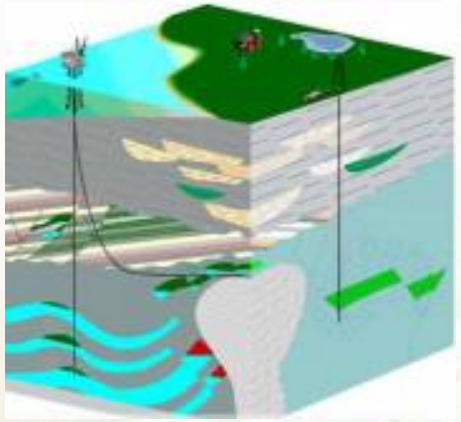


Using Electromagnetics (EM) to map Fluids in Shale

K. Strack

DGH Shale Gas-Oil workshop, Jan 2016 India

www.KMSTechnologies.com

To show:

- How EM can be applied to shale issues in general
- Show the implementation progress of FLUID monitoring with EM leading to a PILOT in Asia
- Pitfalls: What to watch out for

Issues & need for EM --- background
NEW tools --- examples
Future --- workflows

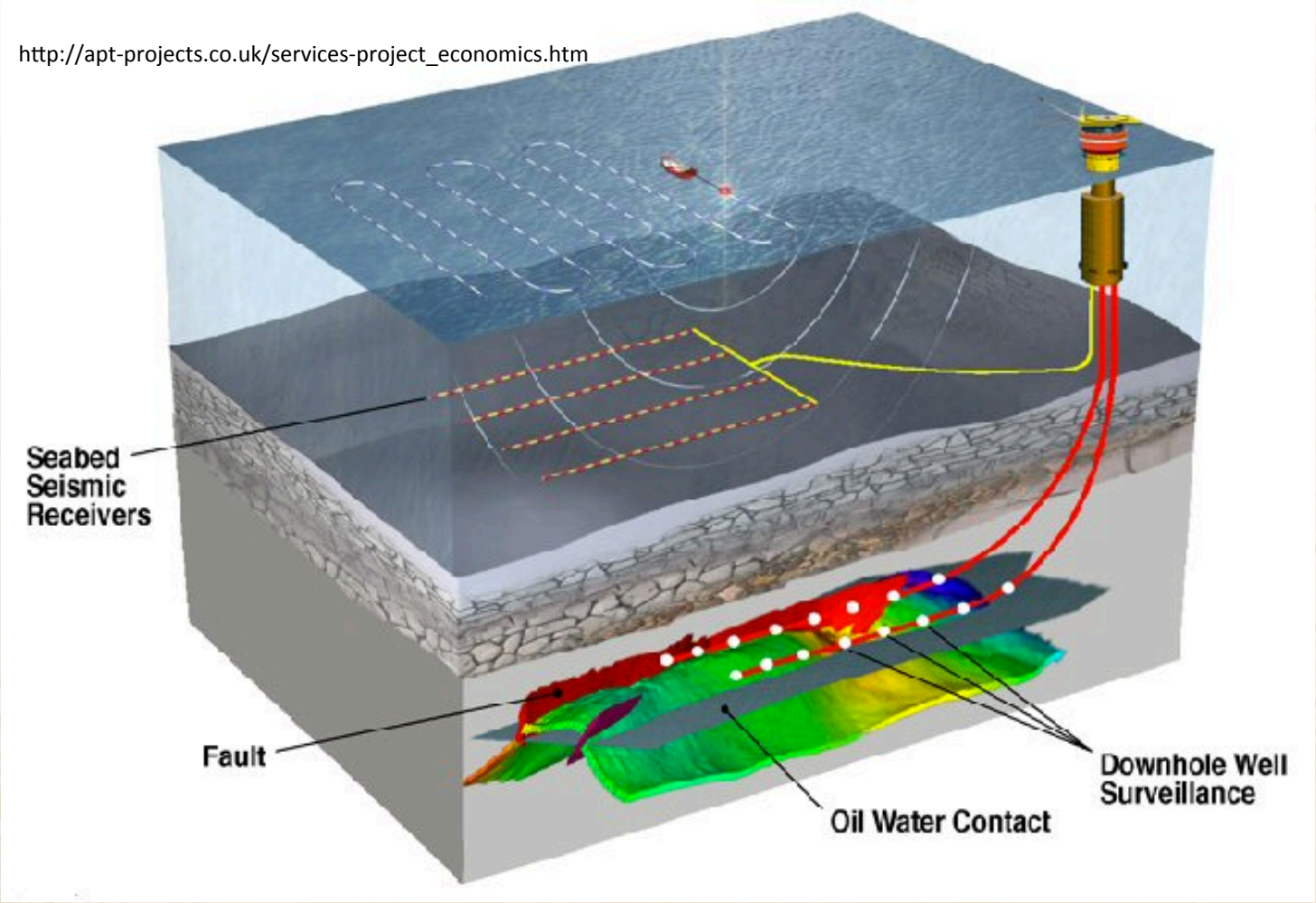
Unconventionals issues:

- Shale gas/oil
  - Oil/gas is:
    - Inside shale …or
    - In thin sand laminations
  - Reservoirs are thin
  - Low porosity/permeability → fracturing
  - Drilling → horizontal / highly deviated wells
  - Fractures → anisotropy
  - Seal integrity concern → seismic/EM
- Other support applications

Unconventionals: issues translated to EM geophysics

- Shale gas/oil
  - Oil/gas is:
    - Inside shale …or **Resistor in a conductor**
    - In thin sand laminations **Anisotropy**
  - Reservoirs are thin – **Thin resistive layer effect –DHI for surface data, 3D induction log for well**
  - Low porosity/perm. → fracturing **Larger volume**
  - Drilling → horizontal / highly deviated wells - **geosteering**
  - Fractures → anisotropy – **3D**
  - Seal integrity → seismic/EM
- Other support applications

What is reservoir fluid monitoring?



Why Electromagnetics?

- Fluid movement causes resistivity variations
- Combination of Seismic and EM offer best solution
- EM has proven as valid DHI (Direct Hydrocarbon Indicator)

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

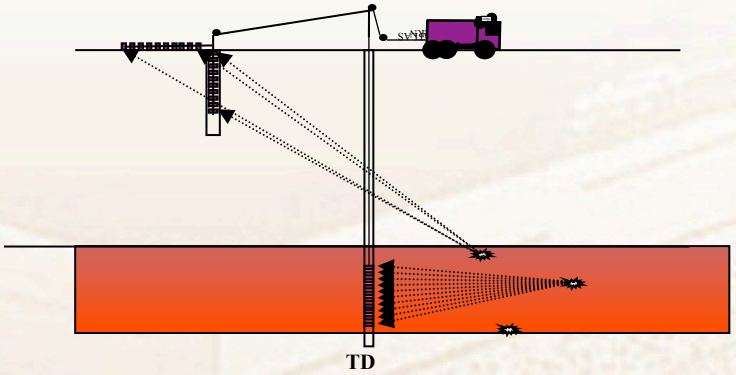
Courtesy Welldynamics

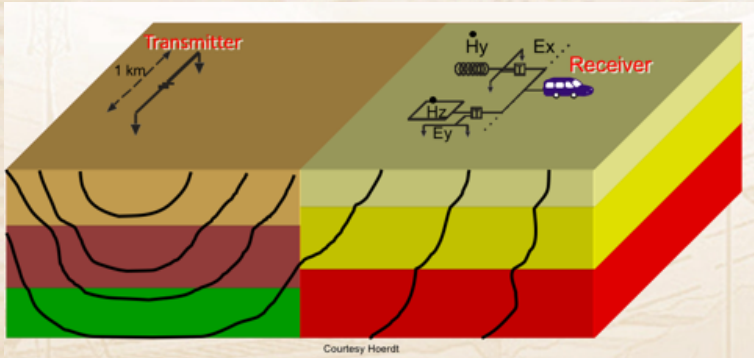
Geophysical methods

- Seismology
  - Earthquakes
  - Seismic
  - Microseismics
- Electromagnetics
  - Magnetotellurics (MT)
  - Controlled source electromagnetics (CSEM)
- Gravity

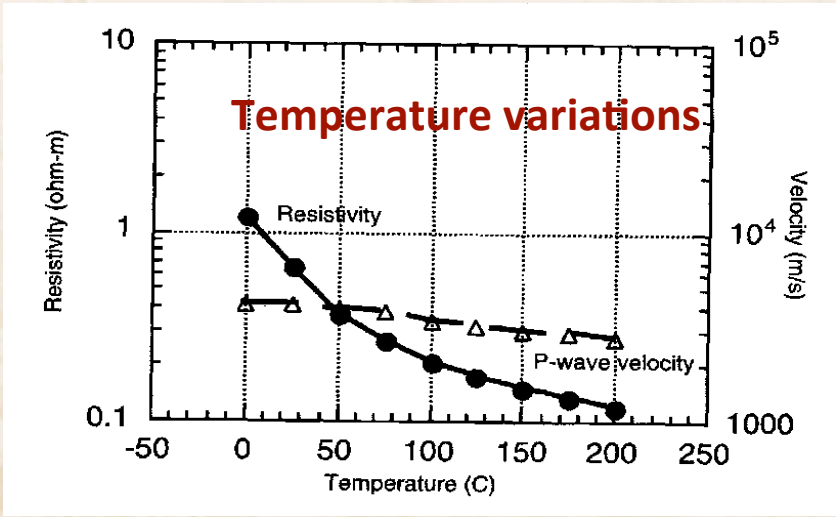
Geophysical methods: IMPORTANT FOR SHALE

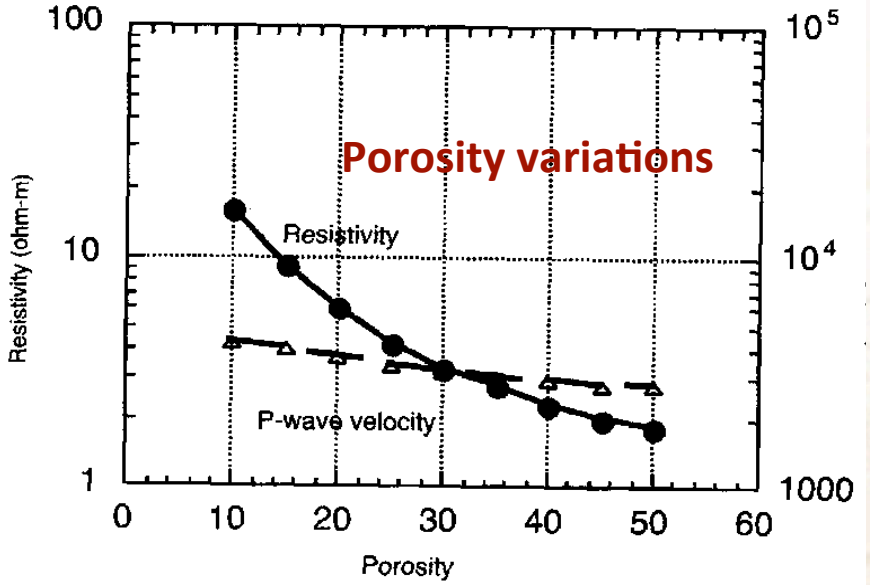
- Seismology
  - Earthquakes
  - Seismic
  - **Microseismics**
- Electromagnetics
  - Magnetotellurics (MT)
  - **Controlled source electromagnetics (CSEM)**
- Gravity

