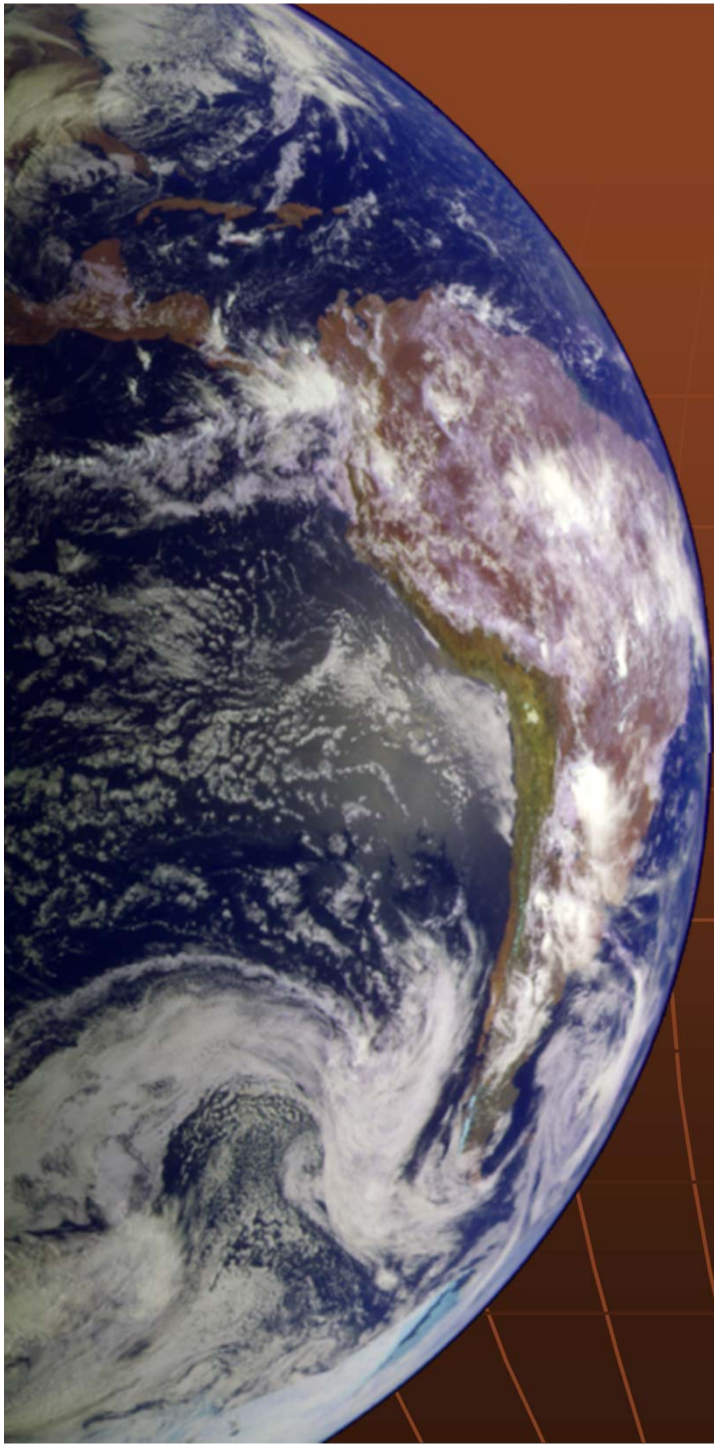

Petro-electric Modeling for CSEM Reservoir Characterization and Monitoring

Presented by

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Jackson School of Geosciences
University of Texas at Austin

Date: February 28th , 2011

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- Constructing a petro-electric reservoir model
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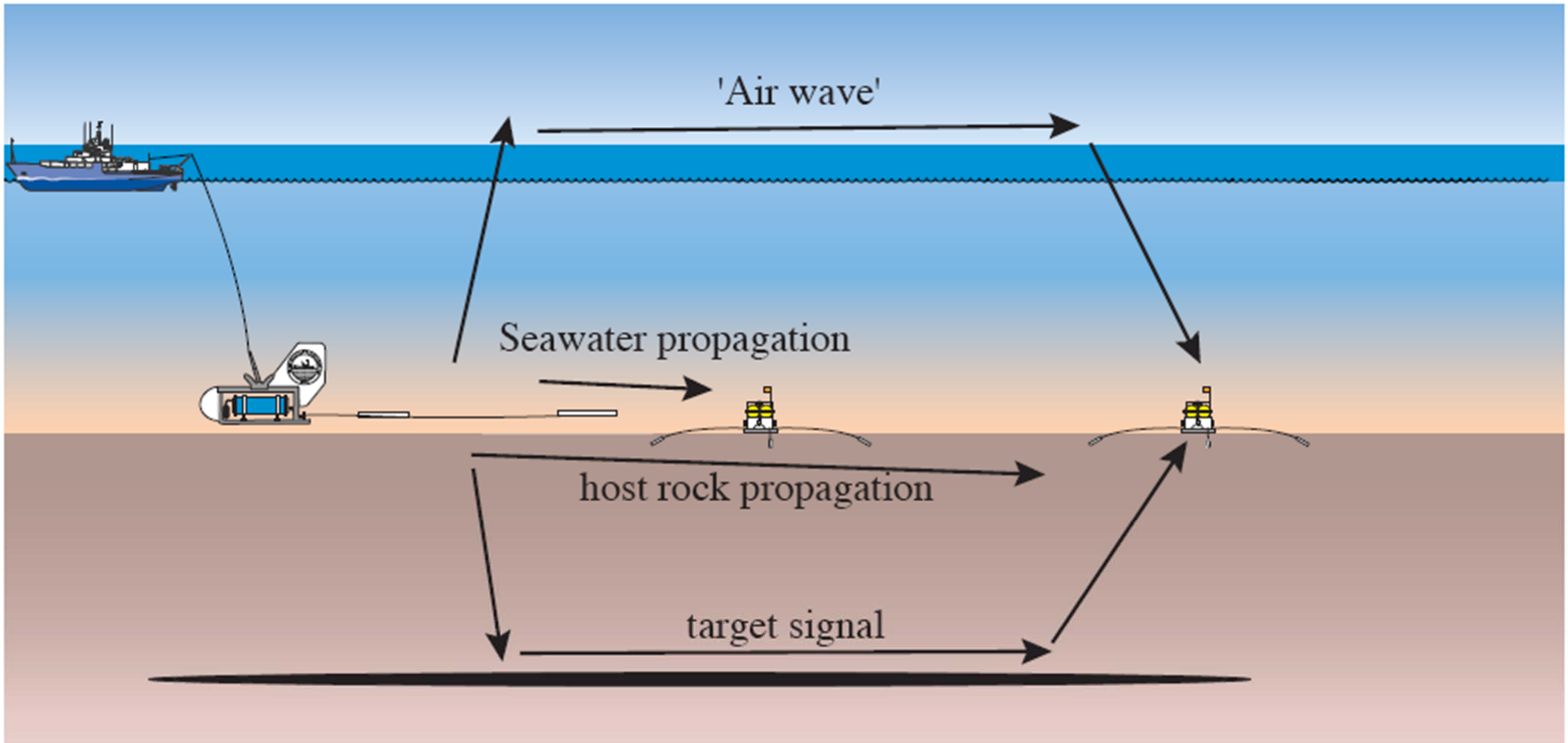
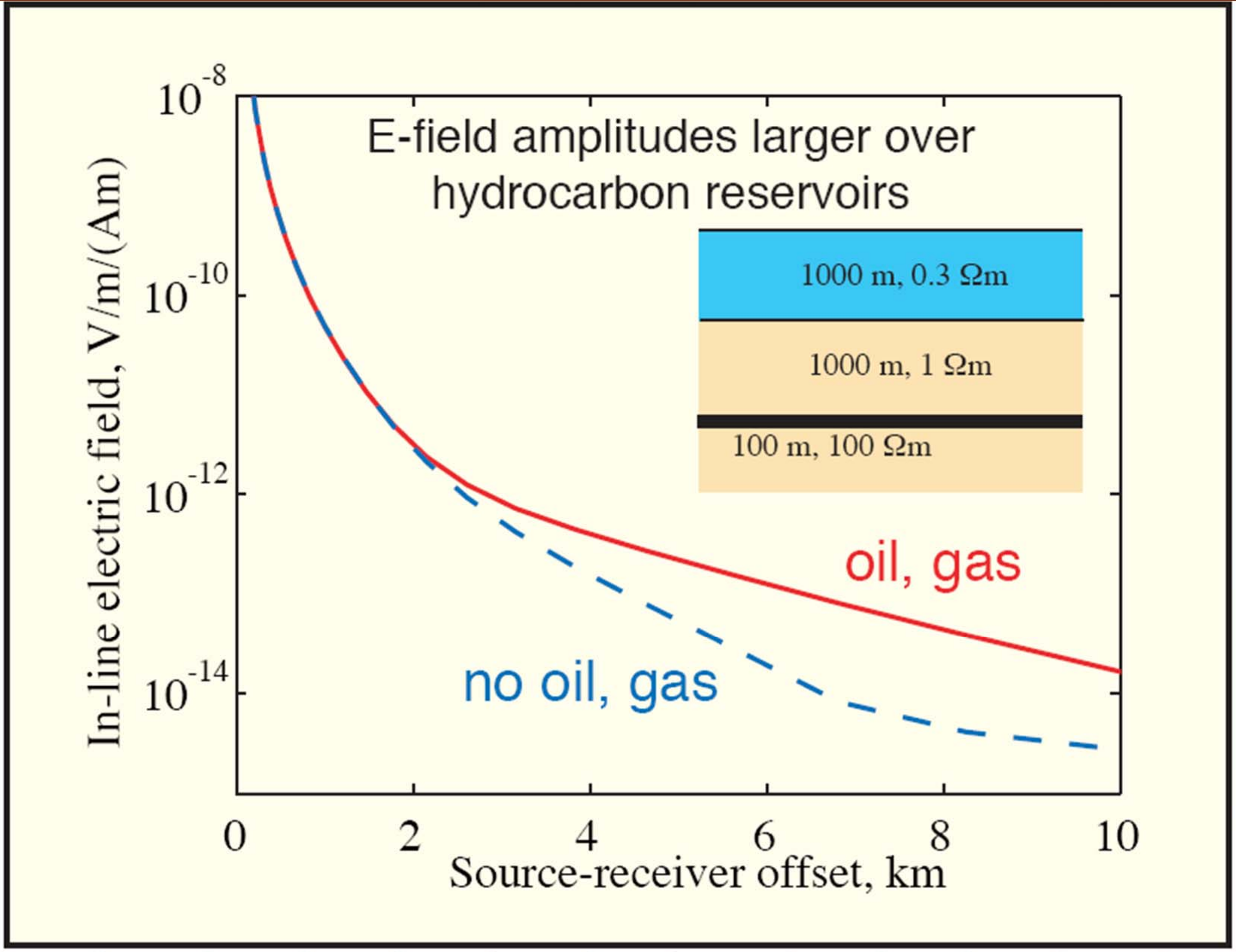
CSEM Acquisition

Energy reaches the receiver after interacting with various parts of the system:



