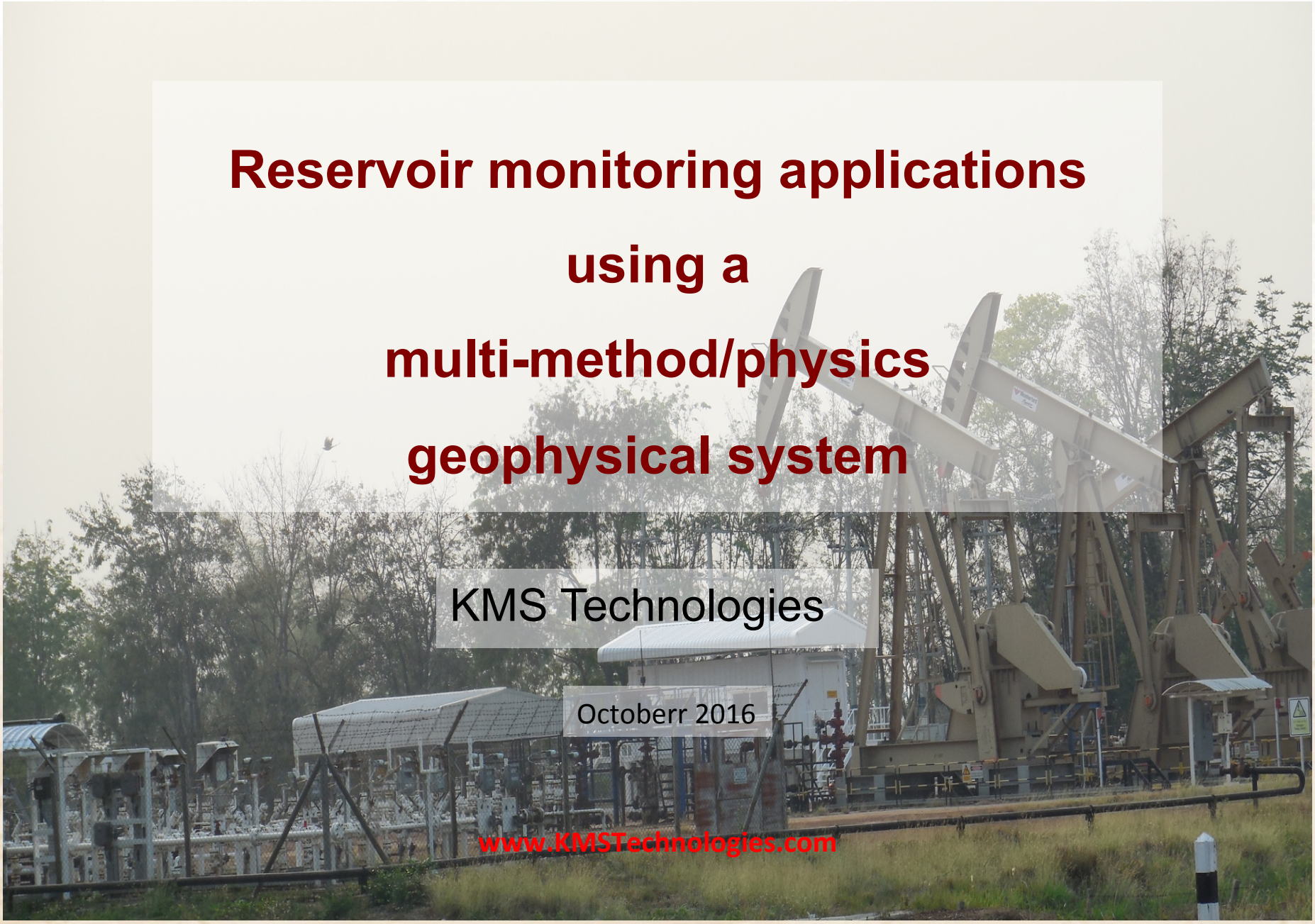
Reservoir monitoring applications using a multi-method/physics geophysical system



KMS Technologies

Octoberr 2016

www.KMSTechnologies.com

Purpose

- Take home?
  - Carry out a 3D Feasibility BEFORE the survey
  - EM expert on Client side (reservoir!)
  - Reservoir monitoring - EOR
    - Great potential
    - Every reservoir is different
    - ALL components exist

Purpose

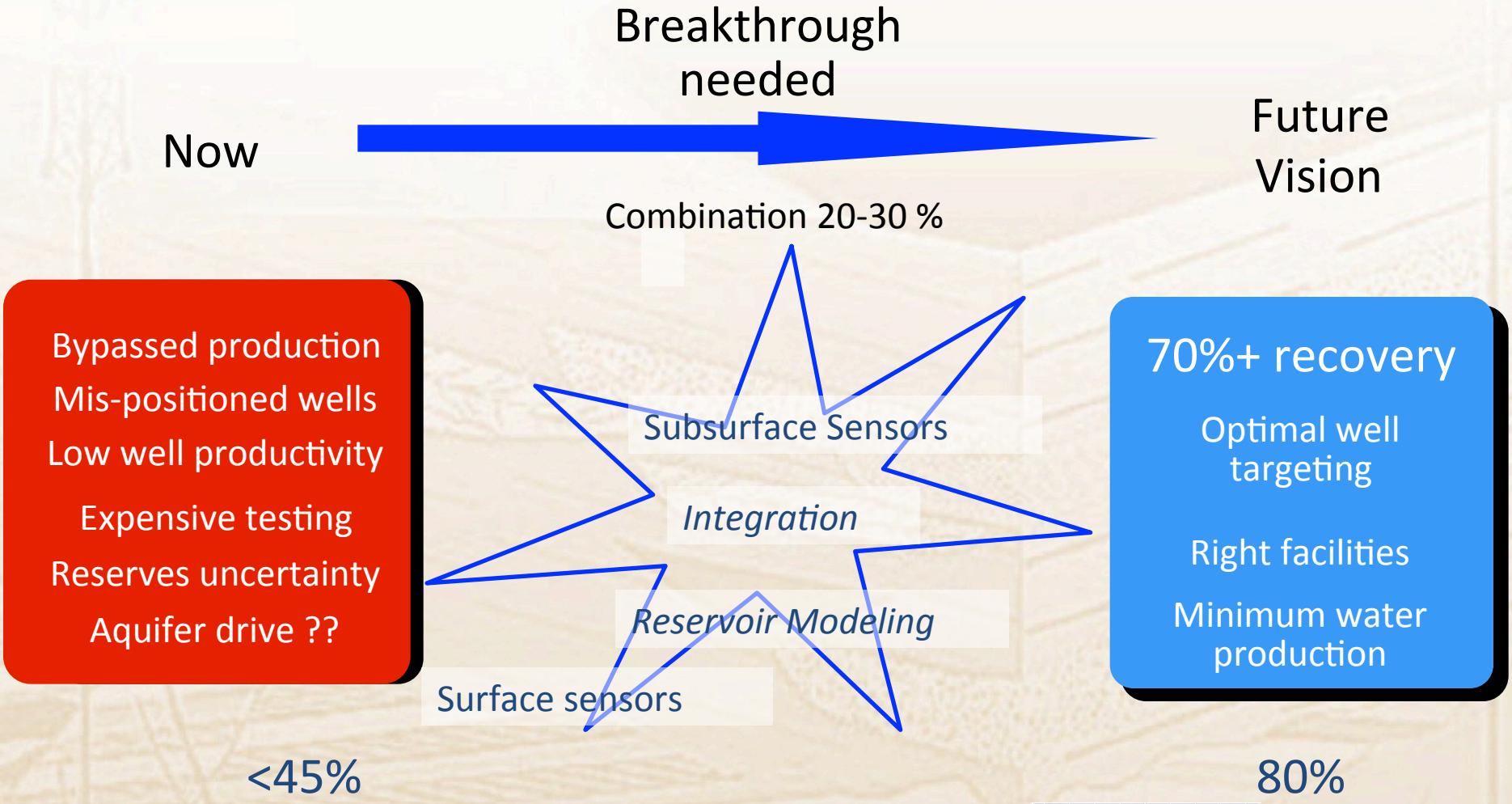
- Wedehof… Feasibility – results –
- EOR
- Feasibility - workflow

- Start with purpose & LIMITATIONS

Multi-physics acquisition system
Outline

- Background
- Architecture & hardware
- Examples:
  - Monitoring
  - FSEM
- Conclusion & Recommendation

Motivation..old but not achieved



After DeepLook consortium vision

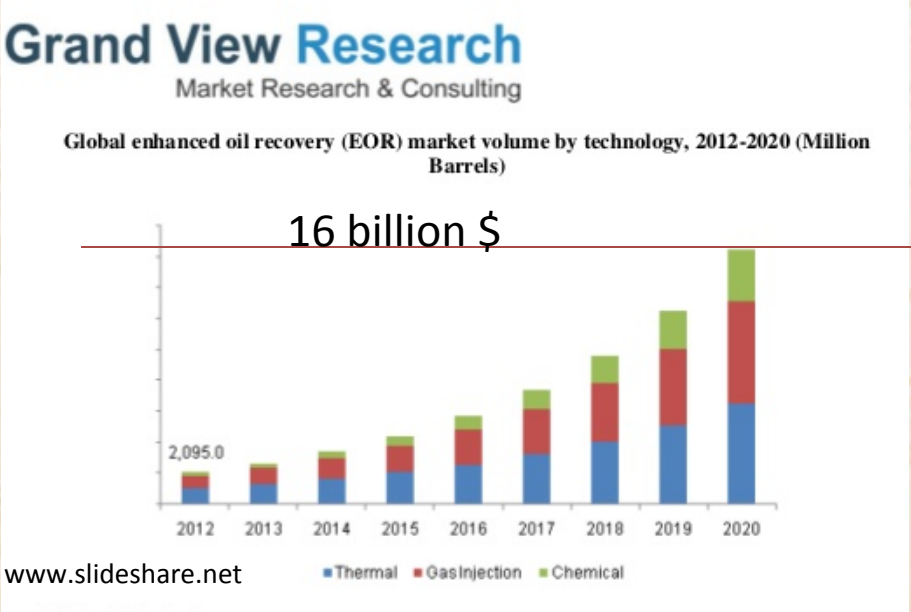
Market overview

- 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/

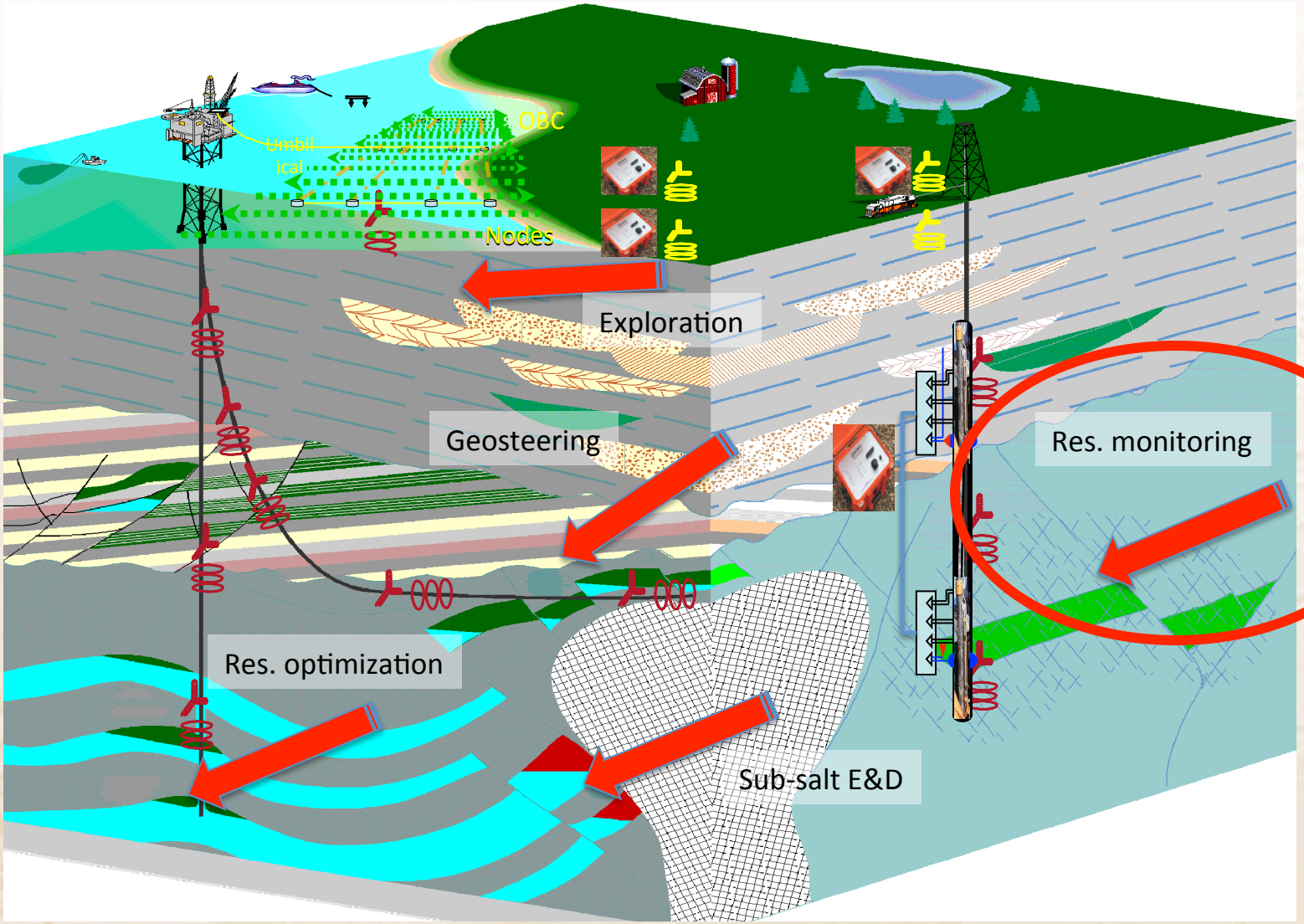
Geophysical data →
ONLY feed forward methods

→ GREAT opportunity

→ ALL cause resistivity contrast



High value APPLICATIONS – LOW to HIGH



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

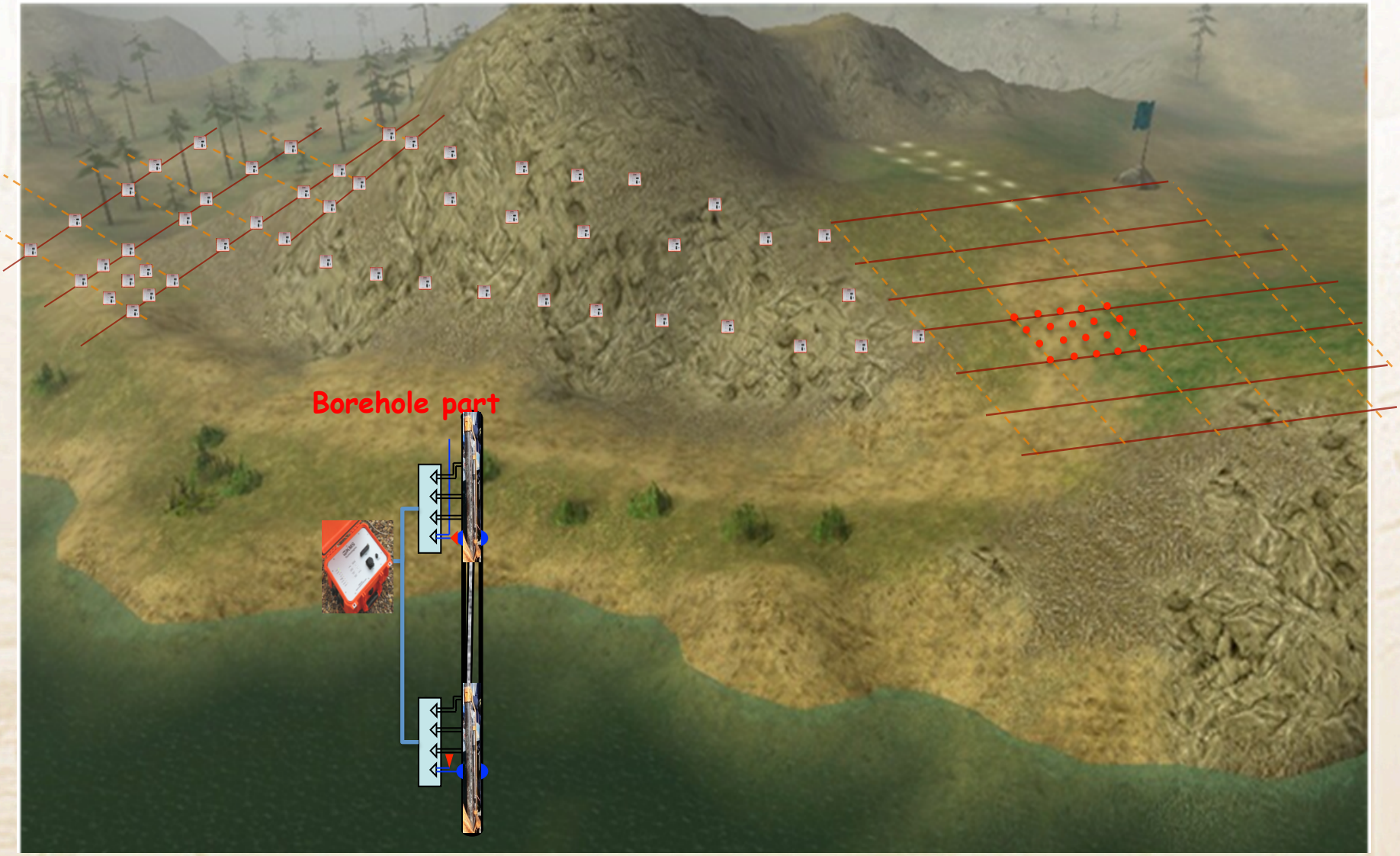
SENSOR CAPABILITY	RESOLVING POWER				
	Distance	Fluid	Surface-to-surface	Surface-to-borehole	Borehole
Seismic	Excellent	Poor	Excellent	Excellent	Ok (more noise)
EM	Ok (5% of depth)	Excellent (water to HC)	Ok	Excellent	Excellent (less noise & distance)
Gravity	Poor	Ok (oil to gas)	Poor	Poor (no source)	Poor (no source)
Strongest Synergy	Seismic	EM/seismic	Seismic/EM/ gravity	Seismic/EM	Seismic/EM/ gravity

