Traditional EM & onshore hydrocarbon exploration

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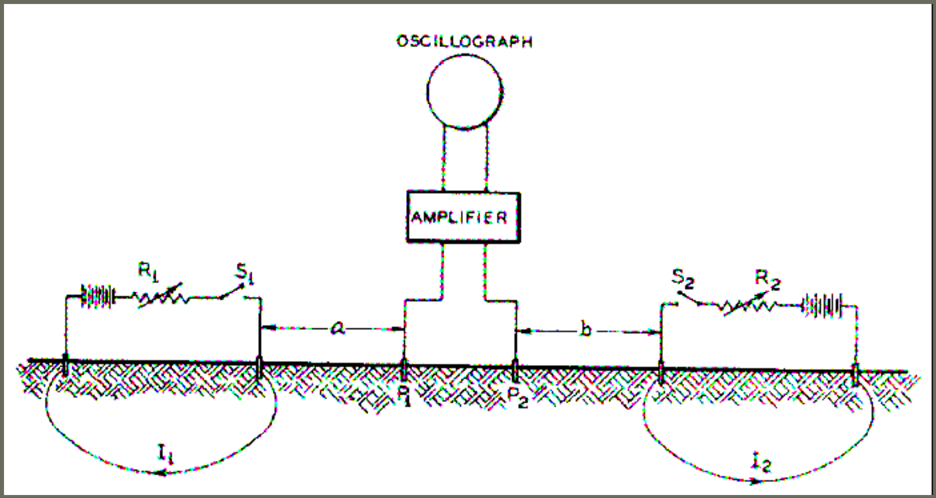
Non-Seismic Methods Workshop Bahrain, 13 Oct. 2008

EM / resistivity methods and the Oil patch



Statham, 1936: Electric earth transients in geophysical prospecting. ***Geophysics*** **Vol. 1**

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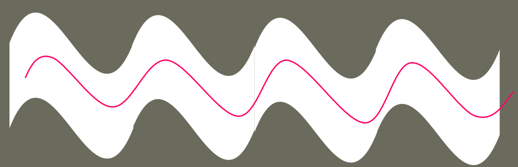
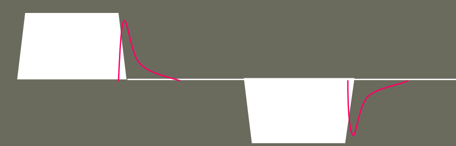
Fundamentals

- Frequency domain EM



- Time domain EM



Diffusive wave propagation !!

- Electric fields
- Magnetic fields
- Natural sources
- Transmitter based systems

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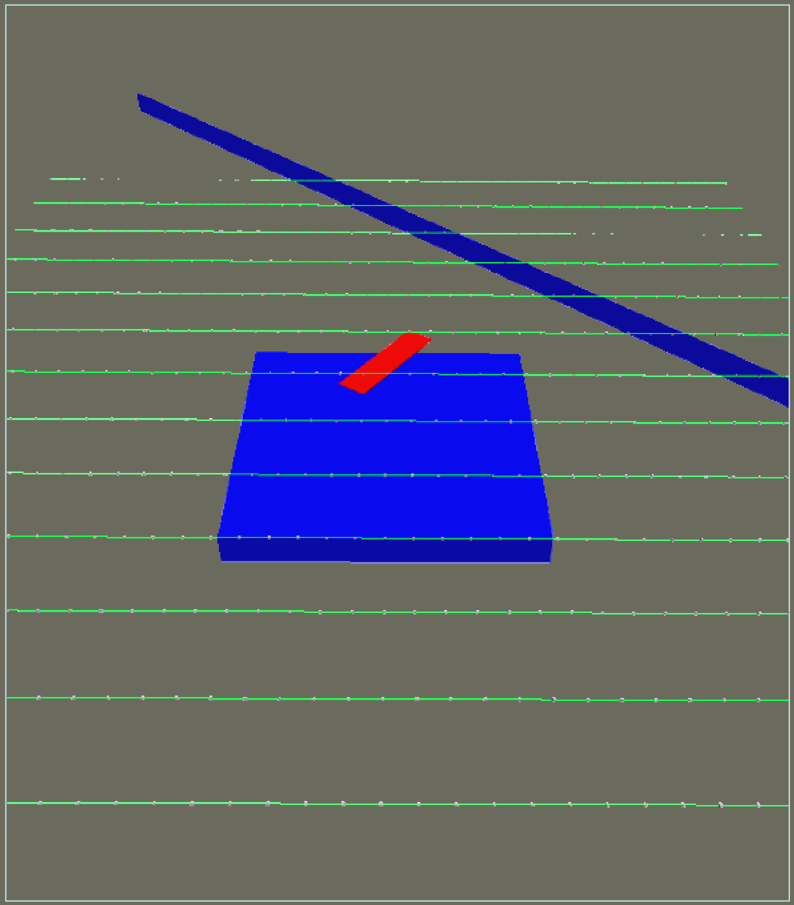
The model

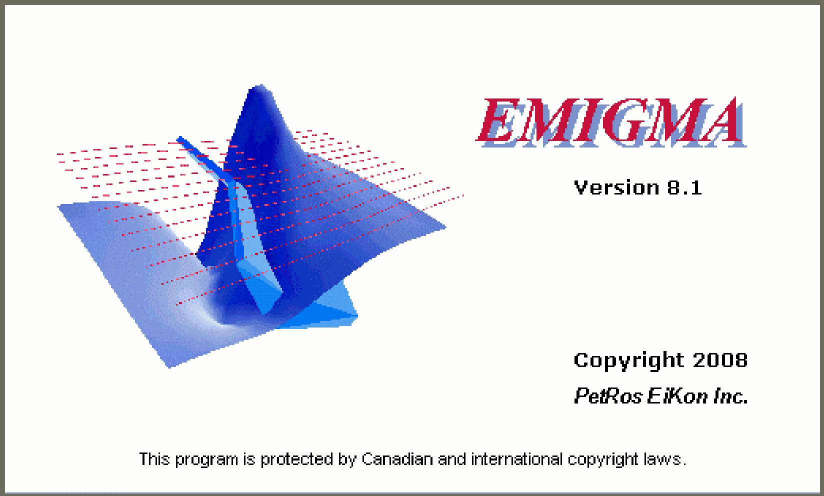
- Reservoir
  - 2 by 2 km, 200 m thick
  - 200 Ωm @ 500 m depth
- Background
  - 30 Ωm sedimentary basin
- Fault
  - 10 km long, 5 Ωm
  - Extending from 25 to 225 m depth
- Clay lense
  - 800 by 200 m, 10 m thick
  - 0.04 Ωm @ 100 m depth



Reviewed methods

- Magnetotellurics
- Controlled source audiomagnetotellurics
- Long offset transient electromagnetics
- Fixed loop transient EM
- Dipole-dipole arrays as…
  - Direct current
  - Frequency domain induced polarization
  - Time domain induced polarization

