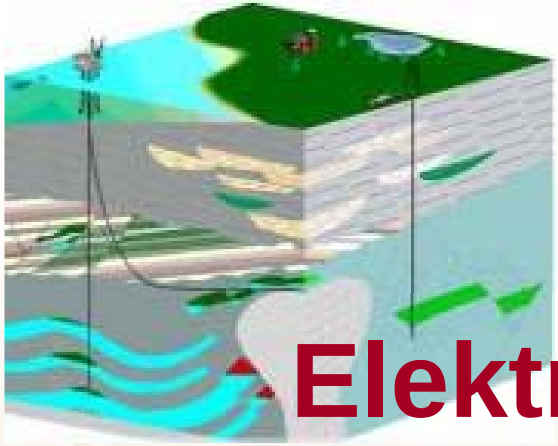

Elektromagnetische Methoden bei der Energie Exploration & Produktion

DGG 2011

K. M Strack

www.KMSTechnologies.com

Aufgabe

- Overview of electromagnetic (EM) methods in applied geophysics
- Viewpoint from the oil industry
  - Depth range1-6 km
  - Same methods for geothermal
- Examples from success stories

- Electromagnetics in applied geophysics
  - Rocks
  - Methods and their use in the industry
- Biggest challenges/opportunities
  - Daily tasks: finding oil
  - Exploration
  - Production
- Future

- Electromagnetics in applied geophysics
  - Rocks
  - Methods and their use in the industry
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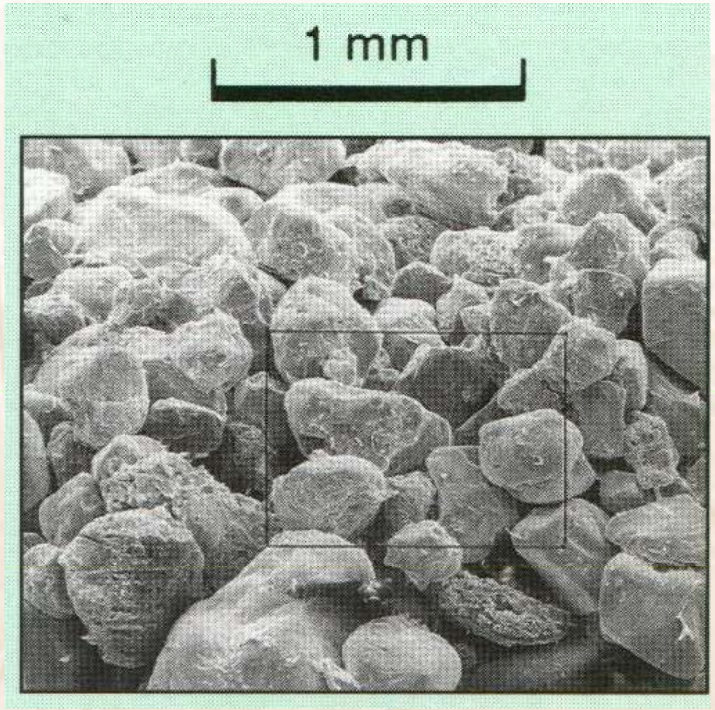
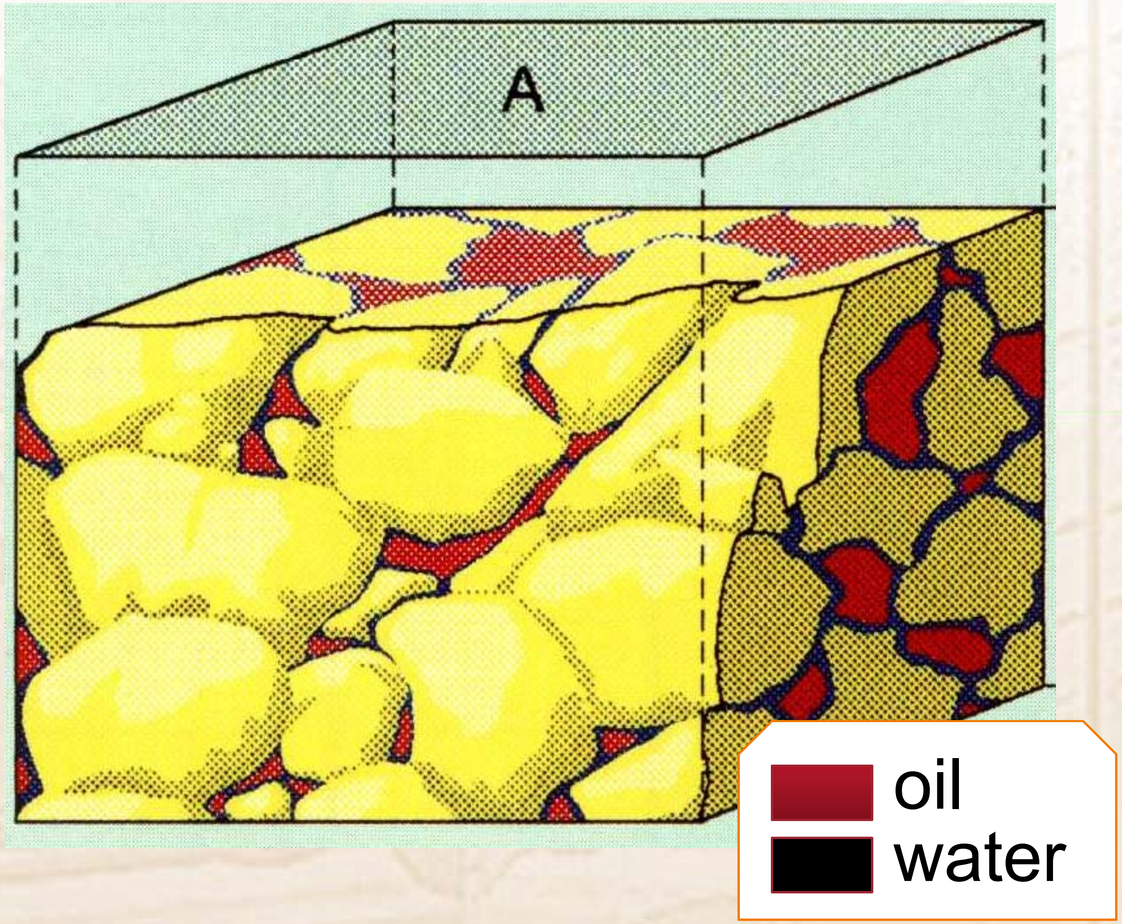
Electrical properties of rocks

Scanning electron
Microscope image



Bulk volume
model



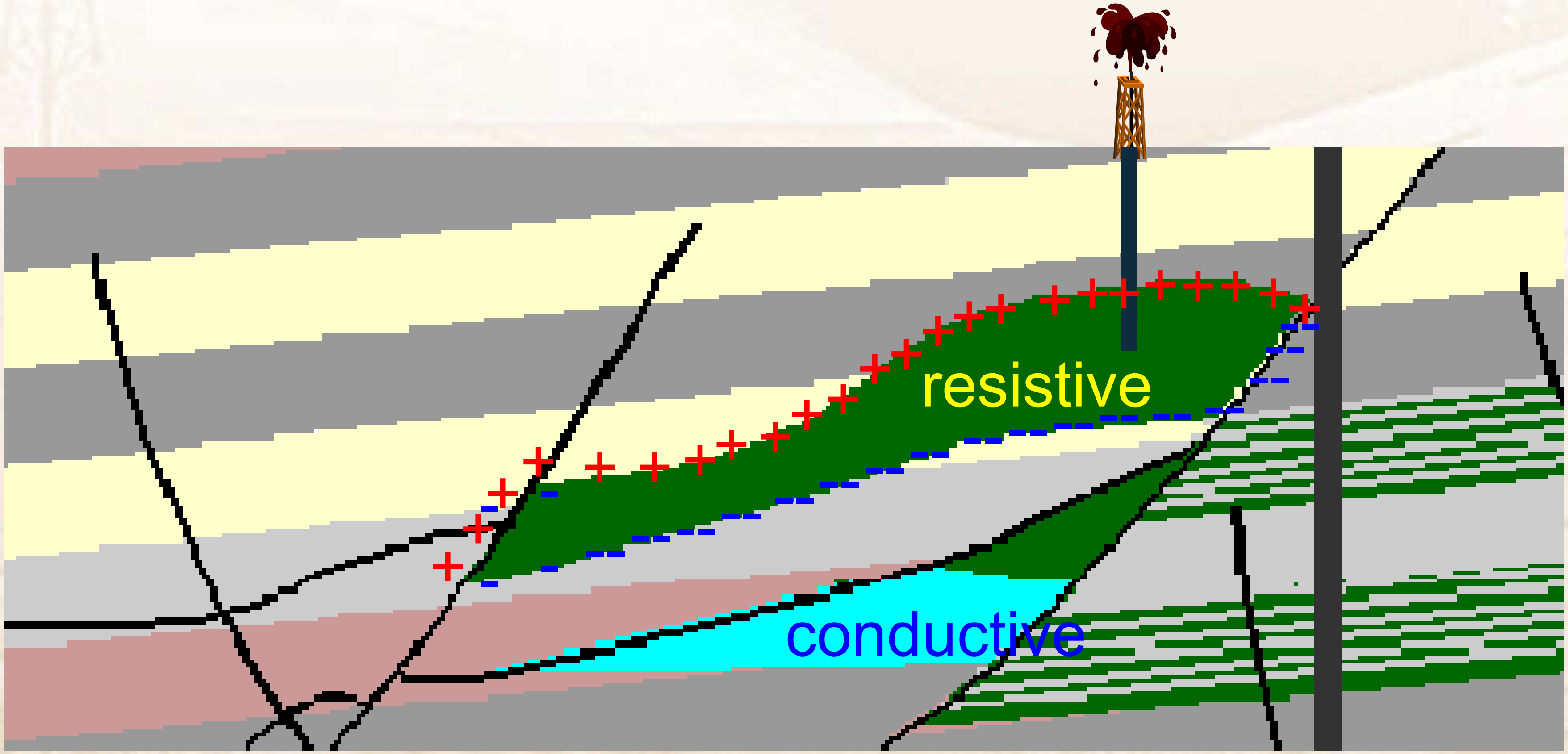
Specific electrical resistivity

simplified:

Spec. electrical resistivity is the resistance of the rock to electron movement through it.

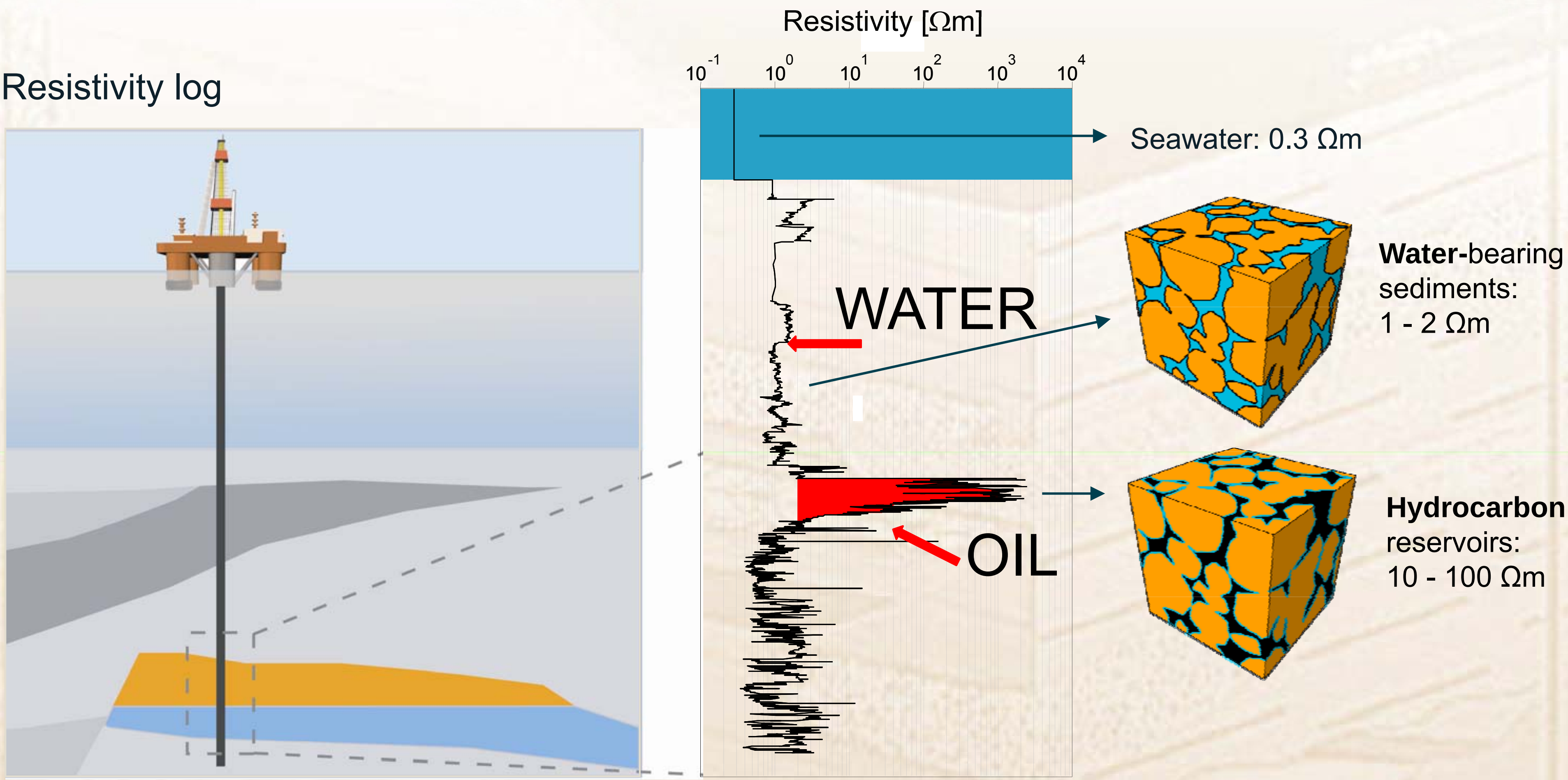
Rock minerals:	high resistivity
Pore fluids:	low resistivity