With permission of WellDynamics

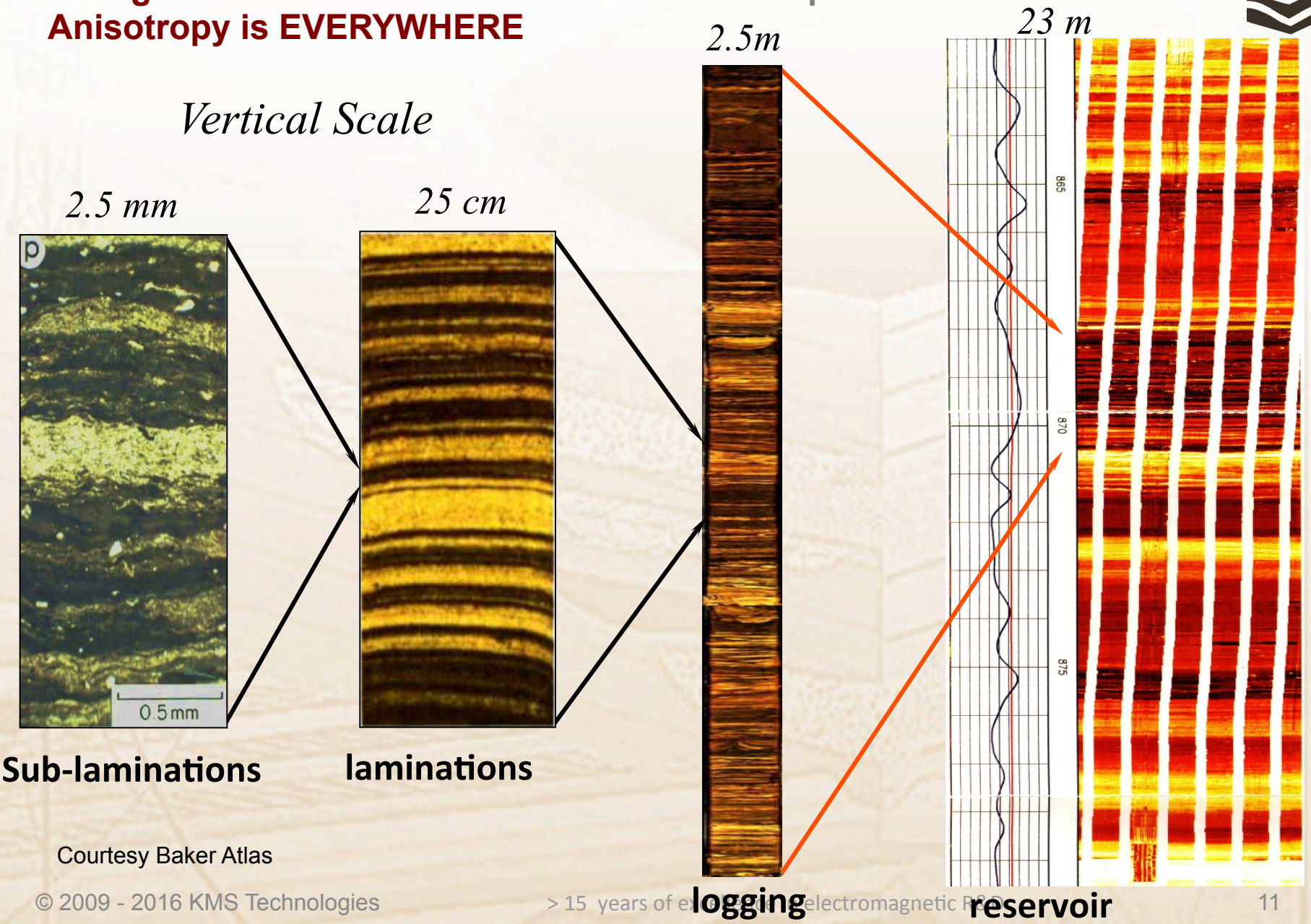
History versus NOW

- 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

Land acquisition requirements

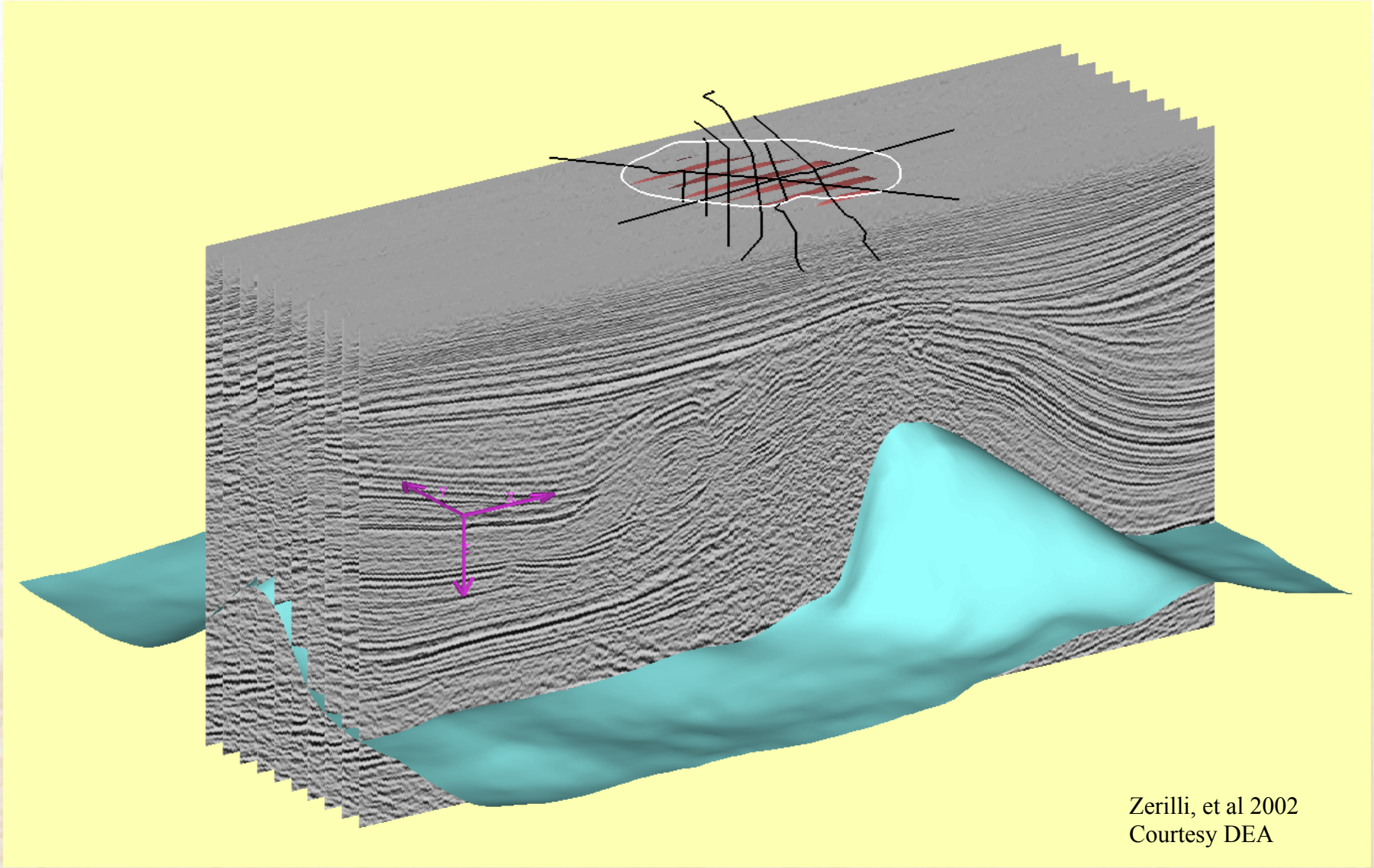


Anisotropy is EVERYWHERE



Courtesy Baker Atlas

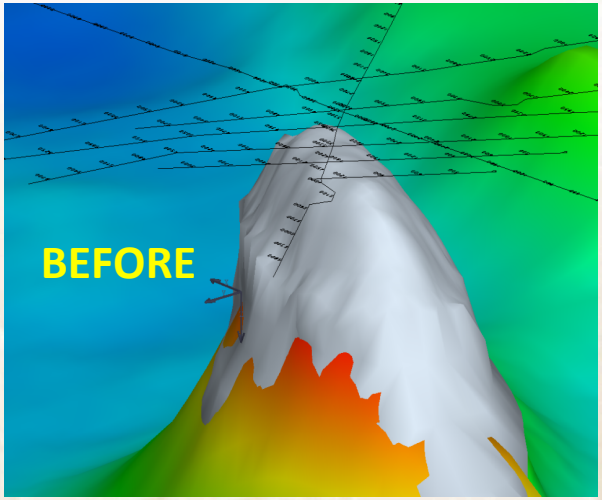
N. Germany: Dense acquisition → better images

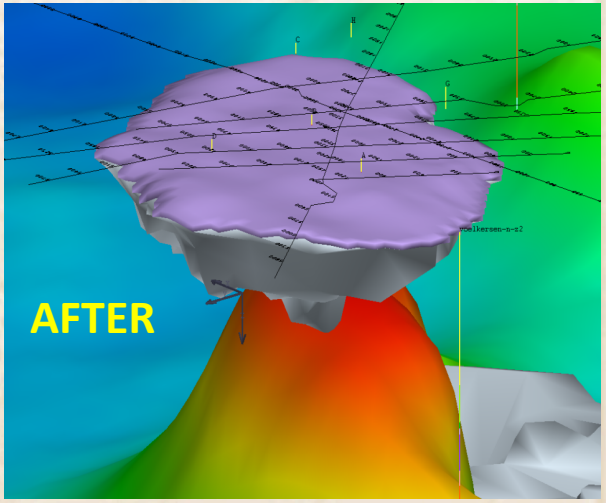


Zerilli, et al 2002
Courtesy DEA

N. Germany: Sub-salt case history PUNCHLINE

- Sub-Salt dome imaging.
- Evaluate noise sources & define model.
- Feasiblity 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

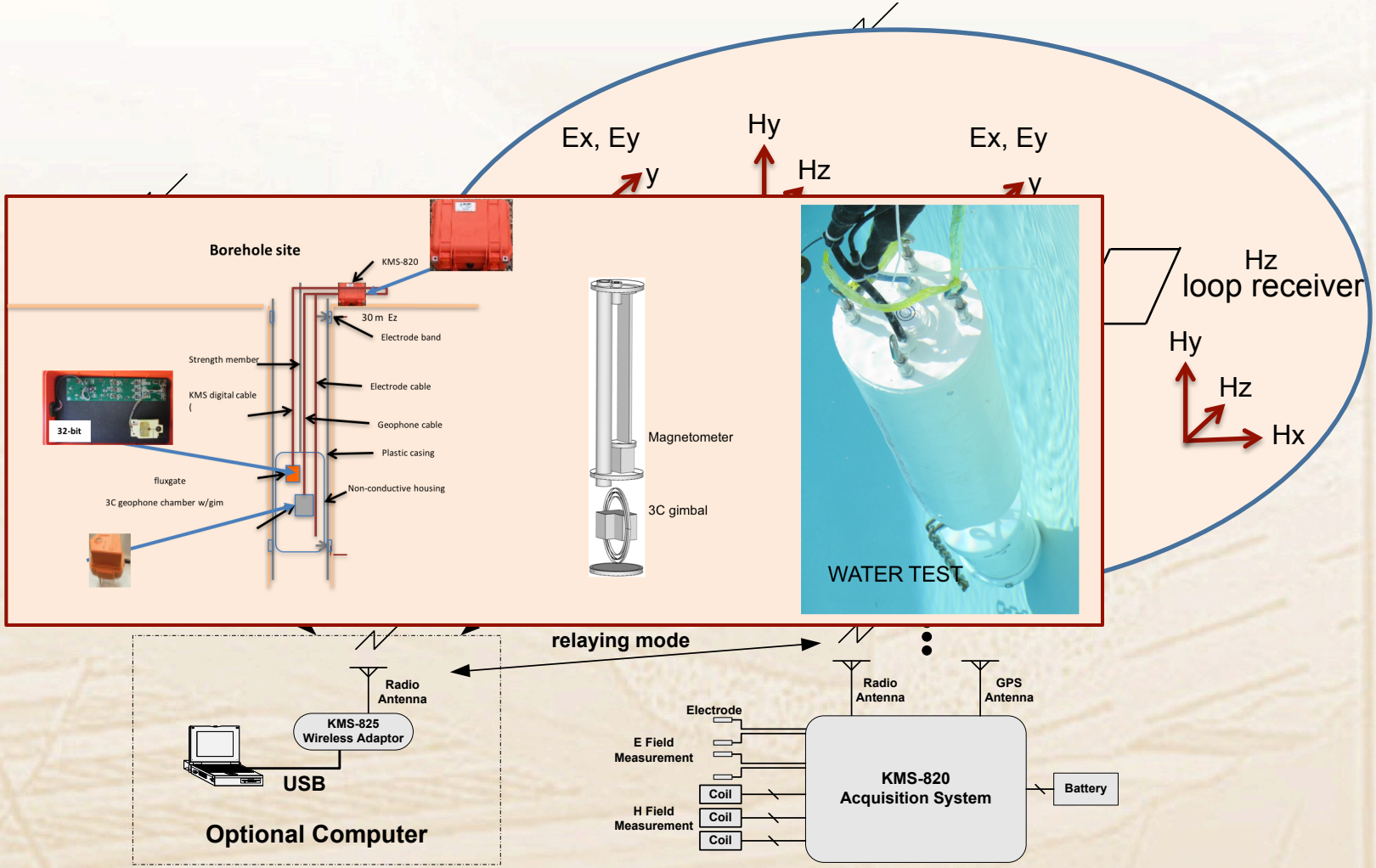




Architecture & hardware

- Objective & history
- Architecture & hardware
- Examples:
  - Monitoring
  - FSEM
- Conclusion

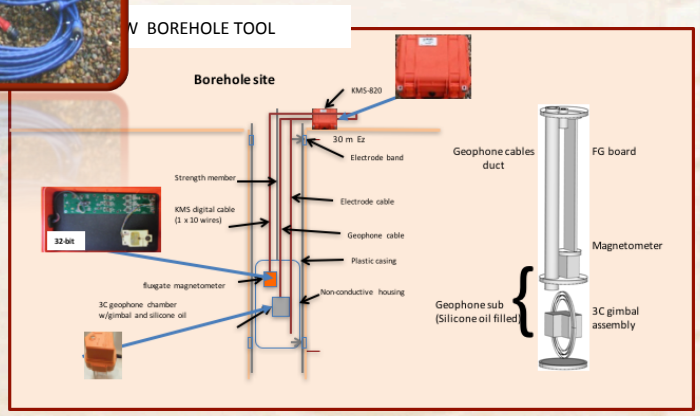
Architecture & hardware: original 2009 design UPDATE



