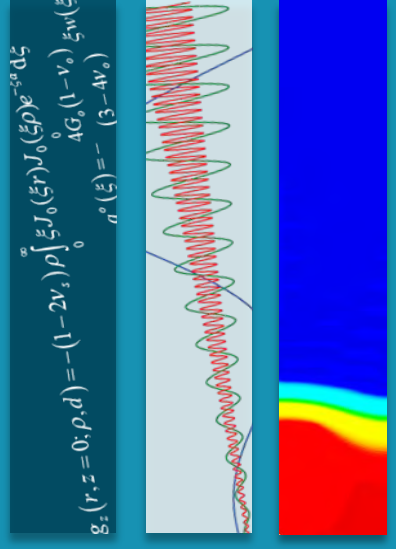

Reservoir stimulation's effect on depletion-induced seismicity

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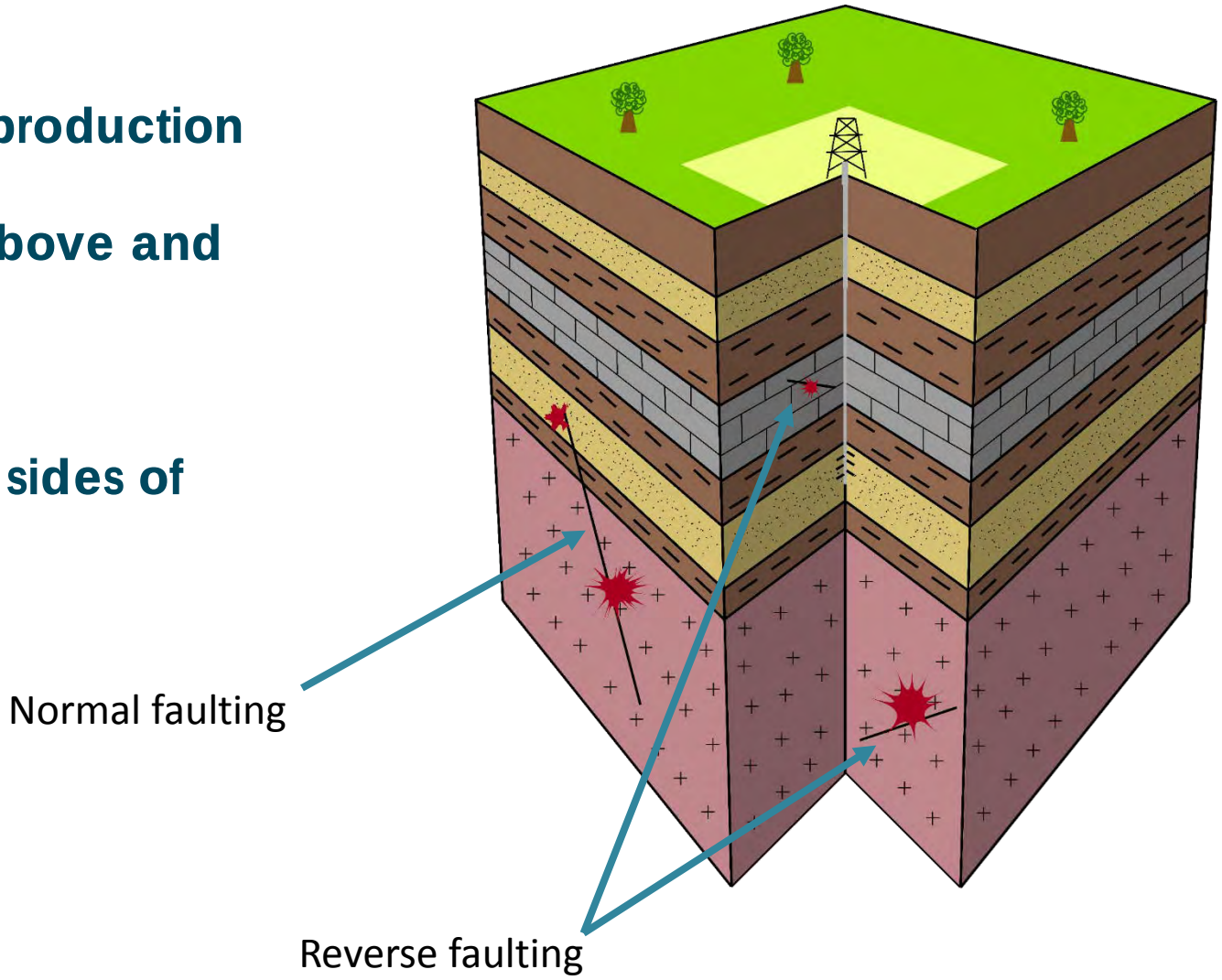
Horw, Switzerland
14 September 2018

Outline

- Introduction
- Tackling the problem
- Numerical experiment
- Discussion & conclusions

