KMS Technologies – KJT Enterprises, Inc.

Marine EM in the Gulf of Mexico: Advances & Outlook

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AGU/SEG Joint Assembly
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Marine EM in the Gulf of Mexico: Advances & Outlook.

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New Orleans, May 2005

The scenario

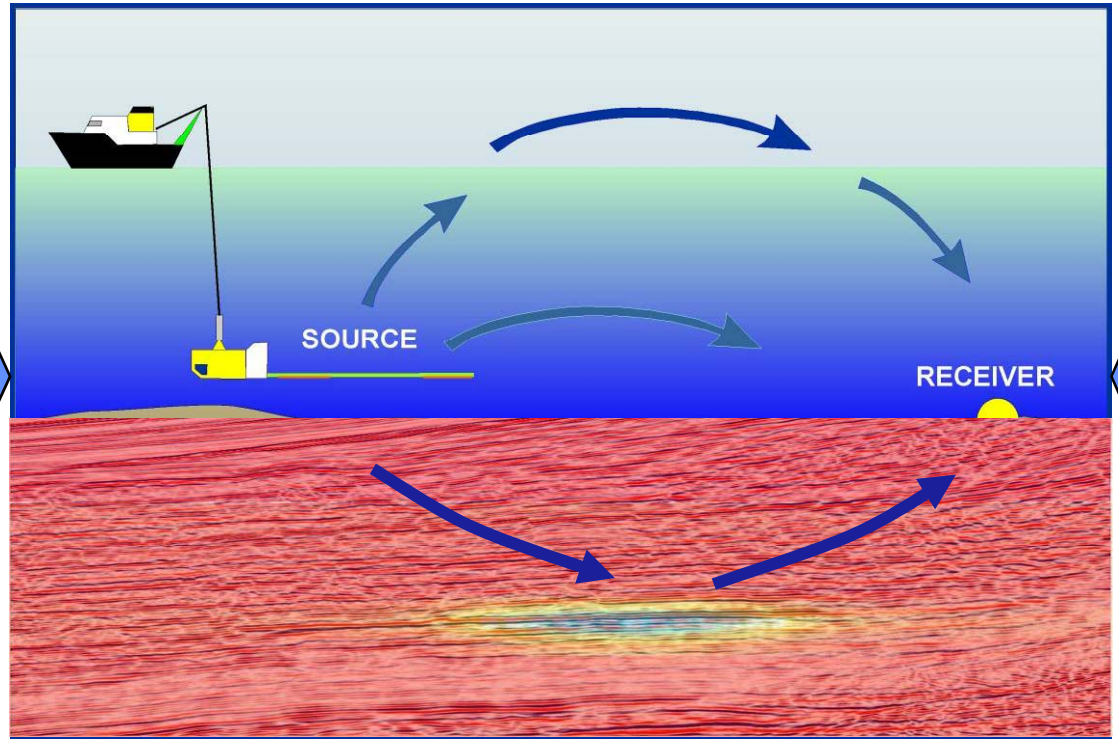
- **Oil price is high**
- **Industry looking for new opportunities**
- **Alternate exploration methods needed**
- **EM is one solution**

Two type of EM solutions

- Active source electromagnetic sounding
  - Source fields generated by a man-made source.
- Magnetotelluric sounding
  - Source fields generated naturally in the Earth's ionosphere and atmosphere.

The controlled source EM technique

Controlled electro-magnetic signals are generated at frequencies which penetrate the earth.



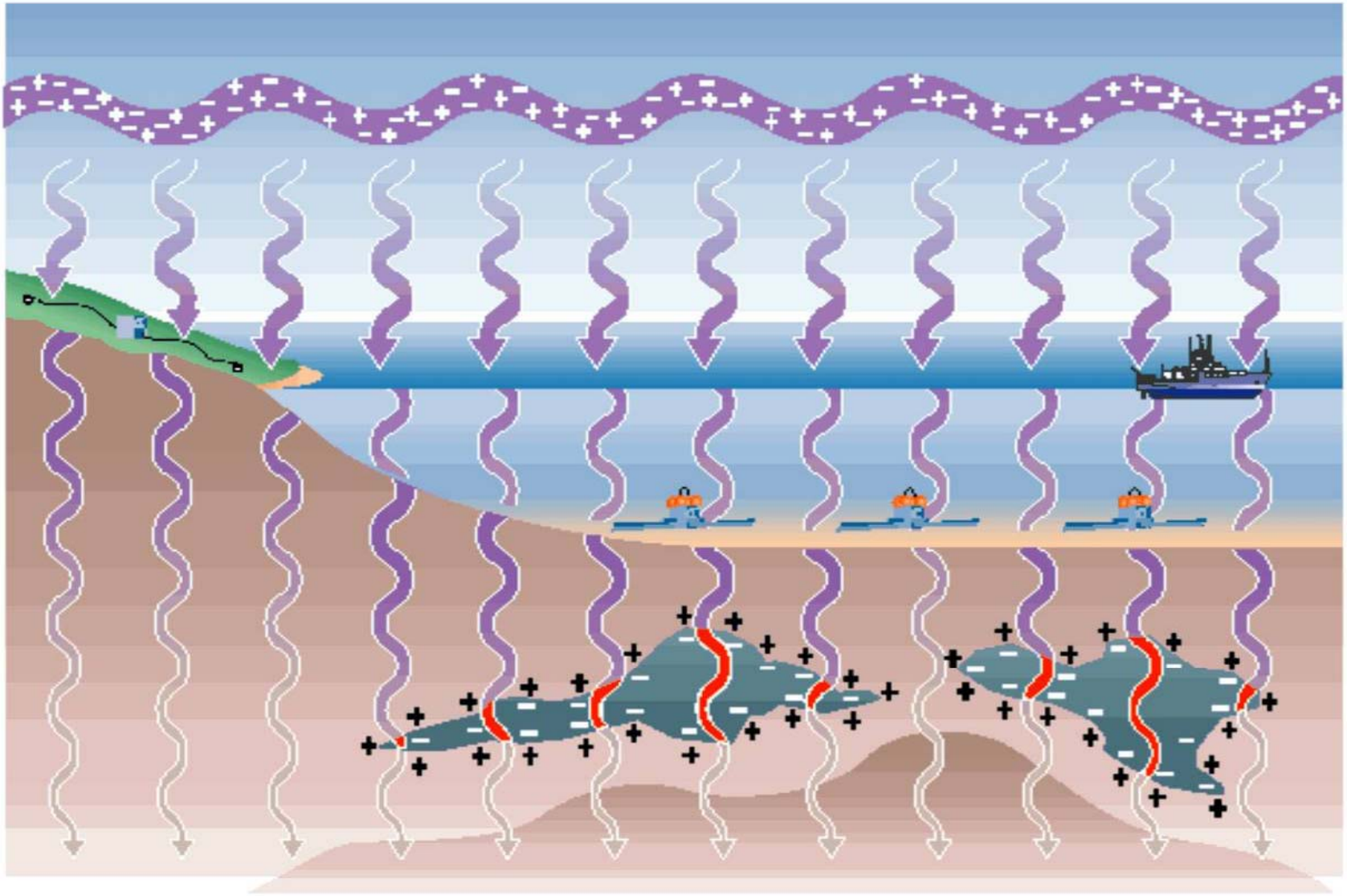
Receiver arrays detect changes in the earth's response to this signal.

The response is sensitive to thin resistive layers - often caused by hydrocarbon reservoirs.

Source ready to be deployed

Receiver nodes on deck

Sources & response



Picture courtesy of Steve Constable, I.G.P.P., Scripps Institution of Oceanography

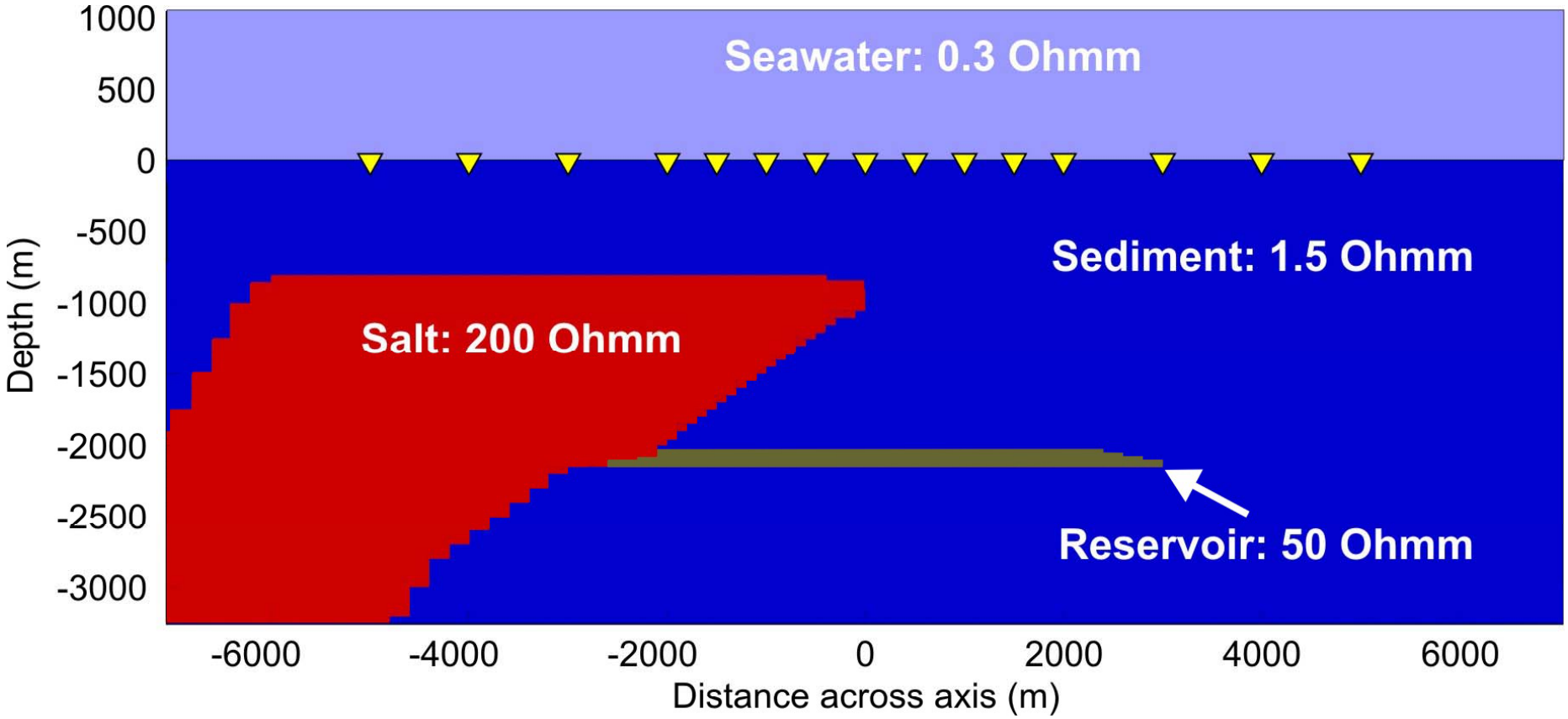
Passive Source EM sounding

- Source fields naturally generated
- Resolution primarily from varying frequency
- Relies on predominantly horizontal current flow – very insensitive to resistors
- Can determine resistivity structure to tens of km below seafloor.
- Background resistivity structure

