King Fahd University of Petroleum and Minerals - KFUPM
College of Petroleum Engineering and Geosciences - CPG
Department of Geosciences

focusing on the energy transition with emphasis on geothermal and reservoir monitoring EOR

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December 13 and 14, 2021
Reservoir Fluid Surveillance, Today and Beyond

Mapping fluid front in Carbonates using Electromagnetic

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WHY we have decided to present this !!

Carbonate reservoir characterization is challenging because,

- the reservoirs has **secondary porosity/fractures**
- seismic as primary geophysical methods has challenges due to the high velocities.

Characterizing fractures needs permeability → necessity of directional sensitivity

INTEGRATING surface and **borehole** geophysical methods. M**icroseismic** with non-seismic (**electromagnetic - passive & active**) & **gravity** leads to fracture characterization & fluid flow direction

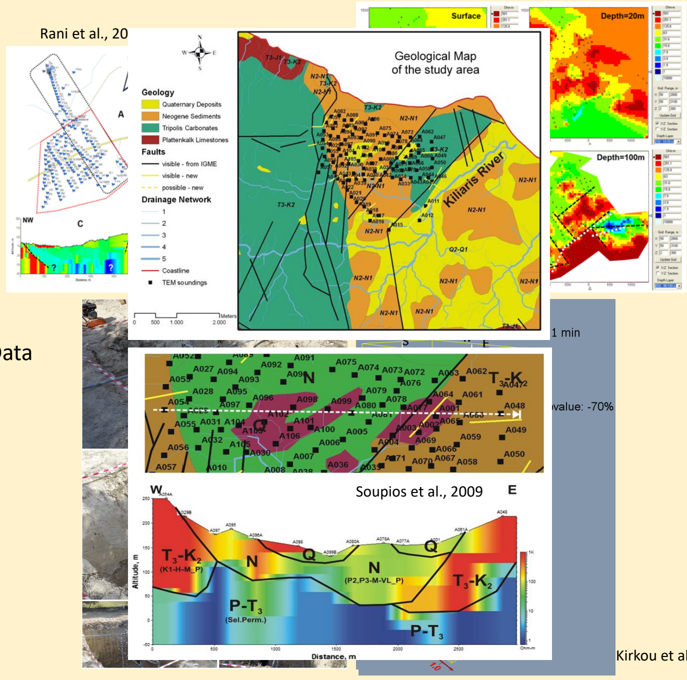
Seismic delineates **geometric boundaries**, EM is sensitive to **fluid movement** from resistive (hydrocarbons) to water (conductive). Gravity senses **density contrasts** between fluids and rock matrix.

OBJECTIVES of a survey is

- **to understand injected fluid performance**
- **to depict flow pattern of fluids**
- **to define fluid interactions at reservoir level**
- **to build a reservoir dynamic model**

Overview

- Reservoir characterization/monitoring
  - Fractures
  - Fluids
  - Lithology
- Phases of work
  1. Feasibility study + Noise test
  2. Proof-of-Concept (Data Acquisition, Data Processing/Interpretation and Data Integration)
  3. Case histories (if 1 and 2 are positive)
- Instrumentation - KFUPM
- Examples, applicability, efficiency
- Conclusions



