Bringing electromagnetics & seismics closer with array electromagnetics: from the borehole to land and marine E&P

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1 - KMS Technologies

2- 3D EM Holdings

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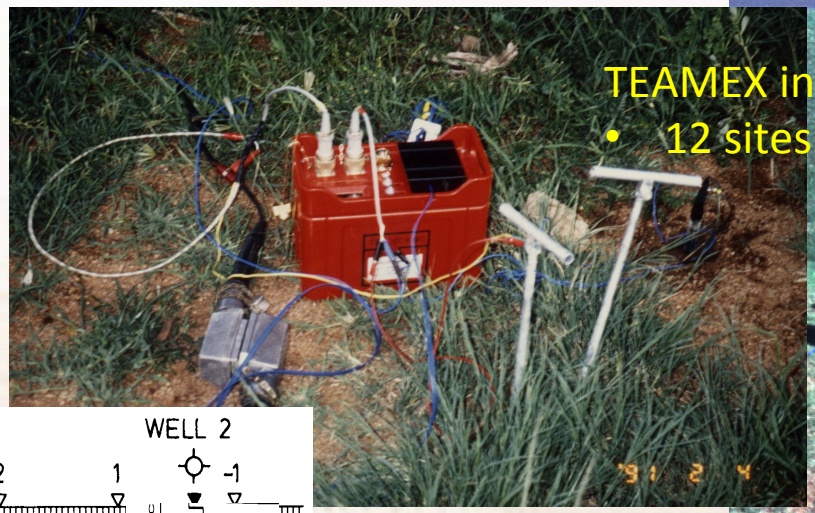
www.KMSTechnologies.com

History: Integration seismic - EM

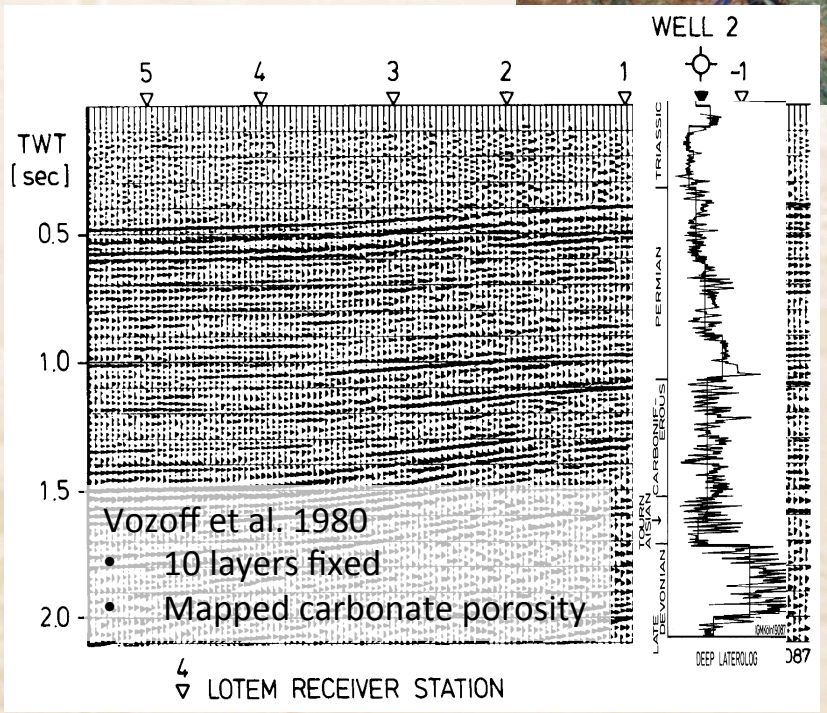
- Early 1980: Prairie Eagle acquired CSEM data with seismic system (Columbia Plateau)
- Vozoff mid 1980 W. Australia, porosity mapping
- 1988, China shows limitations of single site EM/inversion
- 1989, India limit in single site acquisition (Deccan traps)
- Teamex (US patent 5,467,018) 1990
- 1990s: very Quiet & lot of talk
- Gao et al. in Petrophysics, 2013: Combined borehole imaging: array acoustics & array induction
- Since 1999 we ALWAYS integrate seismic & EM: borehole → marine → land → marine

History: Integration seismic - EM



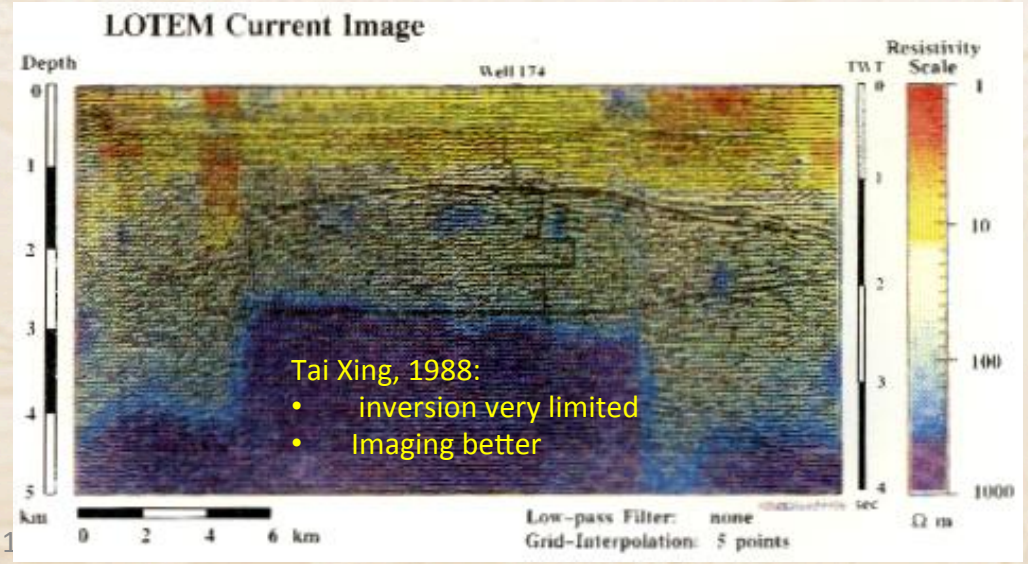
TEAMEX in South Africa 1991

- 12 sites acquired per hour



Vozoff et al. 1980

- 10 layers fixed
- Mapped carbonate porosity



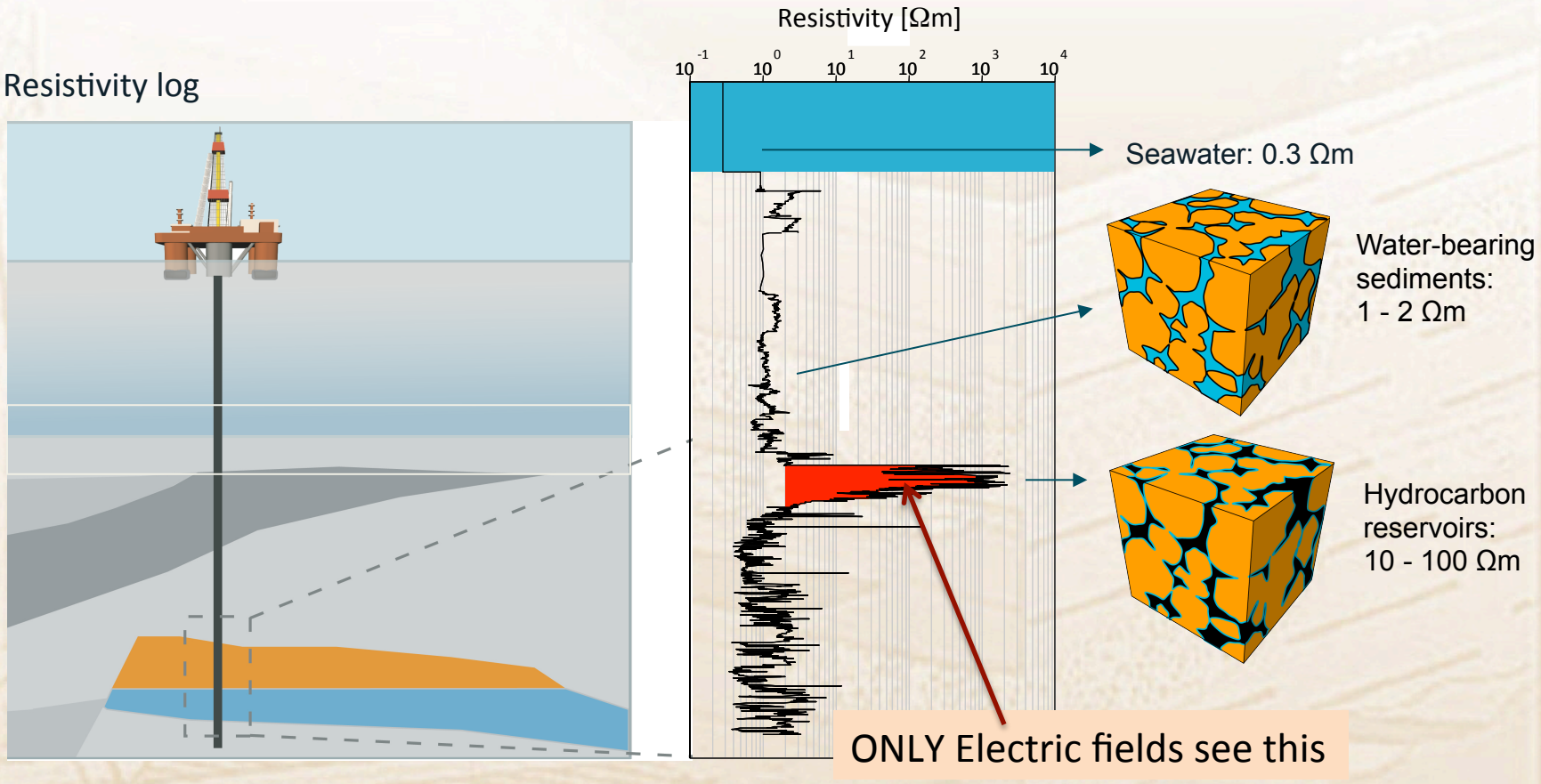
Tai Xing, 1988:

- inversion very limited
- Imaging better

- Different physics
- EM methods generally incomplete
  - E-field sensitive to resistors
  - H-field biased to conductors
  - Anisotropy requires both
  - Anisotropic model mandatory (mostly)
- Comparable data density to seismic needed
- Cost/channel must come down
- **Last but not least: Information focus**

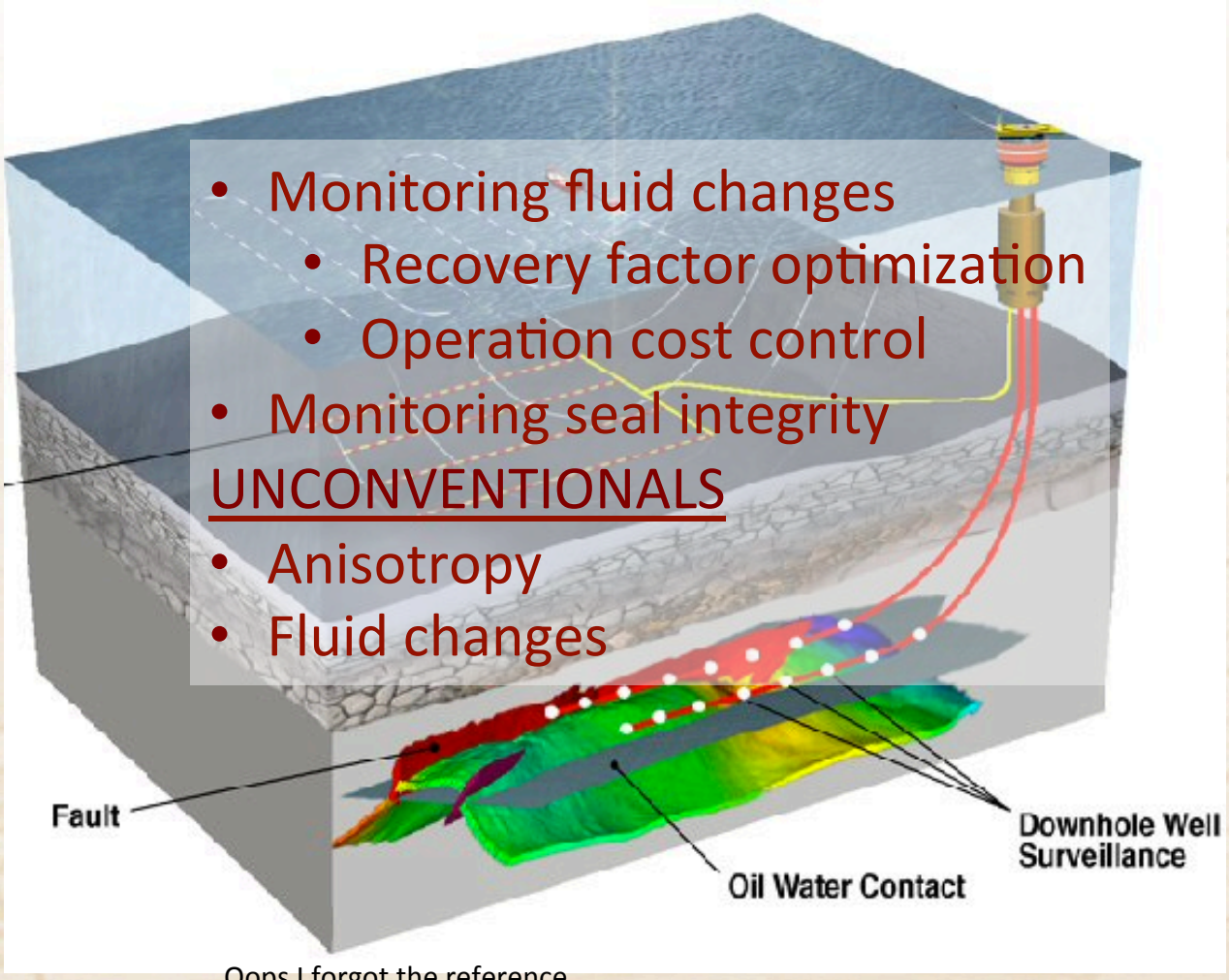
Courtesy EMGS

Hydrocarbons are resistive!...Water is conductive!



