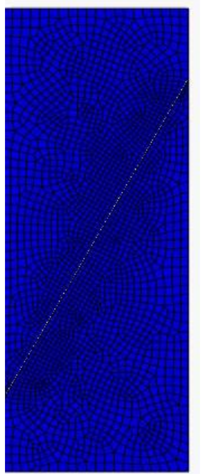
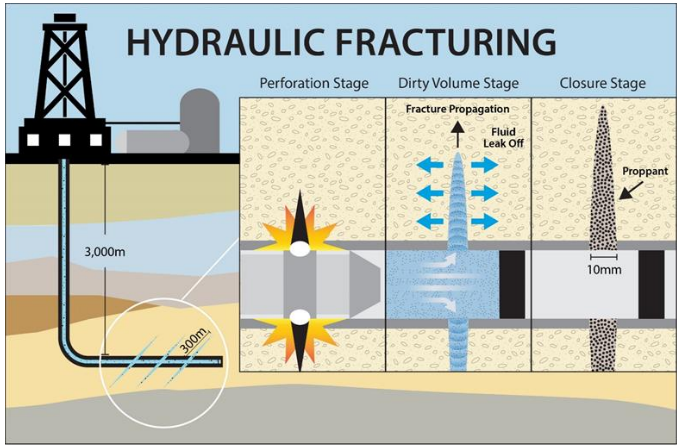
Numerical modelling of fluid-induced fault slip reactivation, application to Geo-Energy systems

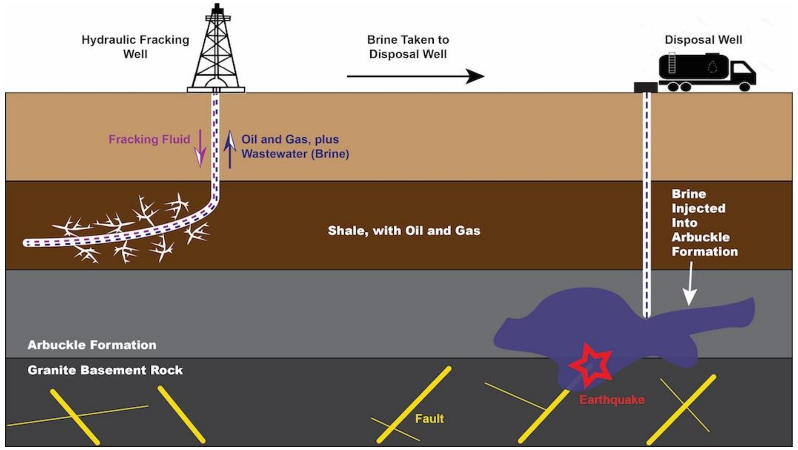


Jinlin Jiang, Pierre Dublanchet, Dominique Bruel, Frederic Pellet

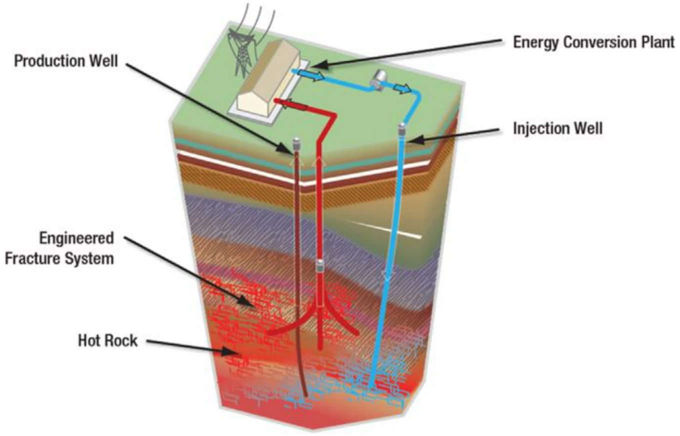
Background



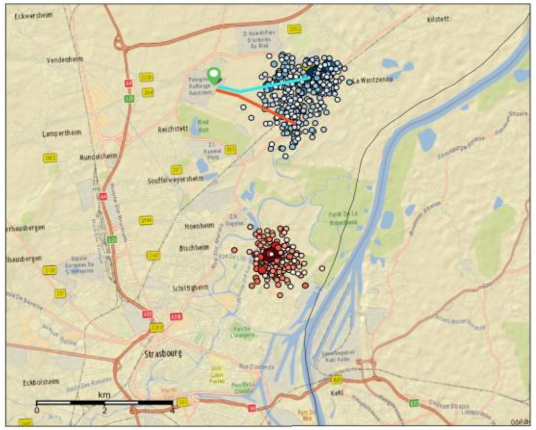
Geoengineer.org, 2020



Wastewater disposal (Manoochehr Shirzaei/ASU, 2018)

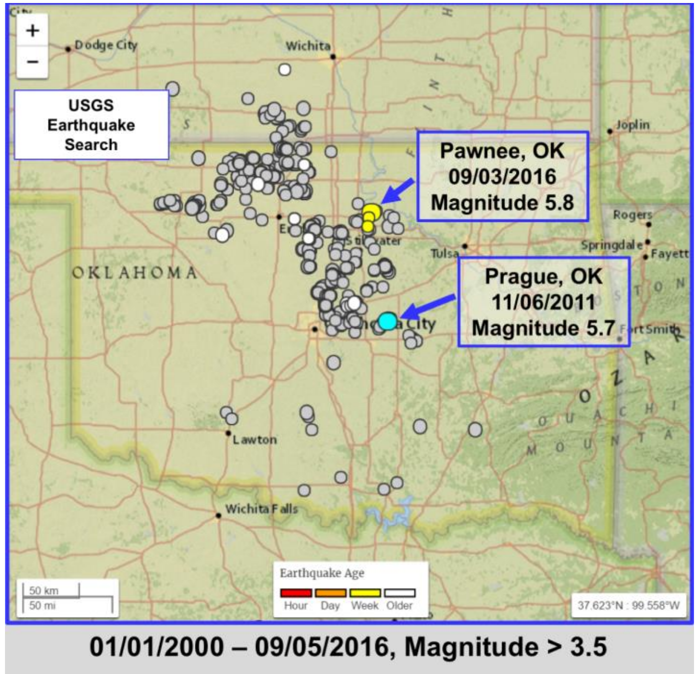


Enhangced Geothermal System (EGS) (P. Olasolo et al. , 2015)

