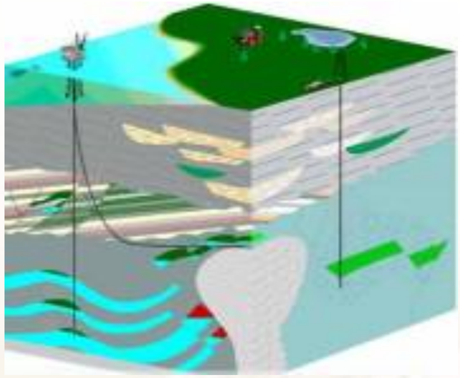


Reservoir monitoring using electromagnetics/microseismics: Experience leading to a 200 channel system

KMS Technologies

K. Strack

September 2015, EMTF -Germany

www.KMSTechnologies.com

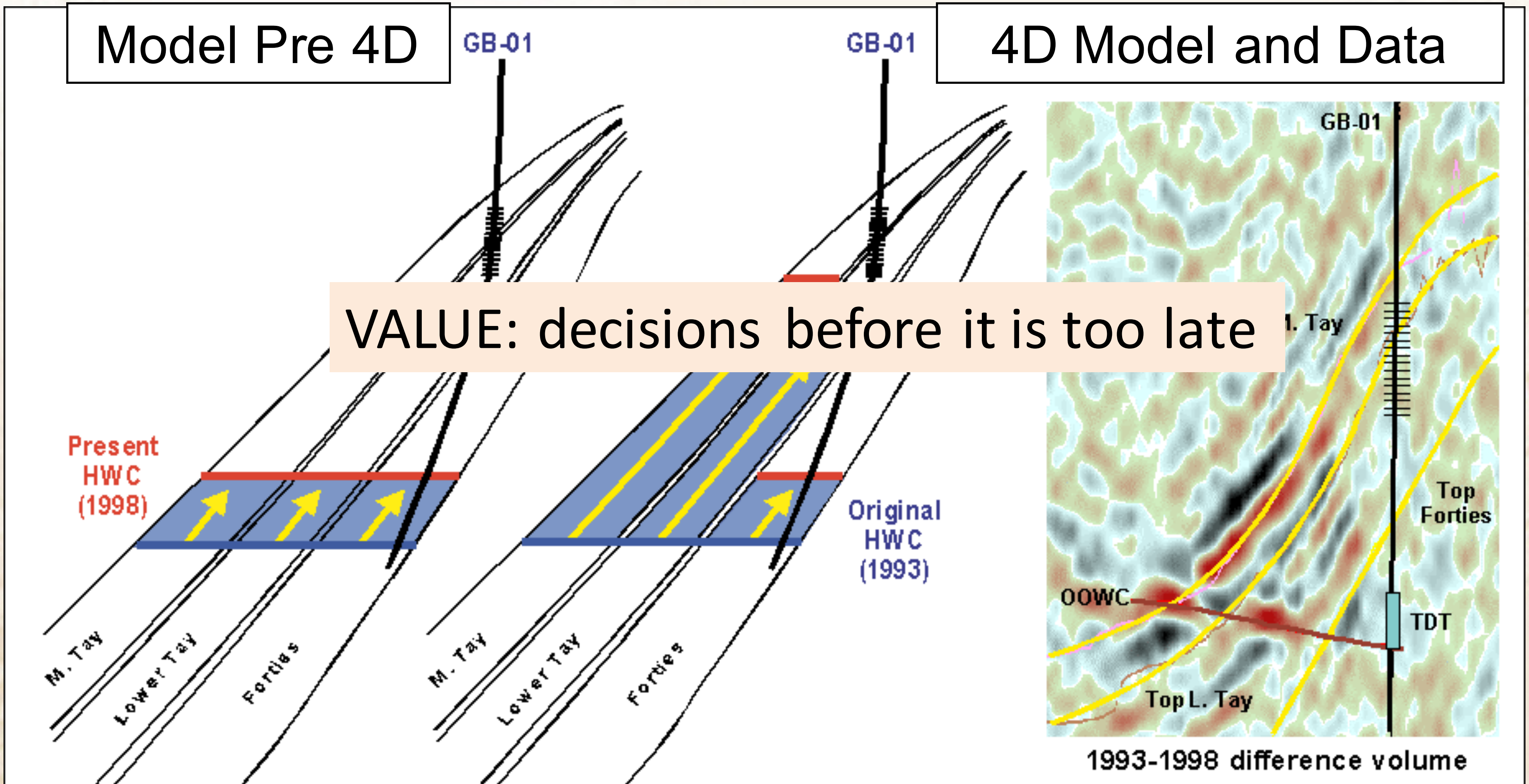
Outline

- Background & Monitoring applications
- Examples:
  - Saudi Arabia
  - Thailand
- Where do we go from here

Definitions

- 4D time lapse: two or more individual measurements giving time snapshots of the reservoir; usually slow & complex interpretation
- Reservoir monitoring: (semi-) continuous measurement of the reservoir leading to operating decisions (fast turn around)

Gannet B - 4D Difference Section



M. Hartung (Shell Expro, EAGE 2000 & SEG 2000)

Why EM and seismic?

- Determining composition, boundaries and movement
- Best quality data!
- Combination of Seismic and EM offer best solution
- EM has proven as valid DHI (Direct Hydrocarbon Indicator)
- EM is best in class in fluid imaging

