The Effect of Correlated Permeability on Fluid-Induced Seismicity

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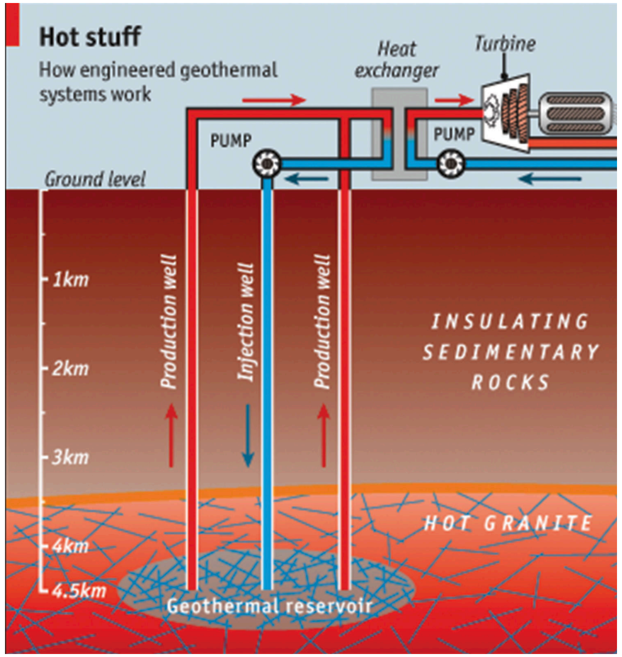
Outline

- Background
- Research Question
- Well-log Data
- The Model
- Results
- Summary

Background: Fluid-Induced Seismicity

Enhanced Geothermal System

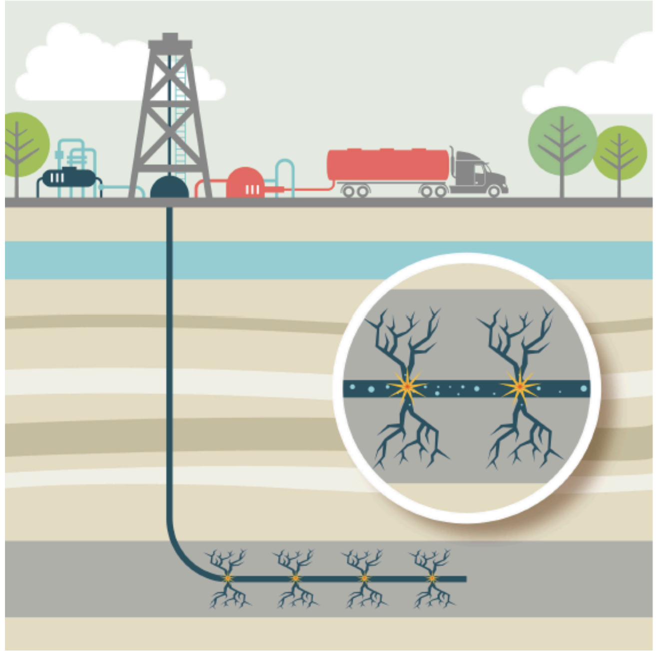


15 Nov 2017 Pohang, South Korea

- **5.5 magnitude earthquake**
- displaced 1700 people
- $75 million in direct damage
- $300 million total economic impact