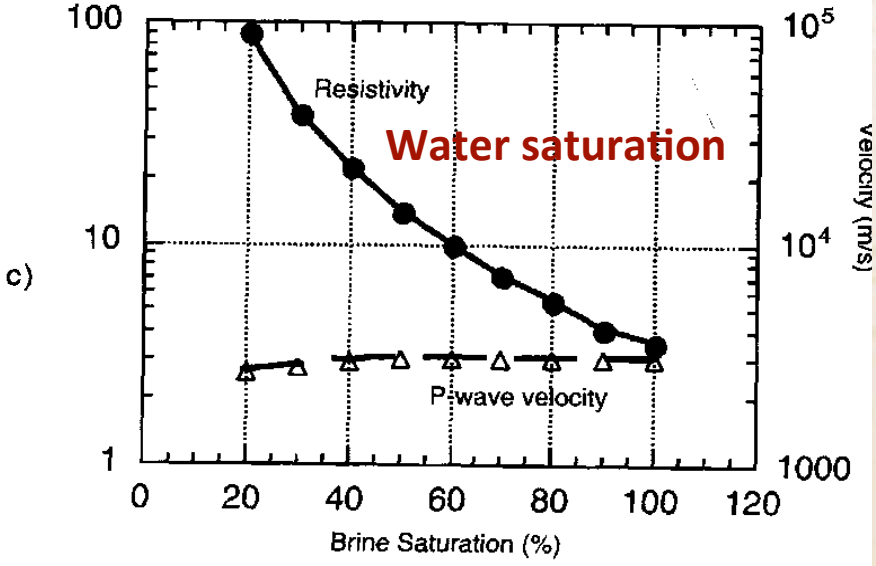




Resistivity & velocity versus porosity brine saturation & temperature

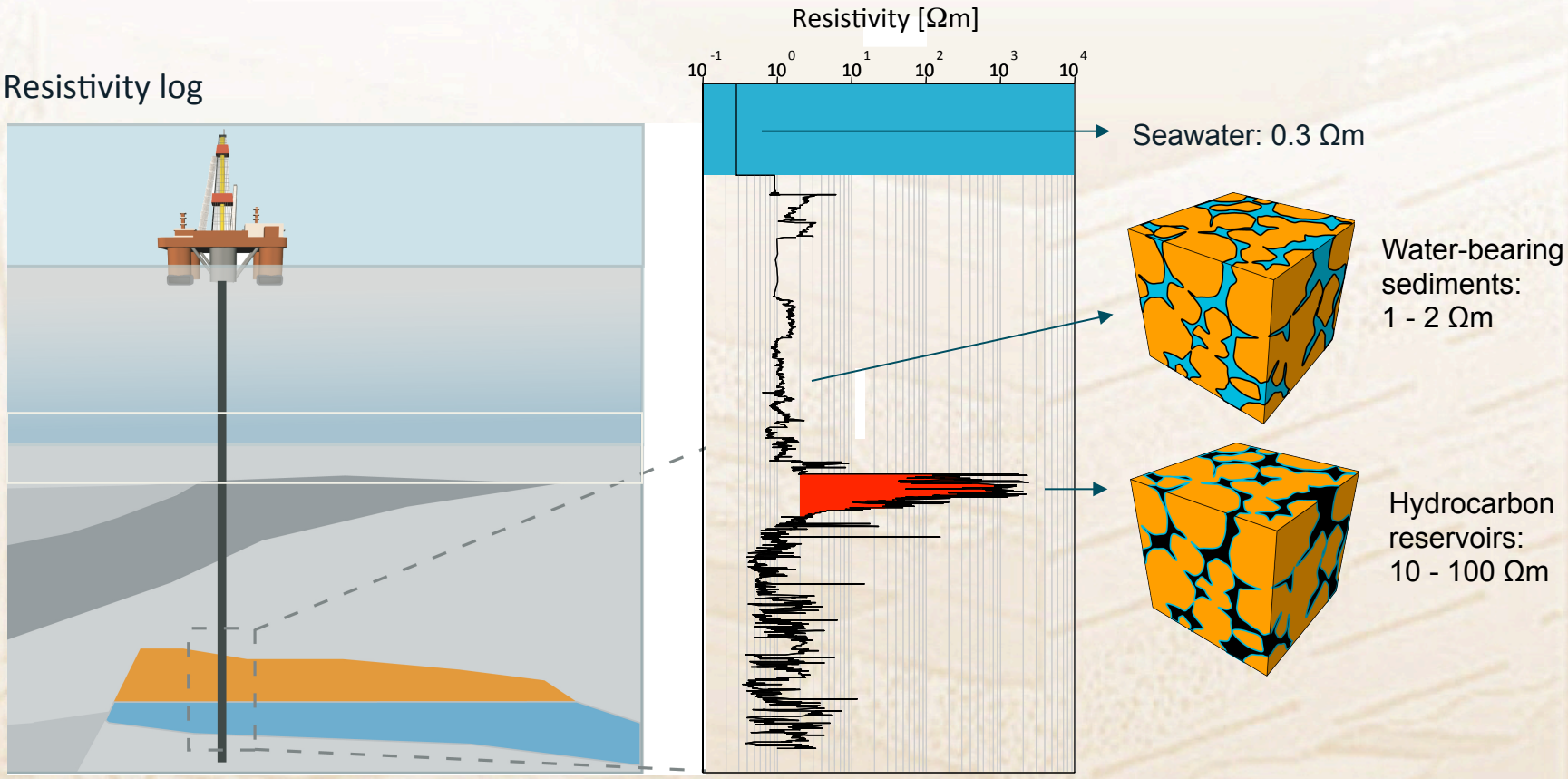






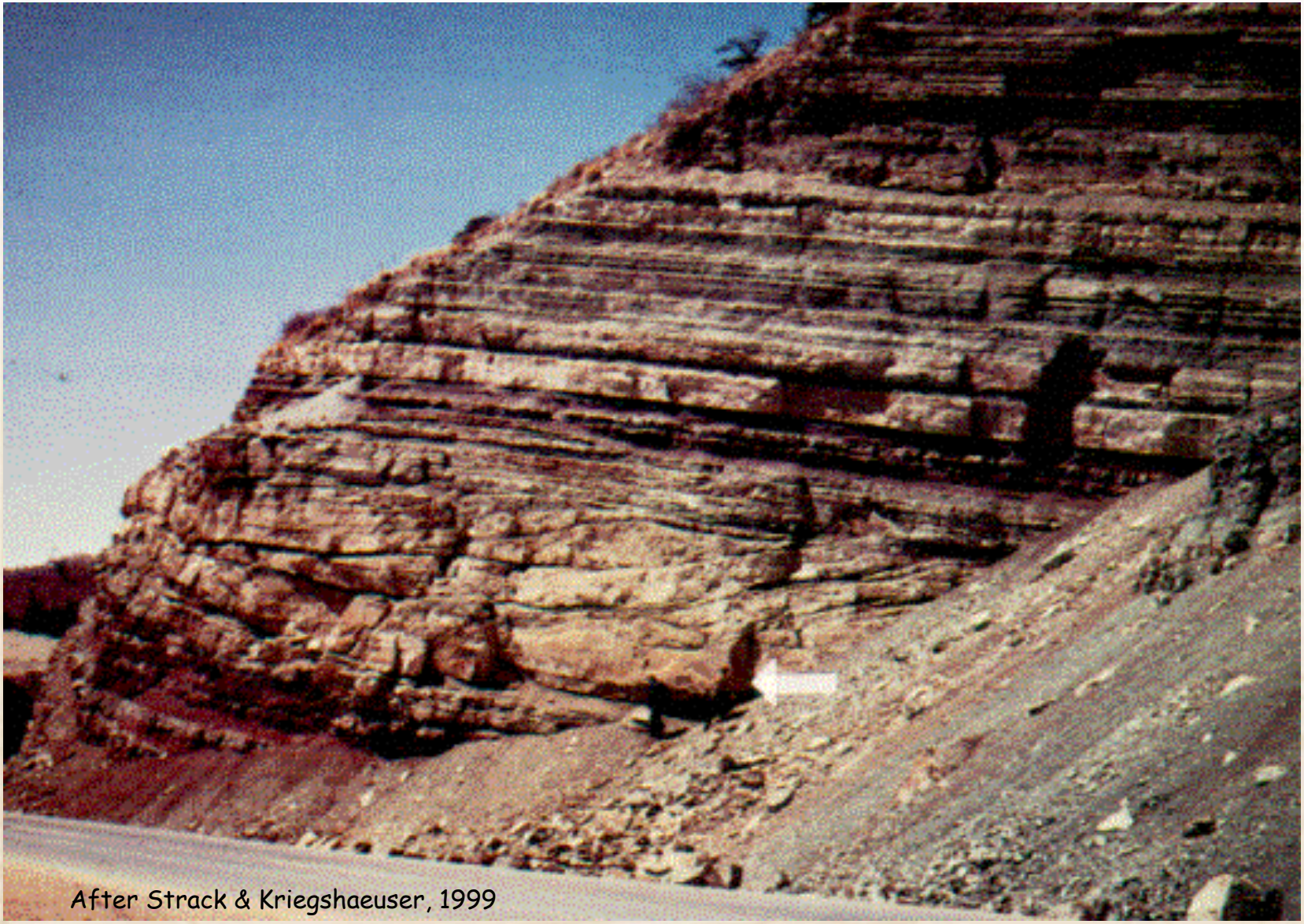
After Willt & Alumbaugh, 1998

Hydrocarbons are resistive! Shales are conductive!