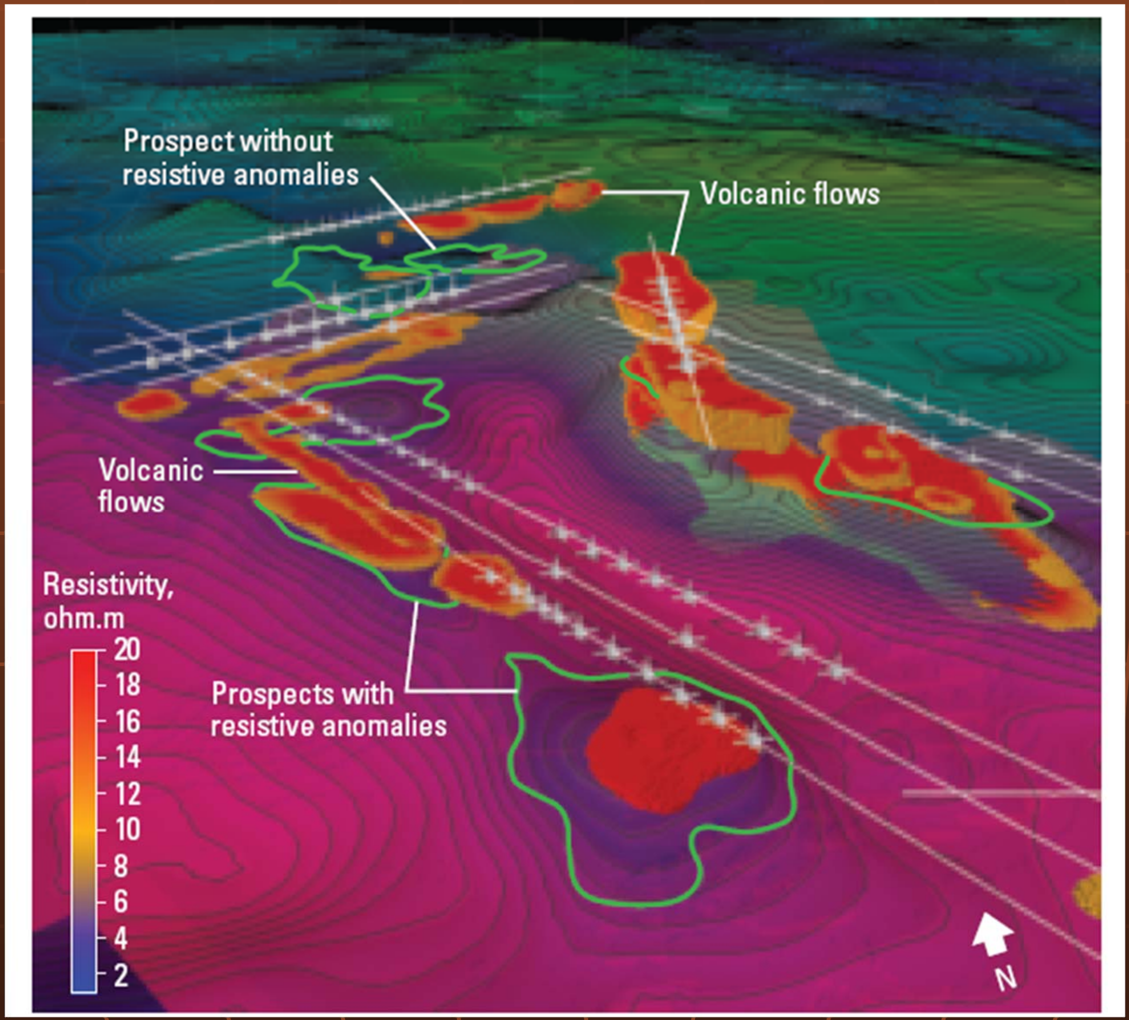
Courtesy of EMGS

CSEM Interpretation



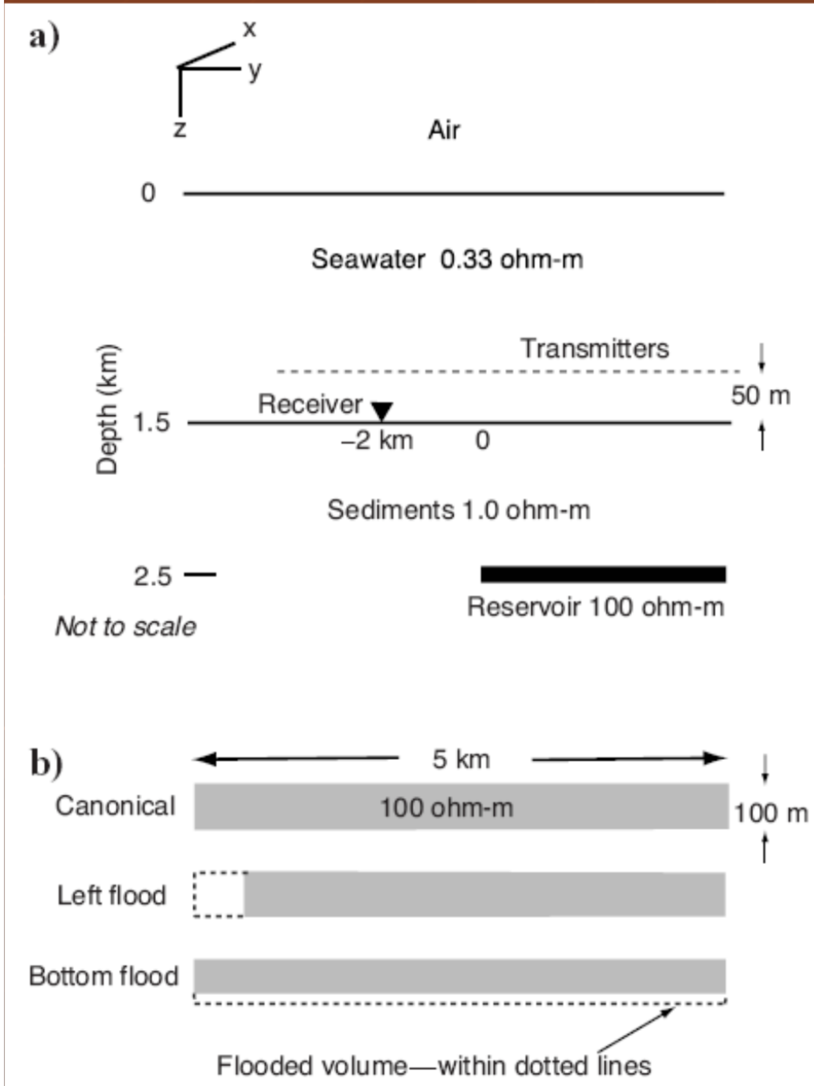
Courtesy of Constable and Key

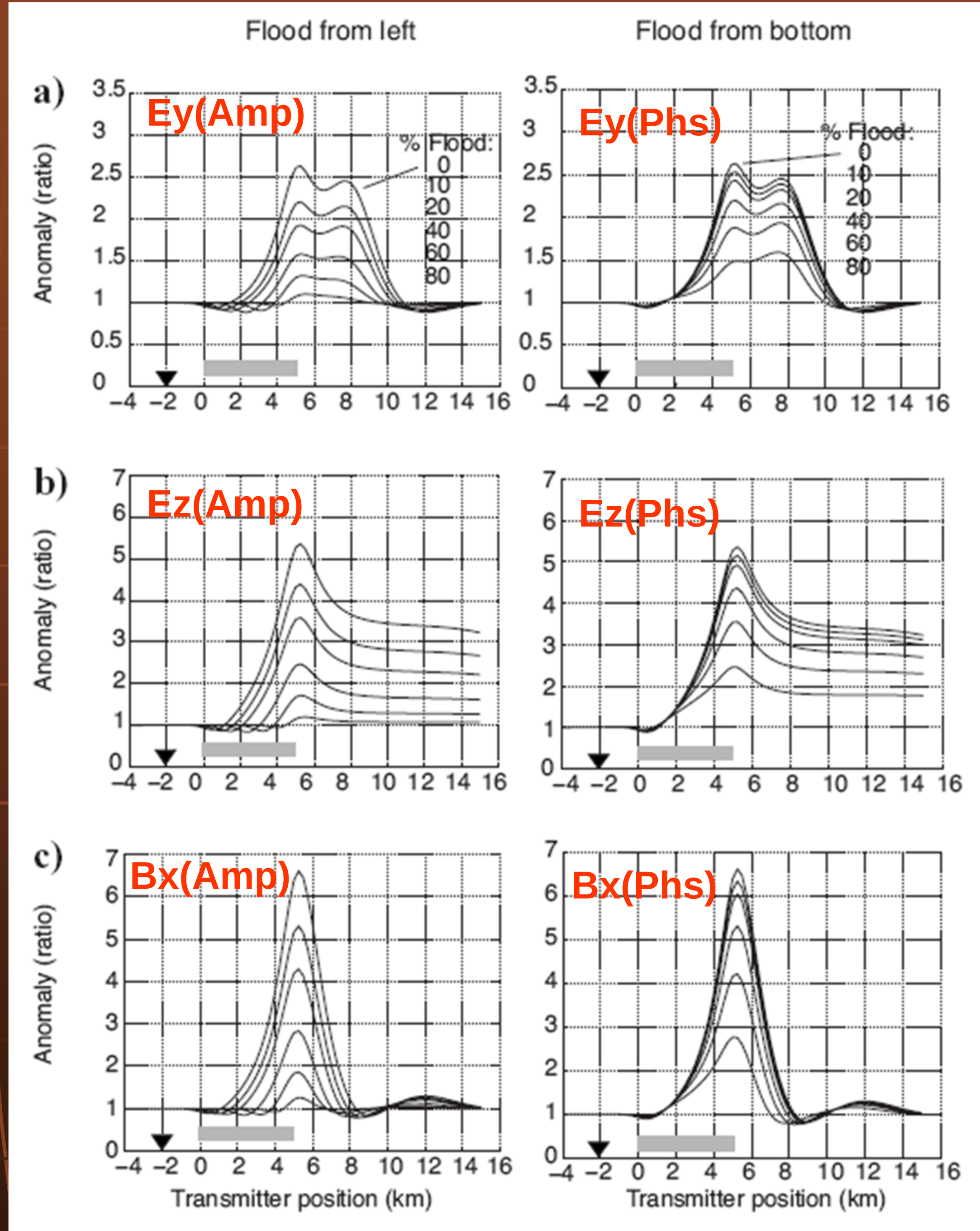
CSEM interpretation



Brady et al. 2009

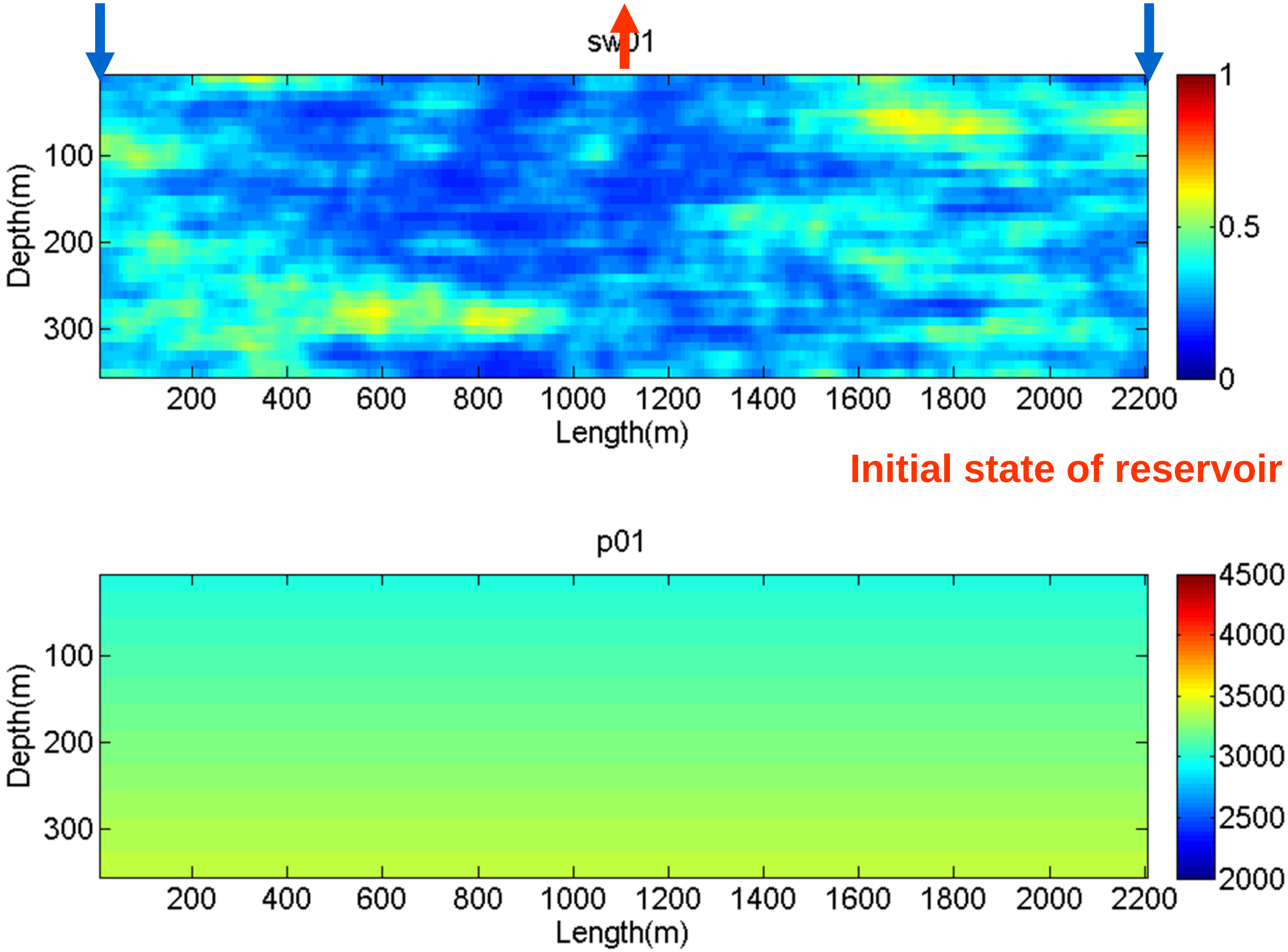
Time-lapse CSEM modeling





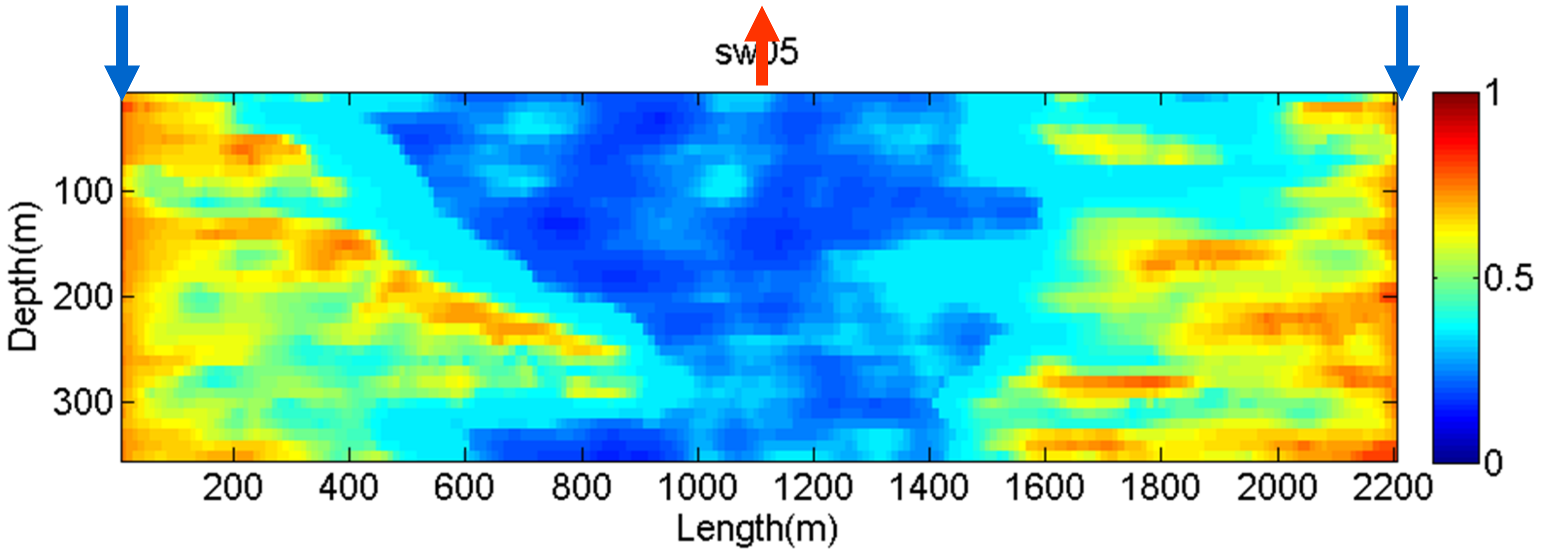