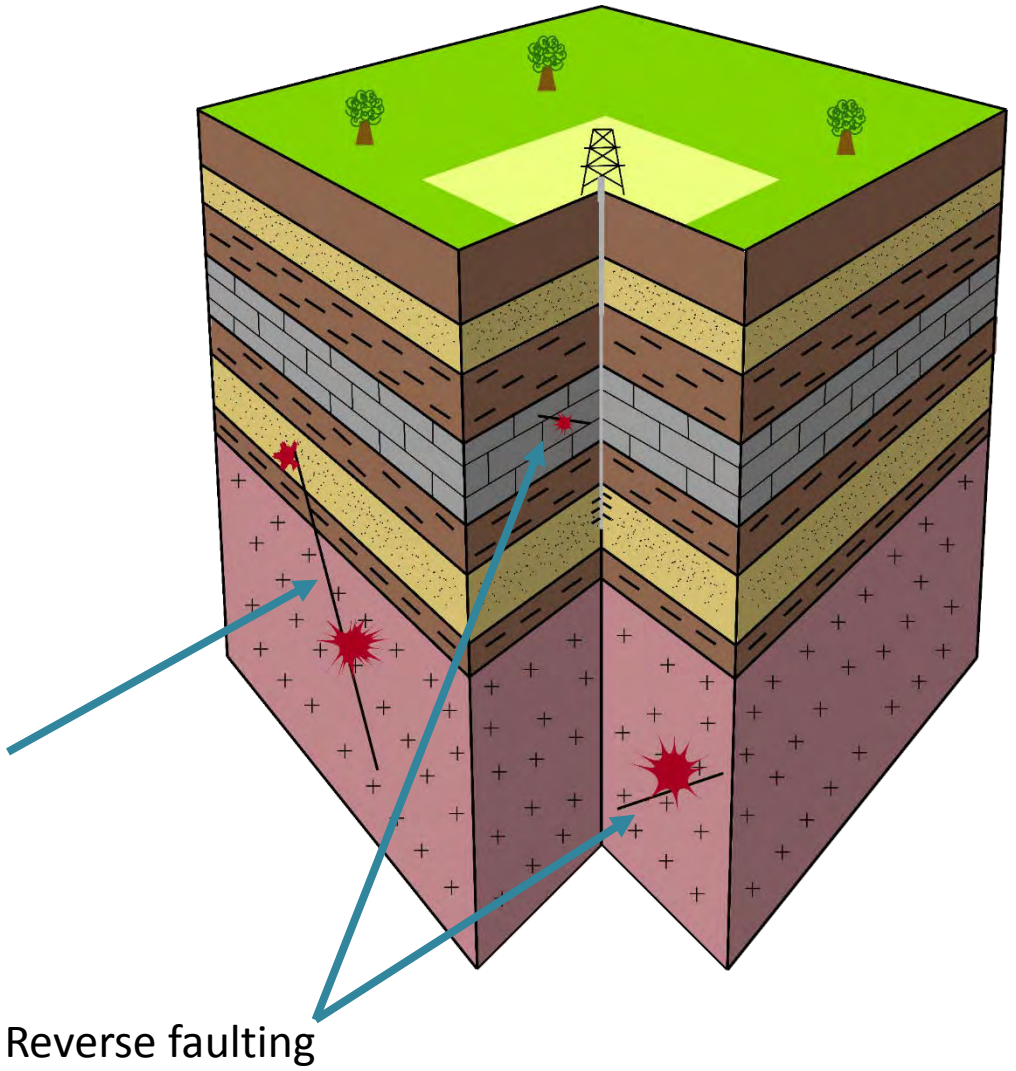
Introduction

- **Seismicity due to production**
- **Reverse faulting above and below reservoir**
- **Normal faulting to sides of reservoir**



Introduction

- **Normal**
  - **USA, Germany, Italy**
- **Reverse**
  - **France, USA, Canada, The Netherlands*, Spain, Uzbekistan**
- **Other**
  - **Oman, Crimea, Russia…**

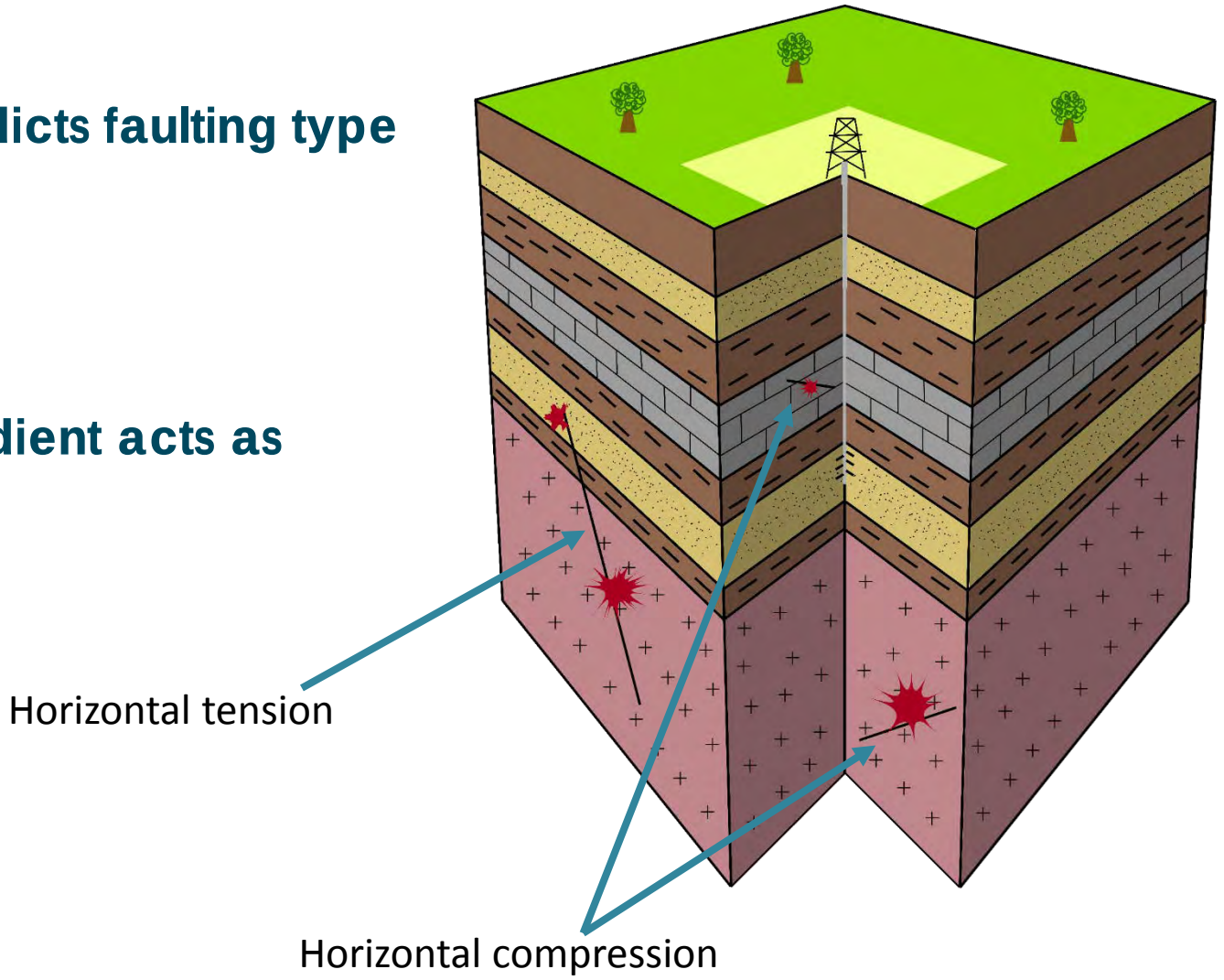


Introduction

- **Poroelasticity predicts faulting type**

  (Segall 1989)

- **Pore pressure gradient acts as internal force**



Tackling the problem

Conservation of momentum

- Pore pressure gradient acts as internal force
- **Large pore pressure gradient** yields **higher** induced **stresses**
- Are there ways to affect this?

$$\nabla \cdot \sigma' + \nabla (\alpha P) = -f$$

Permeability importance

- **Changing** the pore **pressure gradient** required to produce at a certain rate (Darcy's Law)
- What can significantly affect the pore pressure gradient?