Hydrocarbon targets



Borehole measurements

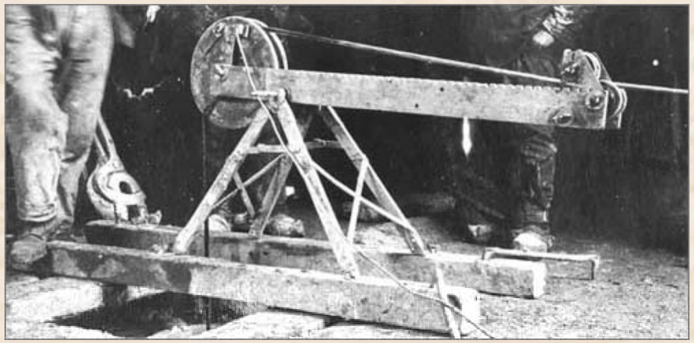
Resistivity log



Courtesy EMGS

Industry → methods - markets

➢ Borehole - logging	1,500 MUSD
➢ Airborne	100 MUSD
➢ Land	25 MUSD
➢ Marine	120 MUSD
➢ Monitoring	trial only, most fields



excl. China & FSU

Industry → methods, history

➢ Borehole - logging	1920s
➢ Airborne	1950s
➢ Land	1950s
➢ Marine	2000s
➢ Monitoring	today

excl. China & FSU

Industry → NEW methods

➢ Borehole - logging	3D anisotropy induction
➢ Airborne	Airborne TEM
➢ Land	Magnetotellurics
➢ Marine	Controlled source EM
➢ Monitoring	Borehole-to-surface

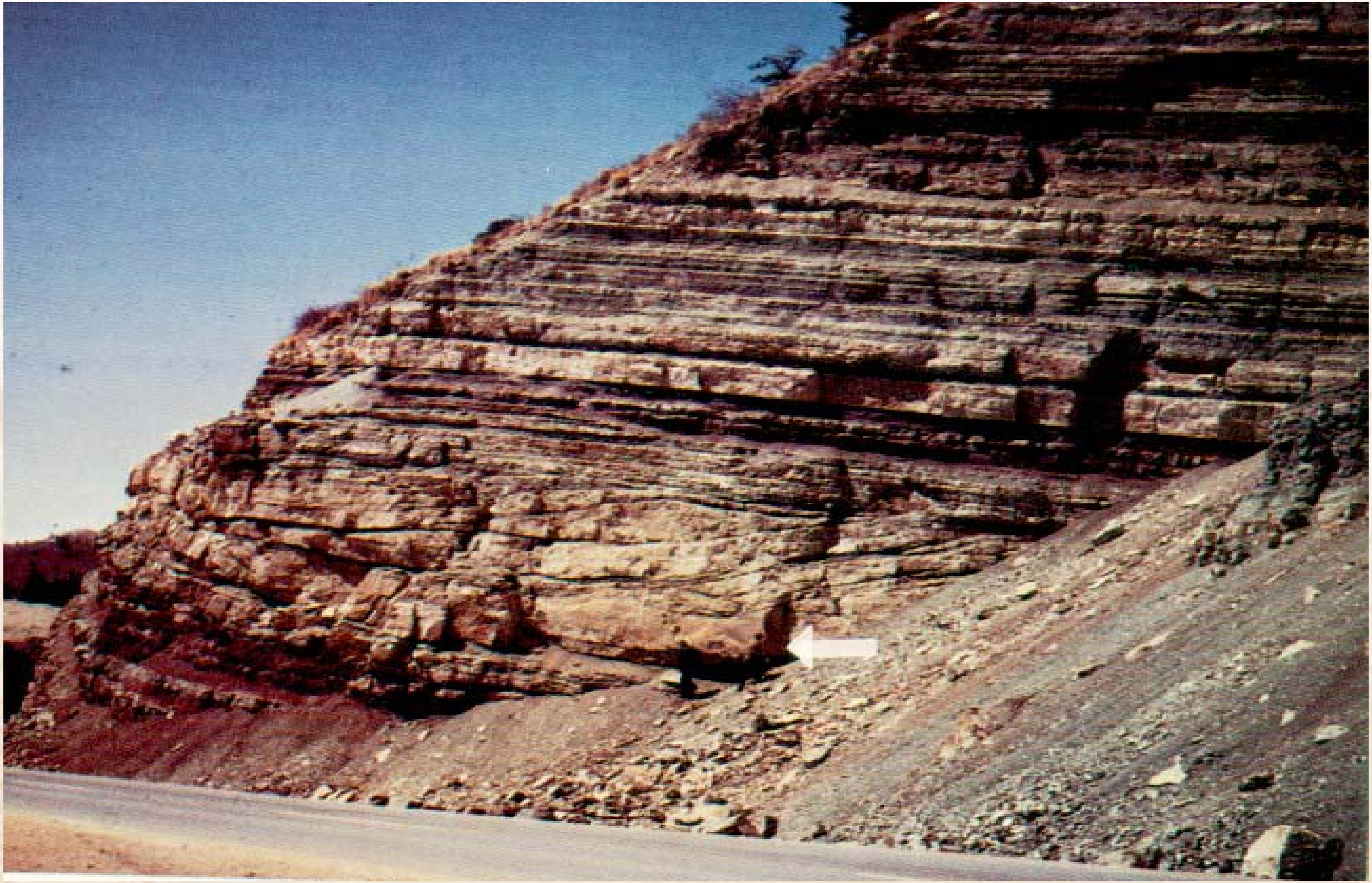
excl. China & FSU

- Electromagnetics in applied geophysics
- Biggest challenges/opportunities
  - Daily tasks: finding oil
  - Exploration
  - Production
- Examples
- Future

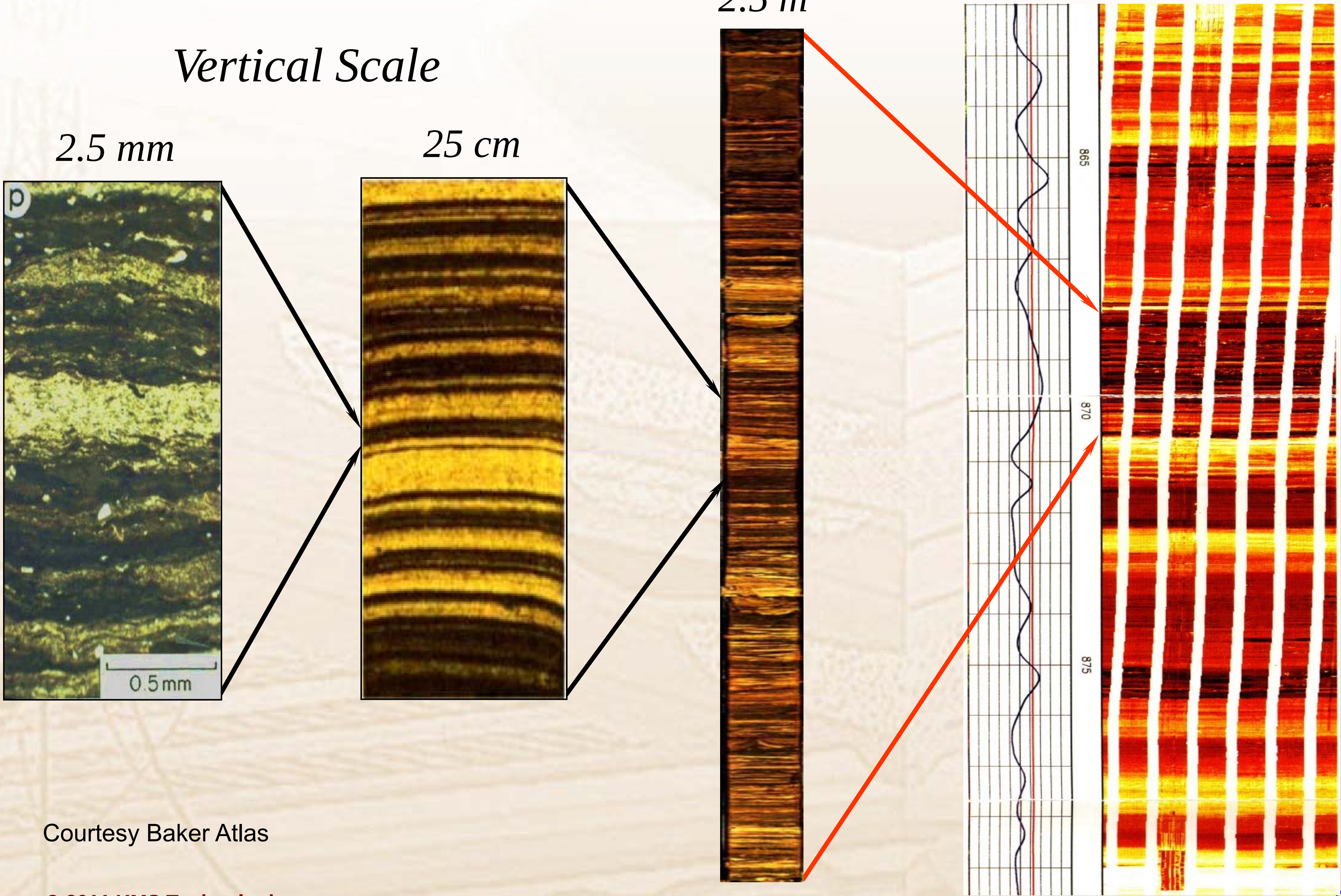
- Daily tasks: Borehole - logging
  - 3D induction
  - Inversion & calibration
  - Borehole-to-surface
  - Deep reading (>3 m from well bore)
  - Cross well
  - Geosteering
- Exploration
- Production

- Daily tasks: Borehole - logging
  - 3D induction
  - Inversion & calibration
  - Borehole-to-surface
  - Deep reading (>3 m from well bore)
  - Cross well
  - Geosteering
- Exploration
- Production