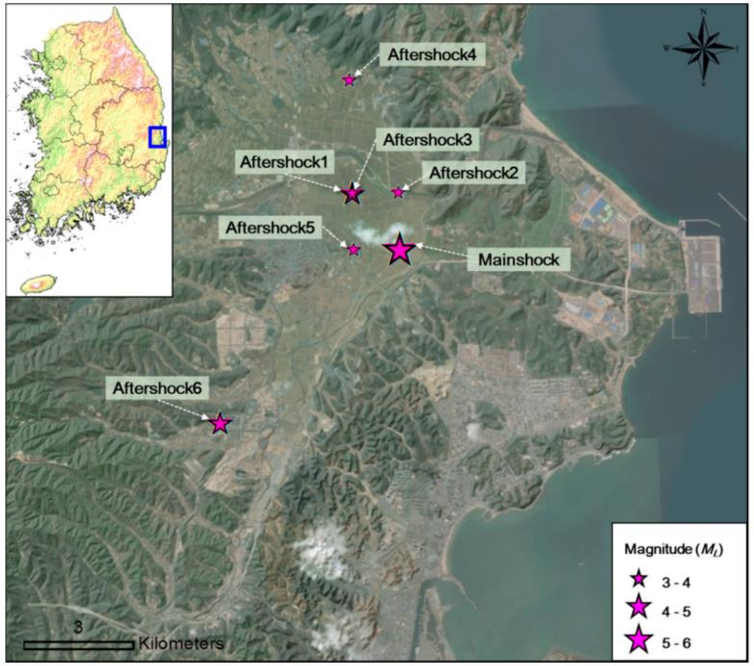


Seismicity in the geothermal site to the north of Strasbourg from March 2018 to January 2021. (Schmittbuhl et al., 2021)

Background



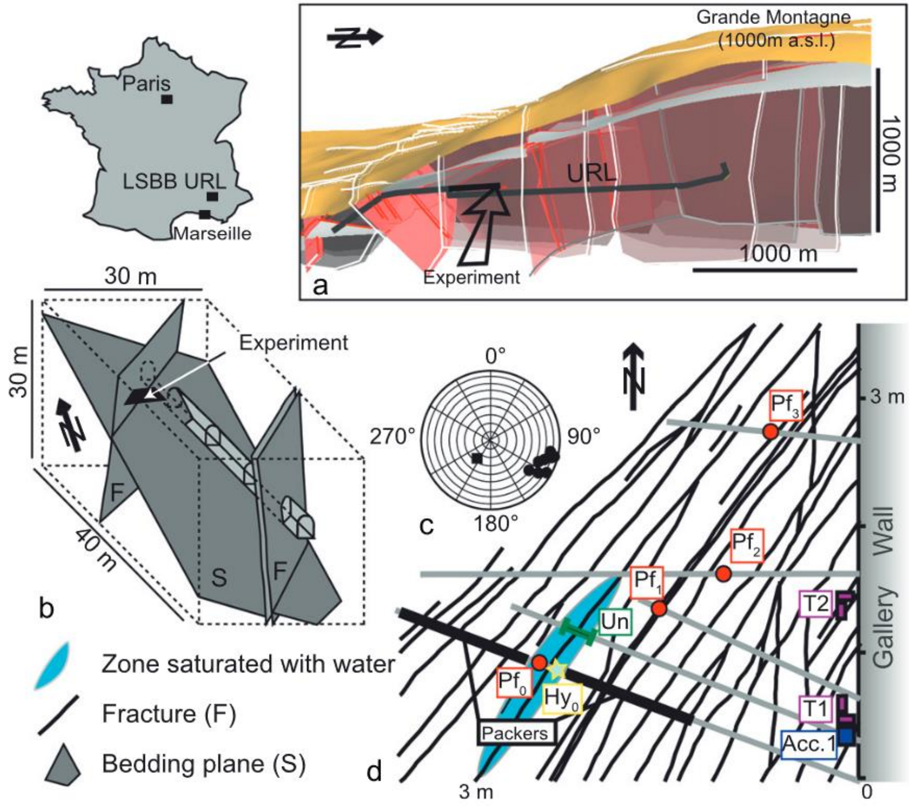
Seismicity in the region surrounding the 2011 (M5.7) and 2016 (M5.8) earthquakes in Oklahoma.



Epicenters of major events of the 2017 Pohang earthquake (Han-Saem Kim et al., 2018)

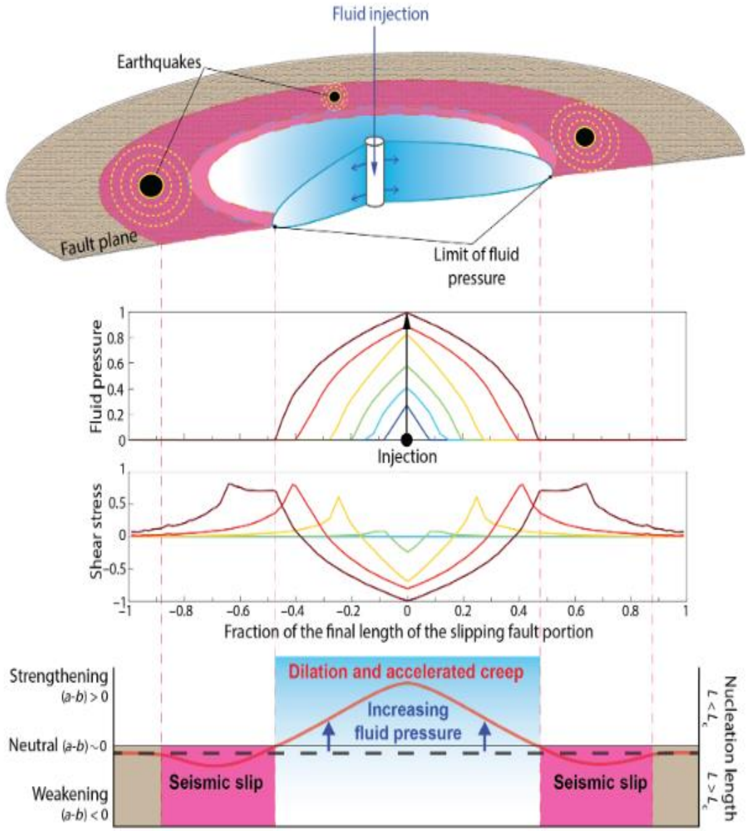
Drilling rig on site in St. Gallen, Switzerland (source: Webcam Project website, Aug. 7, 2013)

Background



Horizontal meter scale map of the geological and experimental set-up (Derode et al., 2013)

