International EGS Projects –the Challange and Benefit of induced seismicity

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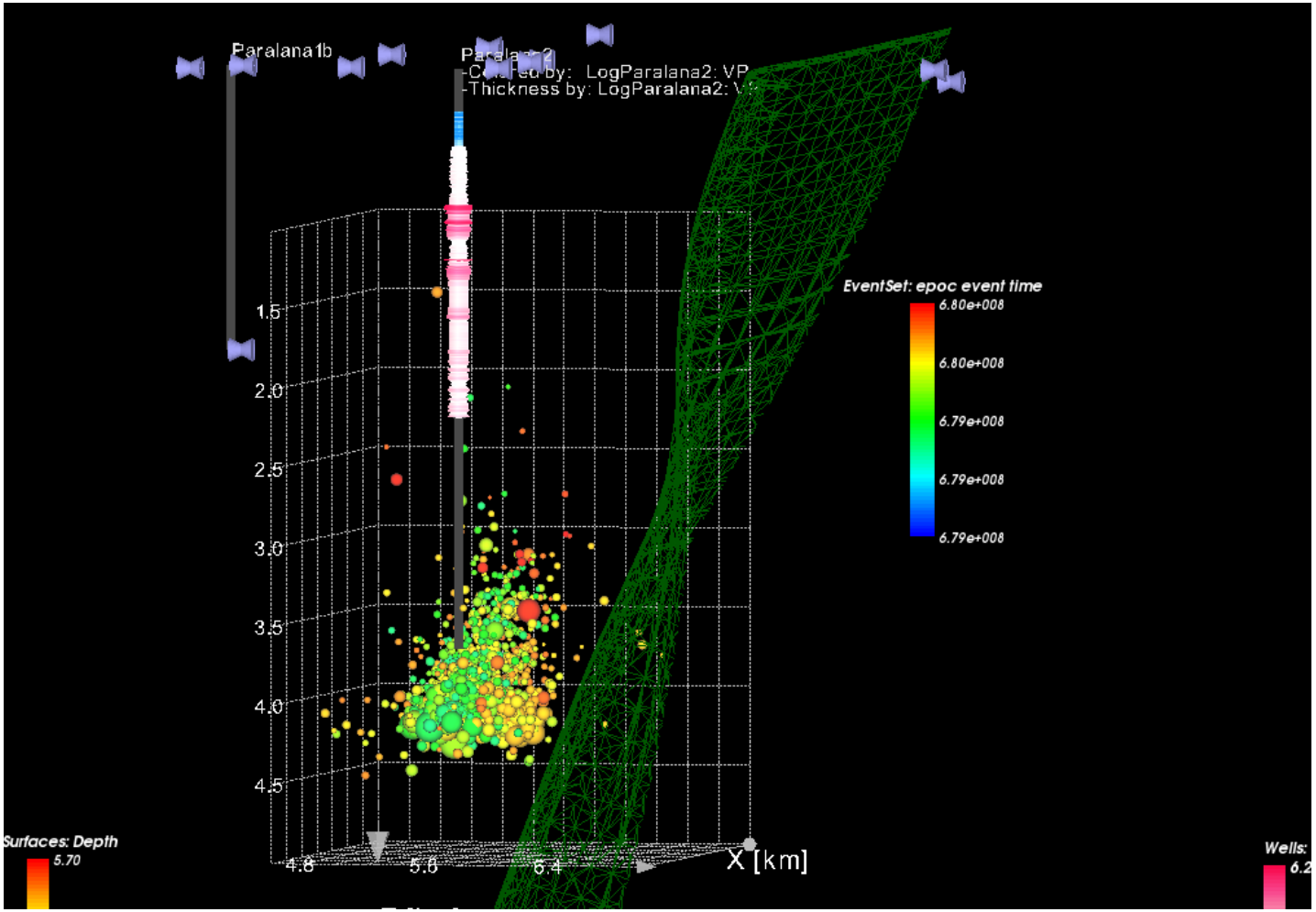
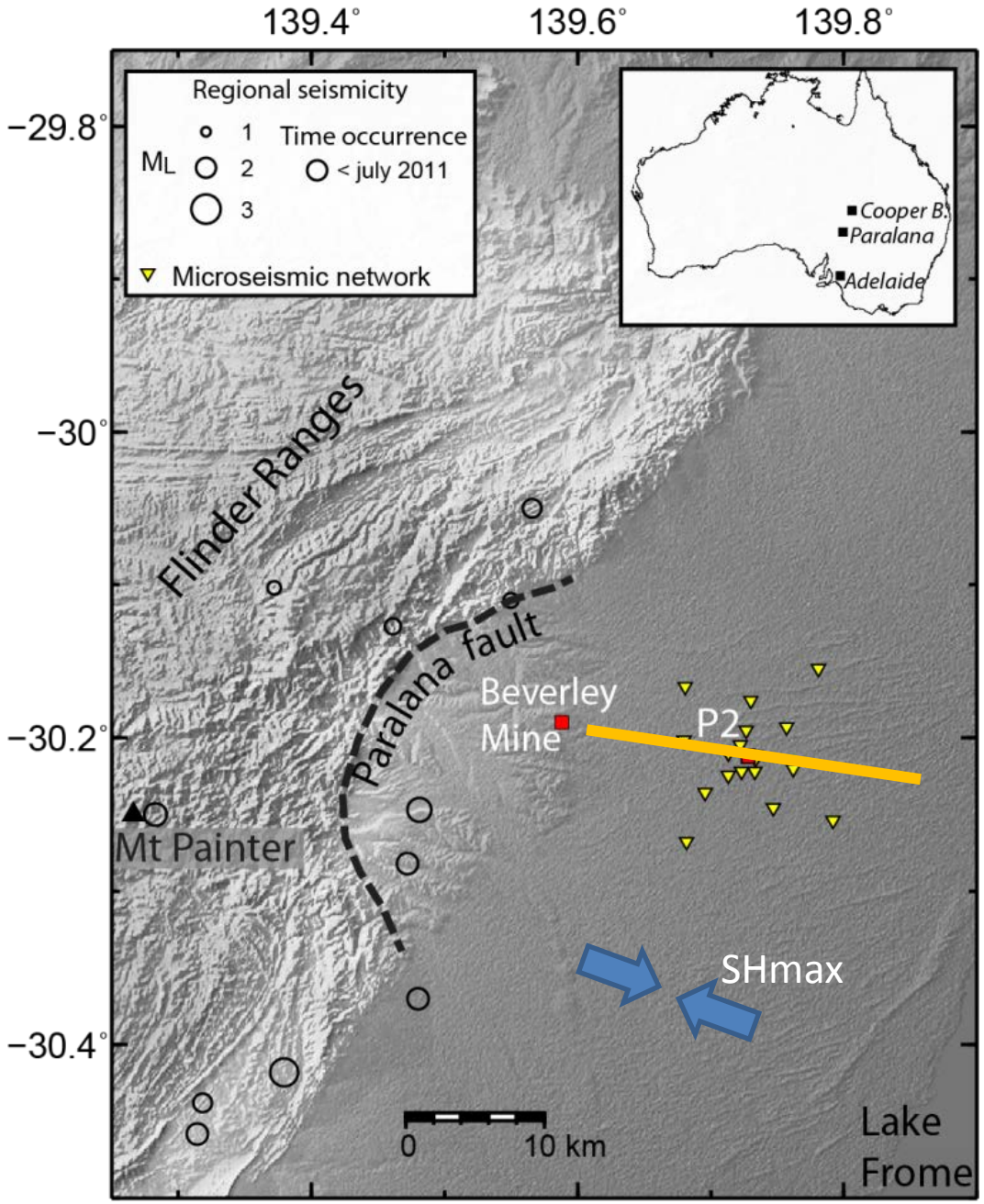
NORSAR GEISER petratherm

