The Seismoelectric Effect

for Inferring Contrast Values between Layers of Porous Rock

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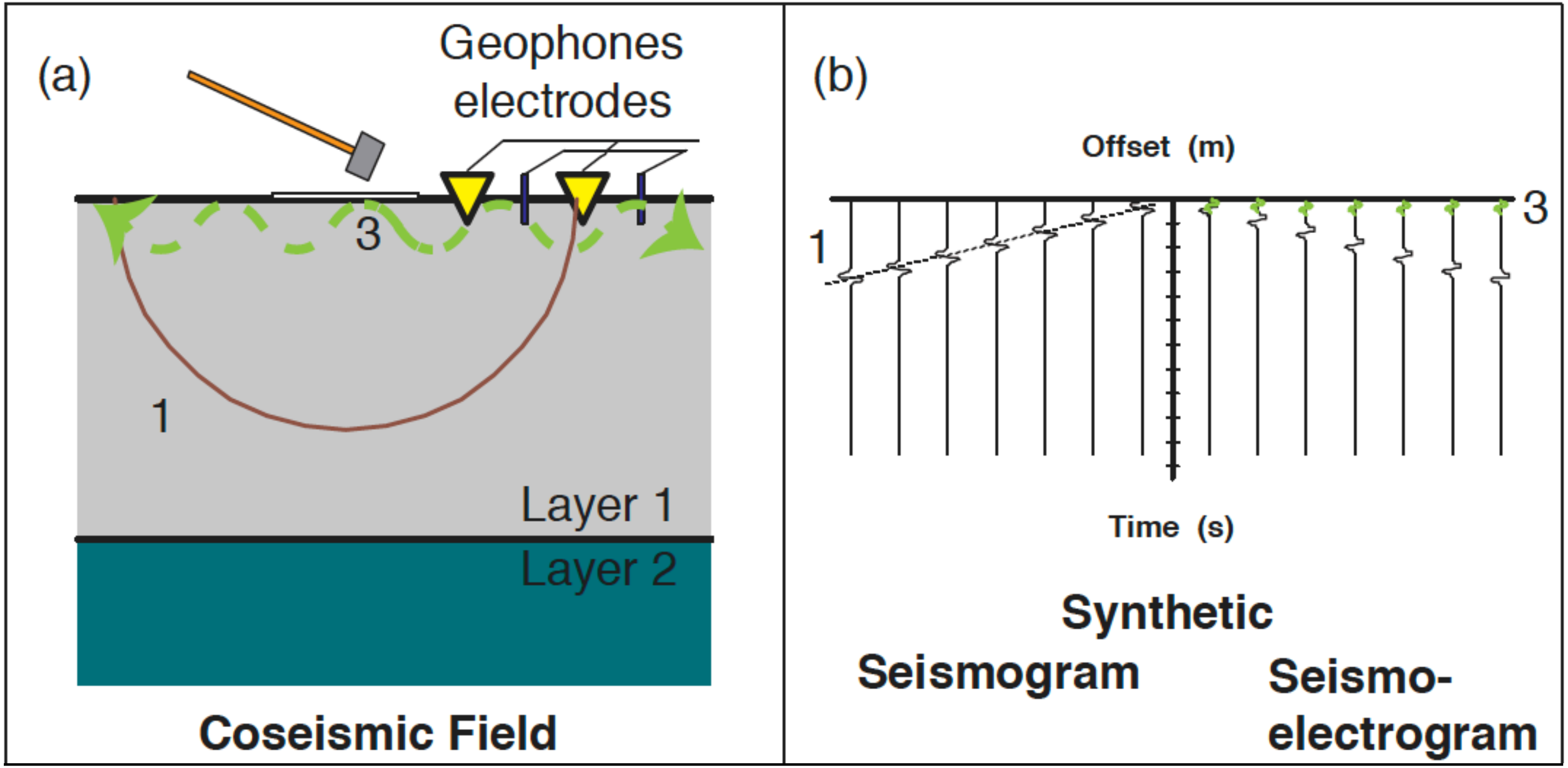
First type of Seismoelectric Coupling: Coseismic