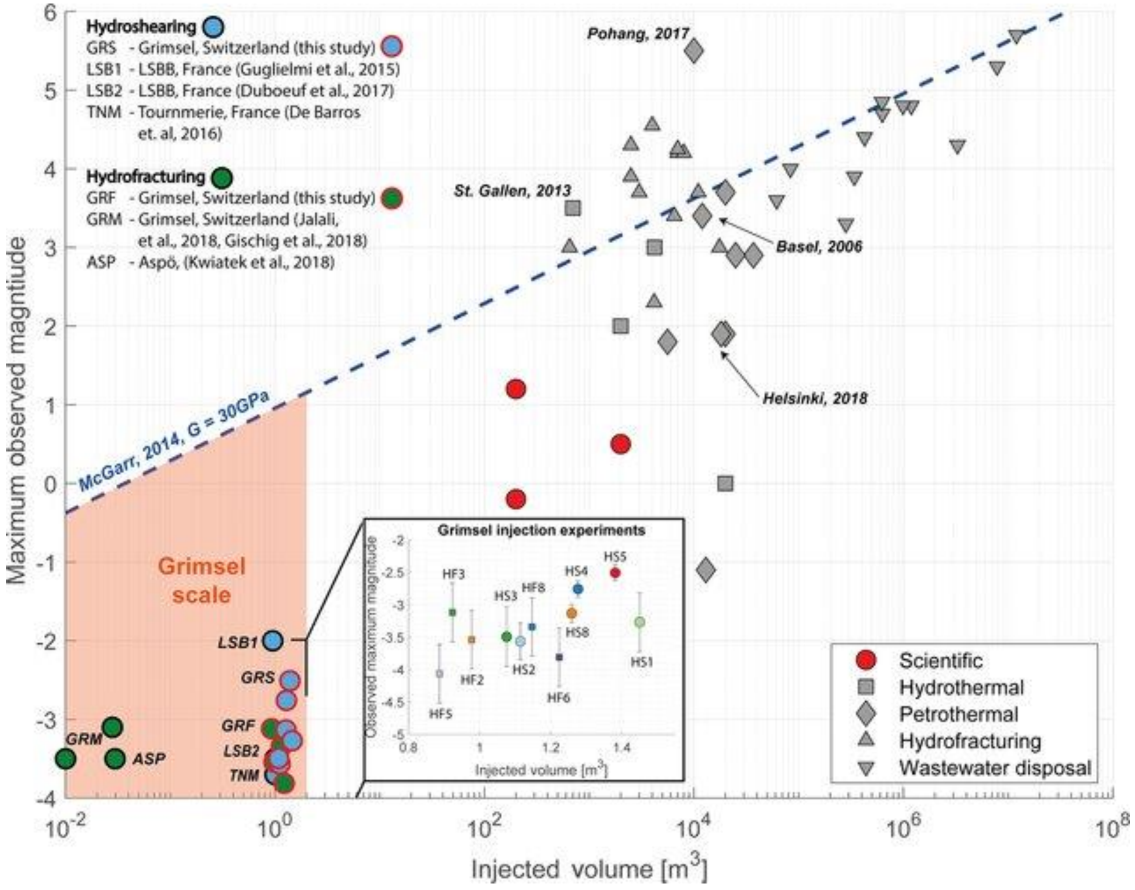
mechanical weakening of the fractures (near field) → normal stress release (across fluid-injection fracture) → fracture slip and permeability increase



Evolution of fault frictional stability during fluid injection (Cappa et al., 2019)

Increase in fluid pressure first induces accelerating aseismic creep and fault opening. As the fluid pressure increases further, friction becomes mainly rate strengthening, favoring aseismic slip. Their study reveals how coupling between fault slip and fluid flow promotes stable fault creep during fluid injection. Seismicity is most probably triggered indirectly by the fluid injection due to loading of nonpressurized fault patches by aseismic creep

Background

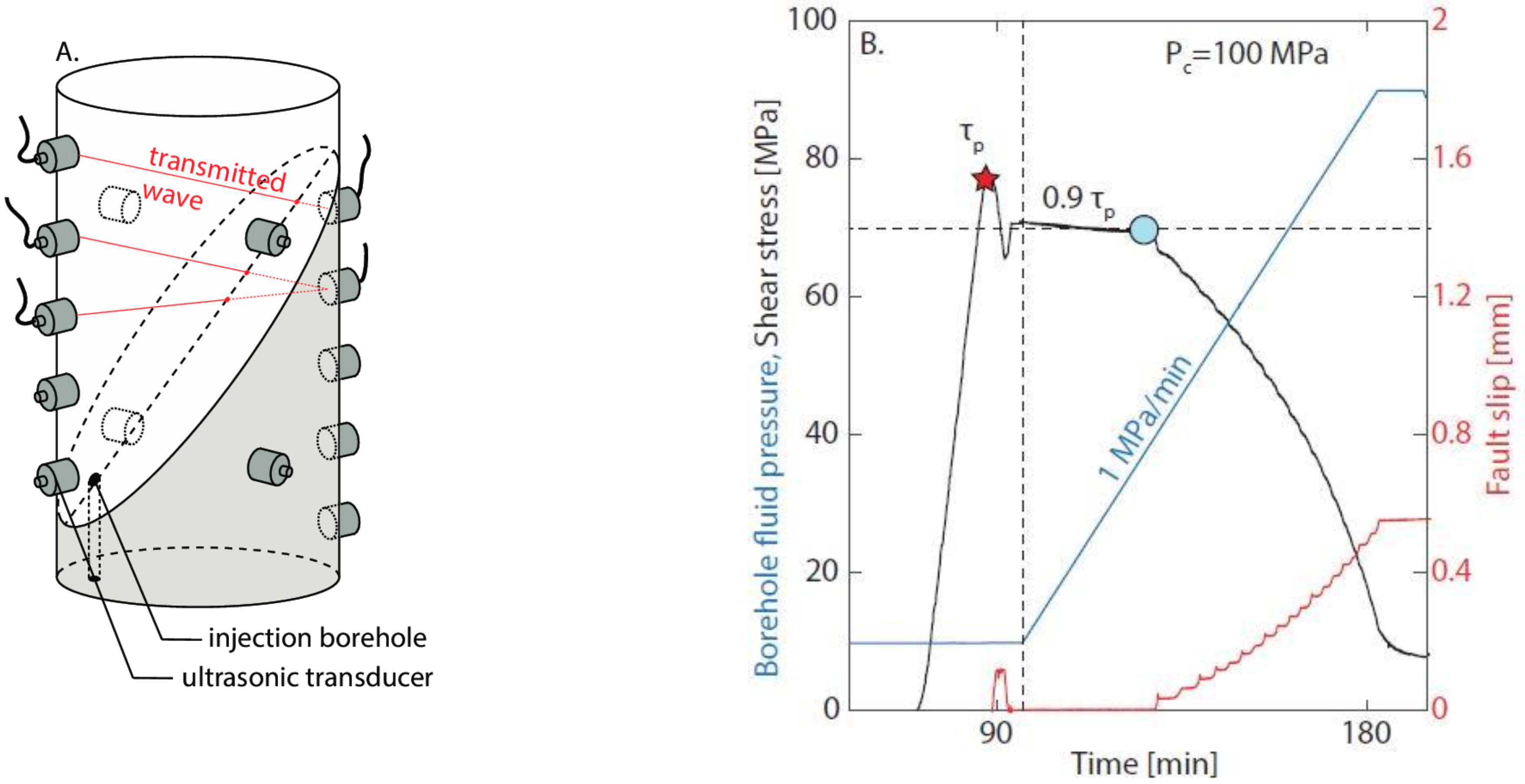


Injected fluid volume vs. maximum observed magnitude of fluid injections at different scales (Linus Villiger et al., 2020)