The final result after creating an Enhanced Geothermal System



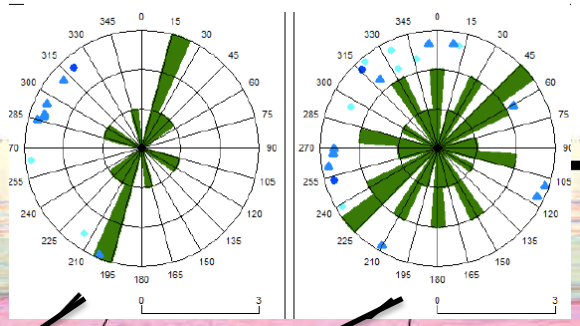
Paralana Enhanced Geothermal System

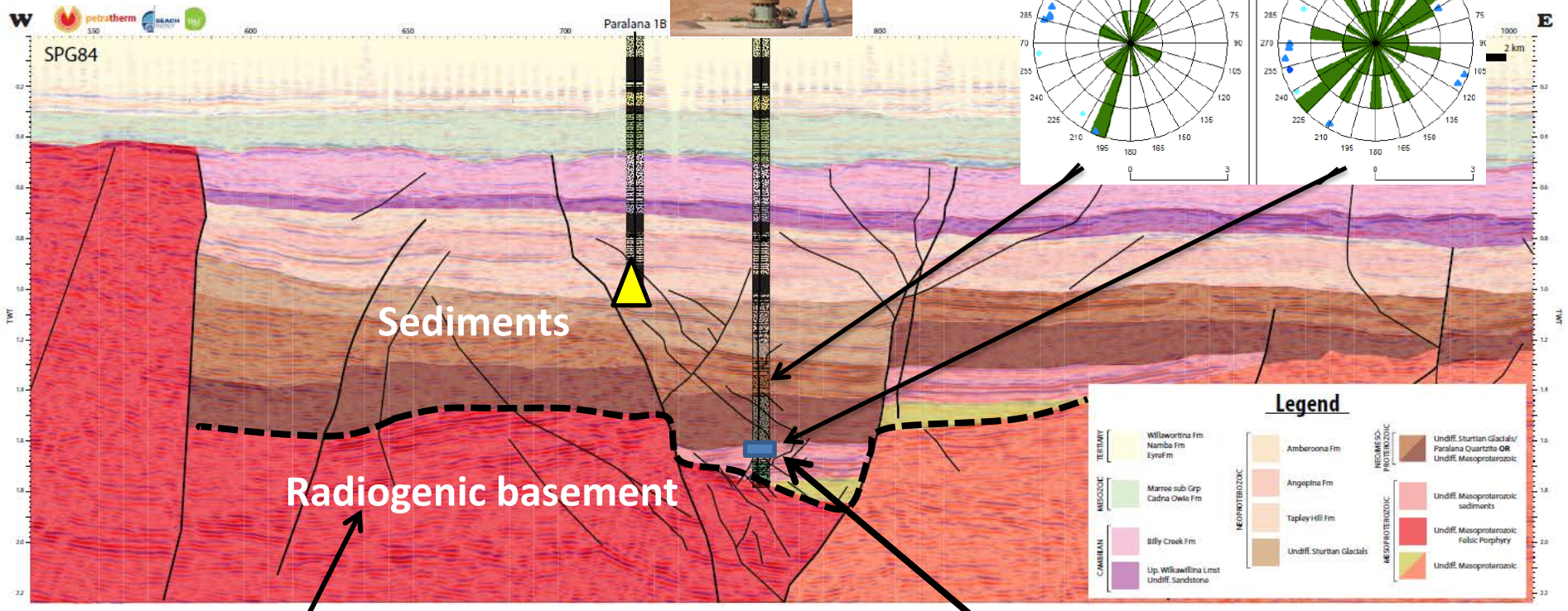


The Site

P2

Fractures orientation

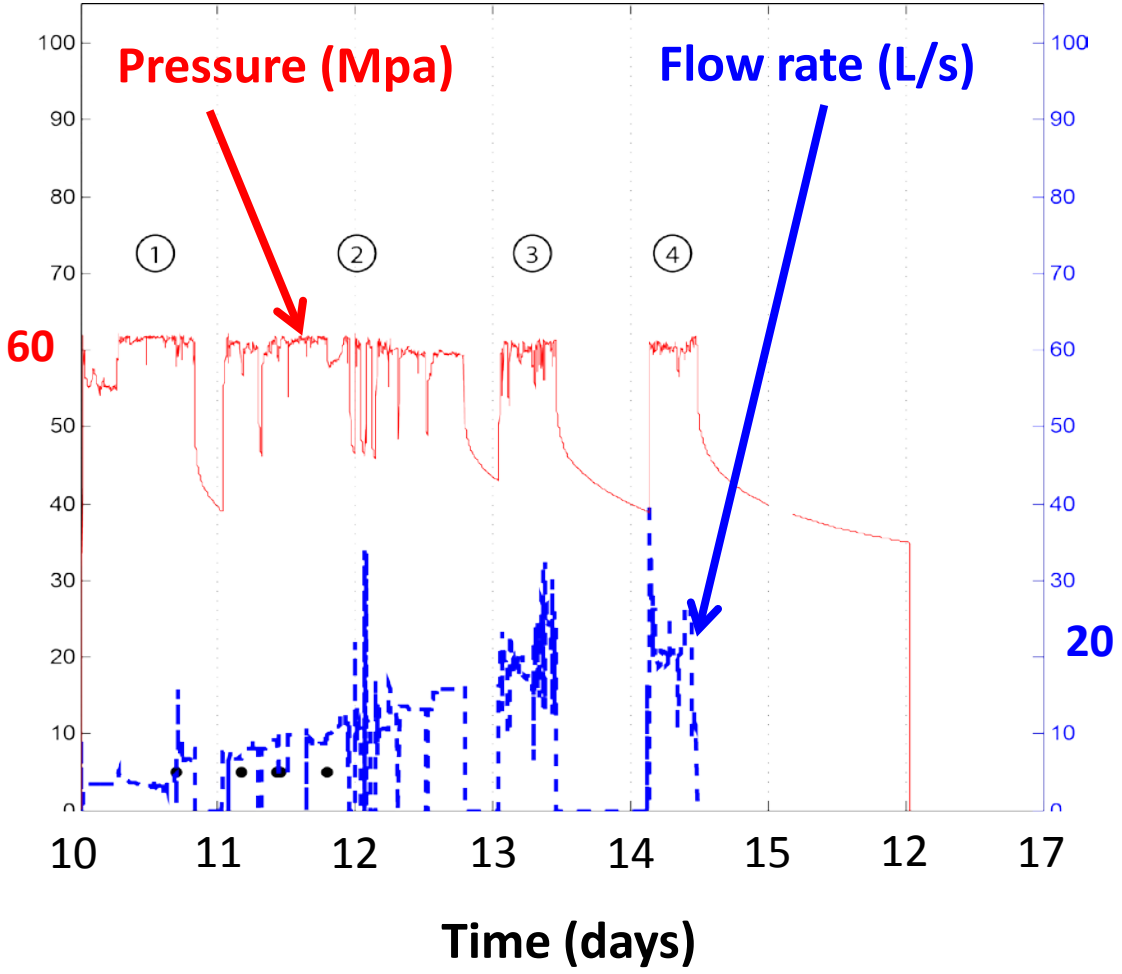




Heat
~176°C at 3.6 km

Injection

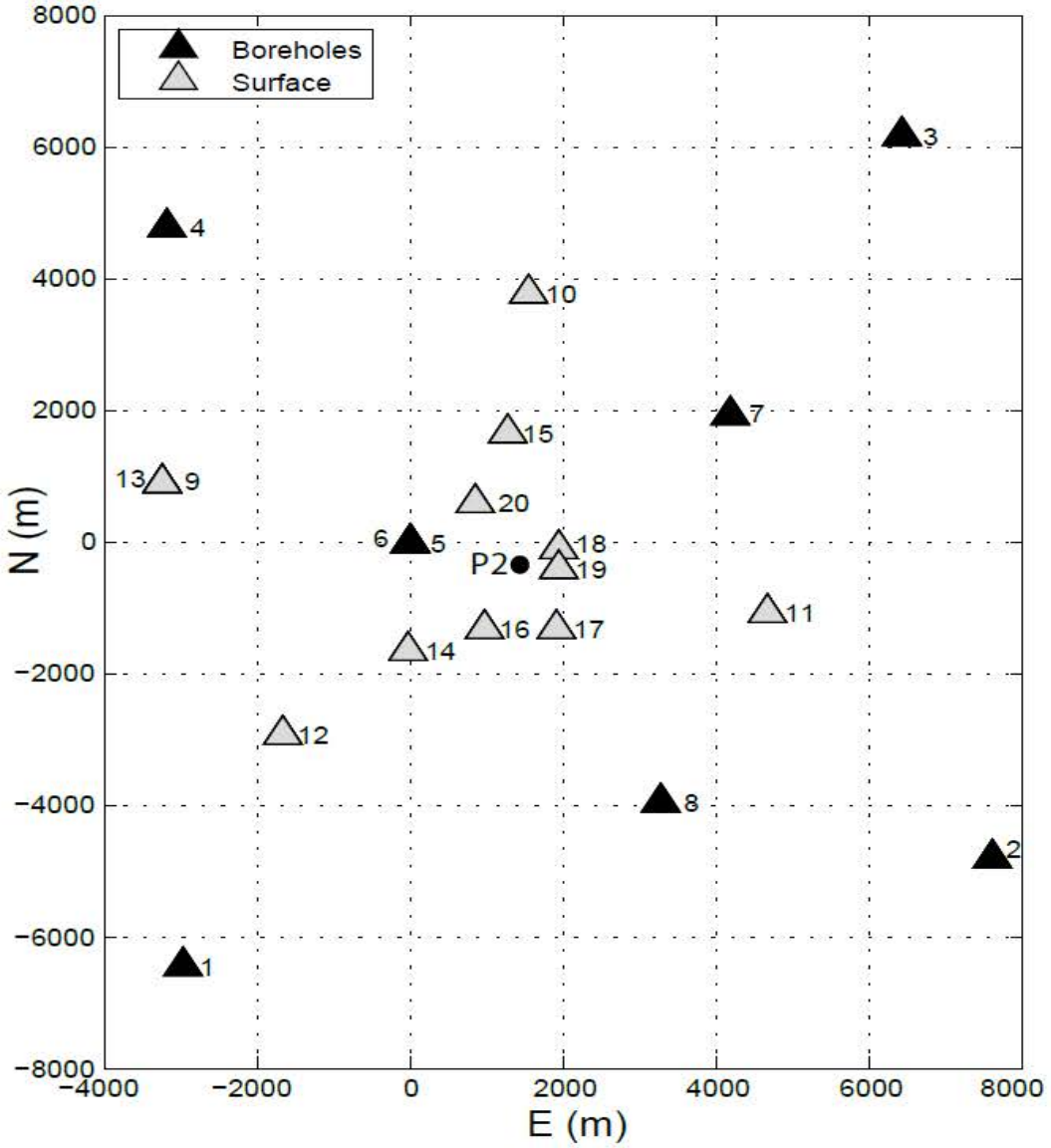
Well stimulation - 2011



Microseismic monitoring : 20 3-C stations

▲ Boreholes
(160 m and 1800 m)