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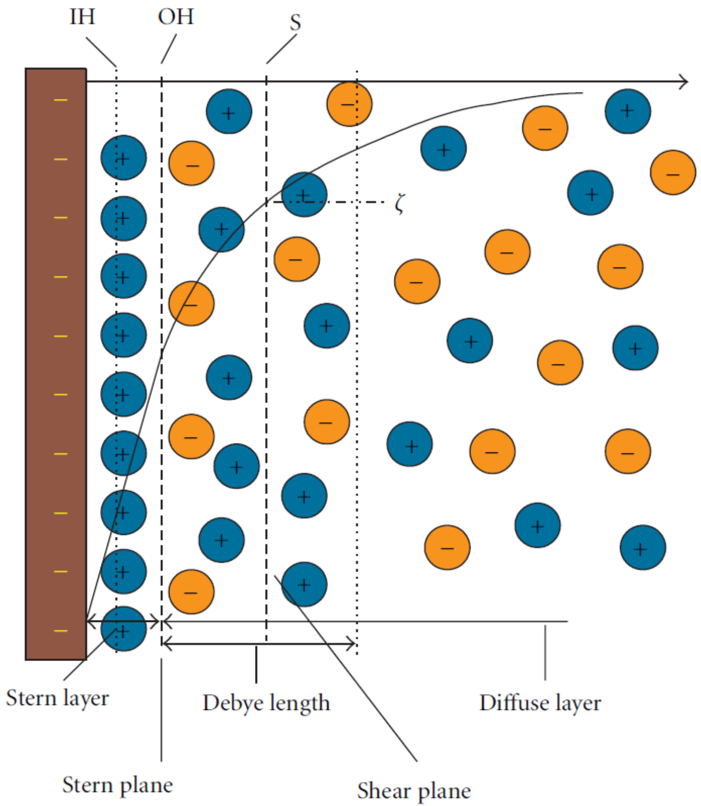