Crossbeds & sand/shale & siltstones

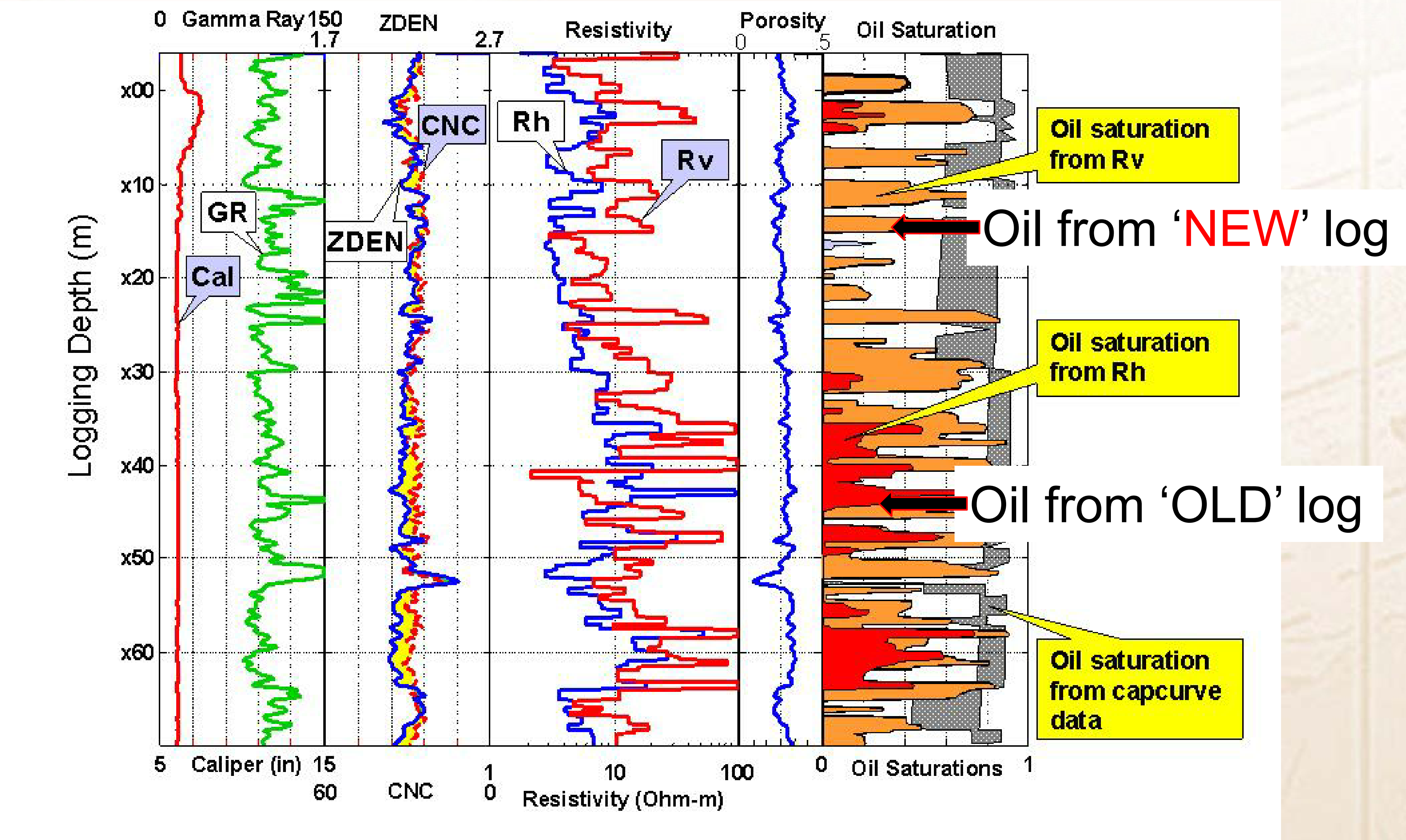


Micro to macro anisotropy



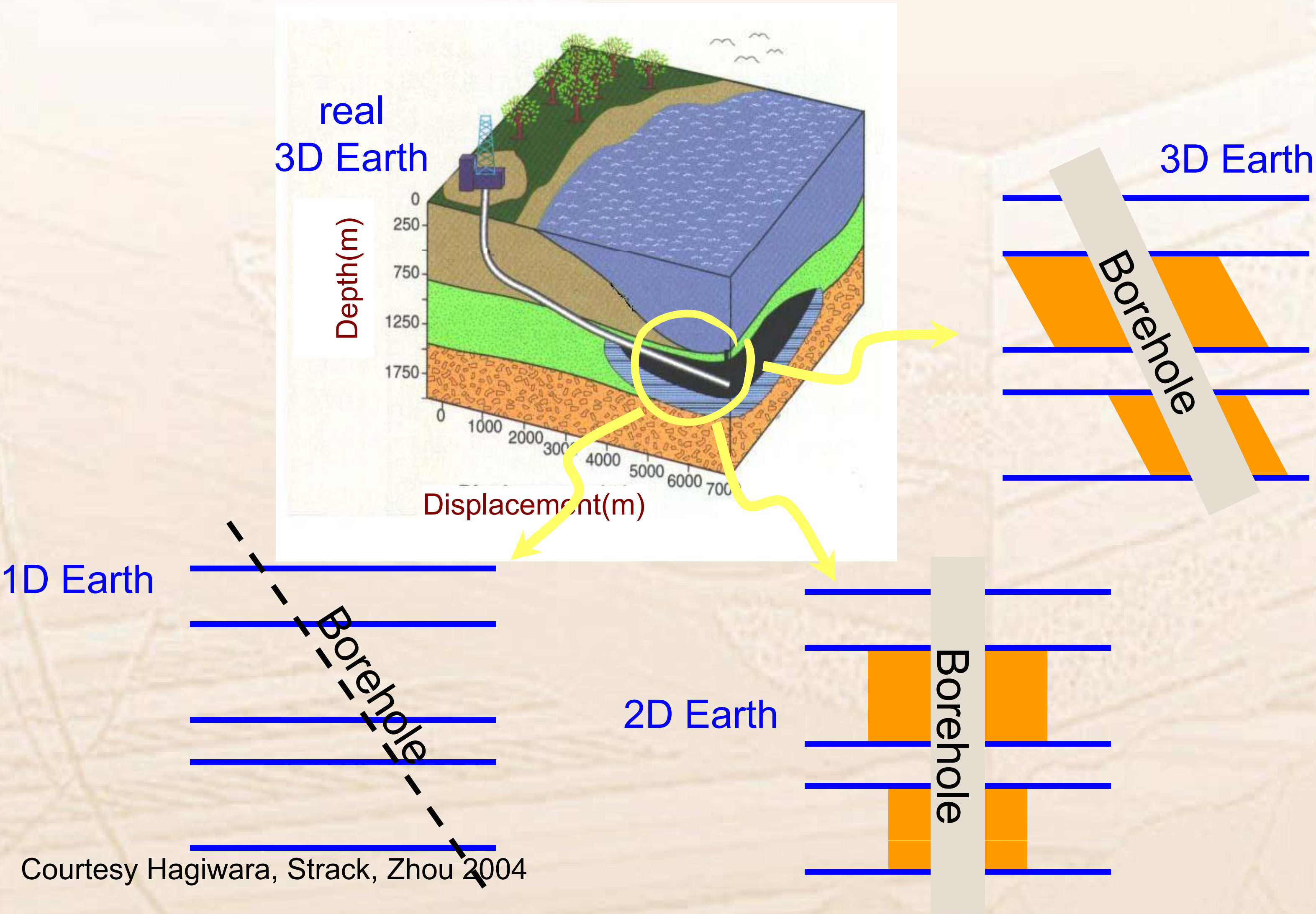
Courtesy Baker Atlas

Example anisotropy log data



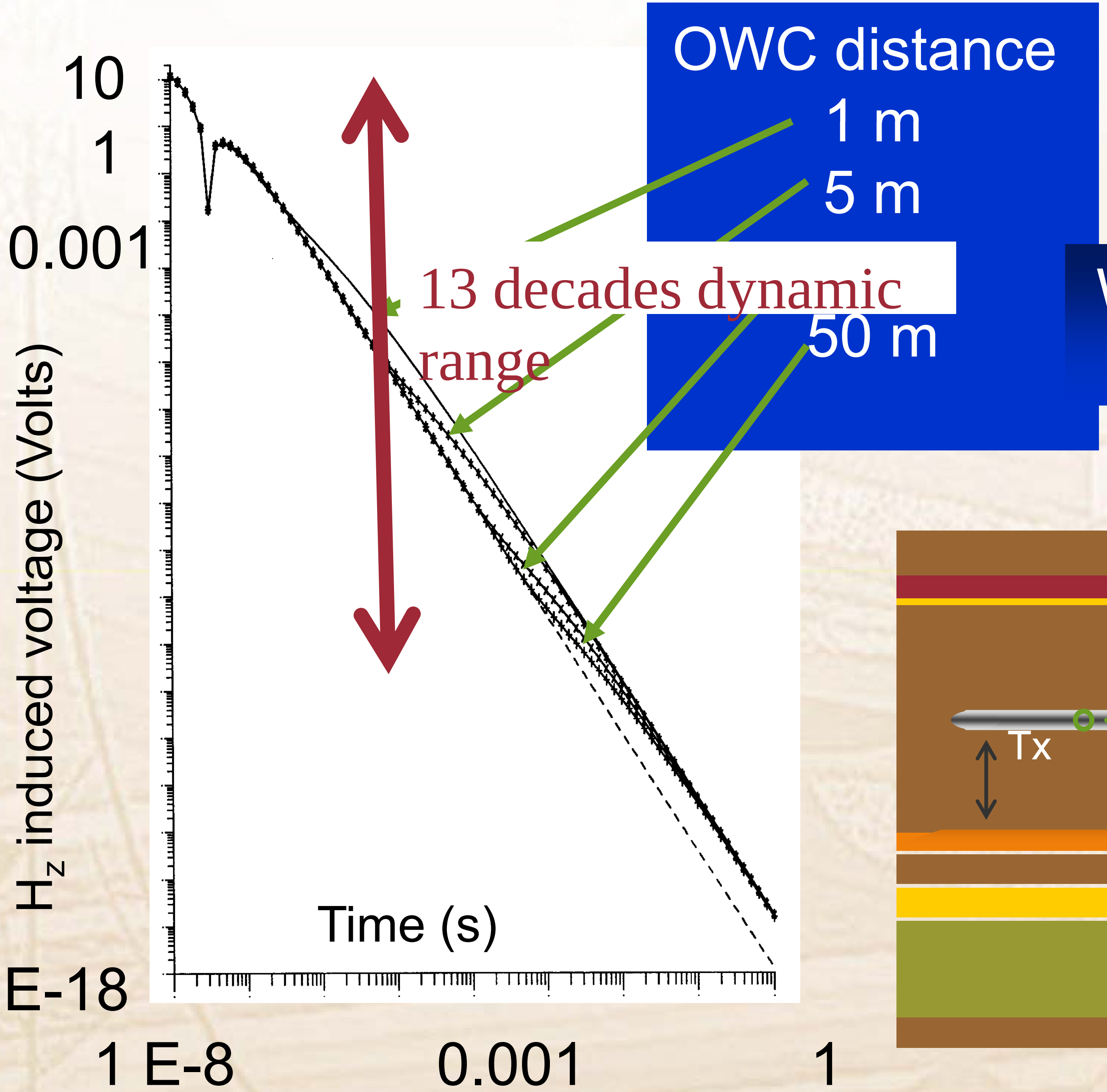
After Yu et al., 2001

Highest value: steering the drill bit

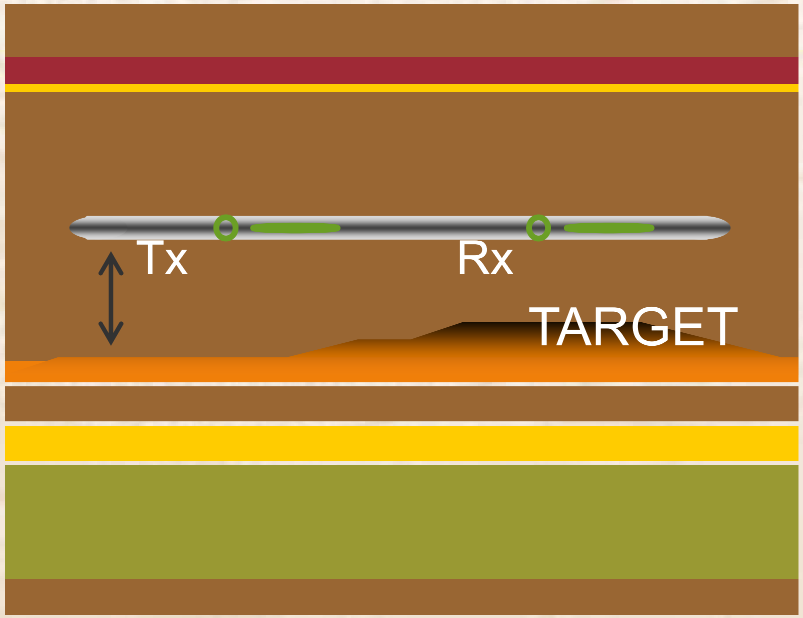


Courtesy Hagiwara, Strack, Zhou 2004

Extended dynamic range required



Water coning in a horizontal well



DGG contributors:

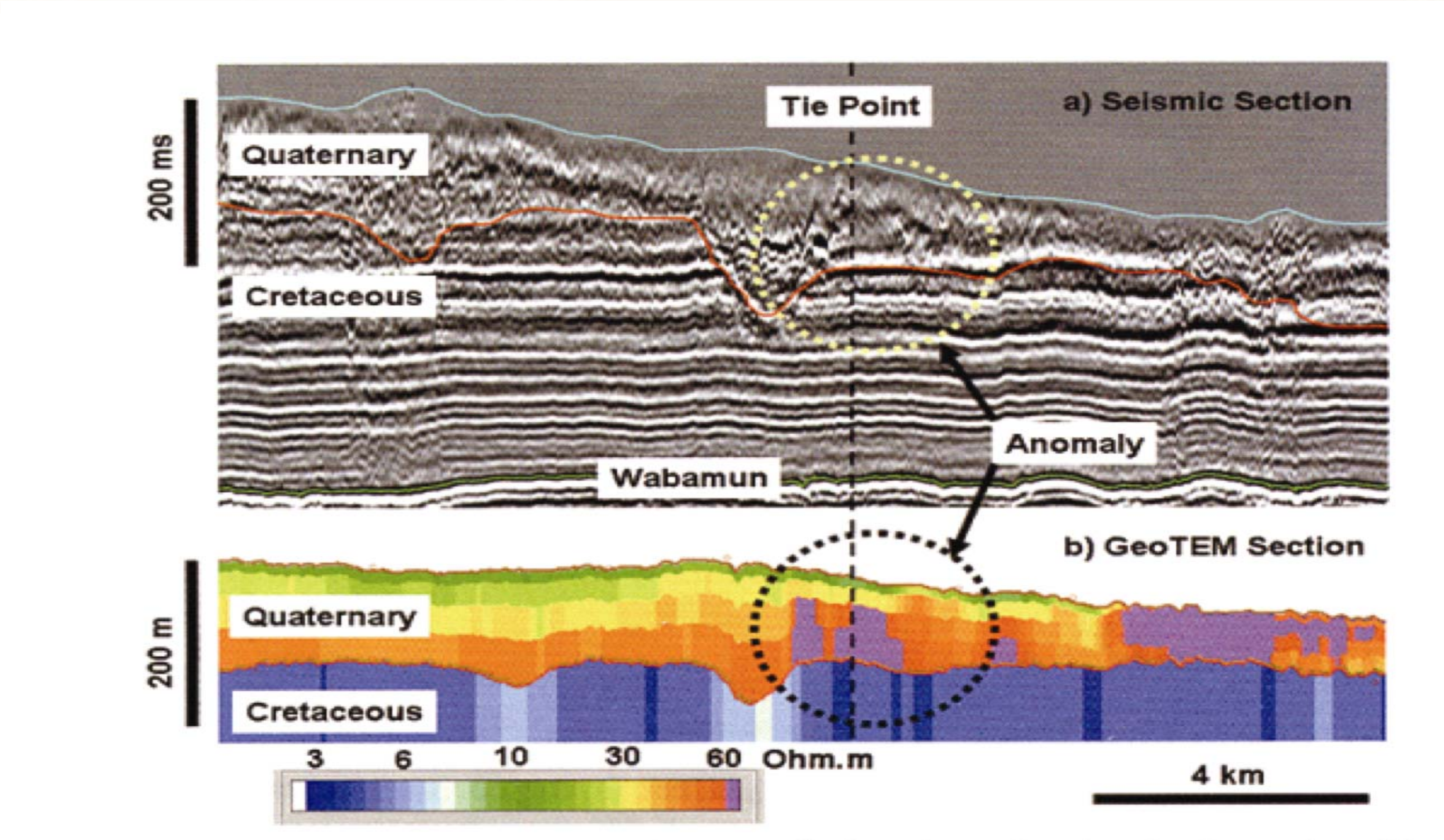
3D induction: A. Hoerdt, F.M. Neubauer, B. Kriegshaeuser
Geosteering: T. Hanstein, H. Rueter
Inversion: M. Echard, R. Busch
Through casing resistivity: H.-M. Maurer

Borehole – Logging - EM highlights

- Much improve New logging tools
- 3D inductions logs → tie to surface EM
- Cross well EM
- Log inversion → better reserve estimates
- Reservoir evaluaton: Through casing resistivity
- Deep reading LWD & geosteering

