Seismic to Electric Conversion: a Tool for Earth Subsurface Characterization

CASIS Workshop

May 15th, 2019

Christina Morency & Saptarshi Mukherjee
Computational Geosciences Group, AEED
morency1@llnl.gov

LLNL-PRES-774025

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Lawrence Livermore National Laboratory

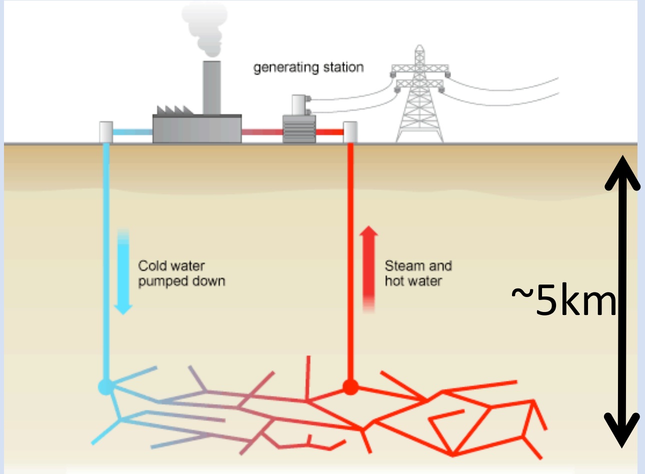
Overview

- Seismoelectric effects – why?
- Seismoelectric effects – what kind of structural sensitivity?
- Governing equations
- Assessing seismoelectric effects for carbon storage monitoring

Where is the fluid (oil, gas, water)?

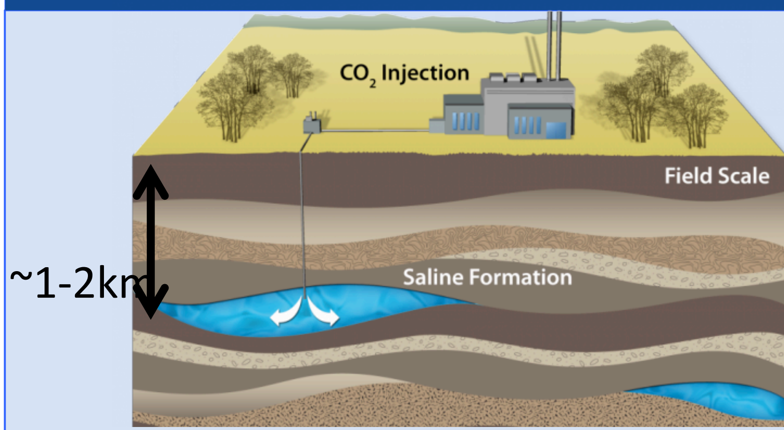
- Currently, subsurface fluid recovery is blind below 1km
- What if we could map fracture network and track leakage at relevant depth

e.g., Enhance Geothermal System
Enhance Oil Recovery



Creating optimal fracture networks
- To optimize reservoir performance
- To increase production

e.g., CO2 storage



Store CO2 in sealed reservoir/risk management
- To monitor leakage

Seismic techniques alone: do not capture fluid properties and fluid related mechanism

