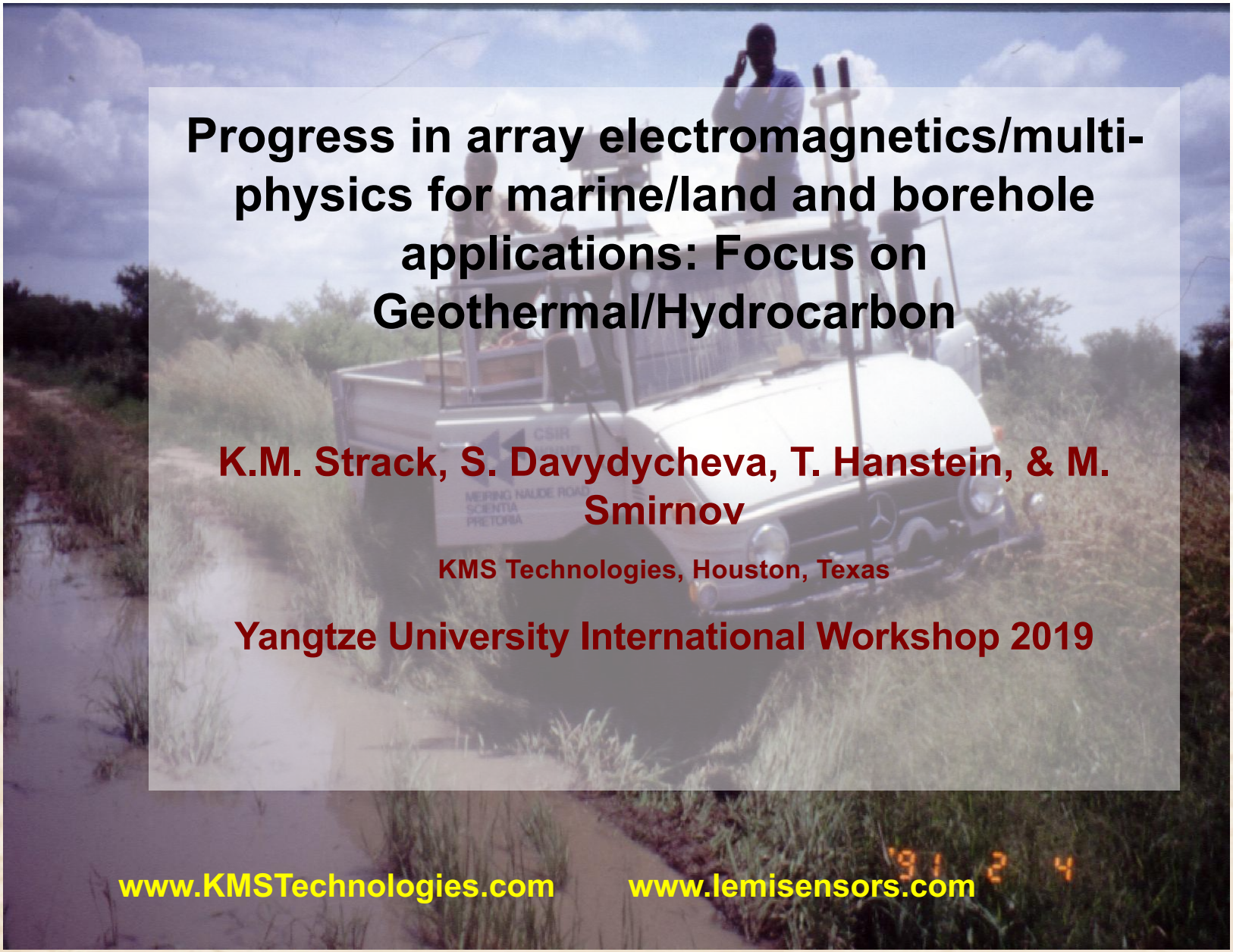


Progress in array electromagnetics/multi-physics for marine/land and borehole applications: Focus on Geothermal/Hydrocarbon

K.M. Strack, S. Davydycheva, T. Hanstein, & M. Smirnov

KMS Technologies, Houston, Texas

Yangtze University International Workshop 2019

www.KMSTechnologies.com **www.lemisensors.com**

- Multi-physics system: all include seismics
  - Time/frequency domain EM
  - CSEM & IP
  - TFEM
- Applications:
  - Hydrocarbon E&P
  - Geothermal E&P
  - Shallow (environmental)
  - Crustal & earthquake prediction

- Multi-physics system all include seismics
  - Time/frequency domain EM
  - CSEM & IP
  - TFEM
- Applications:
  - Hydrocarbon E&P
  - Geothermal E&P
  - Shallow (environmental)
  - Crustal & earthquake prediction

Dissecting the topic… I …Geothermal & Hydrocarbons

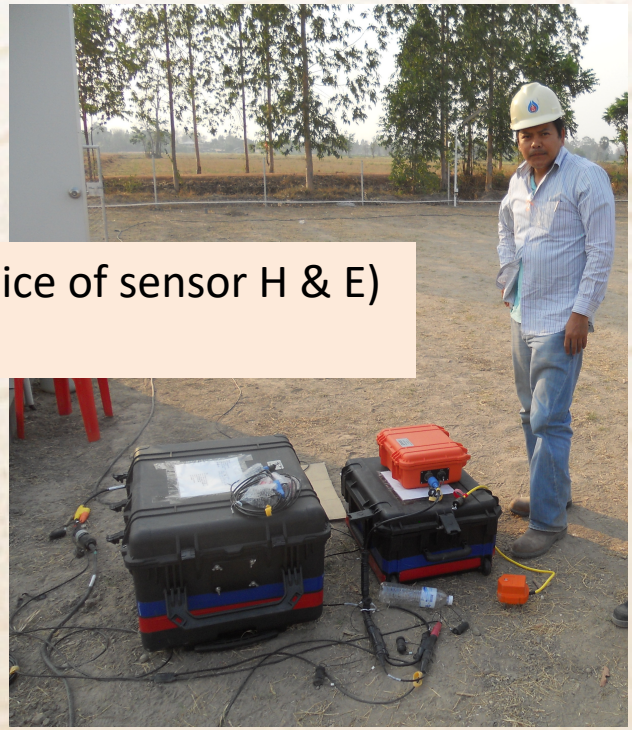
Commonality between Geothermal & Hydrocarbons

- Both benefits from 4D monitoring (cost, reservoir integrity & quality)
- Permanent installations have highest value (4D seismic & induced seismicity monitoring)
- Similar depth range (1 km to 4 km)

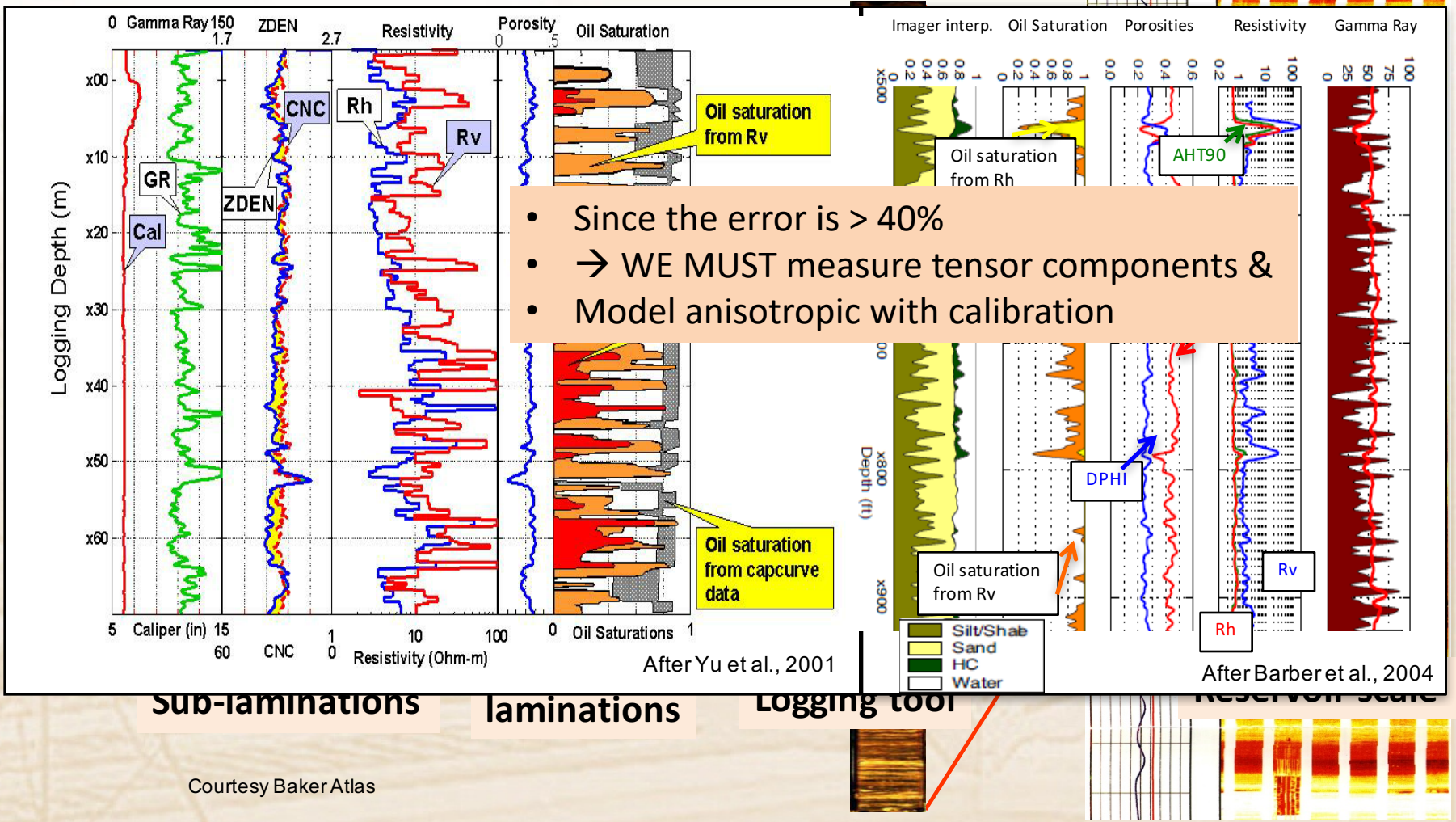
Differences

- Hydrocarbons: resistive (oil) & conductive (water) targets
- Geothermal: mostly conductive target

→ Always image conductive & resistive targets (→ choice of sensor H & E)