Objective

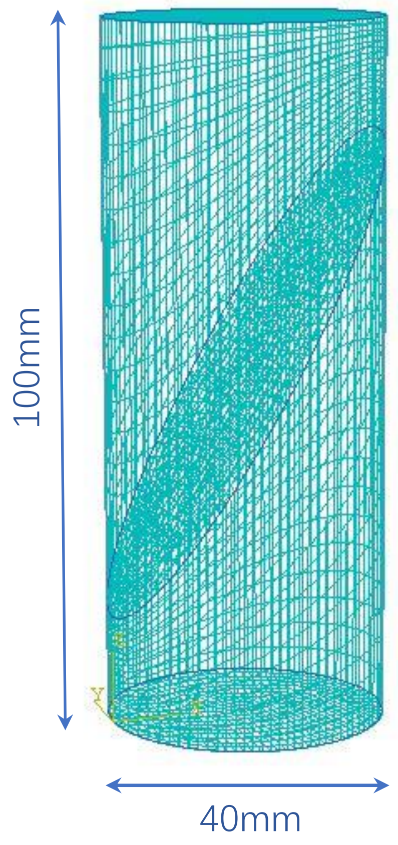
- 3D finite element model
- Fault reactivation induced by fluid injection
- Parameter study (injection rate, diffusivity, frictional parameters...)
- How is the fault reactivated?
- What parameters control the behavior of fault slip?

Numerical model

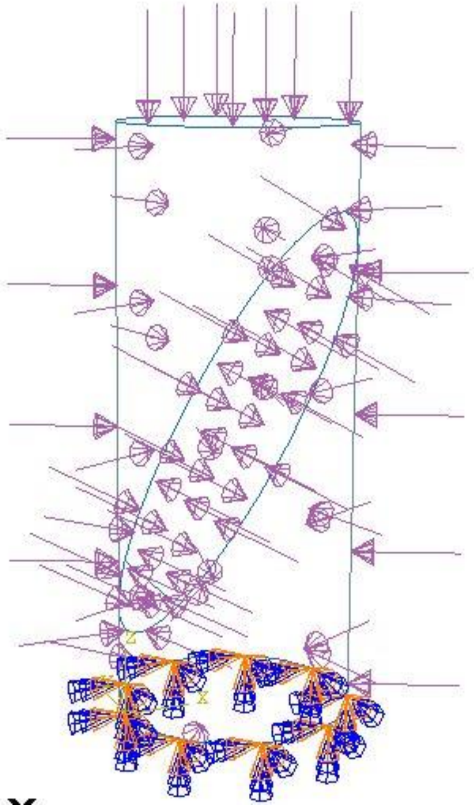


Schematic diagram of the sample assembly. (Passelegue, 2018)

Numerical model



FEM mesh



Loading and boundary condition

- 3D Finite Element Model, pre-existing fault

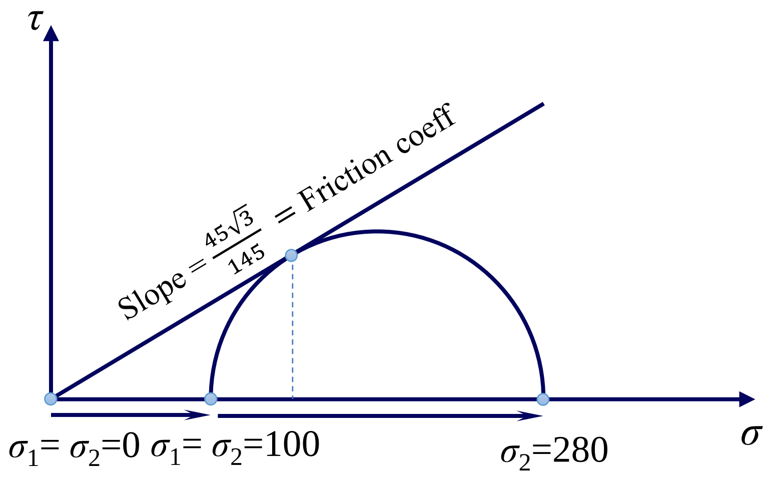
- Loading and boundary condition
  σ_1 0→278MPa→90%
  σ_3 100MPa
  Fluid injection: 10→90MPa
  1,10,100,1000MPa/min
  Bottom U_2=0
  Middle point fixed

- Interaction type: surface-to-surface contact

Tangential Behavior: User-defined Slip-weakening
Coulomb friction law, μ_s=0.578, μ_d=0.5.
Pressure-Overclosure: “Hard” Contact

Methodology

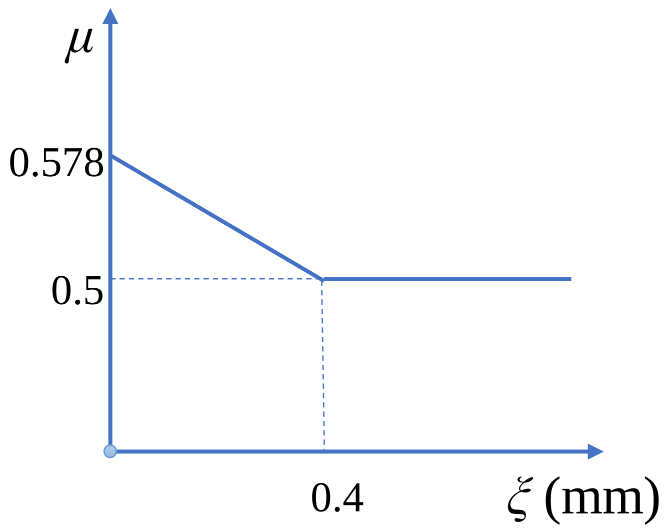
Mohr Diagram



$$\sigma = \frac{1}{2}(\sigma_1 + \sigma_2) + \frac{1}{2}(\sigma_1 - \sigma_2)\cos 2\beta$$