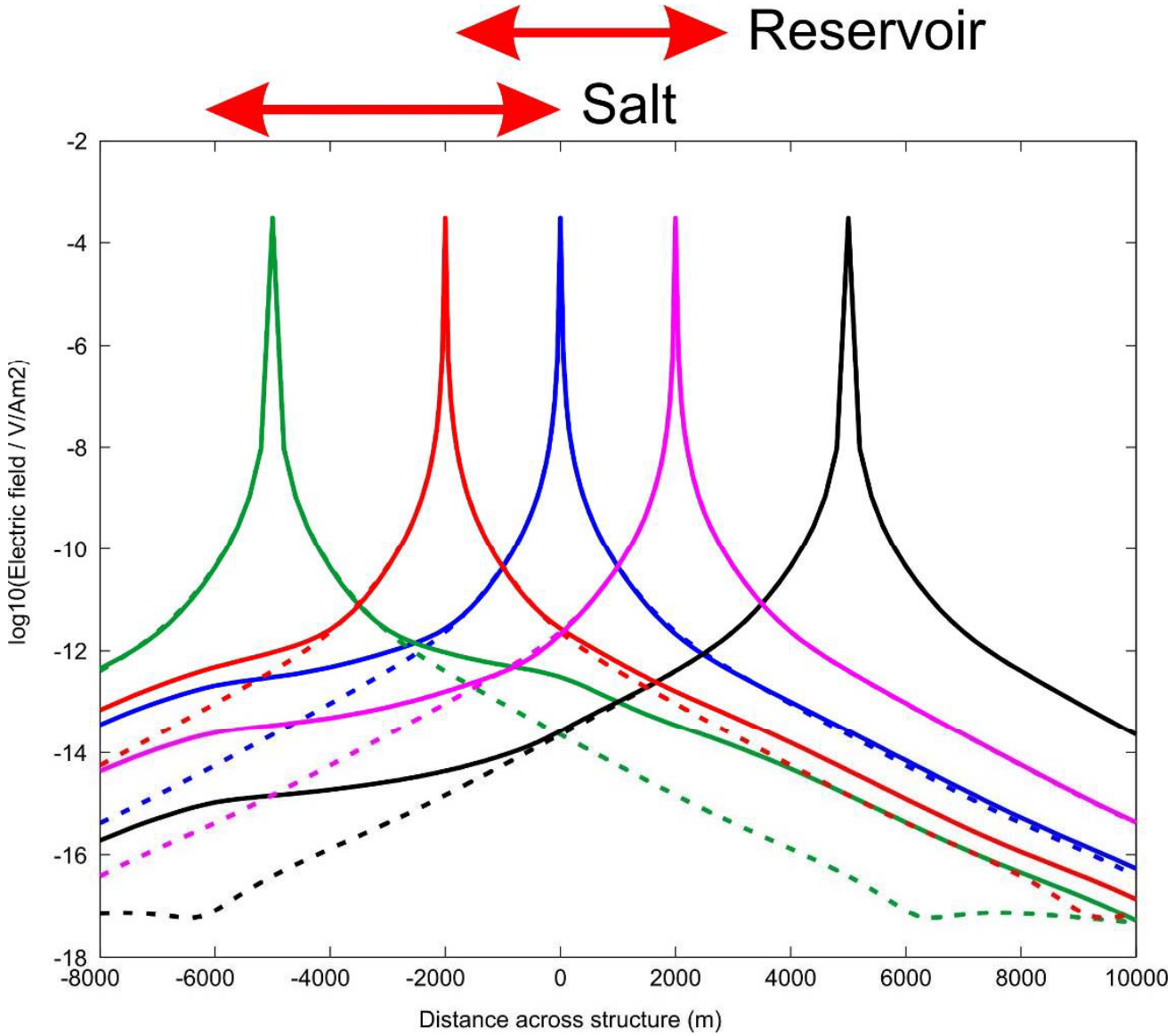
Active source EM sounding

- Source under direct control of operator
- Resolution primarily from varying source-receiver geometry
- Induces both horizontal and vertical current flow – very sensitive to thin resistive layers.
- Can determine resistivity structure to typically ~3-5km below the seafloor.
- Detailed structure

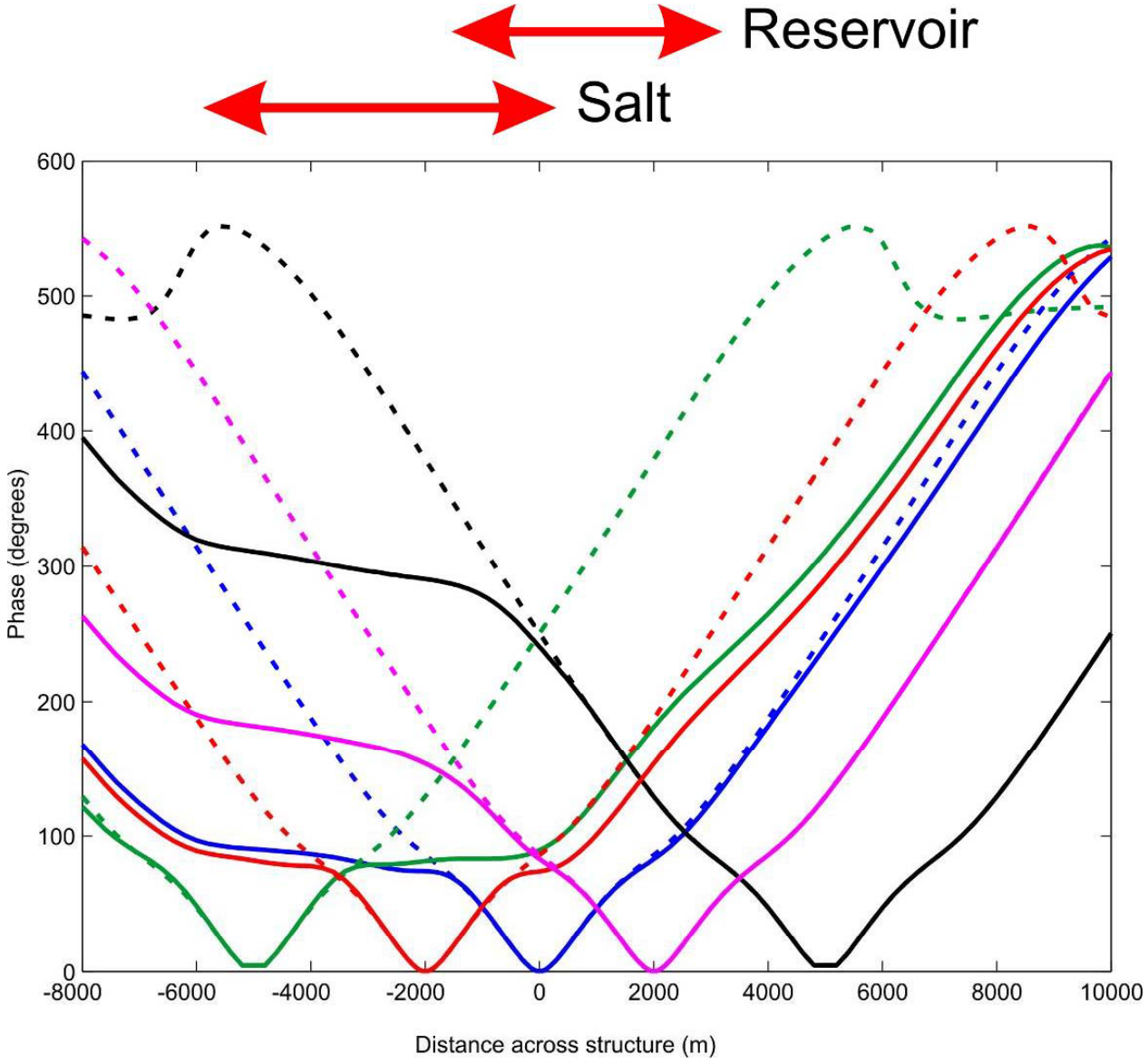
Resolution of reservoir layers in the presence of salt



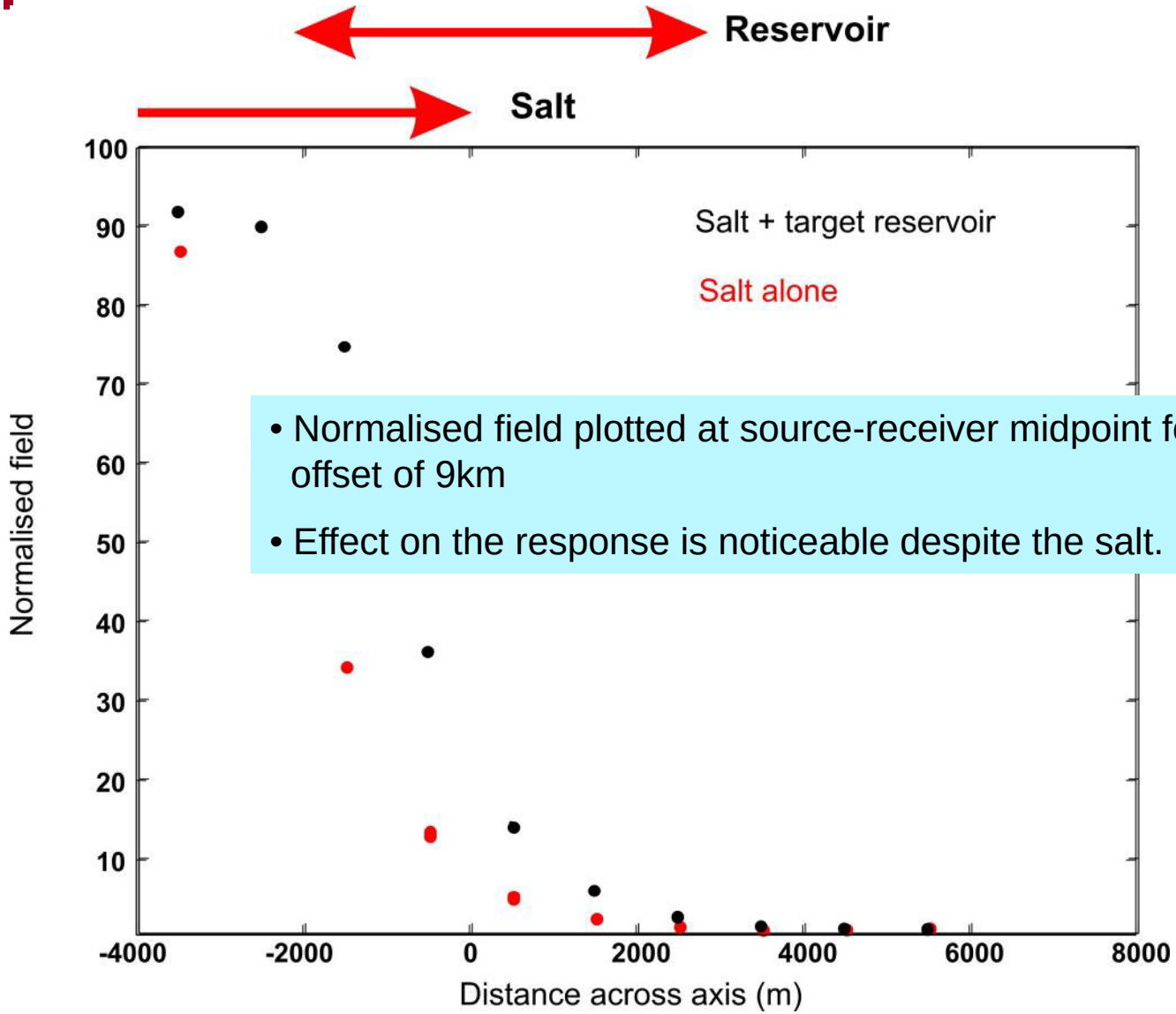
Electric field amplitude: 0.3Hz transmission