Pitfall: ANISOTROPY our biggest problem

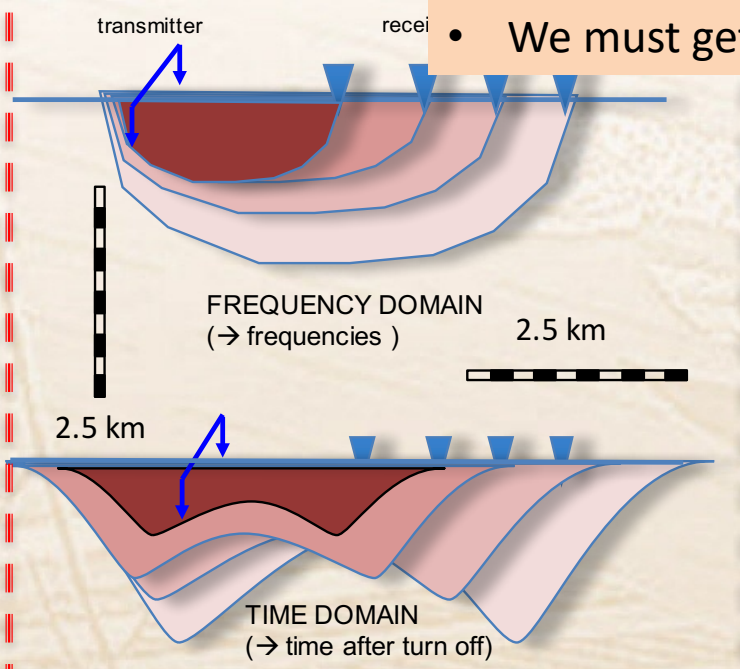


- Since the error is > 40%
- → WE MUST measure tensor components &
- Model anisotropic with calibration

Courtesy Baker Atlas

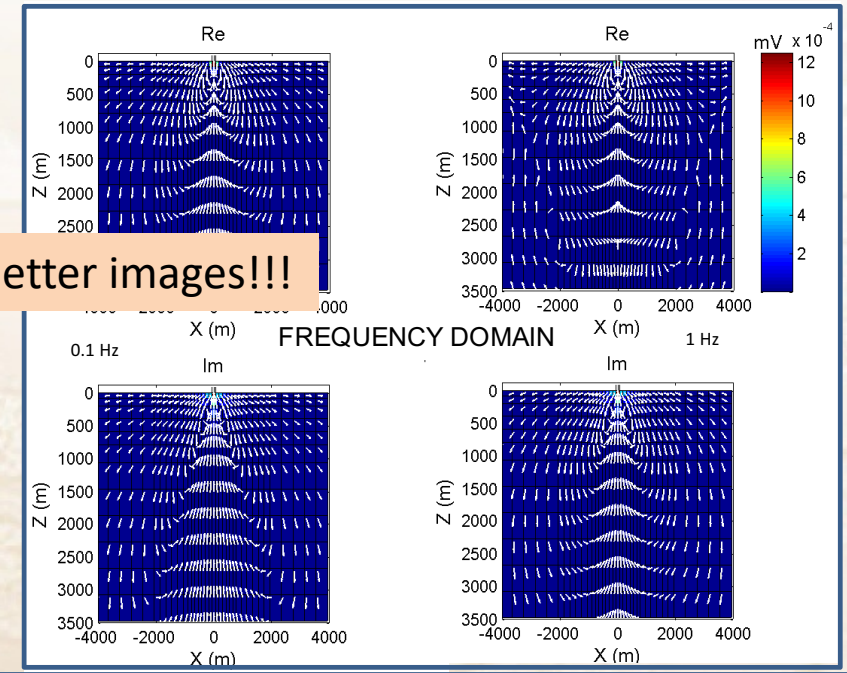
Pitfall: Where does the information come from?..

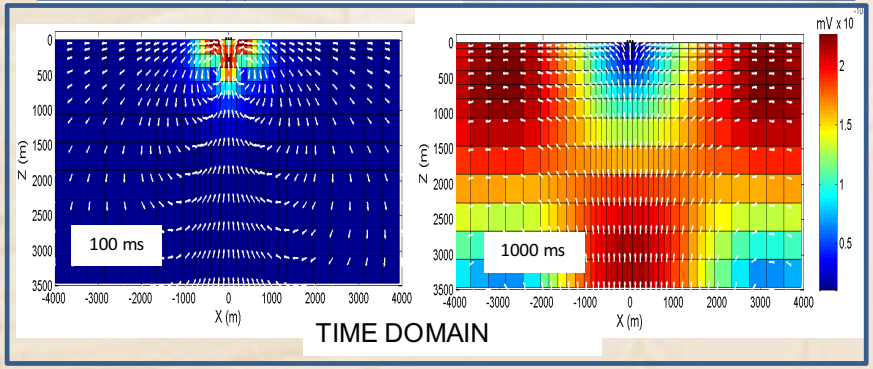
Sensitivity density



- We must get better images!!!

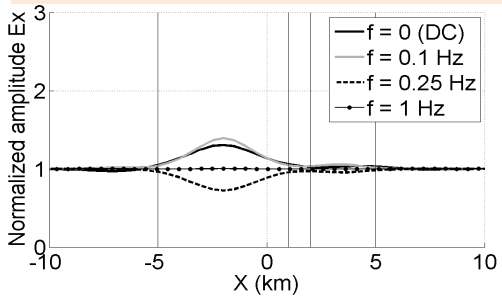
Focused Source EM electric fields

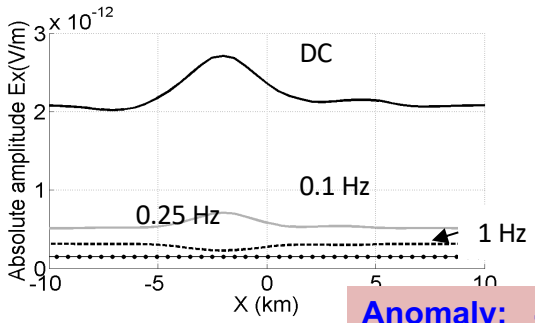




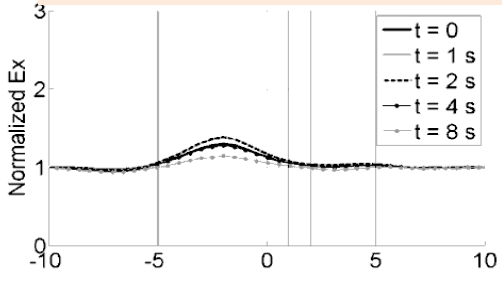
Conventional CSEM versus Focused Source EM