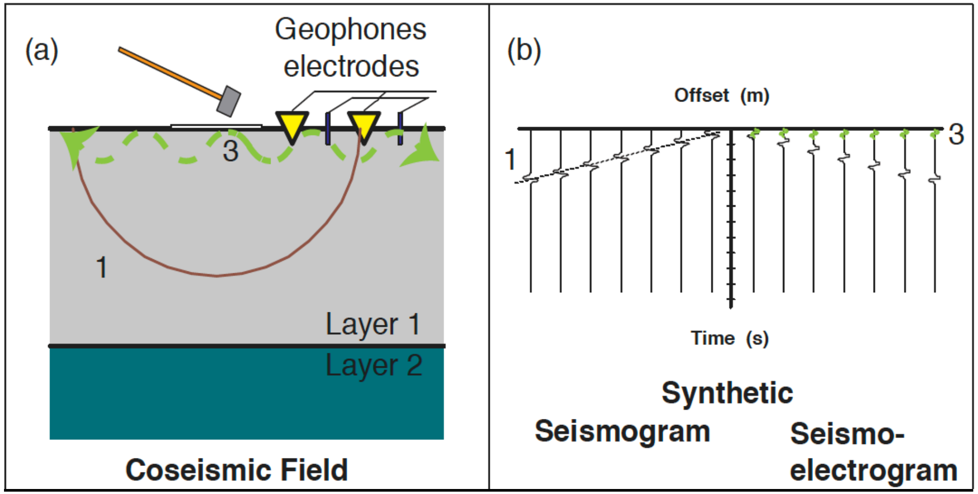
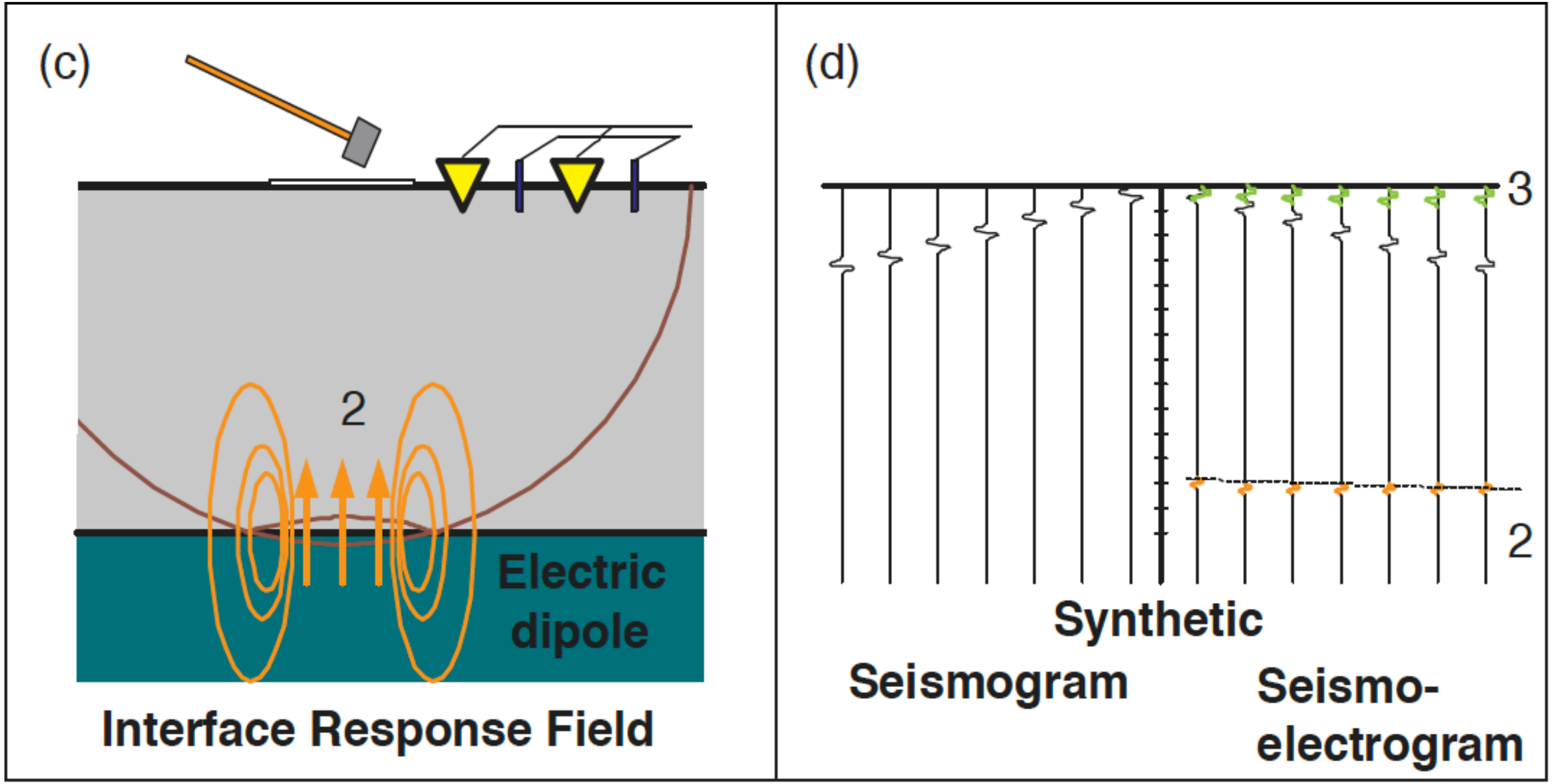
Origin: Microscale





