Multi-physics geophysical acquisition system for land, borehole & marine applications

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- Objective & history
- Architecture & hardware
- Examples:
  - 11 channel MT
  - Monitoring
  - FSEM
- Conclusion

History – the first seismic- EM system

- 26 years ago EAGE Copenhagen 1990
- Seismic architecture (SRATE)
- Only for time domain CSEM
- Multi-channel
  - Multi-components (E&H)
  - High dynamic range – 27 bits
  - Limited by wired digital telemetry (1.5 km)
  - Limited by power (1 day)
  - Timing & GPS issues
- Quantum leap in processing & data volume

Rüter, H., and Strack, K.-M., 1995, Method of processing transient electromagnetic measurements in geophysical analysis, **US patent 5,467,018.**

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History – the first seismic- EM system

A New Multichannel

Transient Electromagnetic System

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26 years ago EAGE Copenhagen 1990

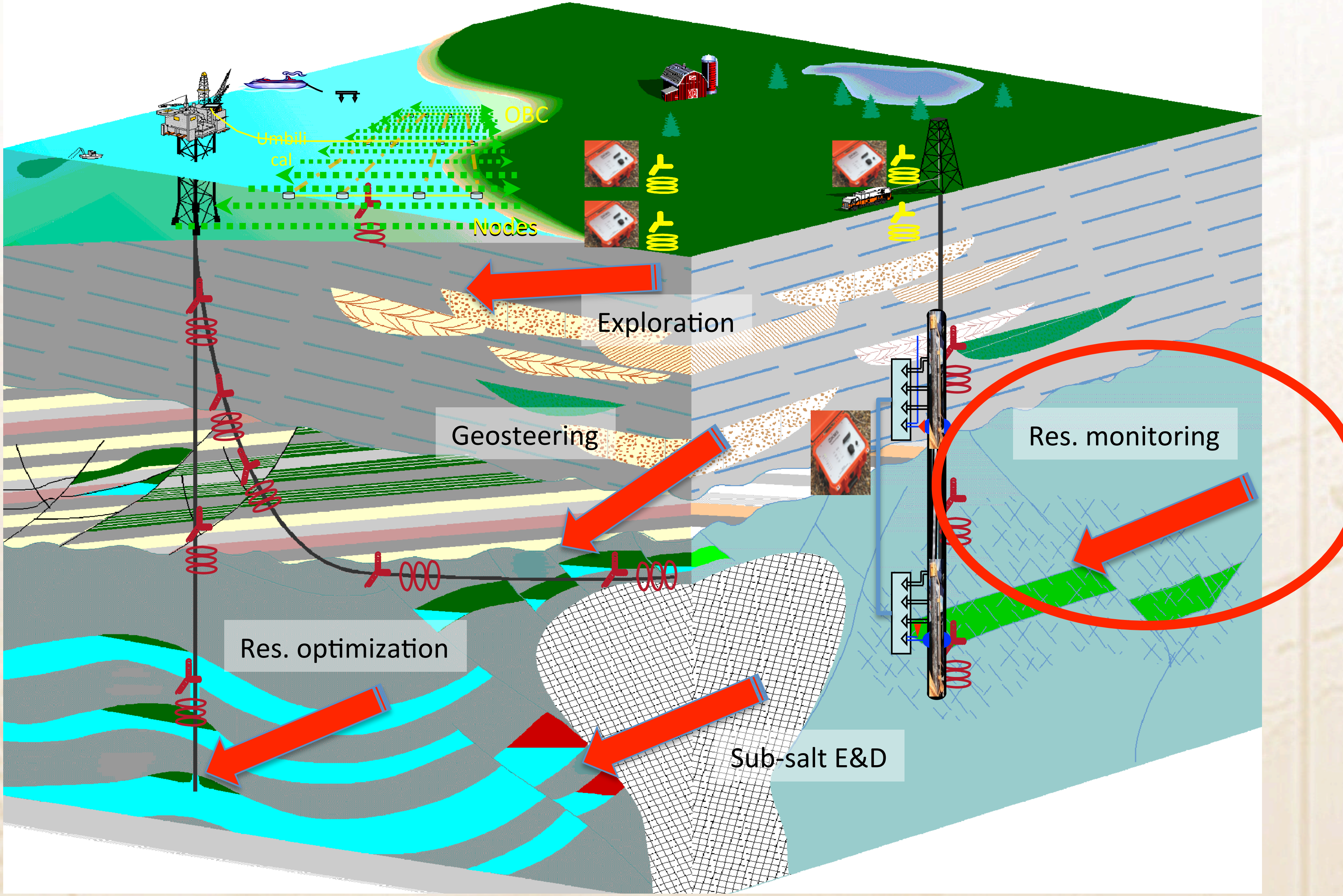
Paper presented at
52nd EAEG Meeting and Technical Exhibition
Kopenhagen, 1990

Rüter, H., and Strack, K.-M., 1995, Method of processing t
electromagnetic measurements in geophysical analysis, **U**
5,467,018.

History versus NOW

- EM & microseismics in one unit
- State-of-the-art seismic architecture (node)
  - Wireless array
  - Large memory SD cards
- EM requirements
  - Broad band (DC-80 kHz, low noise, low drift)
  - Multi-components, multi-physics
  - Transition to digital sensors- partial
  - High dynamic range
  - 8 km long range wireless & WIFI (2 types)
  - Autonomous, can record for weeks
  - GPS timing & atomic crystal (marine option)
  - Lower cost
- Processing is seismic software compatible

High value APPLICATIONS – LOW to HIGH



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EM commercial status - 2016

- Land:
  - Magnetotellurics is the 'workhorse'
  - Land CSEM rarely used
  - Industry: from **few global** → **many local** operators
  - Seismic static correction market slowly emerging (for EM)
- Borehole: EM - major contributor (hydrocarbon delineation, reserve estimates etc)
- Airborne: EM is major contributor (depth to 200-500 m)
- Marine: stable(??) market, 1 major operator

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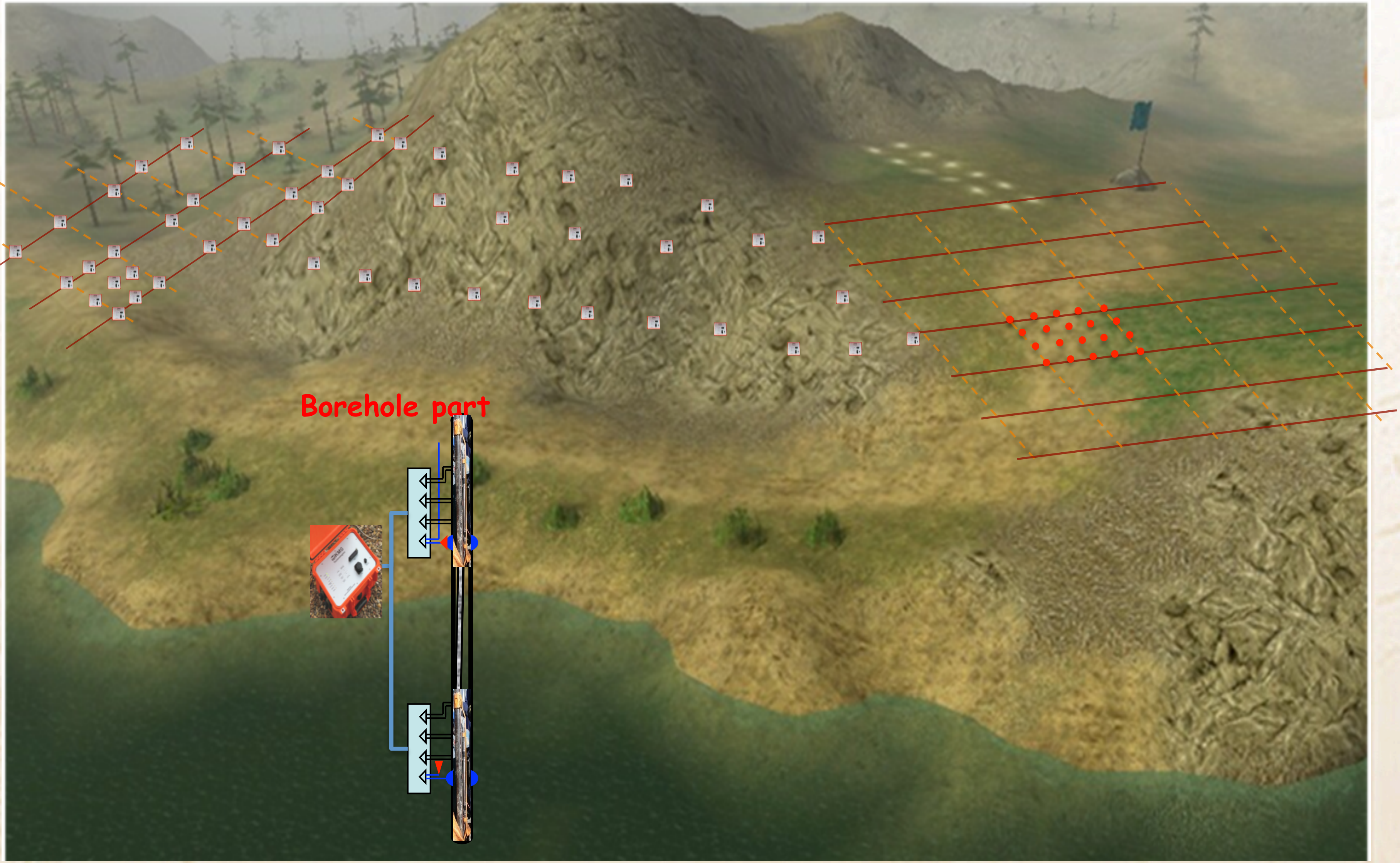
Land acquisition requirements



EM technical status

- Land:
  - Hydrocarbon apps require conductor AND resistor sensitivities
  - Smaller technical challenges: 3D, S/N etc
  - → integration requires unique TALENTS
- Borehole:
  - Induction logs (low resistivities) & Laterologs (higher resistivities)
  - Array tools extend range with large OVERLAP
  - 3D induction
  - Borehole mud gives some limitations (near surface in exploration)
  - Fully integrated into value solutions
- Airborne: mostly conductive targets; fully integrated
- Marine: in principle same as land but easier

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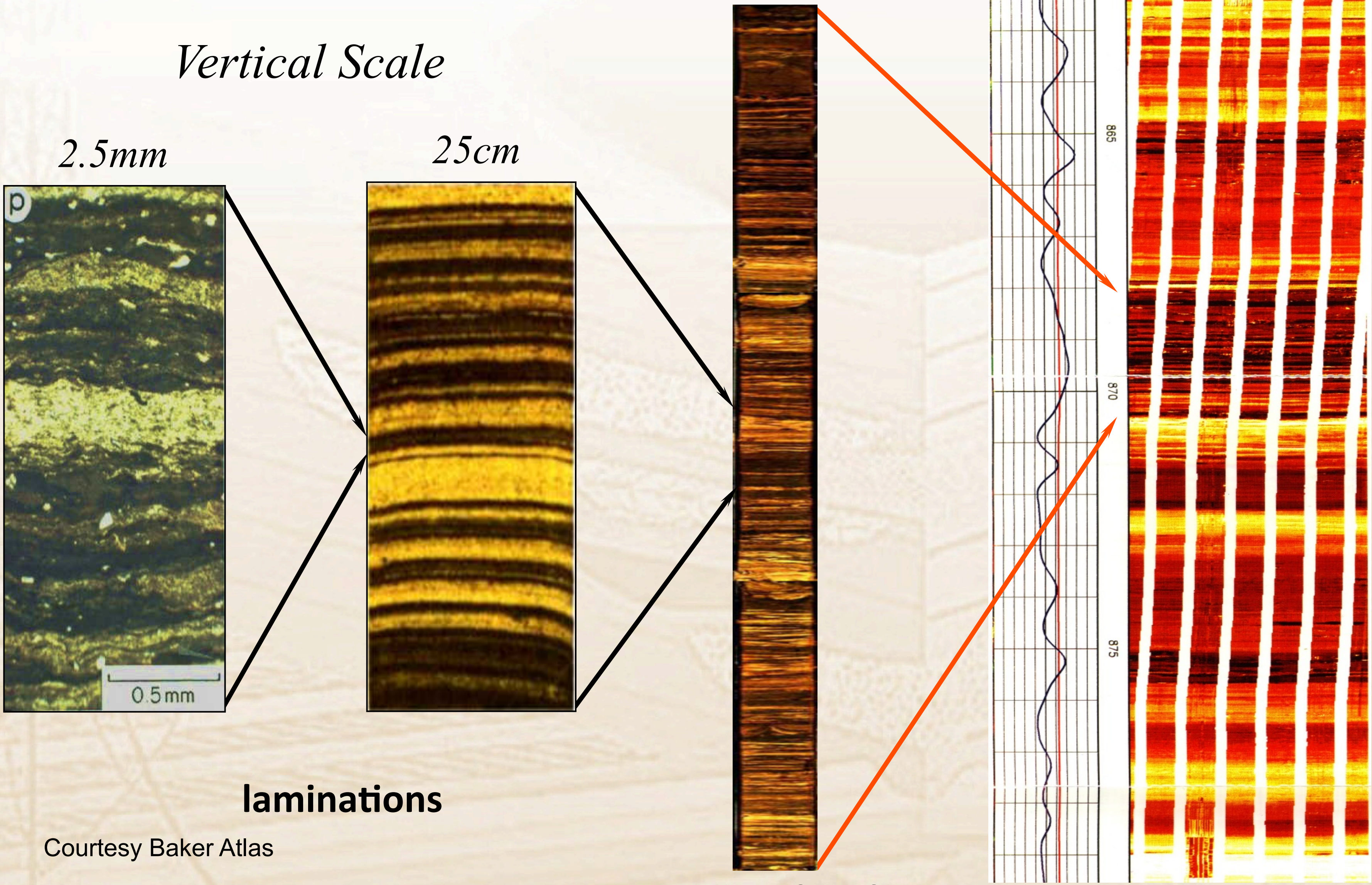
Anisotropy is EVERYWHERE



Courtesy Baker Atlas

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UNBIASED resistivities with contrainted multi-physics