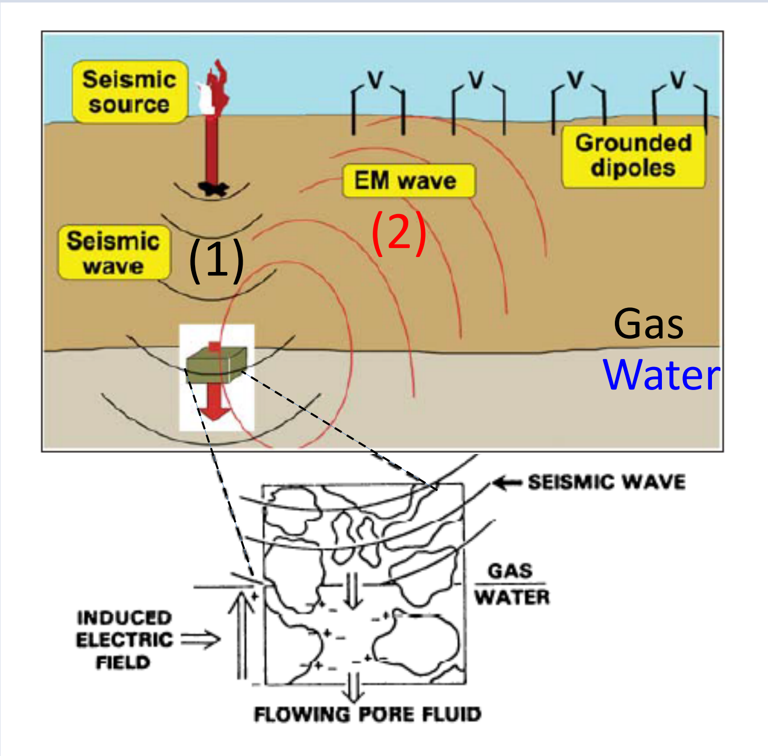
EM techniques alone: do not constrain rock properties, have shallow penetration in ground

Seismic to electric conversion = **Seismoelectric effects**

Seismoelectric conversion enables a probing of subsurface at greater depth than EM & improve sensitivity to fluid compared to seismic techniques