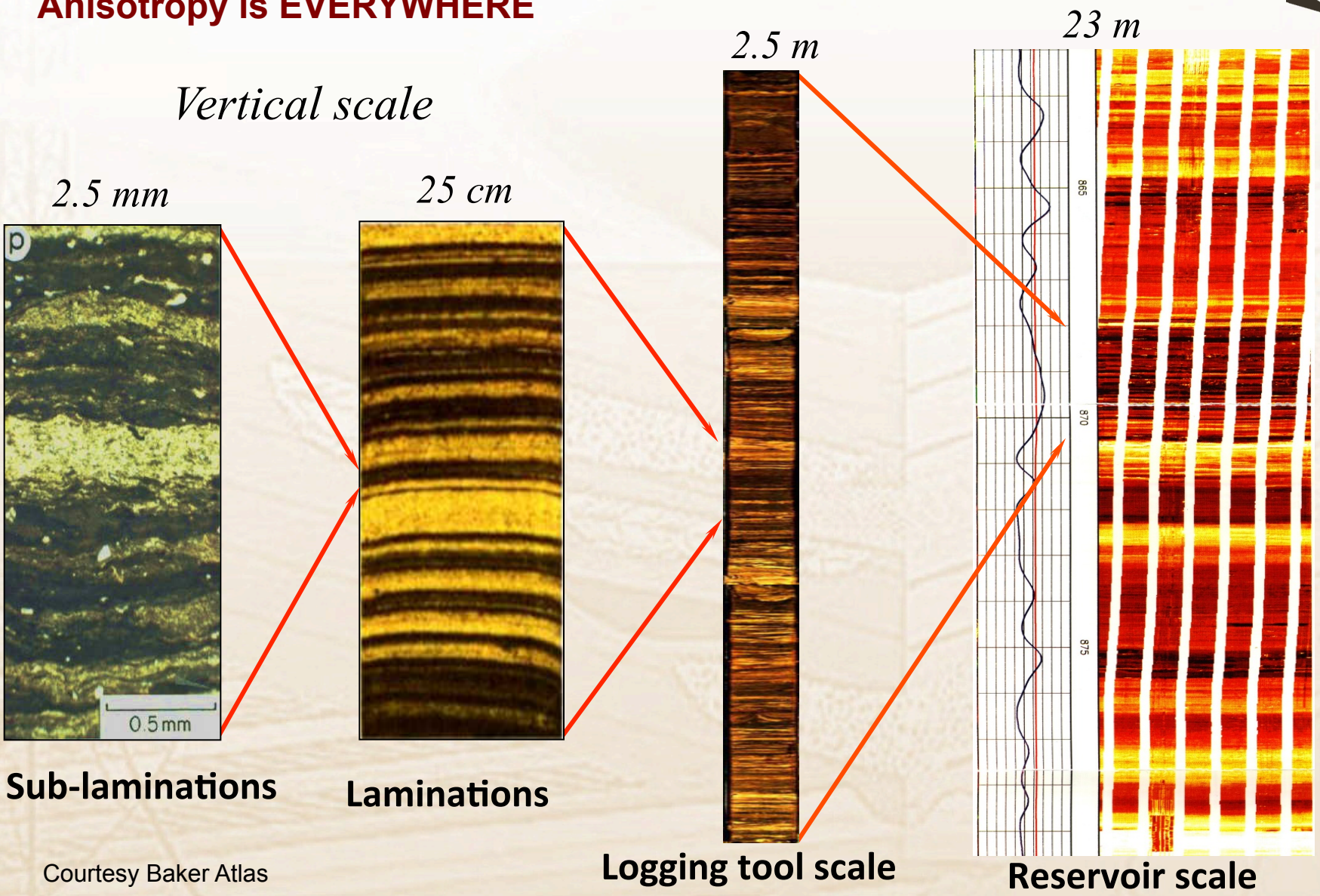


Courtesy EMGS

Anisotropy is EVERYWHERE

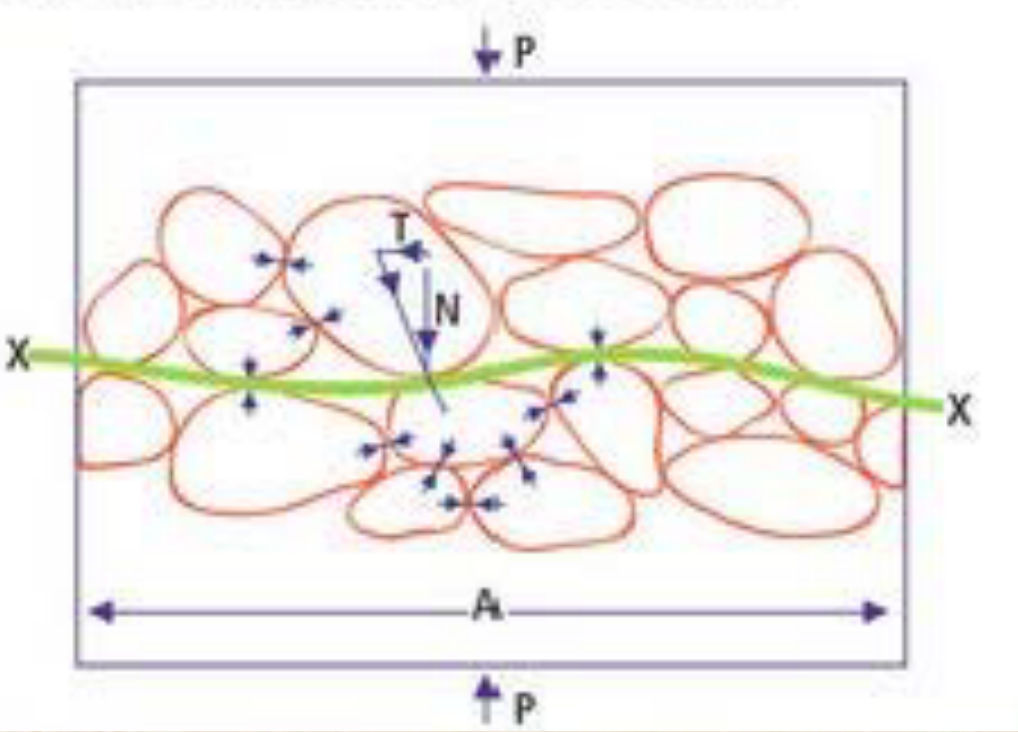


Anisotropy is EVERYWHERE



Courtesy Baker Atlas

Permanent reservoir monitoring: Microseismics → Seal integrity

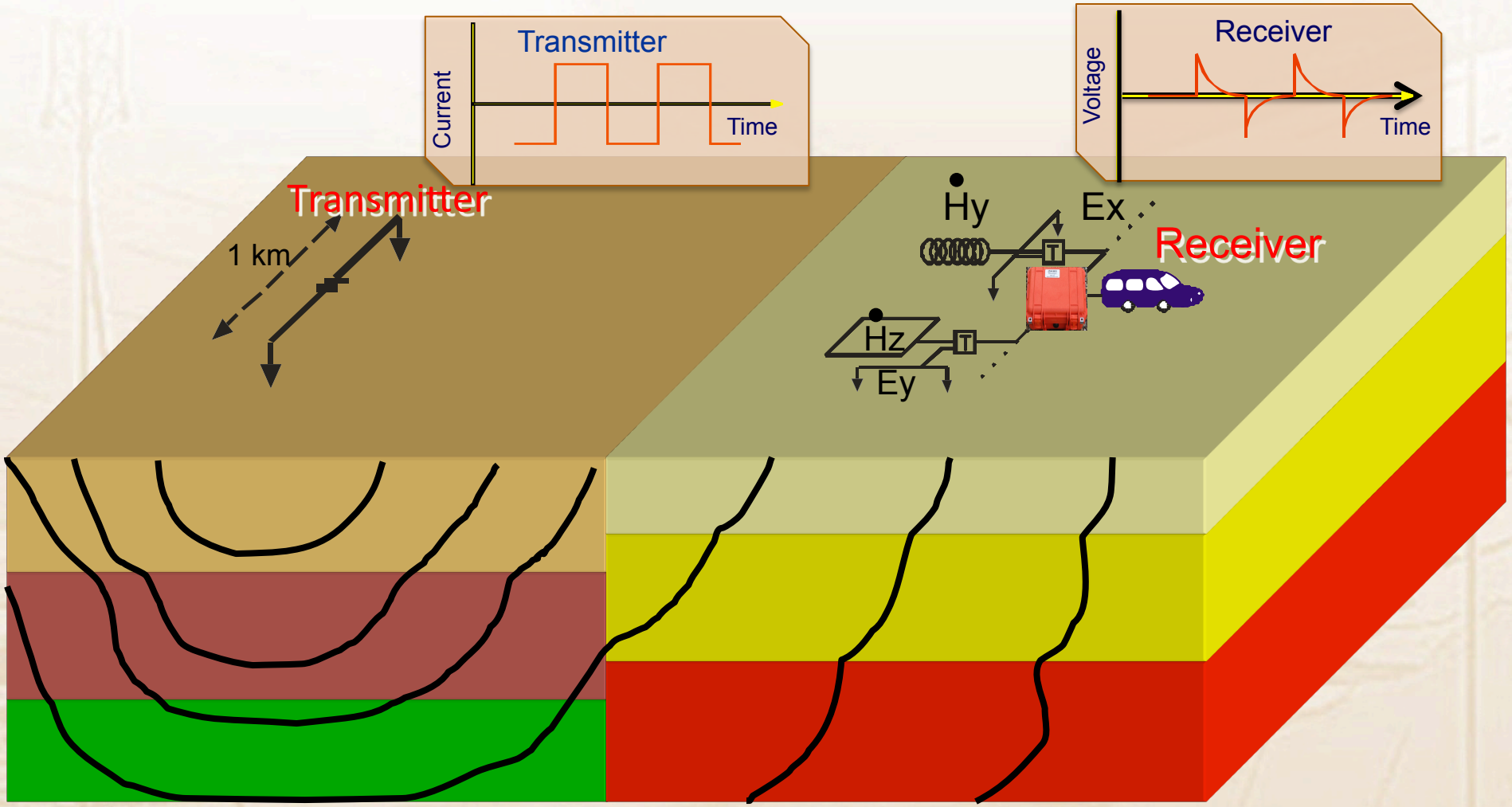


- Overburden & fluid stress in balance
- When fluid pressure too high →quick sand
- Seal BRITTLE → porosity reduction → resistivity increase
- Seal FRACTURE →porosity increase→ resistivity increase
- Microseismic signature from fracturing
- EM responds to fluid movements →
- EM signature from brittle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

Seismic/EM receiver

After Carlson, 2013

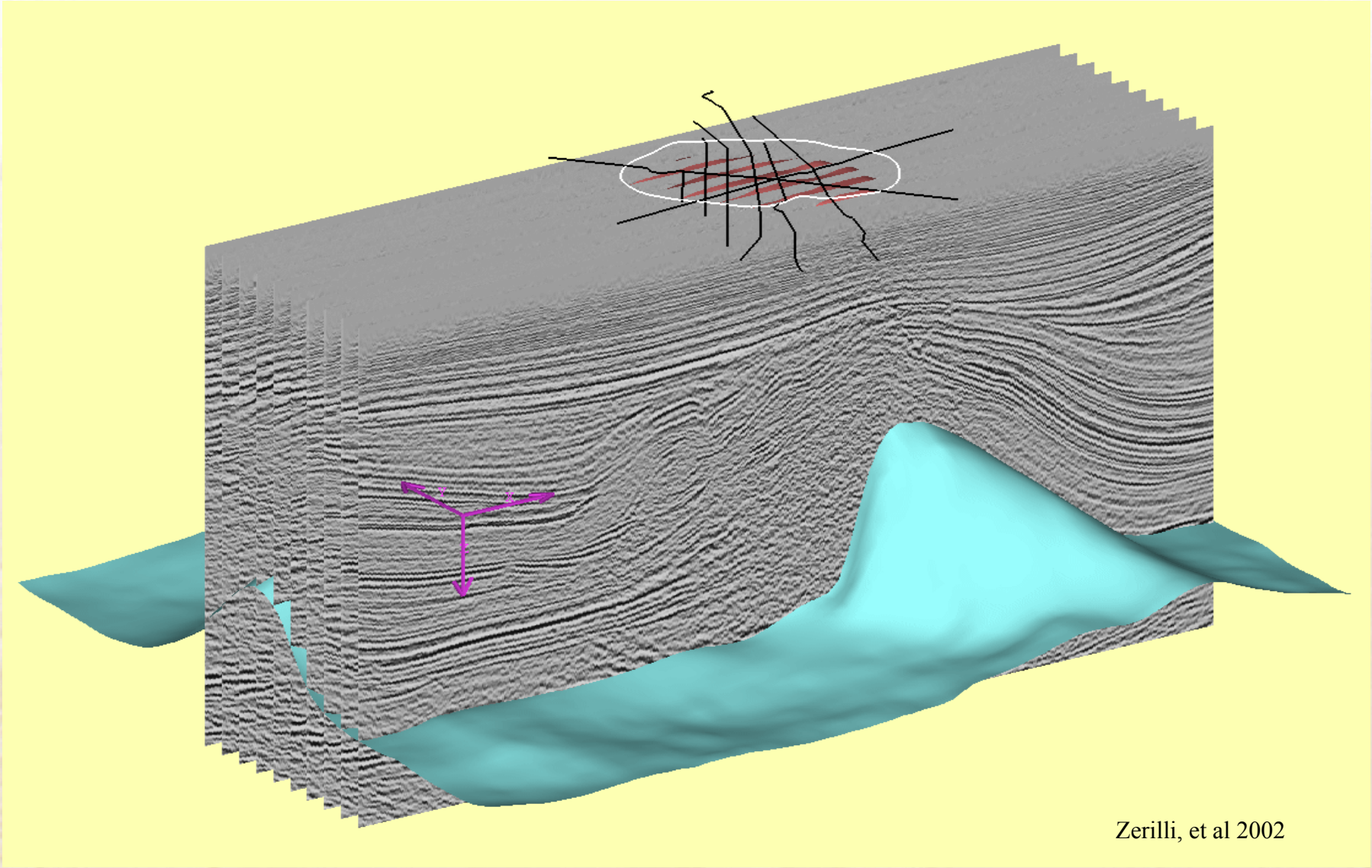
EM Methods: CSEM – a single signal generating event