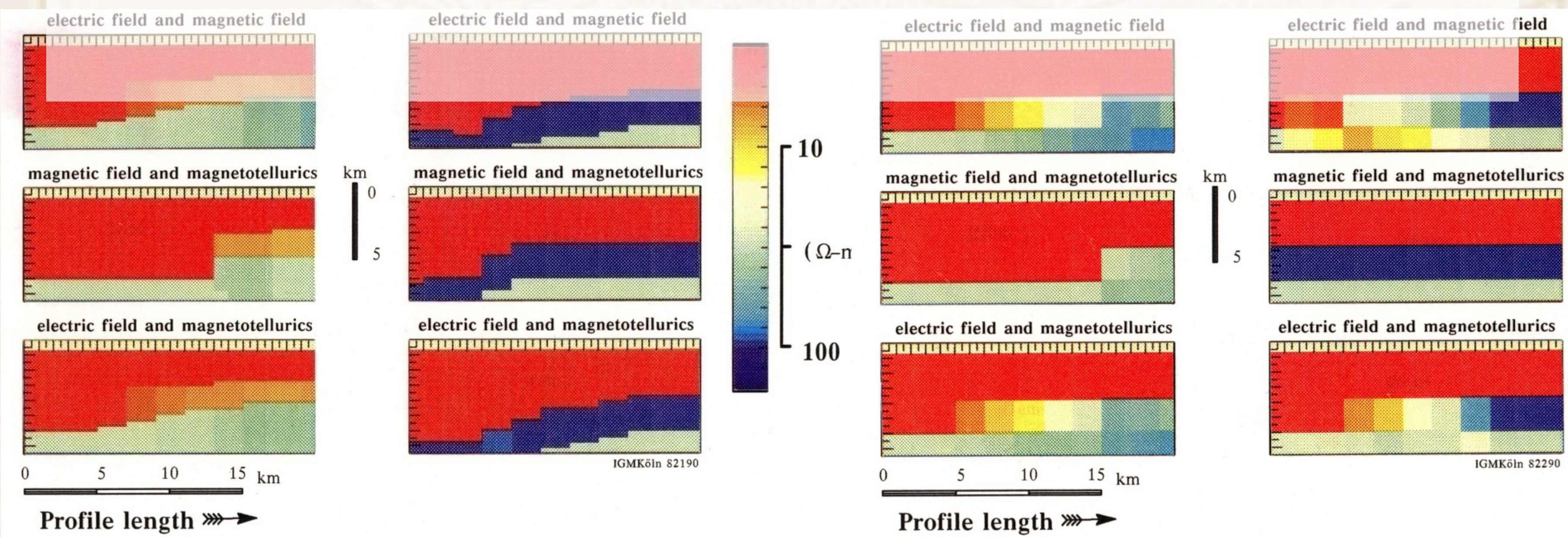
EM methods combined

EM constraint by seismic

Start w/ left log

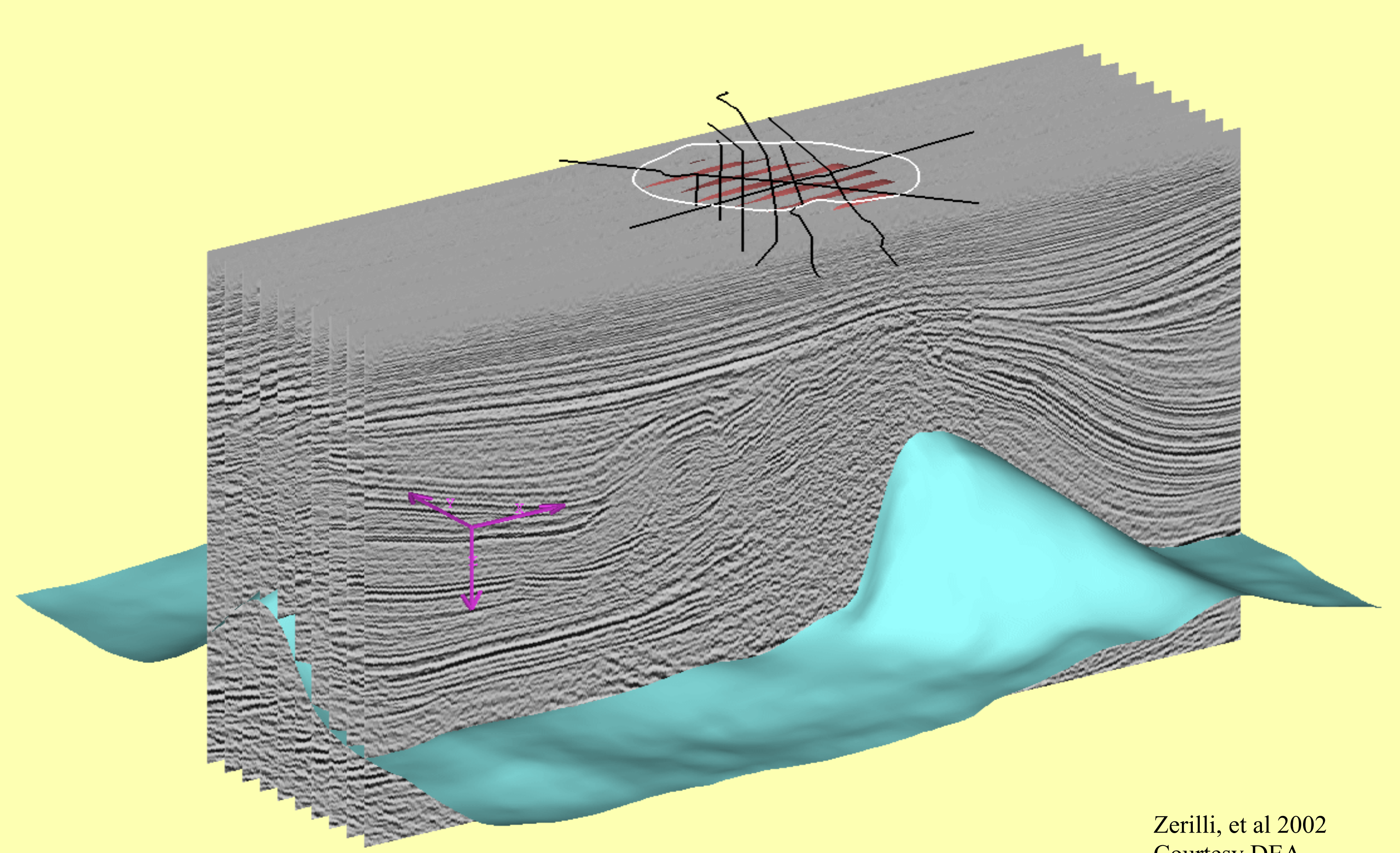
Start w/ right log

- NEED to constrain geometry → SEISMIC data
- NEED to use E and H → unbiased section



After Strack, 1992

Dense acquisition → better images



Zerilli, et al 2002
Courtesy DEA

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Architecture & hardware

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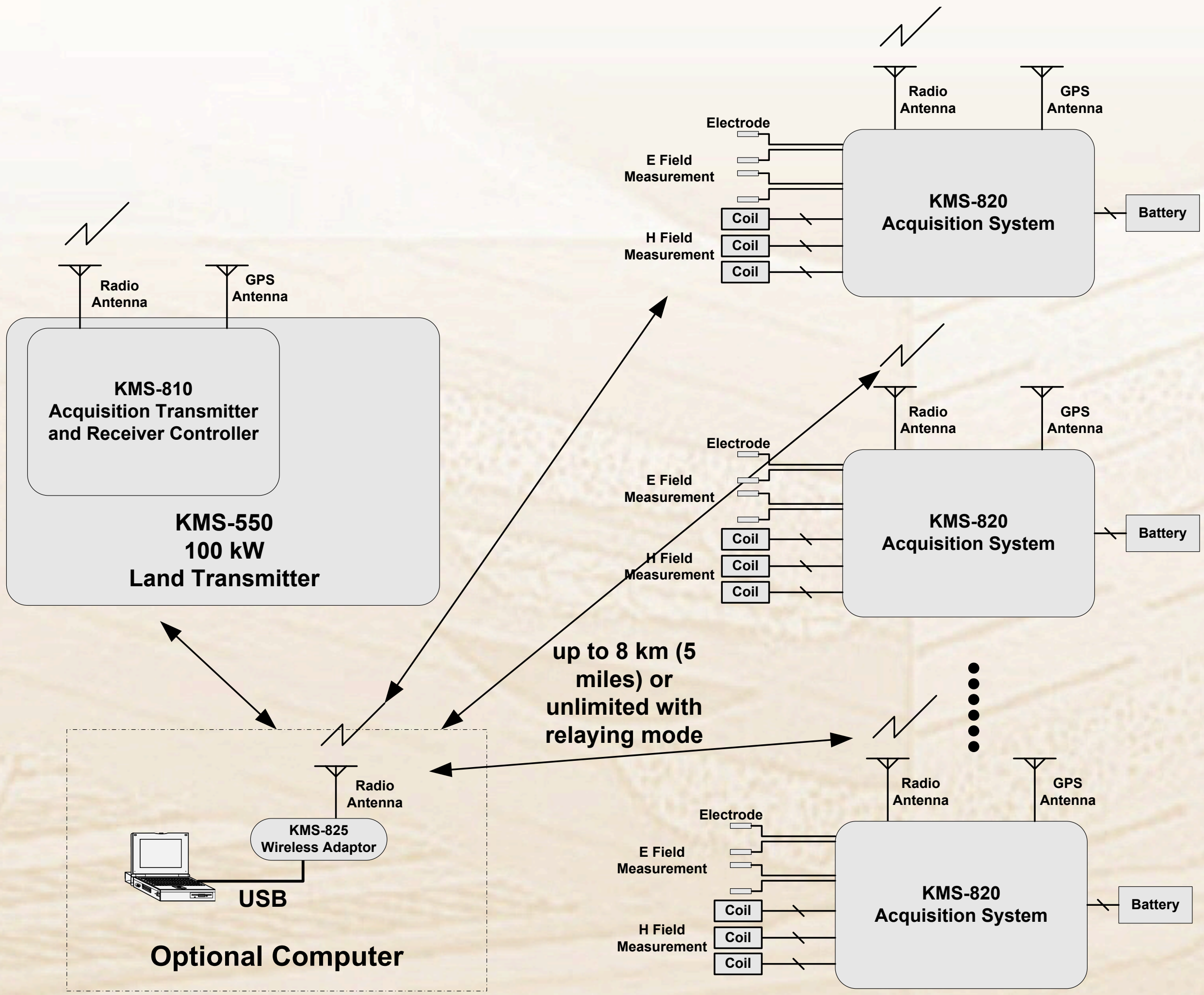
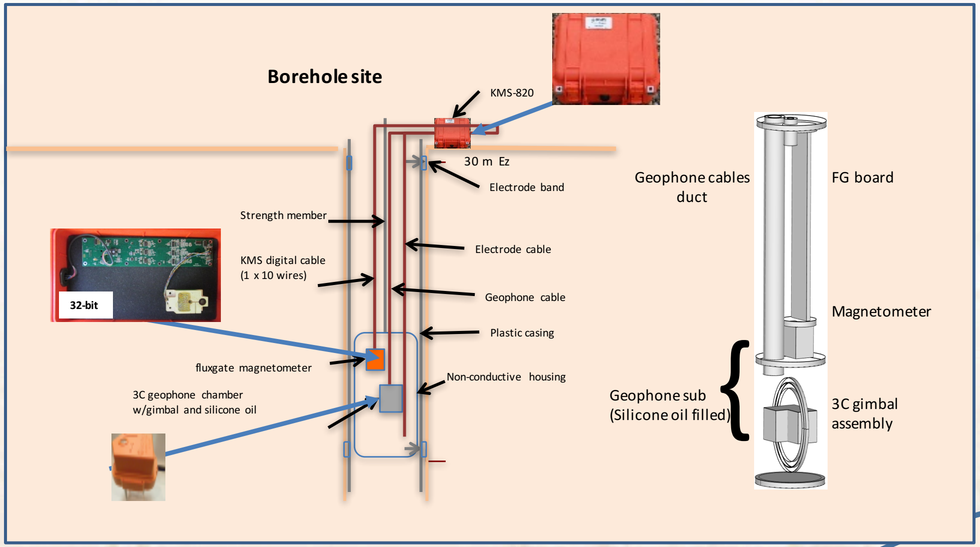
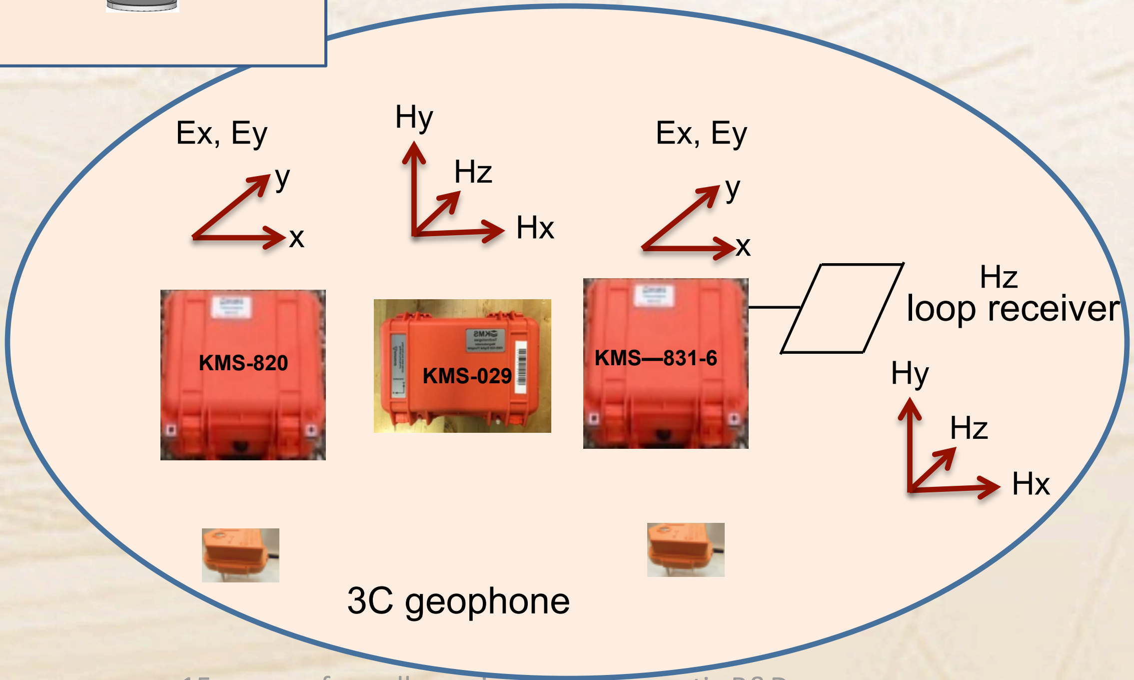
Architecture & hardware: original 2009 design



Architecture & hardware: original 2009 design





Receiver (KMS-820): for MT & CSEM

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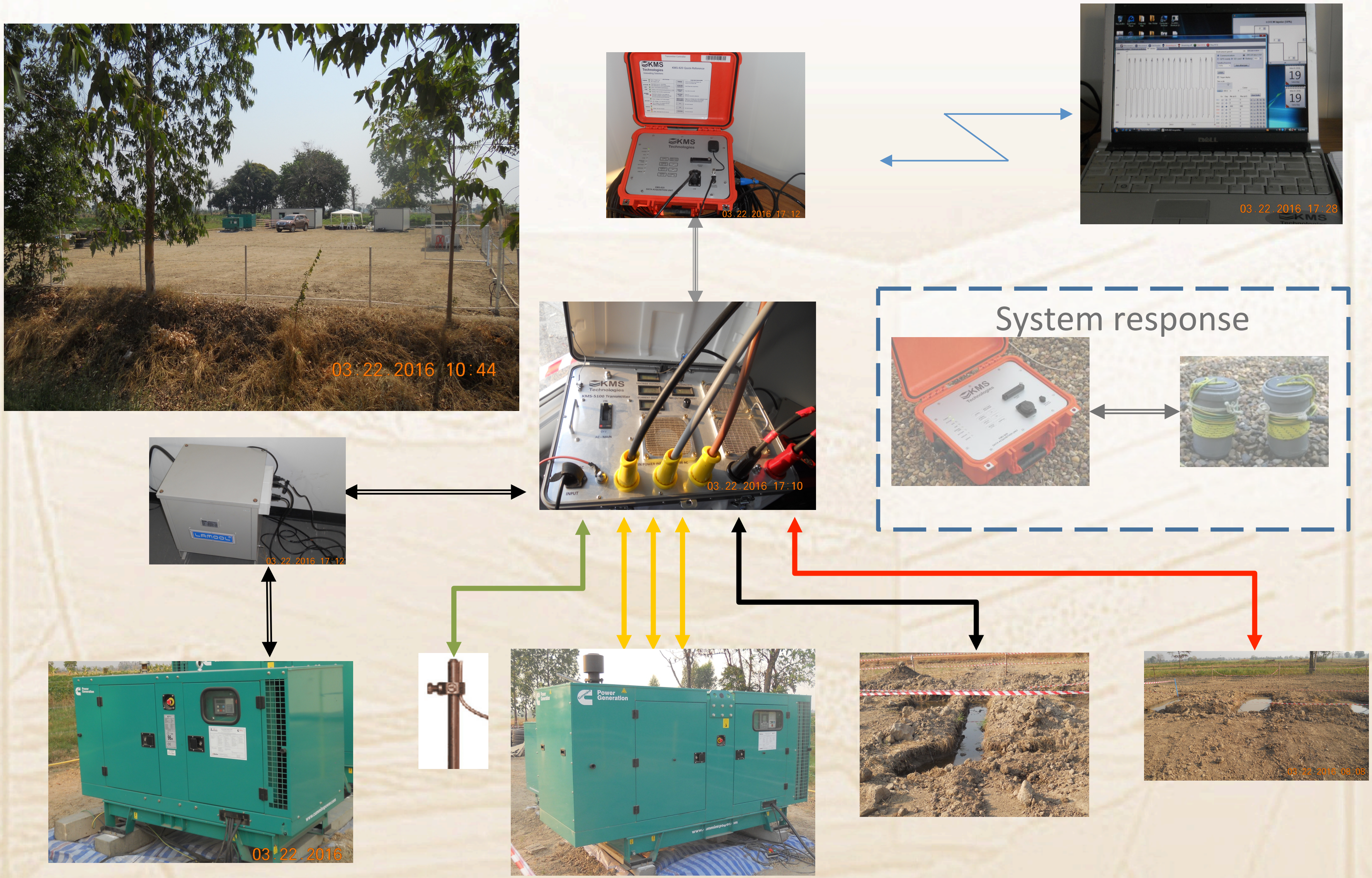
KMS-5100 Transmitter – 100 KVA 2016



