Joint MT/CSEM Anisotropic Inversion Olympic Dam

T.J. Ritchie*
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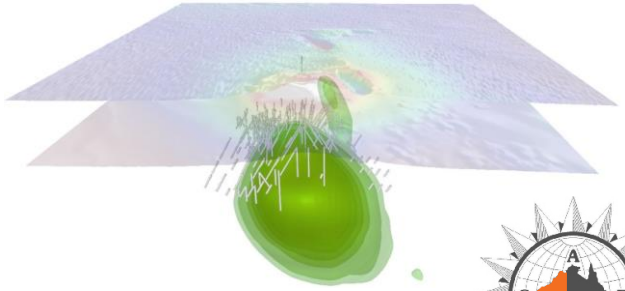
Practical 1 Day Workshop
Geophysical Inversion for Mineral Explorers



* Geophysical Resources and Services Pty. Ltd. Brisbane

Structure of Talk

- Olympic Dam
- GRS Survey History / Specifications & Data
- 2D Inversions DC/IP and MT , UBC2D / Occam2D
- Irreconcilable Differences ?
- Anisotropy ?
- MARE2DEM
- Reposing DC as CSEM
- 2D CSEM Inversion
- 2D MT Inversion
- 2D Joint Inversion CSEM / MT

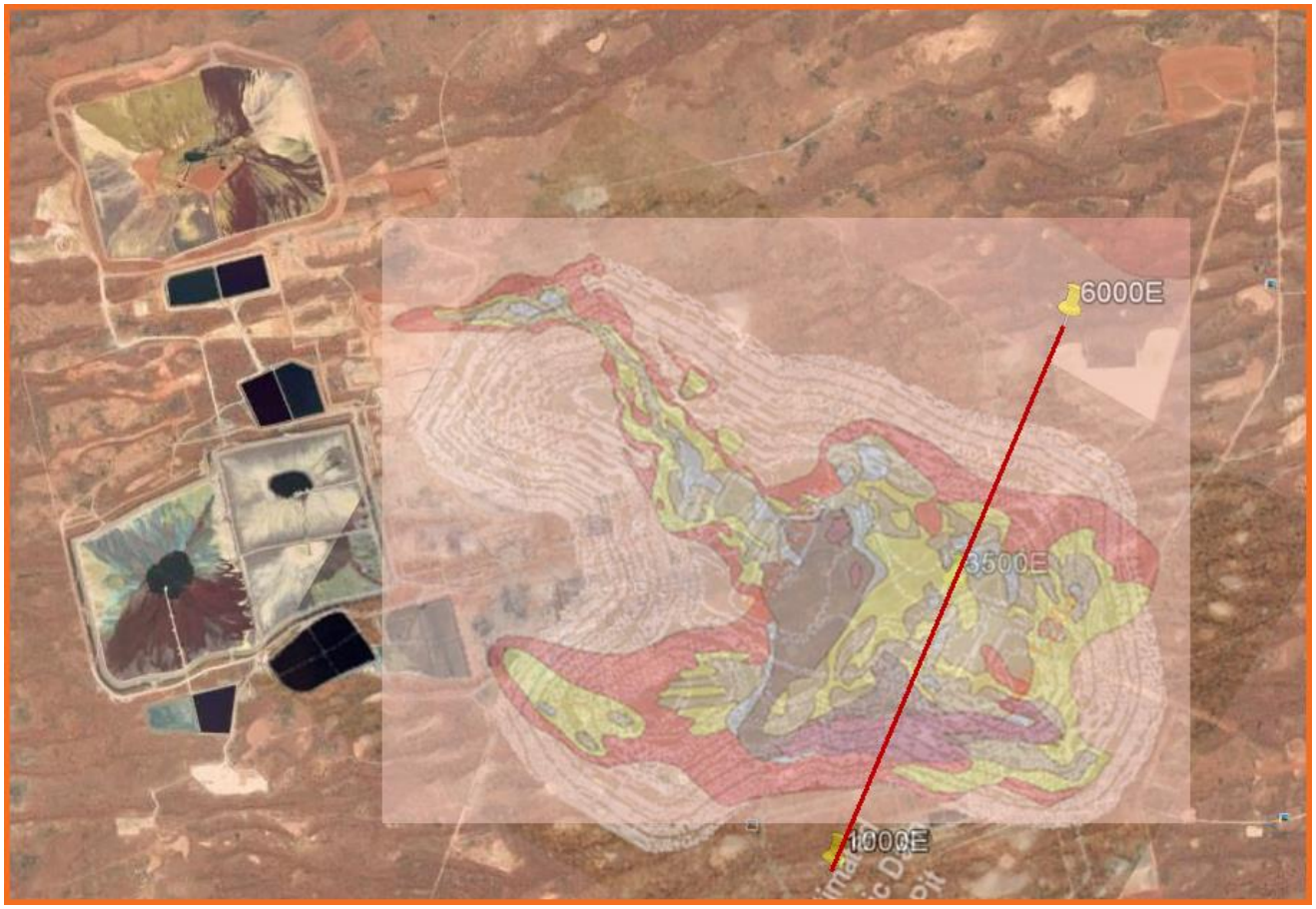
- Summary

Olympic Dam (I)

- Iron-Oxide Cu-Au (Polymetallic) Deposit
- Copper 589mt @1.81%
- Uranium 589mt @ 590g/t
- Gold 589mt @ 3.36gt
- Silver 589mt @ 0.66g/t probable reserve
- It's BIG

- Mineralised magnetic hydrothermally altered magnetite breccia under 350m of overburden
- It's DEEP-ish

Olympic Dam (II)



GRS Survey History

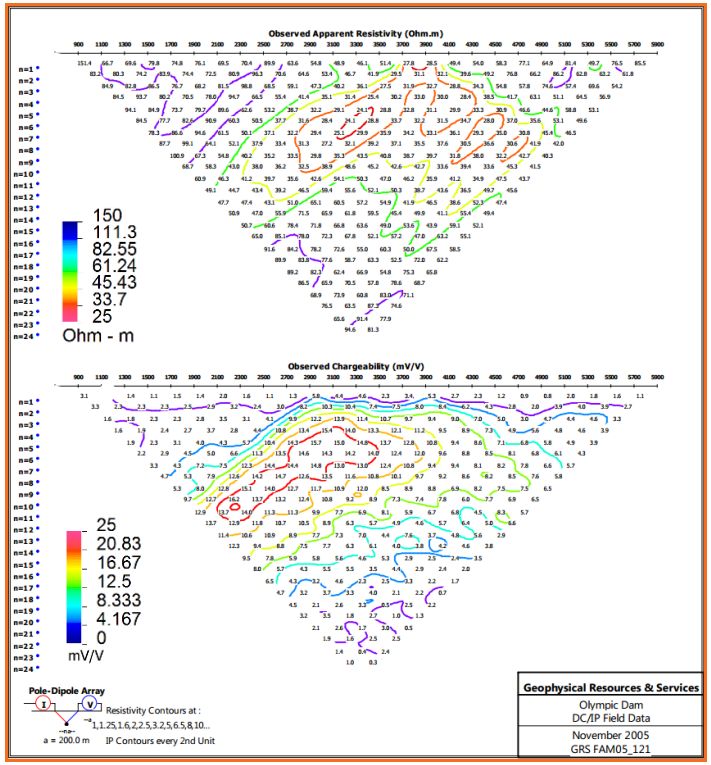
- Survey Commissioned by B.H.P.B.
- One 5km "Test" Line
- 5th – 8th November 2005
  - 2 Days Setup / Induction etc.
  - Morning 7th November, lost to thunderstorm
  - Afternoon 7th November – MT
  - 8th November – DC/IP

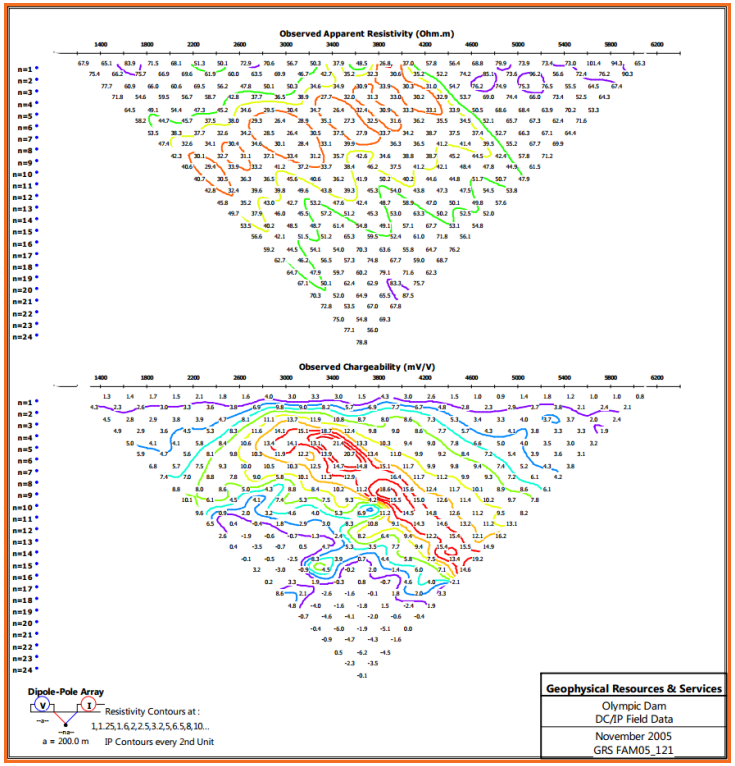
GRS Survey Specifications

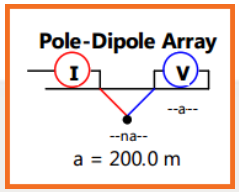
- Tx = Zonge GGT-10 IP Transmitter
- Rx = MIMDAS
- 200m a-spacing Pole-dipole / Dipole-pole with TC
- Tx Freq. 25/512 Hz (5.12 secs off-time equivalent)
- IP Time Slice 3.0-5.1 seconds
- Average Current approx. 5 Amps