Seismoelectric effects (SEE): pore scale phenomena

Observed seismoelectric effects



(1) A seismic source triggers a seismic wave, which propagates in a porous medium

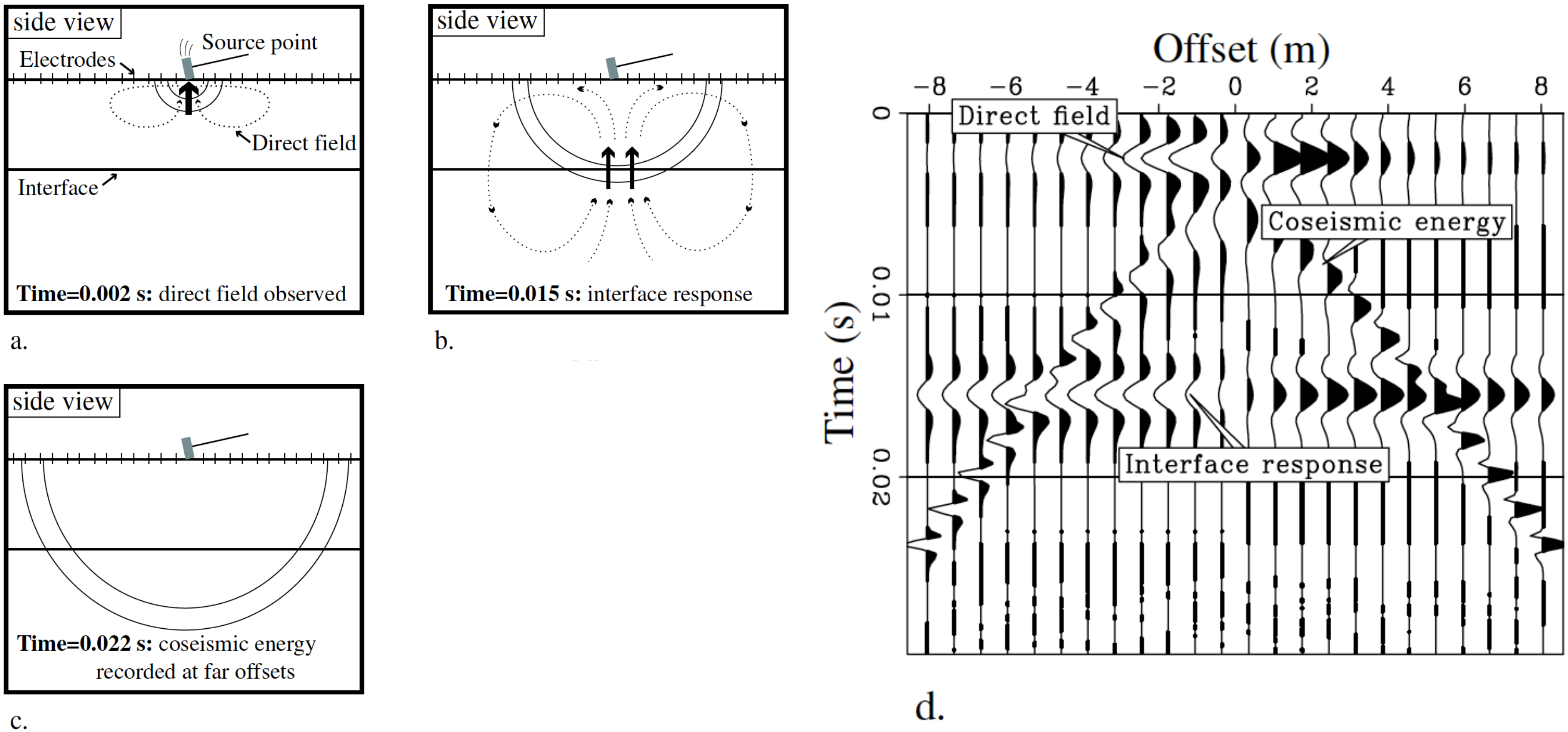
=> Charges are put in relative motion between grain surfaces and pores, generating an electric dipole

