KMS Technologies

A Fit-for-purpose electromagnetic System for Reservoir Monitoring & Geothermal Exploration

Kurt M. Strack and Ingo M. Geldmacher

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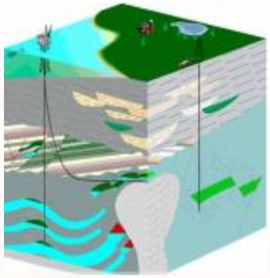
FOR SELF STUDY ONLY



A Fit-for-Purpose Electromagnetic System for Reservoir Monitoring & Geothermal Exploration

K. Strack & I. Geldmacher
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November 2017

Objectives

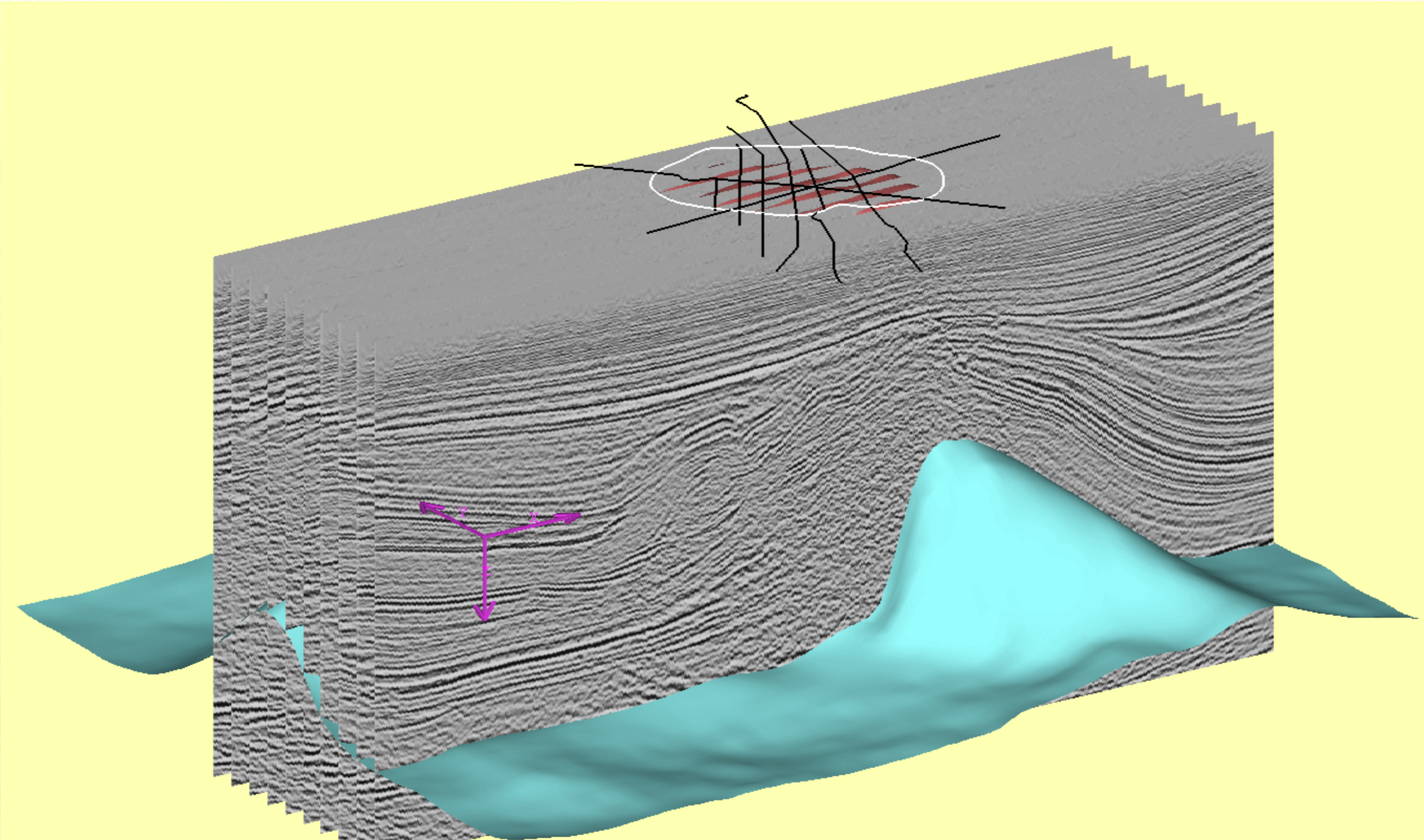
- Address Reservoir Monitoring & Exploration for Hydrocarbon & Geothermal
- Methods required:
  - Broadband magnetotellurics
  - Controlled source ElectroMagnetics
  - Microseismics
  - Others: for research/marketing (TFEM, IP, CSAMT etc.)
- Operations:
  - Be able to use seismic crews/standards
  - Broadband: DC to 40 kHz in one drop
  - Unlimited number of channels

History KMS array system KMS-820 and LEMI sensors

- ✓ 2007: **marine cabled system** → miniatures sensors, 32-bit fluxgate → 2 prototype generations - all 32 bit, low power (2009)
- ✓ 2010: KMS-820 sold to **MT market** → reduce to 24 bit to reach 40 KHz and < 5 W power consumption (benchmark – 15 W +)
  - 32-bit as sub-acquisition controller – 4 kHz
- ✓ 2010 – 2014: sensors DC to 70 kHz, geophone, accelerometer etc.
- ✓ 2014 – 1st large monitoring array **195 channels**
- ✓ 2014-2015: 100 kVA and 150 kVA transmitter
- ✓ 2015: Drone sensor, DEEP water ocean bottom node
- ✓ 2016: **Shallow borehole** seismic/EM **receiver KMS-888**
- ✓ 2017: **Broadband coil LEMI-152**
- ✓ 2018: NEW marine system

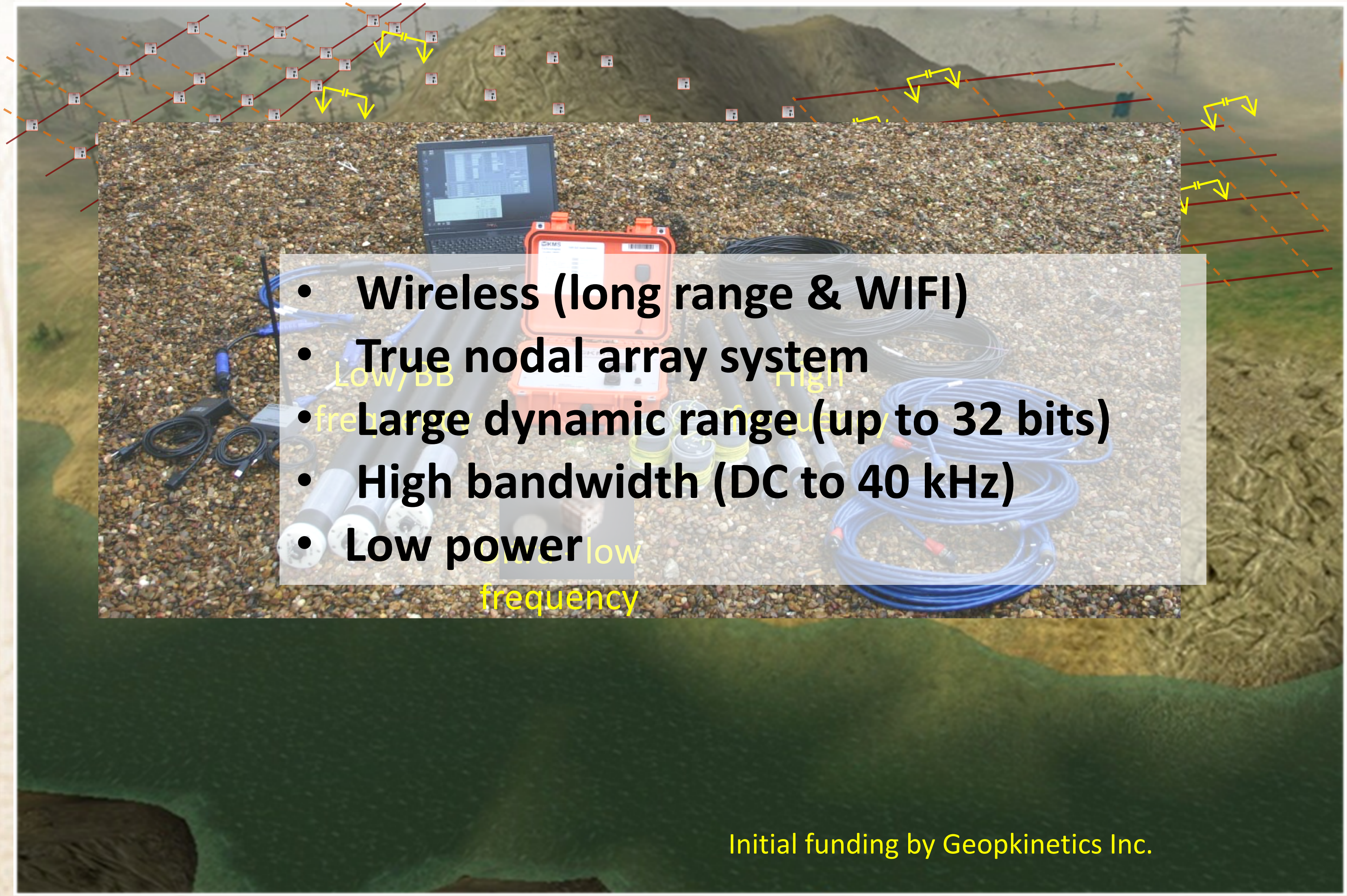
GOAL Dense acquisition (Δx = 50 m) → better images

Fully integrated Hi-res MT, gravity and seismic – KMS survey 2002



Zerilli, et al 2002

Seismic-style modular ARRAY acquisition → better images



Featured array configurations: MT fit for purpose

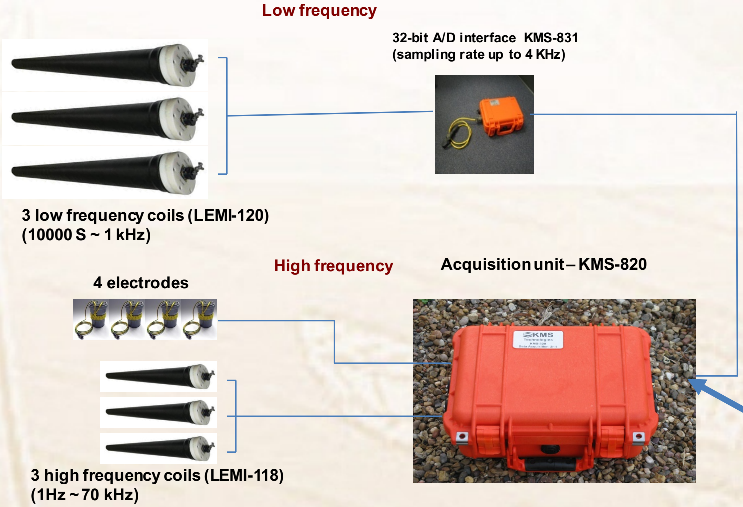
- Advanced MT/AMT
  - **Standard** MT 0.0001 Hz to 20 kHz
    - Low noise < 0.1 pT/VHz
  - Fast AMT acquisition 10 Hz to 20 kHz
  - Max flexibility
  - Max connectivity
  - Deep coverage > 10 km
  - Use AMT for static if HF is ok

- *Mini* MT & AMT
  - **Introductory, low cost** system
  - Low frequency fluxgate DC to 180 Hz
  - AMT 'roving' receiver broadband magnetometer 1 Hz-500 kHz
  - Resolves deep & shallow
  - Fast set-up, no digging, match & correlate system response continuity

- Broadband MT
  - ONE MT/AMT sensor 0.00025 Hz to 10 kHz
  - Good if limited high/low required
  - Reduces cost
  - Simplifies operations
  - Potential signal 'gap' when using amplifier switching or separate bands. **TRUE broadband** the best solution