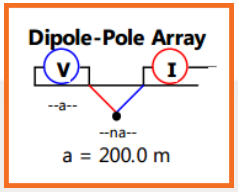
- MT E-Map 200m a-spacing w. Remote X-Ref
- Frequencies used 1.17 - 300.0Hz (approx. 7 per decade)

GRS Survey DC/IP Data



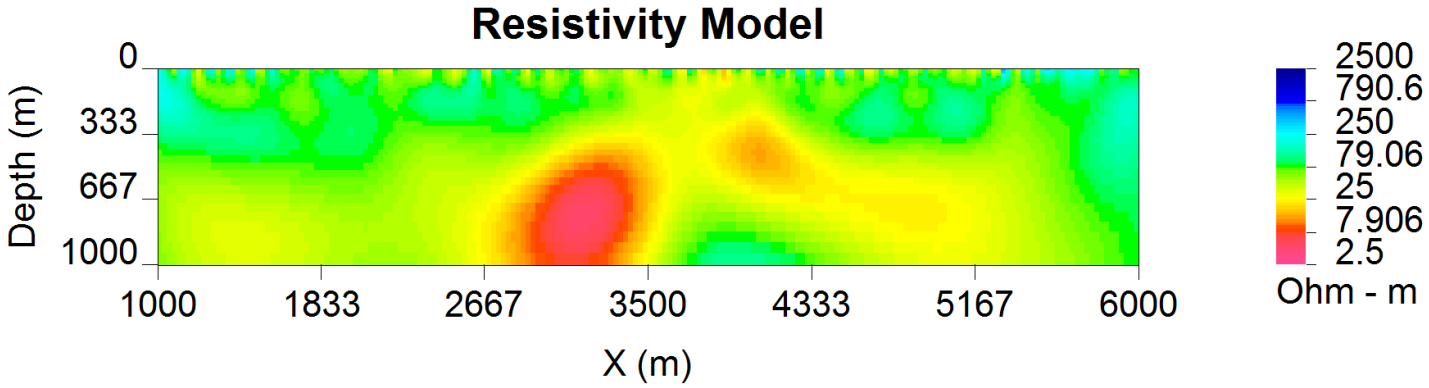


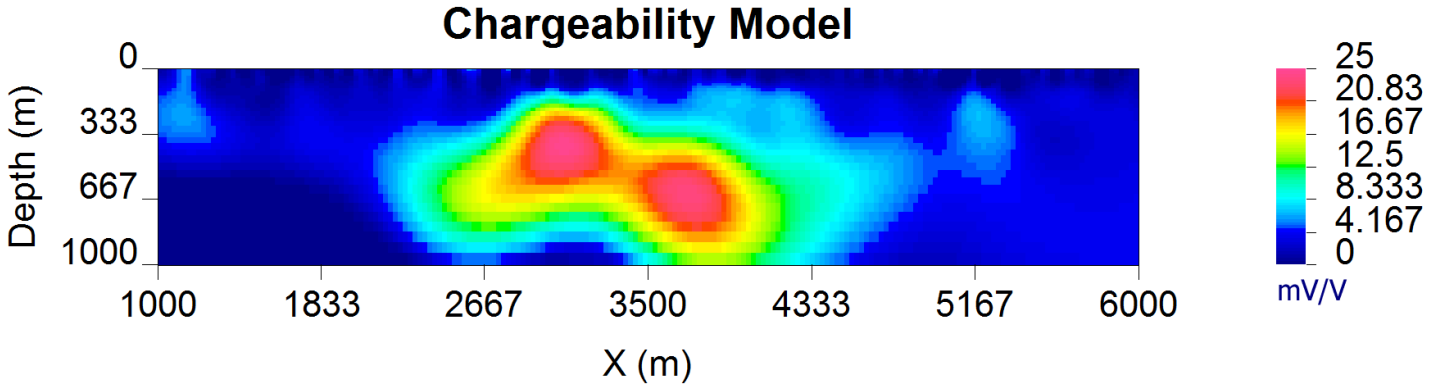




2006 2D Inversions DC/IP

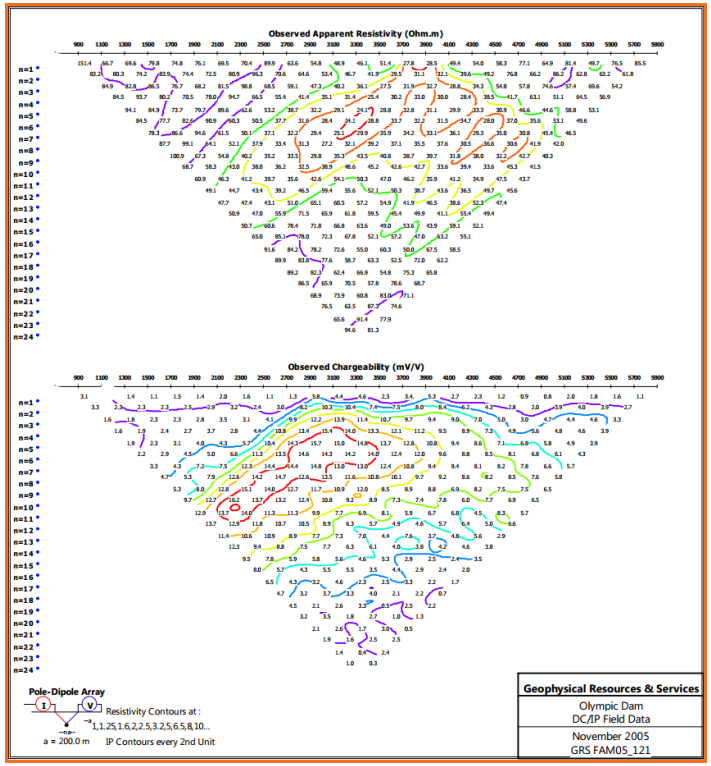
UBC2D using Inversion Defaults
Converges to RMS 1.0 with approx. 1% Vp and 0.8 mV/V



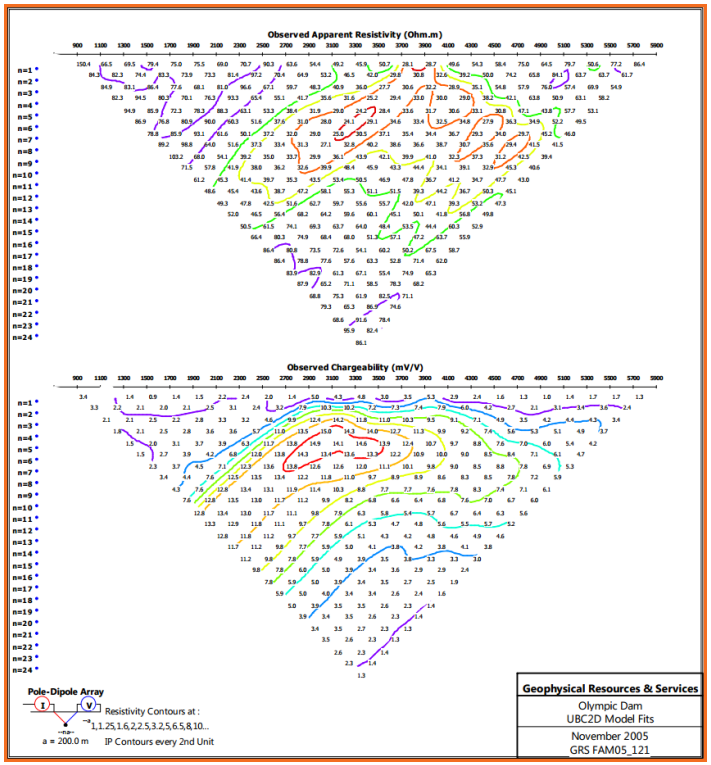


2006 2D Inversions DC/IP (II)