(2) Electric dipole triggers an electromagnetic field

Field test of seismic to electric conversion (Thompson & Gist, 1993)

=> They detected gas-water interface due to seismoelectric effects (~500m).

SEE seismograms vs. radargrams records: different information

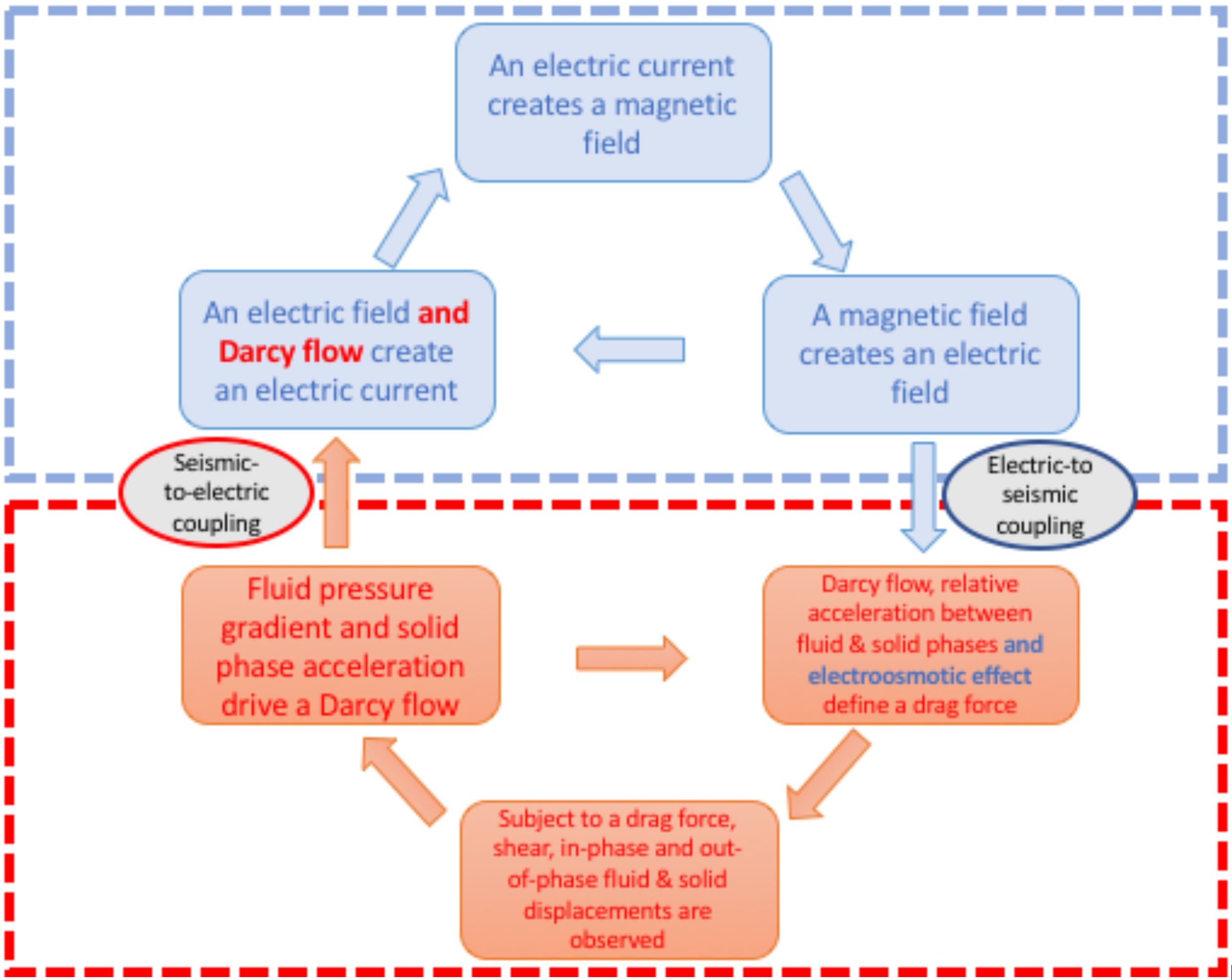


[after Haines, 2004]

Radargram

Seismoelectric conversion generates direct field, coseismic signal, and interface response

SEE governing equations *schematic view*



Electromagnetic module

Poroelastic seismic module

[funded under LDRD 17-LW-029]

In-house new software to model SEE implemented in SPECFEM

SEE governing equations

Poroelastic seismic module

$$\rho\partial_t^2\mathbf{u_s} + \rho_f\partial_t^2\mathbf{w} = \nabla\cdot\mathbf{T} + \mathbf{F}$$

$$\eta k^{-1}\partial_t\mathbf{w} + \frac{\rho_f c}{\phi}\partial_t^2\mathbf{w} + \rho_f\partial_t^2\mathbf{u_s} = \nabla\cdot\mathbf{T_f} + \mathbf{F} + Q_v\mathbf{E}$$

$$\mathbf{T} = (B\nabla\cdot\mathbf{u_s} + C\nabla\cdot\mathbf{w})\mathbf{I} + 2\mu_{fr}\mathbf{D_s}$$

$$\mathbf{T_f} = -p_f\mathbf{I} = (C\nabla\cdot\mathbf{u_s} + M\nabla\cdot\mathbf{w})\mathbf{I}$$

EM module

$$\epsilon\partial_t^2\mathbf{E} = \nabla\cdot(\partial_t\tilde{\mathbf{H}}) - \sigma\partial_t\mathbf{E} - \partial_t\mathbf{j_s}$$