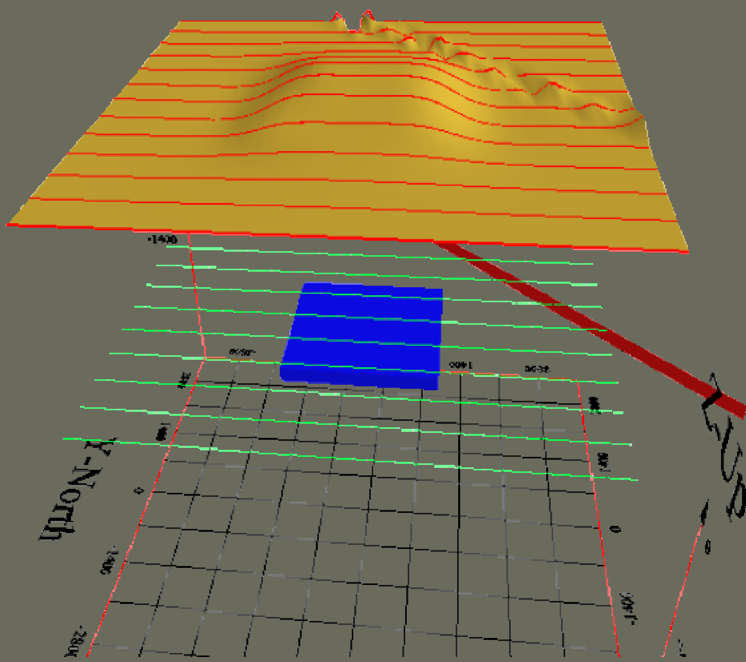
Modelling tool used



- 3D integral equation multi-method modelling package

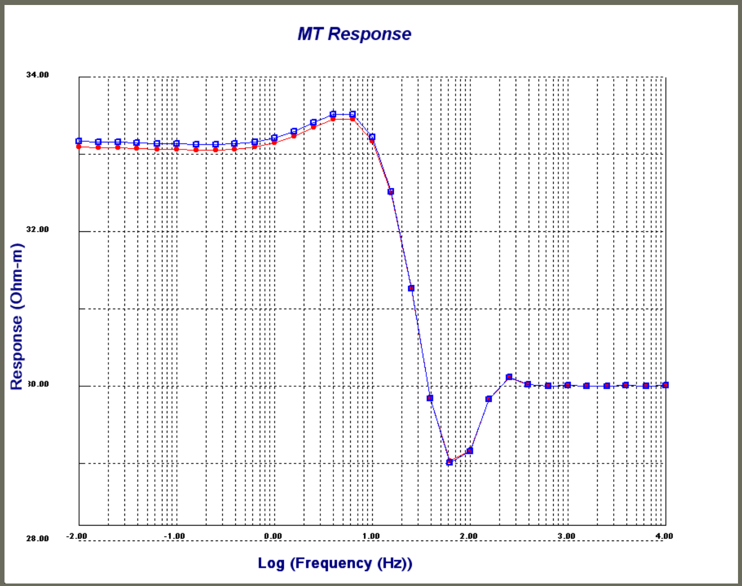
Habashy, T.M., Groom, R.W. and Spies, B.R. [1993] Beyond the Born and Rytov Approximations: A Nonlinear Approach to Electromagnetic Scattering, Journal of Geophysical Research, 98, 1759-1775.

Magnetotellurics (MT)