Field Pole-Dipole

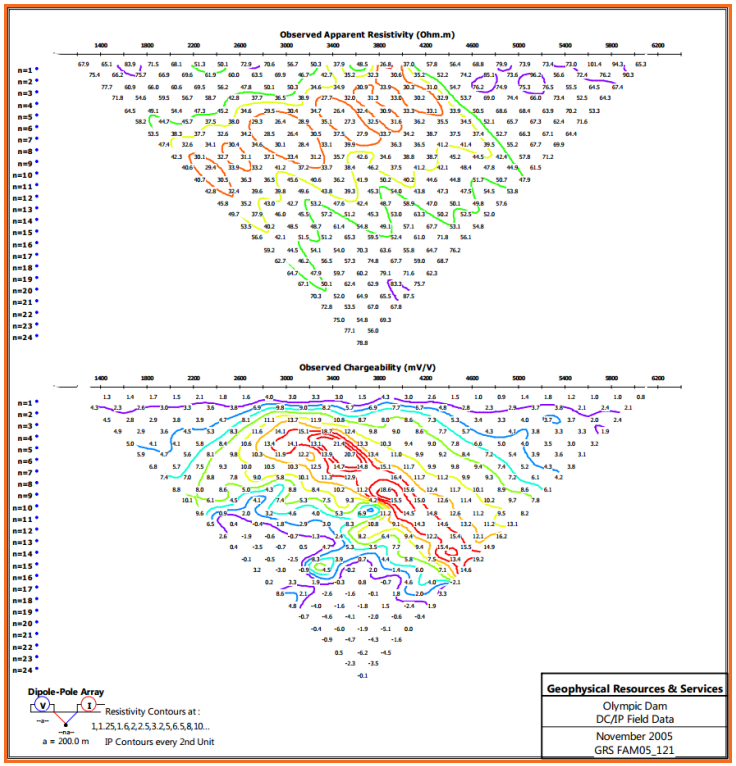


Fits

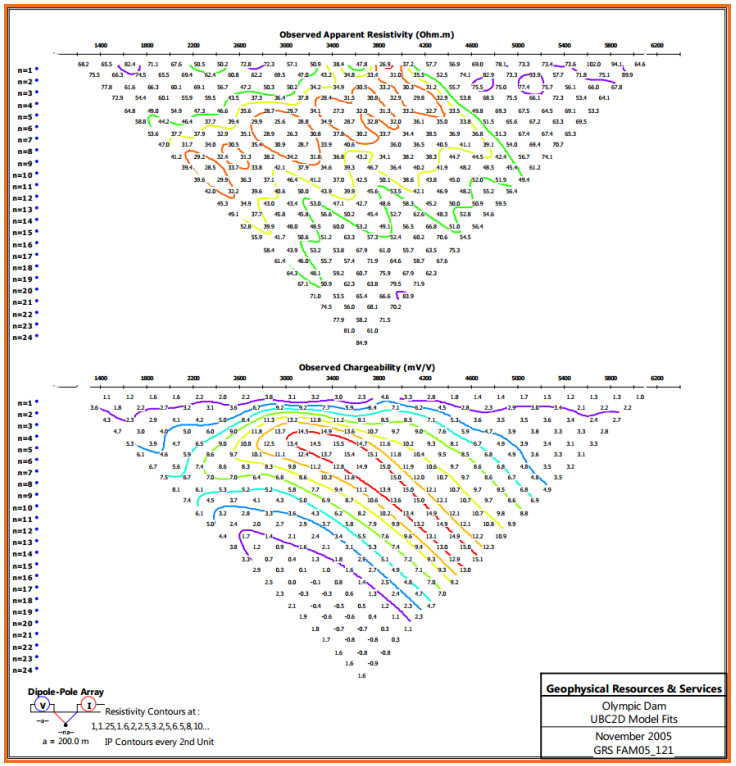


2006 2D Inversions DC/IP (II)

Field Dipole-Pole

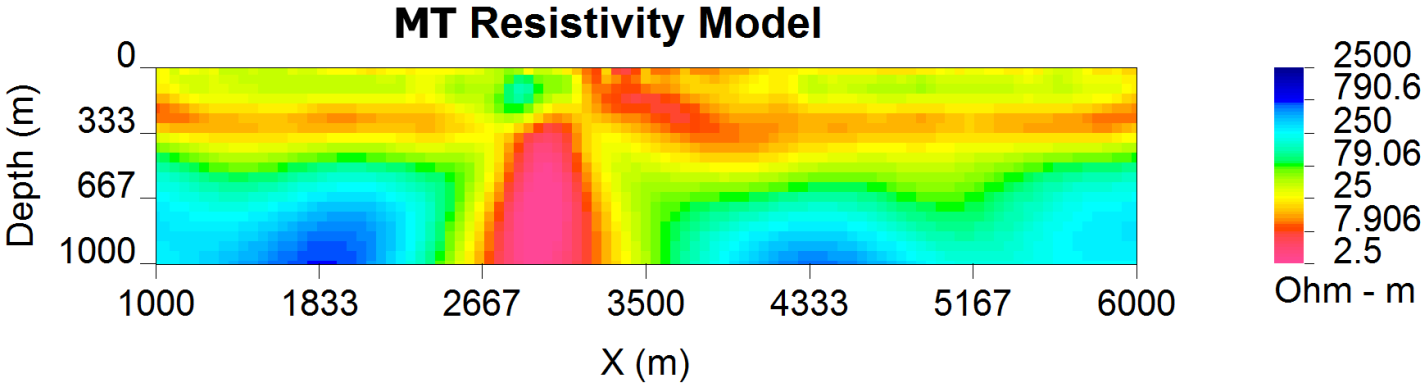


Fits



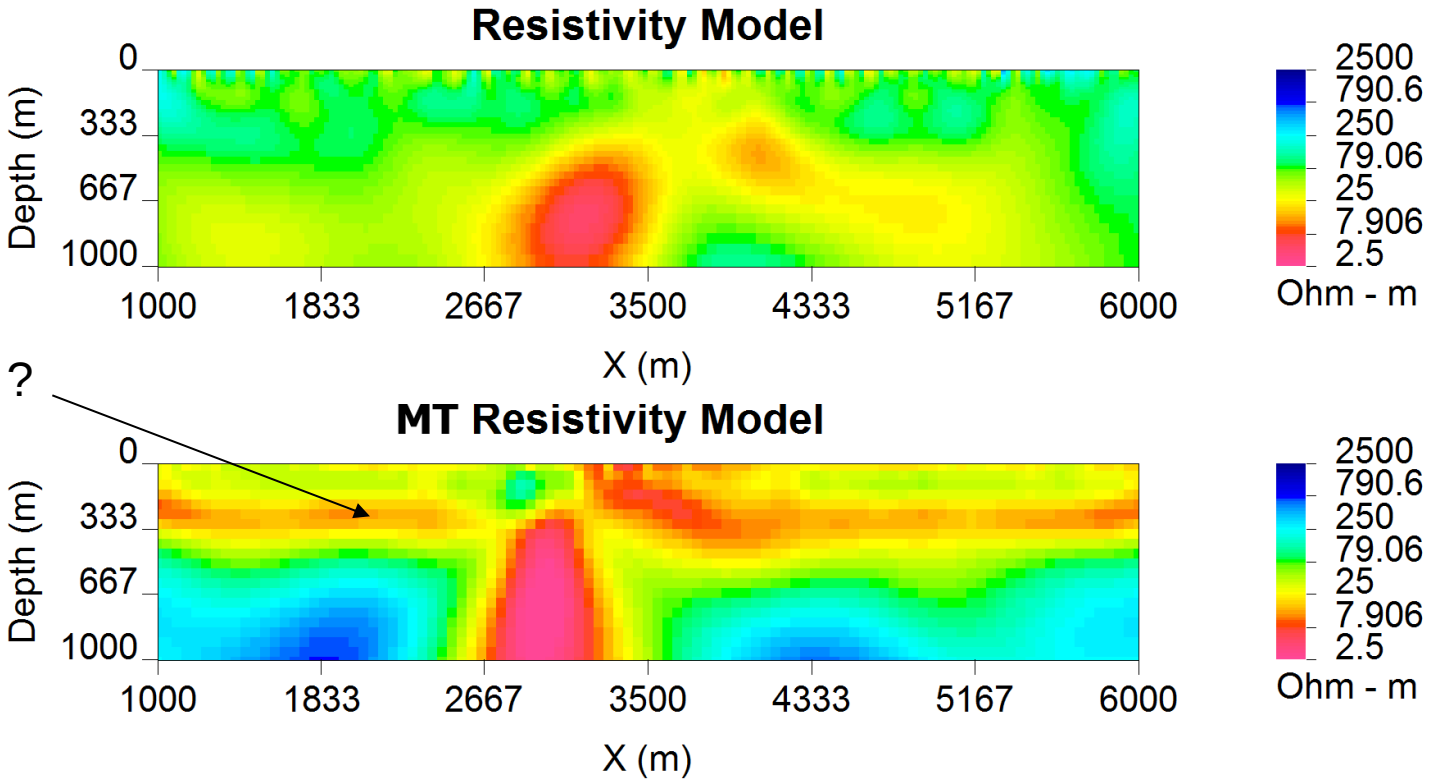
2006 2D Inversions MT

Occam2D using Inversion Defaults Converges to RMS 1.0 with Errors of approx 2% of Apparent Resistivity 0.6 degrees of Phase