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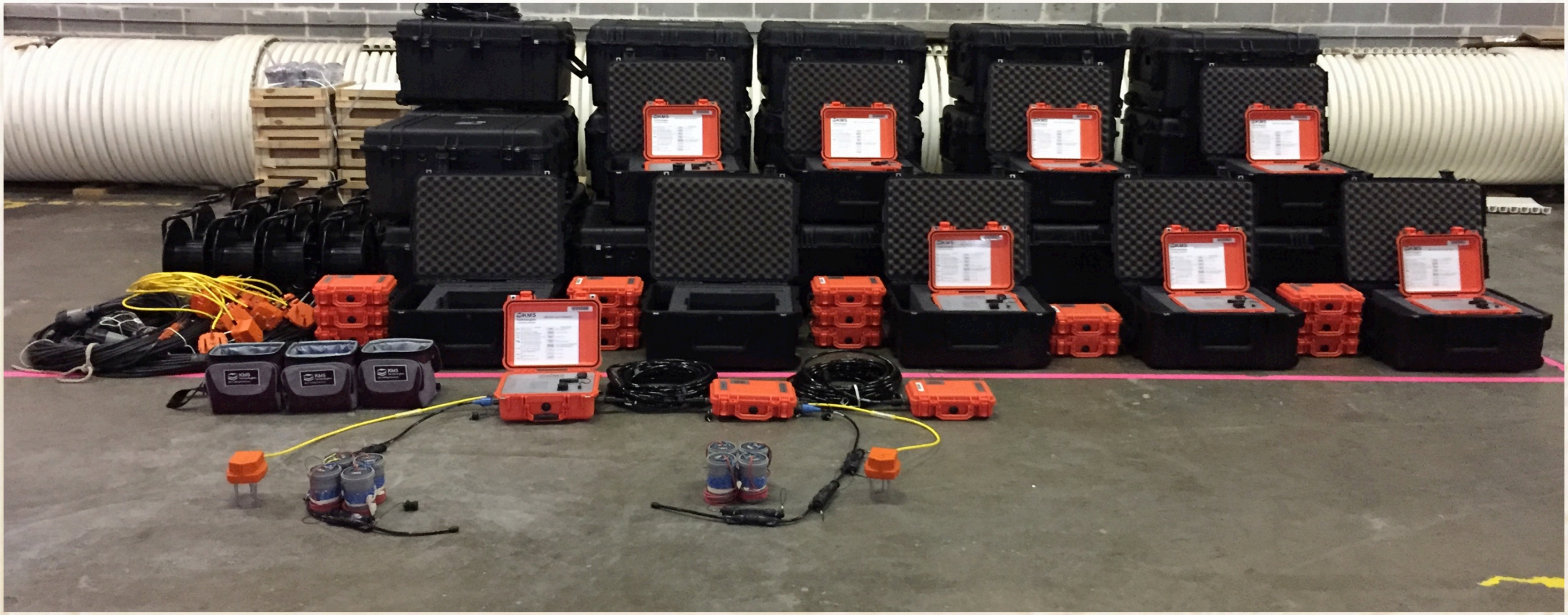
A 195 channel system



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Outline

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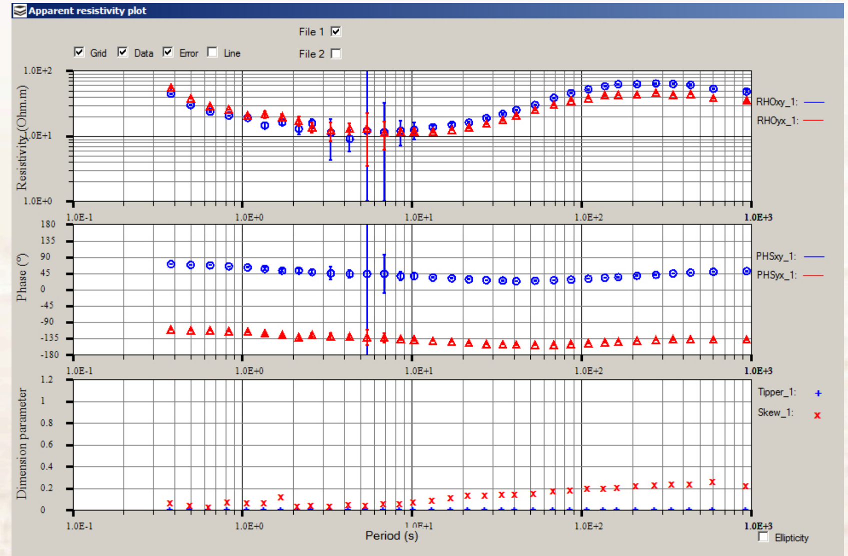
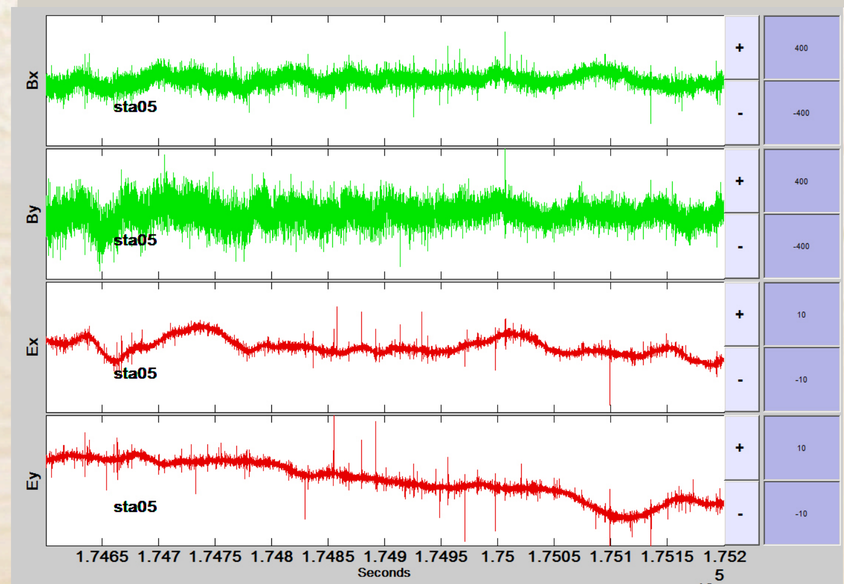
MT data example: KMS 820 data

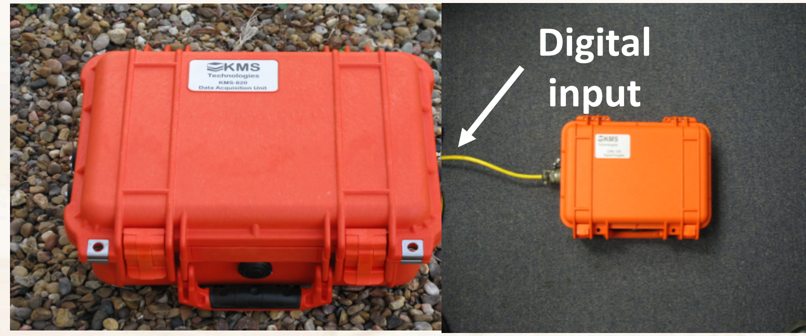




MT: Digital 3-C fluxgate magnetometer:

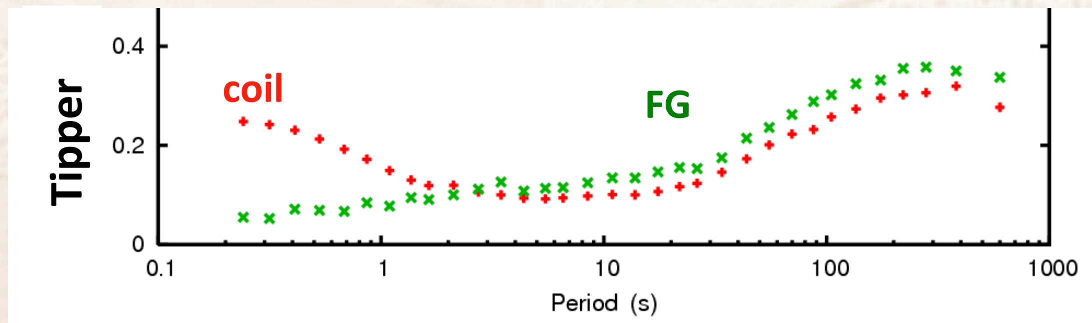
Analogue input (6 ch)

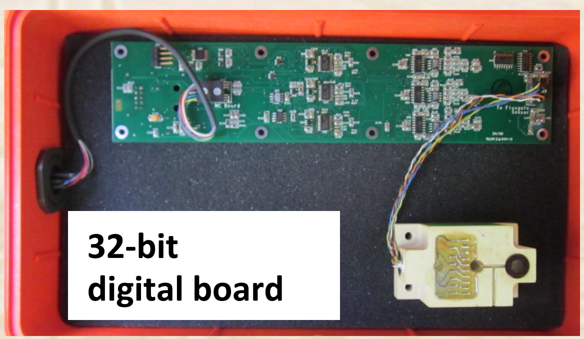
- MT: Hx, Hy, Hz, Ex, Ey

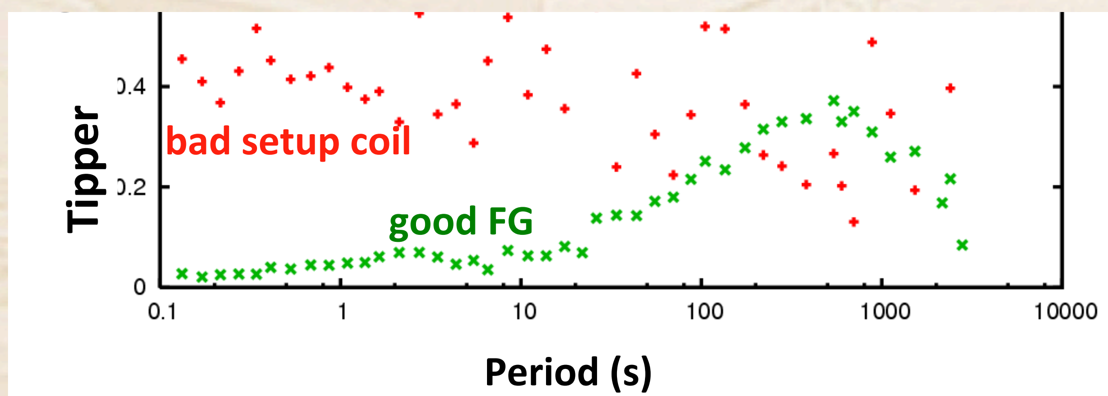


Fluxgate magnetometer

- Digital 32 bit,
- 3 components
- DC to 180 Hz
- Use for Tipper – less digging
- Lower cost







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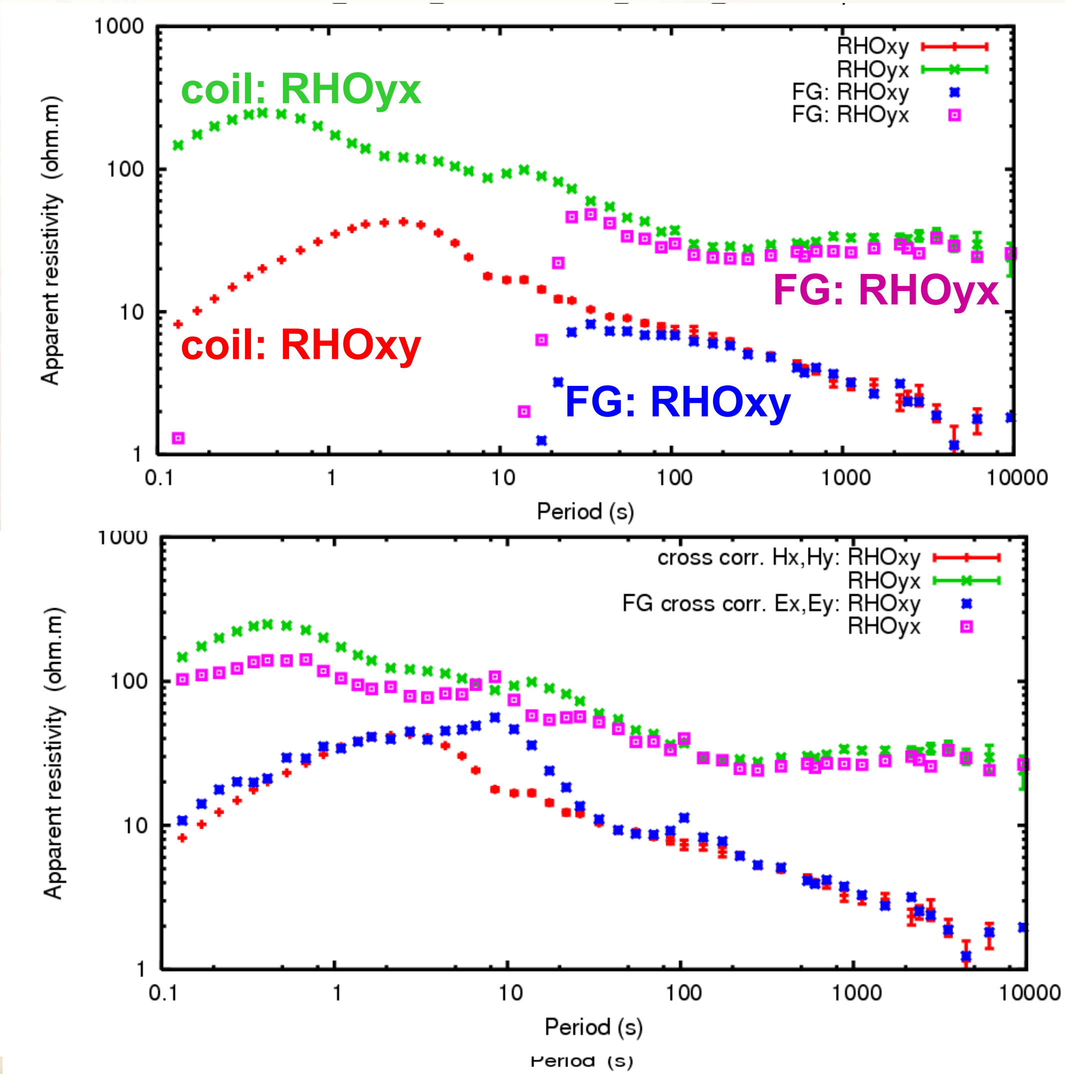
MT: Fluxgate magnetometer & induction coils