Kirkou et al., 2022

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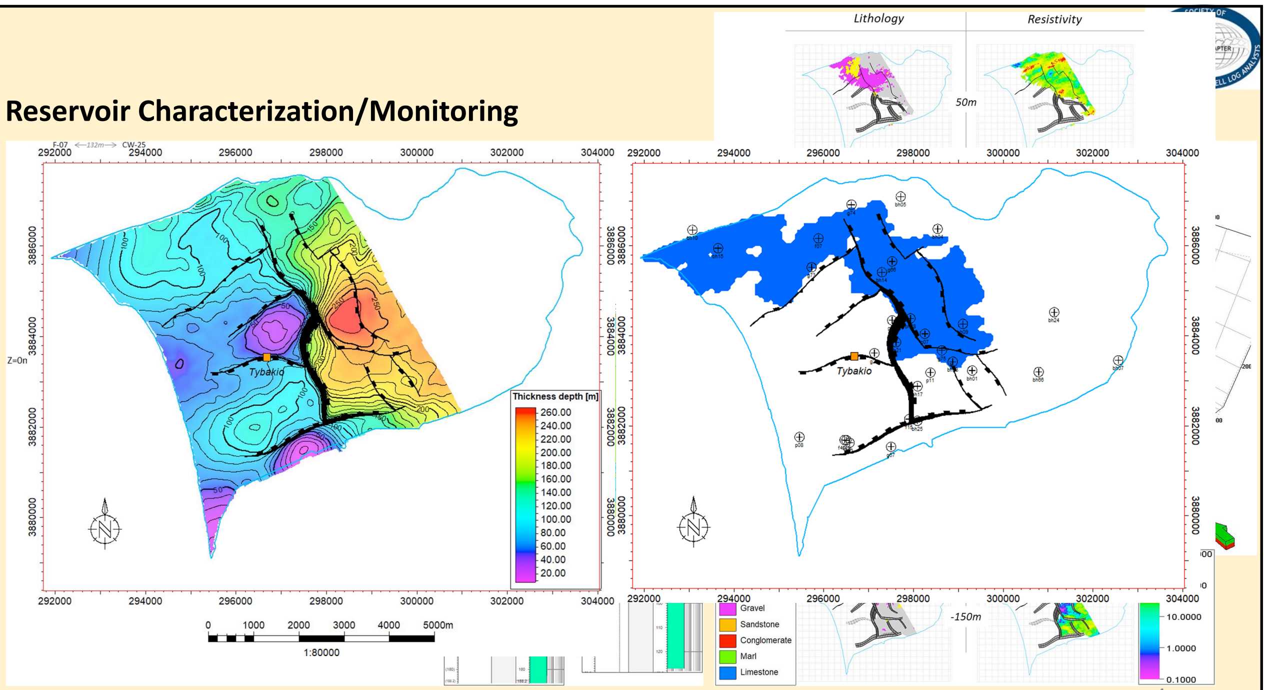
Reservoir Characterization/Monitoring



Panagopoulos et al., 2021

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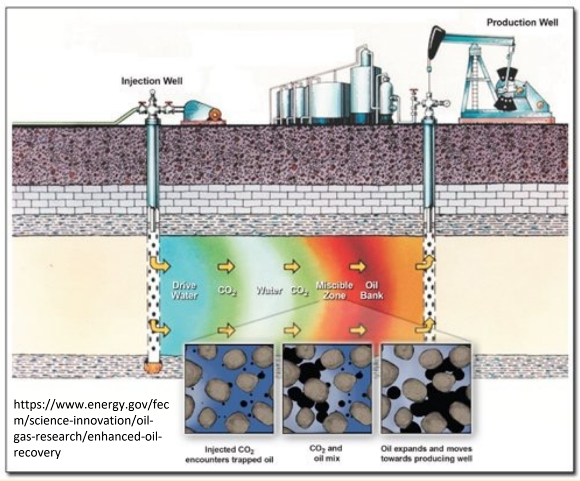
Phases of work (1)



During the EOR (WAG (Water Alternating Gas) (HC gas) or CO_2) → to **improve the flood mobility** → to **squeeze more oil** out of the study reservoir.

A monitoring scheme of an oil-field starts → **oil-field characterization** (reservoir properties) → continues with the accurate **mapping of fluids** (a dynamic process, 100 m/year)

Before the time-lapse monitoring phase (flooding), a **baseline is required (the initial model)**.

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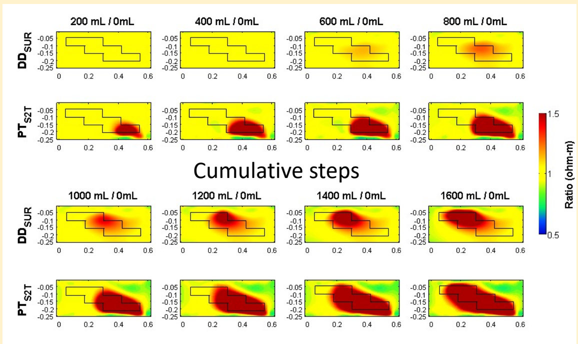
Phases of work (2)

Baseline and Time-lapse images

(Kirkou et al. 2022)

(Power et al. 2014)



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Phases of work (3)