Receiver (KMS-820): for MT & CSEM

DEEP BOREHOLE

V BOREHOLE TOOL



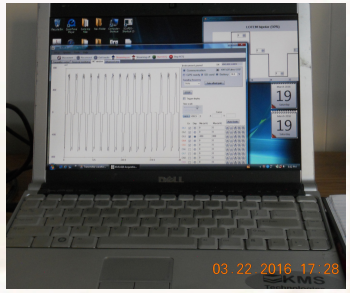
MARINE

Node
on deck

Combined seismic & EM node
For 2 months operation

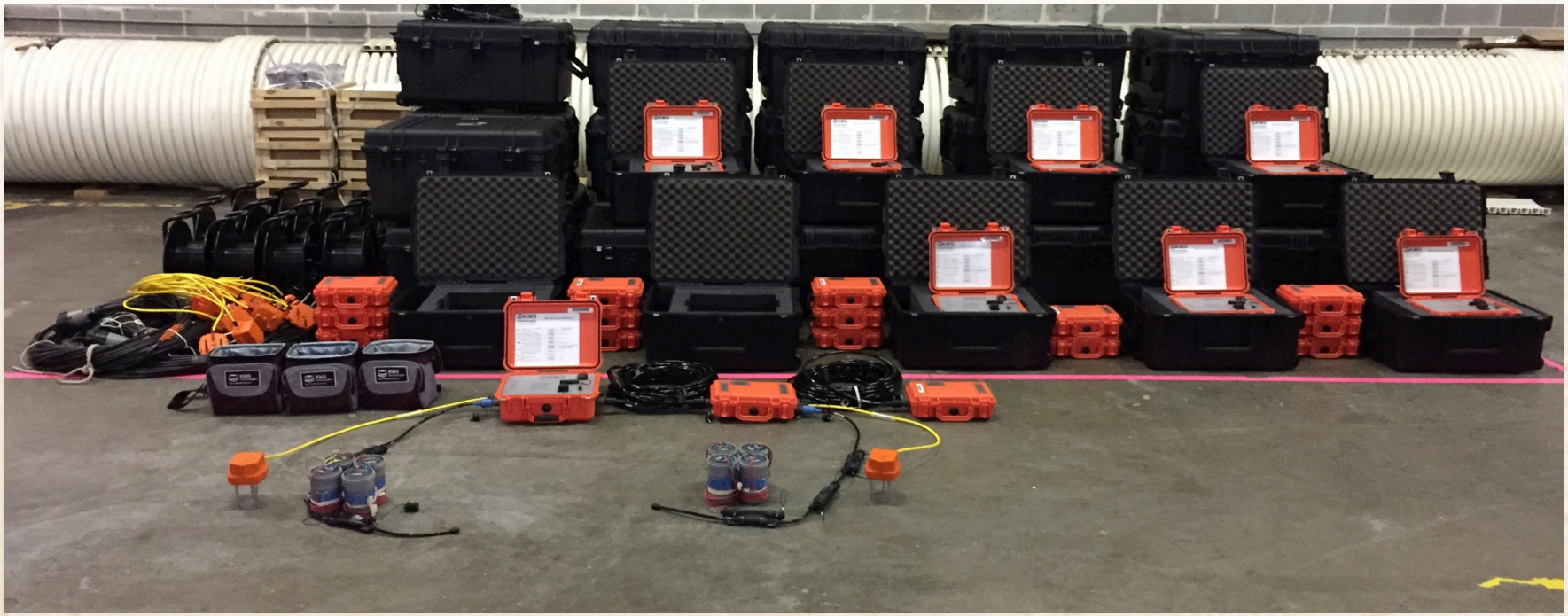
TRANSMITTER

KMS-5100 Transmitter – 100 KVA 2016



System response

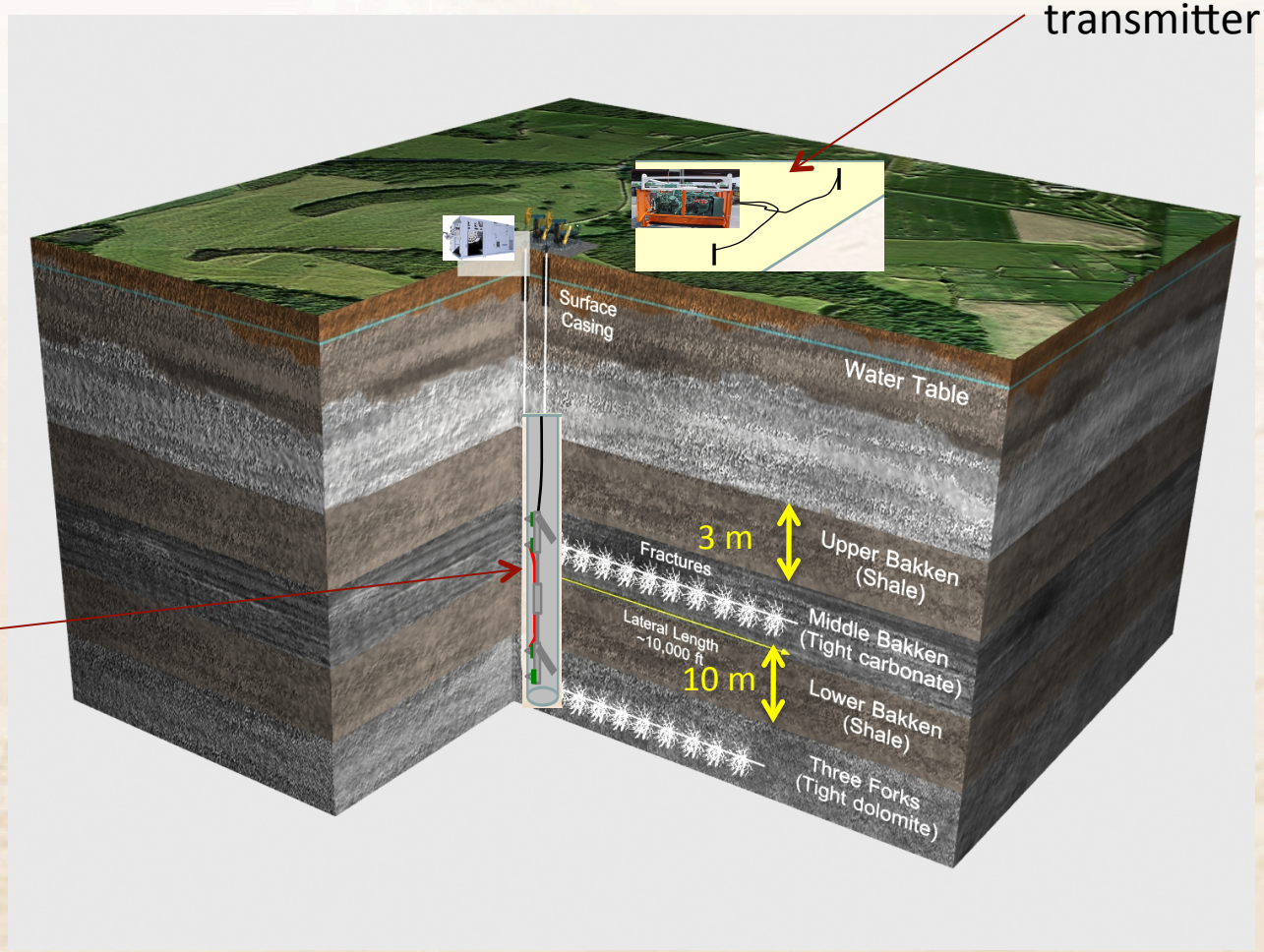
A 195 channel system



Outline

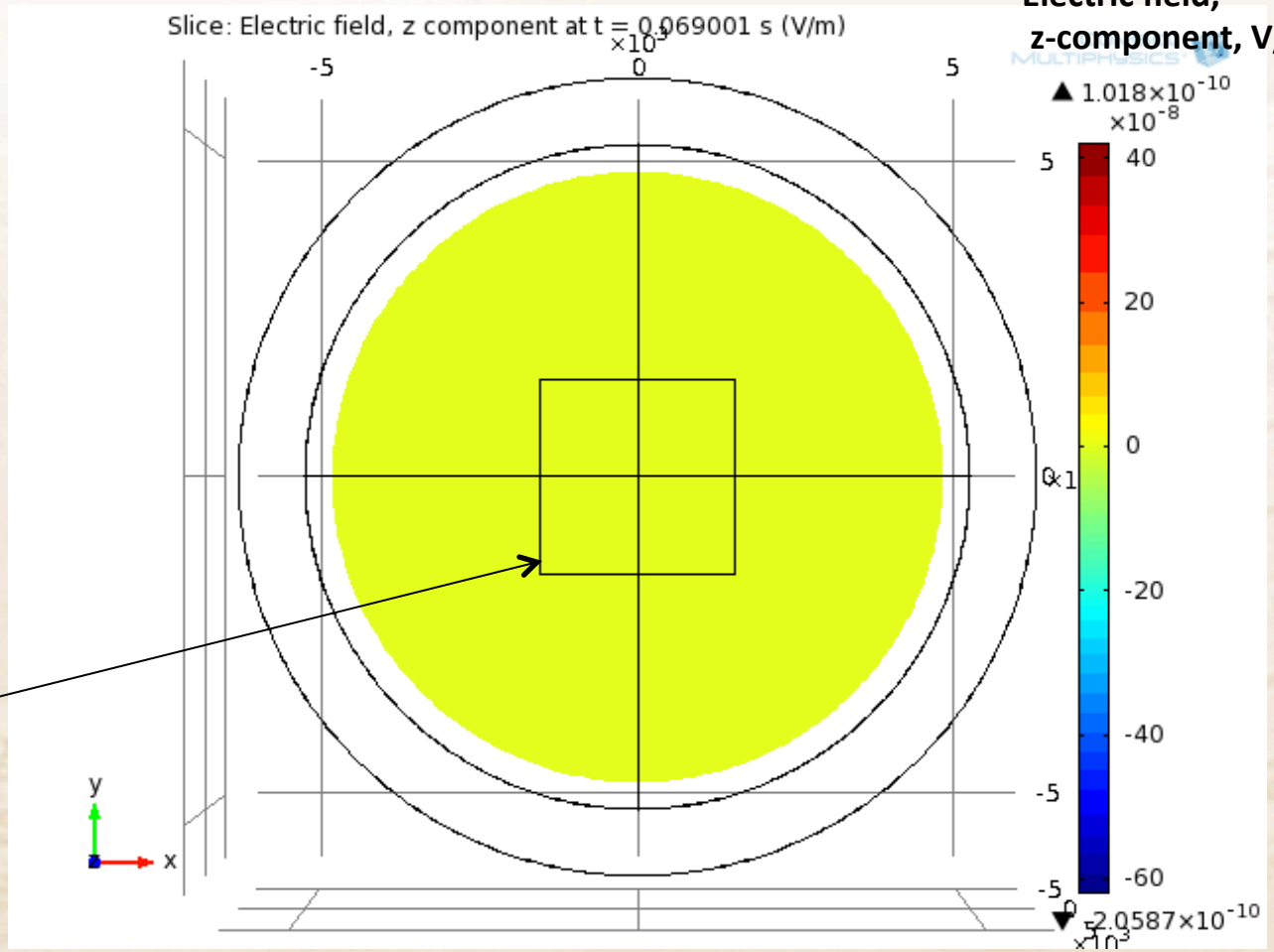
- Objective & history
- Architecture & hardware
- Examples:
  - Monitoring
  - FSEM
- Conclusion

Future: Shale resources: Bakken simulating DEPLETION monitoring

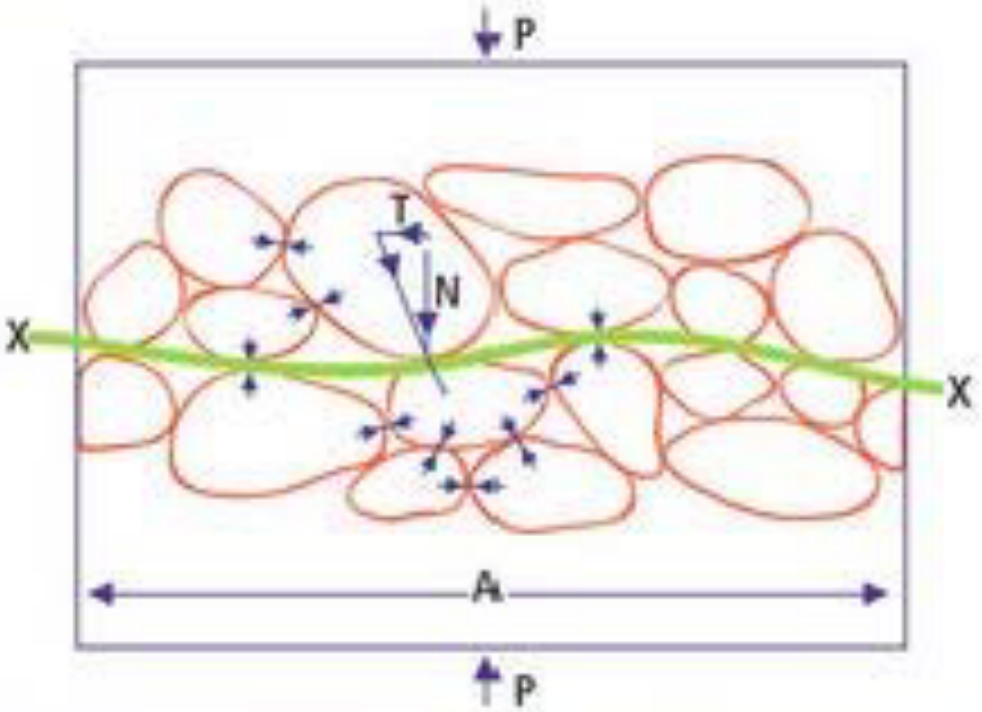


http://www.statoil.com/en/NewsAndMedia/News/2011/Pages/XXX16Oct2011.aspx

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



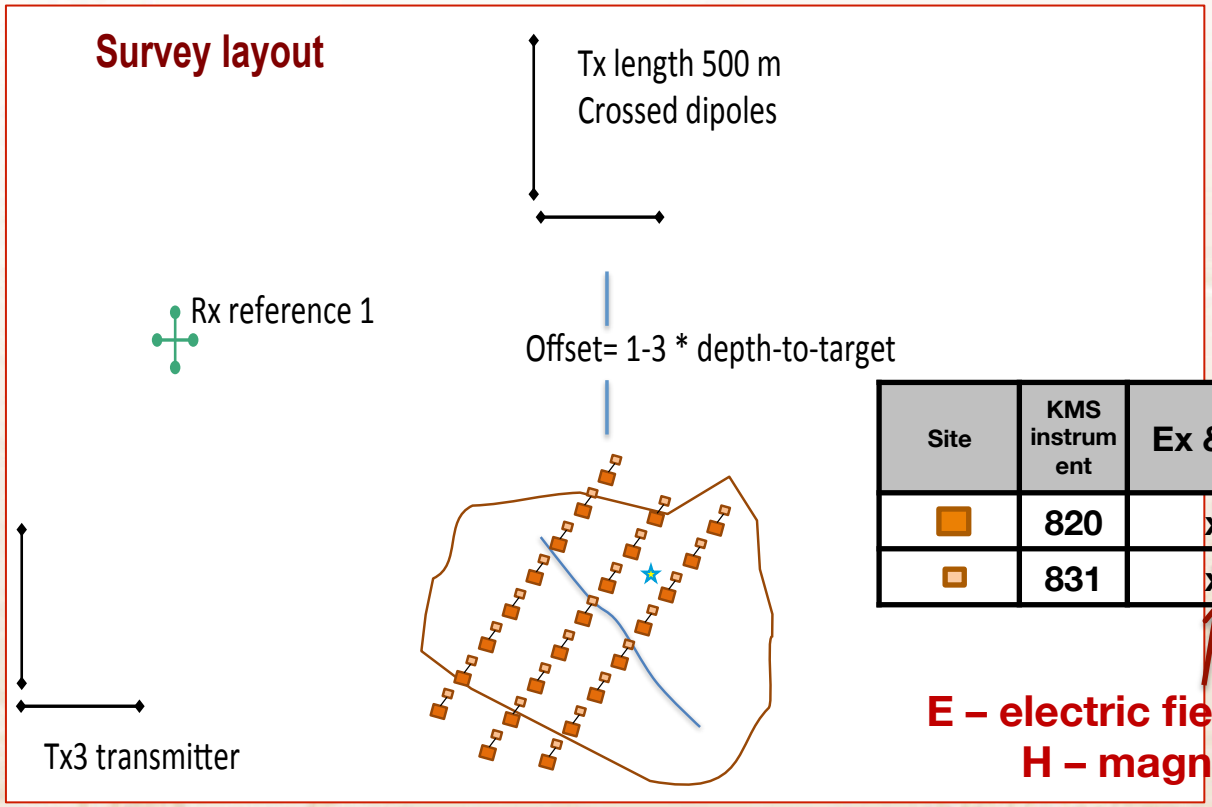
Reservoir Monitoring: Reservoirs seal: EM & microseismic - effective stress



- 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

Reservoir Monitoring: Example layout



Microseismic sensors

Site	KMS instrument	Ex & Ey	Hz	3C fluxgate H	3C geophone	Shallow borehole tool
	820	x	x	x	x	x
	831	x			x	

E – electric field sensors

H – magnetic field sensors

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

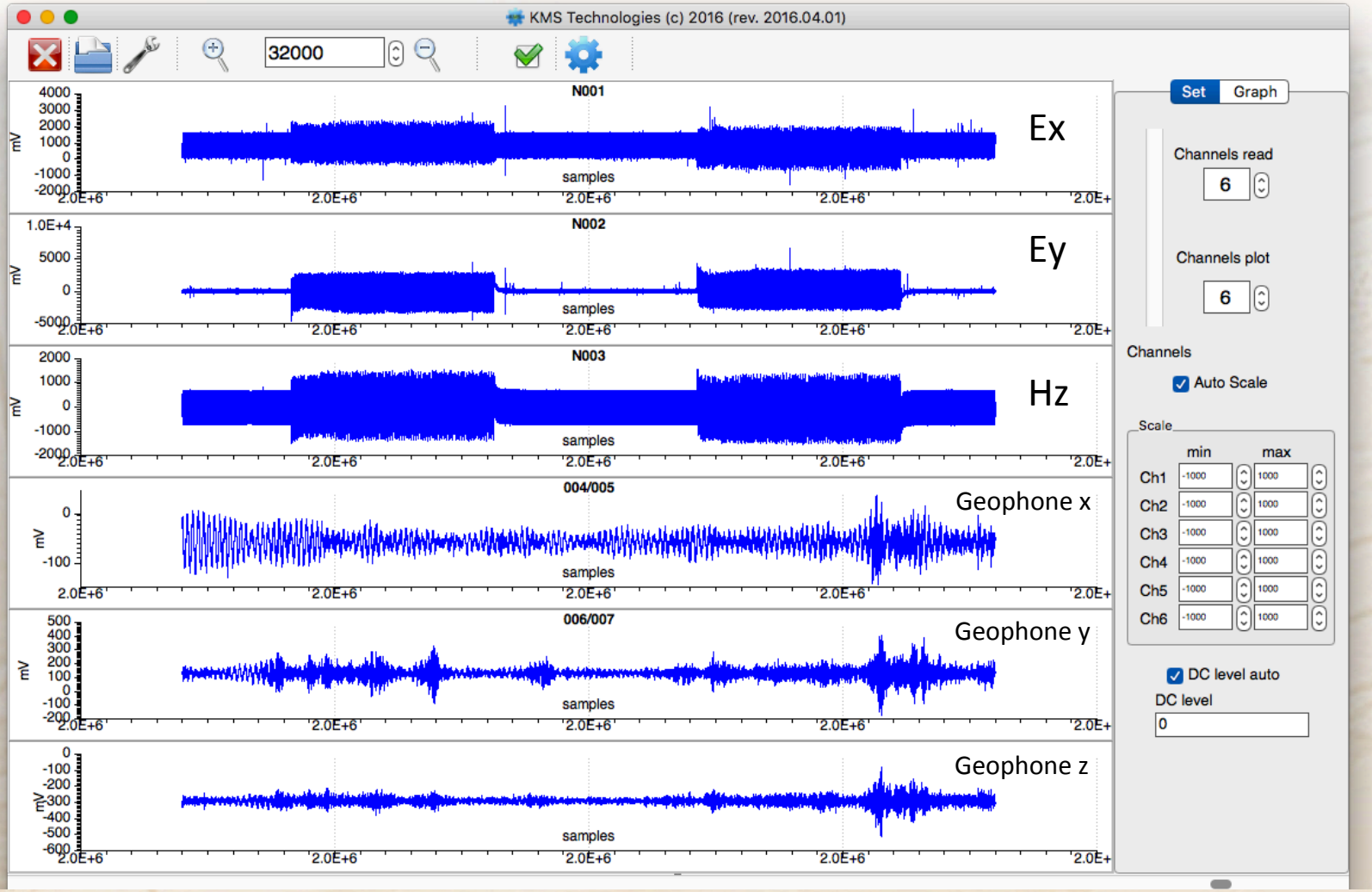
Reservoir Monitoring: 195 channel monitoring system

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)