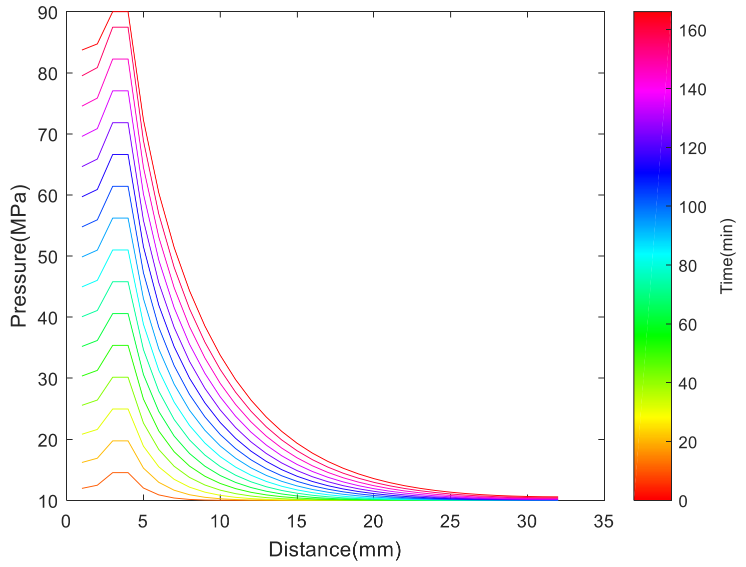
$$\tau = -\frac{1}{2}(\sigma_1 - \sigma_2)\sin 2\beta$$

Slip-weakening friction law



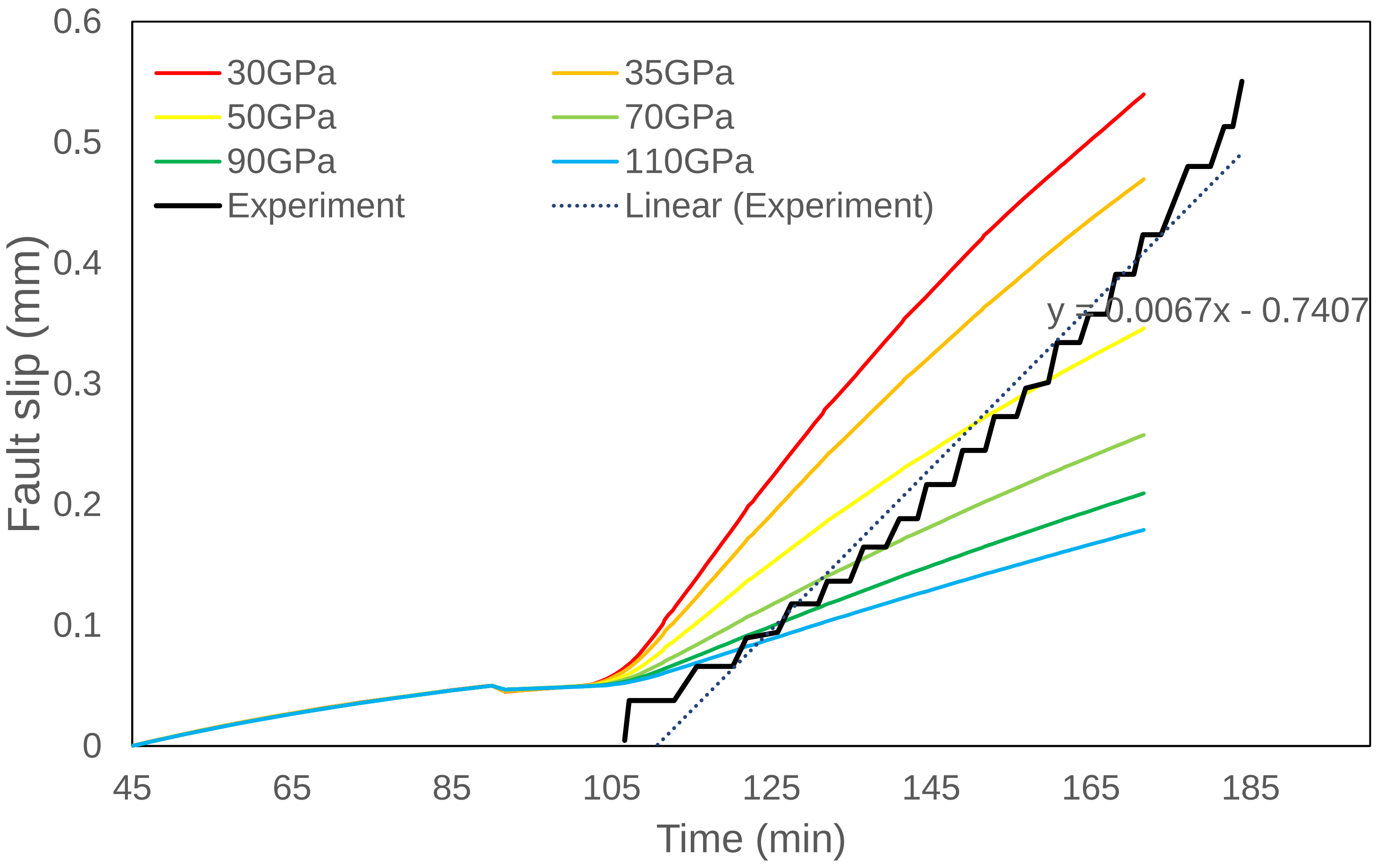
$$\mu = \begin{cases} \dfrac{\mu_d - \mu_s}{d_c}\xi + \mu_s\,, & (\xi < d_c) \\ \mu_d\,, & (\xi > d_c) \end{cases}$$