Standard transfer function estimation

(using H)

Improved transfer function estimation

(using E)

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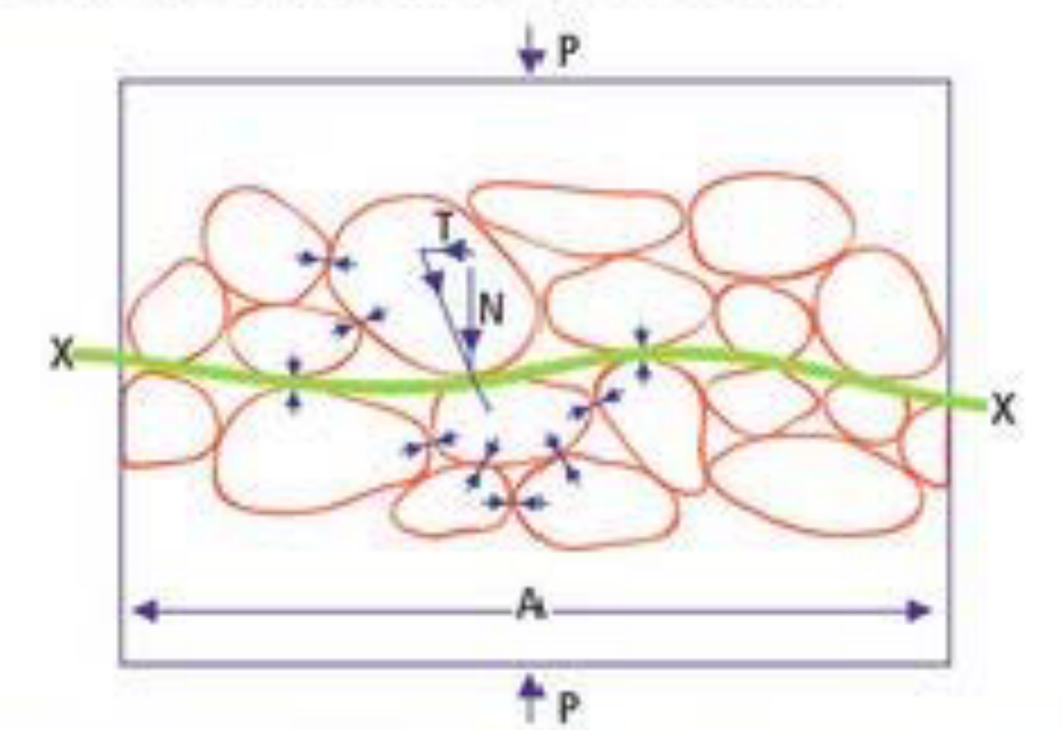
Reservoir Monitoring: Reservoirs seal: EM & microseismic - effective stress



- 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

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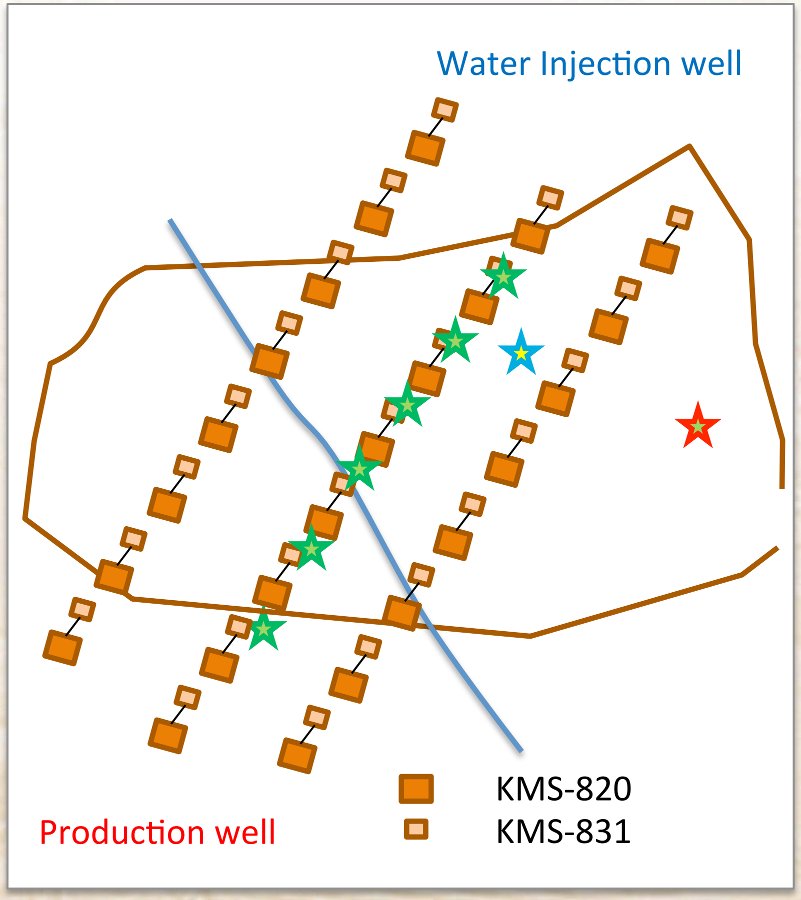
Reservoir Monitoring: Example layout



Microseismic sensors

Site	MODULE	Ex-Ey	Ez	Hz	3C fluxgate H	3C geophone
■	KMS-820	x		x	x	x
□	KMS-831	x				X
★	SBHT	x	x		x	x

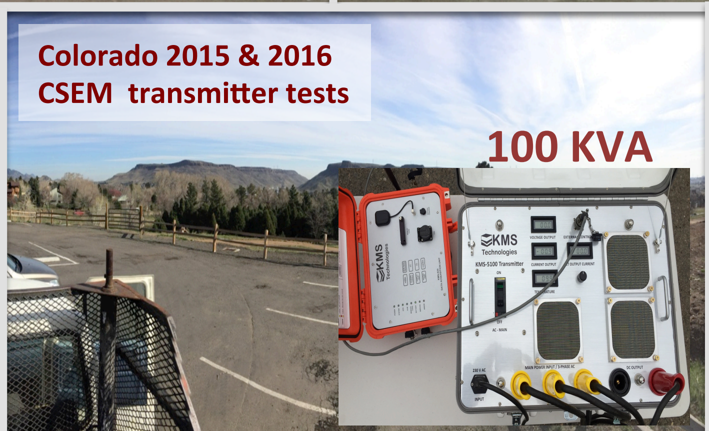
E – electric field sensors
H – magnetic field sensors

Reservoir Monitoring: 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)



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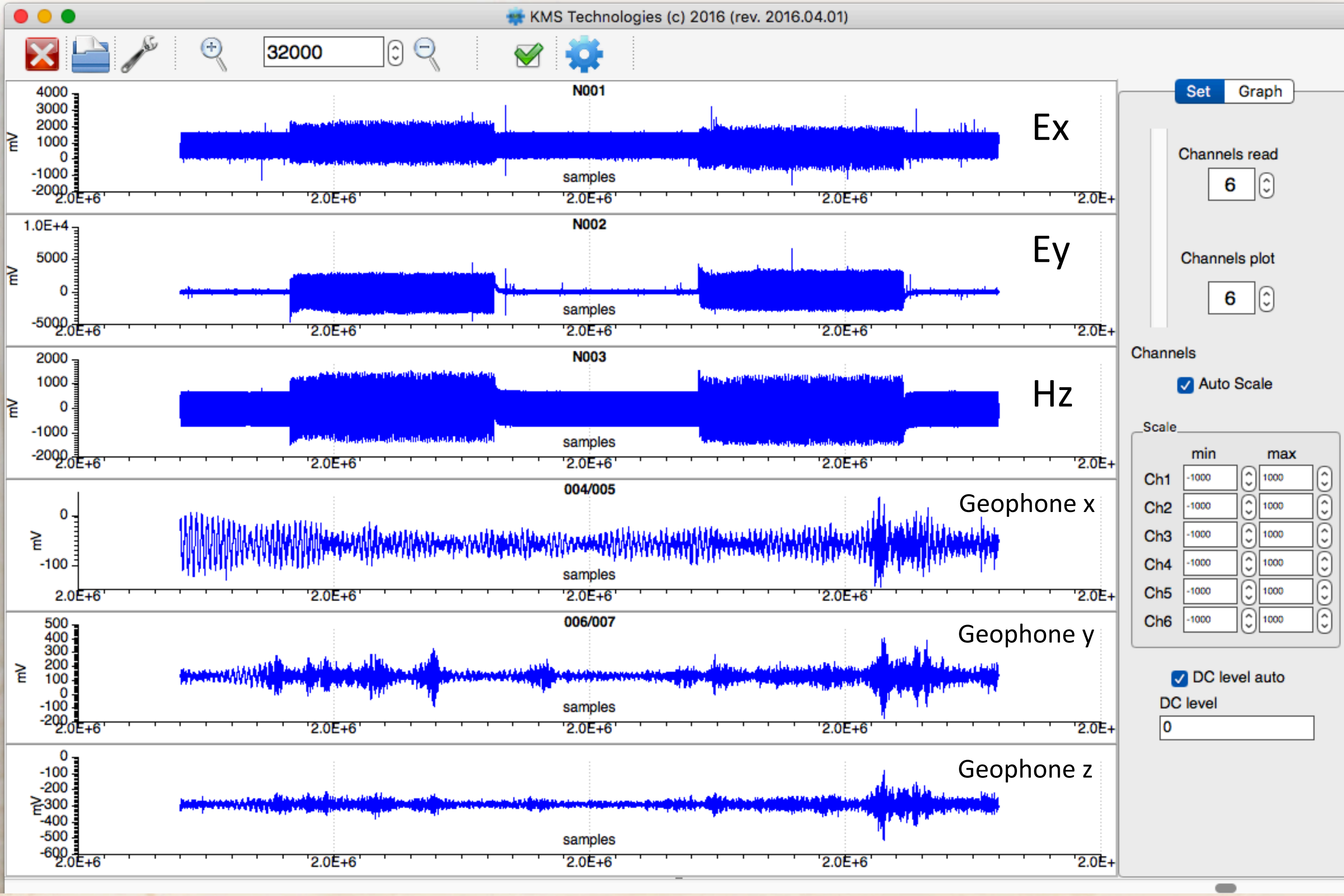
Reservoir Monitoring: Raw data example: microseismic/EM monitoring



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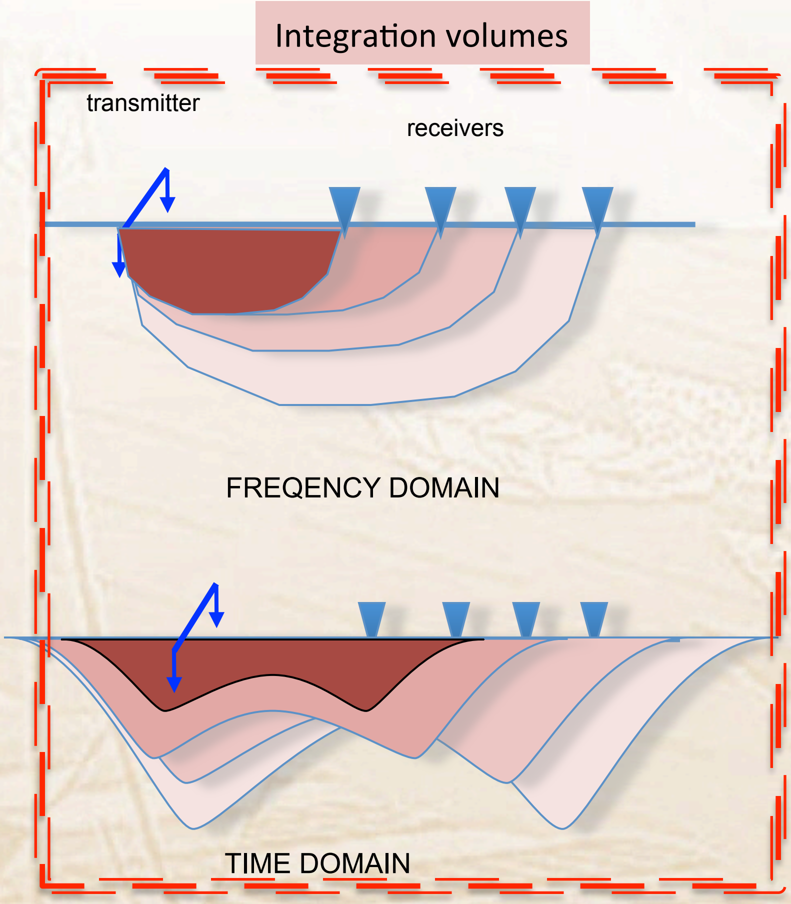
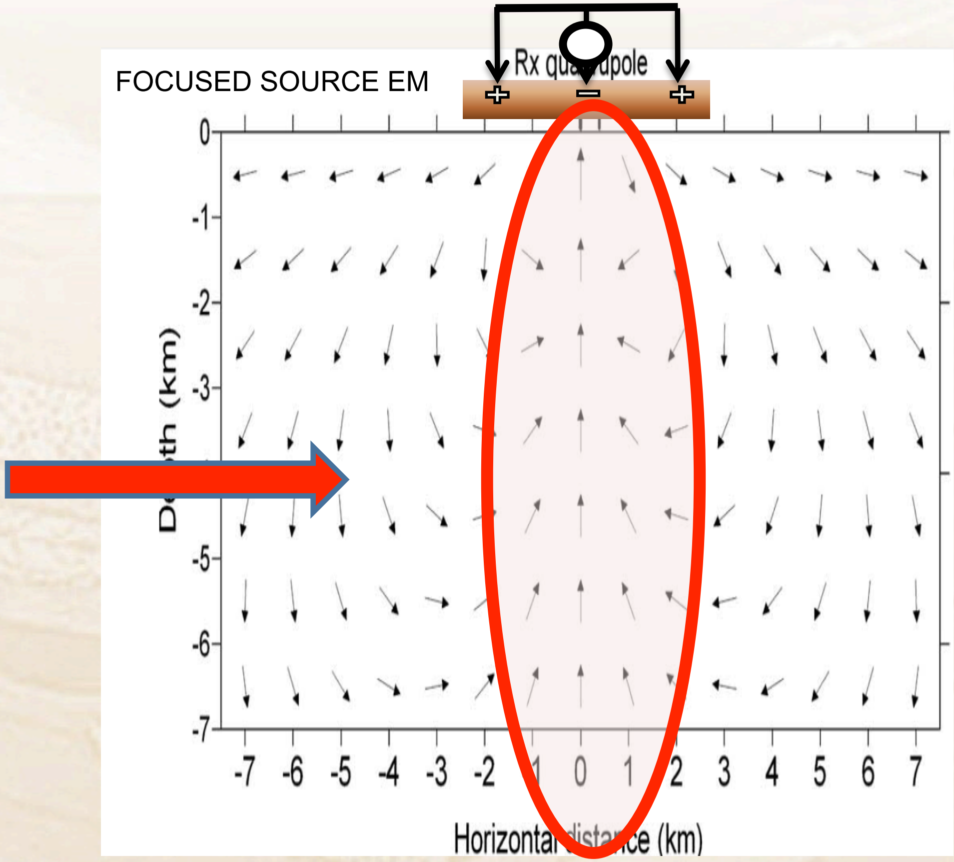
FSEM: Focused source solution to volume imaging

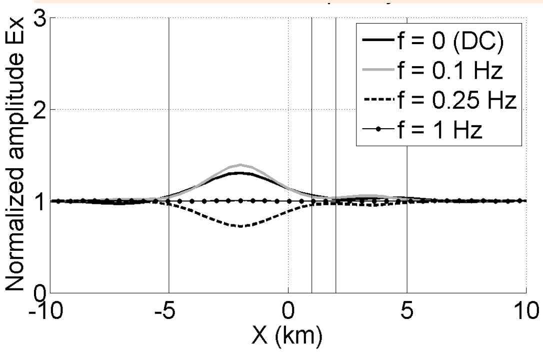


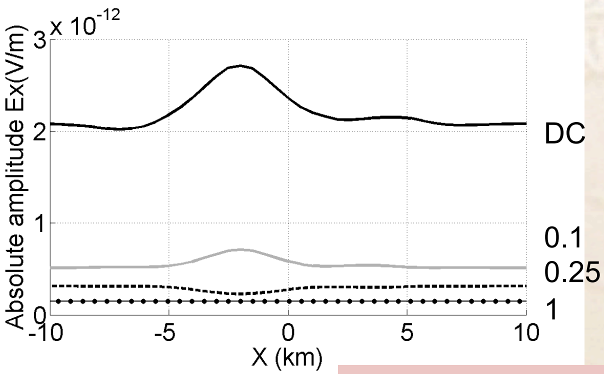


Rykhlinskaya, E., & Davydycheva, S., 2014, U.S. Patent 8,762,062 B2.
Davydycheva, S., 2016, U.S. Patent Application US 2016/0084980 A1.

