Fault reactivation due to fluid injection: fault friction and slip distance

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Induced seismicity, is it only Dp?

Production or injection of fluids from/into the underground has the potential to cause seismic events. Although different physical mechanisms have been proposed and proven possible, nucleation of a seismic event and how the magnitude of the rupture evolves presents still many open questions.

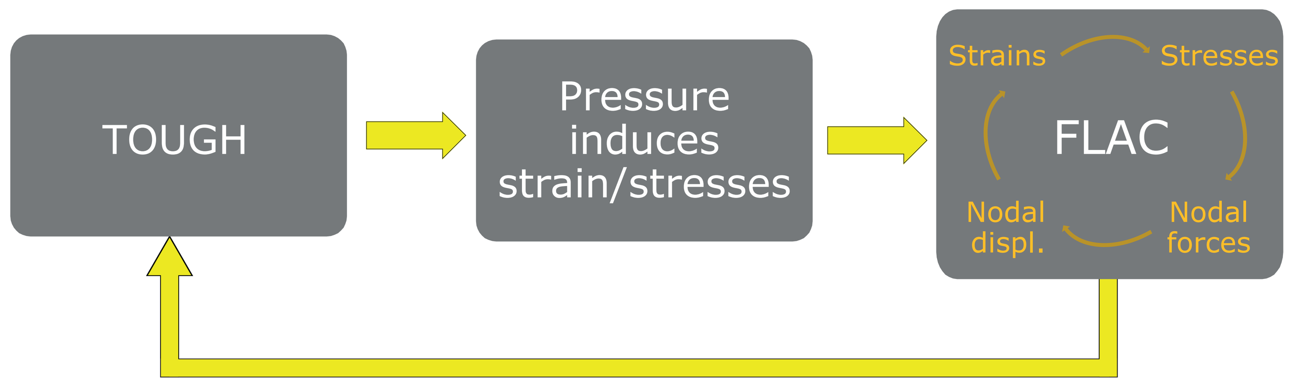
Injection of fluid at shallow crustal depth (1-5 km) can lead to reactivation of existing fault, however it is not yet possible to pinpoint the causality relationship between the human activity and the expected magnitude or the seismic activity.

Similar amount of fluid injected (10-100 thousands of m3) at similar pressures above in-situ condition (1-10 MPa) in proximity of a fault led to a range of different response, from human-felt event to large-scale aseismic motion.

Monitoring of induced and triggered seismicity can provide a vast amount of data, which can be used to upscale results from the lab.

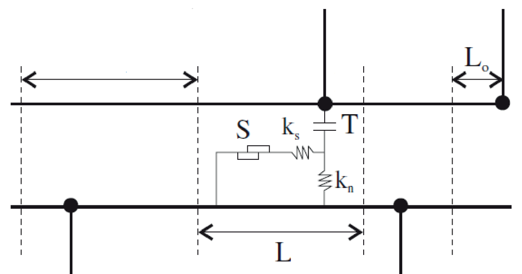
A numerical forward investigation is proposed here, to couple anthropogenic activity and shearing on a fault, with the goal of defining changes due to pressure/temperature and microstructural processes.