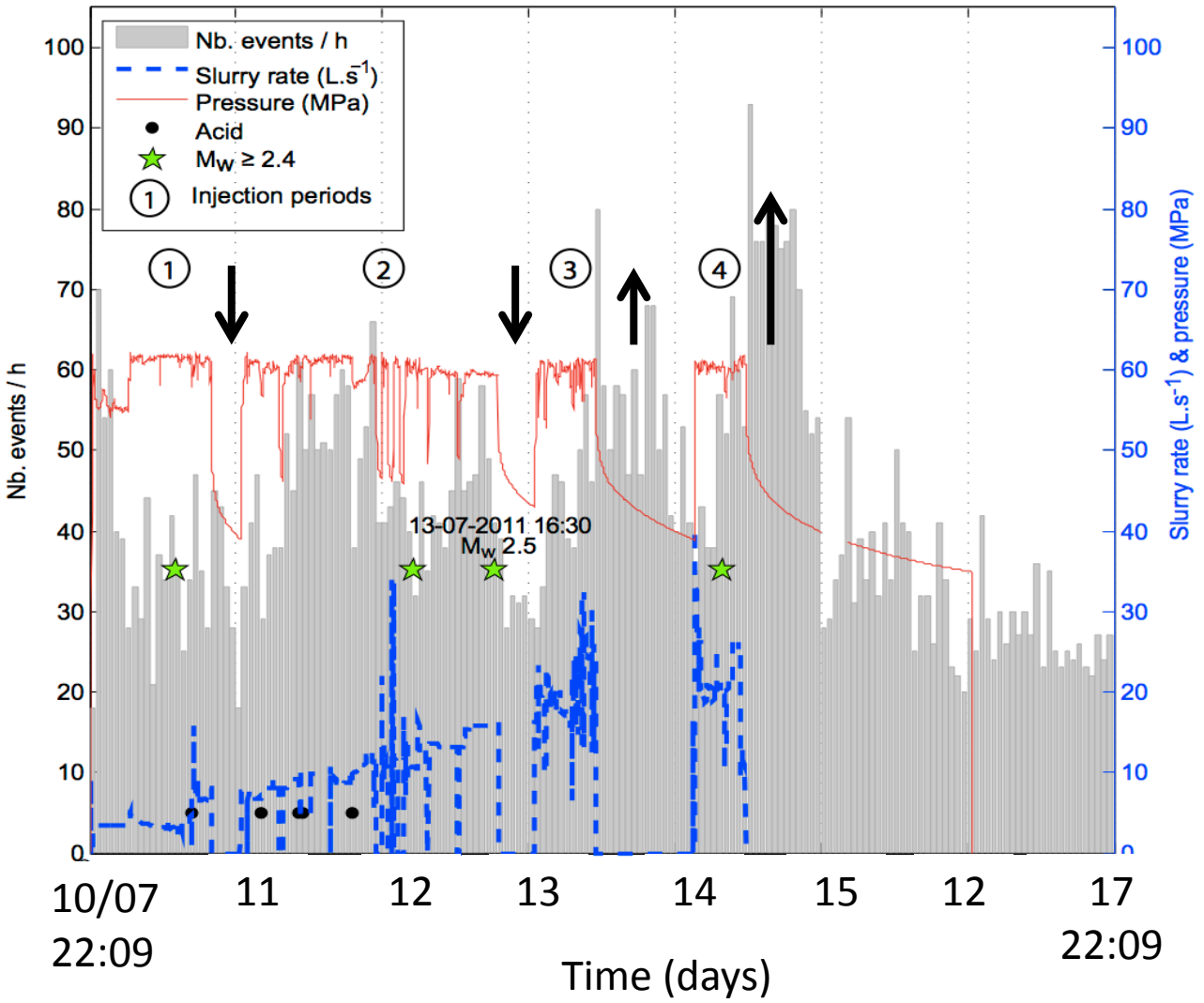
△ Surface stations



Induced seismicity

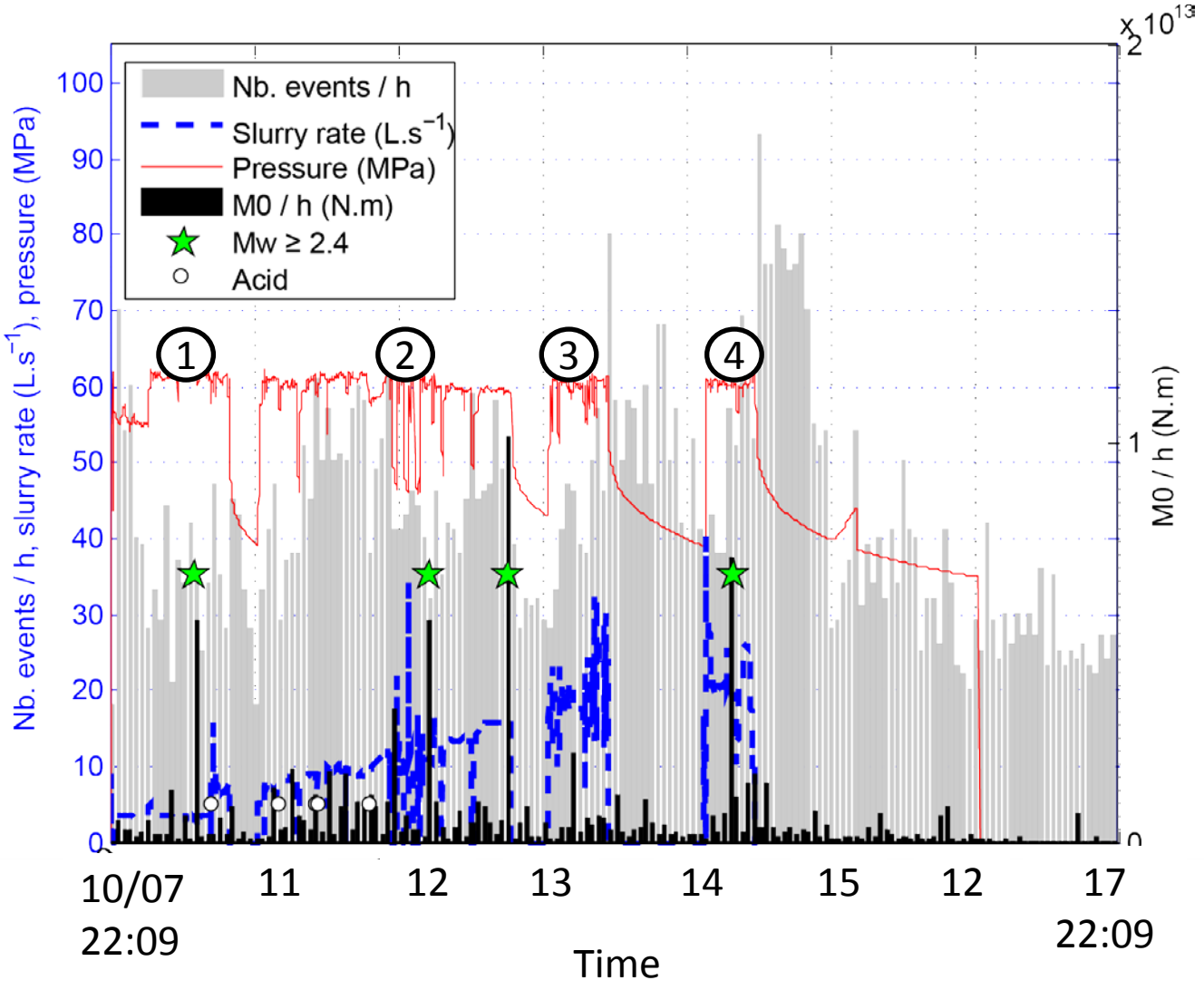
- Automatic processing (Oye & Roth, 2003)
- 7000 microearthquakes (Mw -0.6 to 2.5)