Orange et al. (2009)

Waterflooding to enhance oil recovery

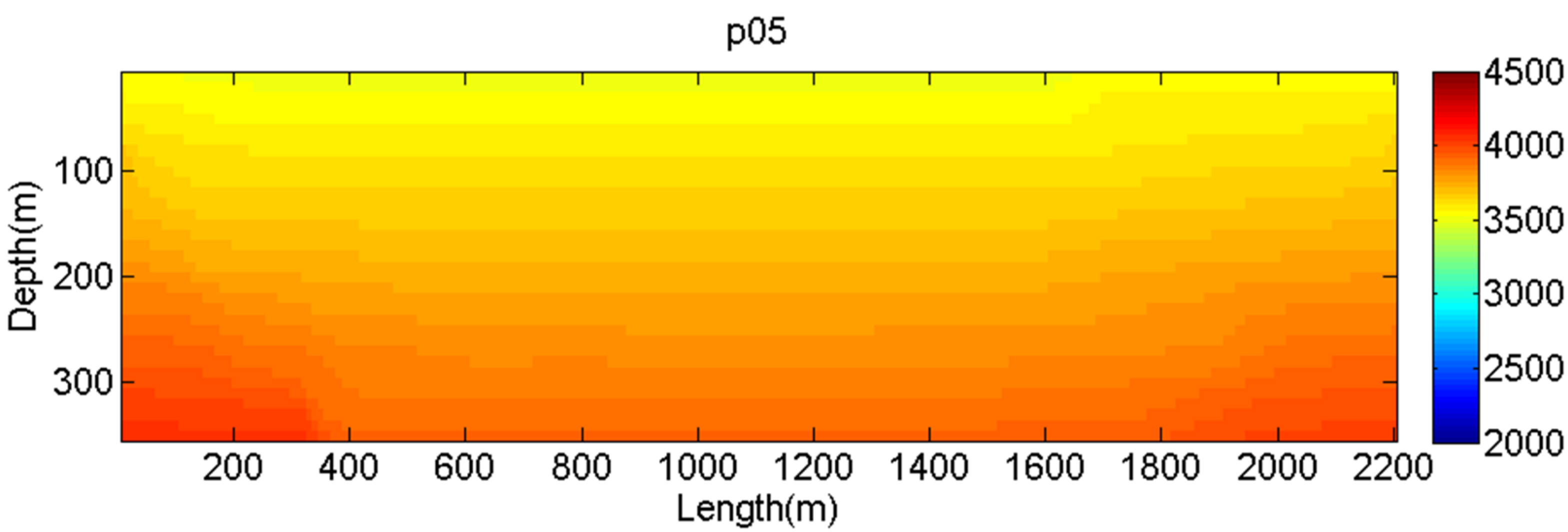


Initial state of reservoir

Waterflooding to enhance oil recovery



After 5 years of waterflooding



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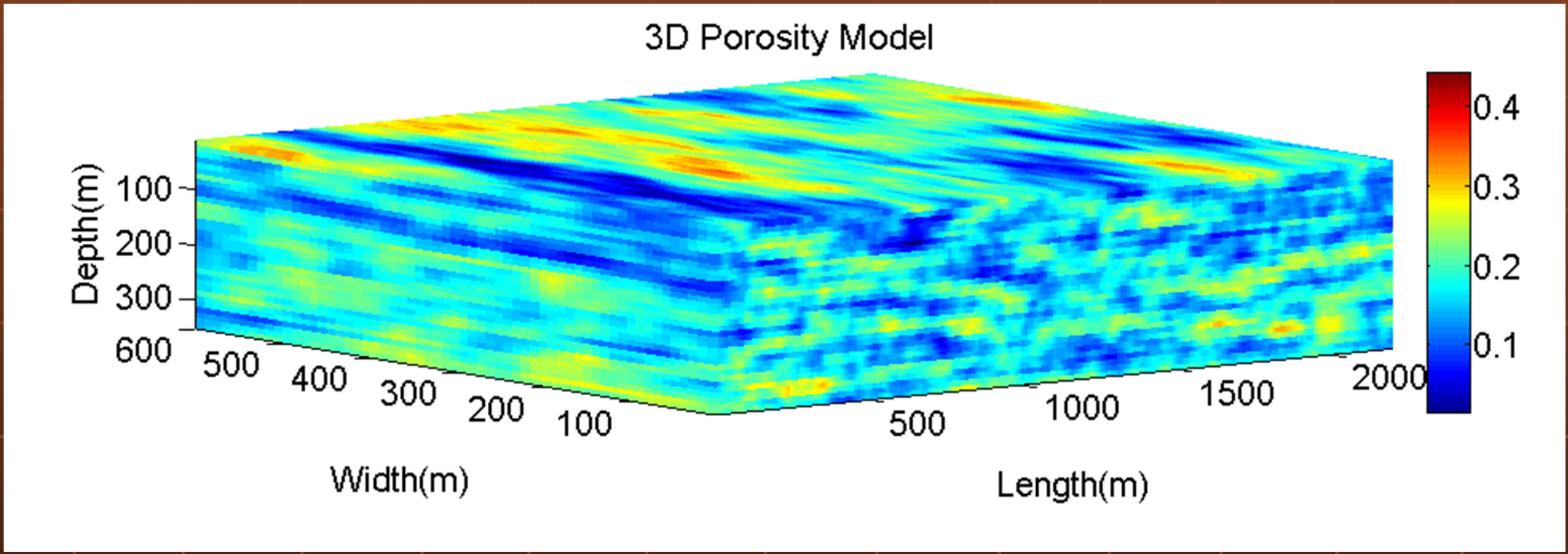
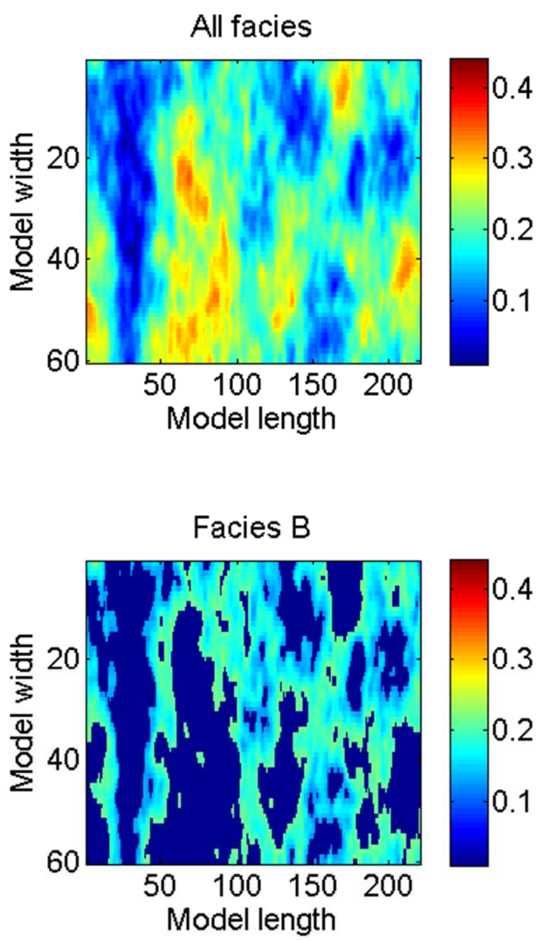
3D effective porosity model