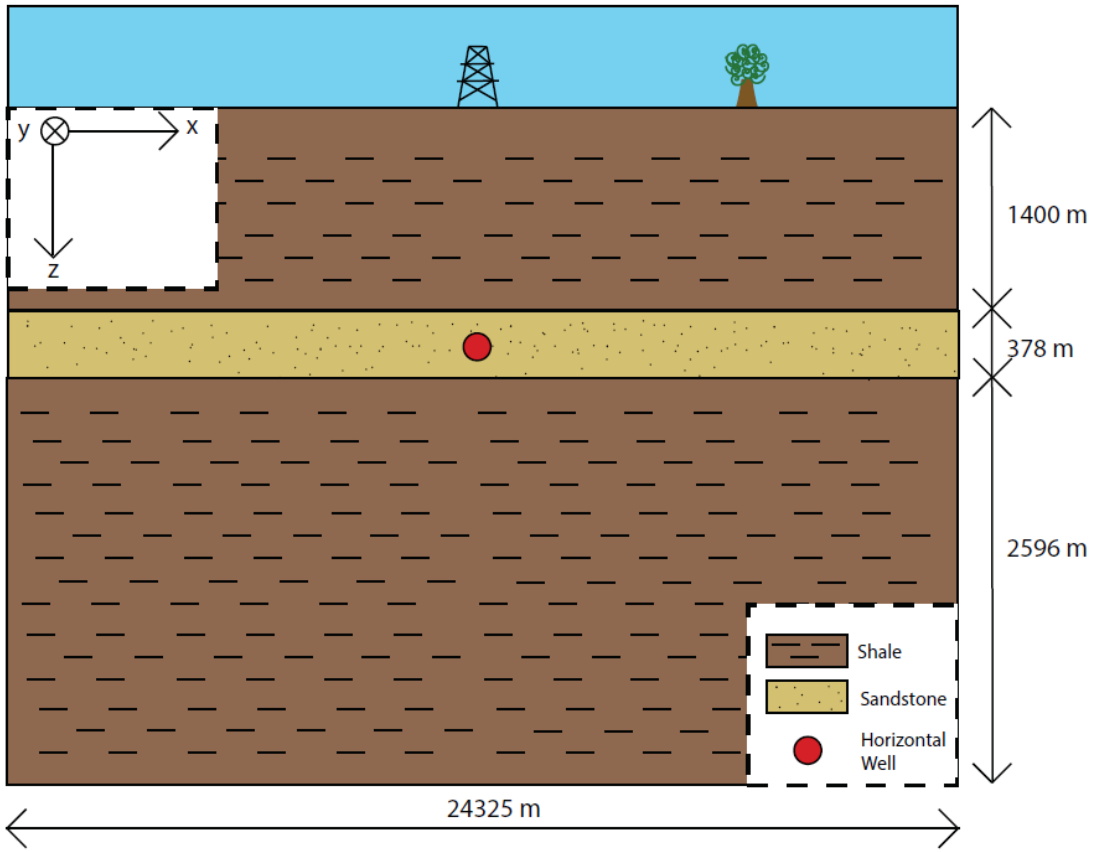
$$u_\alpha = -\frac{\mathbf{K} \cdot k_{r,\alpha}}{\mu_\alpha} \cdot \nabla P$$

Tackling the problem

- **Numerical experiment**
- **Comparison of seismicity with and without stimulation**
- **Seismicity model:**

$$\frac{dR}{dt} = \frac{R}{t_a}\left(\frac{\dot{\tau}}{\dot{\tau}_0} - R\right)$$