The numerical tools



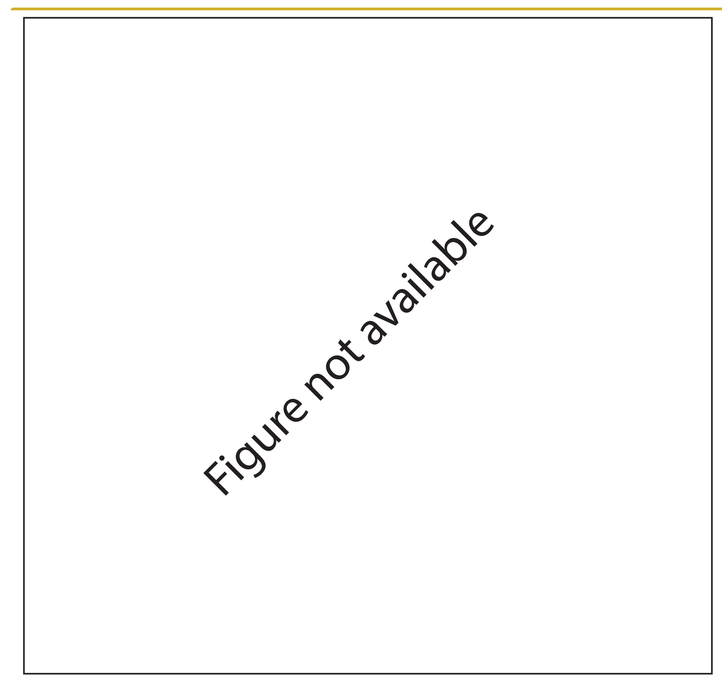
Boundary conditions on fault

- **Before rupture**
  - u_x, u_y = continuous
  - τ_{xx}, τ_{yy} = continuous
- **Rupture criterion**
  - $\tau \geq \mu_s \sigma_{xx} \tau_{yy}$
- **Rupture**
  - τ depending on frictional behaviour
- **After rupture**
  - u_x = continuous
  - τ_{xx}, τ_{yy} = continuous



S= slider (μ, C, ψ)
T= tensile strength
k_n= normal stiffness
k_s= shear stiffness

Laboratory measurements



From Plyumaeker et al. (2014) "Effects of temperature and CO2 on the frictional behavior of simulated anhydrite fault rock".

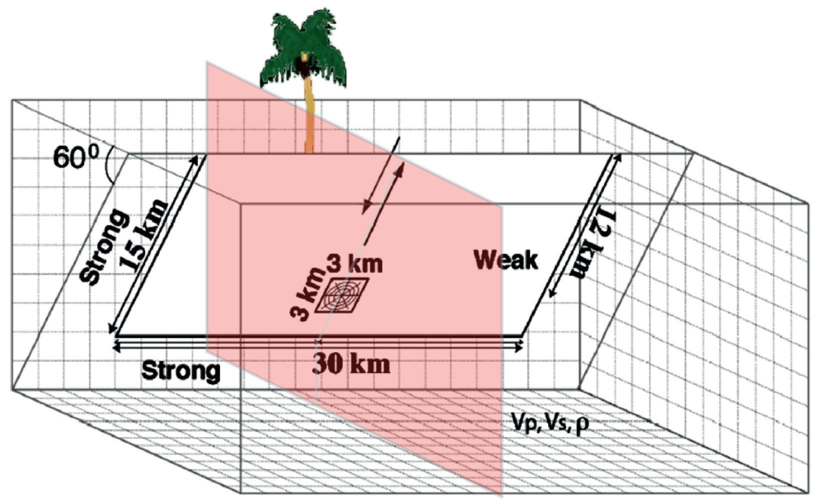
Measurment of change in steady-state (sliding) friction in response to change in sliding velocity from V_0

$$a - b = \frac{\Delta \mu_{ss}}{\ln(V/V_0)}$$

Associated with velocity weakening, stick slip events take place.
Lab equivalent of seismic slip.

Benchmarking of dynamic geomechanical model

The mechancal solver provides results consistent with benchmarks made available by the Southern California Earthquake Center/ U.S. Geological Survey (SCEC/USGS) Dynamic Earthquake Rupture Code Verification Exercise.
The problem shown here is the so-called Problem Version 10-2D & 11-2D