Fluid diffusion



$$\frac{\partial p}{\partial t} = D \cdot \nabla^2 p$$

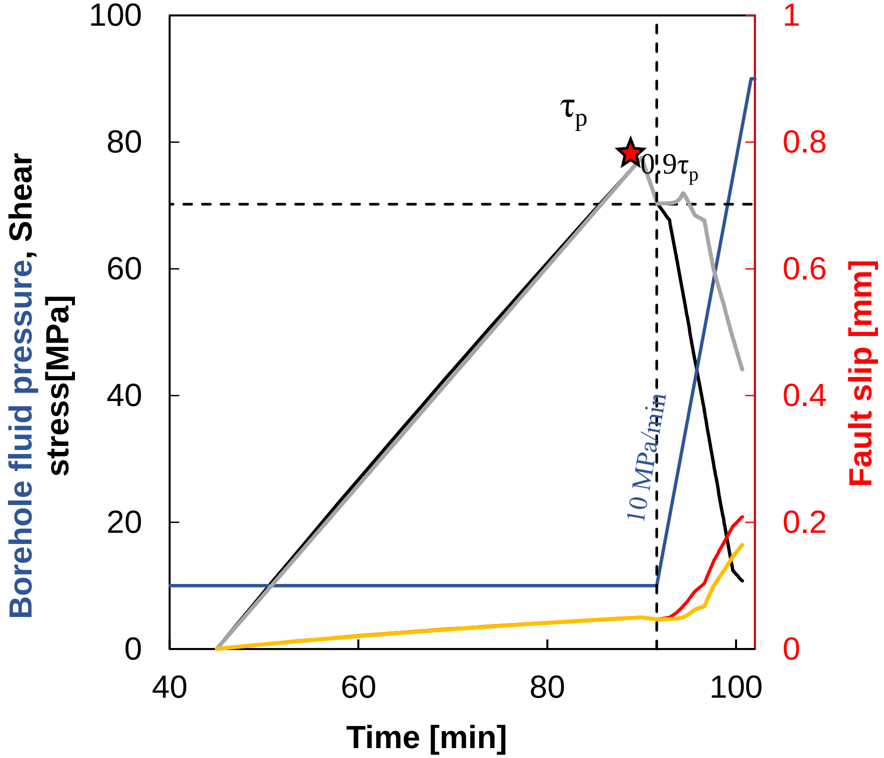
Results

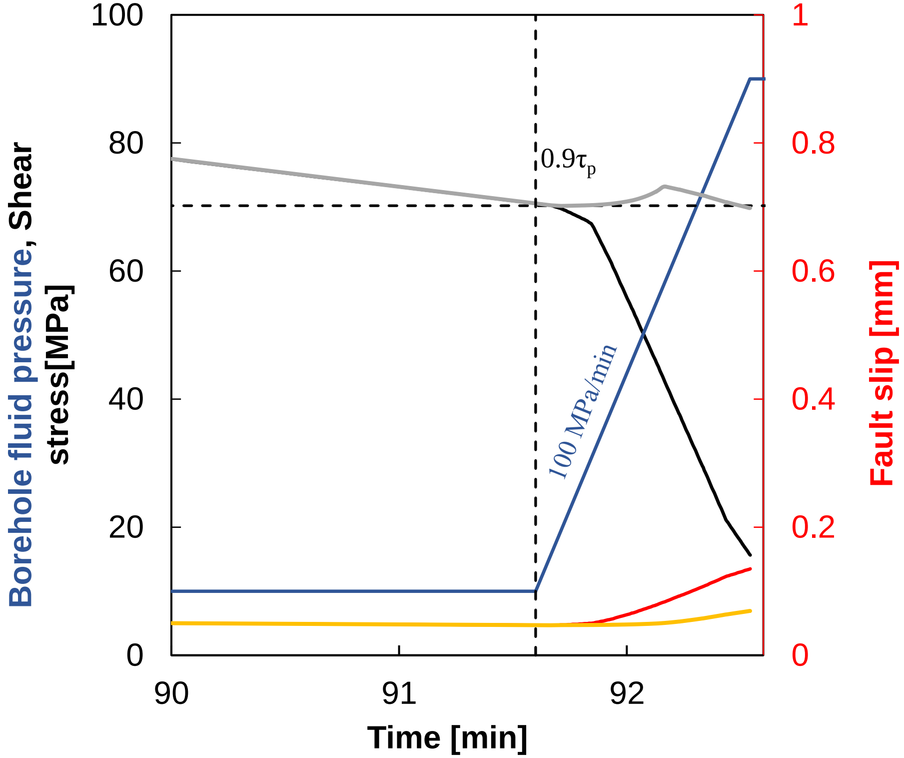


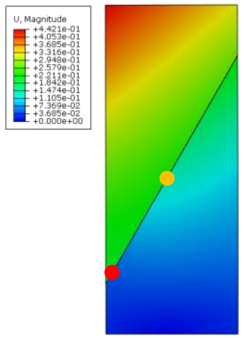
Numerical calibration with different young’s modulus