Any project is divided mainly into **3 phases**,

<u>Phase</u> 1: **3D Feasibility**

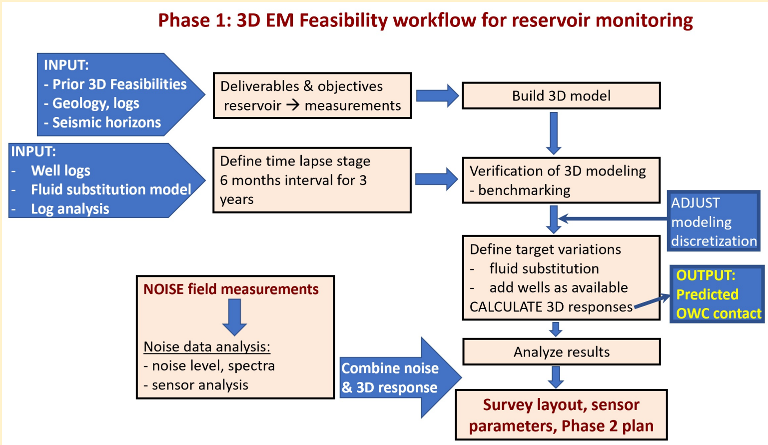
a. <u>Tasks:</u> 3D modeling based on prior feasibilities (geology, logs, reservoir simulator, etc.)

b. <u>Deliverables:</u> 3D Feasibility (time-lapse), **On-site noise test**, **Proof-of-concept pilot plan/survey design**

c. <u>Milestones:</u> Measurable variation of **signal above the noise level**

d. <u>Break Point:</u> **Target response** (reservoir parameters' variation) cannot be extracted from noise test.

C and D are the link point between Phase 1 and 2



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Phases of work (4)

<u>Phase</u> 2: **Proof-of-concept** - **Can we see reservoir parameter variations?**

a. <u>Tasks:</u>

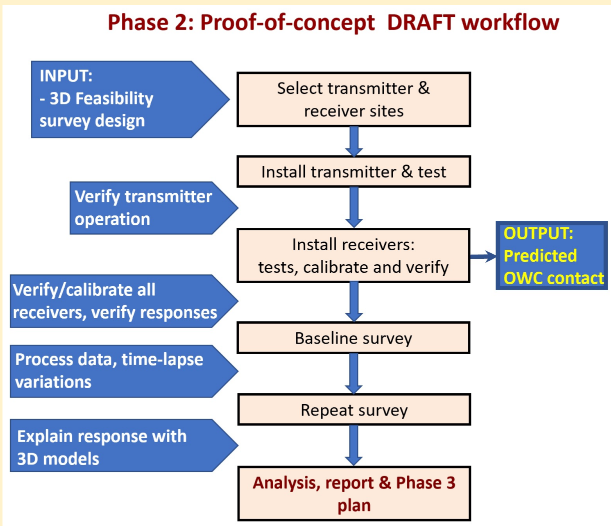
i. **Test measurement during a single injection phase (baseline, post-injection)**, EM-continuous, Gravity – 2 surveys)

b. <u>Deliverables:</u> Survey data, data processing, time-lapse analysis

c. <u>Milestones:</u> We can see the reservoir's parameters variation in the individual datasets.

d. <u>Break Point:</u> There is limited variation of the geophysical responses with petrophysical variations

e. <u>Decision Point:</u> If results are positive, decide on field pilot within this project or a separate one .



