EM/microseismics for water front monitoring: integrated 3D modeling, acquisition and first field pilot

KMS Technologies

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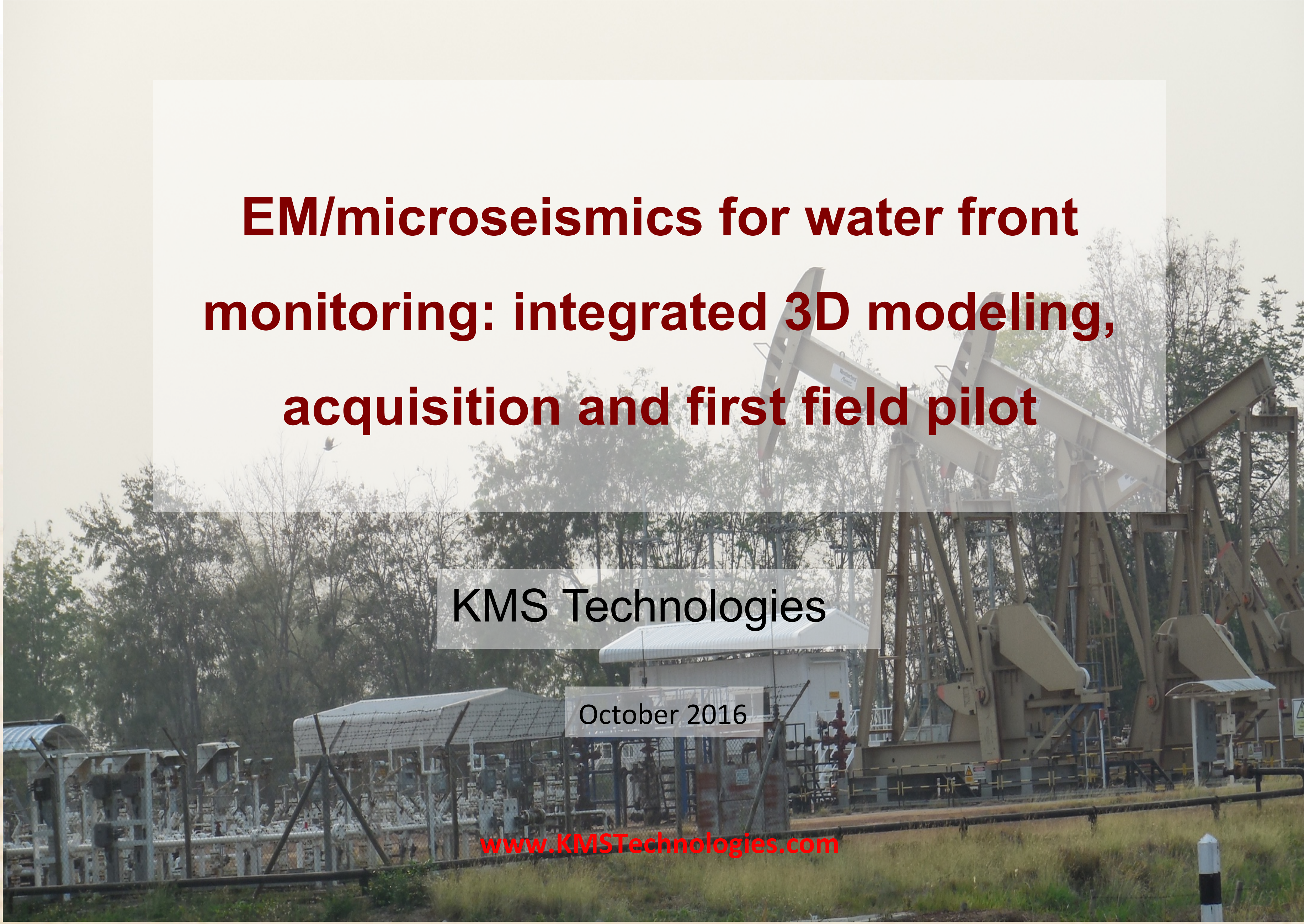
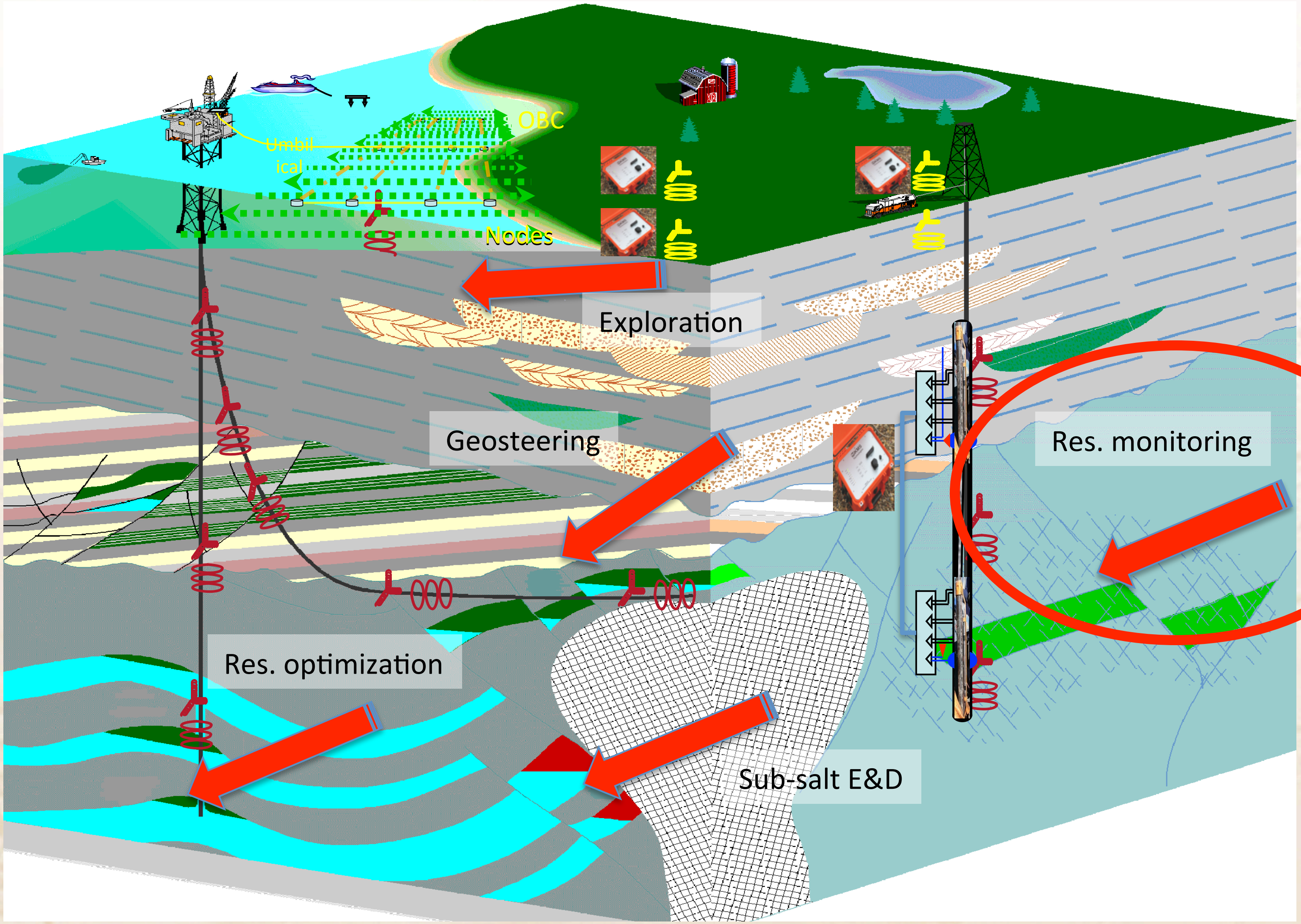
www.KMSTechnologies.com



EM/microseismic
Outline

- Background
- Monitoring workflow
- Hardware architecture
- Examples:
  - 3D feasibilities
  - Tools:
    - FSEM & Ez
    - MM TCR
- Conclusion

High value APPLICATIONS – LOW to HIGH



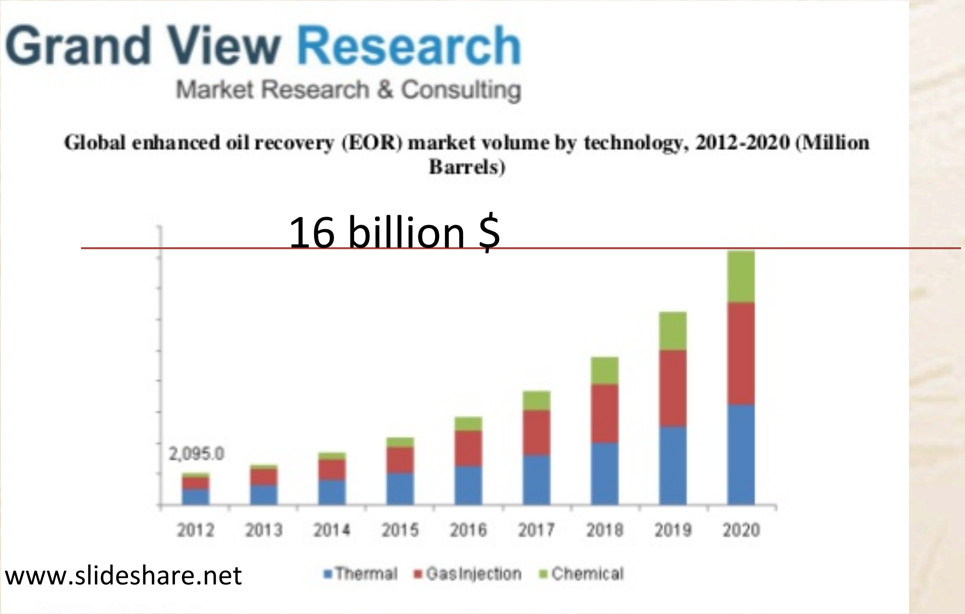
Market overview

- EOR market 2015: 20.4 Billion US $
  - Geophysical data: temperature & pressure
- EOR market predictions 2020:
  - https://globenewswire.com/ - 283 billion US $
  - Conservative 8% growth = 30 billion US $
  - 'more than triple' = 70.6 Billion US $ http://www.environmentalleader.com/

Geophysical data →
ONLY feed forward methods

→ GREAT opportunity

→ ALL cause resistivity contrast



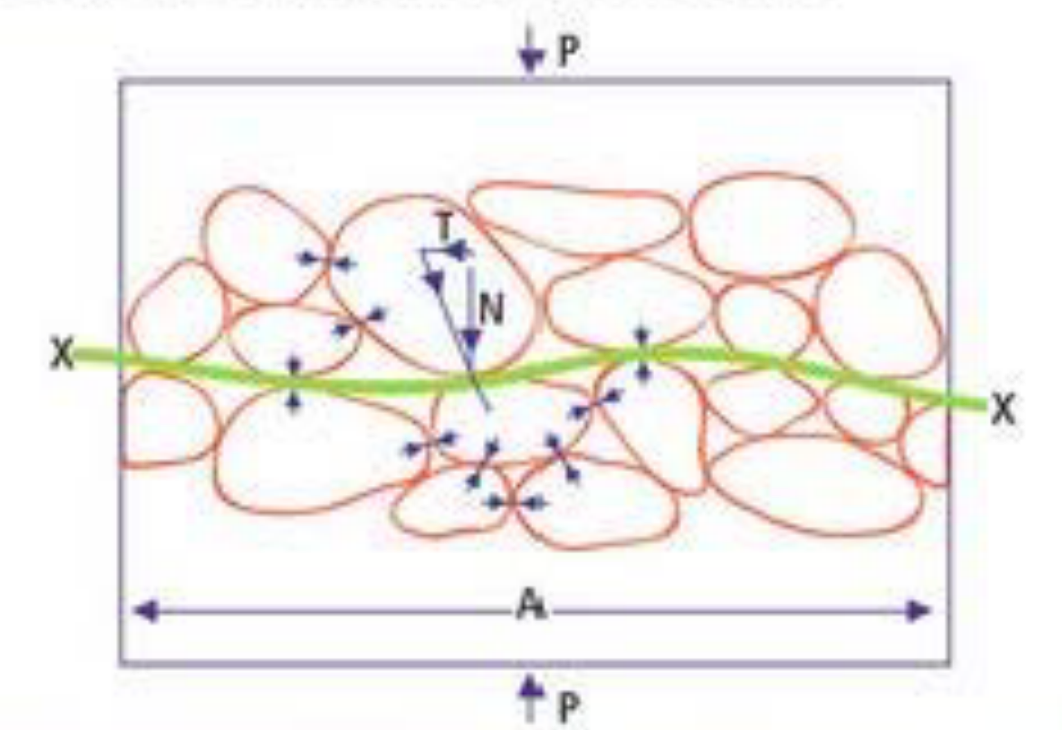
Why electromagnetics (EM)?

- Determining composition, boundaries and movement
- EM images **fluids & fluid movement**
- Combination of Seismic & EM offer best solution
- EM has proven as a valid tool for hydrocarbon detection

SENSOR CAPABILITY	RESOLVING POWER				
	Distance	Fluid	Surface-to-surface	Surface-to-borehole	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

With permission of WellDynamics/Halliburton

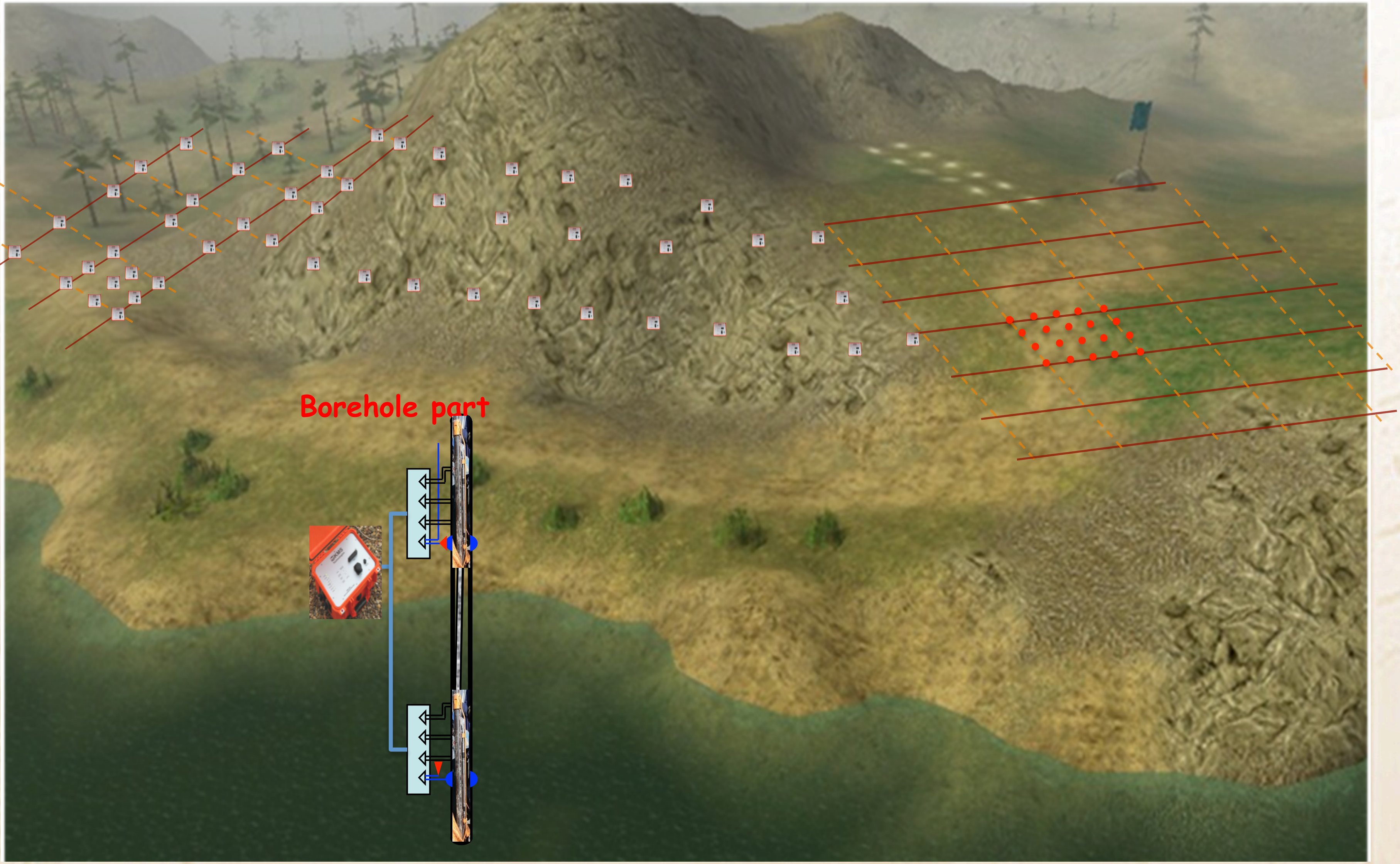
Reservoirs seal: EM & microseismic - effective stress