Featured broadband MT array configurations

- Advanced MT/AMT

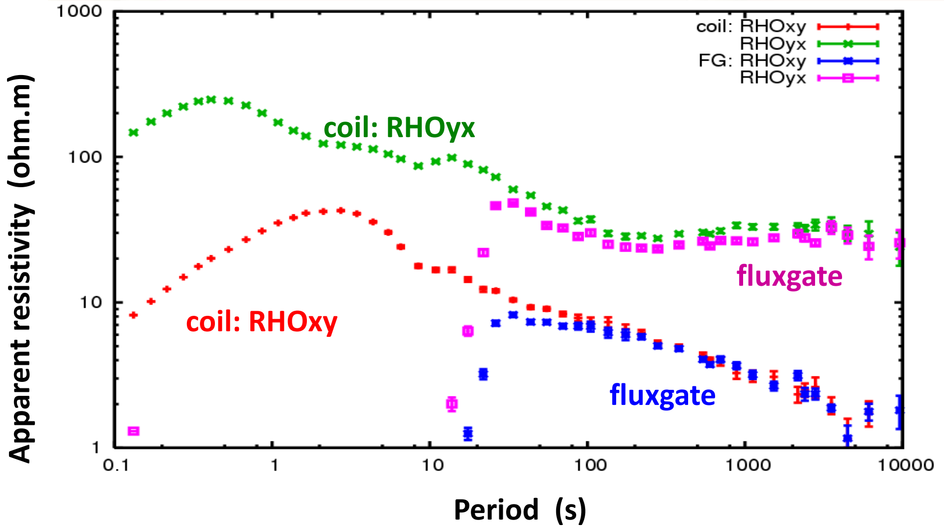


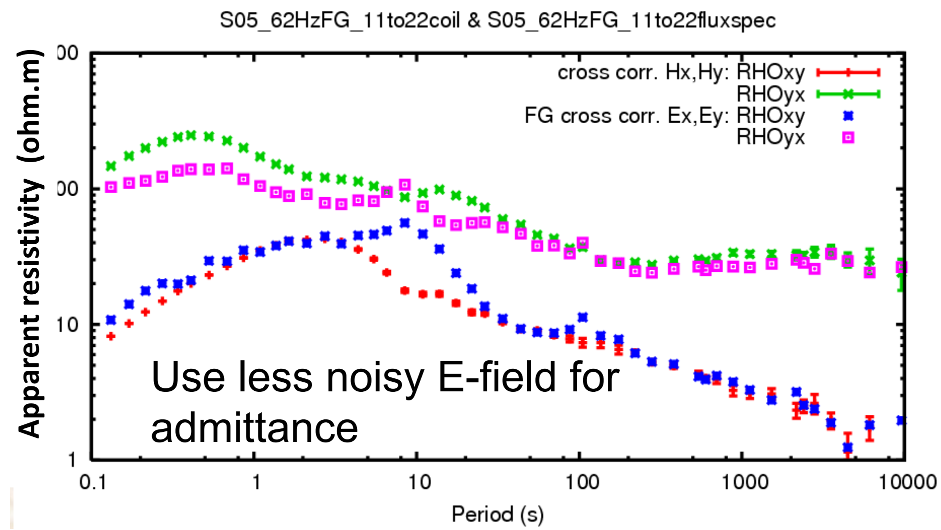
- *Mini* MT (& AMT – option)

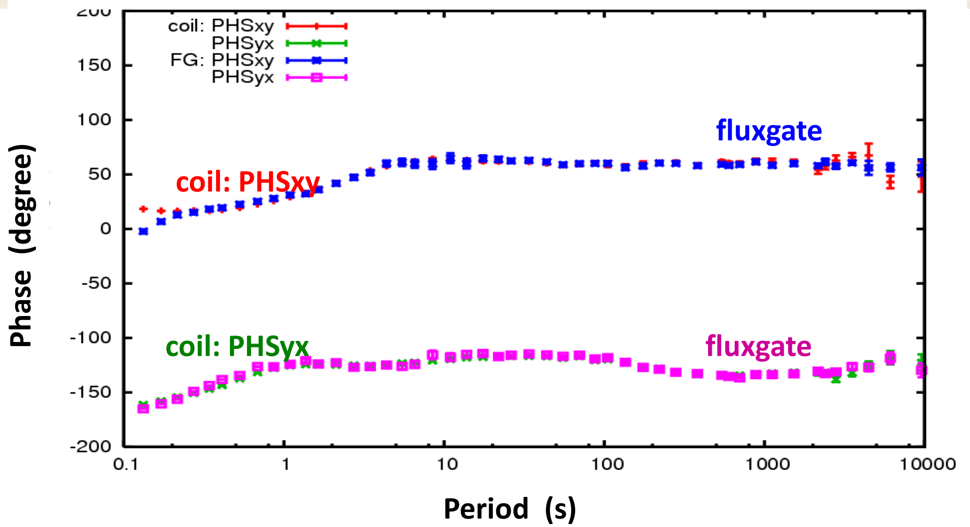
Plus Fluxgate = 11 channels
Many Fluxgate options

Background >>> Case histories >>> Conclusion

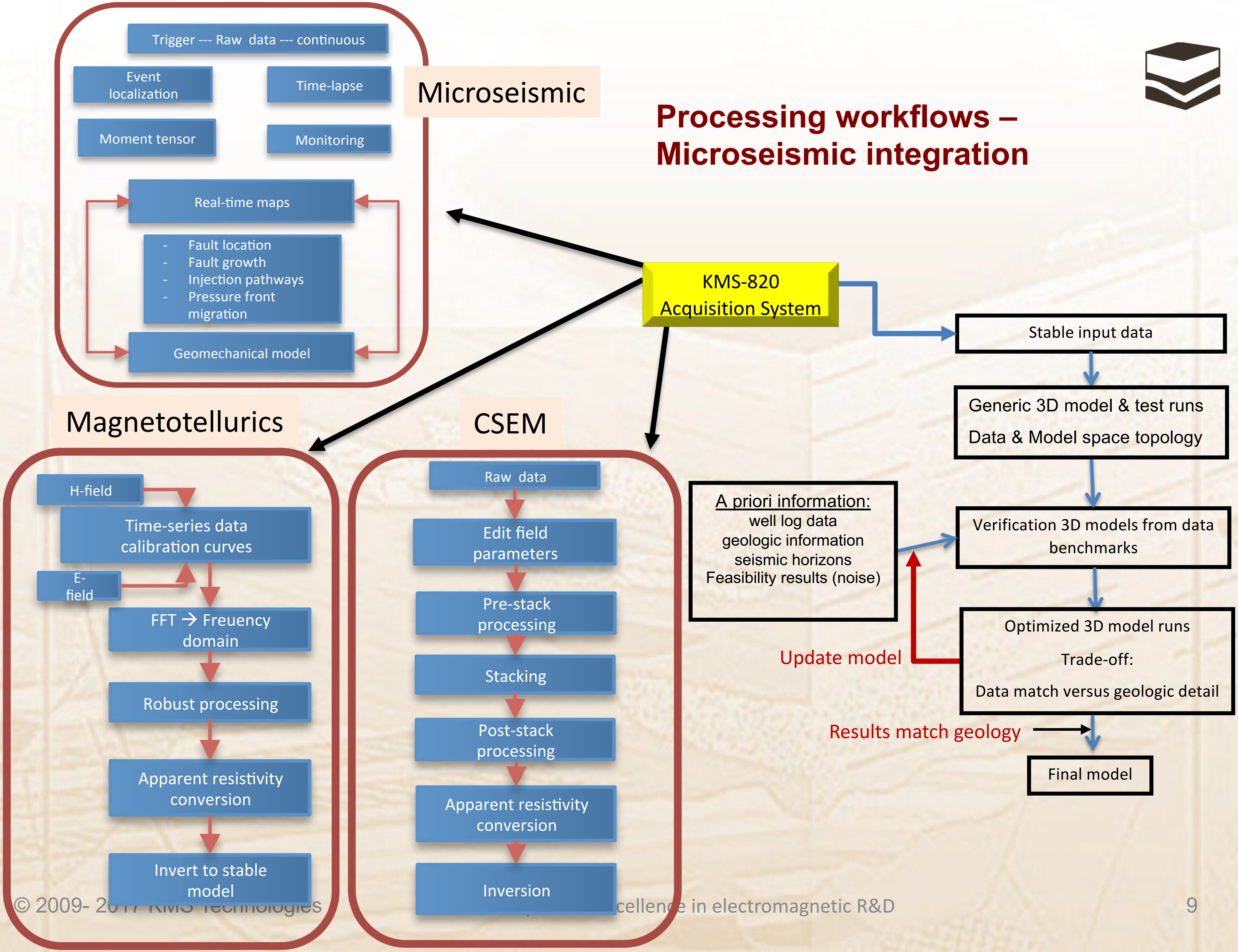
China (ZB): Resistivity coil & fluxgate with sampling rate 62.5 Hz. PHASE







Processing workflows – Microseismic integration



Receiver (KMS-820 array system): for MT & CSEM

DEEP BOREHOLE

SHALLOW BOREHOLE TOOL

MARINE

Node
on deck

Combined seismic & EM node
For 2 months operation

TRANSMITTER

Reservoir Monitoring: 195 channel monitoring system

RESERVOIR MONITORING

ARRAY Electromagnetics

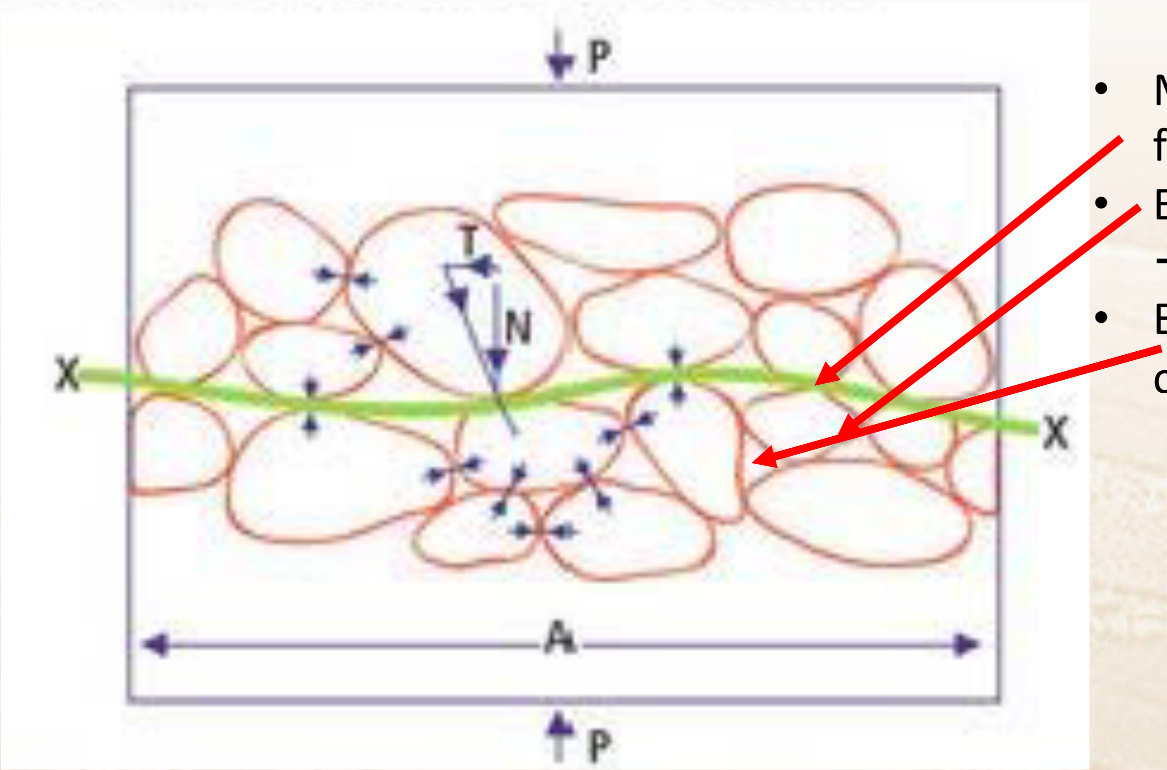
- 195 channels, wifi, wireless or LAN
- 3C magnetic field (DC to 40 kHz)
- 3C microseismic
- 2C electric fields
- Shallow borehole (microseismic/EM)

Colorado 2015 & 2016
CSEM transmitter tests

100 KVA

150 KVA

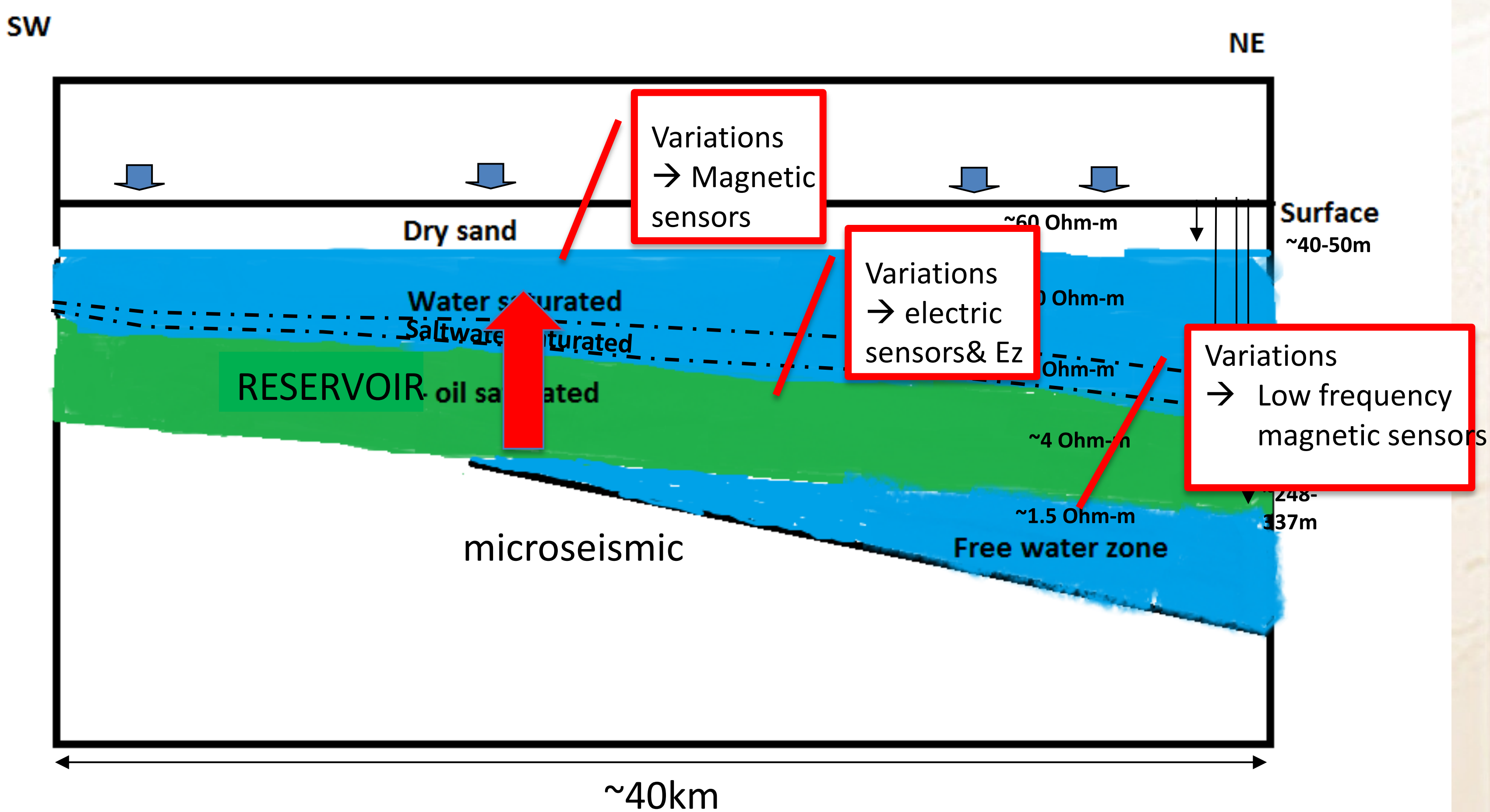
Reservoirs seal: EM & microseismic from seal fatigues



