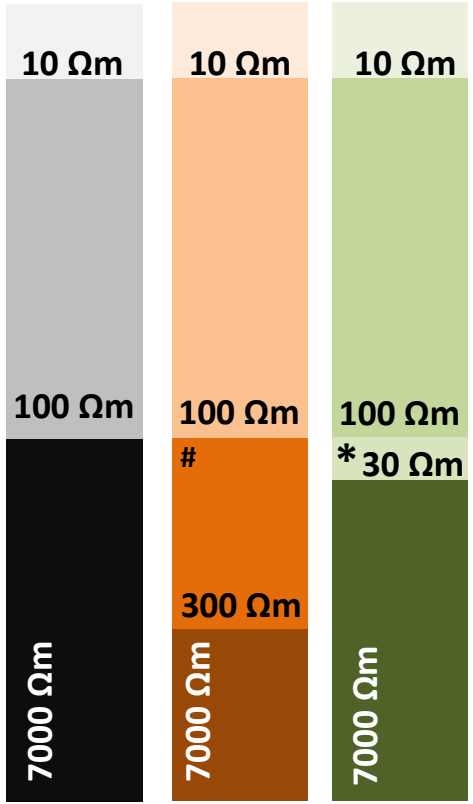
3 models:

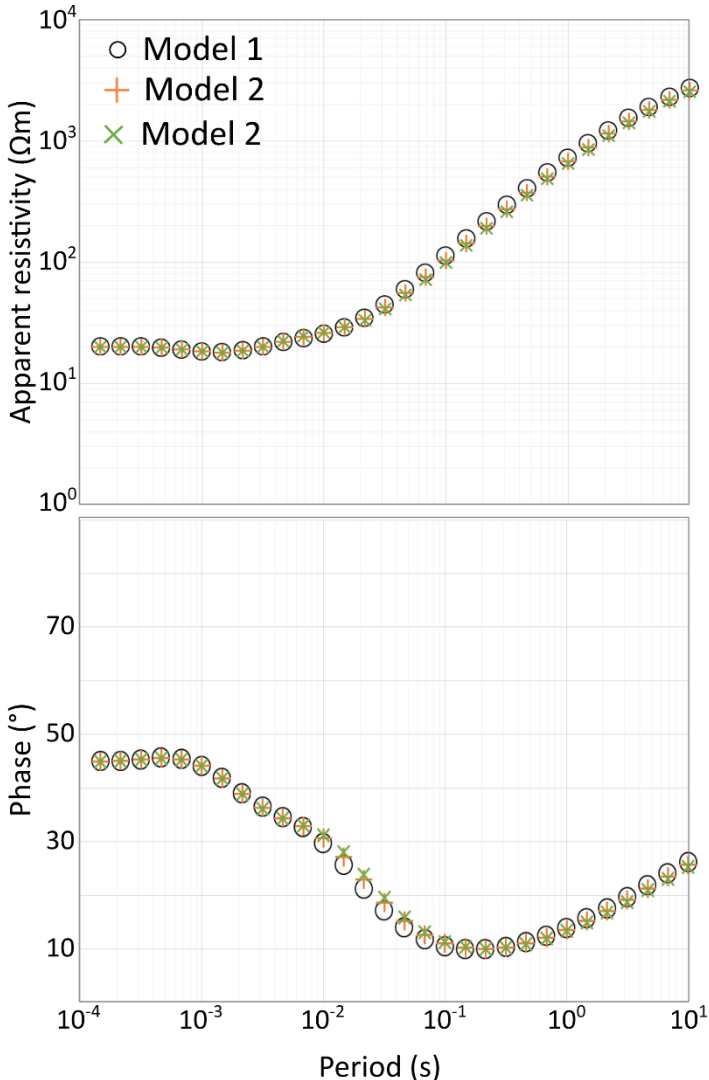
Same 2 surface layers

\# Additional basin units

* Potential exploration target

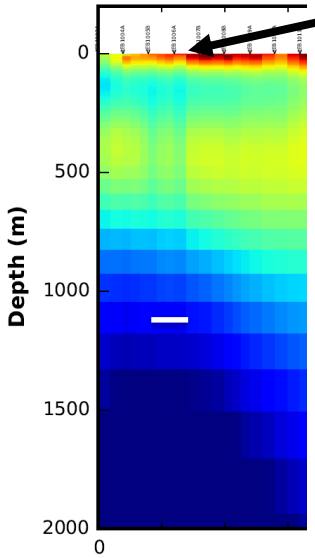
Calculated MT responses almost identical