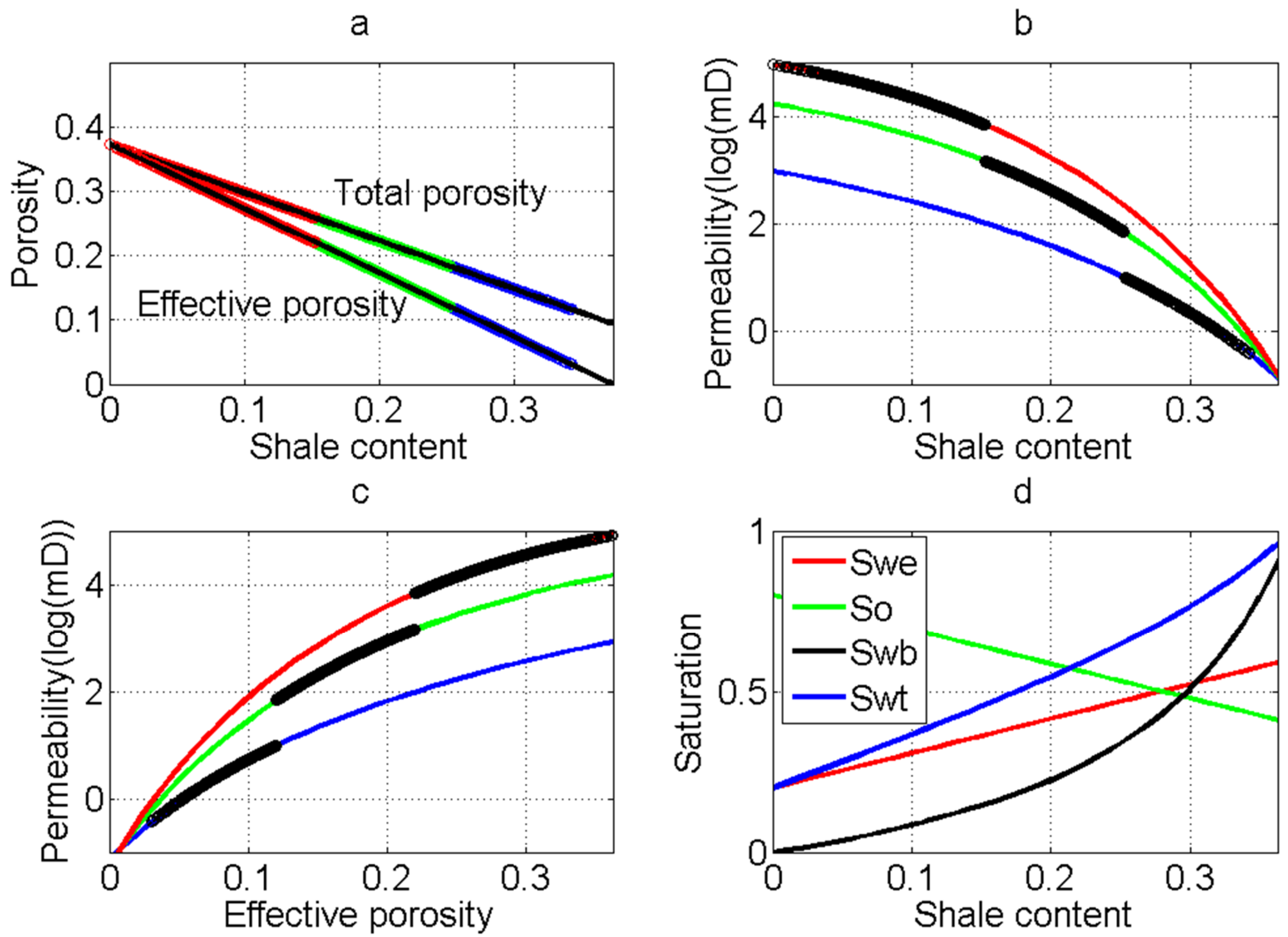


A large geostatistical model widely used in research on upgridding and upscaling approaches (Christie and Blunt, 2001)

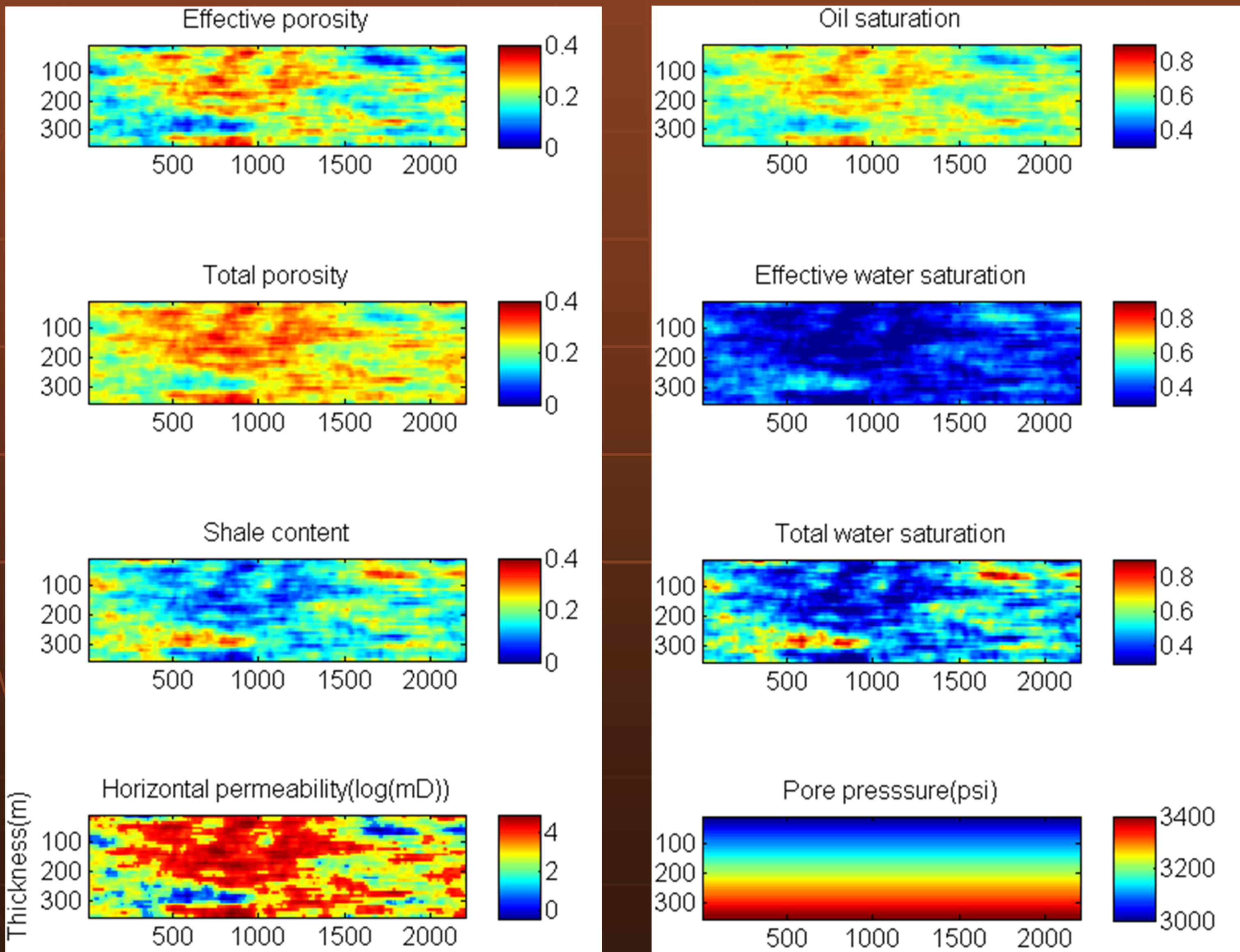
Facies distribution in effective porosity domain
Map view



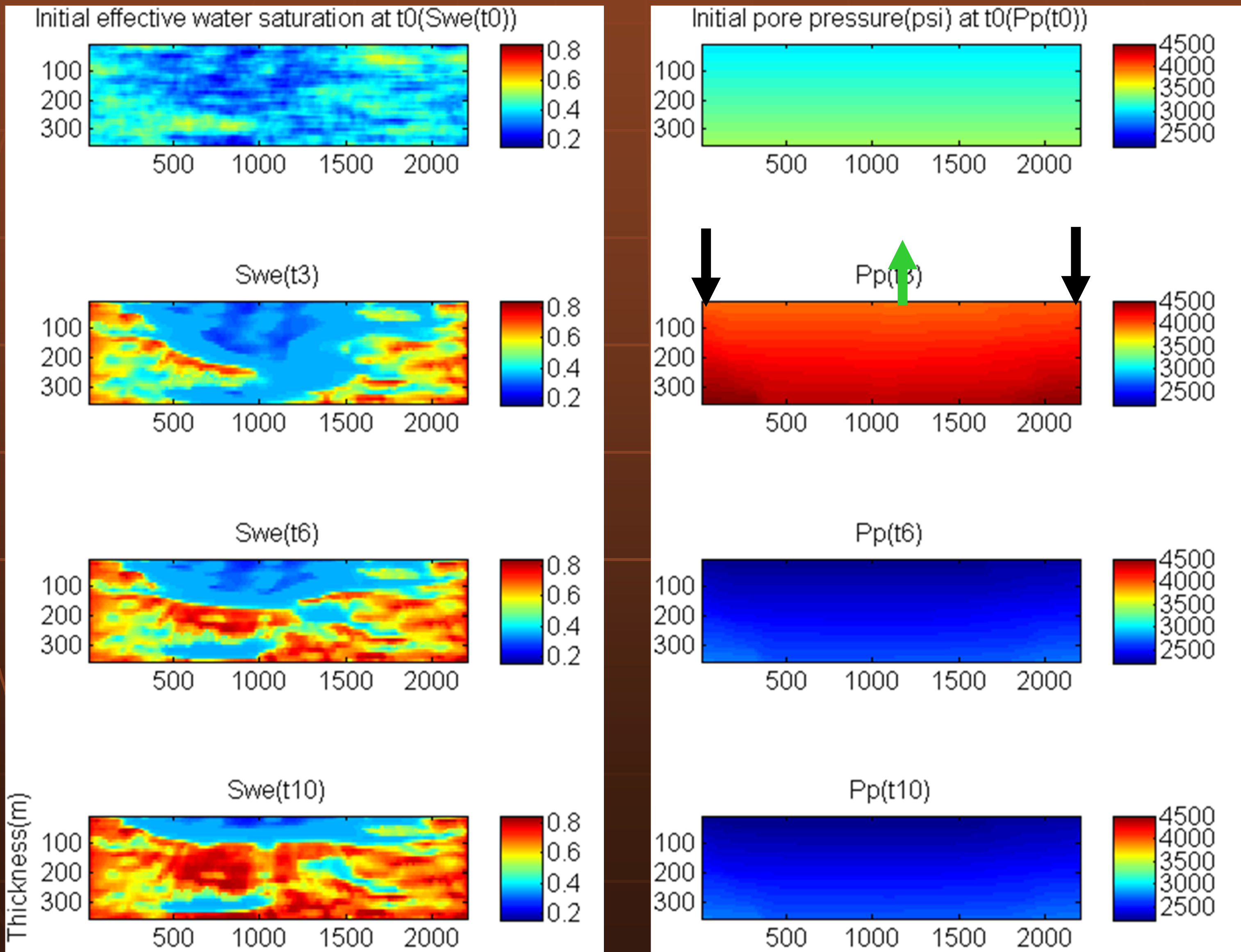
Petrophysics model



Distribution of petrophysical properties

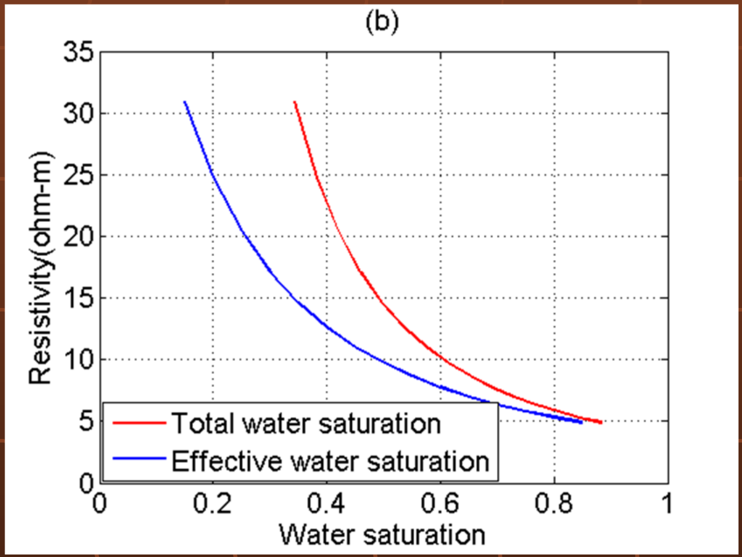


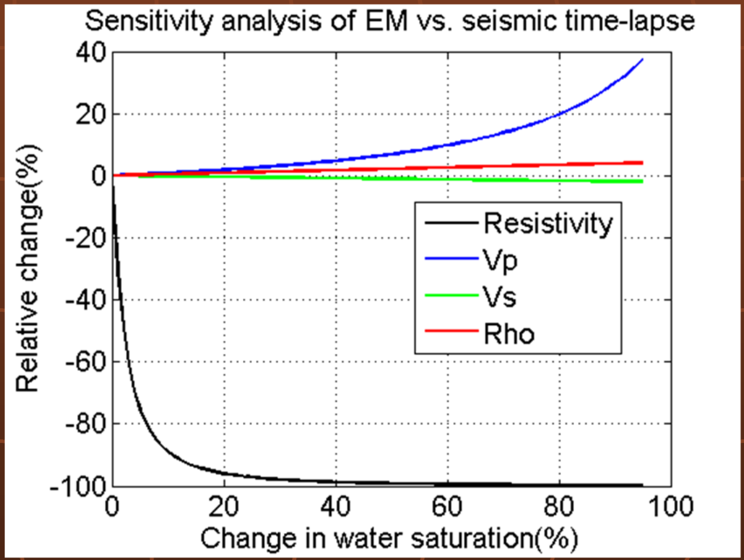
Time-dependent distributions of fluid saturation and pressure