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

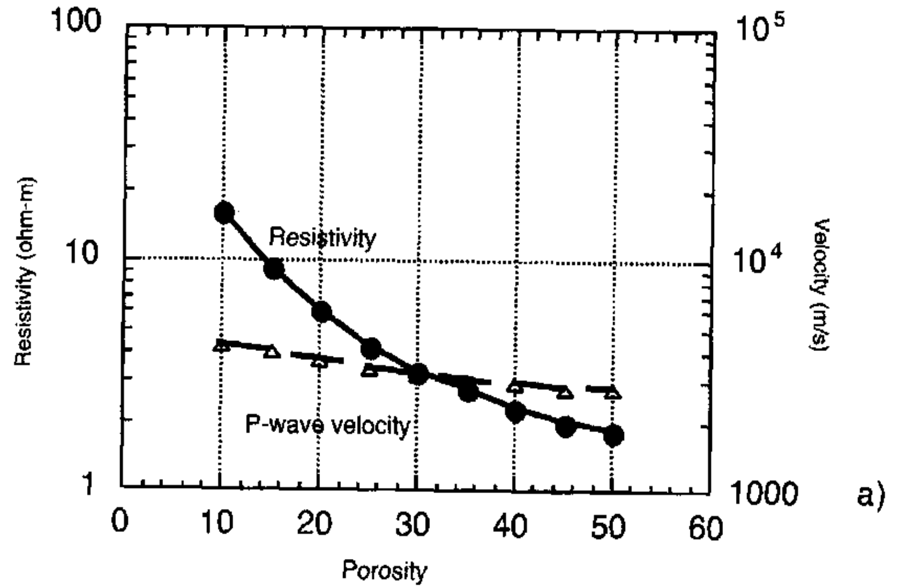
Permanent fluid contrast monitoring

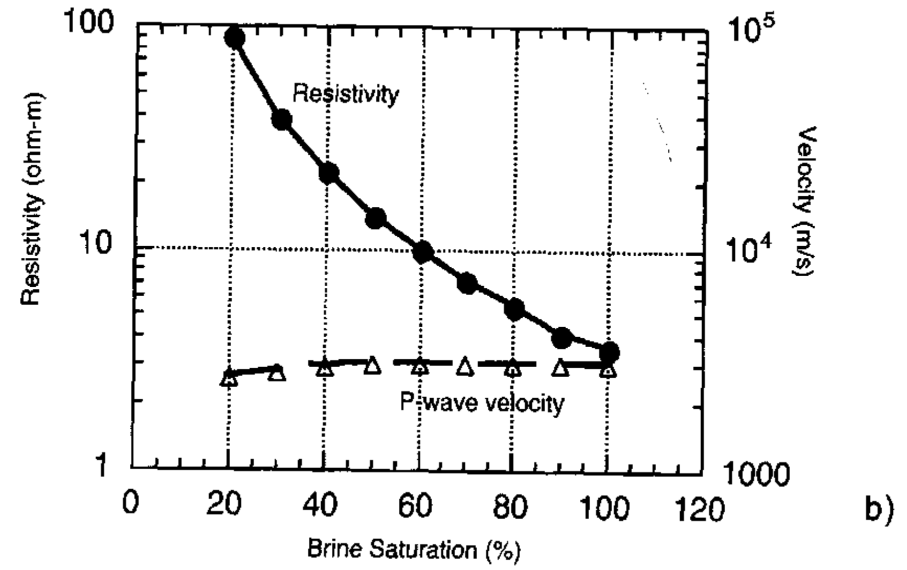
Electrical

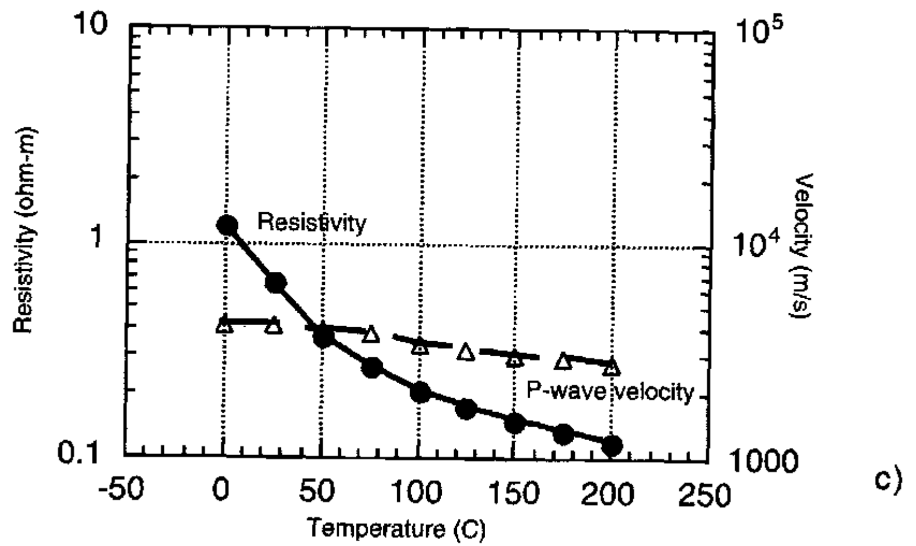
- Basic concept: use natural field for frame work & controlled downhole for keyhole surveys
  or
  use CSEM with multi-transmitter
- Perfect for water flood monitoring
- Evaluation through & outside casing
- Results: needs combined galvanic (oil = resistive) & inductive (brine=conductive)
- Numerous disperse patents, expert groups exist
- Real field study is required

Background & applications >> Examples >> Path forward

Resistivity & velocity versus porosity, brine saturation & temperature

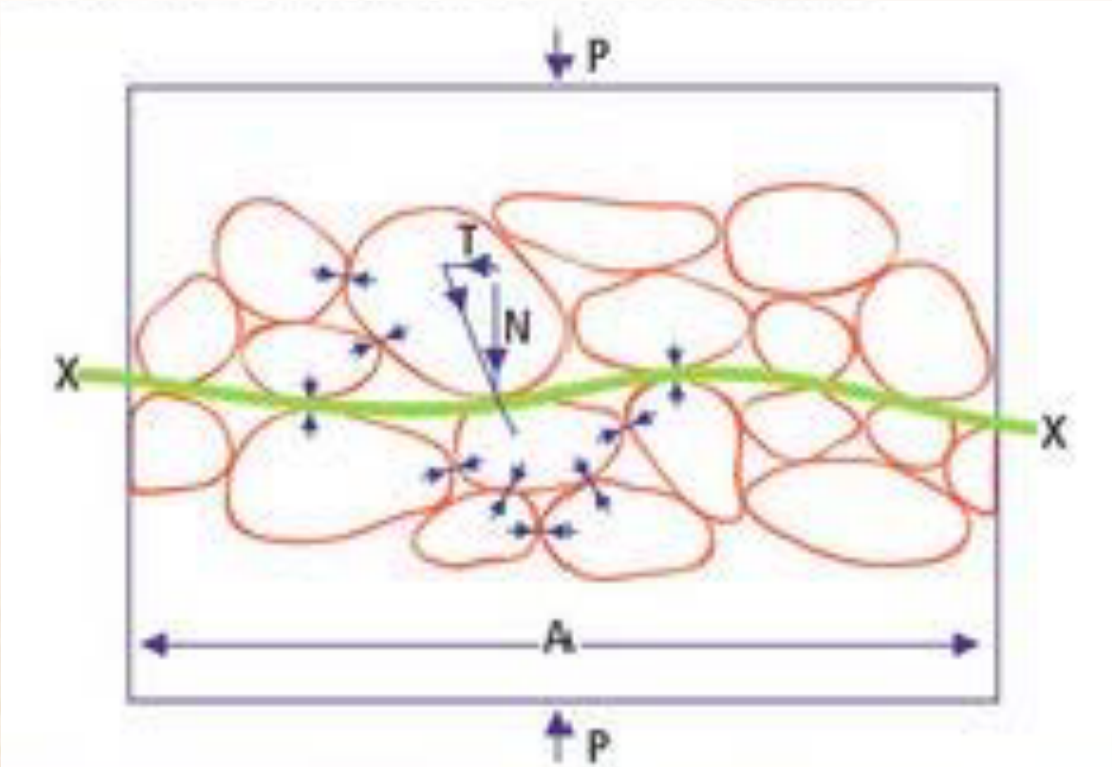






After Wilt & Alumbaugh, 1998

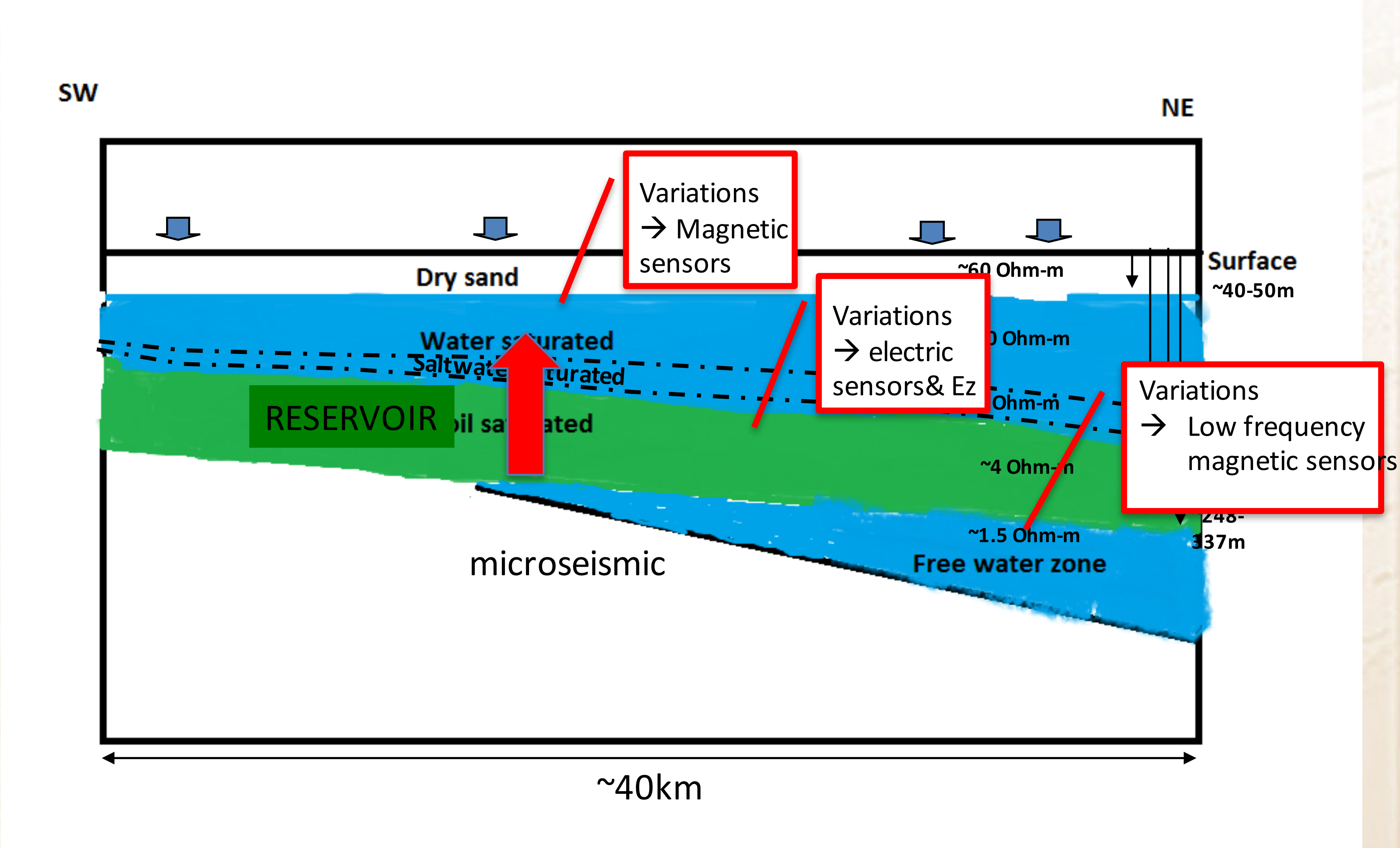
Background & applications >> Sensitivities >> KMS system
Reservoirs seal: EM & microseismic - effective stress