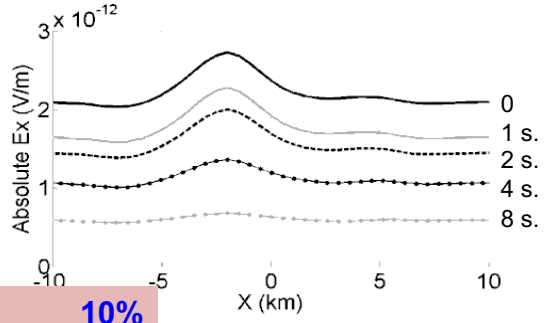
Frequency domain CSEM



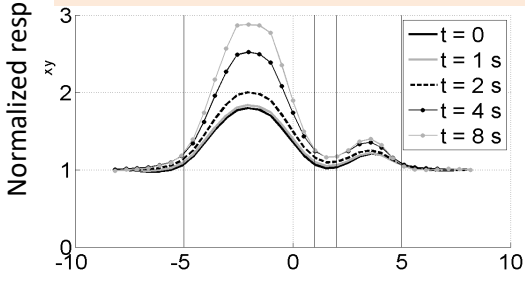


Time domain CSEM

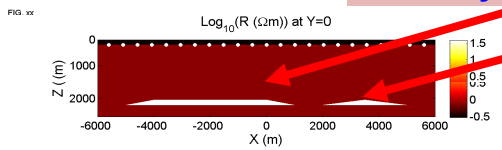


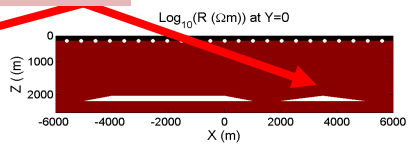


Focused Source EM

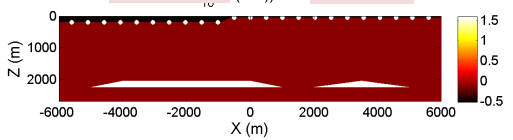


Anomaly: 40% 10%

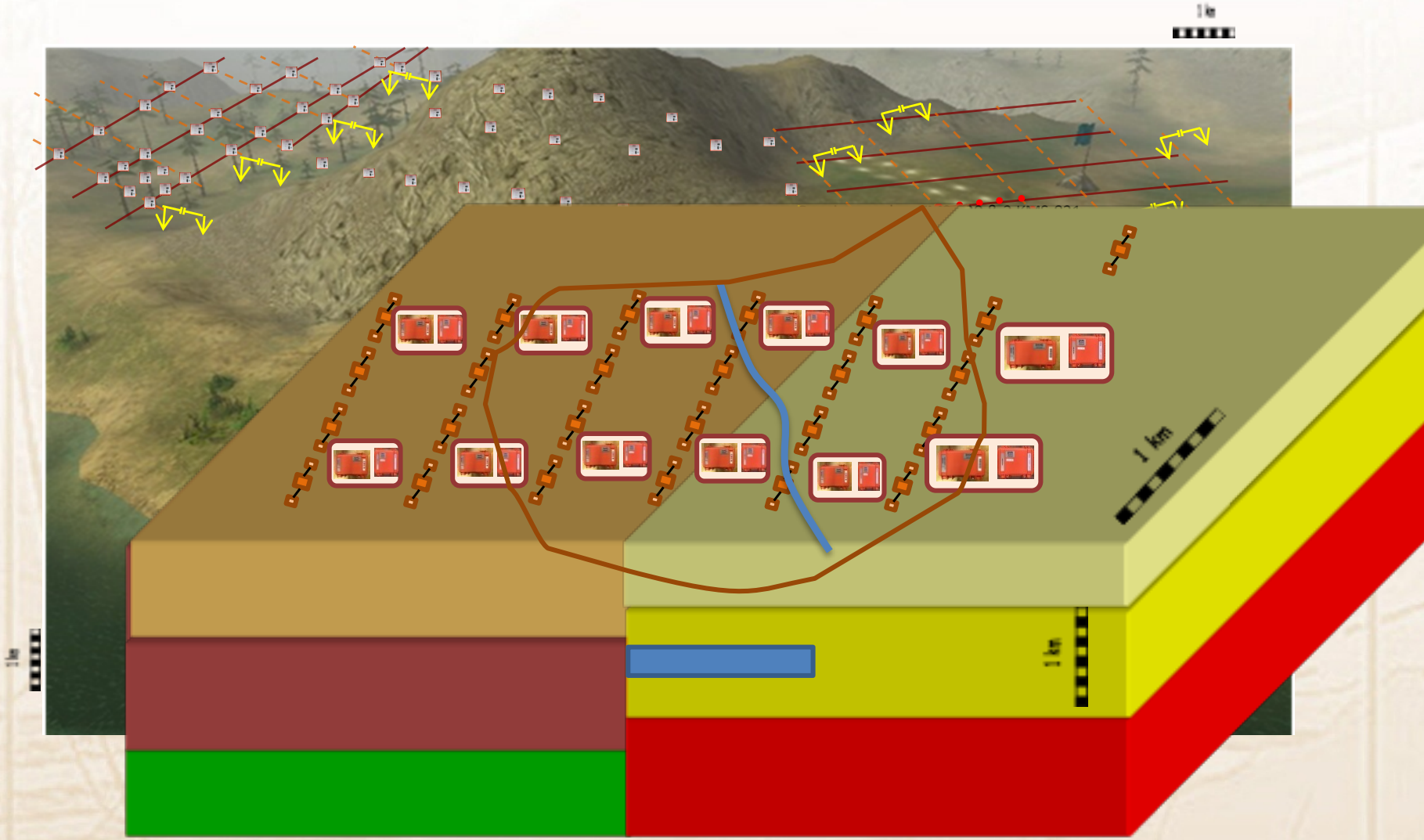




200% **40%**



Exploration & monitoring layouts



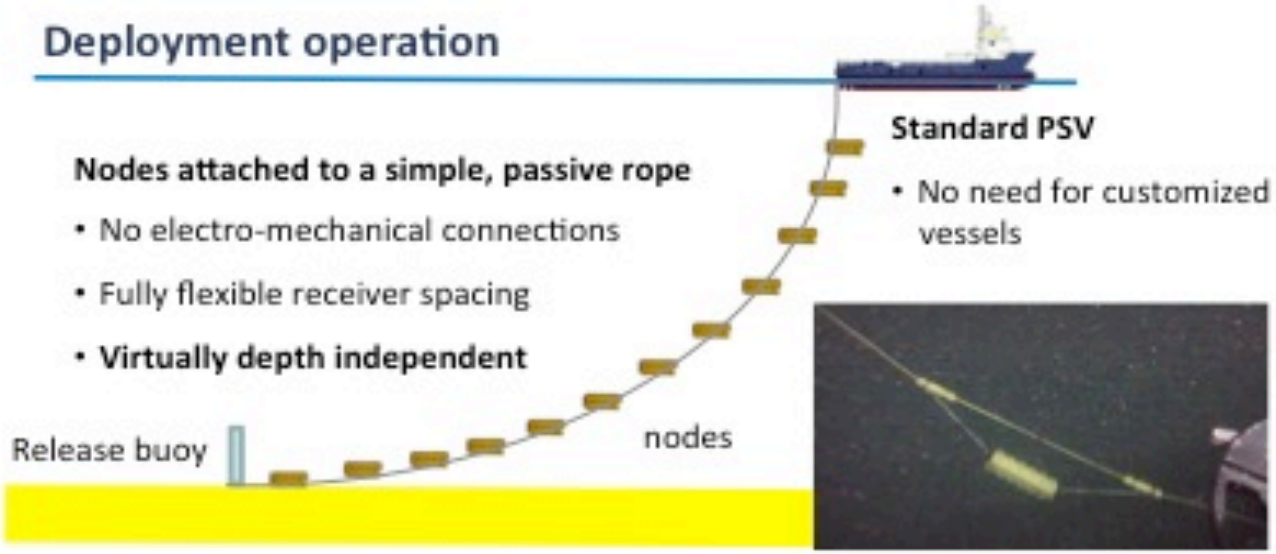
Receiver: New ARRAY acquisition → better images

www.KMSTechnologies.com

Cabled marine array system: EM & seismic

Cabled Autonomous Receiver System (CARS)

Deployment operation



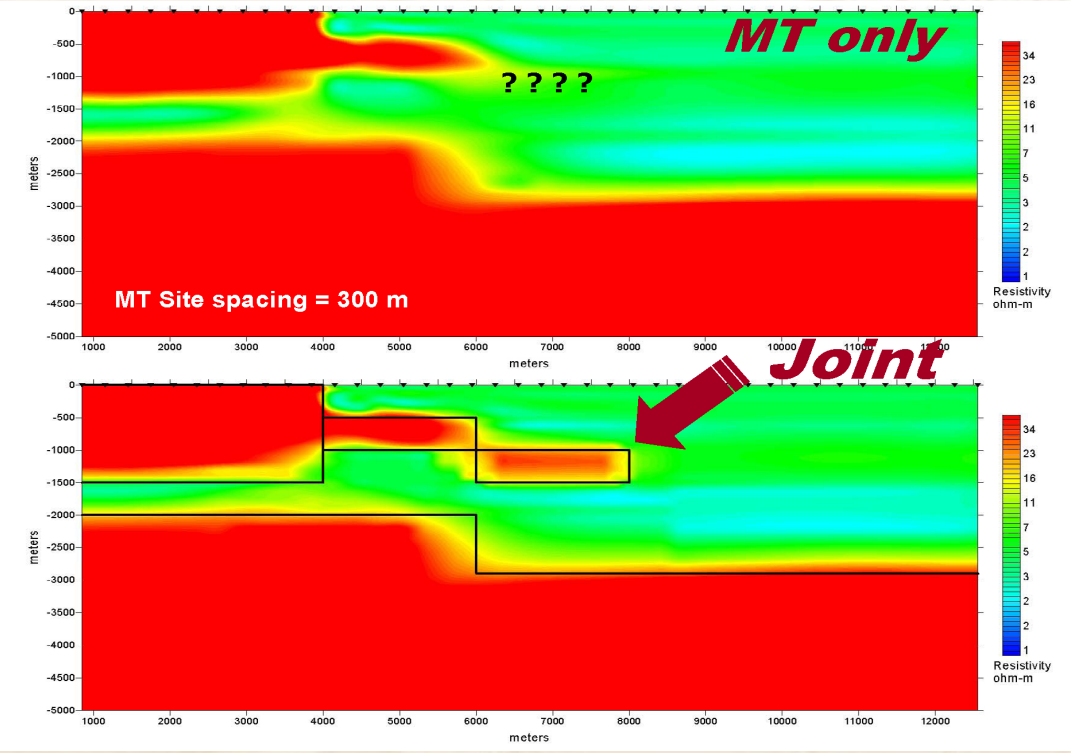
Survey mode - seafloor receiver line

• No connection to the surface
• Release buoy at the end of each line

Cabled system: prototype 1 and 2

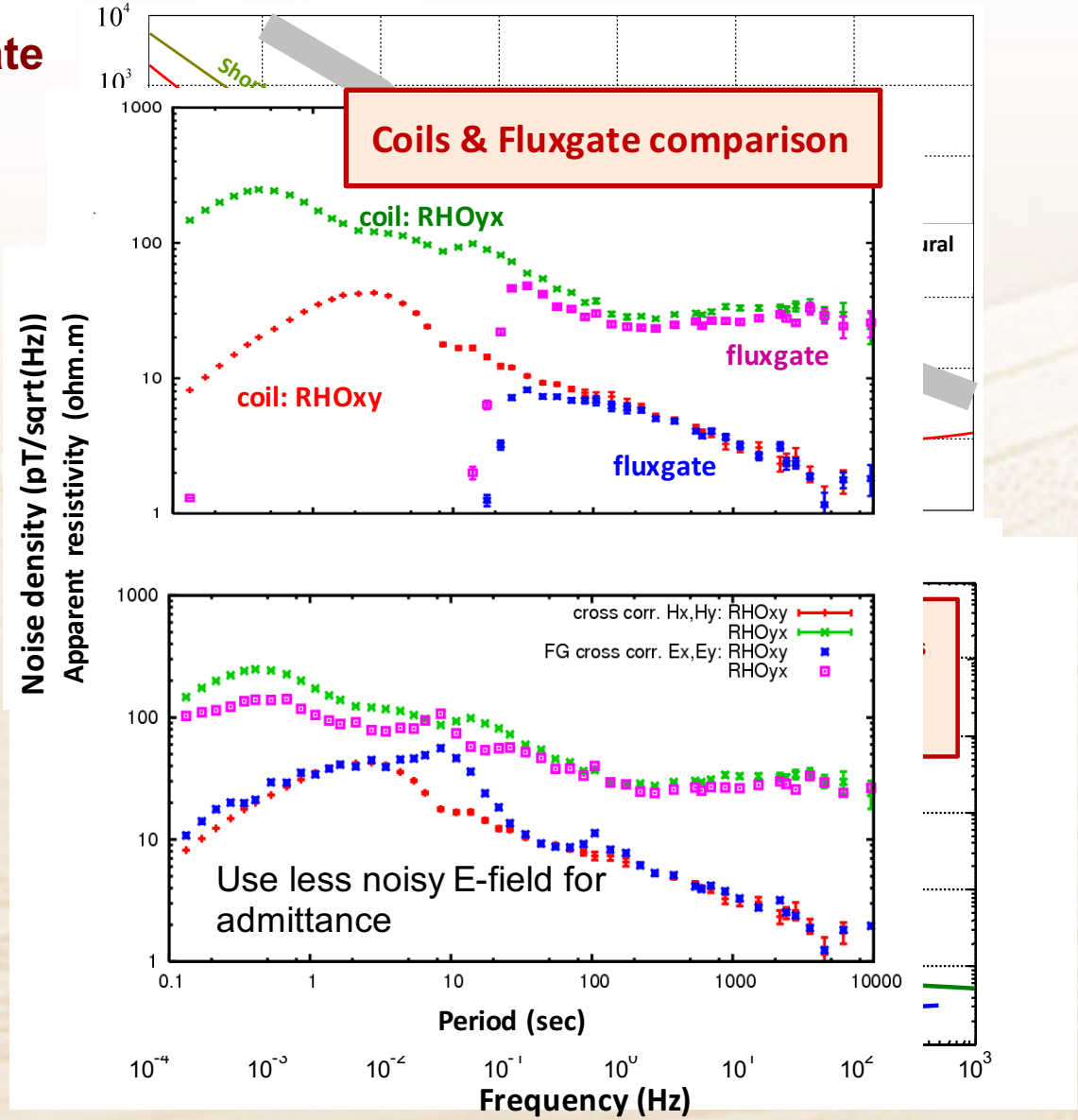
Cabled marine array system: what method?

- Frequency domain: deep water
- Time domain: shallow water
- Can include seismic or FSEM
- Always CSEM & MT



(Zerilli, 2002)

Sensors
Coils & fluxgate



MT systems

1. LEMI-424 MT system

- Lowest power consumption - <0.35 W
- Frequency band – DC - 0.5 Hz
- Crustal investigations; Used by US MT array

2. Mini-MT system

- Low power consumption - <5 W
- Frequency band – DC - 180 Hz
- Crustal investigation; MT & CSEM
- MT system in a suitcase < 30 Kg

3. Super broadband MT system

- Low power - <5 W
- One coil for MT & AMT
- Frequency band - 0.00025 - 10,000 Hz
- MT, AMT, CSEM
- Industrial system for operational efficiency

4. Standard MT system

- Low power - <5 W
- Frequency band - 0.0001 - 1,000 Hz
- Crustal investigation, MT, CSEM

5. MT/AMT system

- Low power - <5 W
- MT Frequency band - 0.0001 - 1,000 Hz
- AMT Frequency band – 1 - 70,000 Hz
- Lowest noise operation