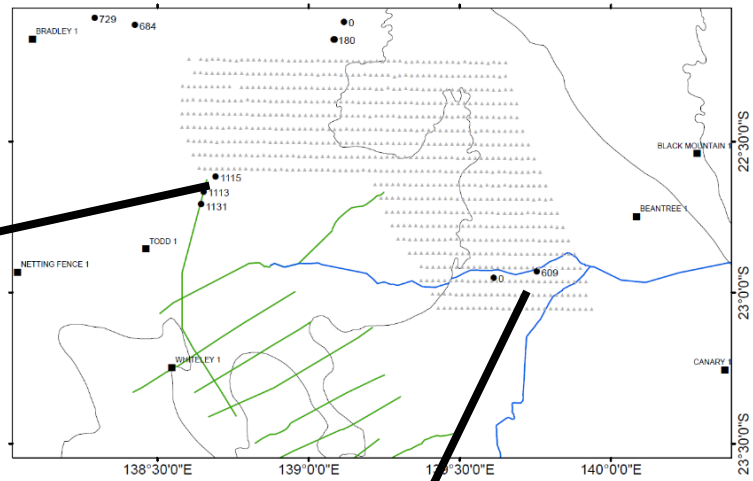


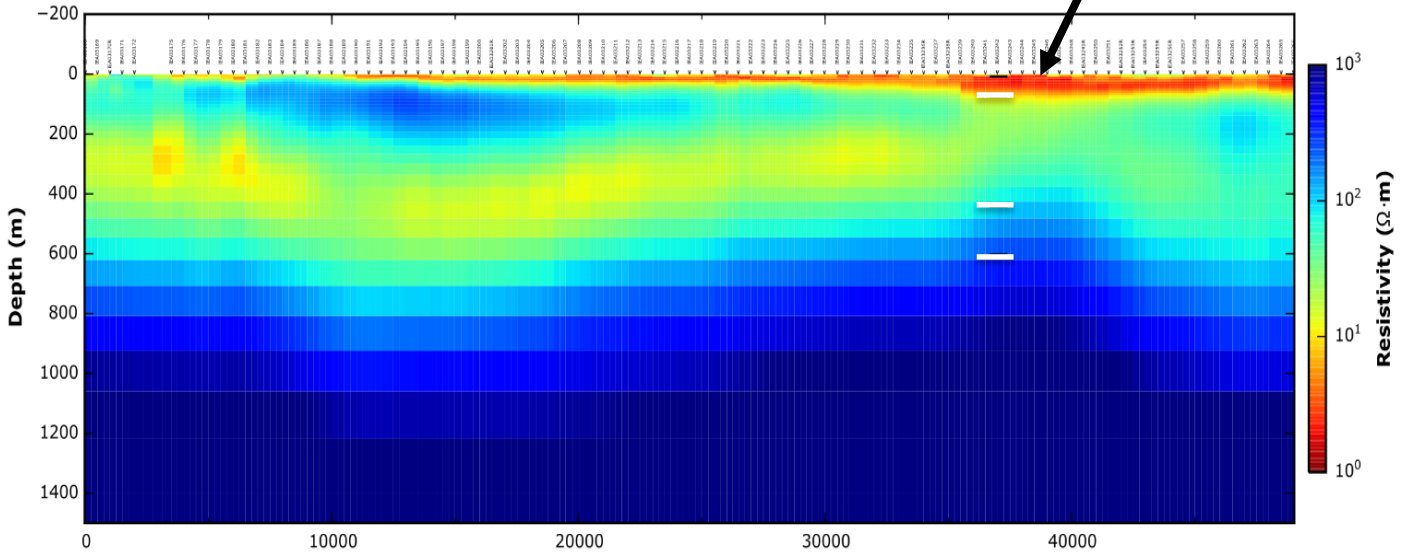


MT limitations - vertical current gathering

Comparison to drilling

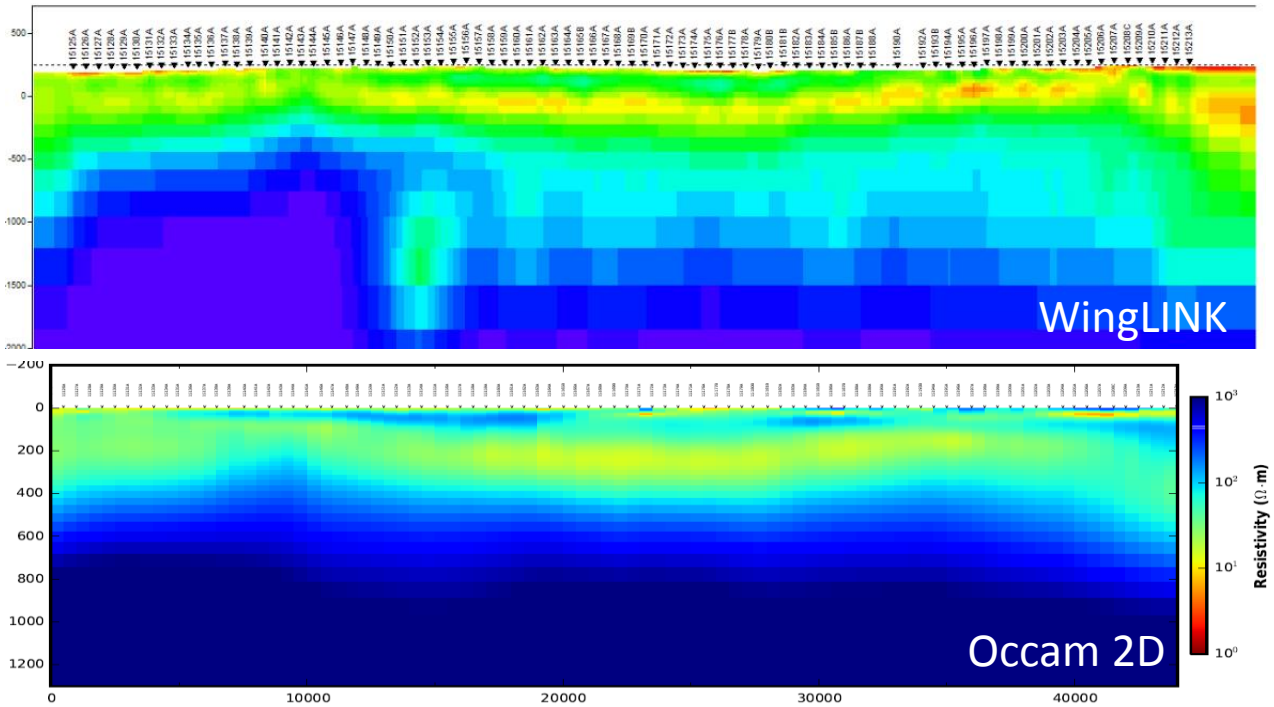






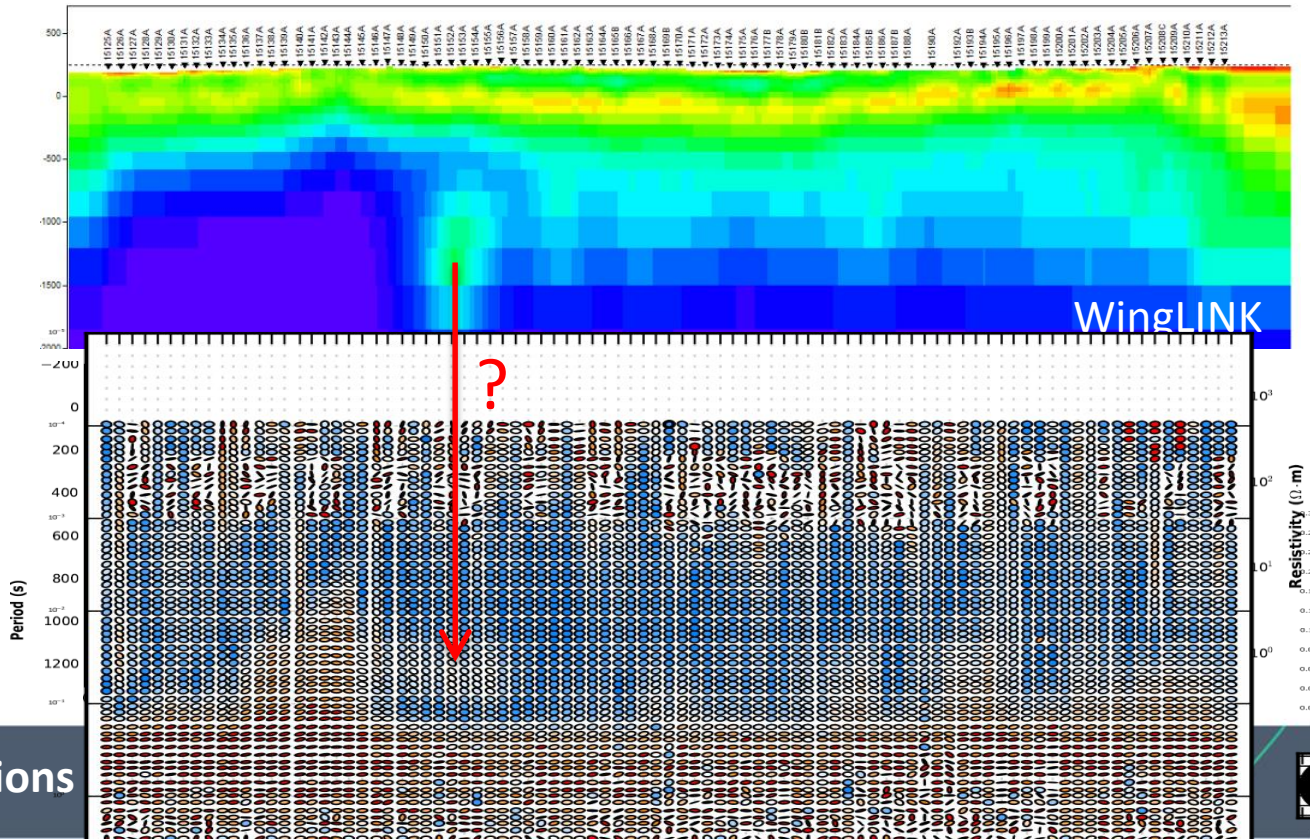
MT limitations – Non-uniqueness

- Models from the same data
  - Different code
  - Different parameters



MT limitations – Non-uniqueness

- Is anomaly visible in data?



Take home messages

- MT data provide information about crustal resistivity at a variety of depths
- Regional MT surveys are designed to help target exploration rather than drilling
- Inversion is used to generate resistivity / depth models for interpretation
- Non-uniqueness and target resolvability can have significant impacts on interpretation

References

Wang, L., Duan, J, Simpson J., 2018. Electrical Conductivity Structures from Magnetotelluric Data in Cloncurry Region. Record 2018/05. Geoscience Australia, Canberra.

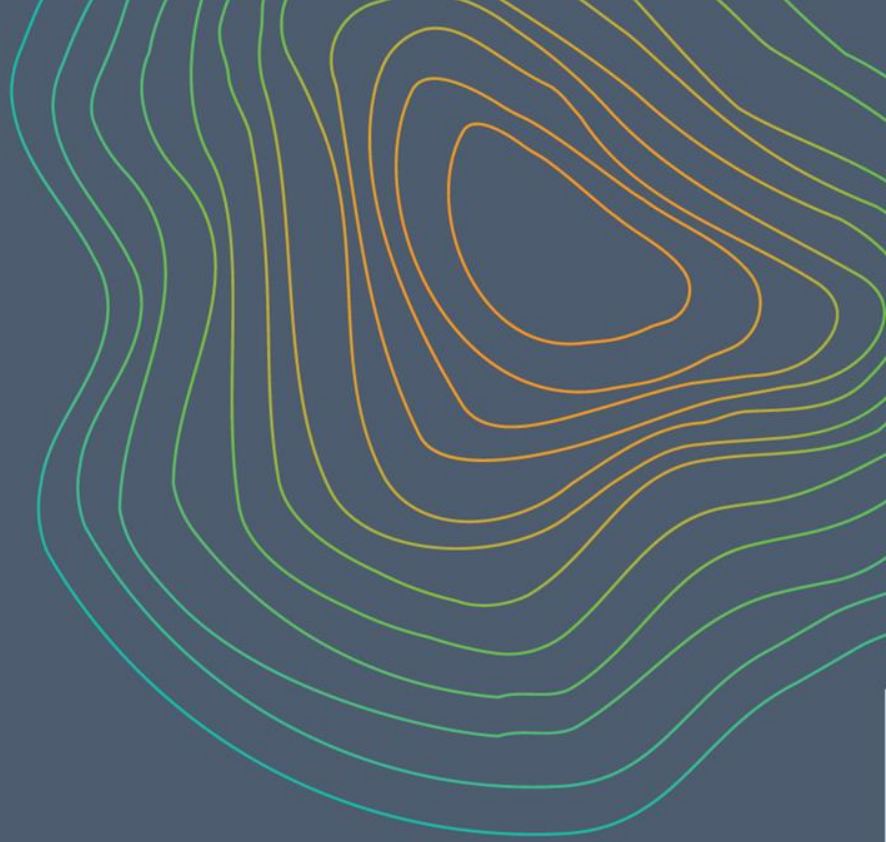
Heinson, G., Didana, Y., Soeffky, P., Thiel, S., Wise, T., 2018. The crustal geophysical signature of a world-class magmatic mineral system. Sci. Rep. 8. https://doi.org/10.1038/s41598-018-29016-2

Korsch, R.J., Huston, D.L., Henderson, R.A., Blewett, R.S., Withnall, I.W., Fergusson, C.L., Collins, W.J., Saygin, E., Kositcin, N., Meixner, A.J., Chopping, R., Henson, P.A., Champion, D.C., Hutton, L.J., Wormald, R., Holzschuh, J., Costelloe, R.D., 2012. Crustal architecture and geodynamics of North Queensland, Australia: insights from deep seismic reflection profiling. Tectonophysics 572–573, 76–99. https://doi.org/10.1016/j.tecto.2012.02.022

Thiel, S., Heinson, G., 2010. Crustal imaging of a mobile belt using magnetotellurics: an example of the Fowler Domain in South Australia. J. Geophys. Res. 115. https://doi.org/10.1029/2009JB006698

Wang, L., Hitchman, A.P., Ogawa, Y., Siripunvaraporn, W., Ichiki, M., Fuji-ta, K., 2014. A 3-D conductivity model of the Australian continent using observatory and magnetometer array data. Geophys. J. Int. 198, 1171–1186. https://doi.org/10.1093/gji/ggu188