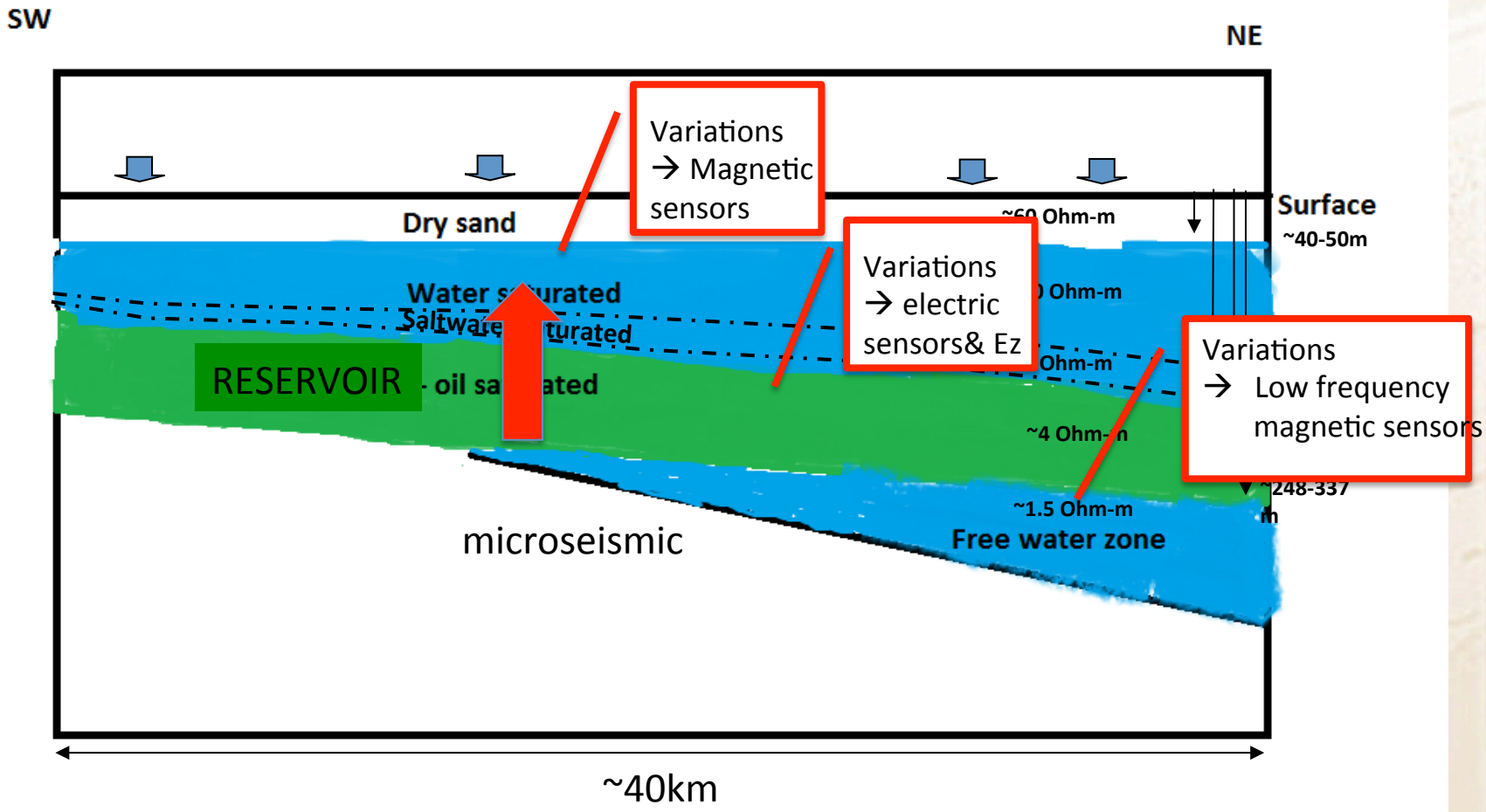
Courtesy EMGS

What is reservoir monitoring? Track fluid movement

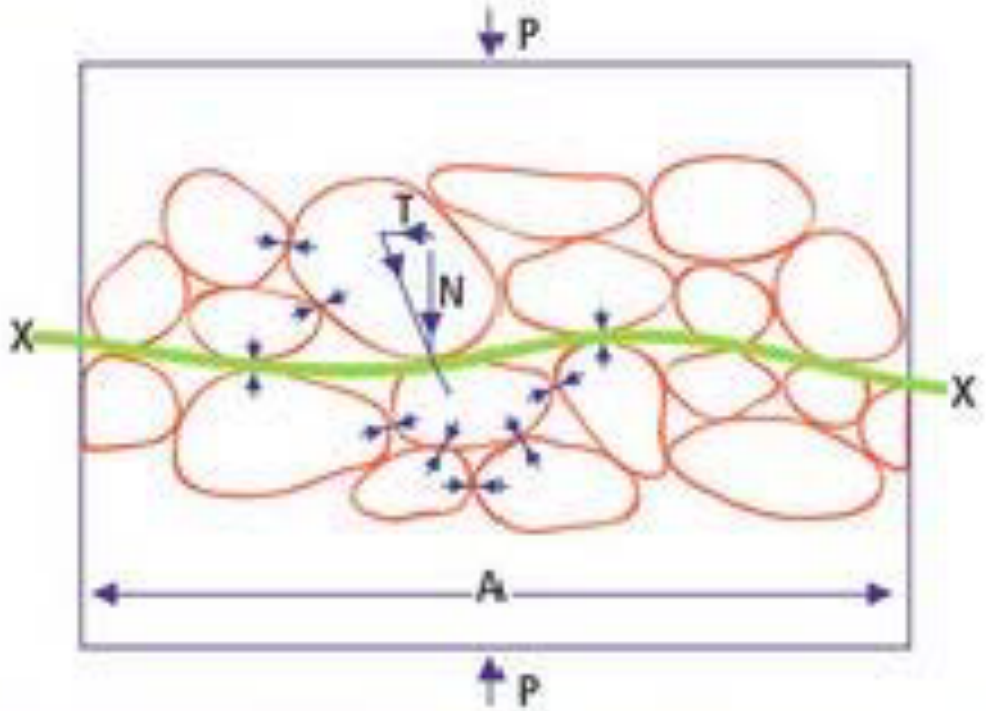


Oops I forgot the reference

Reservoir example: typical mixed sensors required



Reservoirs seal: EM & microseismic - effective stress



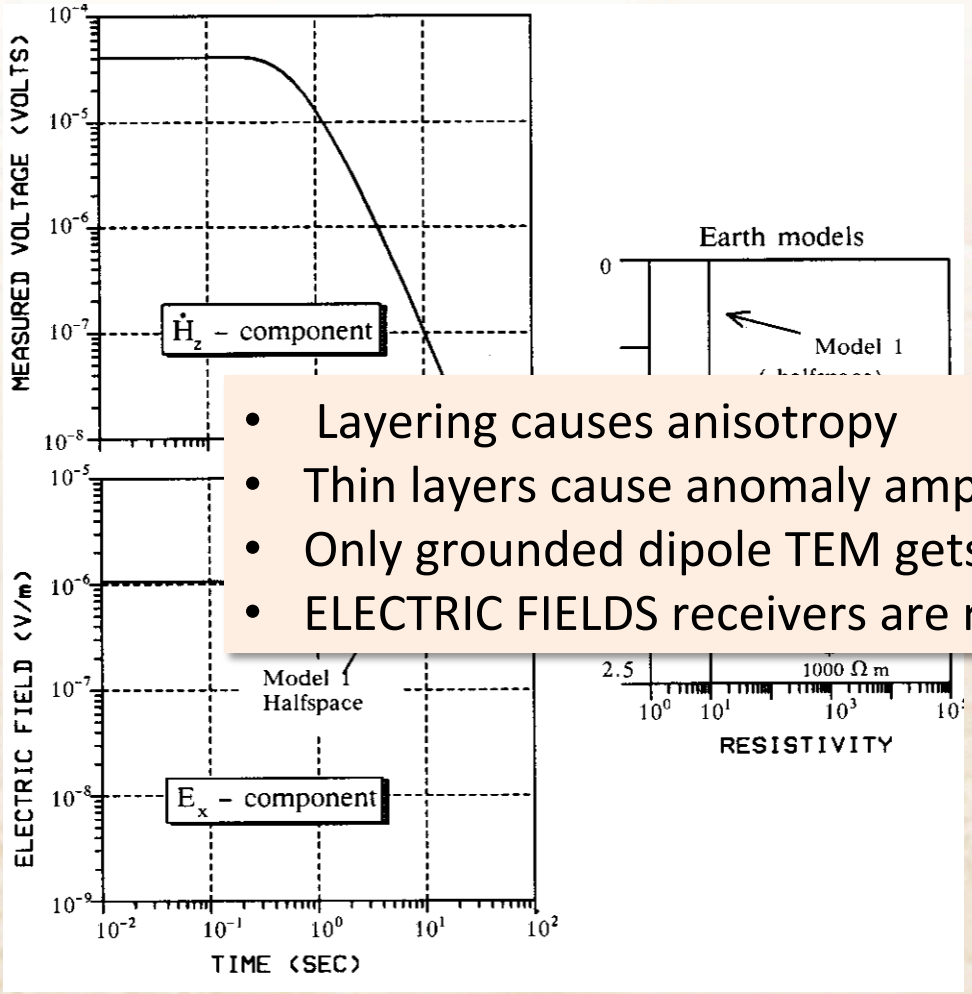
- Overburden & fluid stress in balance
- When fluid pressure too high →quick sand
- Seal BRITTLE → porosity reduction → resistivity increase
- Seal FRACTURE →porosity increase→ resistivity increase
- Microseismic signature from fracturing
- EM responds to fluid movements →
- EM signature from brittle & fracturing

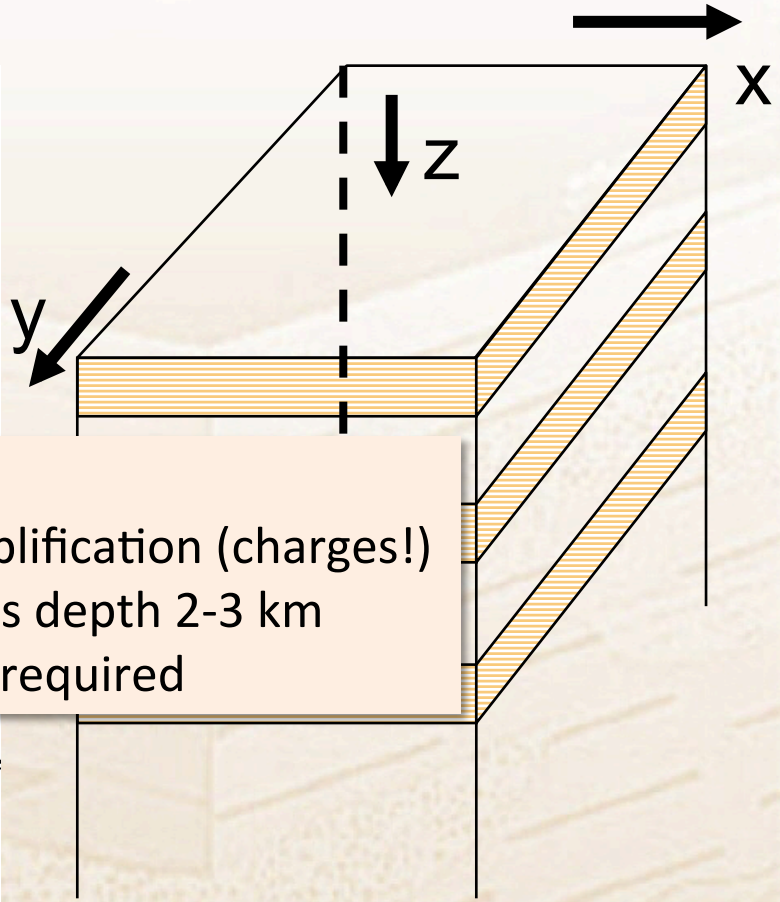
After Carlson, 2013

Limitations overcome during the past 20 years

- Anisotropy
- Anisotropy – Anisotropy
- Borehole to surface calibration/integration
- Target focus

Anisotropy: Layer cake geology → anisotropy



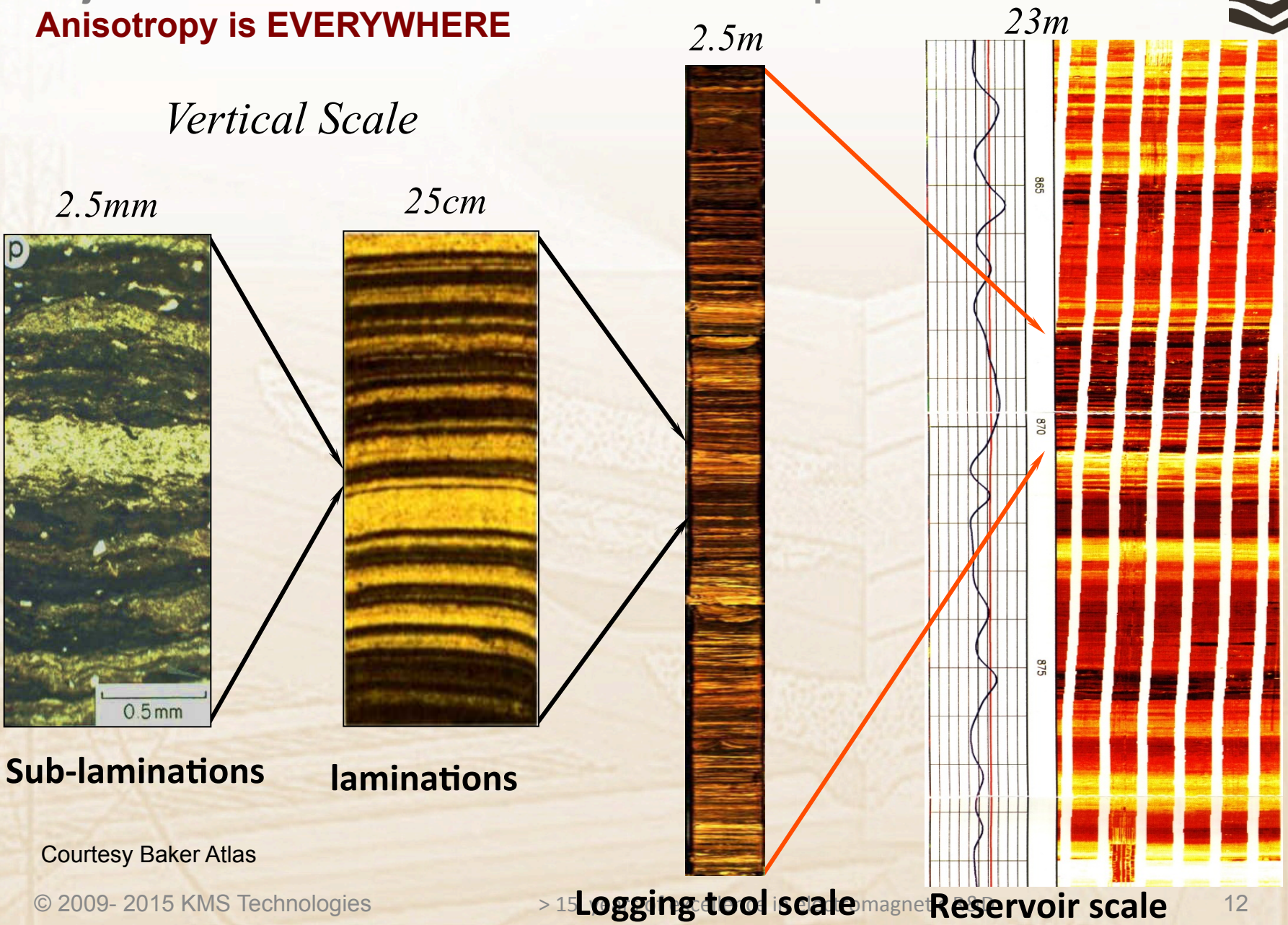


- Layering causes anisotropy
- Thin layers cause anomaly amplification (charges!)
- Only grounded dipole TEM gets depth 2-3 km
- ELECTRIC FIELDS receivers are required