Mw ≥ 2.4



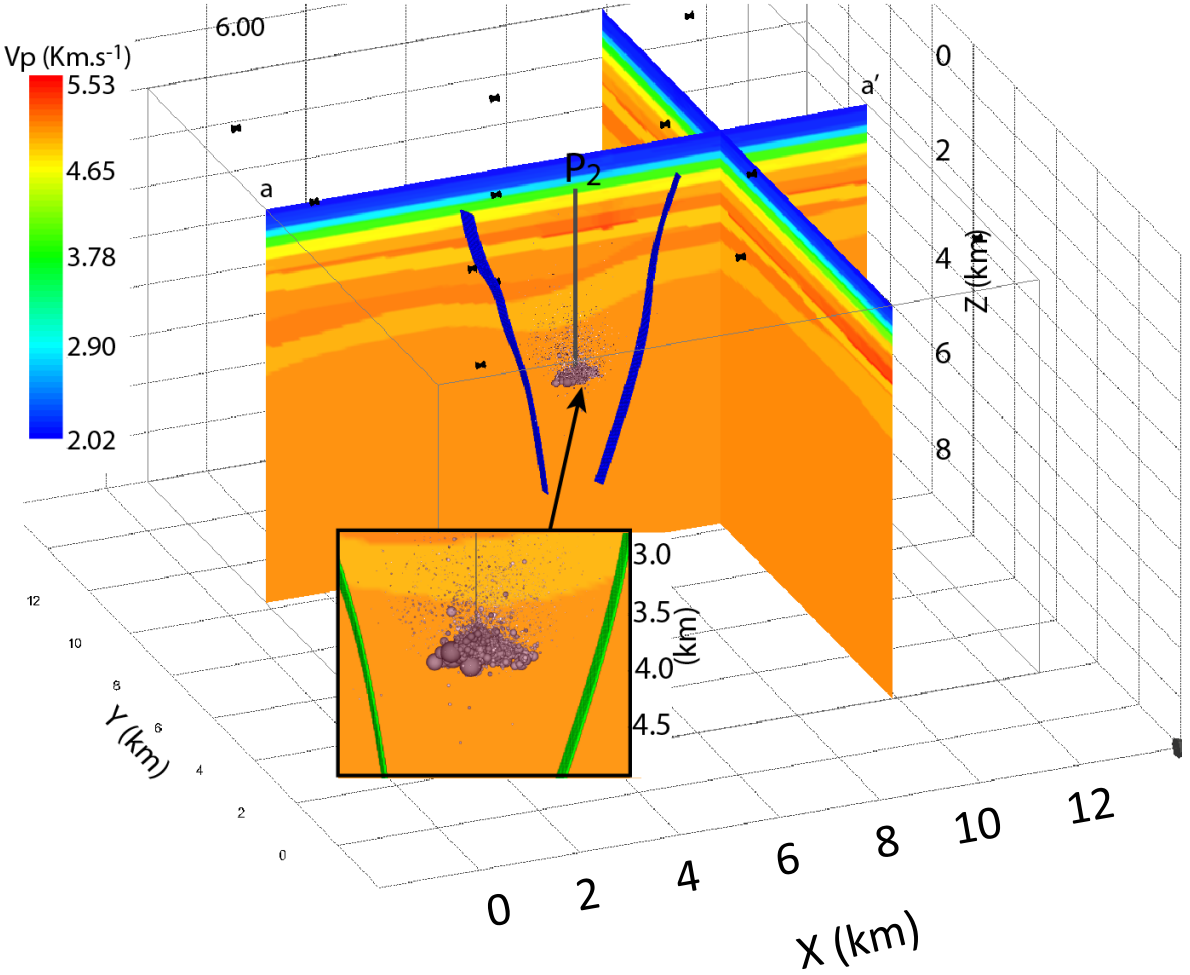
Induced seismicity

- Seismic moment dominated by 4 events occurring **during** fluid injection



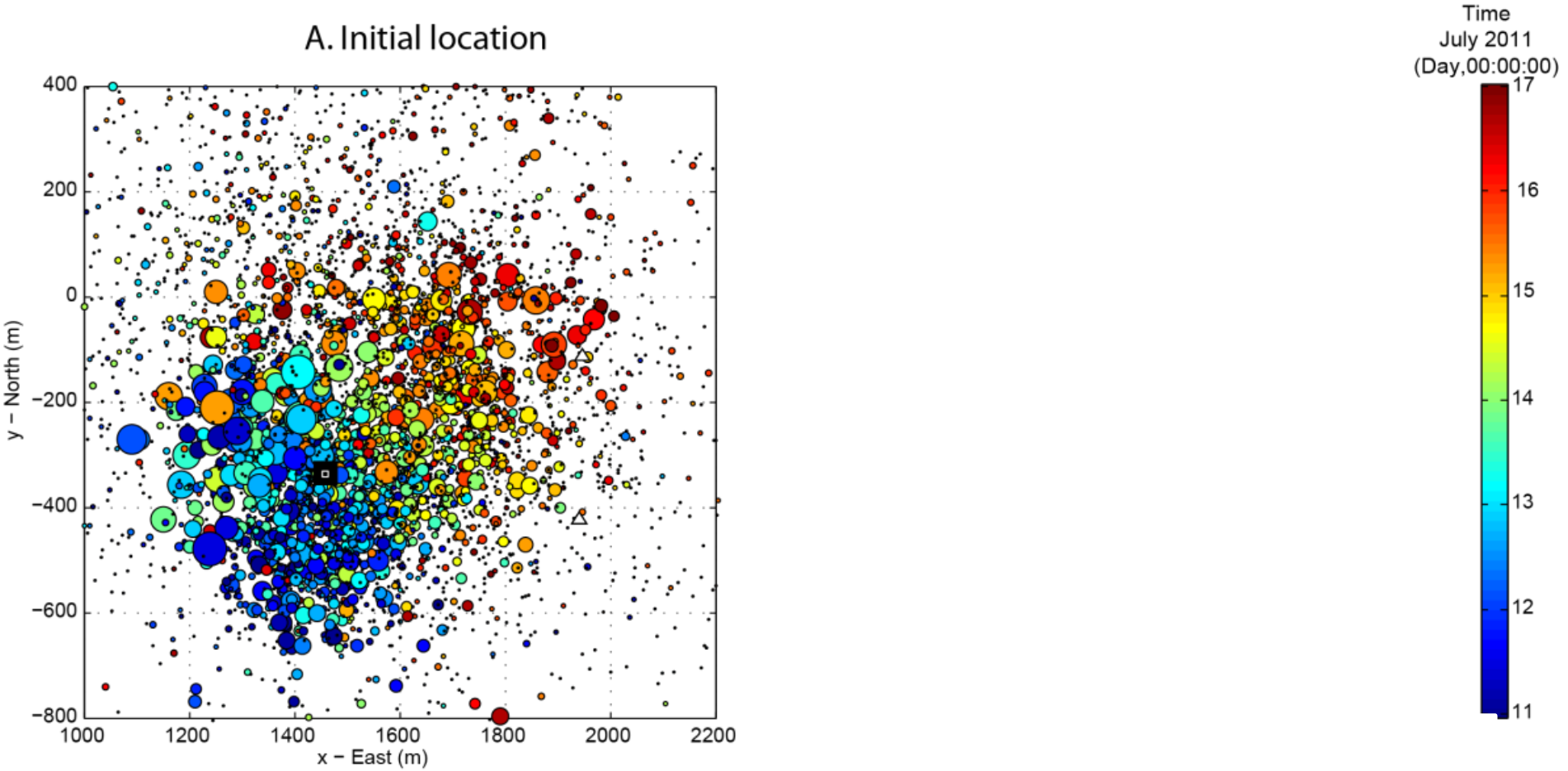
Absolute location

- 3D velocity model built from seismic lines and velocity log data
- Synthetic travel-times : eikonal solver from Podvin & Lecomte (1991)

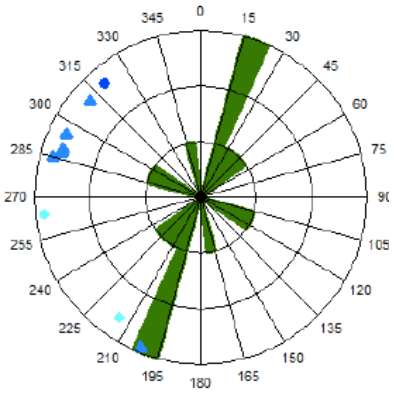


Relocation : double-difference

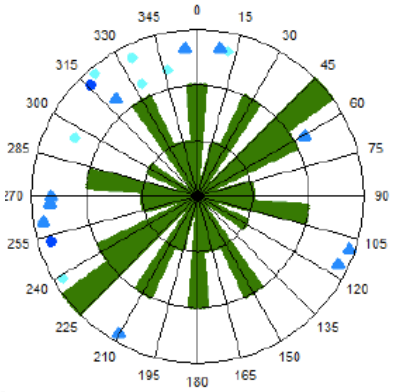
- hypoDD (Waldhauser & Ellsworth, 2000)
- Migration NE

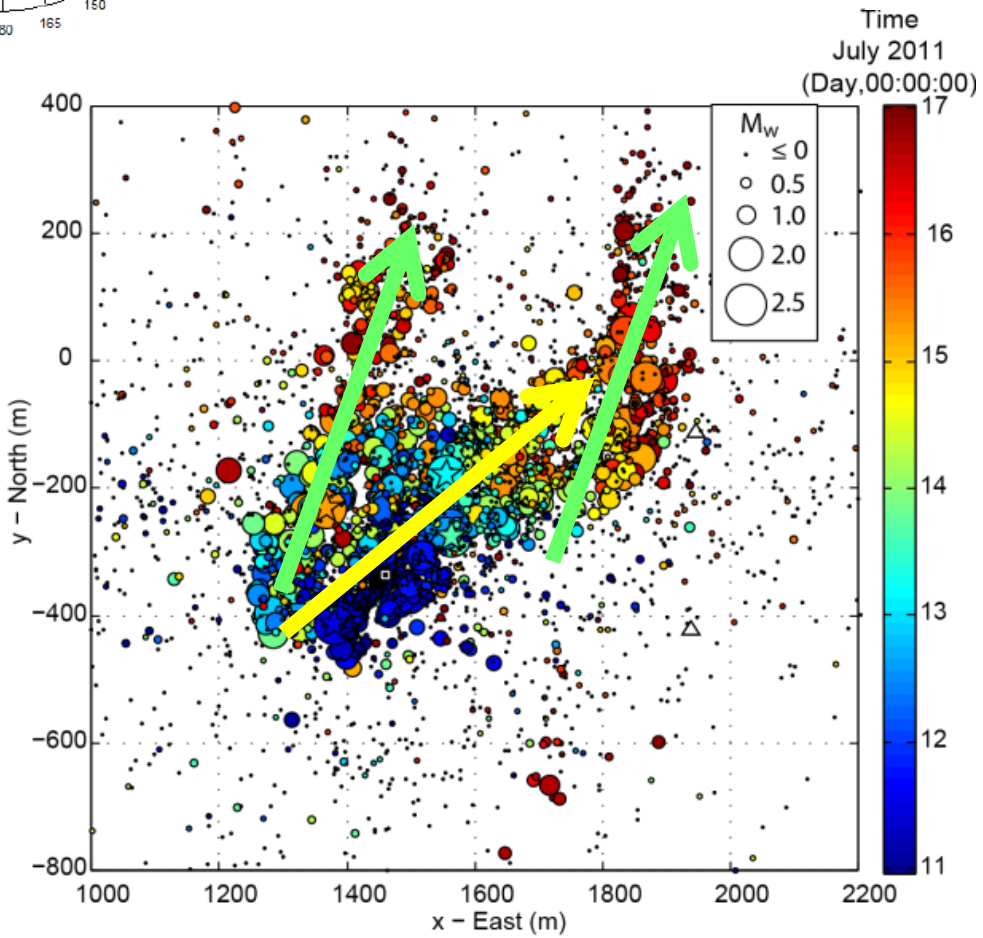


Pre-existing fractures activated?