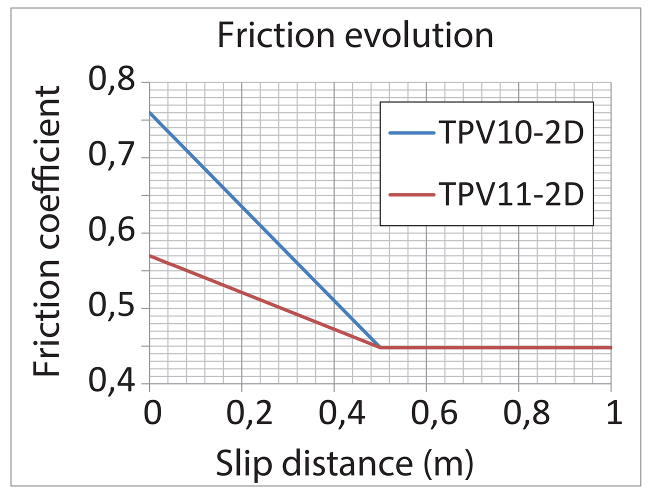


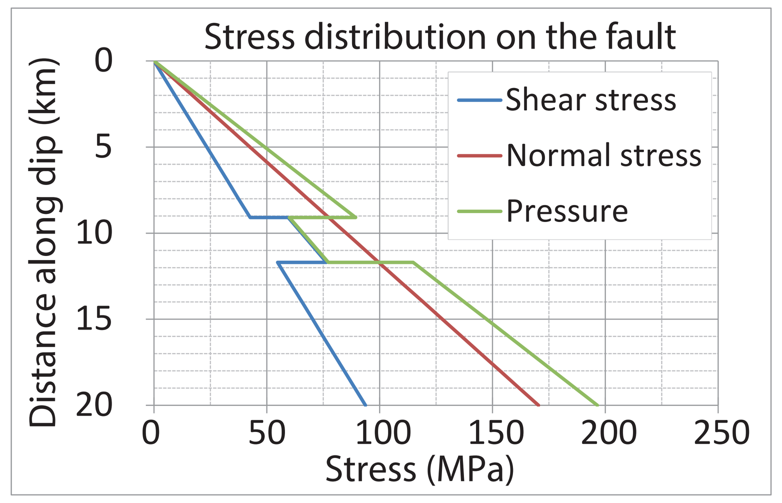
TPV11-2D

- Homogeneous elastic half space
- vp = 5716 m/s
- vs = 3300 m/s
- density = 2700 kg/m3
- Slip-weakening, critical dist 0.5m
- Dynamic friction = 0.448
- Static friction = 0.760
- Cohesion = 0.2 MPa