Reservoir Monitoring: Raw data example: microseismic/EM monitoring



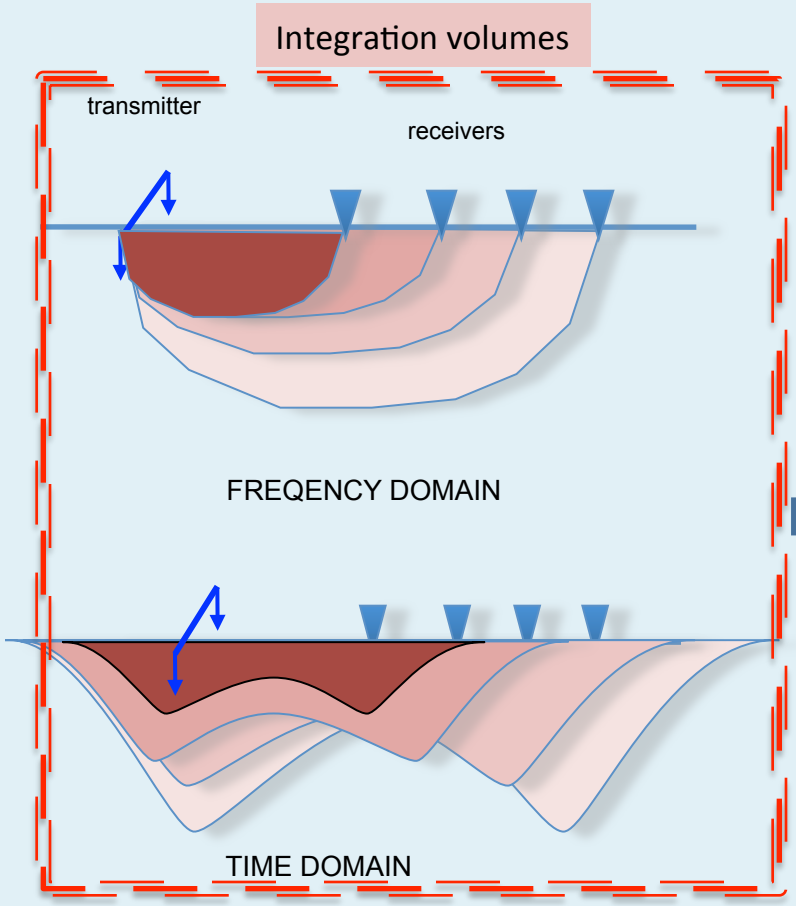
Reservoir Monitoring commnets

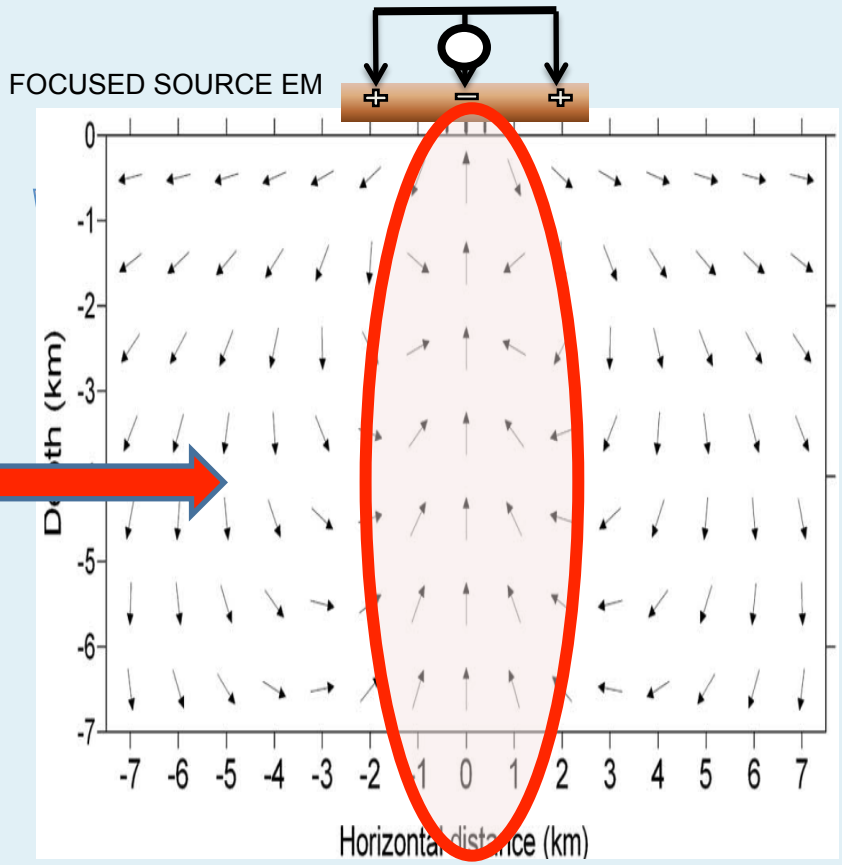
- Monitoring
  - Seeing anomaly - Easy
  - Understanding results – complicated
  - Issue 1: Image focus
  - Issue 2: Borehole calibration !!!!!
    - Surface-to-borehole
    - Through Casing

Outline

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

FSEM: Focused source solution to volume imaging

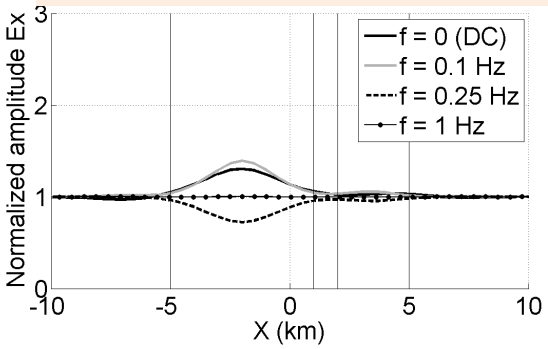


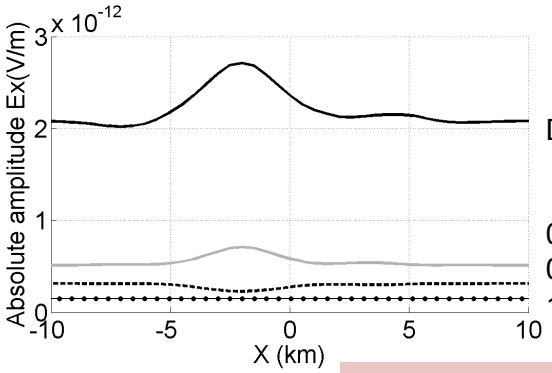


Rykhlinskaya, E., & Davydycheva, S., 2014, U.S. Patent 8,762,062 B2.
Davydycheva, S., 2016, U.S. Patent Application US 2016/0084980 A1.

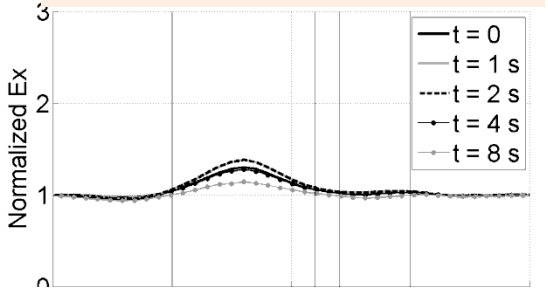
FSEM: Focused source solution to volume imaging

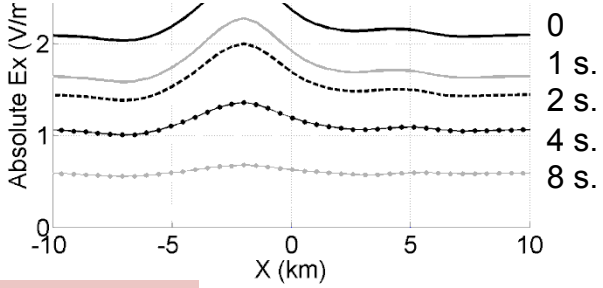
Frequency domain CSEM



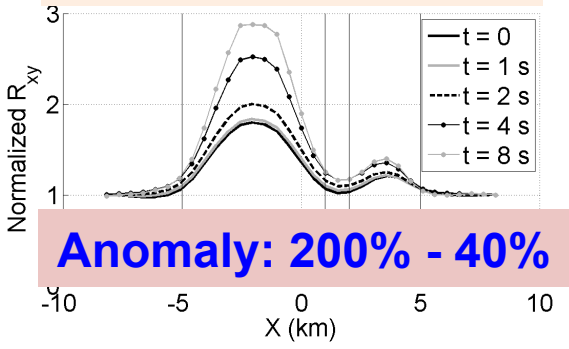


Time domain CSEM

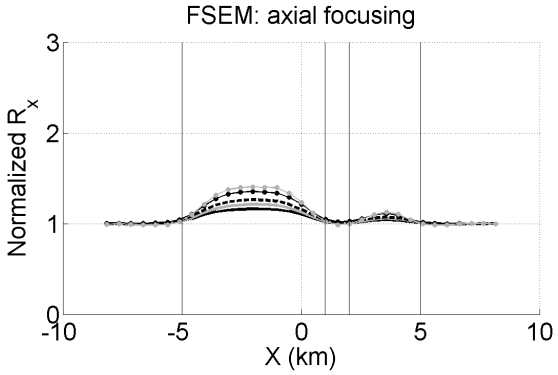




Focused Source EM

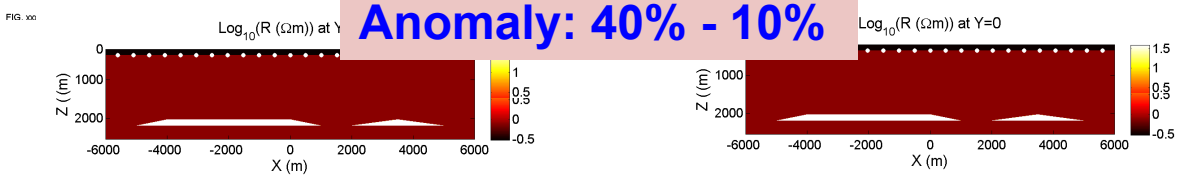


Anomaly: 200% - 40%



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

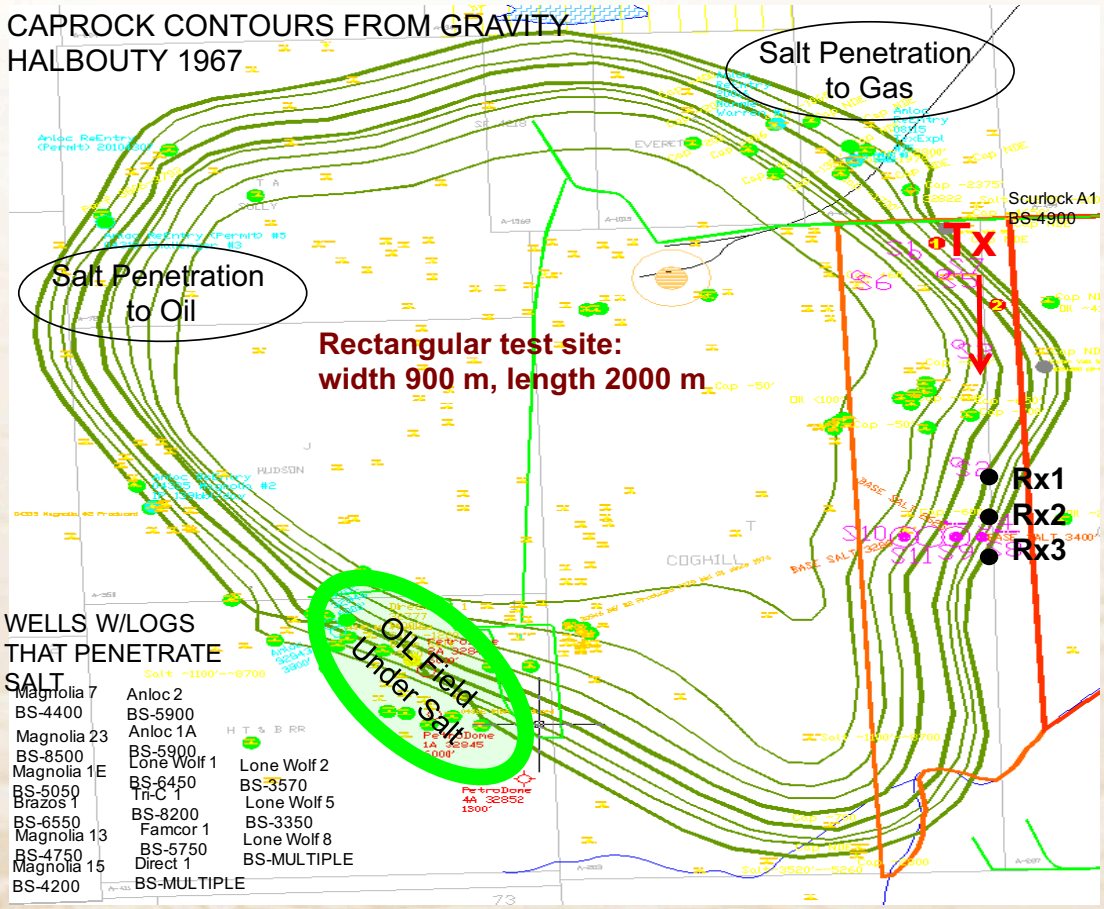
Anomaly: 40% - 10%

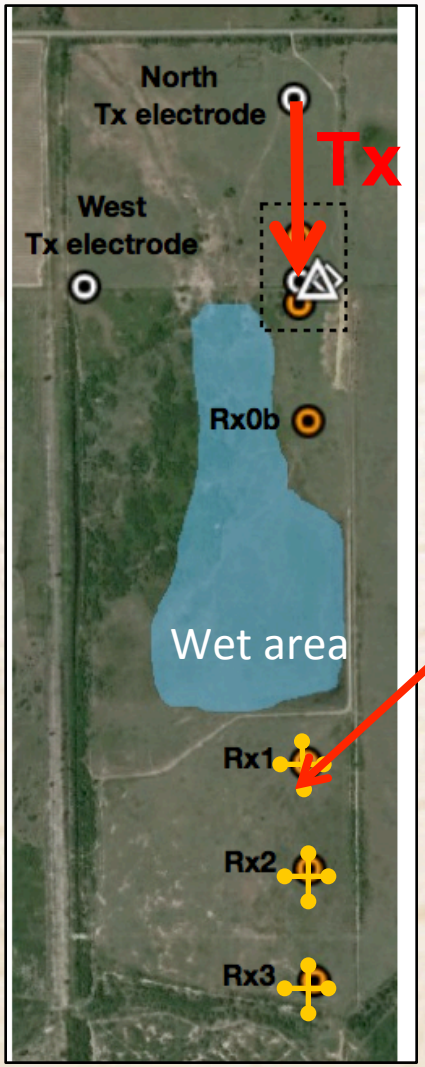


FSEM: Objectives FSEM example salt dome

- 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

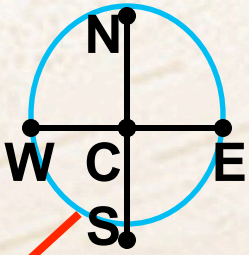
FSEM: Focused Source EM: Survey setting





Tx North: -340 m
(29.9659° 95.8274°)

Tx South: 0
(29.9628° 95.8273°)

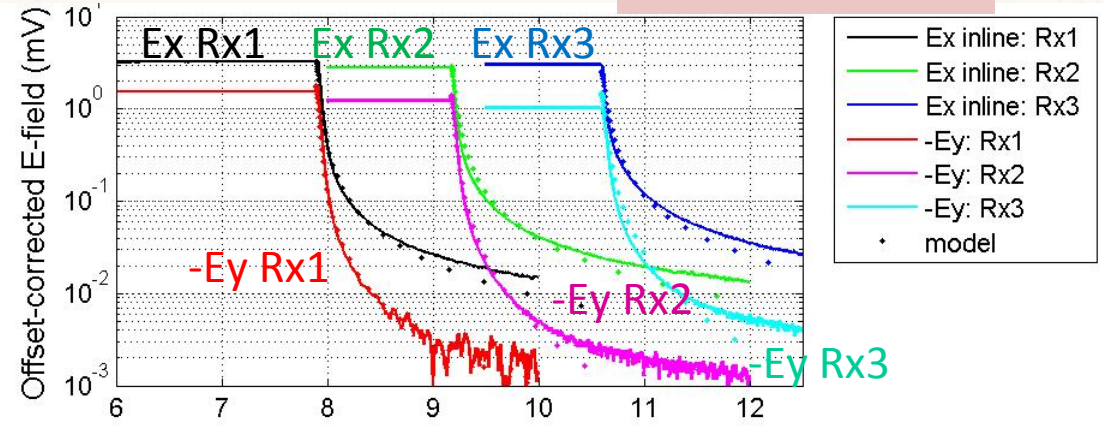


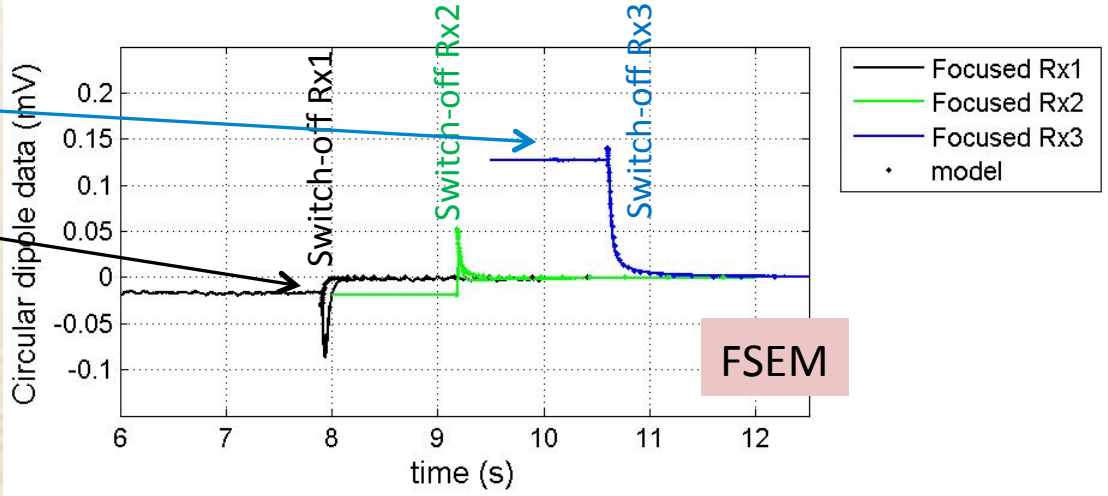
900 m
(29.9547° 95.8272°)
1100 m
(29.9529° 95.8271°)
1300 m
(29.9510° 95.8271°)

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)