(after Strack 1992)

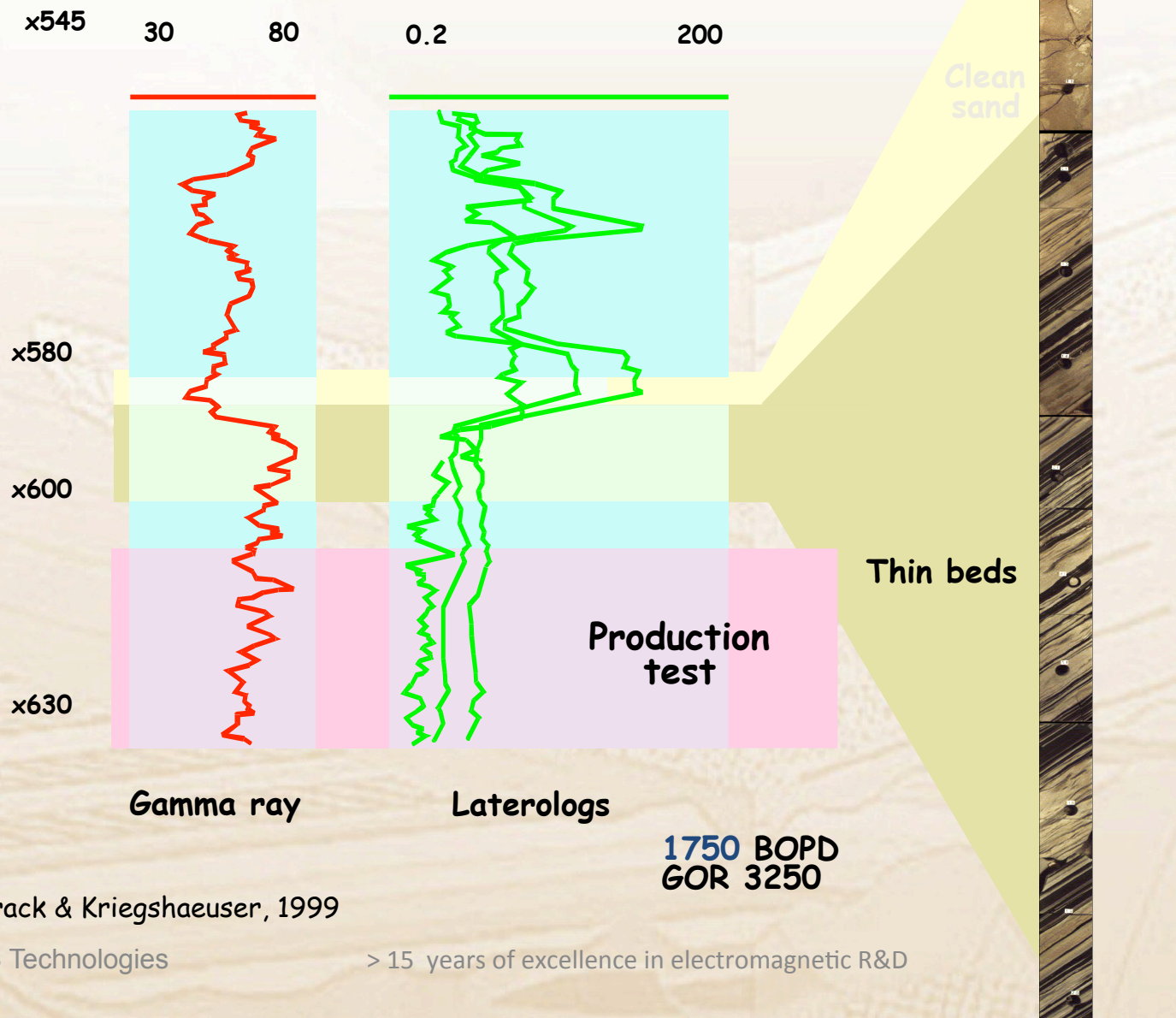
Anisotropy is EVERYWHERE

Anisotropy is EVERYWHERE



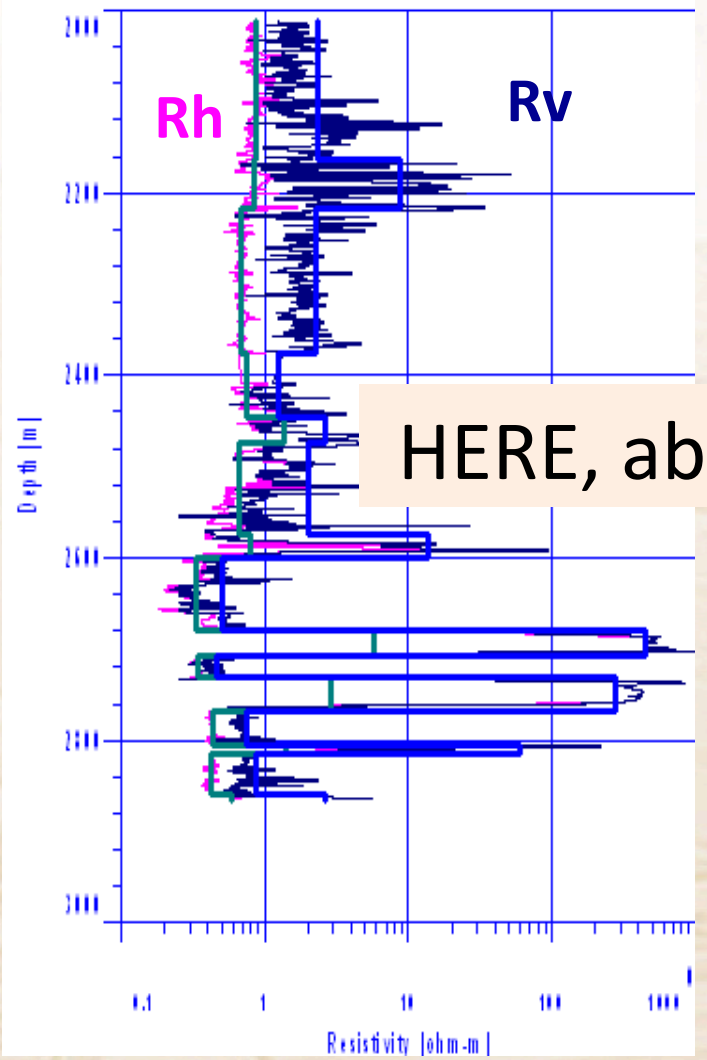
Courtesy Baker Atlas

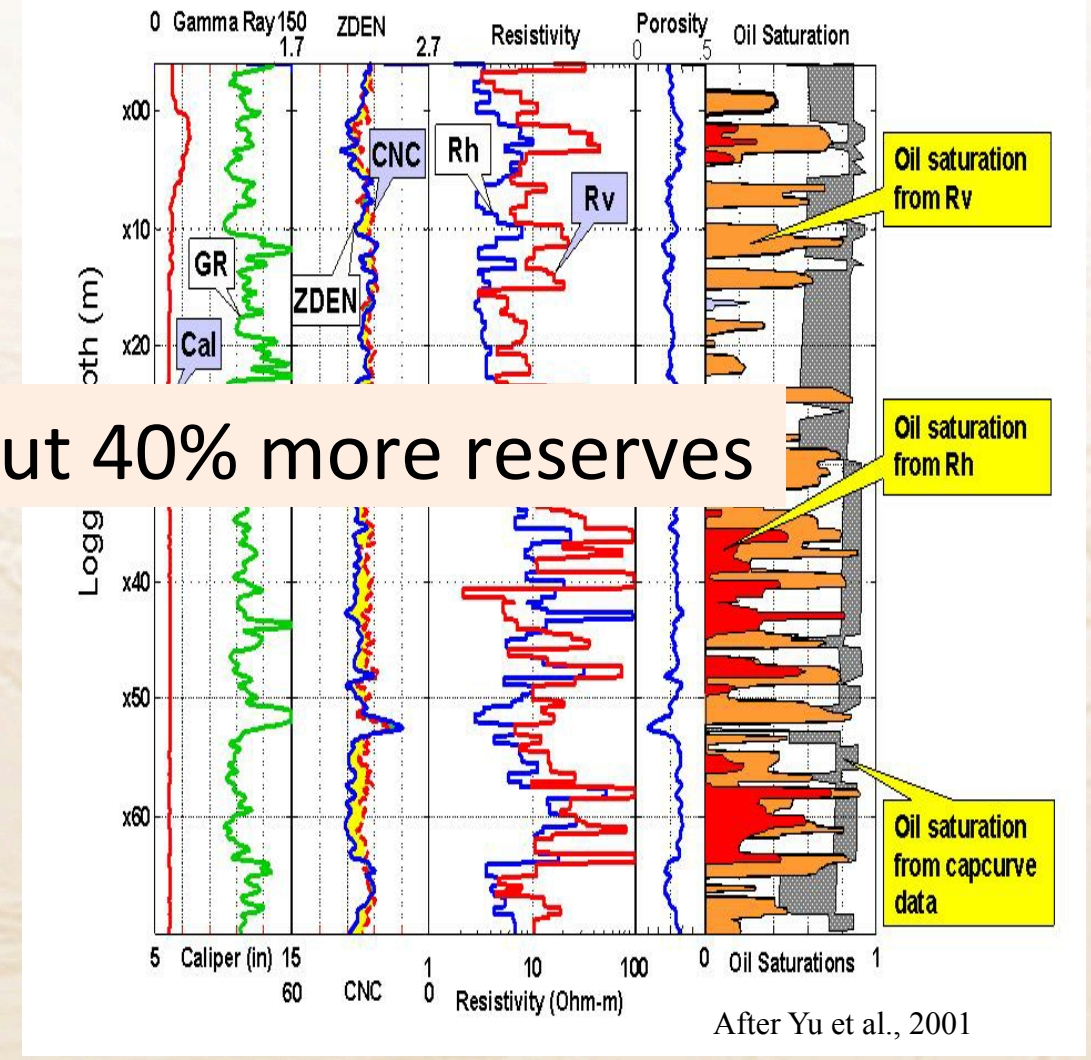
Anisotropy: Original motivating log (Shell 1990)



After Strack & Kriegshaeuser, 1999

Unconventionals: ADD BOREHOLE: Fractures → anisotropy





HERE, about 40% more reserves

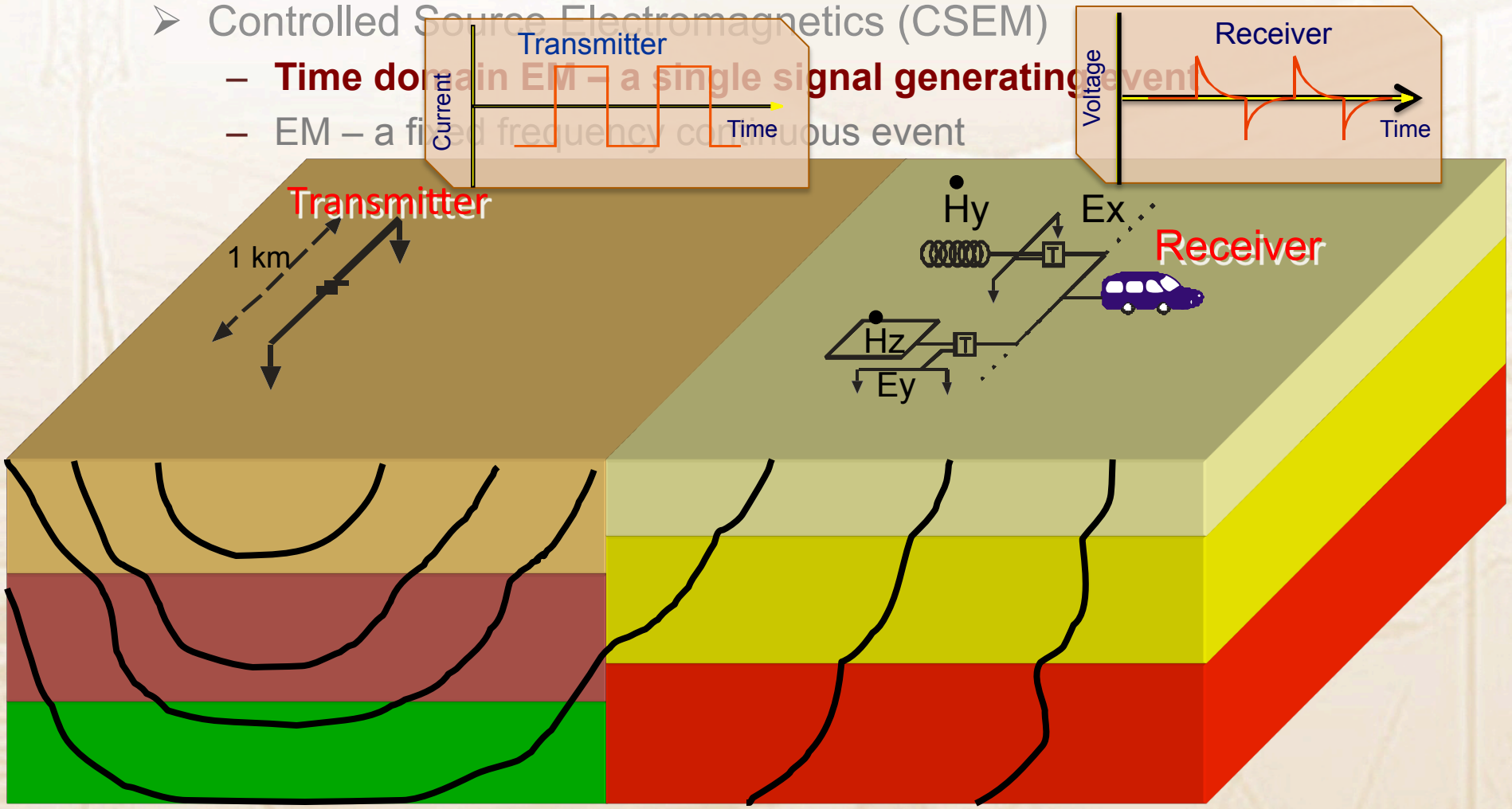
After Yu et al., 2001

- Magnetotellurics – **passive not detailed enough**
- Controlled Source Electromagnetics (CSEM)