Fracture orientation

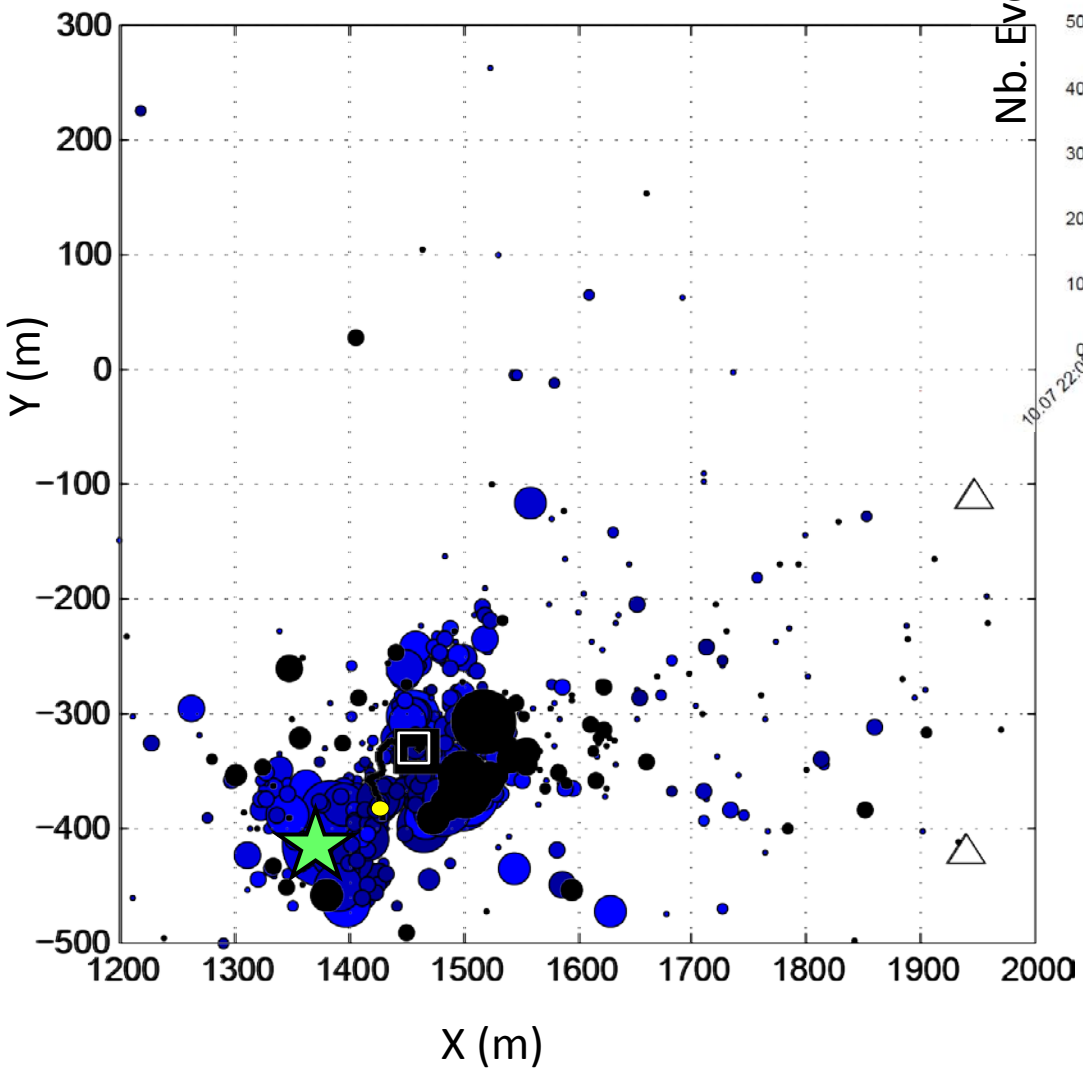


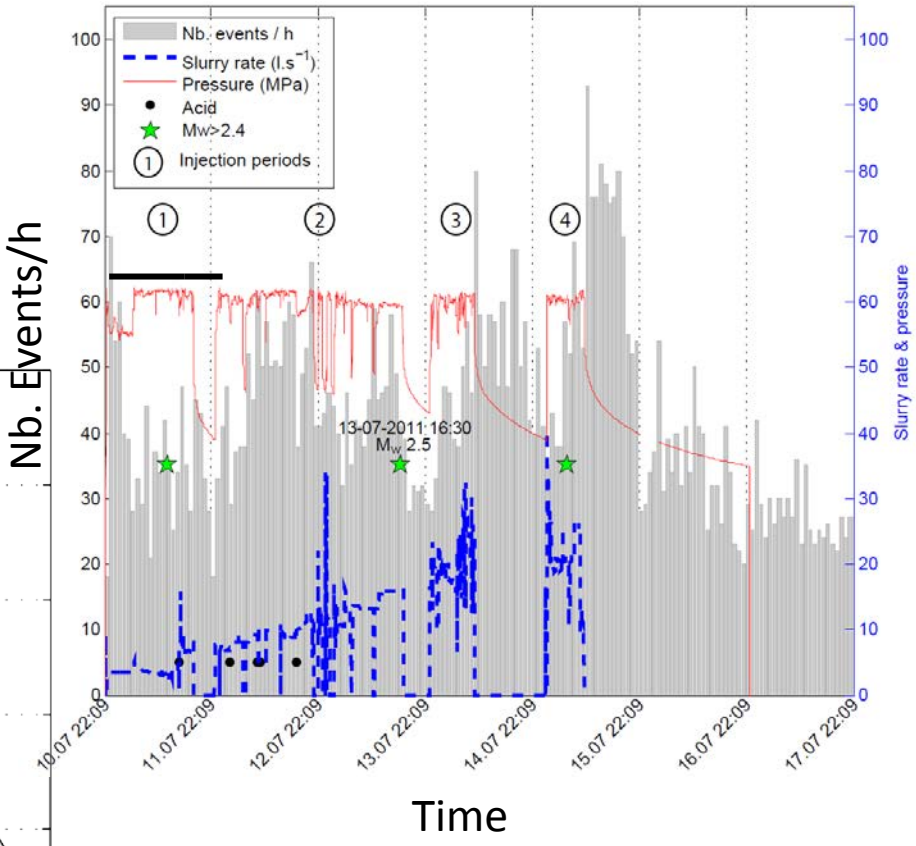


Induced seismicity pattern

During stimulation

Shut-in



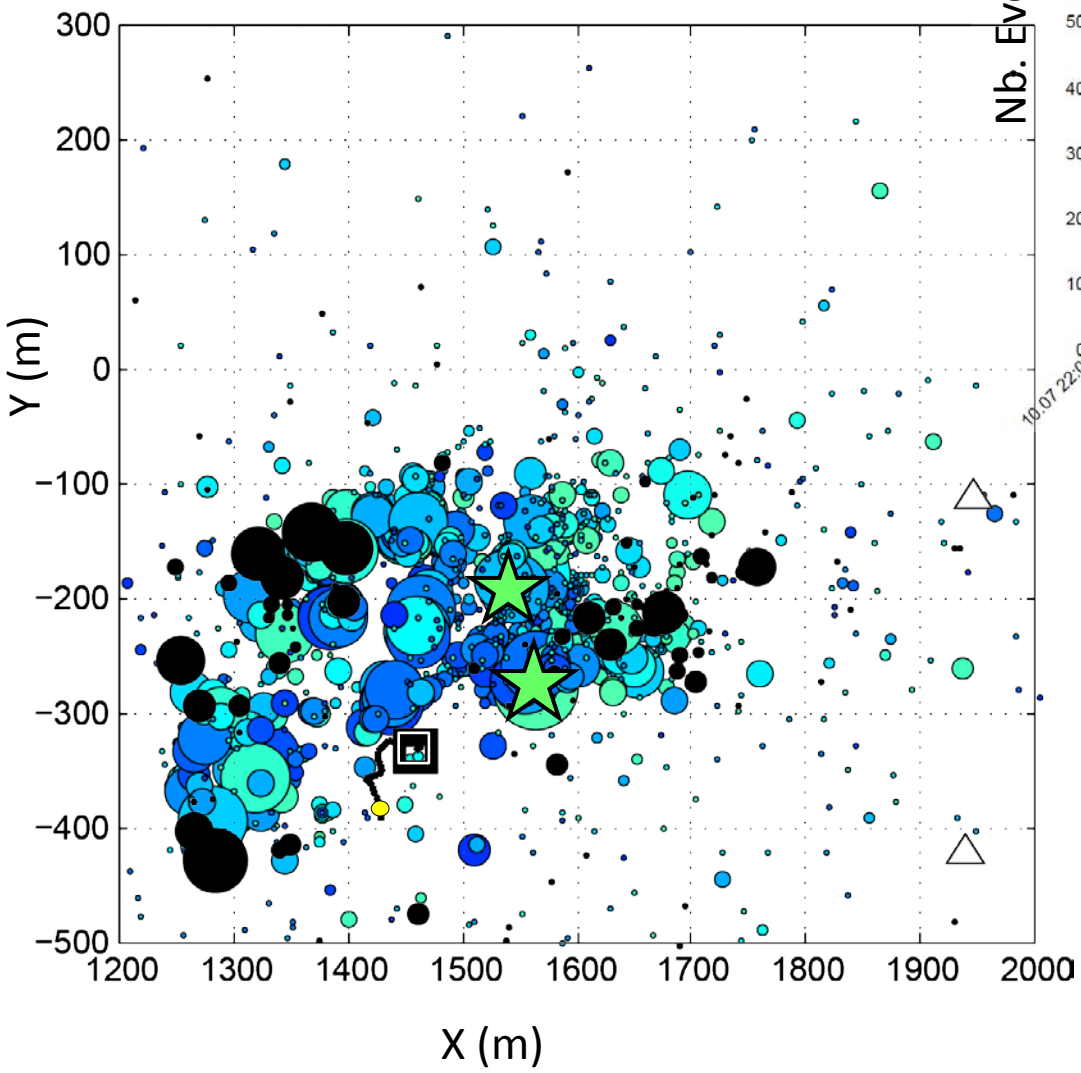


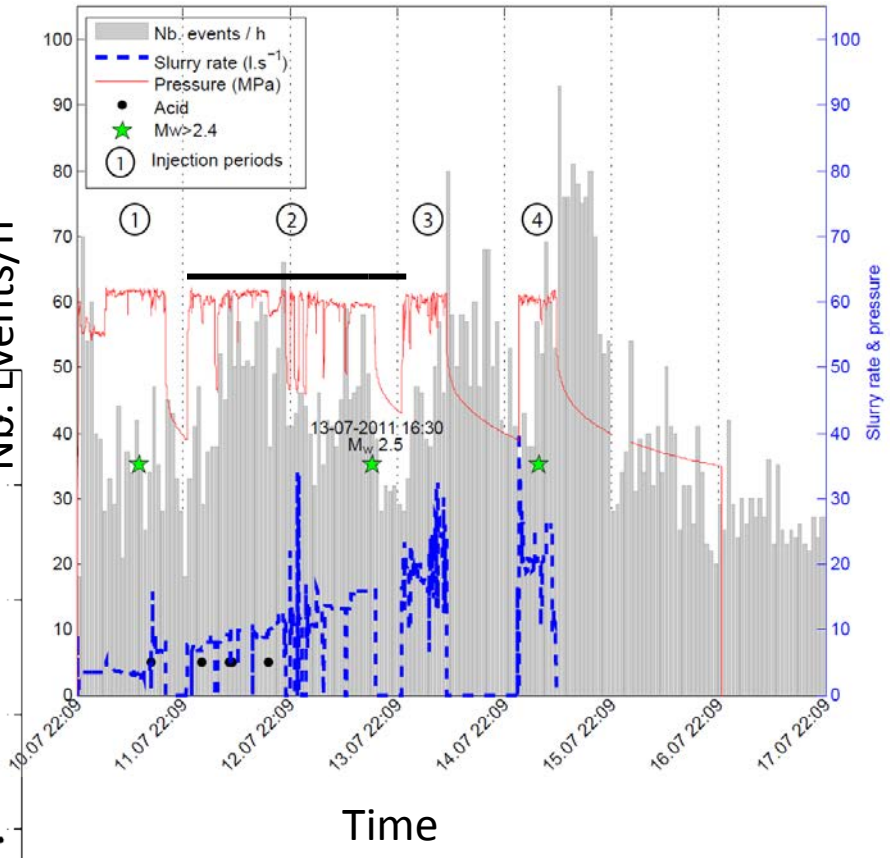
➢ **close to the well**

Induced seismicity pattern

During stimulation

Shut-in



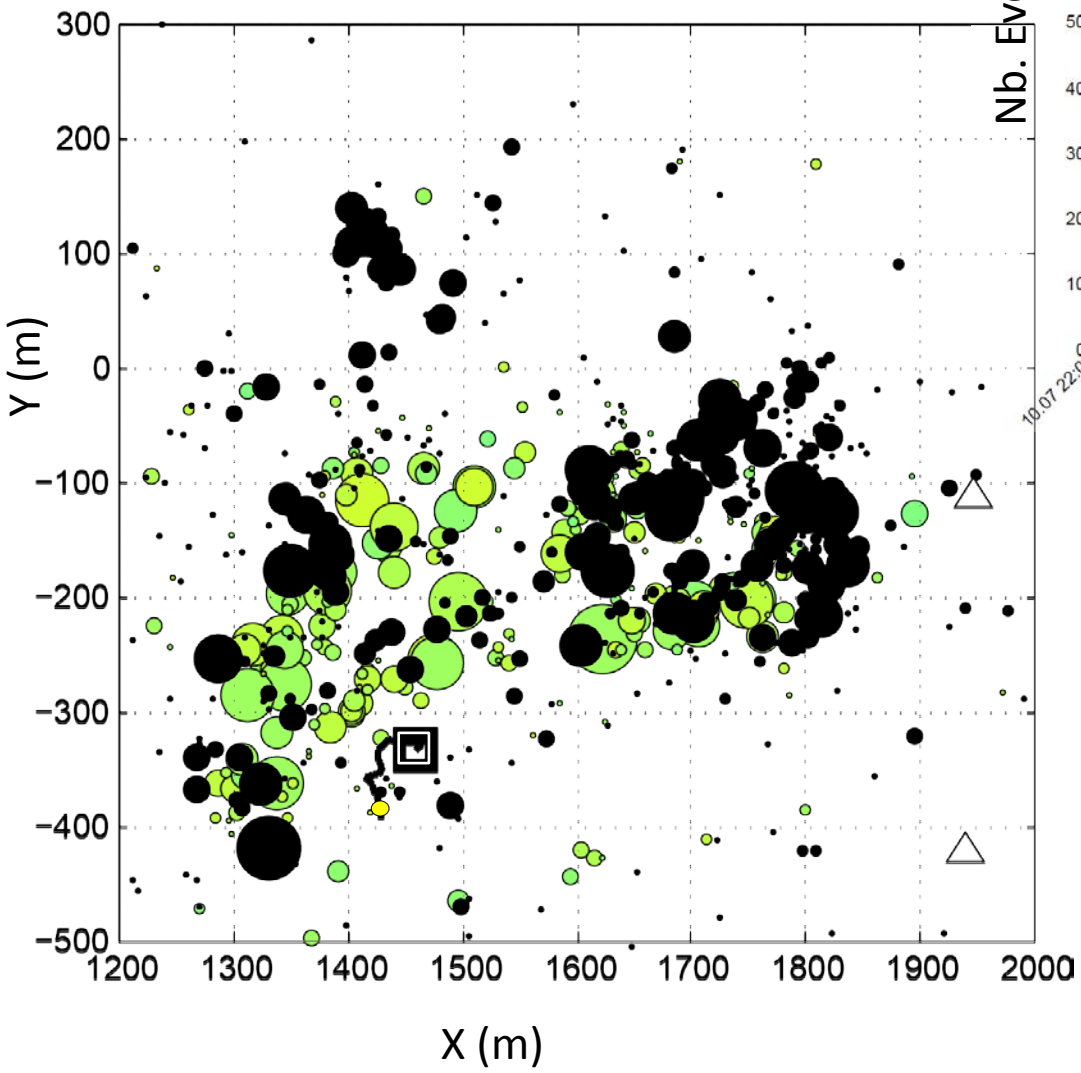