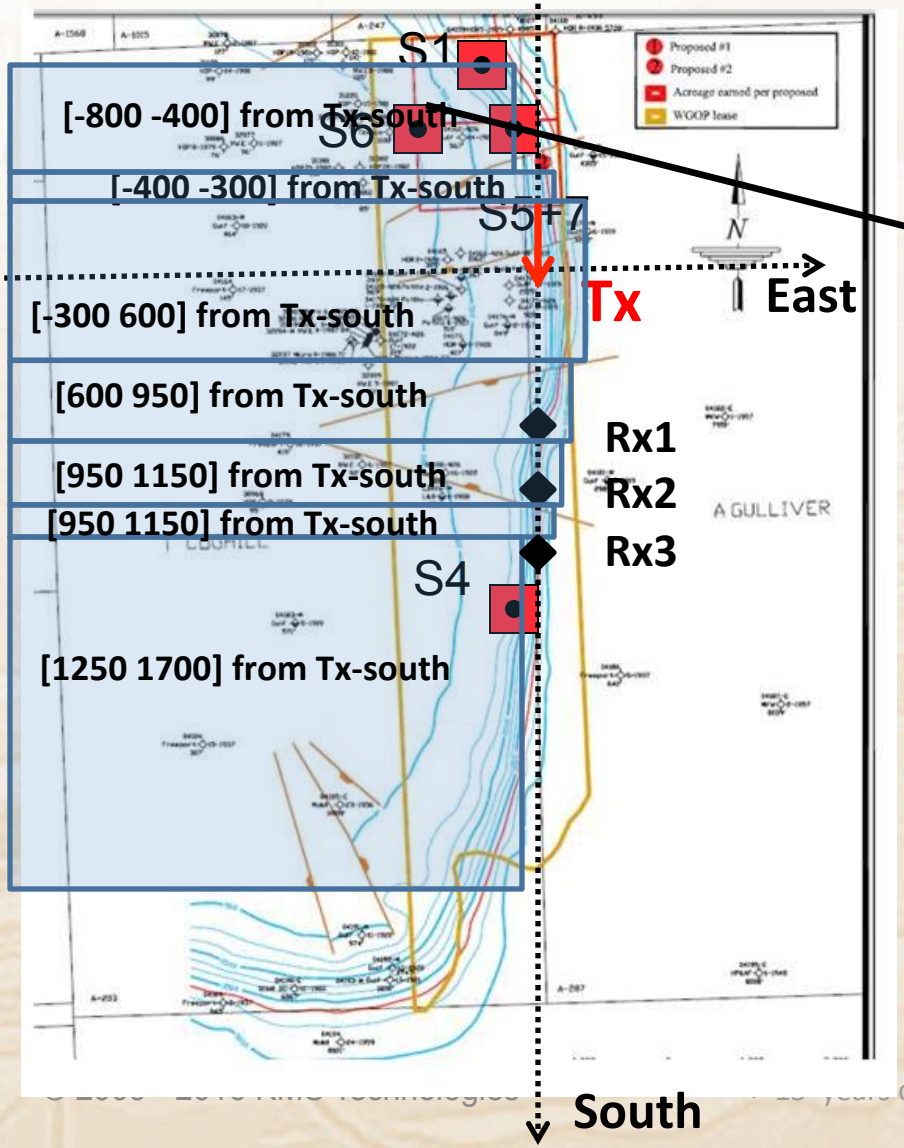
STANDARD CSEM



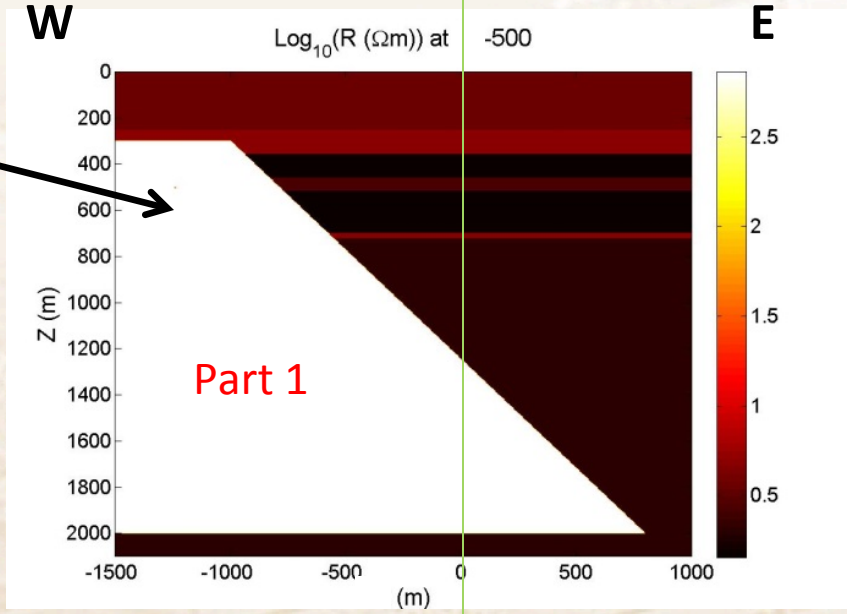


FSEM

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



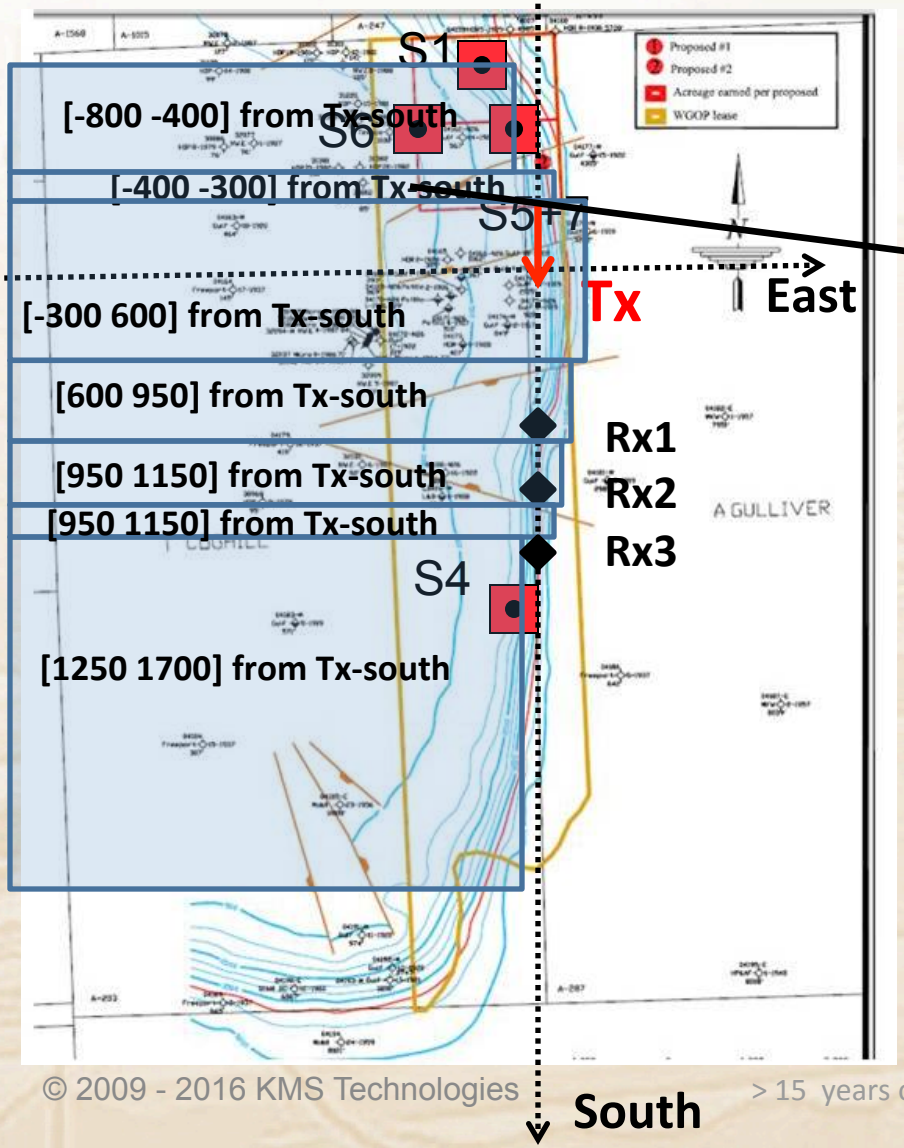
- Best matching salt dome model derived
- It consists of 7 parts

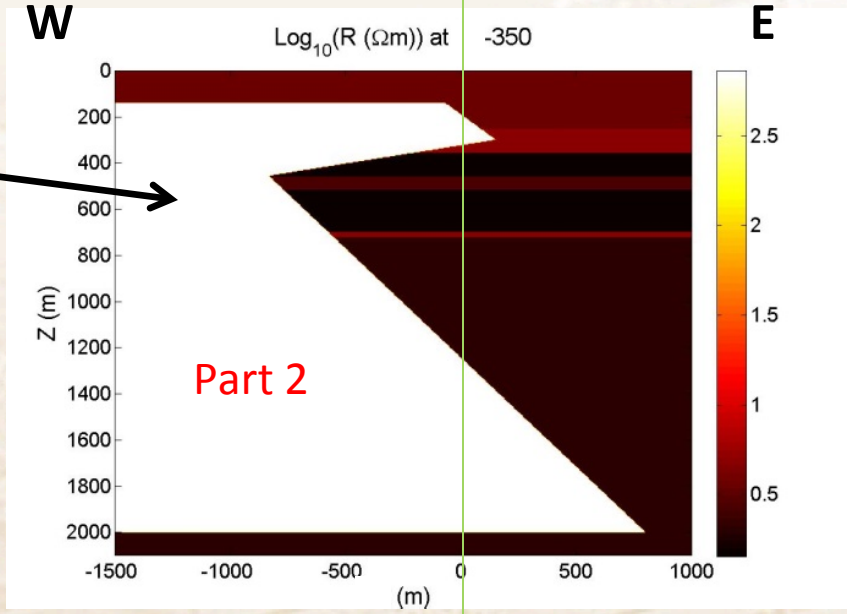


FSEM: 3D model (5) of salt dome (Part 2)

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

◇ Direct Warren well



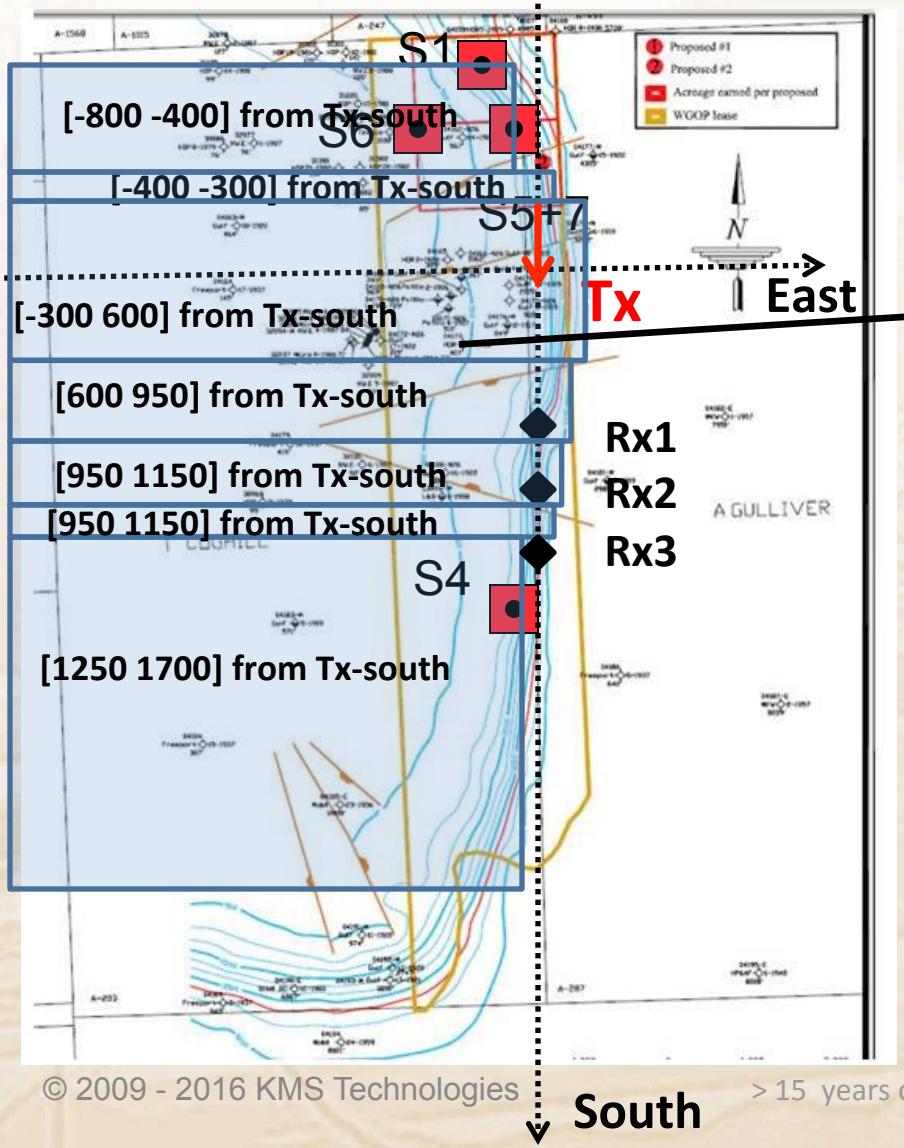


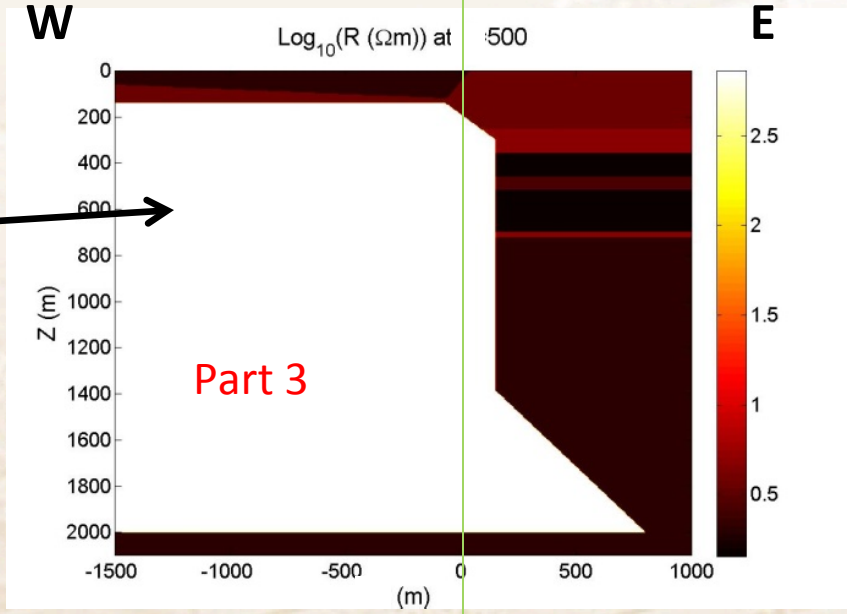
Survey vertical plane

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

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

◇ Direct Warren well

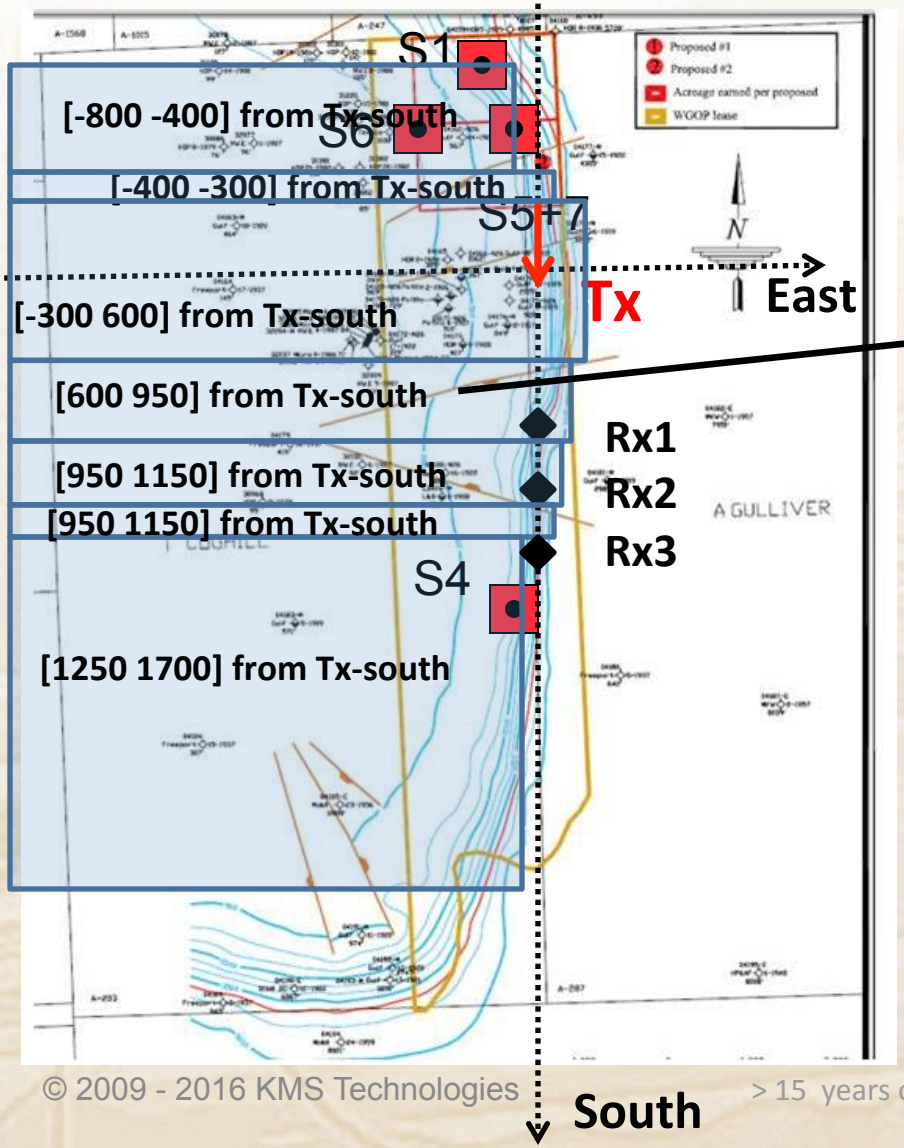


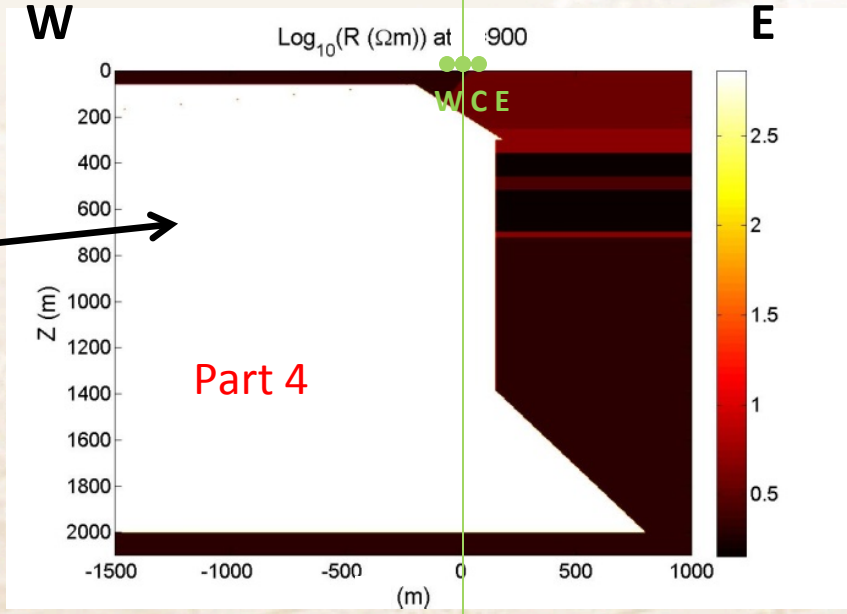


FSEM: 3D model (5) of salt dome (Part 4)

