Fault response to a fluid pressure injection in controlled experiment: first observations on the induced seismicity

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1. Outline

• Fluids are pervasive in the Earth's crust, and play an important role in the fault mechanics and earthquake physics, particularly in the preparatory phase of large ruptures or in reservoir and volcano seismicity.

•The main questions about the fluid effects on fault are:

1) how does the fault slip with fluids? What are the seismic signatures of a rupture triggered by fluids?

2) what are the processes generating the seismic and mechanical observations on faults which can be used to improve the rupture forecasting?

• To bring new insights on these questions, a joint seismological and hydro-mechanical experiment was performed in 2010:

- A 10-m scale, in-situ experiment;
- Controlled fluid injection in a fault zone;
- Measure of deformation, pressure and seismicity.

2. Experiment geometry

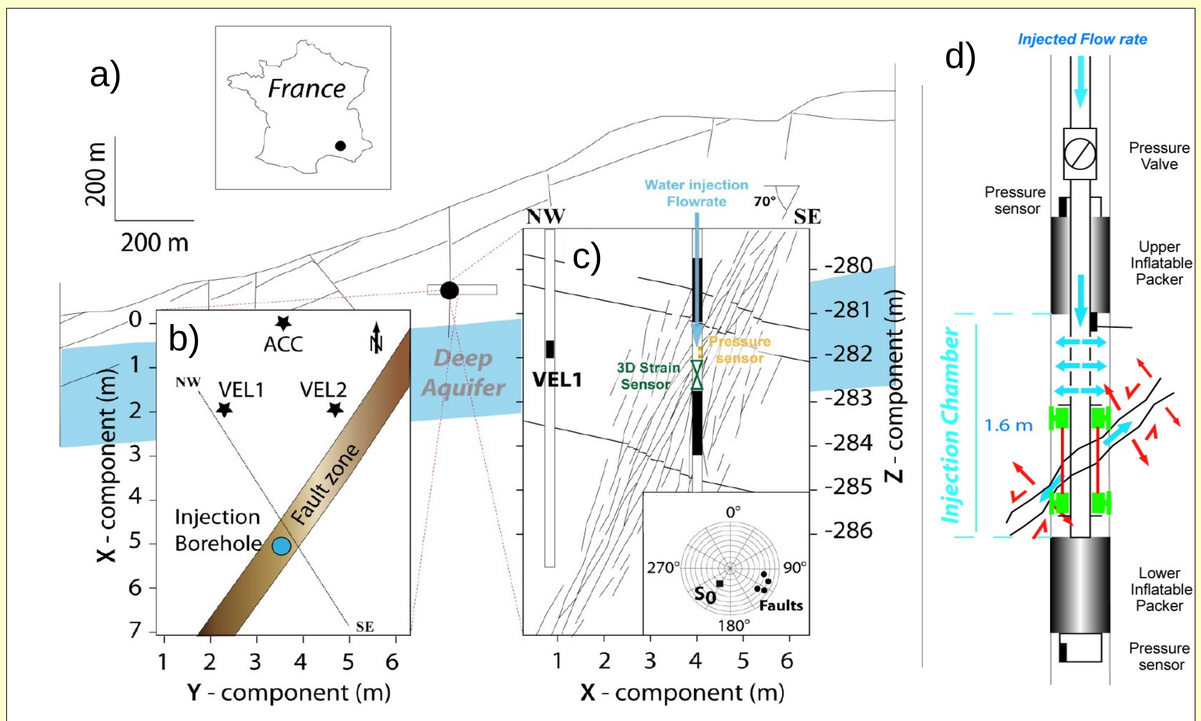

Fig 1: Experimental set-up:

a) Location of the LSBB and of the tunnel; b) Map view and c) cross-section showing the injection zone and the seismic sensor locations (ACC, VEL1, VEL2); d) schematic view of the fluid injection device (HPPP probe).

• Experiment in the underground laboratory of Rustrel (LSBB, Vaucluse, France), at 300m depth, in Urgonian limestone;
• Injection of high-pressure water in a sub-vertical fault, 17 m below the tunnel floor;
• Measure of 3D deformation, flow rate and pressure in the injection chamber;
• Three seismic sensors (2 geophones, 1 accelerometer) at 2-5 m distances.