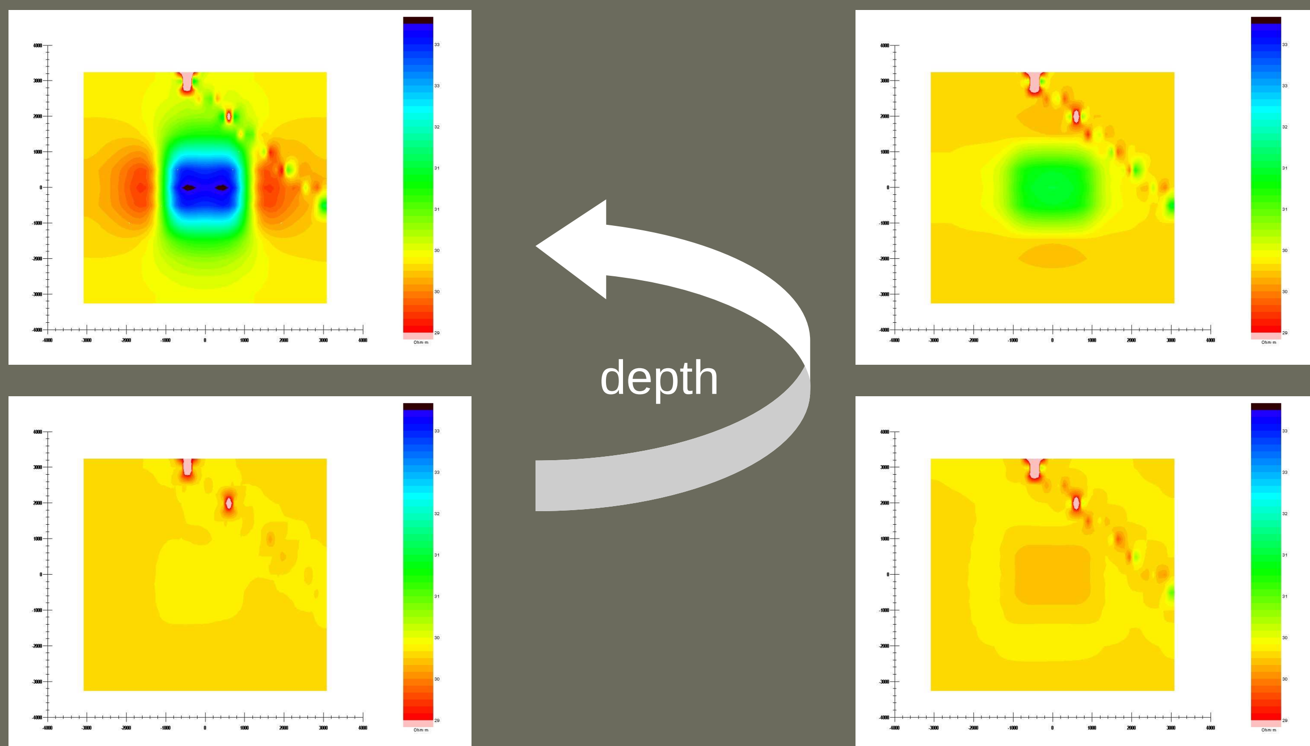
MT survey layout & impedance (Zxy) plot

MT Apparent resistivity

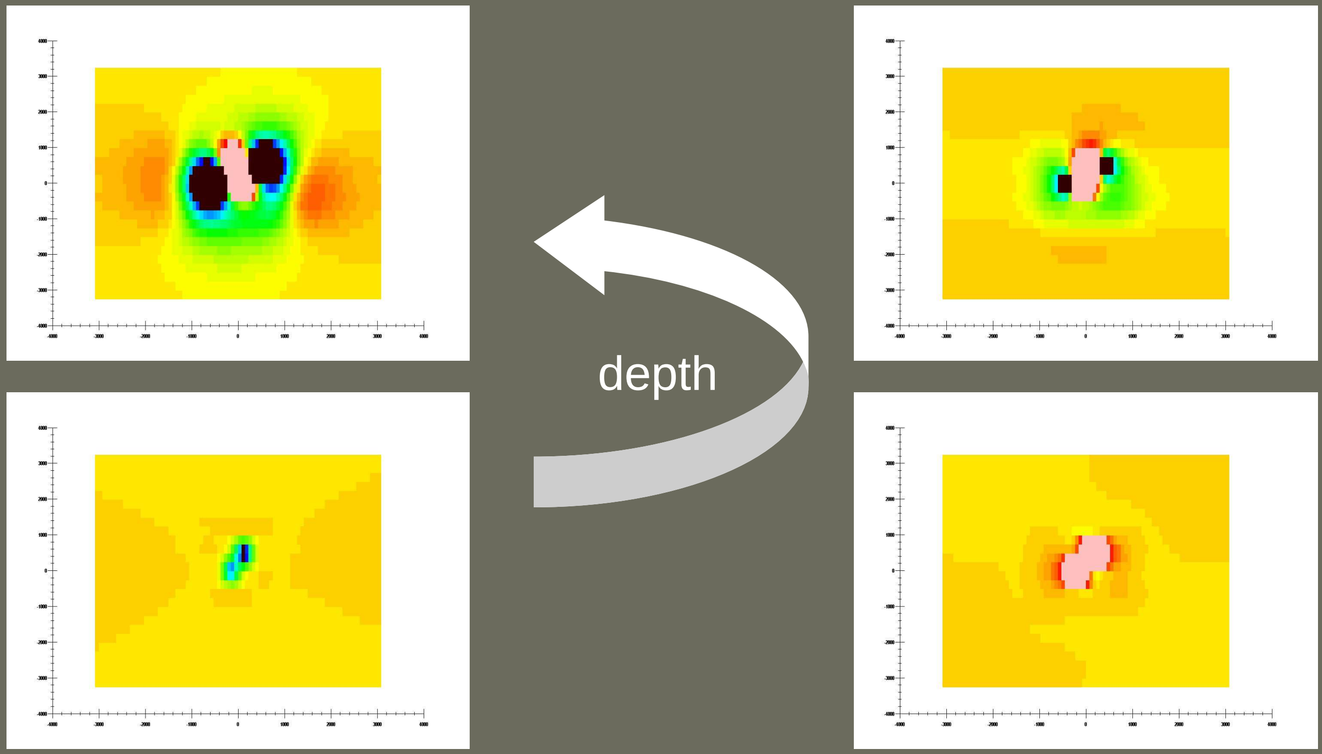


Frequency (0.01 – 10k Hz)