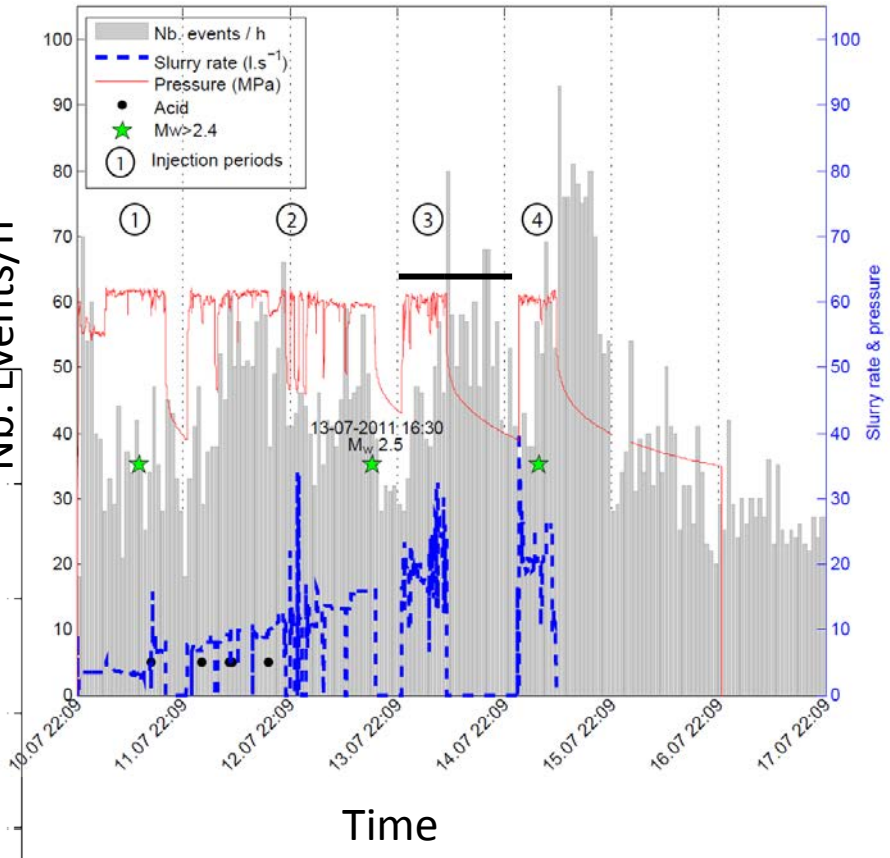
➢ **Distance from injection increases**

Induced seismicity pattern

During stimulation

Shut-in



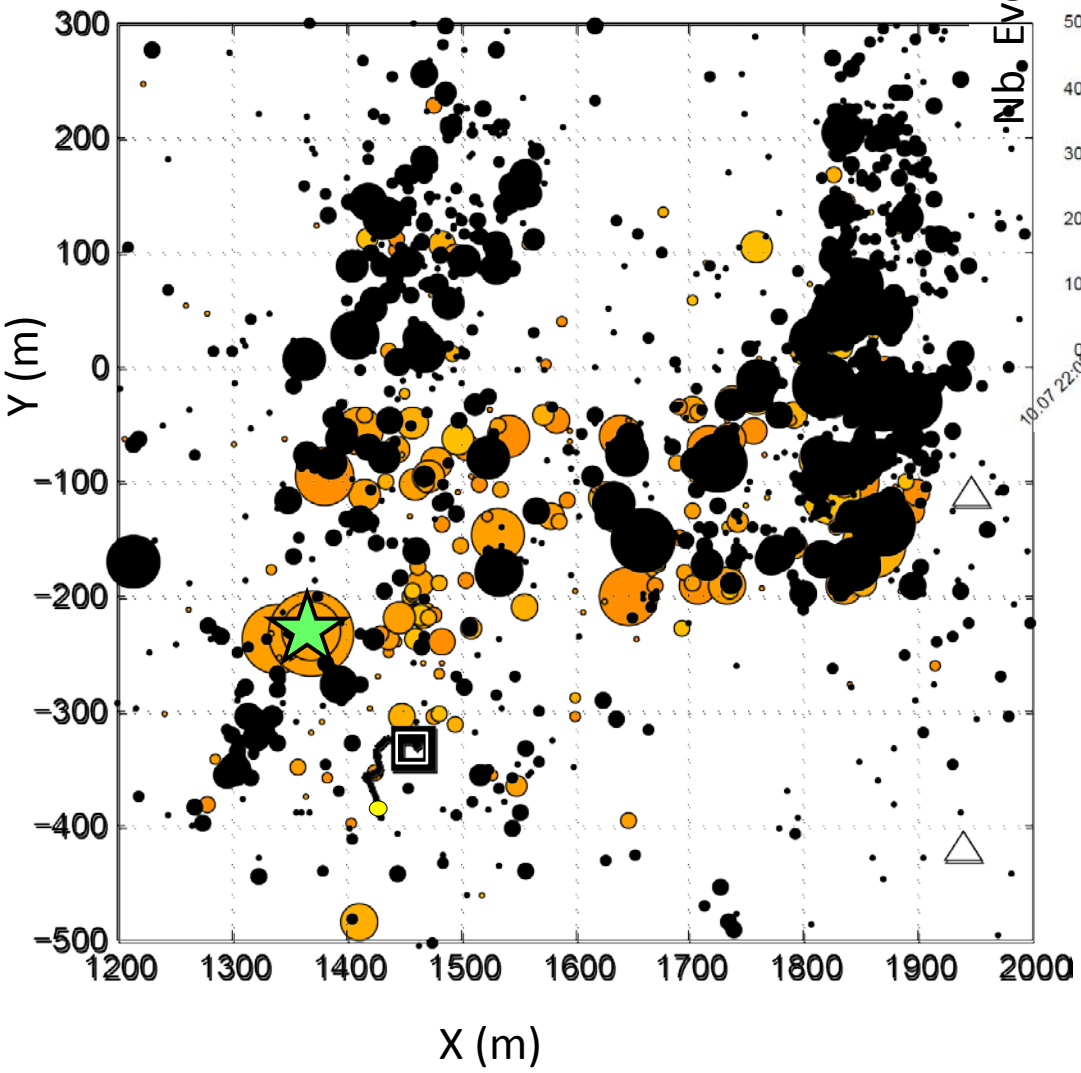


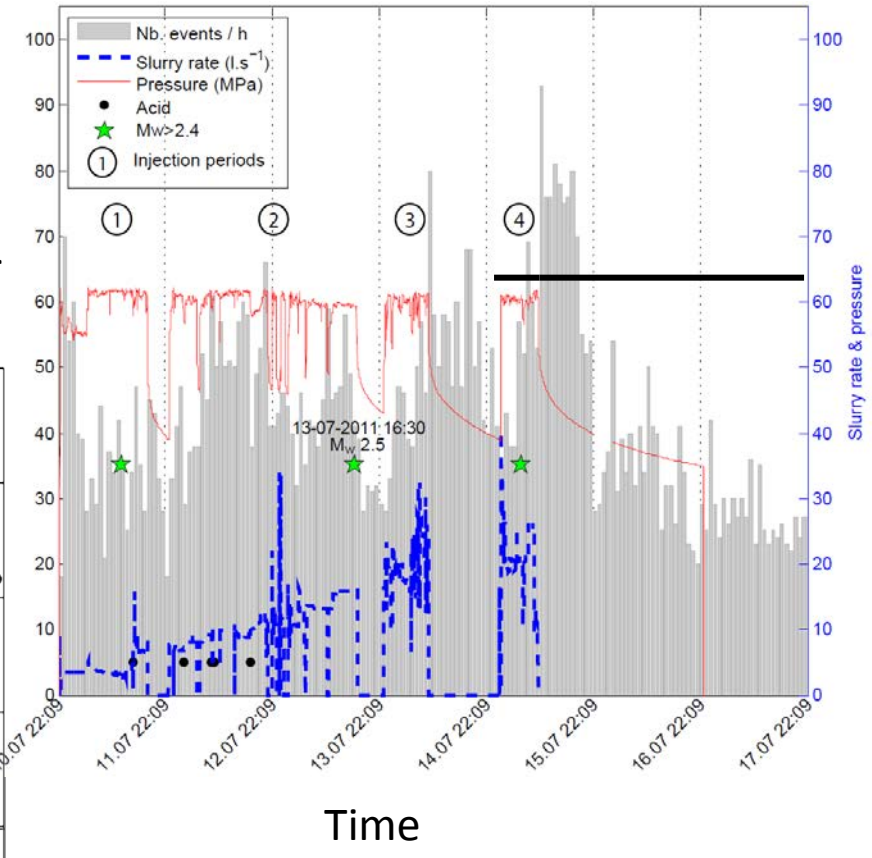
➢ **Distance from injection increases**

Induced seismicity pattern

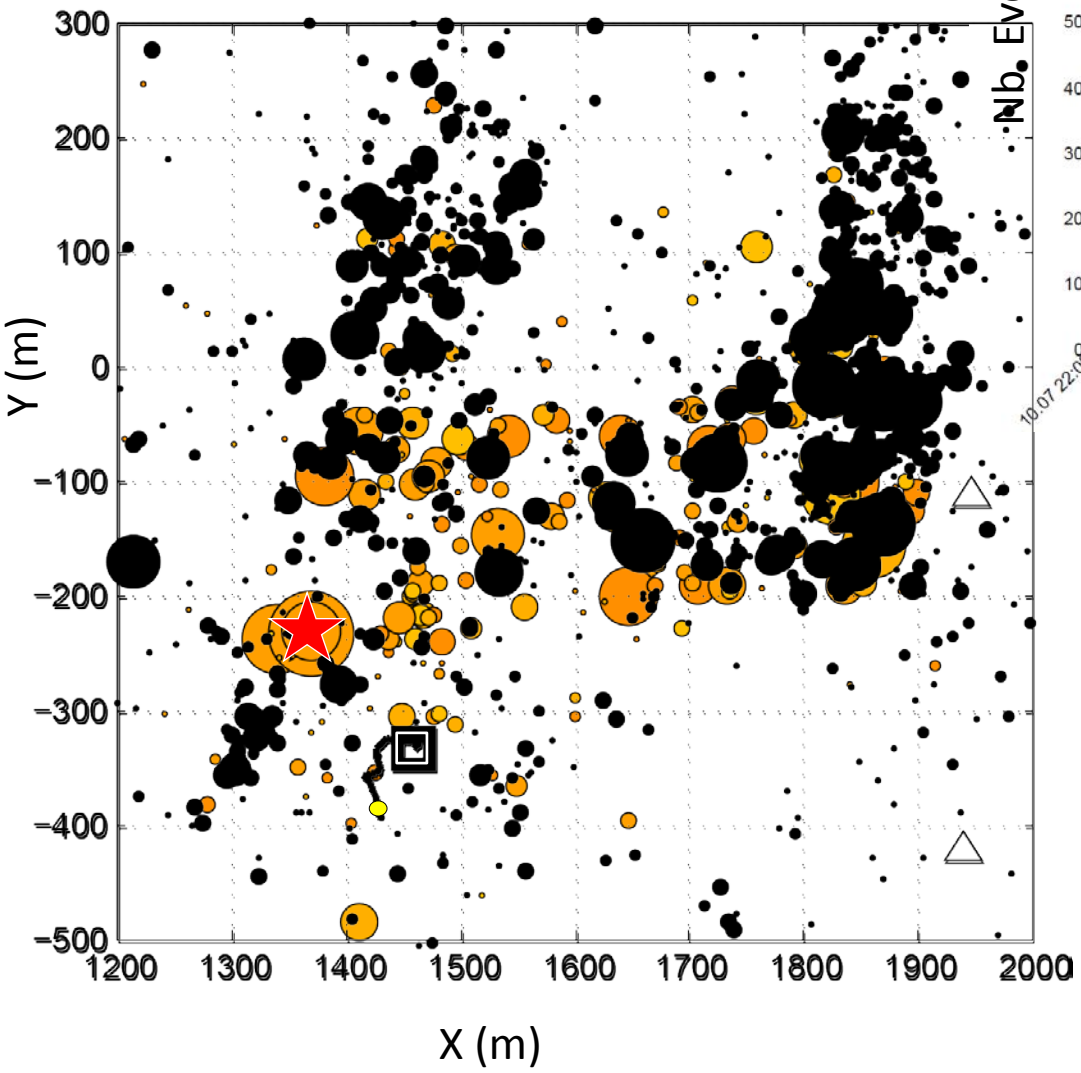
During stimulation

