EGU 2020:
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SEISMIC DIFFUSIVITY

AND THE INFLUENCE OF FRACTURE NETWORKS ON INDUCED SEISMICITY.

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OBJECTIVES

- Present expressions for tracking the seismic triggering front using solutions to linear diffusion equation.
- Apply new triggering front analysis to estimate diffusivity of three domain types: homogeneous, correlated random field, and fractured rock.
- Compare estimates of diffusivity from triggering front analysis to the effective hydraulic diffusivity.
- Rigorously define the concept of **seismic diffusivity.**

TRIGGERING FRONT ANALYSIS

Talwani and Acree (1984) first suggested the concept of **"seismic diffusivity": the diffusivity associated with spread of the triggering front** in injection induced seismicity (IIS). They measured it heuristically.

$$D_s = L^2/t$$

More recently, Shapiro et al. (1997) suggested this expression for tracking the triggering front, based on interpreting fluid flow as a wave problem. This convenient expression is ubiquitously used in IIS studies.

$$r_t = \sqrt{4\pi D t}$$

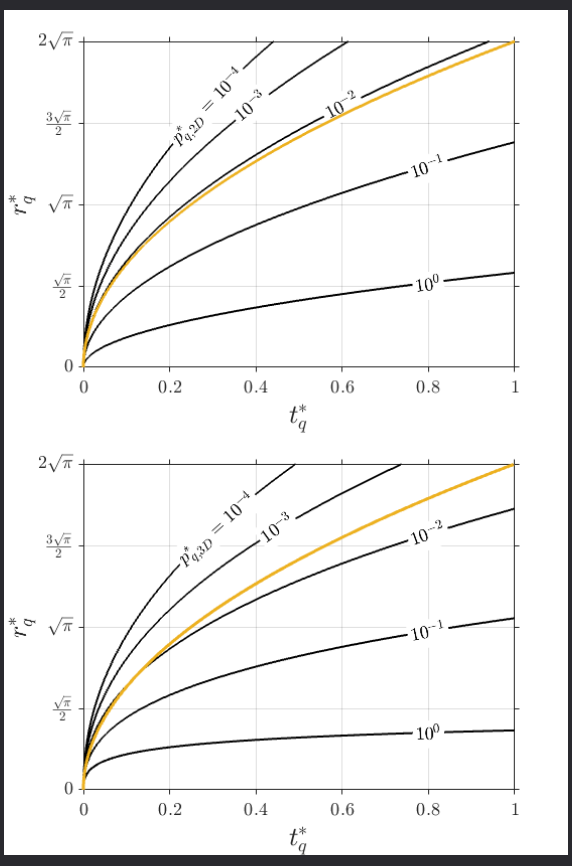
BASED ON DIFFUSION

We instead propose using rigorous solutions to linear diffusion equation.

Advantages include:

1. Incorporates physically meaningful parameters.
2. Helps explain wide range of behavior in observed IIS data.

Dimensionless 2D and 3D solutions plotted - compared with Shapiro et al. (1997) in yellow. Here $r^* = r/\sqrt{Dt}$ and $t^* = t/t_{end}$.



$D_s \approx D_h?$

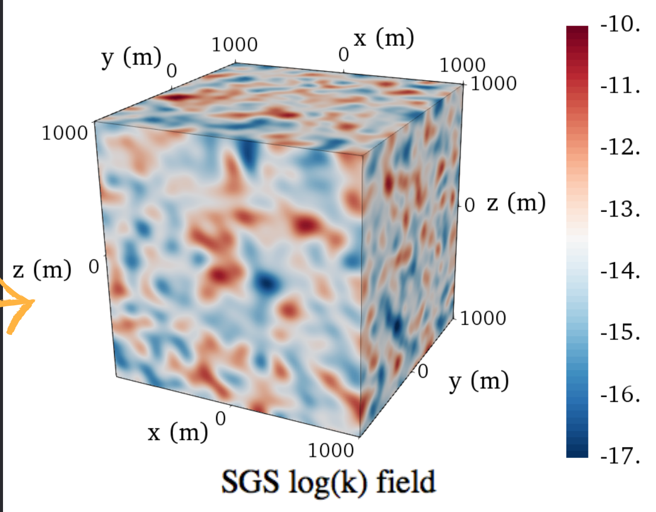
IS SEISMIC DIFFUSIVITY EQUIVALENT TO HYDRAULIC DIFFUSIVITY?