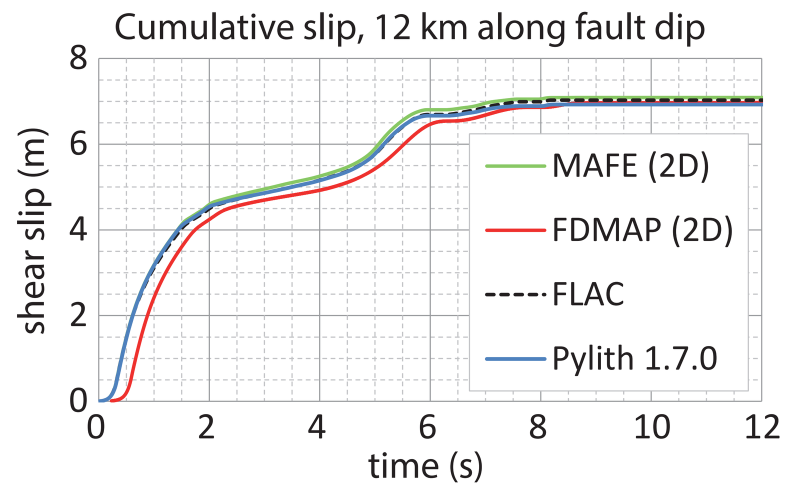
TPV11-2D

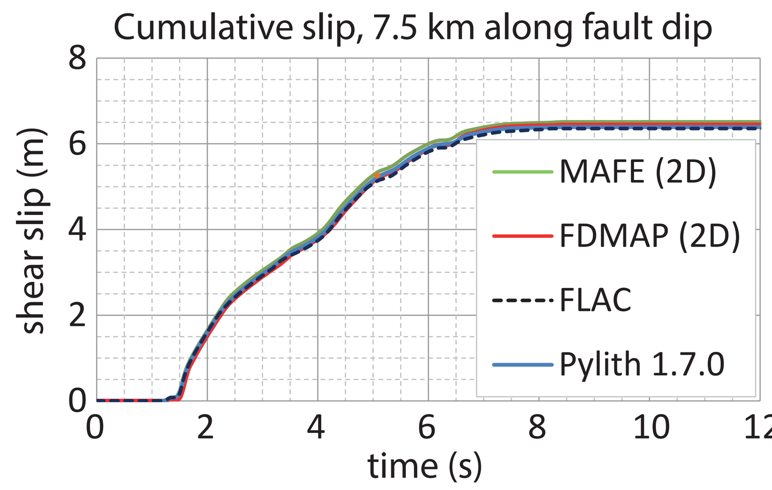
- Static friction = 0.570

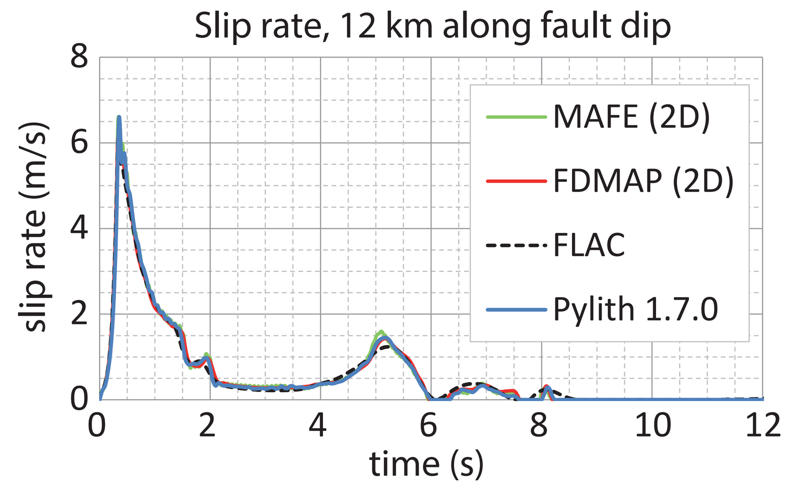


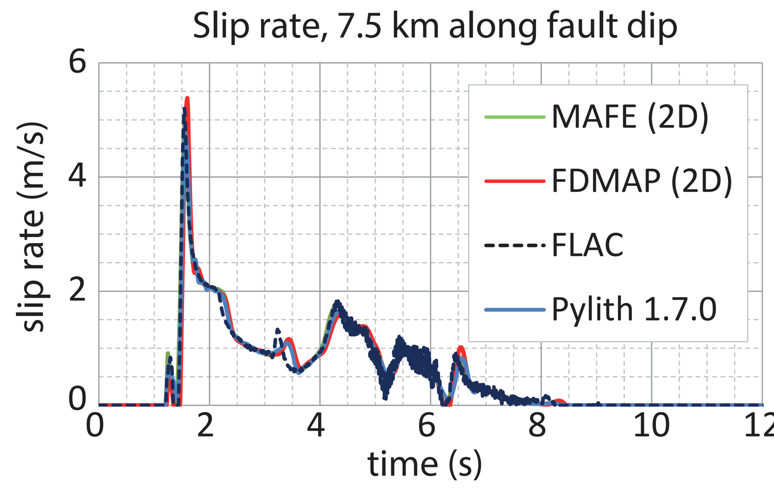