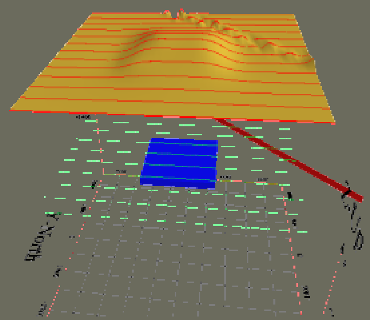
Zxy depth slices, reservoir & fault



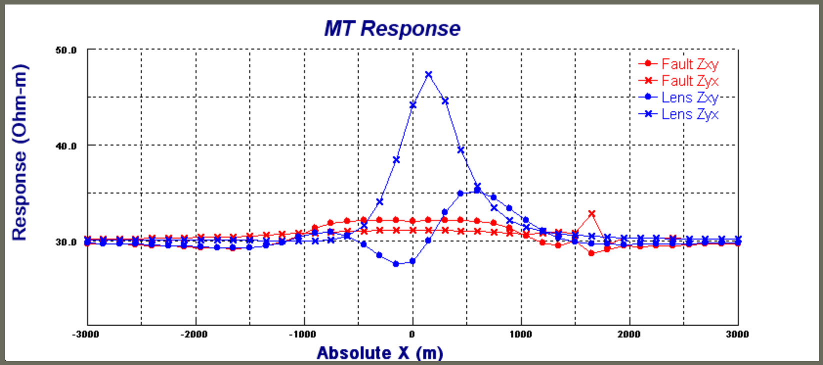
Zxy depth slices, reservoir & lens



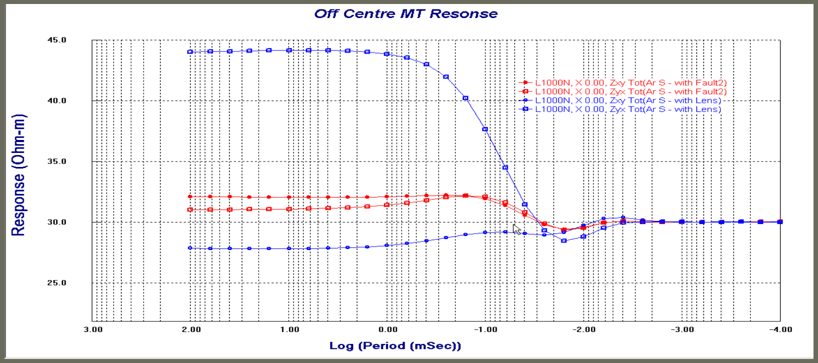
MT impedance response



- Very small response
- Near surface distortion

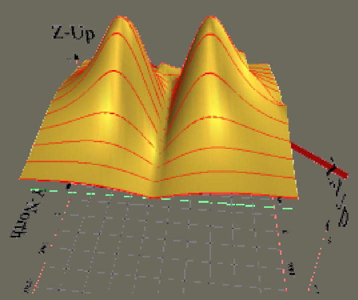


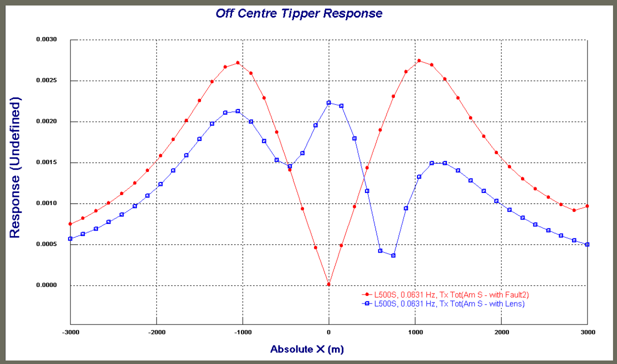
Frequency 0.1 Hz



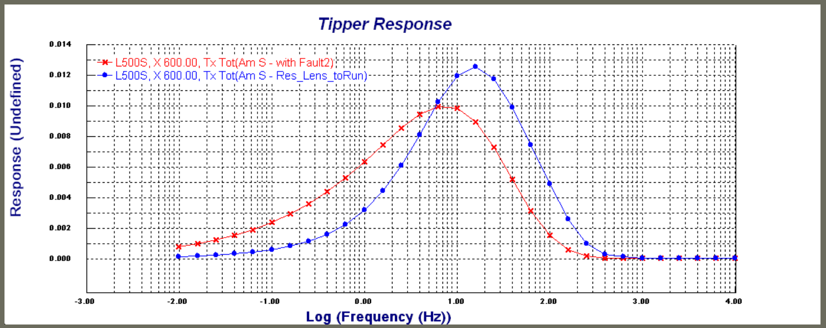
Line 1000N

MT Tipper response



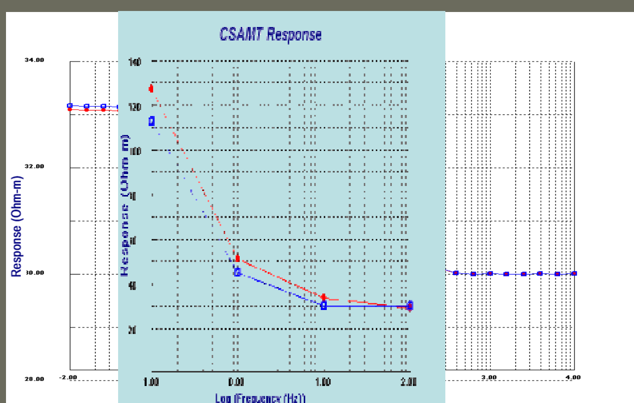


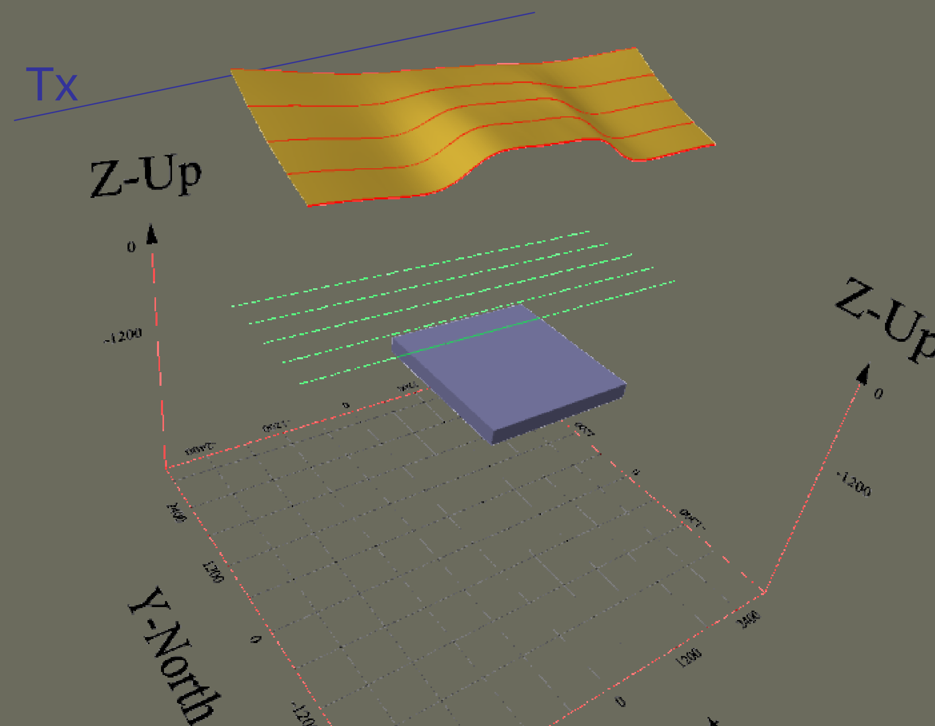
- Tipper below resolution
- Also heavily distorted



Controlled Source Audio-MT (CSAMT)

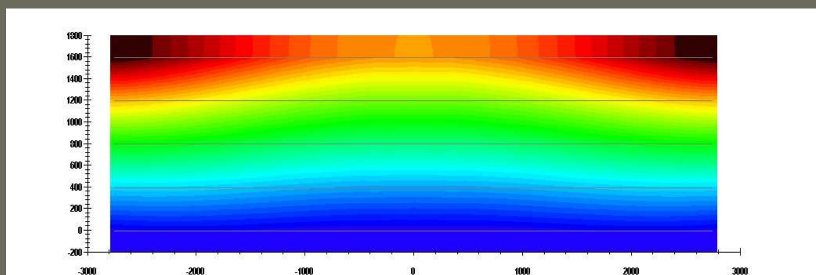
- Tx 10 km wire, 6 km away
- Rx as in MT
- Frequency 0.1 – 100 Hz