Courtesy Hoerdt

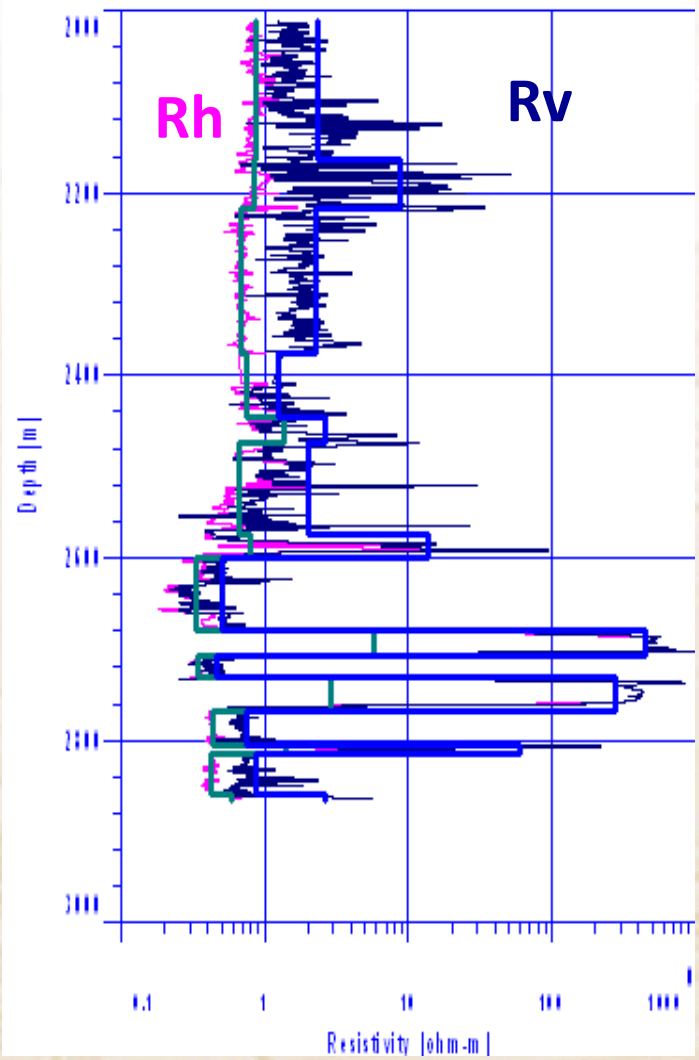
New ARRAY acquisition → better images

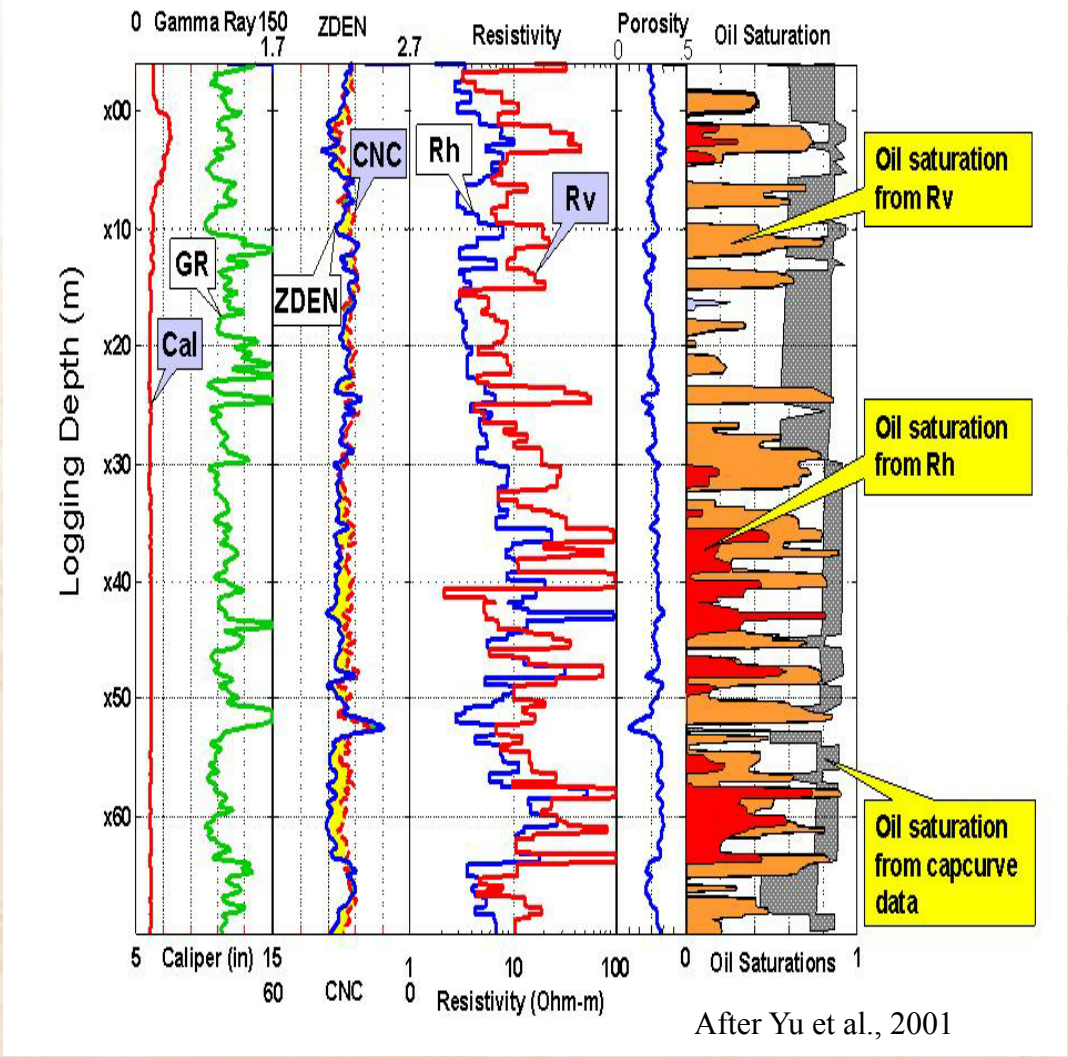
Dense acquisition (Δx = 50 m) → better images



Zerilli, et al 2002

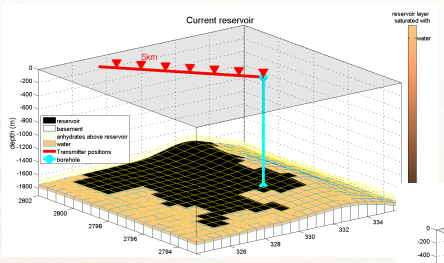
ADD BOREHOLE: Fractures → anisotropy

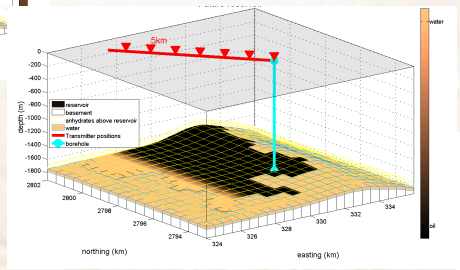


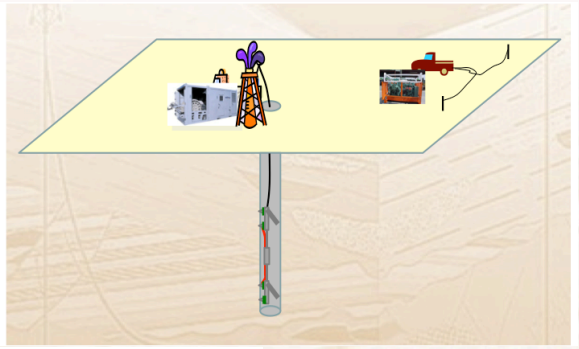


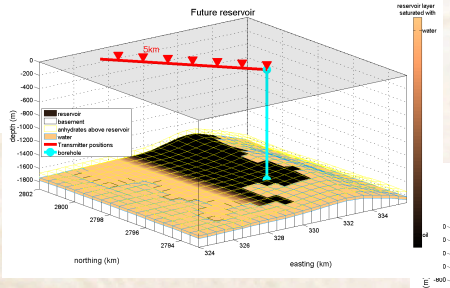
After Yu et al., 2001

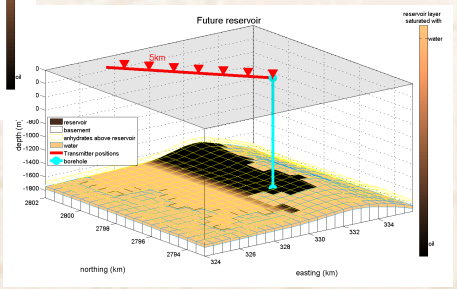
INTEGRATE SURFACE-TO-BOREHOLE:

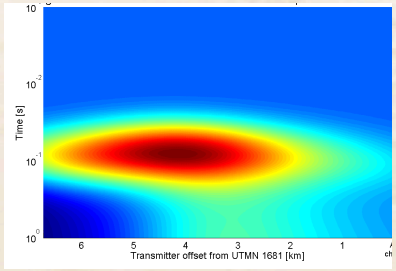


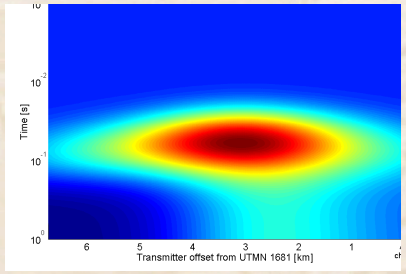


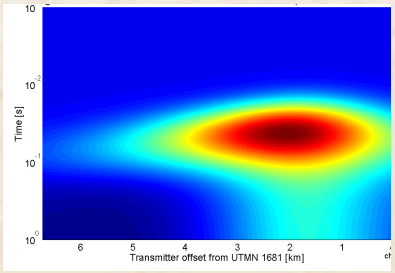


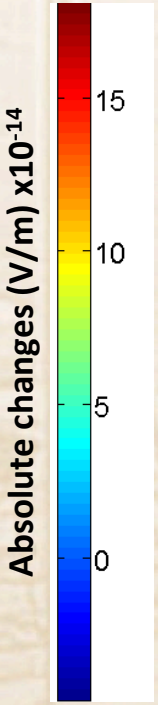








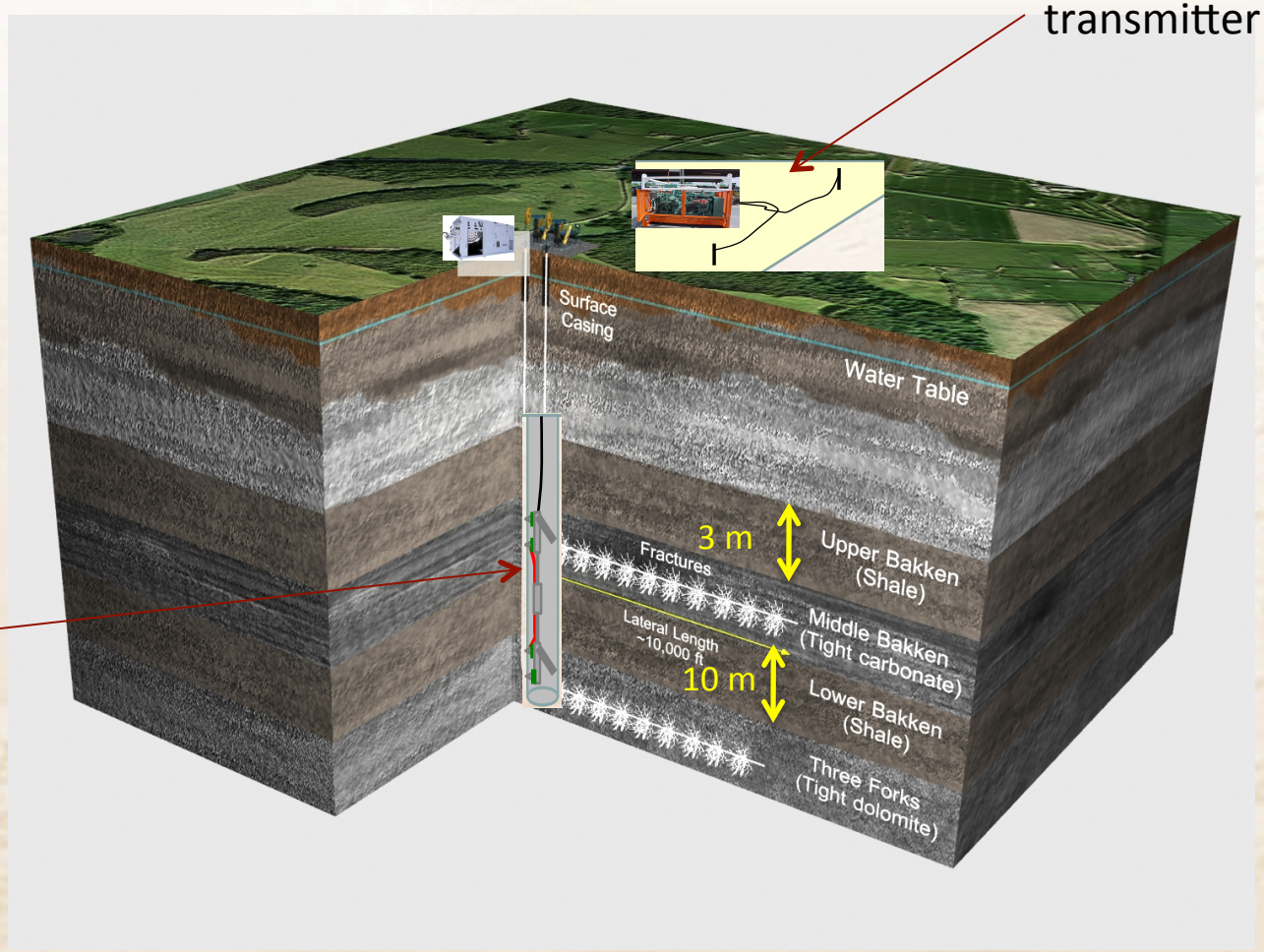




Period of 5 years

After Colombo et al. 2010

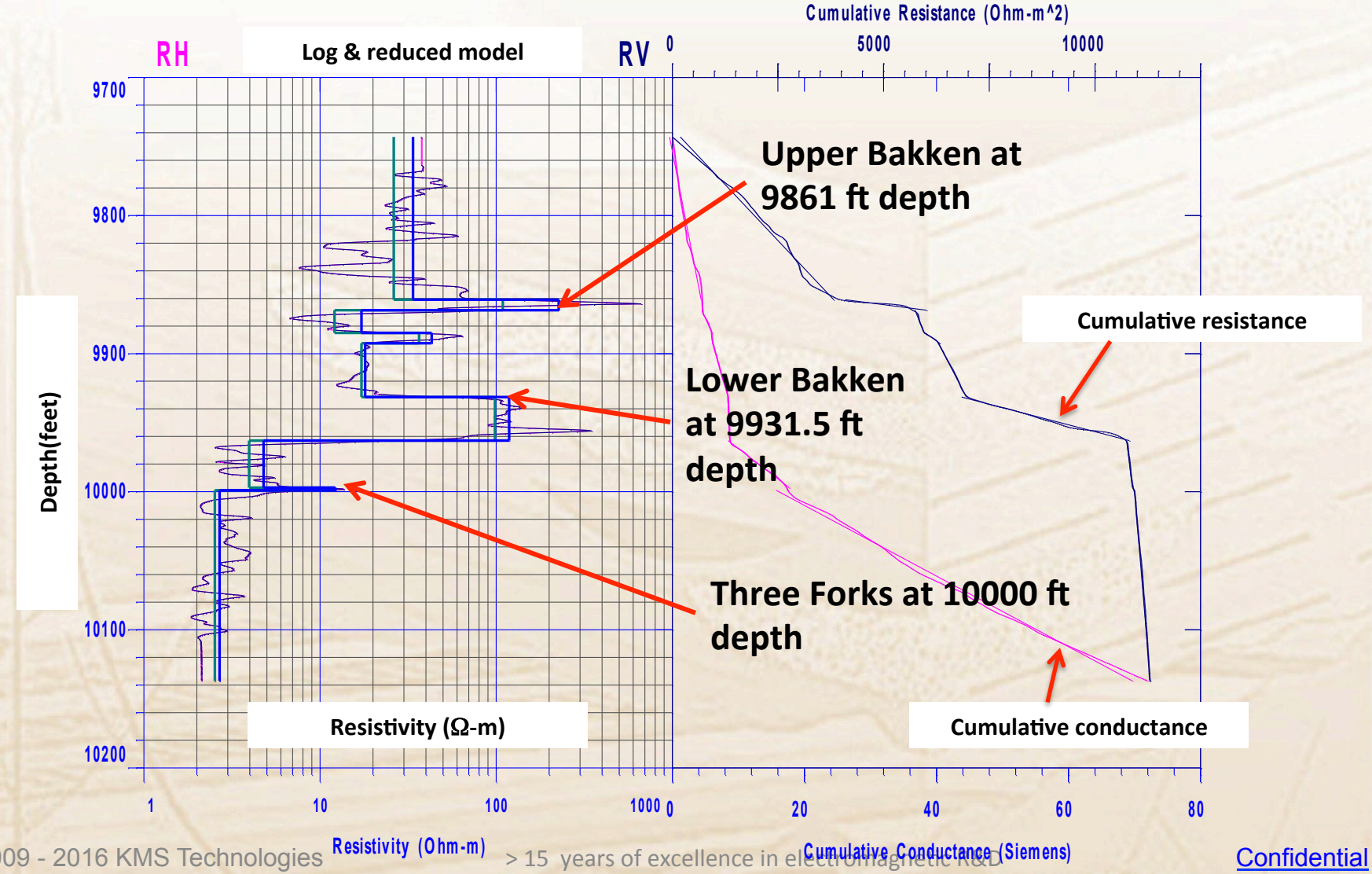
Future: Shale resources: Bakken simulating FRACTURE monitoring



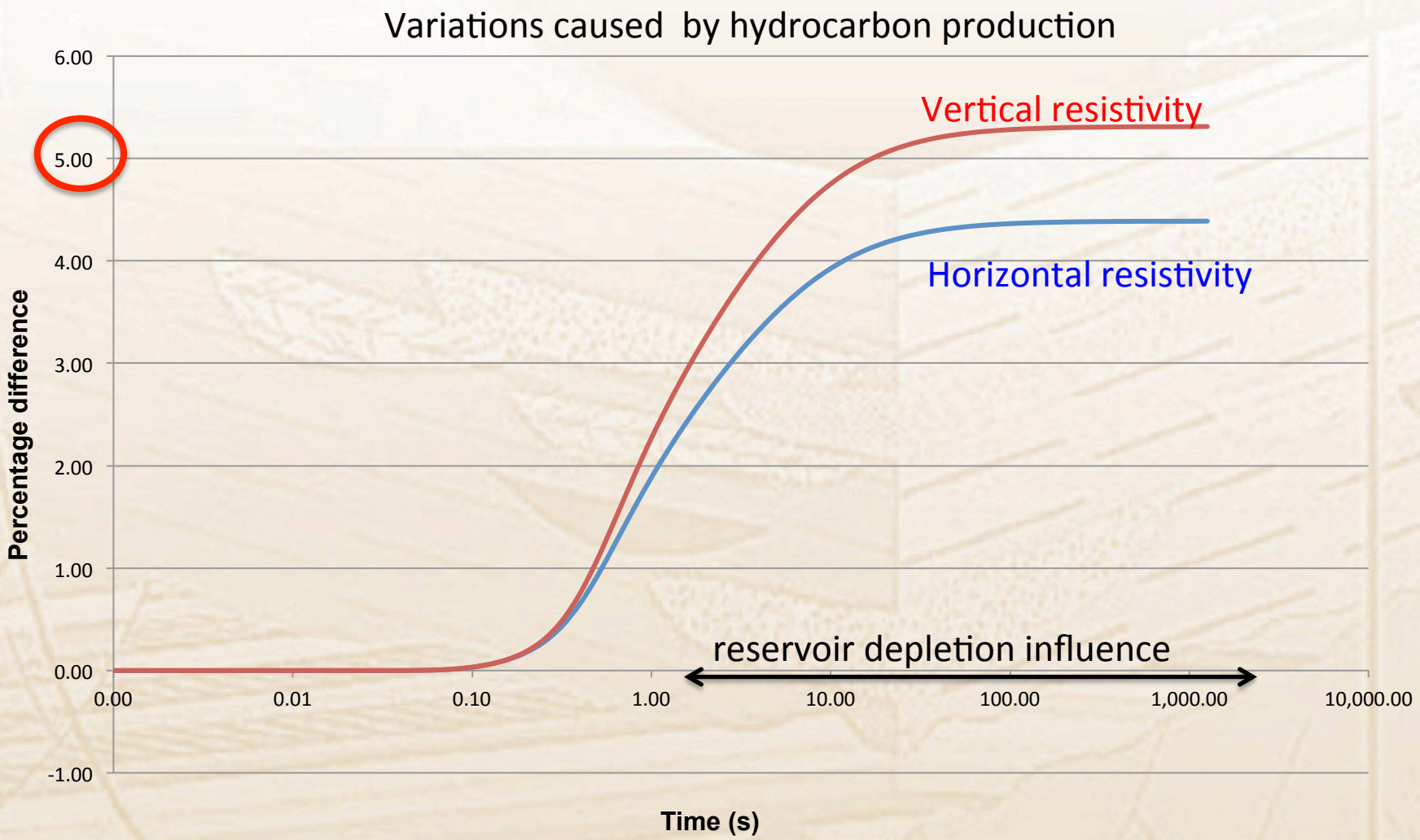
http://www.statoil.com/en/NewsAndMedia/News/2011/Pages/XXX16Oct2011.aspx

From a log to an anisotropic model

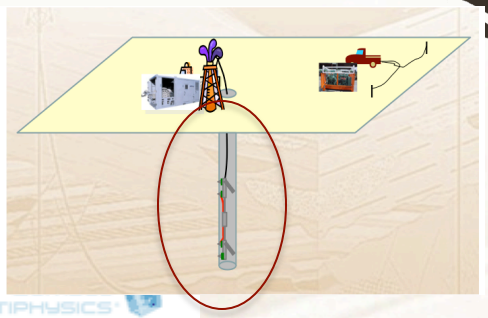
Log data courtesy of Microseismics Inc.

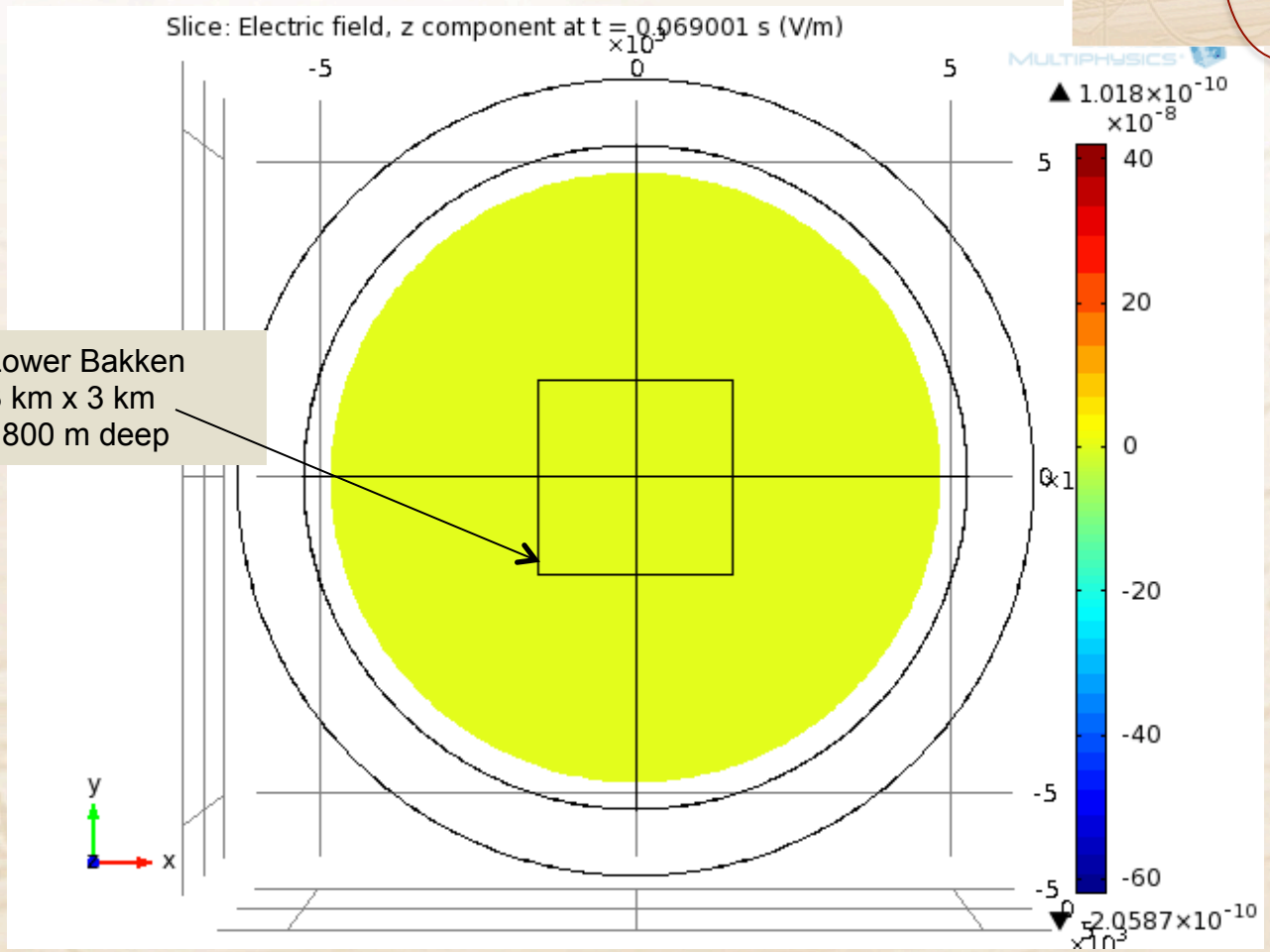


Shale plays: CSEM time lapse: ALL 3 reservoirs, 10% depleted, horiz. well



Bakken simulating PRODUCTION monitoring
Borehole-to-surface, Rx at reservoir level