- Daily tasks: Borehole - logging
- Exploration
  - Airborne — Airborne TEM
  - Land — Magnetotellurics
  - Marine — Controlled source EM
- Production
  - Monitoring

Airborne EM

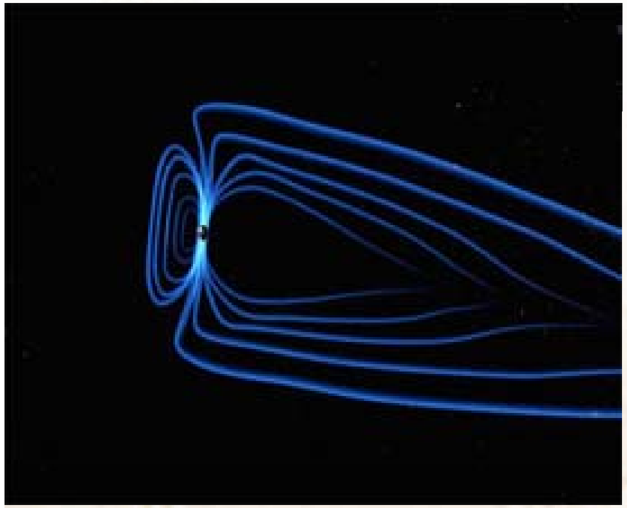


After Smith et al., 2008

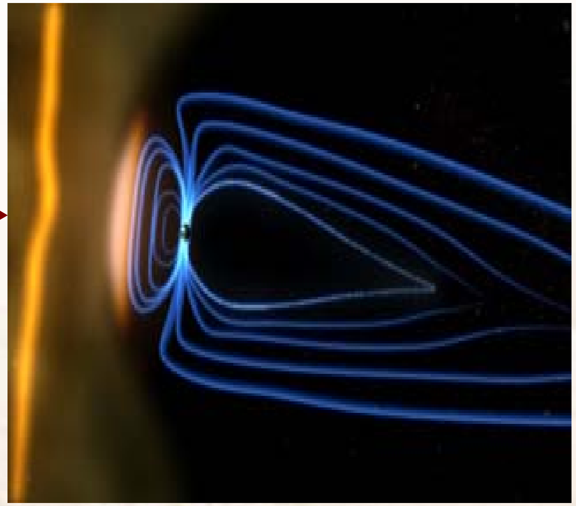
Exploration: land methods

- Common: magnetotellurics
- Rarely used:
  - Controlled Source EM
  - Induced polarization
- NOT used:
  - DC resistivity

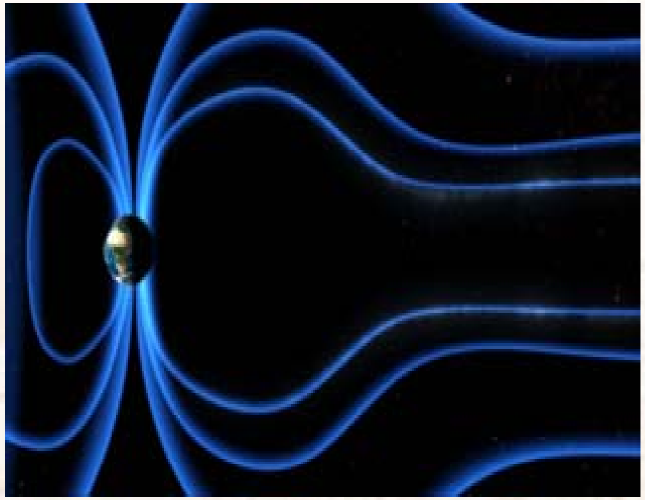
Magnetotelluric field sources



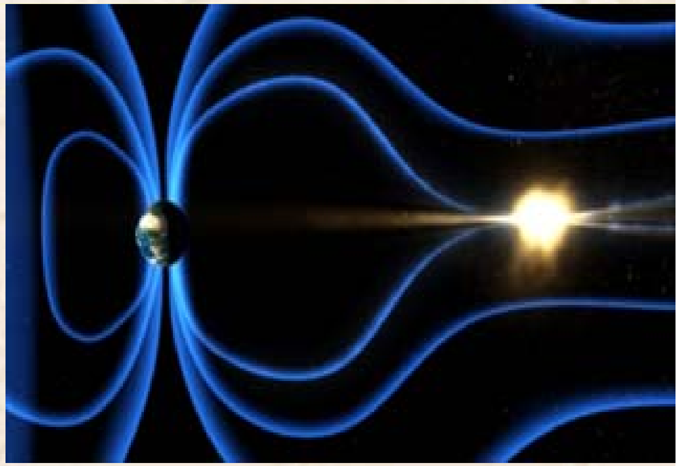
Earth's Magnetic Field



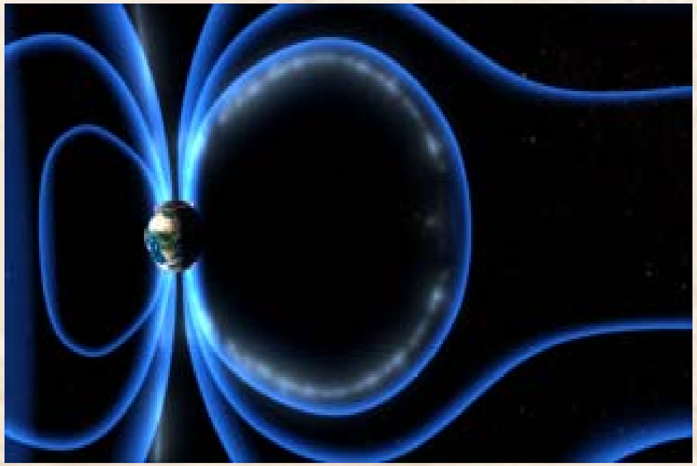
Massive solar outburst travels on the solar wind



The solar wind distorting earth's magnetic field



Two magnetic field lines are reconnecting

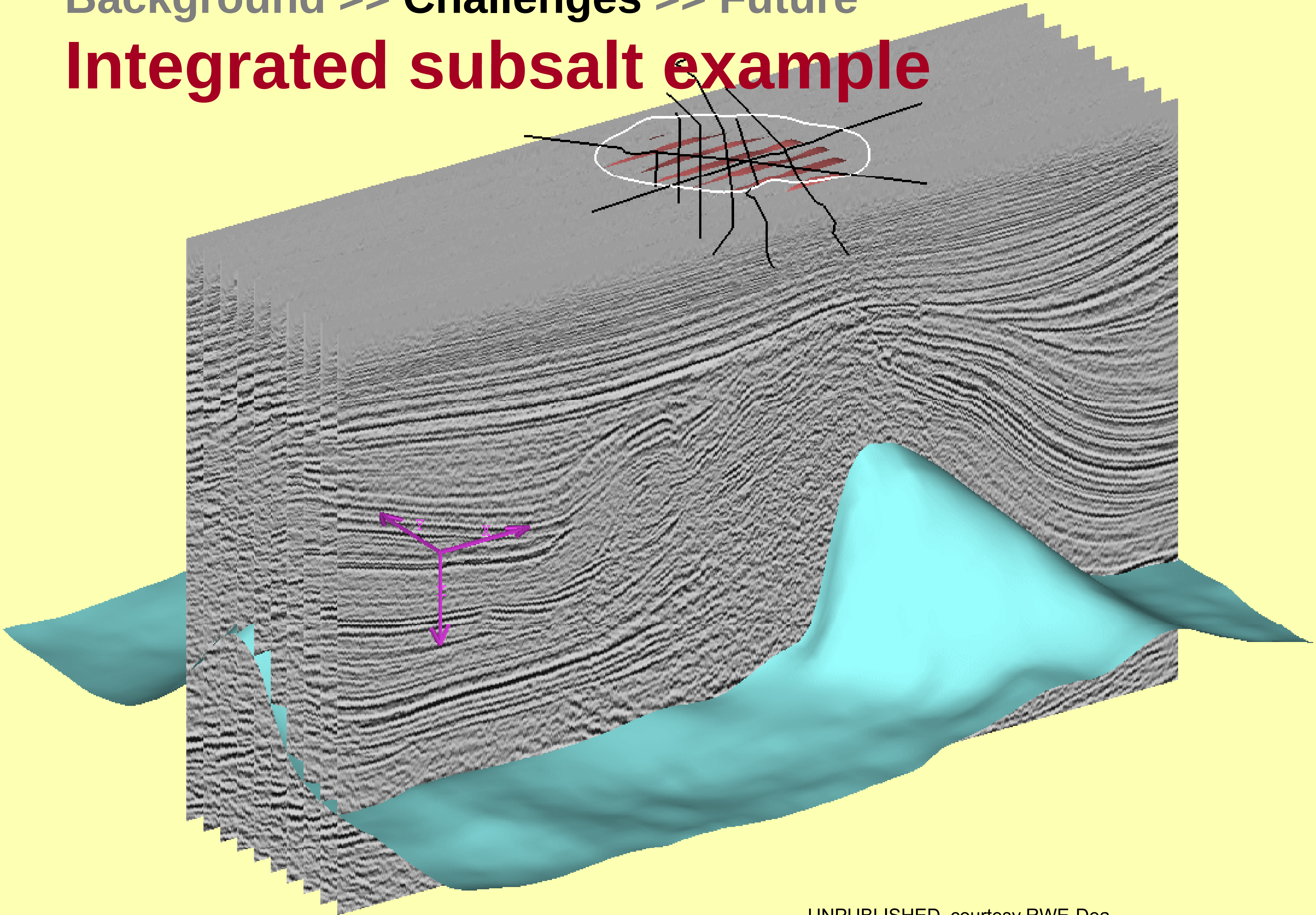


This fired particles towards the earth

It induces electric field in Ionosphere and in extreme cases produces Auroras.