Second-type of Coupling: Interface Response Fields



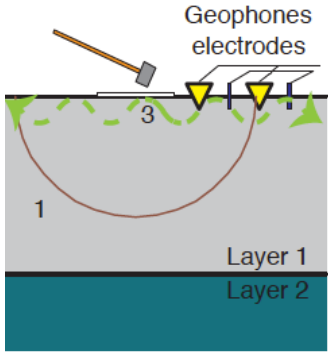
Signal types and key challenges

1. Coseismic Signals:
- Generated locally, e.g. inside seismic wave
- Local information only (close to the receivers)
- Local applications, e.g. boreholes

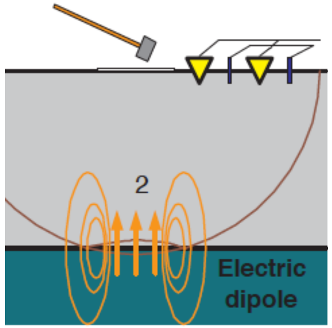
2. Interface Response:
- Independent electromagnetic field
- Second-order coupling effects
- Information at depth

3. Direct source-converted EM-fields

Low signal-to-noise ratio
Complex physical phenomenon



Coseismic Field

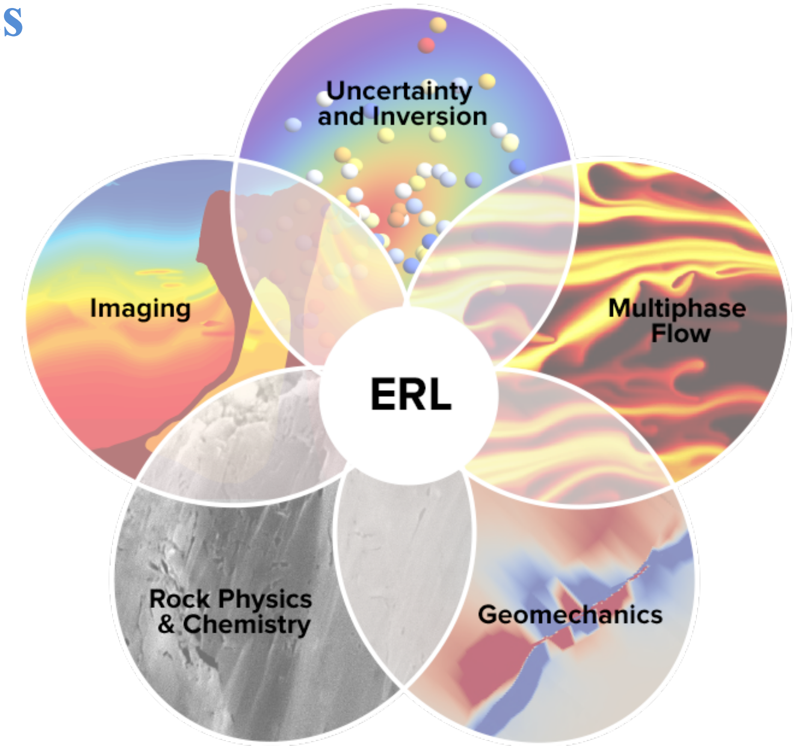


Interface Response Field

Why should we care?

Poroelasticity coupled to electromagnetics

- Seismic resolution and electromagnetic fluid sensitivity at the same time
- Information on crucial reservoir parameters:
  - Porosity
  - Permeability
  - Pore-fluid content (e.g. viscosity)
- More sensitive to thin-beds than seismics → enhanced imaging?
- Better near-surface models?



Investigating the added value

- Compare coupled seismo-electromagnetic signals vs. pure seismic (e.g. poroelastic)
- Not directly comparable:
  - Either; sources that generate wavefields NOT equivalent
  - Or; receivers (and recorded fields) NOT equivalent
    - E.g. seismic [m/s], seismoelectric [V/m]
- Idea:
  - coseismic reflected fields are **similar** to the poroelastic (seismic-seismic) reflected fields
  - Seismoelectric interface response fields are **different**

→ Try to compare reflection coefficients
→ Observe where added value comes in

http://www.pleandstems.ca/wp-content/uploads/2014/05/apples.jpg

Comparing Reflection Coefficients

- **Analytically** → Not straightforward, but under progress
- **Numerically**
  - E.g. compare ratios of coseismic reflected fields with interface response fields
  - Different parameter contrasts of interest
  - Do seismoelectric signals have higher sensitivity to viscosity than poroelastic-seismic?

Poroelastic

Seismoelectric static coupling coefficient

$$\mathscr{L}_0 = \frac{\phi \varepsilon_0 \varepsilon_{rf} \zeta^p}{\alpha_\infty \eta}$$