Magnetotelluric data release products



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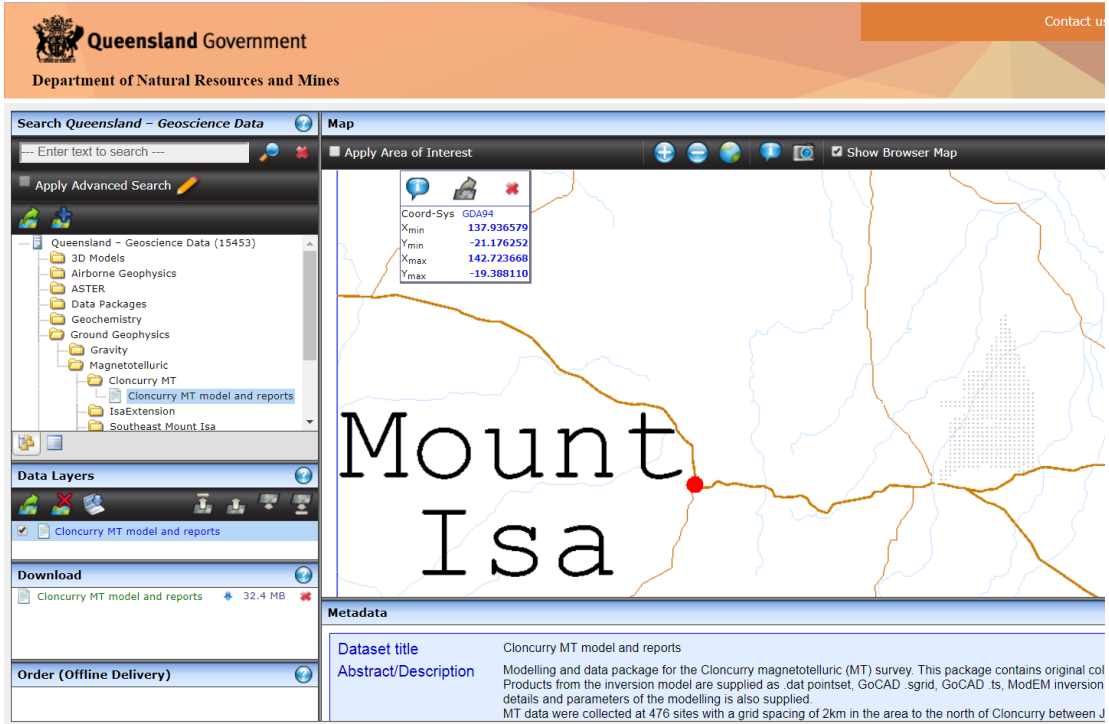
http://qdexdata.dnrm.qld.gov.au/flamingo/

Cloncurry MT dataset

Initial release

- .edi files
- Acquisition reports
- Contractor models (if available)
- Times series data (offline delivery)

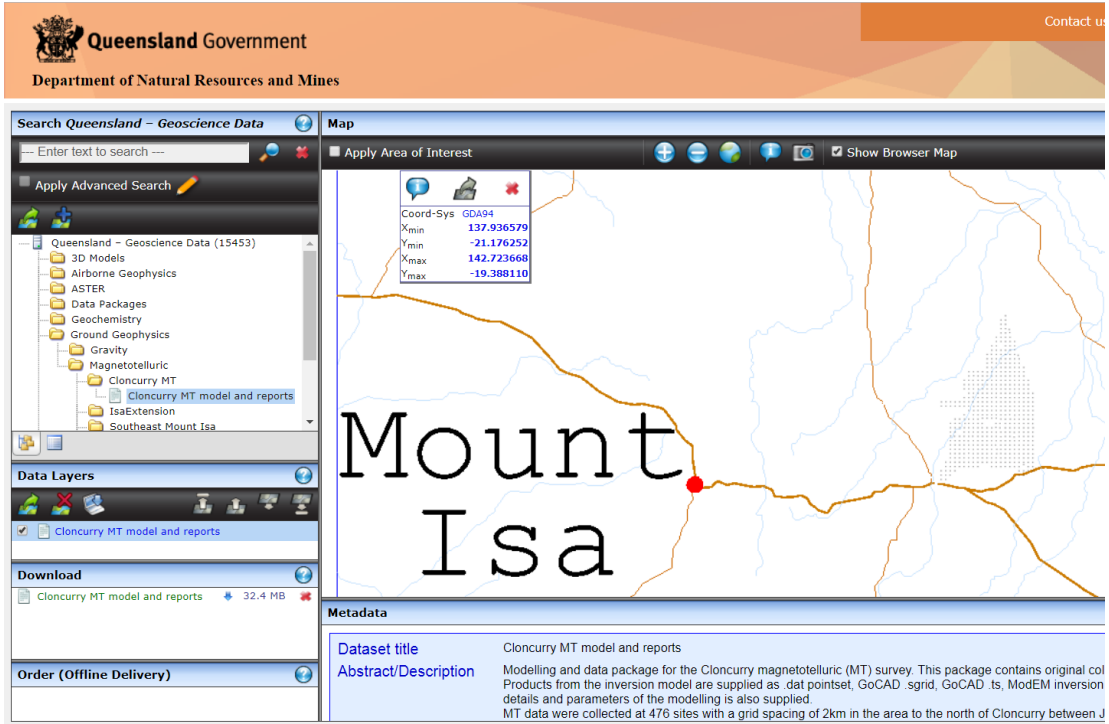


http://qdexdata.dnrm.qld.gov.au/flamingo/

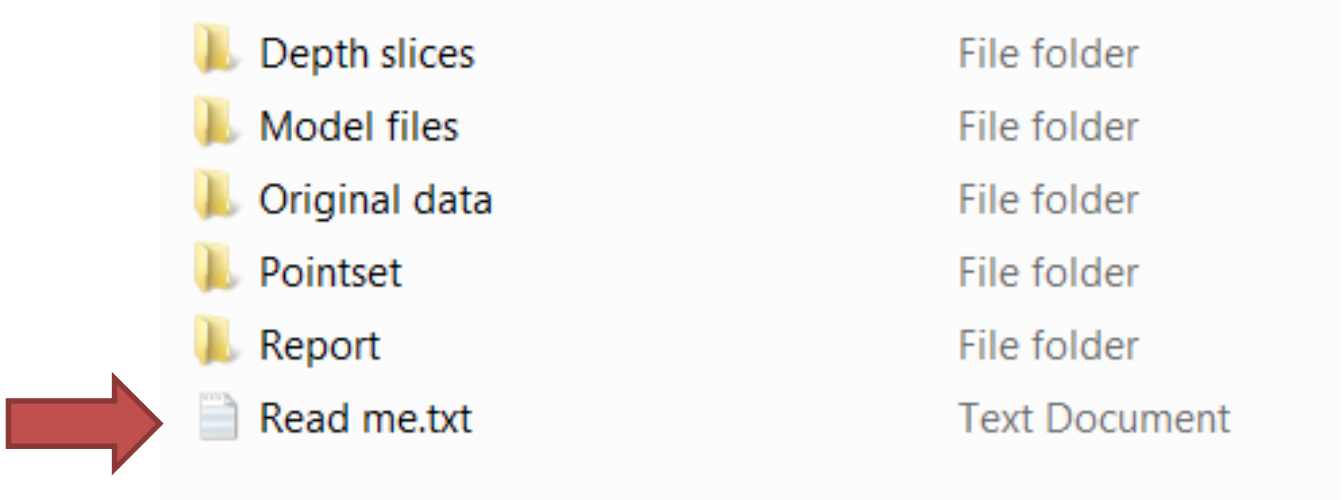
Cloncurry MT dataset

Second data release

- Modelling results
- Modelling report



Cloncurry MT dataset



Cloncurry MT dataset

Readme contains:

- Folder contents
- File formats
- Suggested software (if applicable)
- Contact details
- Information about product generation

```
This package contains a variety files for the Cloncurry MT model.
All products are derived from the Isa_100hz_z_run4_NLCG_051.rho contained in the model folder.
Data package produced by Geological Survey of Queensland
For more information email geophysics@dnrme.qld.gov.au


Folder - Depth Slices
Contents - Georegistered depth slices from 3D resistivity model.
       Colourscale from 1 Ohm.m to 1000 Ohm.m (red-blue)
File formats - .tif
Suggested software - ArcMap, MapInfo


Folder - Model files
Contents - ModEM folder containing inversion files in ModEM format
         - GoCAD folder containing SGrid and selected isosurfaces
File formats - .rho .res and .dat; .sg .ts
Suggested software - 3D Grid, MT-py; Geoscience Analyst, GoCAD


Folder - Pointset
Contents - x,y,z,resistivity file generated from the inversion model.
        All points are centre cell located in x, y and z directions.
File formats - .dat file


Folder - Report
Contents - Report on inversion modelling

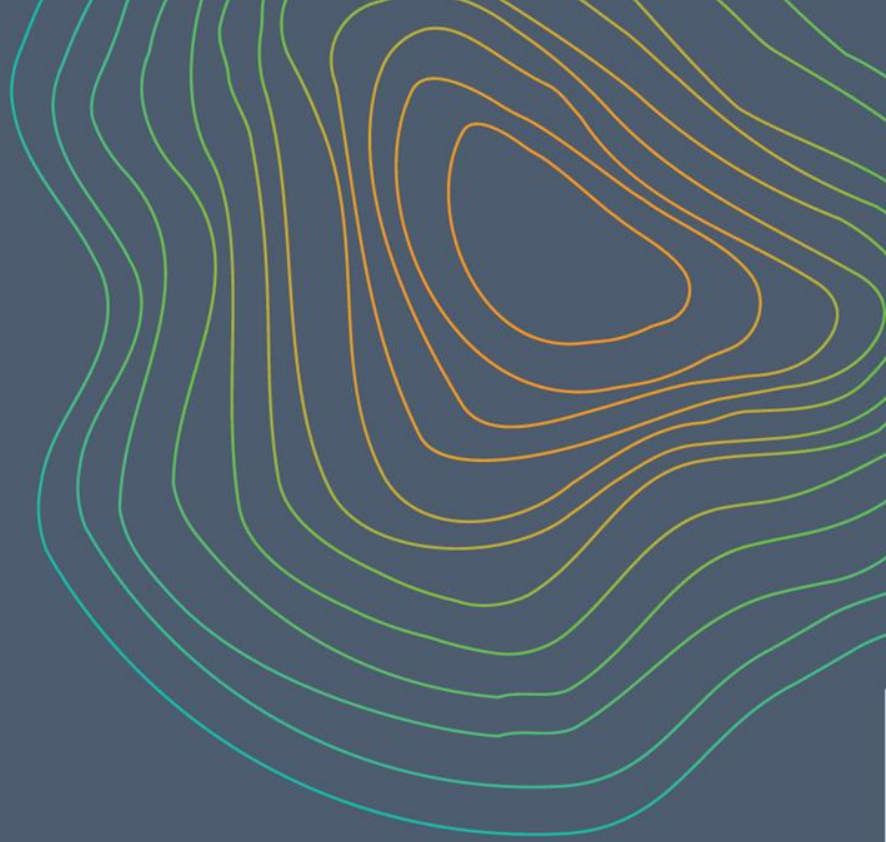

Folder - Original data
Contents - edi format MT stations, station location shapefile and acquisition report
File formats - .edi .pdf .shp
Suggested software - WinGLink, MT-py

Please note - suggested software lists are not exhaustive
```