Cite: WL Ellsworth, et al. SRL, 2019

Hydraulic Fracturing

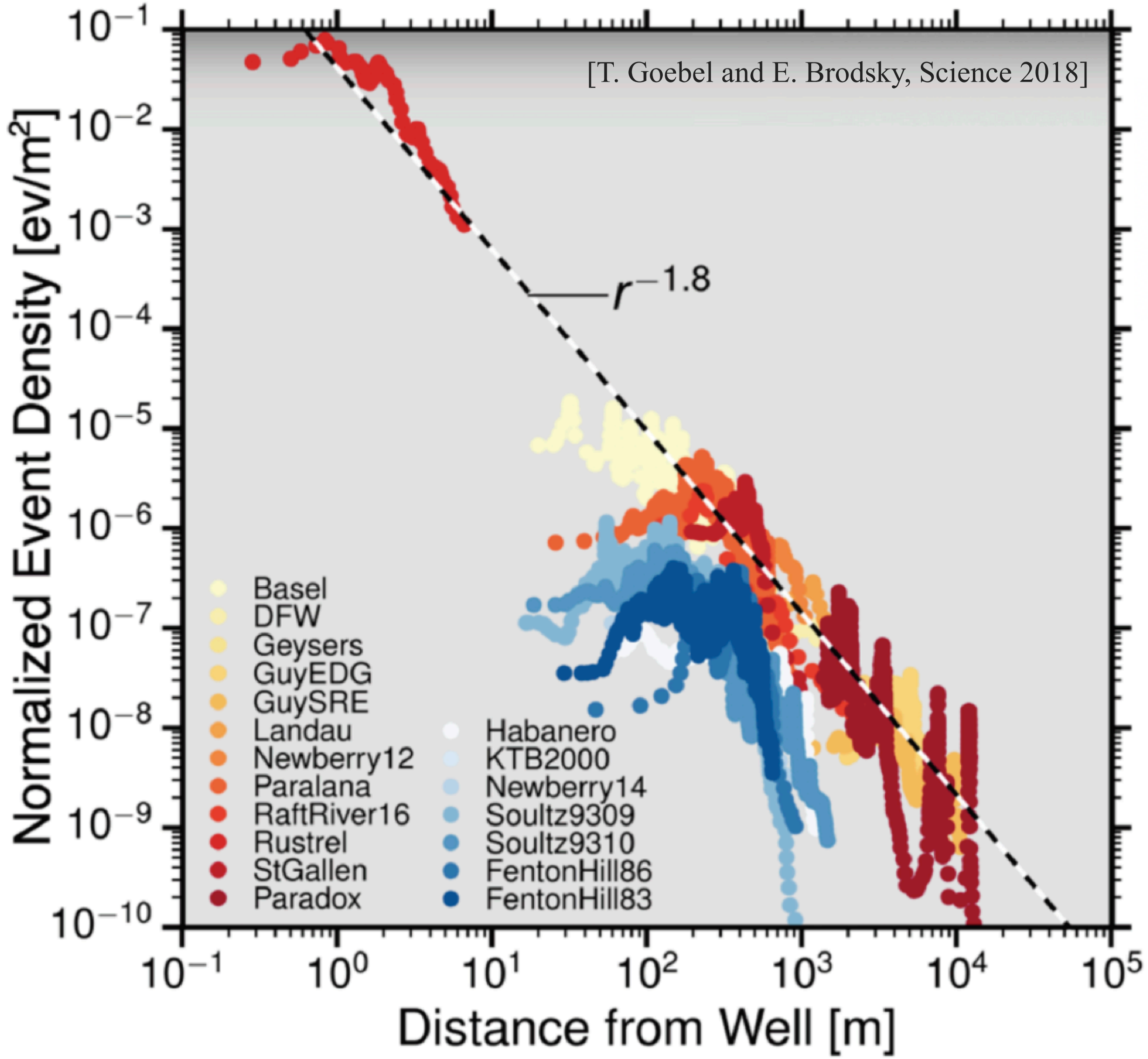


4 March 2019 Red Deer, Alberta

- **4.6 magnitude earthquake**

Cite: Edmonton Journal 2019

Research Question: Can We Model Spatial Footprint?



$$\rho = \frac{\rho_0}{\sqrt{1 + (\frac{r}{r_c})^{2\gamma}}},$$

r_c The corner distance

γ The Decay exponent

Red	Blue
Steady Decay	Abrupt Decay
Above Basement	Within Basement

Well-log Data:

Spatial correlations in porosity and permeability can be captured by the power spectrum as:

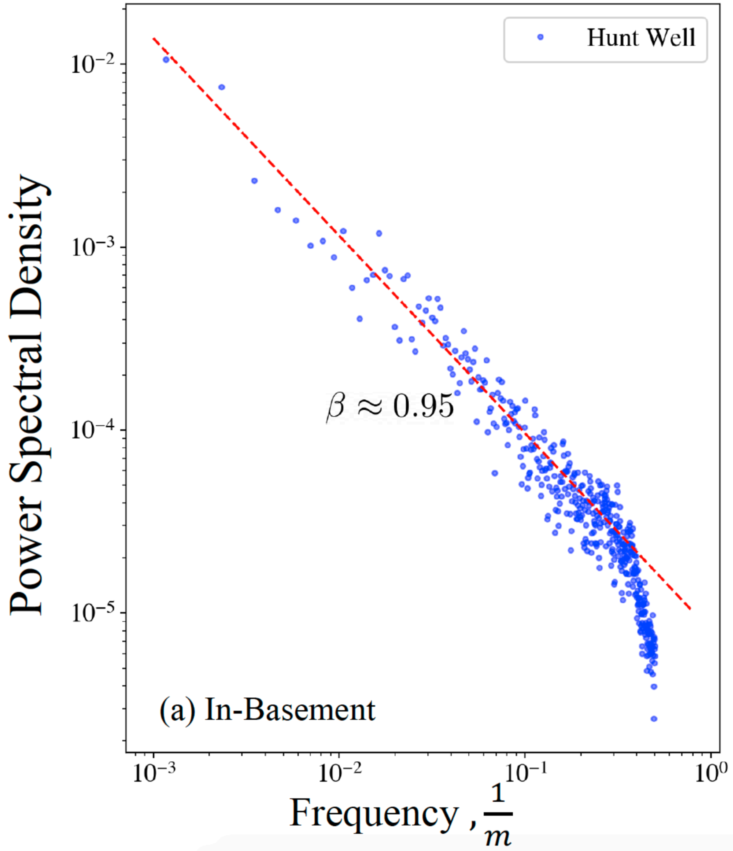
$$S(k) \sim 1/k^{\beta}, 0 < \beta < 2 \qquad 1/Km < k < 1/cm$$