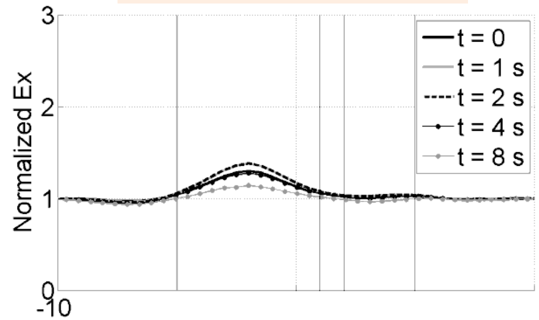
FSEM: Focused source solution to volume imaging

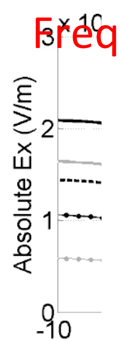
Frequency domain CSEM



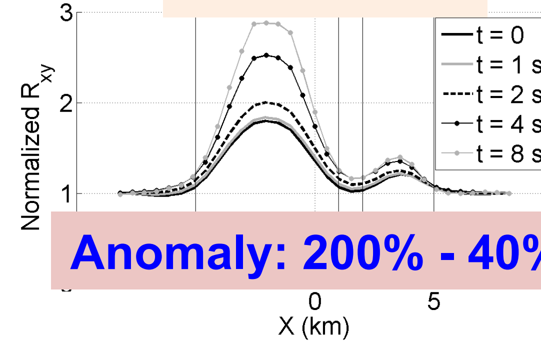


Time domain

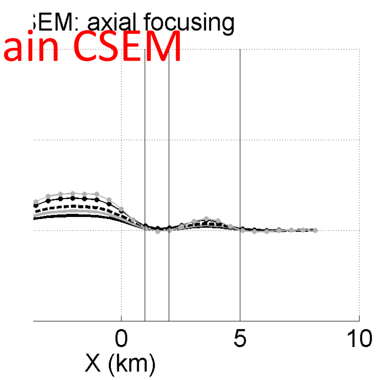




Focused EM

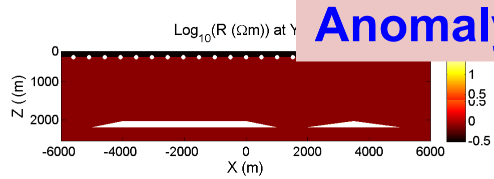


Anomaly: 200% - 40%

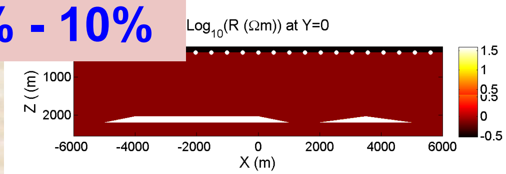


Frequency domain CSEMFrequency domain CSEM

- **Smaller reservoir can be detected**
- **Higher spatial resolution**



Anomaly: 40% - 10%



Two reservoirs 2 km below mudline

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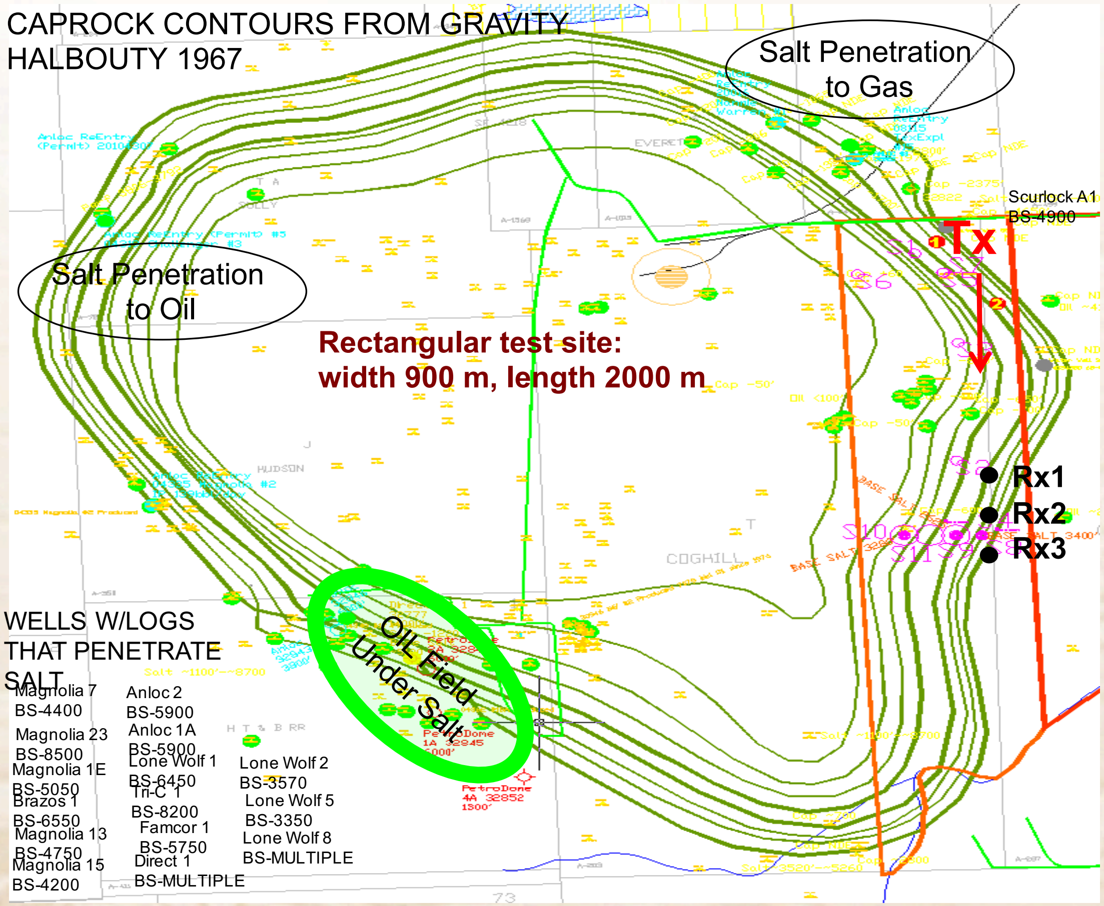
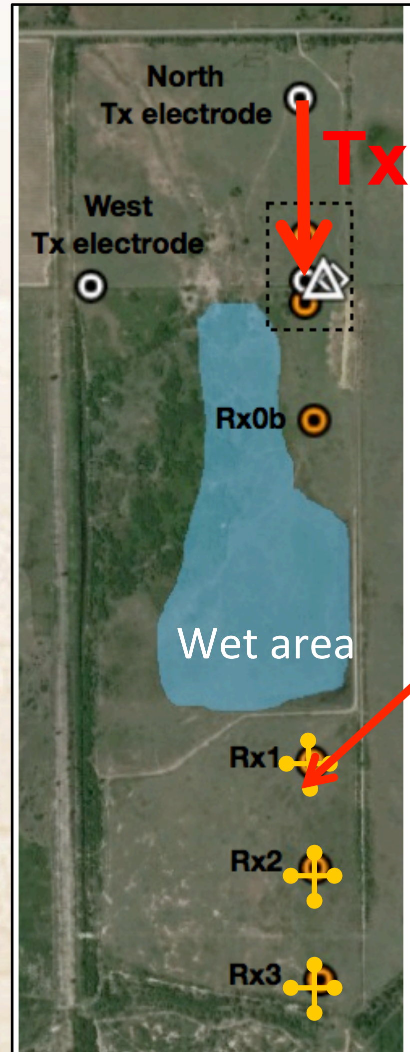
FSEM: Objectives FSEM example salt dome

- Proof that FSEM focuses the image below the receivers on a 3D structure
- Test data was acquired by KMS in 2015 at 2 occasions: 3D structure = salt dome Hockley
- Data was modeled in 3D - Anisotropic
  - Normal CSEM
  - FSEM processed data
- Verification of results with Lease Owner

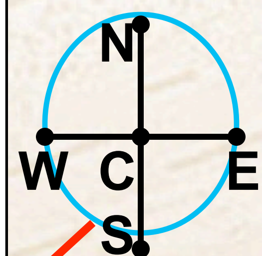
FSEM: Focused Source EM: Survey setting





Tx North: -340 m
(29.9659° 95.8274°)

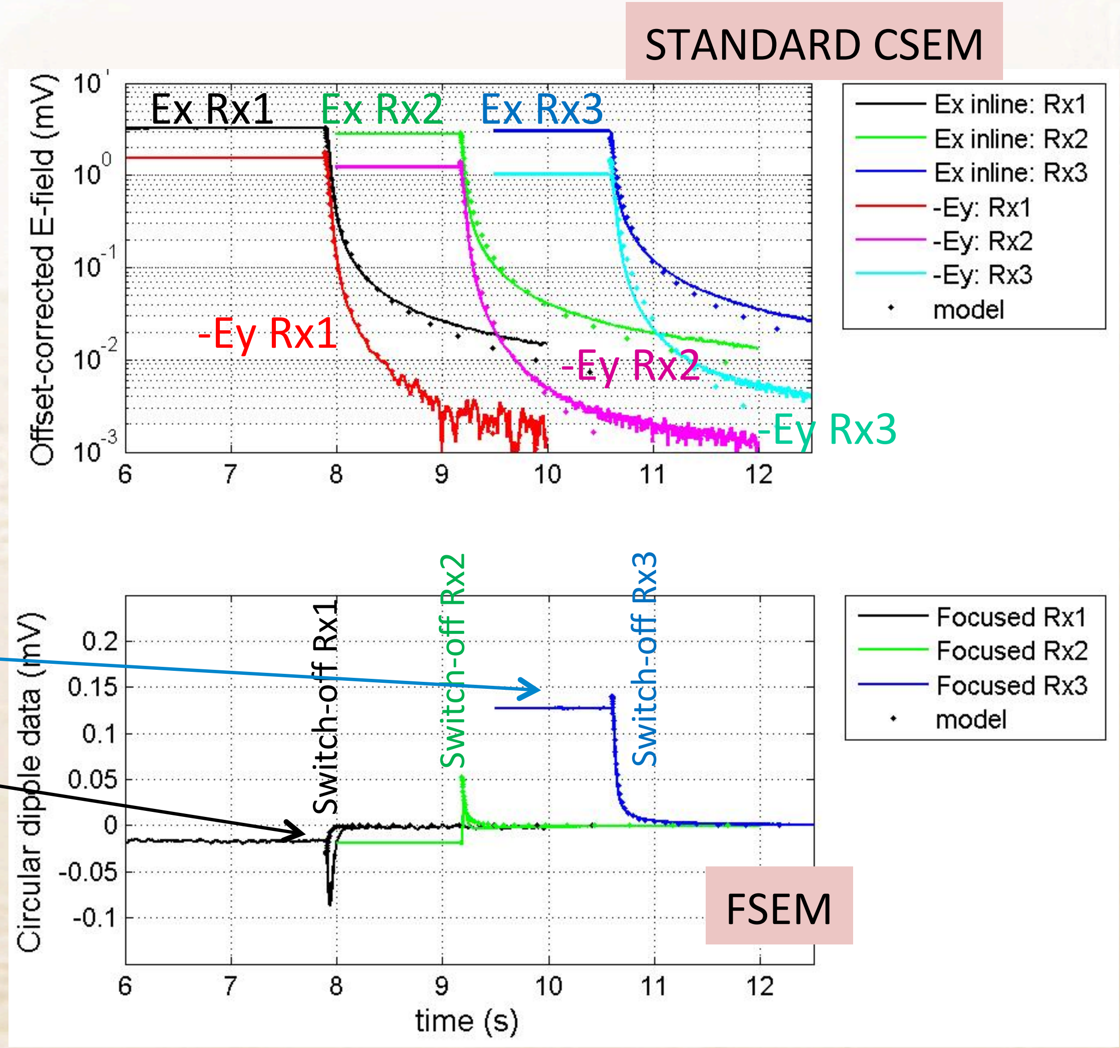
Tx South: 0
(29.9628° 95.8273°)



900 m
(29.9547° 95.8272°)
1100 m
(29.9529° 95.8271°)
1300 m
(29.9510° 95.8271°)

FSEM: Measurements vs 3D model: transients in Rx1, Rx2, Rx3

- Offset-corrected data (lines) vs model (dots)
  - DC levels: checked to 1 nV
  - Time-decay curves
- Ex (inline) & Ey (cross-line):
  - In all receivers: similar time-decay
  - Ey is comparable to Ex because at the edge of the salt dome currents tend to turn around its corner(s)
- Circular dipole data:
  - Show focused vertical current
  - All receivers behave different:
  - **Rx3** is NOT above salt: vertical current is positive
  - **Rx2 & Rx1** are above salt: vertical current is negligible (model) or even slightly negative (data)
  - Difficult to match "zero current down" above shallow resistor
  - Difficult to match the data wiggles at early times (shallow effects)