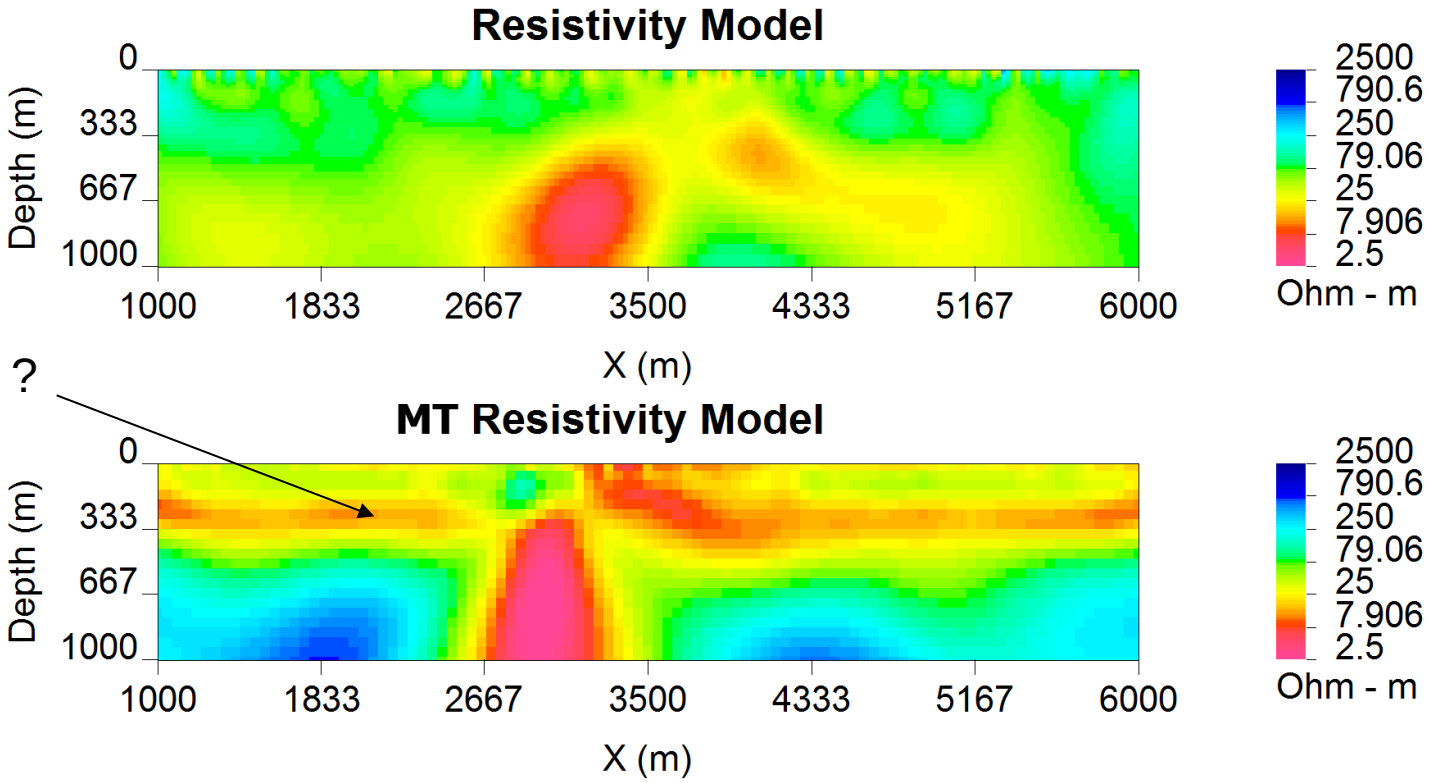
“Irreconcilable” differences

- GRS has been inverting both datasets for a decade and have found that DC and MT 2D models usually match quite well.

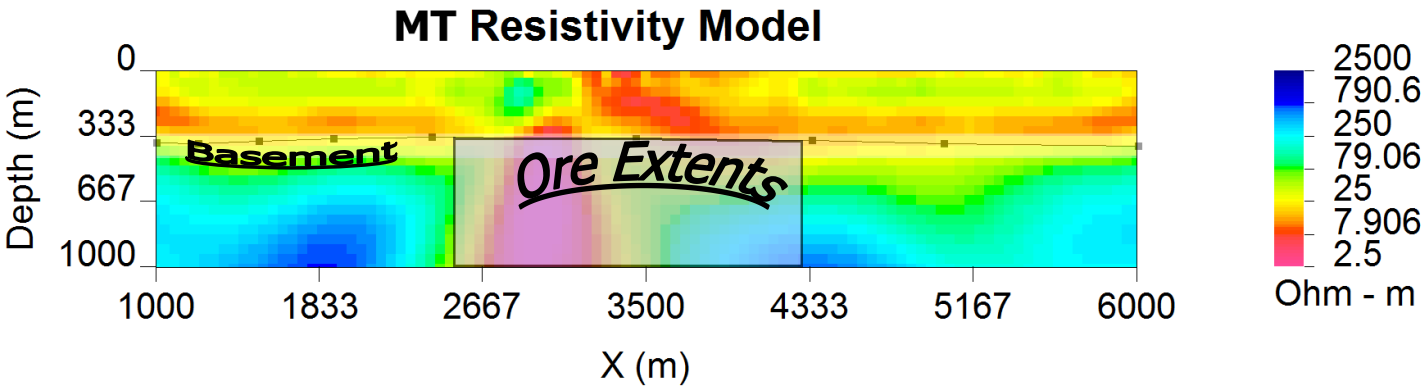


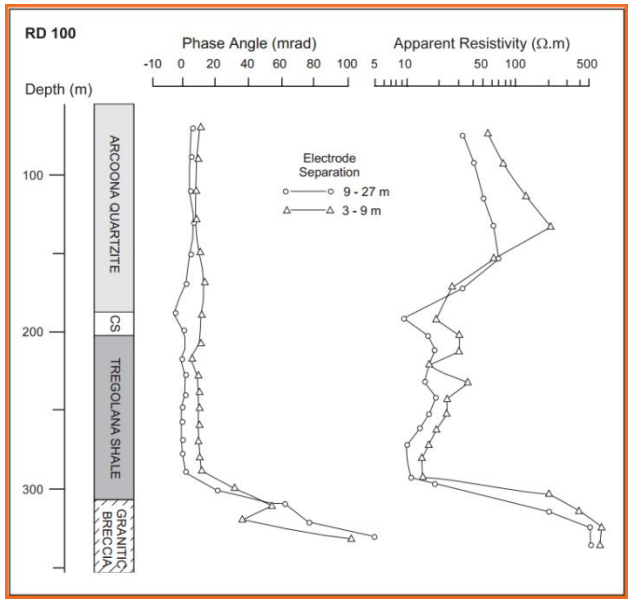
"Irreconcilable" differences

- The Horizontal Conductor's Location (MT) matches the Stratigraphic Location of the Tregolana Shale



“Irreconcilable” differences





- 100m+ Shale atop Basement
- Shales have often been Observed to be Electrically Anisotropic, as are most Sediments

Anisotropy ?

- Terry got to thinking about the Anisotropy Aspect after a chat with James Macnae after he posted a comment on SEGMIN about "systematic differences between airborne and ground resistivities over sediments but not regolith"
- MT, Horizontal Current Flow
- Surface Resistivity Arrays, a Large Component of Flow will be Vertical

- Need an Inversion Program that handles Anisotropy

MARE2DEM (Scripps Institute, Kerry Key)

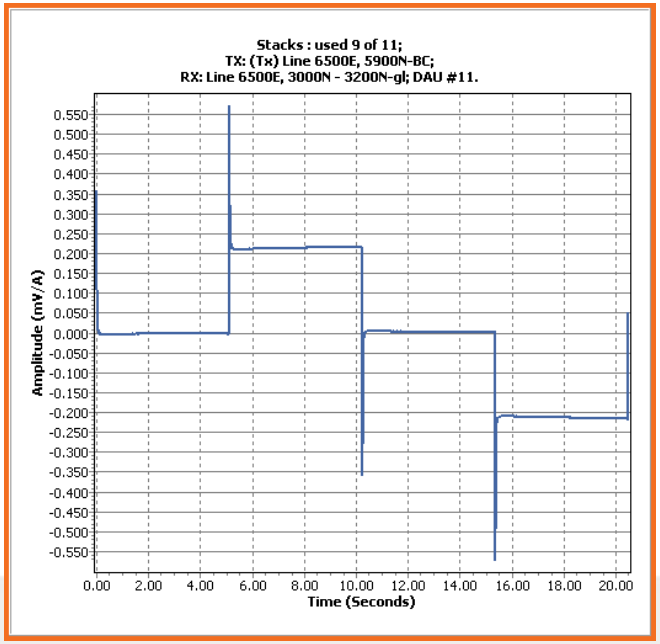
- MARE2DEM (pronounced mahr-ey 2DEM) is a parallel adaptive finite element code for 2D forward and inverse modeling for electromagnetic geophysics. It was developed with funding support from the Scripps Seafloor Electromagnetic Methods Consortium. After a period of exclusive access for consortium members, the code is now being made freely available. MARE2DEM was originally designed with marine controlled-source electromagnetic (CSEM) and marine magnetotelluric (MT) applications in mind, but it can also be applied to onshore electromagnetic modeling problems. Two main features of MARE2DEM are (1) it uses fully automatic mesh generation so that end users are free from the burden of designing numerically accurate grids for complicated models and (2) it is open-source and freely available. The code package has reached a fairly mature state, but there are several planned new features and development is ongoing, so stayed tuned for updates.