[Leary et. al, 2012]

We have analyzed the power spectrum of the porosity well-log sequences in the figures below:

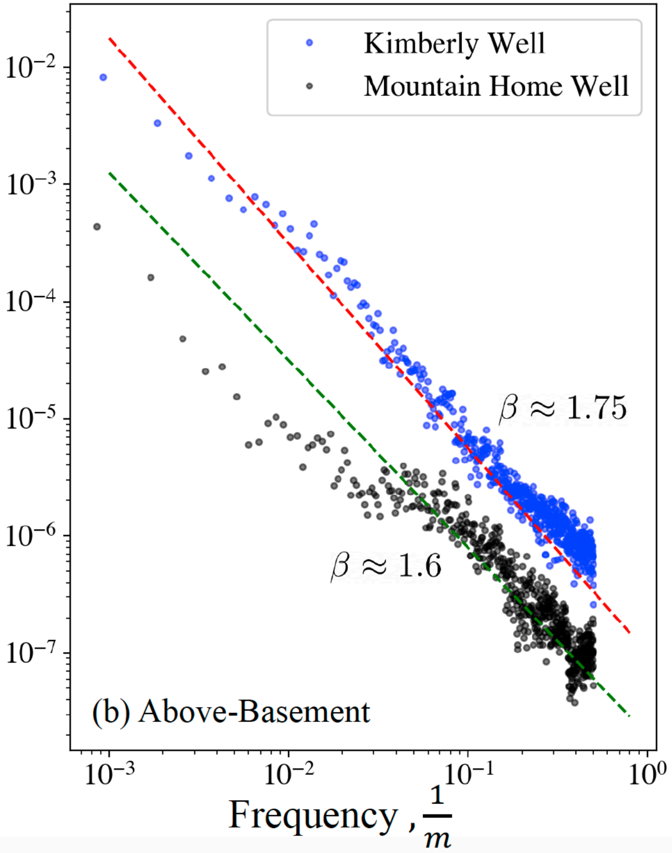
fGn: fractional Gaussian noise

$0 < \beta < 1$



fBm: fractional Brownian motion

$1 \leq \beta < 2$



There is a tendency that porosity within the basement resembles fGn, while above basement it resembles fBm. Based on this observation, we then introduce a novel conceptual model of fluid-induced seismicity with spatially correlated permeability.

Modeling Fluid-Induced Seismicity

Fluid injection and propagation

Rock Fracture

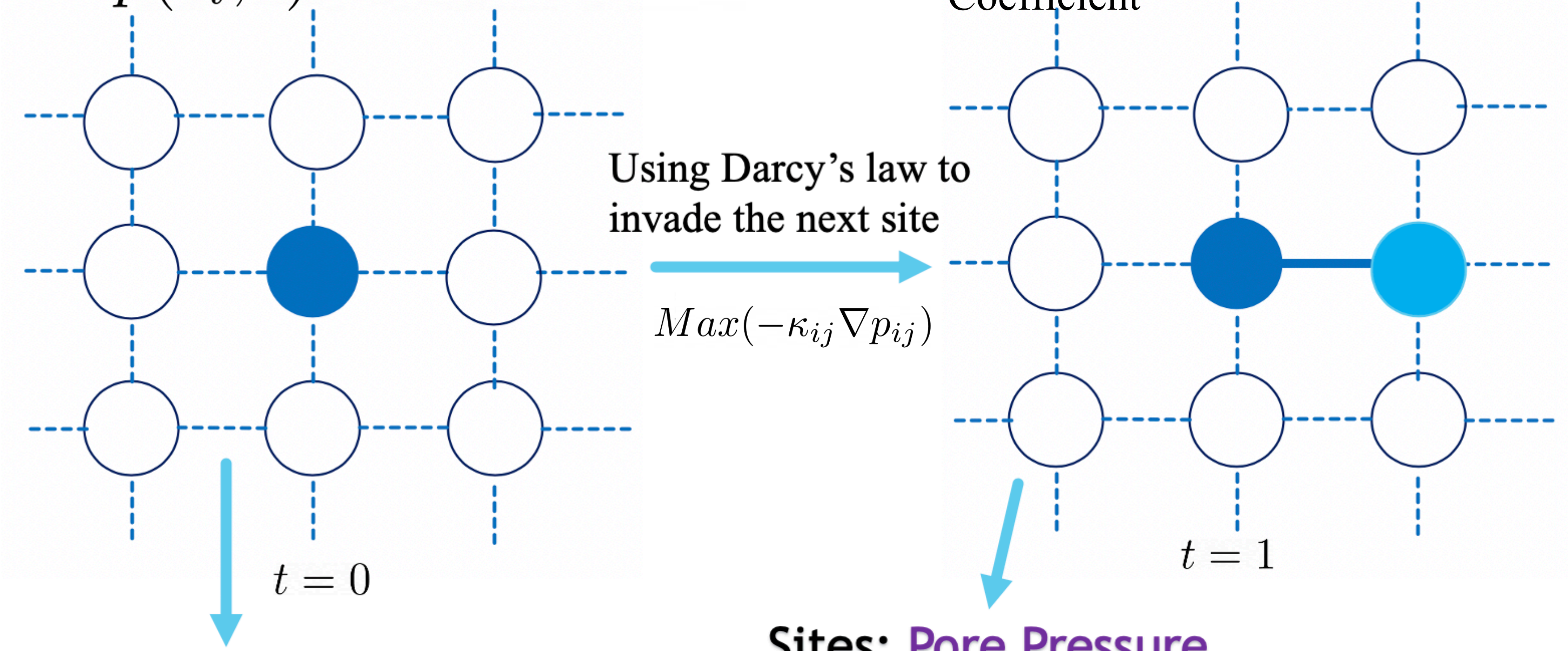
Cite:[Lord-may, et al, 2018]