Electric field phase: 0.3 Hz transmission

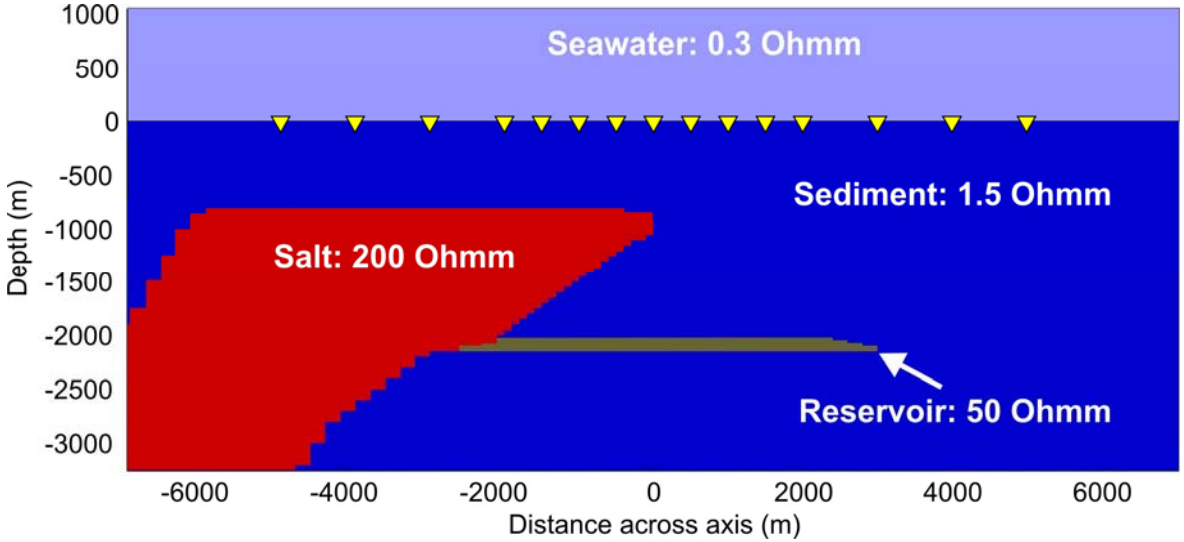


Reservoir has an effect on the response despite the salt…



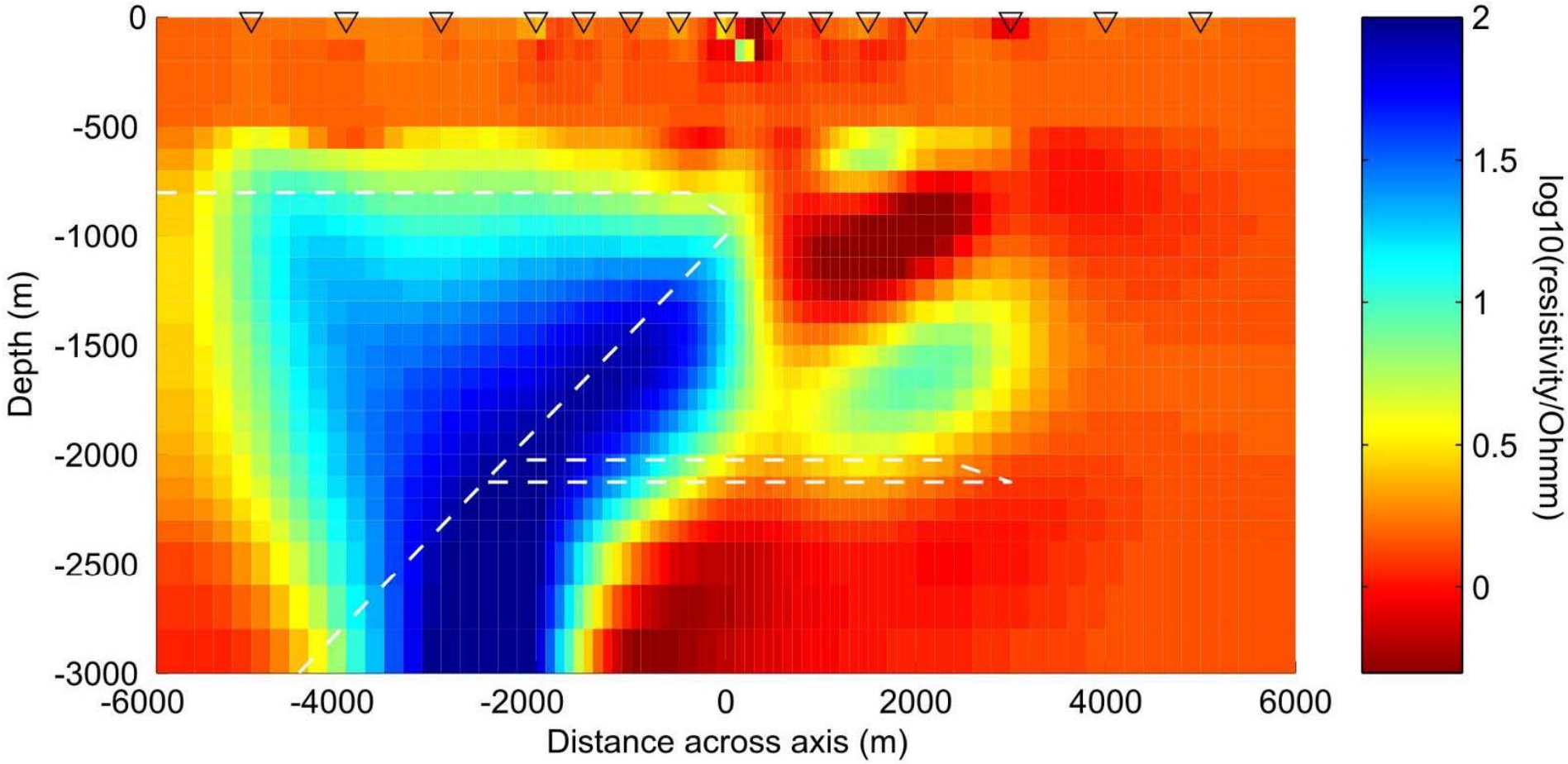
- Normalised field plotted at source-receiver midpoint for a common offset of 9km
- Effect on the response is noticeable despite the salt.

Resolution of reservoir



- Normalisation is a useful way of quantifying the effect of a given structure.
- However it is very dependent on the background structure.
- Instead, generate a synthetic dataset and invert it to examine what structure (if any) can be recovered.
- Data for 22 receivers in and out of plane of page (for geometric coverage), at a frequency of 0.3 Hz, contaminated with 5% Guassian noise, and inverted.

Inversion of CSEM data: transmission frequency = 0.3Hz

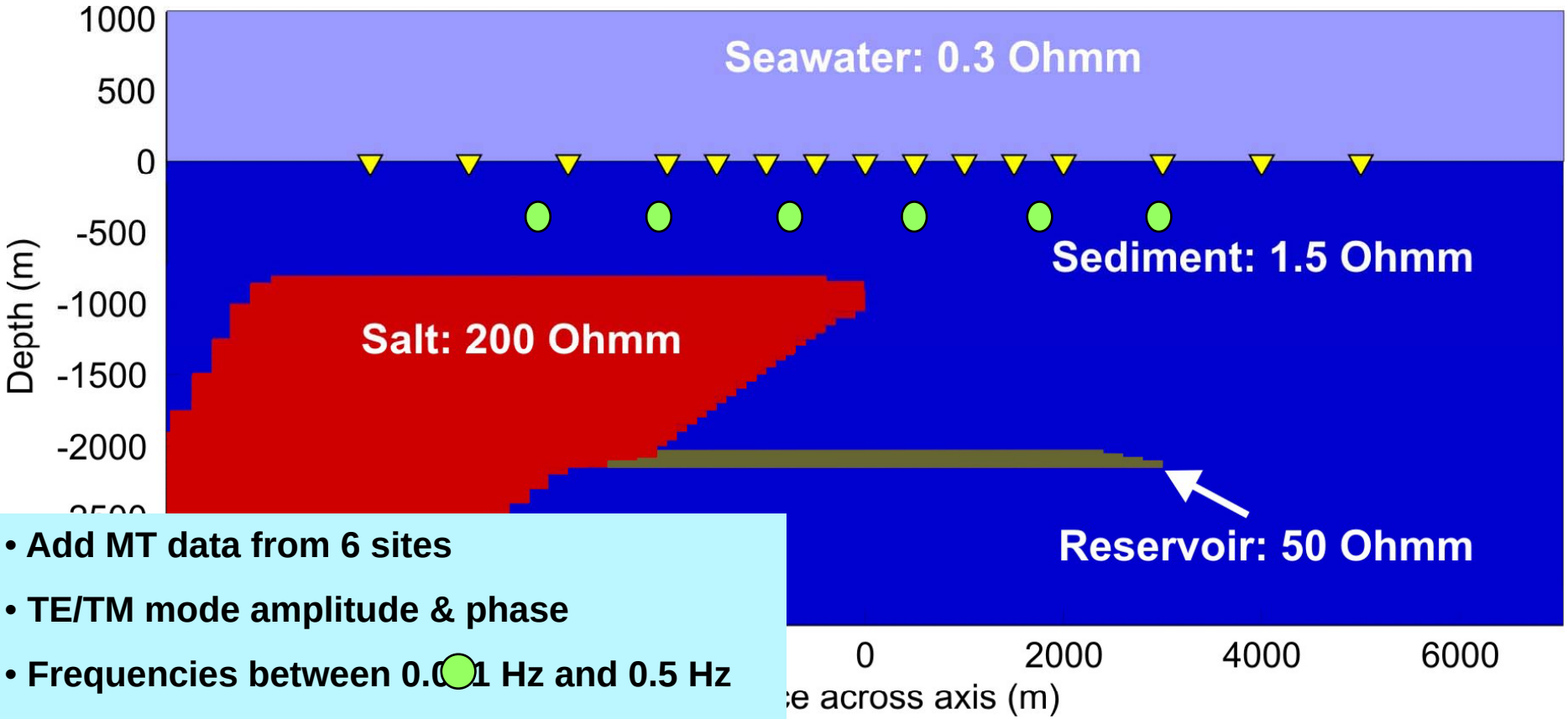


Result is reasonable, but how can it be improved ?

- **Multiple frequencies:**
  - Works reasonably well…

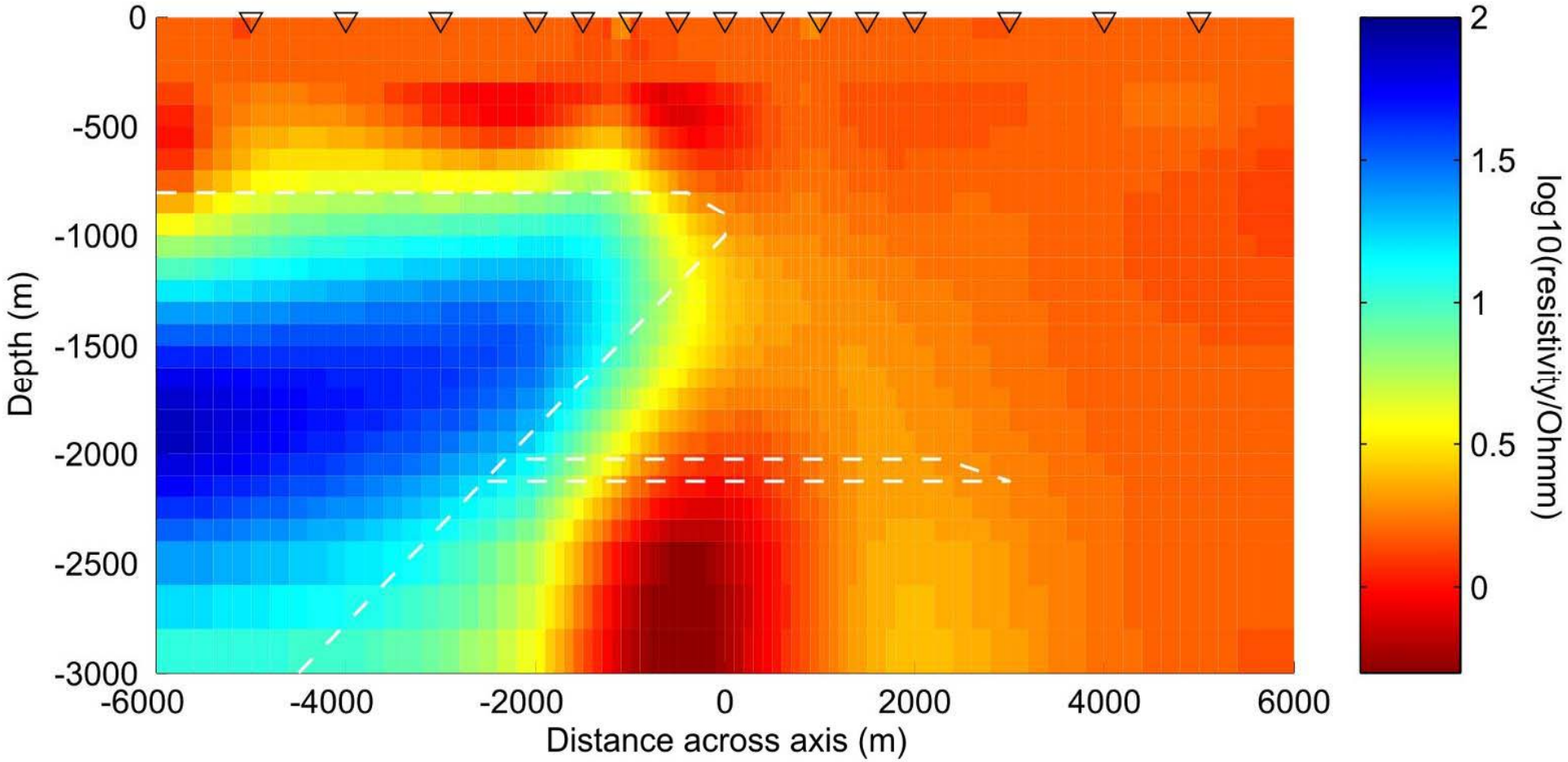
- **Additional constraints from complementary geophysical techniques**
  - Seismic constraints on top/base salt, or expected reservoir level
  - well log constraints on background resistivity
  - MT data – insensitive to thin resistors, but useful for background structure.