- 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

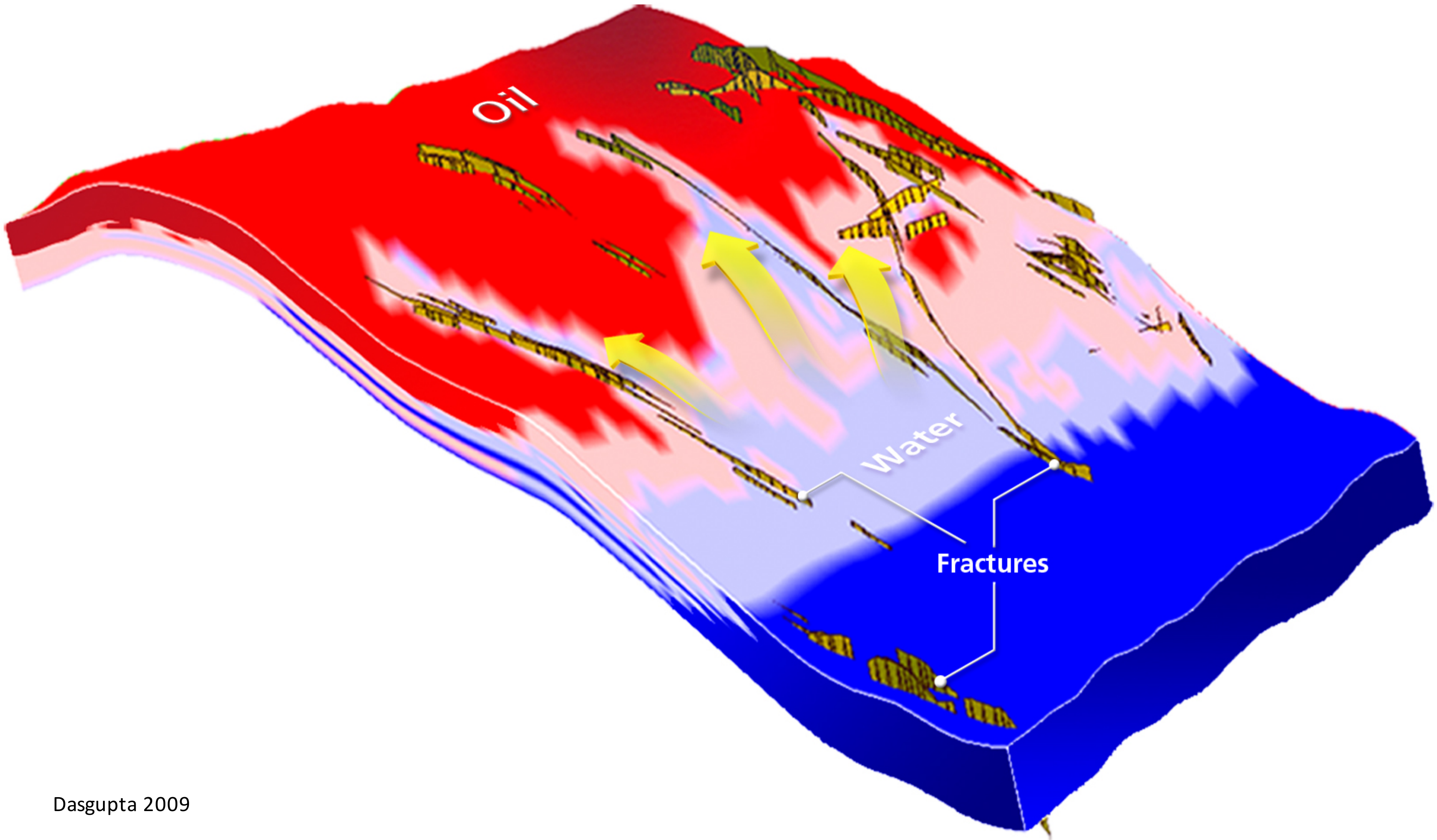
Background & applications >> Sensitivities >> KMS system
Solutions via multi-physics sensors



Saudi Arabia- Ghawar field: feasibility workflow/punch line

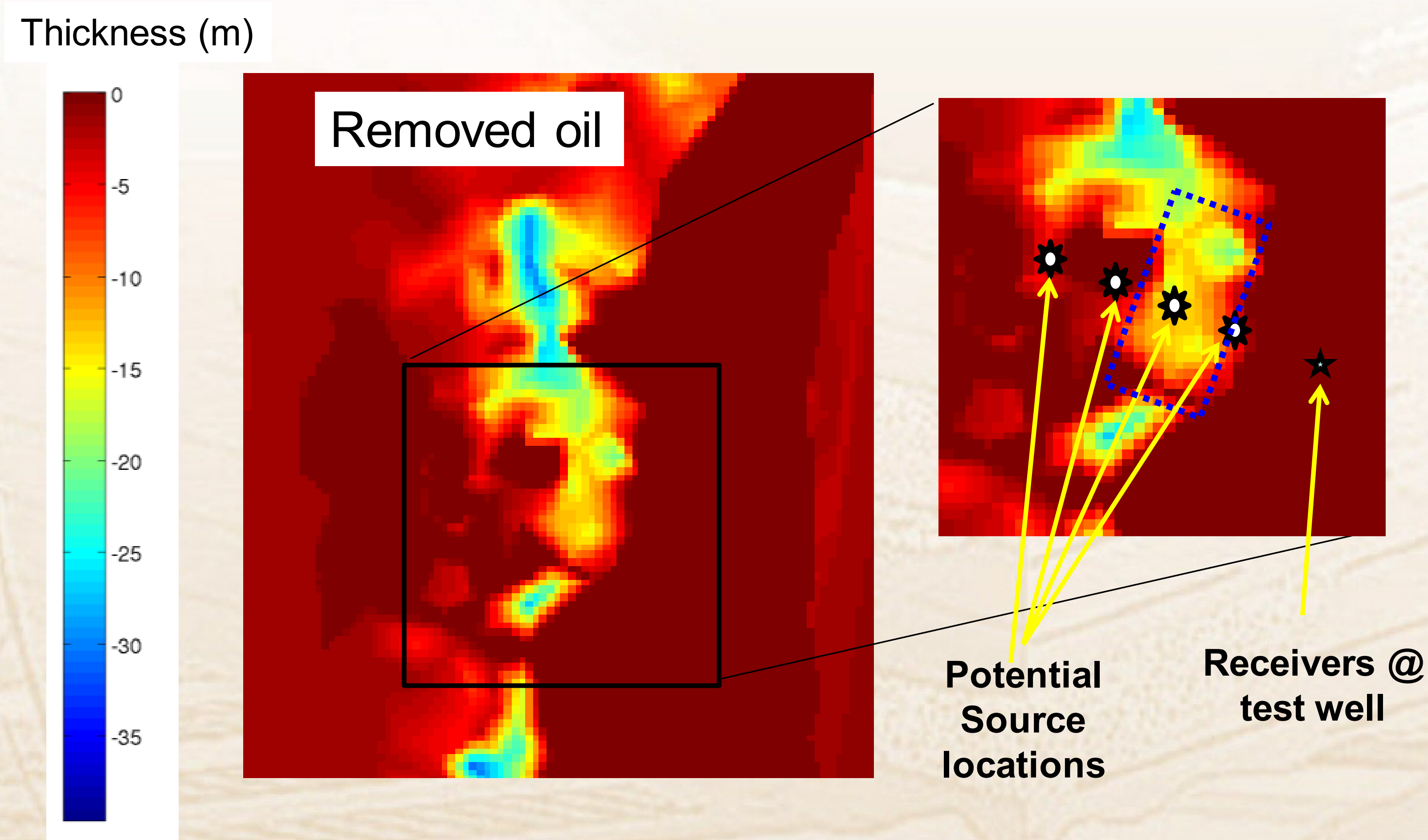
- Detect water fingering in GIANT reservoir
- Petrophysical analysis of background data → resistivity model
- Integrate model with reservoir simulator
  - 1-dimensional CSEM (Lotem)
  - Predict fluid substitution (50 ohm-m → 3 ohm-m)
  - 3-dimensional CSEM (surface-to-borehole) with time lapse sections