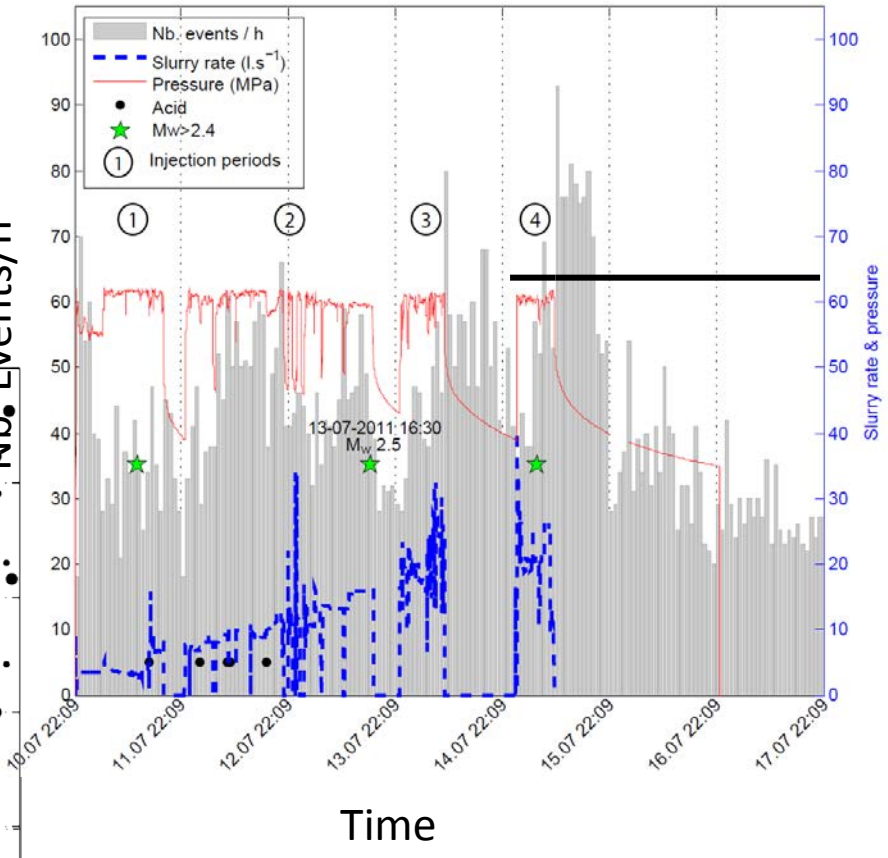
Shut-in





Induced seismicity pattern



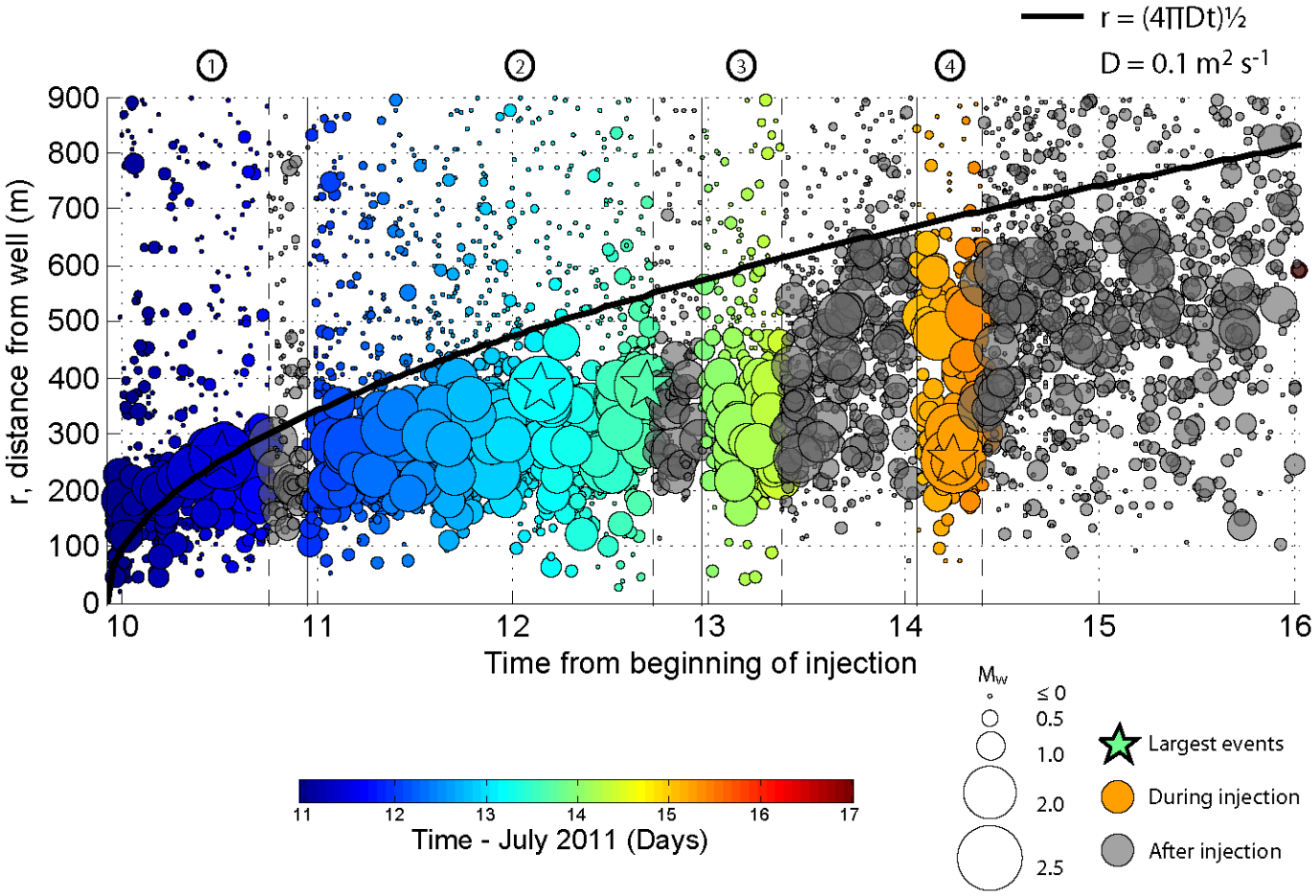


- **Distance from the injection well increases**
- **Post-injection seismicity at the outer rim of previous zone activity**

=> Kaiser effect

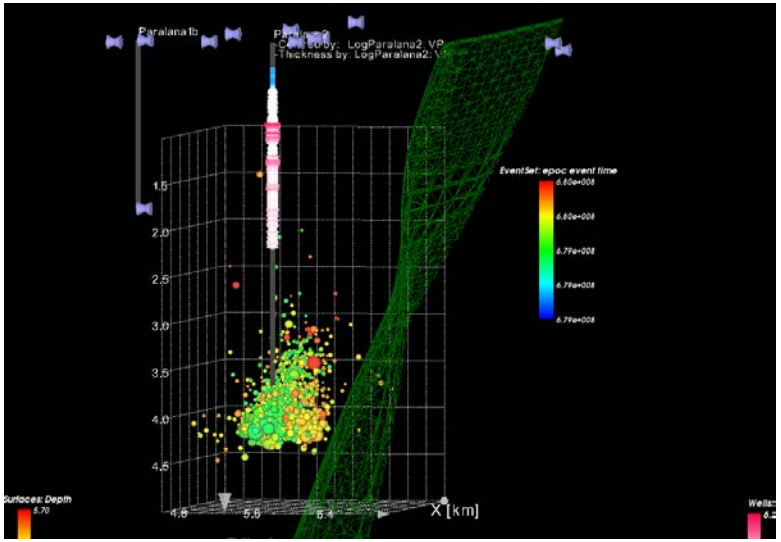
Induced seismicity pattern