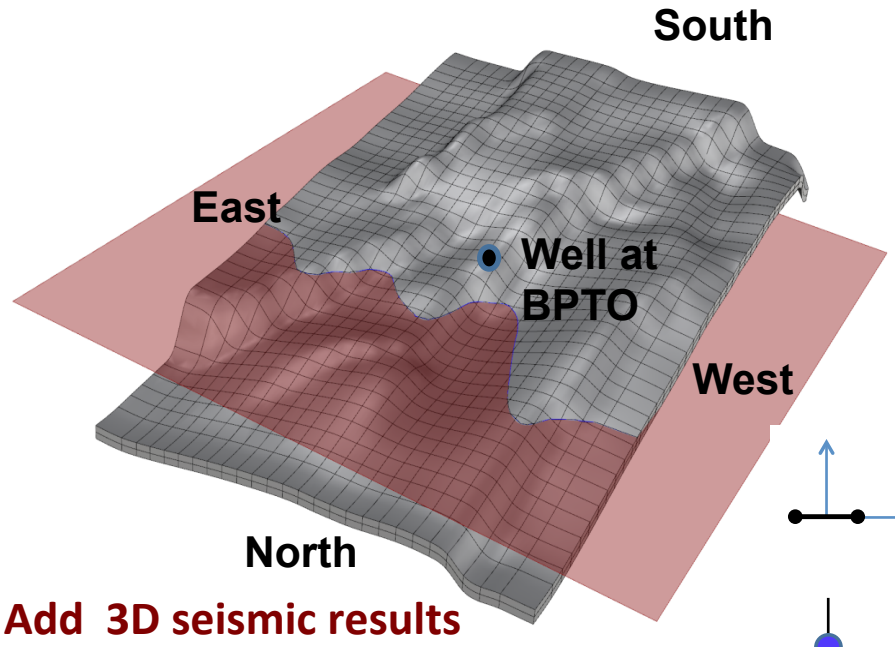
Objectives:

- Image fluids in a pilot, develop supporting borehole tools
- Selected onshore oil field with a steam flood
- Demonstrate then carry to unconventionals

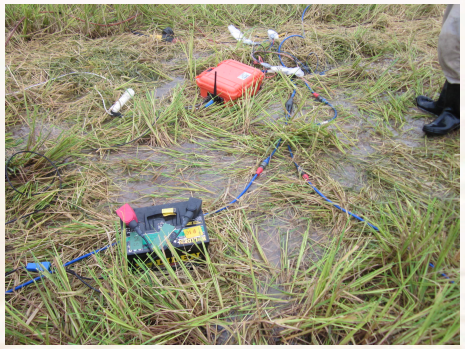
Progress:

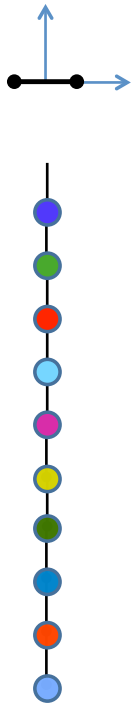
- Selected oil field in Central Thailand
- 3D Feasibility & noise measurements: **2014**
- Build equipment and test: **2015**
- Start pilot & develop new technology **2016**

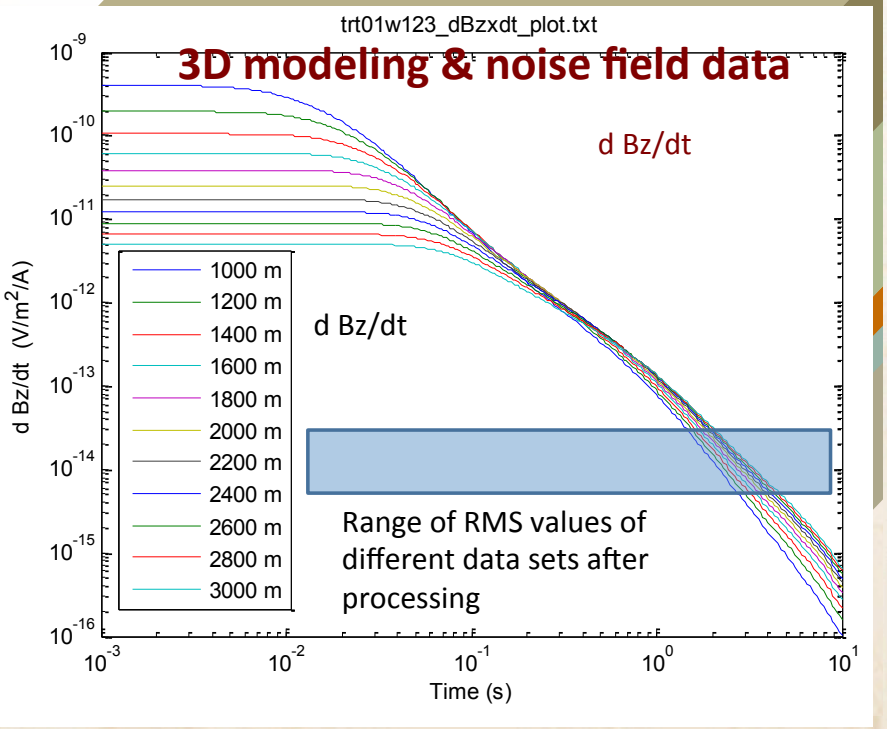
Thailand: 3D reservoir model: 6 single blocks 1000 m x 6000 m



Add 3D seismic results







Thailand Feasibility: Summary 3D noise test - IP map

3D noise test & IP road map:

- Noise test worked better than expected
- Area cultural noise handable since we derived already MT sounding
- Signals are well above noise

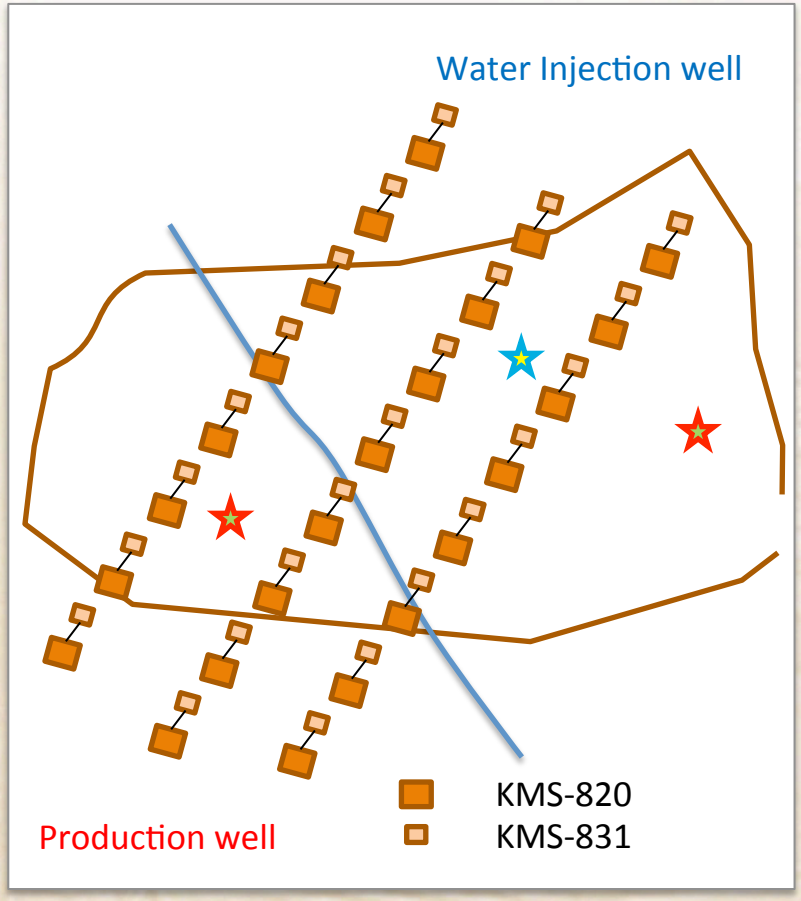
→ **IDEAL PILOT**

- Confidence level is path forward HIGH

Intellectual property road map:

- Unique IP position
- Many tried to enter patent space, not successful

Example layout



Microseismic sensors

Site	KMS instrument	Ex & Ey	Hz	3C fluxgate H	3C geophone
■	820	x	x	x	x
▪	831	x			x

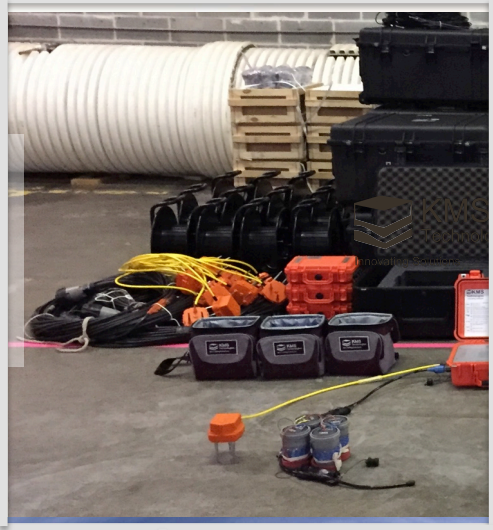
E – electric field sensors
H – magnetic field sensors

195 channel monitoring system

RESERVOIR MONITORING

ARRAY Electromagnetics

- 195 channels, wifi, wireless or LAN
- 3C magnetic field (DC to 40 kHz)
- 3C microseismic
- 2C electric fields
- Shallow borehole (microseismic/EM)

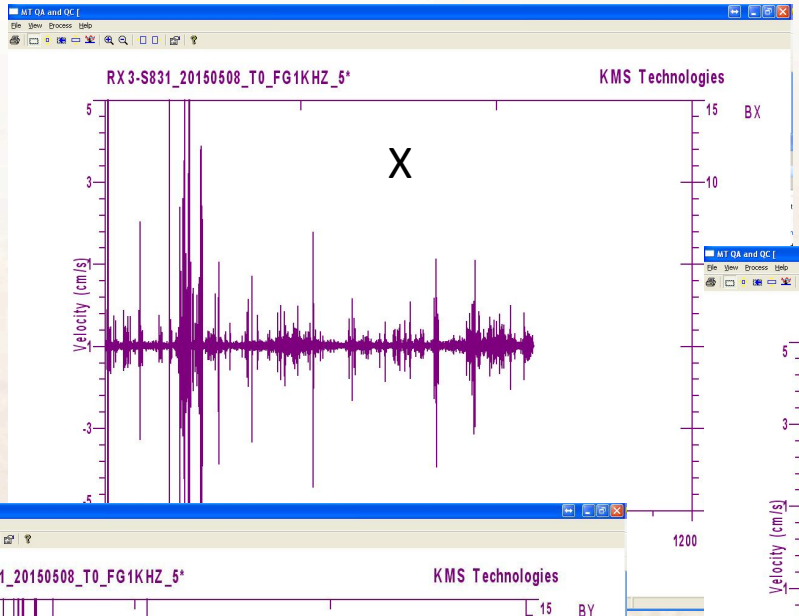


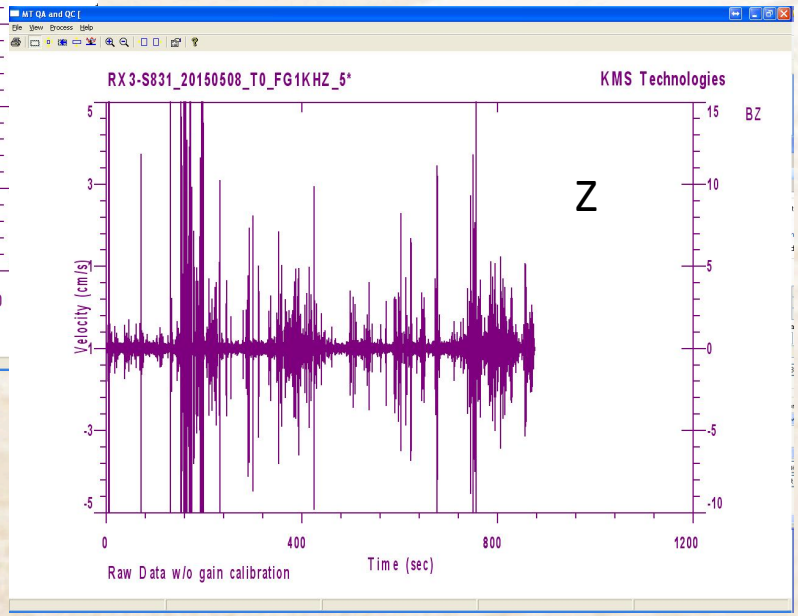
Colorado 2015 CSEM transmitter test

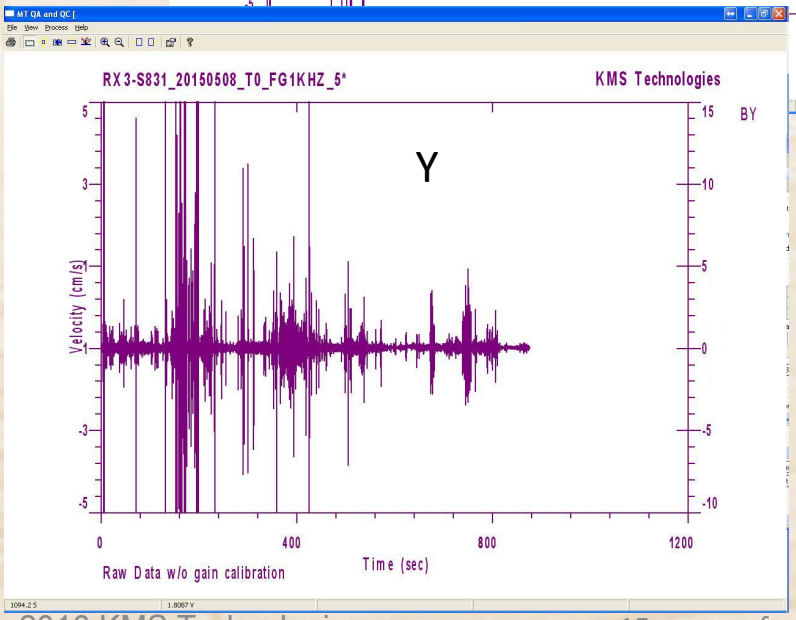
- 100 KVA transmitter up-scalable
- Flexible input. (DC to 3 phase AC)
- Array system integrated