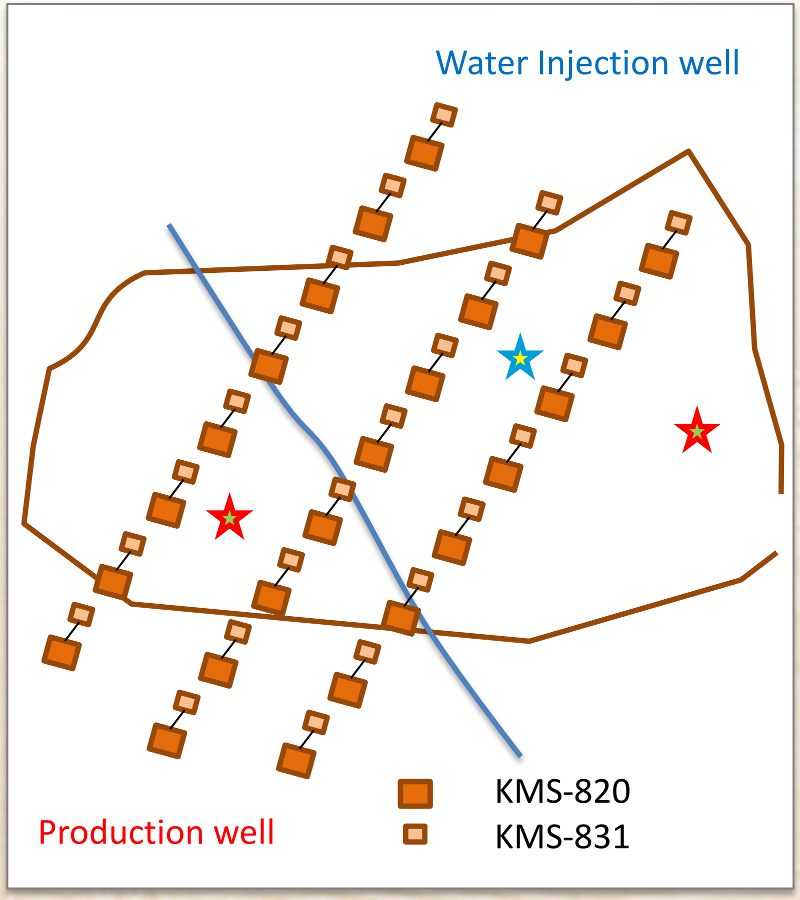
- Microseismic signature from fracturing
- EM responds to fluid movements →
- EM signature from porosity changes

After Carlson, 2013

EXAMPLE: Geologic schematic



Example layout

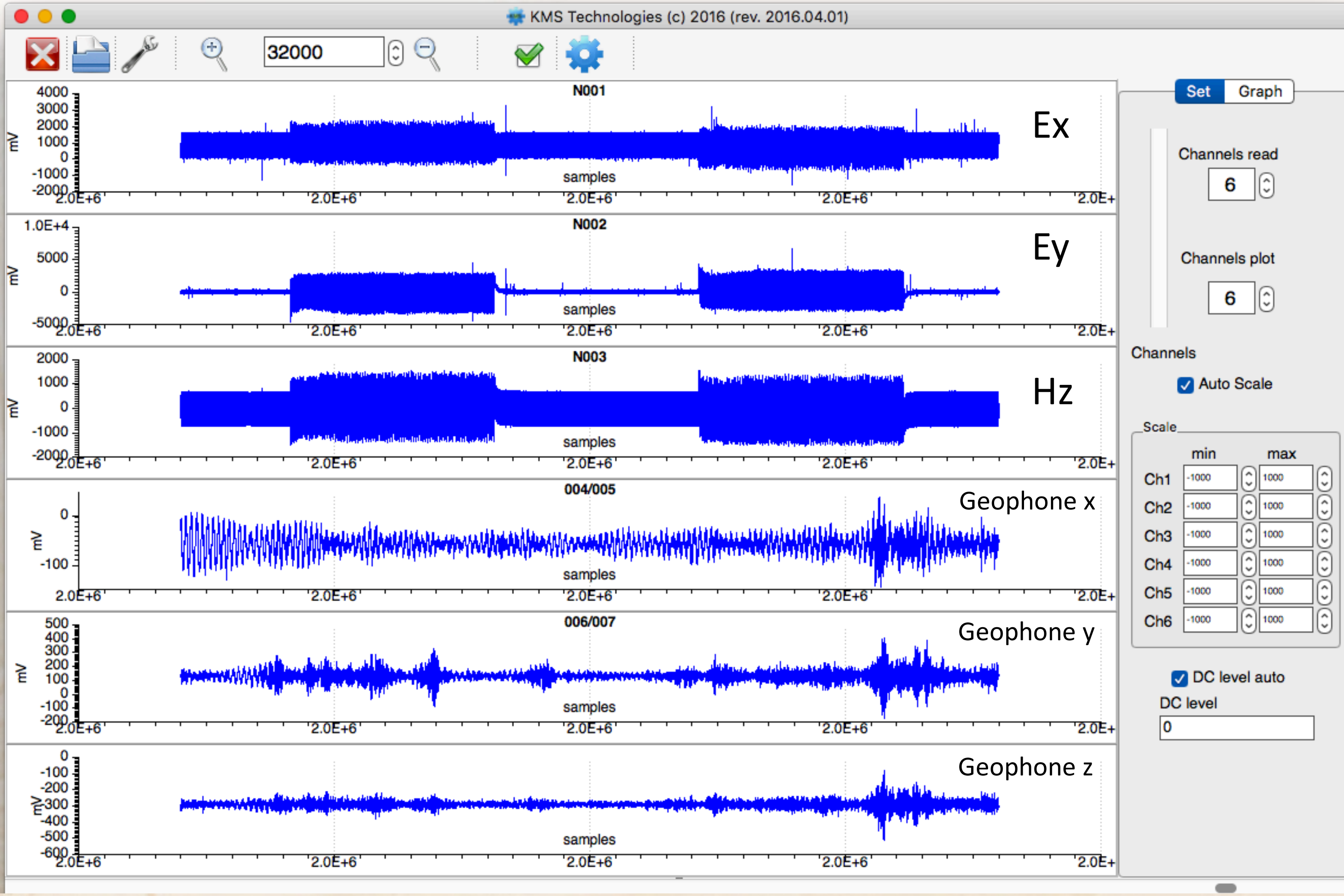


Microseismic sensors

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

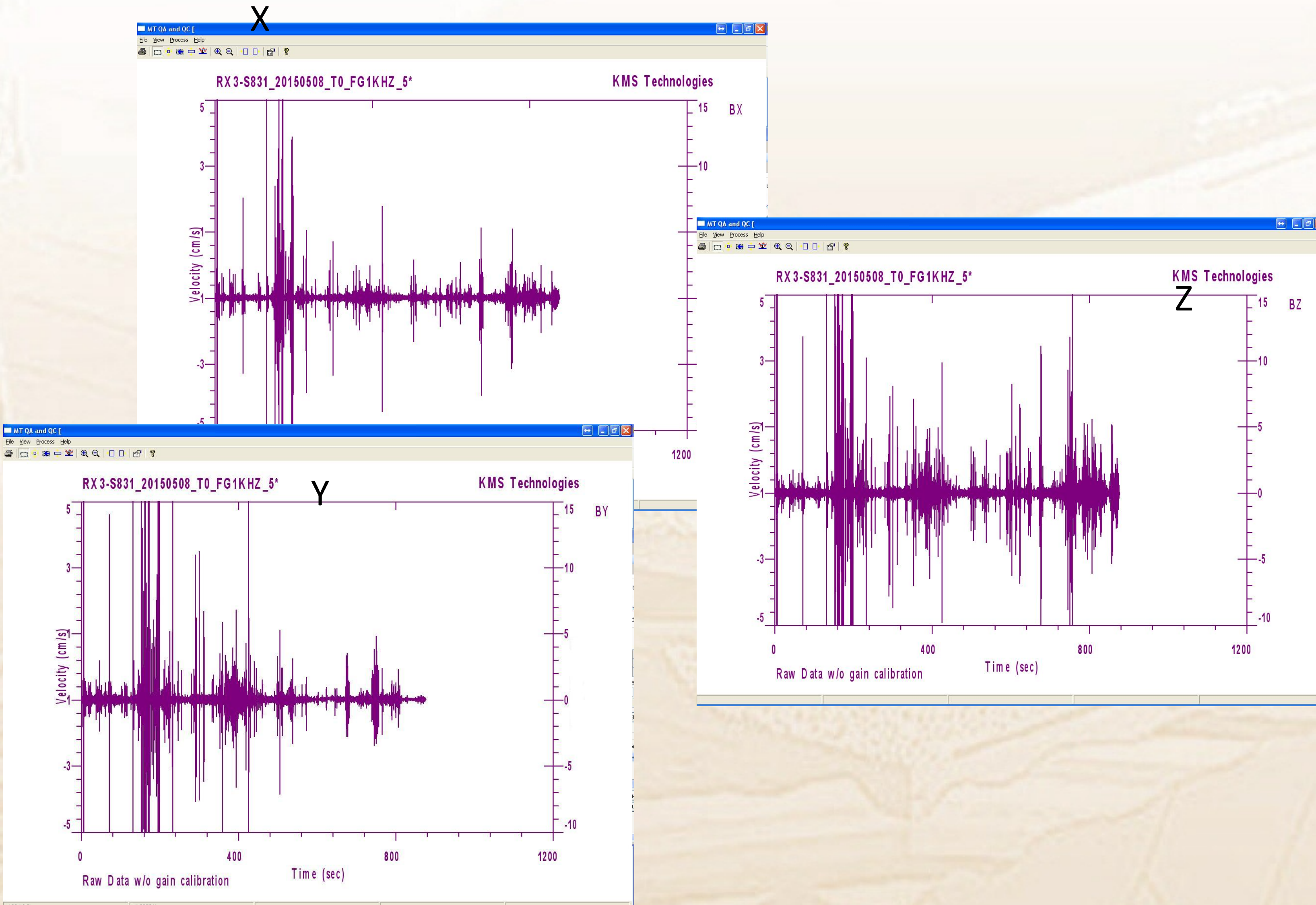
E – electric field sensors
H – magnetic field sensors

Reservoir Monitoring: Raw data example: microseismic/EM monitoring



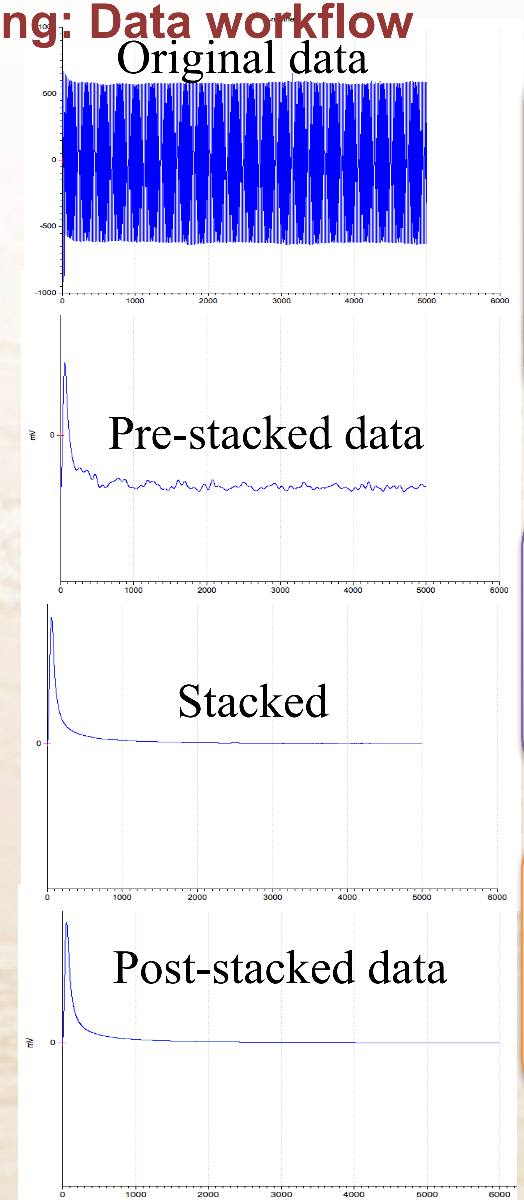
Background >>> **Reservoir monitoring** >>> Sub-salt >>> Conclusion