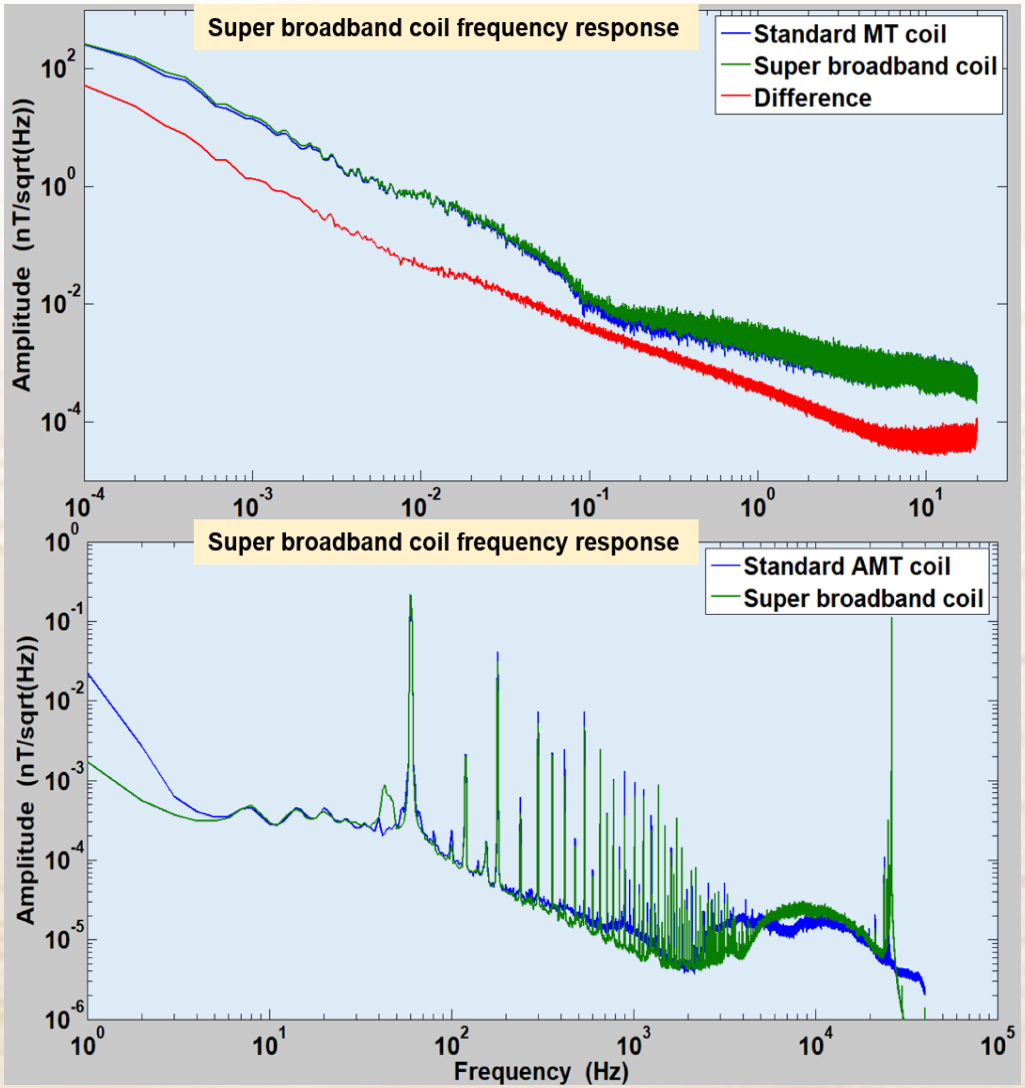
6. MT MAX system – 11 channels

- Low power - <5 W
- MT, AMT, and Fluxgate sensor included

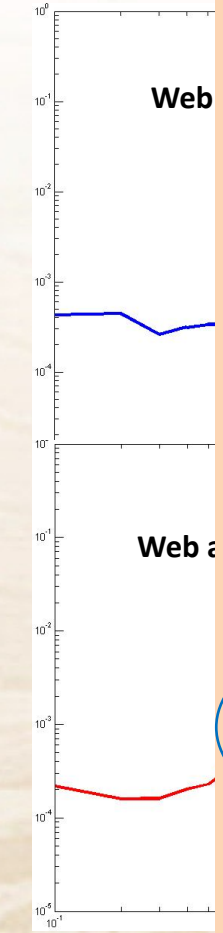
Web access box for all systems

- NOISE FREE data
- Real-time cloud access
- Easy to use

MT systems: broadband coil LEMI-152



MT systems: noise-free data streaming



Source of noise

KMS-820

Plug in

Wi-Fi SD

Wi-Fi

Wi-Fi interface box

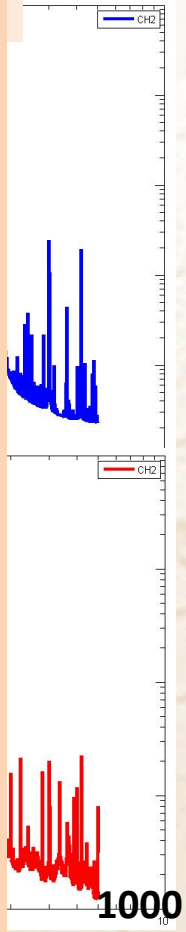
Wired

Noise sensitive
- Induction sensor
- Analog cable

Cellular/Ethernet

Sensors

FTP server



Monitoring: Transmitter: log time stable current controlled

Transmitter site

Array receiver / controller

Laptop

switchbox

Voltage isolator

Auxiliary generator

100/150 KVA generator

Electrode pits

KMS array system history

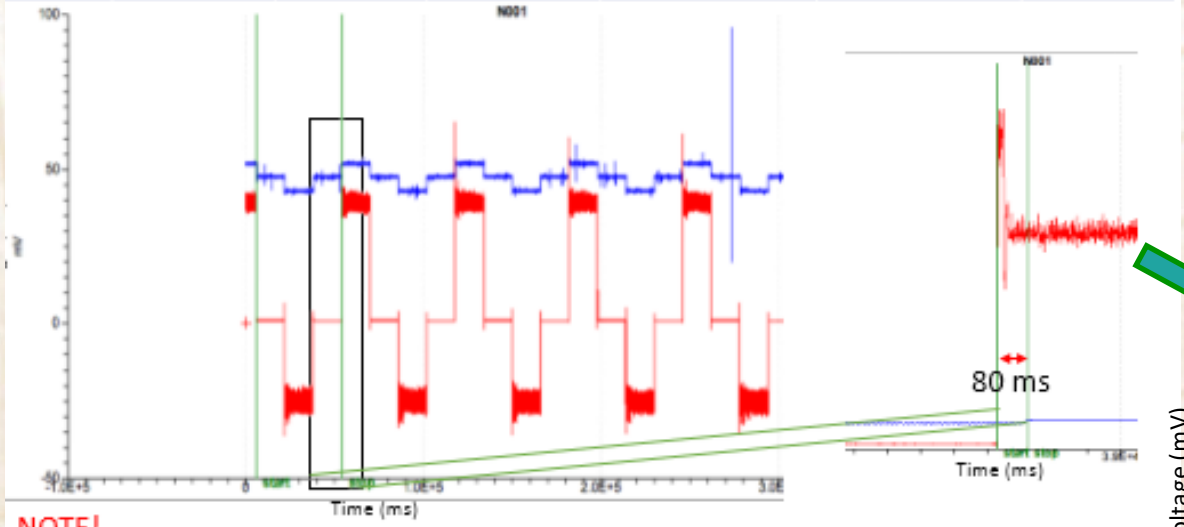
- Developed s
  - Large char
  - Industrial s
- 2008: purch A
- Since 2010
- 2014: added) & 150 KVA)
- 2015: added
- Can be used ismic in single receiver dro

Acquisition system requirements

- Receiver:
  - Continuous recording
  - EM/seismic @ high sampling rate
  - Amplifiers very stable
  - Active bias for CSEM
  - NOISE FREE data streaming
- Transmitter:
  - Electrode plants very stable with time
  - Current control < 0.5%
  - Current timing control & **verification only for monitoring**
  - Multiple safety circuits (failure & operations)
    - Electric circuitry
    - Wire cut - SAFETY
    - Waveform/current adopted
    - Controller (KMS-820) adopted

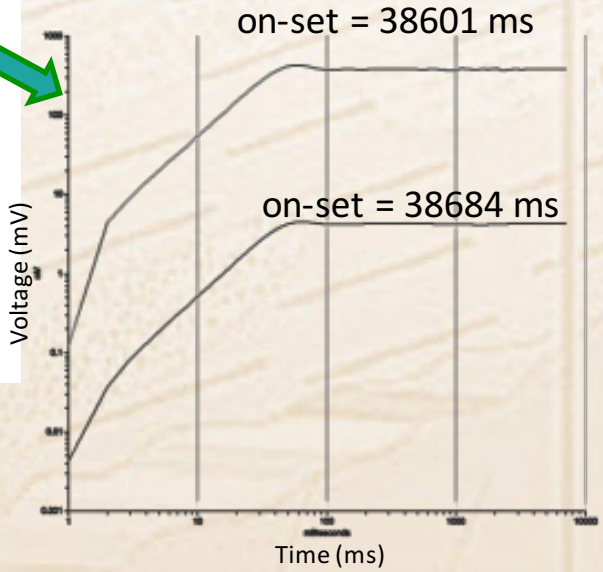
Transmitter timing: correct and verify

Data	Tx on-set (ms)	Rx on-set (ms)	Time shift (ms)	Start time	End time	Remarks
Raw	38630	38710	80	6/30/2016 9:35:45 PM	6/30/2016 9:54:45 PM	
Process	38601	38684	83	6/30/2016 9:35:45 PM	6/30/2016 9:54:45 PM	

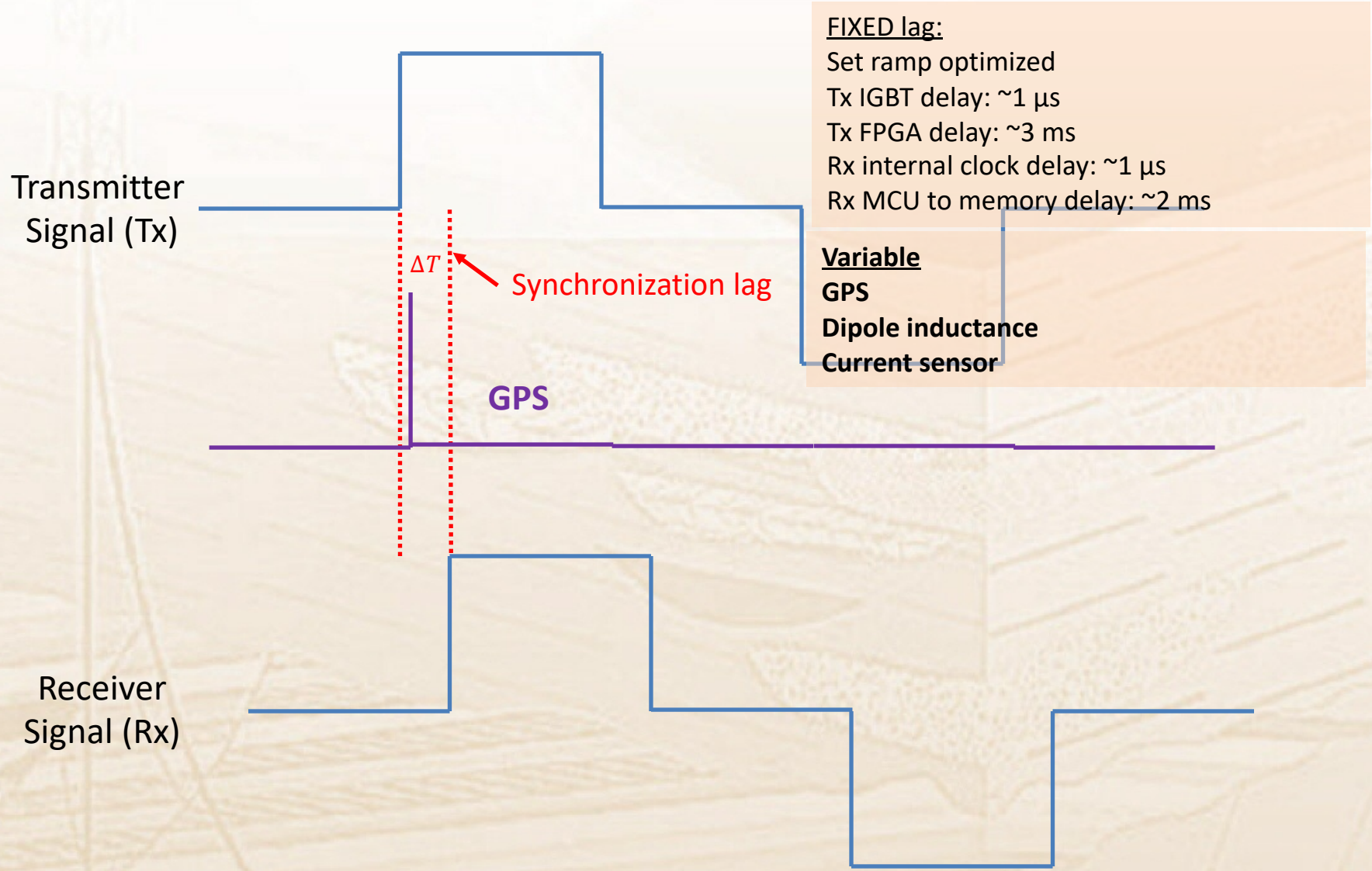


NOTE!