Jiang, J., Aziz, A.A., Liu, Y., and Strack. K.M., 2015, Geophysical acquisition system, US 9,057,801

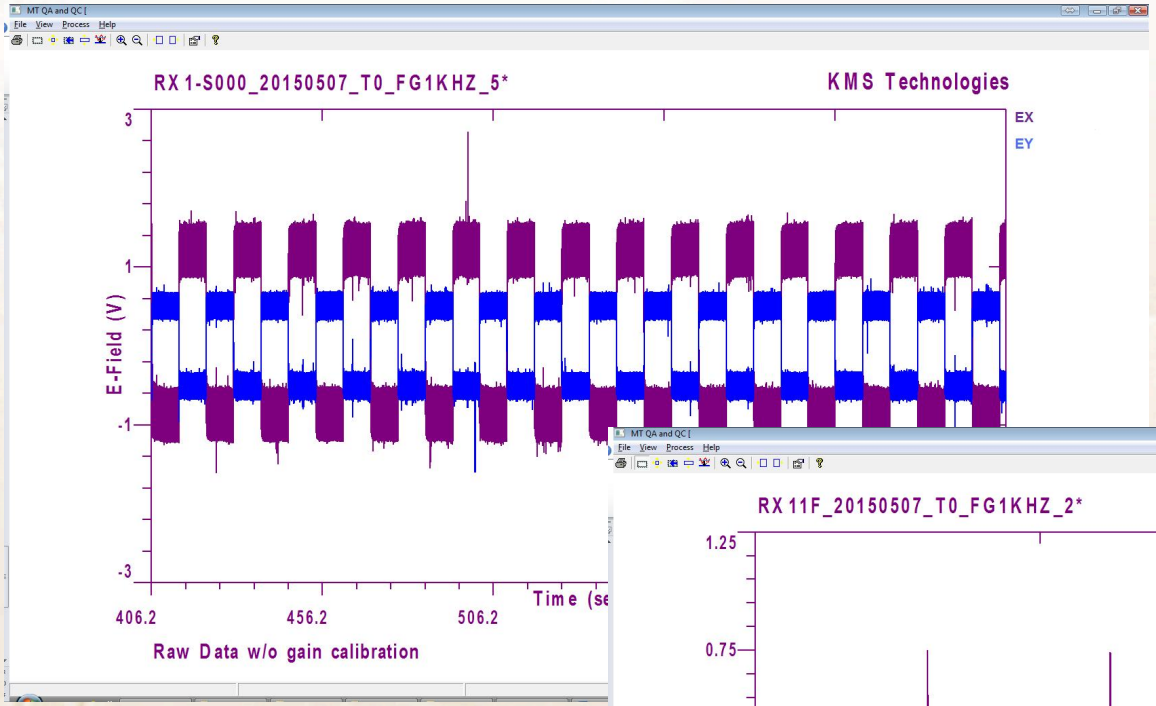
Seismic data samples KMS-831



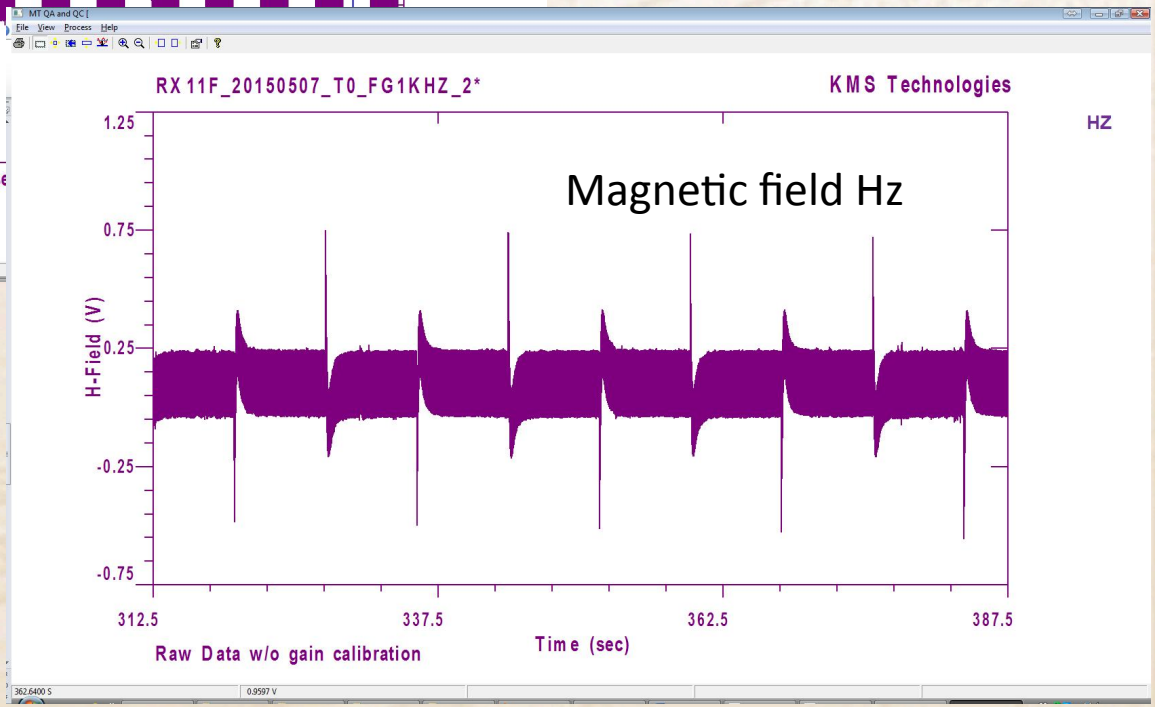




Electromagnetic data samples KMS-831



Electric fields (x,y)

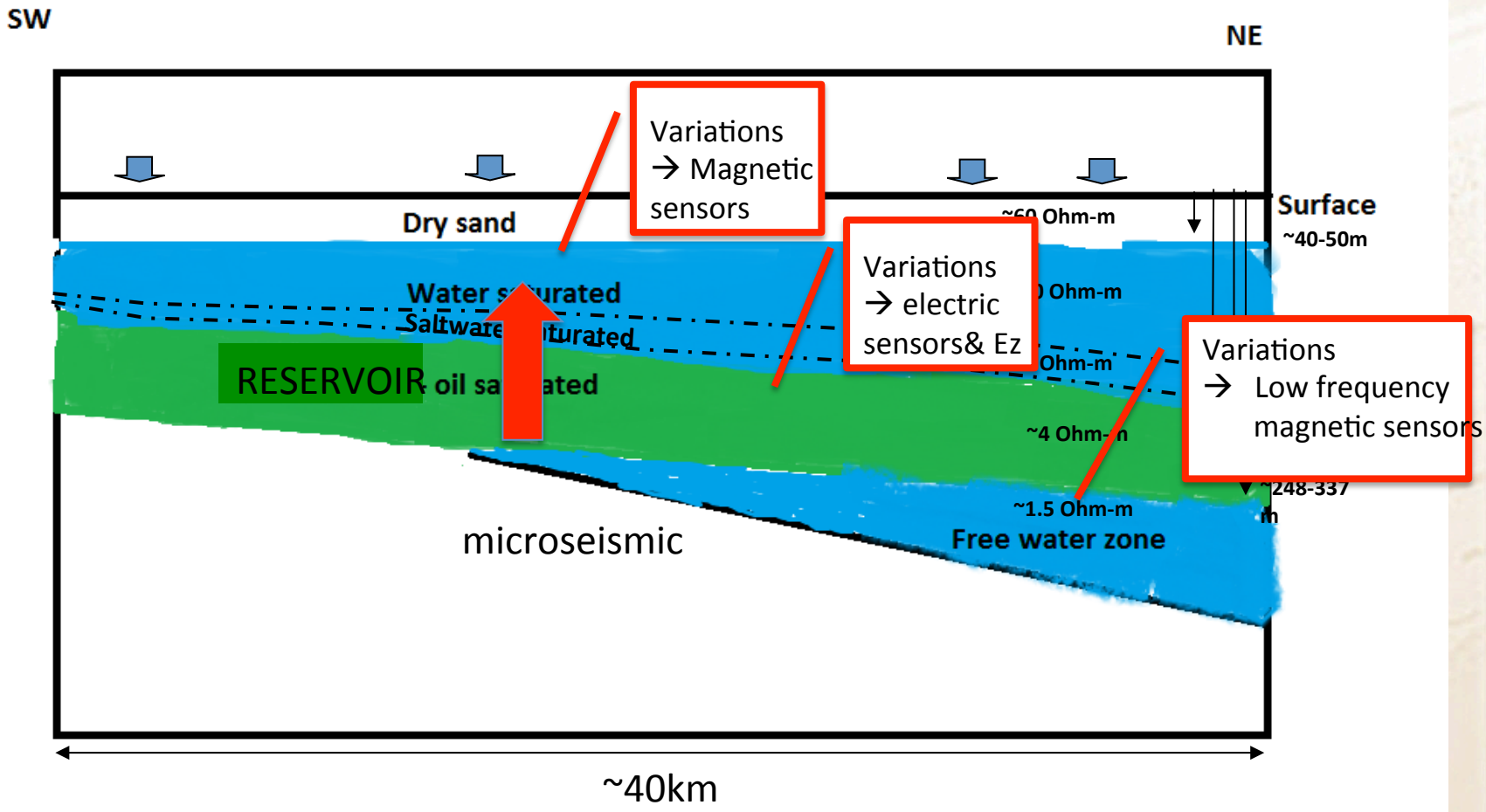


Pitfalls

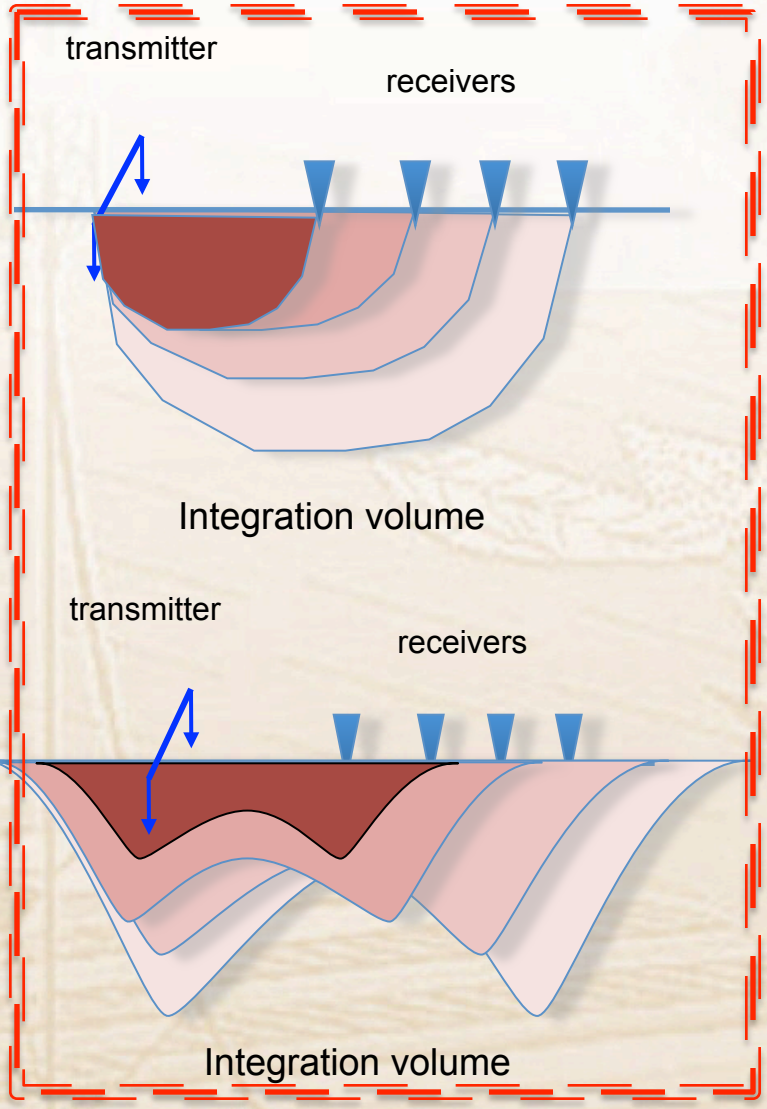
- Sensitivity & multi-components
- Information focus
- Anisotropy solved ✔