After Carlson, 2013

- 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

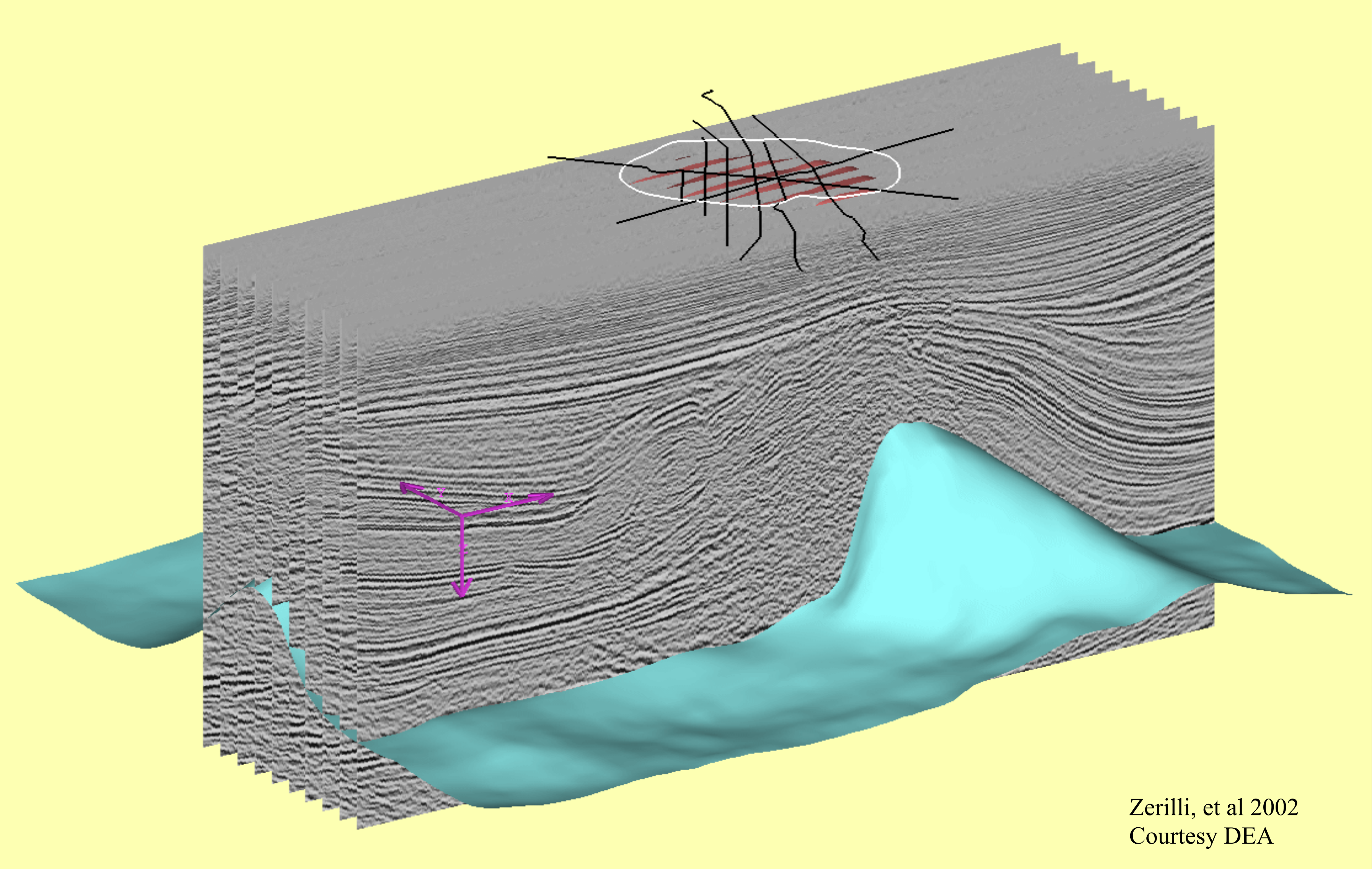
Land acquisition requirements



Status 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

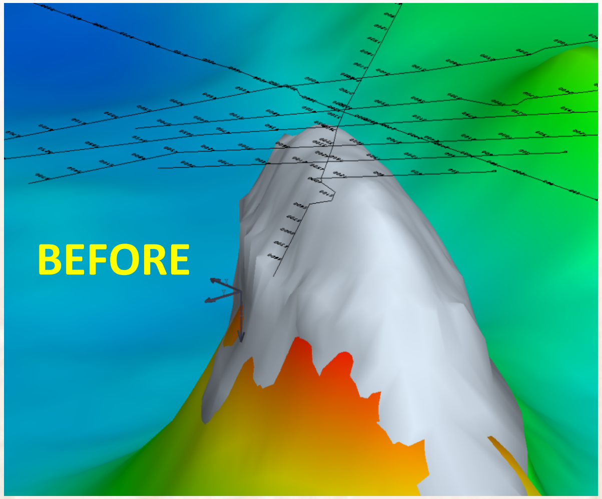
N. Germany: Dense acquisition → better images

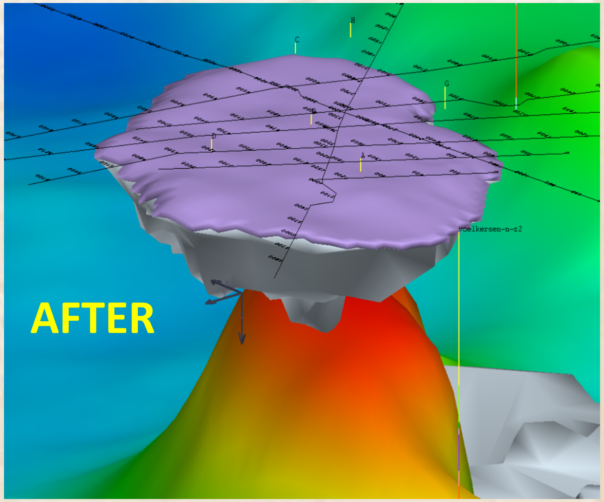


Zerilli, et al 2002
Courtesy DEA

N. Germany: **Sub-salt case history PUNCHLINE**

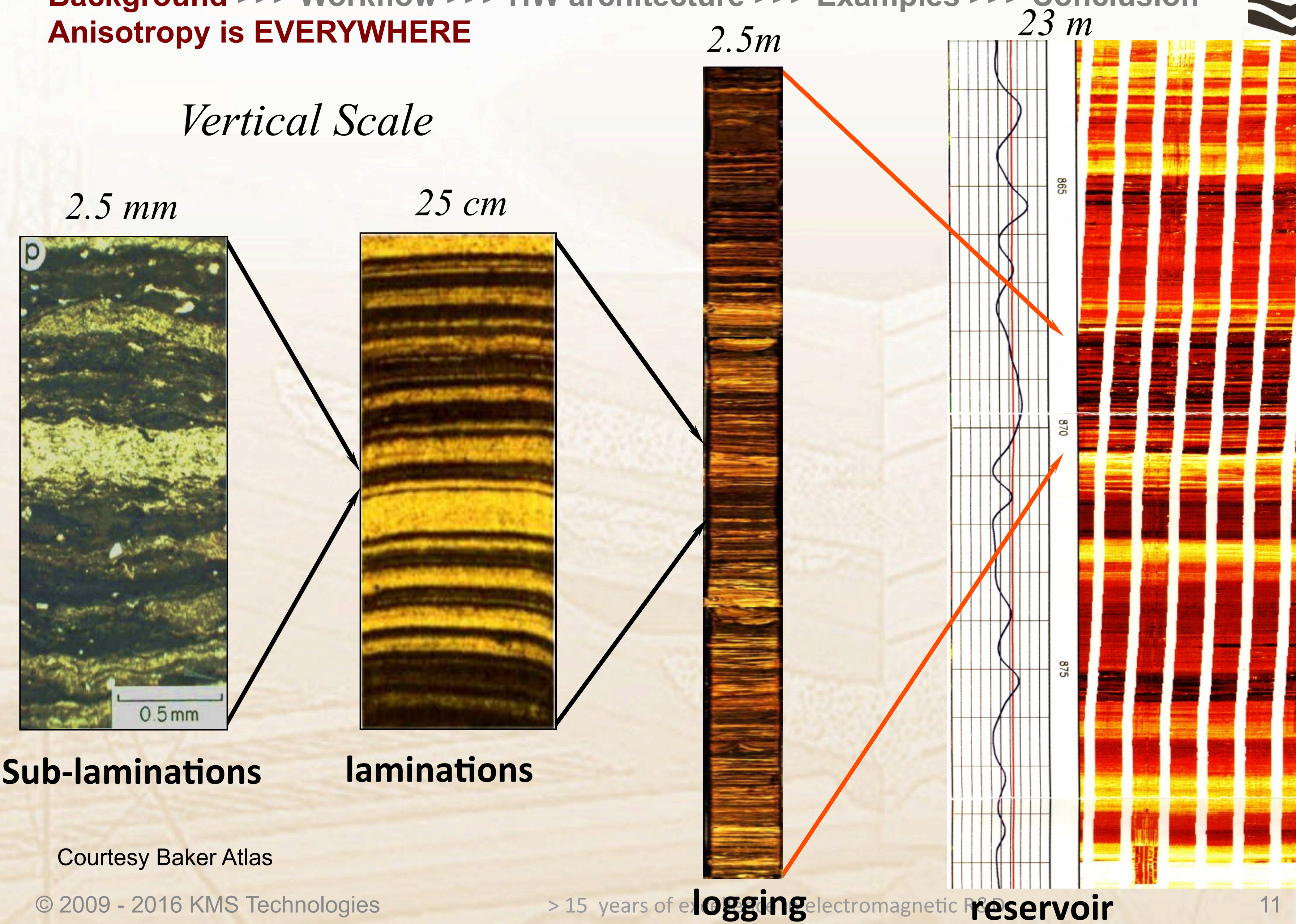
- Sub-Salt dome imaging.
- Evaluate noise sources & define model.
- Feasibility w/ forward models.
- Risk: noise.
- Survey: extensive parameter testing.
- Production: 370 sites in 2 months (incl. tests)
- MT interpretation to stable 2D model
- 3 weeks of integration in Client office
- Multi-methods → final model





Buehnemann et al 2002
Courtesy DEA

Anisotropy is EVERYWHERE

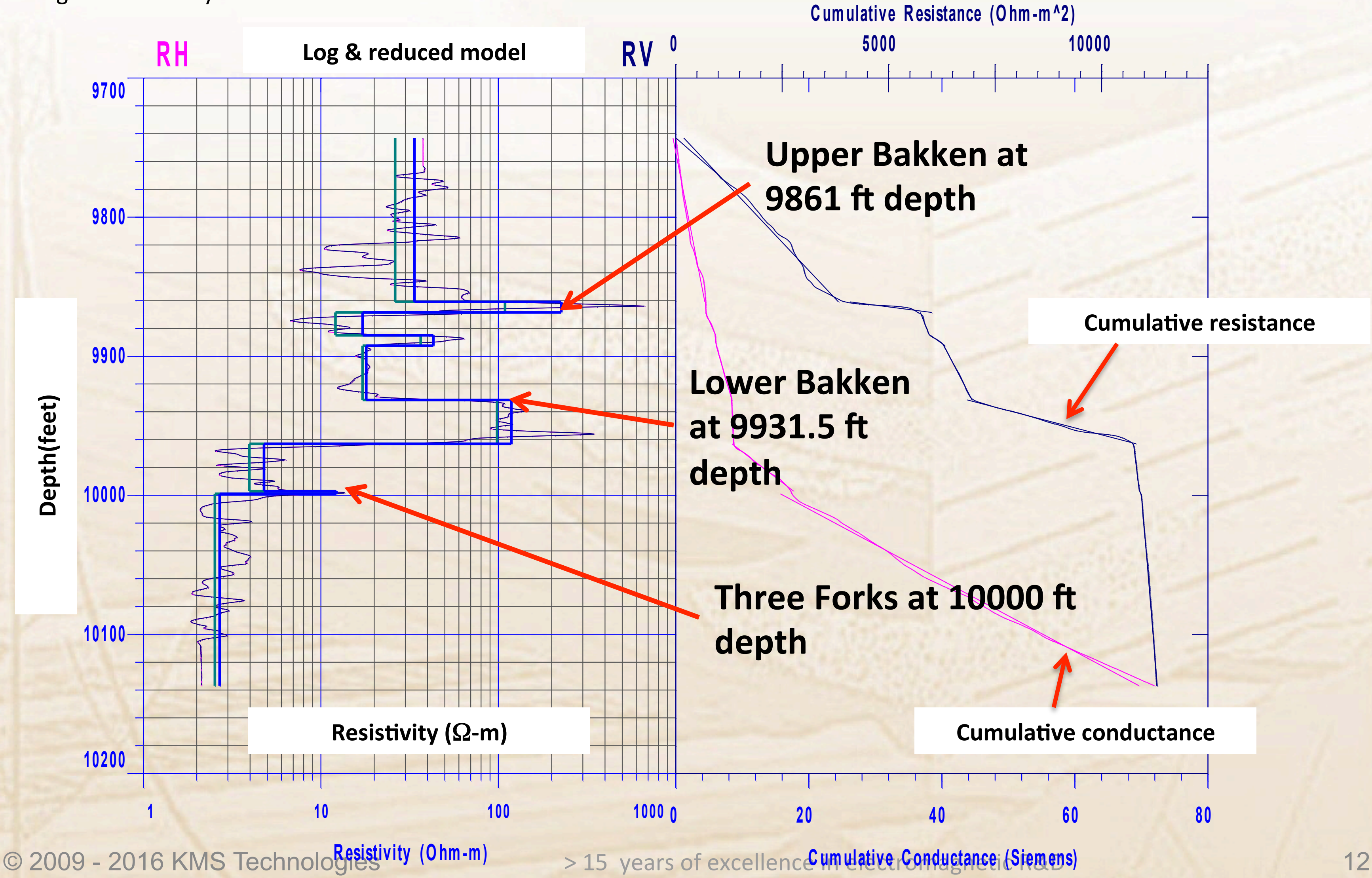


Courtesy Baker Atlas

HOW DID WE GET STARTED: Bakken unconventional

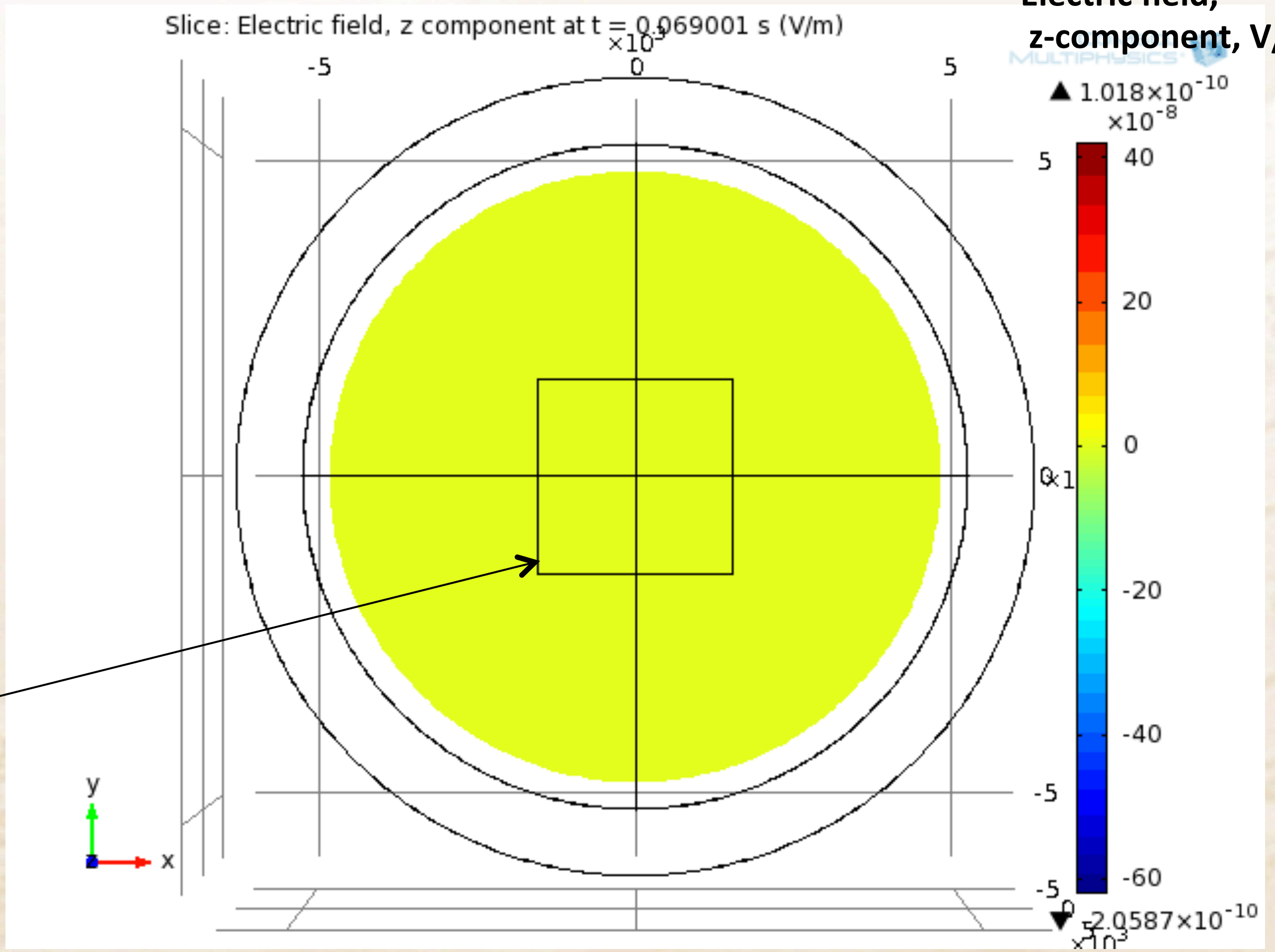
BAKKEN: From a log to an anisotropic model

Log data courtesy of Microseismics Inc.