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

◇ Direct Warren well



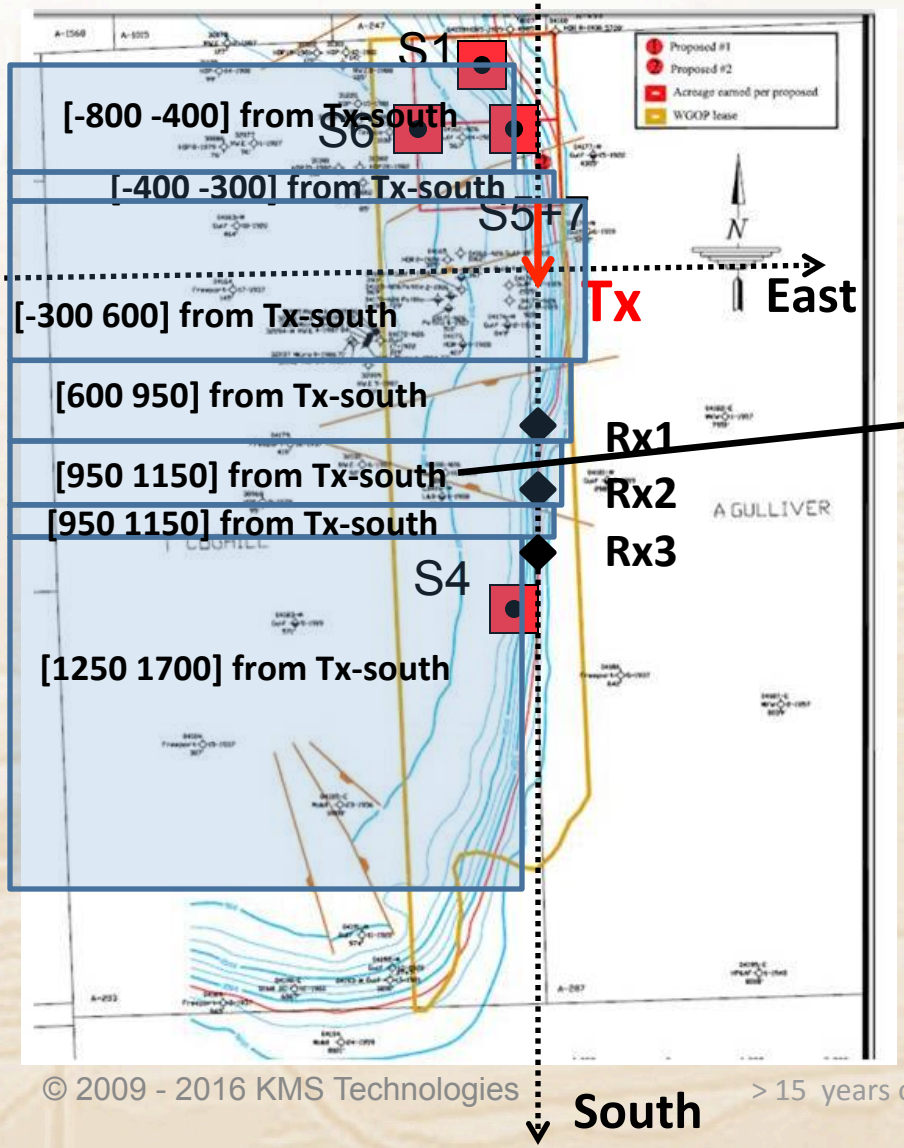


Survey vertical plane

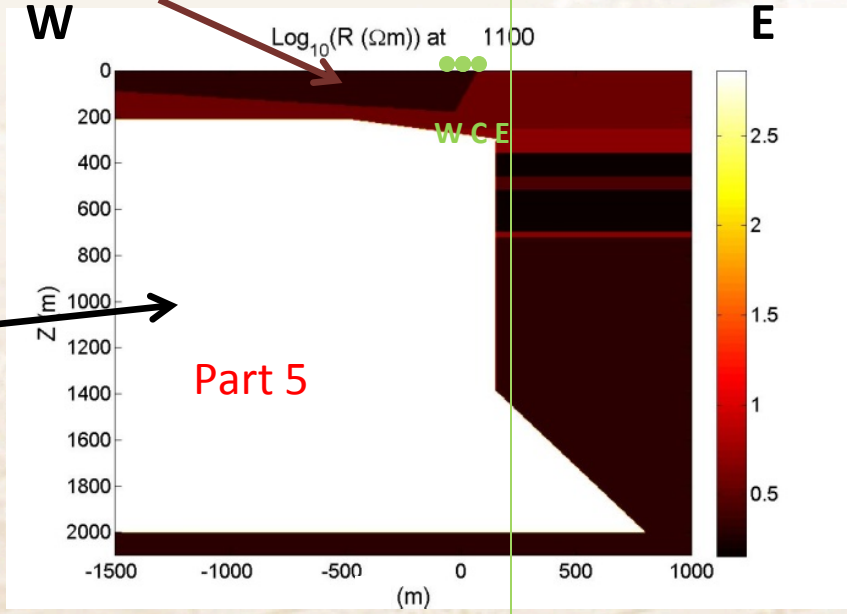
FSEM: 3D model (5) of salt dome (Part 5)

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

◇ Direct Warren well



Shallow conductive wet area

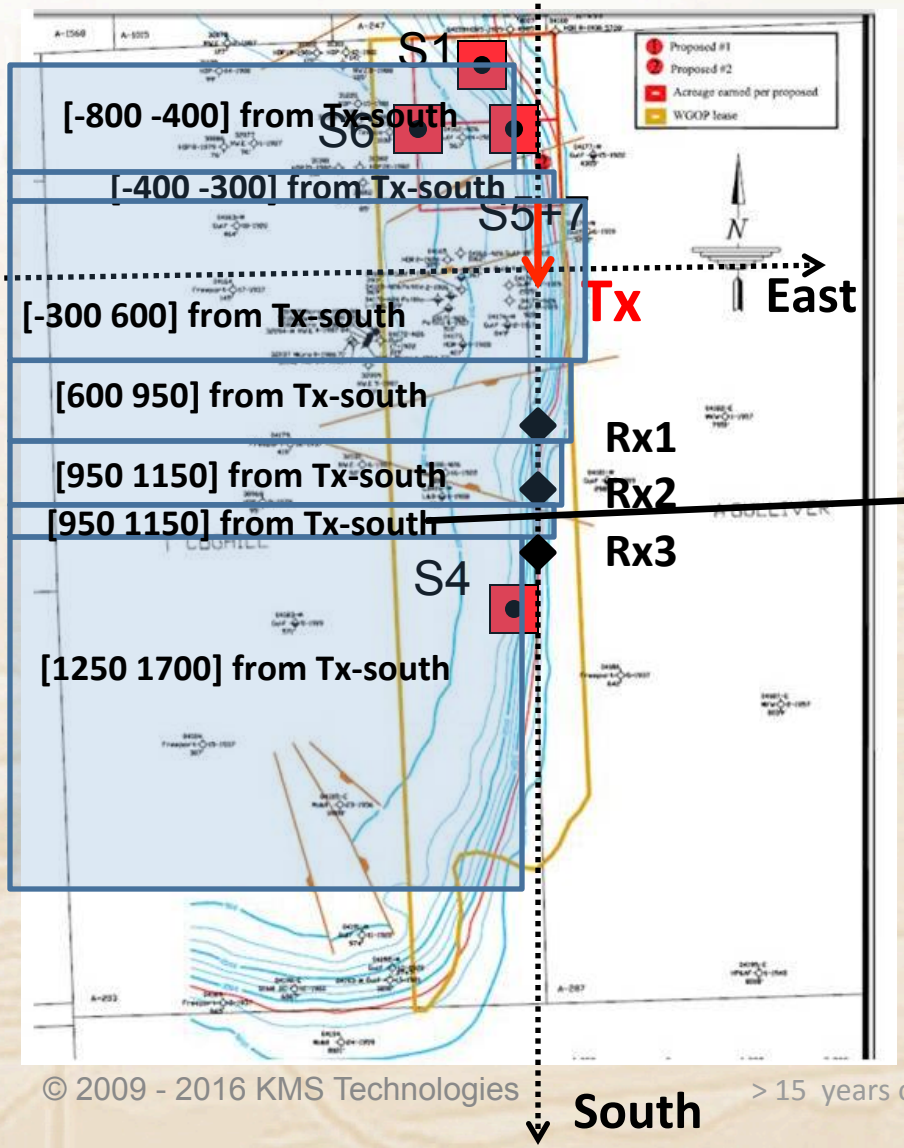


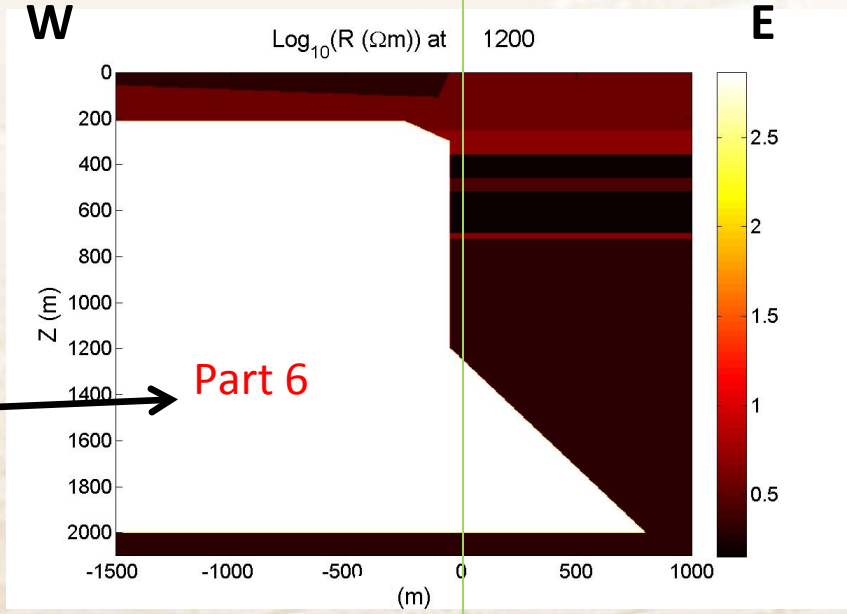
Survey vertical plane

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

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

◇ Direct Warren well

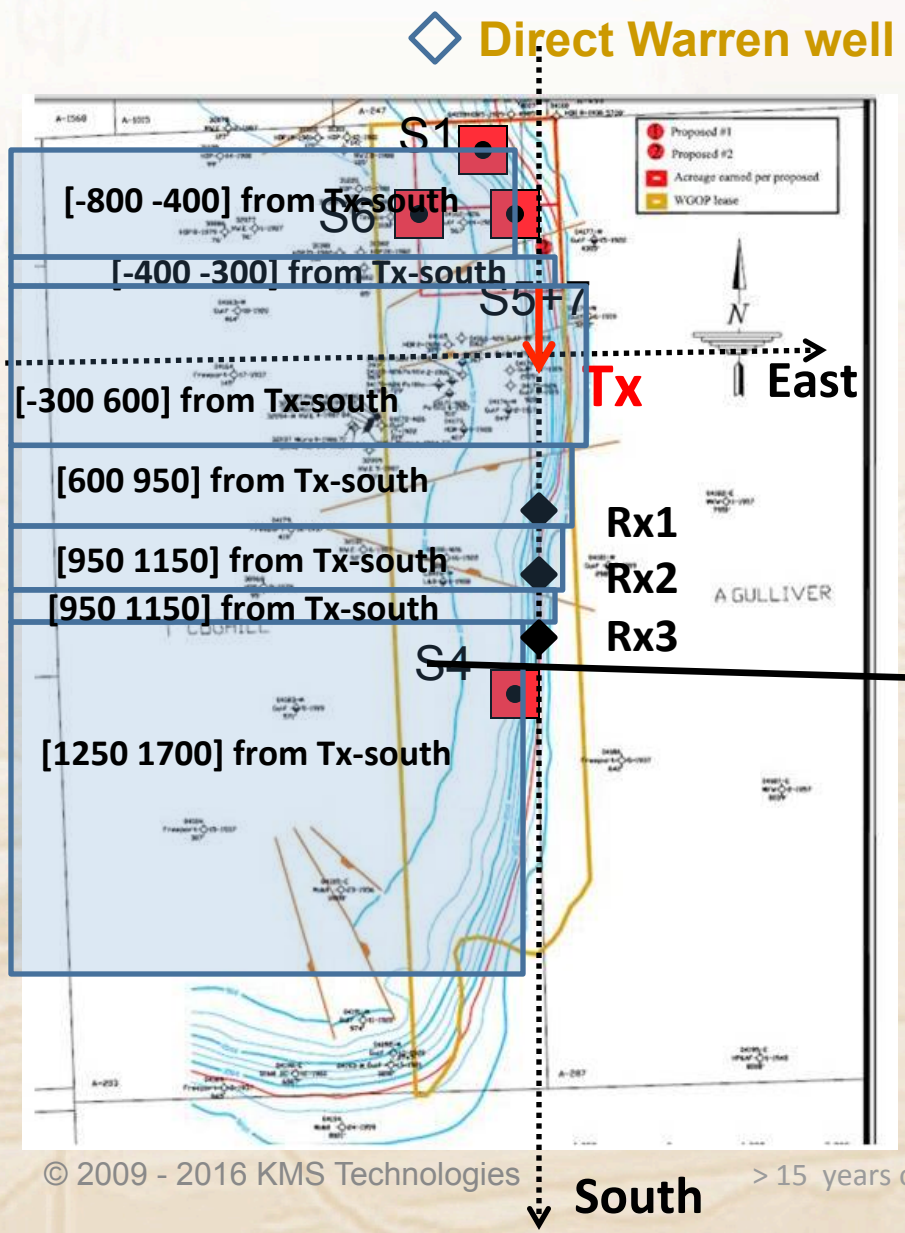


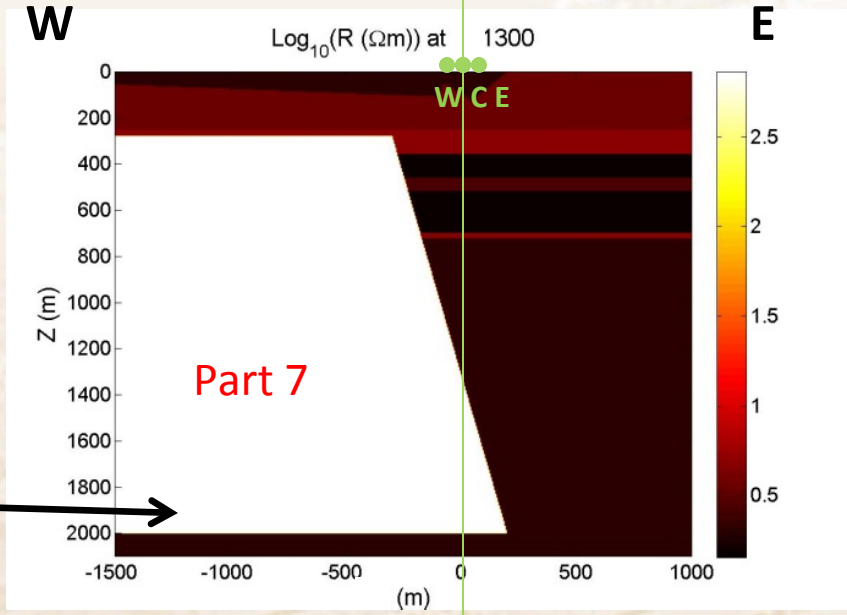


Survey vertical plane

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

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

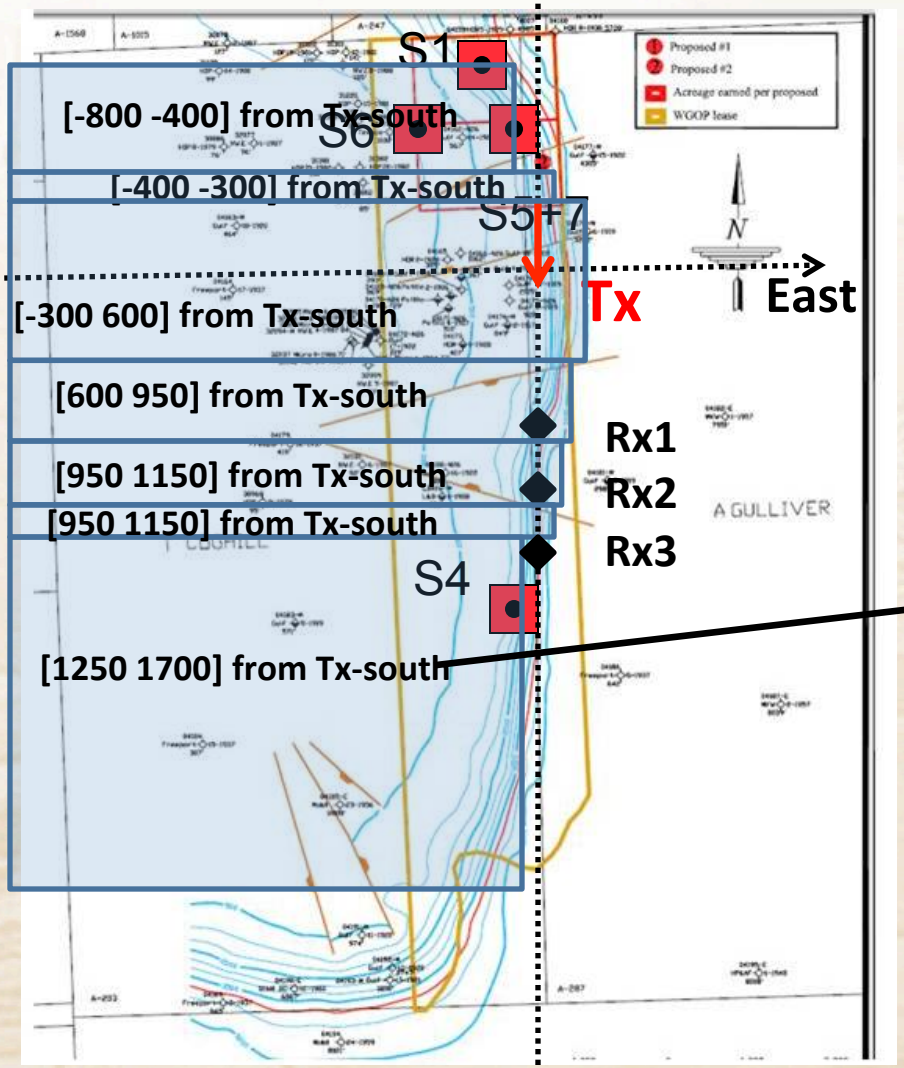


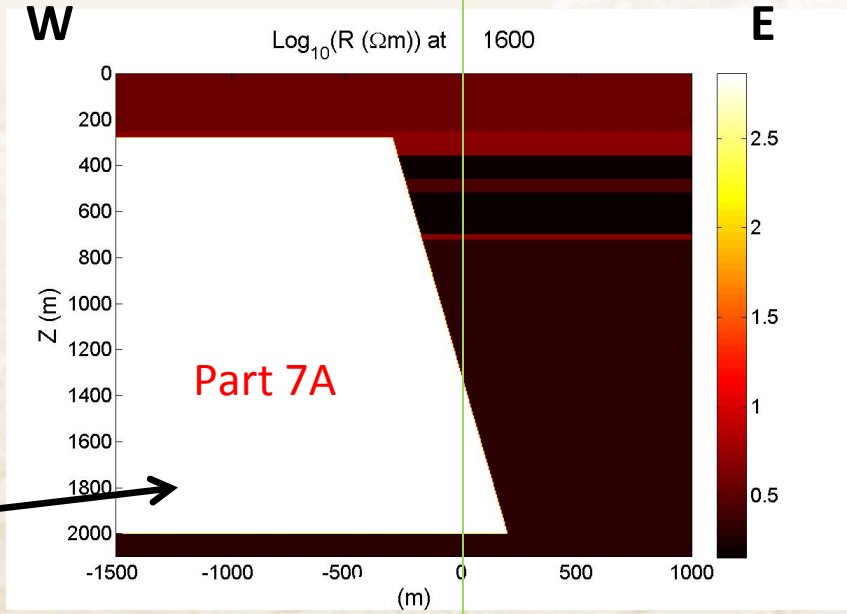


FSEM: 3D model (5) of salt dome (Part 7A)