  (the ONLY way to get vertical current flow)

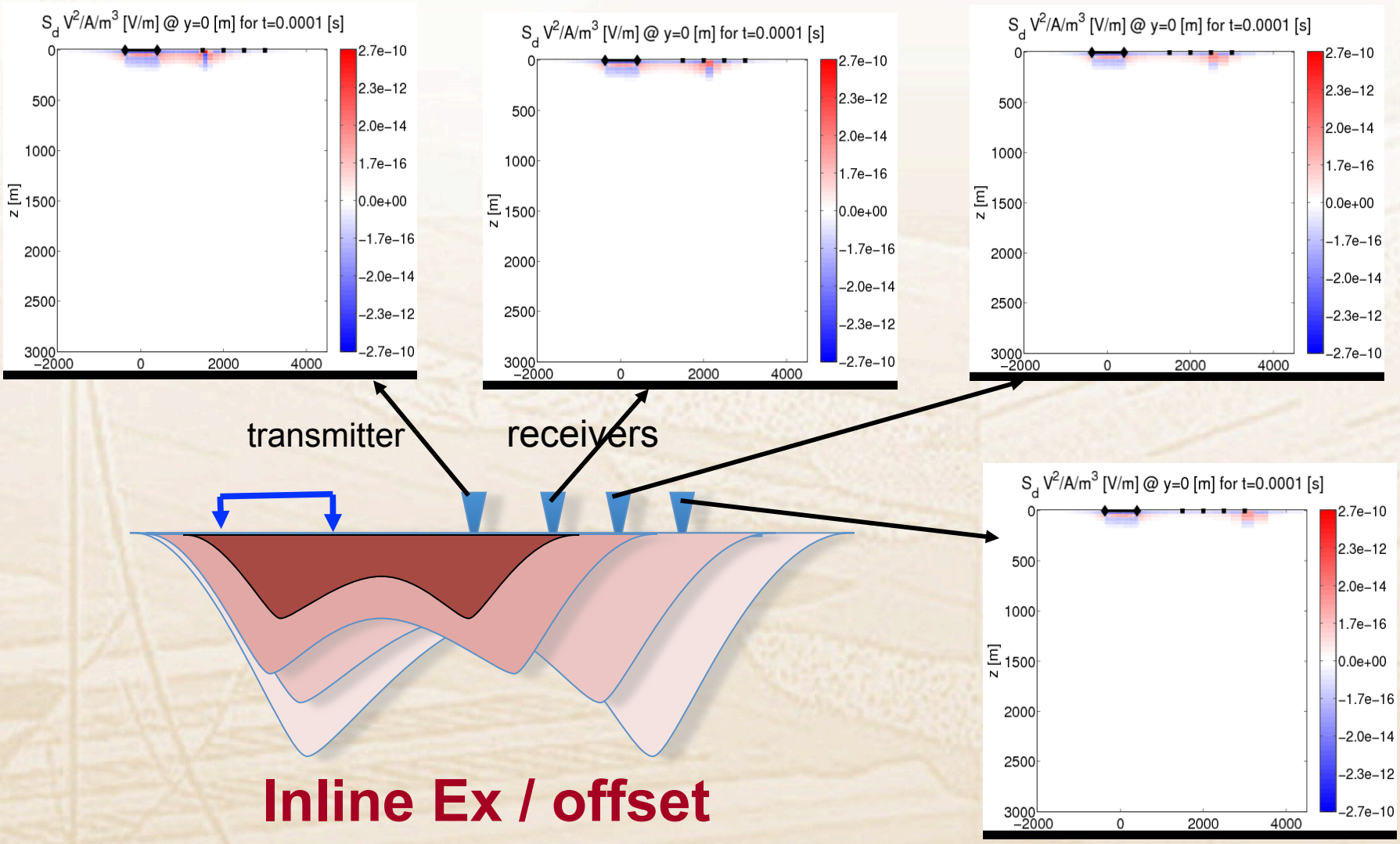
  - Time domain EM – a single signal generating event
  - Frequency domain EM – a fixed frequency continuous event

- Magnetotellurics – **passive not detailed enough**
- Controlled Source Electromagnetics (CSEM)
  - **Time domain EM – a single signal generating event**
  - EM – a fixed frequency continuous event