HOW DID WE GET STARTED: Bakken DEPLETION monitoring
Borehole-to-surface, Rx at reservoir level

Electric field, z-component, V/m



Lower Bakken
3 km x 3 km
2800 m deep

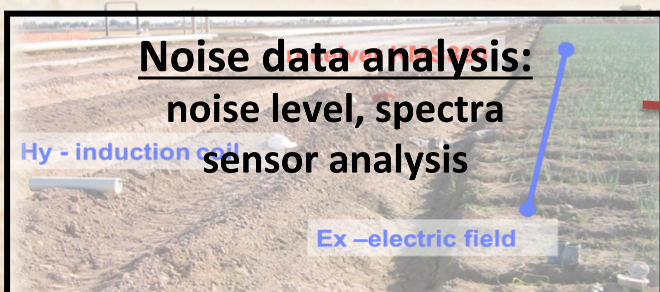
Overall Workflow

Deliverables & objectives → **Feasibility & noise test**

Input data:
well log data
geologic information
seismic horizons
noise measurements
→ Verification 3D modeling benchmarks

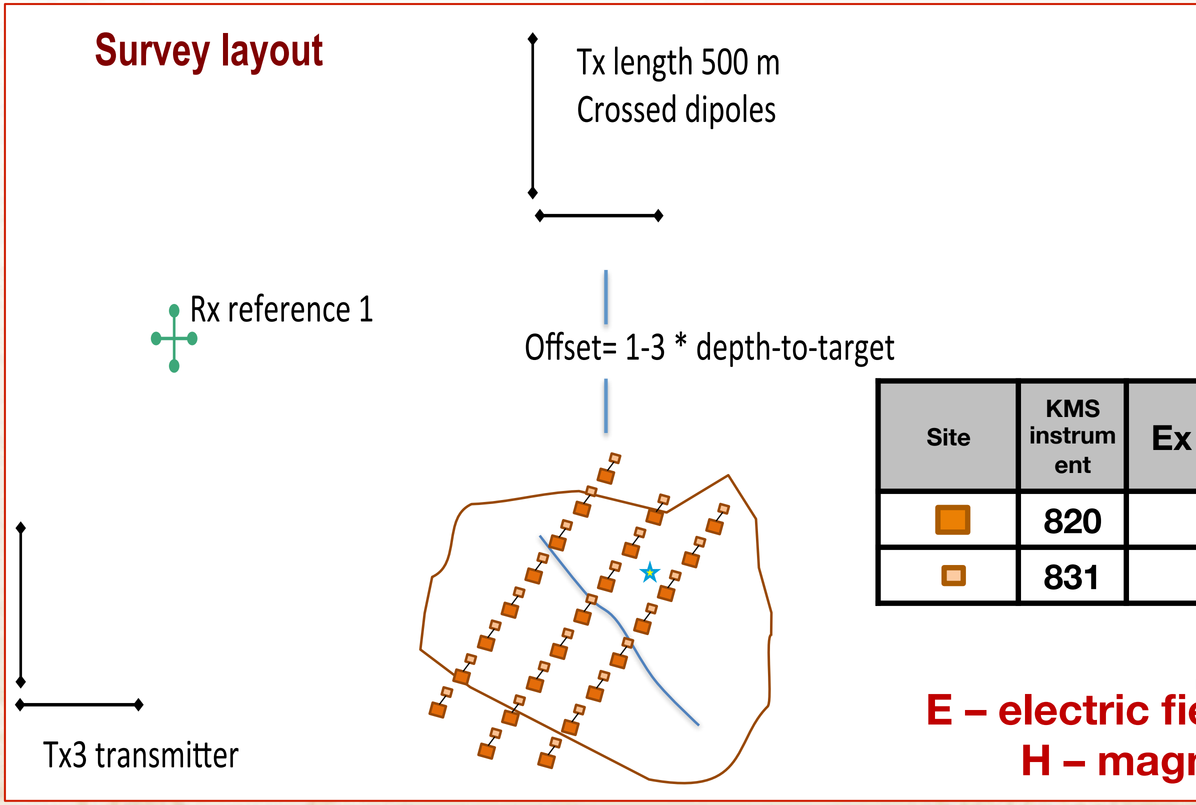
Define target variations

Resolution study



Noise data analysis:
noise level, spectra
sensor analysis
→ Pilot study design

Workflow: design



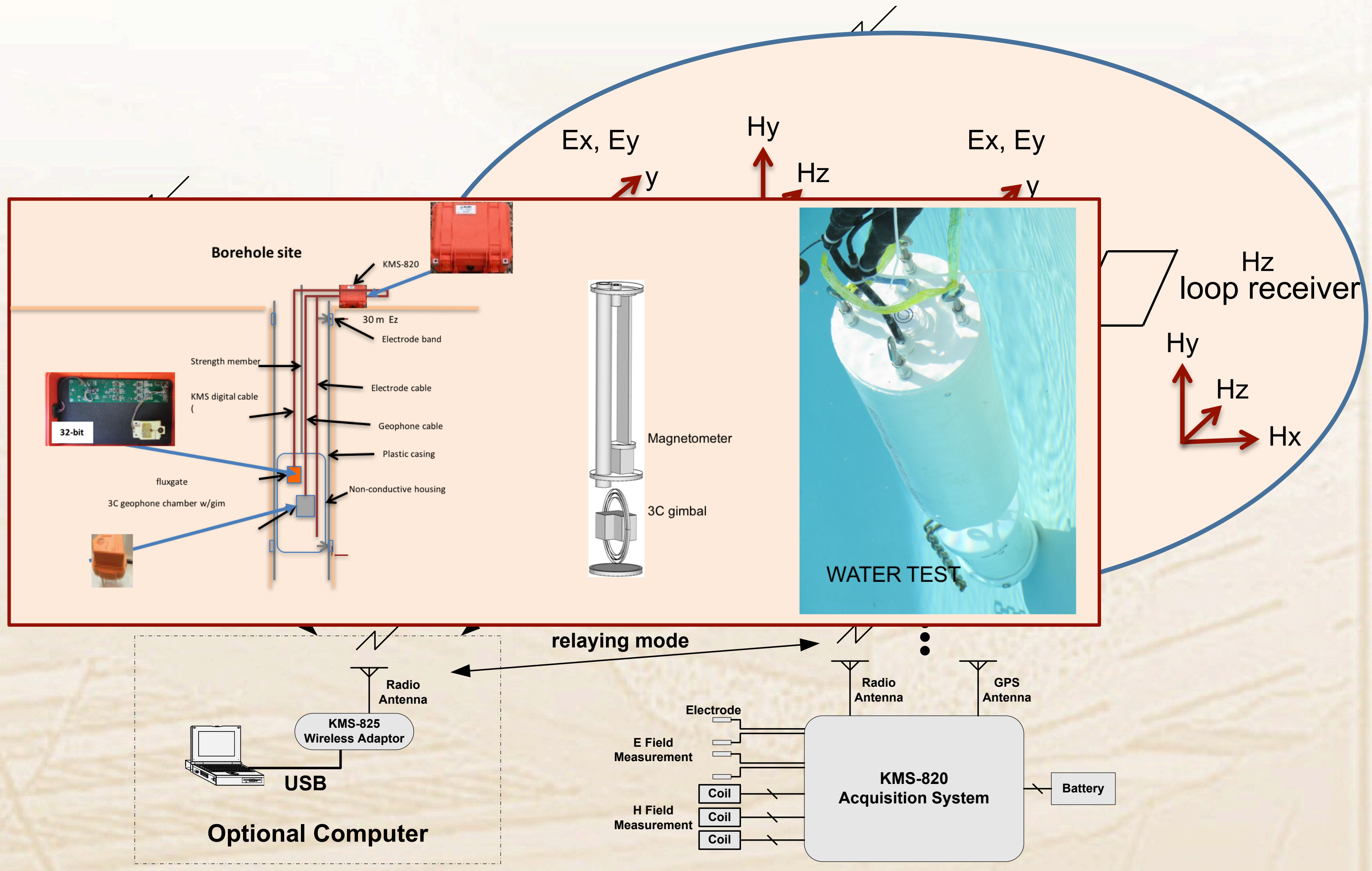
Microseismic sensors

Site	KMS instrument	Ex & Ey	Hz	3C fluxgate H	3C geophone	Shallow borehole tool
(large square)	820	x	x	x	x	x
(small square)	831	x			x	

E – electric field sensors
H – magnetic field sensors

Shallow Borehole Tool – KMS-888
includes 3C seismic, 3C magnetic & 3C electric sensors

Architecture & hardware: original 2009 design UPDATE



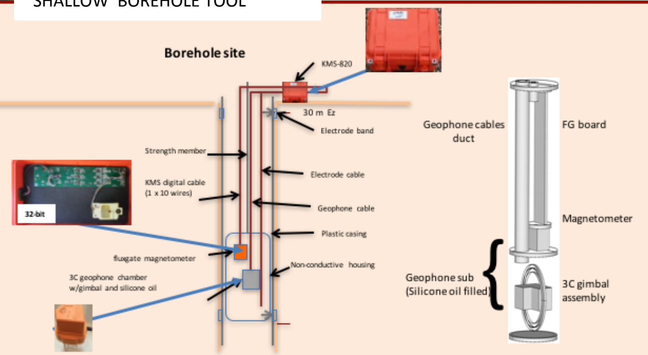
Receiver (KMS-820): for MT & CSEM

MARINE

Node
on deck

Combined seismic & EM node
For 2 months operation

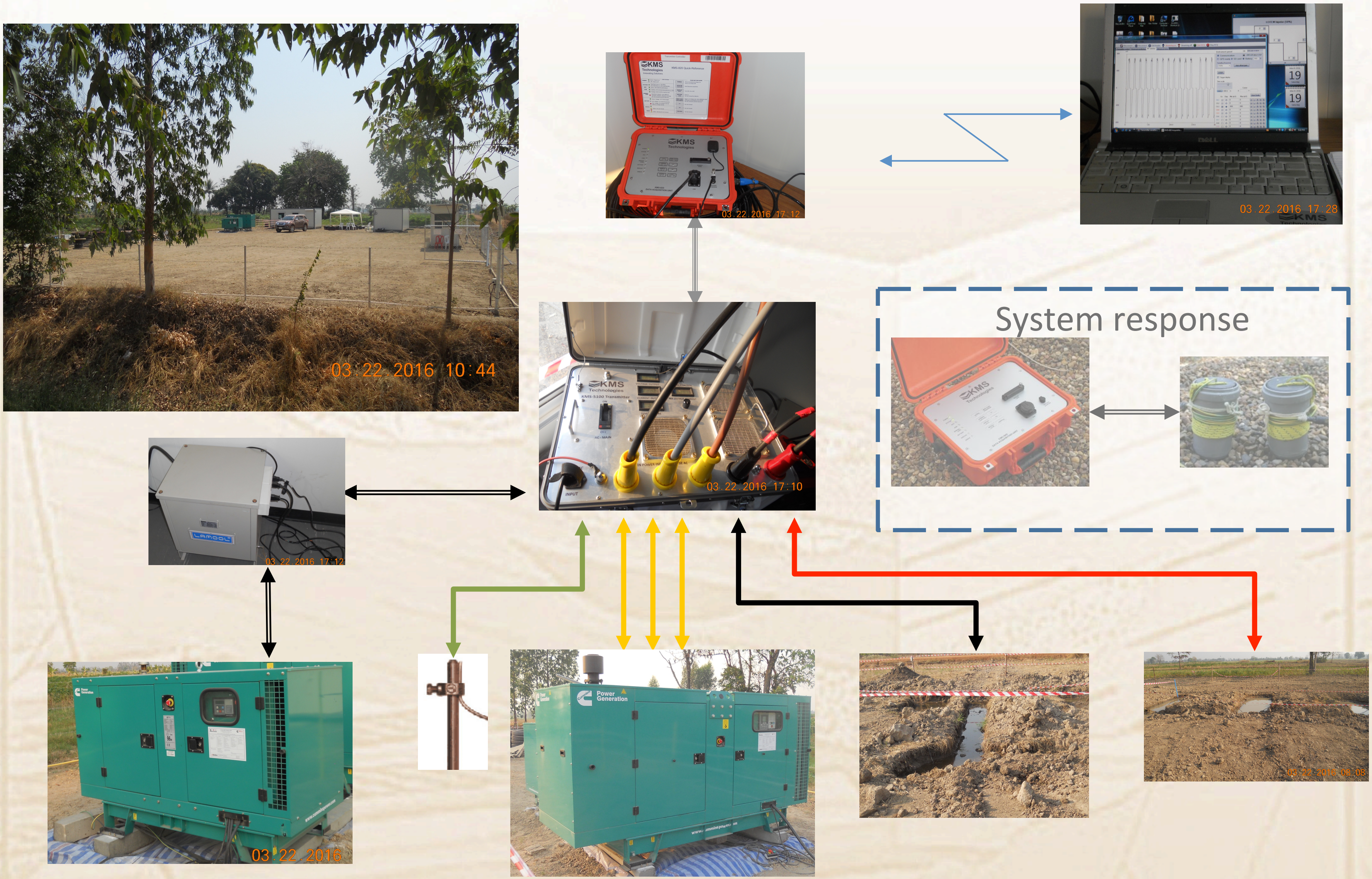
SHALLOW BOREHOLE TOOL



DEEP BOREHOLE

TRANSMITTER

KMS-5100 Transmitter – 100 KVA 2016



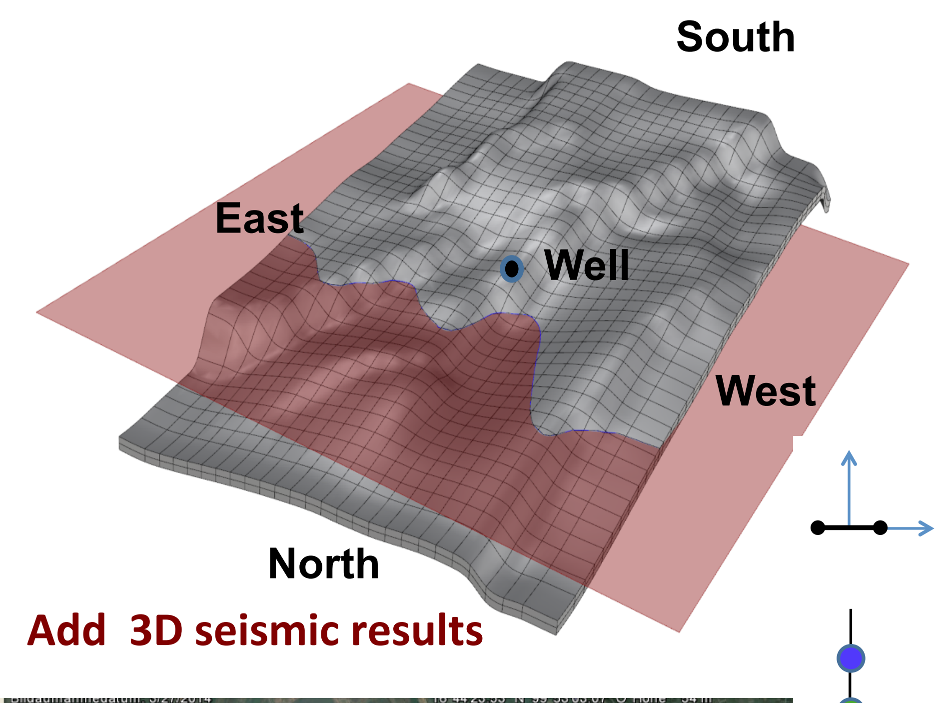
A 195 channel system

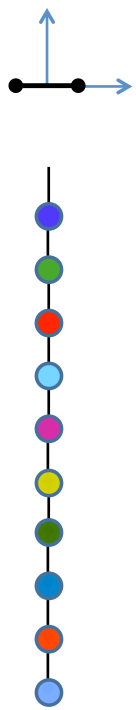
100 KVA

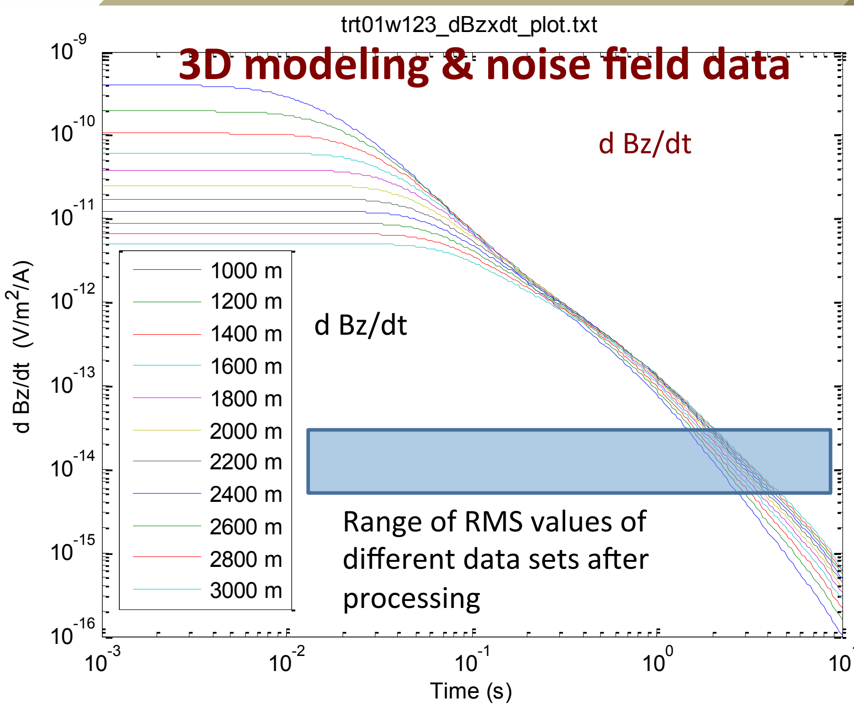
TRANSMITTER

- Background
- Hardware
- Examples:
  - Monitoring
  - FSEM & Ez
  - MM TCR
- Conclusion