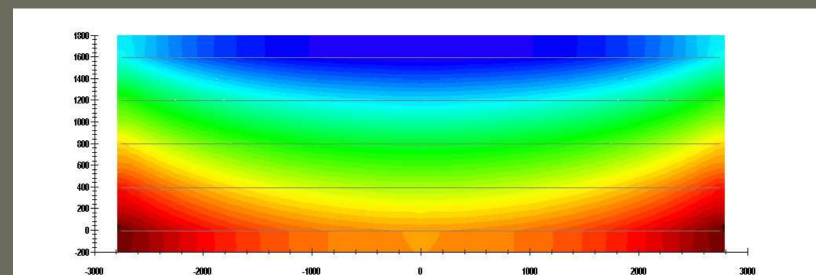


CSAMT impedance & electric field

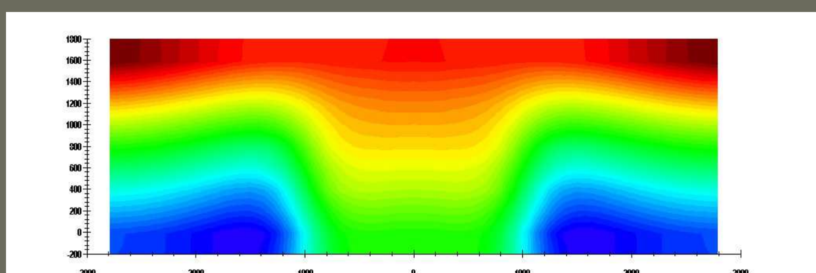
Zxy background



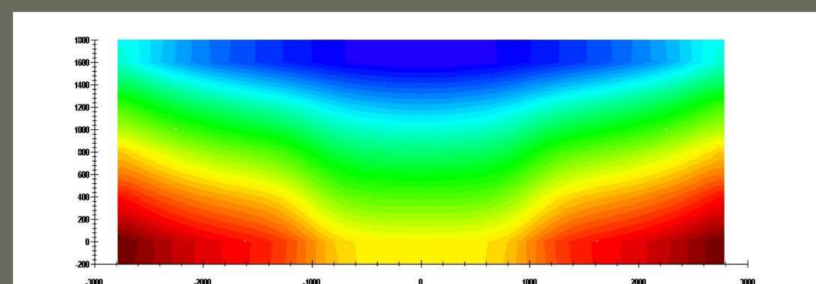
Ex background



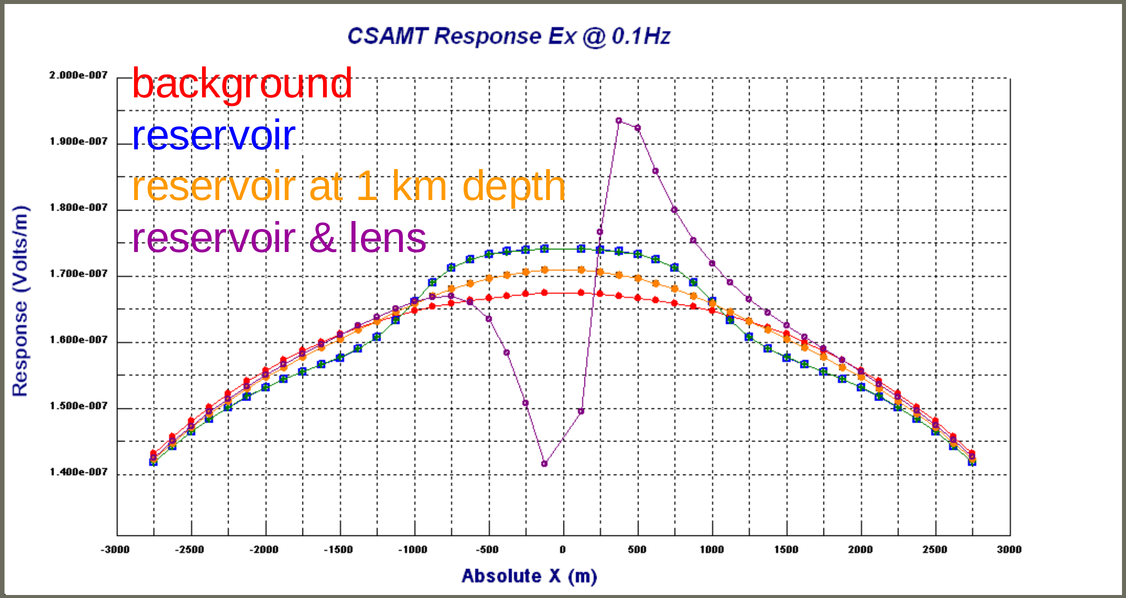
Zxy reservoir



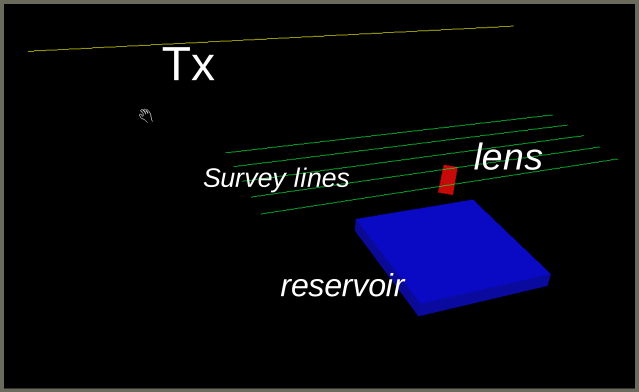
Ex reservoir



Traditional CSAMT configuration

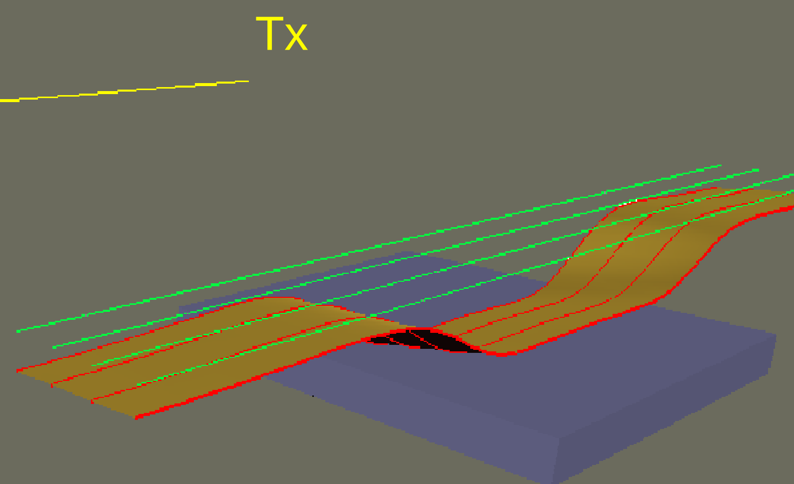


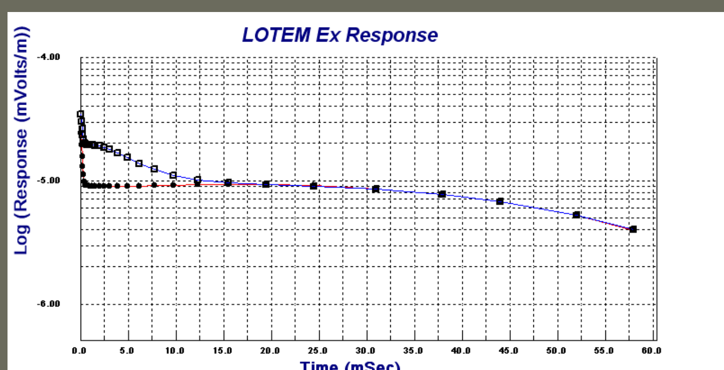
- Sensitivity small
- Source effects dominate
- Big distortion from near surface



Long Offset Transient EM (LOTEM)

- Tx 10 km wire, 6 km away
- Rx dipoles Ex & Ey
- Step response 0.1 - 60 ms

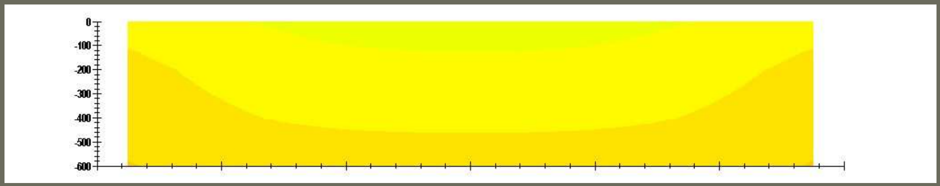




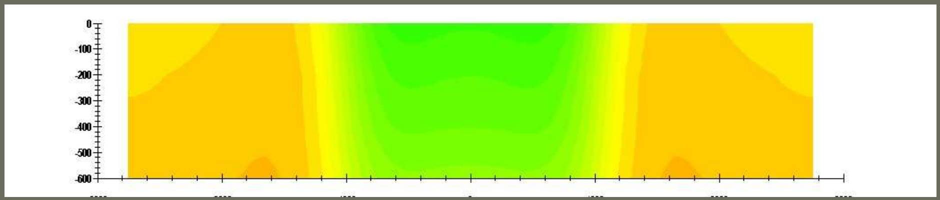
LOTEM decay for two models

LOTEM Ex maps

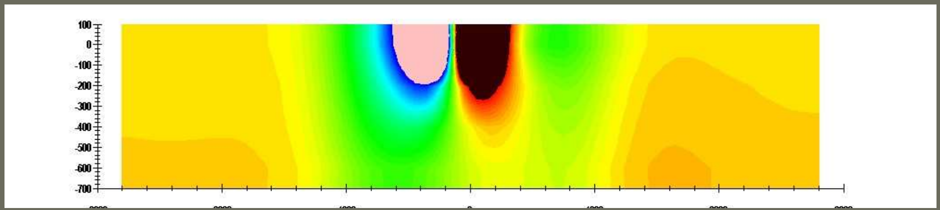
- Near surface anomaly beats reservoir in magnitude
- Reservoir footprint still indicative