Cloncurry MT dataset

- Modelling report
- x,y,z,restivity point file
- Located geotif depth slices
- Sgrid
- Inversion files
- Data (.edi files)

Targeting exercise



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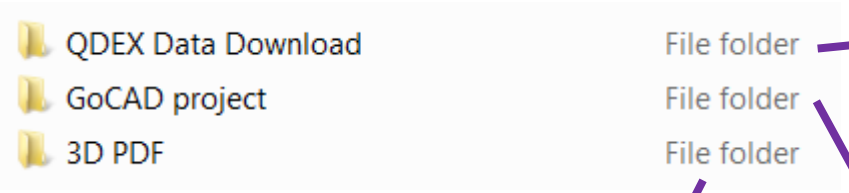
Use provided MT data package to target 5 km^2 exploration area(s)

- Cloncurry MT data package
  - Geoscience Analyst – sgrid/point set
  - GIS package - depth slices

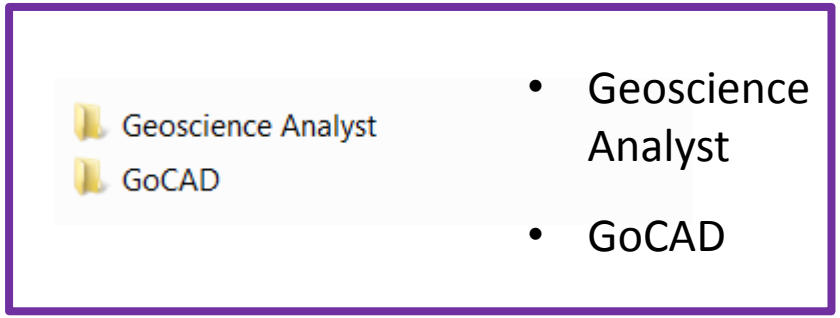
Use provided MT data package to target 5 x 5 km exploration area(s)

- Cloncurry MT data package
  - Geoscience Analyst – sgrid/point set
  - GIS package - depth slices

Some how to screenshots



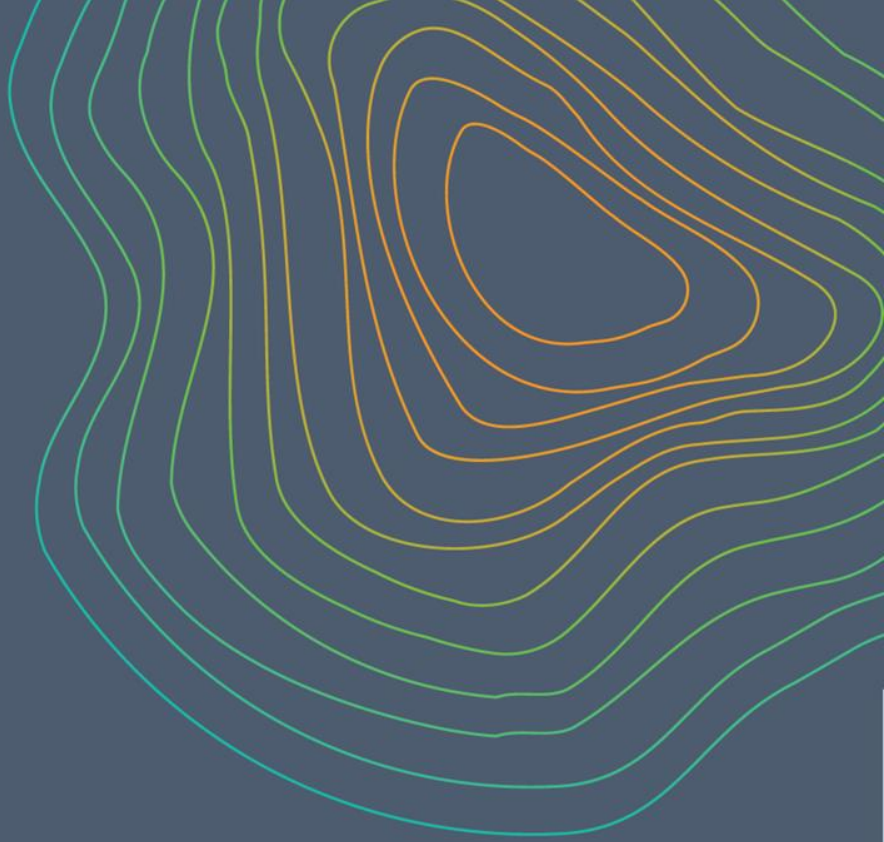
View and rotate model only



HoloLens

- Augmented reality view of the Cloncurry MT model

Targeting discussion



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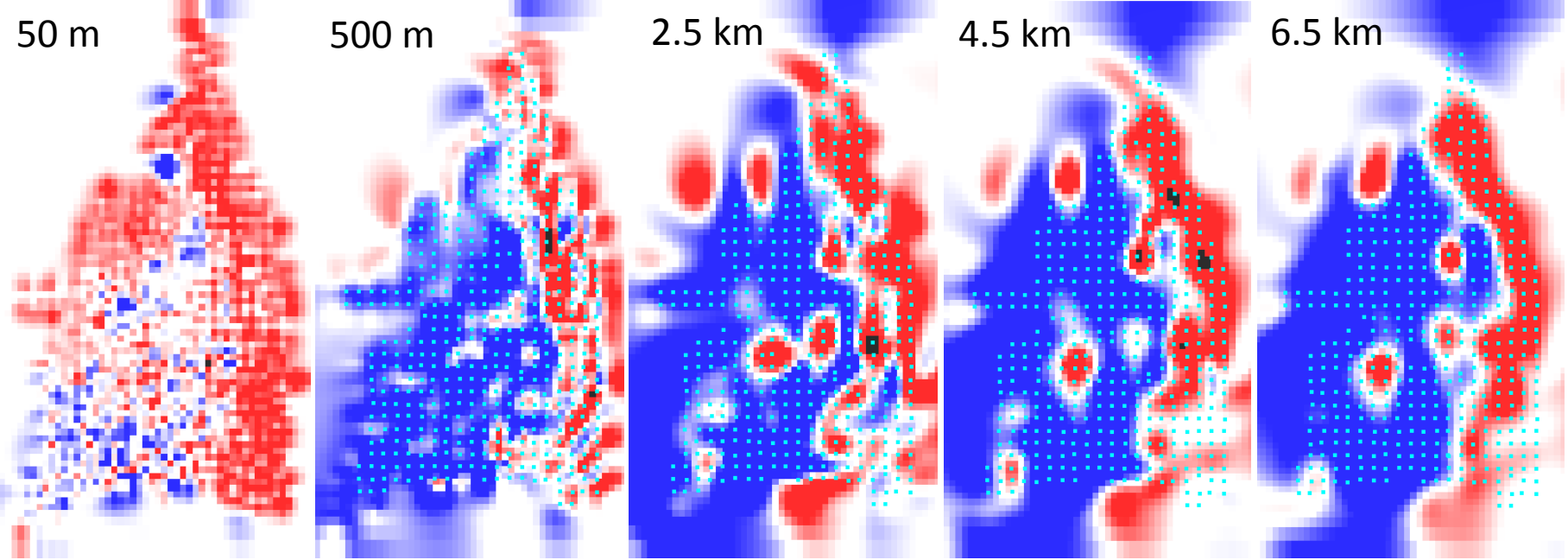
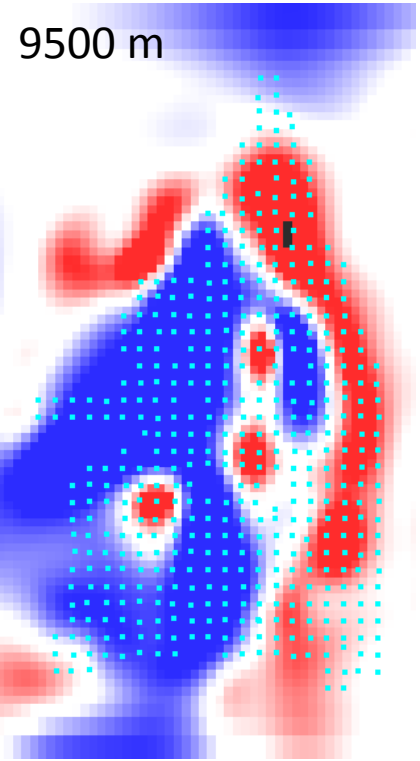
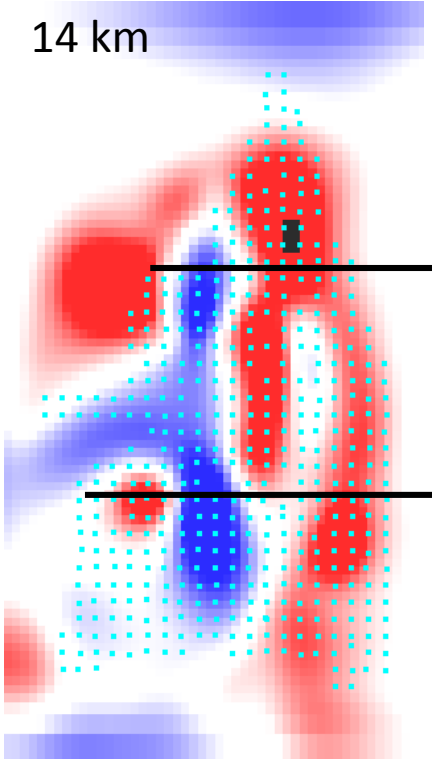
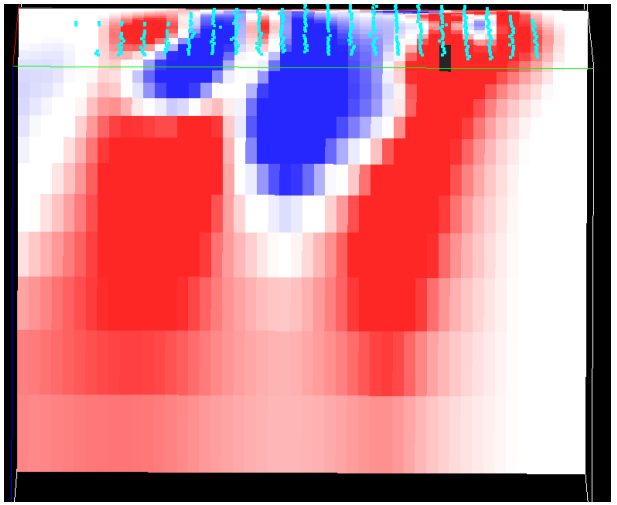
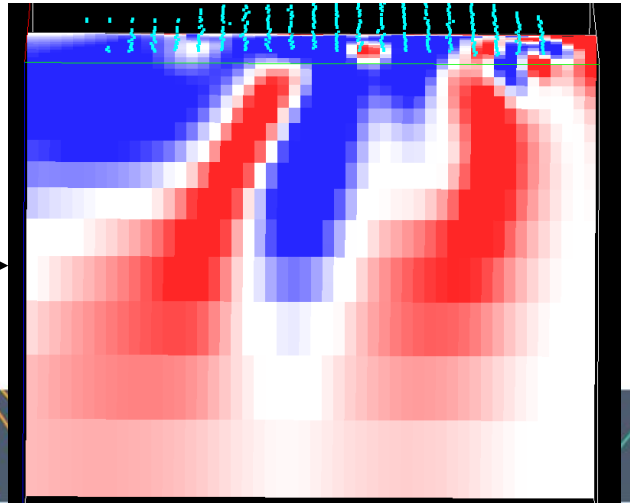