Resolution of reservoir

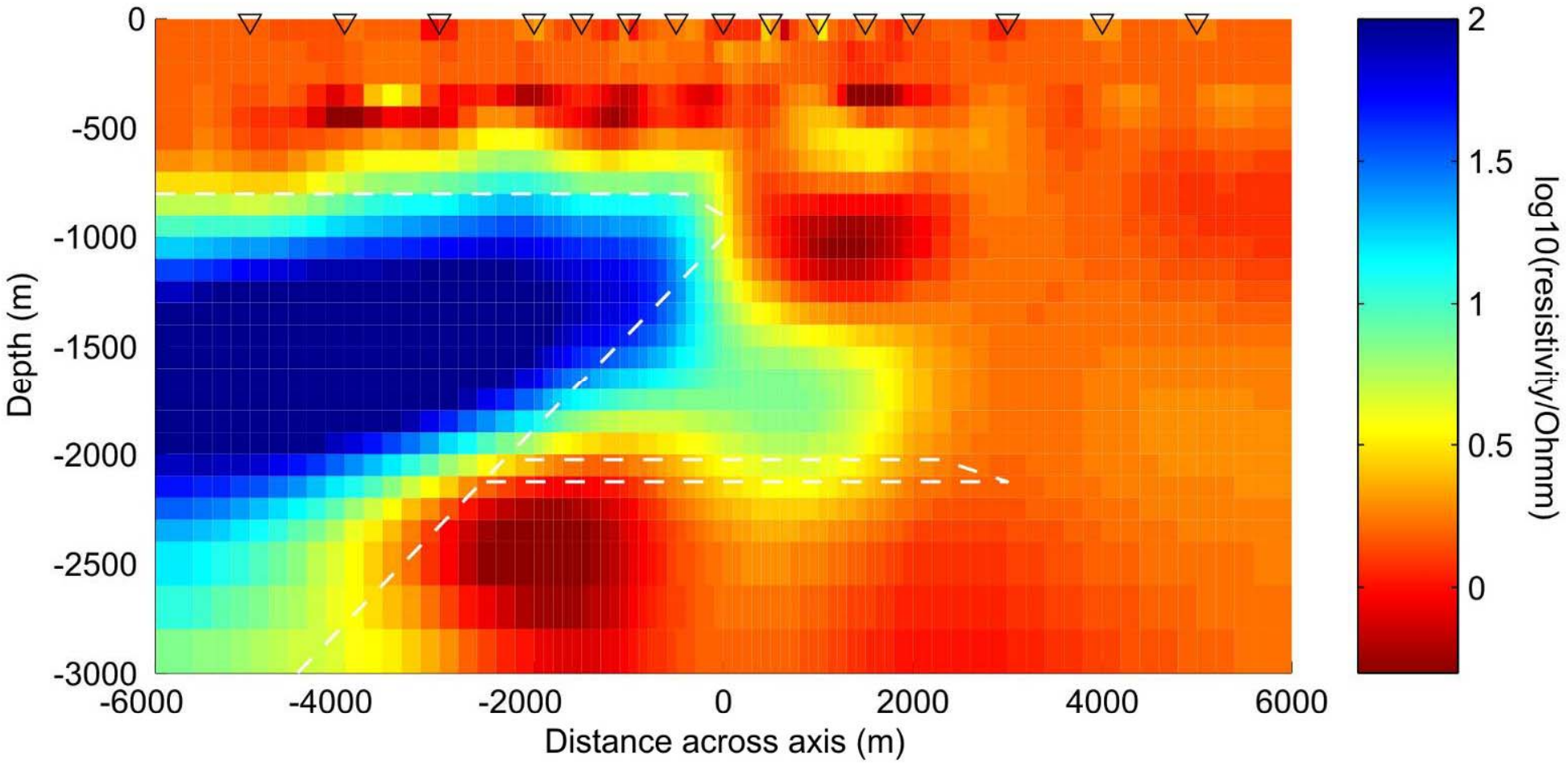


- Add MT data from 6 sites
- TE/TM mode amplitude & phase
- Frequencies between 0.01 Hz and 0.5 Hz
- 5% Gaussian noise added & inverted
- Also imaged with marine TEM