Courtesy Hoerdt

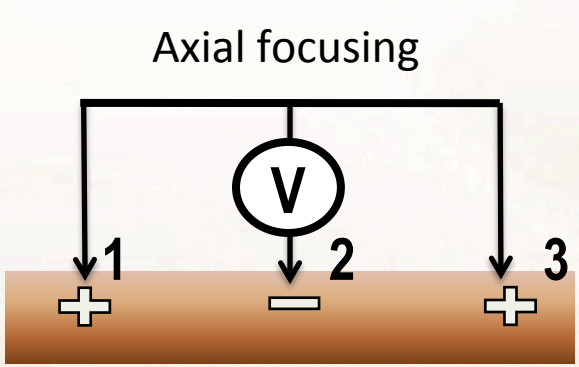
EM Methods: dual focus time domain CSEM

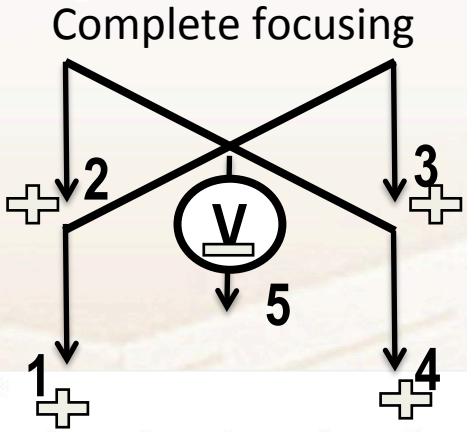


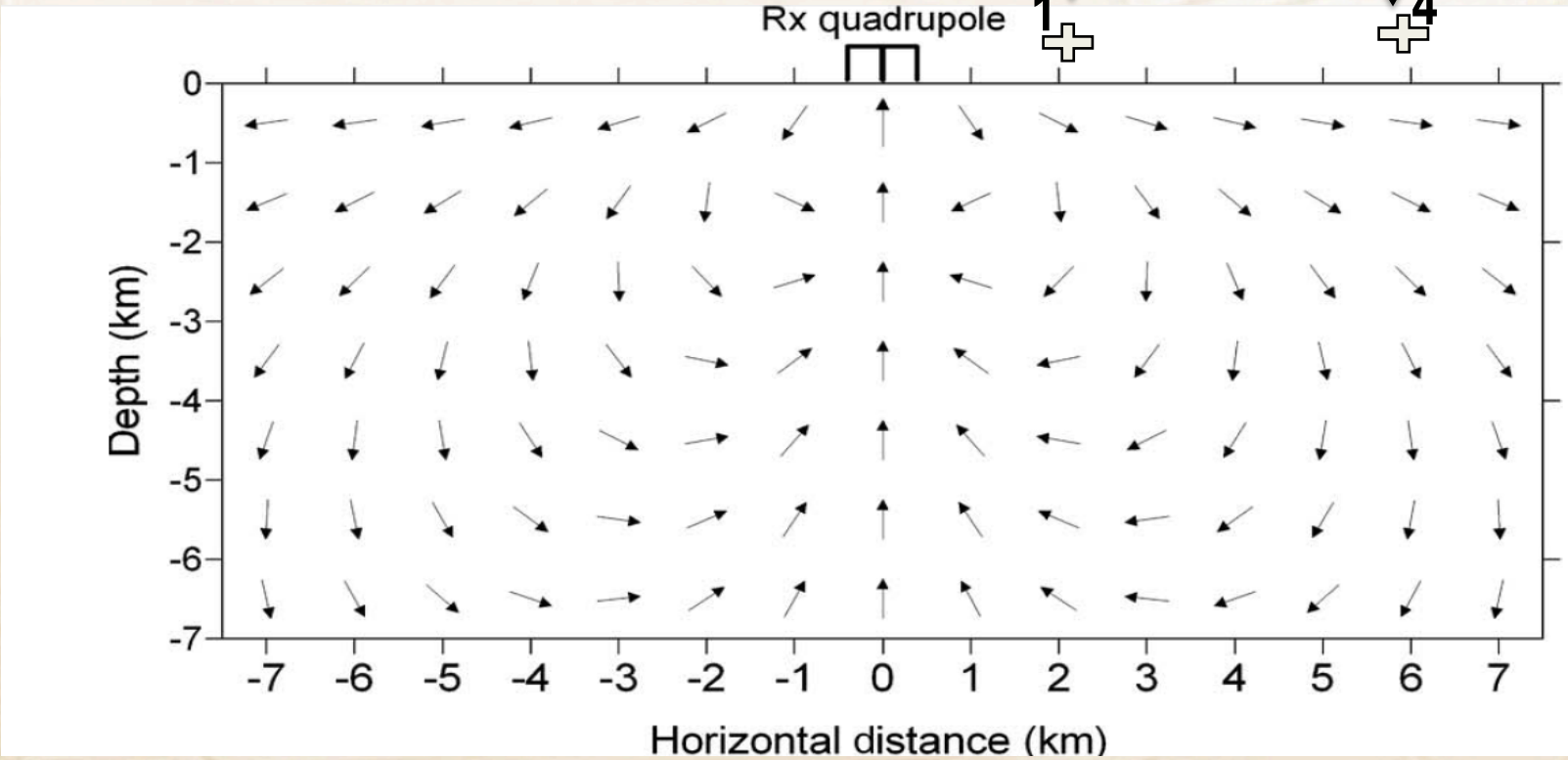
Inline Ex / offset

Courtesy Martin, 2008

EM Methods: Focussed Source EM - FSEM



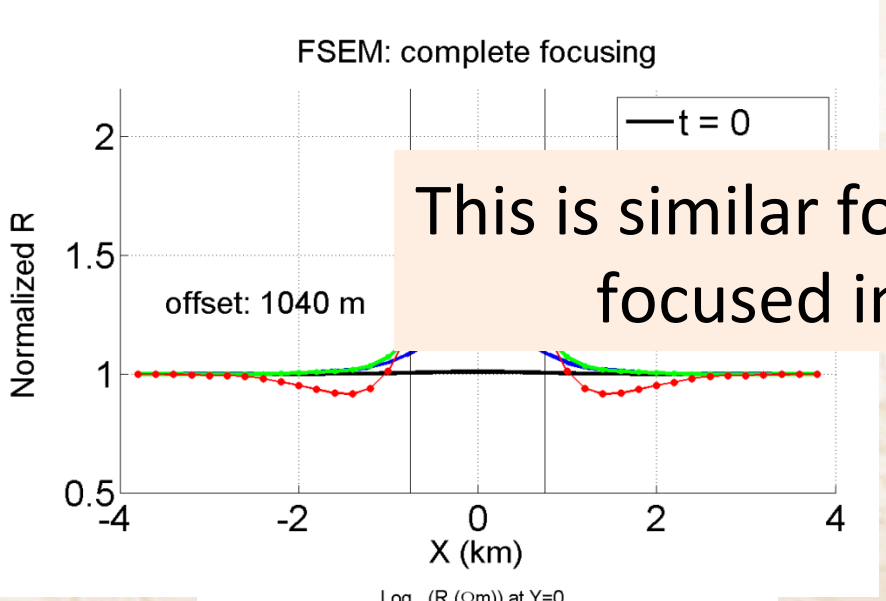


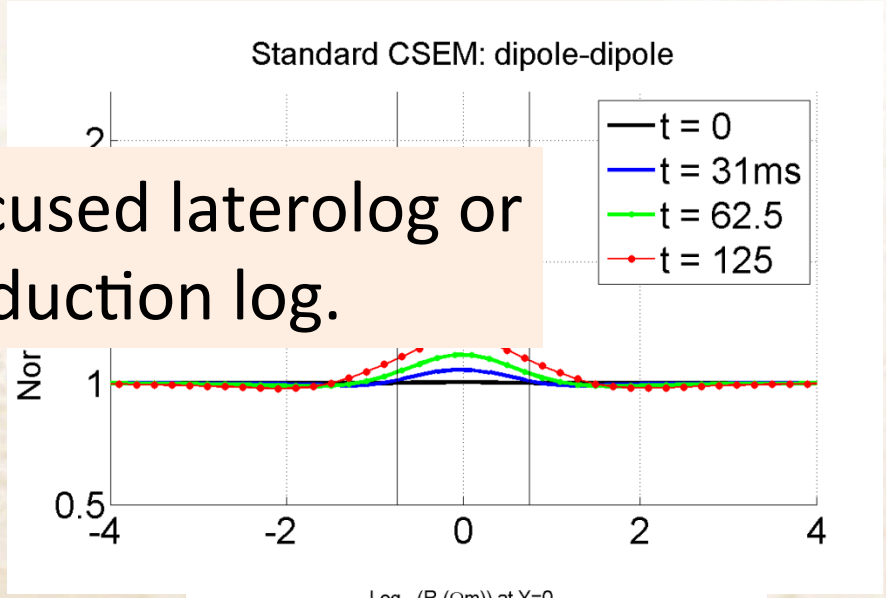


EM Methods: Focussed Source EM - FSEM

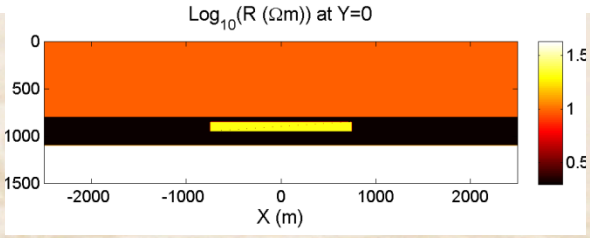
FOCUSED: Anomaly ~75%

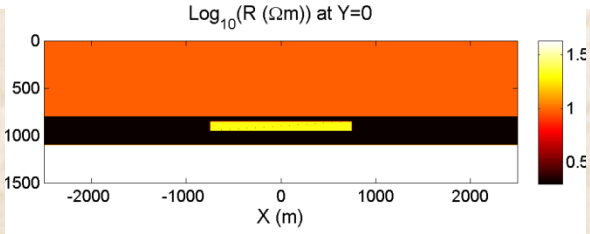
Anomaly ~20%





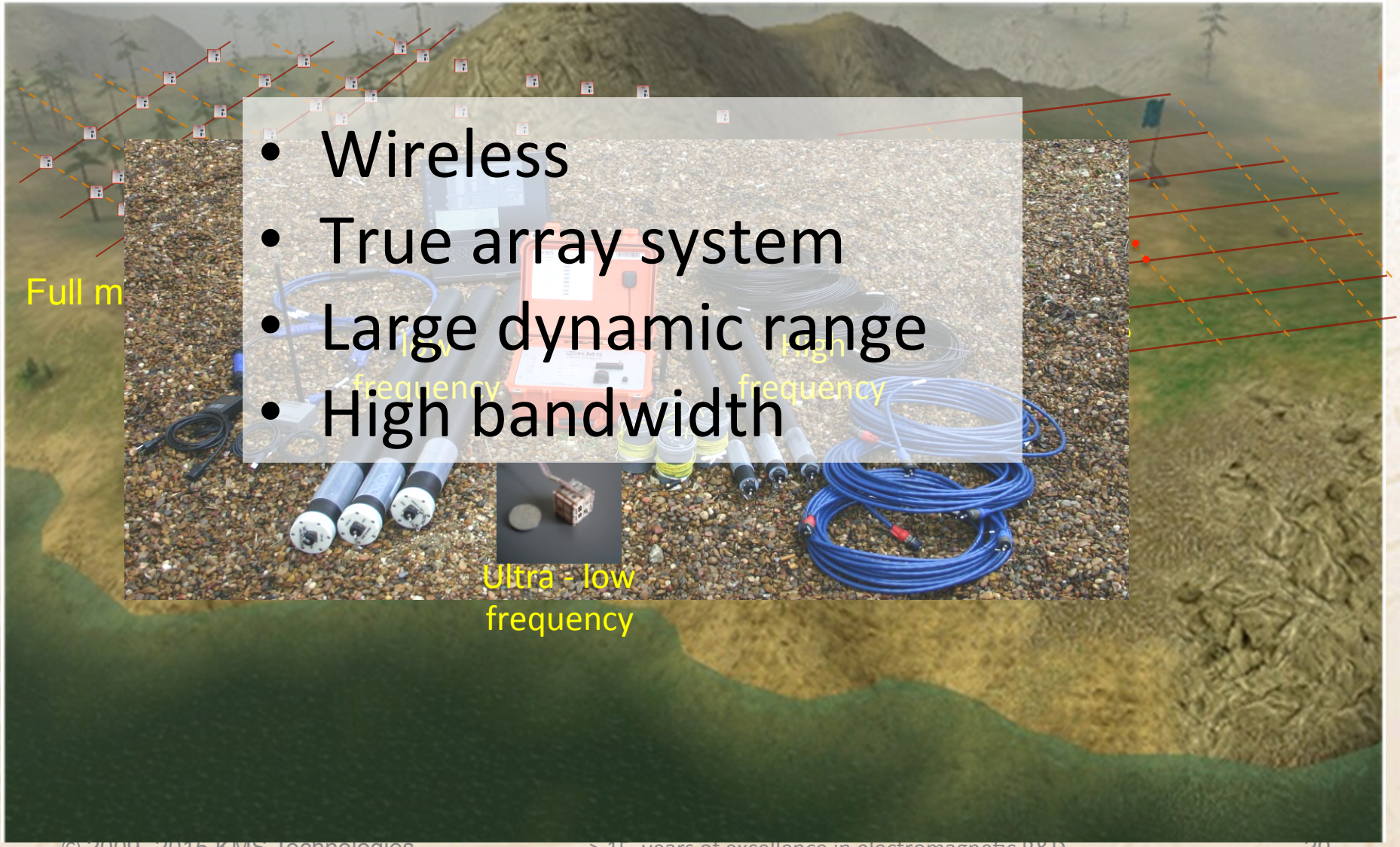
This is similar focused laterolog or focused induction log.





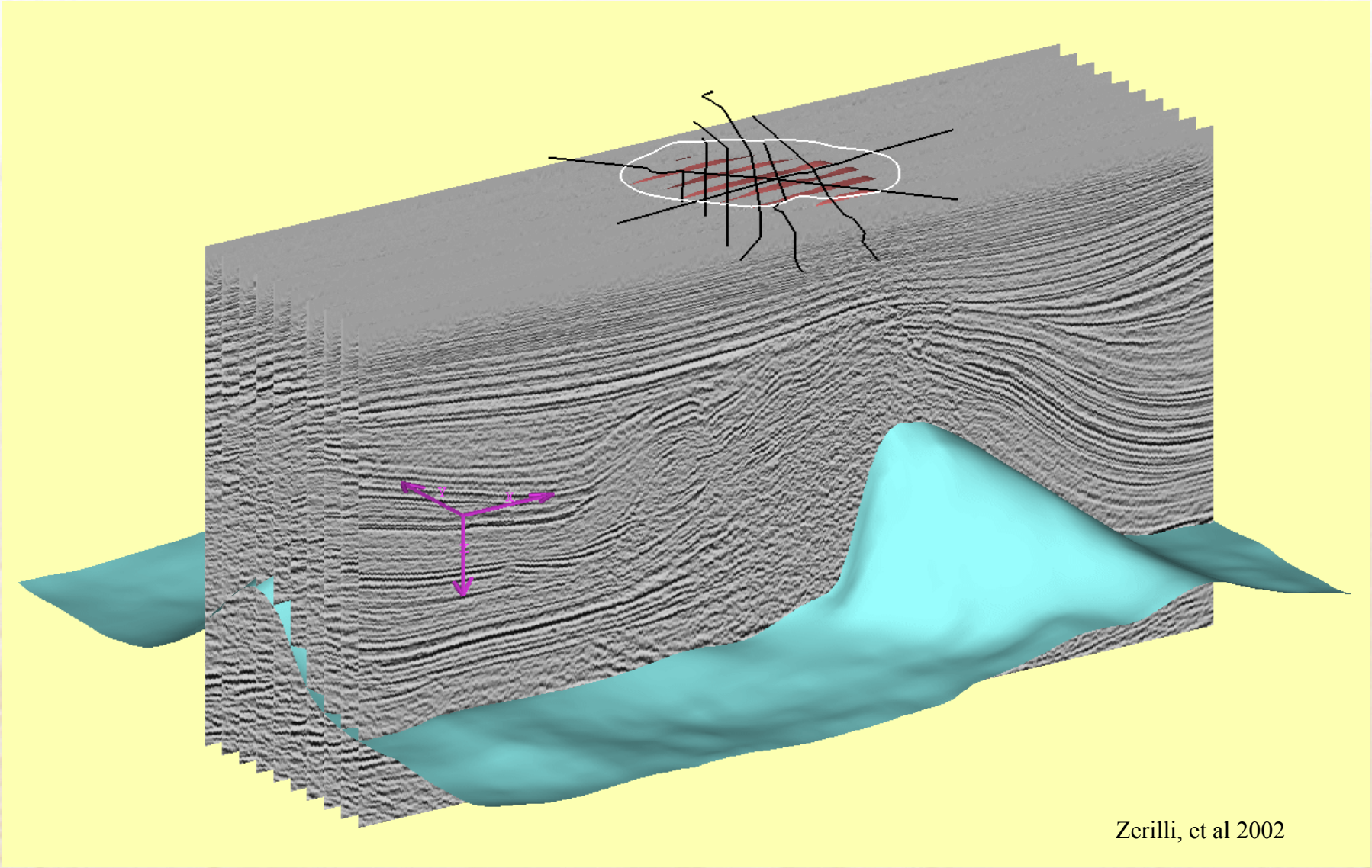
Courtesy Davydycheva

New ARRAY acquisition → better images



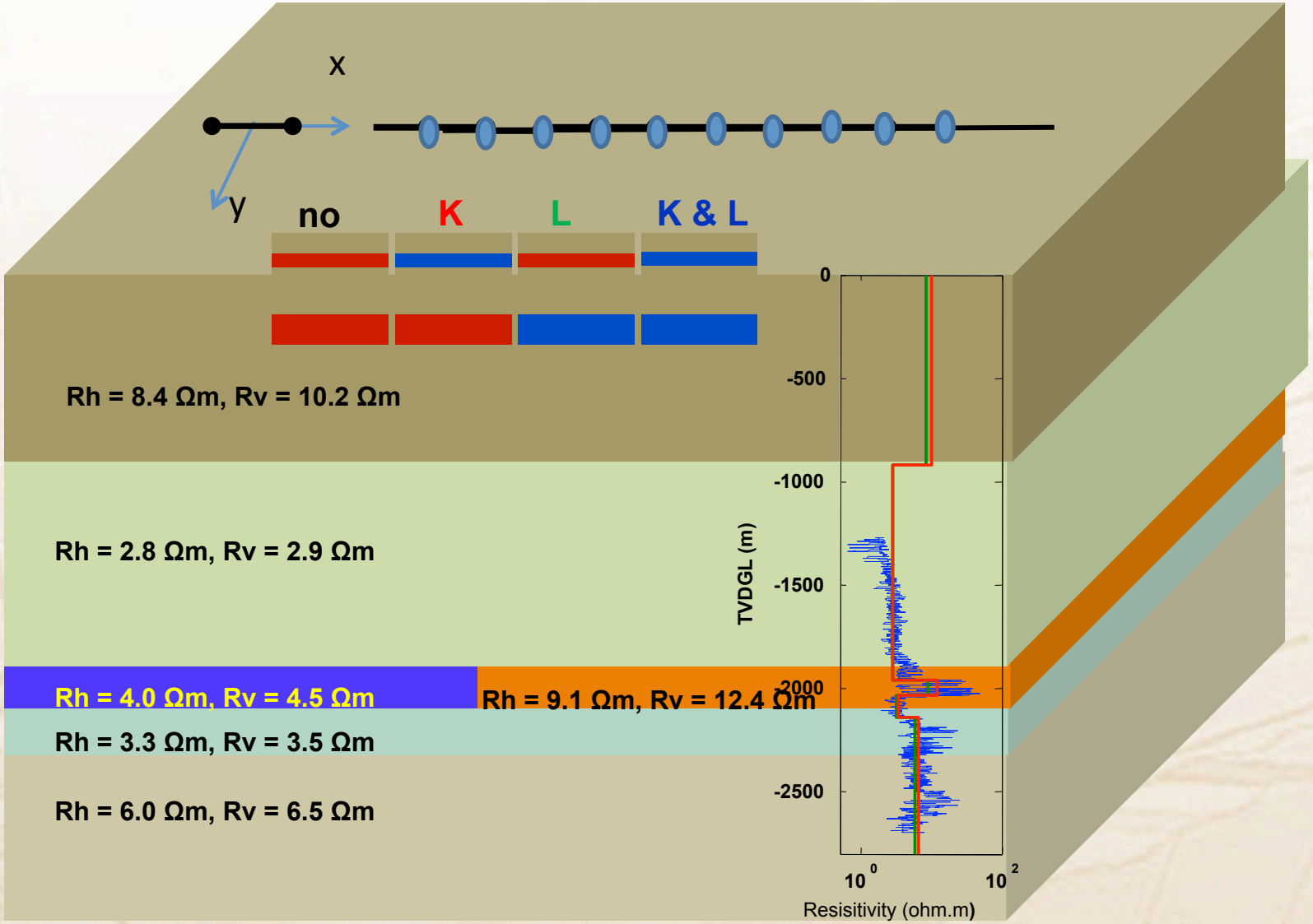
- Wireless
- True array system
- Large dynamic range
- High bandwidth

Dense acquisition (Δx = 50 m) → better images

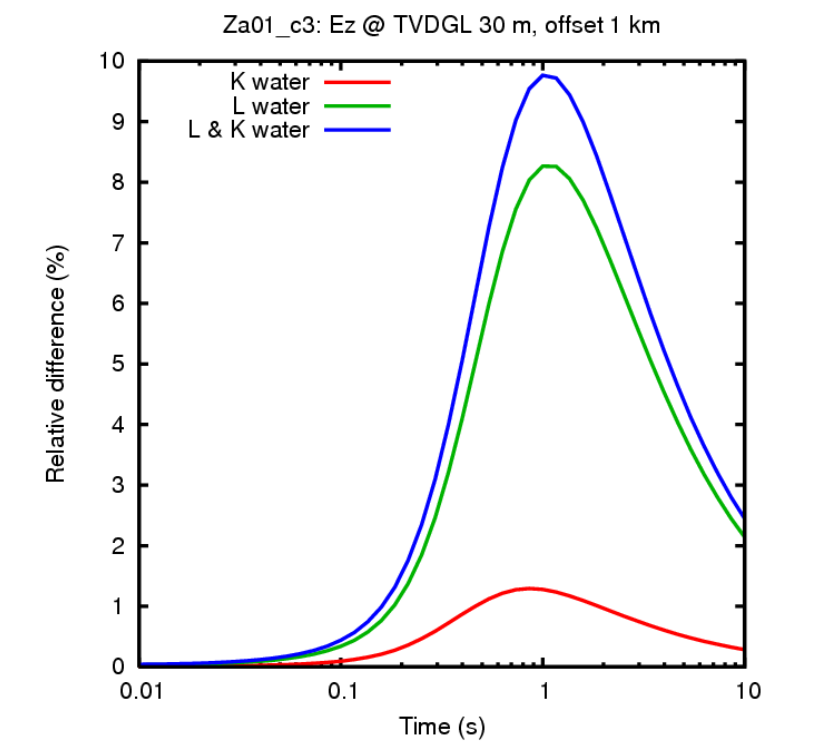


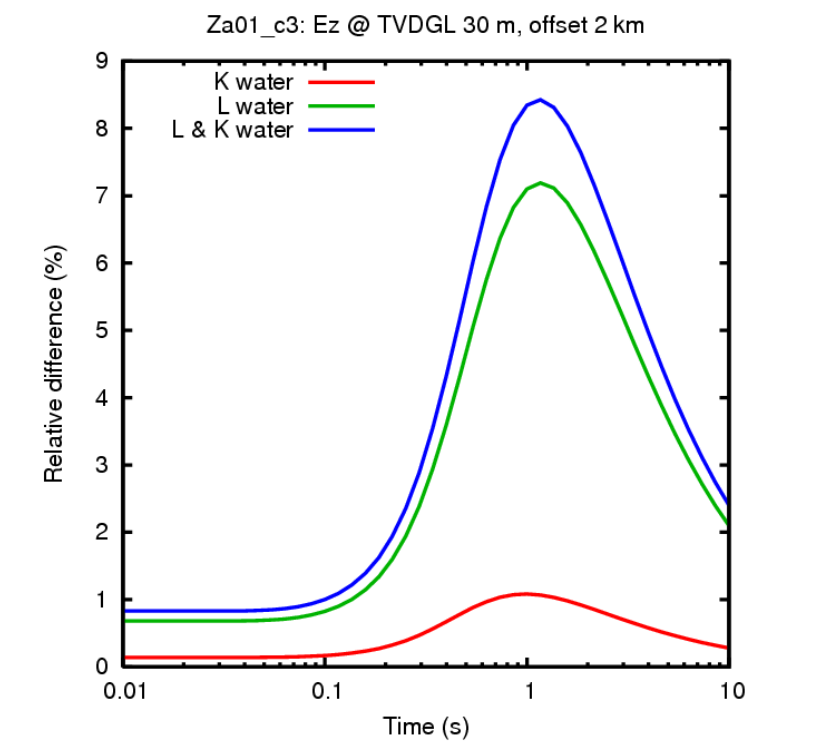
Zerilli, et al 2002

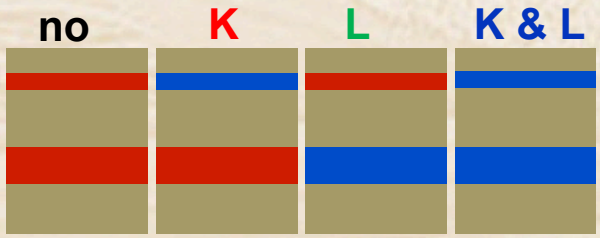
3D modeling & noise test: Real Asian oil field: Model & a priori data