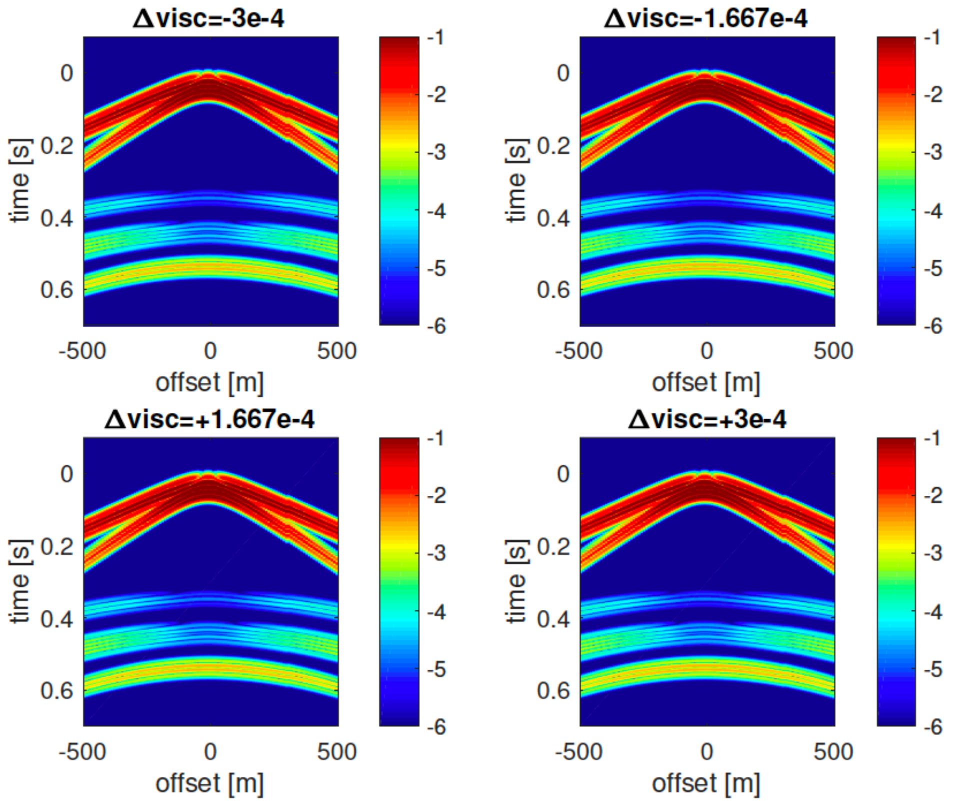
Electromagnetic

Poroelastic: v_1^{f1b}

- Dynamic viscosity - solid density contrasts
- Different viscosity contrasts for a single density contrast

$$\Delta\rho^s = +450\ \mathrm{kg/m^3}$$

→ **No visible sensitivity to the viscosity contrasts**



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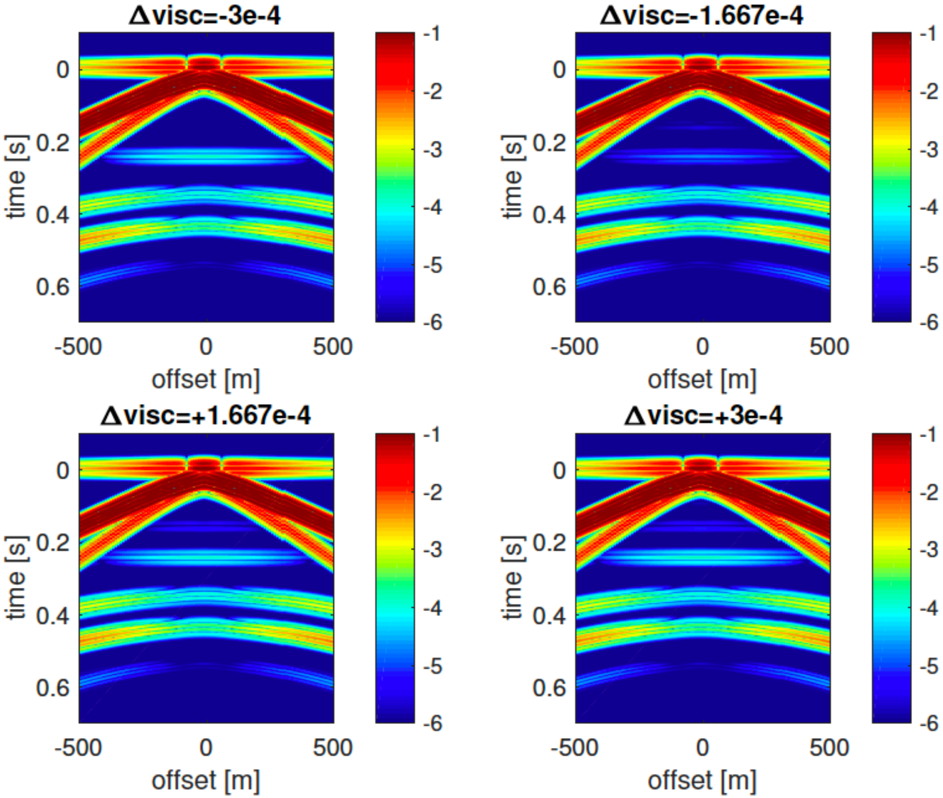
Seismoelectric: E_1^{f1b}