Ghawar: Fluid displacement heterogeneity



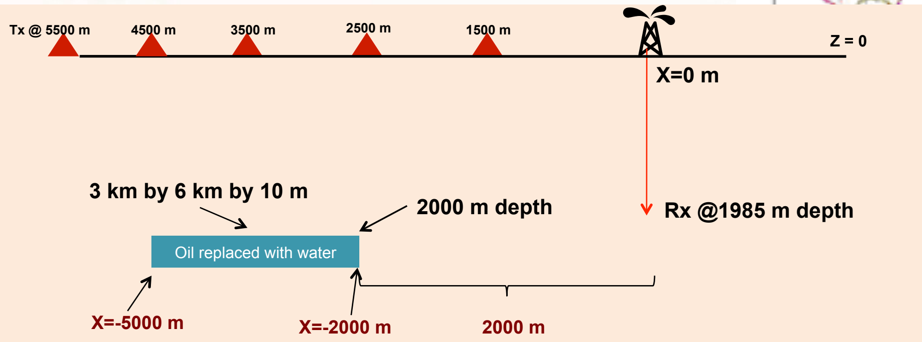
Dasgupta 2009

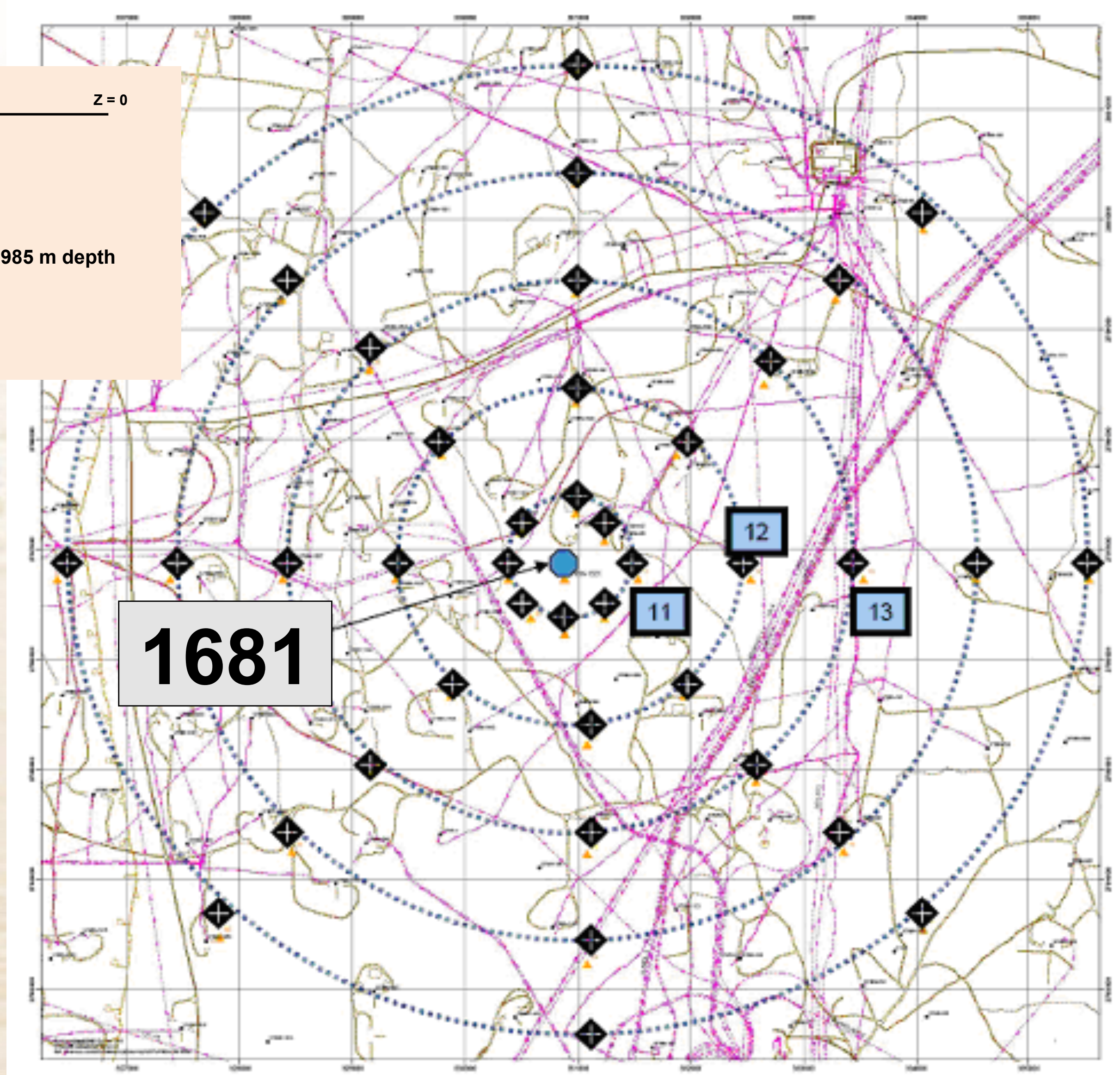
Ghawar: 3D model differences



After Colombo et al. 2010

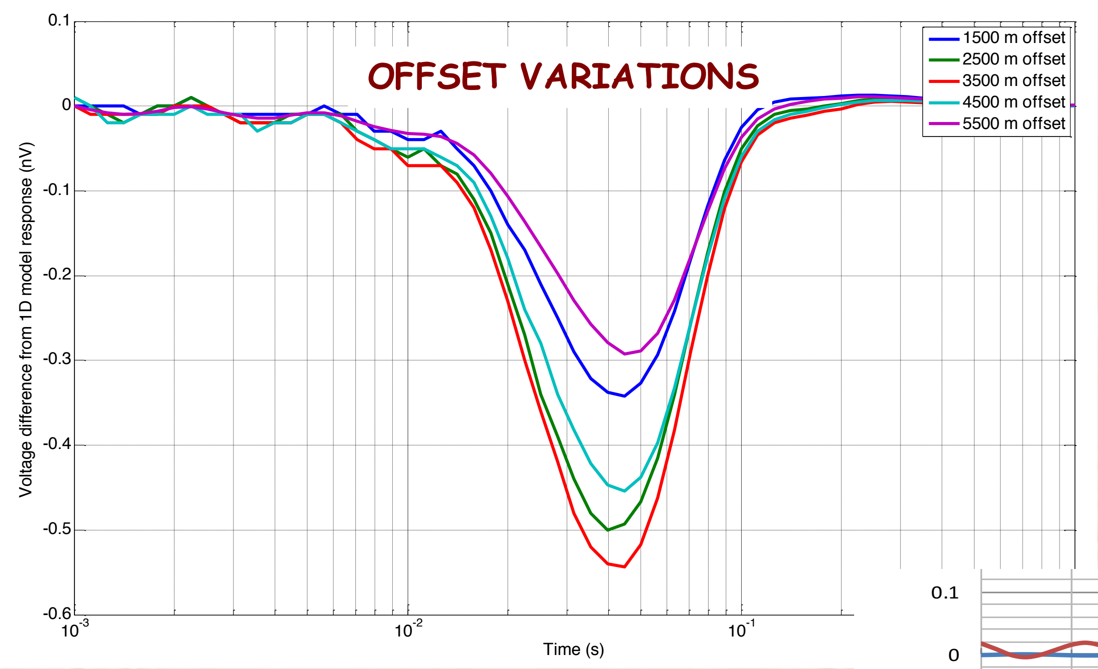
Ghawar: survey plan

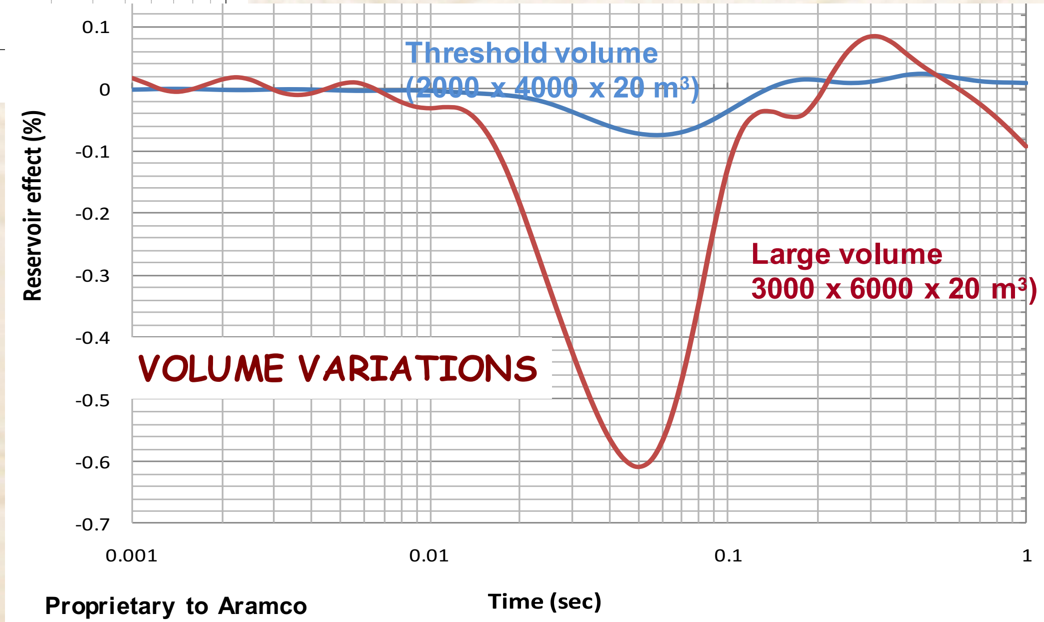




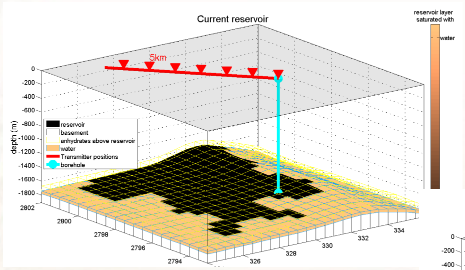
After Colombo et al. 2010

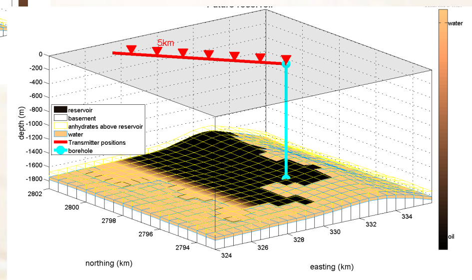
Surface-to-borehole anomaly (%): E_z

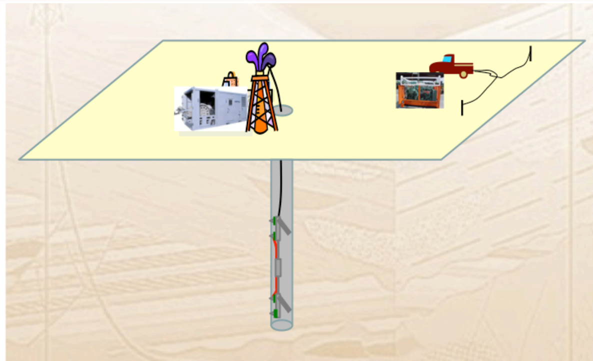


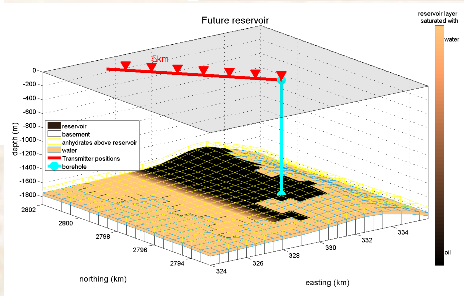


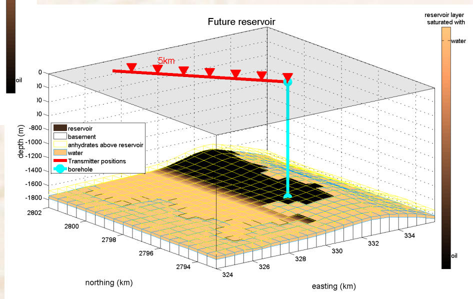
Ghawar: ADD BOREHOLE: Integration!

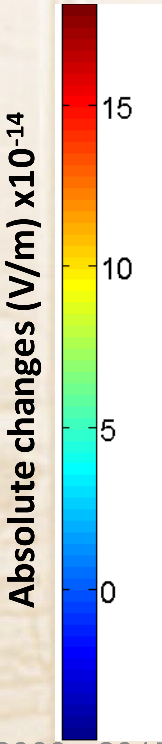


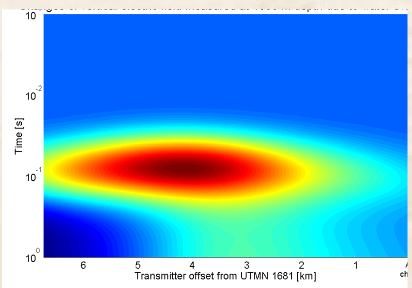


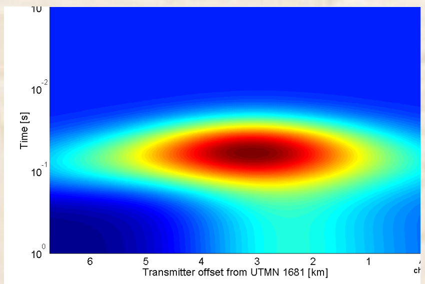


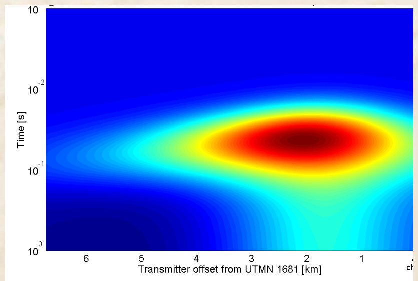








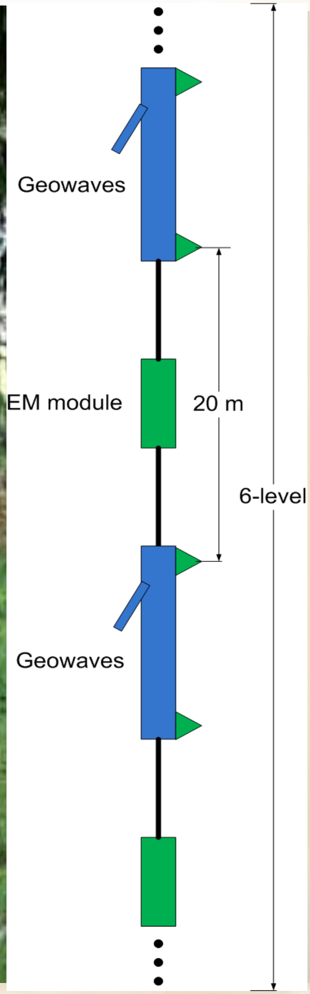




Period of 5 years

After Colombo et al. 2010

Surface-to-borehole 4C/EM system



What are sensitivities - definition

Sensitivity & resolution gets often confused

- **Sensitivity (Wiki)(instrument)**. It refers to the smallest signal that certain instrument can measure.

  Here, the smallest voltage corresponding to a change in sub-surface target parameter.

- **Resolution**: Sensor/method resolution (Wiki) – the smallest change a sensor/method can detect in the quantity it is measuring

Sensitivity & resolution gets often confused

- **Sensitivity (Wiki)(instrument).** It refers to the smallest signal that certain instrument can measure.

  Here, the smallest voltage corresponding to a change in sub-surface target parameter. **DONE by FEASIBILITY**

- **Resolution**: Sensor/method resolution (Wiki) – the smallest change a sensor/method can detect in the quantity it is measuring. **DONE by PILOT**

Thailand: Advanced EOR implementation workflow

Identified that reservoir monitoring is needed ✓

Get data: FEASIBILITY:
- Logs, geology, seismic horizons; additional surveillance