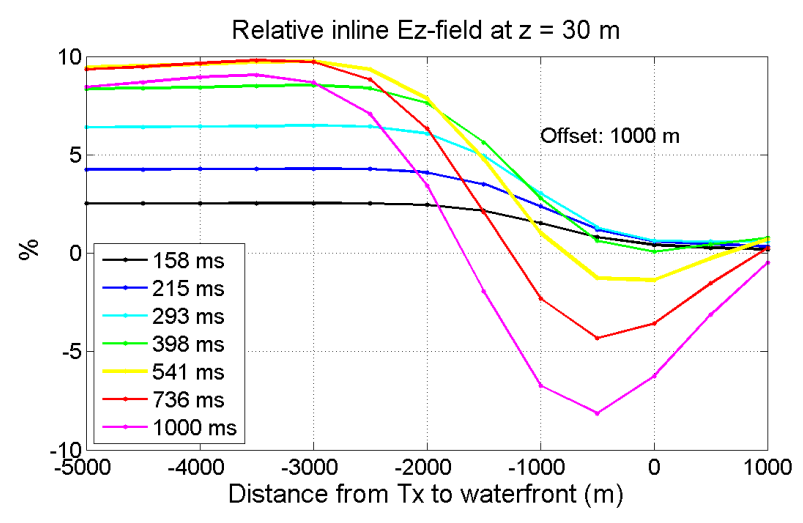
3D modeling & noise test: Real Asian oil field: 1D - Ez step off response in 30 m well with offset 1 & 2 km

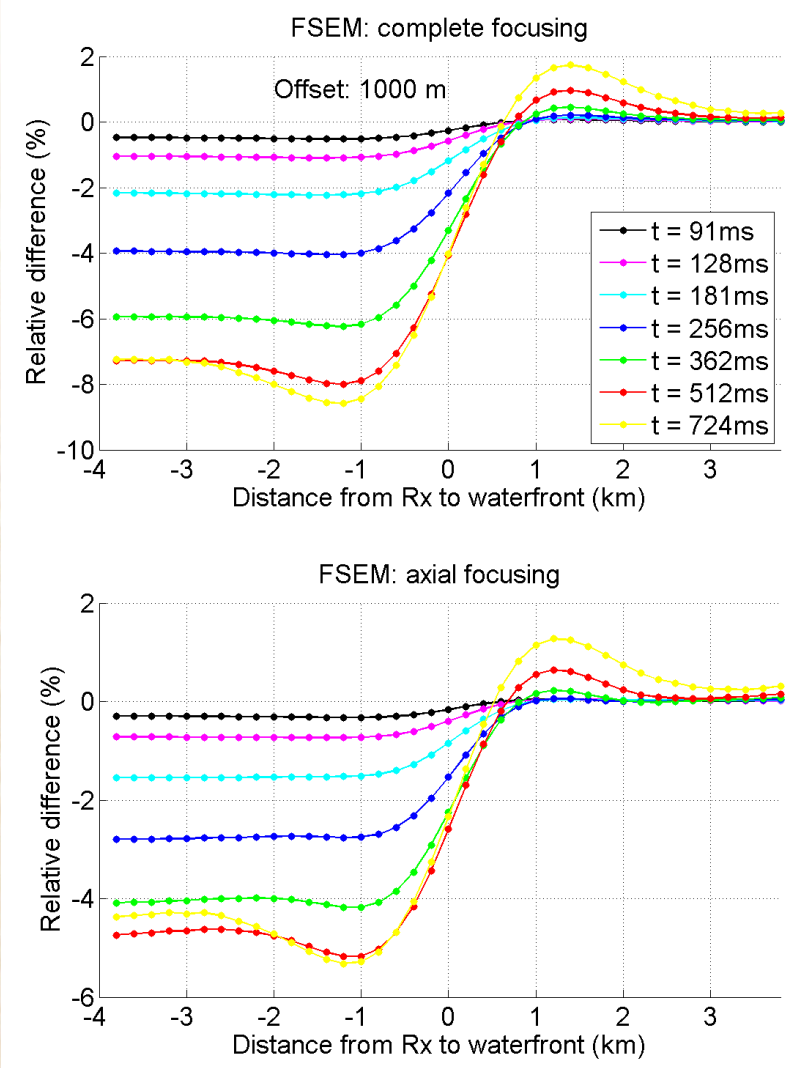




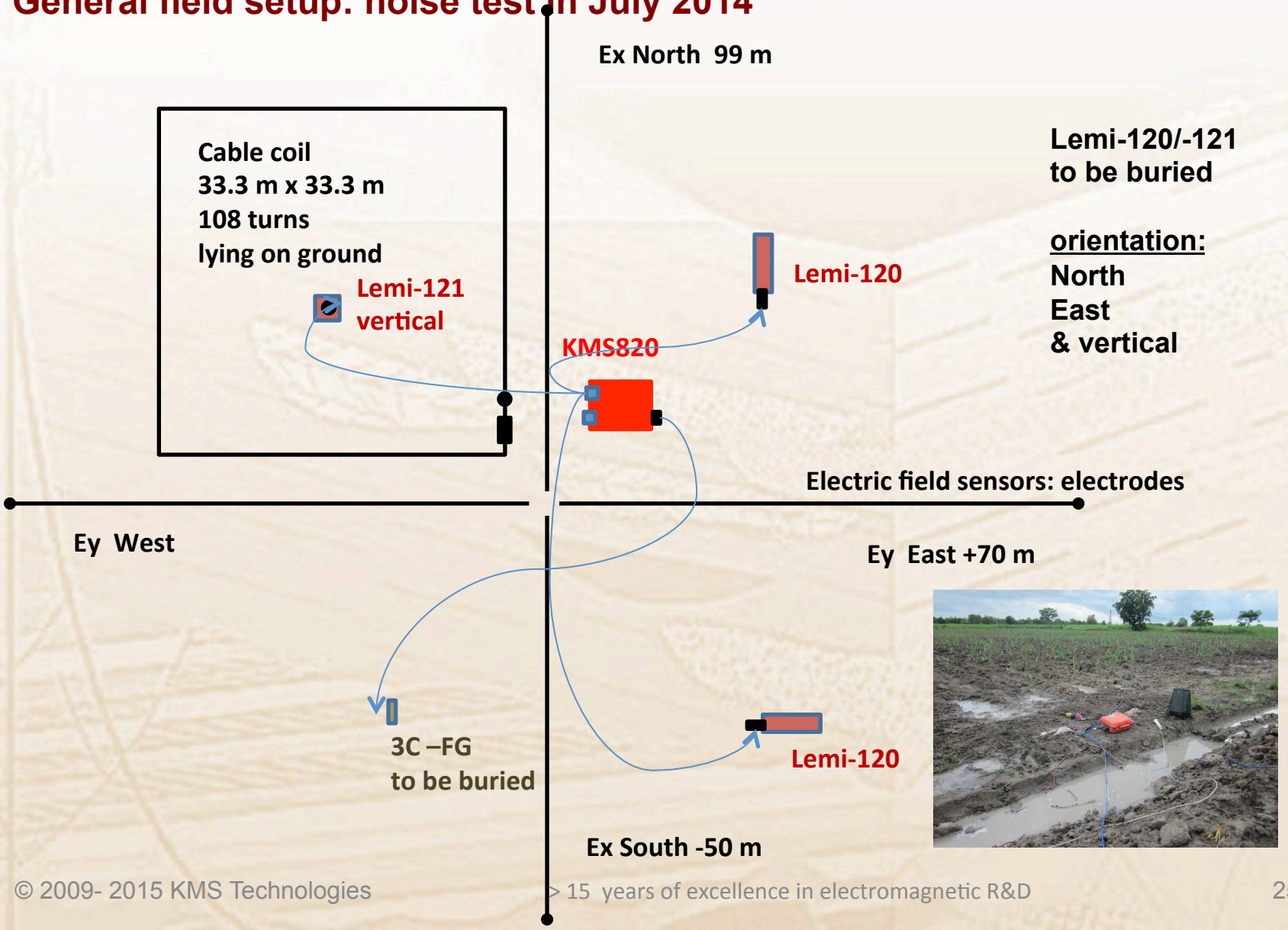


ALTERNATIVE: 3D modeling & noise test: Real Asian oil field FSEM

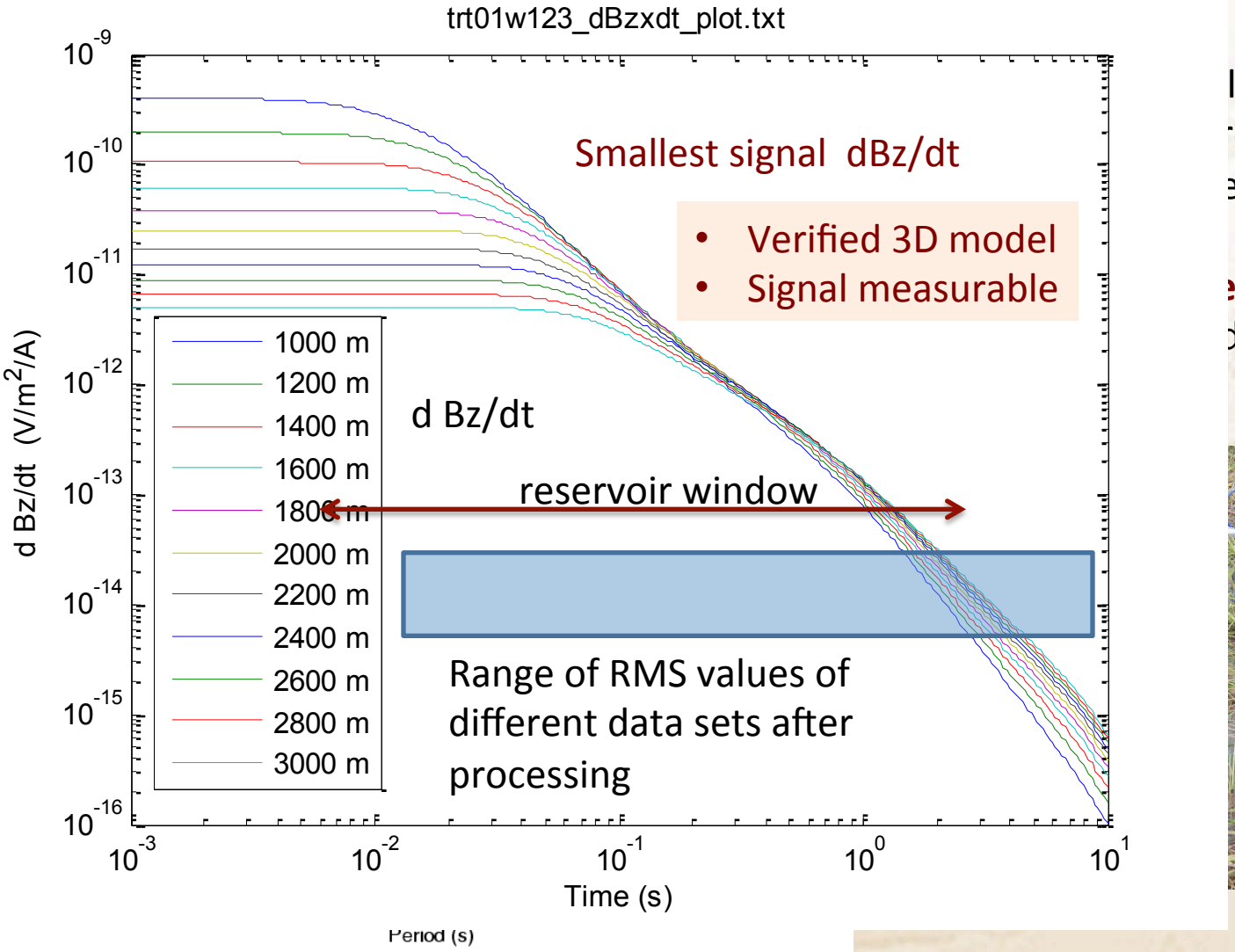




3D modeling & noise test: Real Asian oil field:
General field setup: noise test in July 2014

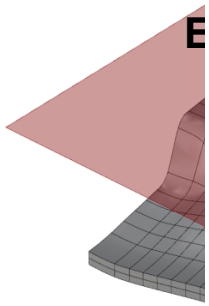


3D modeling & noise test: Real Asian oil field: Resistivity and phase. 2.5 hours recording time