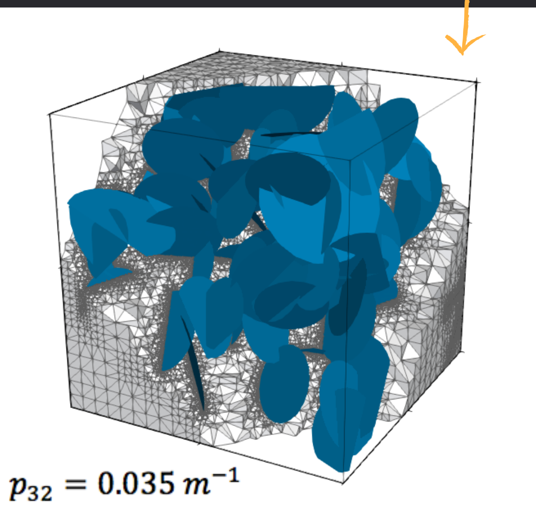
Previous studies assume that the seismic diffusivity is an accurate estimate of the effective hydraulic diffusivity of the subsurface, making no distinction between the two.

NUMERICAL STUDY

We investigate this question with **numerical simulations of fluid injection** in three domains:

1. Homogeneous domain.
2. Correlated random field generated with Sequential Gaussian Simulation (SGS).
3. **Novel discrete fracture network in matrix (DFNM) domain.**





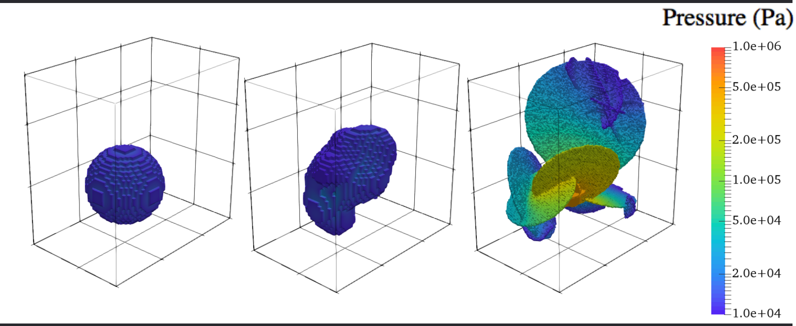
EFFECTIVE HYDRAULIC DIFFUSIVITY

The effective hydraulic diffusivity of each domain is measured rigorously with a numerical permeameter and pumping tests. This will then be compared to seismic diffusivity.

RESULTS: PRESSURE DIFFUSION

FLUID PRESSURE

Homog SGS DFNM



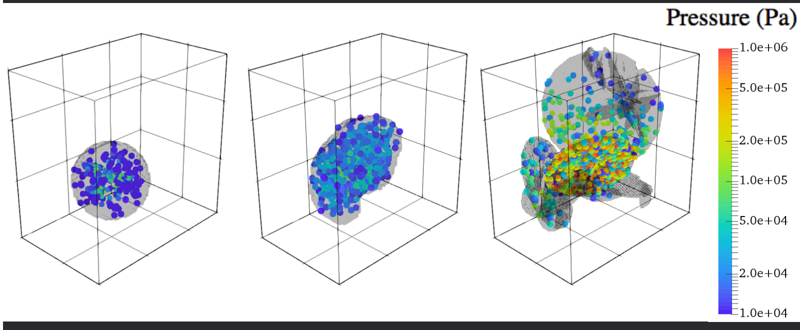
Triggering pressures reached farthest in the DFNM domain. Pathways of high diffusivity allow pressure from injection to rapidly propagate. Plots are normalized using effective hydraulic diffusivity of each domain for clear comparison.

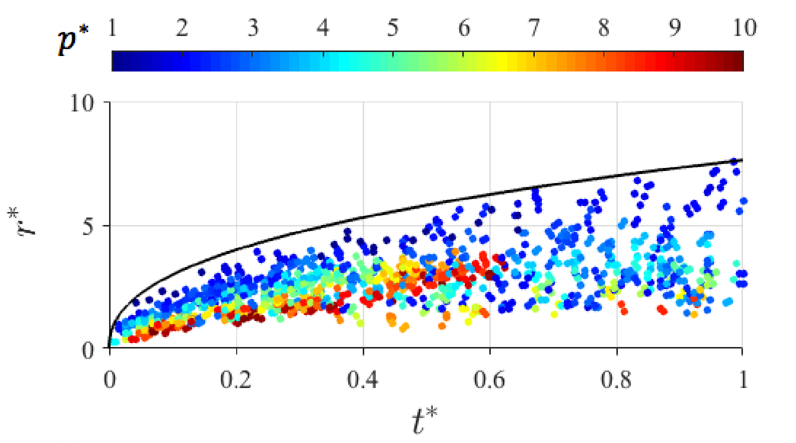
RESULTS: INDUCED SEISMICITY

Resulting induced seismicity - tracked with Mohr Coulomb at randomly seeded points - extends farthest in DFNM domain. Results are normalized for accuarte comparison.

SEISMICITY

Homog SGS DFNM





Using the synthetic seismic dataset in *rt*-plots, we estimate the seismic diffusivity of each domain. We used the diffusion based triggering front analysis described above for robust measurement. Here, $p^* = p/p_t$ showing pressure that triggers each event.