- Dynamic viscosity - solid density contrasts
- Different viscosity contrasts for a single density contrast

$$\Delta\rho^s = +450\ \mathrm{kg/m^3}$$

→ Variations for different viscosity contrasts



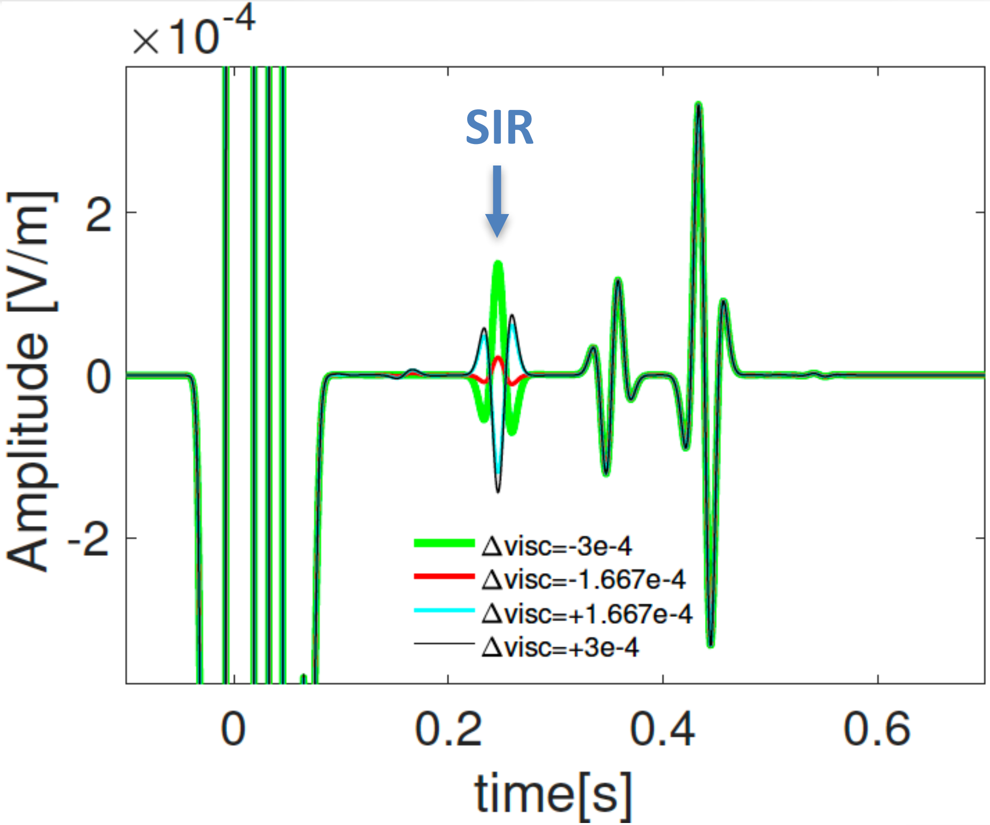
Seismoelectric zero-offset trace: E_1^{f1b}