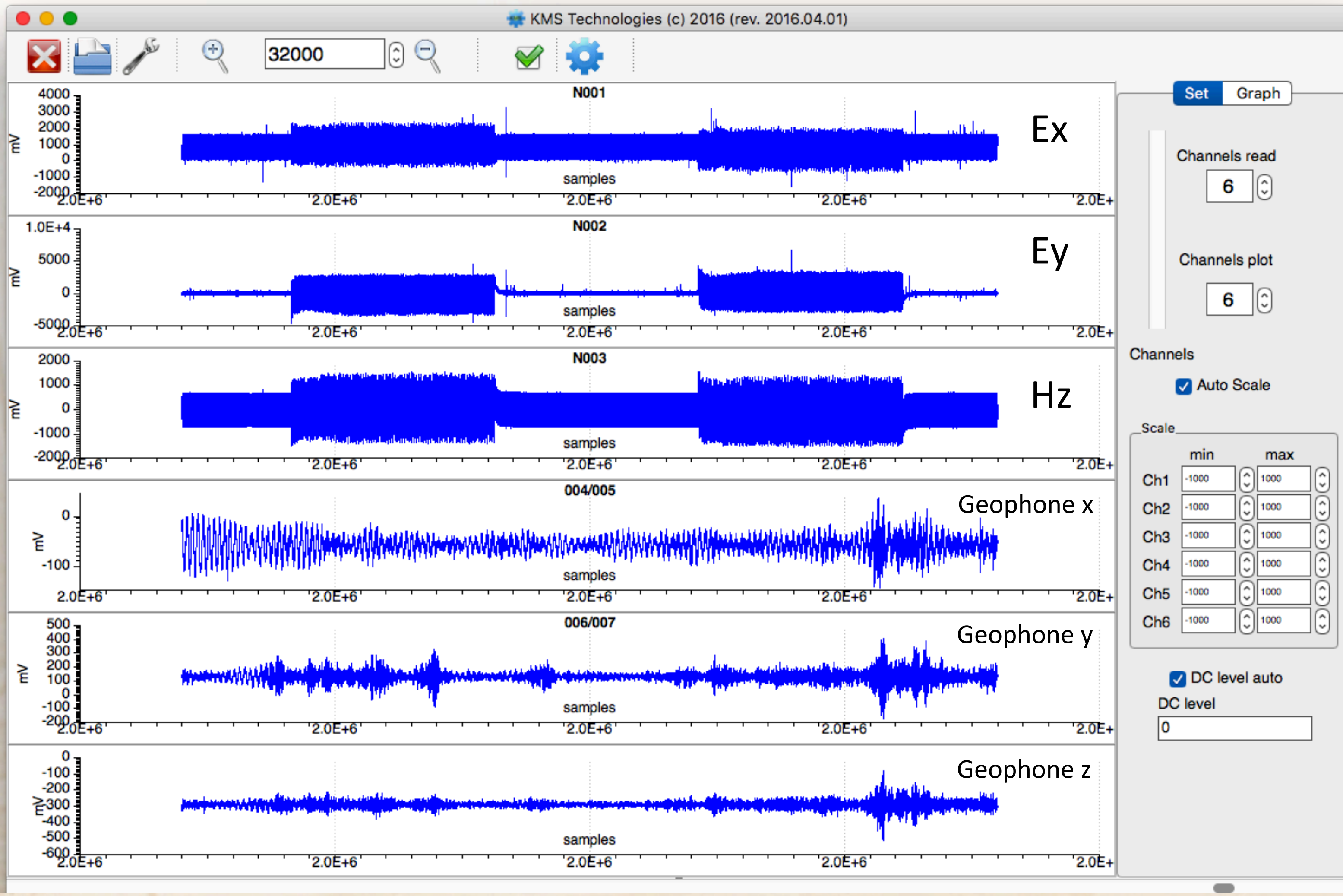
Example: 3D reservoir Feasibility



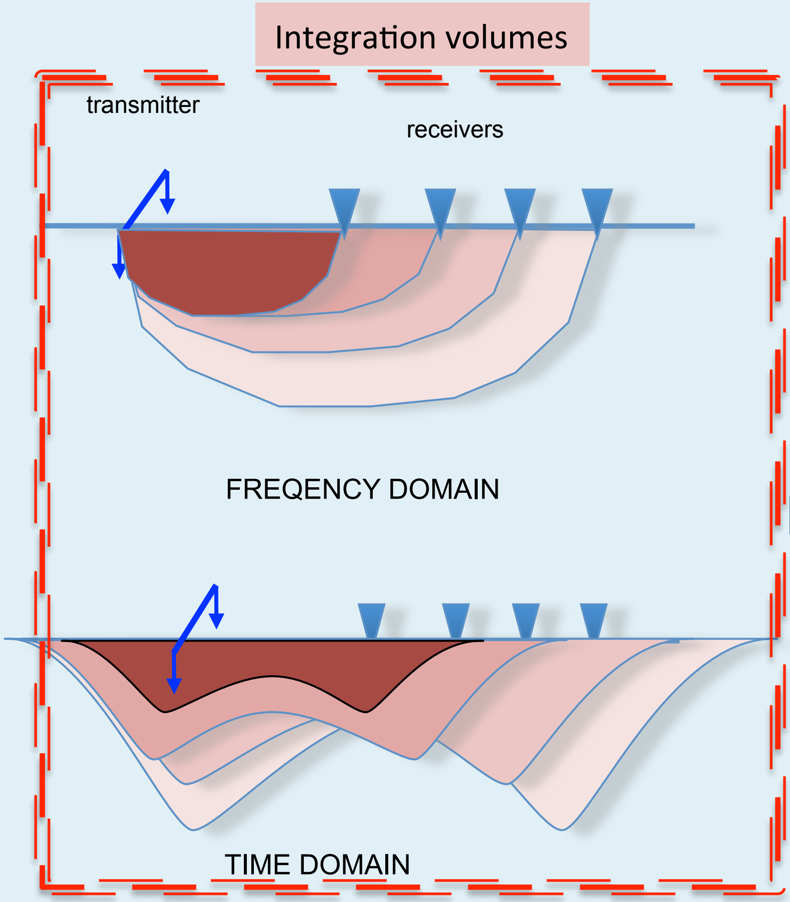


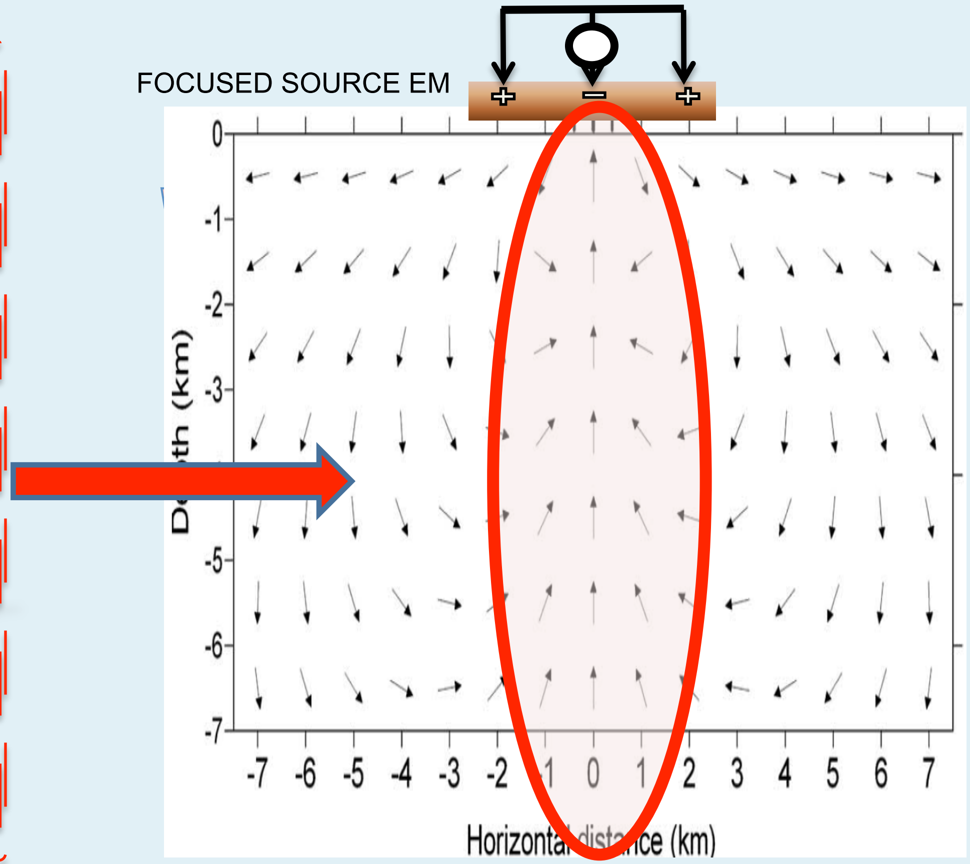


Reservoir Monitoring: Raw data example: microseismic/EM monitoring



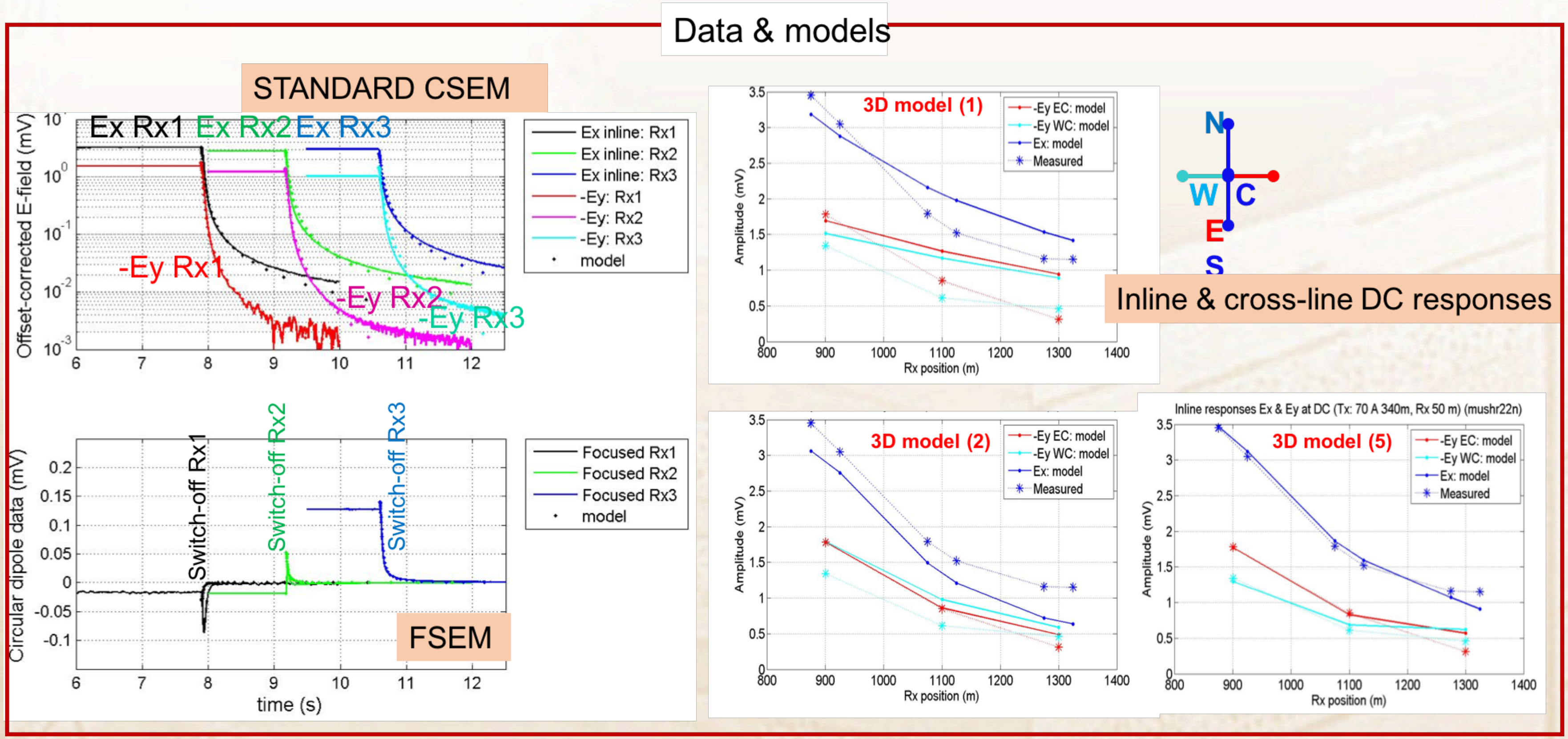
FSEM: Focused source solution to volume imaging



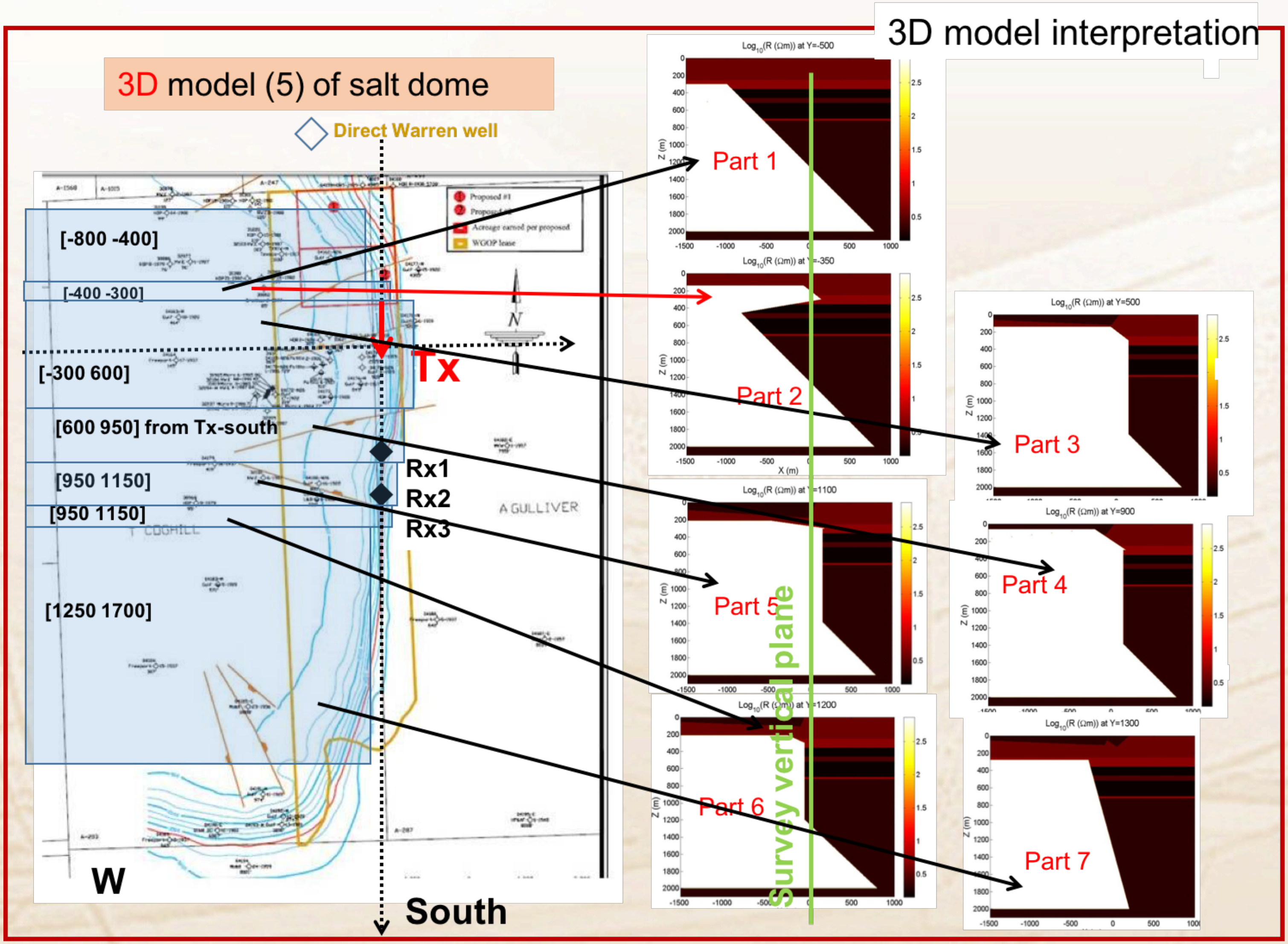


Rykhlinskaya, E., & Davydycheva, S., 2014, U.S. Patent 8,762,062 B2.
Davydycheva, S., 2016, U.S. Patent Application US 2016/0084980 A1.