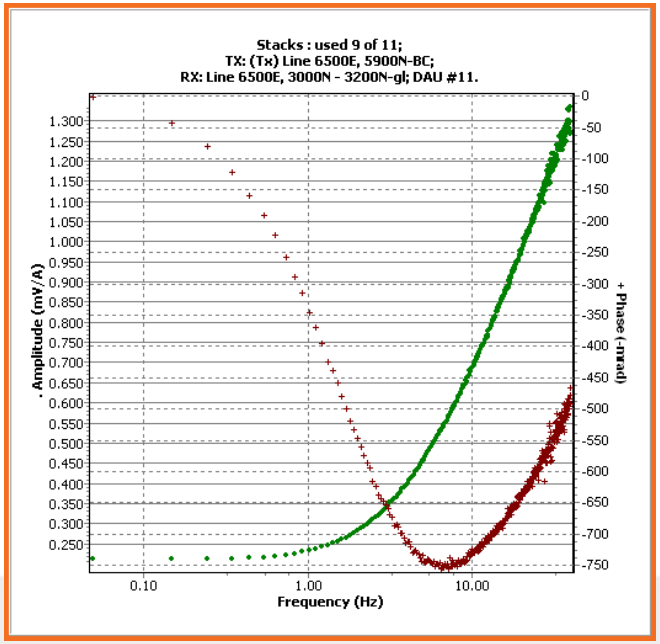
- Features:

- Forward calculations using fully automatic goal-oriented adaptive finite elements
- Non-linear inversion using a new faster implementation of Occam's method
- Models electric & magnetic dipoles and magnetotelluric (MT) plane waves
- Models marine, land and borehole transmitters and receivers (but is not yet configured for airborne EM)
- Models point or finite length dipole wires
- Models isotropic, transversely isotropic or triaxial anisotropic conductivity
- Inverted conductivity parameters can be bounded using non-linear transforms
- Run in parallel on laptops to large clusters. The forward code uses a parallel data decomposition for a nearly linear speedup with the number of processors. The inversion code performs dense matrix operations efficiently in parallel using the ScaLAPACK library.
- Model Builder Assistant (Mamba2D) for MATLAB
- Inversion model and response plotting tools for MATLAB
- Open source under the GNU GPL license
- Languages: Fortran (modern), C, MPI. Requires the Intel C and Fortran compilers.

Pole-Dipole DC Resistivity to CSEM (I)

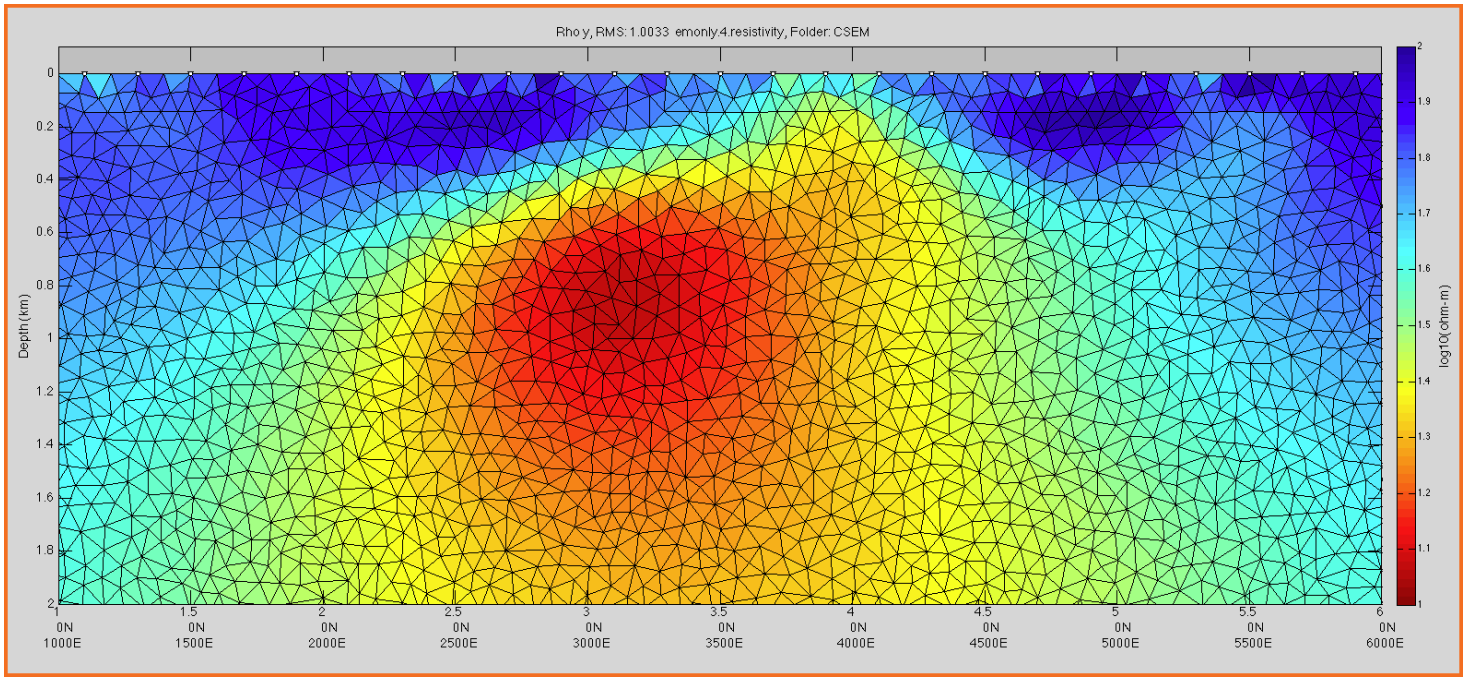
- MARE2DEM Input : Frequency Domain CSEM
- MARE2DEM Input : Tx Dipole or Bipole
- MIMDAS records full time series data of Tx I and Rx V
- Finely synced Tx and Rx recording allows Frequency Domain Transformation
- Superposition of Tx geometry to create 400m bipole





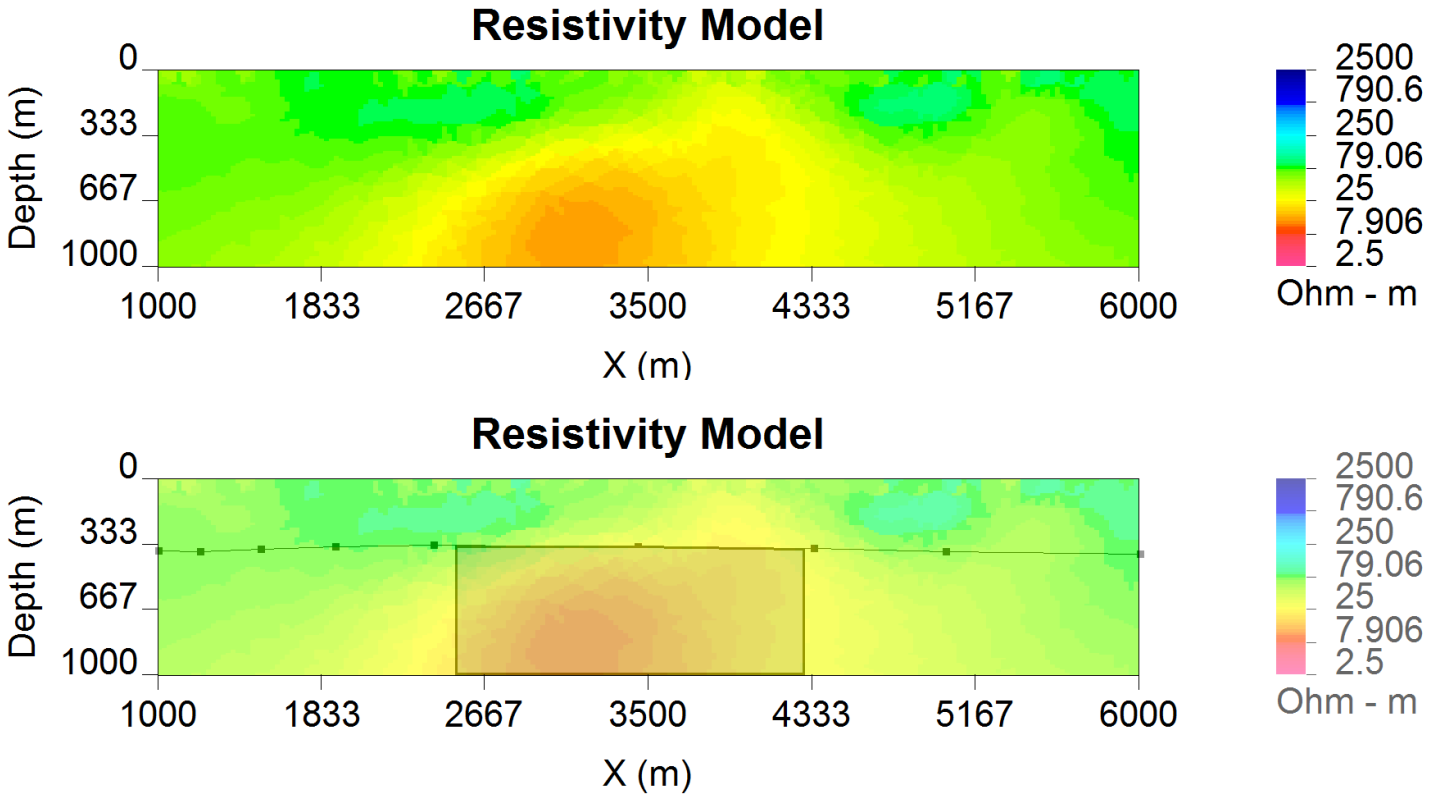
CSEM 2D Inversion MARE2DEM (I)