50 m
500 m
2.5 km
4.5 km
6.5 km


9500 m


14 km





Exercise 1

- Targets supported by several sites
- Targets on edges
- Anomalies associated with 1 site
- Targets consistent in the sensitivity analysis

Q&A

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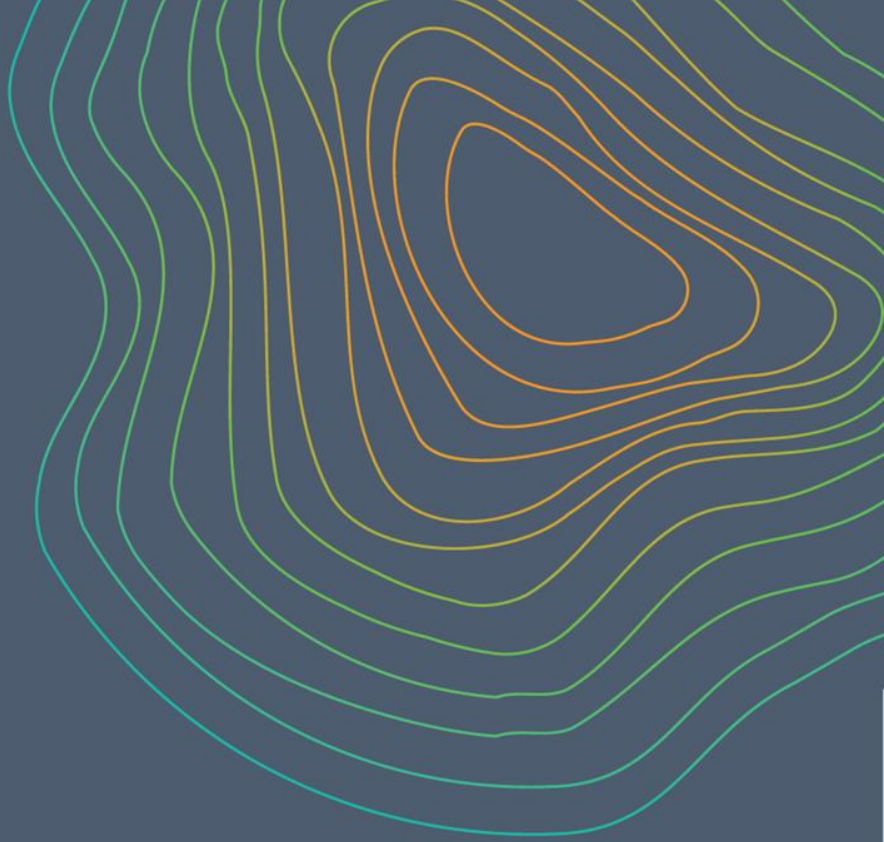
Take home messages

- Regional surveys are designed for exploration targeting NOT drill targeting
- MT inversions produce variable results
  - Edge effects
  - Poorly constrained features
- Petrophysical properties of cover can play a significant role in target resolvability

Sensitivity Analysis: why should you care?



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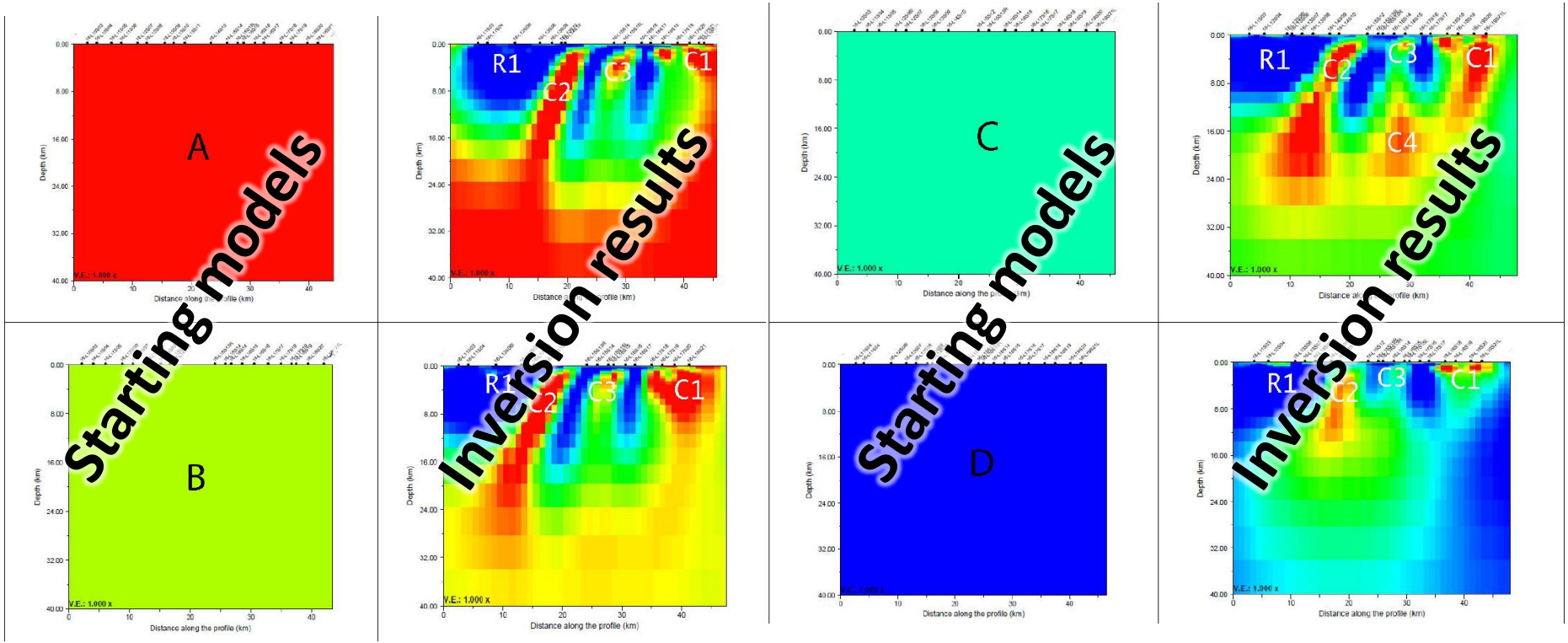
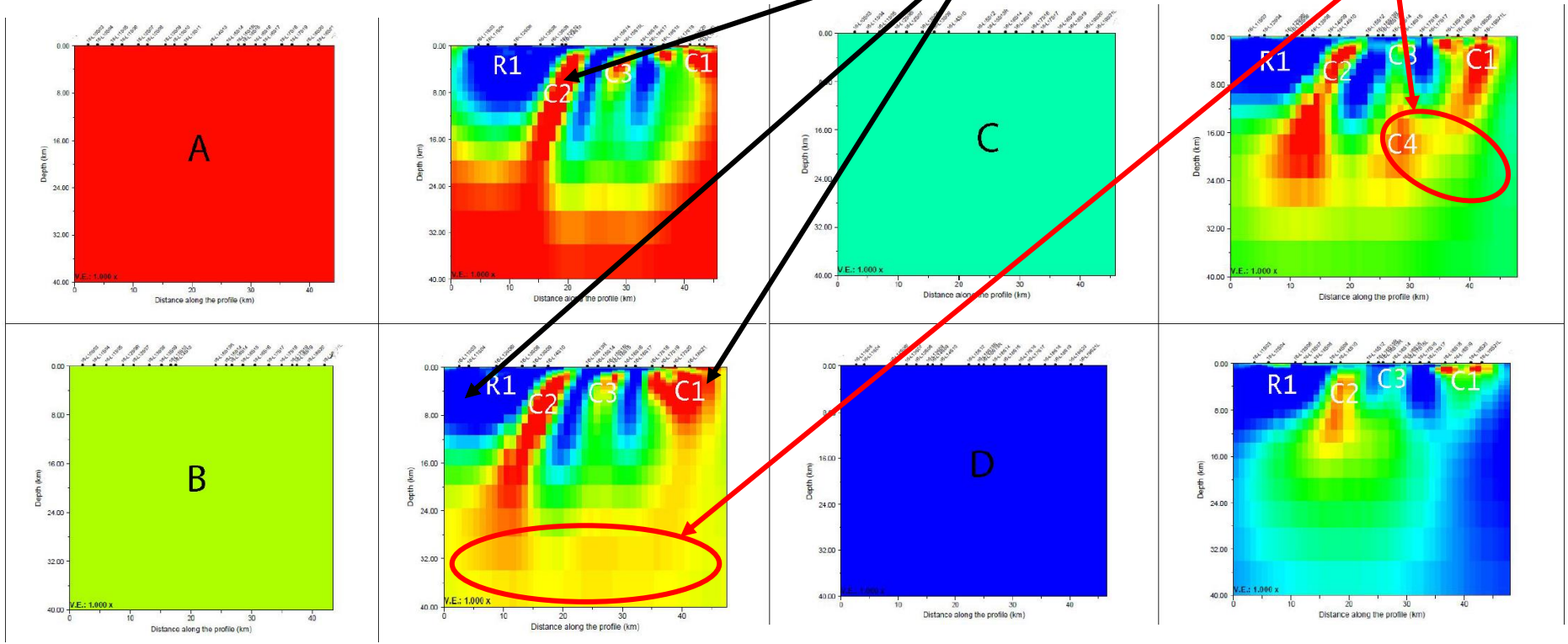
What is sensitivity analysis for?