Seismic data samples KMS-831



Reservoir Monitoring: Data workflow

Load data (.kms)
↓
Select channel
↓
Pre-stack (Filtering)
↓
Stacking
↓
Post-stack (smoothing)
↓
Plot the time-lapse



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

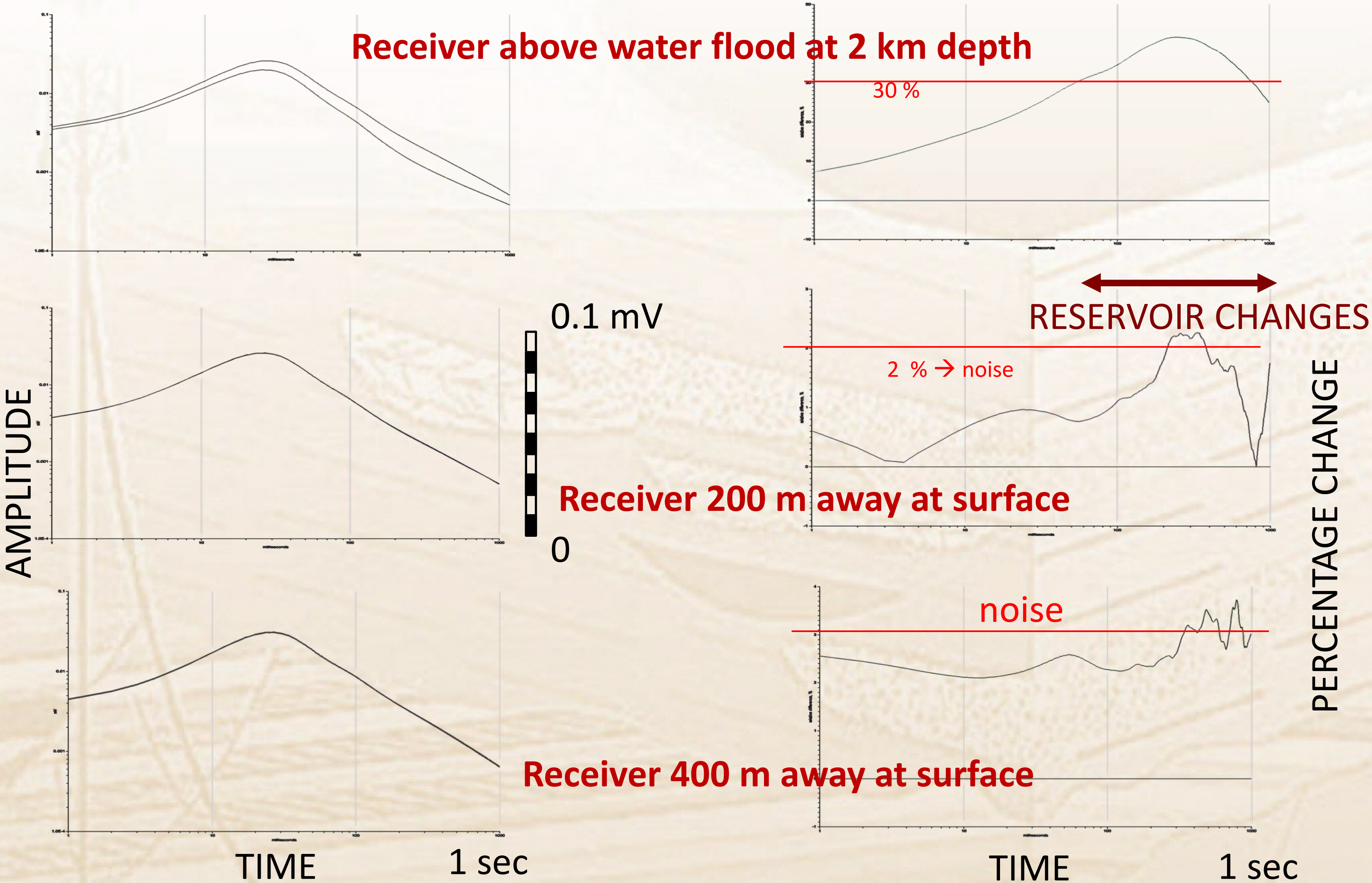
Stacking
Trimmed mean
T/2 additional stacking

- **Smoothing & time lapse**

Recursive average filter
DC-level adjust

Courtesy A. Paembonan

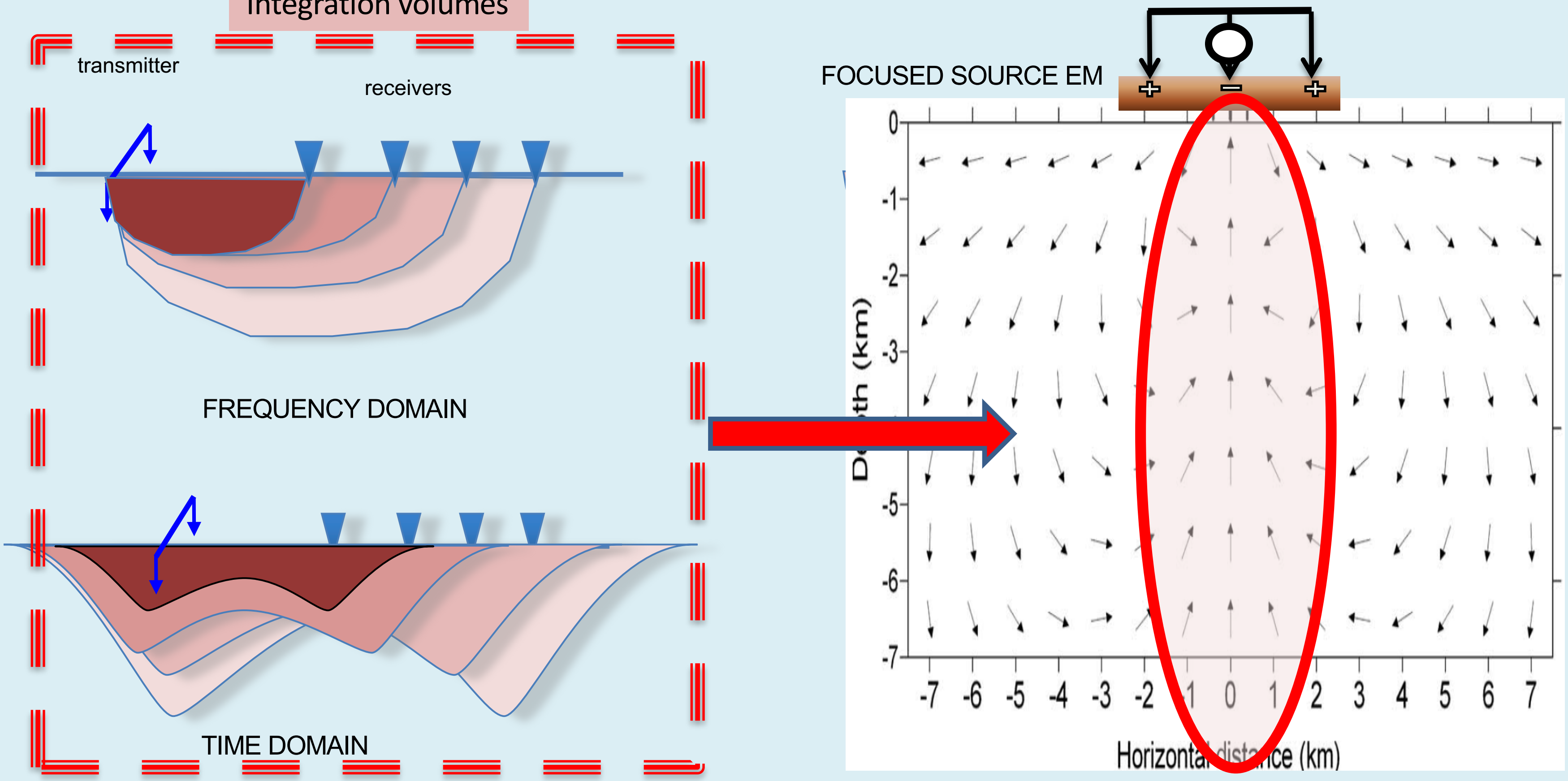
Reservoir Monitoring: Magnetic field sees water flood influence



Courtesy A. Paembonan

NEXT: FSEM: Focused source solution for CORRECT volume imaging

Integration volumes

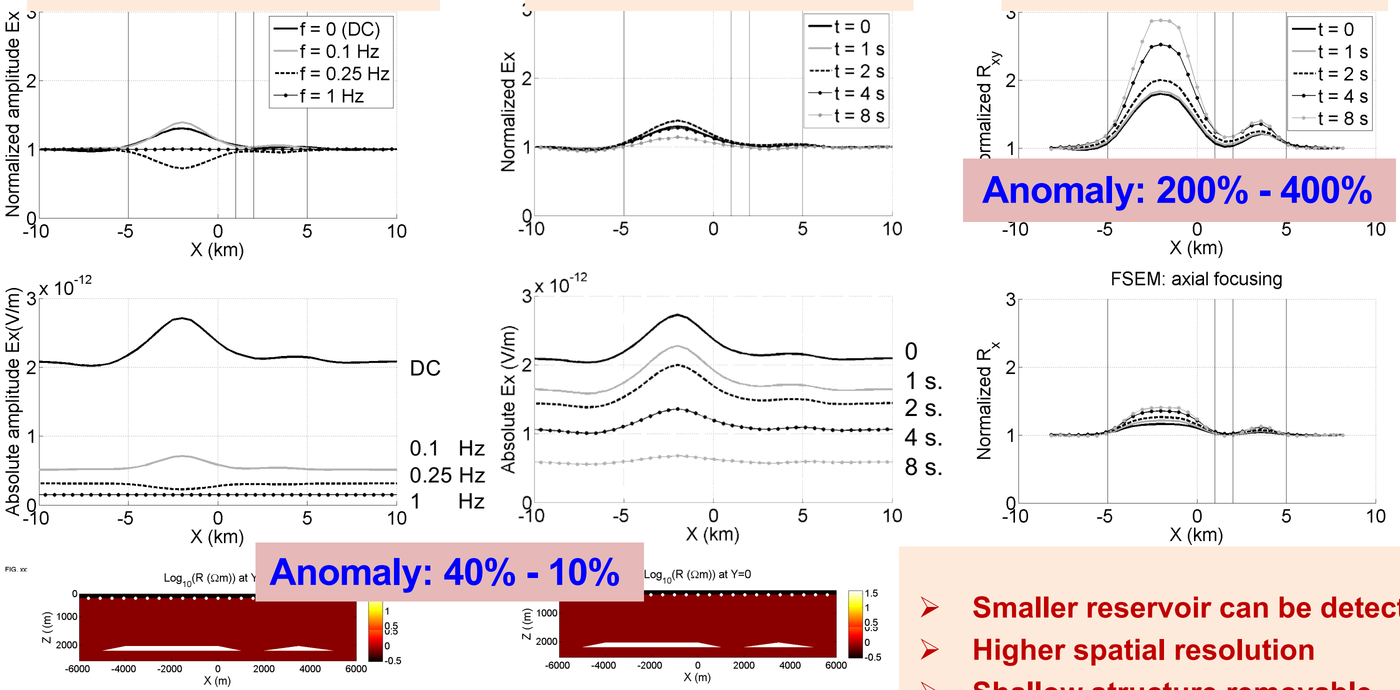


Rykhlinskaya, E., & Davydycheva, S., 2014, U.S. Patent 8,762,062 B2.
Davydycheva, S., 2016, U.S. Patent Application US 2016/0084980 A1 – allowed 10/2017.