Tx and Rx data with same start time and end time



Transmitter signal timing diagram



FIXED lag:
Set ramp optimized
Tx IGBT delay: ~1 µs
Tx FPGA delay: ~3 ms
Rx internal clock delay: ~1 µs
Rx MCU to memory delay: ~2 ms

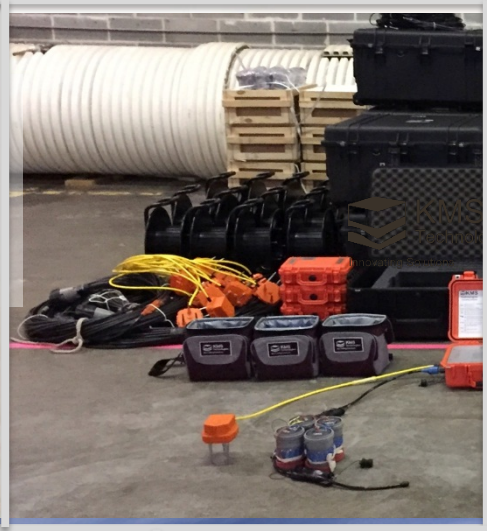
Variable
GPS
Dipole inductance
Current sensor

195 channel monitoring system

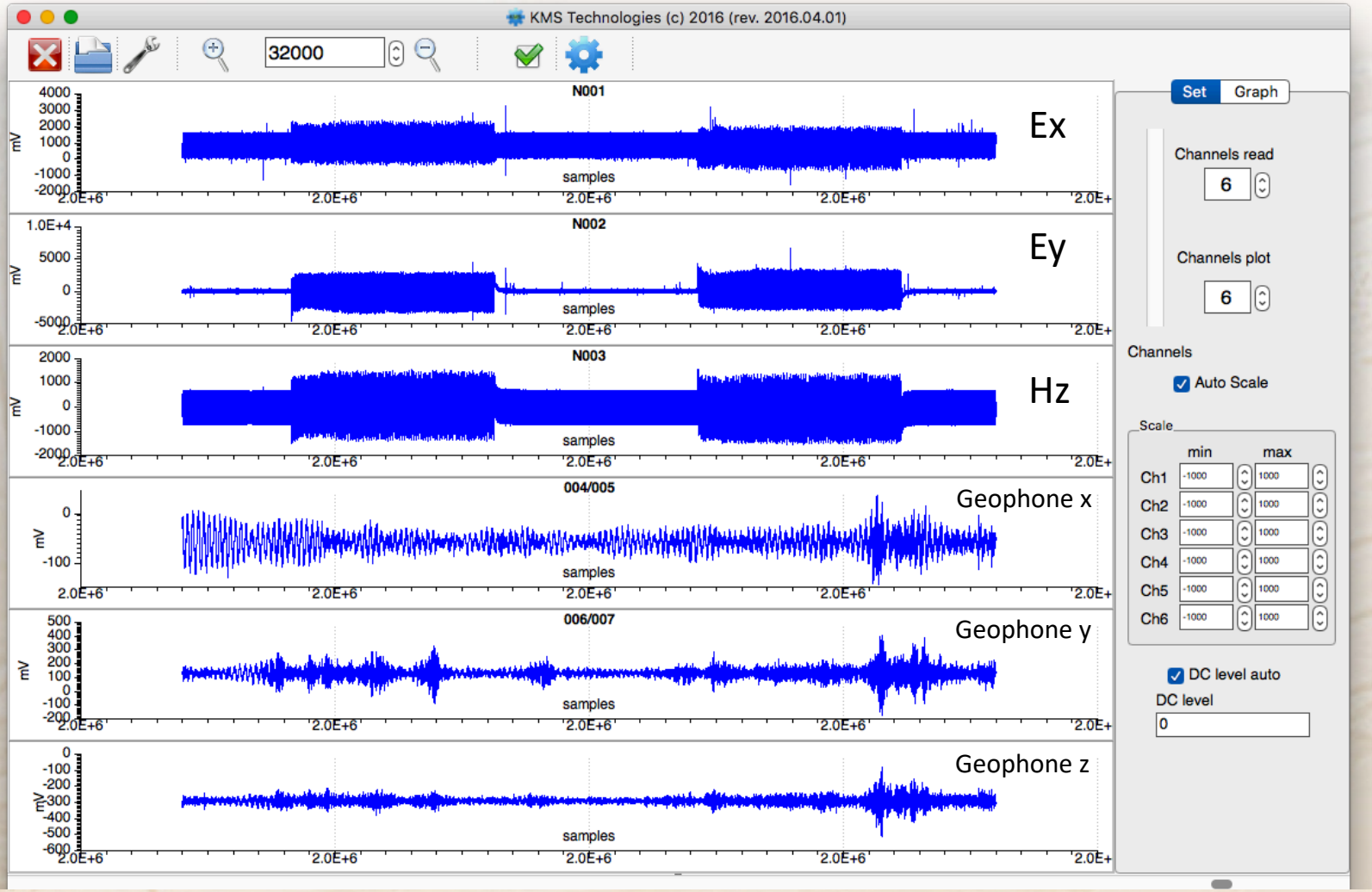
RESERVOIR MONITORING

ARRAY Electromagnetics

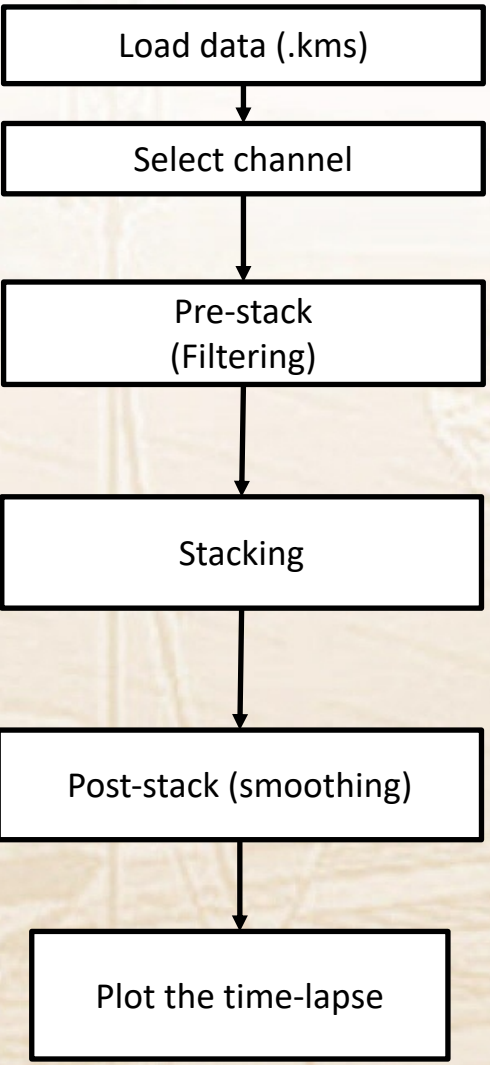
- 195 channels, wifi, wireless or LAN
- 3C magnetic field (DC to 40 kHz)
- 3C microseismic
- 2C electric fields
- Shallow borehole (microseismic/EM)

