Fluid pressure mostly drives aseismic motion: Insights from a controlled in-situ experiment at meter-scale in limestone

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Fluid and Seismicity: a complex relationship

- Fluids are known to trigger seismicity,
- Example of Brawley Geothermal field (California, US; Wei et al, 2015)
  → Triggering mechanisms not simple

Wei et al, 2015
Fluid and seismicity: main questions

What is the underlying mechanisms behind fluid-triggered earthquakes?

→ How does a fault respond to a fluid pressure perturbation?
→ Does the seismicity allow for a direct mapping of the fluid flow?
Meter-scale: bridging the gap in observations

- Controlled processes (stress, pressure,...)
- Near field monitoring

- Full complexity of the natural processes
- Lack of hydromechanical context near the sources
Experimental principle

- Idea: reactivate a well-identified geological structure with fluid pressure
- A 2 m long part of a borehole (containing a few structures) is isolated
- Fluid injection into those structures
Experimental context

- Gallery at 300 m depth, in the Deep underground laboratory (Rustrel, 84, France)
- Fractured limestone in the extended damage zone of a kilometric faults
- 20 m long boreholes to access the test areas and for the monitoring sensors
10 areas have been tested.

Monitoring at the injection point:
- Flow rate
- Fluid pressure
- 3D deformation

Dense monitoring network at a few meter distance:
- Accelerometers (10Hz-5 kHz)
- Geophones (10 Hz-1 kHz)
- Acoustic sensors (1Hz-10 kHz)
- Tiltmeters
Overviews on hydraulic/seismic data

- Wide range of permeability

- Seismicity:
  - Occurred after a pressure threshold (FOP)
  - 250 events with magnitude between -3.5 and -4.2
  - Uneven distribution among tests
  - No seismicity close to the injection points

- Hydro-mechanical failure is observed for all tests
  => Aseismic failure?
Aseismic motion dominates

- Seismic budget: more than 98% of the deformation is aseismic
- In particular:
  - aseismic motion at the injection point
  - Some tests are totally aseismic

- McGarr (2014): \( M_o = \mu \Delta V \)
- Comparison with other scales (from lab to reservoir)

=> Discrepancy for low injected volume?
Location and structural heterogeneities

- Location highlights particular structures (confirmed by mechanisms)
- Seismicity usually not on the injected structures
- Distribution of seismicity depends on the density of fractures
Fluid diffusion? Stress transfer?

Distance Vs Time (R-T plot):

- Events clustered in time, scattered in space
  $\Rightarrow$ stress transfer

- Overall increase of distance with injection time
  $\Rightarrow$ Fluid diffusion
Conclusions et scenario?

- Fluid pressure mainly induces aseismic motion
- Seismicity is not directly induced by fluid pressure, but by the aseismic motion through stress transfer
- Dual behavior between fluid diffusion and stress transfer

=> Seismicity is only an indirect probe for fluid monitoring