- **PIR and SIR values show strong variability with viscosity contrasts**

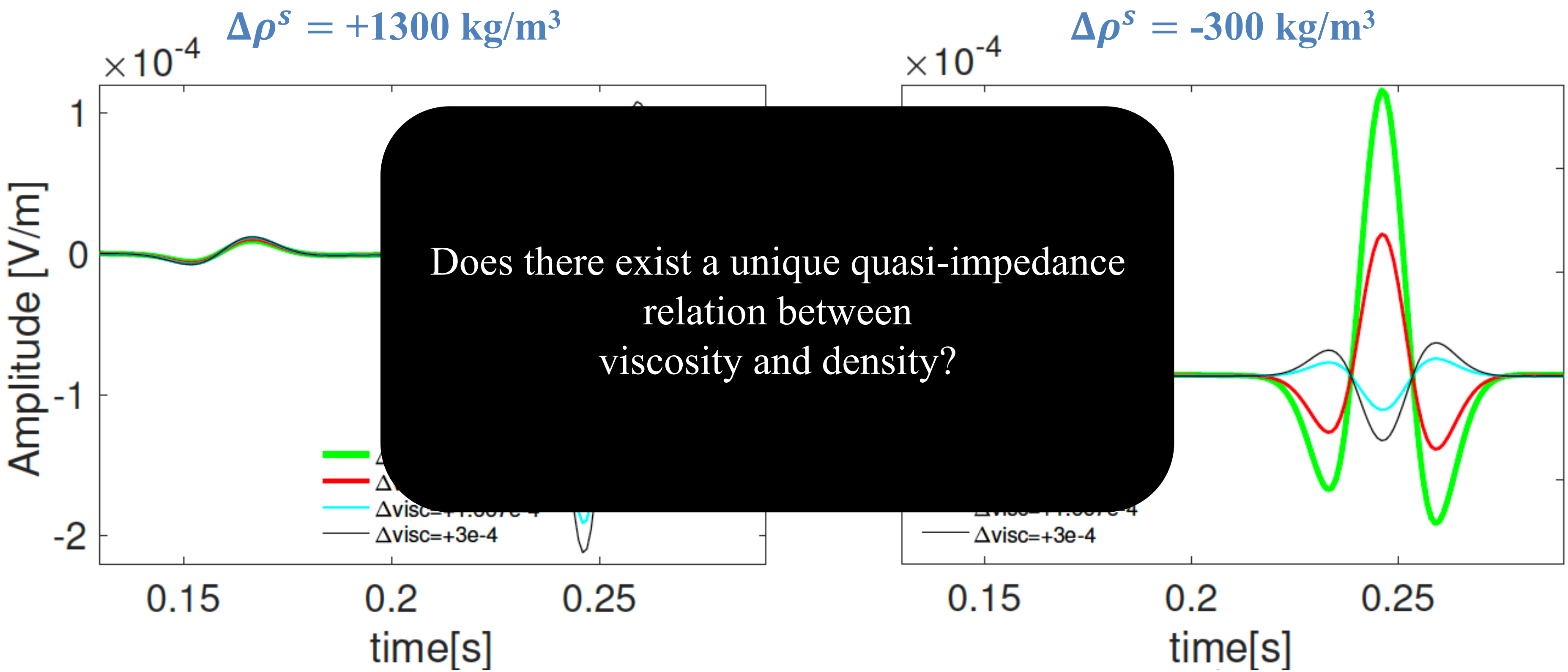
- **Coseismic reflections show no visible variability**

$$\Delta\rho^s = +450\ \mathrm{kg/m^3}$$

→ How about changing the solid density contrast?



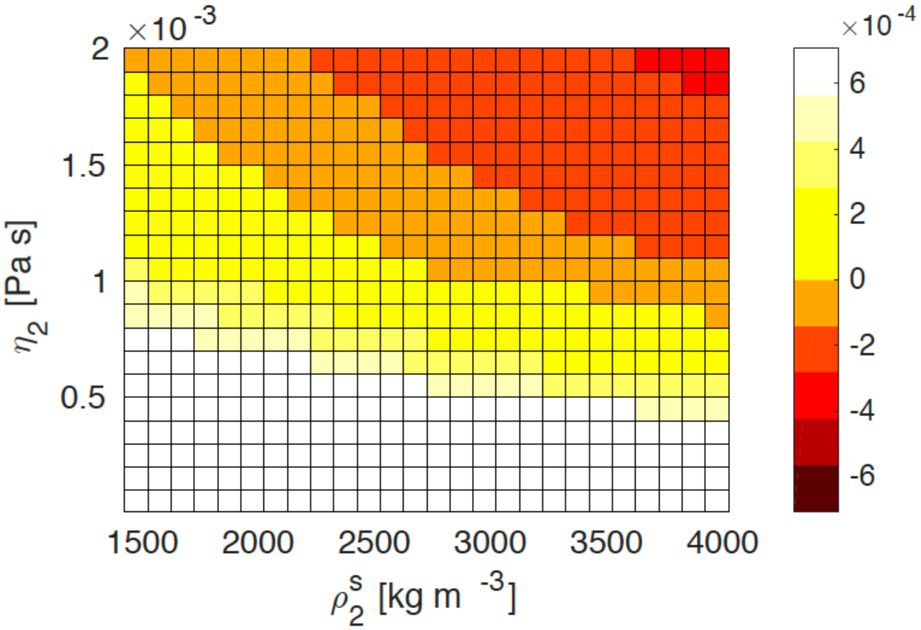
Seismoelectric: E_1^{f1b} for varying viscosity-density