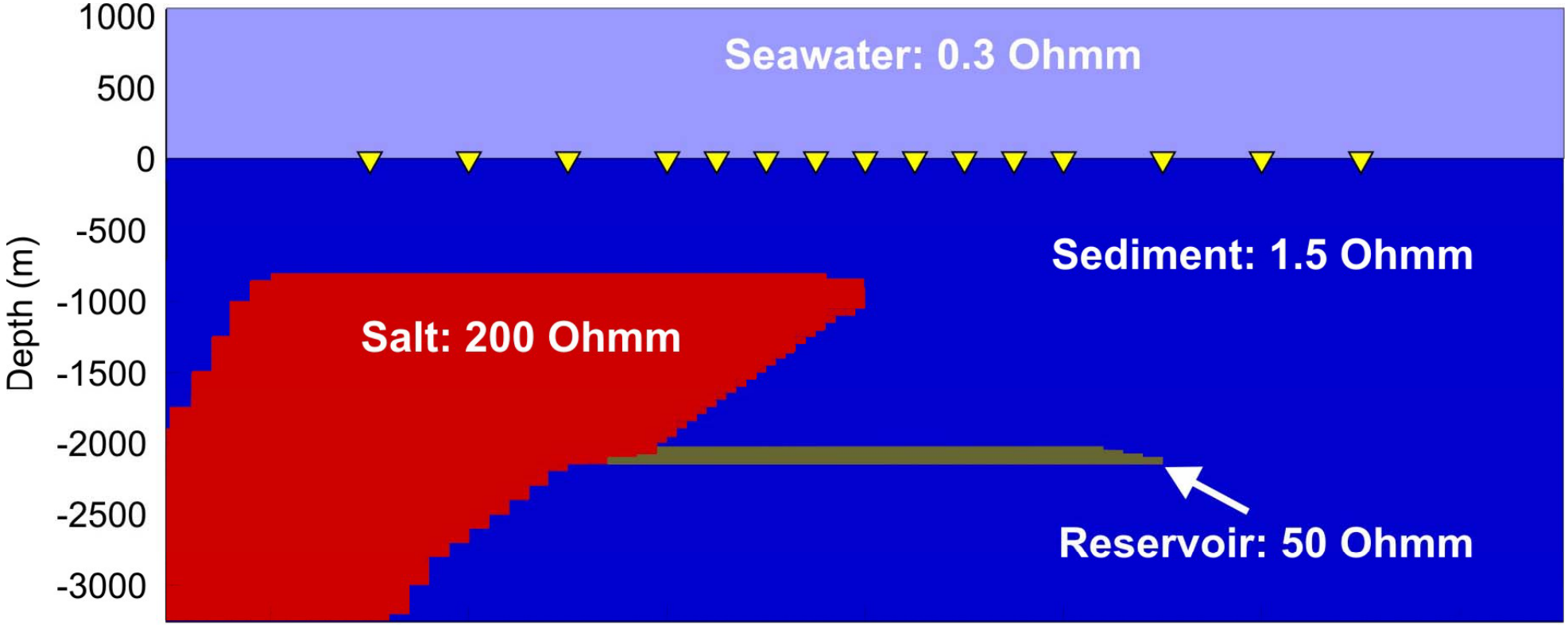
Inversion of MT data alone



Joint inversion of CSEM and MT data

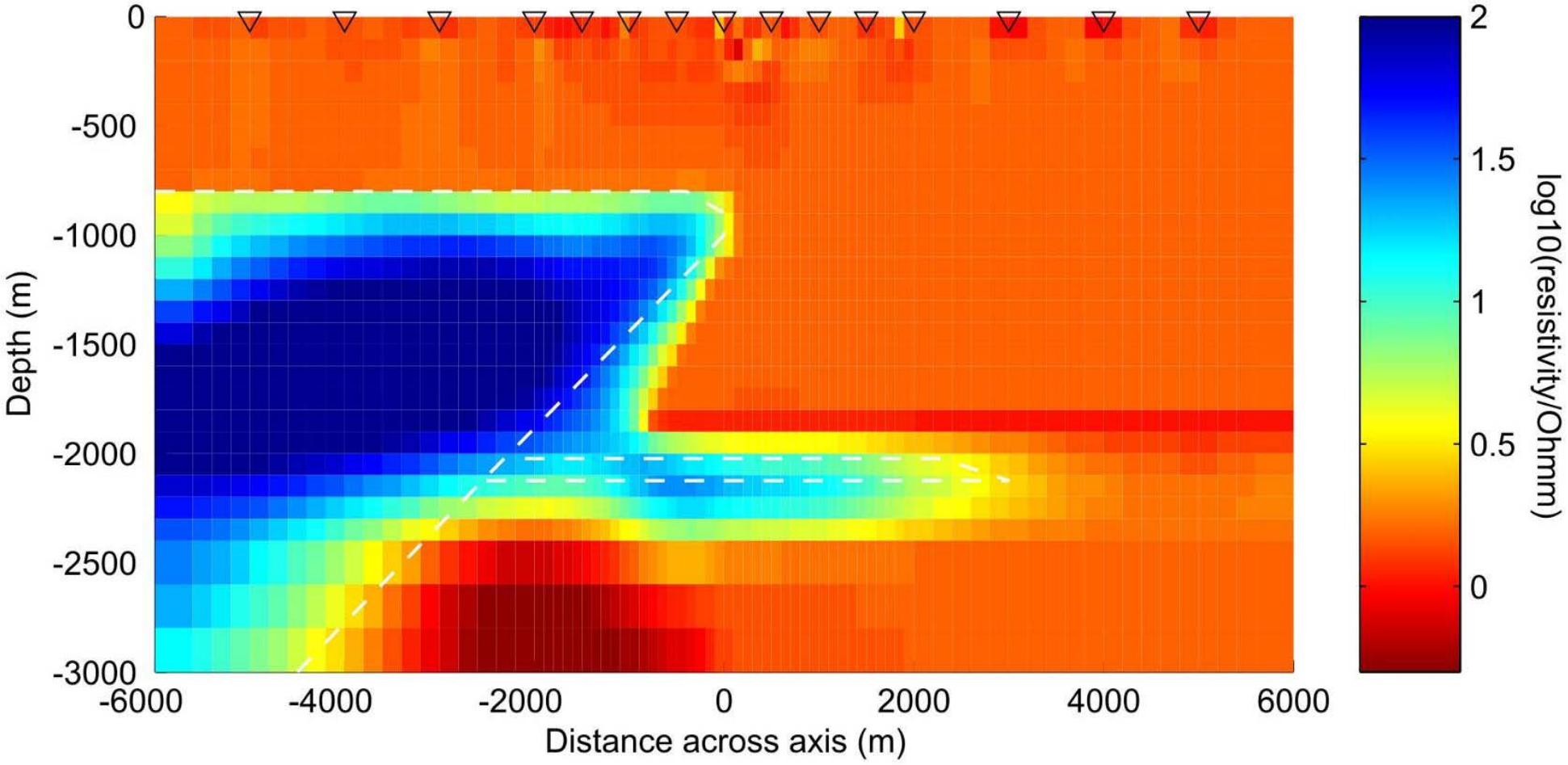


Constrained inversion

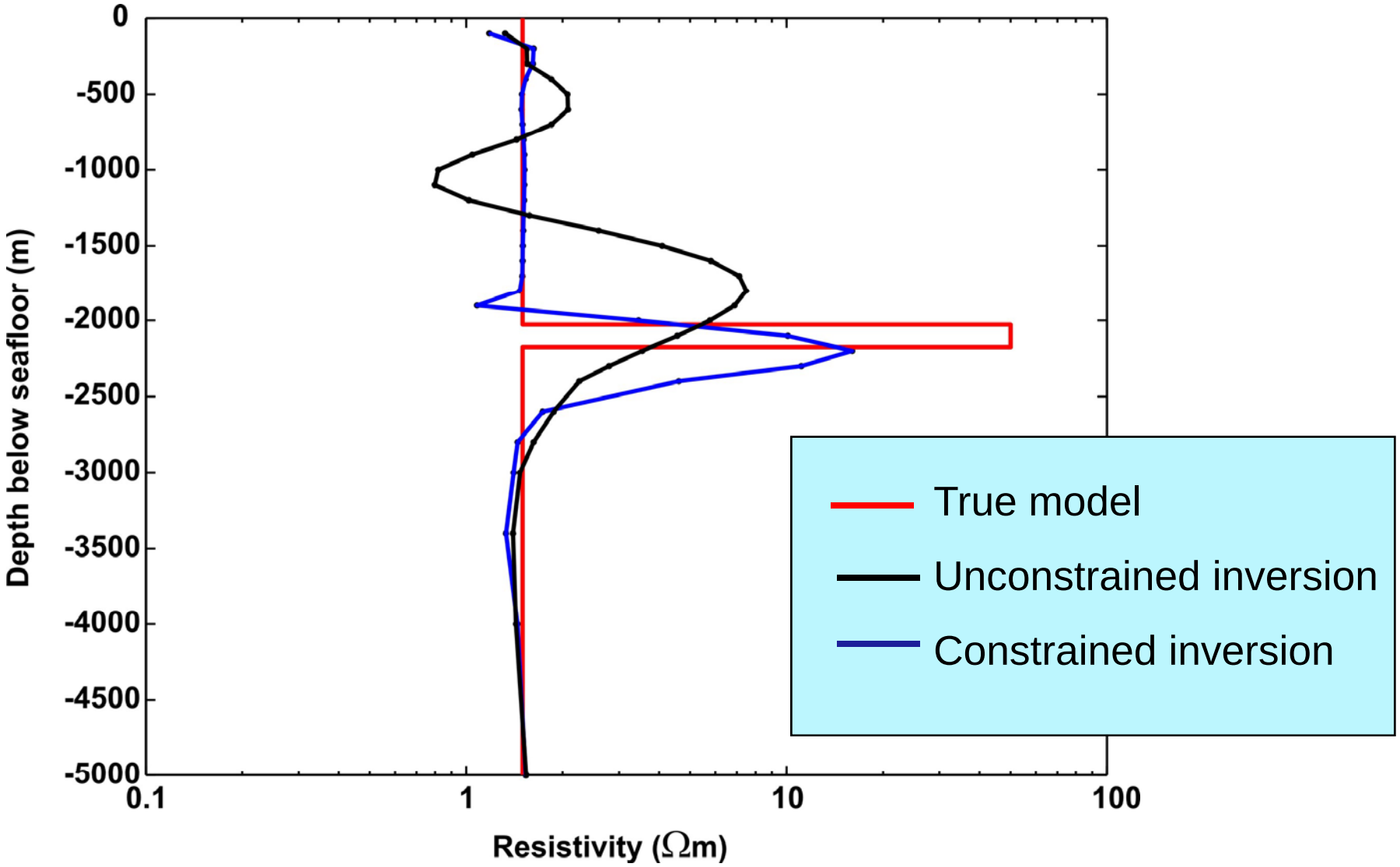


- Sharp boundary allowed at top of salt (constrained from seismic data)
- Inversion is free for 500m interval around reservoir depth
- Background prejudiced to known value (note no values are fixed to pre-defined values)

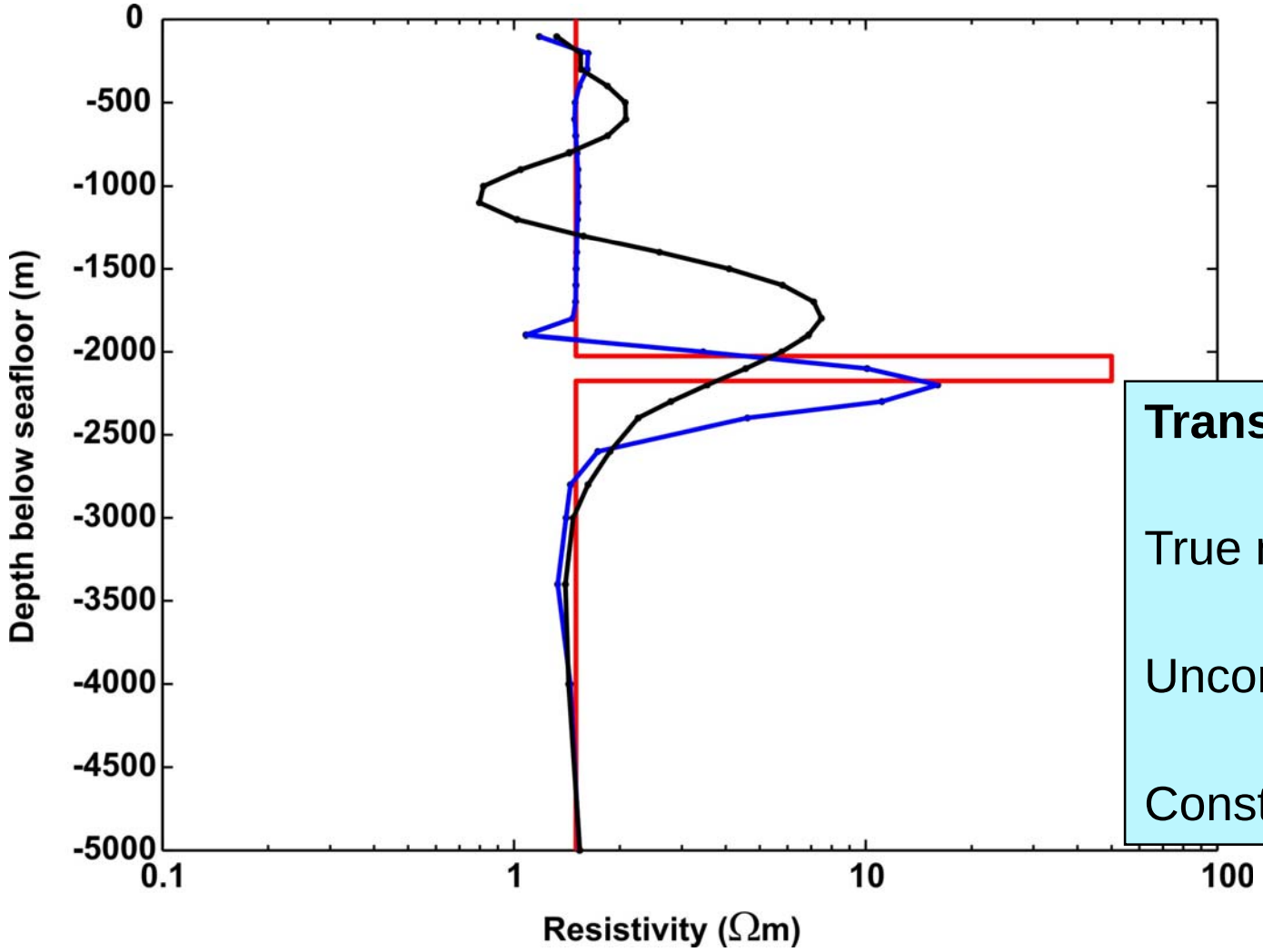
Constrained inversion of CSEM and MT data:



Vertical profile through reservoir at x=800m



Regularised inversion returns the minimum transverse resistance compatible with the data.

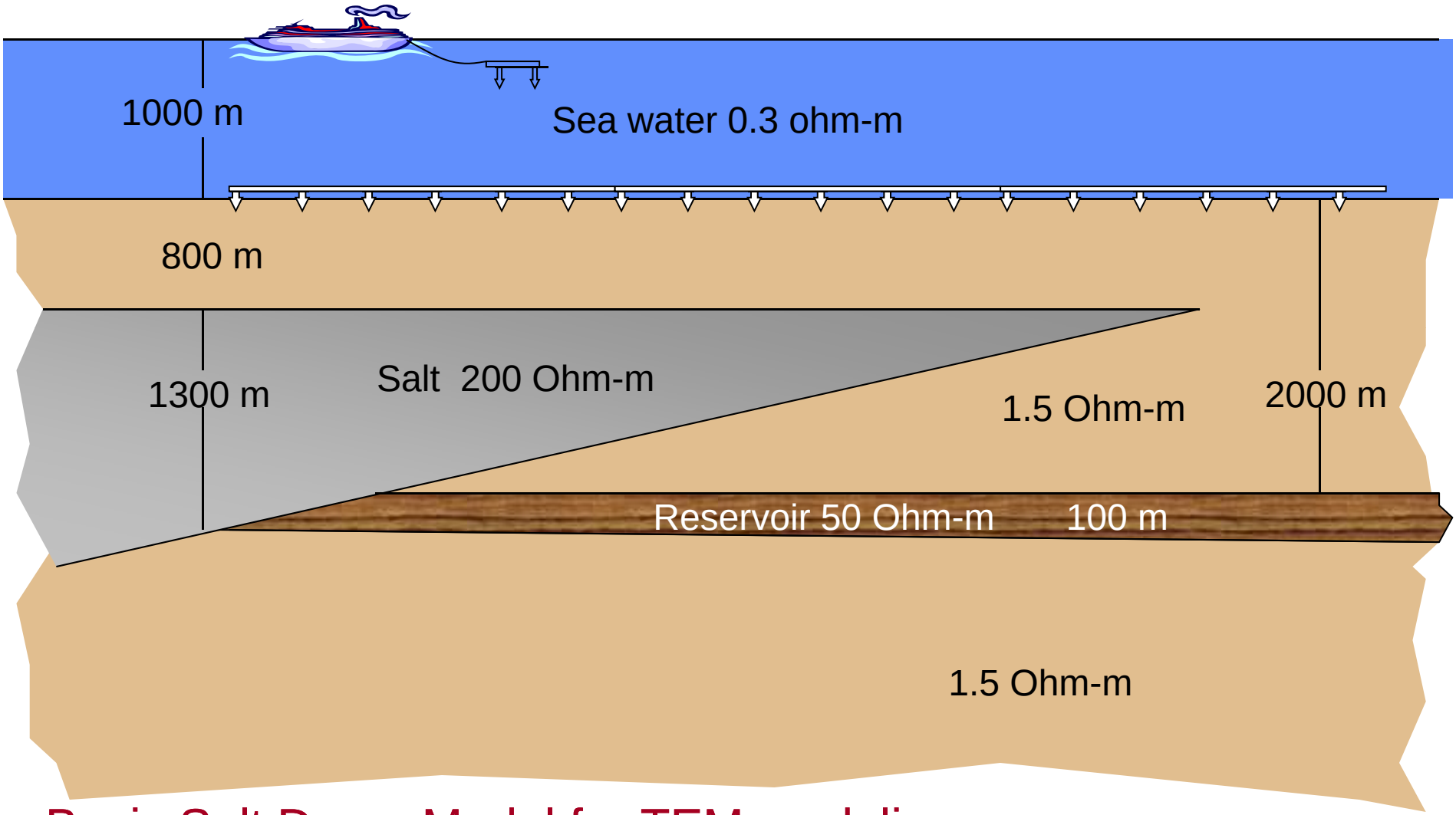


Transverse resistance:

True model: 7500 Ωm^2

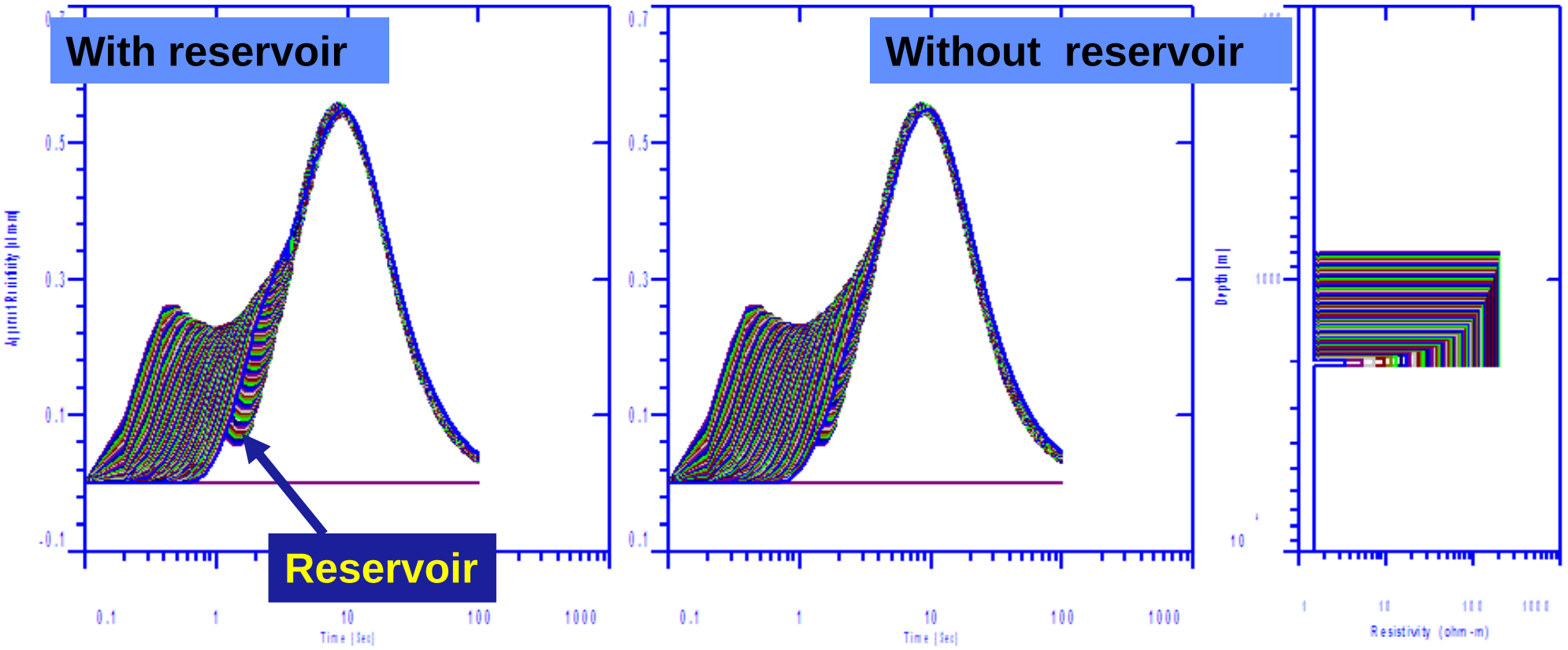
Unconstrained: 6250 Ωm^2

Constrained: 5900 Ωm^2

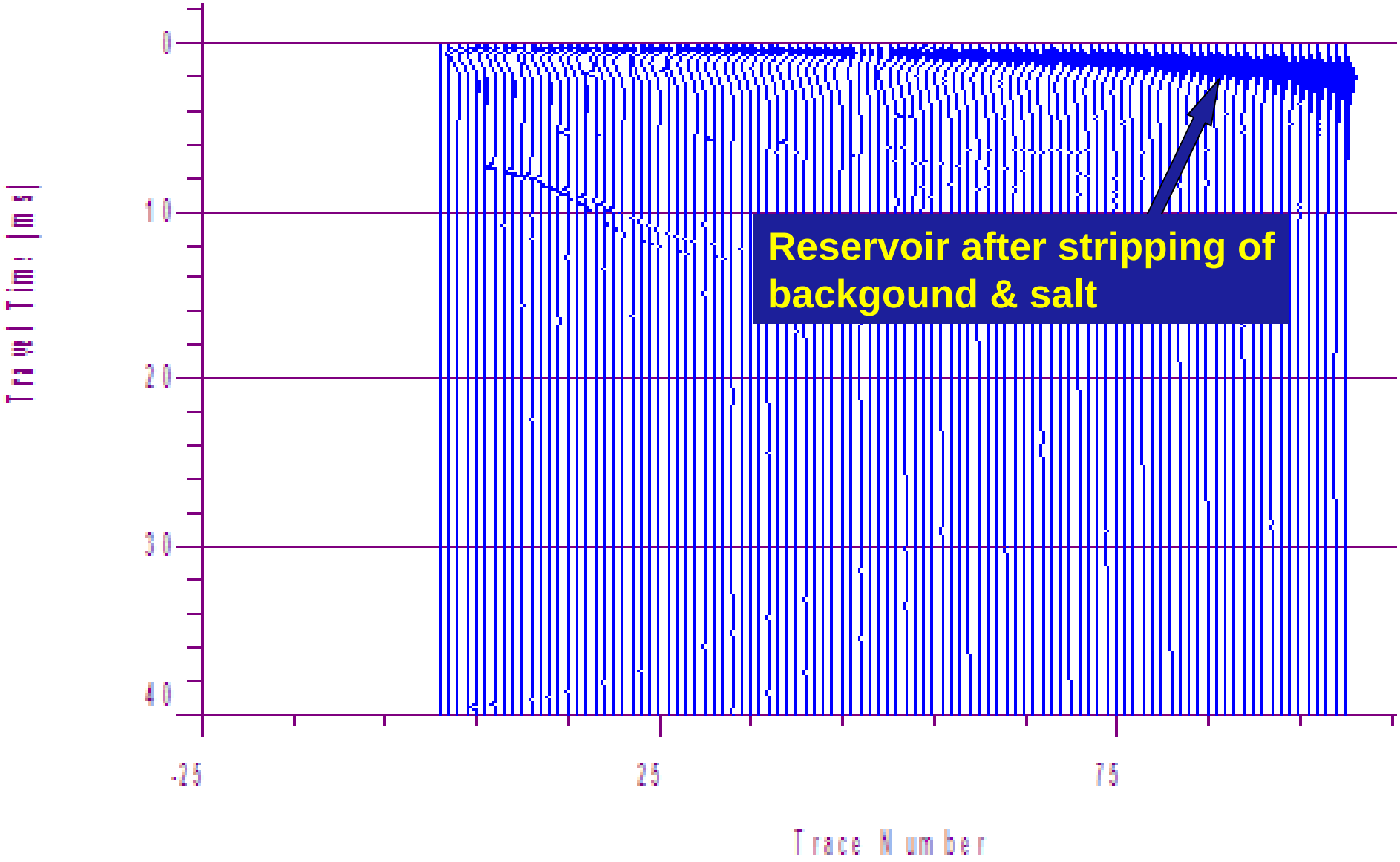


Basic Salt Dome Model for TEM modeling

Apparent resistivities

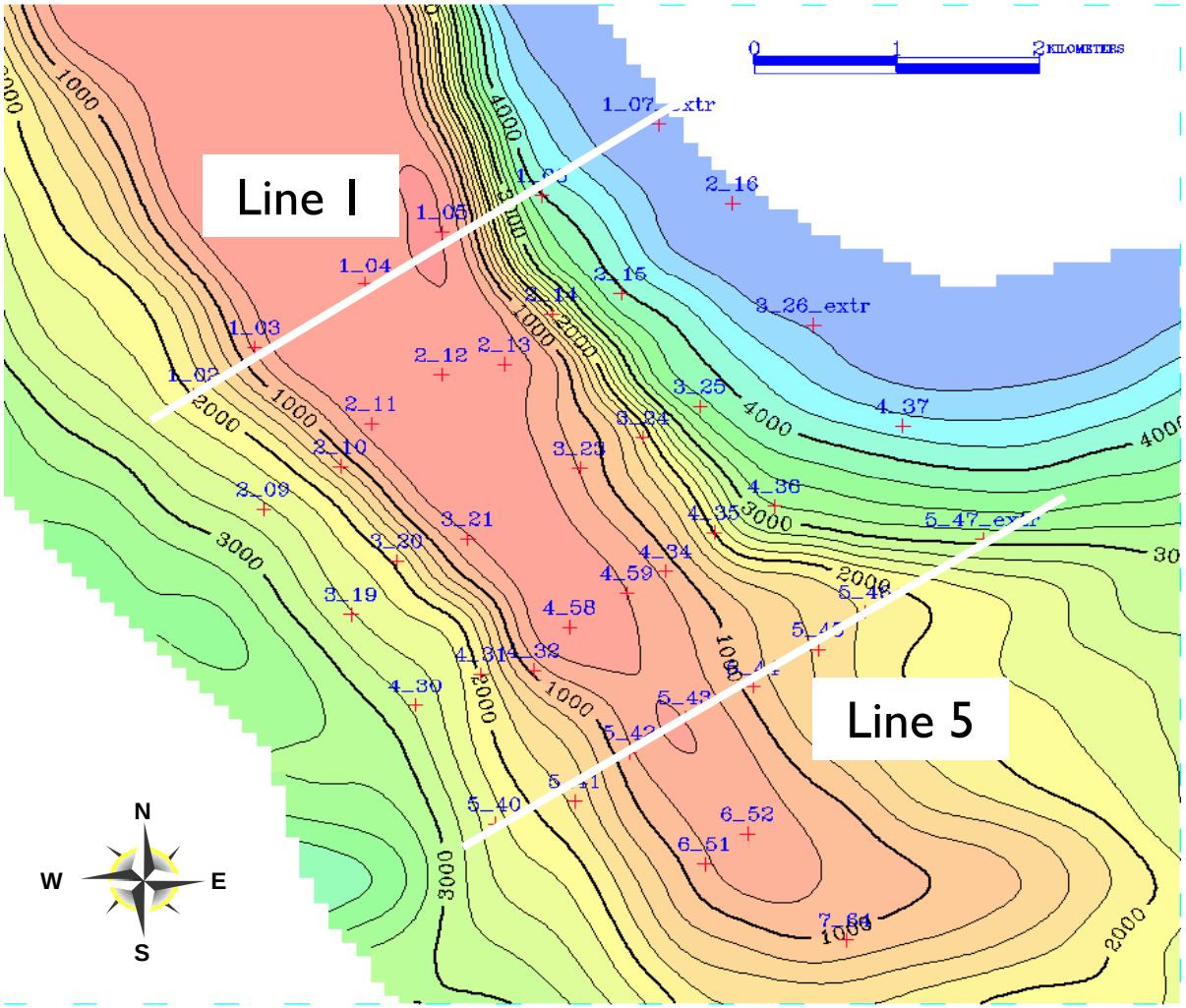


Imaging the reservoir



GOM survey

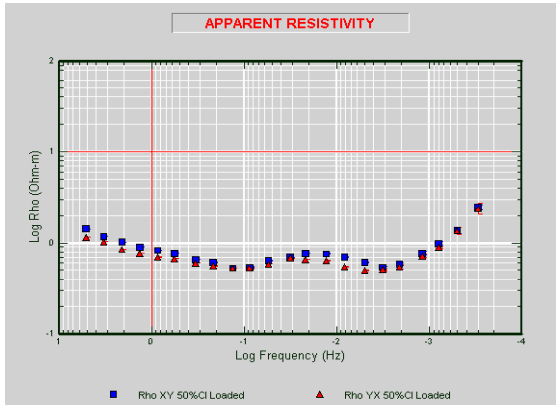
Seismic top salt depth map with MMT sites