Results

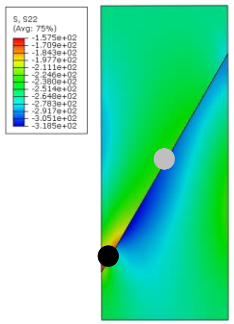
- 5×10^{-6} m²/s







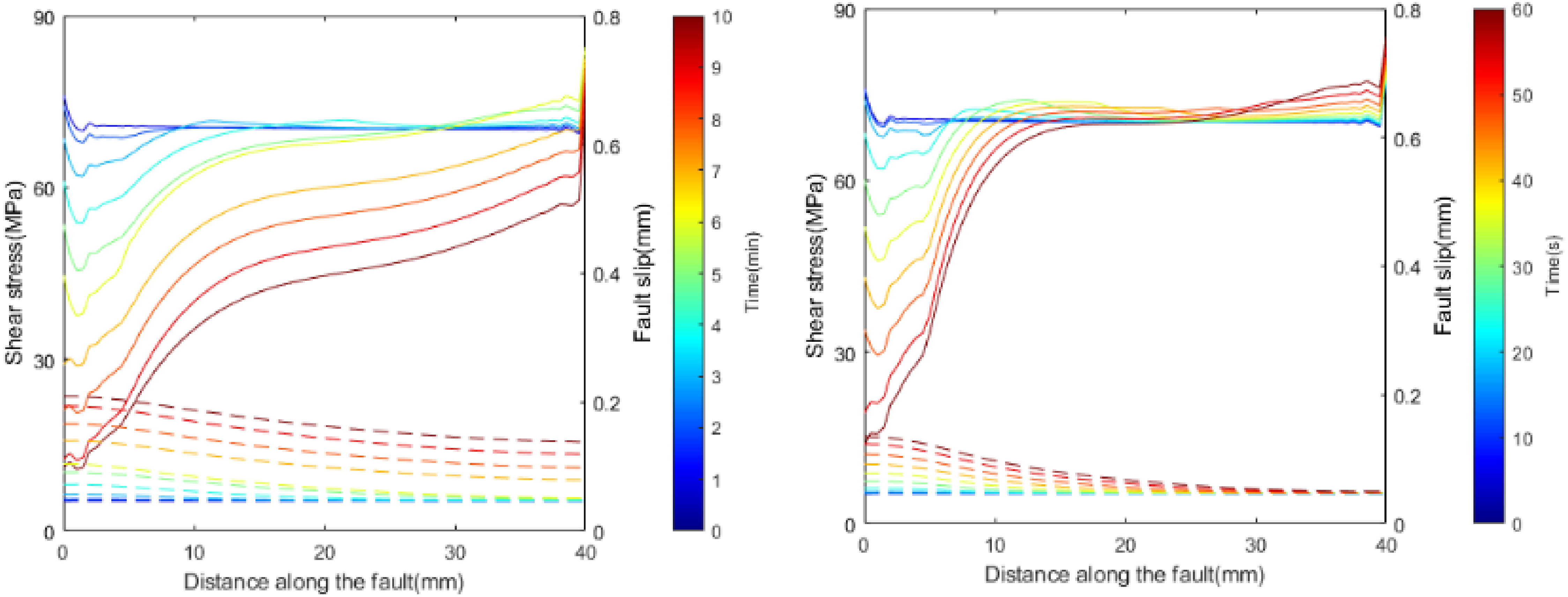
Displacement nephogram



Stress nephogram

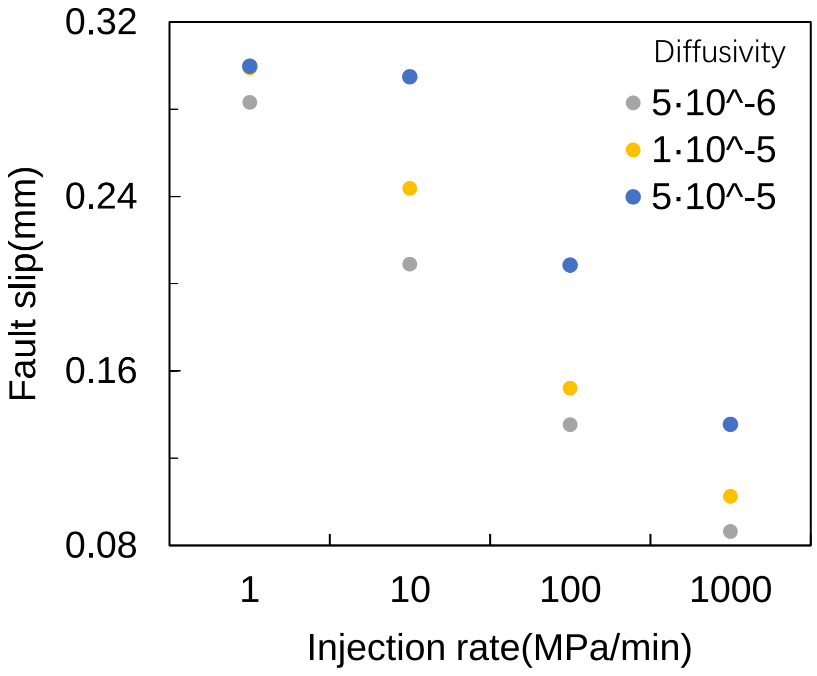
- Location mechanical performance difference
- Maximum slip with injection rate

Results

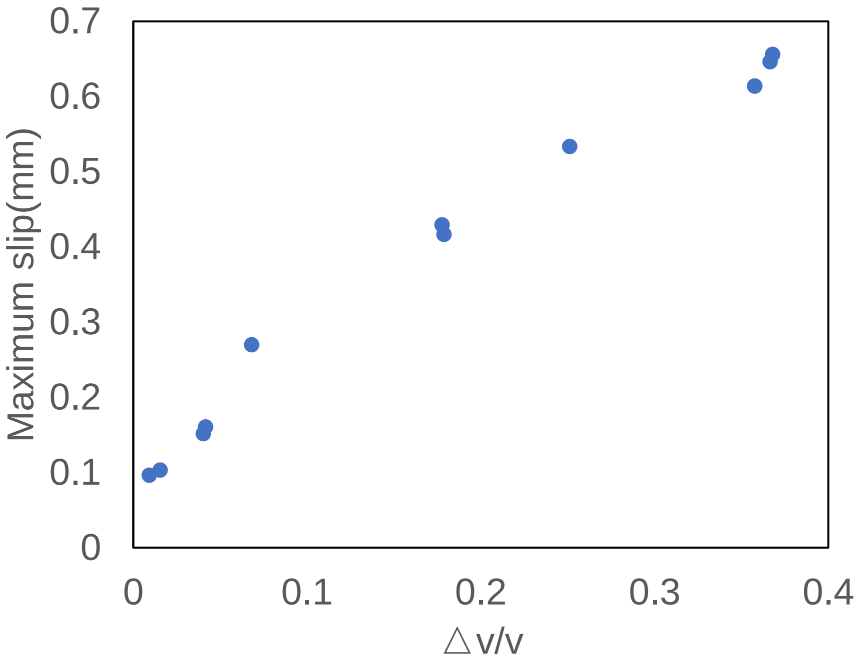


Time history of shear stress and relative fault slip evolution along the fault. The solid is shear stress and the dashed is fault slip. Left: injection rate V_{inj} = 10MPa/min. Right: V_{inj} = 100MPa/min.