- Input Fundamental and first 2 Harmonics
- 0.0488 Hz, 0.1465 Hz and 0.2441 Hz
- Converges to RMS of 1.0 with amplitude error 5% - 4 iterations = 27 hours
- Adaptive Triangular FEM. Frees user from Mesh Design



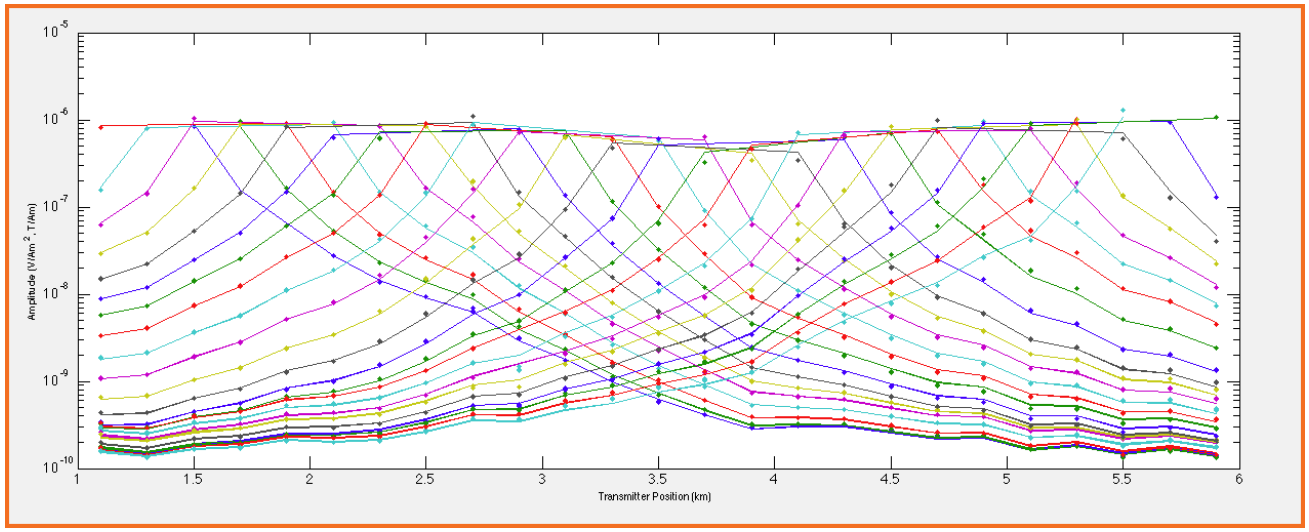
CSEM 2D Inversion MARE2DEM (II)

- No Layering in Overburden



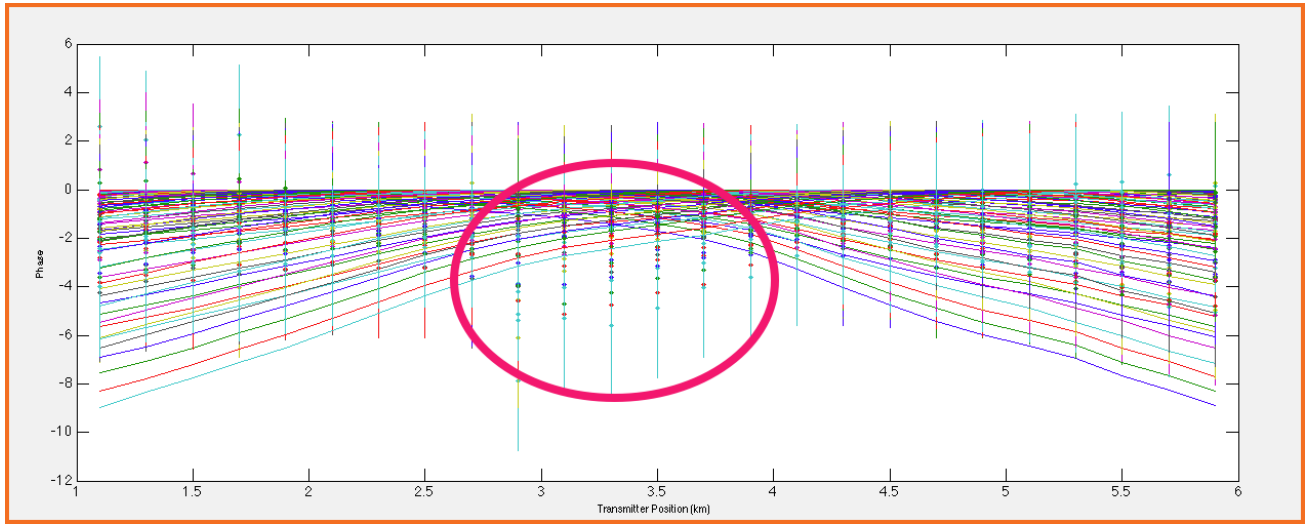
CSEM 2D Inversion MARE2DEM (III)

- Data fits, Amplitudes well fit



CSEM 2D Inversion MARE2DEM (IV)

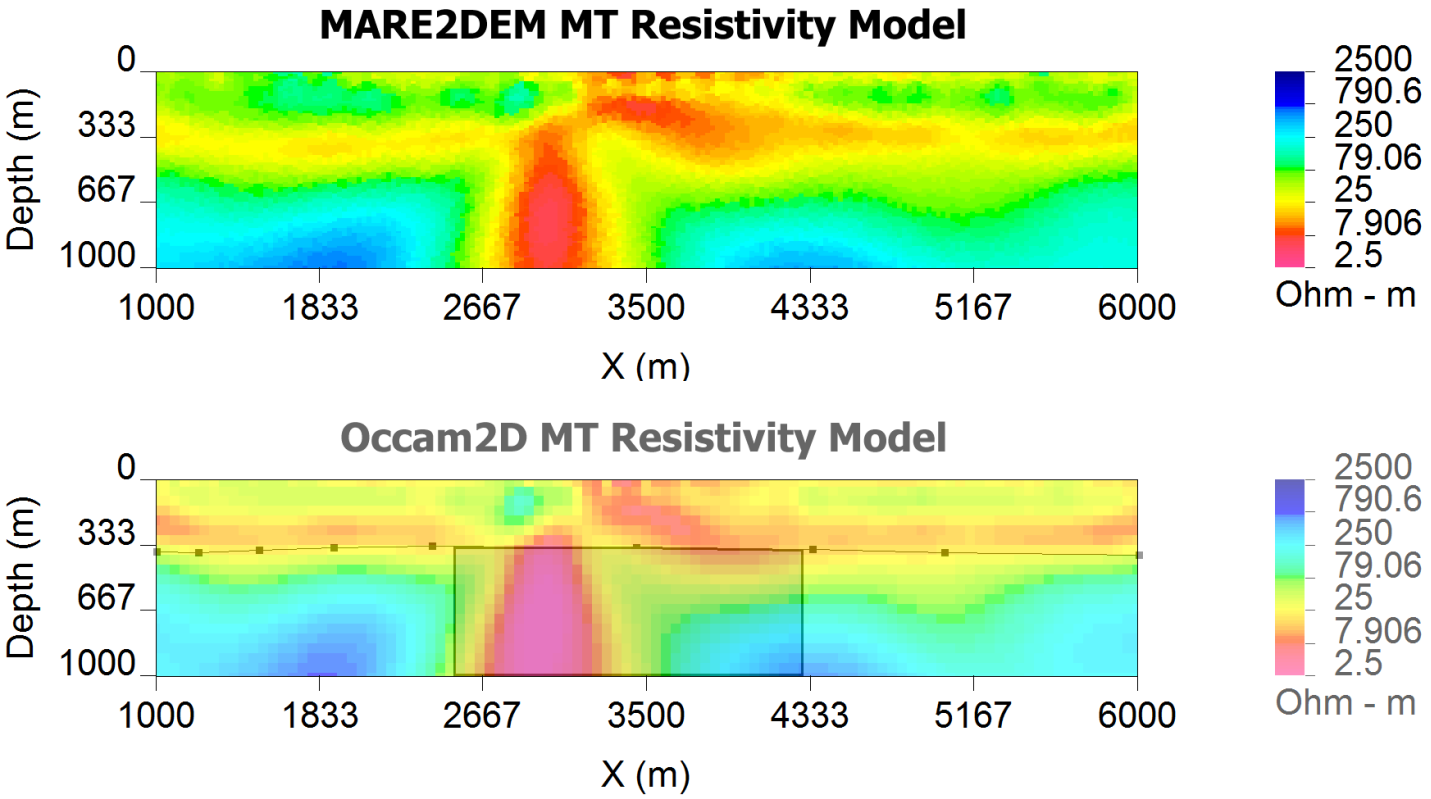
- Data fits, Phase can not be fit
- MARE2DEM Anisotropy, Yes. Complex resistivity, No
- Can't solve for IP component of phase
- Biggest misfit's over the Orebody