FSEM: Focused source solution to volume imaging

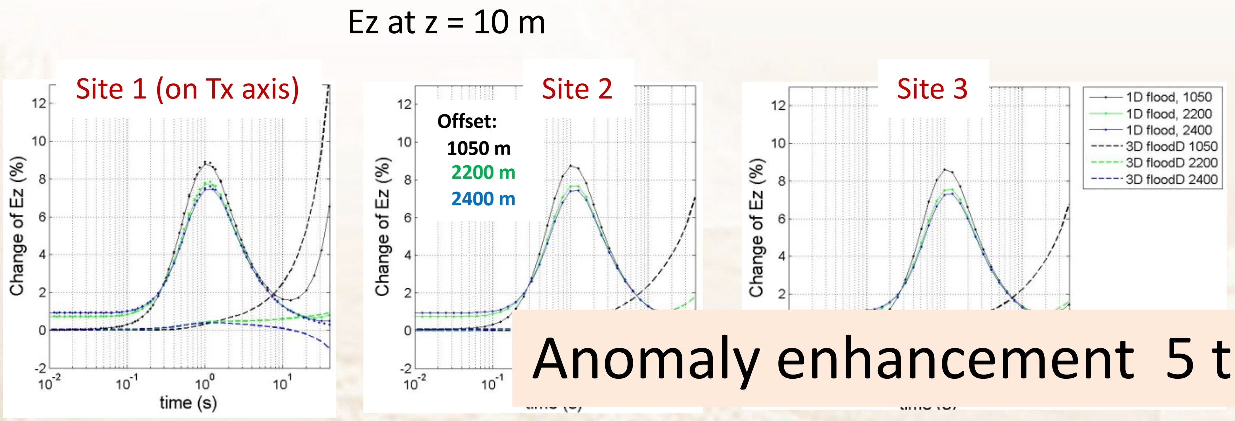
CSEM versus Focused Source

Frequency domain CSEM | Time domain CSEM | Focused Source EM

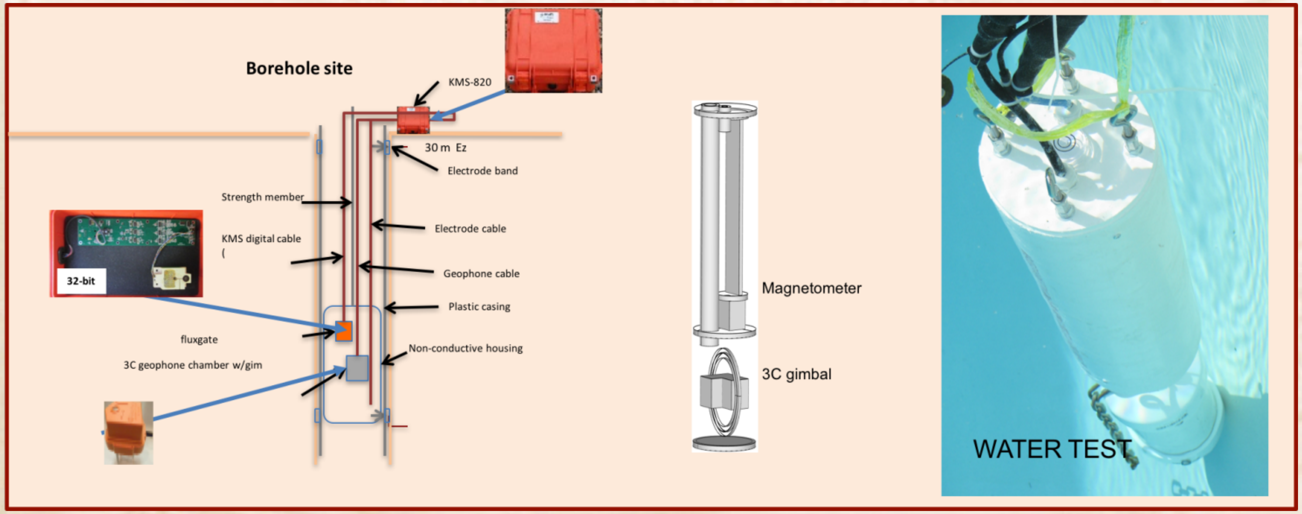


- Smaller reservoir can be detected
- Higher spatial resolution
- Shallow structure removable

Alternative: Shallow borehole tool - Ez



Anomaly enhancement 5 times



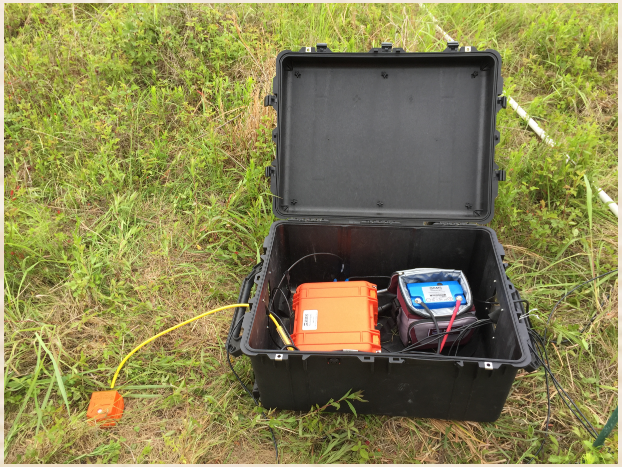
195 channel monitoring system: Technology

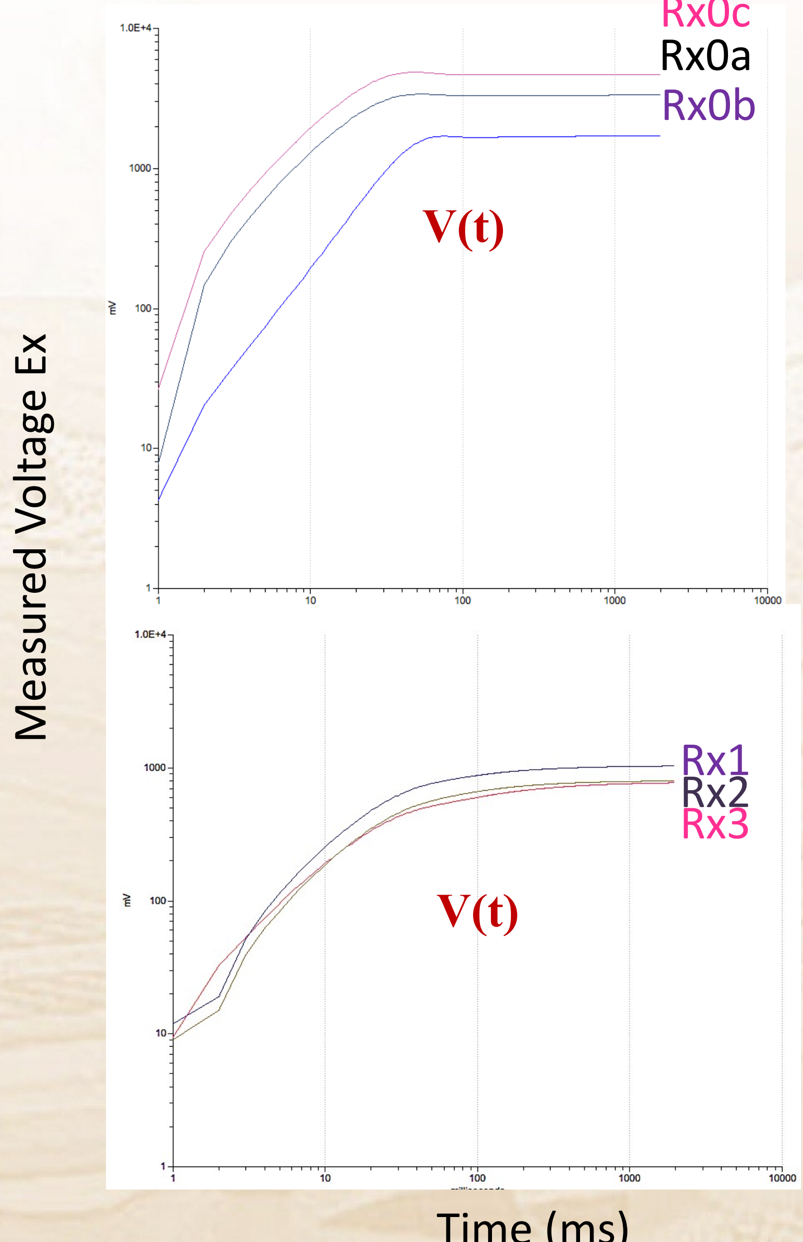
- Acquisition box KMS-820: 6 analoge, unlimited digital channels Microseismic/EM
- Sub-acquisition box: KMS-831 (32-bit, n* 3 channels; cabled to node)
- Sensors: magnetic, electric fields, air loops, small 3C fluxgate magnetometers, 3C geophones
- Telemetry: WIFI (2 options), long range wireless, LAN

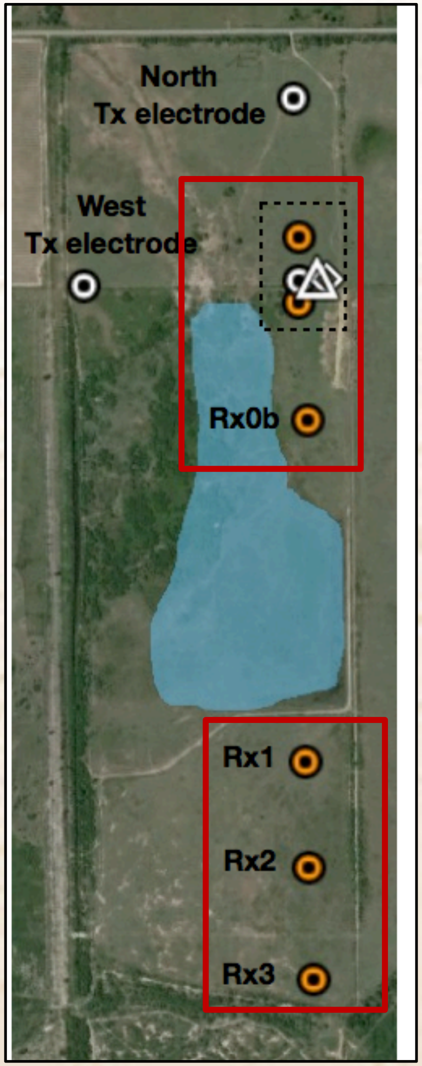
195 channel monitoring system: Challenges

- Detailed logs required
- Well sketches needed
- EOR pumping rates
- This calibrates 3D model
- A LOT of 3D modeling and reservoir engineering to close the loop