FSEM: Focused source solution to volume imaging

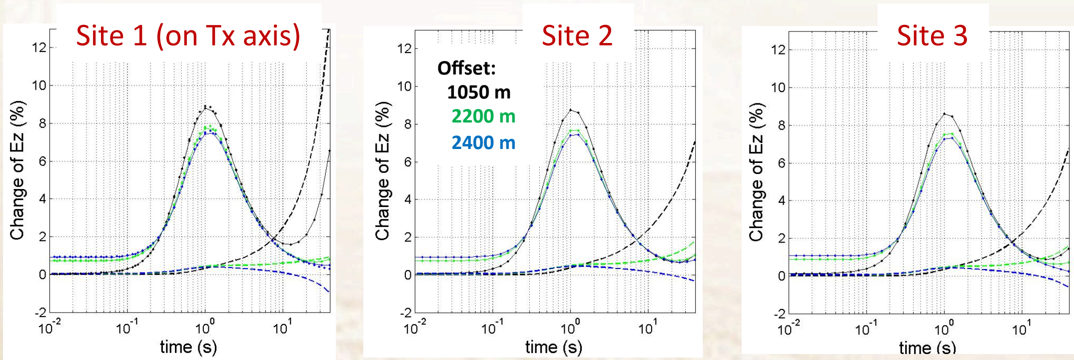


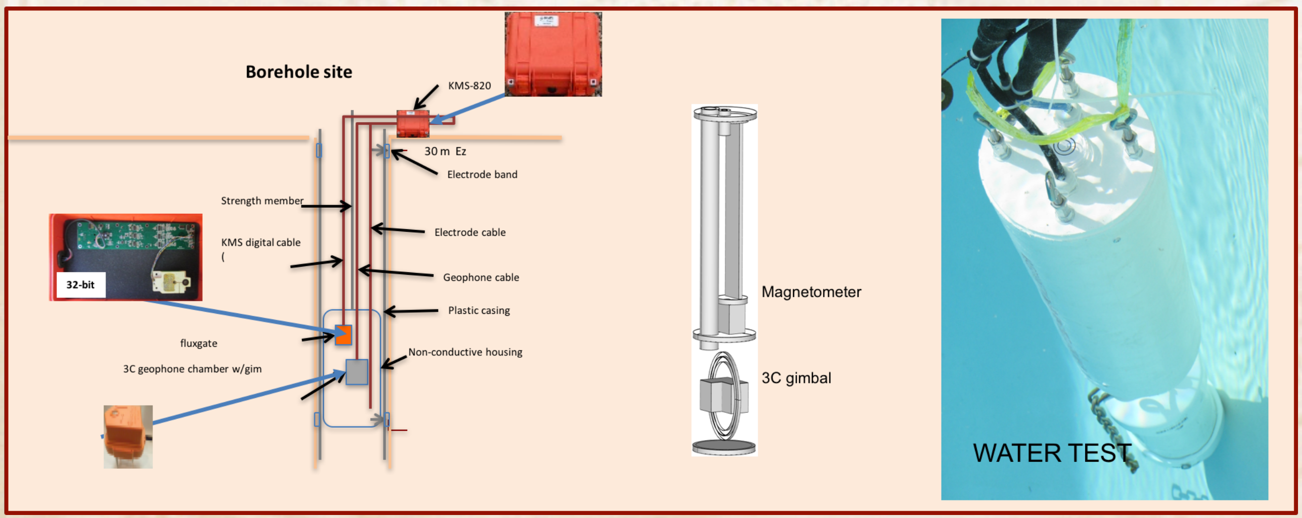
FSEM: Focused source solution to volume imaging



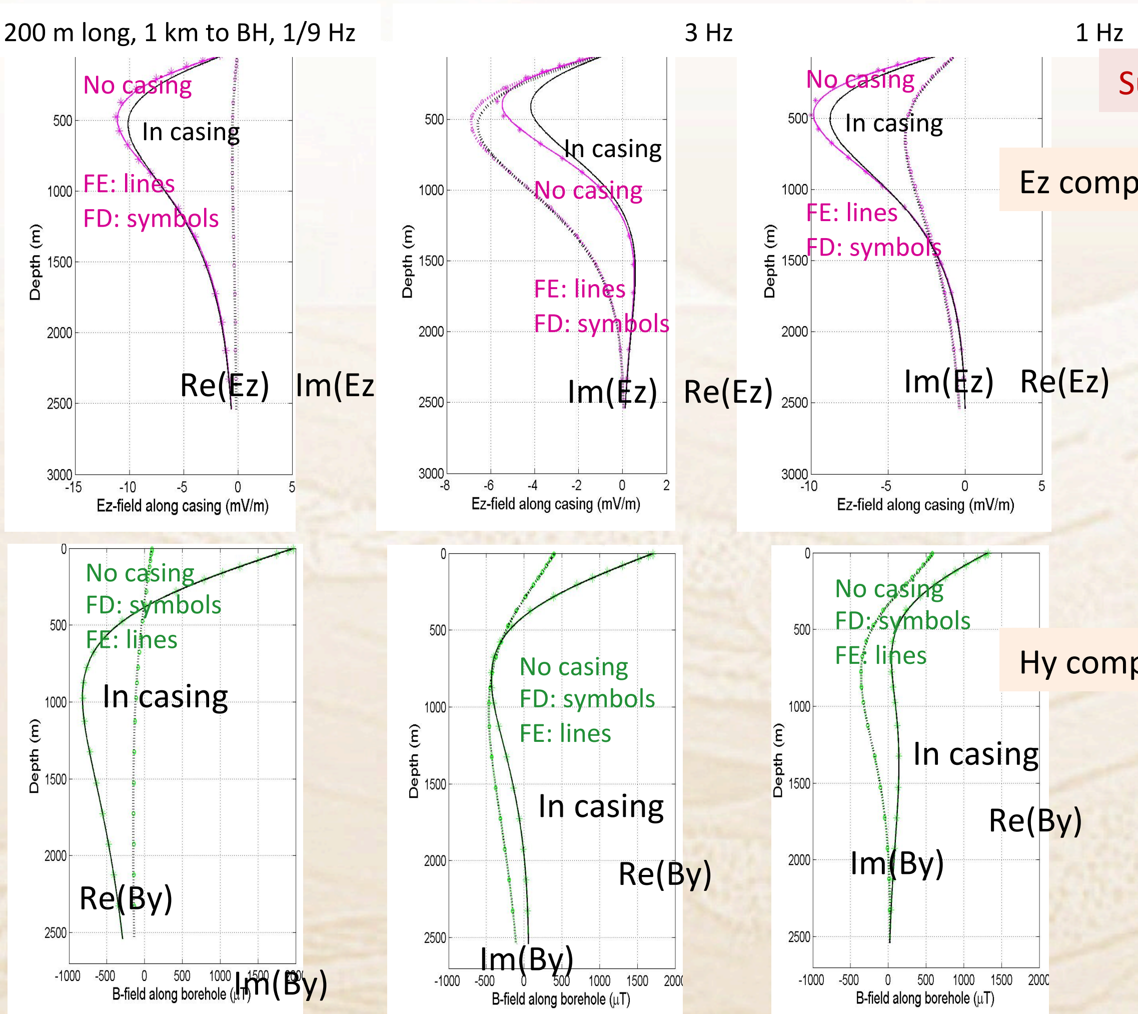
Alternative: Shallow borehole tool - Ez

Ez at z = 10 m





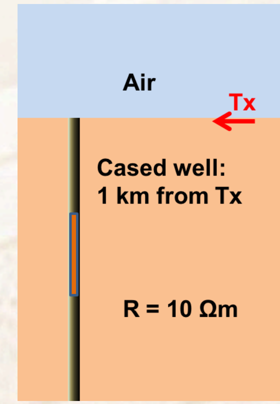
Deep borehole tool: Through Casing; H, & E



Surface – to – borehole tool

Ez component

Hy component



Signal well above our sensor level

Summary

- Monitoring
  - EM technology for CSEM monitoring available
  - Seeing anomaly - Easy
  - Understanding results – complicated
  - Issue 1: Image focus
  - Issue 2: Borehole calibration !!!!!
    - Surface-to-borehole
    - Through Casing
  - FINAL goal permanent sensors

Acknowledgements

Thanks to supporters of various parts:
Aramco, DeepLook consortium (BP, Chevron, ConocoPhillips, Shell), ENI, Ormat, PTTEP, Shell, WellDynamics

...and all KMS staff.

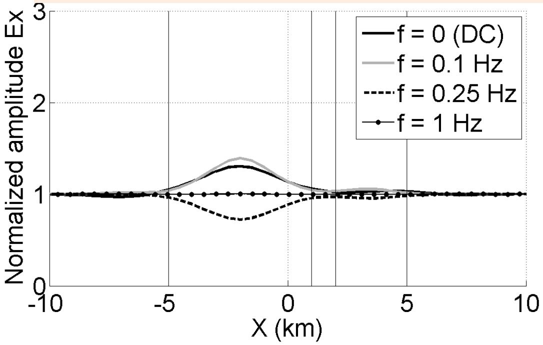
All technology protected by US & Foreign patents
(see KMS Technologies website)

Outline

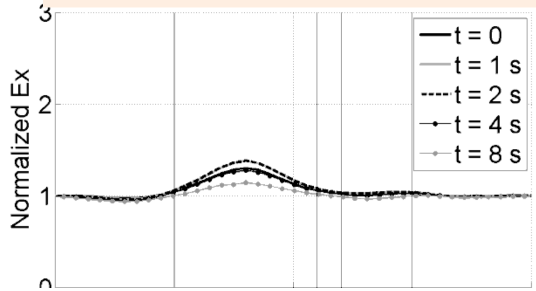
- Objective & history
- Architecture & hardware
- Examples:
  - 11 channel MT
  - Monitoring
  - FSEM
- Conclusion

FSEM: Focused source solution to volume imaging

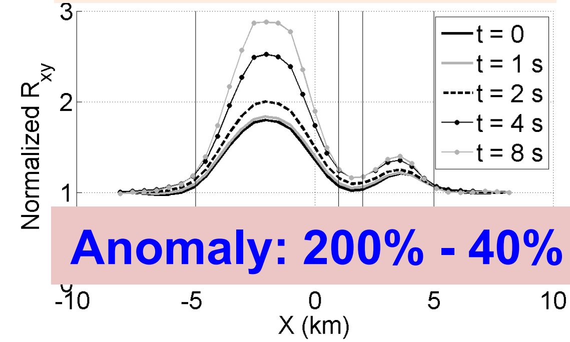
Frequency domain CSEM



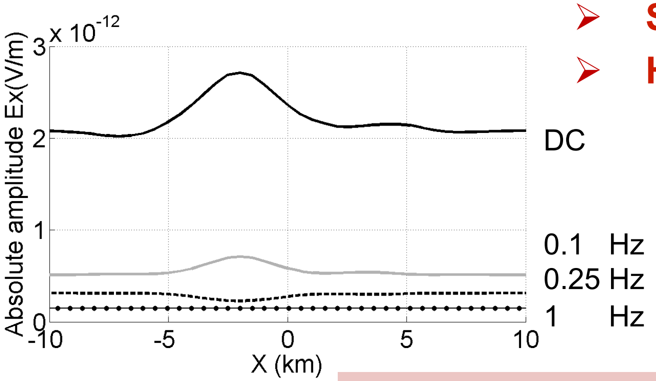
Time domain CSEM



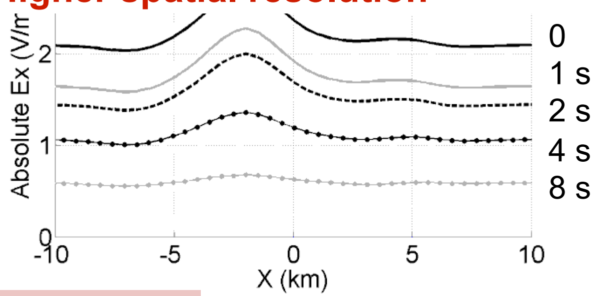
Focused Source EM

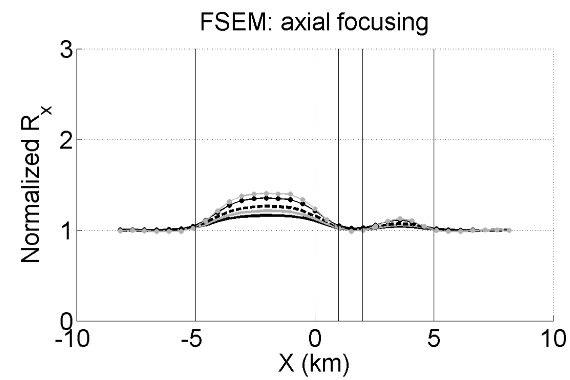


Anomaly: 200% - 40%

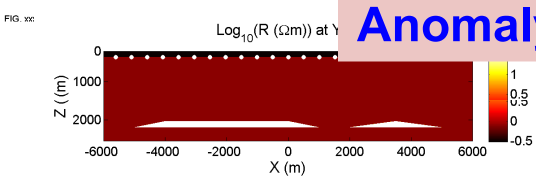


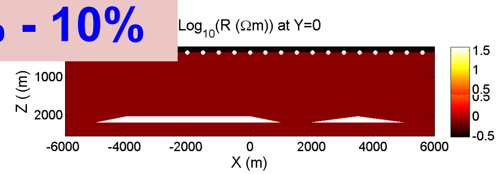
- **Smaller reservoir can be detected**
- **Higher spatial resolution**





Anomaly: 40% - 10%

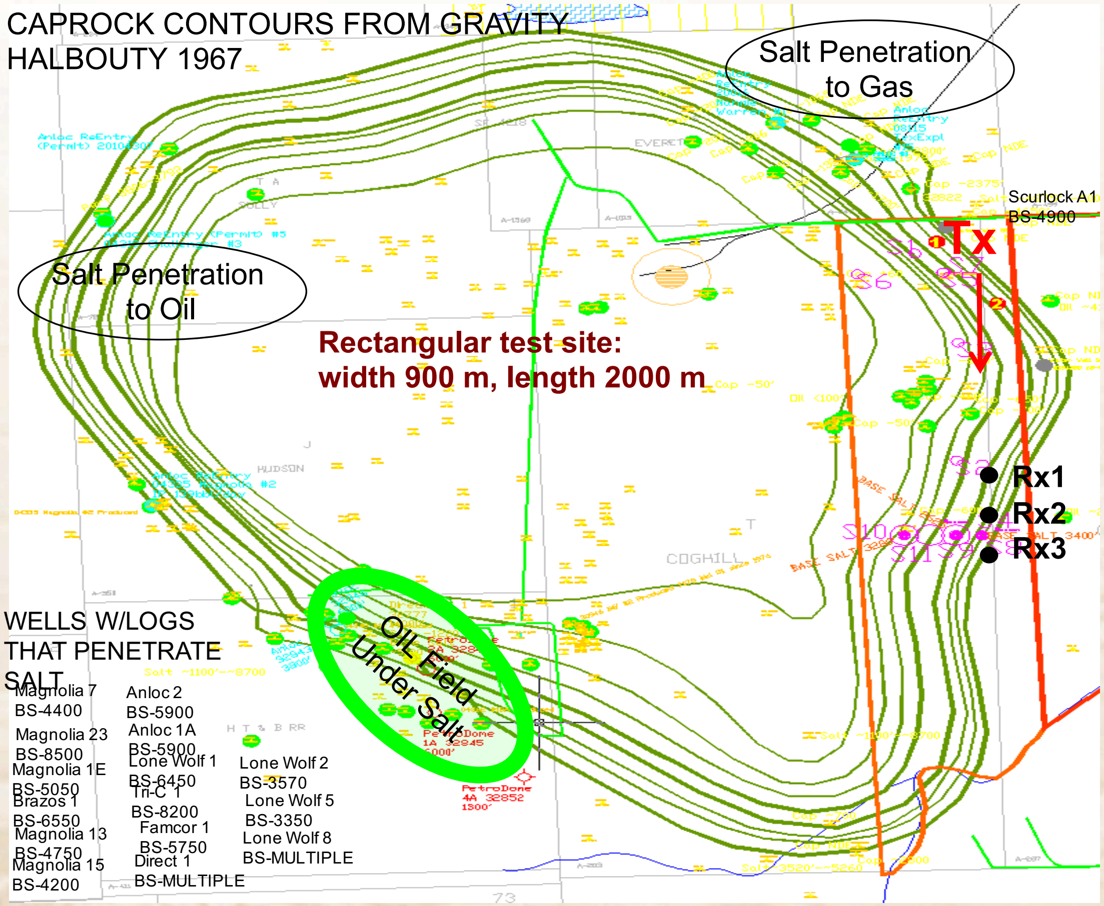


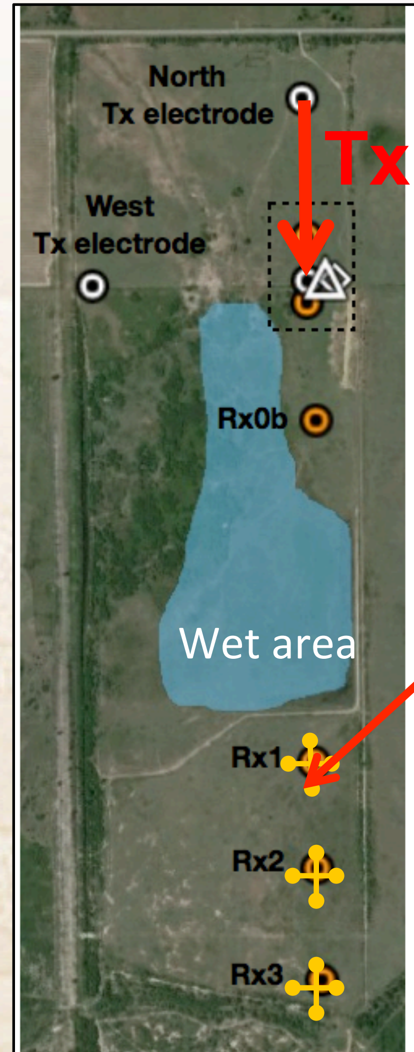


FSEM: Objectives FSEM example salt dome

- 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

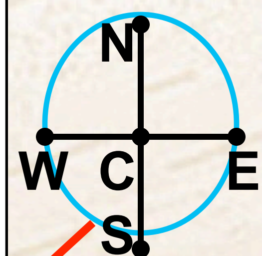
FSEM: Focused Source EM: Survey setting





Tx North: -340 m
(29.9659° 95.8274°)