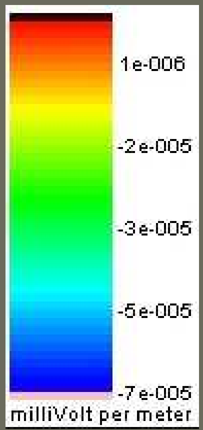
Timeslice 2ms background



Timeslice 2ms reservoir

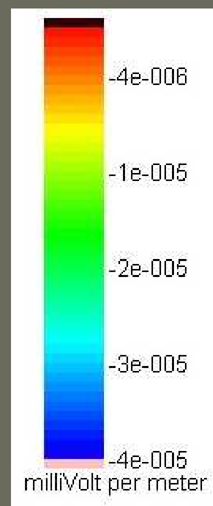


Timeslice 2ms reservoir & NS lens

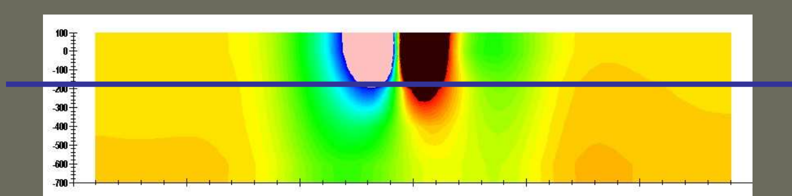


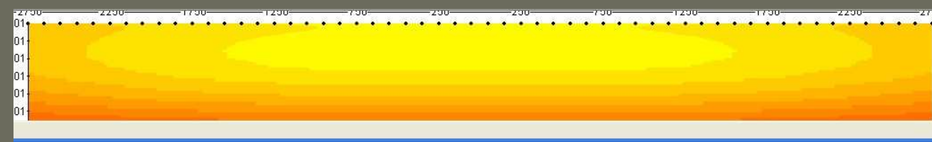
LOTEM Ex sections

- Need to be far enough away from near surface features

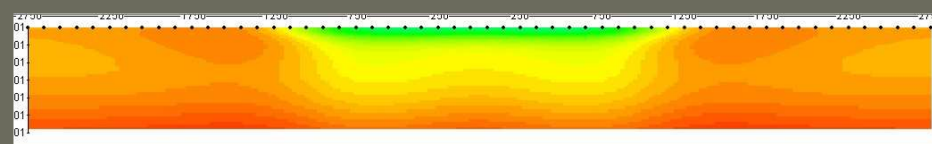


Section location on timeslice

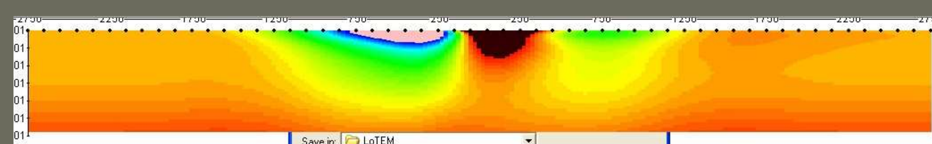




Pseudo section background



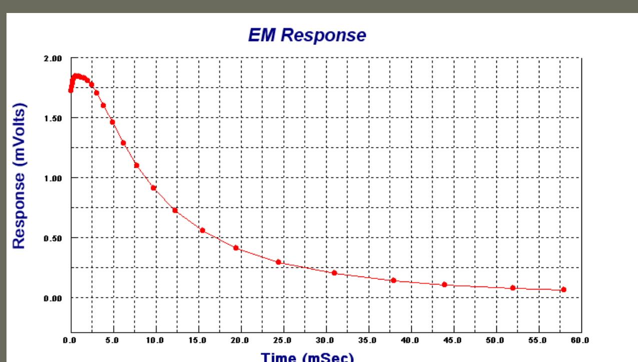
Pseudo section reservoir



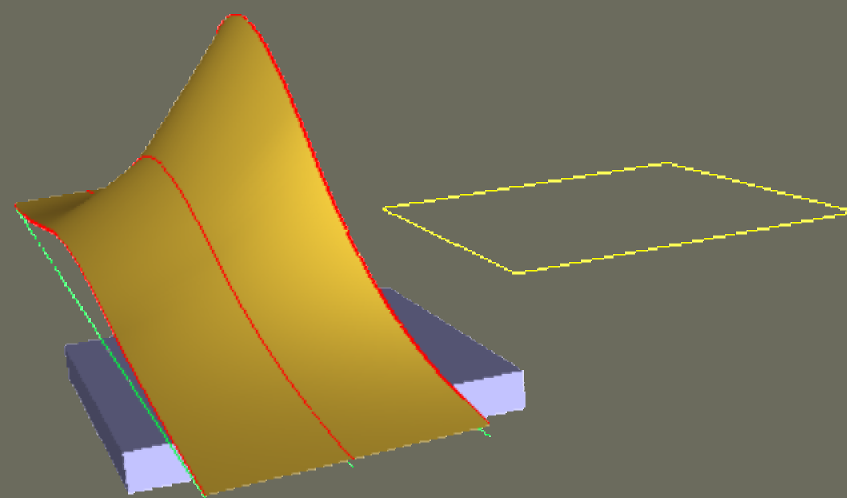
Pseudo section reservoir & NS lens

Fixed loop TEM

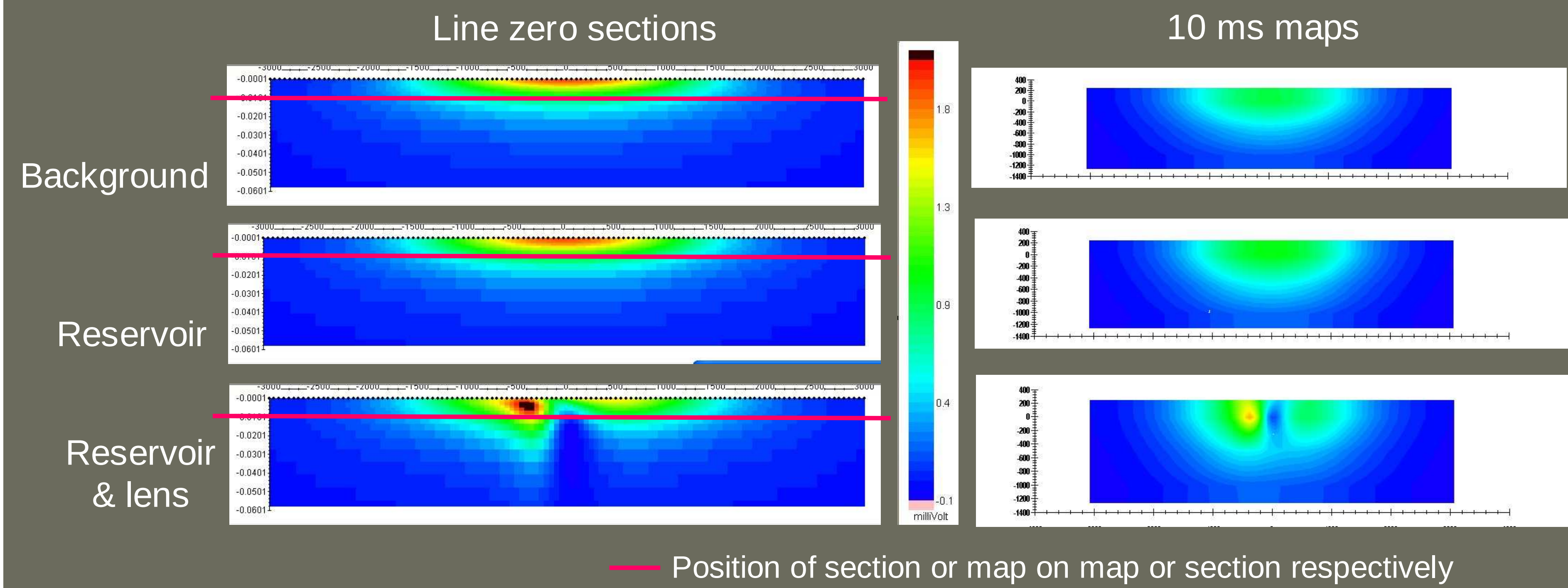
- 2x2 km loop transmitter
- Step response 0.1 - 60 ms
- 300m dipole receivers



Fixed loop TEM decay



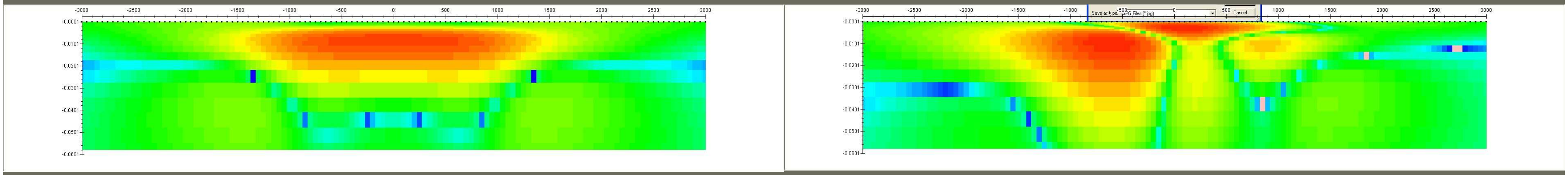
Loop source response

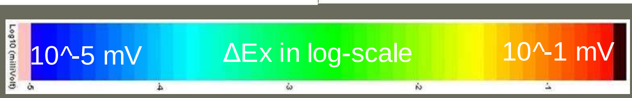


Loop source sensitivity

- Same issues as other methods
- Removal of source field possible
- Slightly less near surface distortion due to loop source