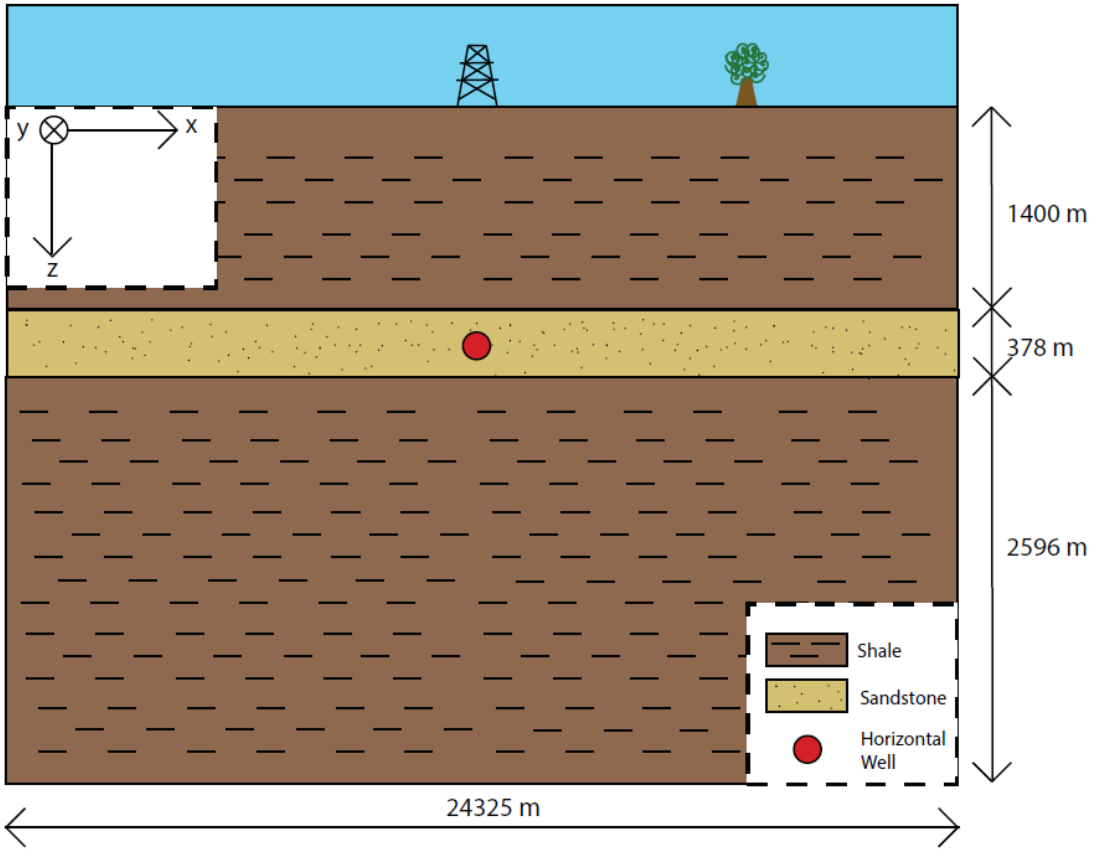
Dieterich 1994



Tackling the problem

- **Reverse faulting**

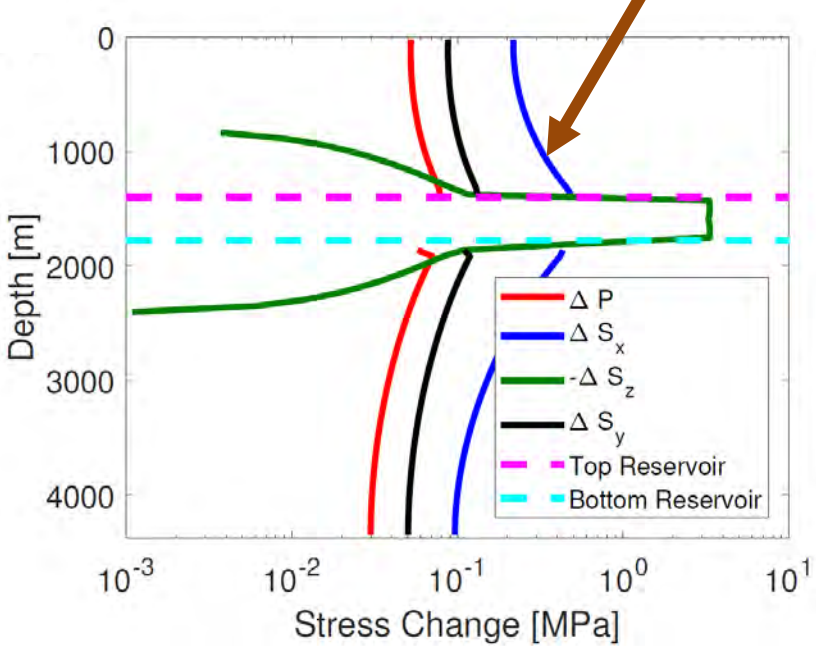
$$(S_x > S_y > S_z)$$

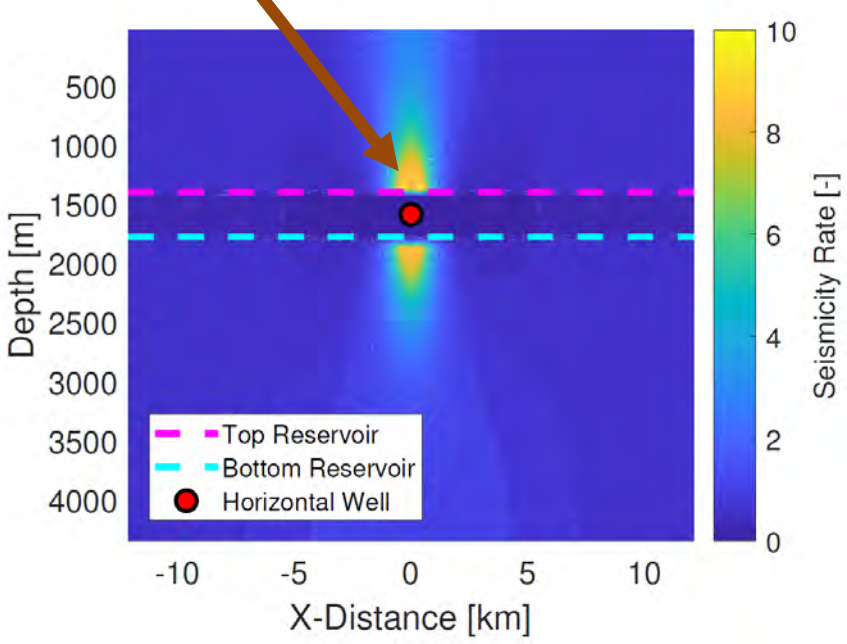


Numerical experiment

- **Reverse faulting – results NO stimulation**

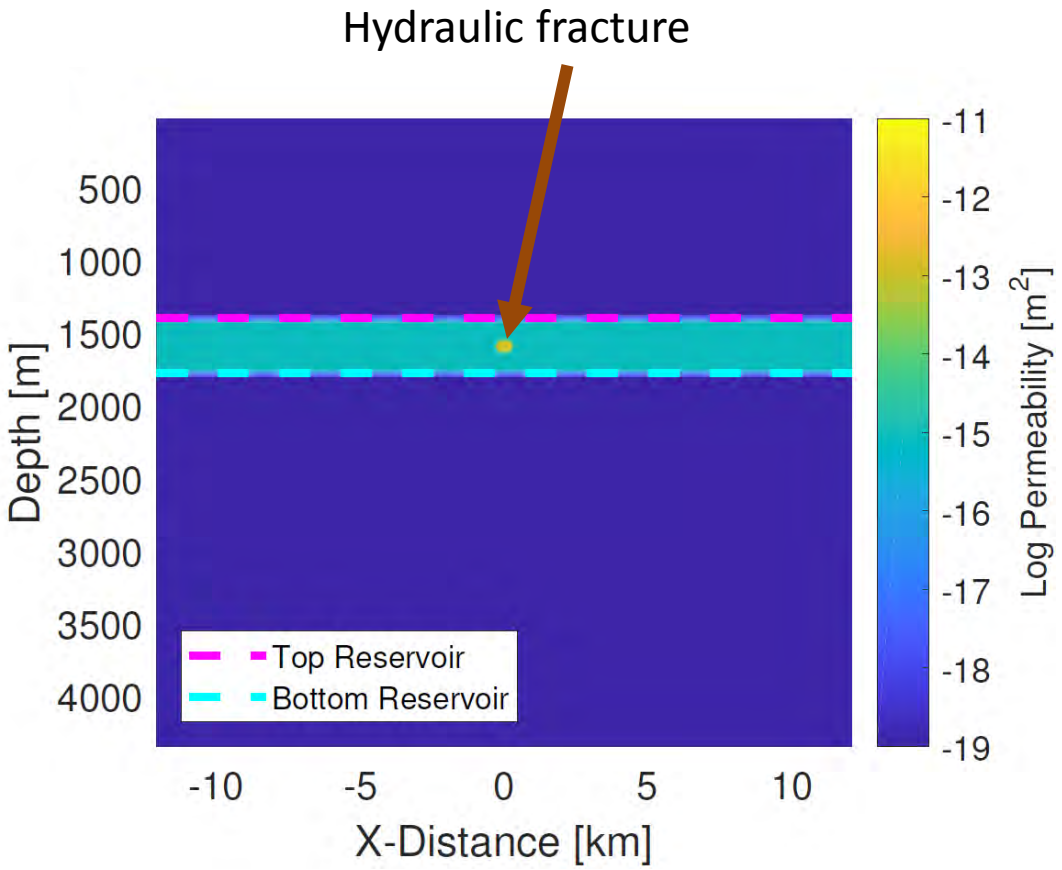