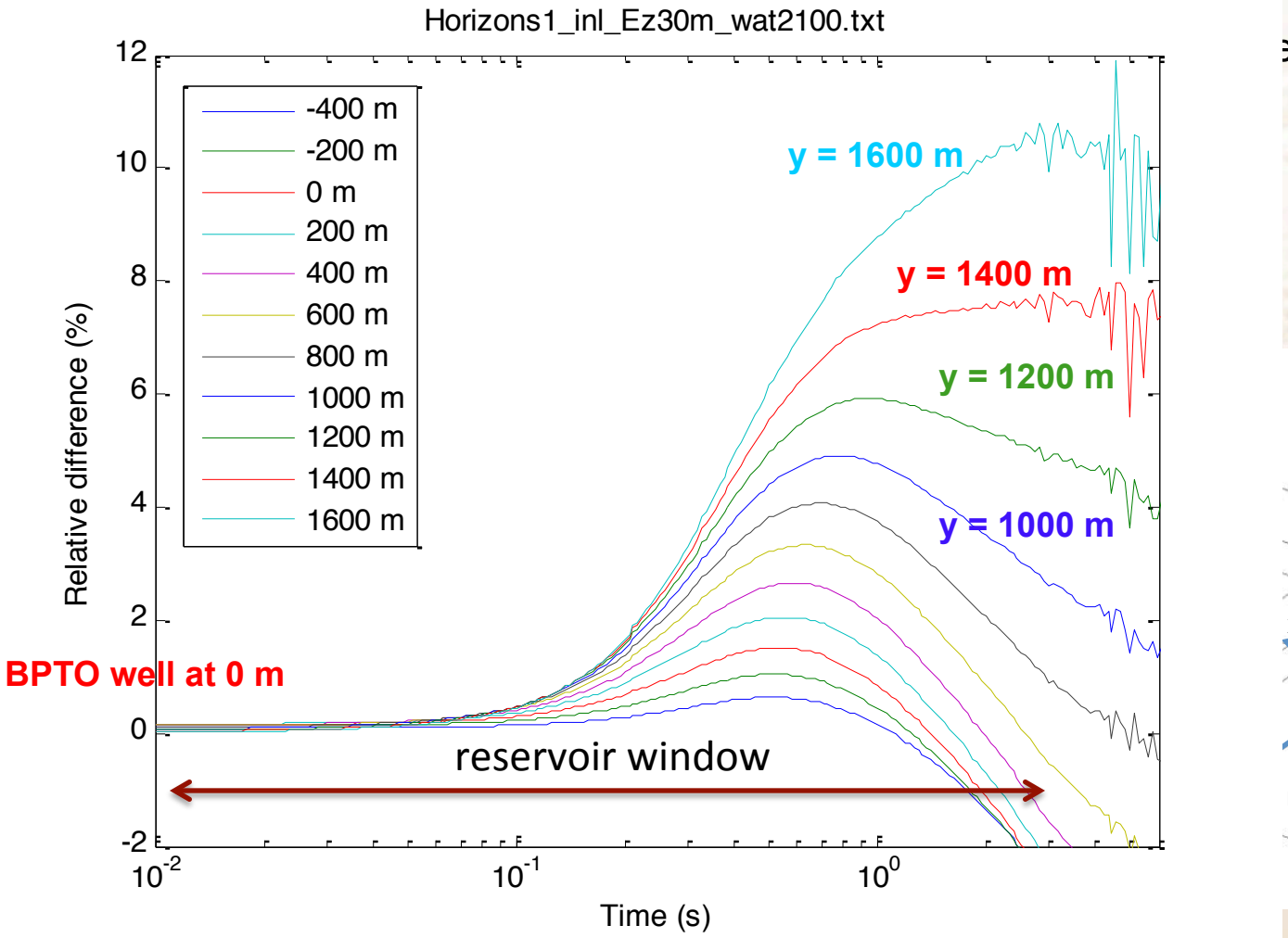


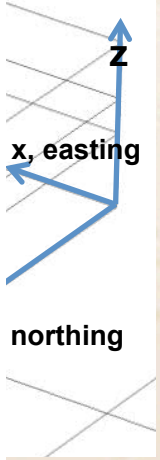
le
response
es very
1D → **use**
er crosses
d → **noise**