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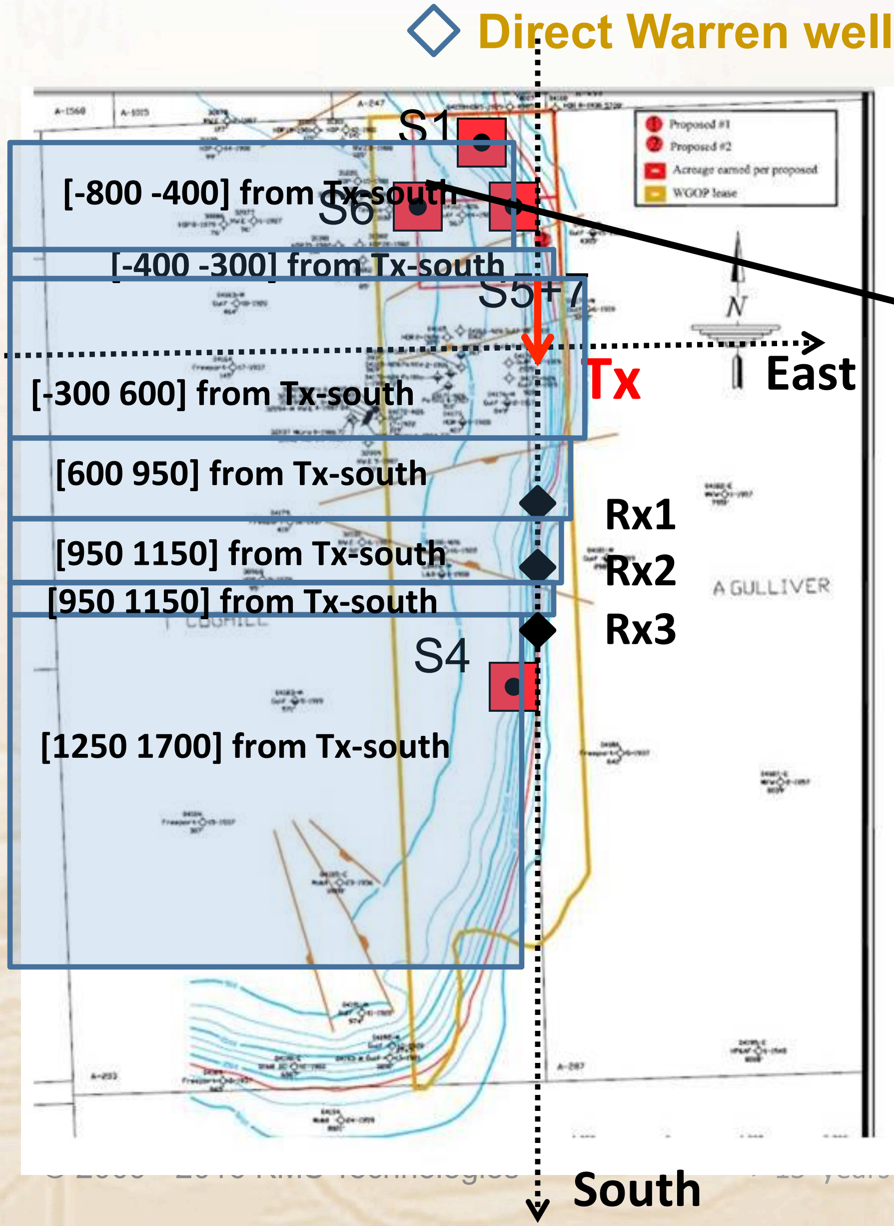
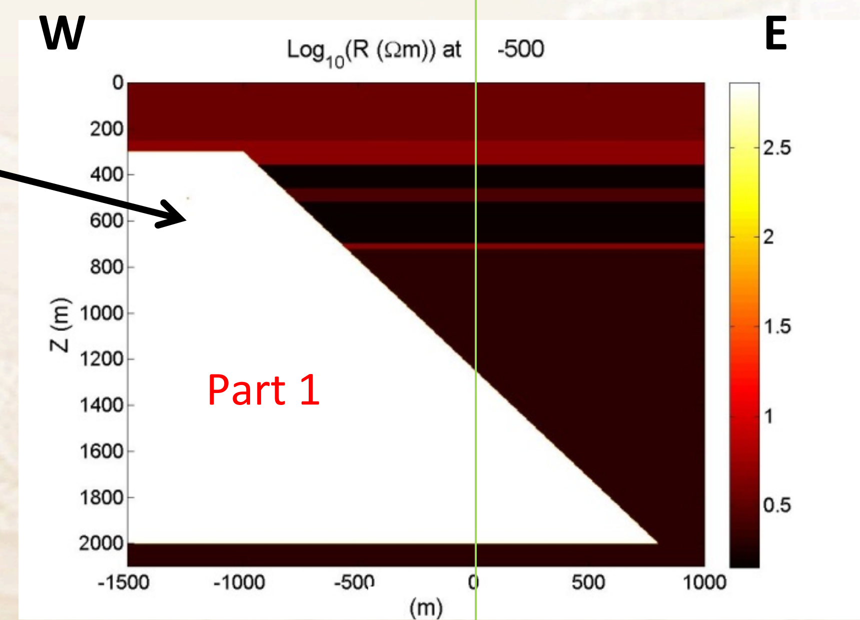
FSEM: 3D model (best) of salt dome (Part 1)

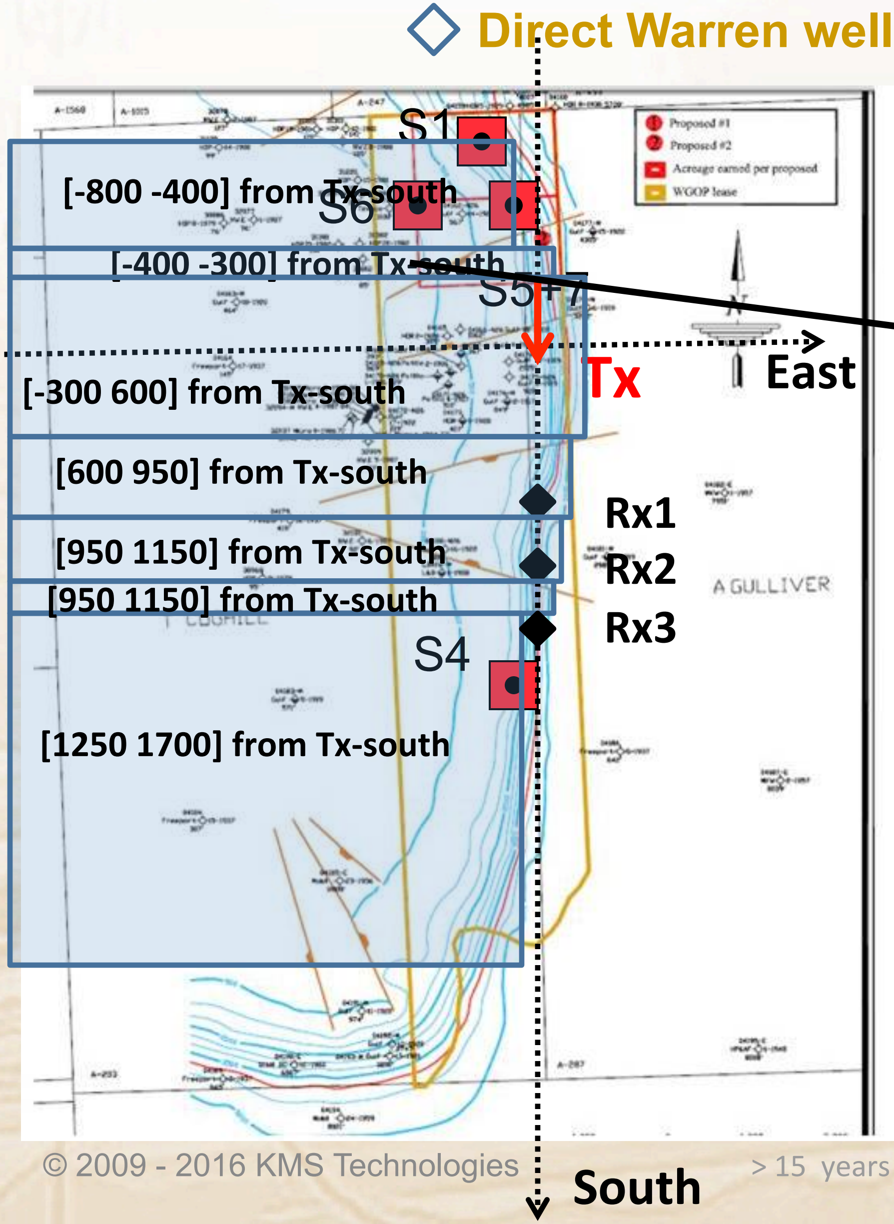
- Best matching salt dome model derived
- It consists of 7 parts

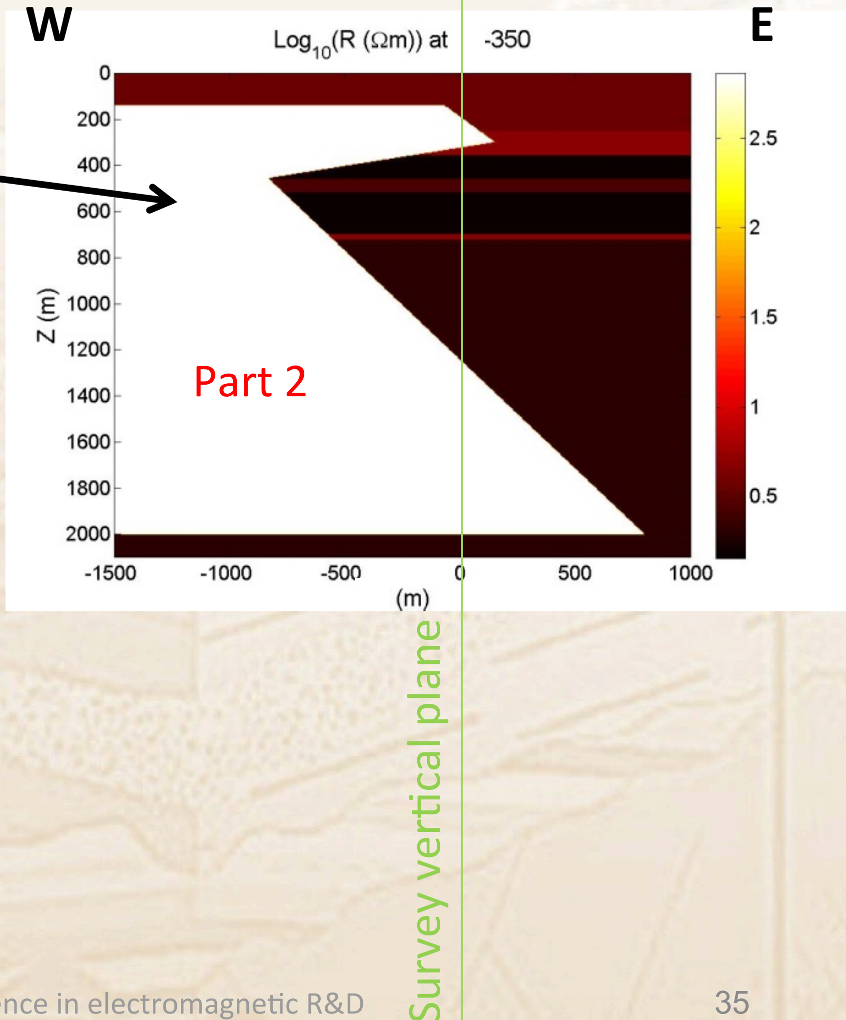




FSEM: 3D model (5) of salt dome (Part 2)

- Best matching salt dome model derived
- It consists of 7 parts





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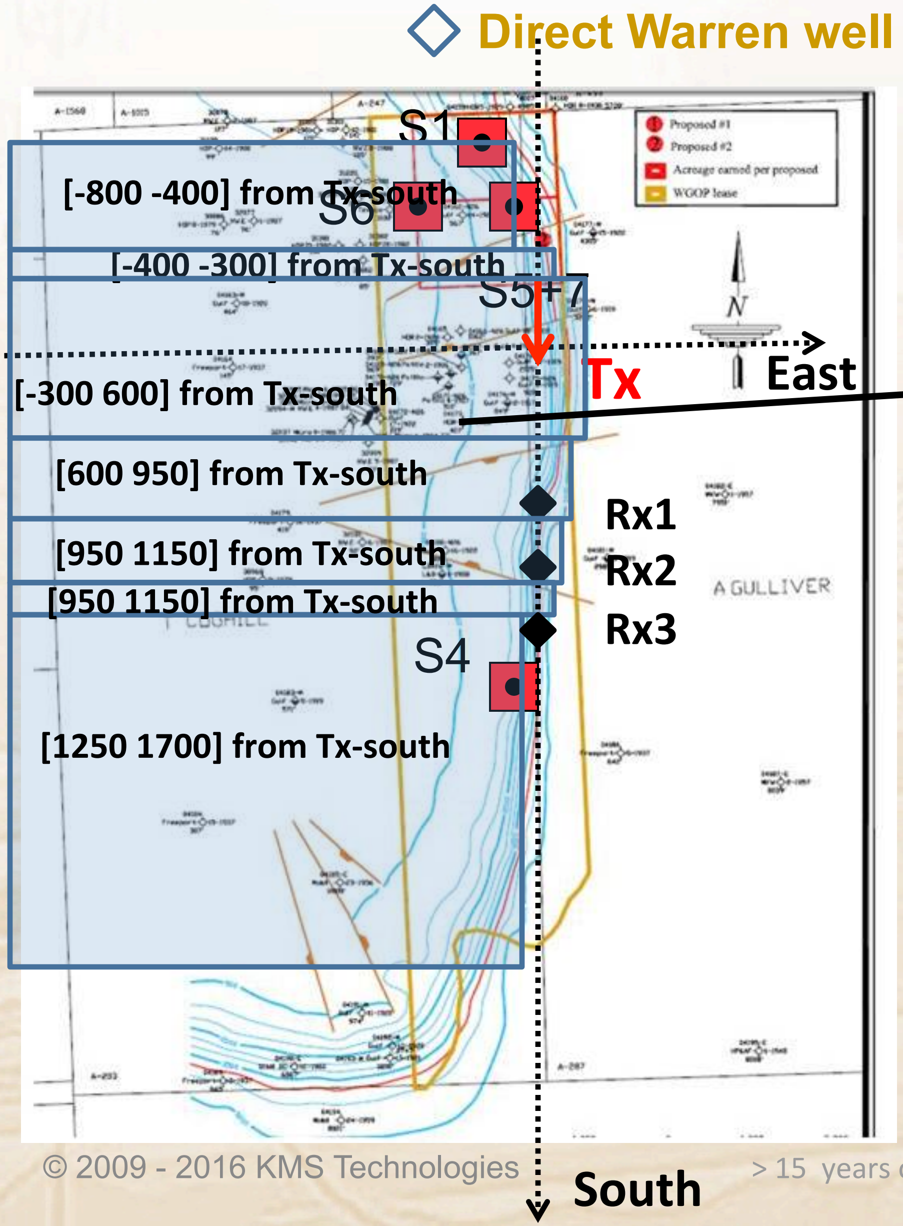
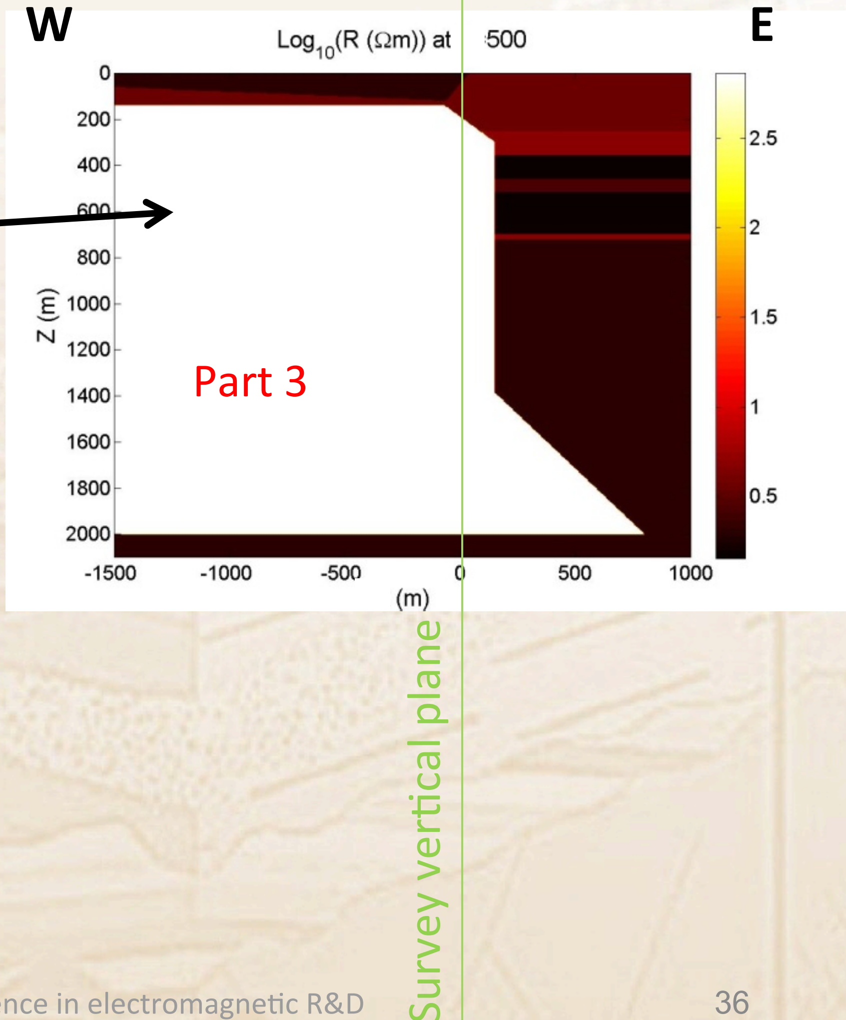
FSEM: 3D model (5) of salt dome (Part 3)