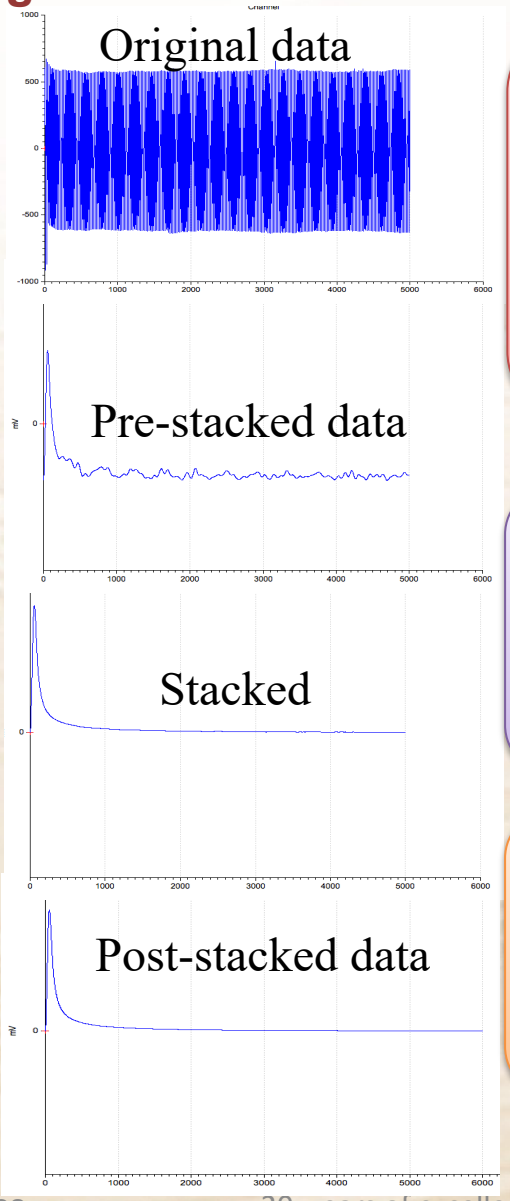


Reservoir Monitoring: Raw data example: microseismic/EM monitoring



Reservoir Monitoring: Data workflow





Filtering

•Harmonic Noise

Harmonic noise filters: Low pass filter

Power line harmonic : 50 Hz

threshold:3.00

•Smoothing

Low pass filter : time domain

Cut off frequency: 15 Hz

Averaging filter: Recursive average = 0.01,T/2 smoothing

Stacking

Trimmed mean

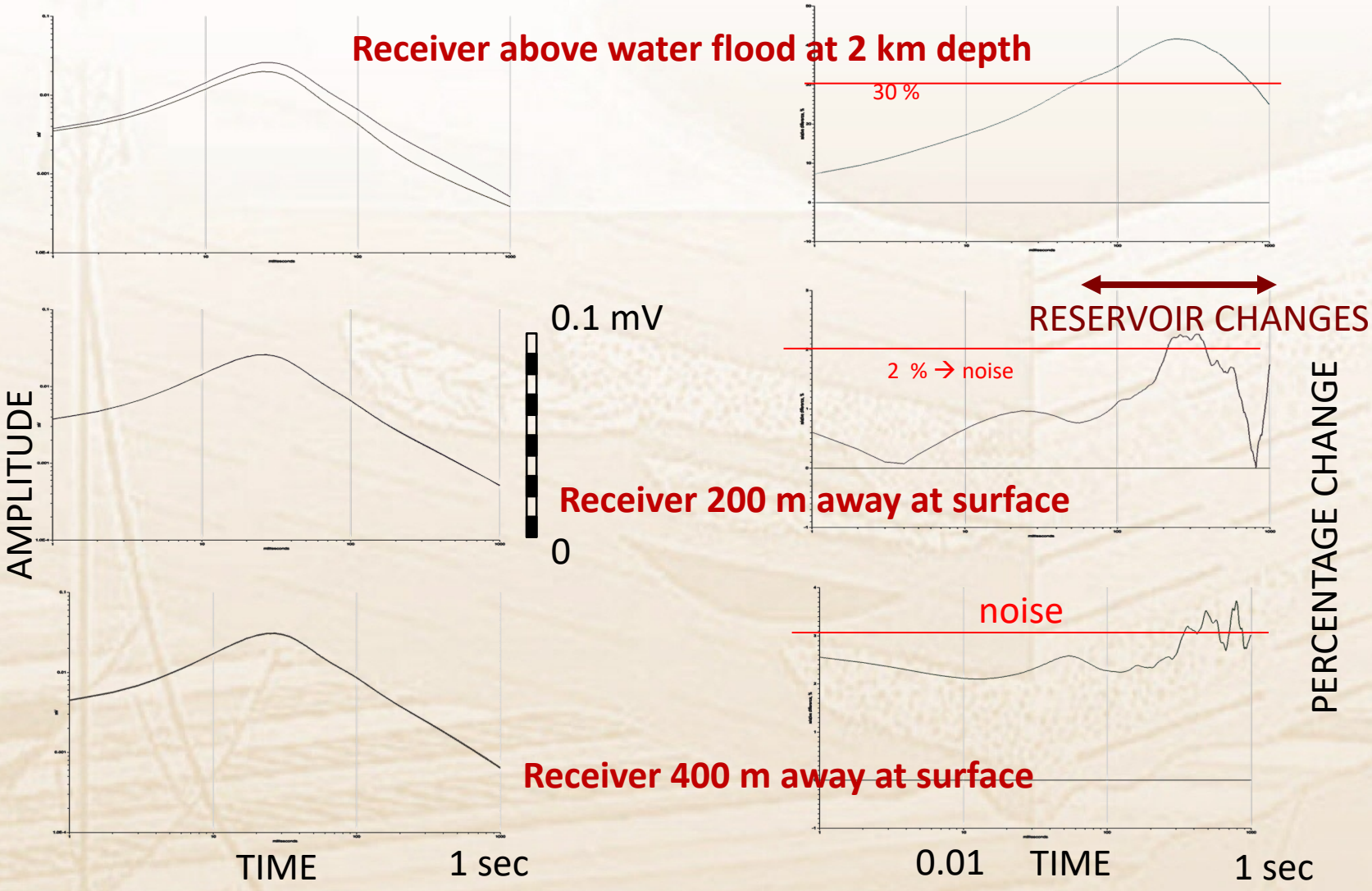
T/2 additional stacking

- **Smoothing & time lapse**

  Recursive average filter

  DC-level adjust

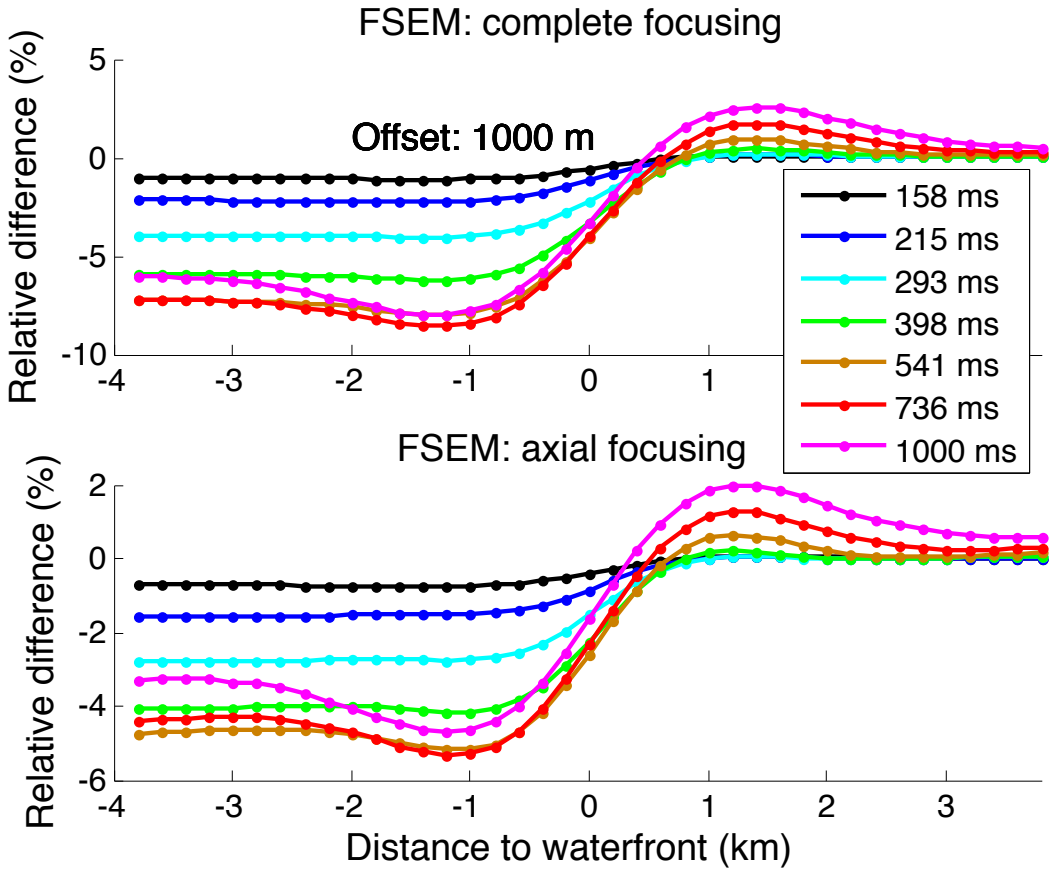
Reservoir Monitoring: Magnetic field sees water flood influence



Courtesy A. Paembonan

3D anisotropic models for FSEM/shallow borehole tool verification

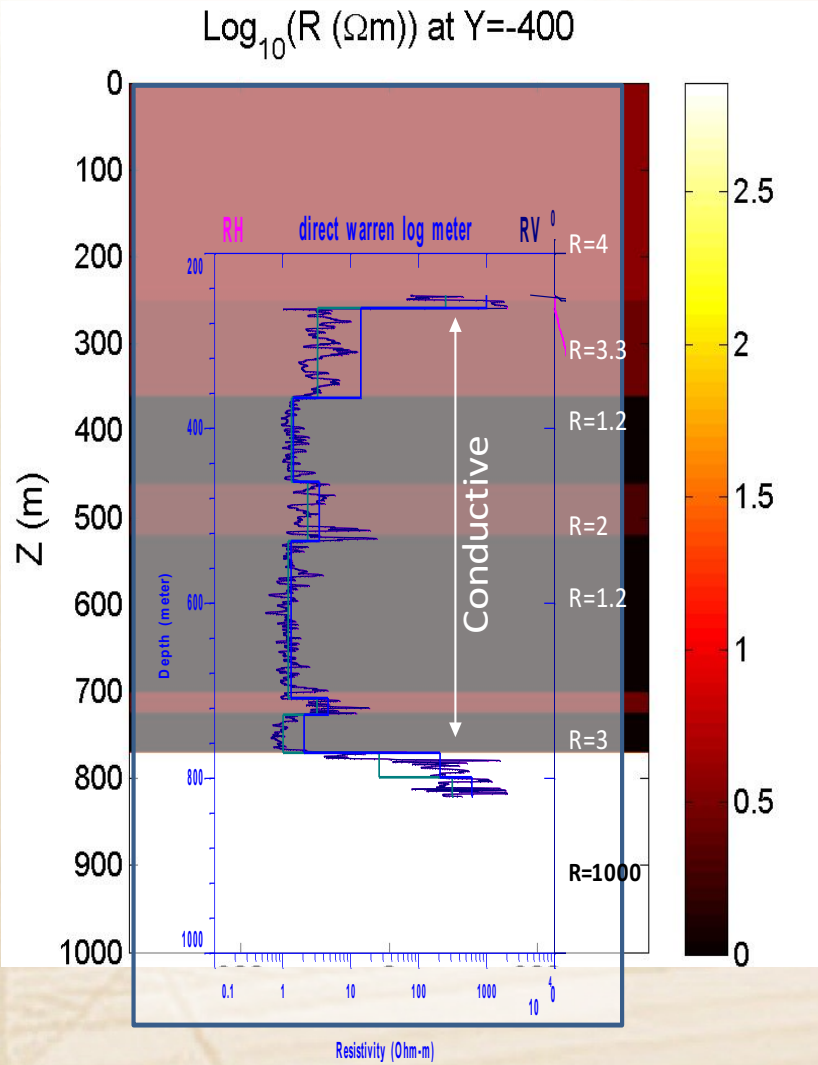
- Anomaly approx.10%
- Physics similar to Ez (shallow borehole tool)
- More field trials needed