Horizontal compression & seismicity





Numerical experiment

- **Reverse faulting – stimulation**



Numerical experiment

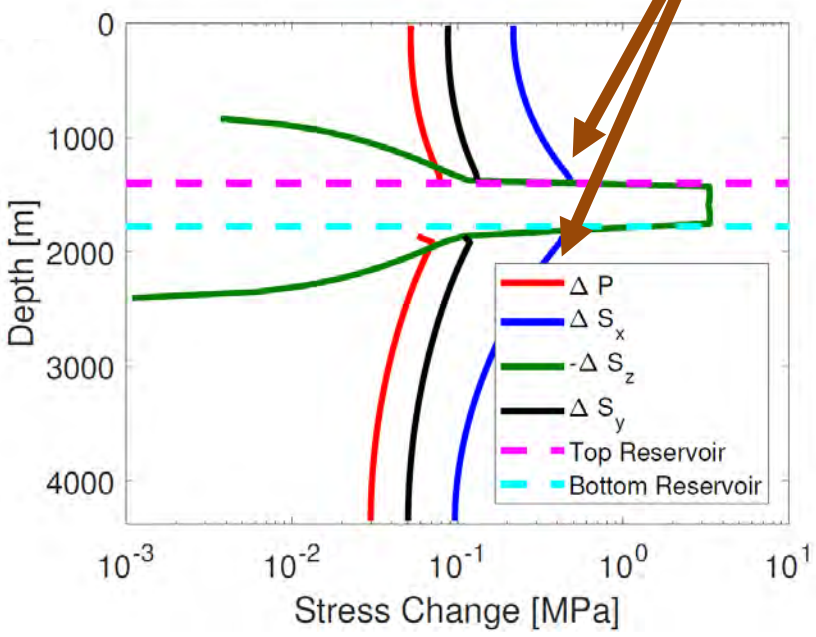
- **Reverse faulting – result comparison**

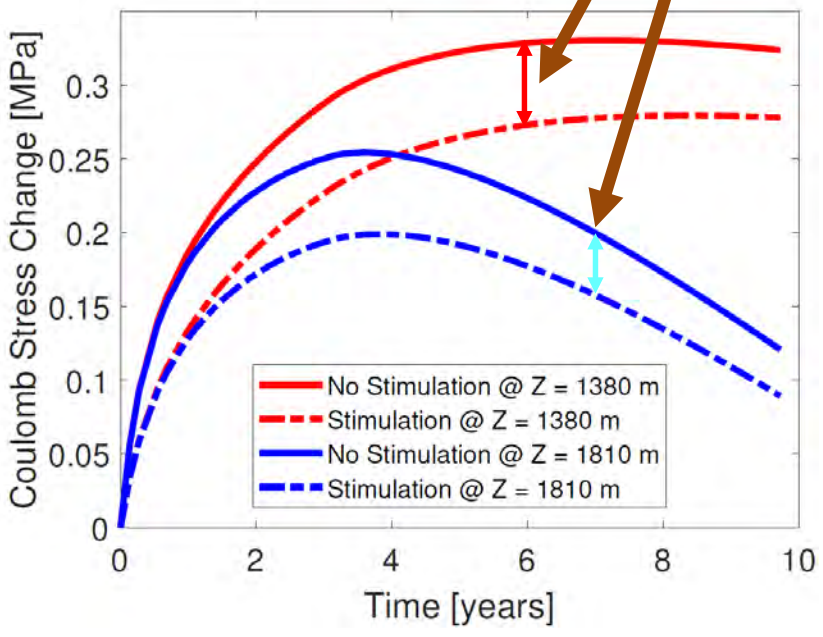
Horizontal compression above and below reservoir