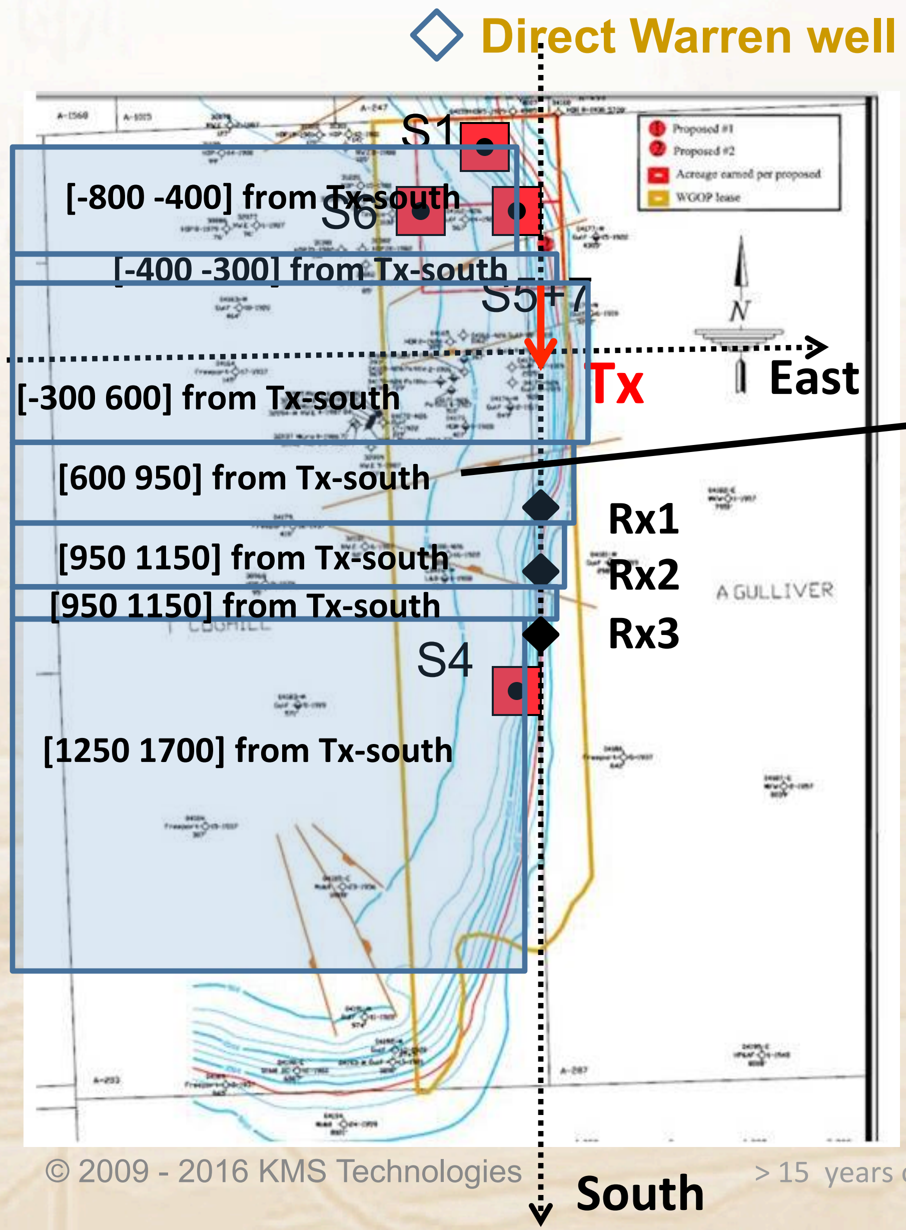
- Best matching salt dome model derived
- It consists of 7 parts

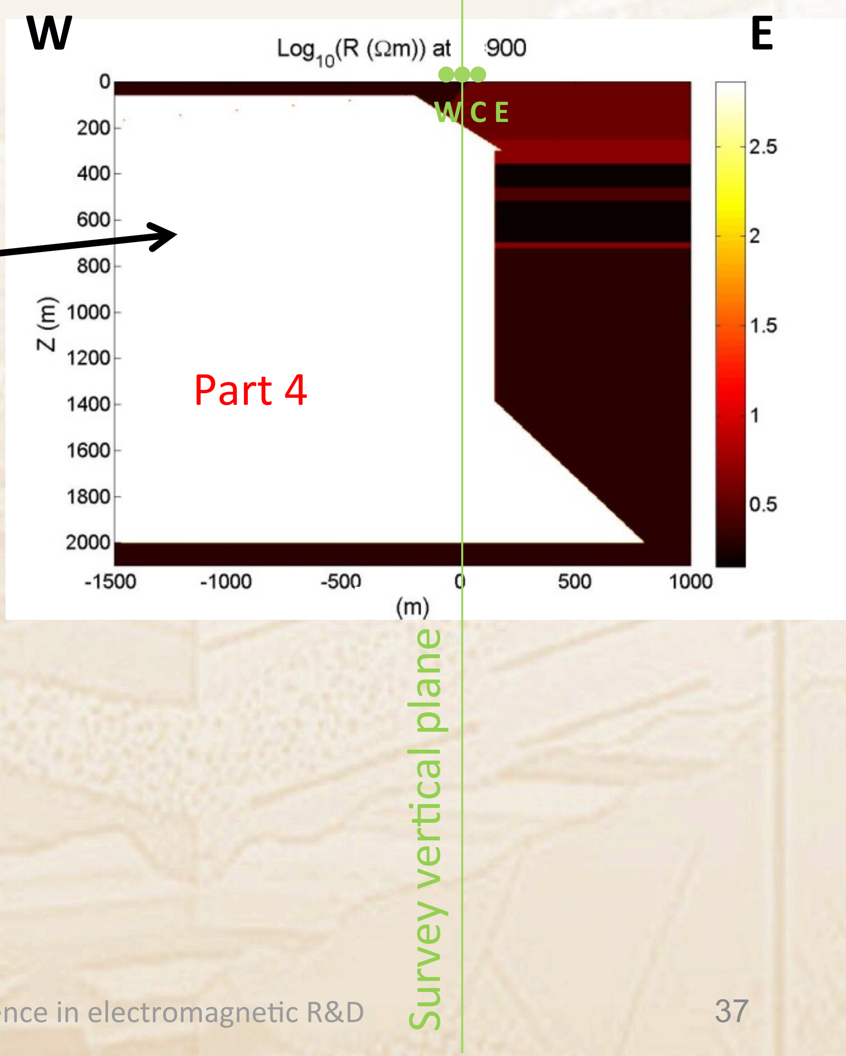




FSEM: 3D model (5) of salt dome (Part 4)

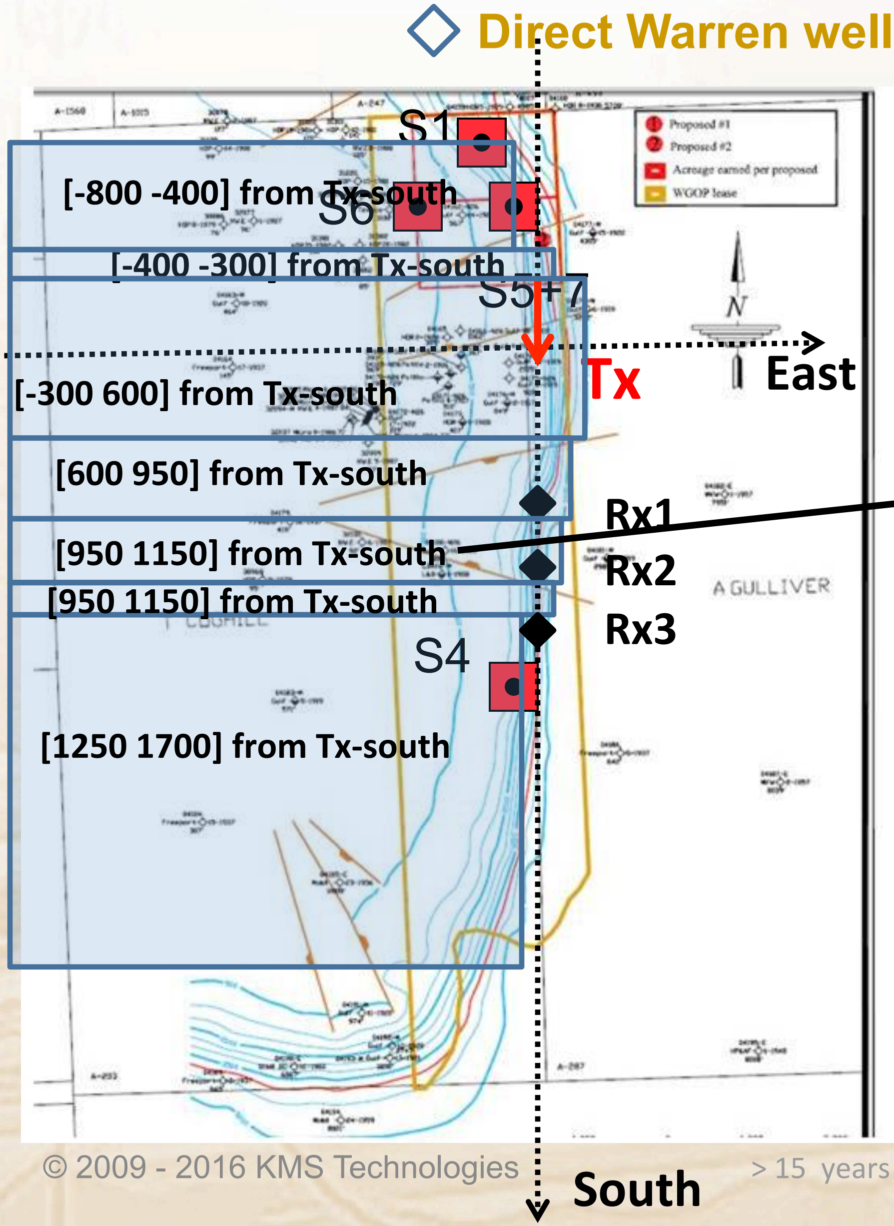
- Best matching salt dome model derived
- It consists of 7 parts

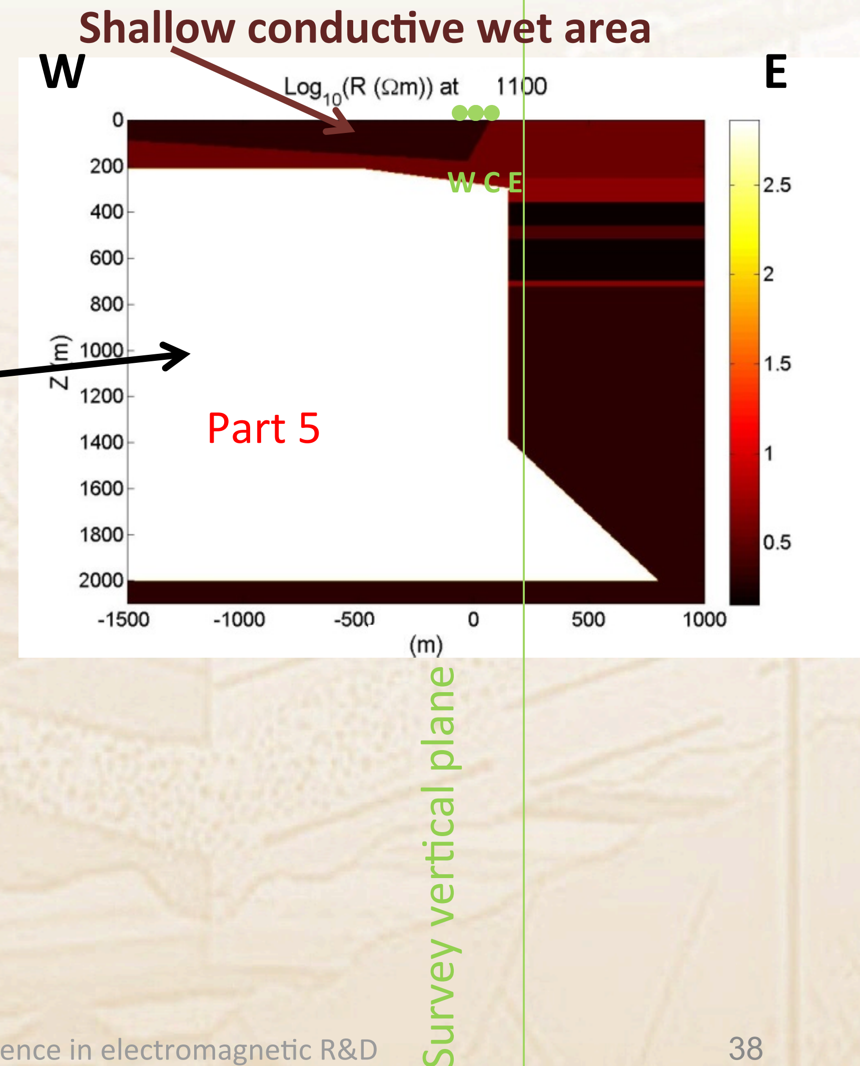




FSEM: 3D model (5) of salt dome (Part 5)

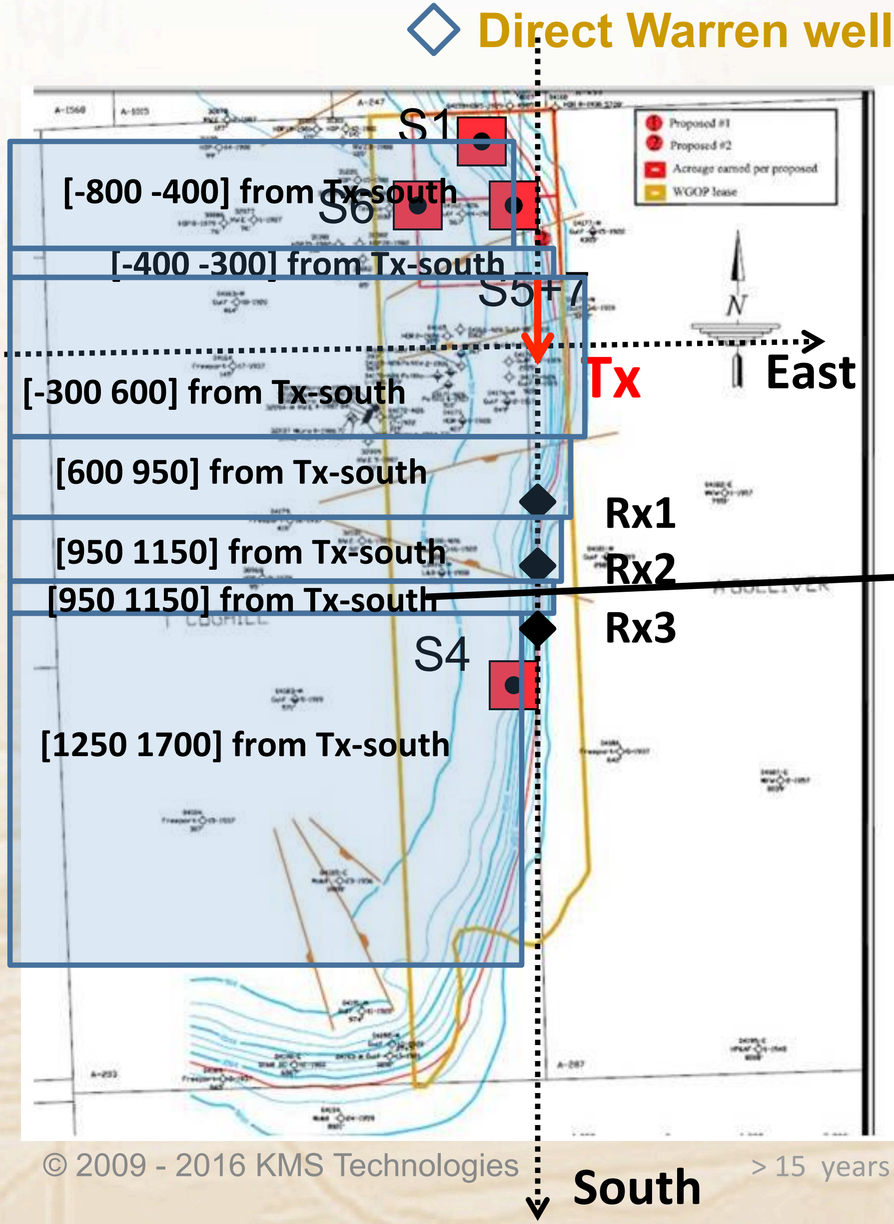
- Best matching salt dome model derived
- It consists of 7 parts