Subshear rupture

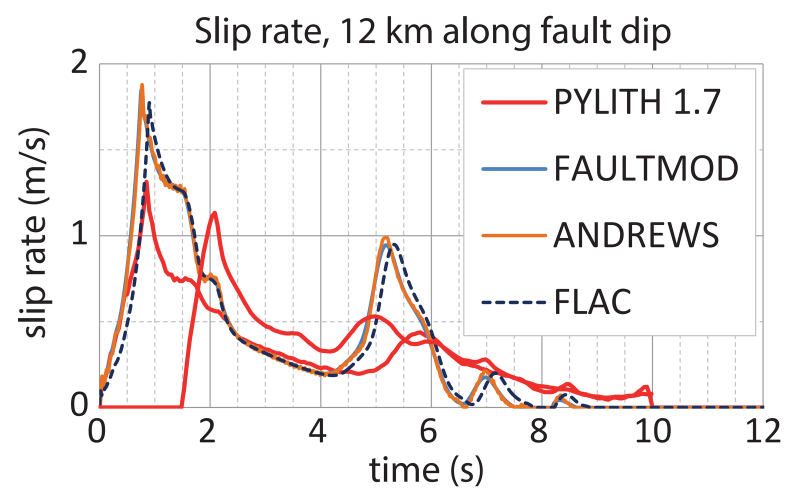


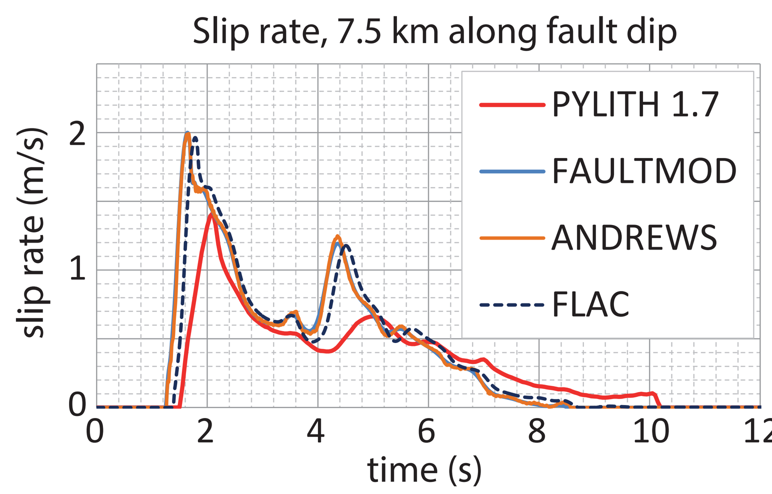






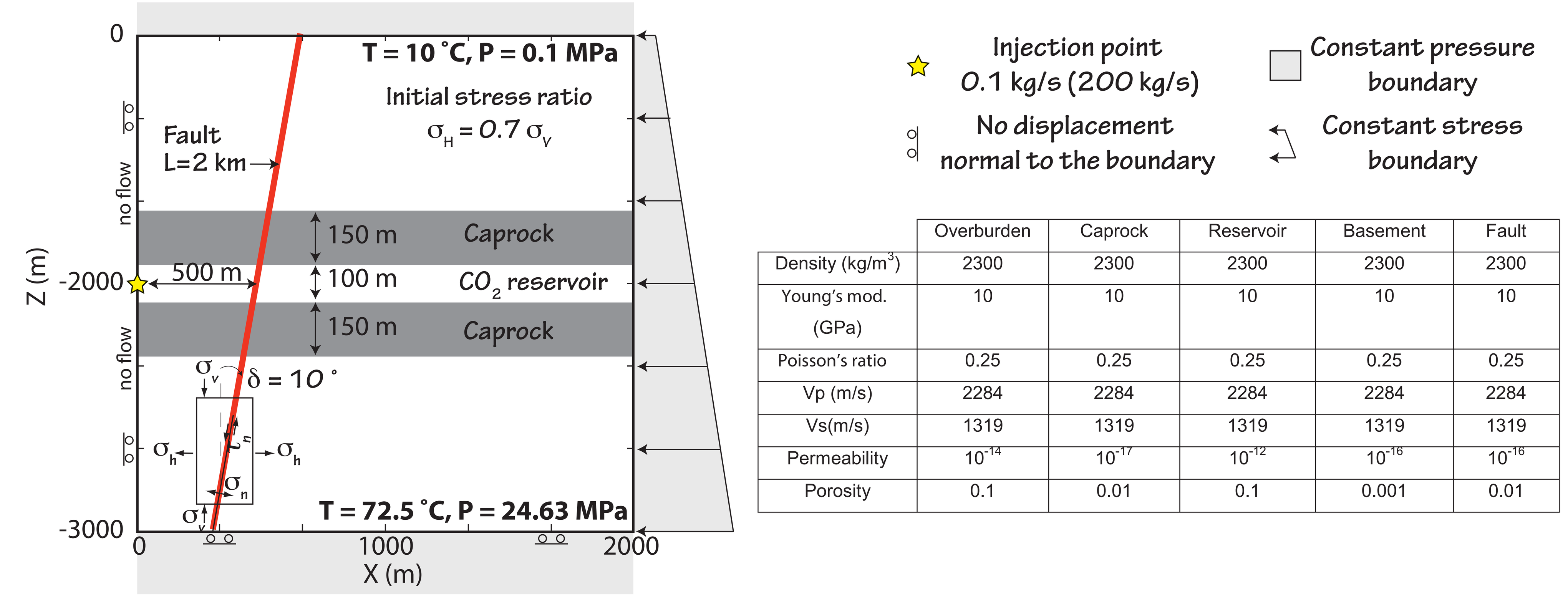
Supershear rupture



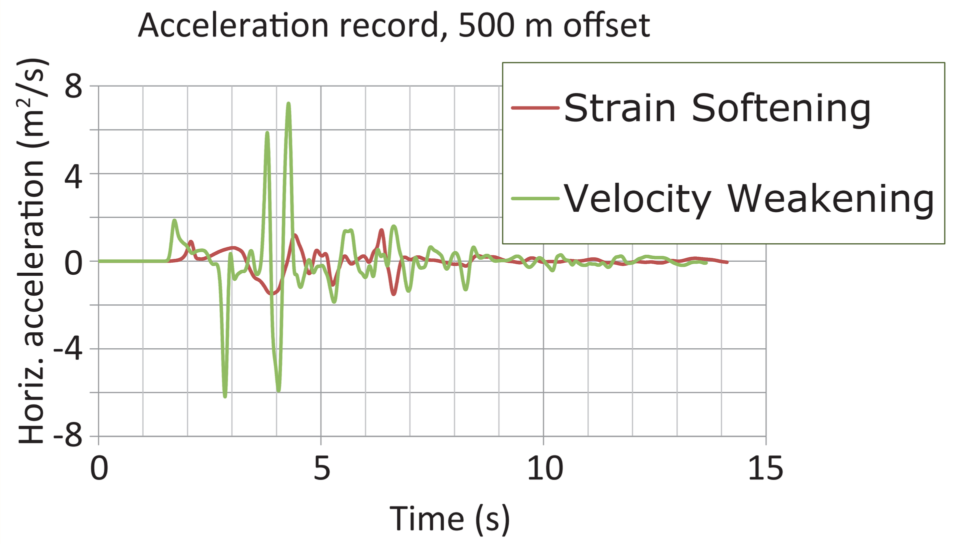