Determine which reservoir parameter varies ✓

Link data with variations → FEASIBIILITY ✓

Risk reduction: Hardware purchase

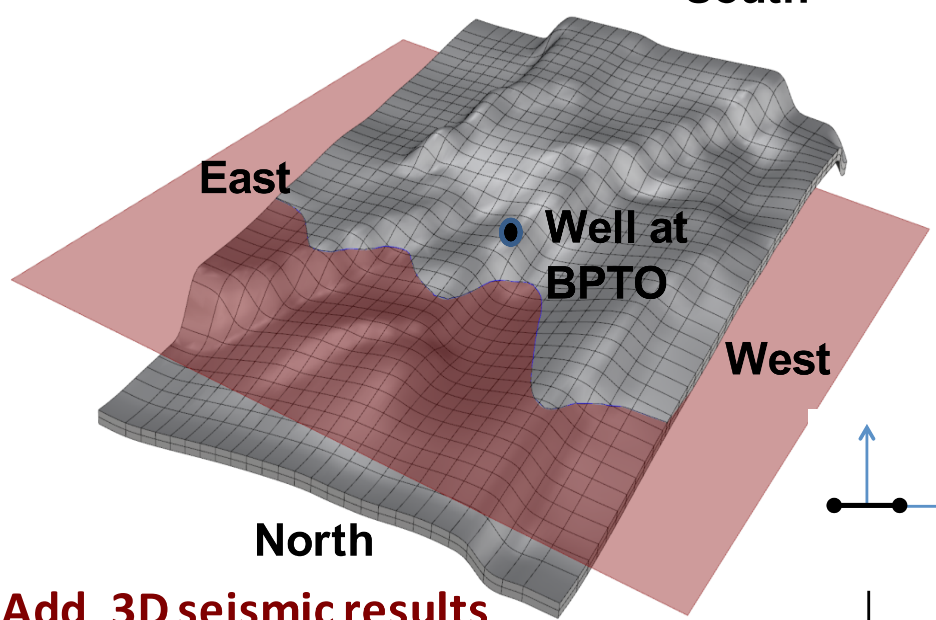
Define PILOT → 2-3 monitoring cycles

Evaluate / decide

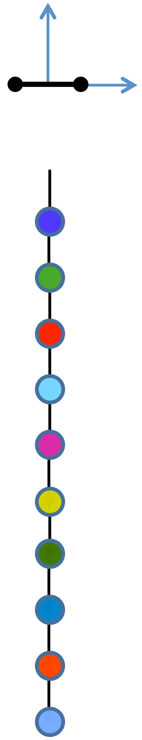
Full Field Installation

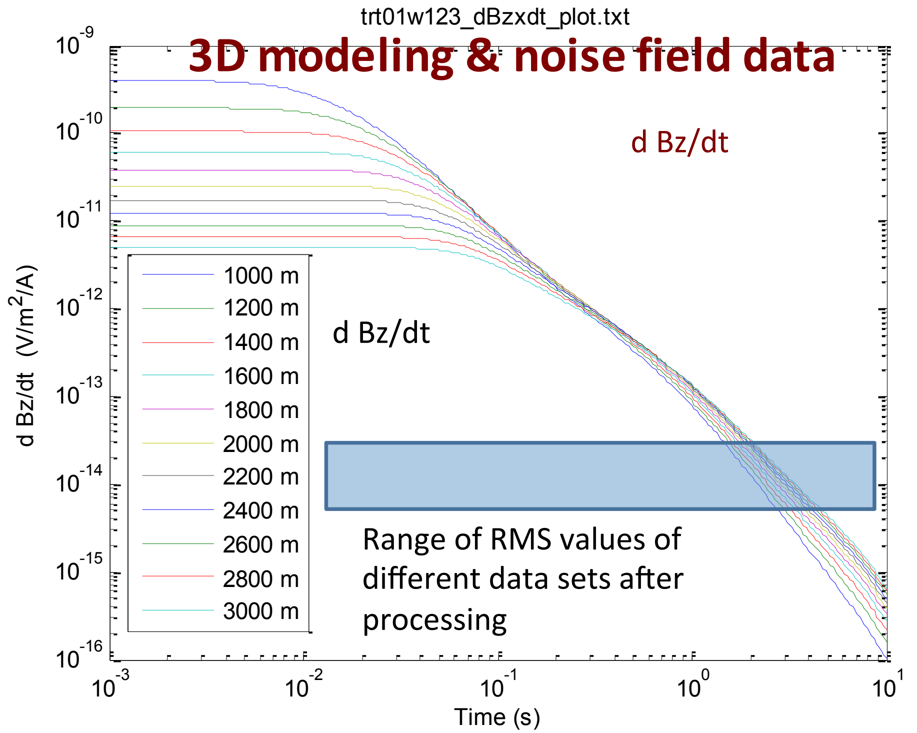
Project toll gates

Thailand: 3D reservoir model: 6 single blocks 1000 m x 6000 m



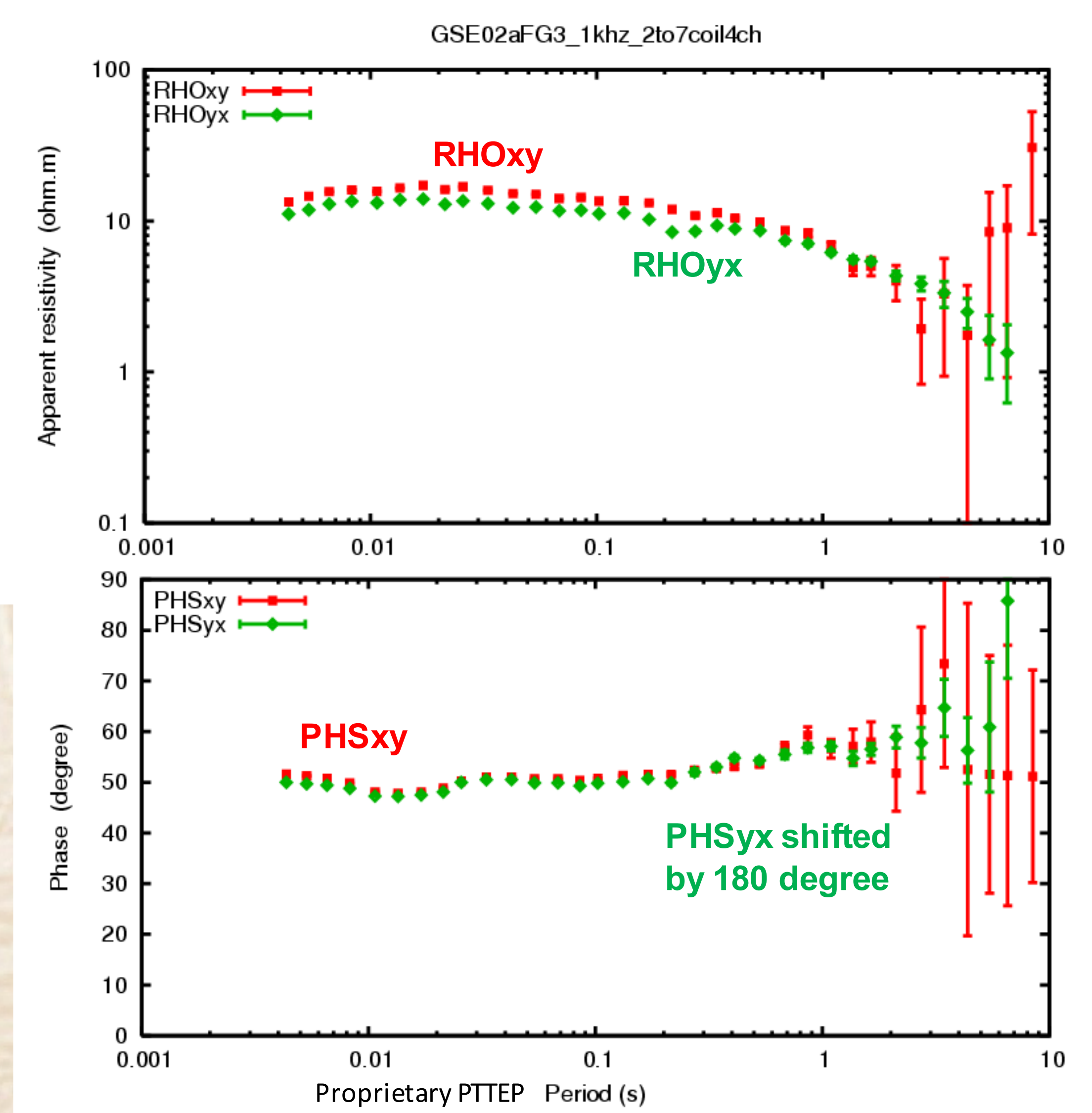
Add 3D seismic results





Proprietary PTTEP

Thailand: GSE 02 : resistivity and phase, 2.5 hours recording time

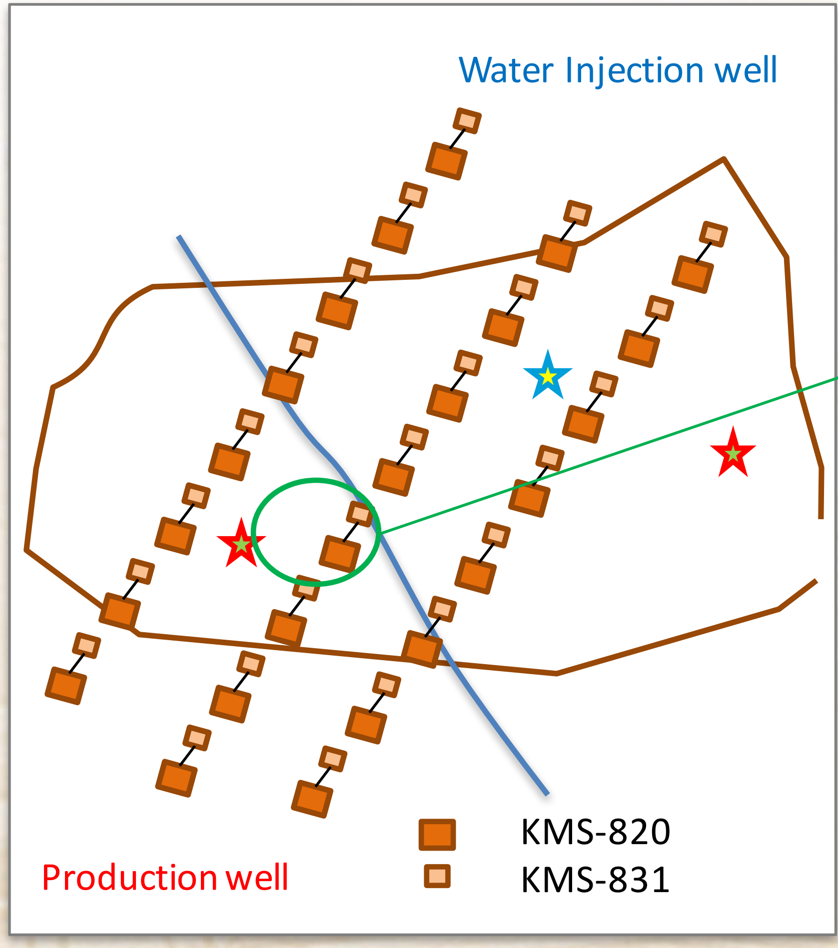


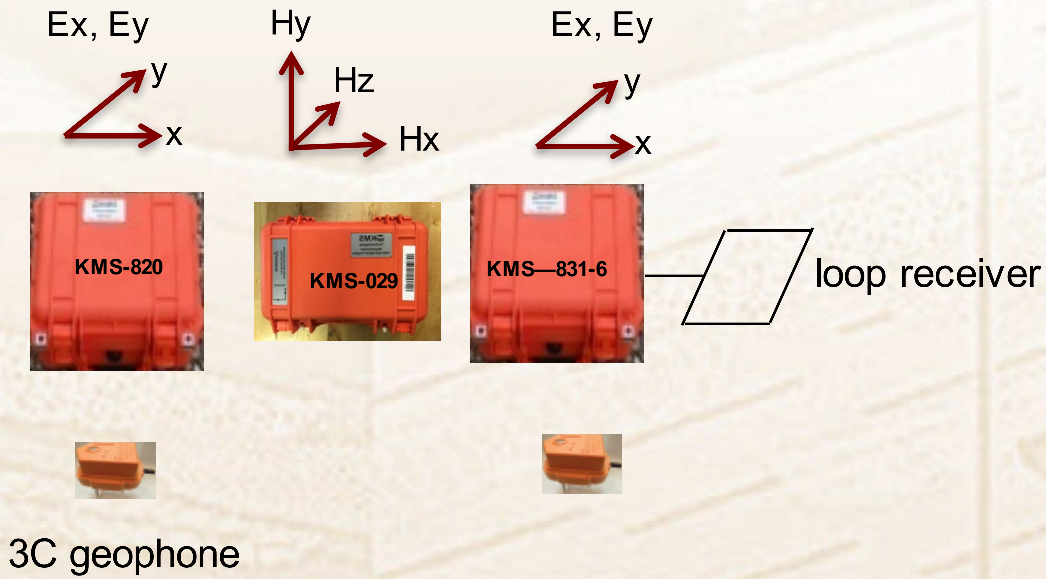
- Shows reasonable magnetotelluric response
- Tensor resistivities very similar → area is 1D → **use only 2 transmitter crosses**
- Data quality good → **noise level low**

Thailand: Technical summary Noise Test

- 3D anomalies show SIMILAR values as 1D (unusual – usually lower) →
  - Area's 3D effect smaller
  - Response to fluid changes LARGER
- Optimum components: Shallow Ez, inline Ey, Hz time derivative