No stimulation

Yes stimulation

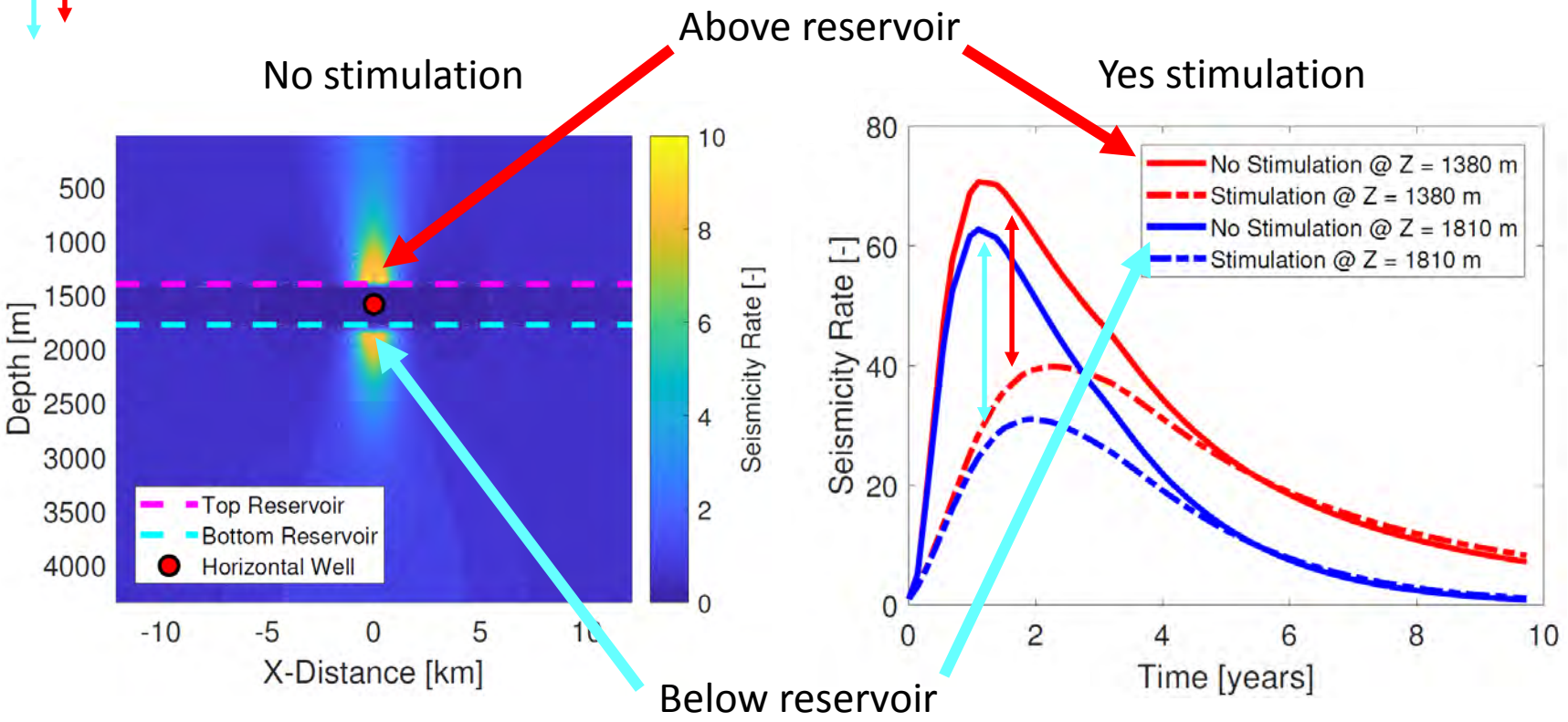
Reduced Coulomb stress





Numerical experiment

- **Reverse faulting – seismicity rate comparison**
- **mark seismicity reduction**



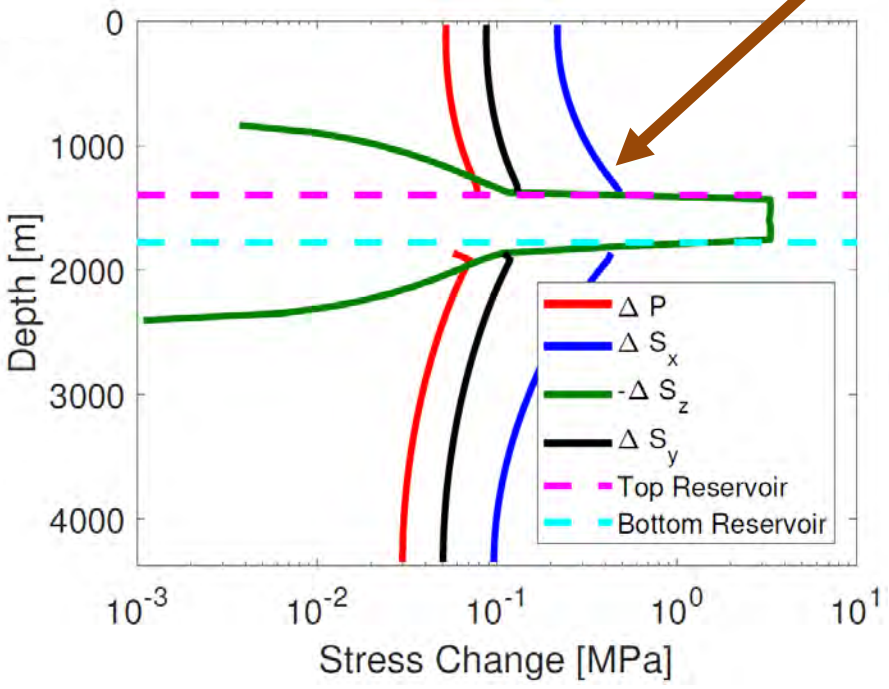
Discussion & conclusion

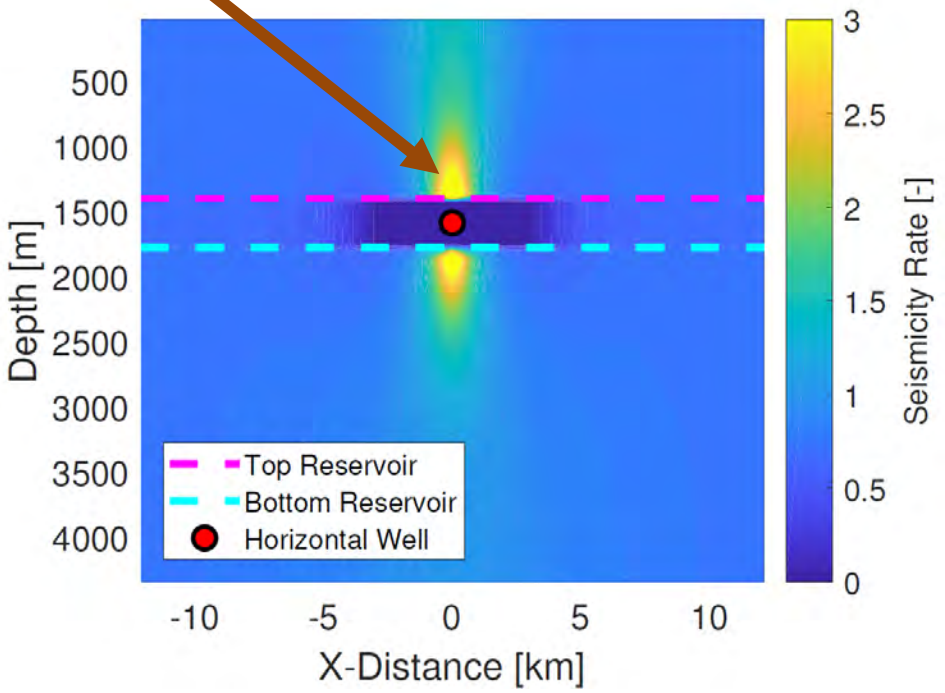
- **Summary of results (reverse faulting):**
  - **Production causes horizontal compression above and below reservoir**
  - **This stress increase causes seismicity**
  - **Hydraulic fracturing reduced the pore pressure gradient needed to produce fluid**
  - **This reduced horizontal compression induced**
  - **Resulting in less seismicity**