MT 2D Inversion MARE2DEM (I)

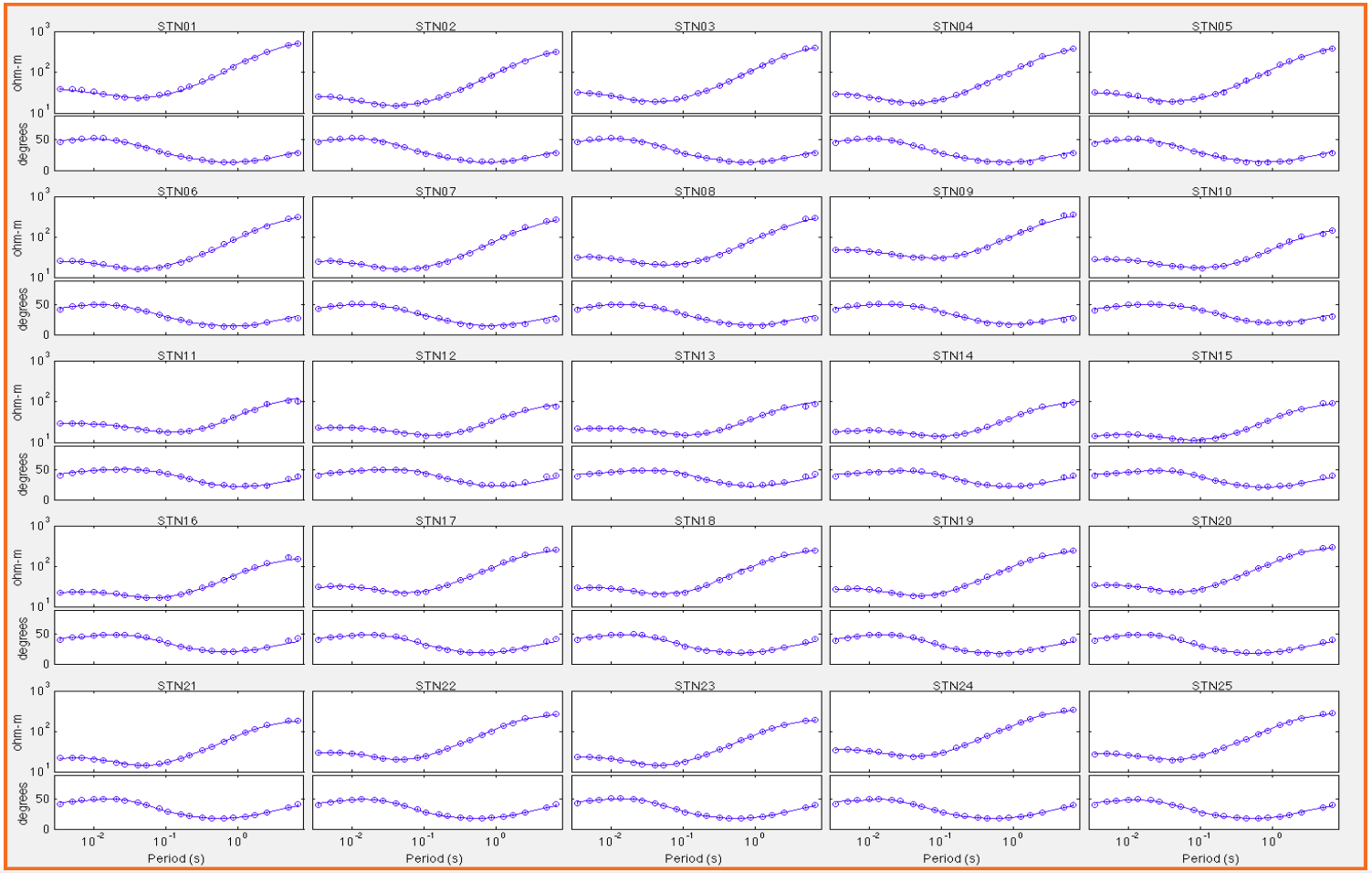
- Overburden Layering, agrees with Occam2D
- Converges to RMS 1.0 with error of 3.5%

1 degree of phase - 18 iterations = 2.6 hours



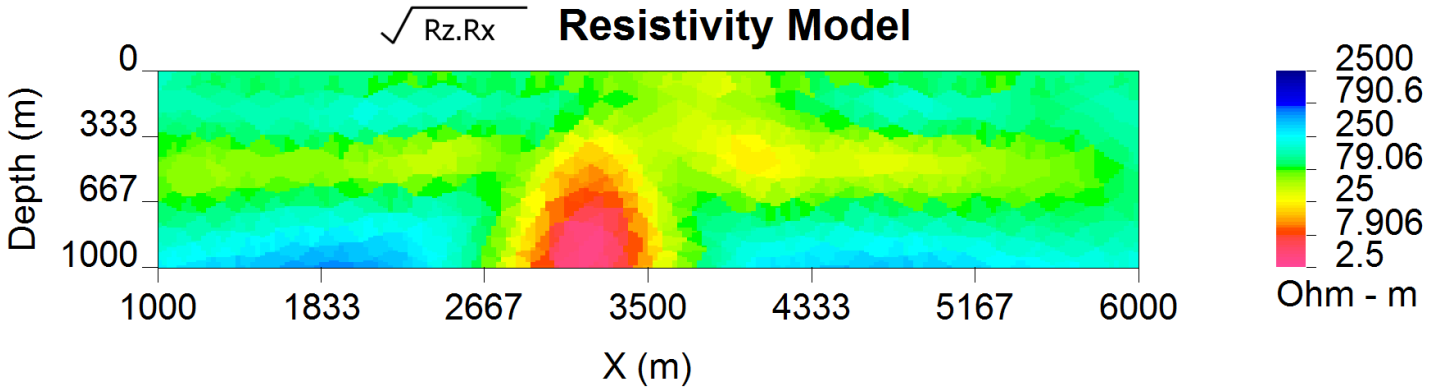
MT 2D Inversion MARE2DEM (II)