- Inversion testing to establish sensitivity and resolvability of key features
- Generally included in modelling report

Cloncurry example



Cloncurry example



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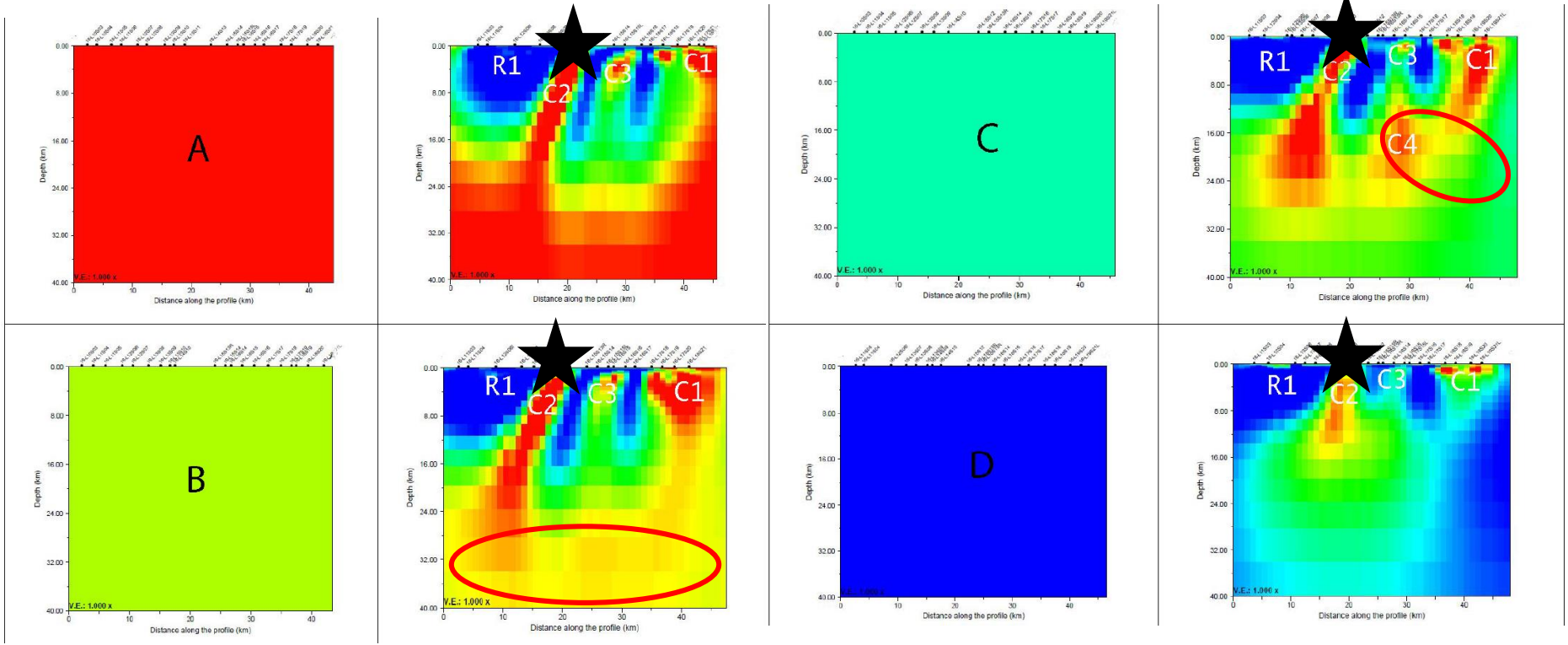
Sensitivity analysis

0 0.5 1 1.5 2 2.5 3

LOG10[Resistivity (Ohm.m)]

Cloncurry example

★ **Ernest Henry here**



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Sensitivity analysis

0 0.5 1 1.5 2 2.5 3

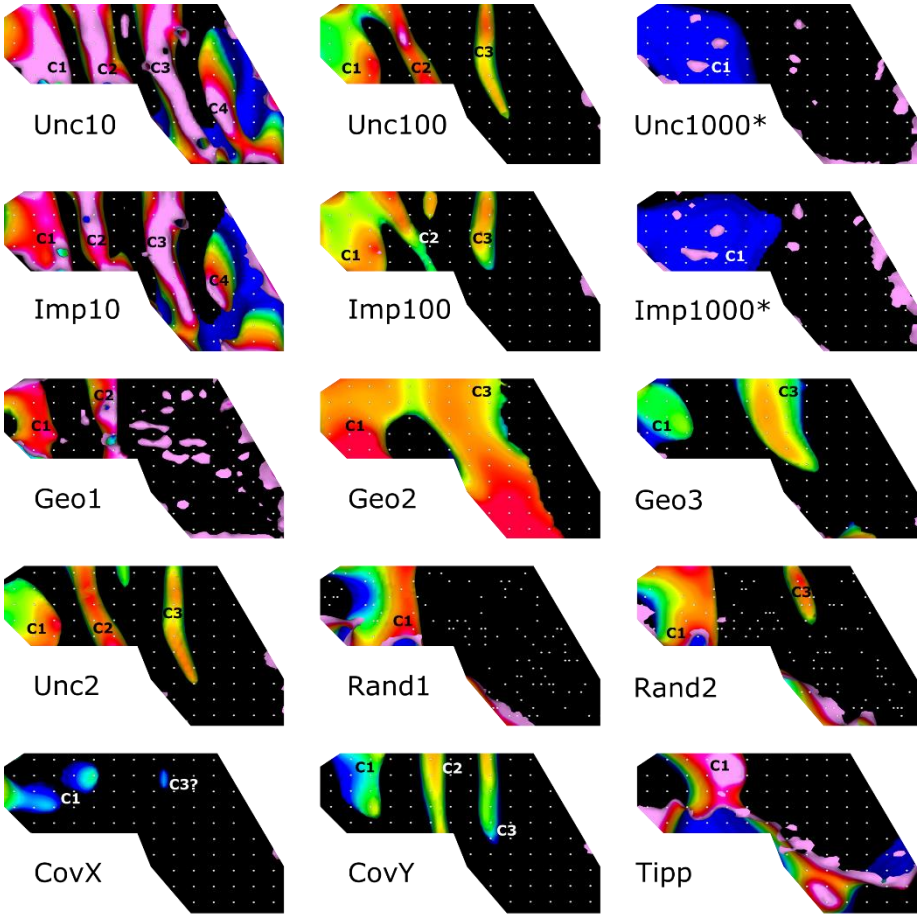
LOG10[Resistivity (Ohm.m)]