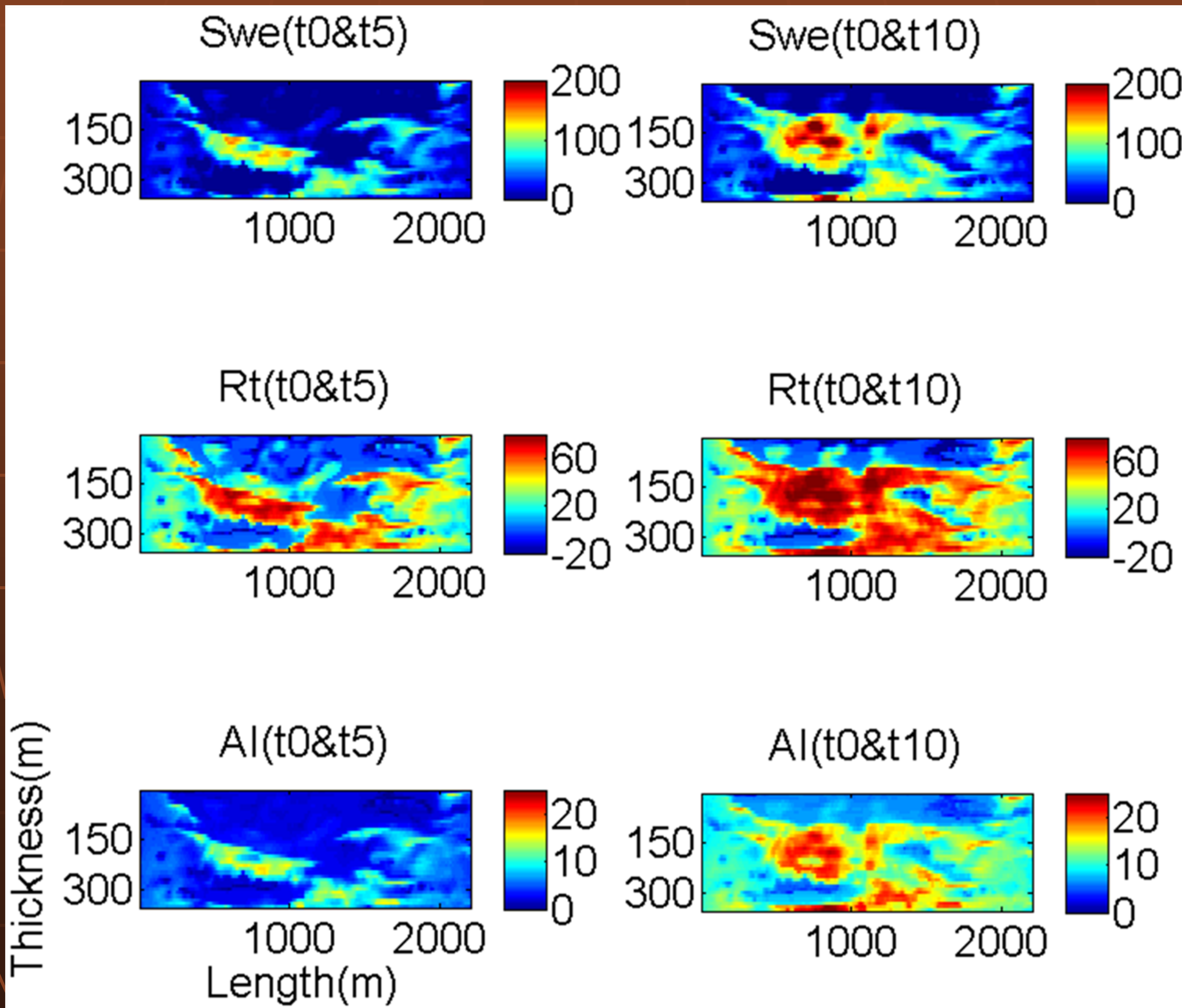
Petro-electric model

Combining Thomas and Stieber petrophysics model (1975), dual water rock physics model (Best 1980; Clavier, 1984), and Arps' empirical equation (Arps, 1953)





Comparison of elastic and resistivity time-lapse changes



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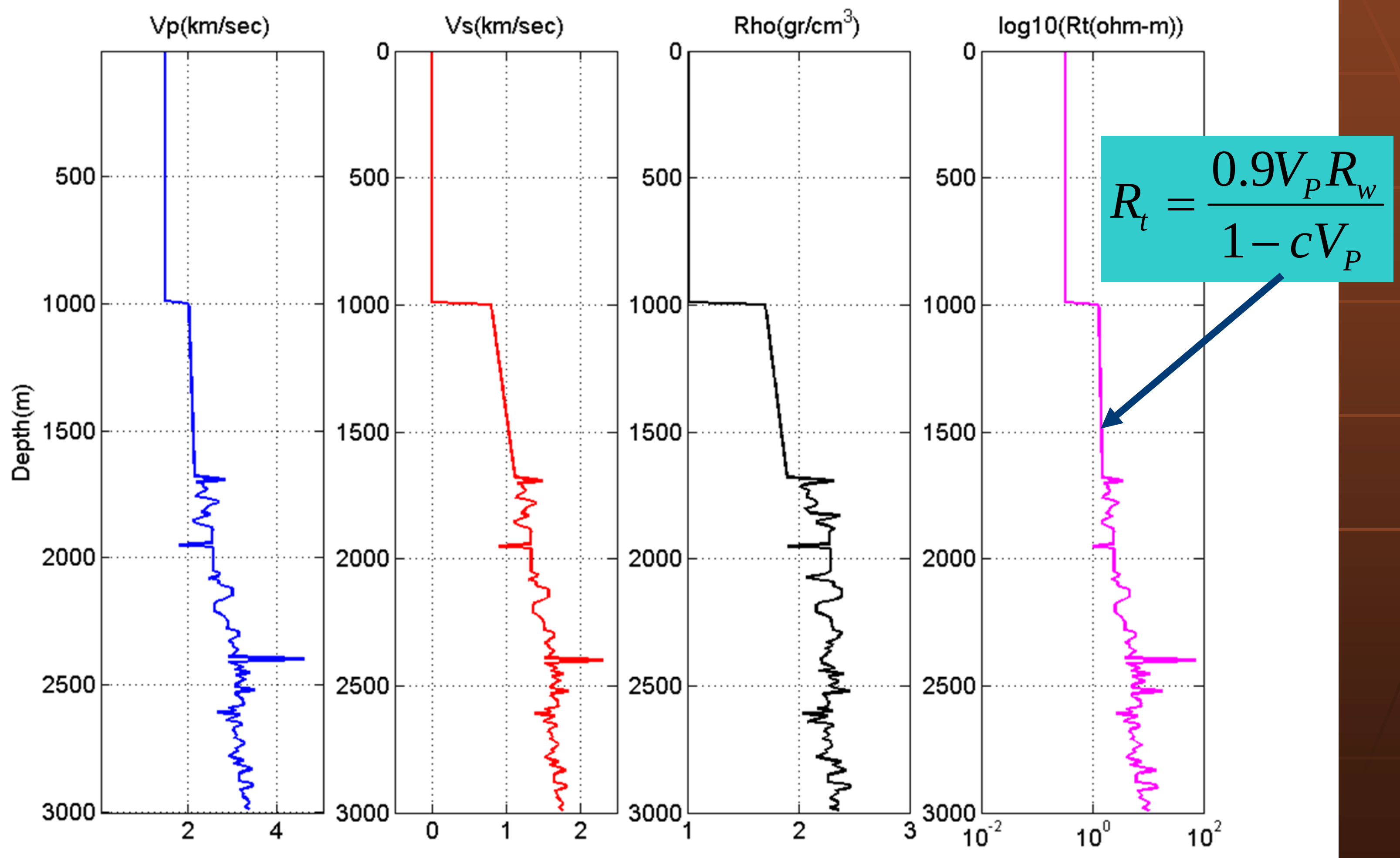
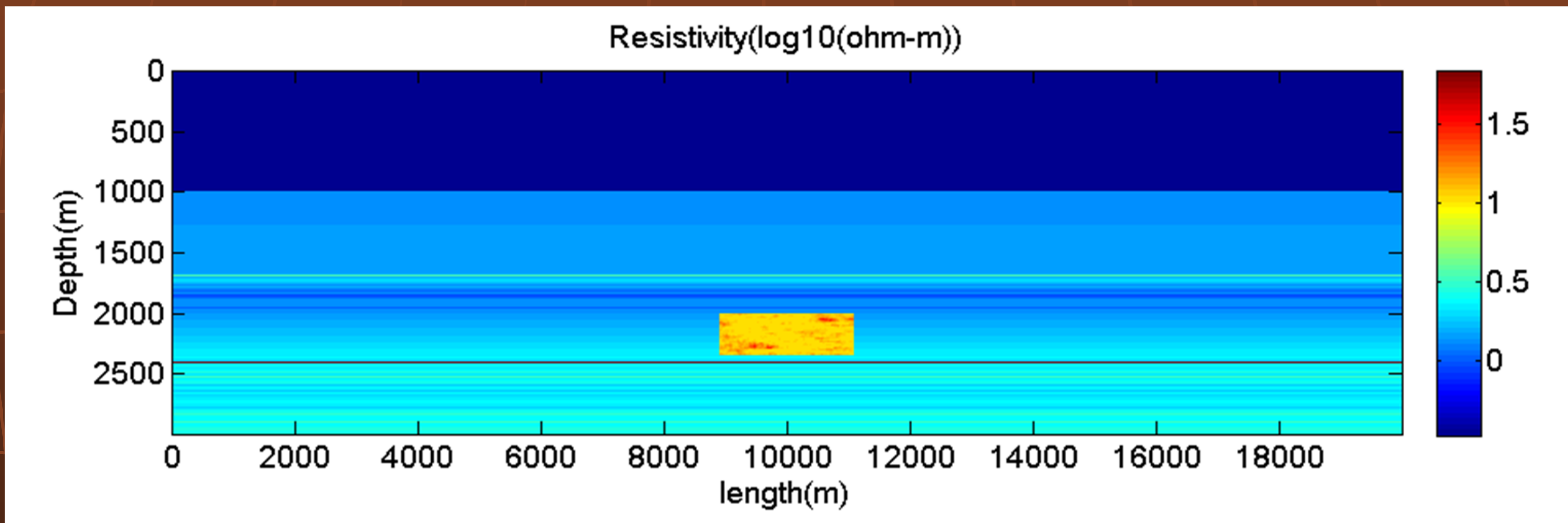
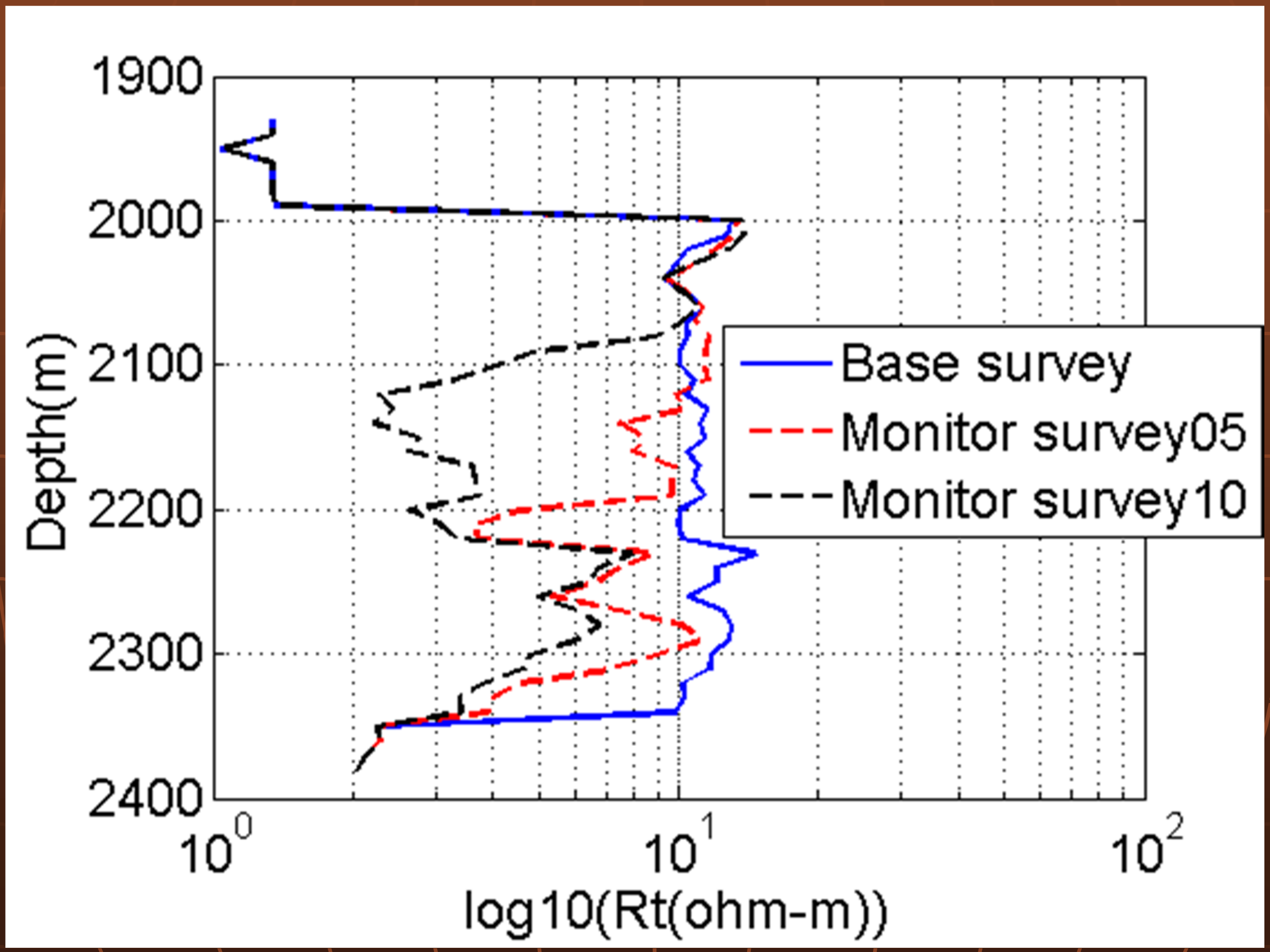
Background elastoelectric model (Modified Faust equation by Hacikoylu et al. 2006)