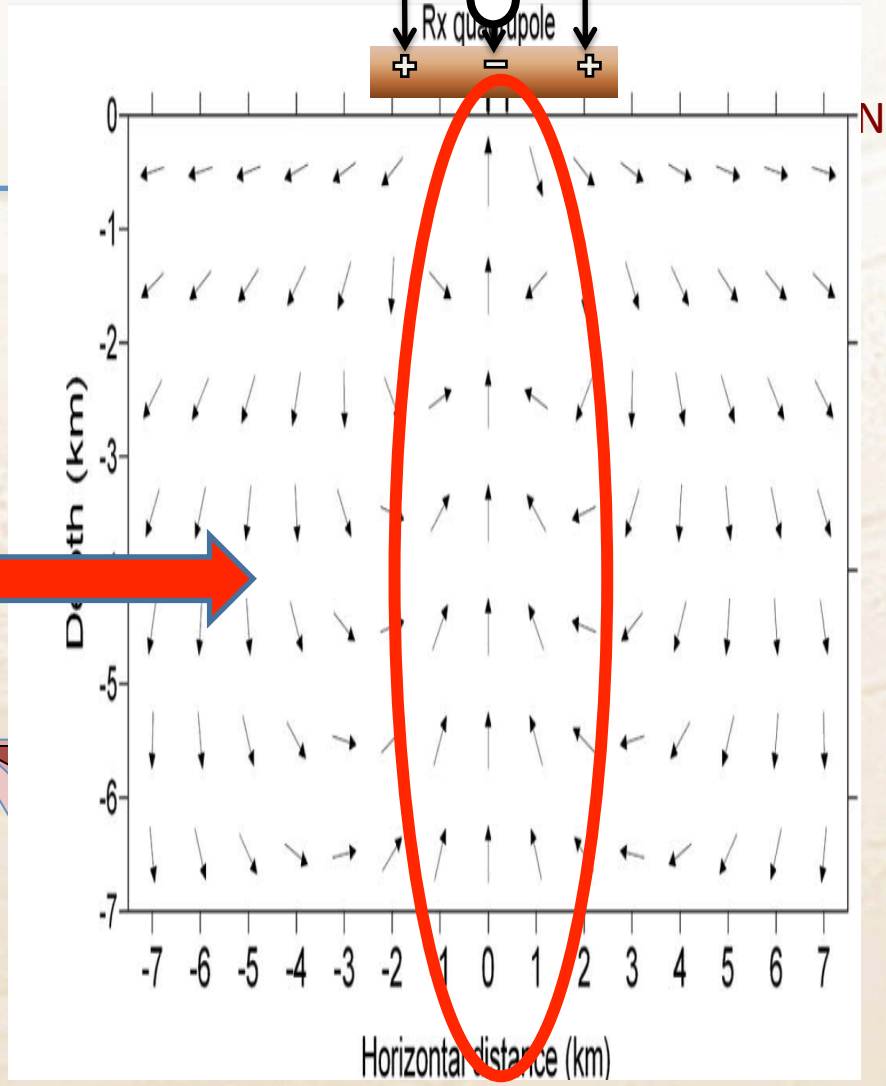
- → **Workflows**

PITFALLS: Reservoir objectives require multi-components



Information focus of EM Methods: frequency versus time domain

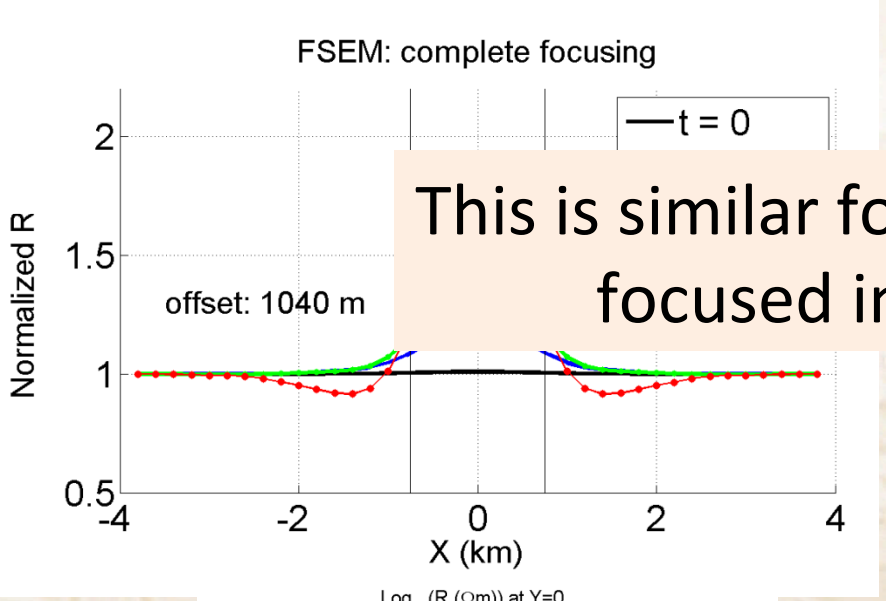


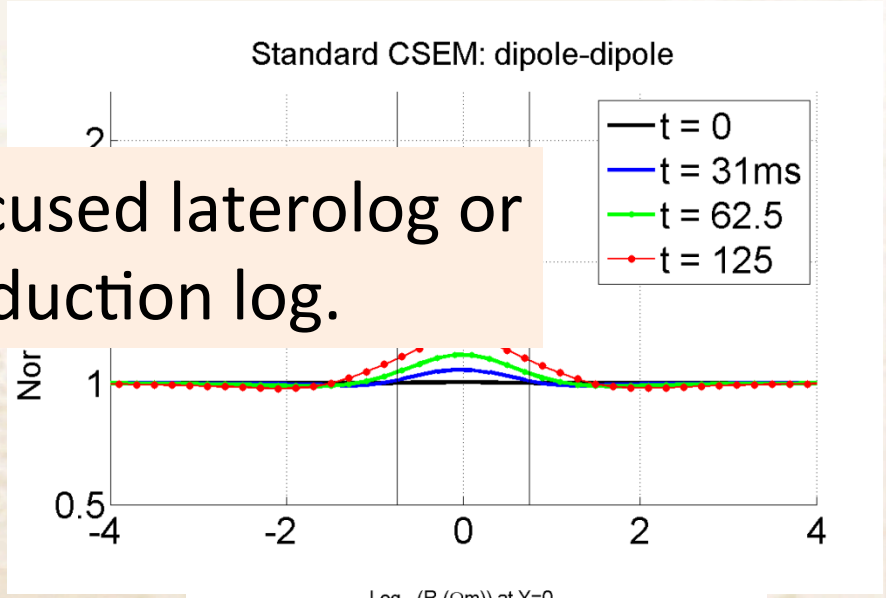


Information focus of EM Methods: Focused Source EM - FSEM

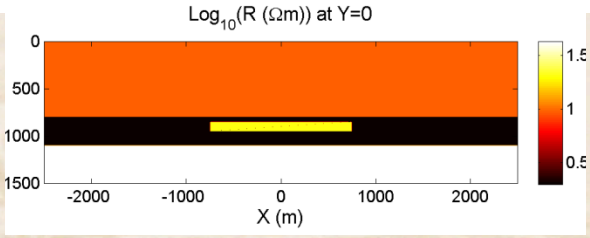
FOCUSED: Anomaly ~75%

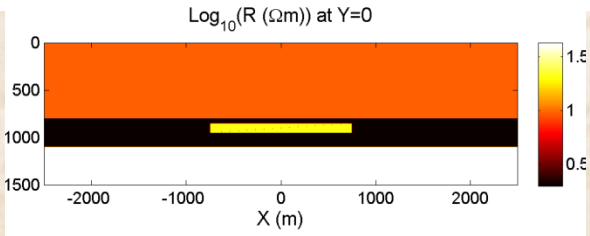
Anomaly ~20%





This is similar focused laterolog or focused induction log.





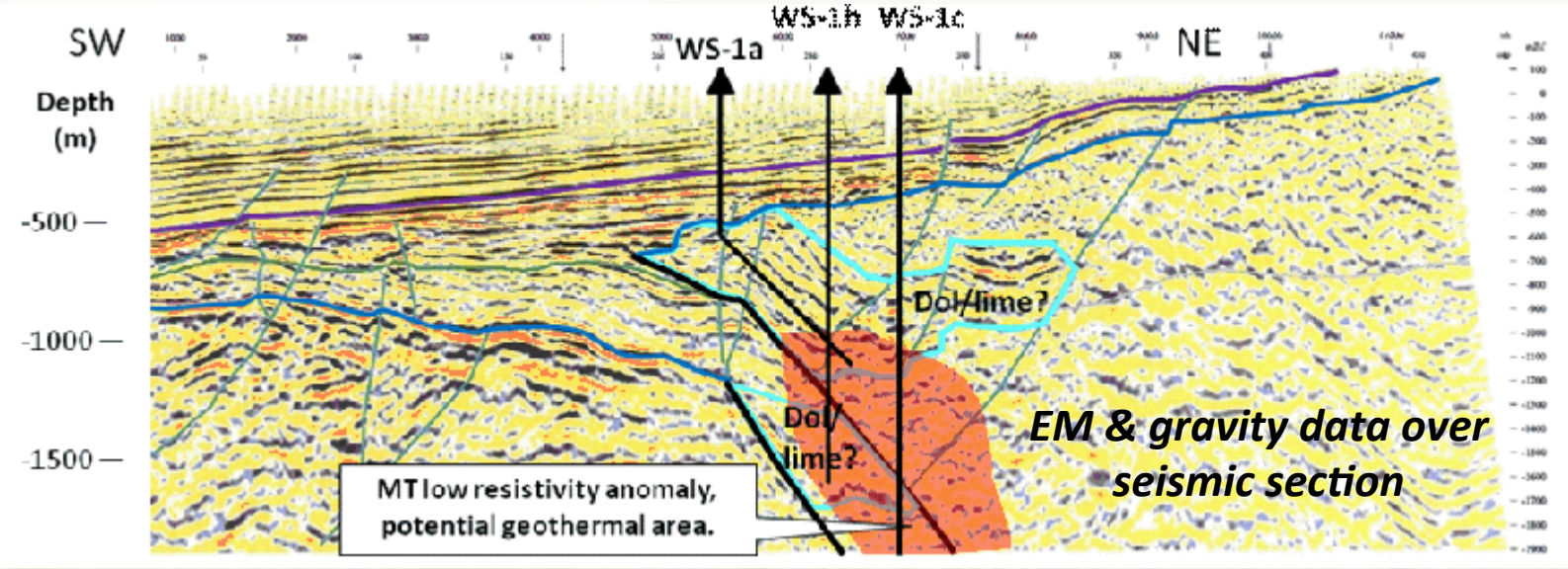
Courtesy Davydycheva

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

- TODAY: we can measure data from the surface & borehole
- MUST Calibrate with borehole
- Dense data → get better resolution & compare with seismic
- **→ PILOT study is needed!**

…. SUCCESS

A 4 MW geothermal well drilled on EM



THANK YOU!

Acknowledgements:

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