COMPARING DIFFUSIVITIES

After rigorously measuring the effective hydraulic diffusivity of each domain (with numerical permeameter and pumping tests), we **compare the seismic and hydraulic diffusivities.**

homog: $D_s/D_h = 1$
SGS: $D_s/D_h = 2.1$
DFNM: $D_s/D_h = 10.2$

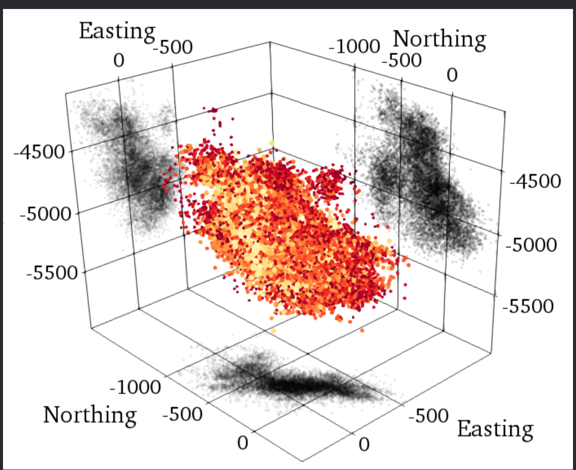
$$D_s \neq D_h$$

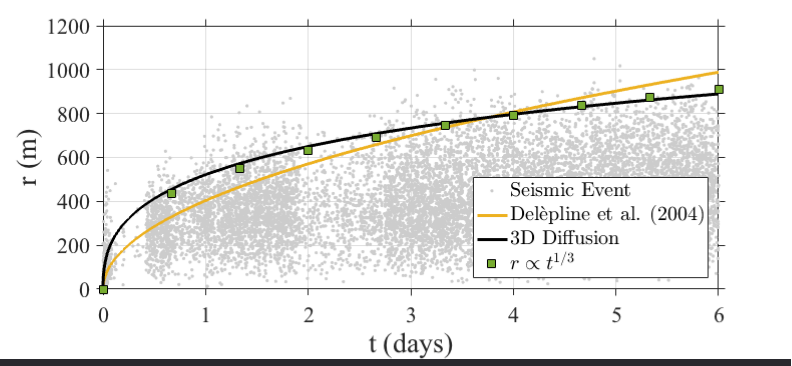
SIESMIC DIFFUSIVITY

Results suggest that seismic diffusivity is distinct from the hydraulic diffusivity. In DFNM case, the seismic diffusivity was an entire order of magnitude larger. Spatiotemporal patterns of IIS are well-described by the seismic diffusivity rather than the hydraulic diffusivity.

CASE STUDY

To find **evidence showing that seismic diffusivity is distinct from hydraulic diffusivity**, we studied the fluid injection at Soultz-sous-Forêts, France. Site is a highly fractured, crystalline rock formation. Delèpline et al. (2004) studied this data set with Shapiro et al. (1997) approach.





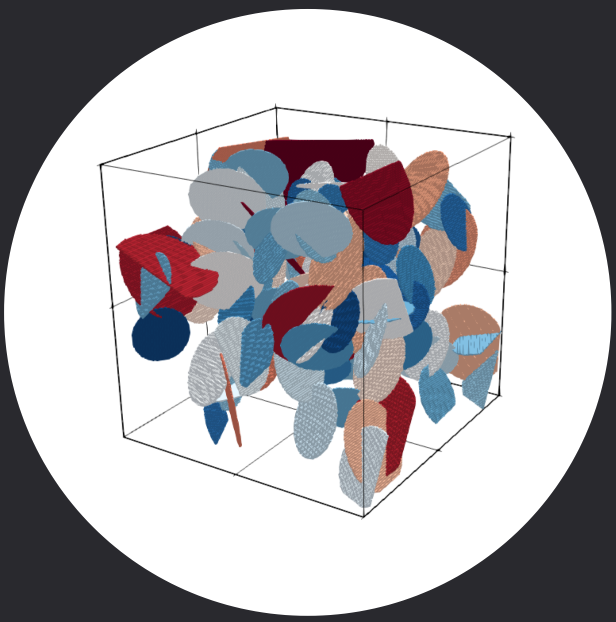
SEISMIC DIFFUSIVITY MEASUREMENT

Results indicate:

- Dataset is better fit with $r_t \propto \sqrt[3]{t}$.
- 3D Diffusion solution for triggering front provides excellent fit to IIS data.
- Seismic diffusivity is two orders of magnitude larger than the hydraulic diffusivity (measured in laboratory and *in situ* tests).

IMPLICATIONS

- Highlights the importance of fractures in IIS problems.
- Informs flow models for IIS problems: homogeneous domains using hydraulic diffusivity may be inadequate.
- Allows for better analysis of IIS data used for subsurface characterization.



CONCLUSIONS

- We propose new diffusion based solutions for location of the triggering front.
- Numerical study indicates that seismic diffusivity is distinct from hydraulic diffusivity.
- Real world case study of Soultz IIS provides empirical evidence corroborating results from numerical simulations.
- In preparation for submission to Journal of Geophysical Research: Solid Earth.

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