Reservoir inserted into background electric model



Resistivity logs extracted from the middle of the 2D reservoir for base survey, the two monitor surveys after 5 and 10 years of water flooding



CSEM Physics (Maxwell's equations): mathematical formulation of the laws explaining the interaction of electric and magnetic fields.

Electromagnetic induction in a picture:

Faraday's Law says that a moving (or time-varying) magnetic field will induce electric fields in a conductor.

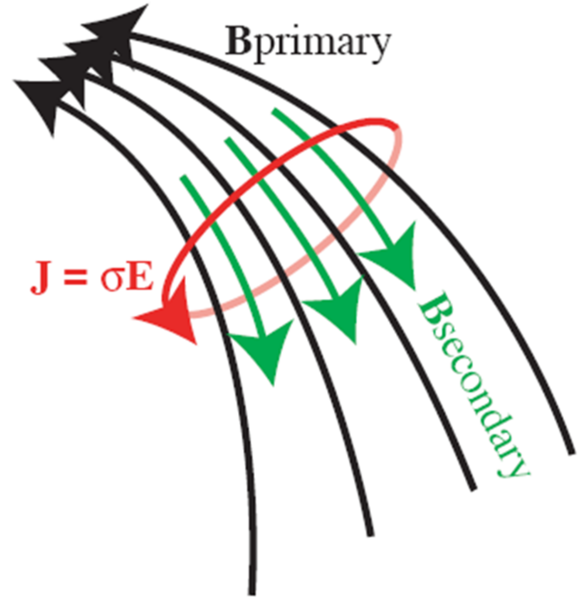
$$\oint_C \mathbf{E} \cdot d\mathbf{l} = -\frac{d\Phi}{dt}$$

Ohm's Law says that a current will be generated from the electric field in a good conductor.

$$\mathbf{J} = \sigma \mathbf{E}$$

Ampere's Law says that the current I will generate a secondary magnetic field.

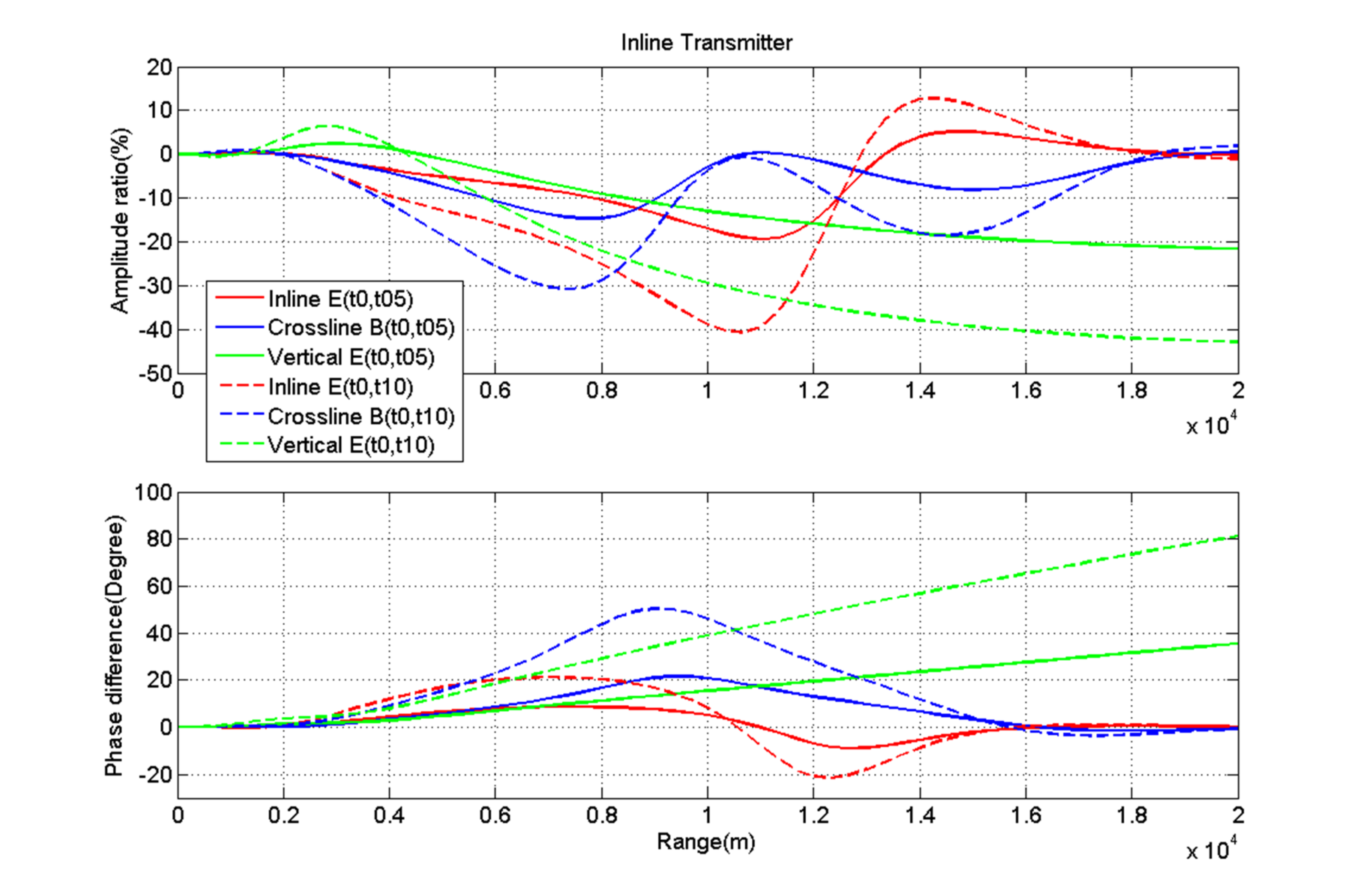
$$\oint_C \mathbf{B} \cdot d\mathbf{l} = \mu I$$



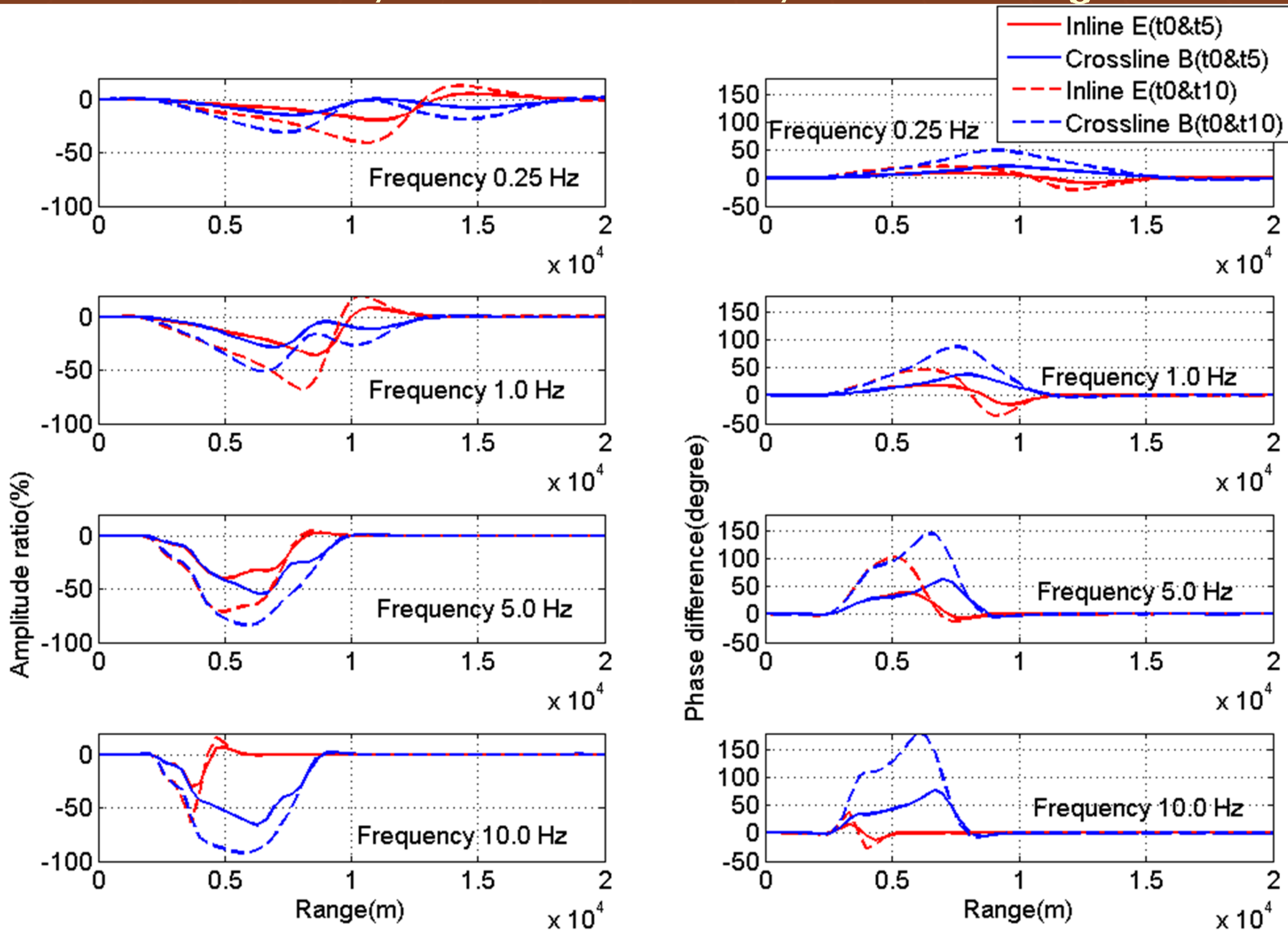
Minus sign in Faraday's Law shows that conductors attenuate EM fields and so EM fields propagate in resistive materials.