after http://svs.gsfc.nasa.gov/

Integrated subsalt example

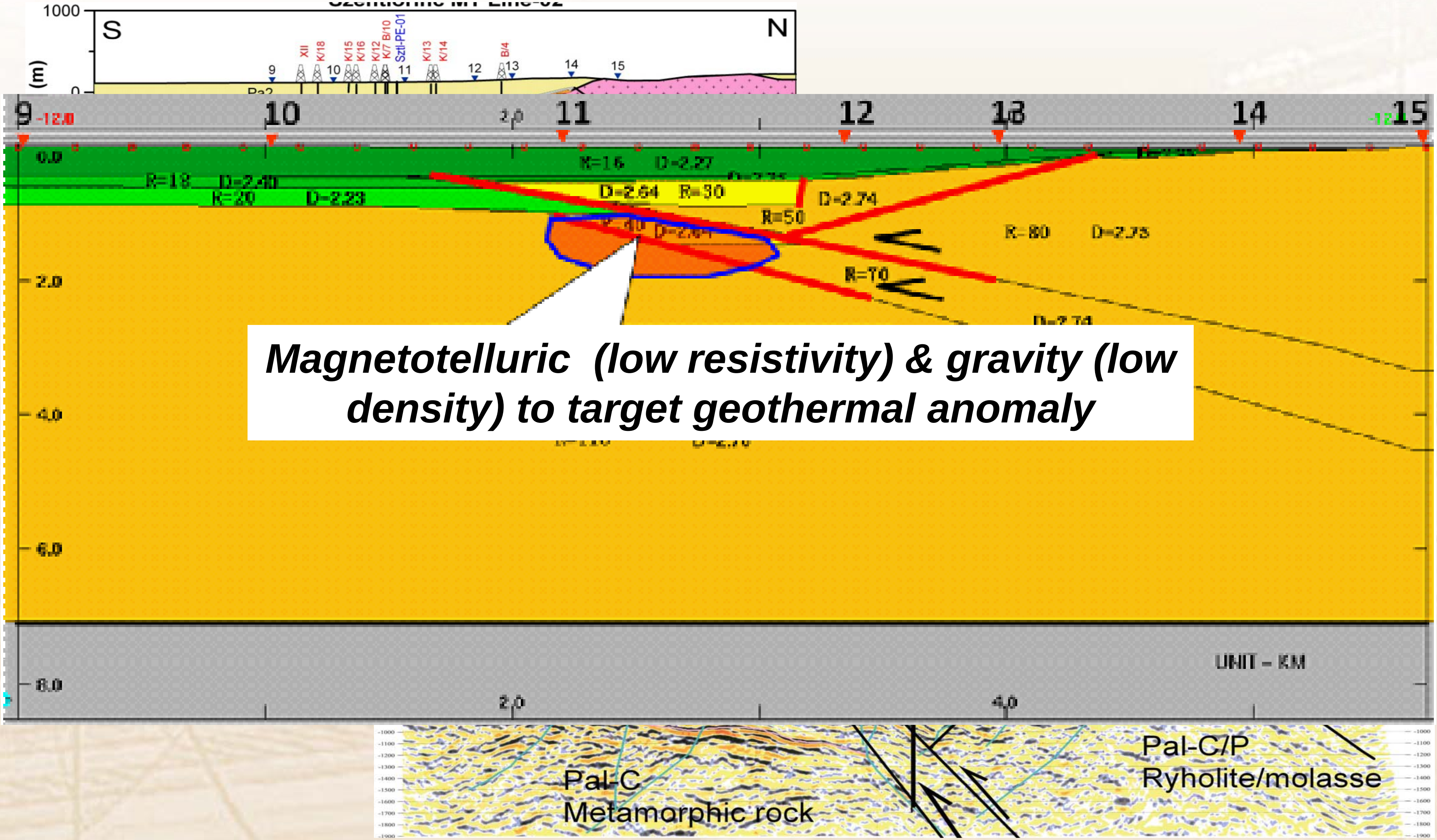


UNPUBLISHED, courtesy RWE-Dea

Zerilli, et al 2002

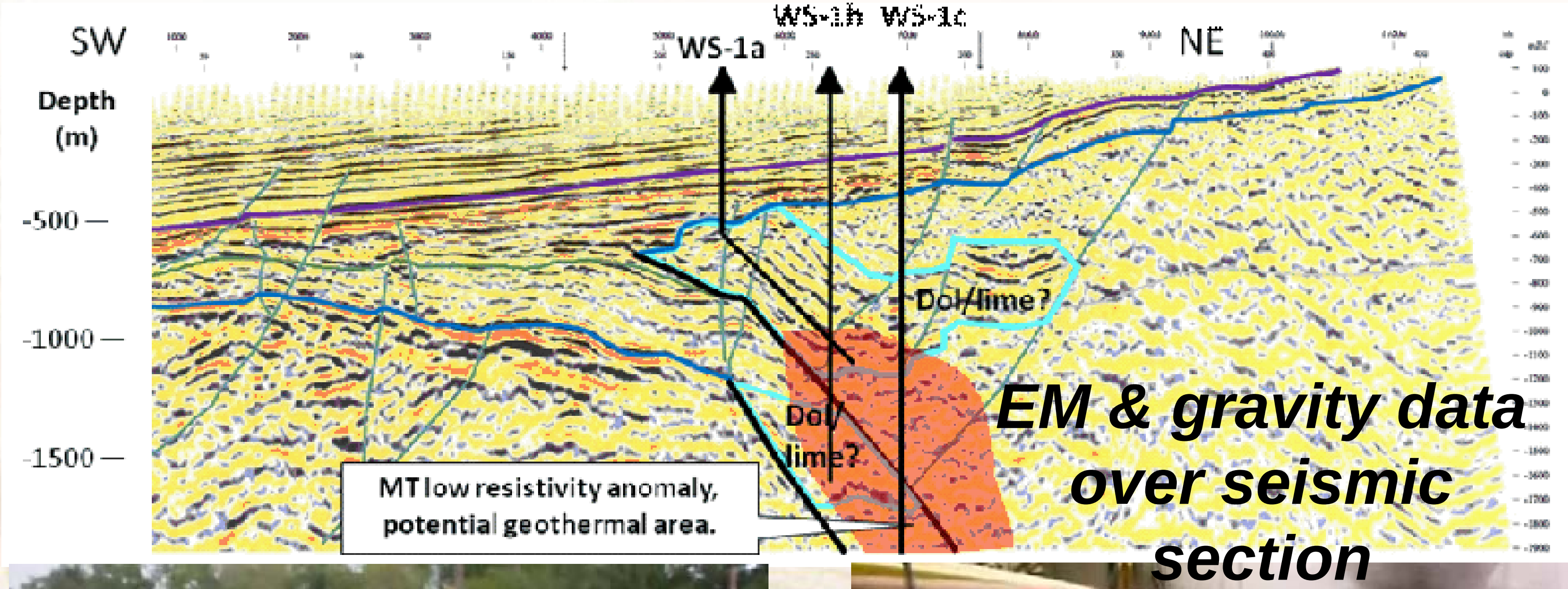
Geothermal energy !

Integrated interpretation



Magnetotelluric (low resistivity) & gravity (low density) to target geothermal anomaly

Drilling

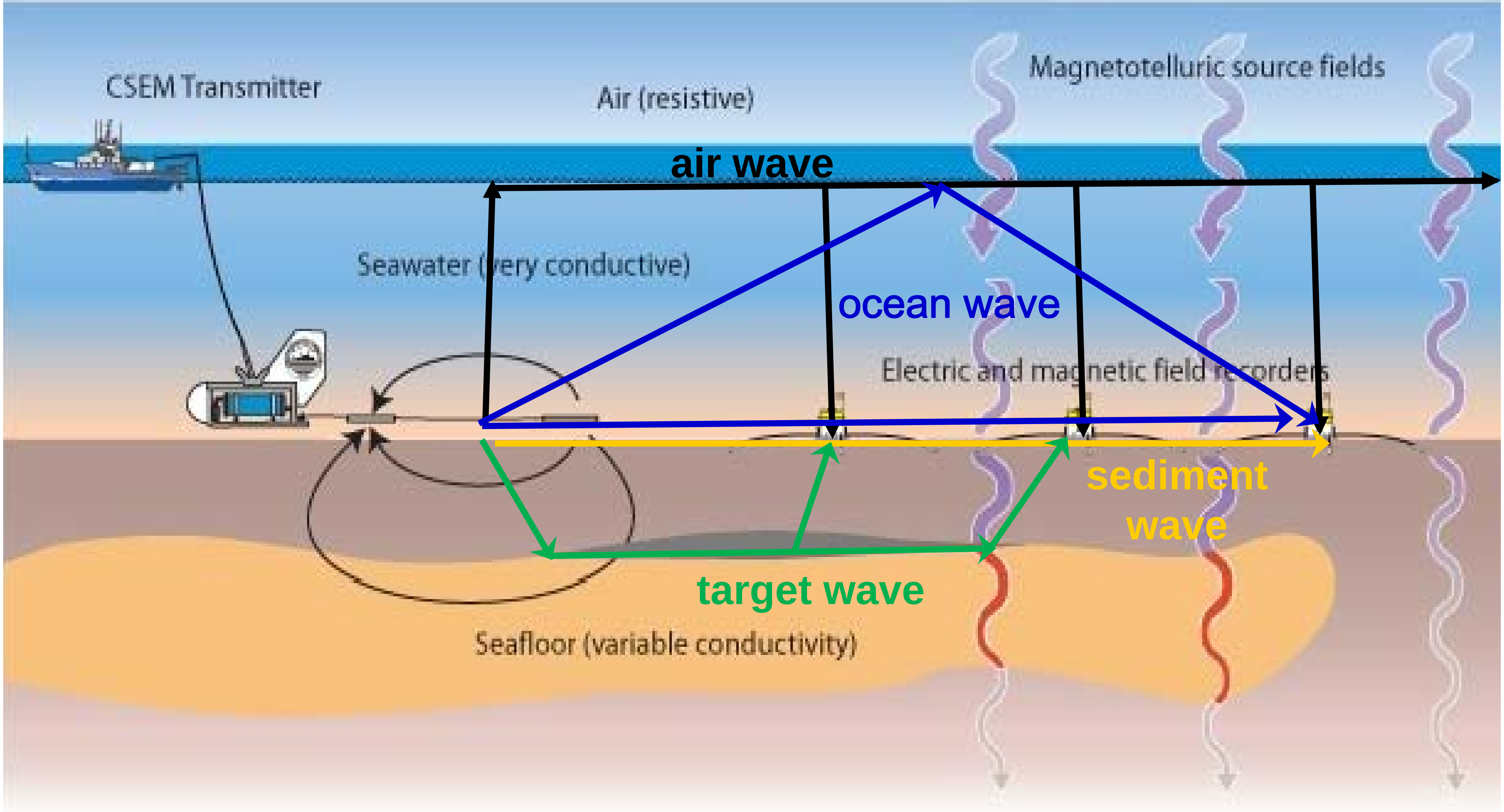

SW
NE
WS-1a
WS-1b
WS-1c
Depth
(m)
-500
-1000
-1500
Dol/lime?
Dol/
lime?
MT low resistivity anomaly,
potential geothermal area.
EM & gravity data
over seismic
section


Total success!

Exploration: marine methods

- Common:
  - Controlled source EM
  - magnetotellurics
- Rarely used:
  - Induced polarization
  - DC resistivity

Marine CSEM acquisition



Base figure From http://marineemlab.ucsd.edu/index.html

Using the Skin depth

The **skin depth** δ describes how much the energy is attenuated:

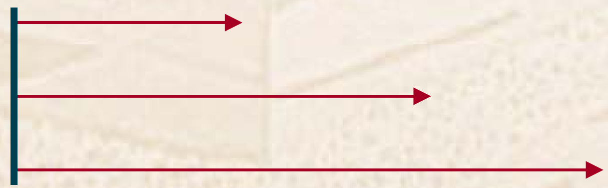
$$\delta = \sqrt{\frac{\rho}{\mu_0 \pi f}} \cong \sqrt{\frac{\rho}{f}}\ 500\ \sqrt{\frac{m}{\Omega s}} \cong 500\ m \quad (\rho = 1\ \Omega m,\ f = 1\ Hz)$$