$$\partial_t\tilde{\mathbf{H}} = \tilde{\mu}^{-1} : \nabla\mathbf{E}$$

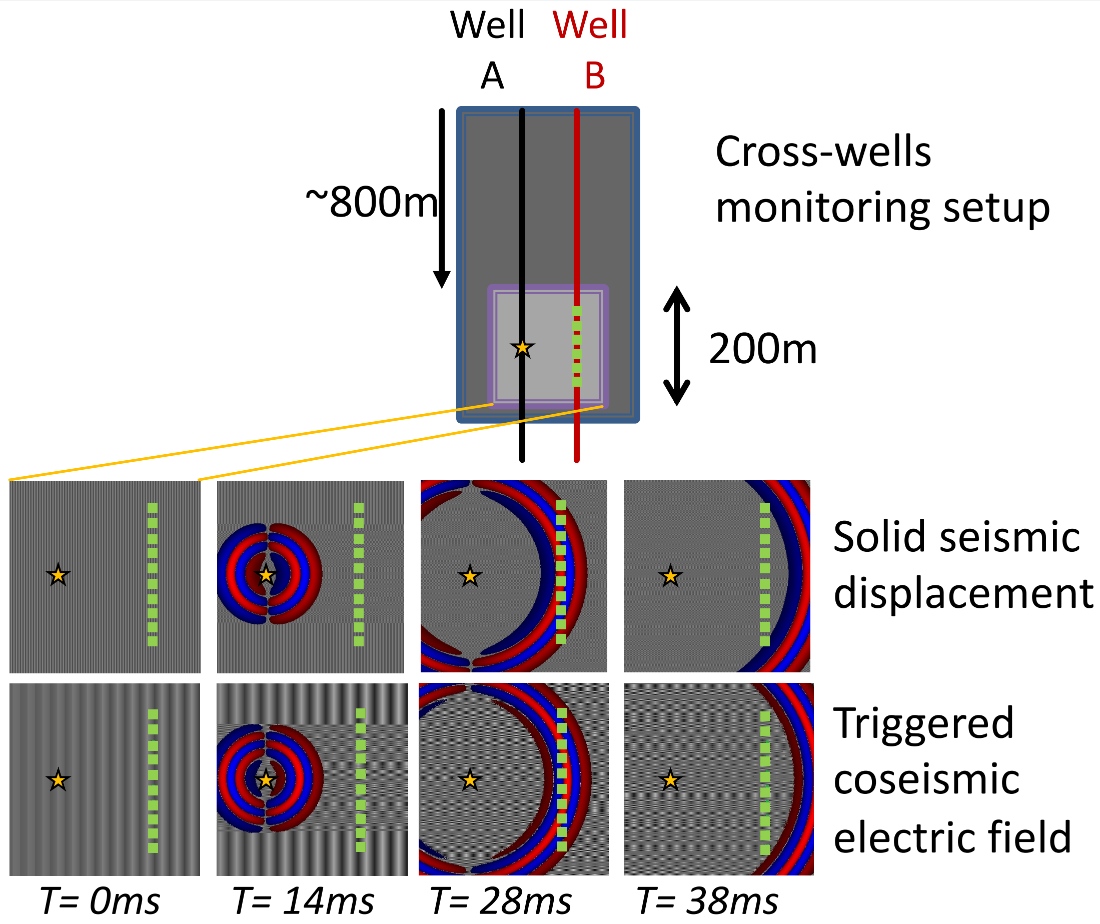
$$\mathbf{j_s} = Q_v\partial_t\mathbf{w}$$

Qv is the moveable charge density, which acts as a coupling factor (Revil et al., 2015)

[funded under LDRD 17-LW-029]