3. Seismic and hydromechanical responses

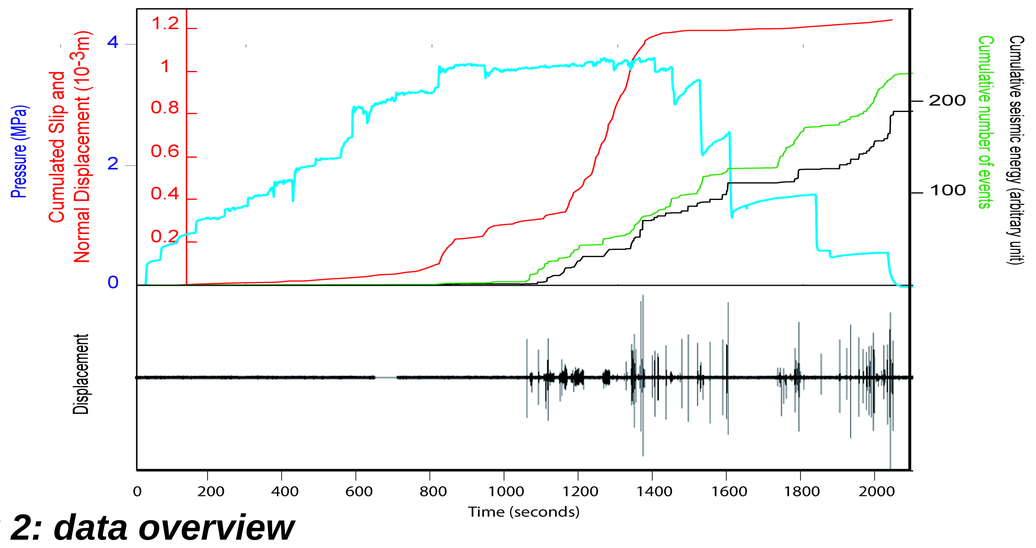

Fig 2: data overview

Pressure, cumulated slip of the fault, number of events, seismic energy and seismic data measured during the 35-minute injection experiment.

- Step Rate test: Pressure is increased step-by-step up to a plateau (~40 bars);
- Fault activation => the fault slips on a millimeter scale;
- Disagreement between the beginning of the seismicity and the slip:
  => Most of of the movement is aseismic;
- Seismicity toward the end of injection and during pressure decrease.

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4. Seismic events

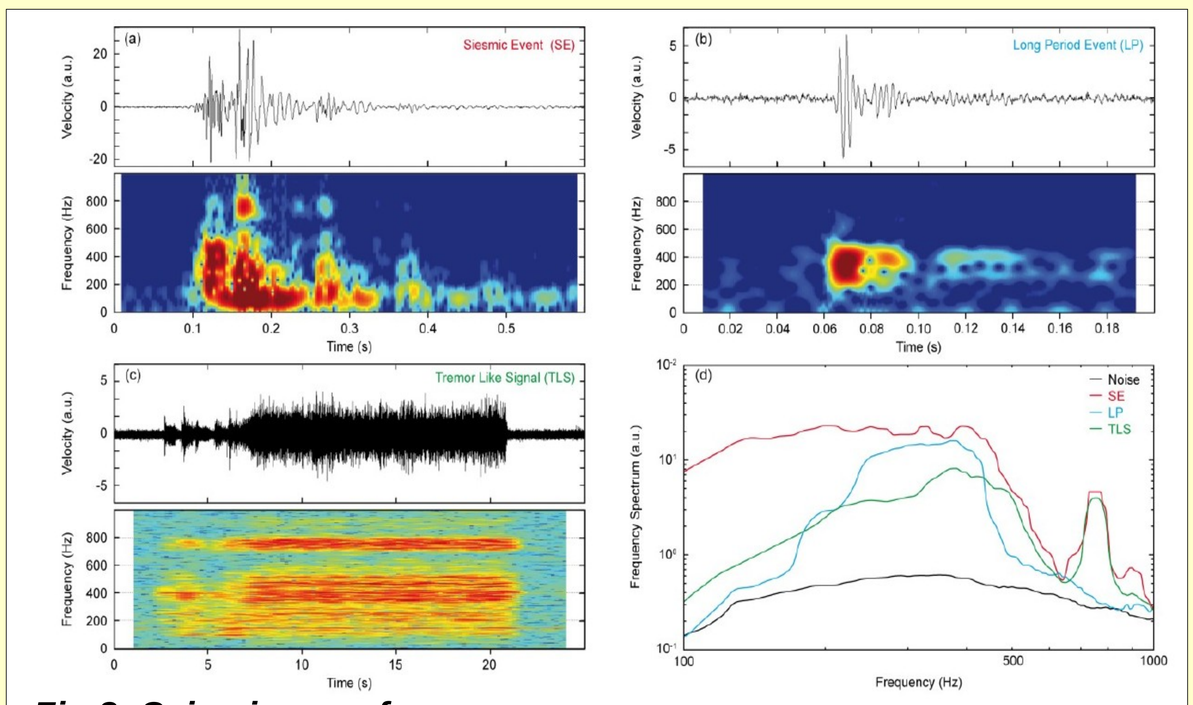

Fig 3: Seismic waveforms

Different types of events recorded during the injection: a) seismic events (SE), b) Long Period type signals (LP) and c) tremor like signals (TLS). Panel (d) shows the frequency spectrum for the 3 types of events plus noise.