Modeling: Fluid Injection and Propagation

We implemented the evolution of the fluid pressure within the **invasion percolation** [Wilkinson & Willemsen, 1983] framework coupled with the **classical diffusion process**.

$$p(\vec{r}_i, t) = e^{-|\vec{r}_i|^2/4D_{ij}t}$$

Diffusion Coefficient $D_{ij} \propto \kappa_{ij}\phi_{ij}$



Bonds: Permeability & Porosity

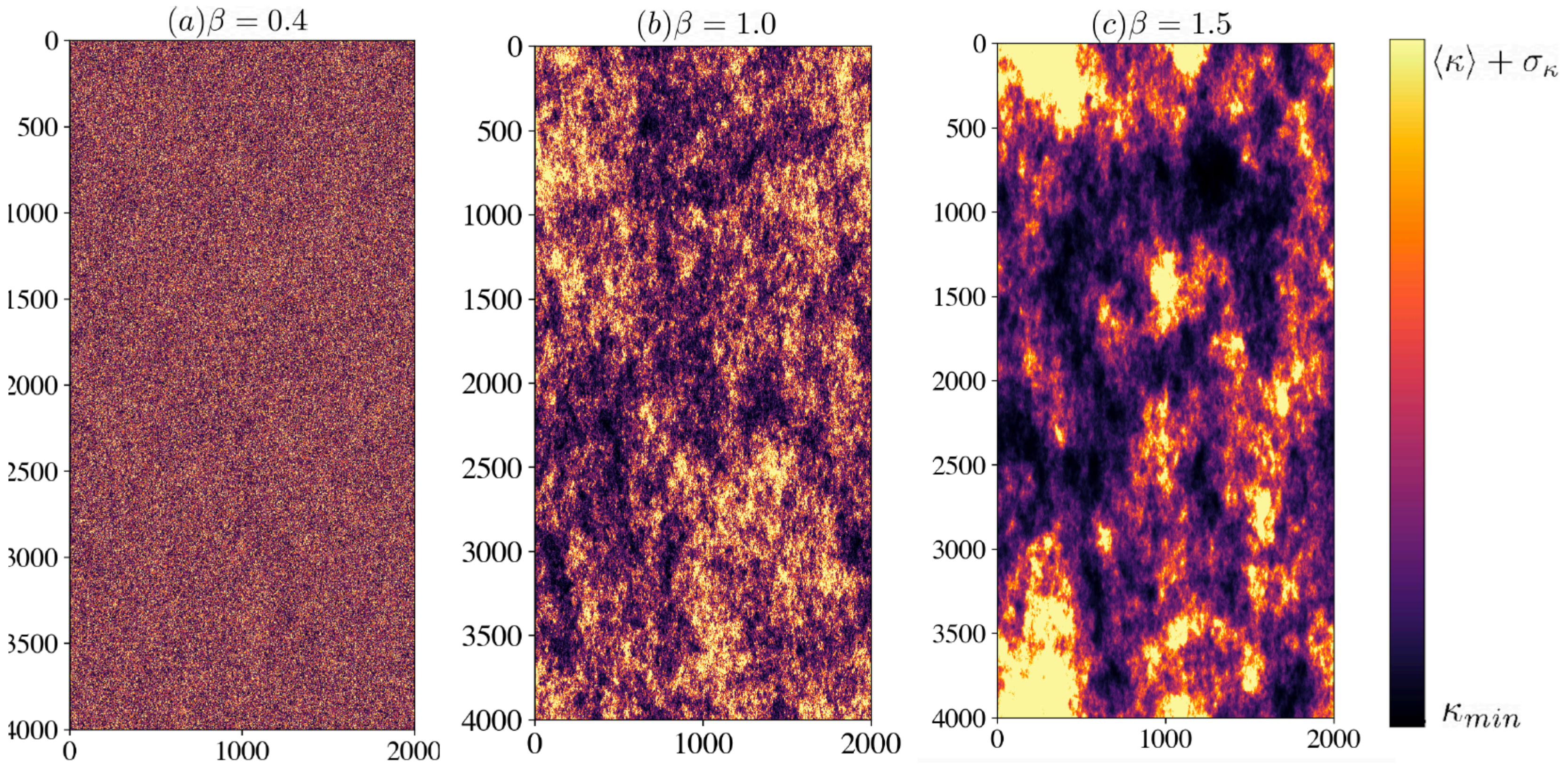
κ_{ij} ϕ_{ij}

Sites: Pore Pressure

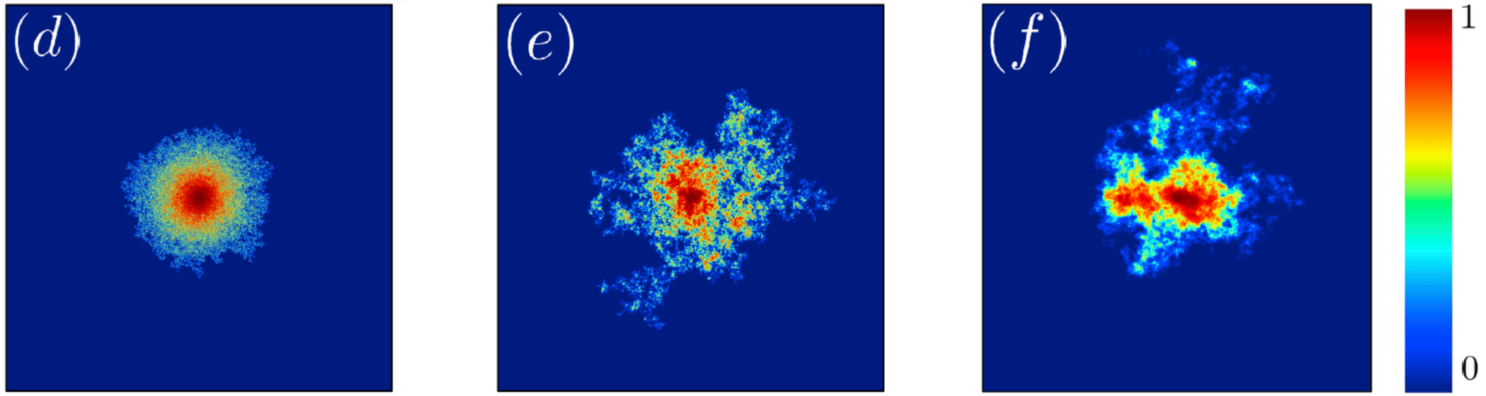
$p(\vec{r_i}, t)$