Isa Extension example

Isosurface models for 15 inversions

Comparable data fits

Up to 4 conductive features

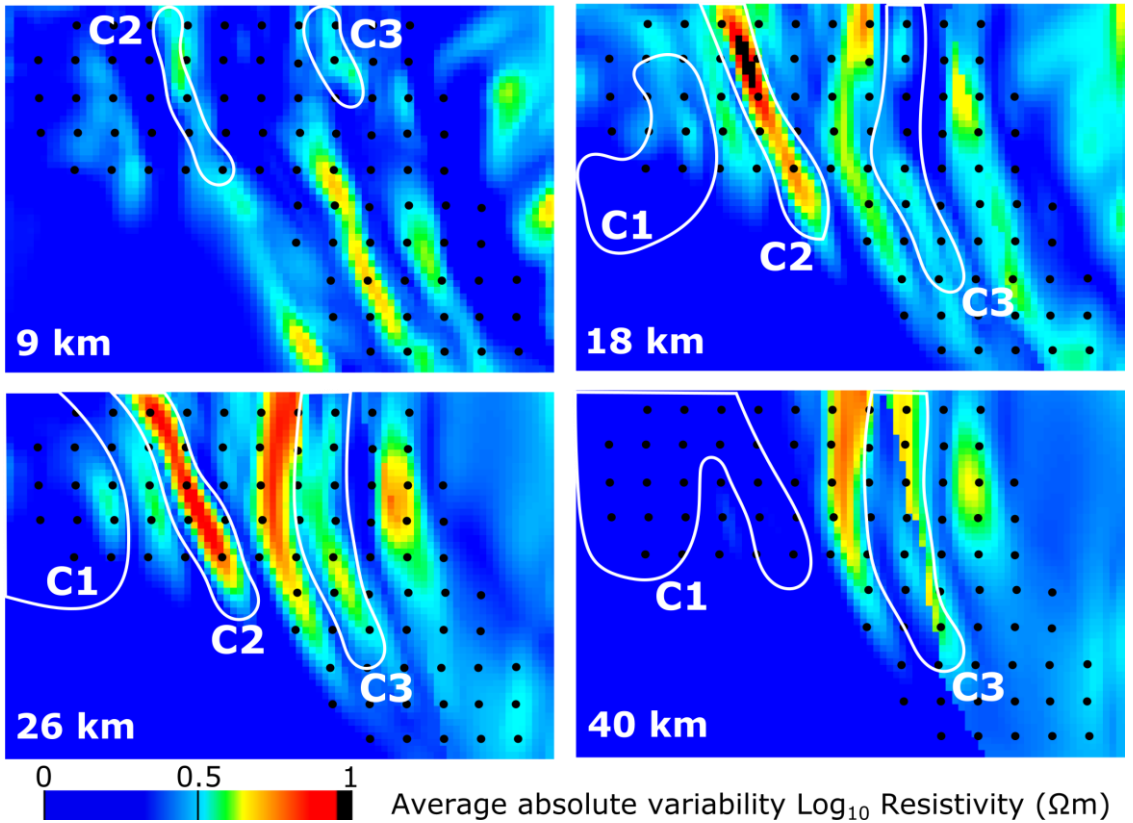


Isa Extension example

Variability distribution with depth

Blue features low variability = low uncertainty

Red features high variability = high uncertainty



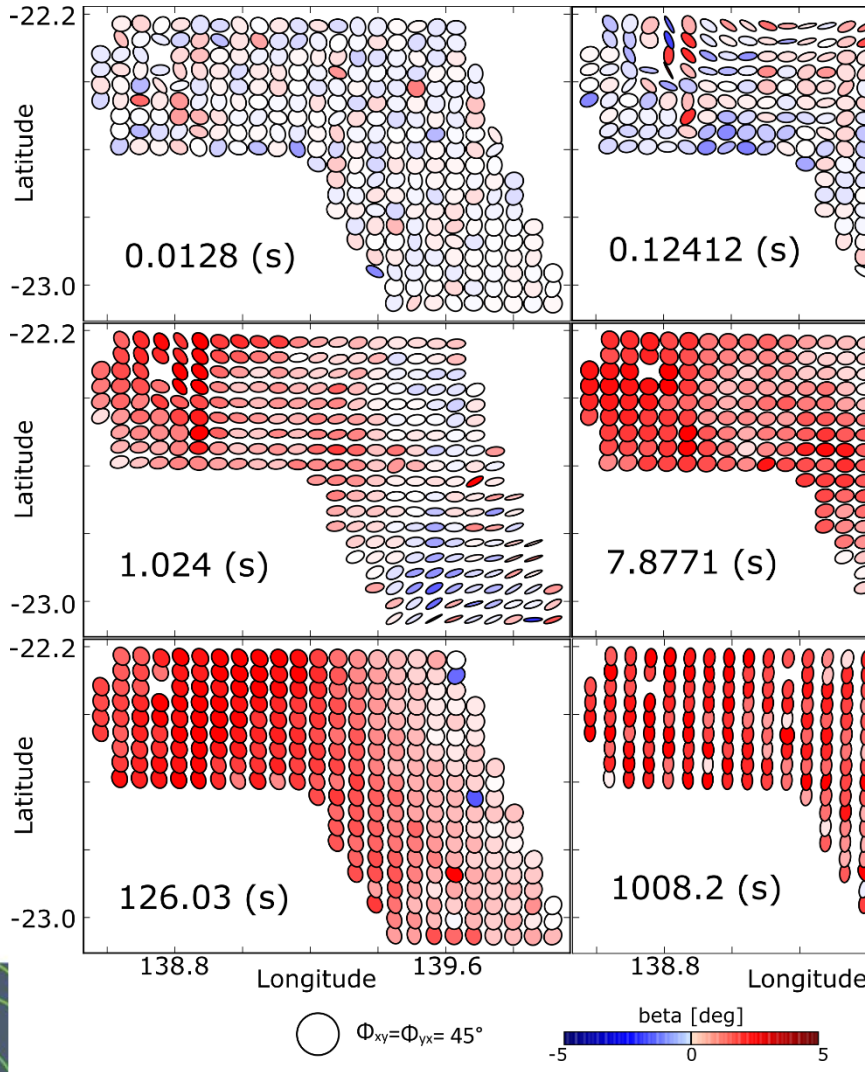
Sensitivity analysis provides a quick evaluation about the reliability of inversion features

What are phase tensor plots?

Plots of data rather than interpretative products of the data

Used to assess

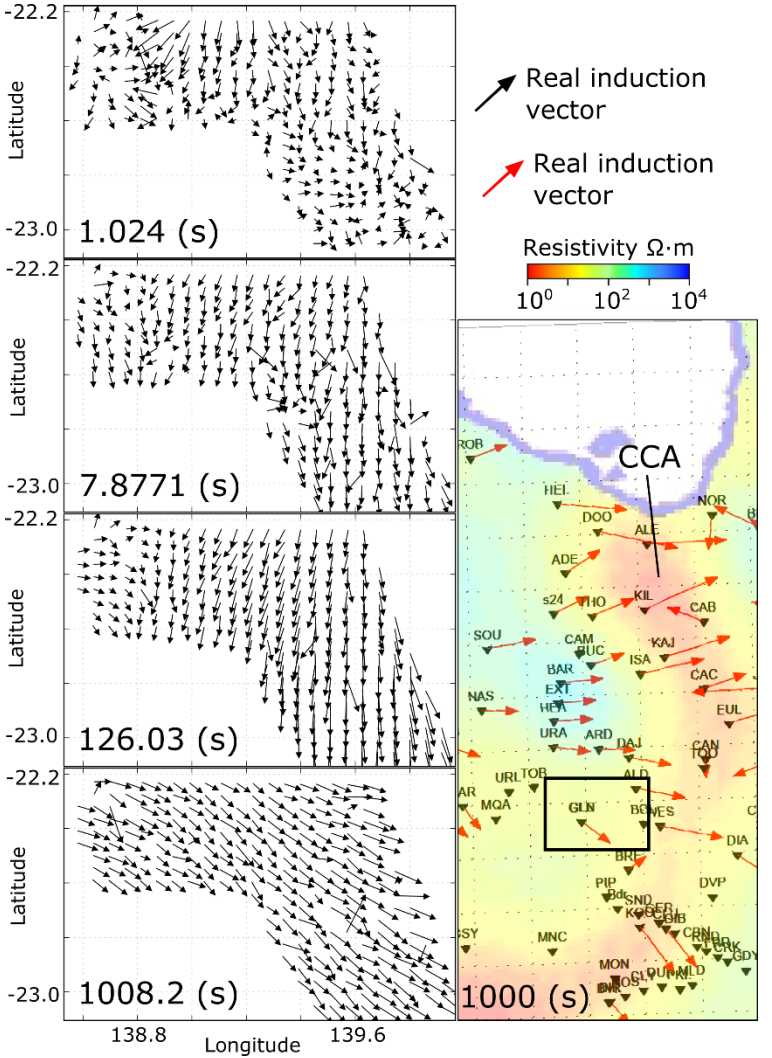
- Data noise
- Dimensionality
- Gain high order understanding of the dataset



What are induction arrows?

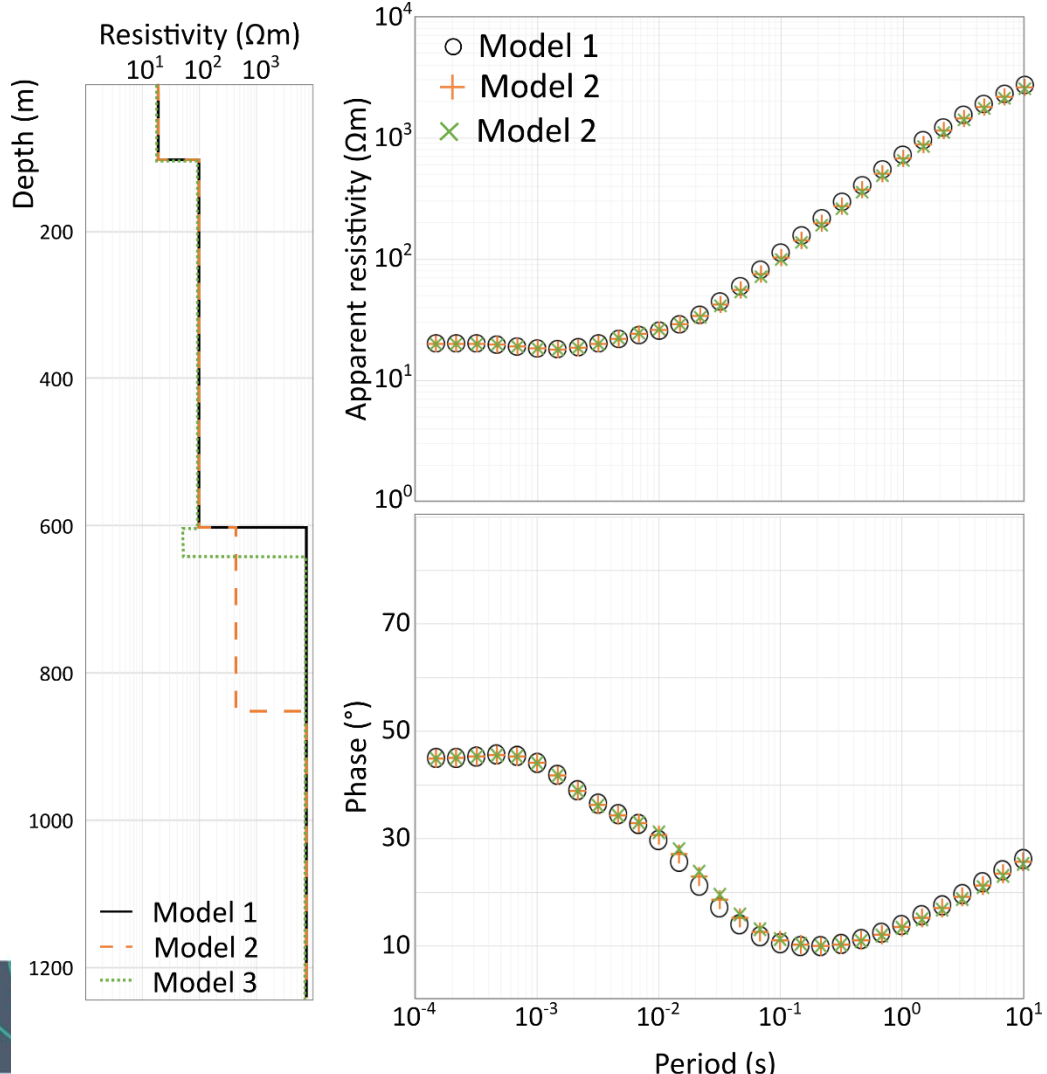
Indication of the presence of subsurface conductors