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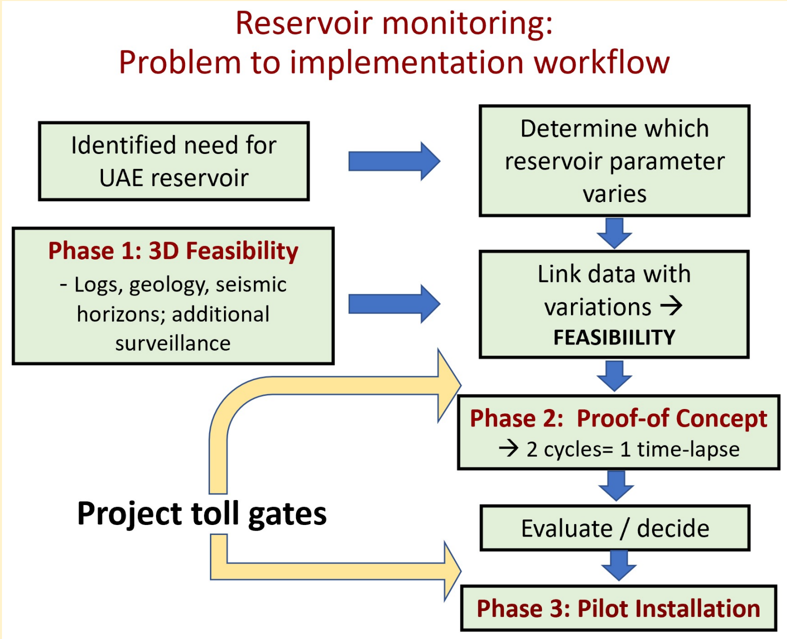
Phases of work (5)

Phase 3: **Field pilot study** (if Phases 1 and 2 are positive)



Instrumentation (1)

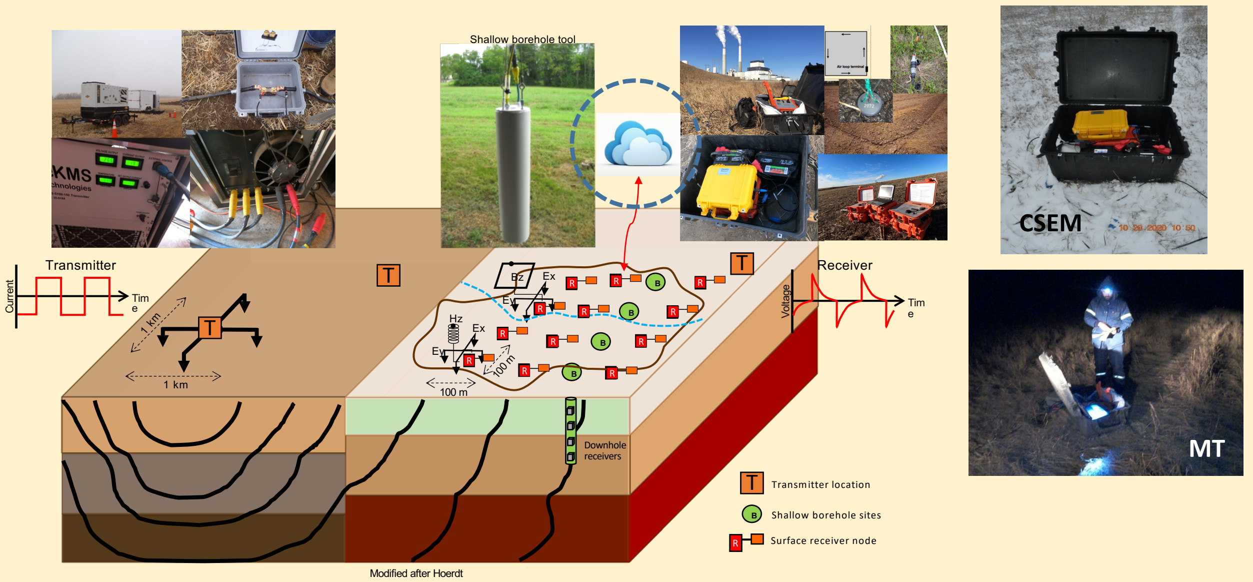
KFUPM CSEM system

A multi-function transmitter is ruggedized, portable, compact yet providing reliable maximum output power of **150 KVA** + **5 sets of sensors** (wireless). In additional to **Time domain** application, it is also capable to do application in **Frequency domain** and **Time Frequency EM (TFEM)**

↓

CSAMT, MT, TDEM, Long Offset TEM-LOTEM, IP

Instrumentation & optimum configuration (2)