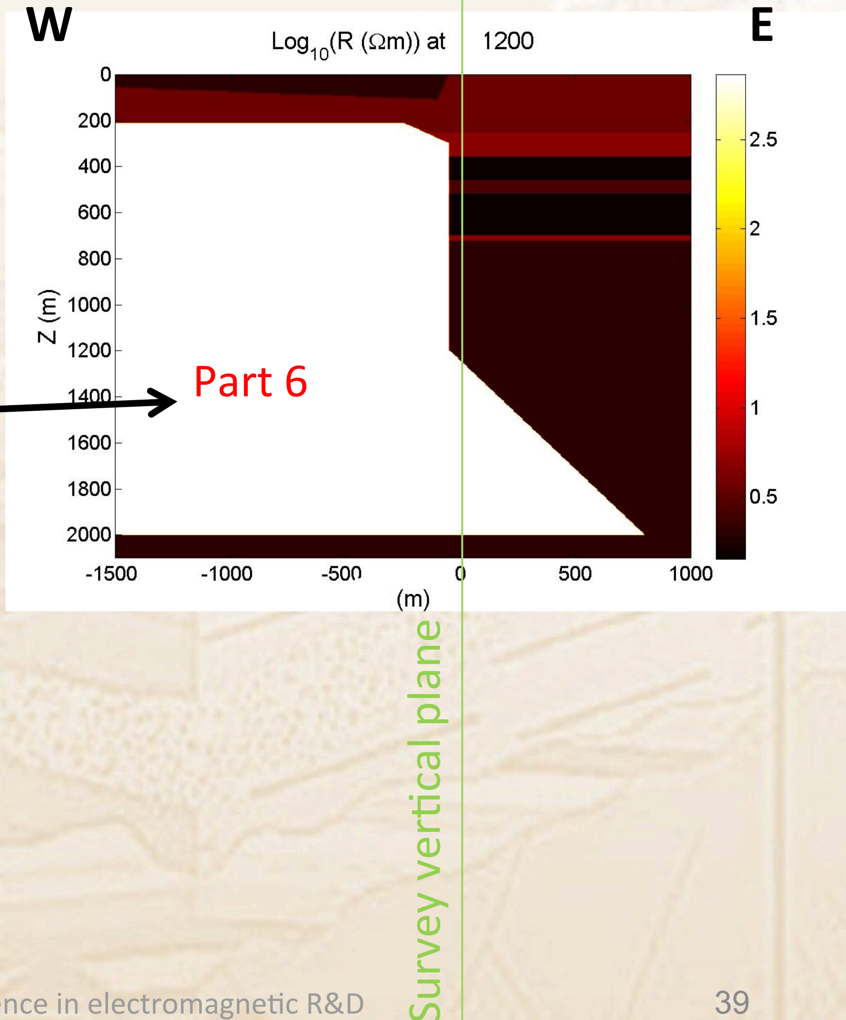




FSEM: 3D model (5) of salt dome (Part 6)

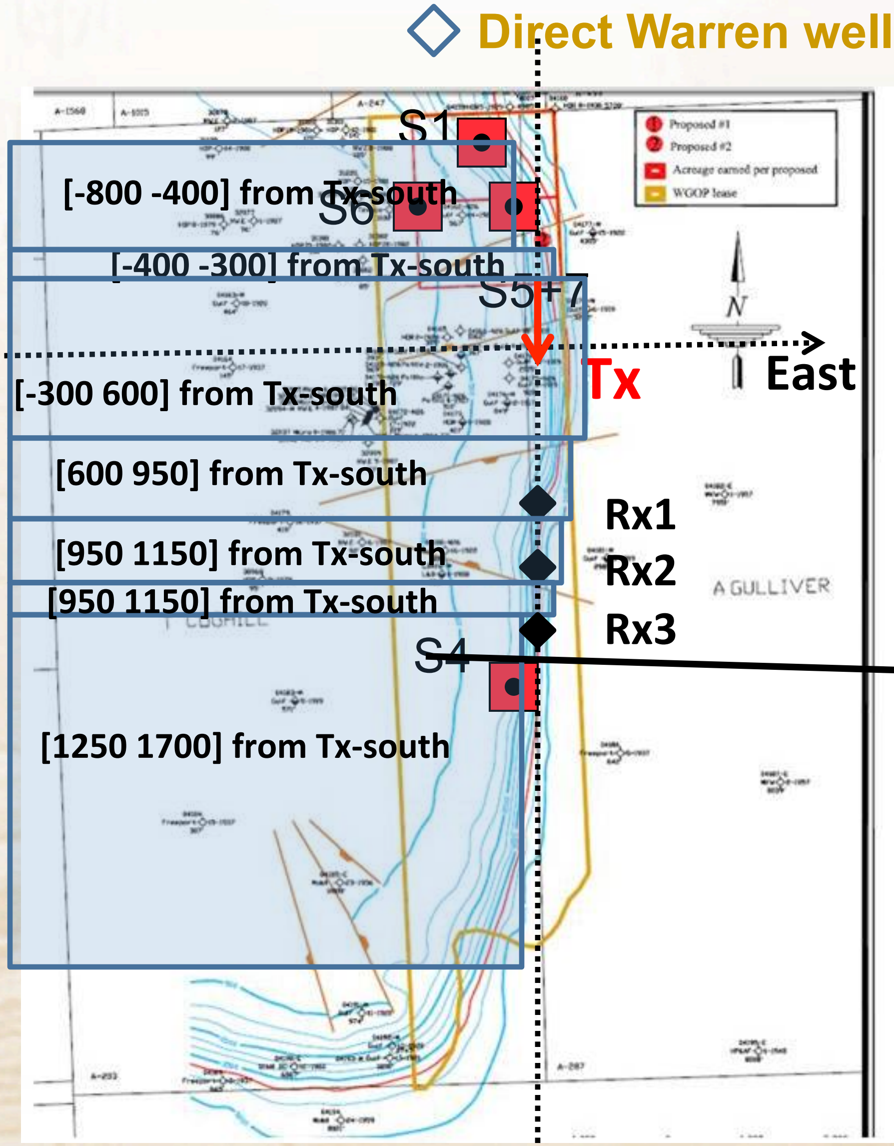
- Best matching salt dome model derived
- It consists of 7 parts

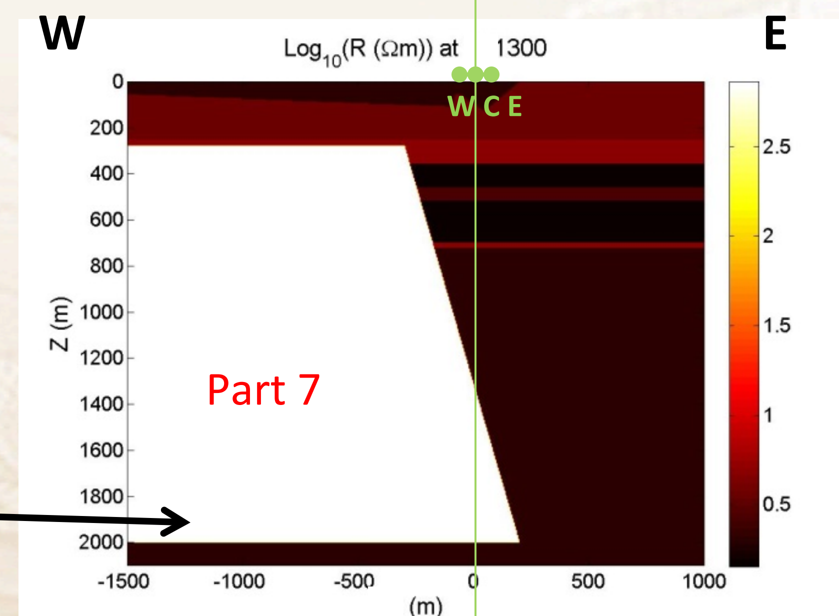




FSEM: 3D model (5) of salt dome (Part 7)

- Best matching salt dome model derived
- It consists of 7 parts





South

Survey vertical plane

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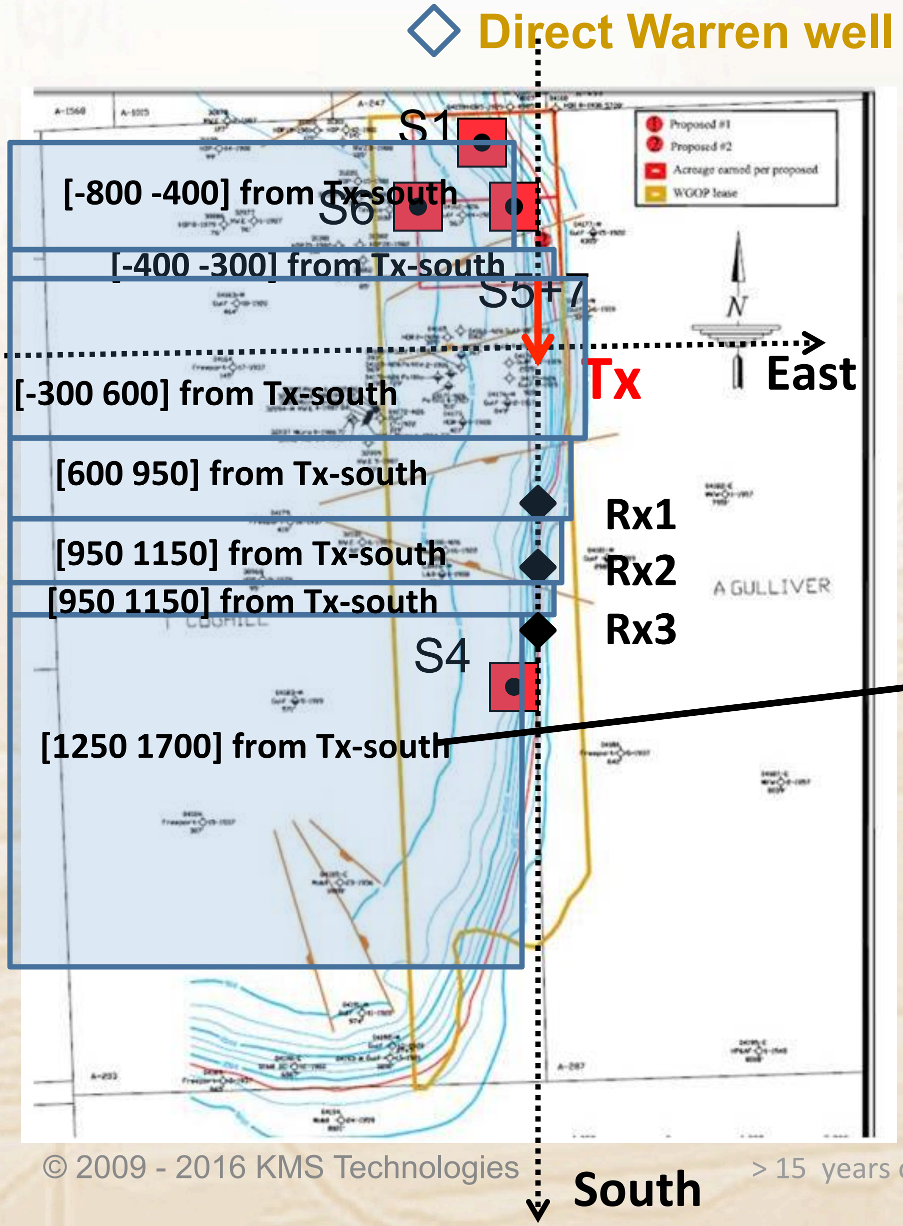
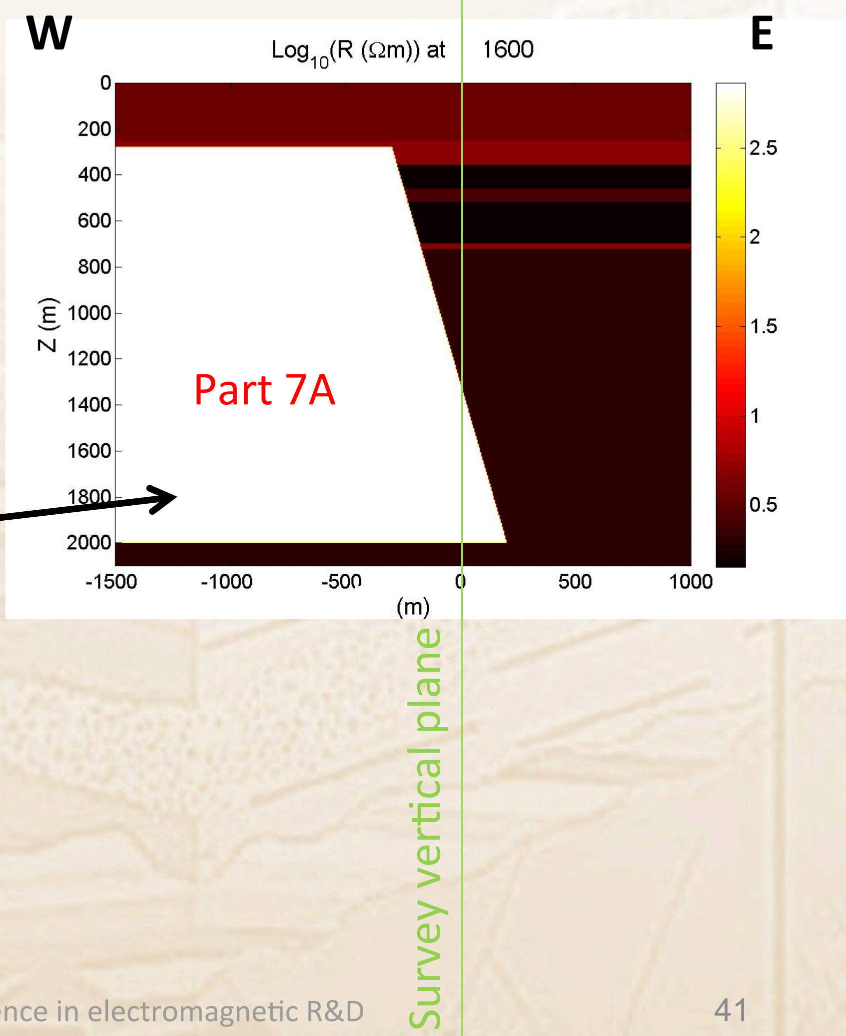
FSEM: 3D model (5) of salt dome (Part 7A)

- Best matching salt dome model derived
- It consists of 7 parts





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Summary & 5 year vision

- New instruments allow us to re-visit
  - Full anisotropy 3D models
  - 3D tensor acquisition
  - Tie to borehole measurements
- Value recognized (but NOT understood) →
- Integration with other methods is key
- Big potential in reservoir monitoring

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