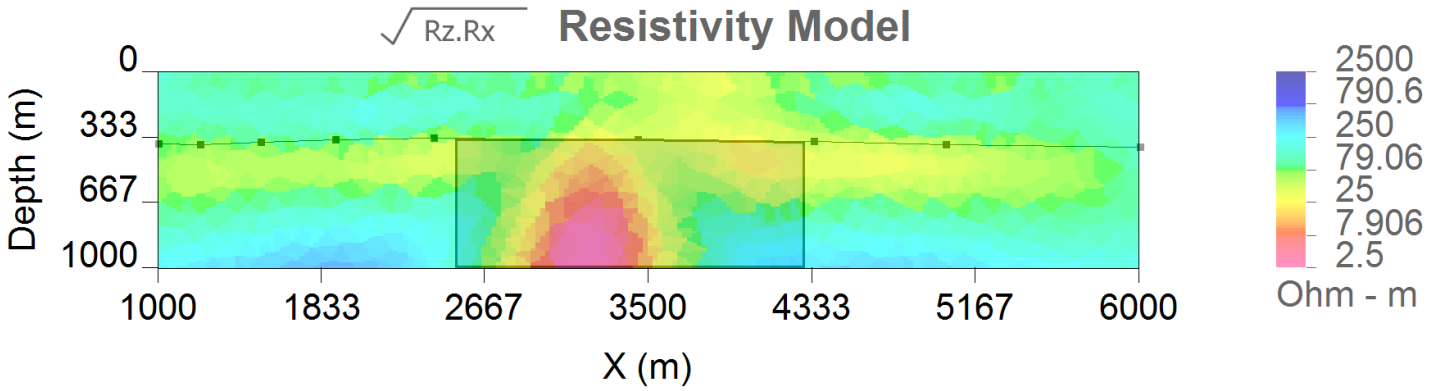
- Data Fits App. Resistivity and Phase



MT/CSEM Joint 2D Inversion MARE2DEM (I) with Anisotropy

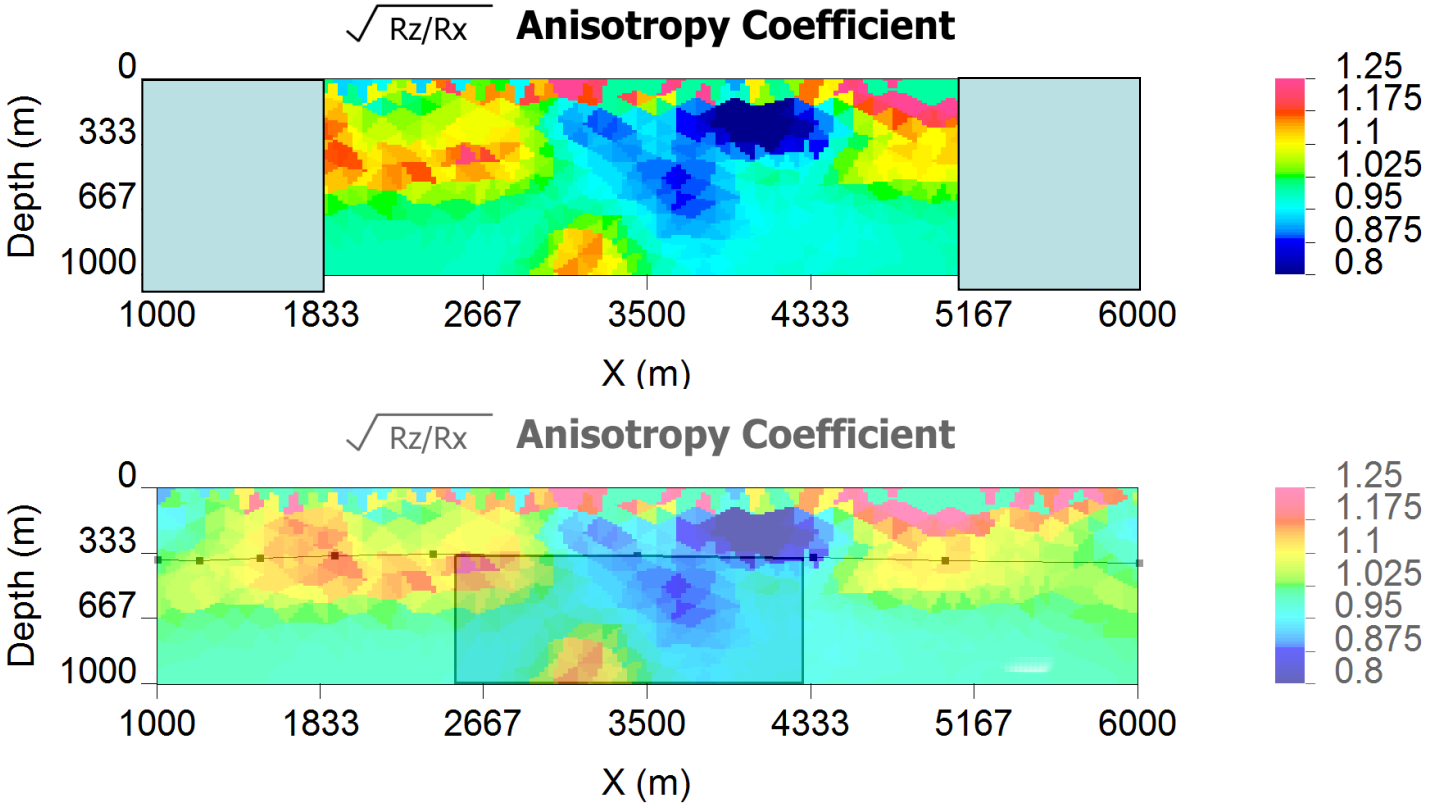
- Overburden Layering ?
- Similar convergence to other Inversions
- 22 Iterations 17.6 Days – 9 Threads / 8 cores





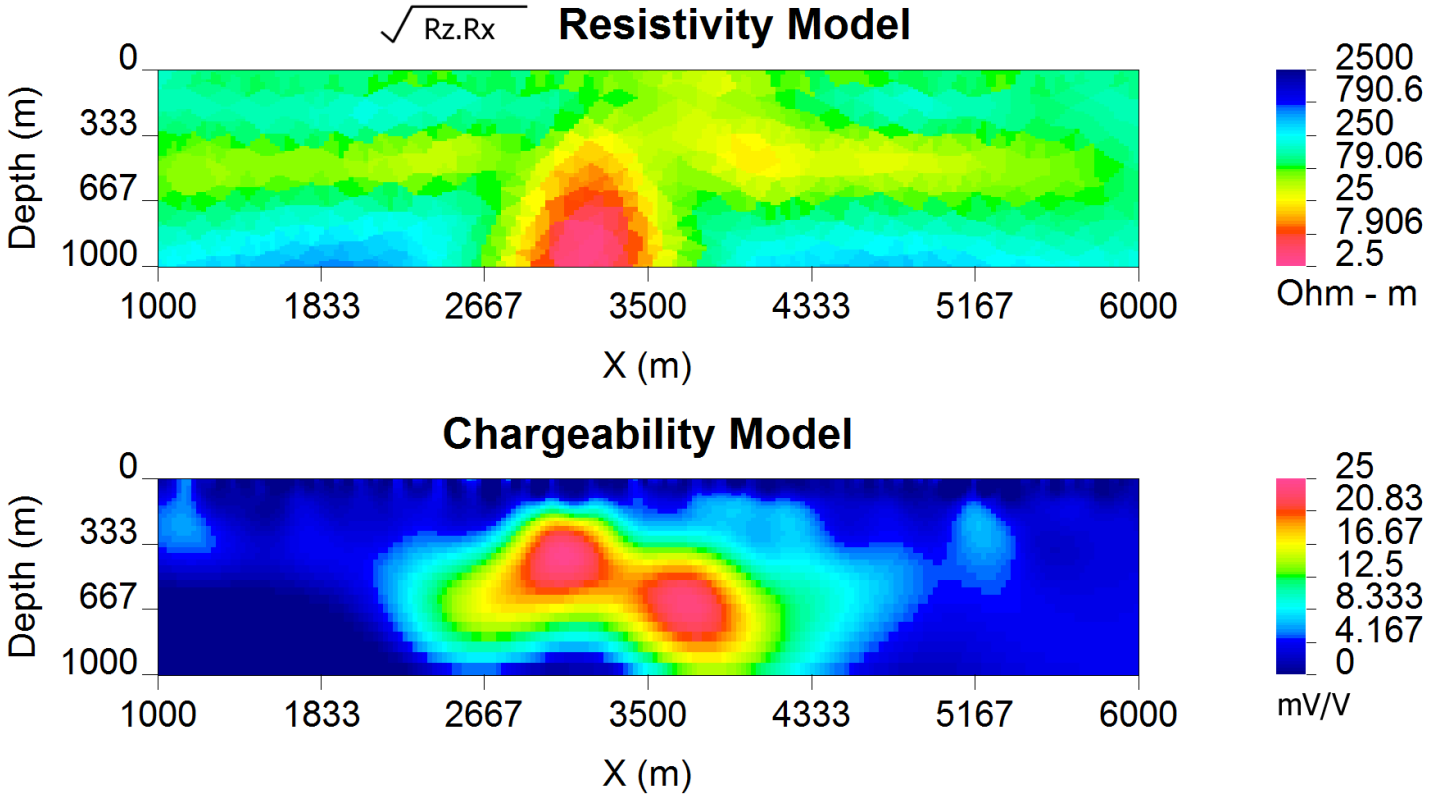
MT/CSEM Anisotropic Joint 2D MARE2DEM (II)

- Superposition has left us 1850E – 5150E
- Horizontal Anisotropy clearly
- Over Orebody Anisotropy swaps, Faulting?



Summary

- Solving for Anisotropy has added value (Shale and IP Source associated with Vertical Anisotropy)
- Reposing Surveys as CSEM makes EM Coupling part of the solution and not part of the problem
- Need more experience with the MARE2DEM Code



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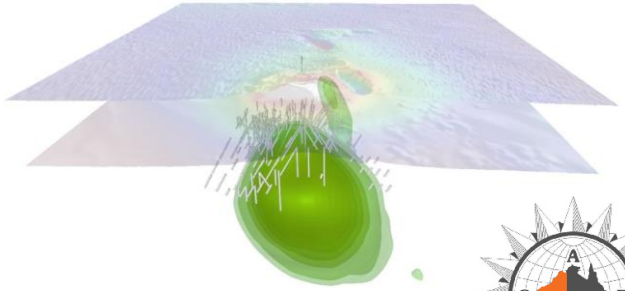

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