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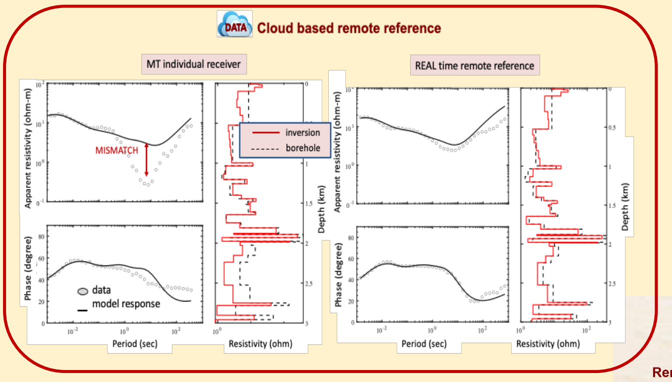
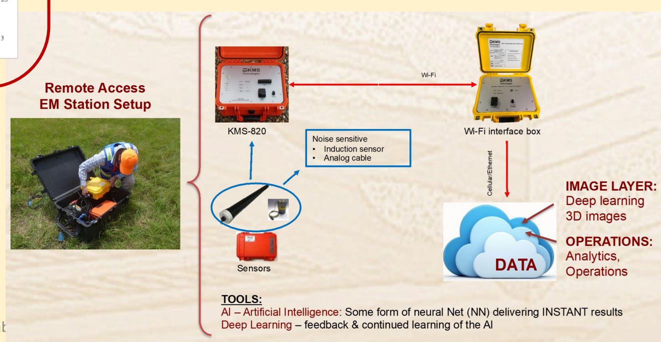
Instrumentation, remote reference & capabilities (3)



MT QA via Cloud: Quality Assurance RR (1400 miles) & 3D model



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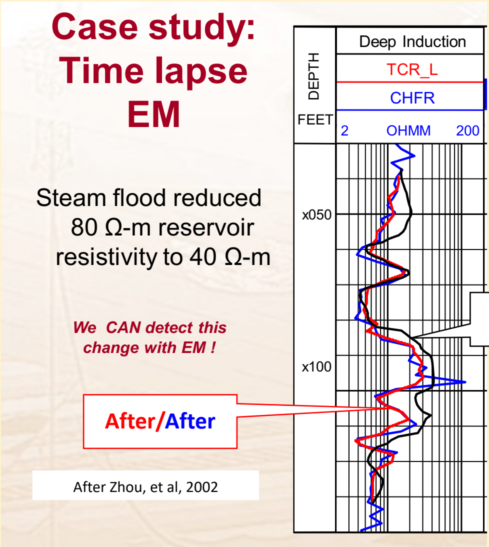
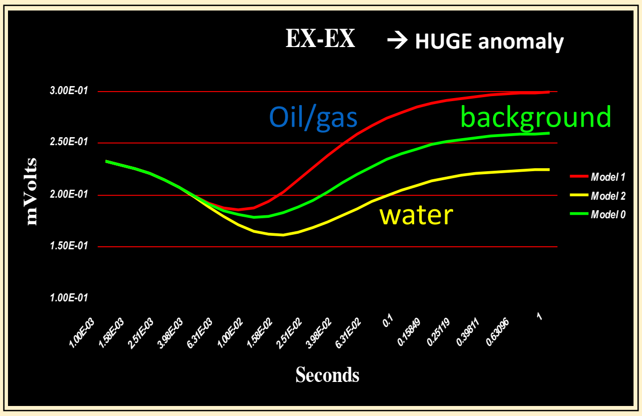
Examples, Applicability, Efficiency (1)

Example from Venezuela (Chevron)



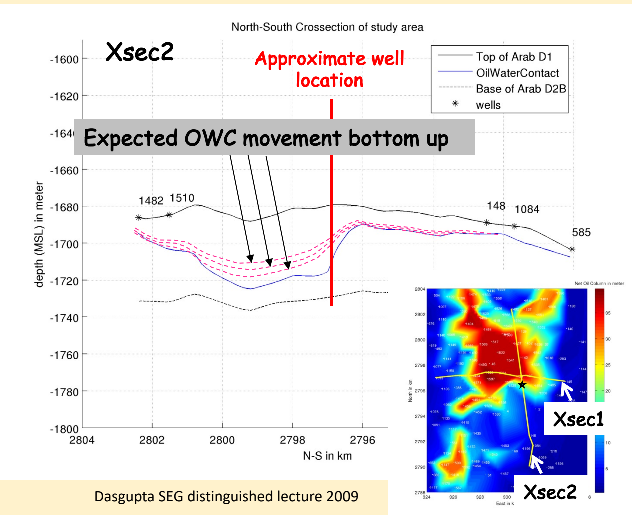
Steam-flooding makes local changes in resistivity that are large enough to be easily detected.