f **= 0.25 Hz**

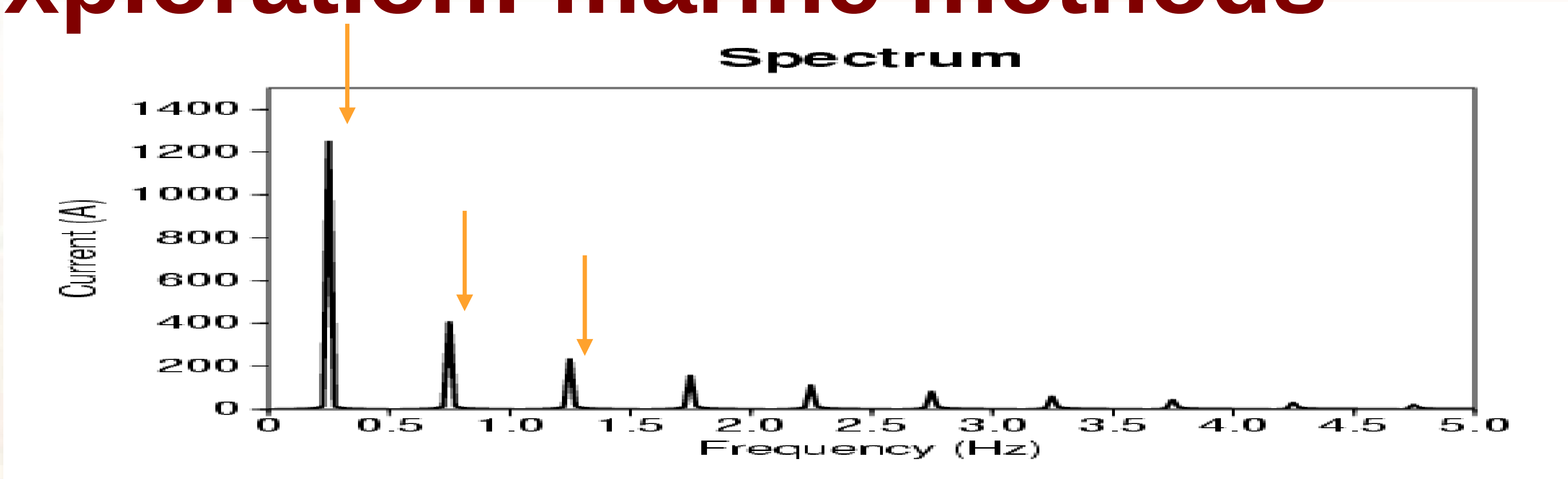
Water (0.3 Ωm): δ = 548 m

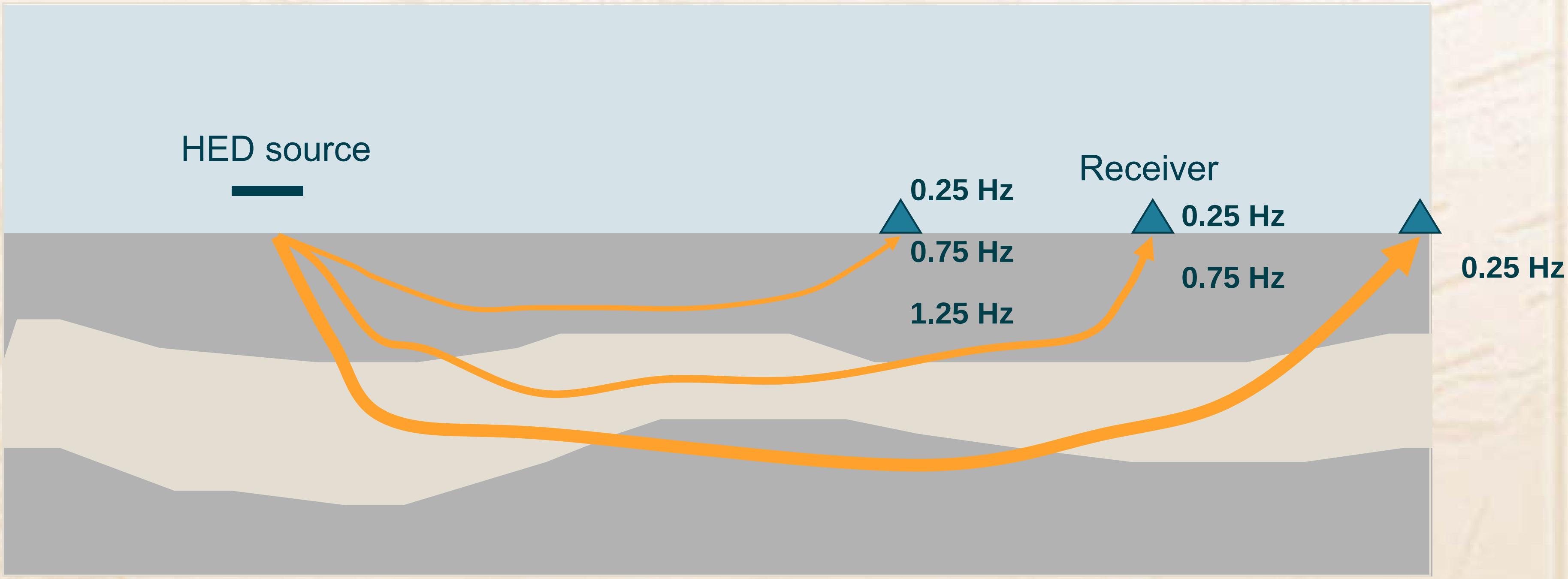
Overburden (1.0 Ωm): δ = 1000 m

Overburden (2.0 Ωm): δ = 1414 m

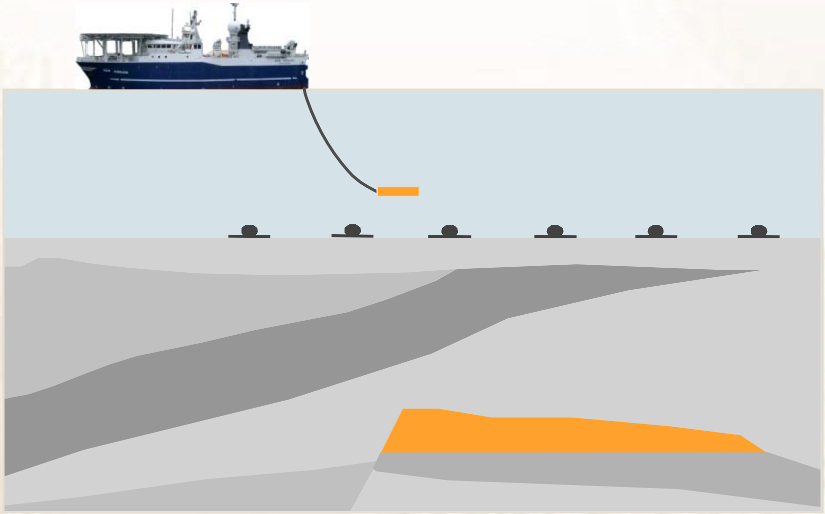


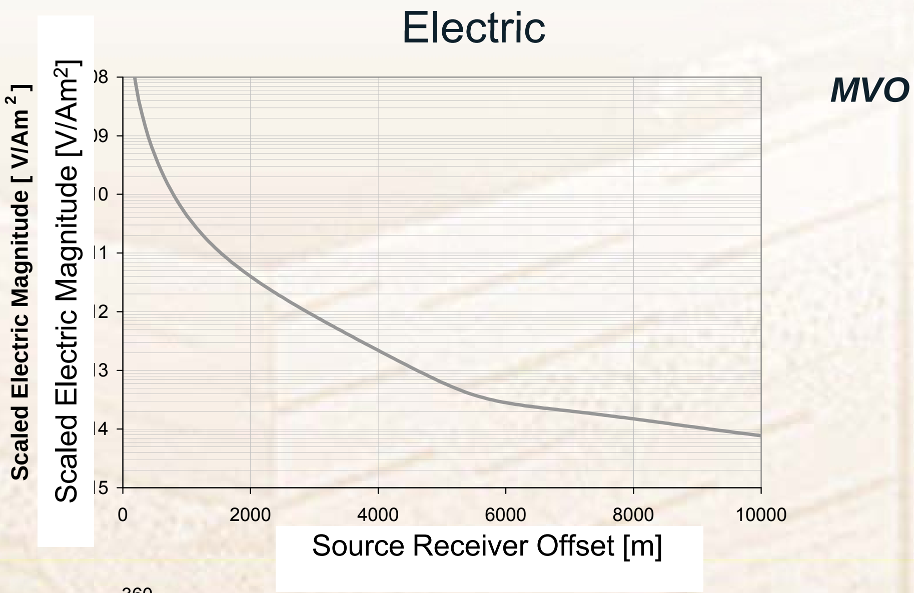
Exploration: marine methods

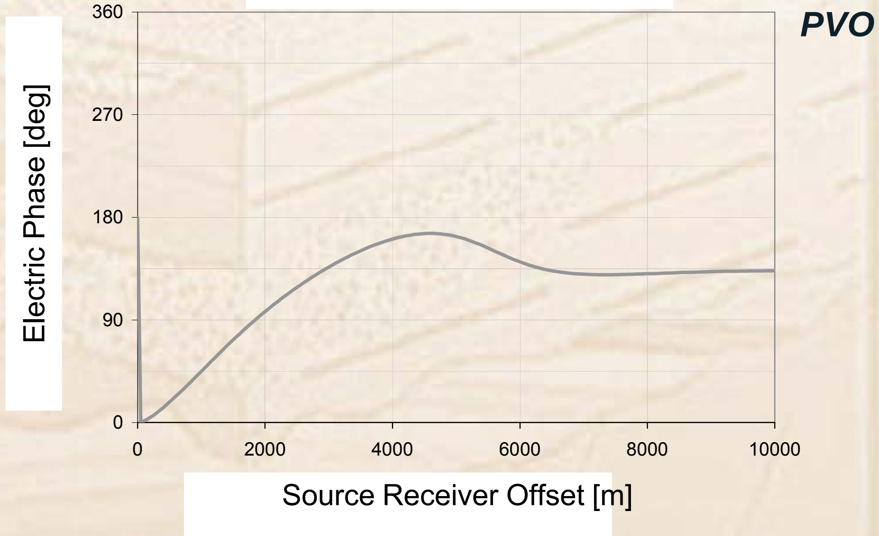




CSEM over a DRY reservoir







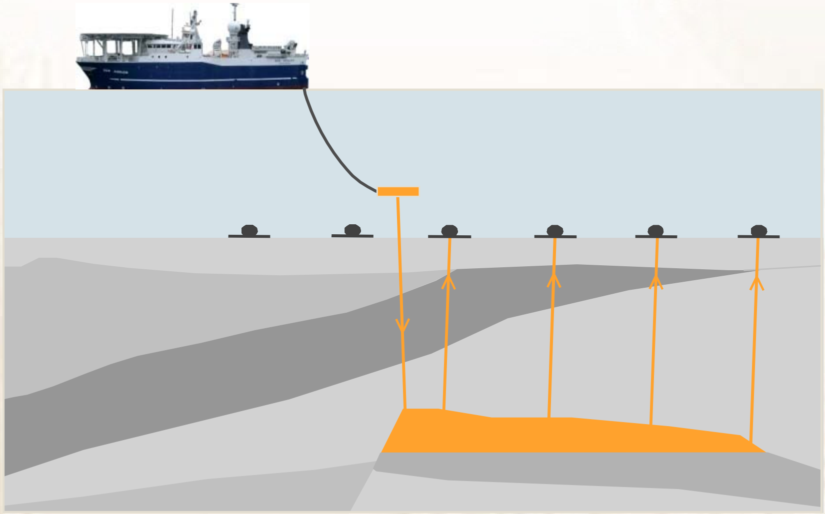
Dominating energies

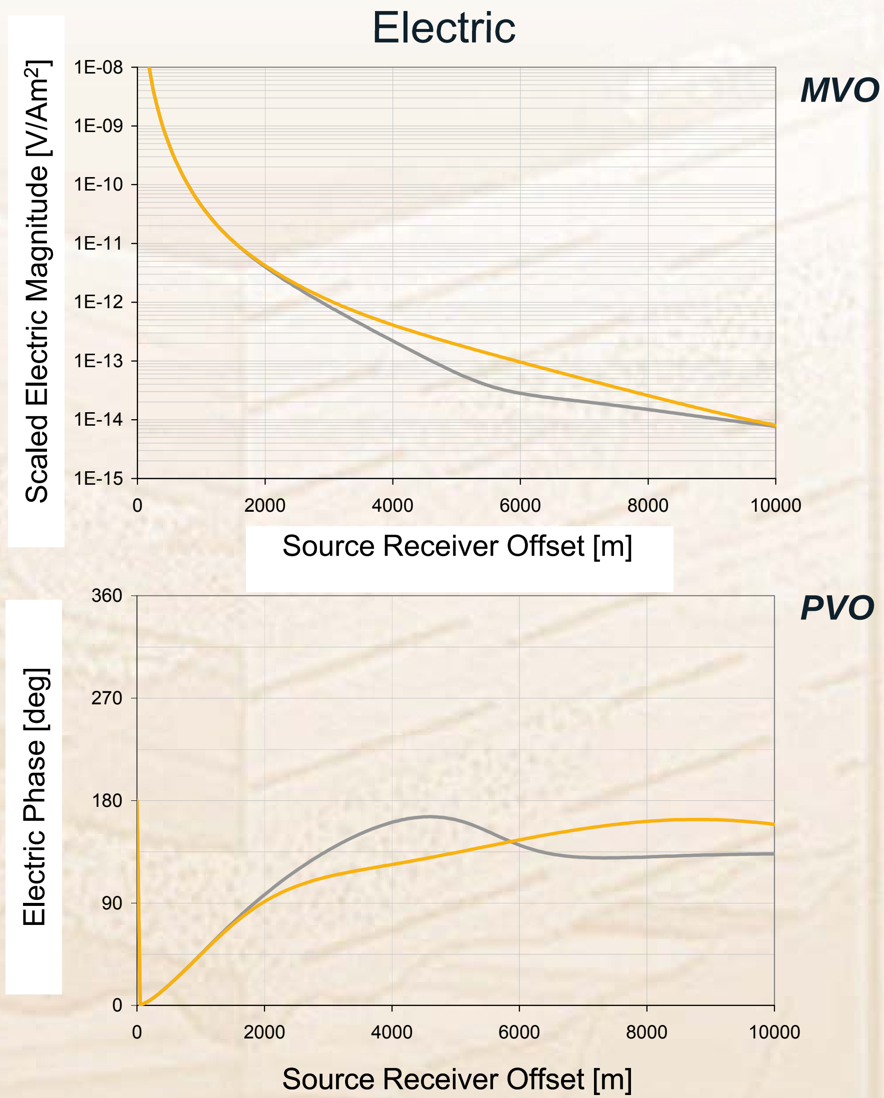
Short Offsets
- Direct and lateral subsurface energy

Intermediate offsets
- Subsurface energy

Large offsets
- Energy related to a finite water layer

CSEM over an OIL reservoir





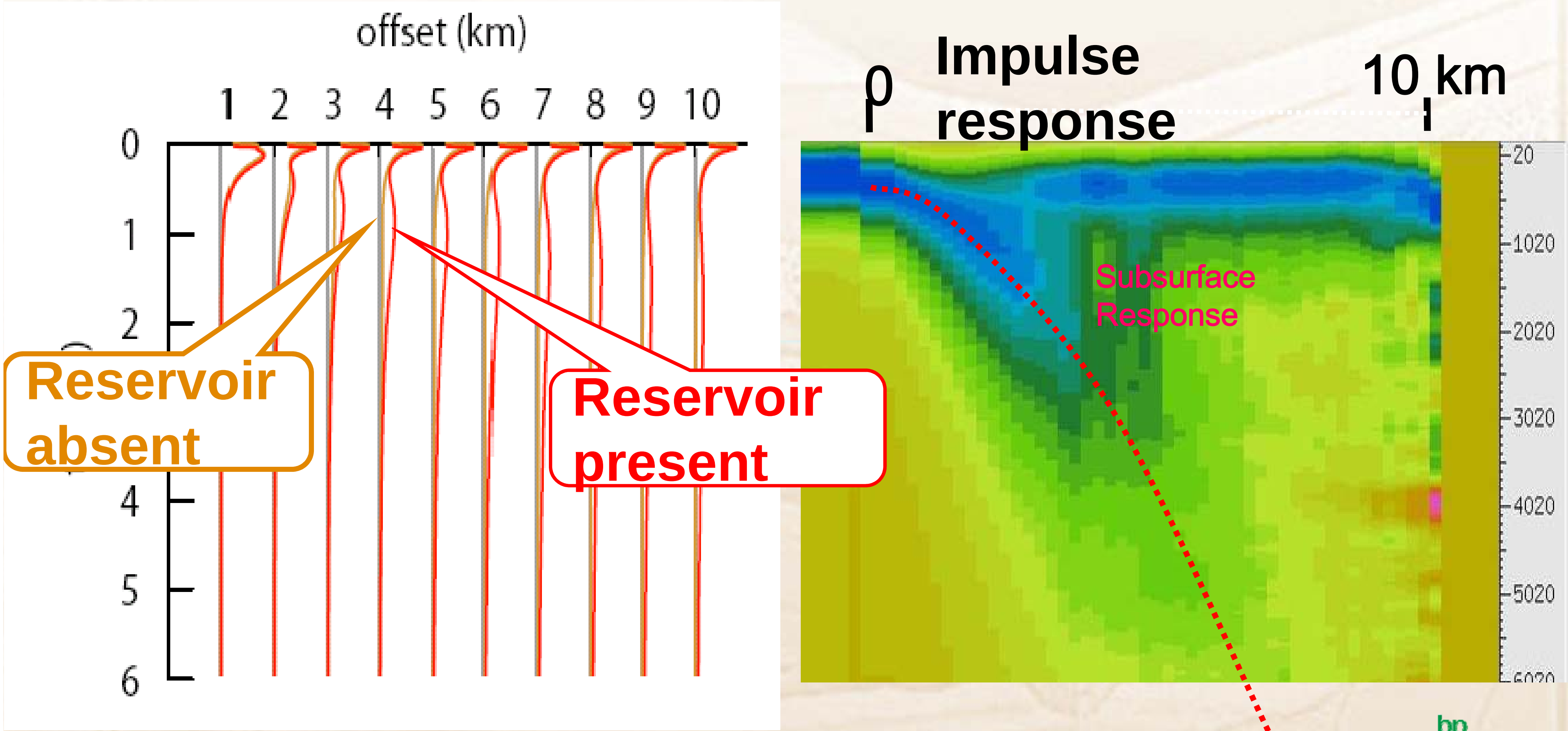
Dominating energies

Short Offsets
- Direct and lateral subsurface energy

Intermediate offsets
- Subsurface energy

Large offsets
- Energy related to a finite water layer

tCSEM™ over a reservoir



After Thomsen etal., SEG 2007

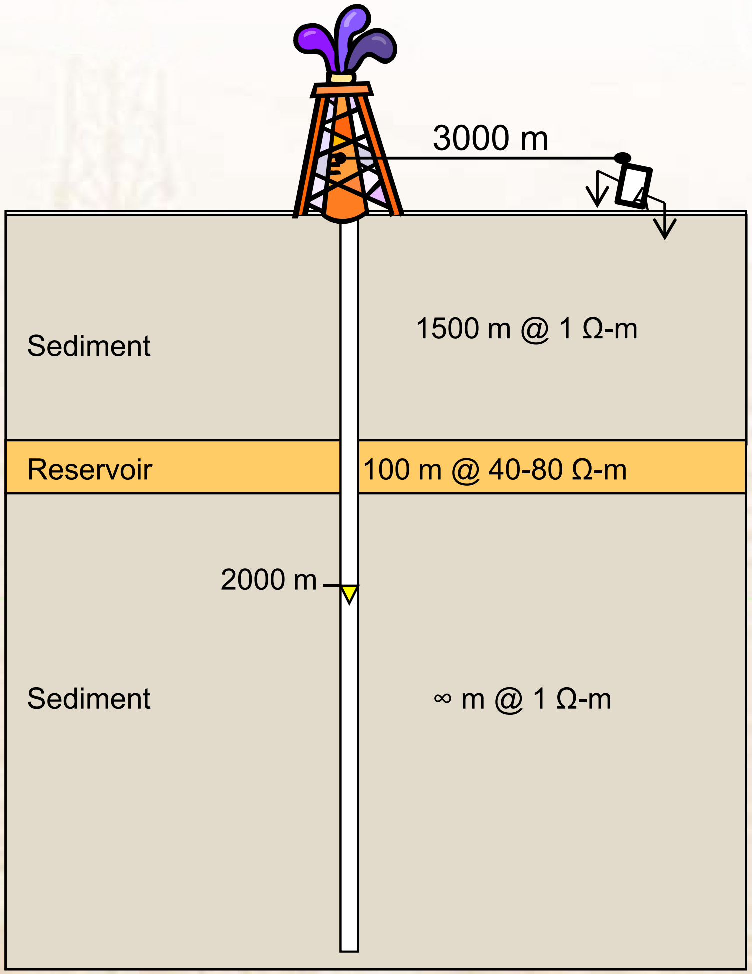
- Daily tasks: Borehole - logging
- Exploration
- Production
  - Monitoring