Distance from injection

Permeability Fields



Pressure Profile



- Fluctuations in **well-core** porosity and the log(permeability):

$$\delta\phi \approx \delta log\kappa$$

[Leary et al., 2012]

Modeling: Fractures

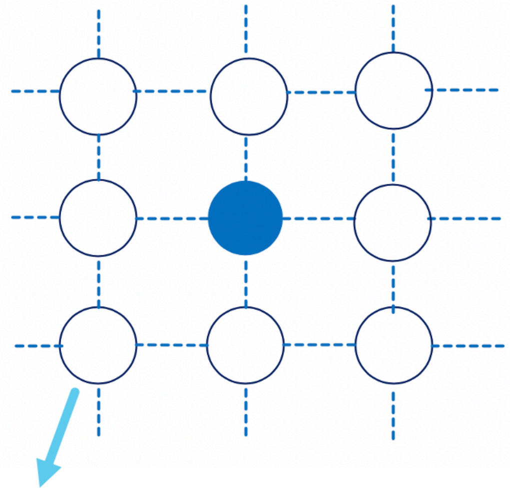
The **Mohr–Coulomb failure** condition is simplified as stick-slip dynamics:

$$\tau_i + p_{p,i} > S_i$$

Confinement and Friction: $S_i = [s_{min}, s_{max}]$

Shear Stress: τ_i

(Stress + Fluid Pressure) > (Rock Strength)