(Courtesy of Key and Constable)

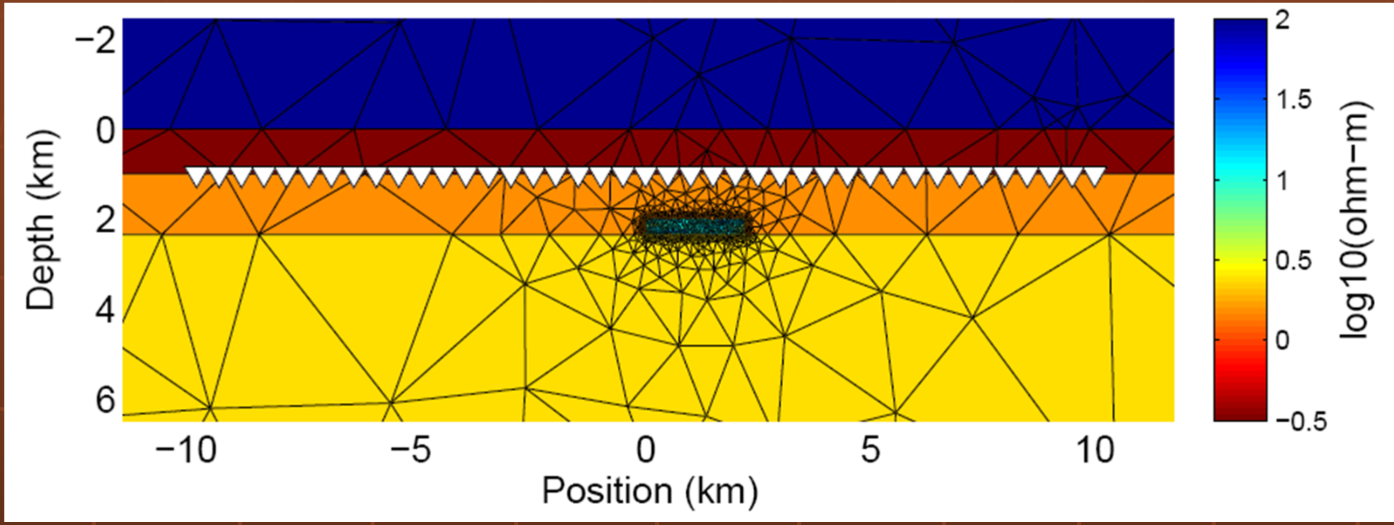
1D-CSEM time-lapse changes in response to waterflooding after 5 years (solid lines) and 10 years (dashed lines)

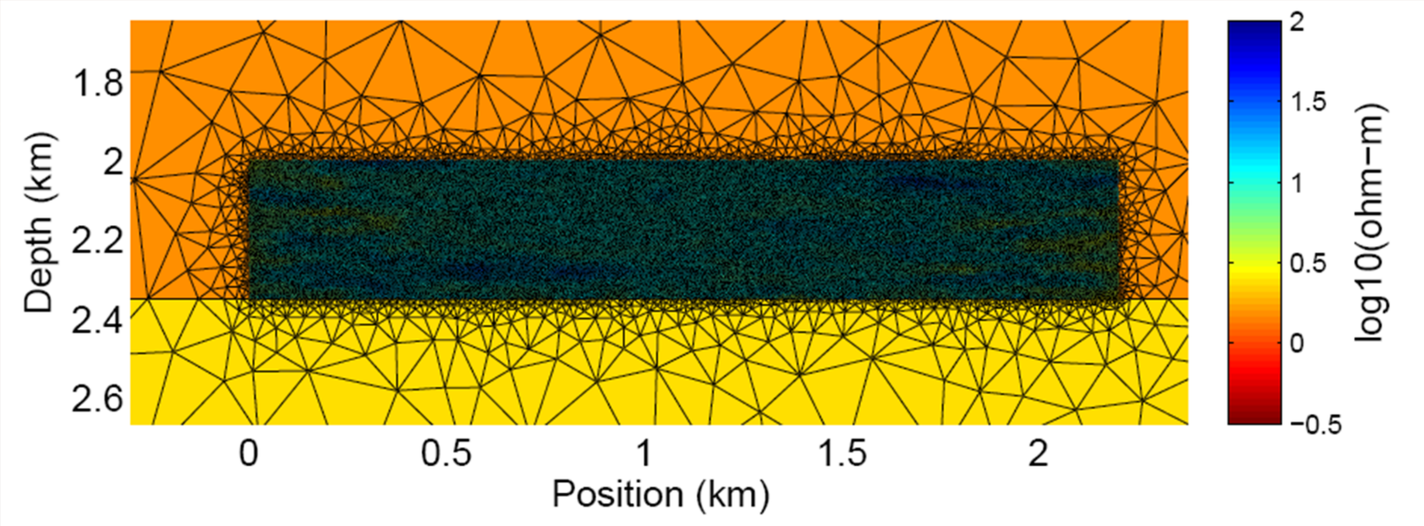


1D frequency analysis
Inline transmitter, inline electric filed, and xline magnetic field



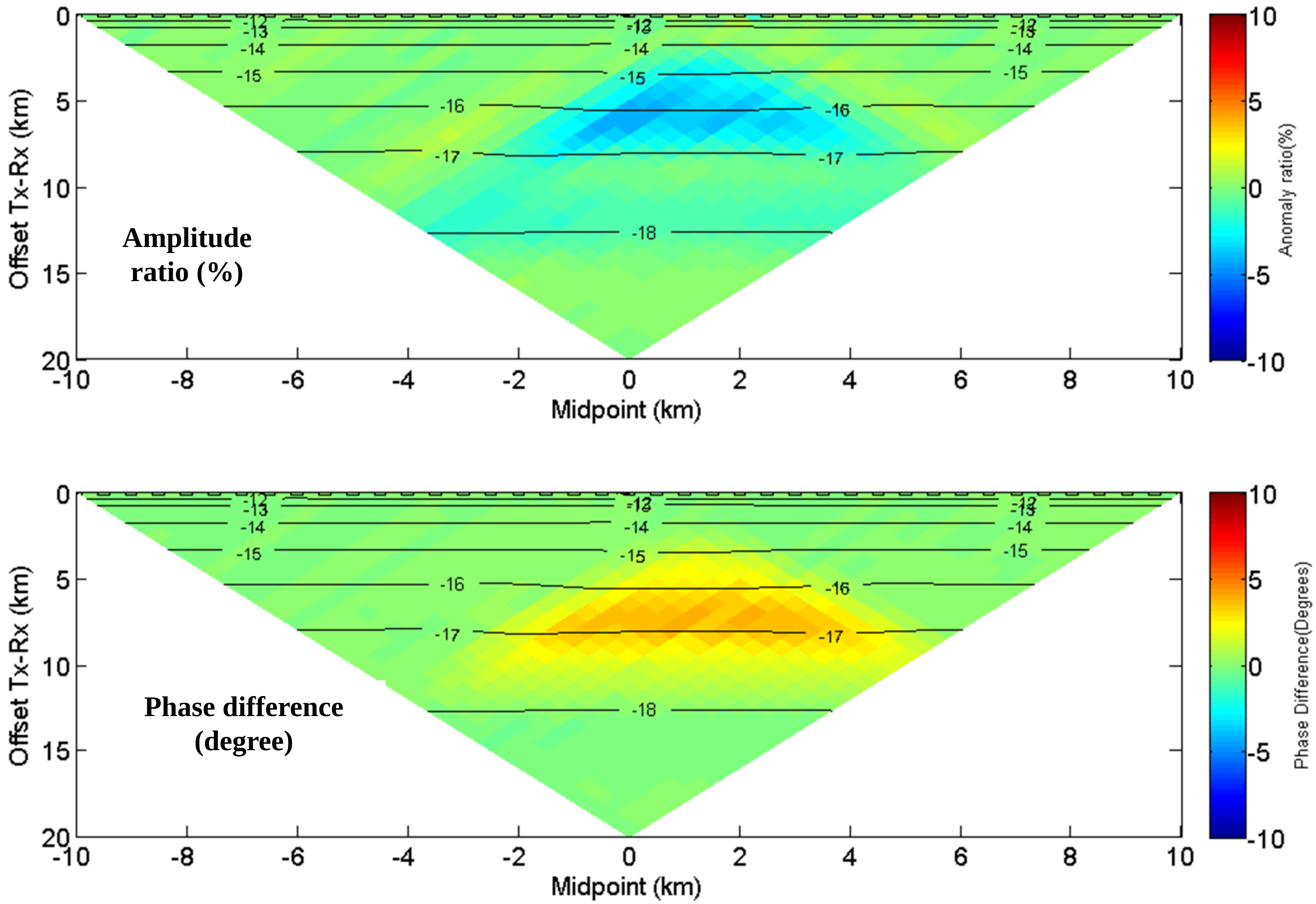
The coarse starting grid (top) and the final refined gird (bottom) created by triangular meshing over the 2D reservoir model embedded into 1D background