In-house new software to model SEE implemented in SPECFEM

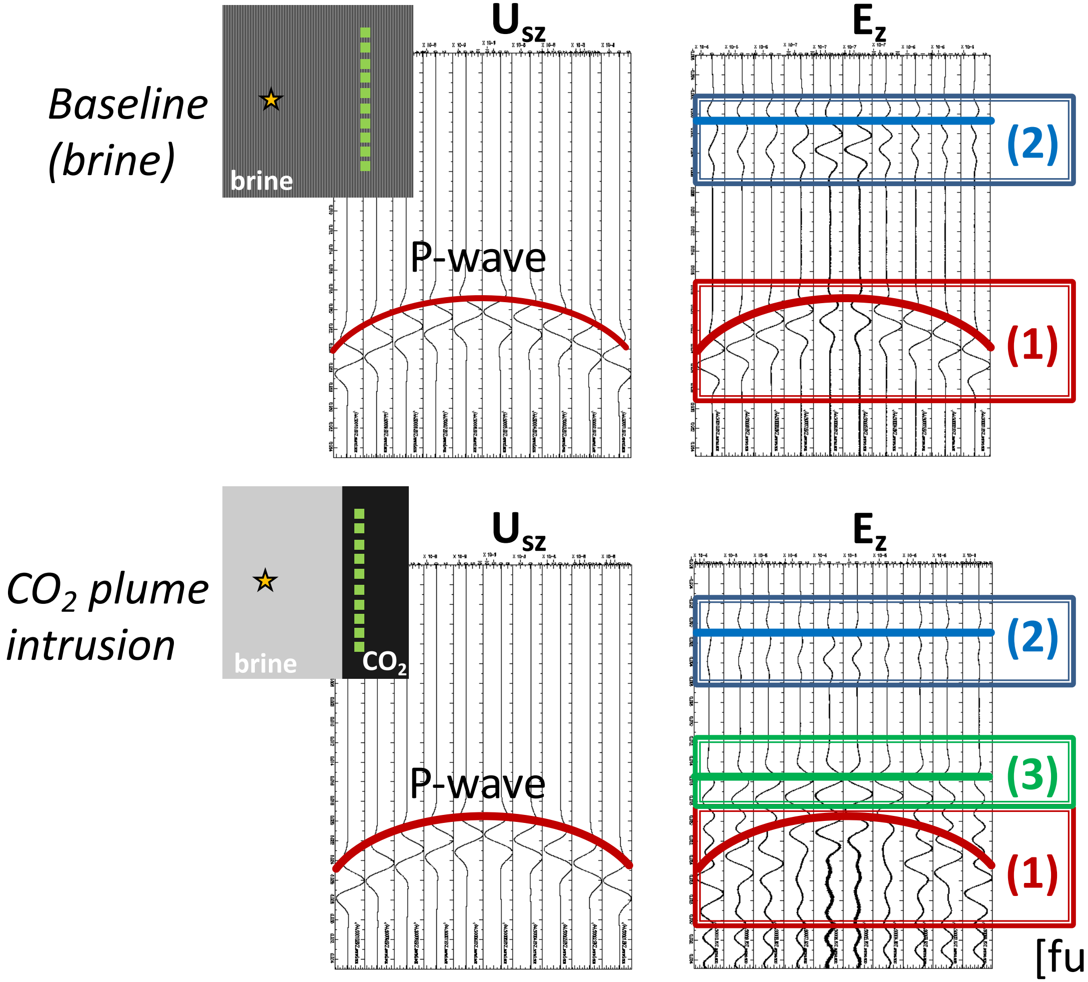
Carbon storage monitoring



[funded under LLNL Carbon Storage Program]

Coseismic signal accurately modeled

Carbon storage monitoring



Our in-house software accurately detects 3 types of seismic-to-electric conversions:

(1) coseismic electric signal,

(2) quasi-instantaneous electric signal generated when the seismic source occurs, and

(3) quasi-instantaneous seismo-to-electric conversion at material discontinuity.

[funded under LLNL Carbon Storage Program]

SEE can detect brine/CO_2 interface

Conclusion

- Coupling between Biot-poroelastic and Maxwell-EM wave equations was implemented in a spectral-element code.
- Seismic-to-electric conversion can be assessed to monitor CO_2.
- Instantaneous seismic-to-electric conversion when the seismic source occurs can be used to provide the exact time an event happens but can also be used to determine source mechanism information.

Next: SEE adjoint capability

Finite frequency sensitive kernels have been derived for:

- pure Biot poroelastic seismic parameters (Morency et al, 2009)
- pure electromagnetic parameters (Mukherjee & Morency, 2018 in preparation)

➢ We are now working on deriving finite frequency sensitivity kernels for the coupled system.

➢ These kernels will be the first step towards new full waveform inversion for SEE parameters and SEE imaging.