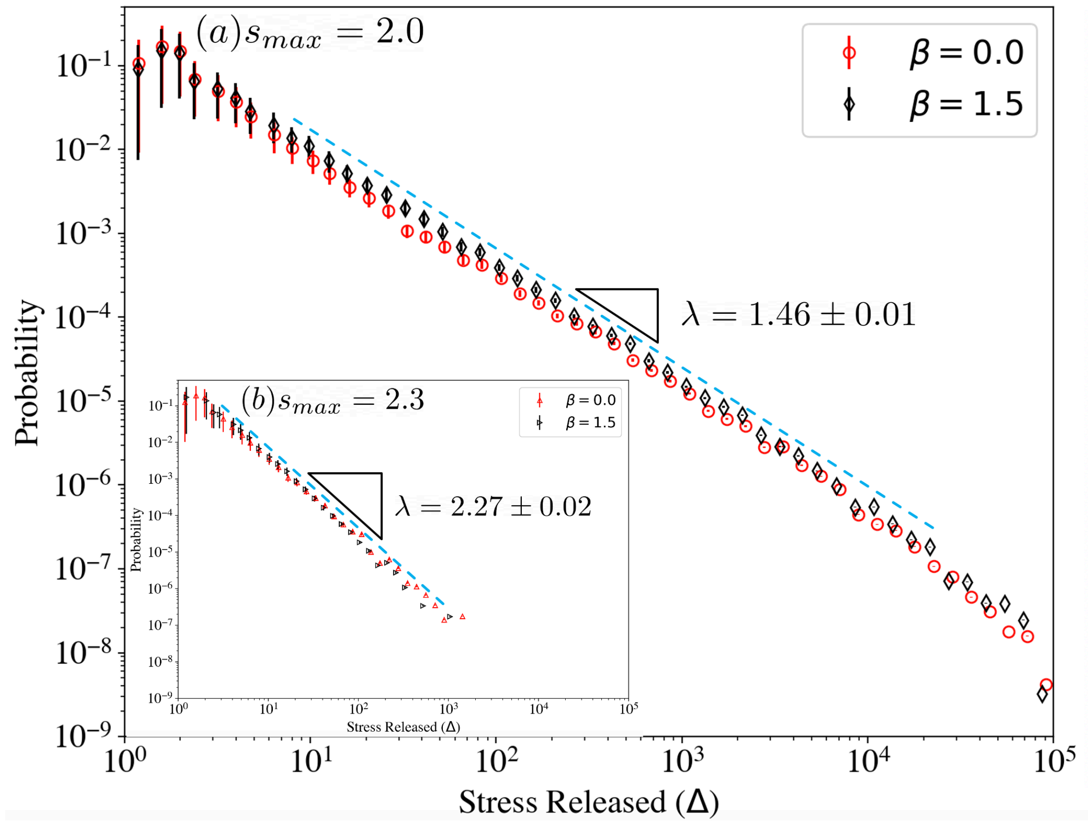
If the criteria is satisfied → The site will fail → shear stress is redistributed among the 4 nearest neighbors → Stress redistribution will continue until are sites stable → we interpret this as the earthquake, defined by the stress released: $\Delta = \sum_{i \in event} \tau_{s,i}$