E-field transients as a function of time. The different in measured signal is in millivolts and easily detectable.

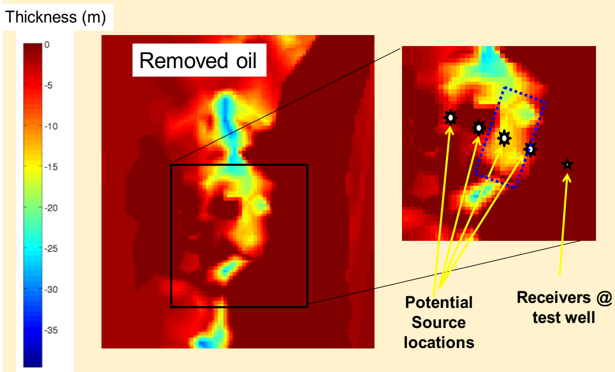


Examples, Applicability, Efficiency (2)

Ghawar model building: North-south cross-section

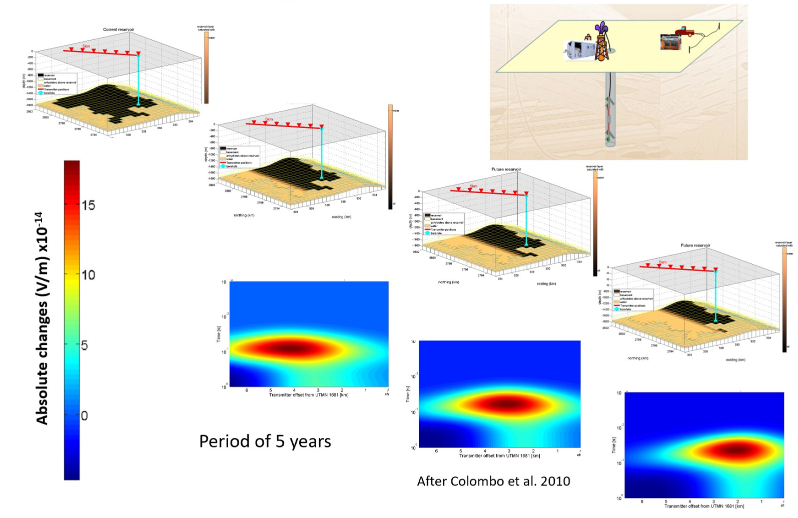


Dasgupta SEG distinguished lecture 2009



Examples, Applicability, Efficiency (3)

Example Phase 1 output after 3D modeling:
Reservoir models, time-lapse resistivity section, surface & borehole



Four different reservoir states several years apart. They indicated that the changes increase with encroaching waterflood (after Colombo et al., 2010).

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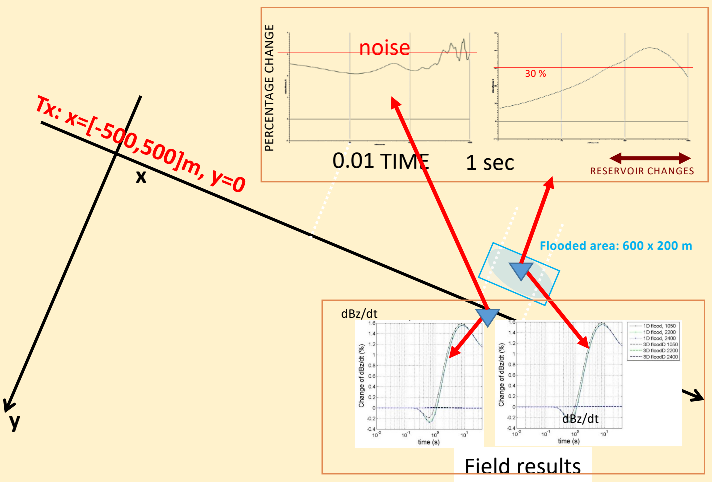
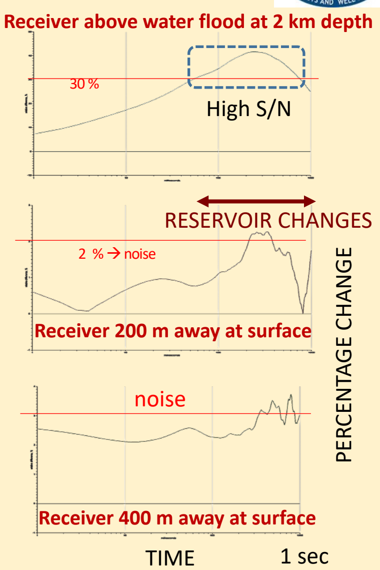
Examples, Applicability, Efficiency (4)