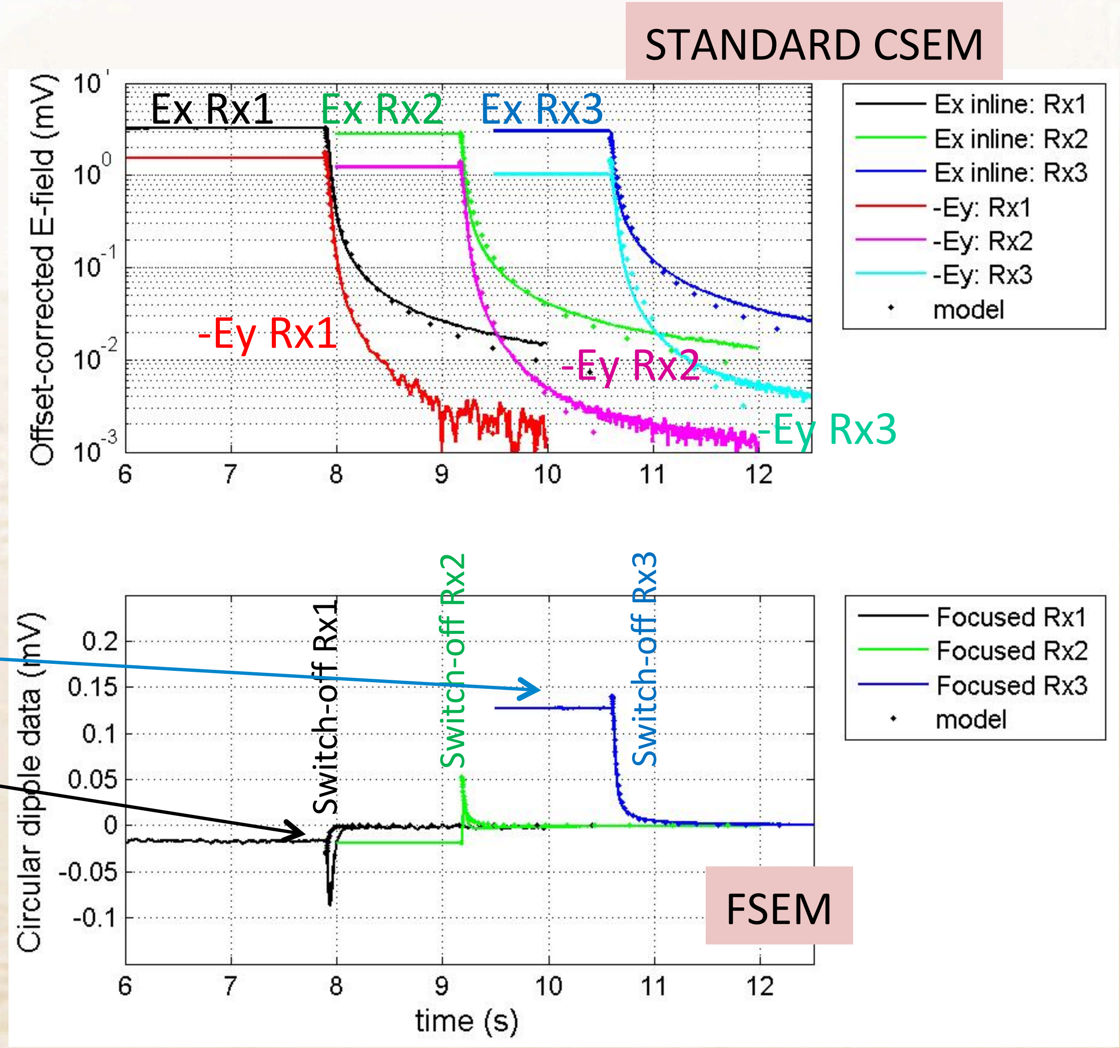
Tx South: 0
(29.9628° 95.8273°)



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

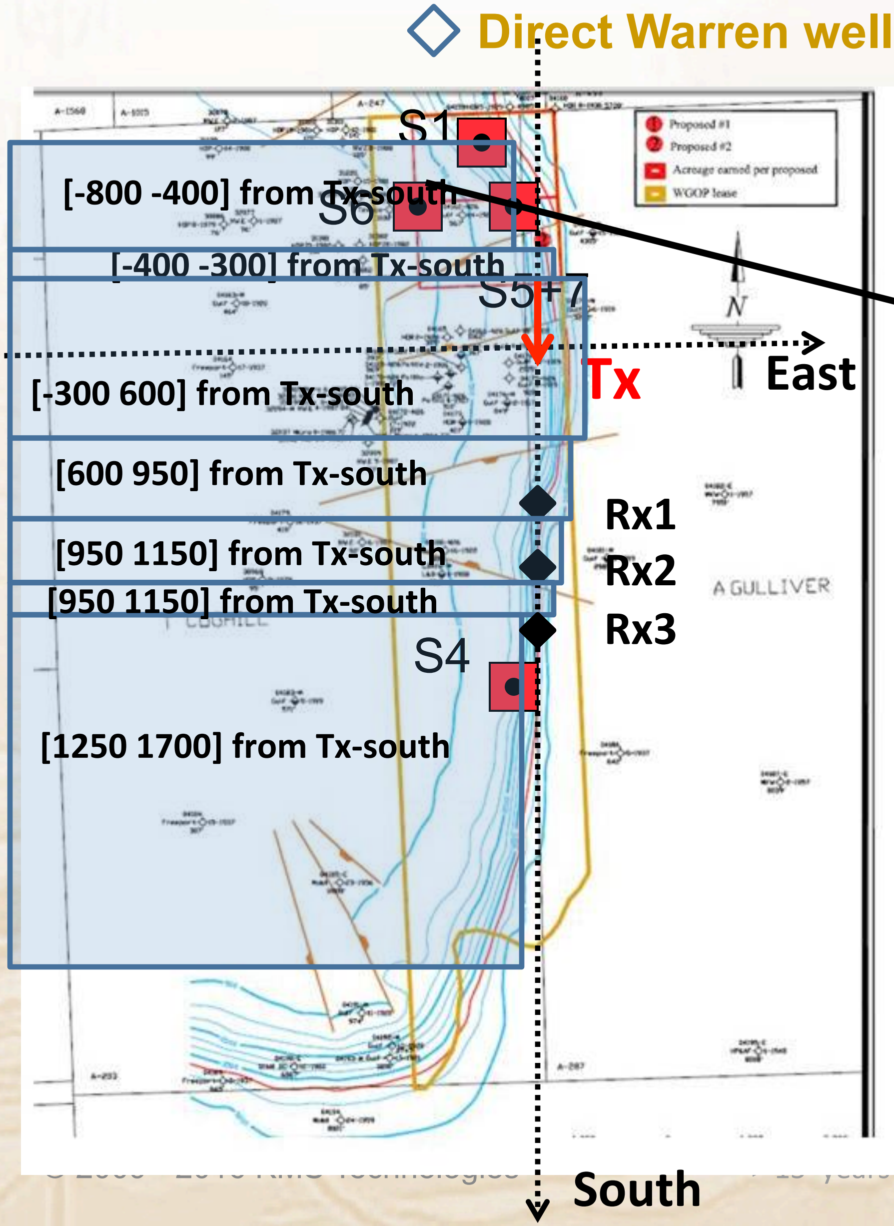
FSEM: Measurements vs 3D model: transients in Rx1, Rx2, Rx3

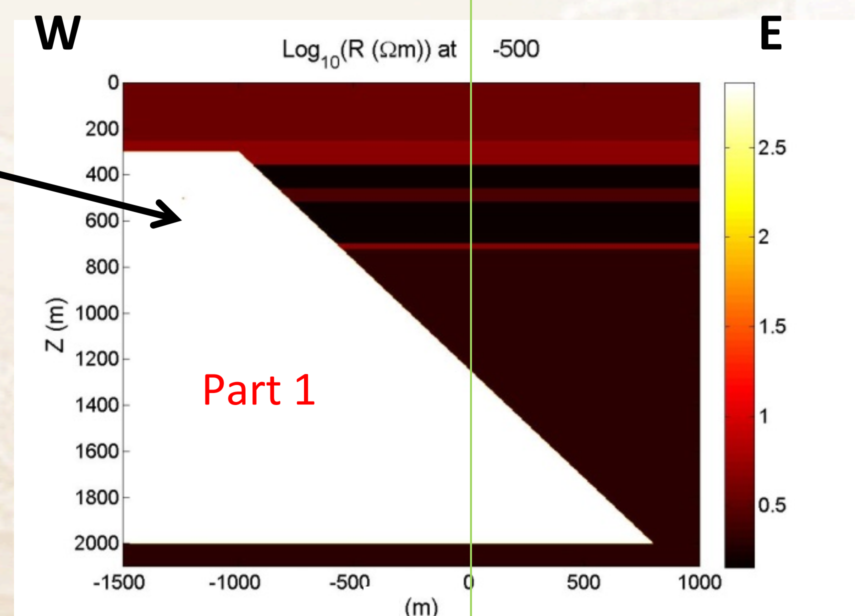
- Offset-corrected data (lines) vs model (dots)
  - DC levels: checked to 1 nV
  - Time-decay curves
- Ex (inline) & Ey (cross-line):
  - In all receivers: similar time-decay
  - Ey is comparable to Ex because at the edge of the salt dome currents tend to turn around its corner(s)
- Circular dipole data:
  - 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)



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

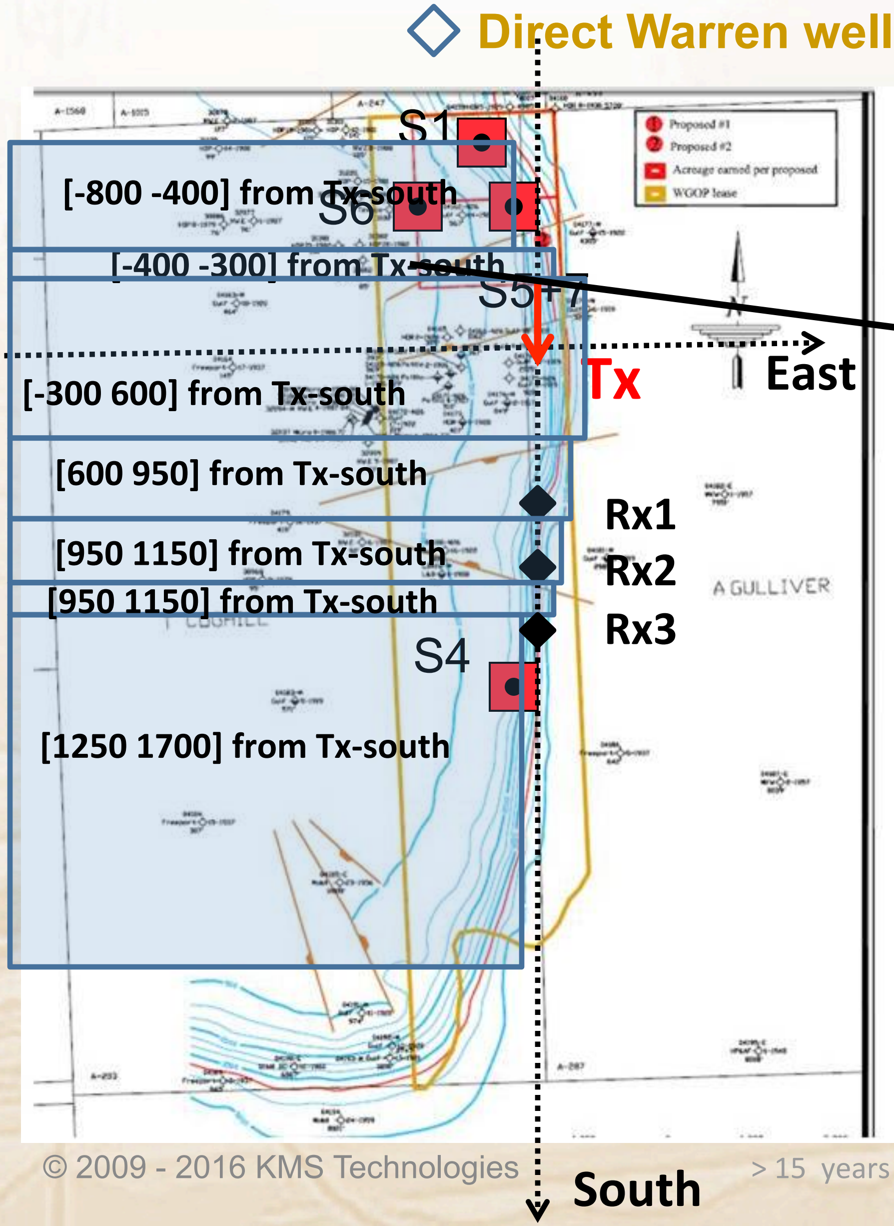
- Best matching salt dome model derived
- It consists of 7 parts

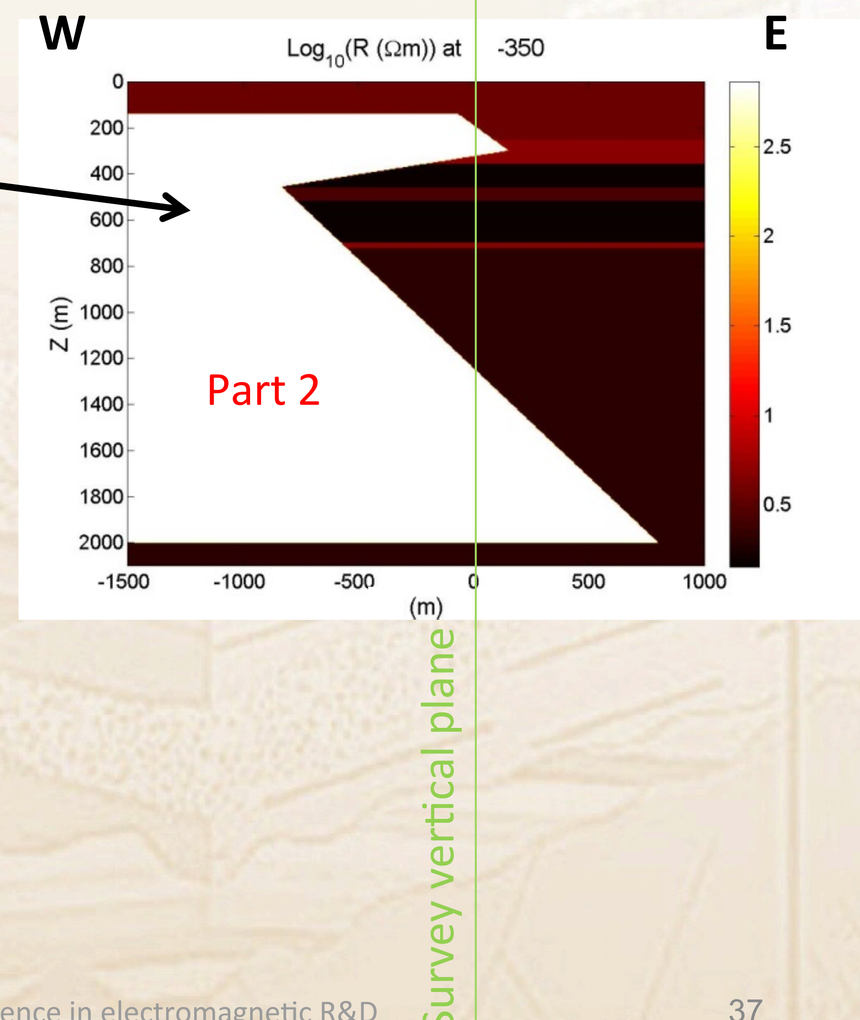




FSEM: 3D model (5) of salt dome (Part 2)