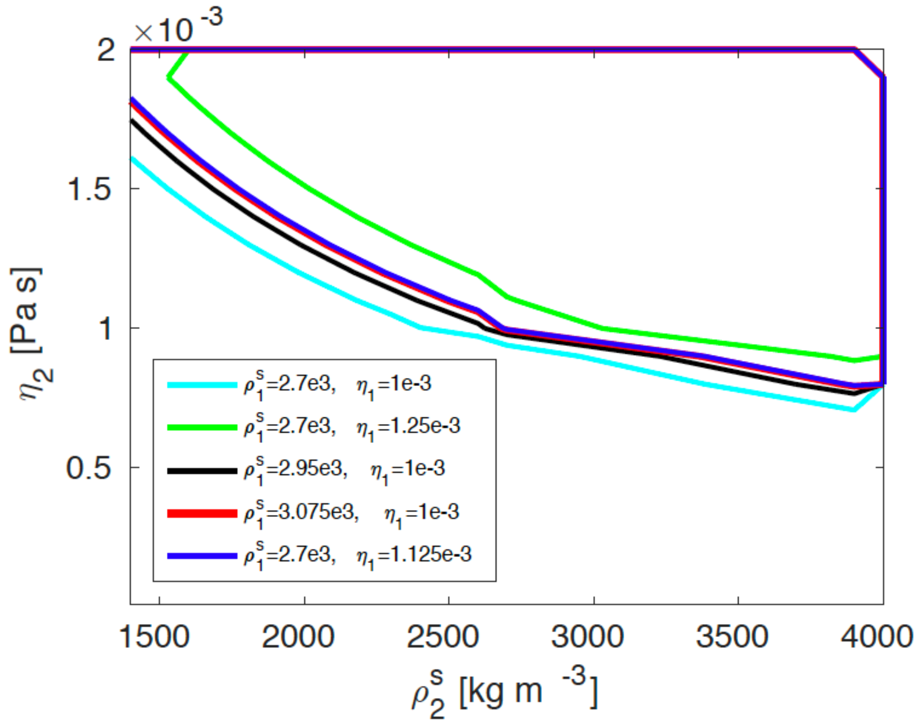


Does there exist a unique quasi-impedance relation between viscosity and density?

Numerical analysis of zero-crossings SIR

$$\eta_1 = 1 \cdot 10^{-3} \text{ [Pa s]}$$
$$\rho_1^s = 3.075 \cdot 10^3 \text{ [Kg/m}^3\text{]}$$





Conclusions

- The two kinds of seismoelectric fields exhibit clearly a **different reflectivity** to relevant reservoir-parameter contrasts, like a contrast in viscosity

- This can be used to investigate the **Value of Information of seismoelectric data**, as compared to e.g. purely seismic data

- Numerical analysis shows there exists a **unique quasi-impedance relation** between dynamic viscosity and solid density

- Seismoelectric data seems useful for remotely **inferring crucial reservoir properties**

Future directions

- Find an (approximate) analytical expression for various quasi-impedances of interest
- Derive & analyze analytical reflection coefficients
- Seismoelectric inference of crucial reservoir parameters

From: https://smartsdk.eu/wp-content/uploads/sites/8/2016/11/Road-Ahead.jpg

- Use those parameters for example for updating a reservoir model
- Morphological Component Analysis to isolate the seismoelectric interface response
  - Synthetic models with noise
  - Borehole or field data (?)

Questions?

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