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

◇ Direct Warren well





Survey vertical plane

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

Acknowledgements

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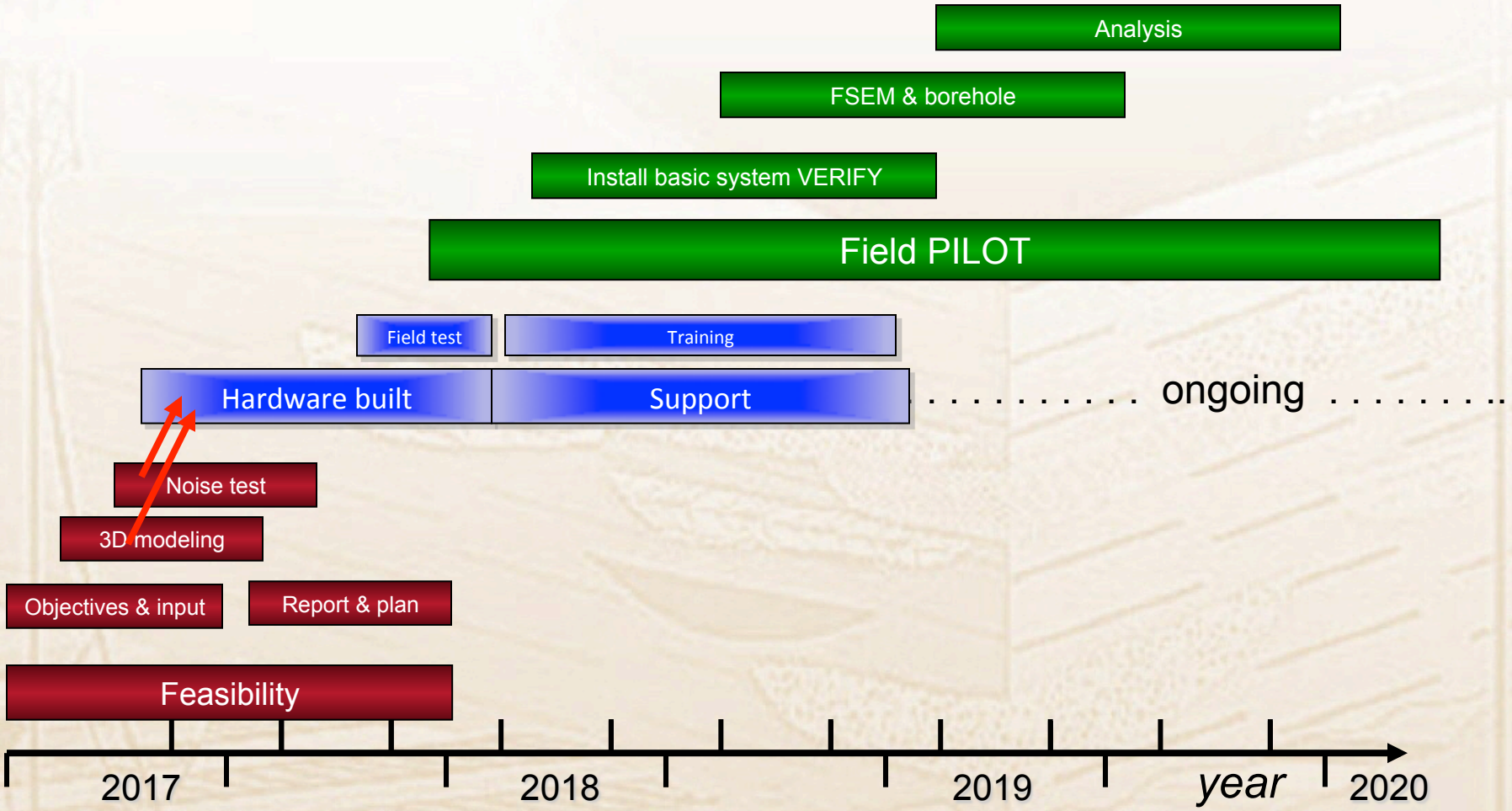
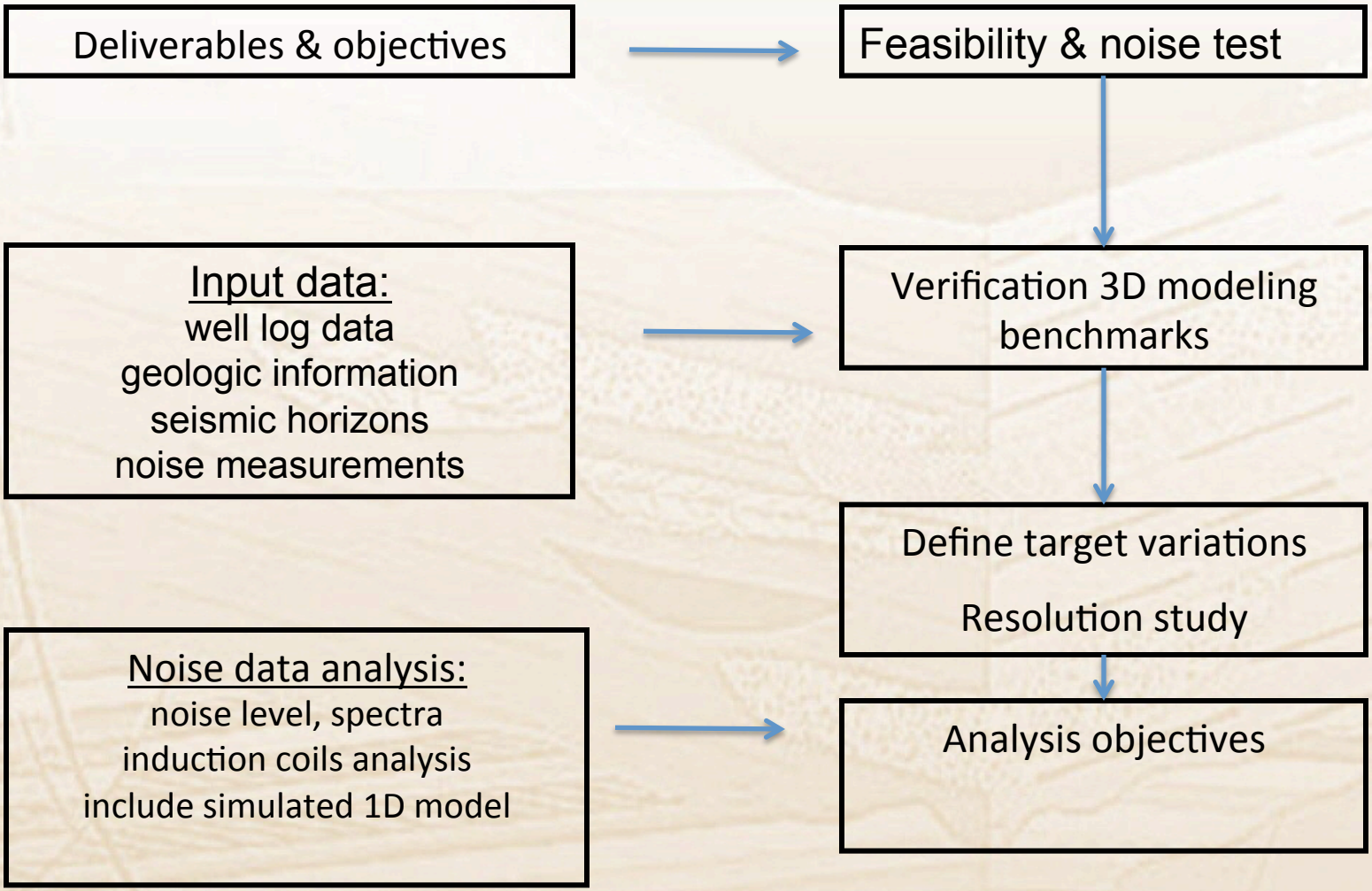
All technology protected by US & Foreign patents

(ref. KMS Technologies website)

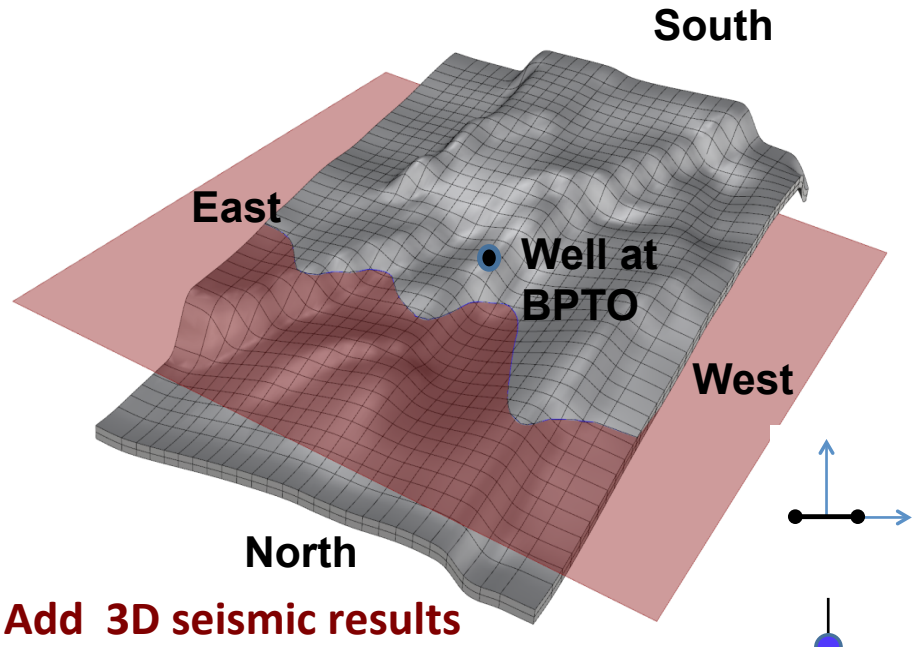
Monitoring Overall Roadmap
Timeline: Feasibility – System built & Pilot



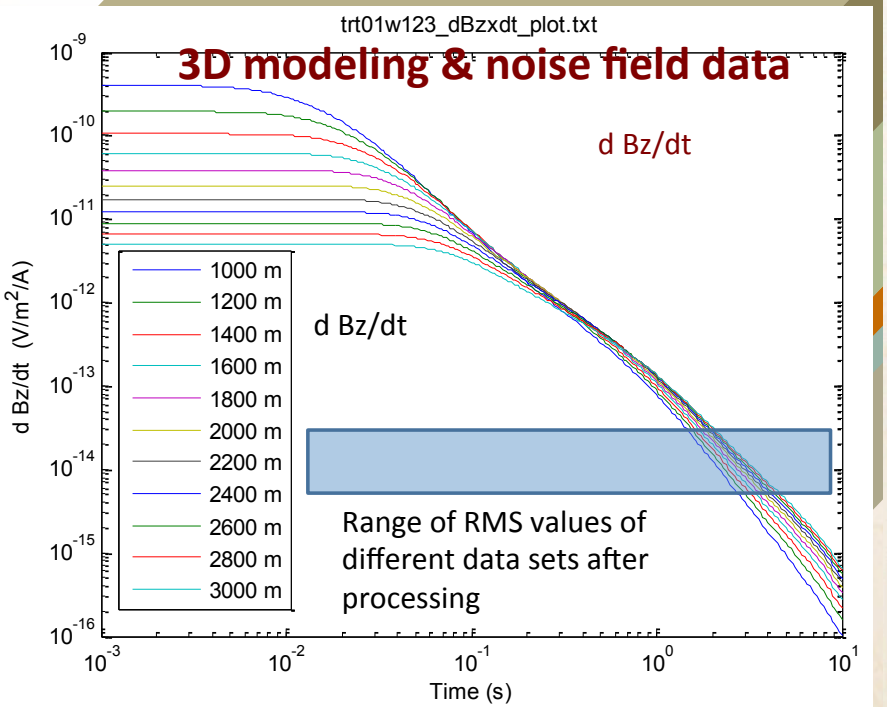
Monitoring project road map
Overall **Workflow**



Monitoring project road map
Thailand: 3D reservoir model: 6 single blocks 1000 m x 6000 m