Results

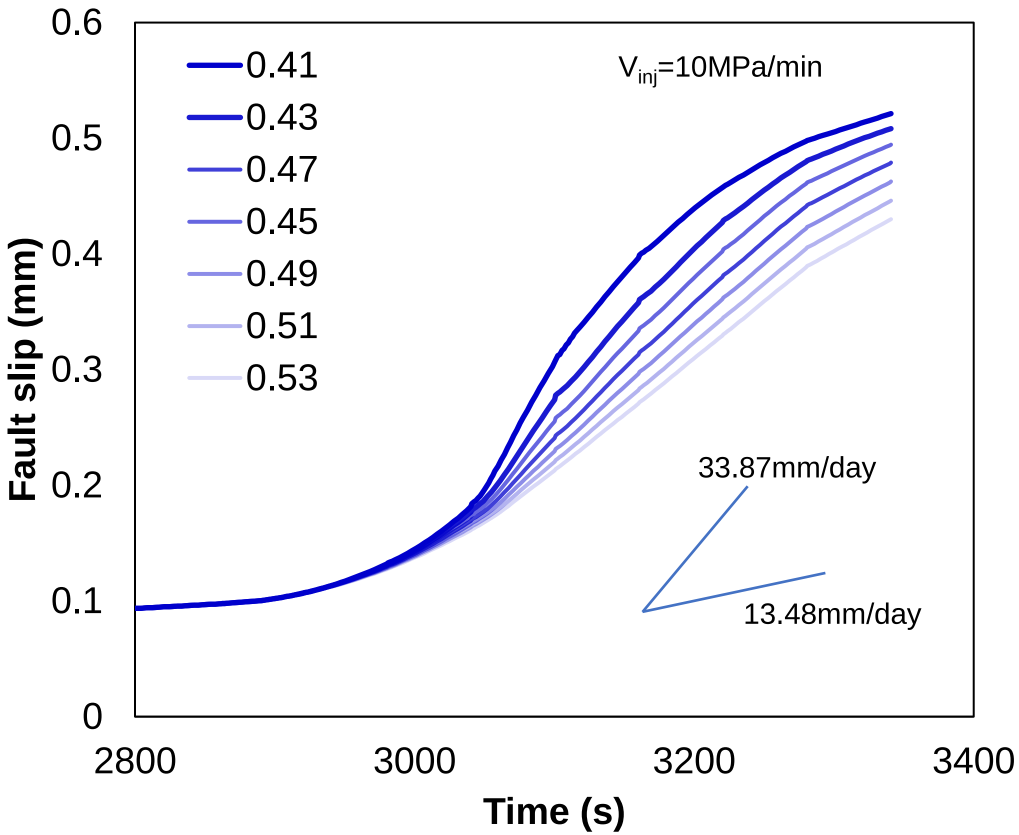


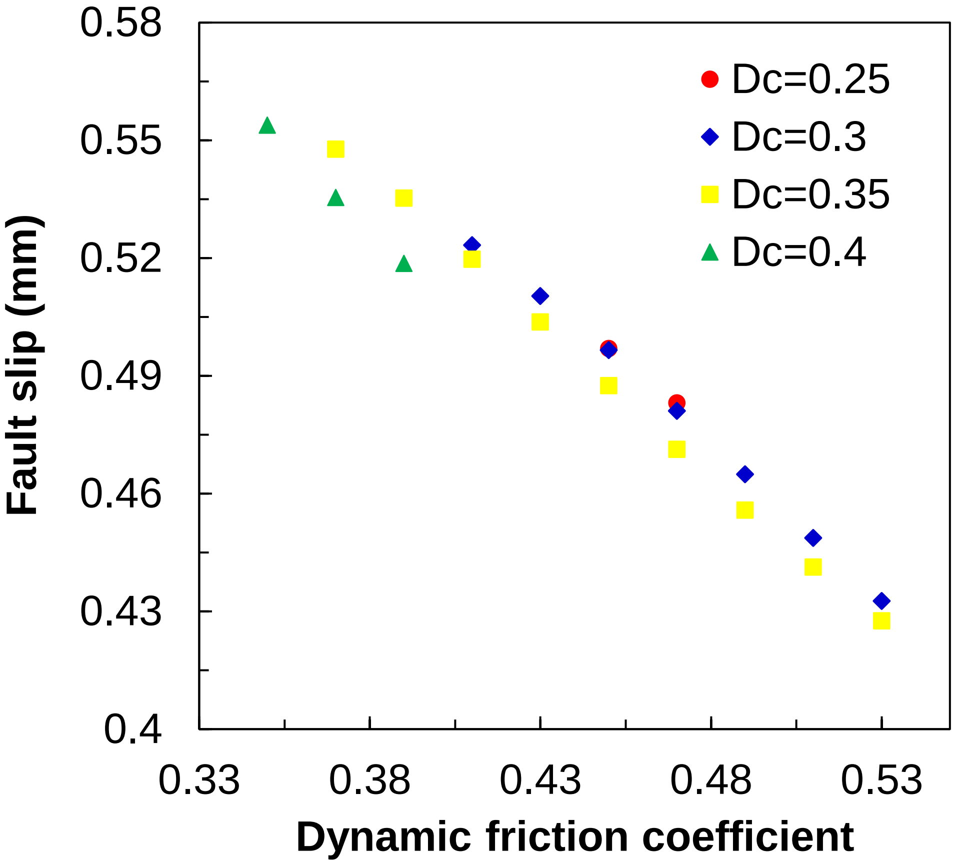
Fault slip tests with three groups of diffusivities and diverse injection rates.



Maximum slip dependent on fluid volume.

Results

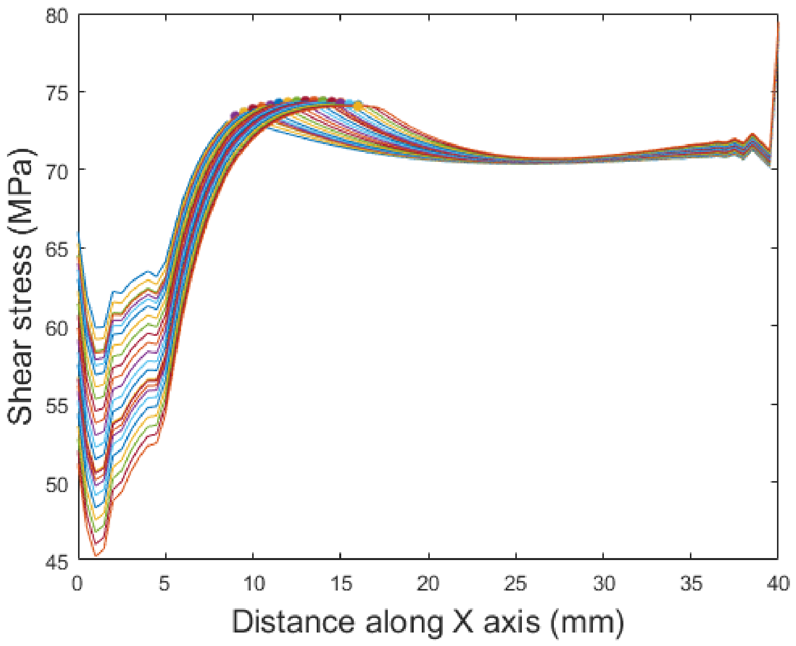




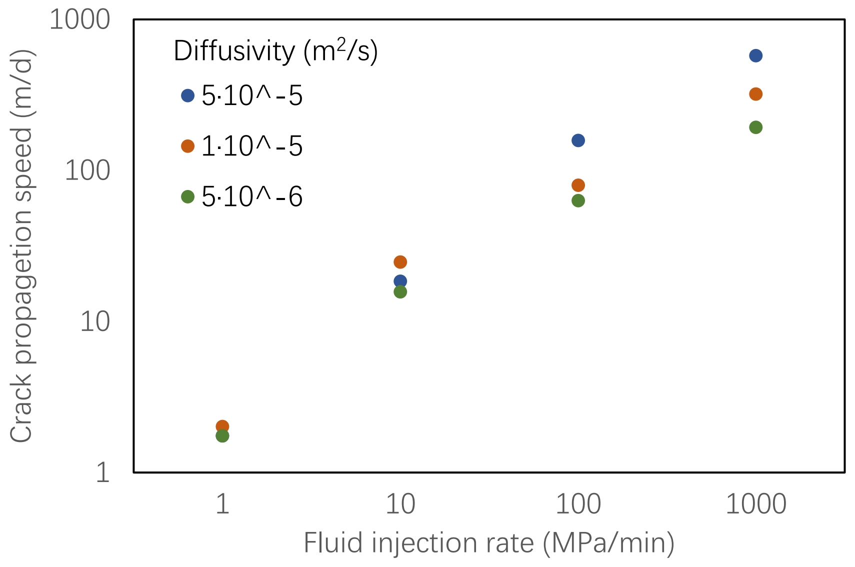
Parameter study of slip weakening friction law. Relationship between fault slip with dynamic friction coefficient μ_d and slip weakening threshold Dc.

Results

Shear front along the strike and calculation of crack propagation speed



$$v_{p,t} = \frac{x_{sp,t+\Delta t} - x_{sp,t}}{\Delta t}$$



Crack propagation tests with three groups of diffusivities and diverse injection rates.

Conclusion & Prospect

- Conclusion

1. Fault slip is dependent on injection rate, diffusivity and injection volume. An increase of diffusivity and injection volume results in higher fault slip. Lower injection rates lead to larger amount of fluid injected and higher fault slip.

2. Crack propagation speed ranges from 1 to 300 m/day and increase with diffusivity and injection rate.

- Prospect

How initial stress and confining pressure affect fault reactivation behavior?