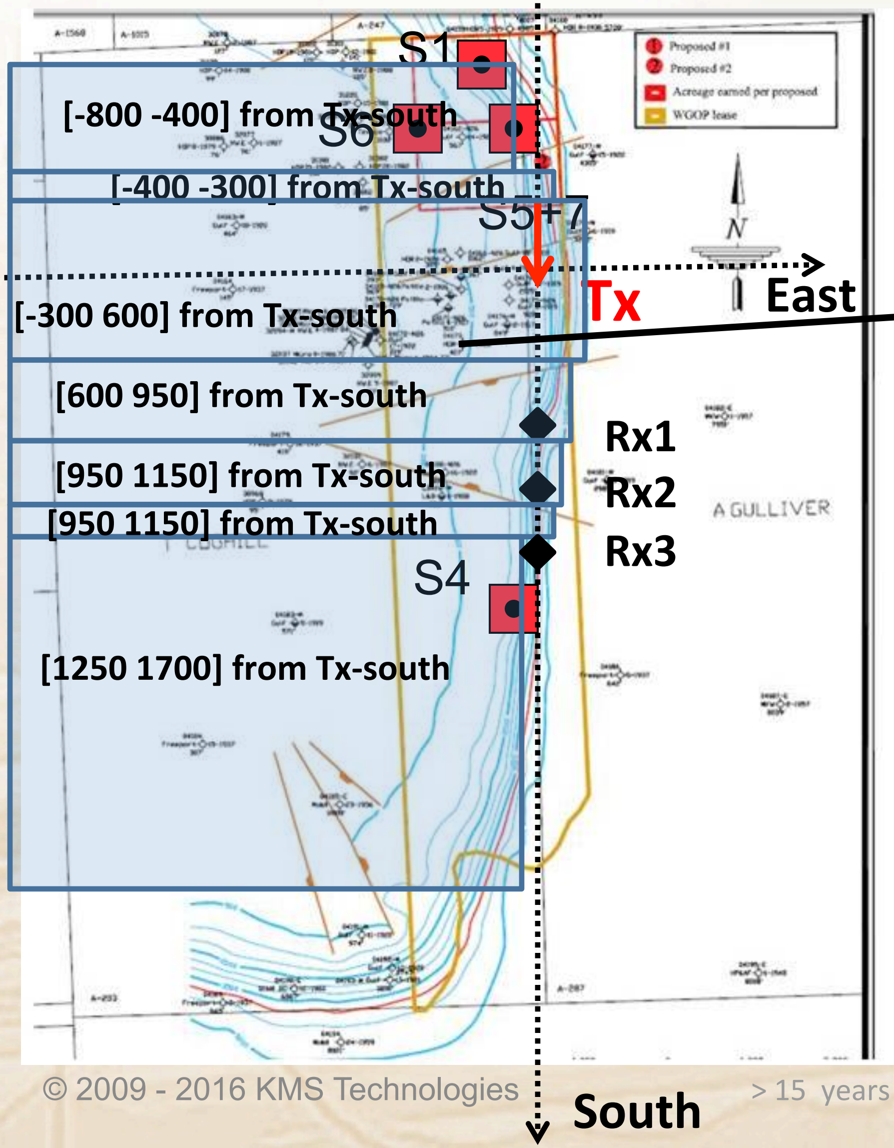
- Best matching salt dome model derived
- It consists of 7 parts

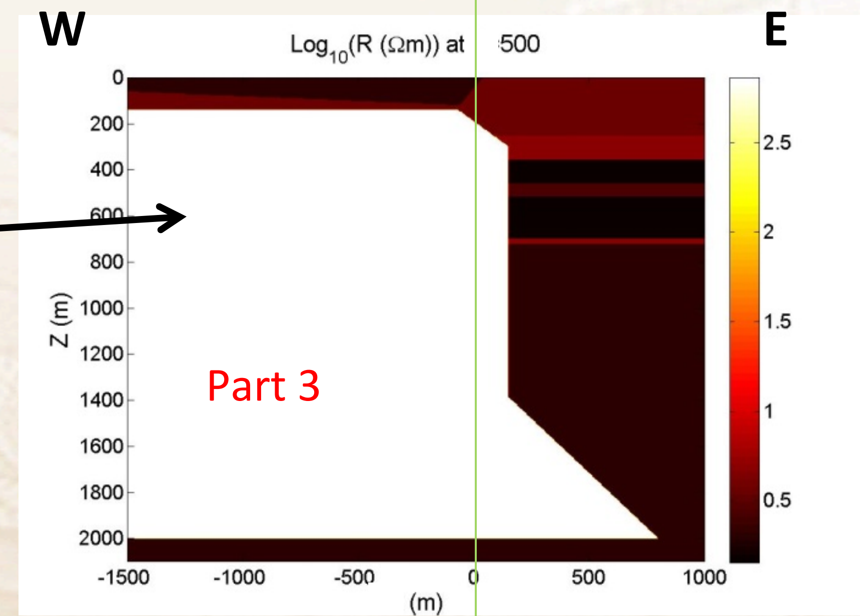




FSEM: 3D model (5) of salt dome (Part 3)

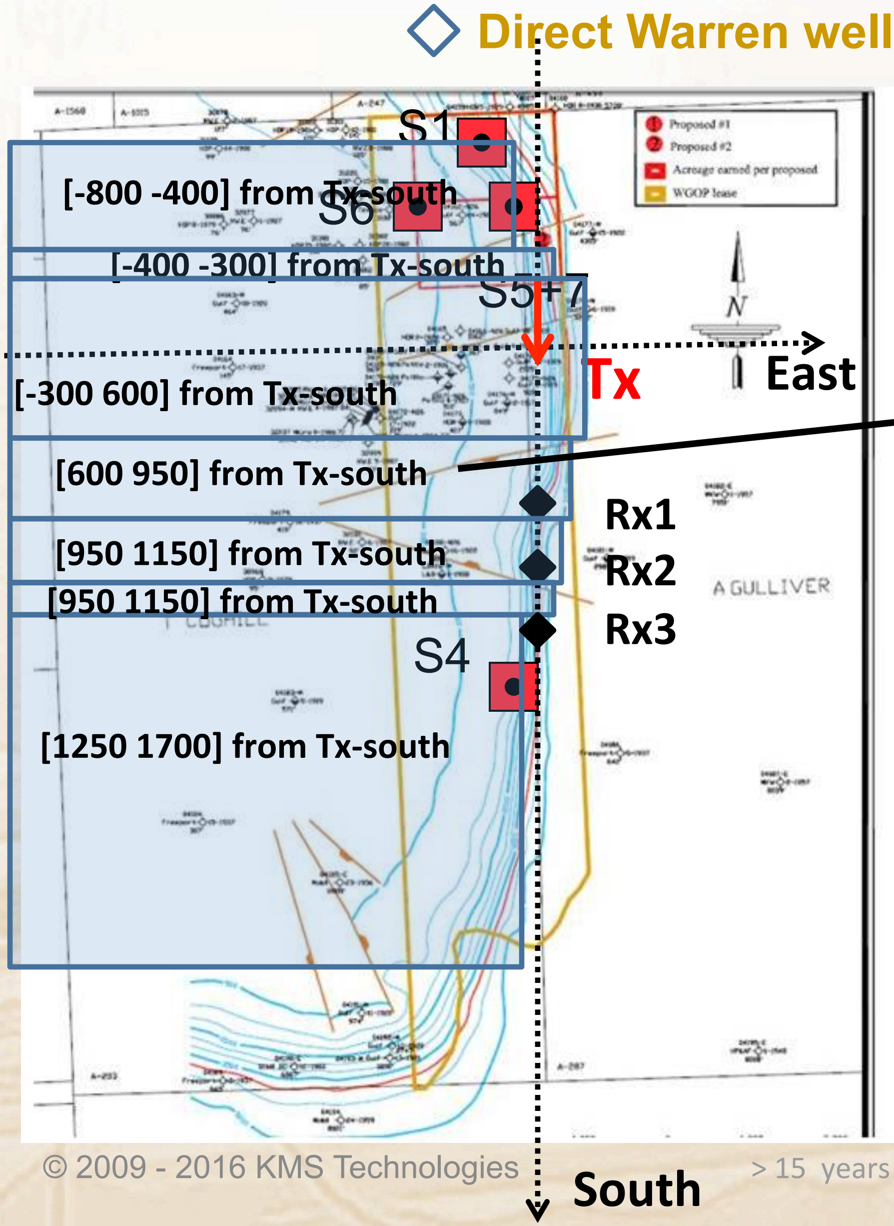
- Best matching salt dome model derived
- It consists of 7 parts

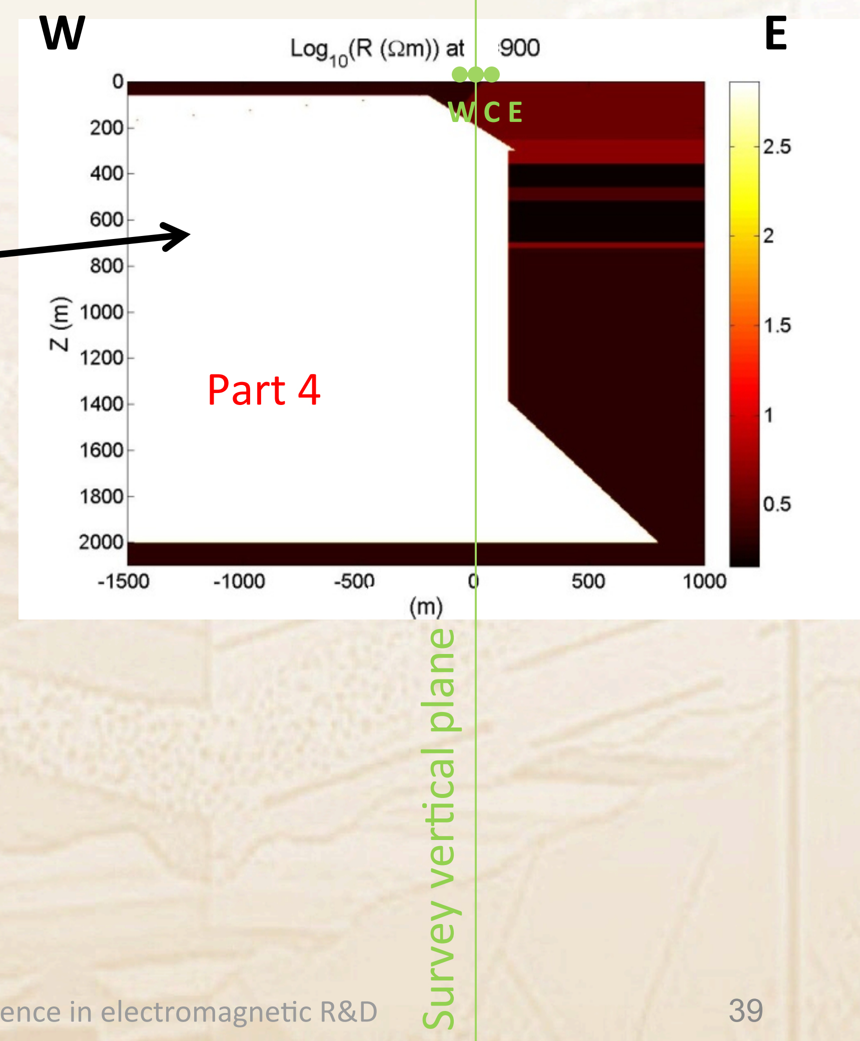




FSEM: 3D model (5) of salt dome (Part 4)

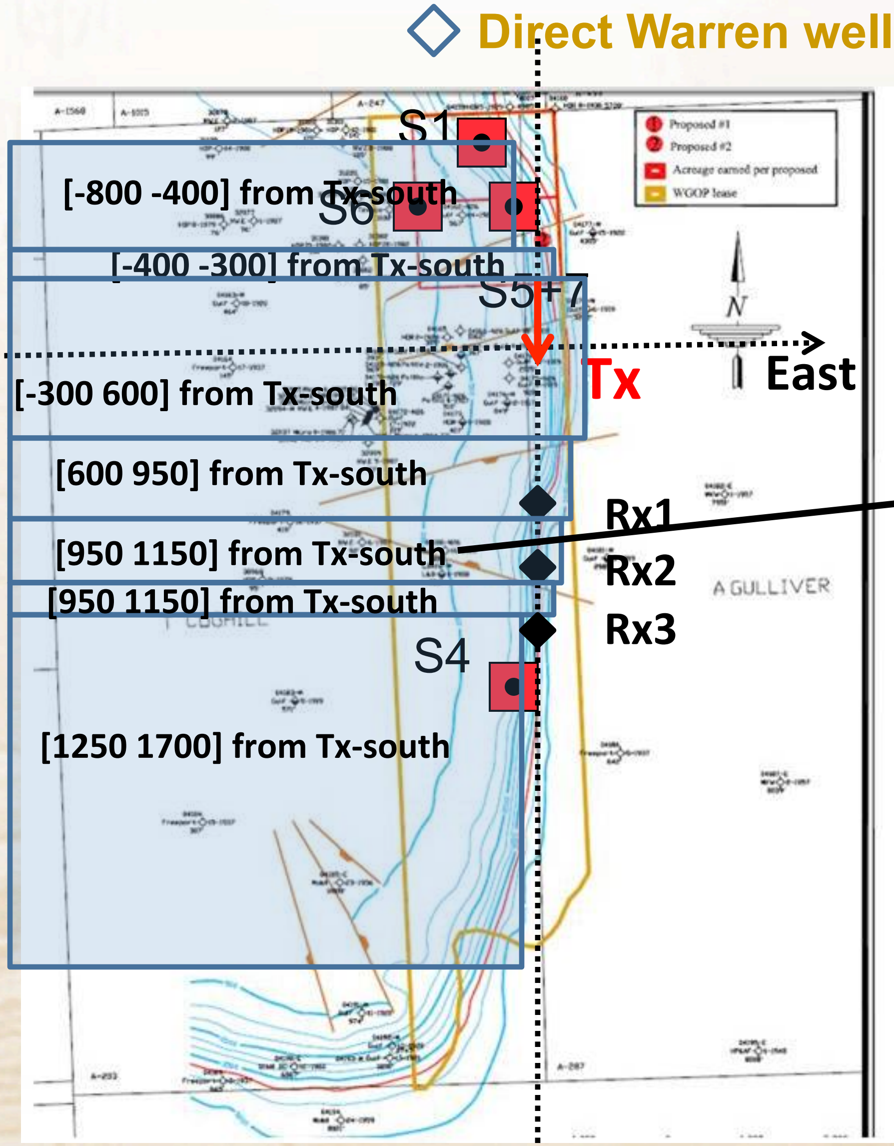
- Best matching salt dome model derived
- It consists of 7 parts

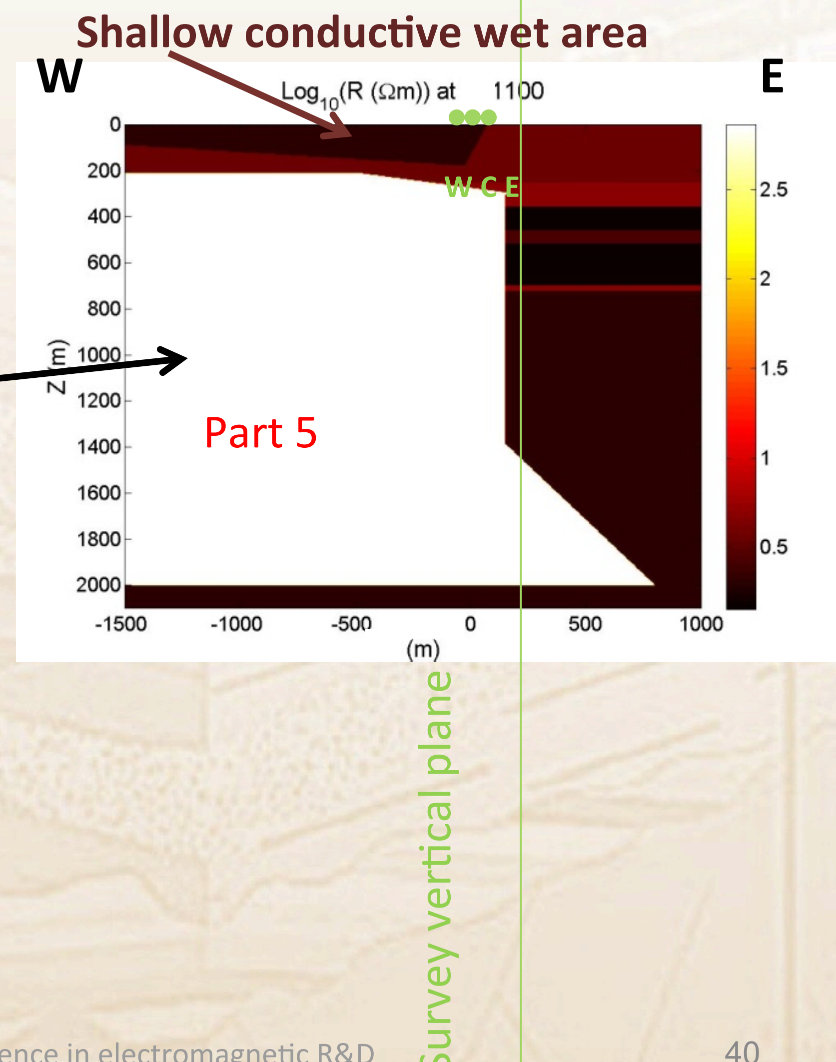




FSEM: 3D model (5) of salt dome (Part 5)