scattered E-field sections for reservoir and reservoir & NS lens





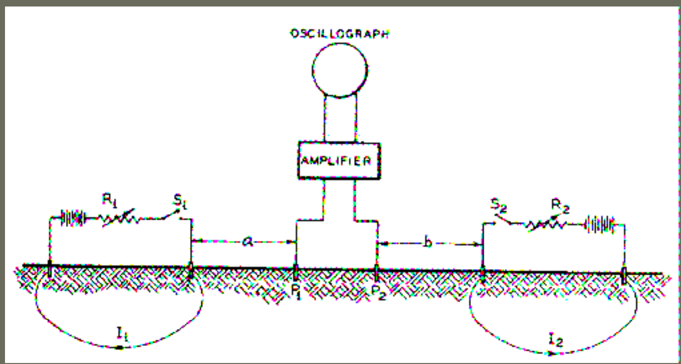
Interim resume

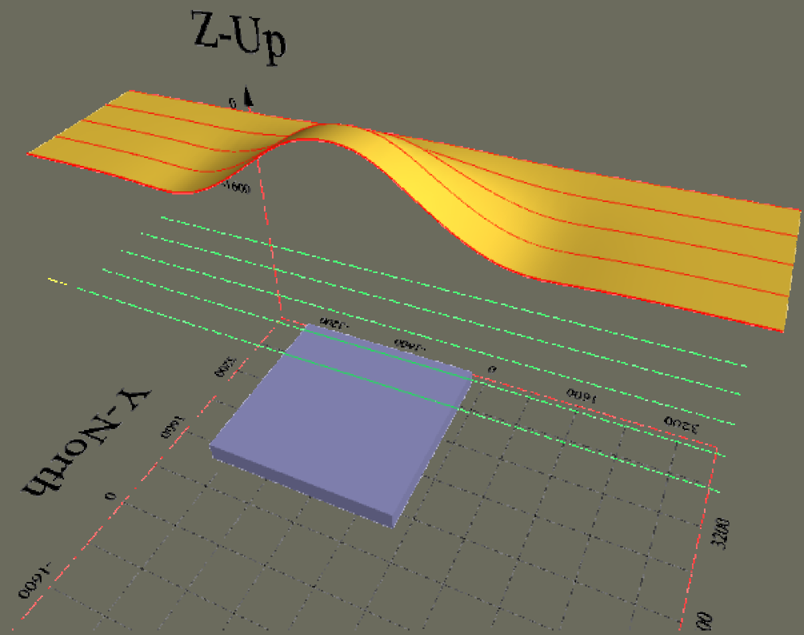
- Near surface inhomogeneities distort anomaly, especially electric field

- No fundamental difference between frequency and time domain

Dipole – dipole configurations

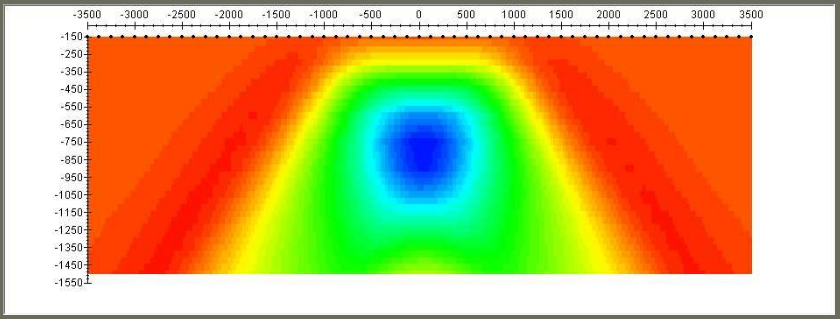
- electric resistivity tomography
- Induced Polarization
- MTEM, FTEM, etc ..



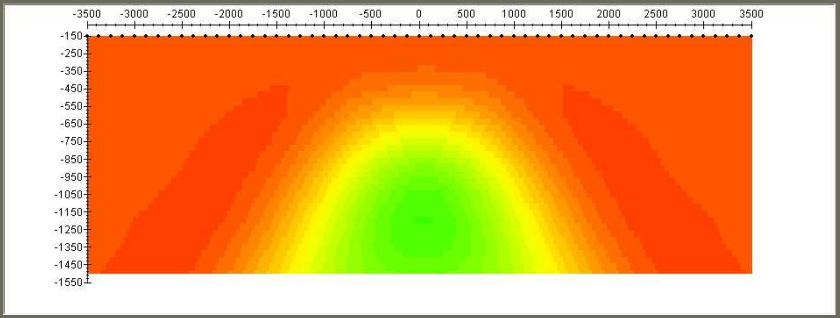


DC apparent resistivity pseudo sections

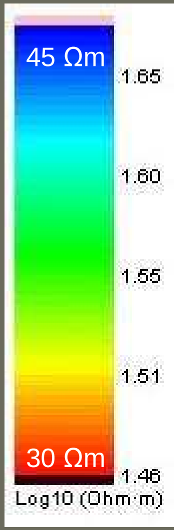
- Good sensitivity to resistivity contrast