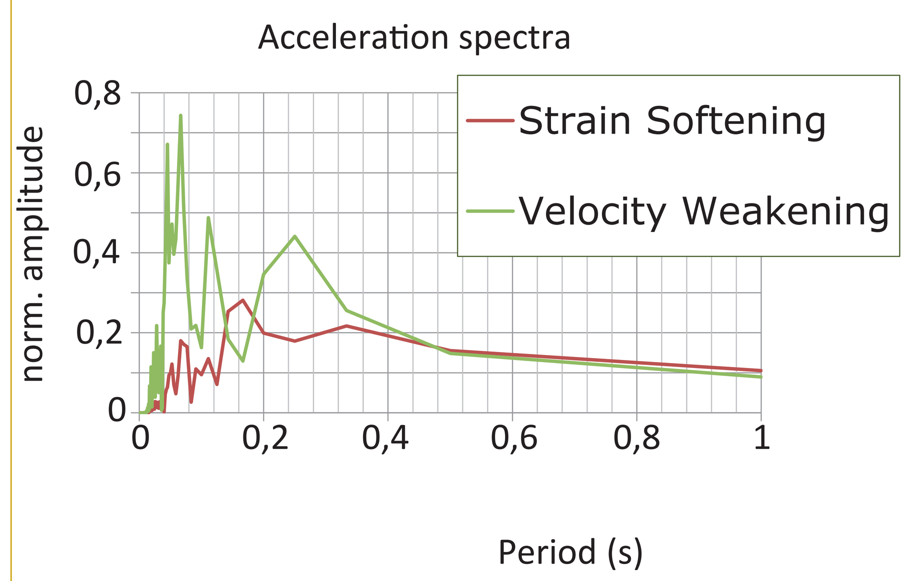
This research has been carried out in the context of the CATO-2-program (www.co2 cato.org), the Dutch national research program on CO2 Capture and Storage technology (CCS). The