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

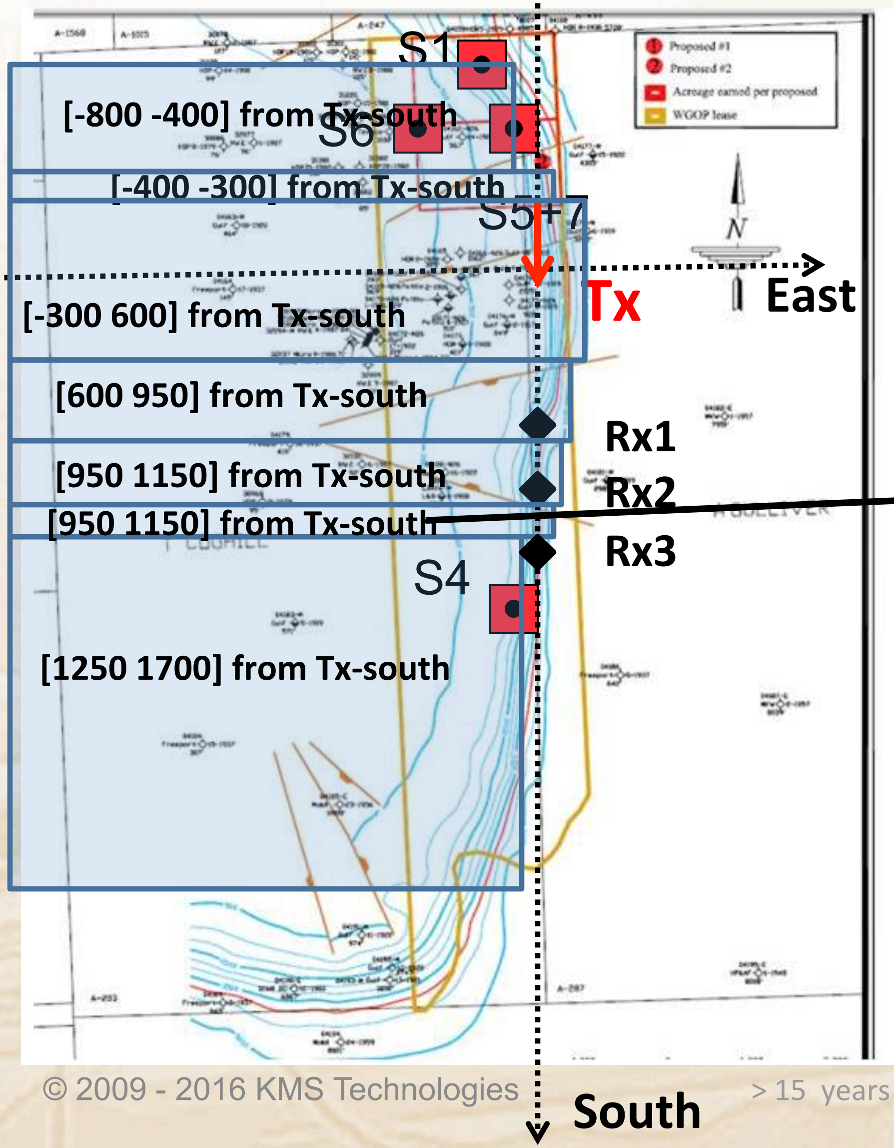


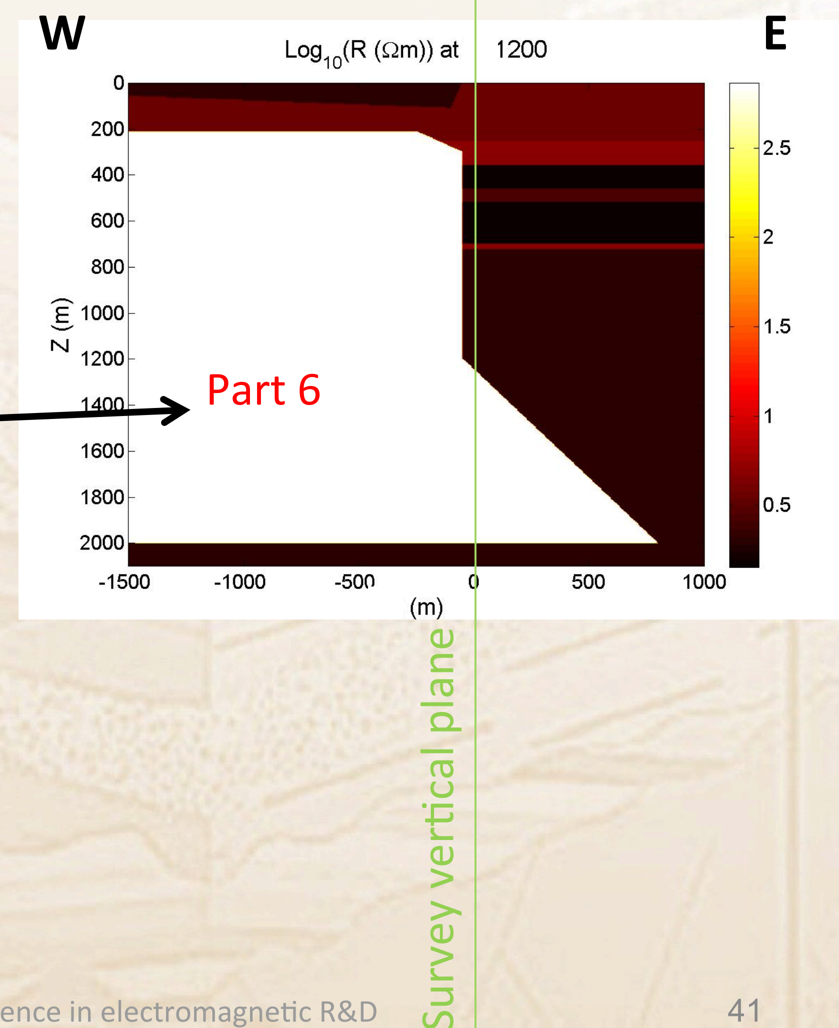


FSEM: 3D model (5) of salt dome (Part 6)

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

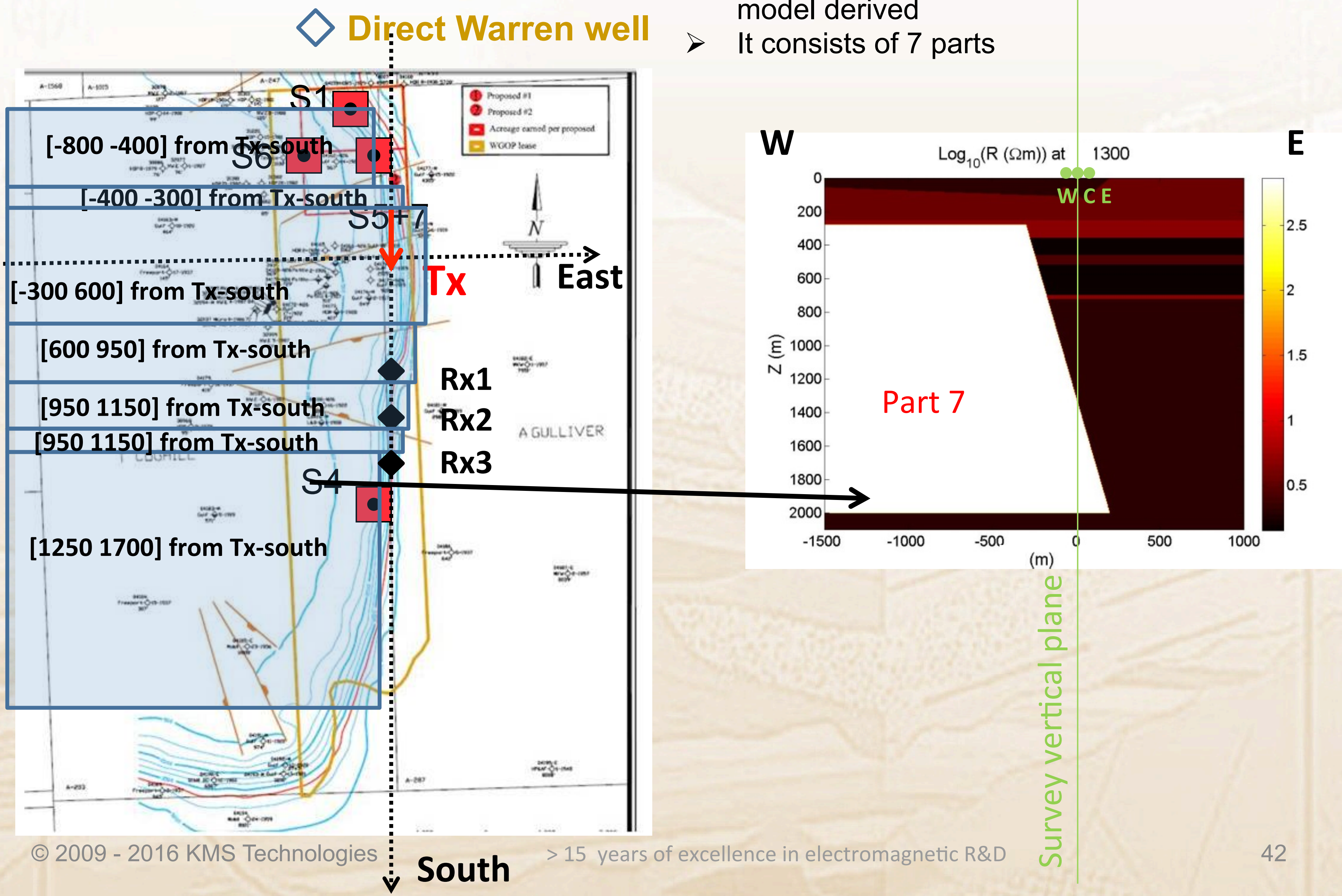
◇ Direct Warren well





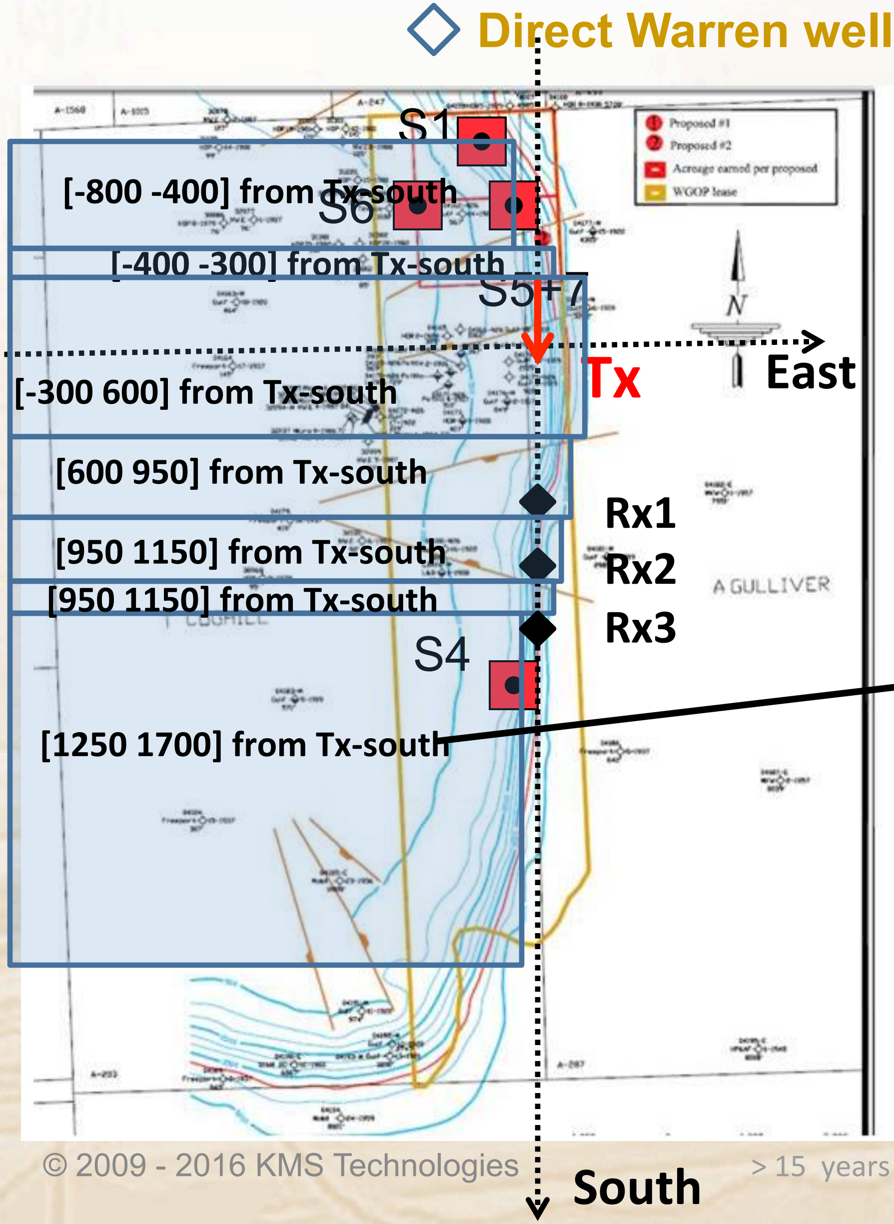
FSEM: 3D model (5) of salt dome (Part 7)

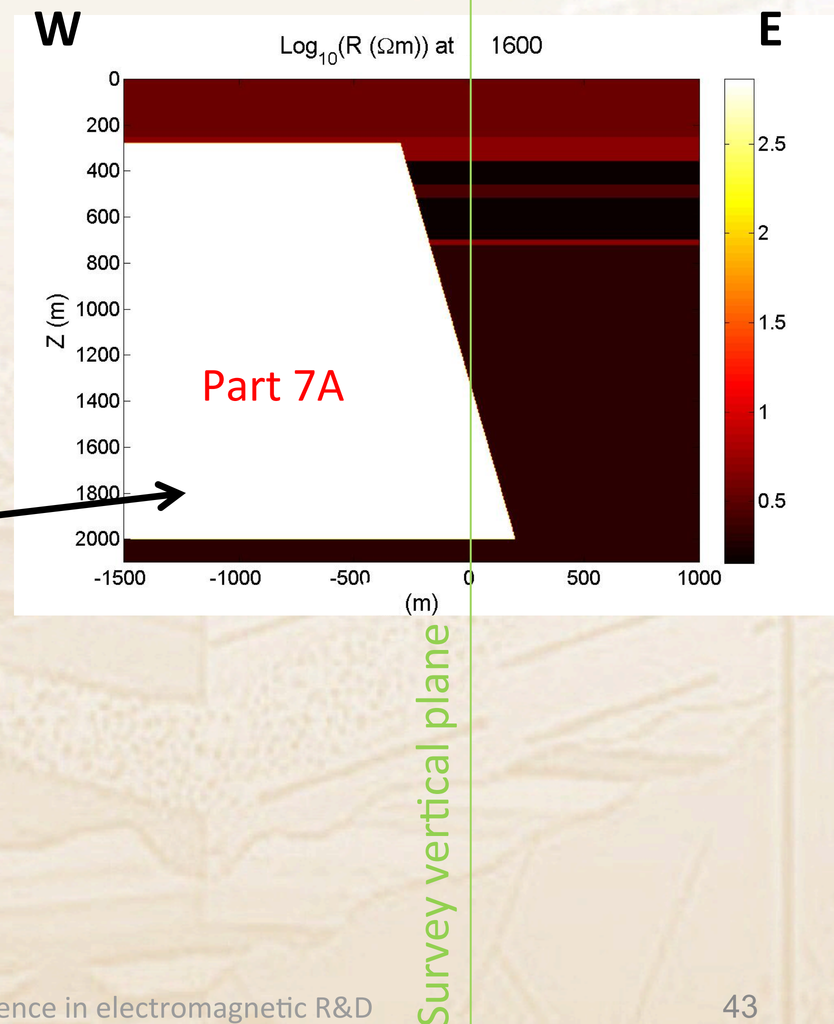
- Best matching salt dome model derived
- It consists of 7 parts



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

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





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