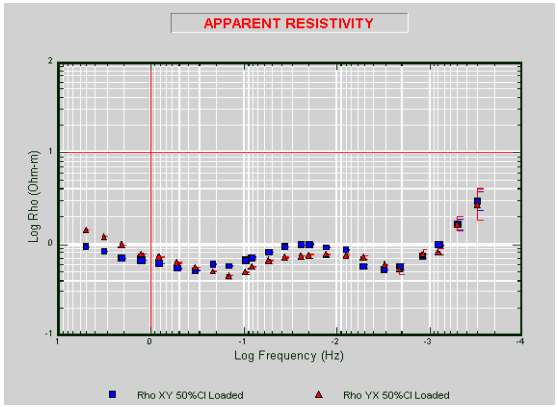
Zerilli, 2000
Courtesy Eni-Agip

GOM data - Line 1

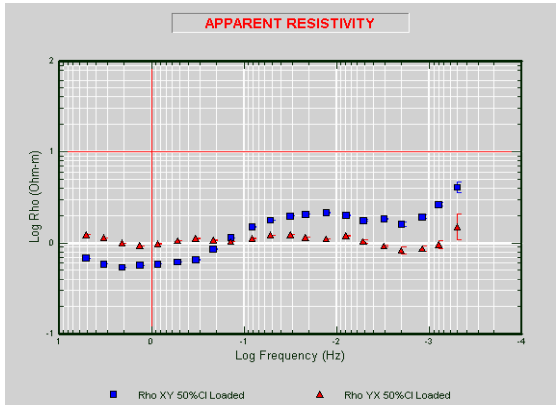
L1_S02



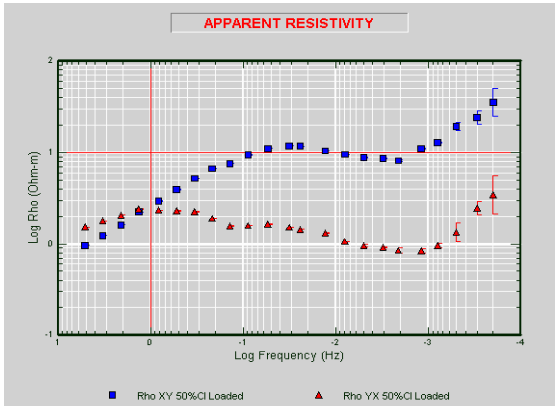
L1_S03



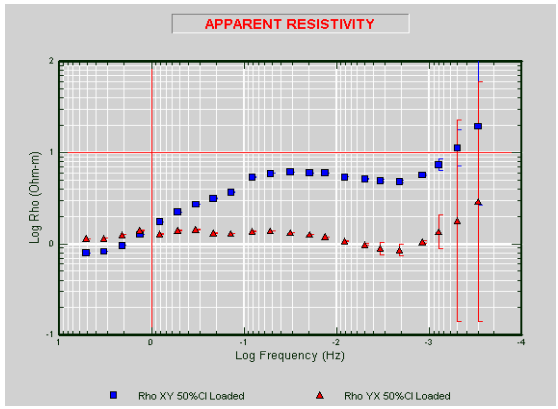
L1_S04



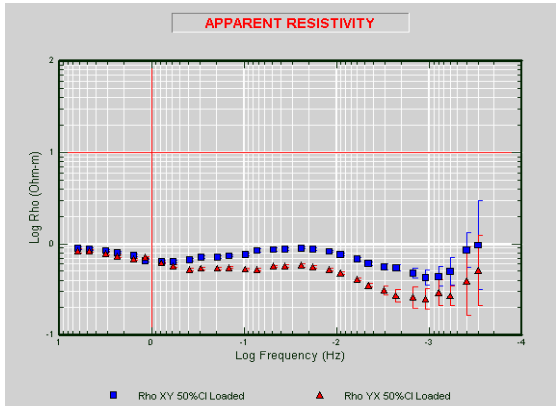
L1_S05



L1_S06

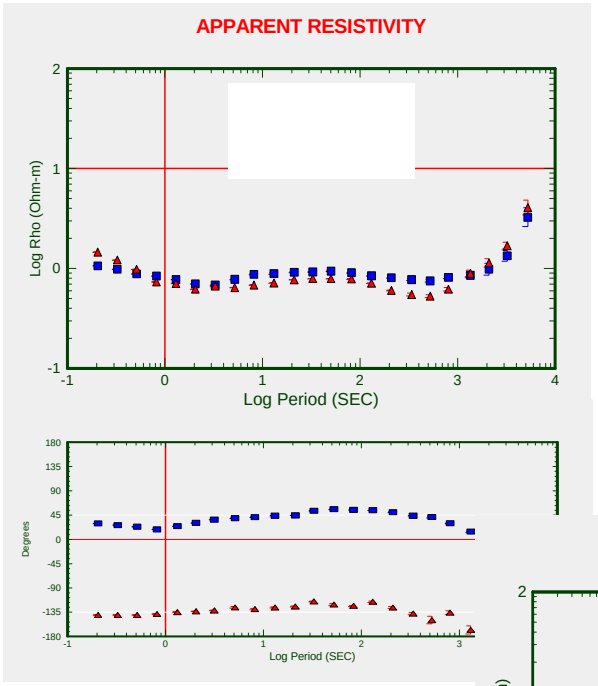


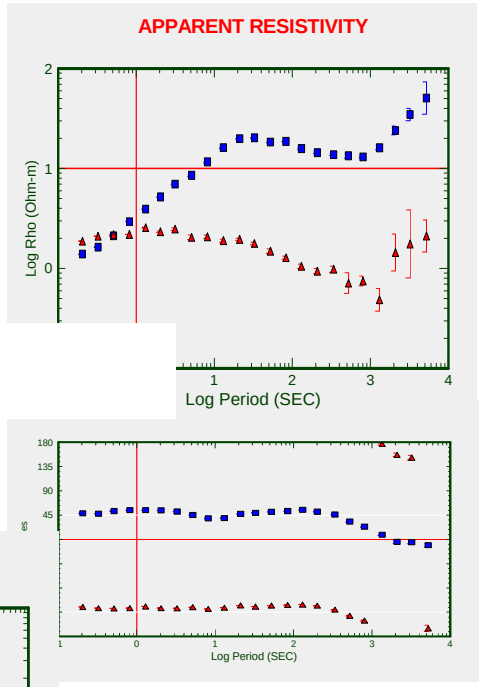
L1_S07

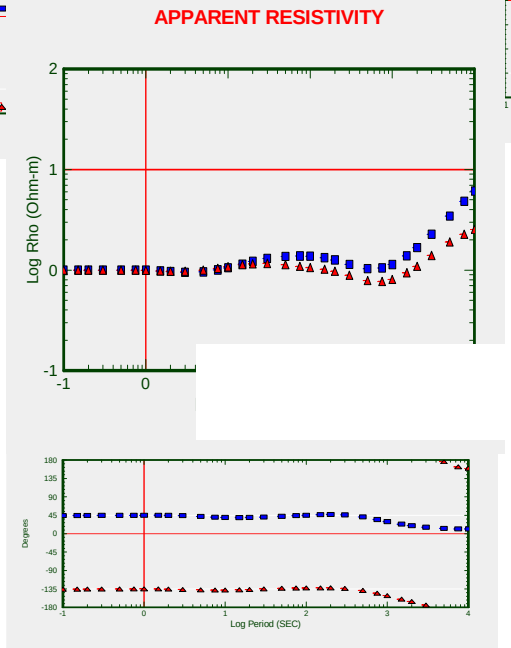


Zerilli, 2000
Courtesy Eni-Agip

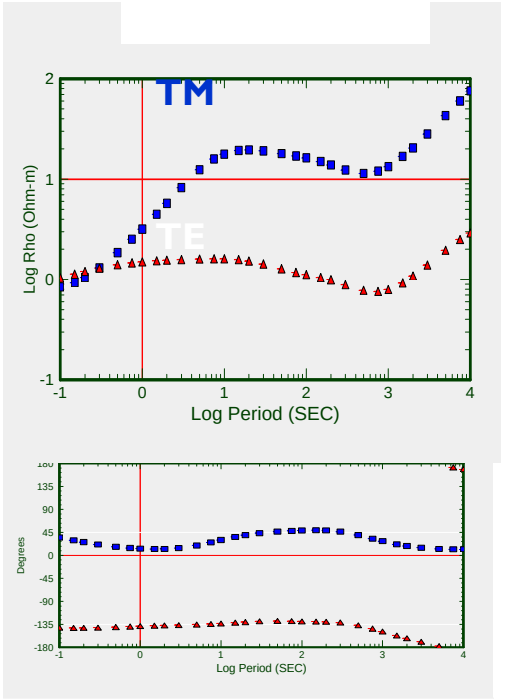
Modeled versus data







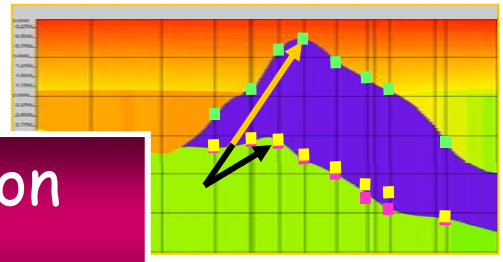
L2_S09



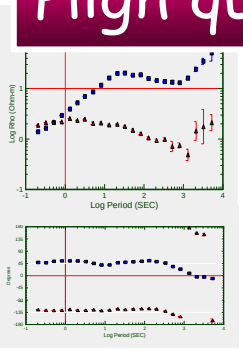
L2_S12

Zerilli, 2000
Courtesy Eni-Agip

MT interpretation flow



Input:
High quality data



MT: 1-D & 2D inversion
Output: Model

Compare model w/ seismic

Redo seismic velocity field w/ MT model

Compare model w/ seismic & gravity

Great fit

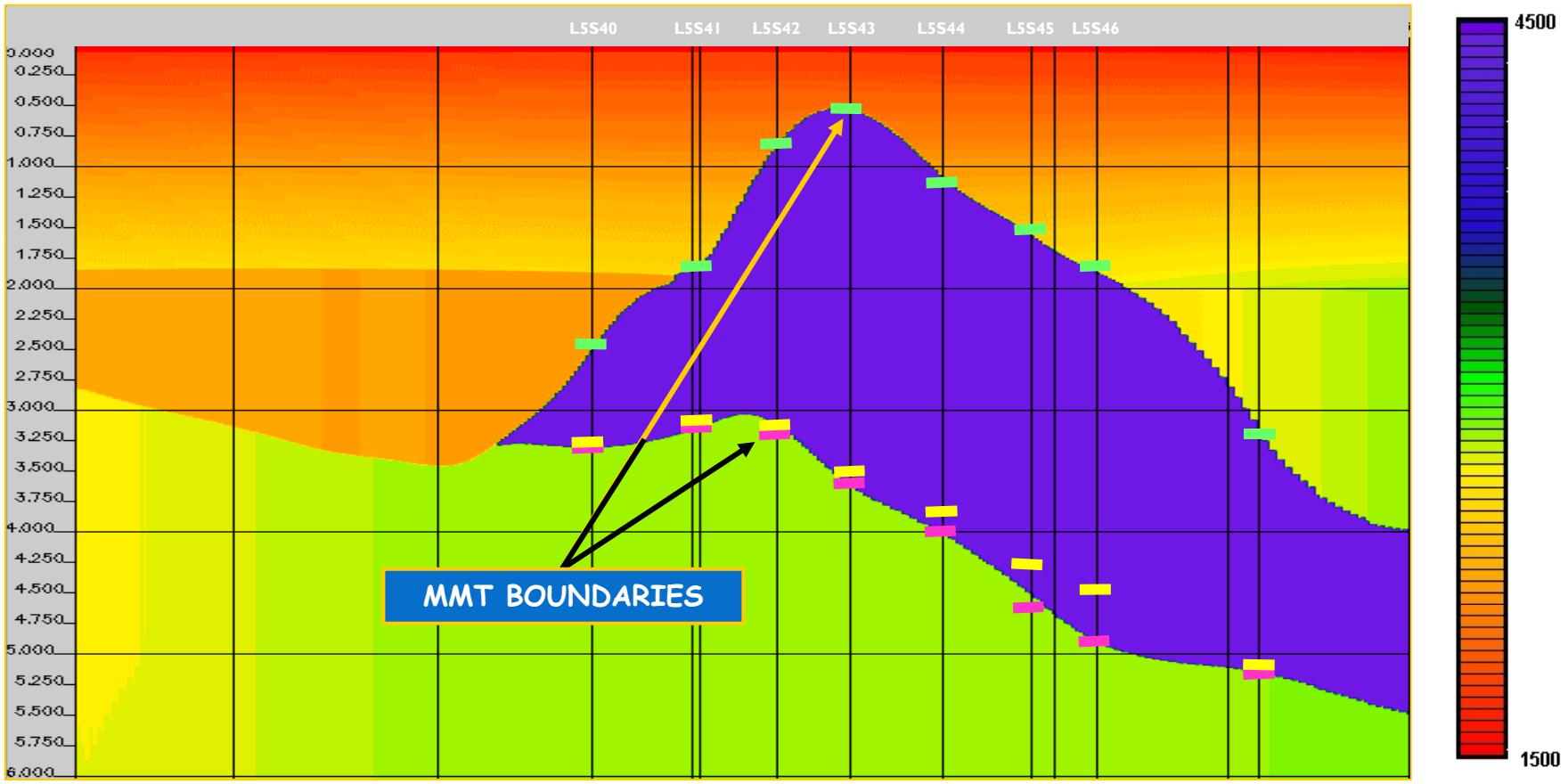
Result