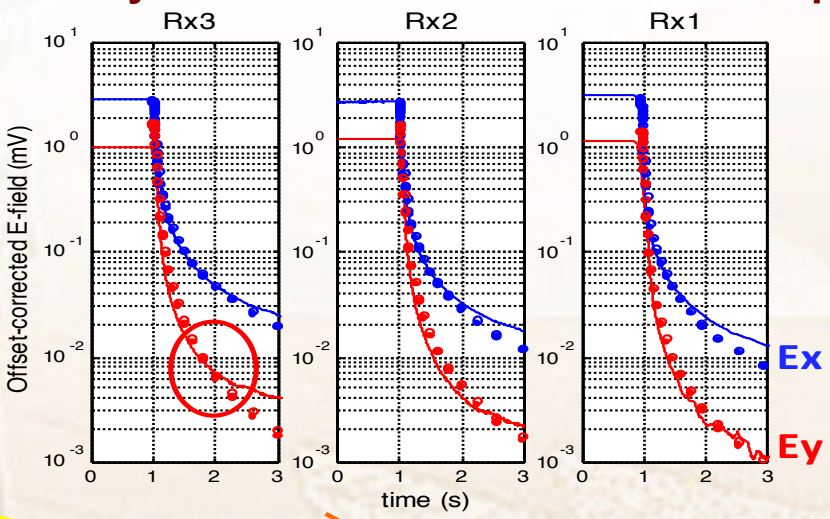
Reservoir Monitoring: summary

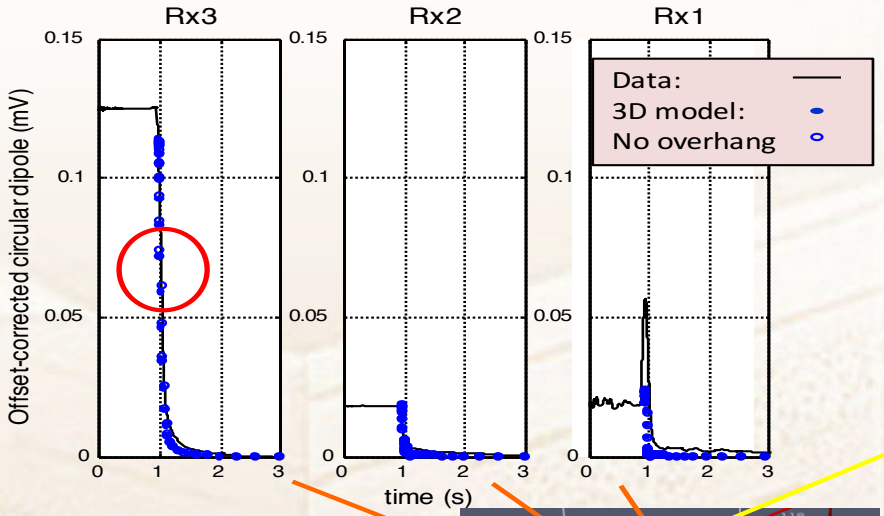
- Carefully log integration & 3D model confirms observed anomaly
- Data from initial test → room for improvements
- Water flood seen in MAGNETIC field
- 3D anomaly discrepancy points to current channeling
- Would need improved image focus

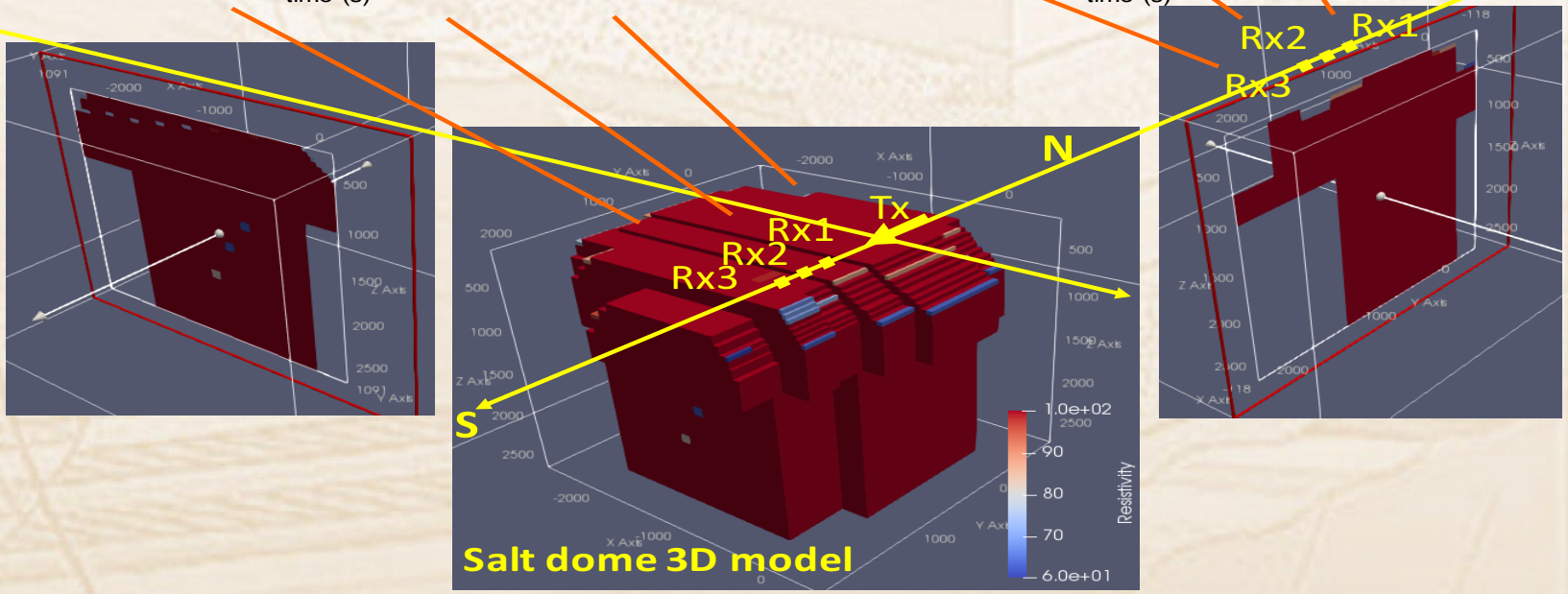
IMAGE FOCUS EXAMPLE: Hockley salt dome 10 km W of Houston



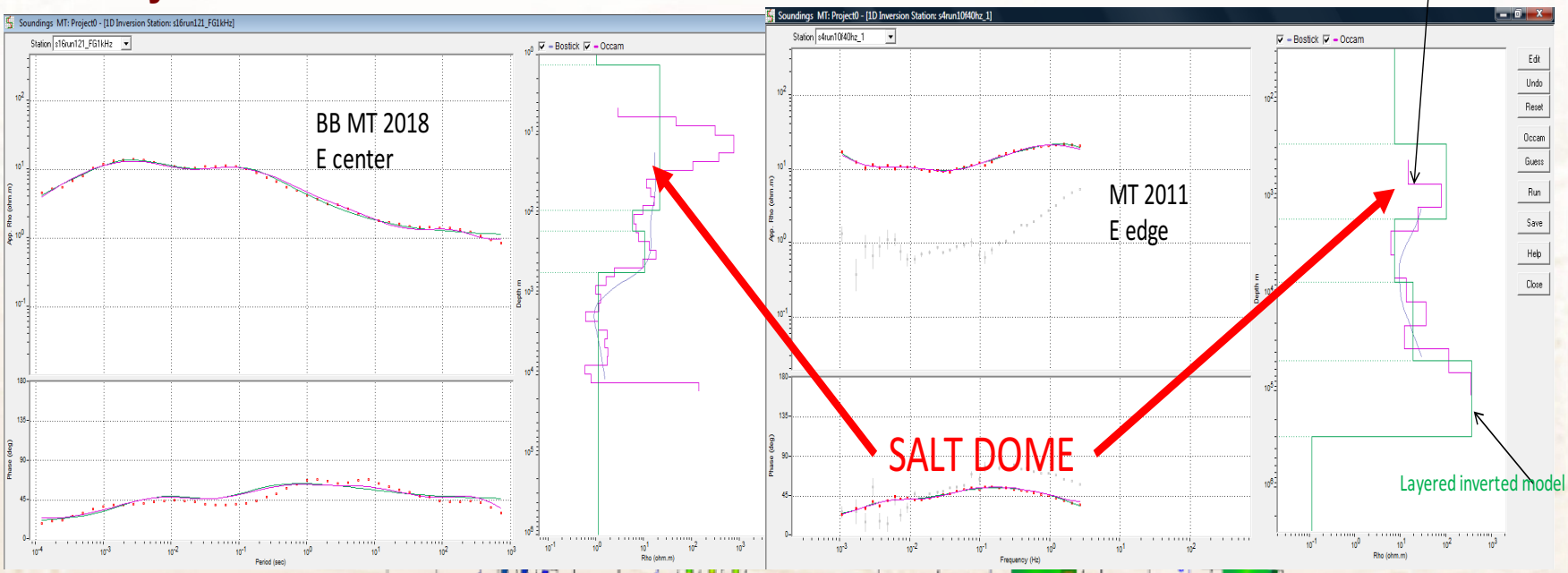
Hockley salt dome: Focused 3D anisotropic model