Thailand: Sample survey layout with 2014 test set





New ARRAY acquisition → better images

- Wireless (long range & WIFI)
- True array system
- Large dynamic range (up to 32 bits)
- High bandwidth (DC to 40 kHZ)

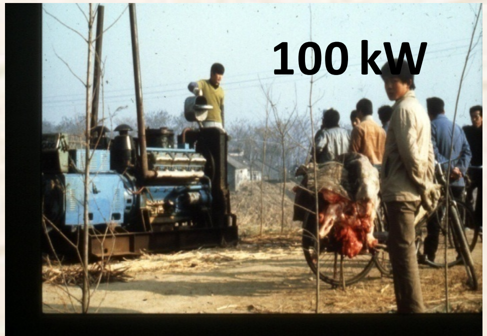
Transmitters

Large surface source

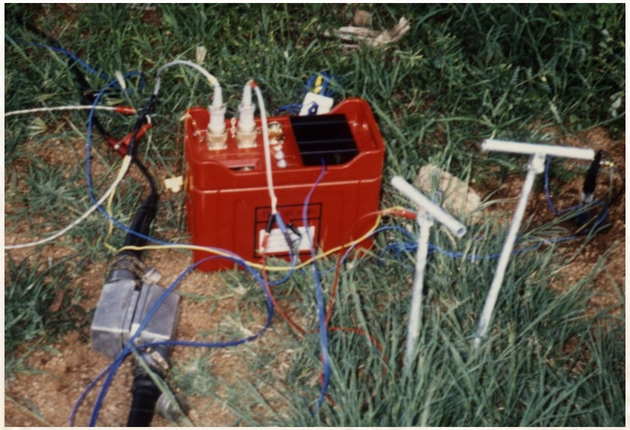
Through casing resistivity


(Aulia et al., 2001)

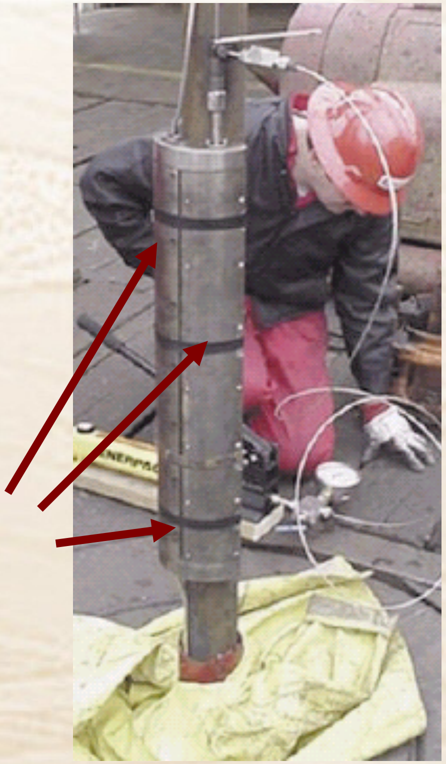
Small surface source



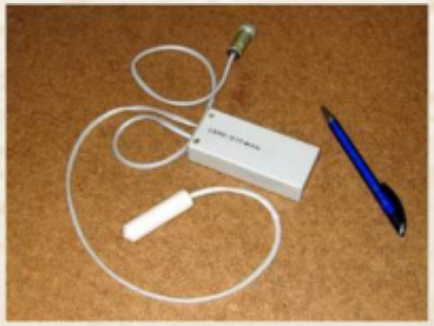
Sensors



Land seismic, magnetic & electric field sensors



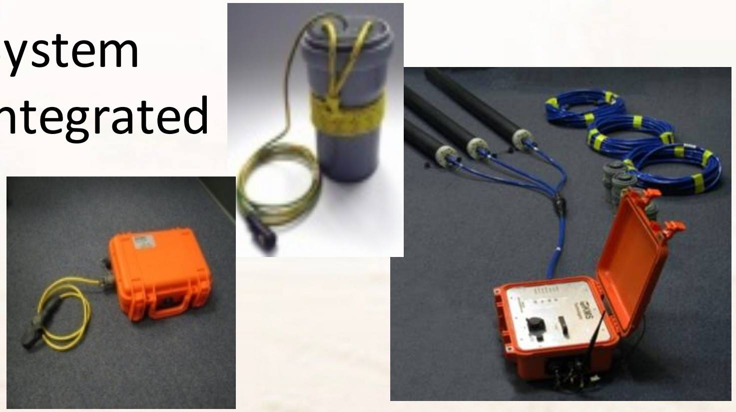
Land, marine, borehole sensor



borehole electric field

Smaller & lower cost hardware

System integrated



Fluxgates – 3 components

Induction coils – T & F domain

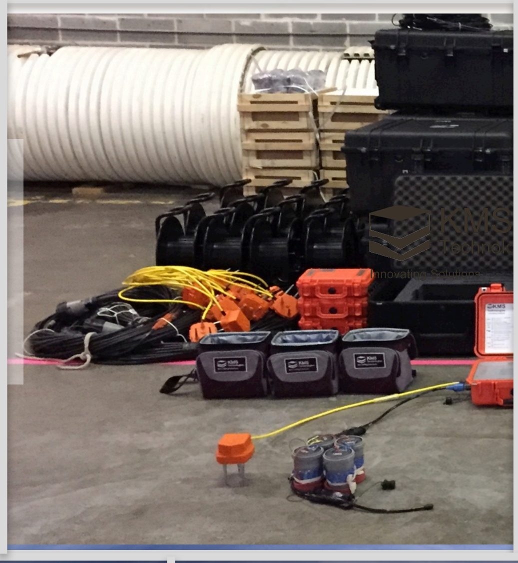
Benefits land array system

- Transition to large channel count seismic systems
- Record EM/micro-seismic (low/high frequencies!)
- Wireless array system
- Low power
- DC to 40 kHz bandwidth
- Can be used for EM based static corrections