Insufficient fit

Correct MT model or seismic
Velocity or gravity model

AGIP: Gulf of Mexico MT model

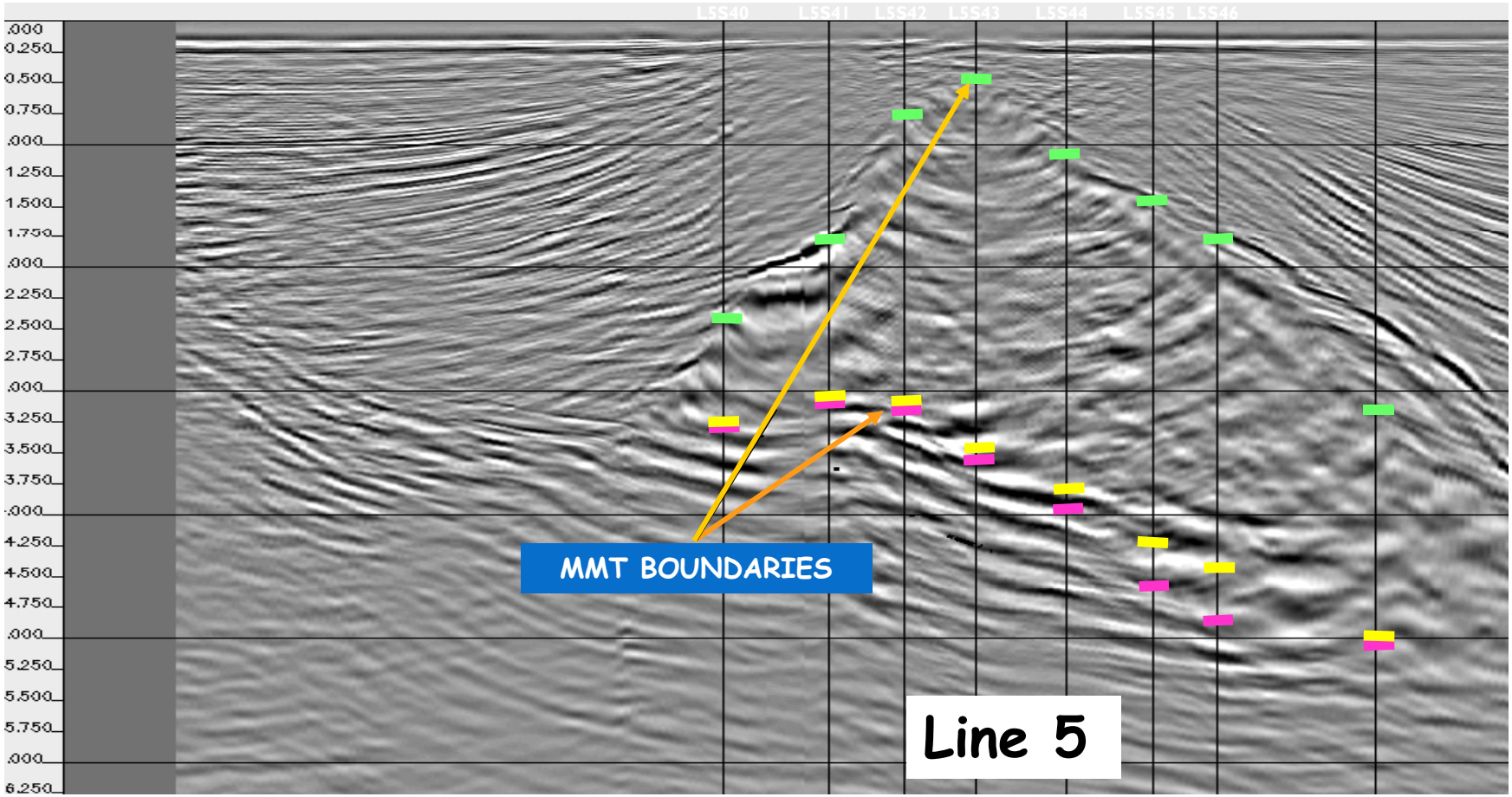
MT was used to derive seismic velocity model



Zerilli, 2000
Courtesy Eni-Agip

GOM seismic data & MT inversion

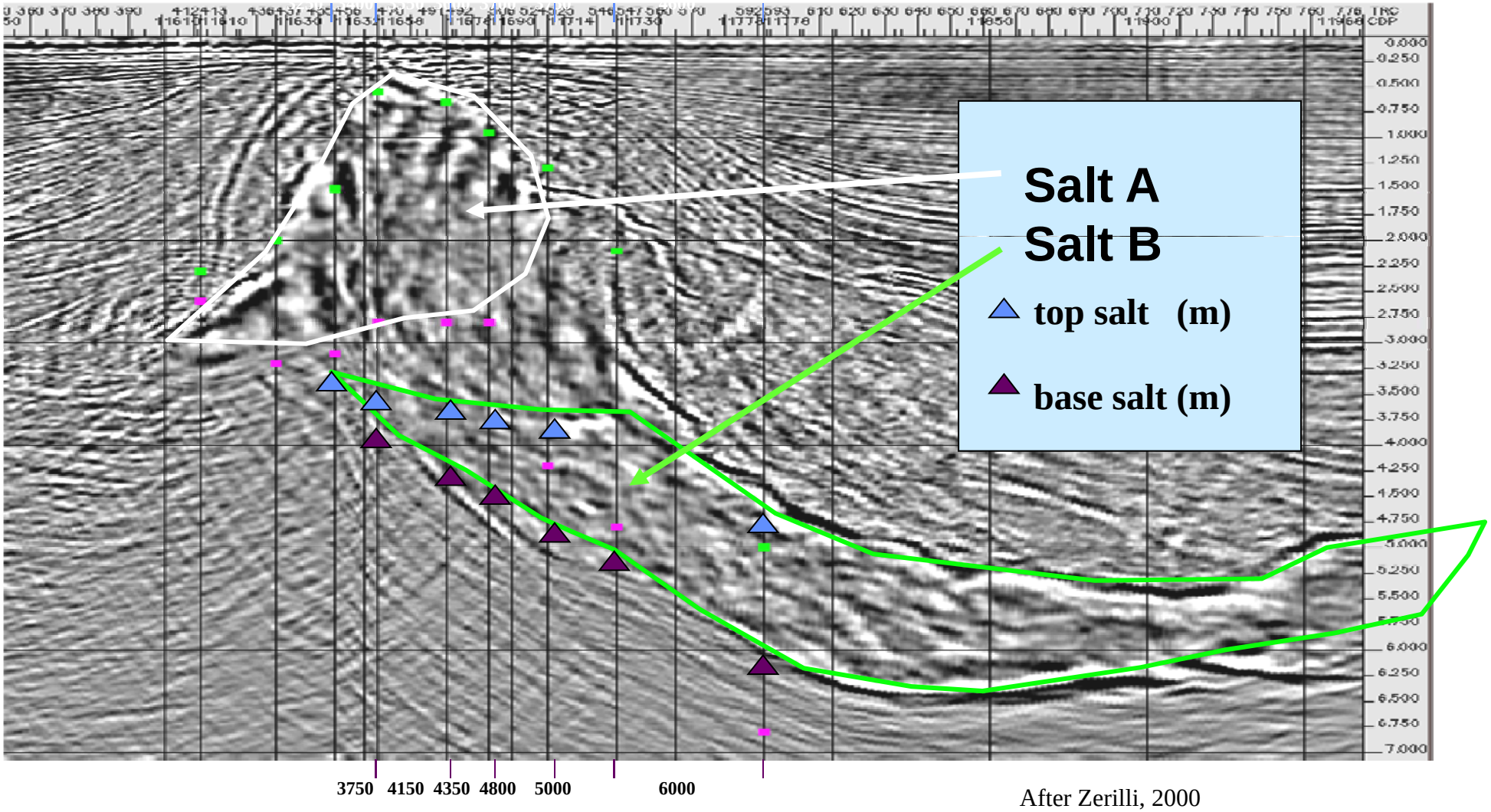
3D PreSDM from MMT - derived velocity model



Zerilli, 2000
Courtesy Eni-Agip

Gulf of Mexcico – sub salt example

Seismic - MT integrated interpretation



After Zerilli, 2000
Courtesy ENI-Agip

Conclusions

- **Marine electromagnetic (EM) provides complementary information to conventional exploration.**
- **Success stories include:**
  1. **Direct hydrocarbon indicator from strong resistive anomalies**
  2. **Complimentary structural exploration tool**
- **Combined MT & controlled source electromagnetic yields better geometry**
- **EM powerful when with well logs or seismic data**

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