3D modeling & noise test: Asian oil field: Seismic horizons & water front

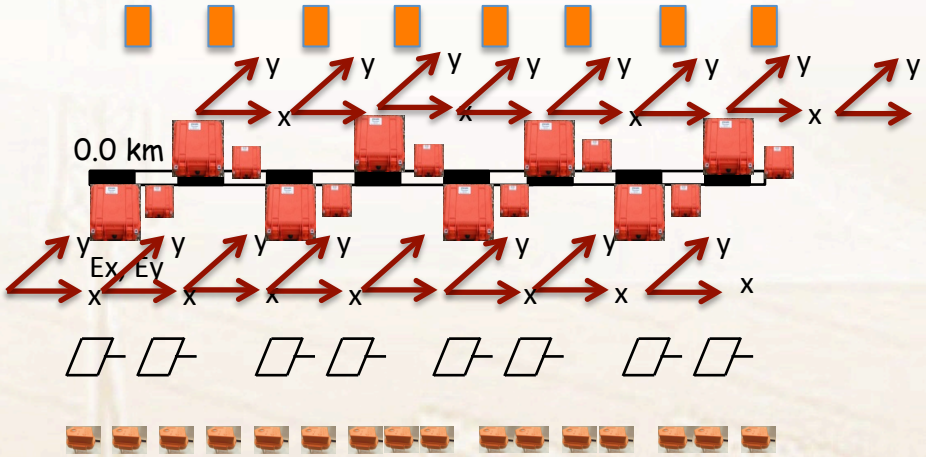


South

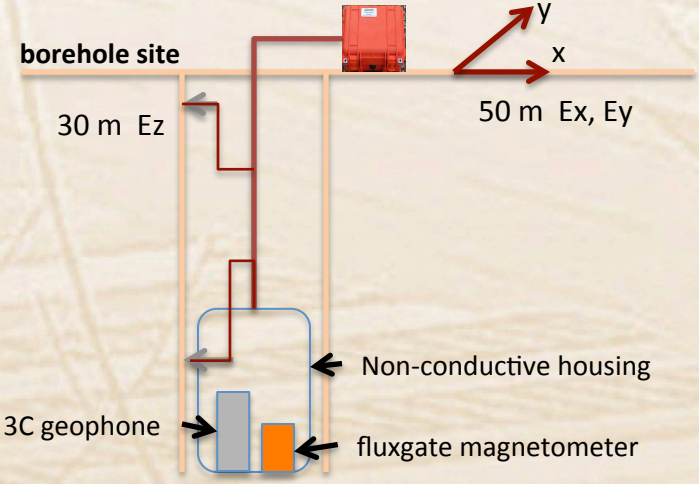


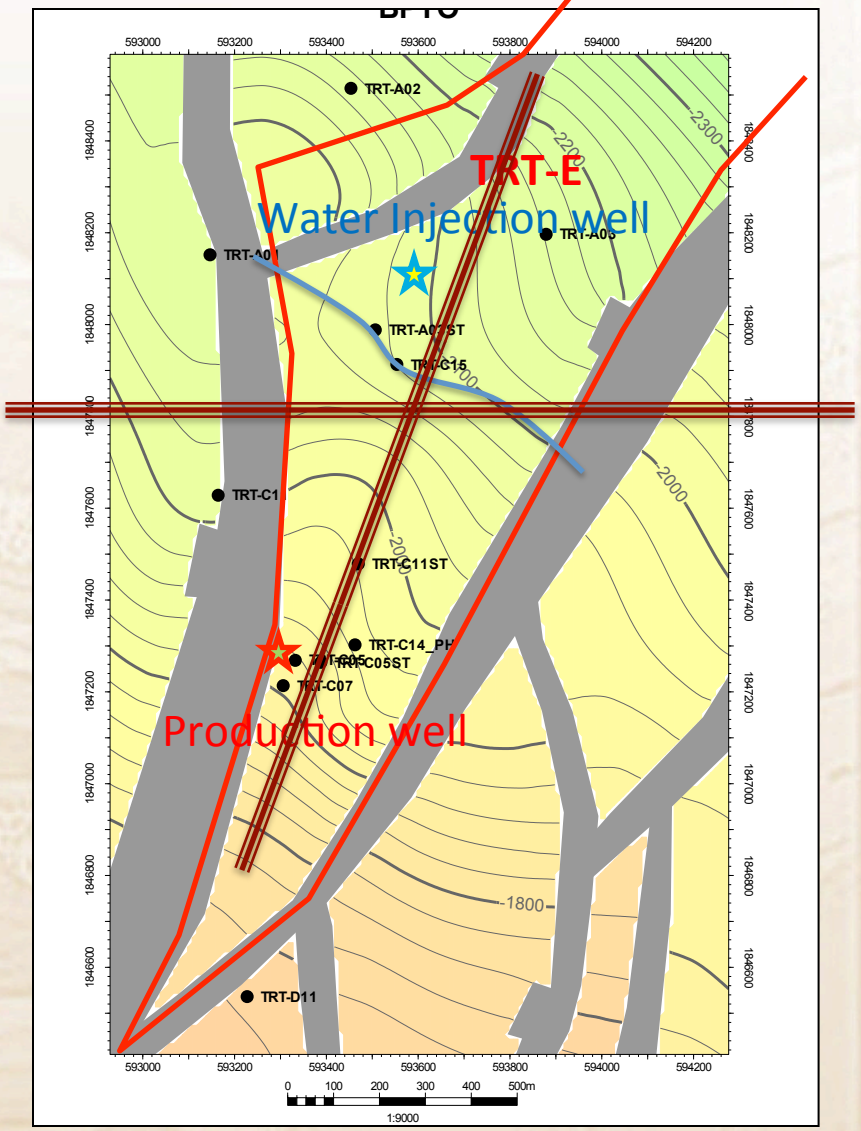


3D modeling & noise test: Real Asian oil field: Sample survey layout



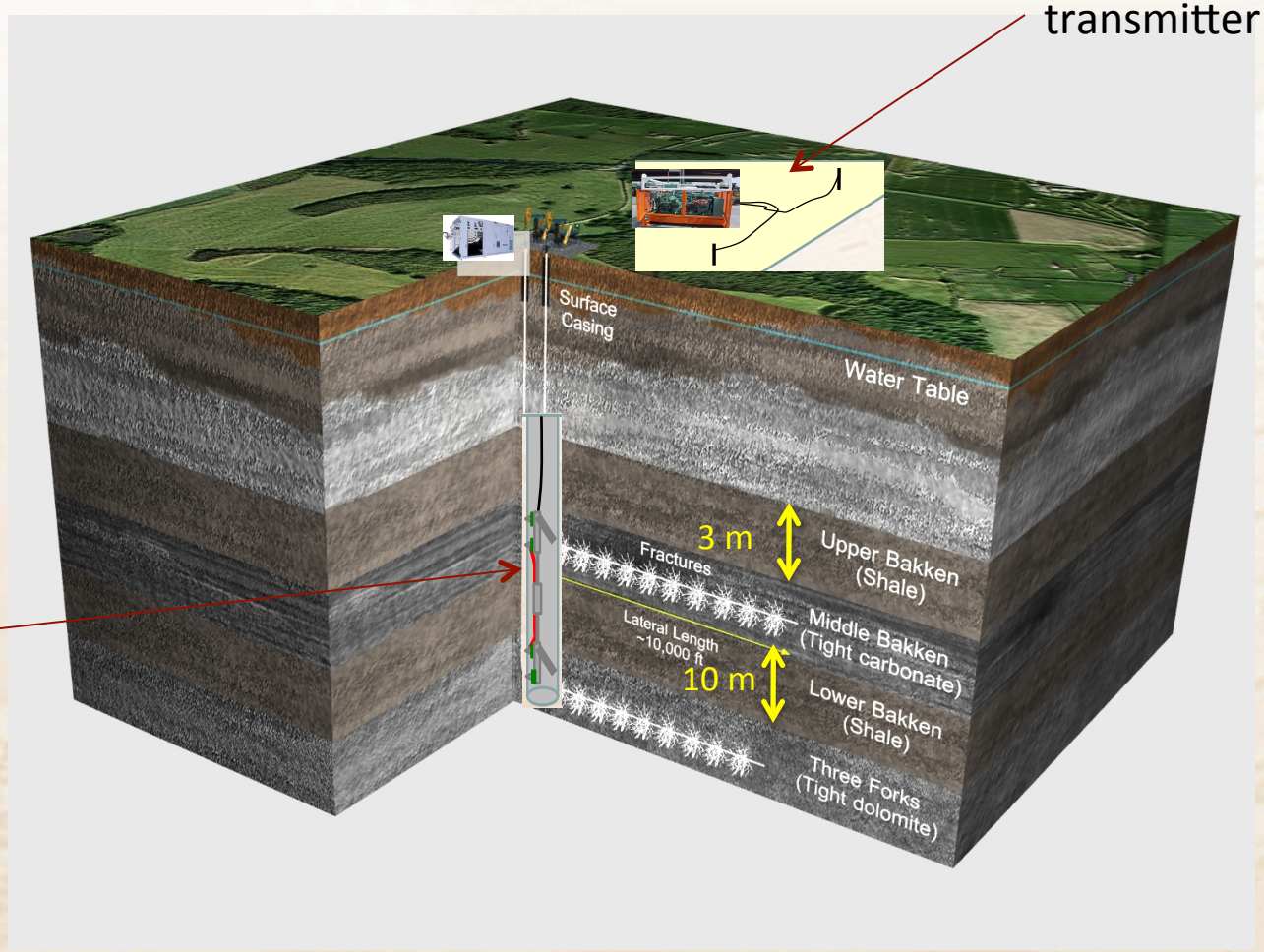
16 3C geophones at every location





Asian reservoir monitoring equipment 4/2015

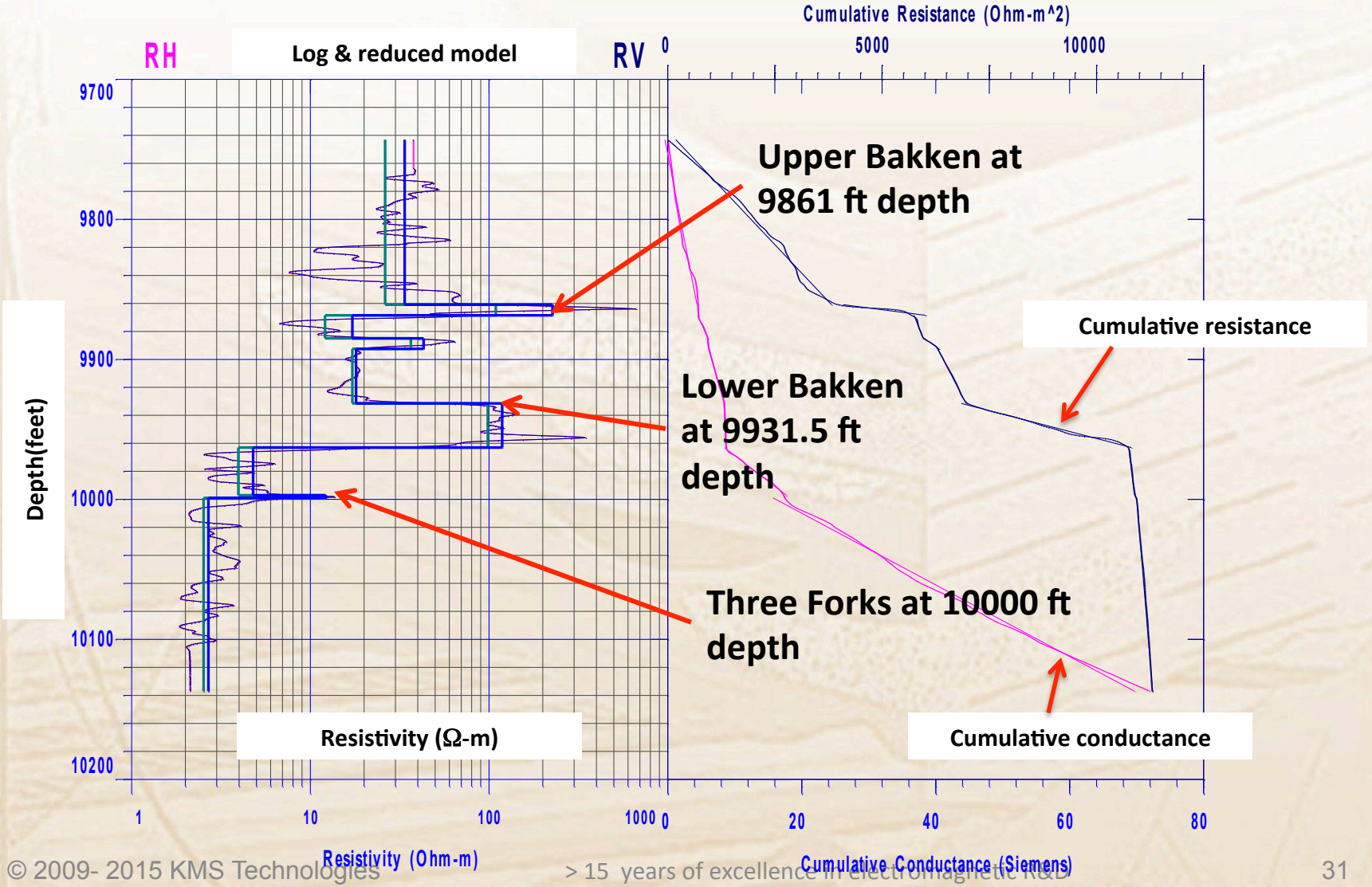
UNCONVENTIONALS: Bakken simulating FRACTURE monitoring



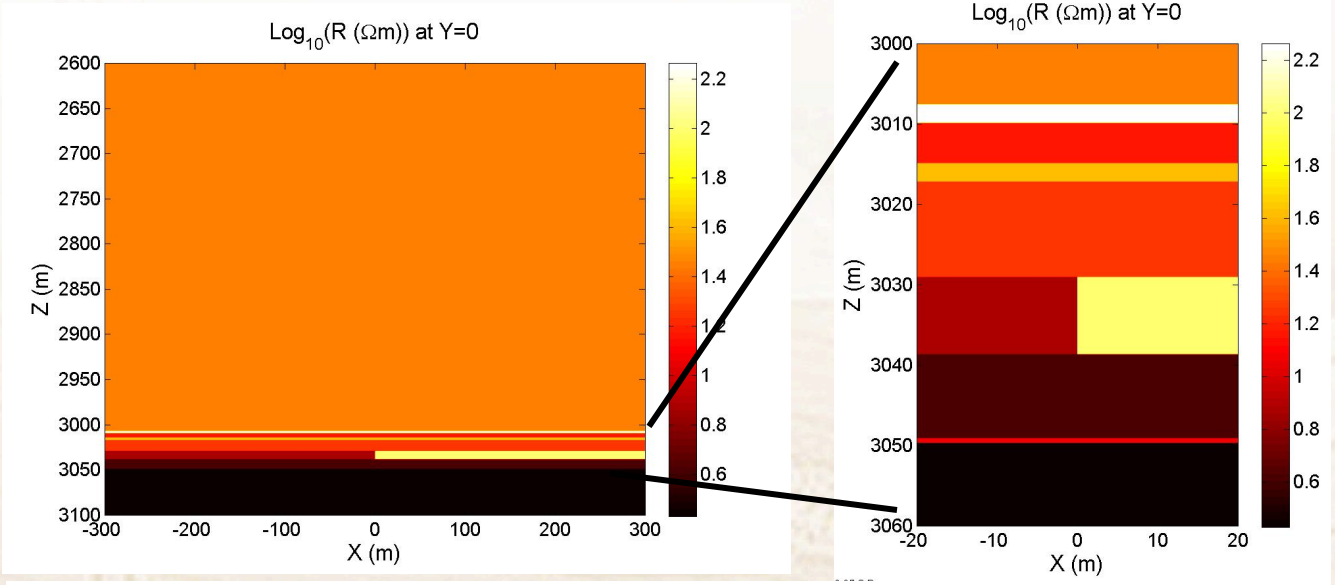
http://www.statoil.com/en/NewsAndMedia/News/2011/Pages/XXX16Oct2011.aspx

UNCONVENTIONALS: From a log to an anisotropic model

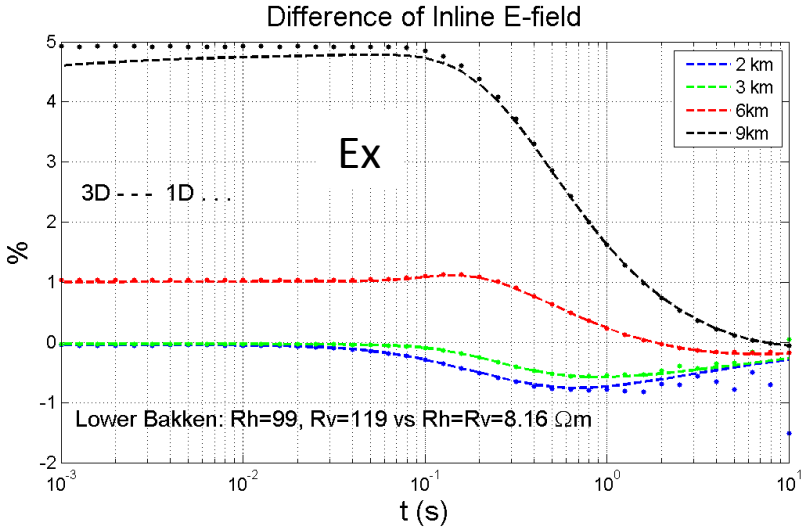
Log data courtesy of Microseismics Inc.

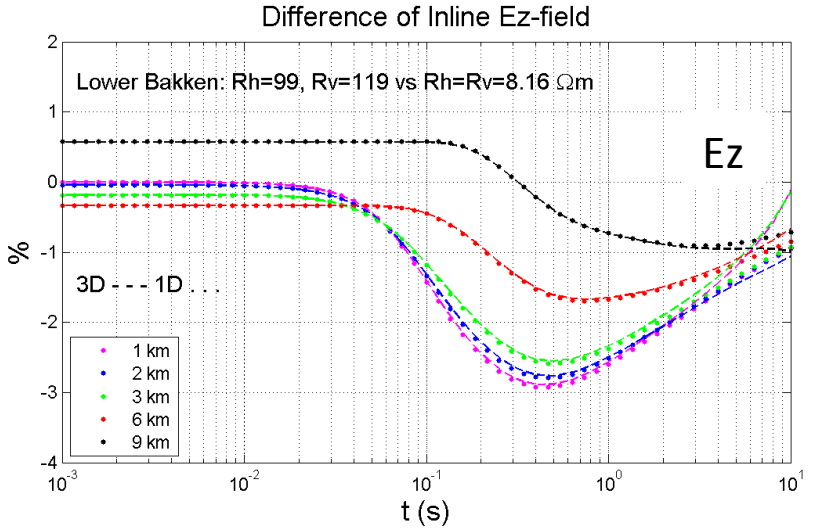


UNCONVENTIONALS: : Lower Bakken before & after production



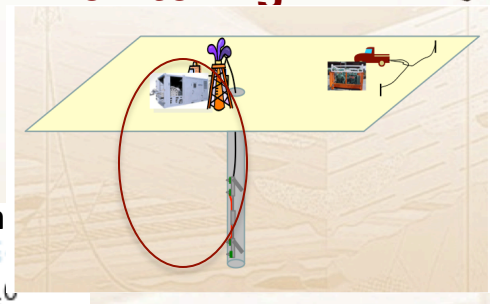
	RHO-H	RHO-V
1	26.23	33.74
2	109.2	227.06
3	12.1	17.2
4	36.55	43.14
5	17.22	18.05
6	98.56	118.64
7	3.96	4.78
8	12.1	12.25
9	2.53	2.69



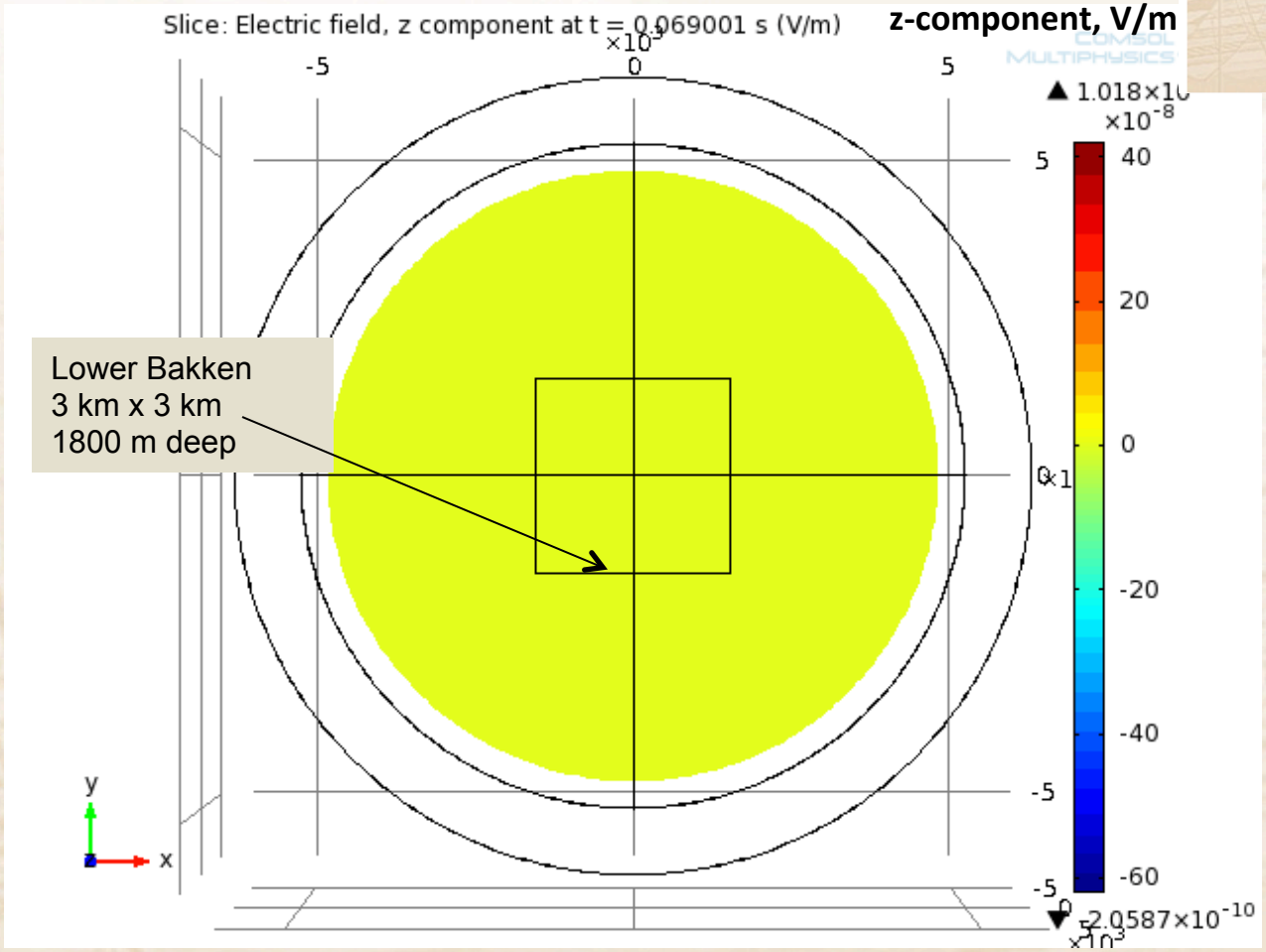


UNCONVENTIONALS: Bakken simulating PRODUCTION monitoring

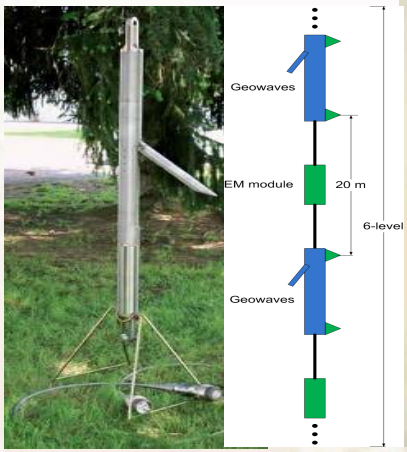
Borehole-to-surface, Rx at reservoir level



Electric field, z-component, V/m

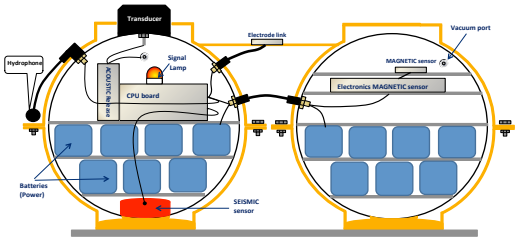


Extending array EM to marine and borehole



Borehole system:

- Shallow holes – permanent
- Deep – standard BHS system add on



Marine MT + SEISMIC acquisition system KMS870

Marine system:

- Cabled exploration
- Deep – using standard OBS; add EM

- Electromagnetics has BIG potential in shale gas/oil development & monitoring
- We need NEWEST methods
  - Land CSEM,
  - E & H measurements,
  - 3D induction logs,
  - Surface-to-borehole integration,

Why are wireless arrays so late?

WHAT HAS CHANGED?

- Wireless ..unlimited*[2] EM channel system
- Scalable transmitter wireless integrated

More technical:

  - Optimized 3D design is mandatory
  - Like focused logs we can NOW focus below the receiver
- NOW 3D imaging makes sense

THANK YOU!

Acknowledgements:

Aramco; A. Aziz, Baker Hughes; BGP; BP; W. Doerner; LBNL; Mannvit; Microseismics Inc.; Northern Hill University, India; ONGC; PTTEP, RWE-Dea; RXT; A. Zerilli.

Thank You