195 channel monitoring system

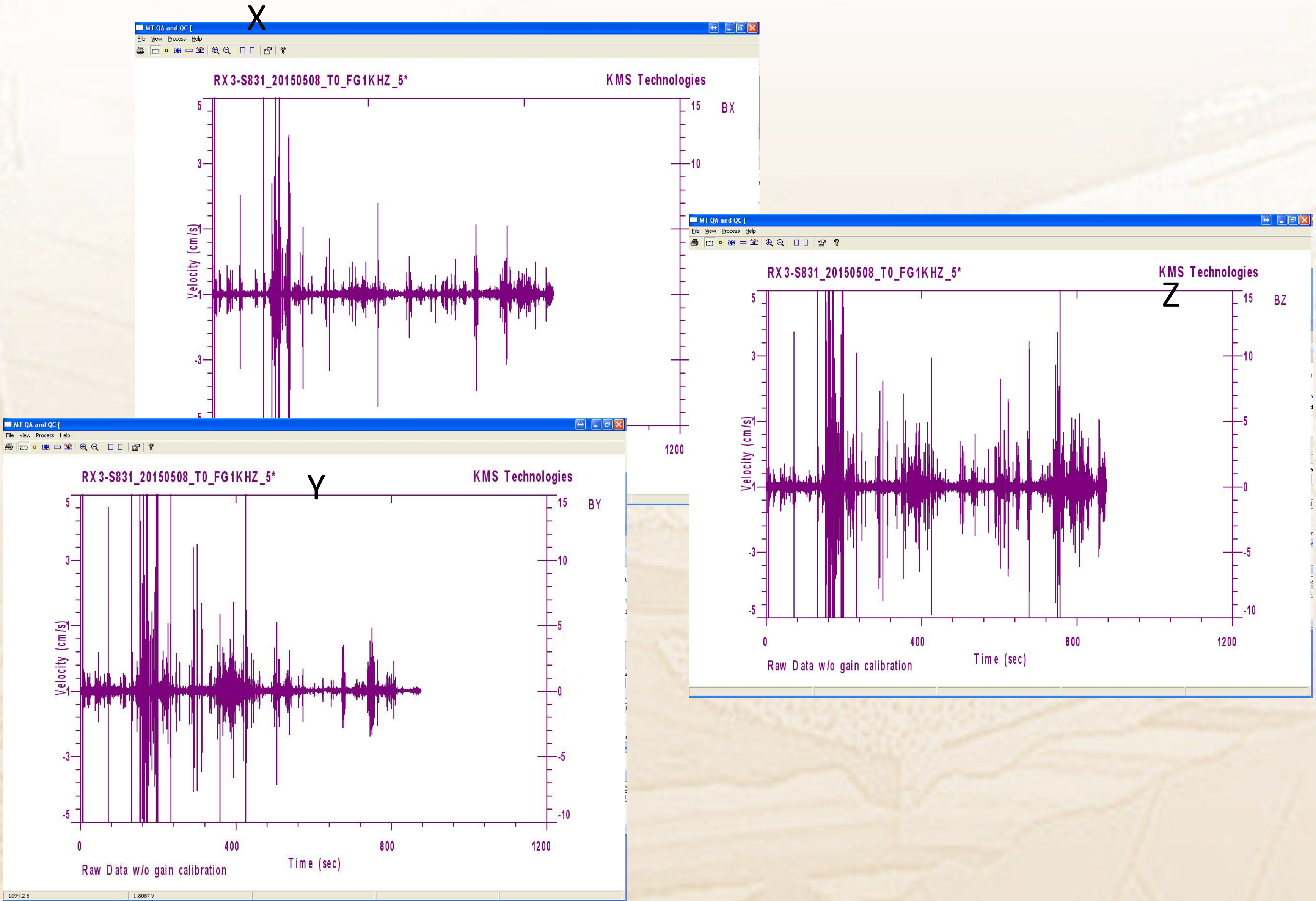
RESERVOIR MONITORING

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

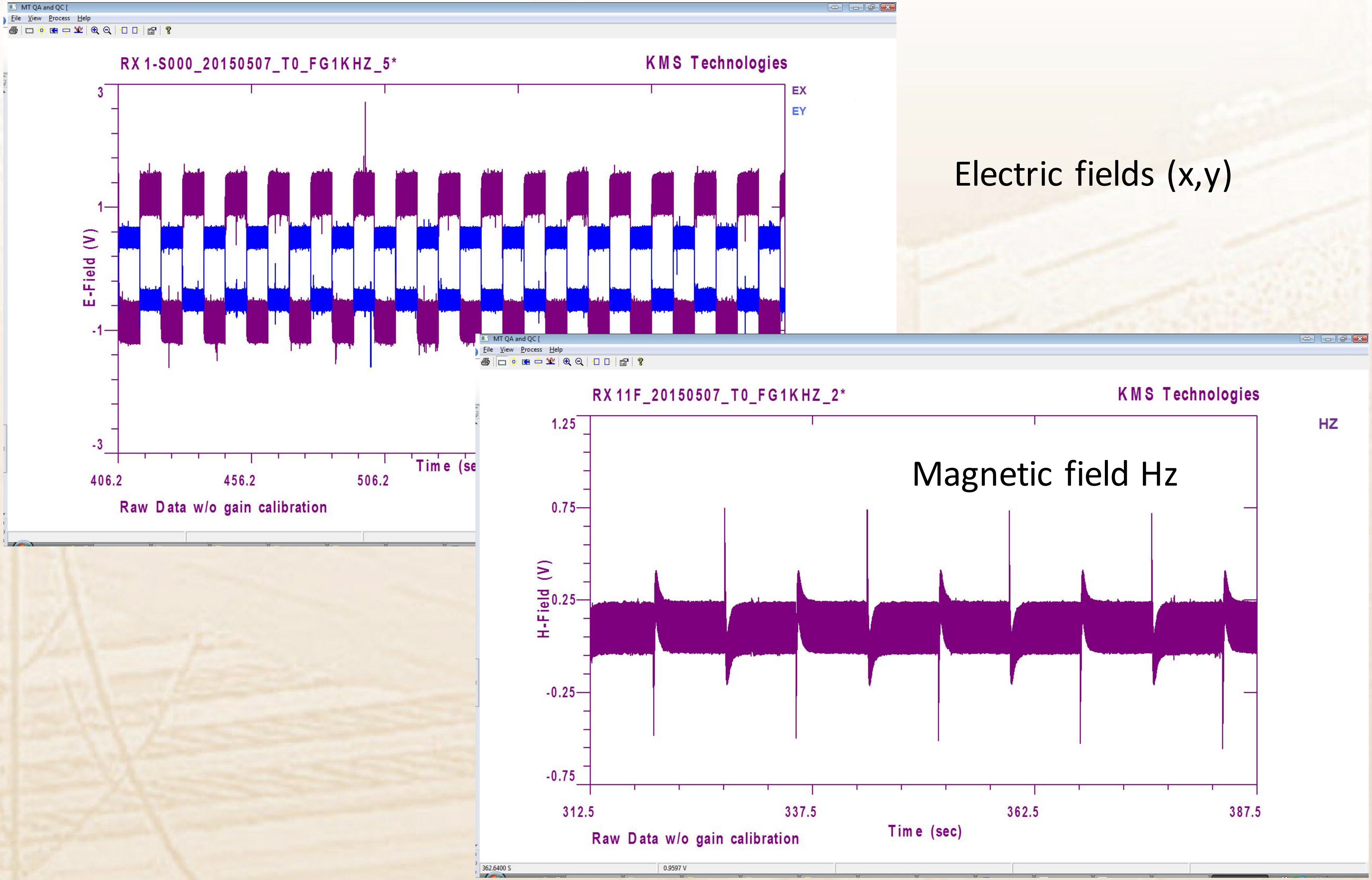


Colorado 2015 CSEM transmitter test
- 100 KVA transmitter up-scalable
- Flexible input. (DC to 3 phase AC)
- Array system integrated

Seismic data samples KMS-831



Electromagnetic data samples KMS-831



Electric fields (x,y)

195 channel monitoring system

- Acquisition box KMS-820: 6 analoge, unlimited digital channels Microseismic/EM NODE
- 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, ethernet (preferred with power)

Reservoir monitoring: Value

- **Permanent sensors:** **HIGHEST**
  Lowest cost/life time, excellent data quality
- **Surface-to-borehole 4D:** **INTERIM HIGHEST**
  Links surface to borehole, sufficient depth of investigation
- **Borehole-to-borehole:** **MEDIUM to HIGH**
  cost effective, good data quality, depth limited
- **Surface-to-surface:** **LOWEST, INTERIM**
  for selective applications

5 year vision

- Seismic/EM systems will be installed
- Value recognized
- Permanent installation starting→ value
- Semi-permanent in routine work flow

Array concept will extend to borehole and marine