Simulations are run to reach 30,000 events

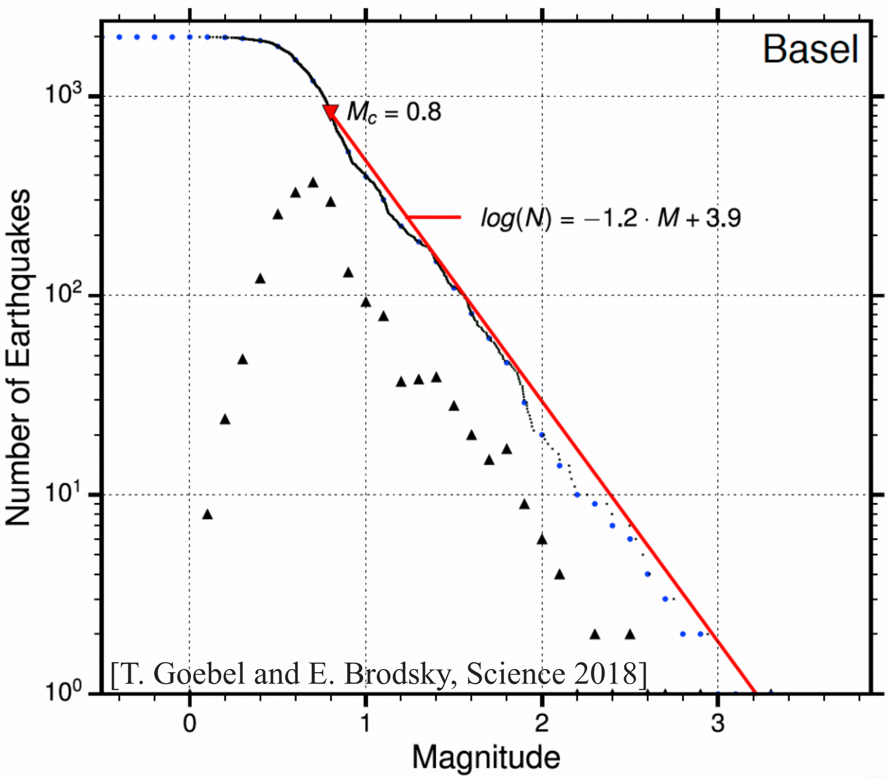
Fixed $s_{min} = 1 + 1/e$

Lattice size = 2001×2001

***Result*:** Frequency Magnitude Distribution



$$P(\Delta) \sim \Delta^{-\lambda}$$



$$N(\geq m) = 10^{a-bm}$$

Gutenberg-Richter

***Result*:** Seismicity Density

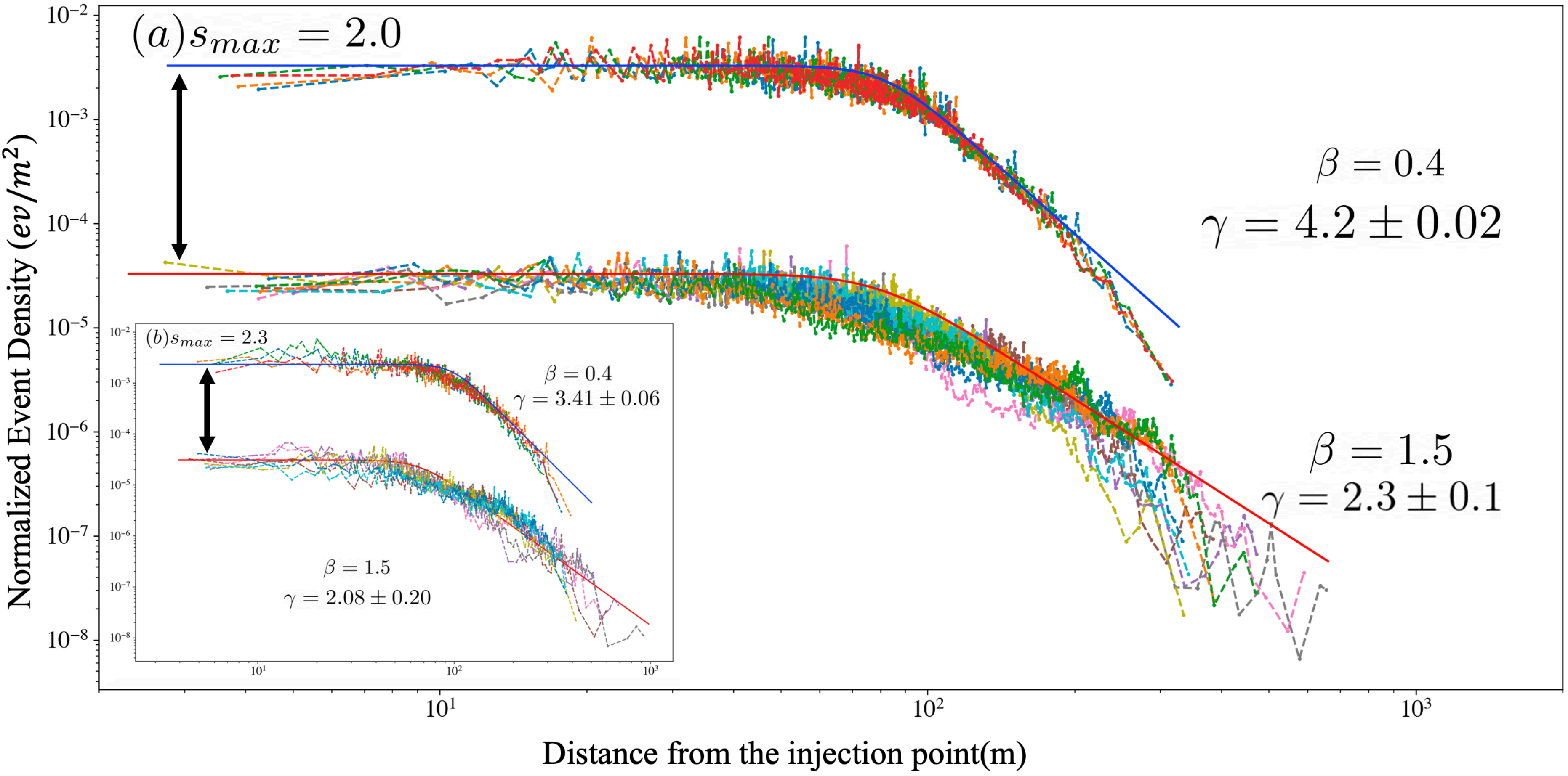
$$\rho = \frac{\rho_0}{\sqrt{1+(\frac{r}{r_c})^{2\gamma}}},$$