program is financially supported by the Dutch government (Ministry of Economic Affairs) and the CATO-2 consortium parties.

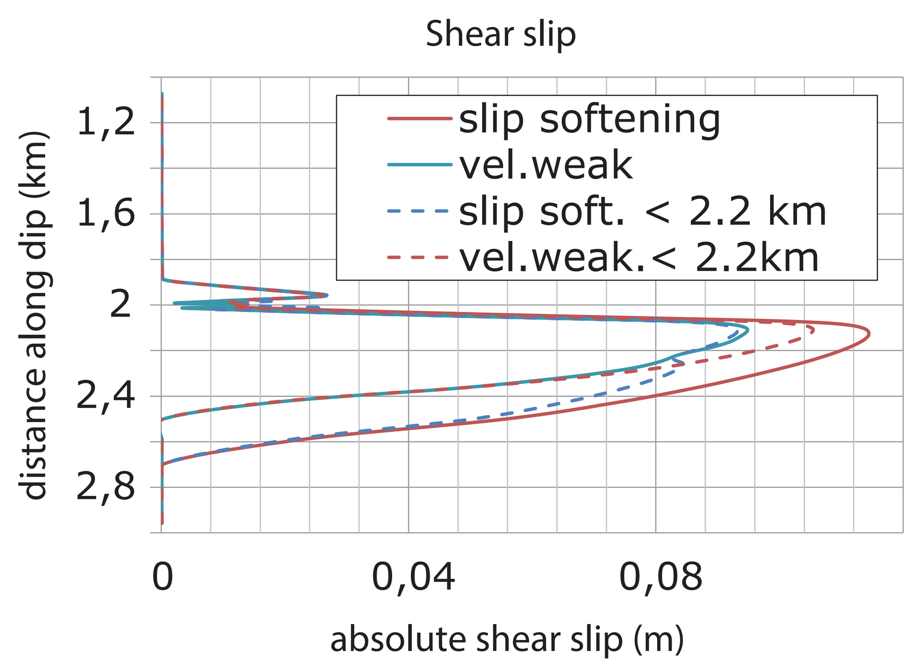
Coupled hydromechanical model and dynamic failure