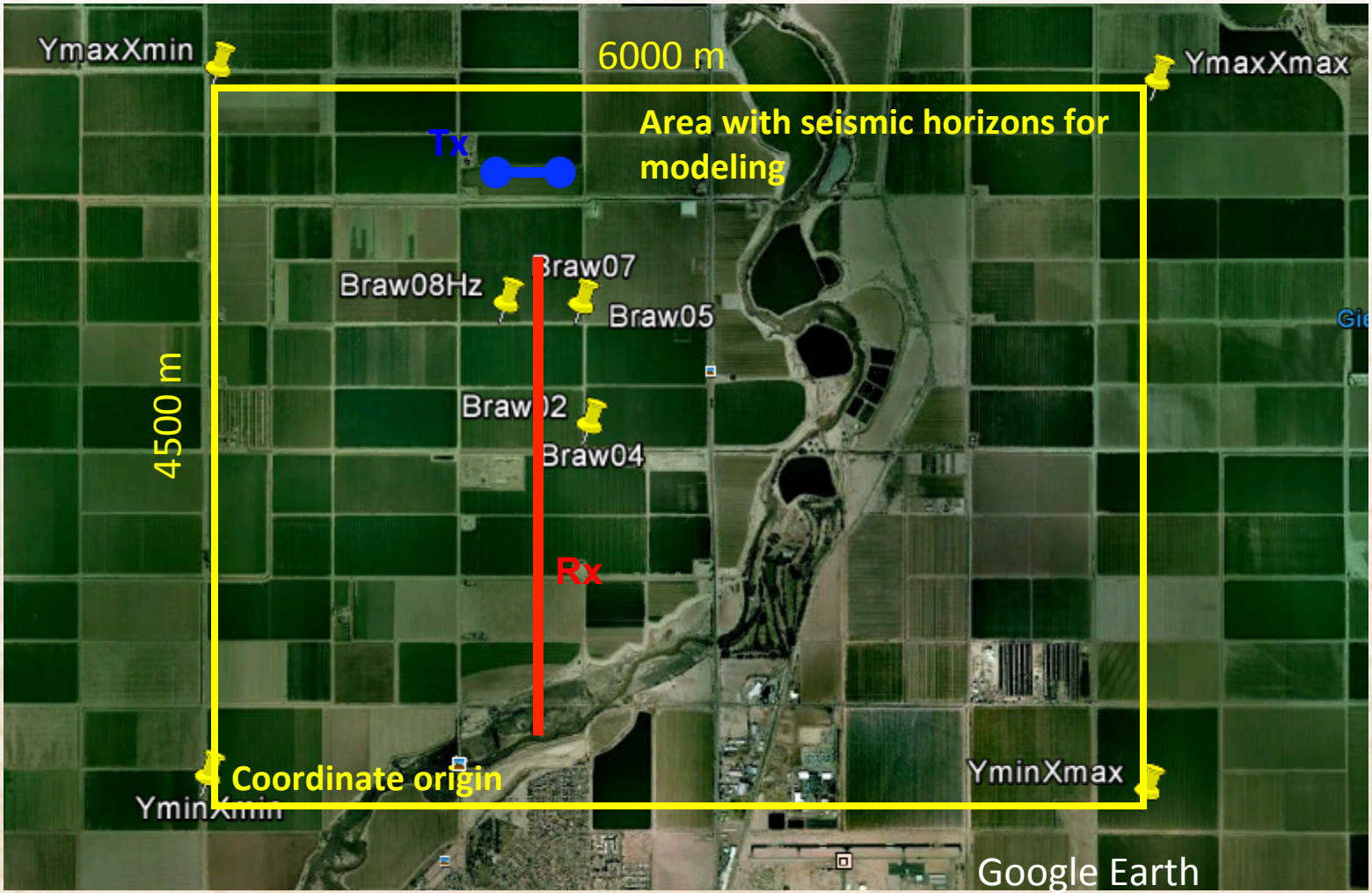


Add 3D seismic results

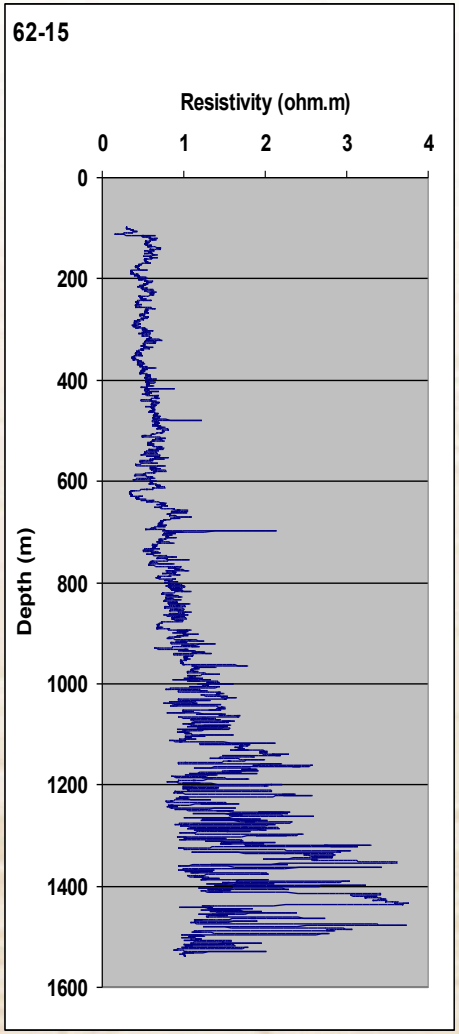


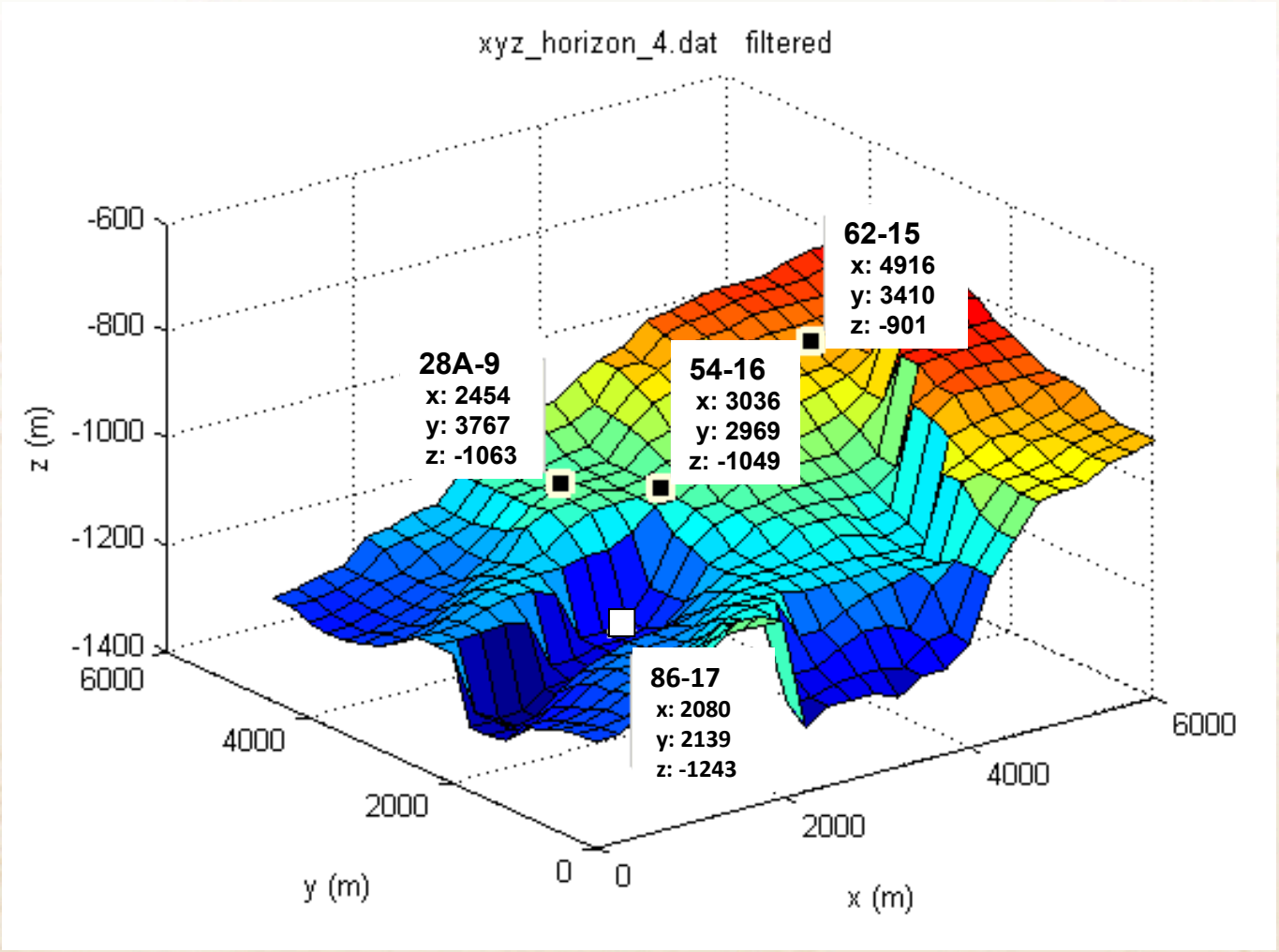
Monitoring project road map
California: Area with seismic horizons

Transmitter Tx and receiver profile Rx

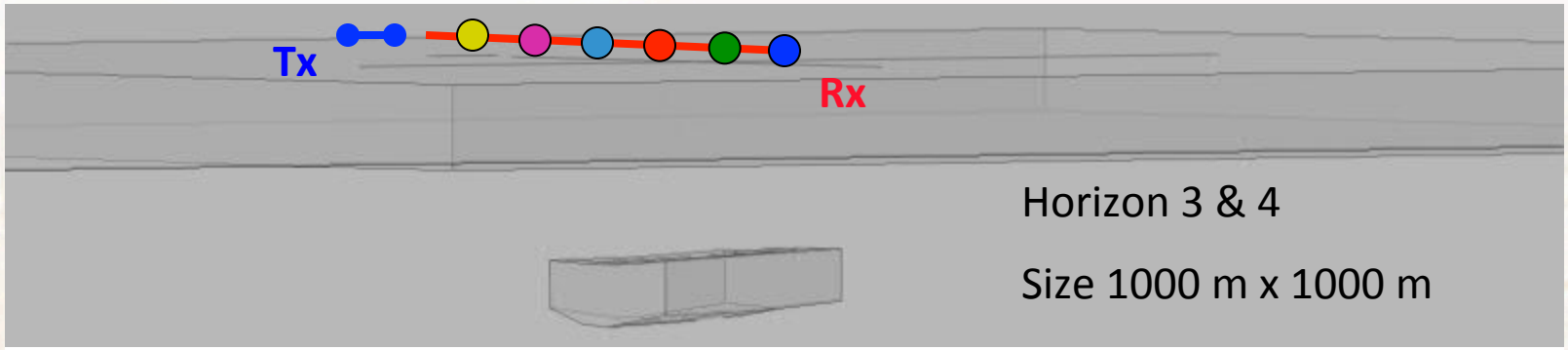


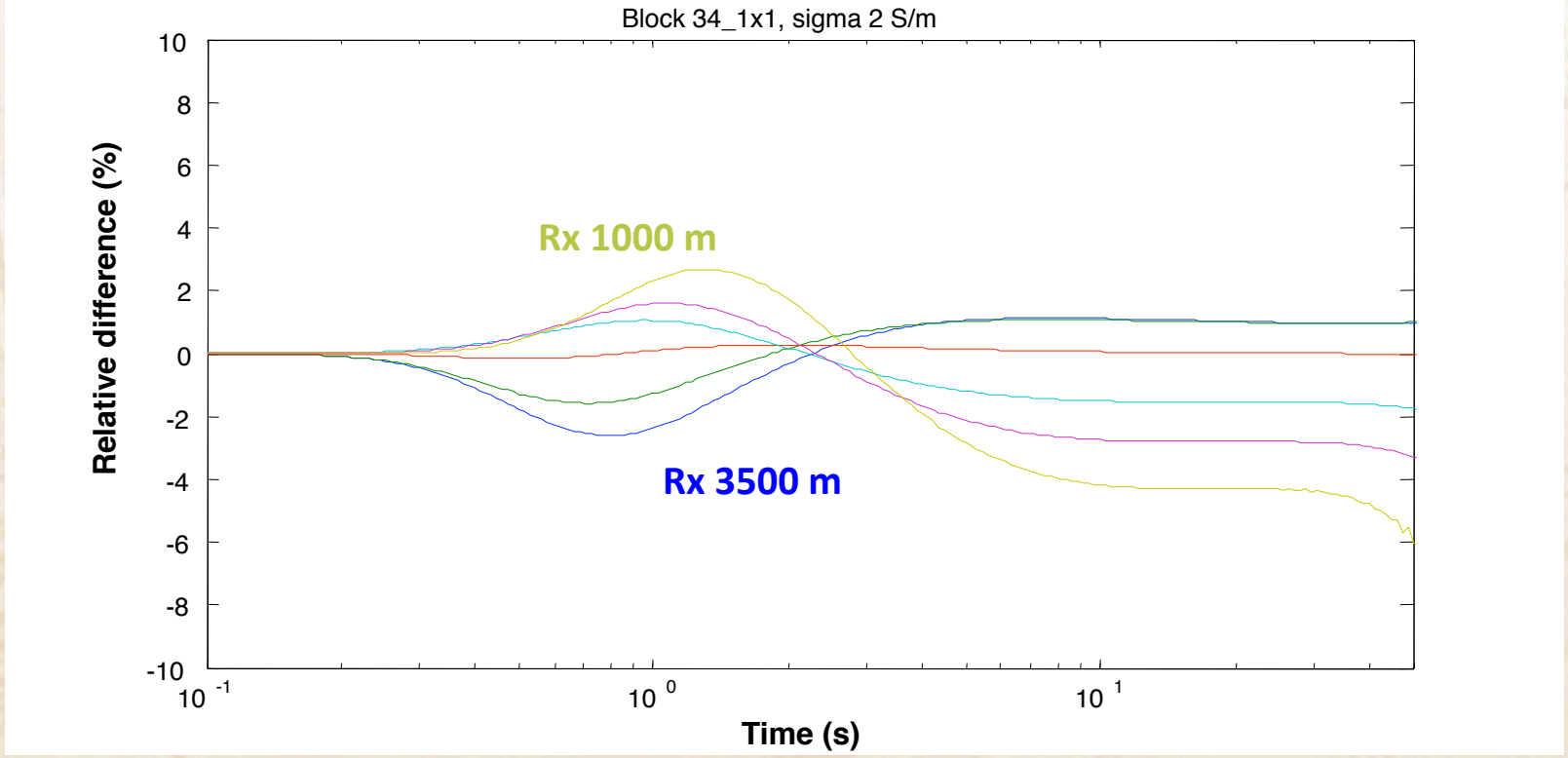
Monitoring project road map
INPUT DATA: seismic horizon 4 with well positions



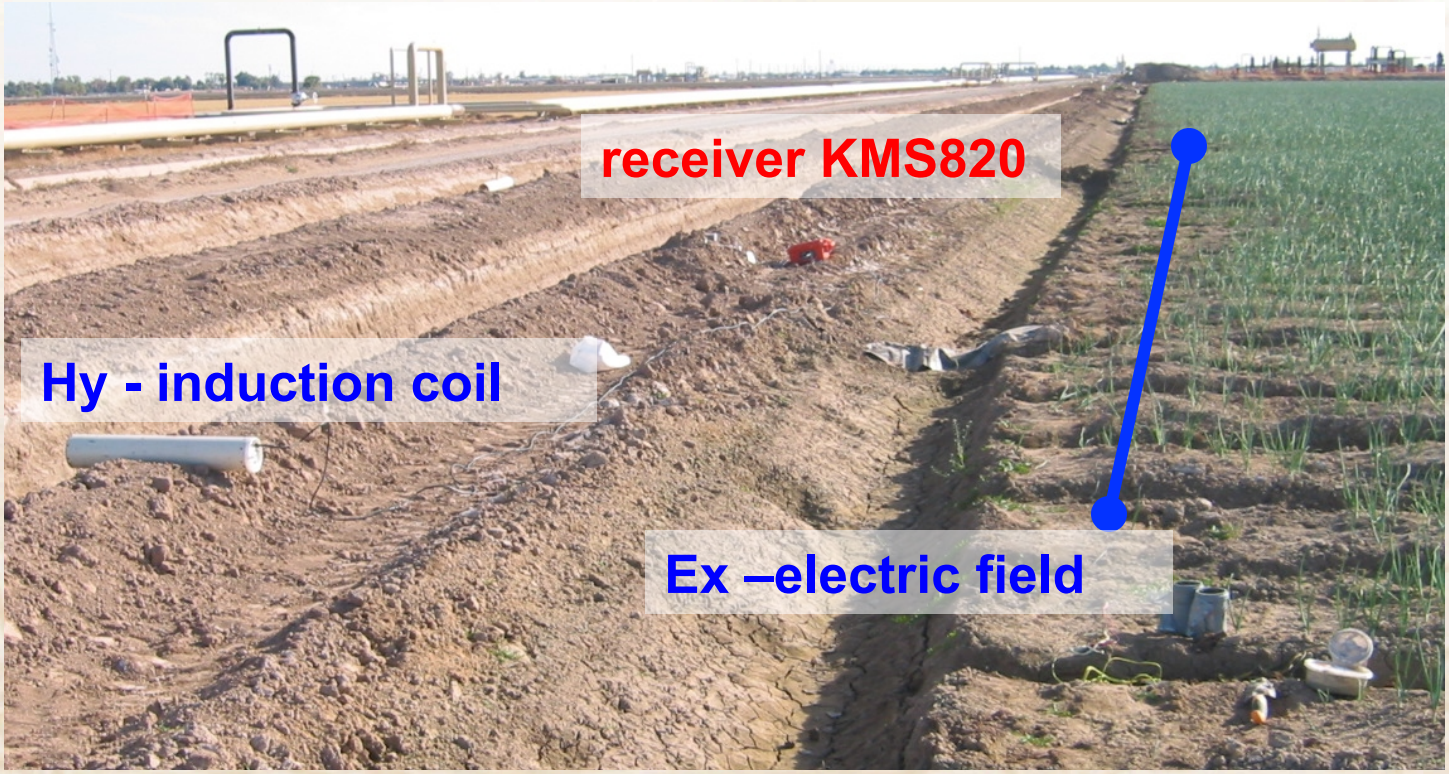


Monitoring project road map
3D reservoir: relative difference, SMALL block

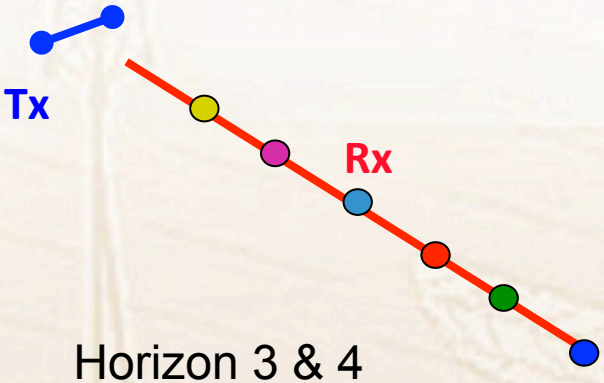




Monitoring project road map
Noise test setup



Monitoring project road map
RESULT: transients with expected noise levels / Tx current



Horizon 3 & 4

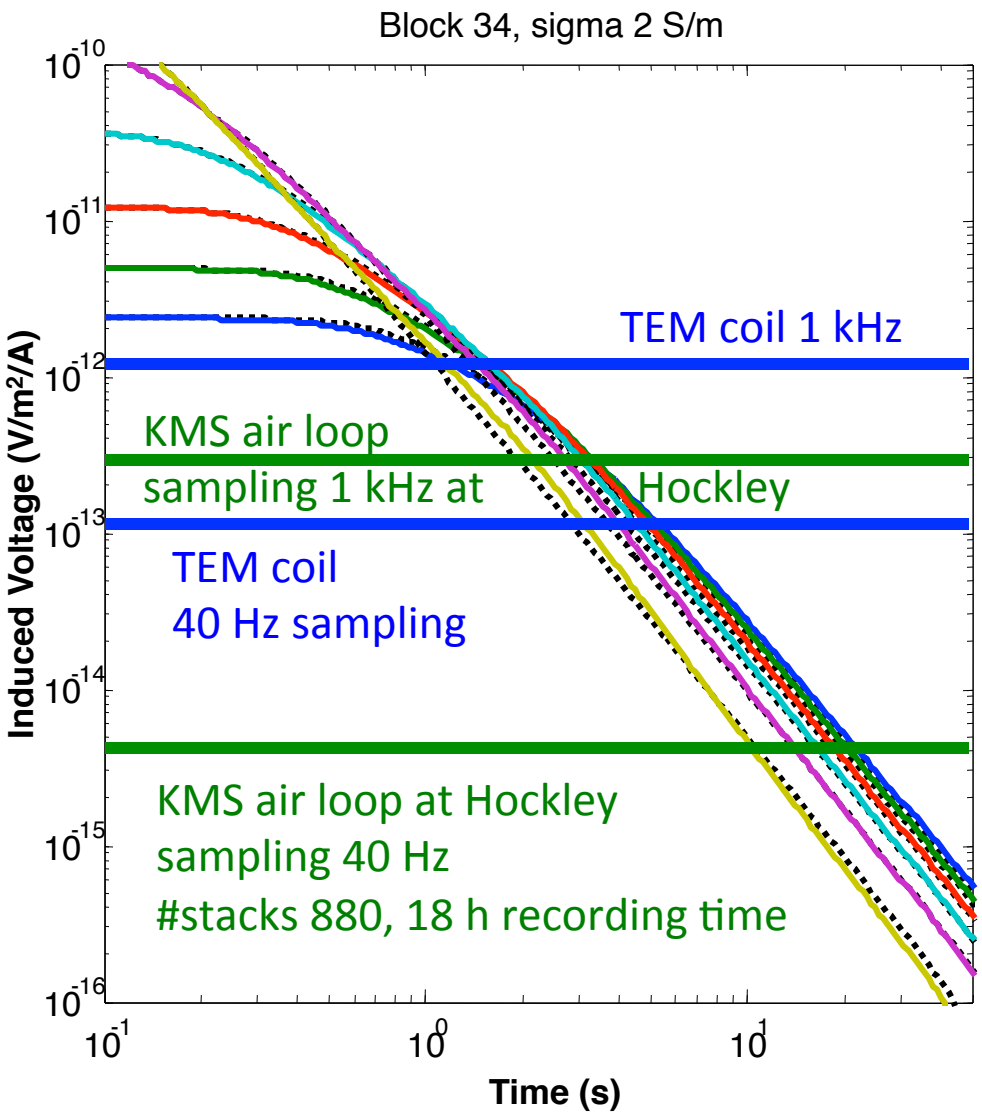
size 6000 m x 4500 m

whole block

Tx -current:

300 A
2x longer than 200 m
2x switch step over

= 1200 A



Monitoring project road map
Summary

- Feasibility is MANDATORY
- Since 30 years → agreement with prediction
- Quality Assurance throughout MUST
- 3D modeling support MUST
- Failures have always been operational NEVER technical