Monitoring – choice of methods

SENSOR CAPABILITY	RESOLVING POWER				
	Distance	Fluid	Surface-to-surface	Borehole-to-surface	Borehole
Seismic	Excellent	Poor	Excellent	Excellent	Ok (more noise)
EM	Ok (5% of depth)	Excellent (water to HC)	Ok	Excellent	Excellent (less noise & distance)
Gravity	Poor	Ok (oil to gas)	Poor	Poor (no source)	Poor (no source)
Strongest Synergy	Seismic	EM/seismic	Seismic/EM/ gravity	Seismic/EM	Seismic/EM/ gravity

Courtesy Welldynamics

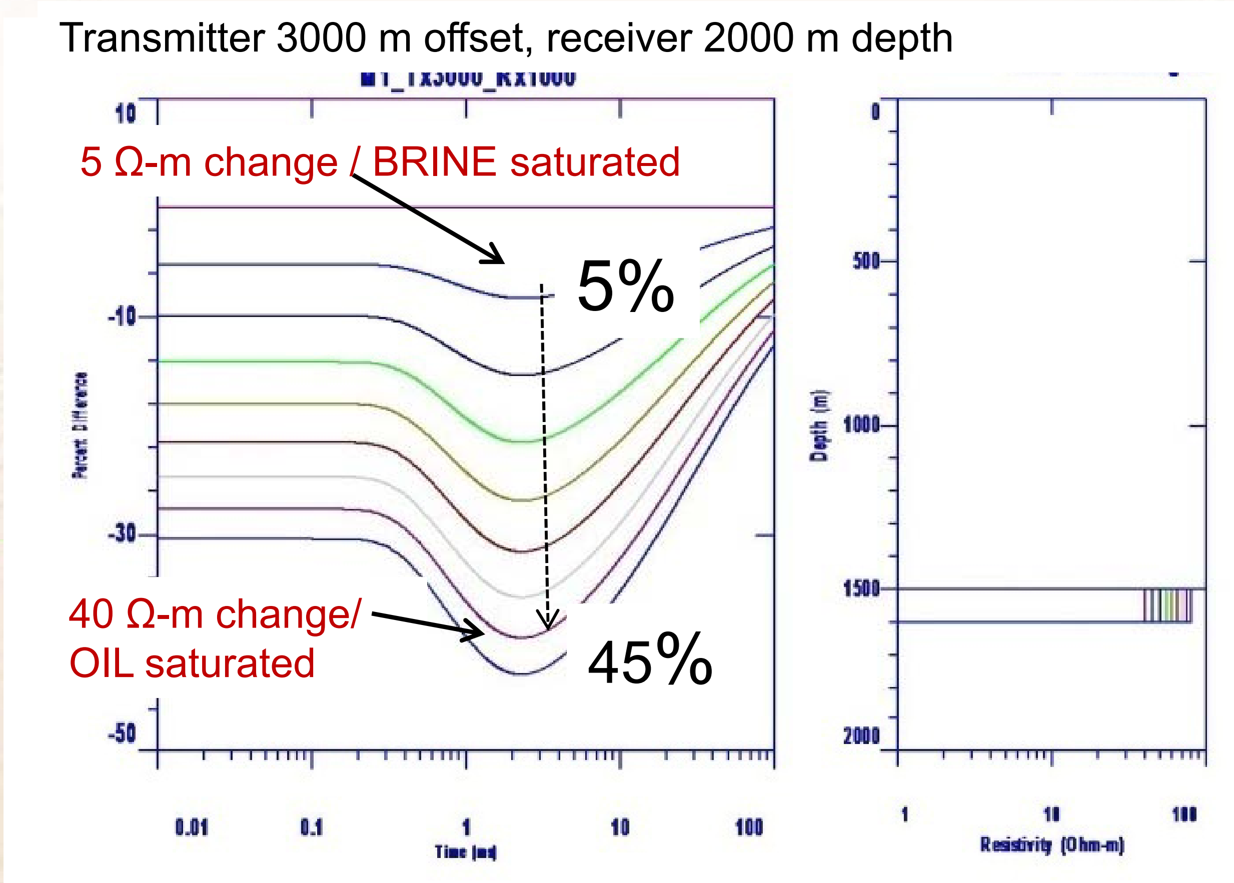
EM monitoring: time lapse simulation



Background model subtracted, all layers @ 1 Ω-m

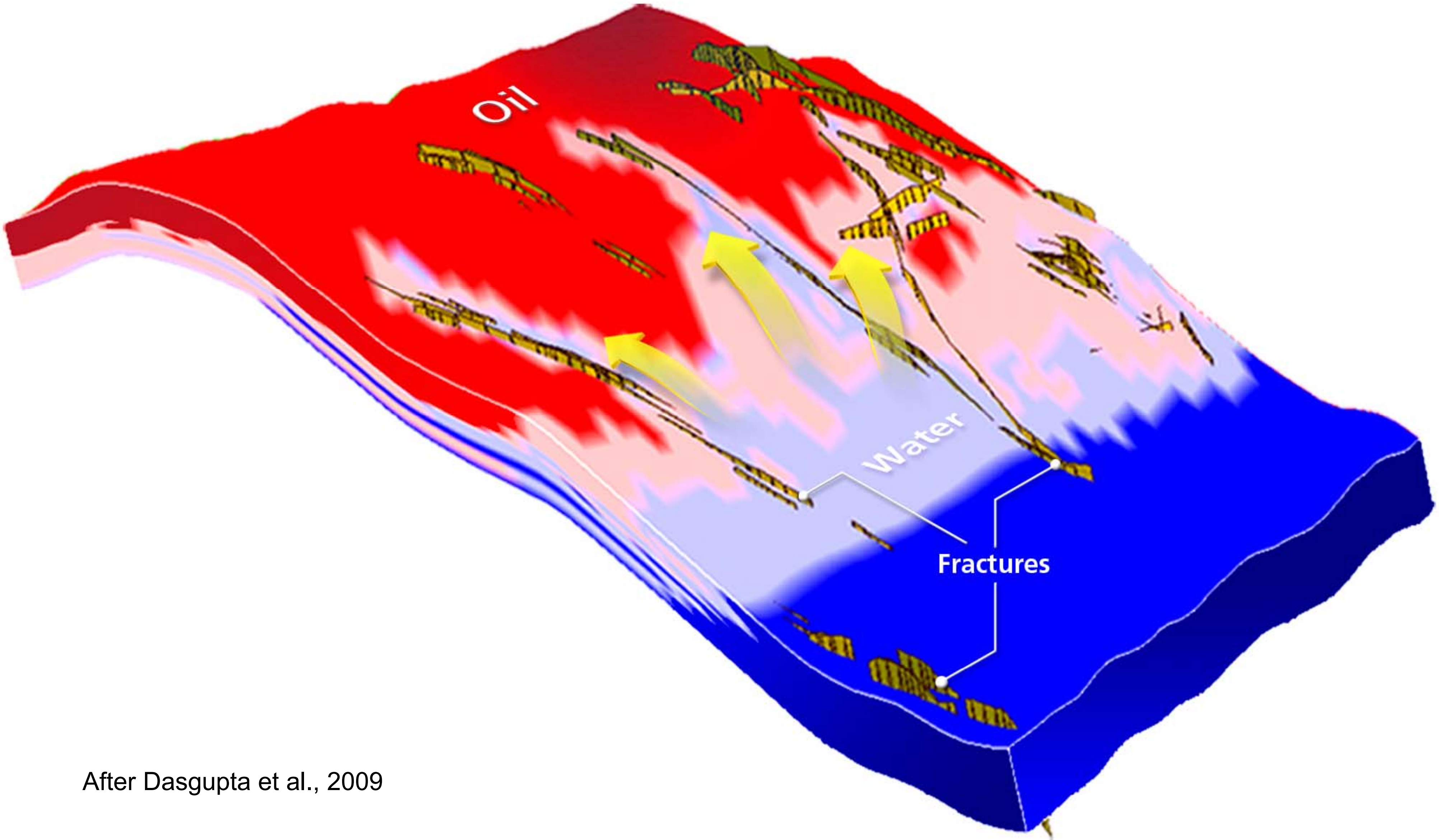
Source

Receiver



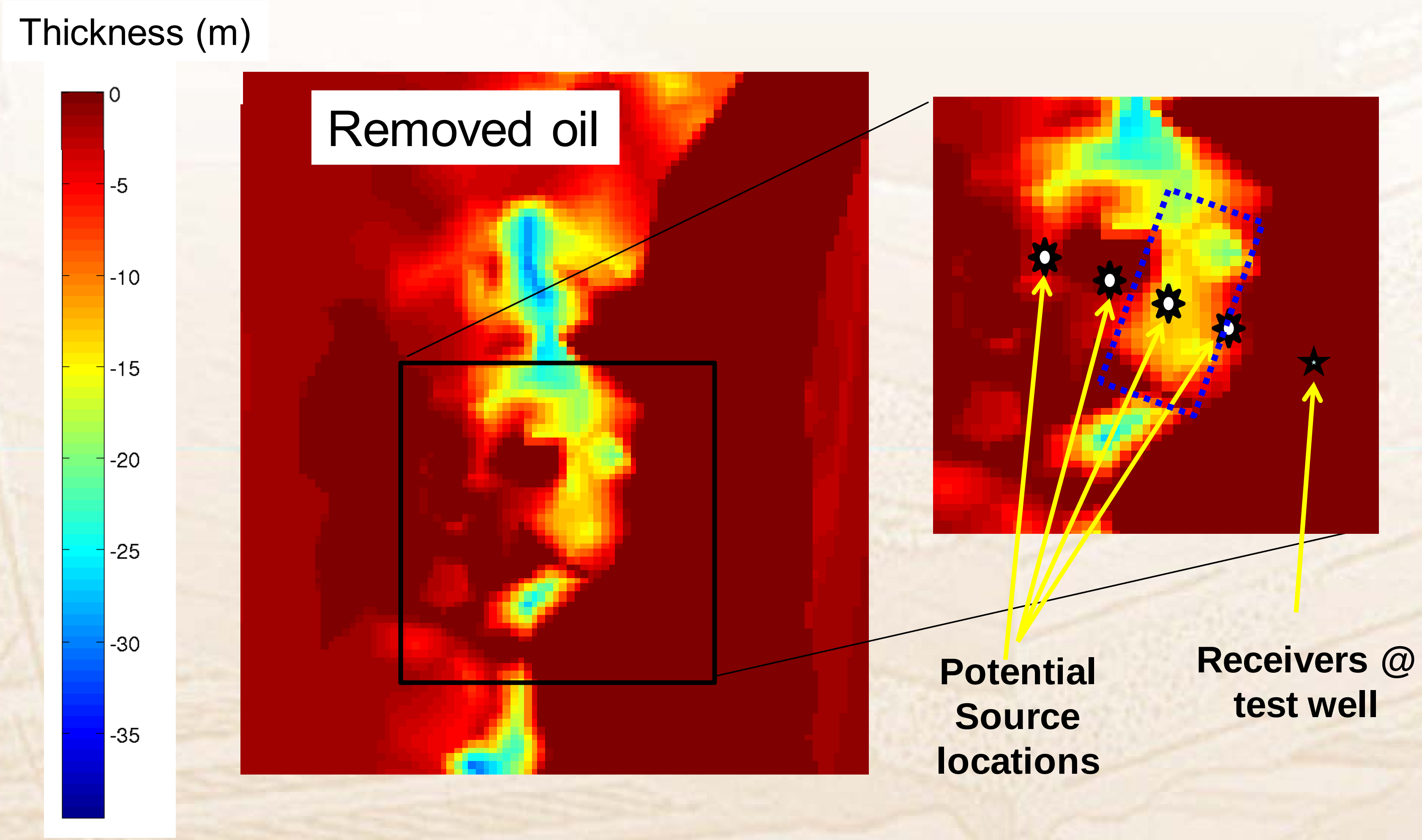
40 Ω-m change in resistivity produces 45% change in borehole EM response