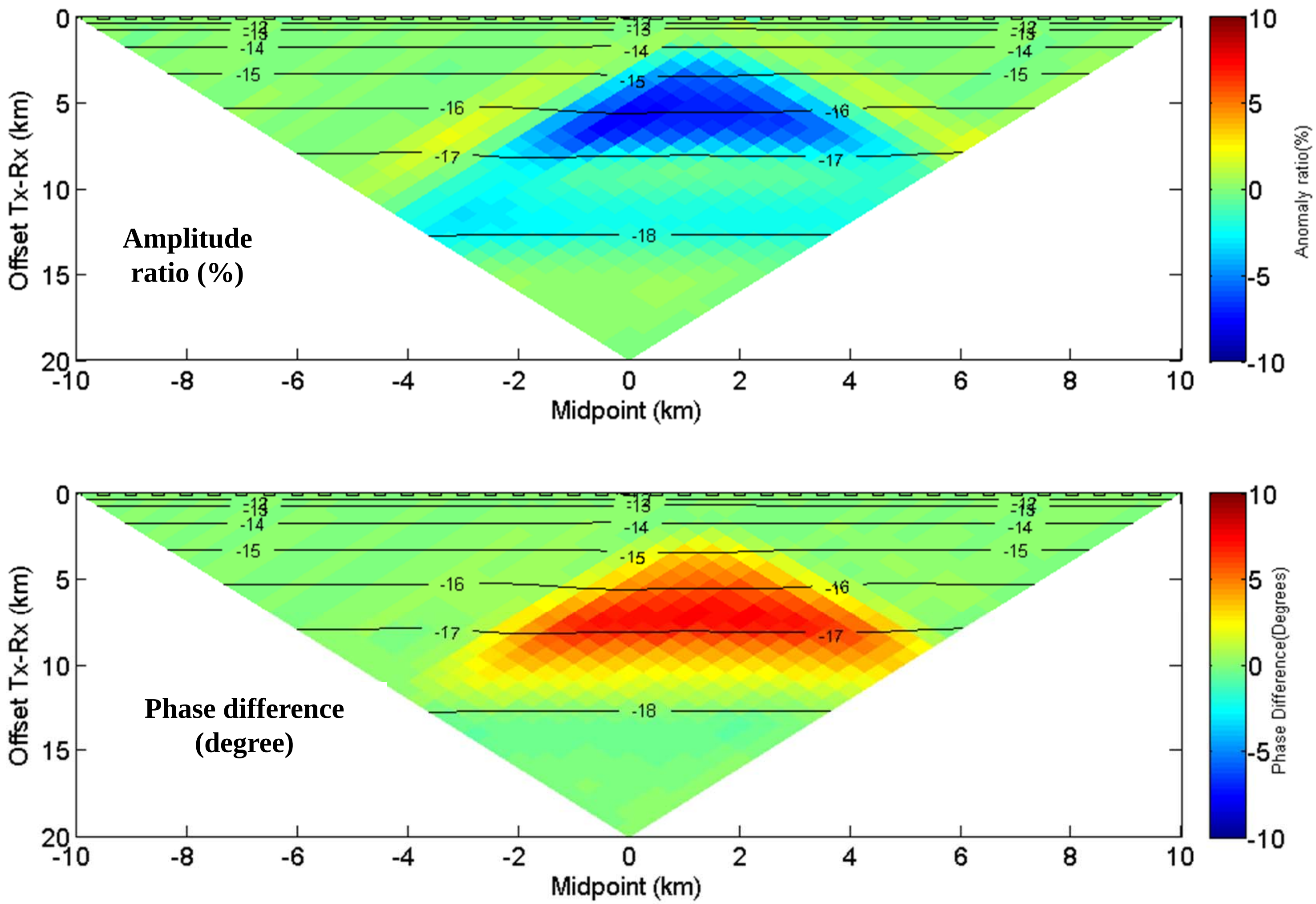


SEG abstract presented at Denver meeting 2010

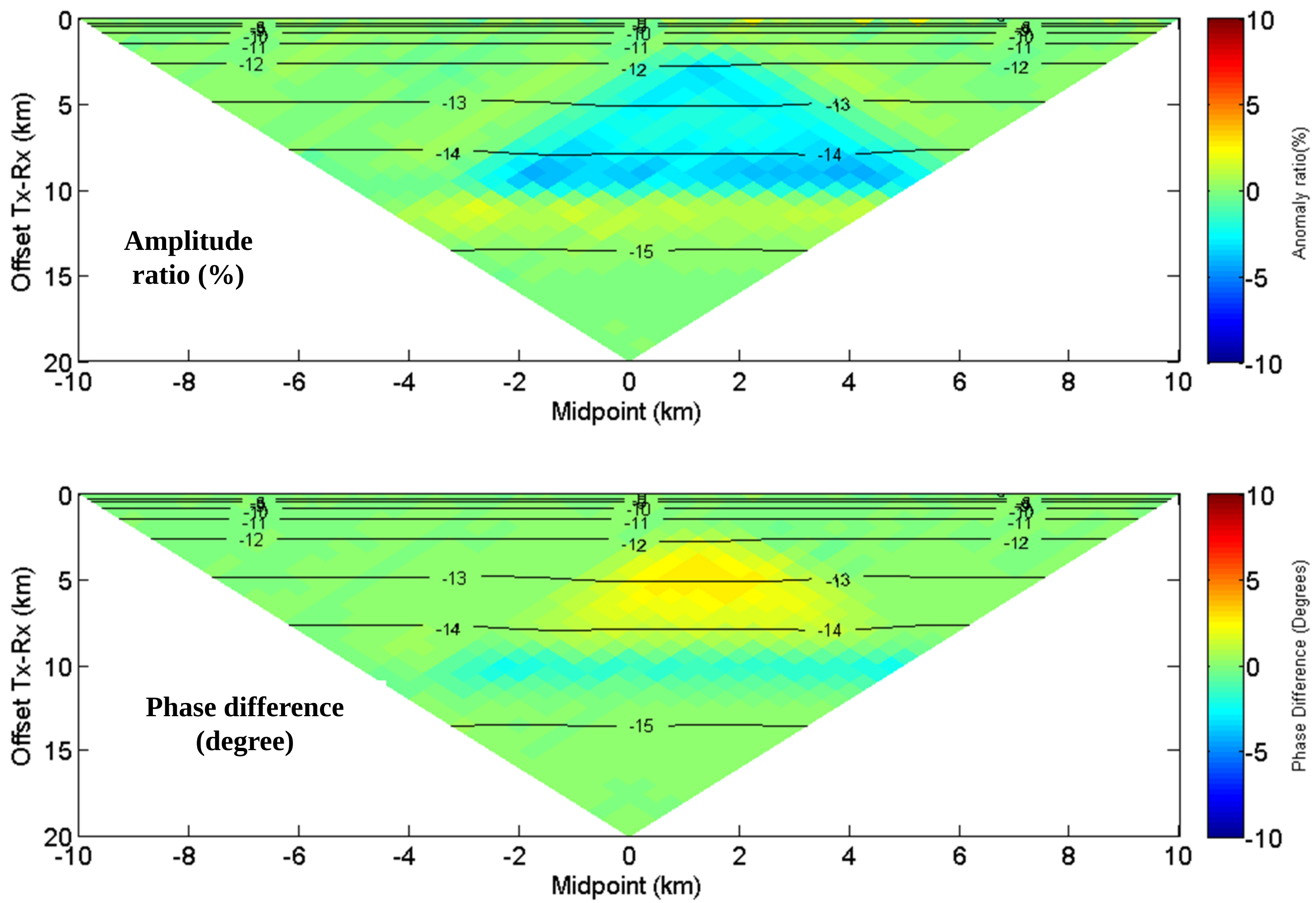
2.5D CSEM time-lapse response of crossline magnetic field in midpoint-offset geometry after 5 years of waterflooding



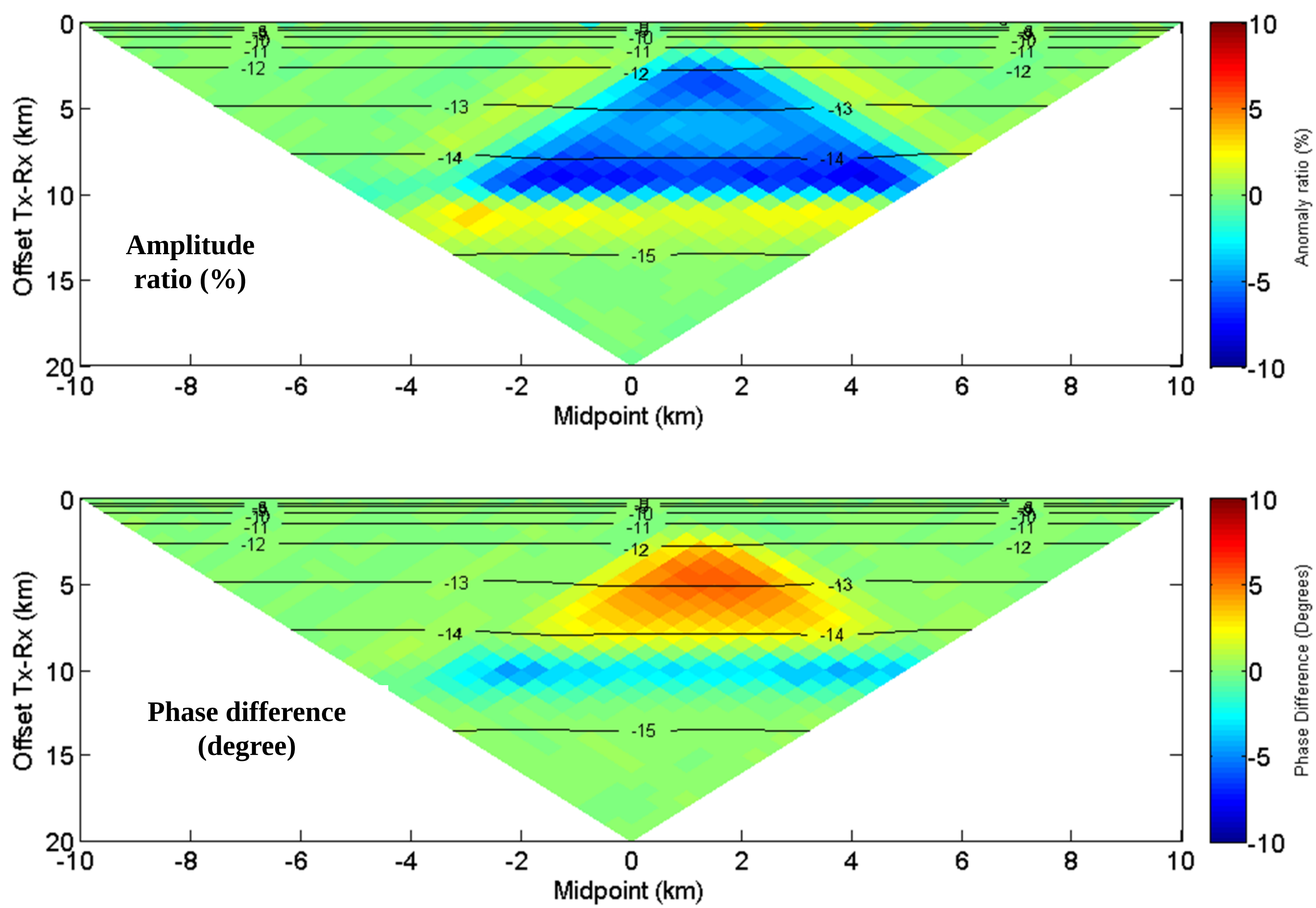
2.5D CSEM time-lapse response of crossline magnetic field in midpoint-offset geometry after 10 years of waterflooding



2.5D CSEM time-lapse response of inline electric field in midpoint-offset geometry after 5 years of waterflooding



2.5D CSEM time-lapse response of inline electric field in midpoint-offset geometry after 10 years of waterflooding



Summary of time-lapse CSEM feasibility study

- 2.5D CSEM modeling demonstrates that a detectable time-lapse signal after 5 years and a strong time-lapse signal after 10 years of waterflooding are attainable with the careful application of currently available CSEM technology.
- 1D CSEM data acquired at the middle of reservoir exhibits relatively strong time-lapse signals for both monitor surveys.
- These observations demonstrate that 1D modeling of a 2D reservoir can be misleading and results in the overestimation or under prediction of the time-lapse signal and the associated swept oil in the waterflooding enhance recovery.
- Repeatability issues during CSEM data acquisition, processing, and interpretation are critical steps to preserve these relatively small, but noticeable, time-lapse signals.

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Publications and presentation

1. **Shahin, A.**, Stoffa, P.L., Tatham, R.H., Sava, D., Sensitivity analysis of multi-component seismic attributes to fluid content and pore pressure, presented in 78th Annual International Meeting, Society for Exploration Geophysicists (SEG), Las Vegas, Expanded Abstracts, November 2008.
2. **Shahin, A.**, Stoffa, P.L., Tatham, R.H., Sava, D., Multicomponent seismic time-lapse cross-plot and its applications, presented *in* 79th Annual International Meeting, Society for Exploration Geophysicists (SEG), Houston, Expanded Abstracts, November 2009.
3. **Shahin, A.**, Tatham, R., H., Stoffa, P., L., Spikes, K., T., 2010, Comprehensive petro-elastic modeling aimed at quantitative seismic reservoir characterization and monitoring, presented at SEG 80th annual meeting, Denver, Colorado.
4. **Shahin, A.**, Key, K., Stoffa, P., L., Tatham, R., 2010, Time-lapse CSEM analysis of a shaly sandstone simulated by comprehensive petro-electric modeling, presented at SEG 80th annual meeting, Denver, Colorado.
5. **Shahin, A.**, Stoffa, P.L., Tatham, R.H., Sava, D., Uncertainty in rock physics modeling: Impact on seismic reservoir characterization and monitoring, presented at SEG 2008 Development and production Forum, The University of Texas at Austin (July 2008).
6. **Shahin, A.**, Stoffa, P.L., Tatham, R.H., Sava, D., Multi-component seismic AVO/TVO analysis: sensitivity to saturation & pressure, presented at SEG 2008 Development and production Forum, The University of Texas at Austin (July 2008).
7. **Shahin, A.**, Stoffa, P.L., Tatham, R.H., Sava, D., A statistical approach to quantify the detectability of dynamic reservoir properties using multi-component time-lapse seismic attributes, presented at SEG 2008 Development and production Forum, The University of Texas at Austin (July 2008).
8. **Shahin, A.**, Key, K., Stoffa, P., L., Tatham, R., Petro-electric modeling for CSEM reservoir characterization and monitoring, Geophysics (in review).
9. **Shahin, A.**, Tatham, R., H., Stoffa, P., L., Spikes, K., T., Optimal dynamic rock-fluid physics template validated by petro-elastic reservoir modeling, Geophysics (in review).
10. **Shahin, A.**, Stoffa, P.L., Tatham, R.H., Sava, D., Multi-component time-lapse seismic: on saturation-pressure discrimination and statistical detectability of fluid flow (in preparation, to be submitted to Journal of exploration seismology).
11. **Shahin, A.**, Stoffa, P.L., Tatham, R.H., Seif, R., Accuracy required in seismic modeling to detect production-induced time-lapse signals (in preparation, to be submitted to Journal of Geophysical International).
12. **Shahin, A.**, Stoffa, P.L., Tatham, R.H., Sava, D., Derivative-bases sensitivity analysis: a viable tool in reservoir geophysics (in preparation, to be submitted to Journal of exploration seismology).

Recommendations and future work

- The development of the petro-electro-elastic model is based on the dispersed clay distribution. An extension of the current work will be the generation of a model with layered distribution of clay and then perform seismic and CSEM feasibility studies.
- Extend the current work to time domain and a 3D reservoir
- Joint inversion of seismic and CSEM data may lead to better estimation of the reservoir properties and results in lower uncertainties in the estimated properties compared to the properties estimated from seismic or CSEM alone.
- Seismic and CSEM reservoir history matching will be the ultimate application of the developed petro-elastic-electric model .
- Real data application will be the final stage of this research study.

Acknowledgment

- My supervisors, Dr. Paul Stoffa and Dr. Bob Tatham
- Dr. Kerry Key for helping with CSEM codes
- Dr. Anton Ziolkowski for discussion on CSEM results
- Tom Hess, Mark Wiederspahn, Kevin Johnson, and John Gerboc for technical support
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Thanks for your attention

Questions?