• Rich seismicity: more than 300 events extracted in less than 15 min;
• Complex seismicity: events were classified in three types:
Seismic events (SE), tremor-like events (TLS) and Long Period signals (LP).

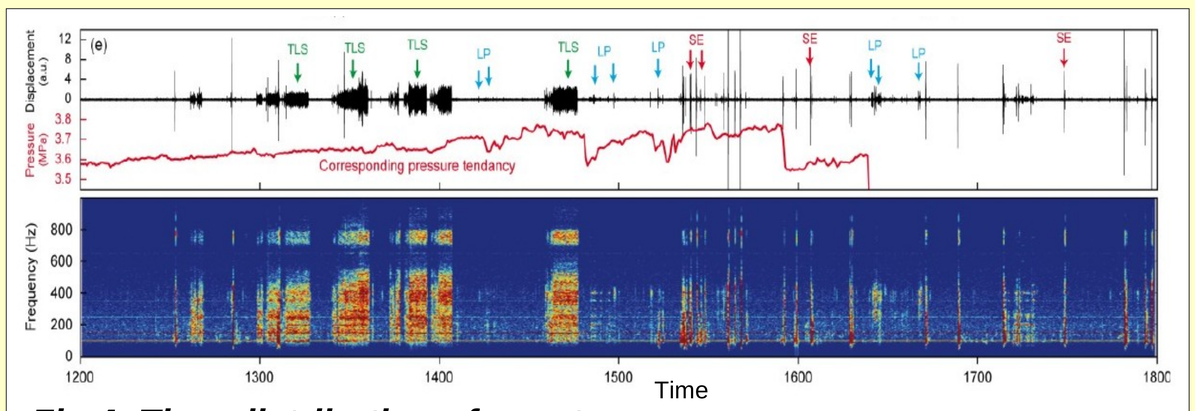

Fig 4: Time distribution of events

Zoom on the seismic data and the pressure, with some events identified and spectrogram.

• Seismicity starts with tremors, followed by swarms of seismic events;
• LP associated with fluid pressure drops.

5. Scaling laws

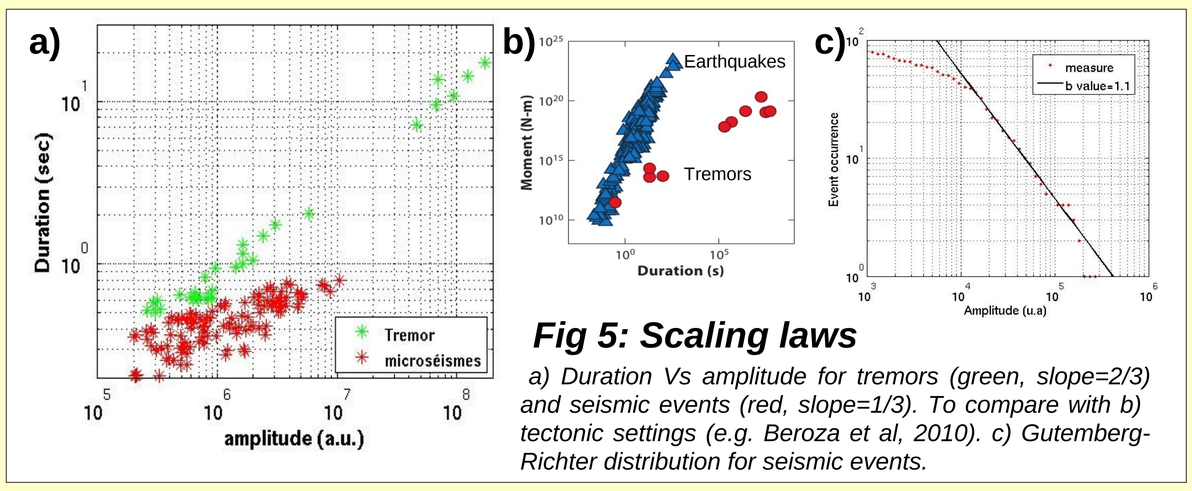

Fig 5: Scaling laws

a) Duration Vs amplitude for tremors (green, slope=2/3) and seismic events (red, slope=1/3). To compare with b) tectonic settings (e.g. Beroza et al, 2010). c) Gutemberg-Richter distribution for seismic events.

• Duration Vs amplitude distribution shows distinct patterns for TLS and SE;
• Slopes of the scaling laws are comparable to the tectonic ones.

6. Conclusions/Future work

• **Strengths**:
  • intermediate scale experiment,
  • joint hydro-mechanical and seismological analysis,
  • Observation of complex and rich processes;
• **Drawback**:
  • Only 3 seismic sensors => no location, no mechanism ....

=> **New experiment** (jan. 2015), including:
  • 30 seismic instruments, 4 microphones, 5 deformation sensors...
  • Time-lapse seismic velocity measures...

Fig 6: New experimental set-up

References

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