EM monitoring: a real reservoir



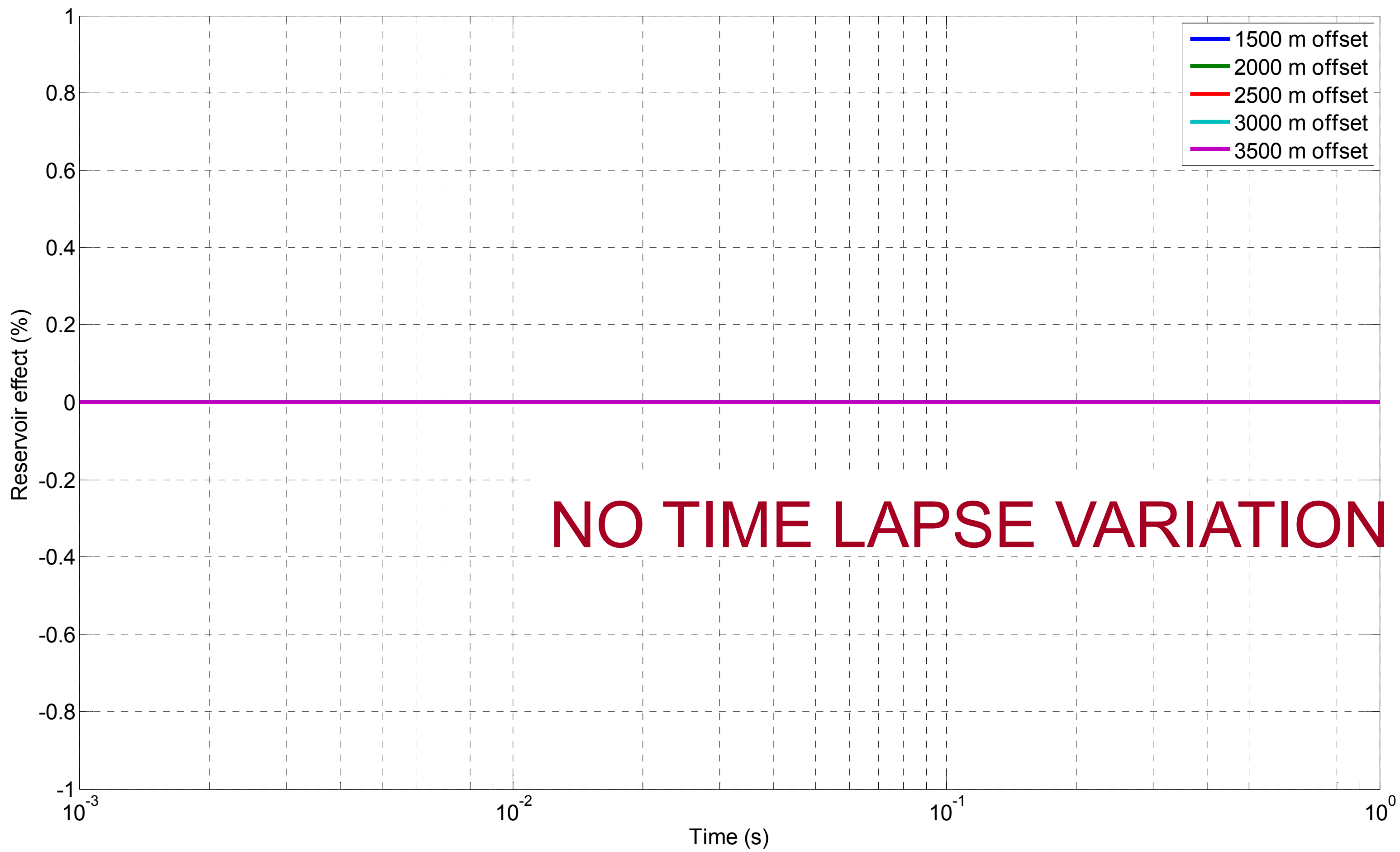
After Dasgupta et al., 2009

EM monitoring: 3D model differences

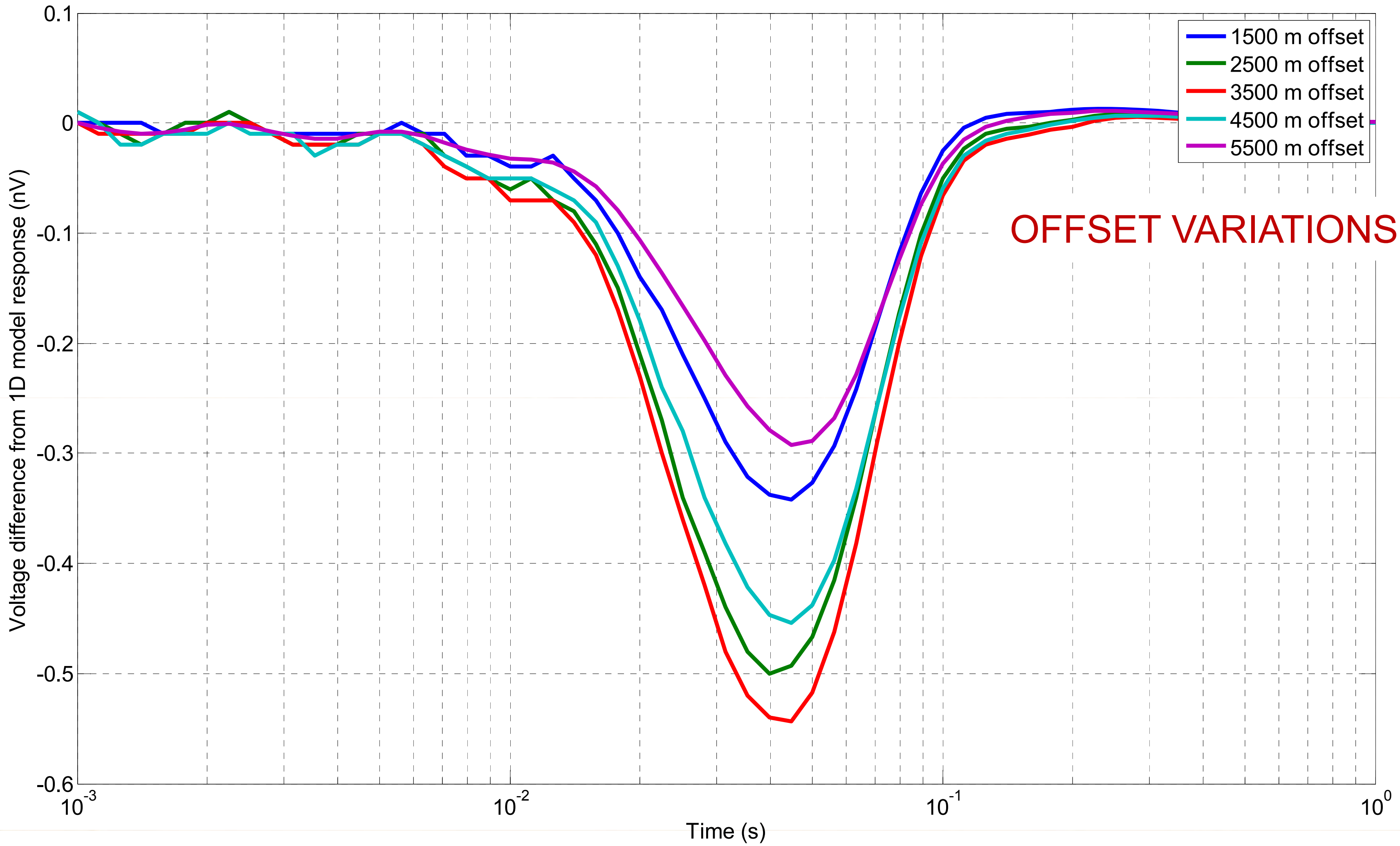


After Dasgupta et al., 2009

EM monitoring: Surface-to-surface



EM monitoring: Borehole-to-surface



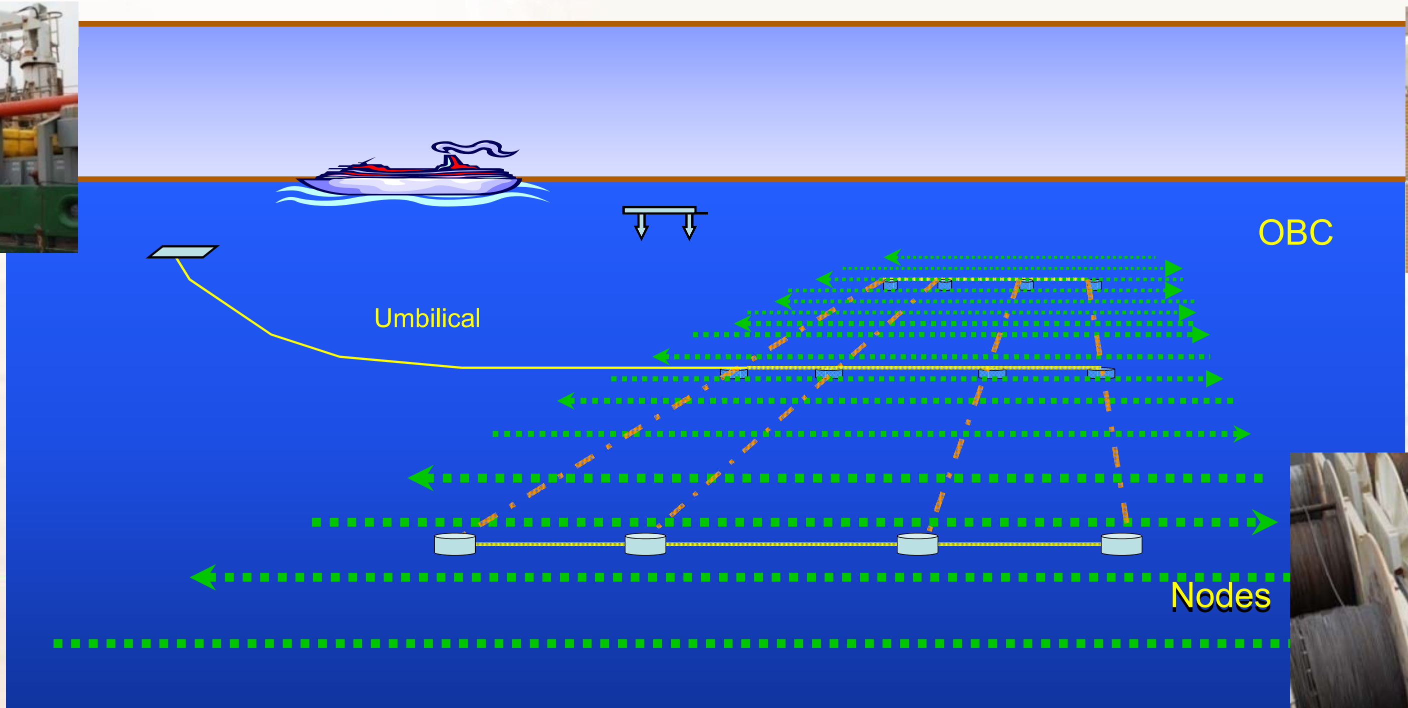
EM for Monitoring summary

- Surface-to-surface CSEM
  - Commercial land/marine
  - Needs improvement, low coverage
  - LOWEST value due to selective applications
- Single-well CSEM
  - Feasibility shown
  - In research phase
  - MEDIUM to HIGH value: cost effectiveness, best data
- The future
  - Permanent sensors: HIGHEST value
  - Borehole-to-surface 4D: INTERIM HIGHEST
  - Under field trial

Future is defined by:

- More surface data (10 maybe 1000 times)
- Lower cost per site (50% NOW)→new hardware
- Operational integration
  - With seismic →Shared cost base
- Integration:
  - Exploration strategy: airborne & land/marine
  - GP methods: gravity/EM; seismic/EM
  - Calibration to boreholes
  - Land – transition zone - marine

More surface data



- Multi-components → anisotropy
- Link to seismic acquisition, processing, etc.
- Land & marine!!!

Future

- More surface data (10 maybe 1000 times)
- Lower cost per site (50% NOW)→new hardware
- Operational integration
  - With seismic →Shared cost base
- Integration:
  - Exploration strategy: airborne & land/marine
  - GP methods: gravity/EM; seismic/EM
  - Calibration to boreholes
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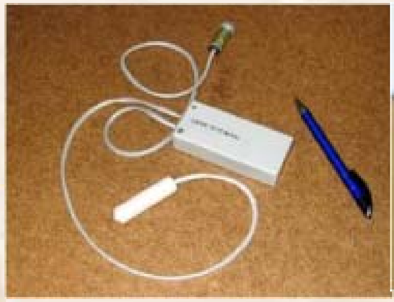
Smaller, lower cost hardware



Fluxgates – 3 components

Induction coils – T & F domain

Future is defined by:

- More surface data (10 maybe 1000 times)
- Lower cost per site (50% NOW)→new hardware
- Operational integration
  - With seismic →Shared cost base
- Integration:
  - Exploration strategy: airborne & land/marine
  - GP methods: gravity/EM; seismic/EM
  - Calibration to boreholes
  - Land – transition zone - marine

Integrated seismic/EM operation:

Future is defined by:

- More surface data (10 maybe 1000 times)
- Lower cost per site (50% NOW)→new hardware
- Operational integration
  - With seismic →Shared cost base
- Integration:
  - Exploration strategy: airborne & land/marine ✔
  - GP methods: gravity/EM ✔; seismic/EM (✔)
  - Calibration to boreholes (✔)
  - Land – transition zone – marine (✔)

DGG members that contributed

- R. Busch, M. Eckard, O. Engels, T, Hanstein, A. Hoerdt, H. Joedike, B. Kriegshaeuser, J. & I. Loehken, H.-M. Maurer, F.M. Neubauer, J. Schoen, P. Weidelt, P. Wolfgram

Acknowledgements

Individuals: N. Allegar, L. Bell, D. Colombo, S. Dasgupta, E. Dory, T. Hanstein, Y. Martinez, P. Pandey, C. Stoyer, L. Thomson, P. Wolfgram, G. Yu, A.Zerilli, Q. Zhou

Organizations: Aramco, BP, GOK, RWE-Dea, Shell, WellDynamics, Wintershall