r_c The corner distance

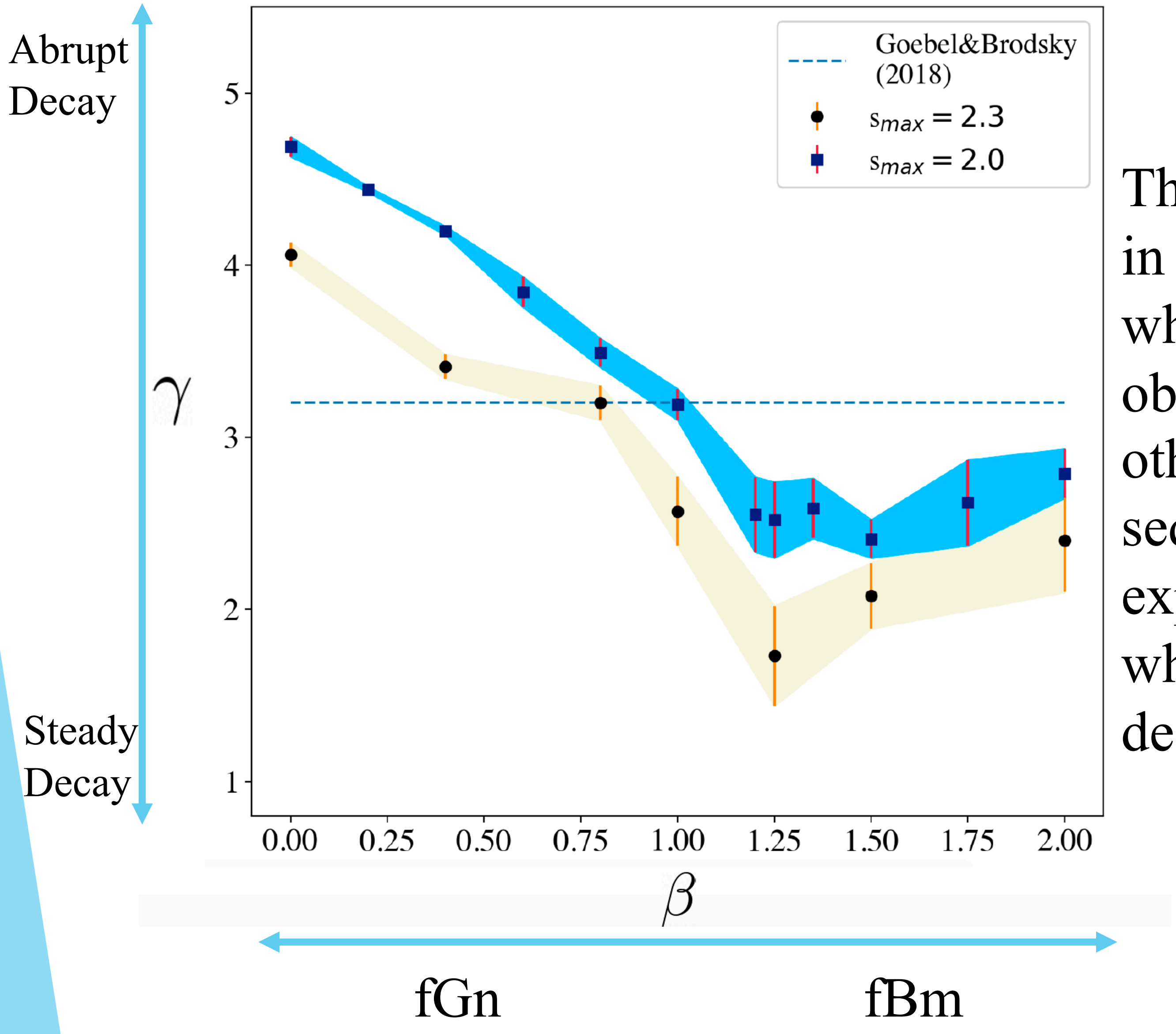
γ The Decay exponent

We consider the initiation point of the failure of an event as the epicenter, e. g:

We have used k-nearest neighbor method to calculate the seismicity density



Result: Spatial Decay Exponent Vs Beta



The spatial decay exponent is in the regime of abrupt decay when the well-log sequence obeys fGn behavior. On the other hand, for fBm well-log sequences the spatial decay exponents are much smaller which means that the spatial decay is steadier.

Summary

- Porosity well-log sequences within the basement resemble fGn, while above basement resembles fBm.
- We introduce a novel model of fluid-induced seismicity with spatially correlated porosity and permeability.
- Increasing the degree of correlation in permeability and porosity fields led to more seismic activity in farther distances, and lower spatial decay exponent.

Thanks!

References

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