USA Texas: Hockley salt dome map with MT stations



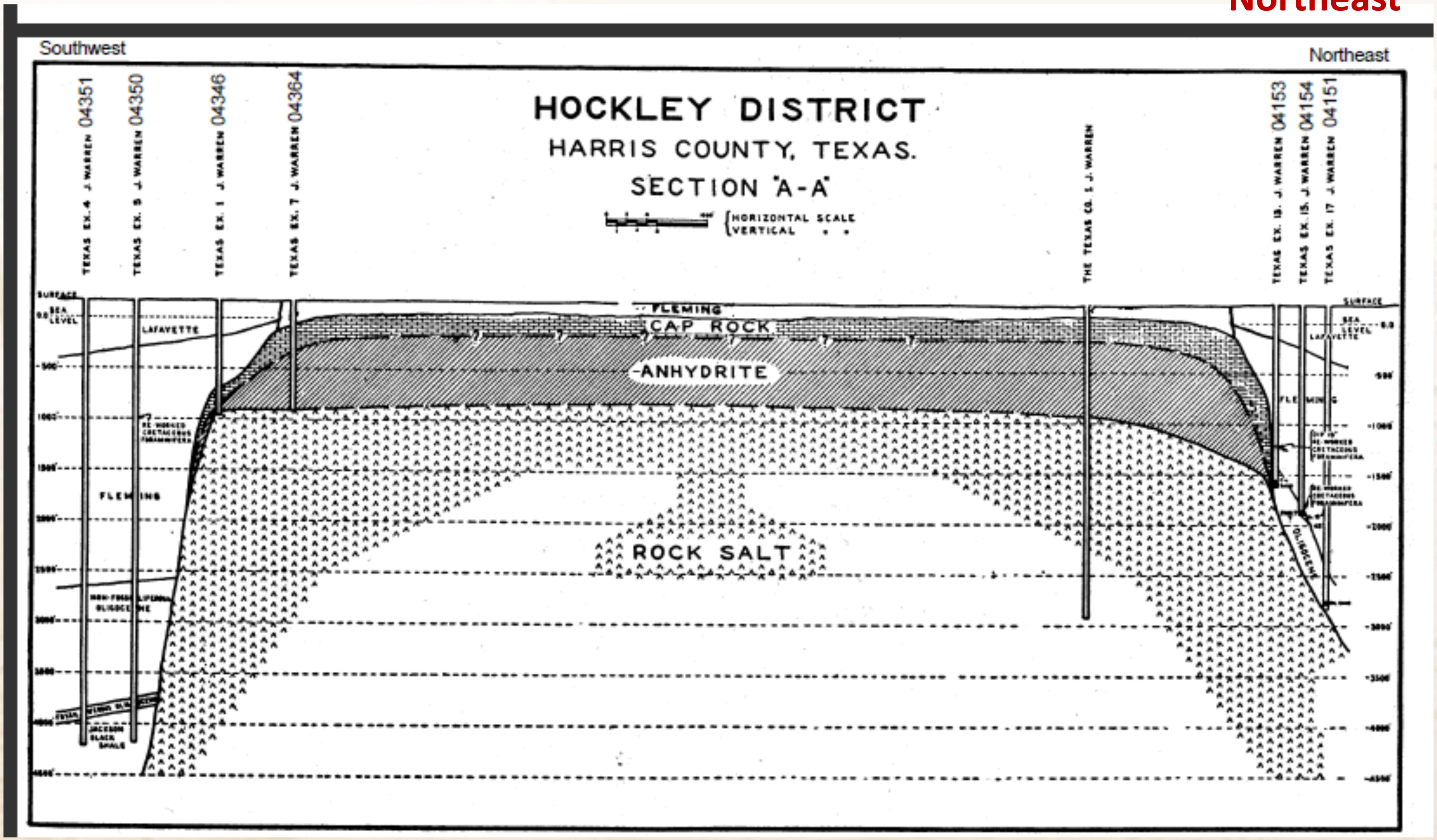




USA Texas: salt dome structure – known part

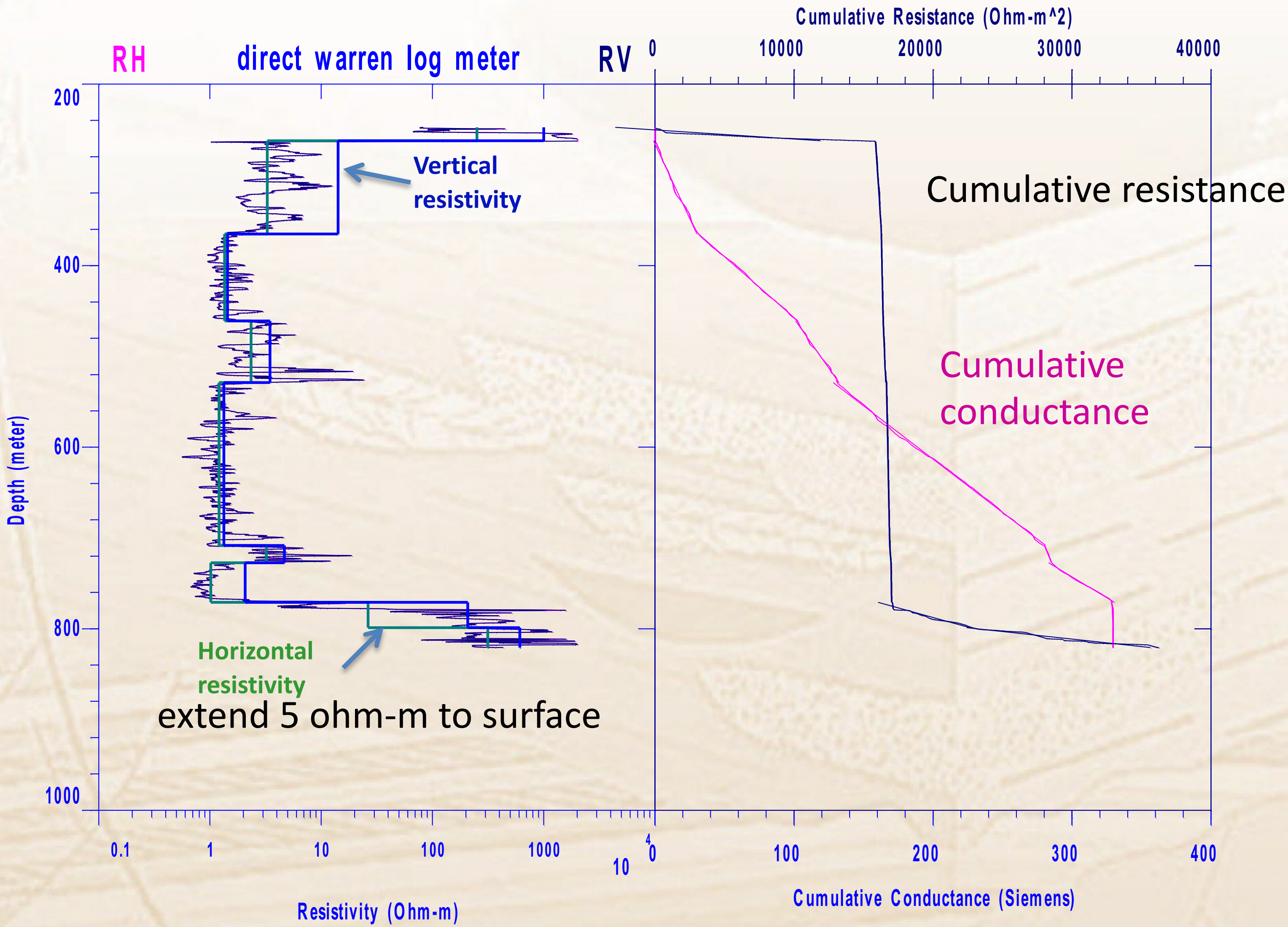
Southwest

Northeast

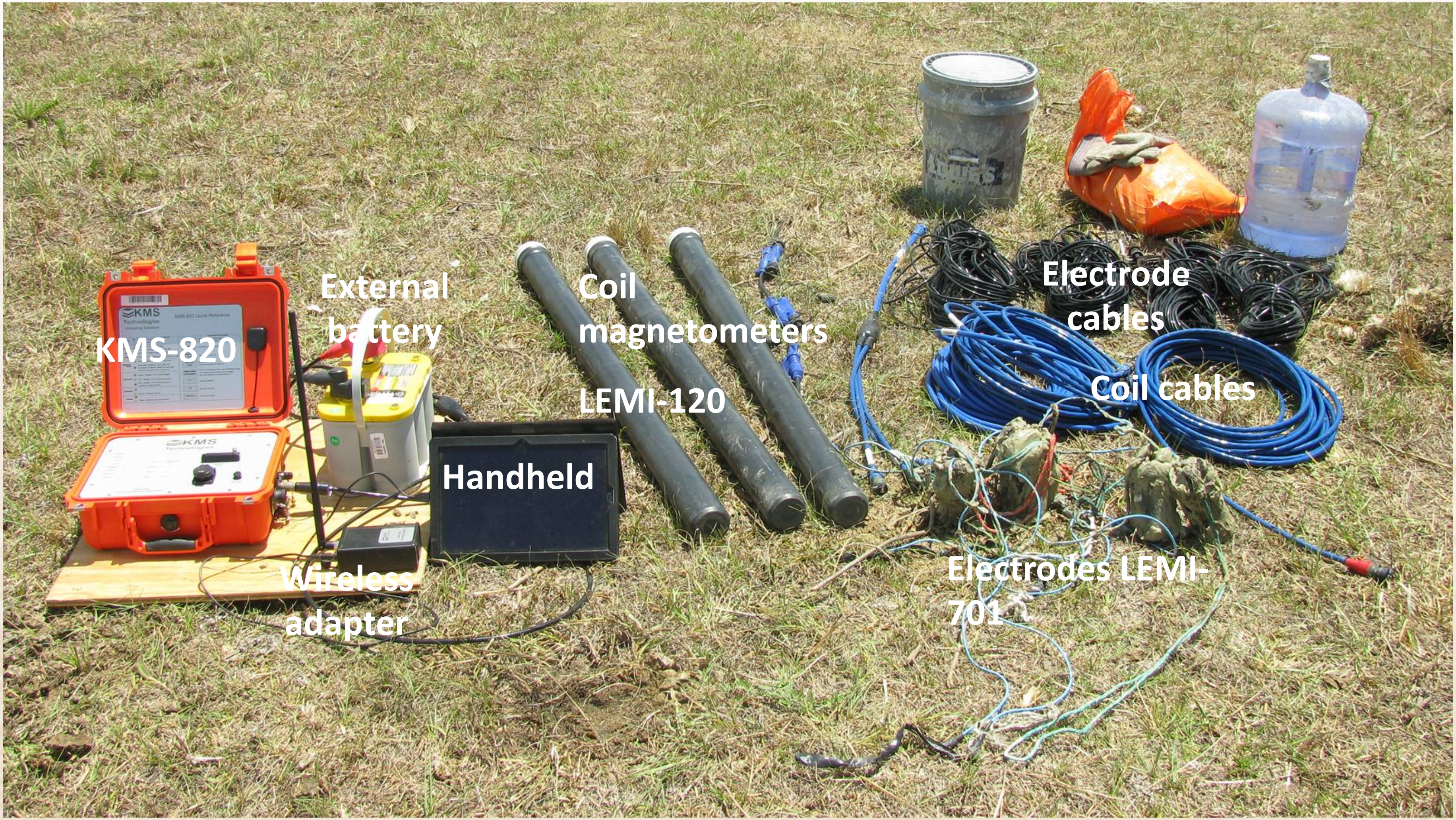


Deussen A. et al.

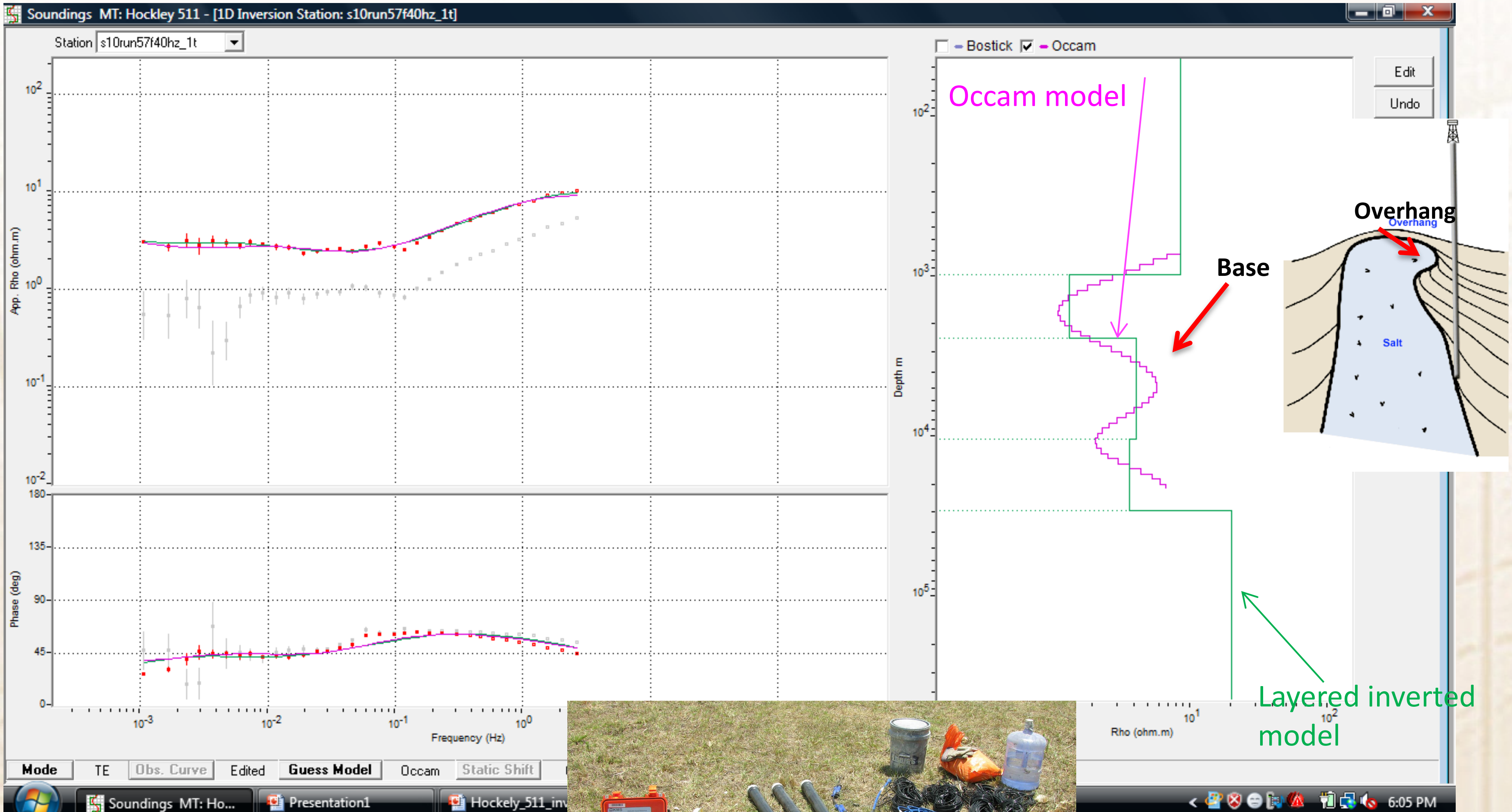
USA Texas: Direct Warren- ANISOTROPIC reduced well log model