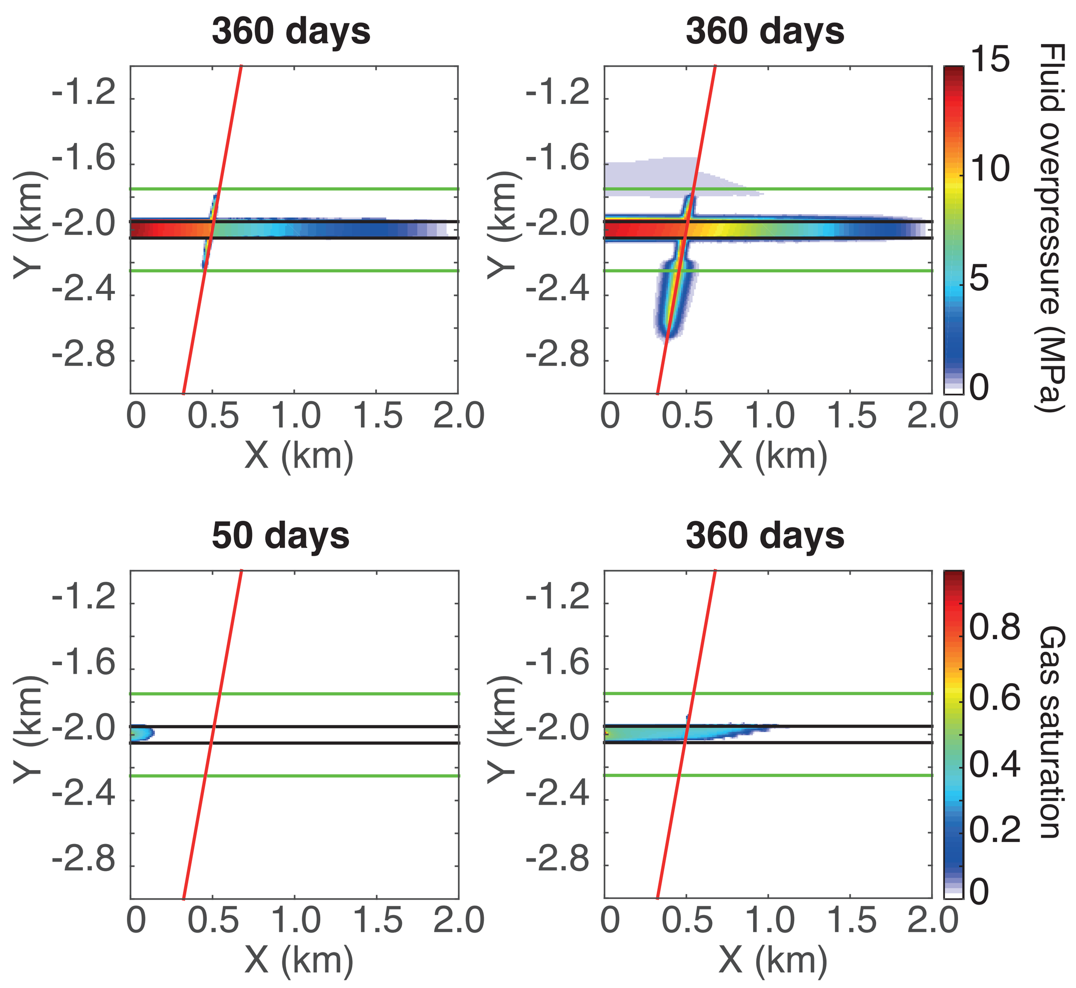


	Overburden	Caprock	Reservoir	Basement	Fault
Density (kg/m^3)	2300	2300	2300	2300	2300
Young's mod. (GPa)	10	10	10	10	10
Poisson's ratio	0.25	0.25	0.25	0.25	0.25
Vp (m/s)	2284	2284	2284	2284	2284
Vs(m/s)	1319	1319	1319	1319	1319
Permeability	10^{-14}	10^{-17}	10^{-12}	10^{-16}	10^{-16}
Porosity	0.1	0.01	0.1	0.001	0.01









Conclusion

- Dependency of friction behavior on slip and slip-rate change the rupture characteristics.
- Seismicity phases & amplitude can different for same stress changes but different constitutive fault properties
- Numerical models can predict the area undergoing slip and the amount of shear/normal slip. However, although all seismic events are failure of weakness plane, rupture events can also lead to aseismic deformation.
- Assuming most of the crust is critically stressed, how can we control seismicity?
- How does it happen that only in "a few" unlucky spots human activity can be associated with human-felt seismic events?