Derived from 3 component measurement of the magnetic field



Extra exercise

- What is hiding beneath conductive cover?
- 1D modelling exercise



Exercise 2

- 30% rule of thumb

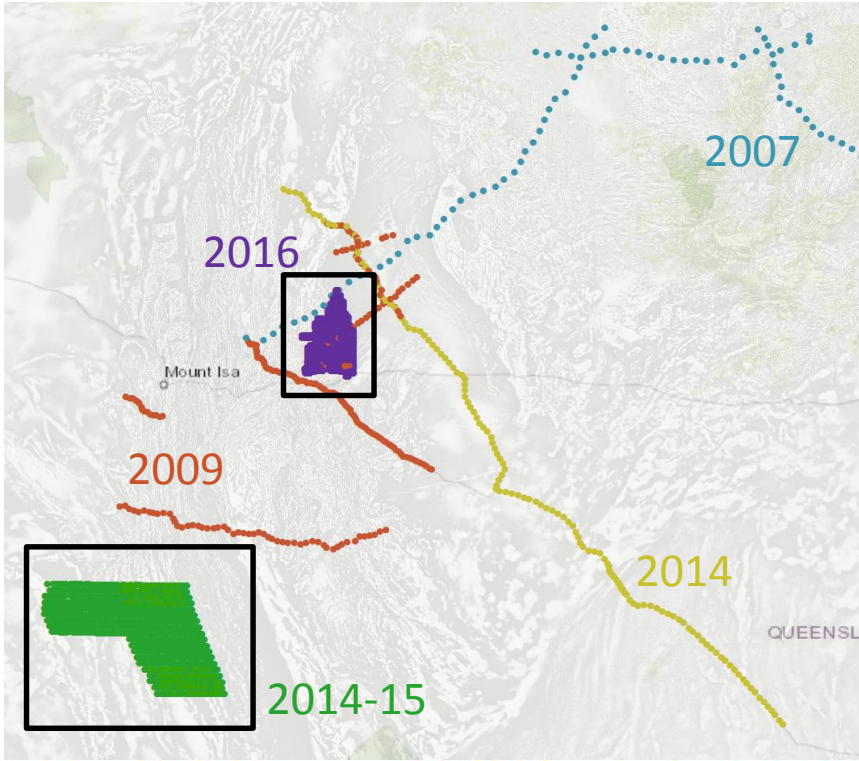
Regional survey design

Cloncurry MT survey

- 2 km grid
- 1000 Hz to 1000 s

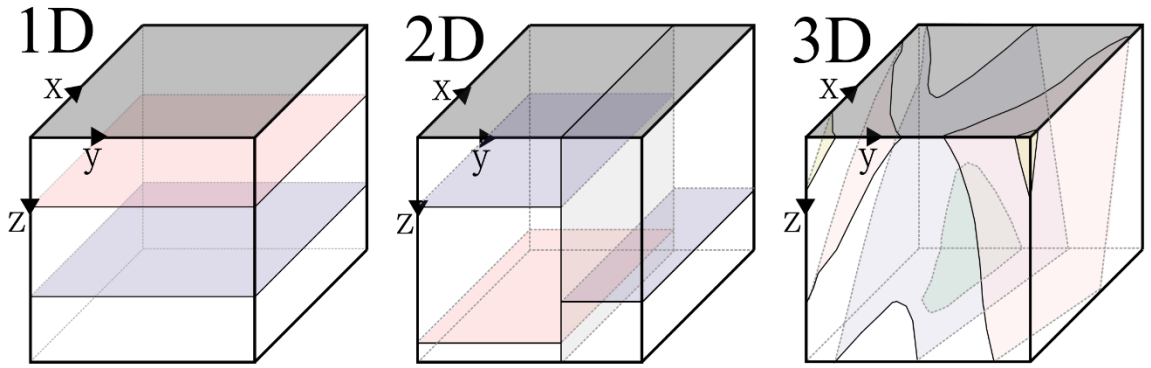
Isa Extension MT survey

- BBMT sites 2 km x 5 km spacing
- AMT 500 m sites
- AMT 10,000 Hz to 1 Hz
- BBMT 250 Hz to 2000 s



MT limitations – inappropriate inversion

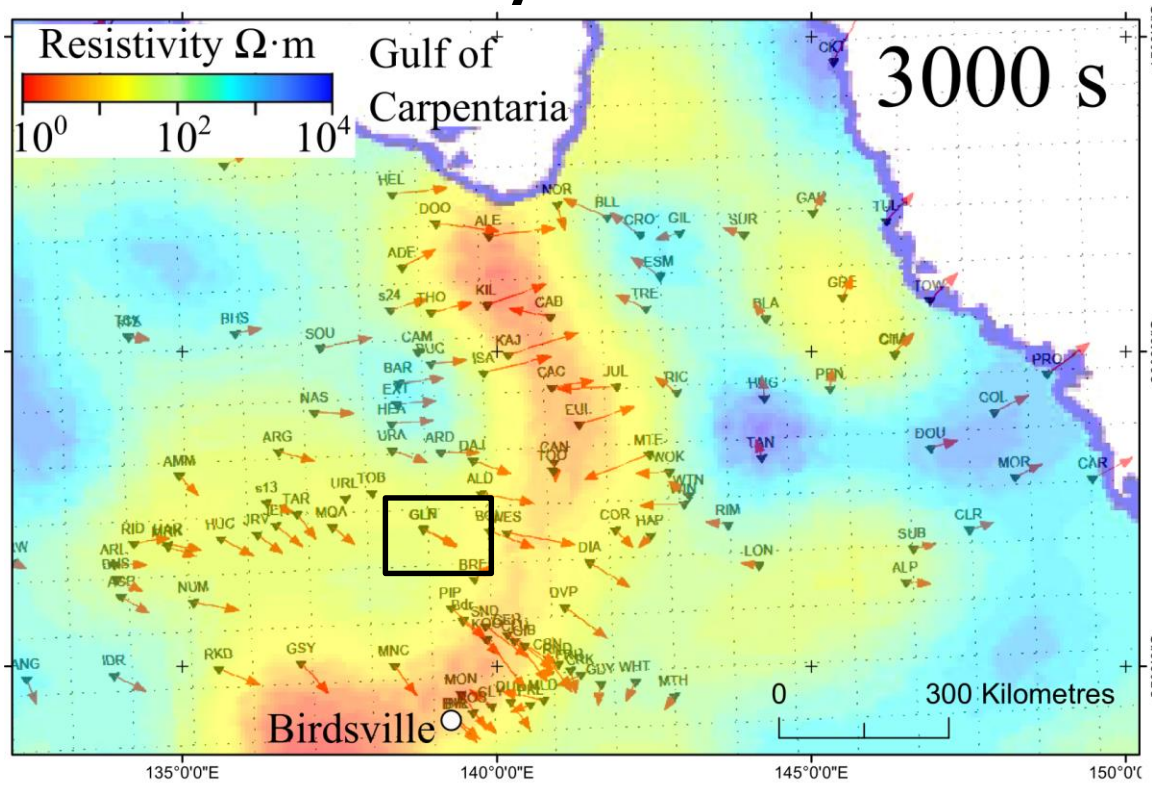
- MT data have inherent dimensionality
- 1D data can be modelled by 3D inversion
- 3D data cannot be modelled by 1D or 2D inversion



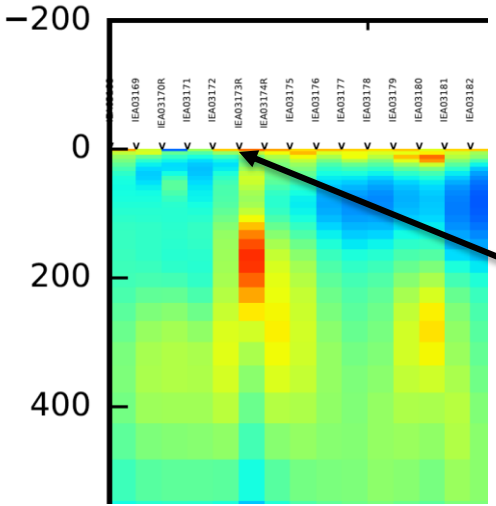
MT limitations – out of array effects

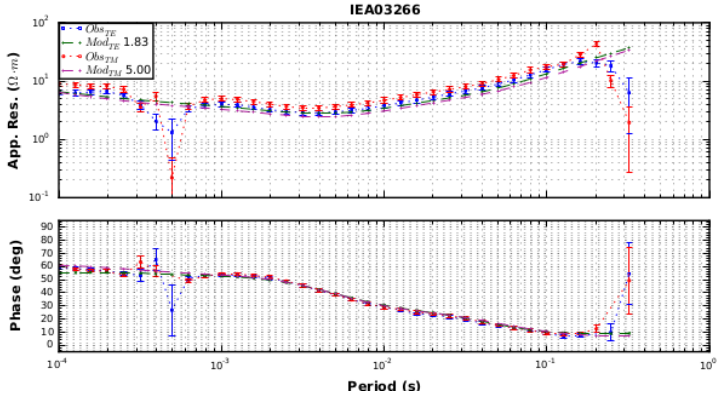
MT data can be sensitive to a feature but unable to resolve it

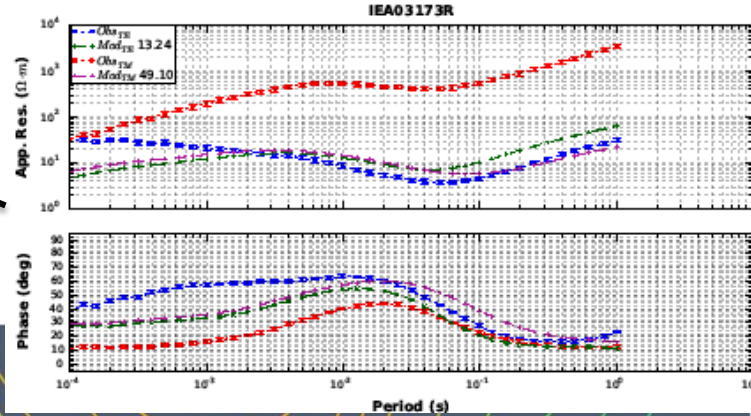
Isa Extension dataset
- Long period data unable to be modelled



MT limitations – modelling noise







Finding inversion features in data