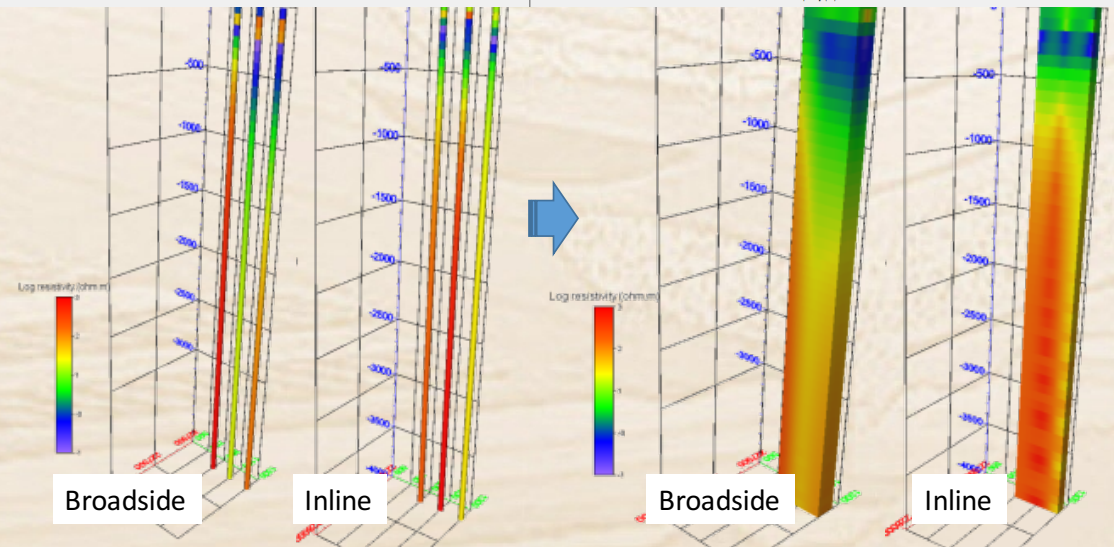






Hockley salt dome: Lotem & MT inversions

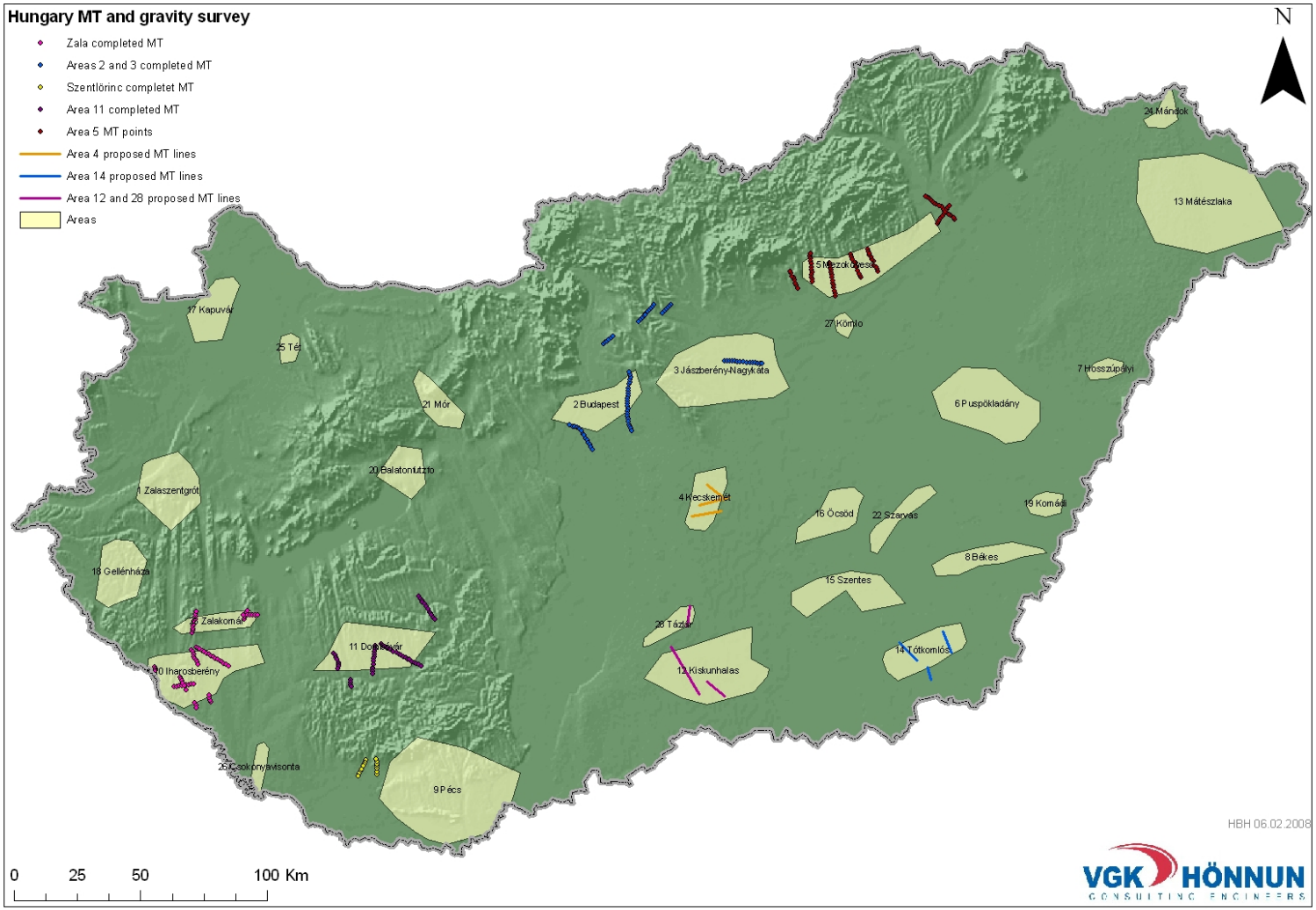




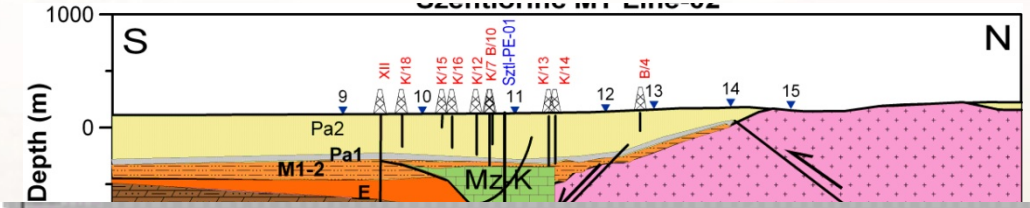
Hockley salt dome: Summary

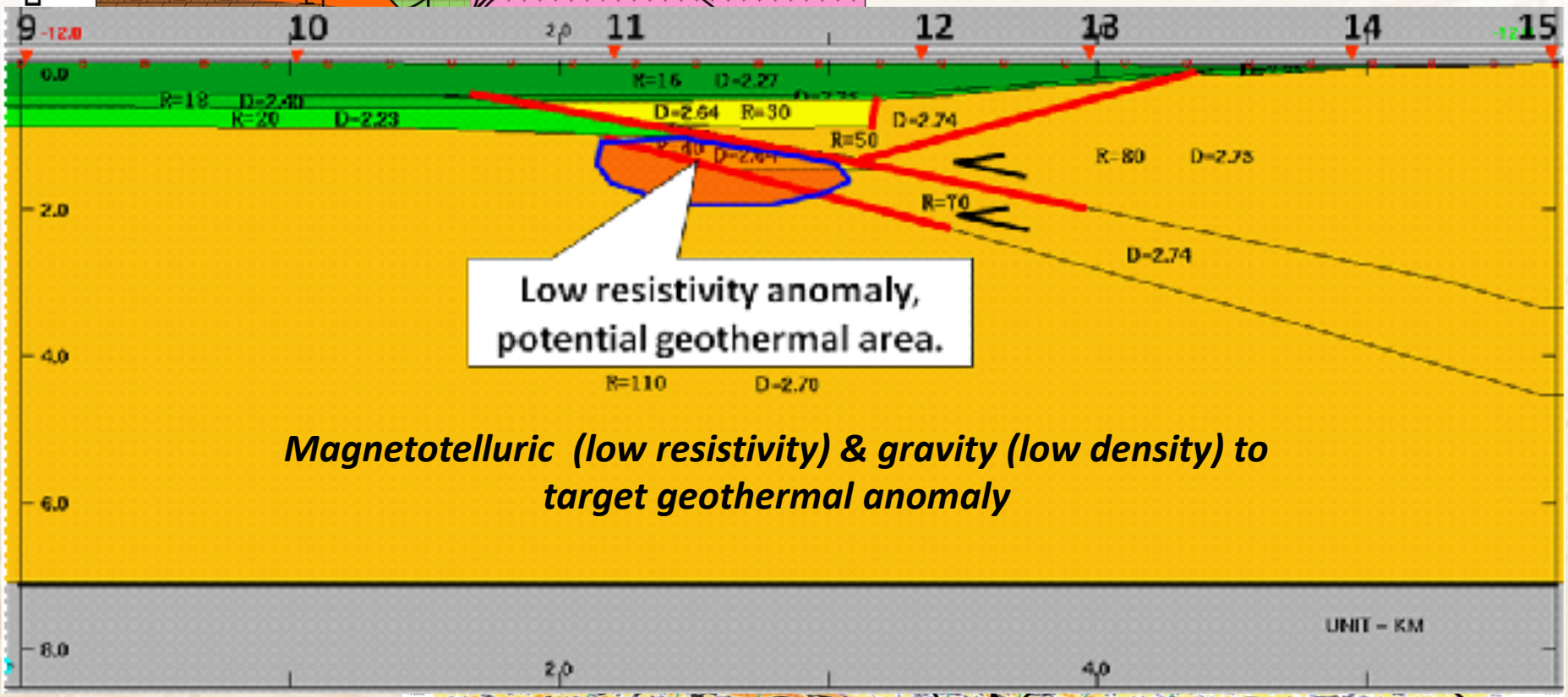
- Focused Source EM (FSEM) sees overhang
- Consistent for Dipole-dipole, Lotem & MT, but both are 1d wi unknown image focus
- More data will be acquired

Hungary geothermal

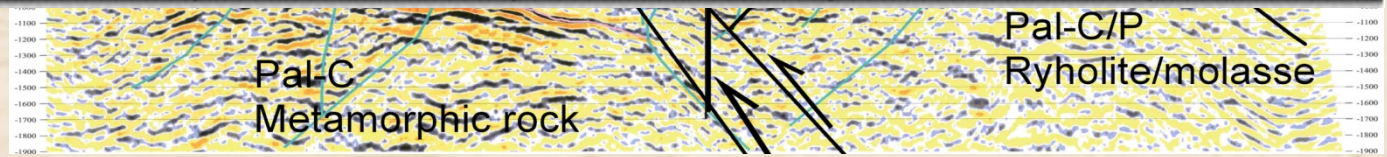


Hungary: Integrated interpretation

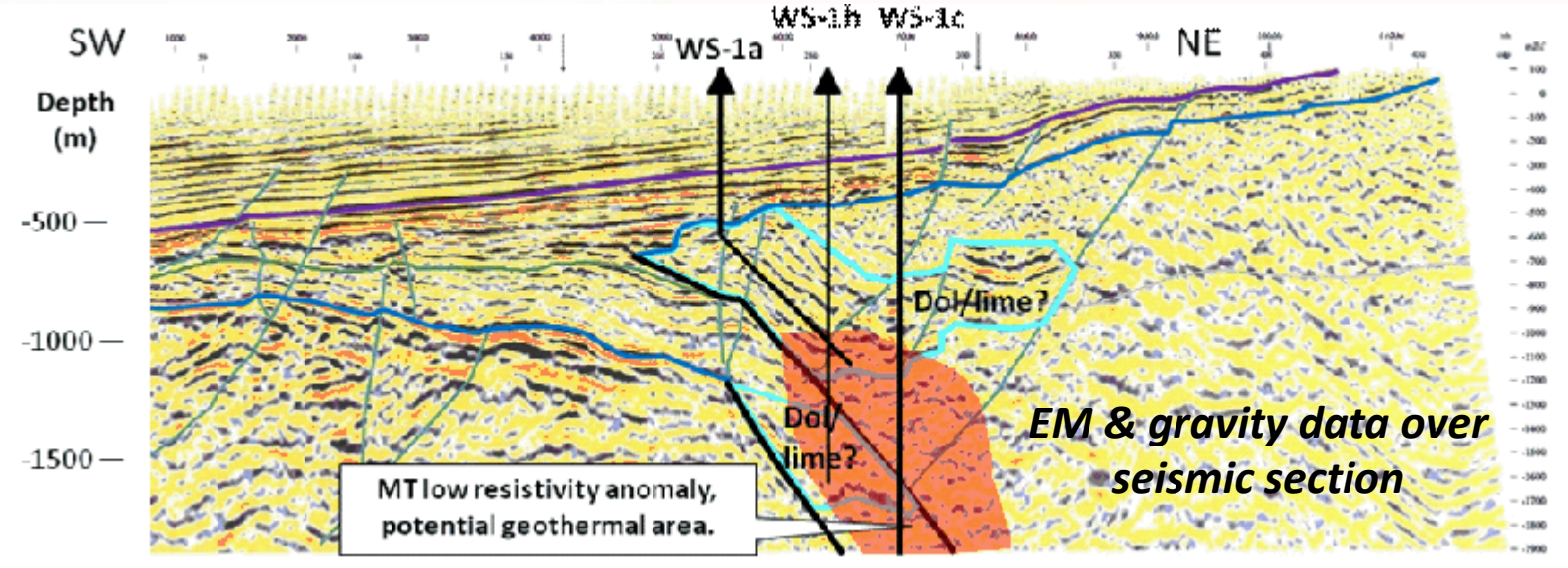




Magnetotelluric (low resistivity) & gravity (low density) to target geothermal anomaly



Hungary: Drilling gives 3 MW



- We have addressed the accuracy issue with EM system to get repeatable data
- Image focus can be improved via FSEM (similar with shallow borehole tool)
- Anisotropic 3D models are required
- → works well with monitoring & geothermal

THANK YOU


Thanks to supporters of various parts:
Aramco, DeepLook consortium (BP, Chevron, ConocoPhillips, Shell), ENI, Ormat, PTTEP, Shell, WellDynamics
…and all KMS staff.
All technology protected by US & Foreign patents
(see KMS Technologies website)
03 . 22 . 2016 10 : 44