Reservoir Monitoring: Water-flood monitoring: modeling setup





Courtesy A. Paembonan

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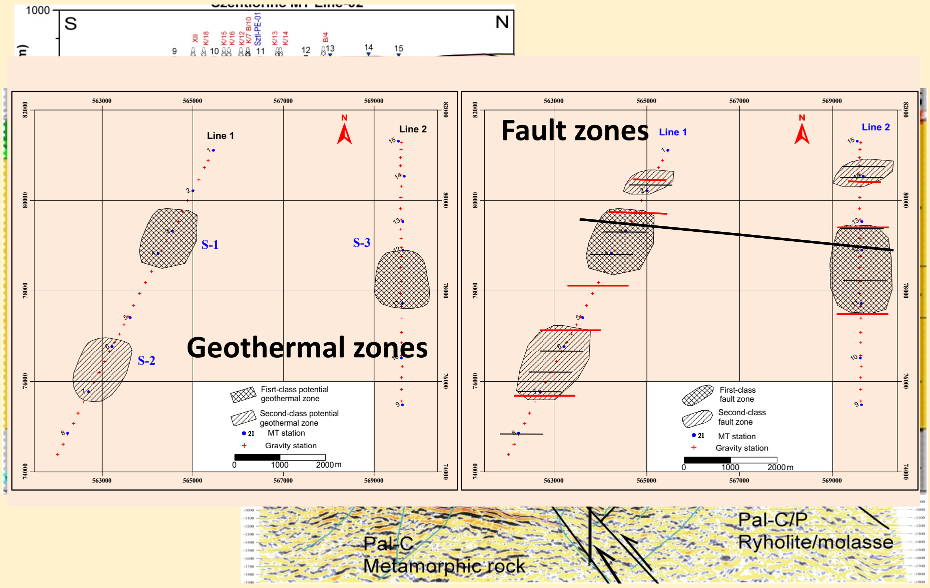
Examples, Applicability, Efficiency (6)

Geothermal Exploration in Hungary



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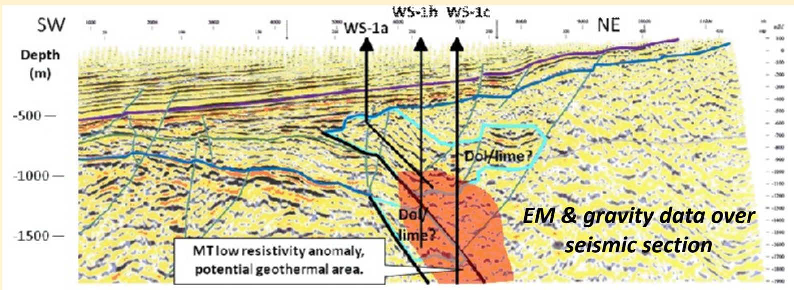
Examples, Applicability, Efficiency (7)

Geothermal Exploration in Hungary



Total success! (4 MW)

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CONCLUSIONS

- CSEM is well suited for fluid imaging
- Depth 1 to 6 km requires high power Tx (150 KVA)
- O&G, Geothermal: use in exploration & production
- CO_2 storage: monitoring & with seismic for seal integrity
  - Combined seismic/EM Same crew = > 50% saving
  - Same instruments record microseismic/EM acquisition
- Interpretation/integration
  - CSEM: 3D anisotropic model available
  - Integrated interpretation
- **MUST: Calibrate – calibrate - calibrate**

Future plans:

- Implement more ML/AI
- Acquire denser data: Seismic & EM
- Use EM for monitoring
- Integrate surface with borehole
- Integrate land & marine