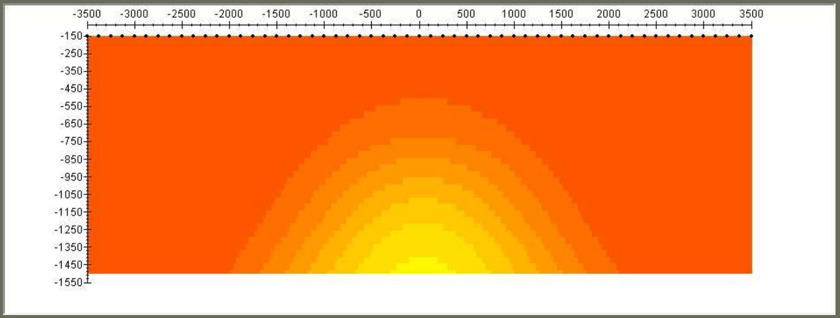


Reservoir @ 500m depth



Reservoir @ 1000m depth

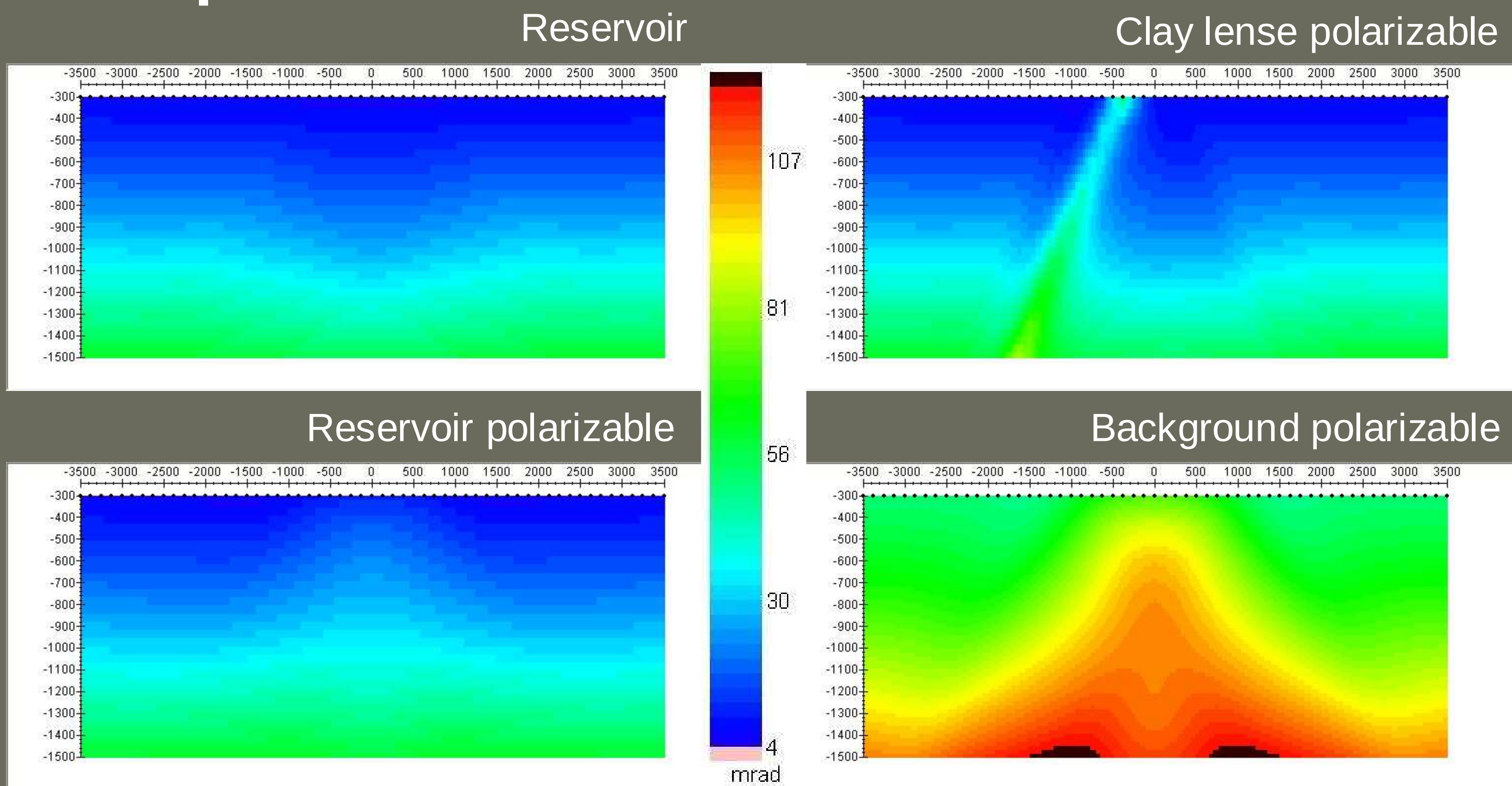




Reservoir @ 1500m depth

Results shown at 0.01 Hz frequency domain IP

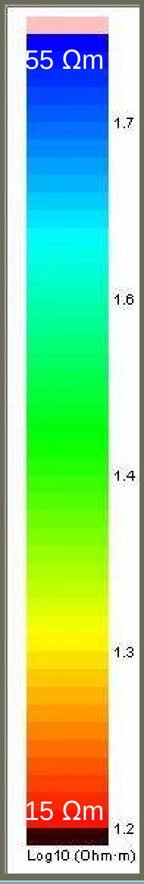
IP response

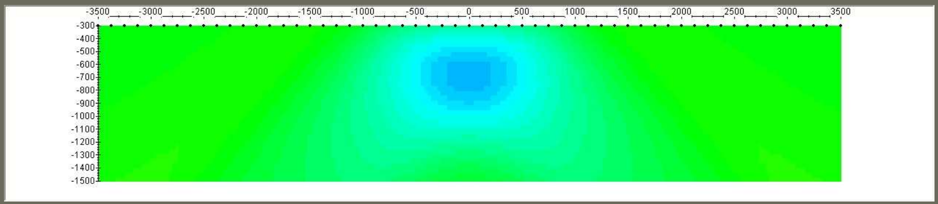


Pseudo sections of IP phase [mrad] @ 0.1 Hz, Cole-Cole parameter: c=0.5, m=0.3, T=1s

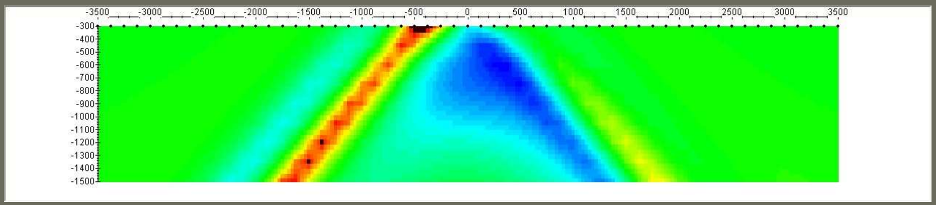
Near surface inhomogeneities

- Also very strong distortion





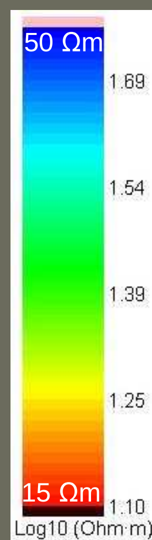
Reservoir @ 500m depth

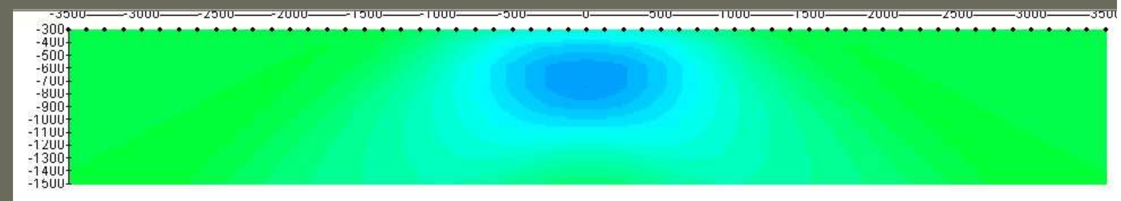


Reservoir & overburden lens

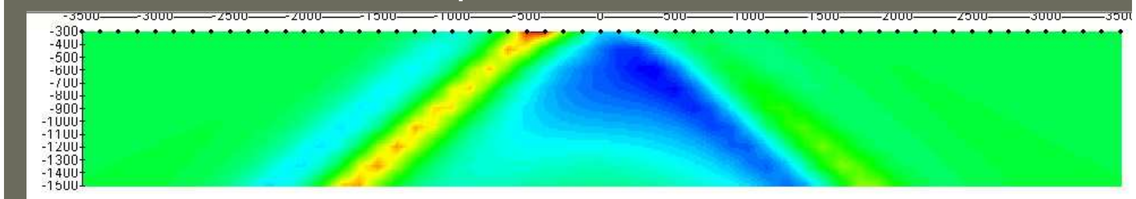
Electrode spacing

- Size matters !

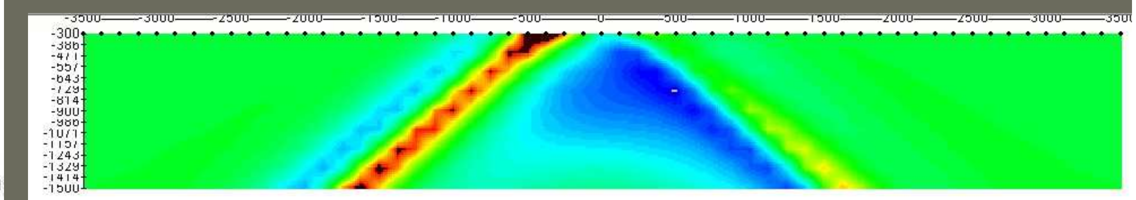




Reservoir @ 500m depth



Reservoir & clay lens with 500 m bipole size



Reservoir & clay lens with 300 m bipole size

So is there a winner?

- target resolution ~ inhomogeneities
- Frequency domain <> Time domain
- Survey geometry crucial

Where is the real challenge?

- Processing / inversion / interpretation
- Integration with seismic et al. crucial

- Further approaches not considered here e.g.
  - Borehole surveys
  - AEM for proxies