USA Texas: MT system



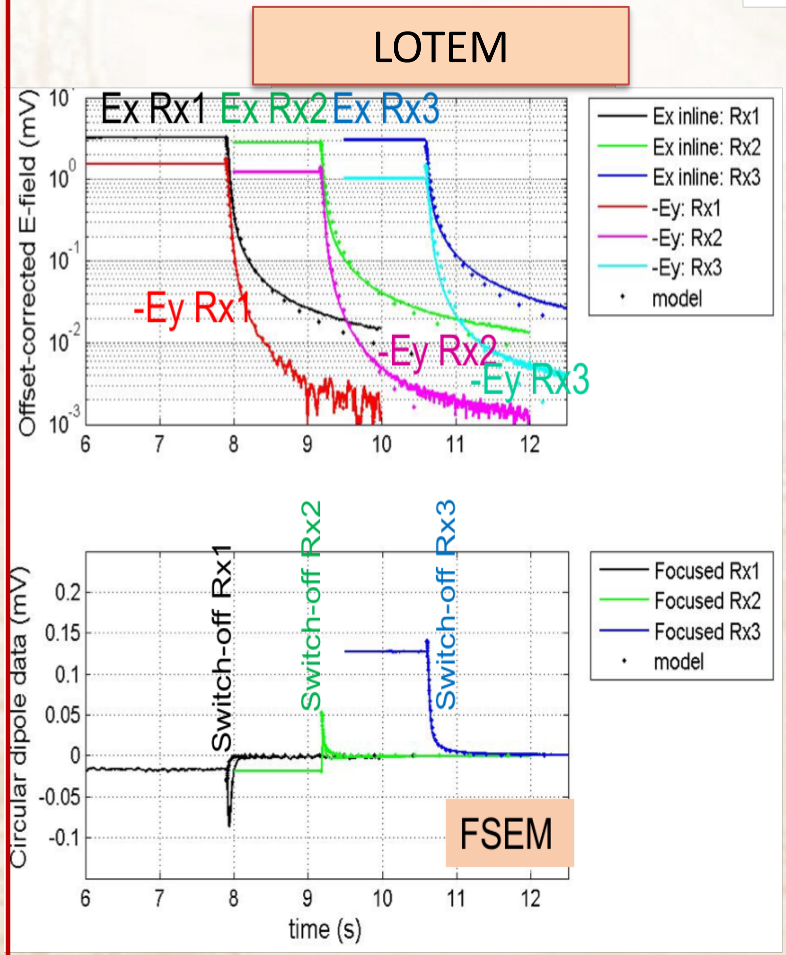
Hockley salt dome: Output of inversion - Station 10

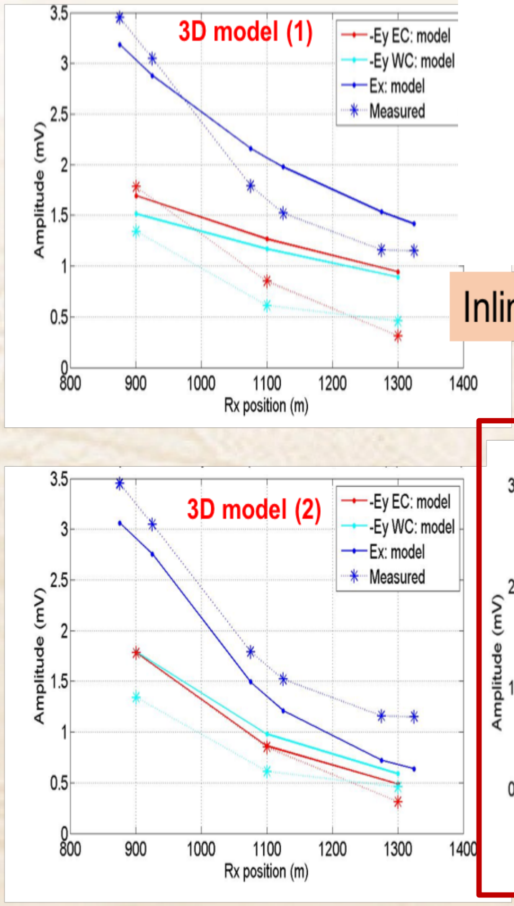


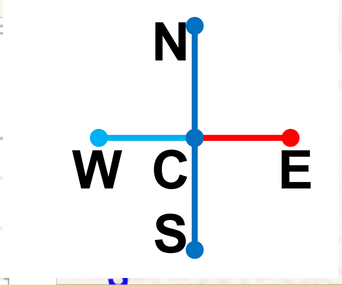
Focused source solution to volume imaging