Discussion & conclusion

- **Other stress regimes** $(S_x > S_z > S_y)$
  - **Strike-slip faulting (No stimulation)**

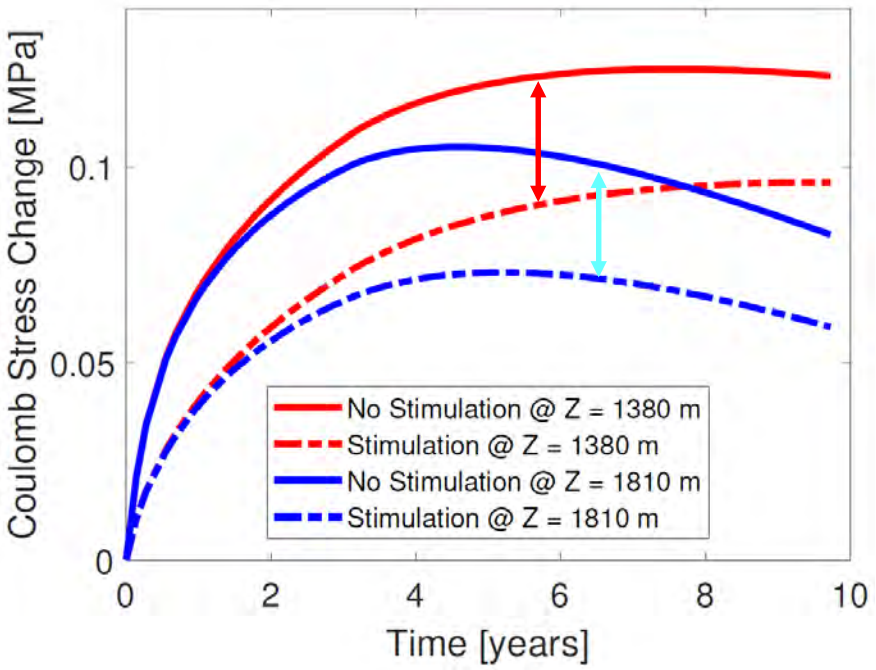
Horizontal compression & seismicity

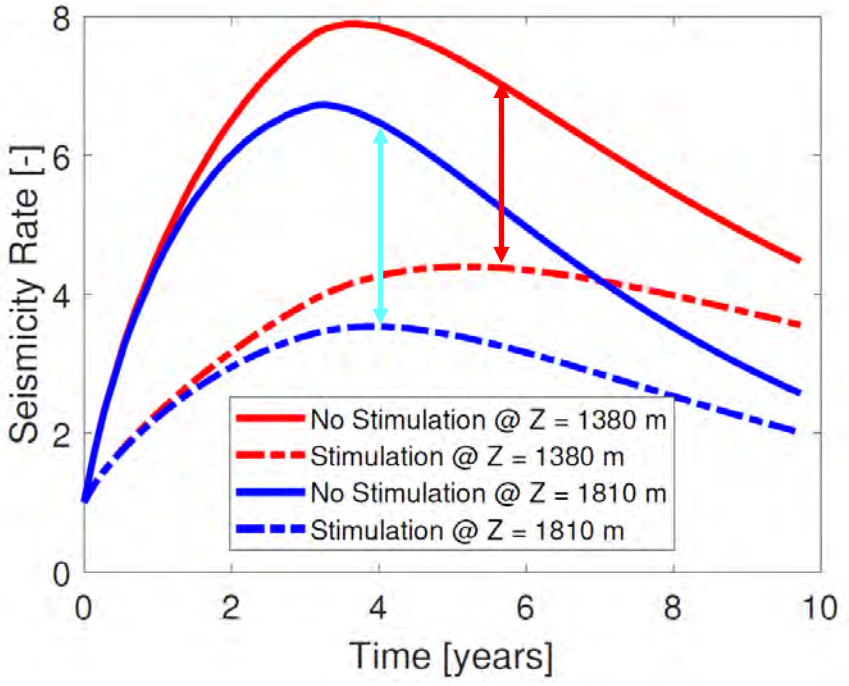




Discussion & conclusion

- **Other stress regimes**
  - **Strike-slip faulting (With stimulation)**





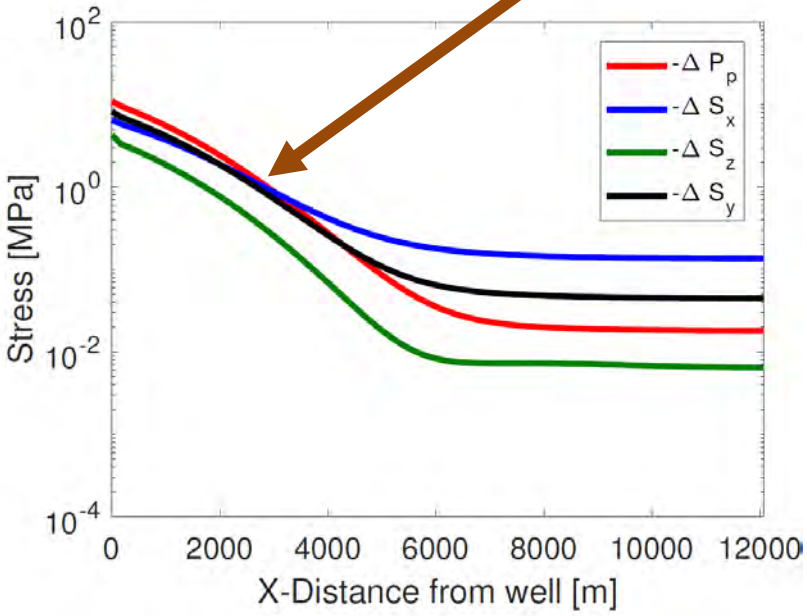
Discussion & conclusion

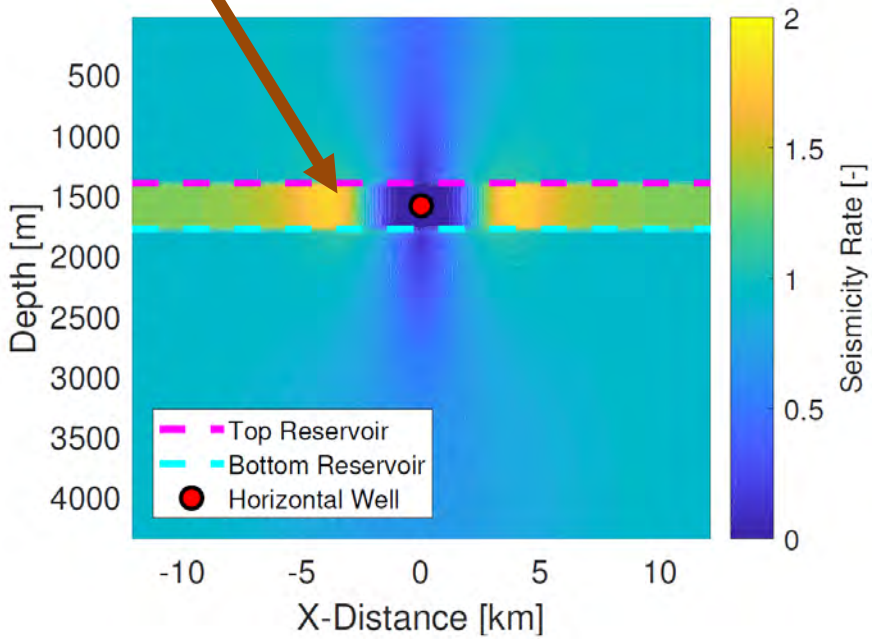
- **Other stress regimes**

$$(S_z > S_x > S_y)$$