Duty circle= 50%

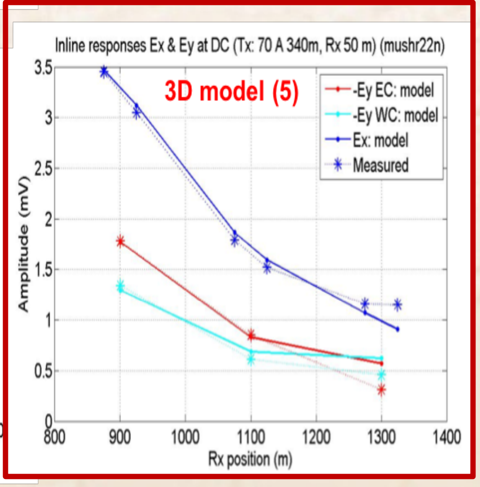
Data & models





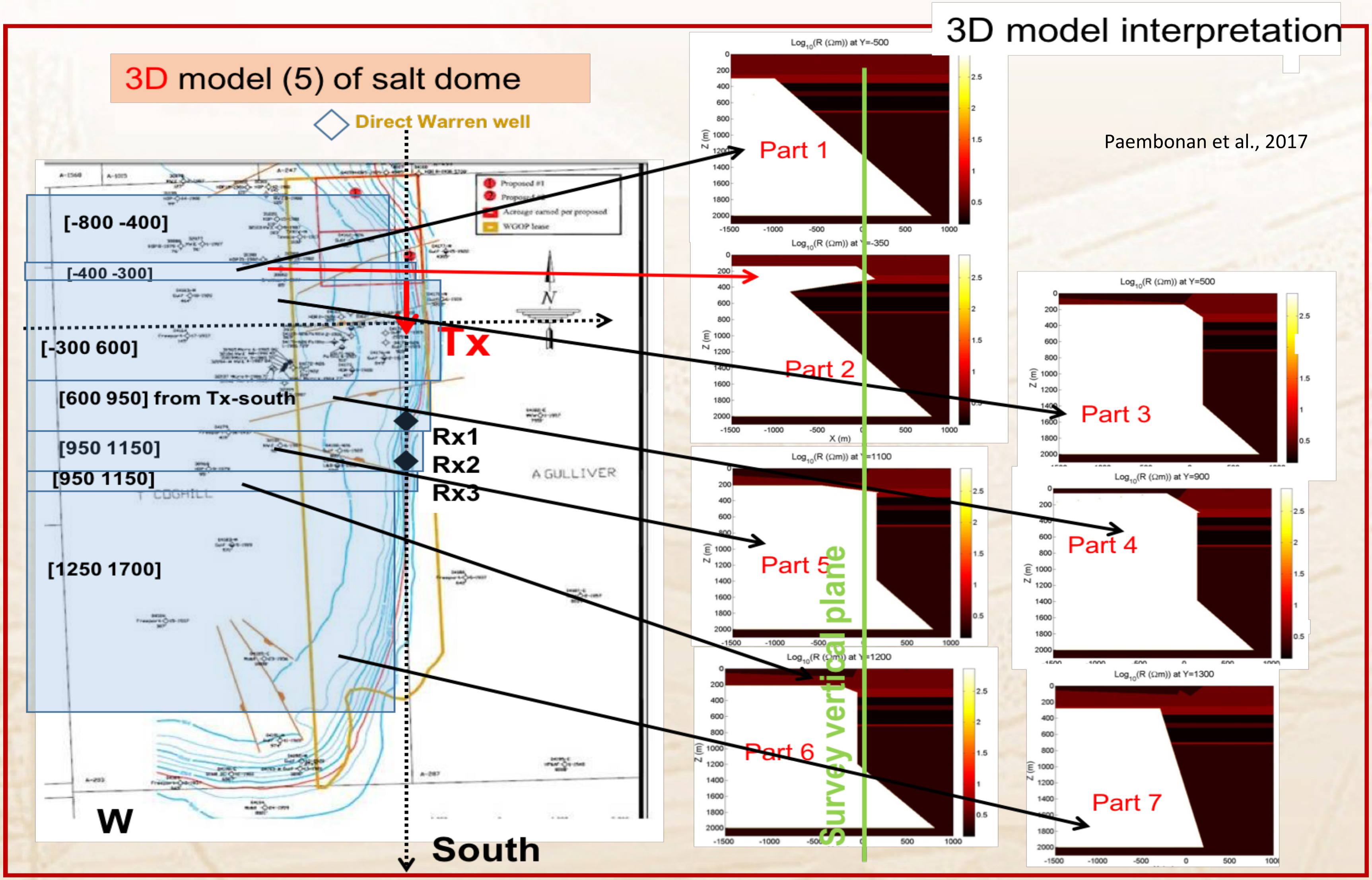


Inline & cross-line DC responses

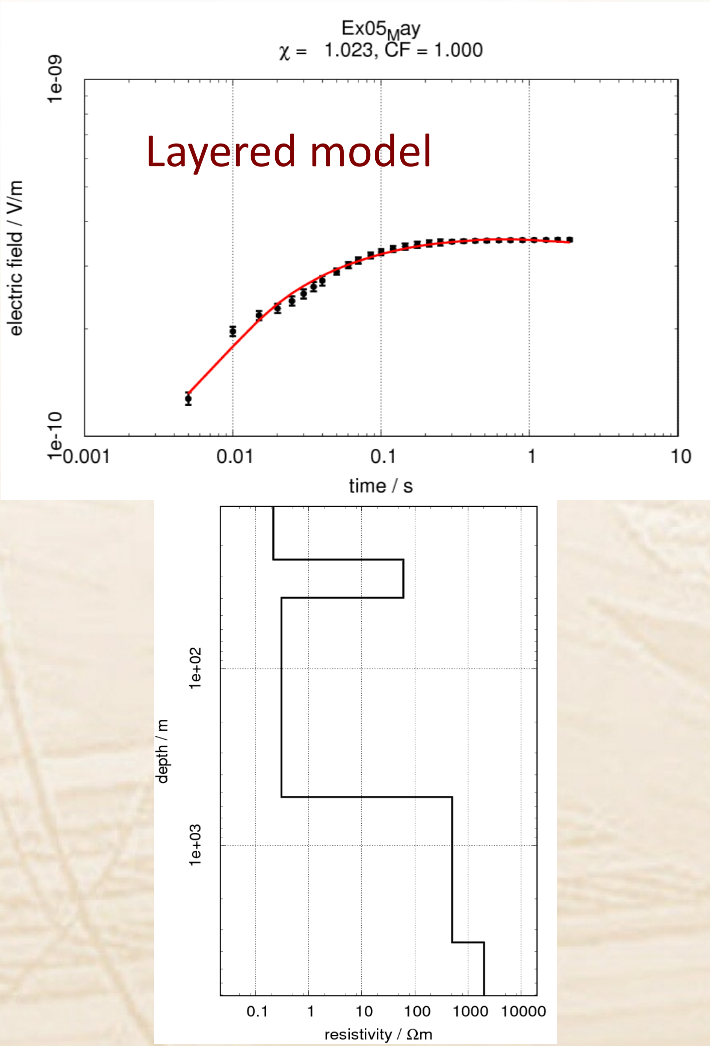


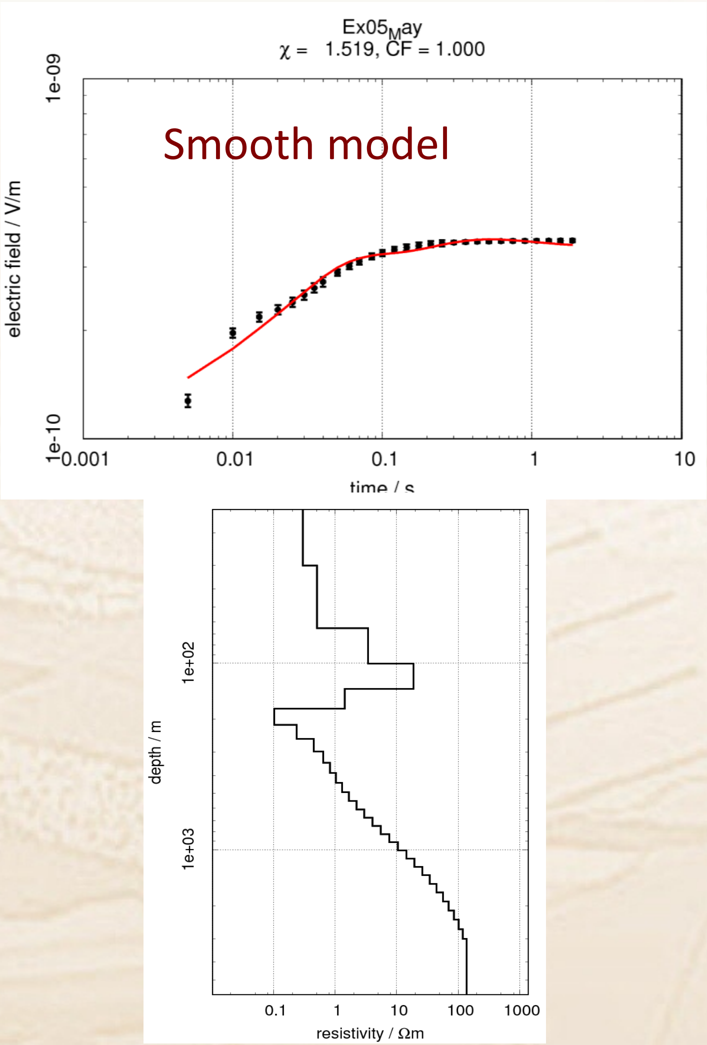
Paembonan et al., 2017

FSEM: Preliminary 3D results



Limit of 1D versus 3D: Inversion -Rx1 – Ex Hockley 5/5/2015



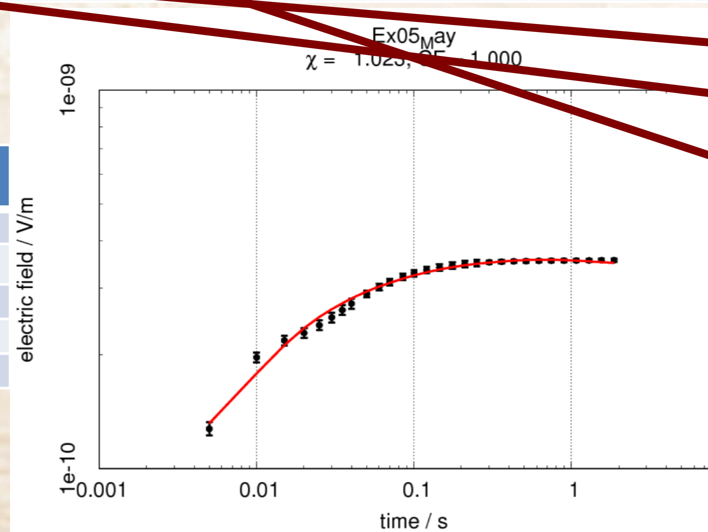


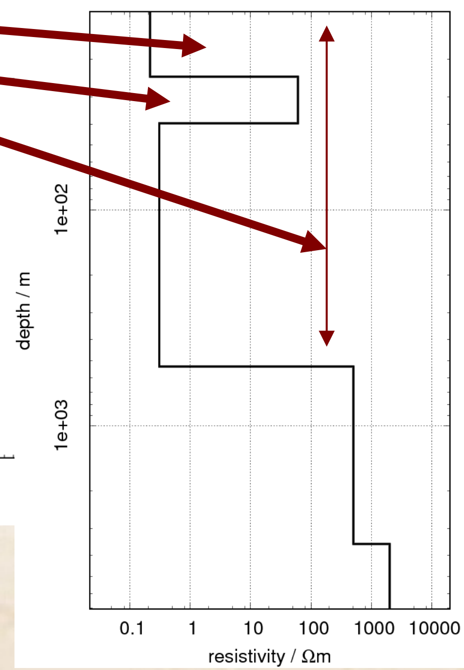
Limit of 1D versus 3D: Inversion statistics -Rx1 – Ex Hockley 5/5/2015

	P1	P2	P3		P5	P6	P7	P8	P9
ρ_1	0.015	-0.798	0.221	-0.309	0.441	-0.154	0	0	0
ρ_2	0.308	0.124	0.062	-0.057	-0.179	-0.922	0.001	0	0
ρ_3	0.111	0.201	-0.148	-0.936	-0.17	0.146	0	0	0
ρ_4	0	0	0.001	0	0	-0.001	-0.87	0.493	-0.001
ρ_5	0	0	0	0	0	0	0.003	0.007	1
h_1	-0.5	0.446	-0.06	-0.117	0.691	-0.238	0	0	0
h_2	0.8	0.201	-0.109	0.089	0.517	0.181	0	0	0
h_3	-0.054	-0.259	-0.954	0.067	0.014	-0.124	-0.001	0.001	0
h_4	0	0	0	0	0	0	-0.493	-0.87	0.008
Damping Factor	1	1	0.975	0.644	0.007	0.001	0	0	0
Resolved combination	$h_2*\rho_2/h_1$	h_1/ρ_1	$1/h_3$	$1/\rho_3$					

Effective parameter: 3.6

#Layer no	Resistivity	Thickness	Anisotropy
1	0.21	24.15	1
2	60.11	15.53	1
3	0.31	491.69	1
4	500.11	3000.29	1
5	1999.73	0	1

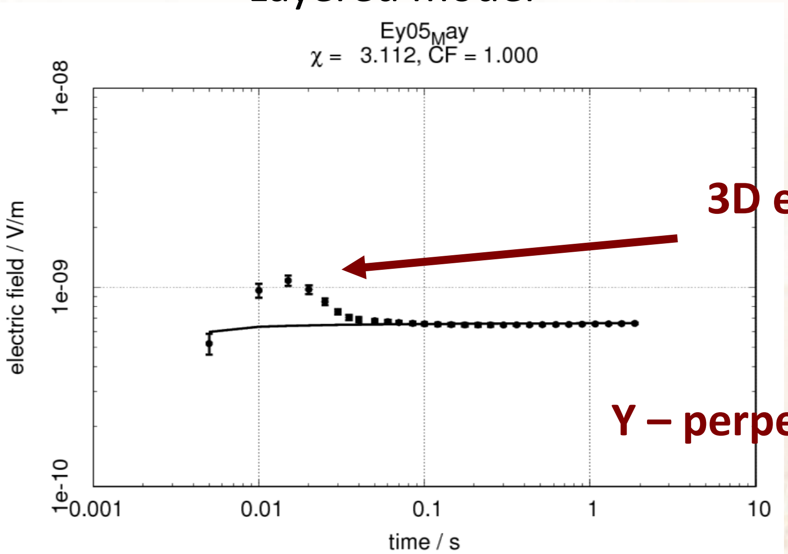




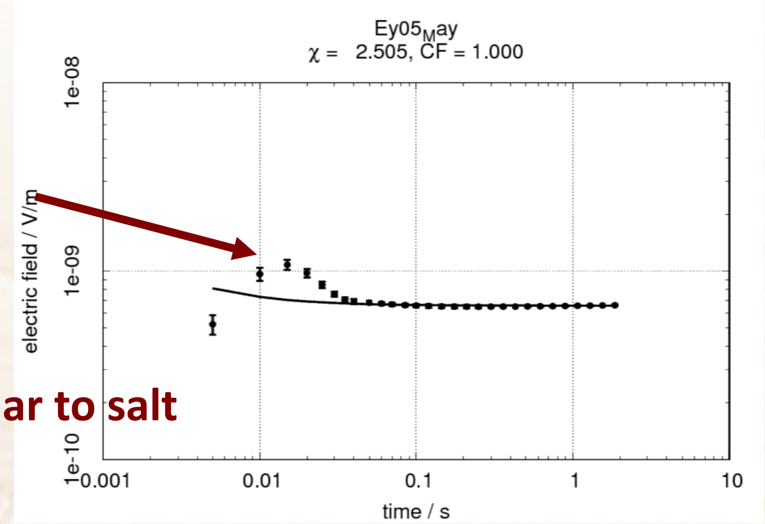
Calibration factor: 1.0000
Tx-Distortion Txx: 1.0000
Tx-Distortion Txy: 0.0000
Error: 1.023

Limit of 1D versus 3D: Inversion -Rx1 – Ey Hockley 5/5/2015

Layered model

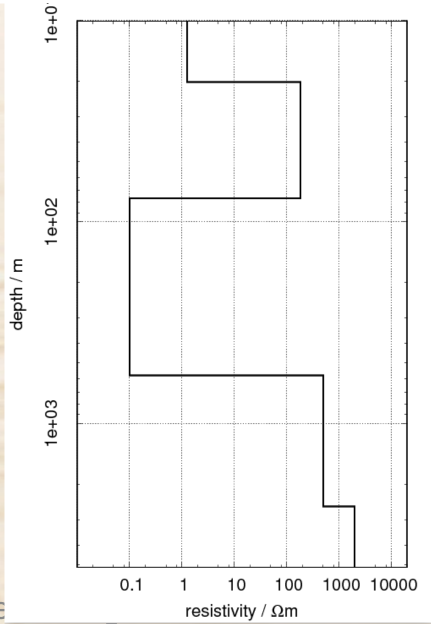


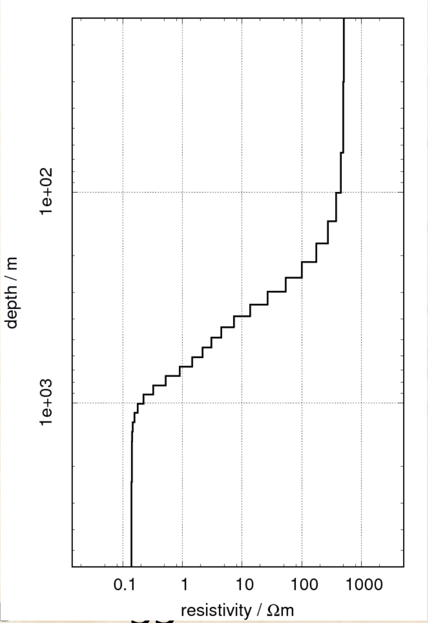
Smooth model



3D effects

Y – perpendicular to salt

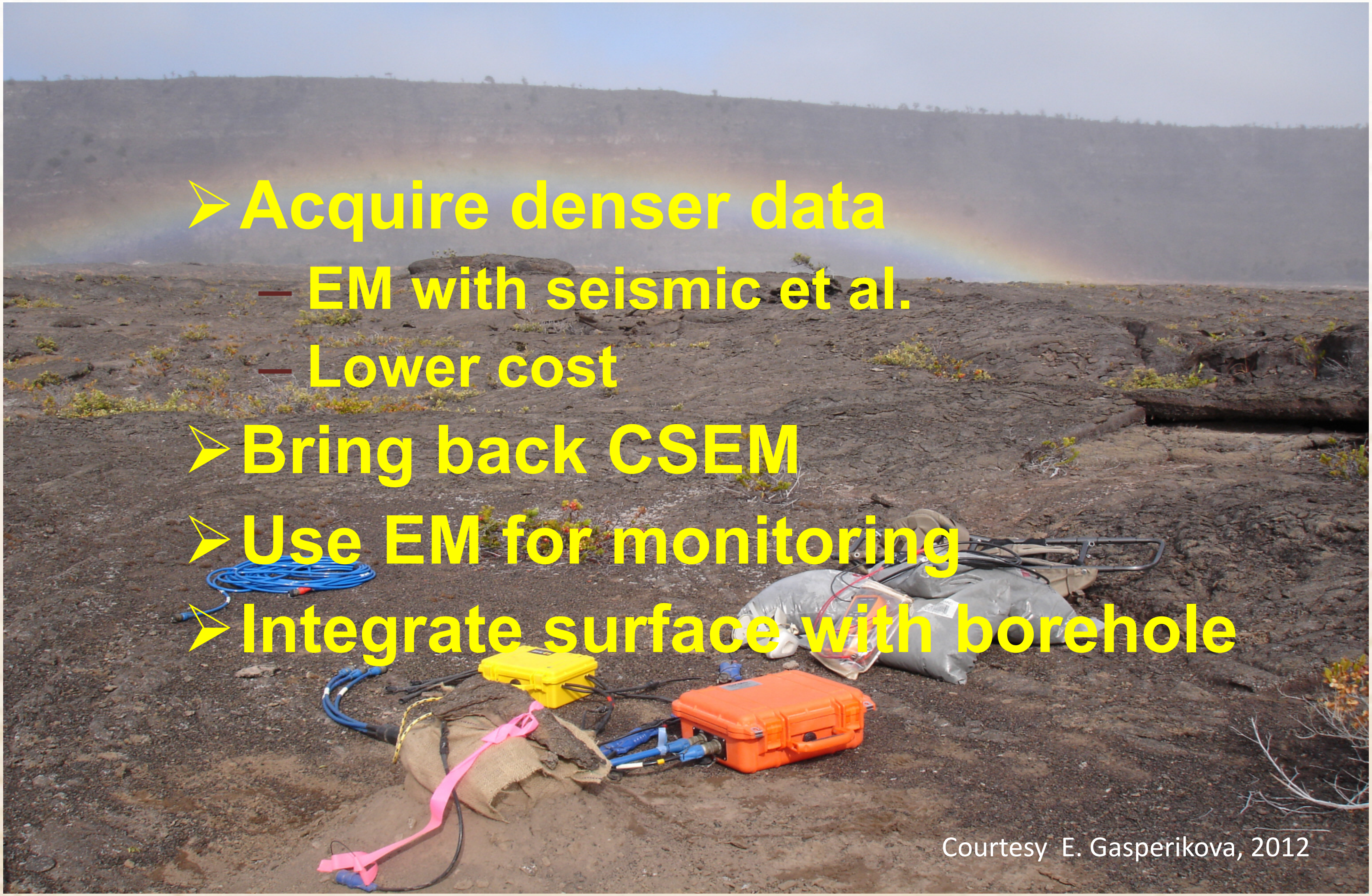




Hockley conclusion

- Clearly see an overhang on NE salt flank
- Multiple EM methods indicate this
- Field data was only equipment test
- More shallow and array data required

Overall



- **Acquire denser data**
  - **EM with seismic et al.**
  - **Lower cost**
- **Bring back CSEM**
- **Use EM for monitoring**
- **Integrate surface with borehole**

Courtesy E. Gasperikova, 2012

Acknowledgements

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…and all KMS staff.

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

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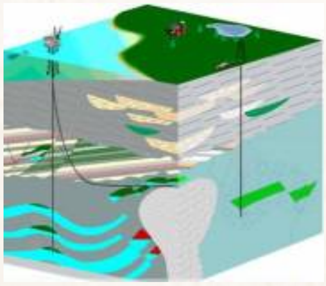

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