  - **Normal faulting (No stimulation)**

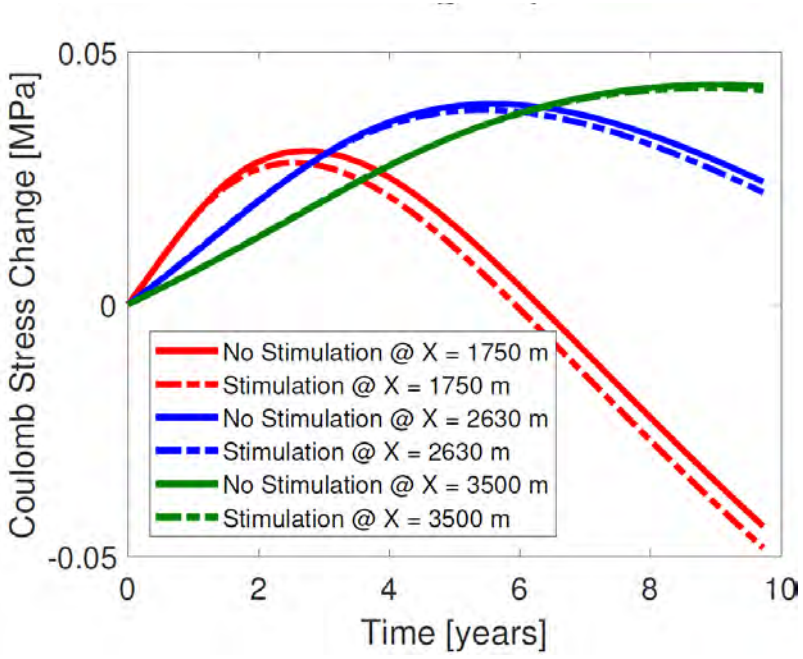
Horizontal tension & seismicity

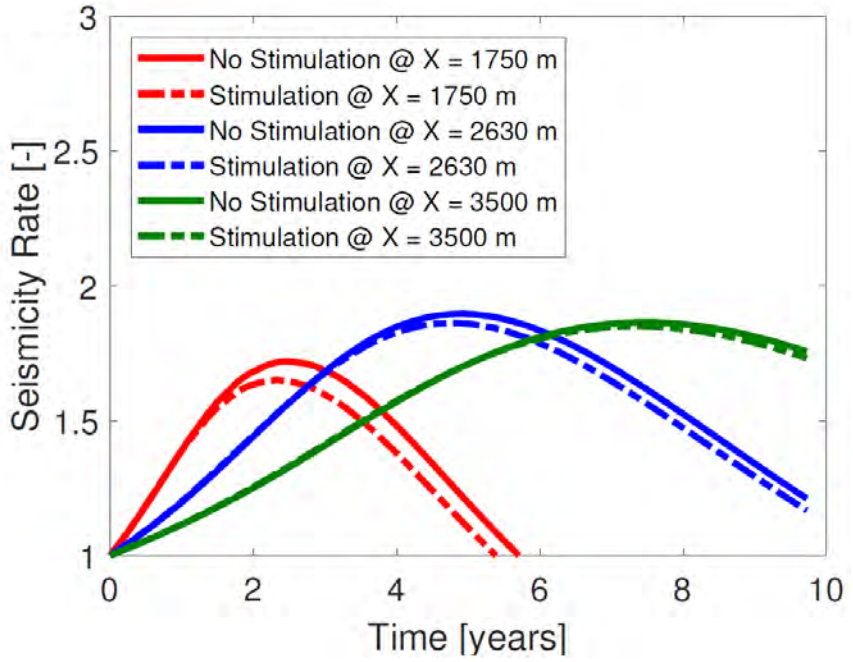




Discussion & conclusion

- **Other stress regimes**
  - **Normal faulting (With stimulation)**
  - **Only small effect**





Discussion & conclusion

- Production induces stress changes based on pore pressure gradient
- These stress changes can cause seismicity
- Stimulation reduces pore pressure gradient
- Resulting in less stress changes
- Resulting in less seismicity