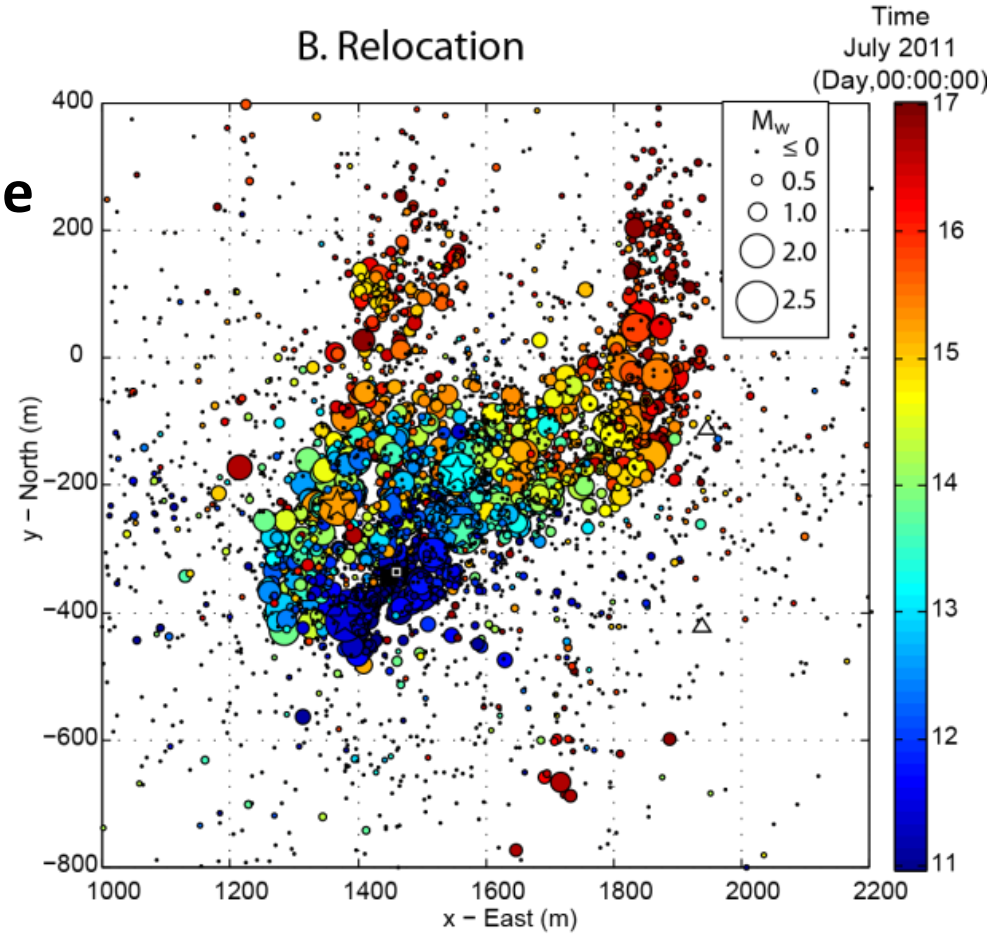
- Pore pressure front at r= $\sqrt{4\pi Dt}$ (Shapiro et al., 1997)



Here we are back at the final **Benefits**

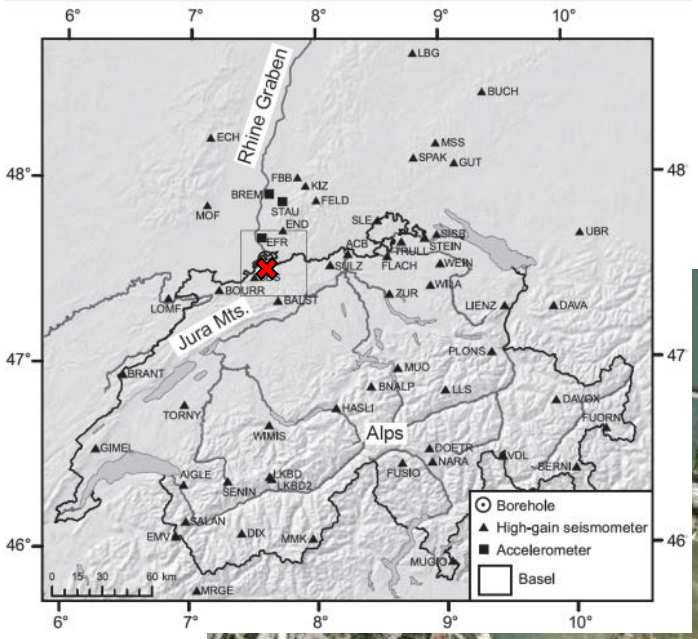
- **Get image on the created fracture network**
- **Can place secondary wells**
- **Understand behaviour of the system during production**





Some more benefits and challenges

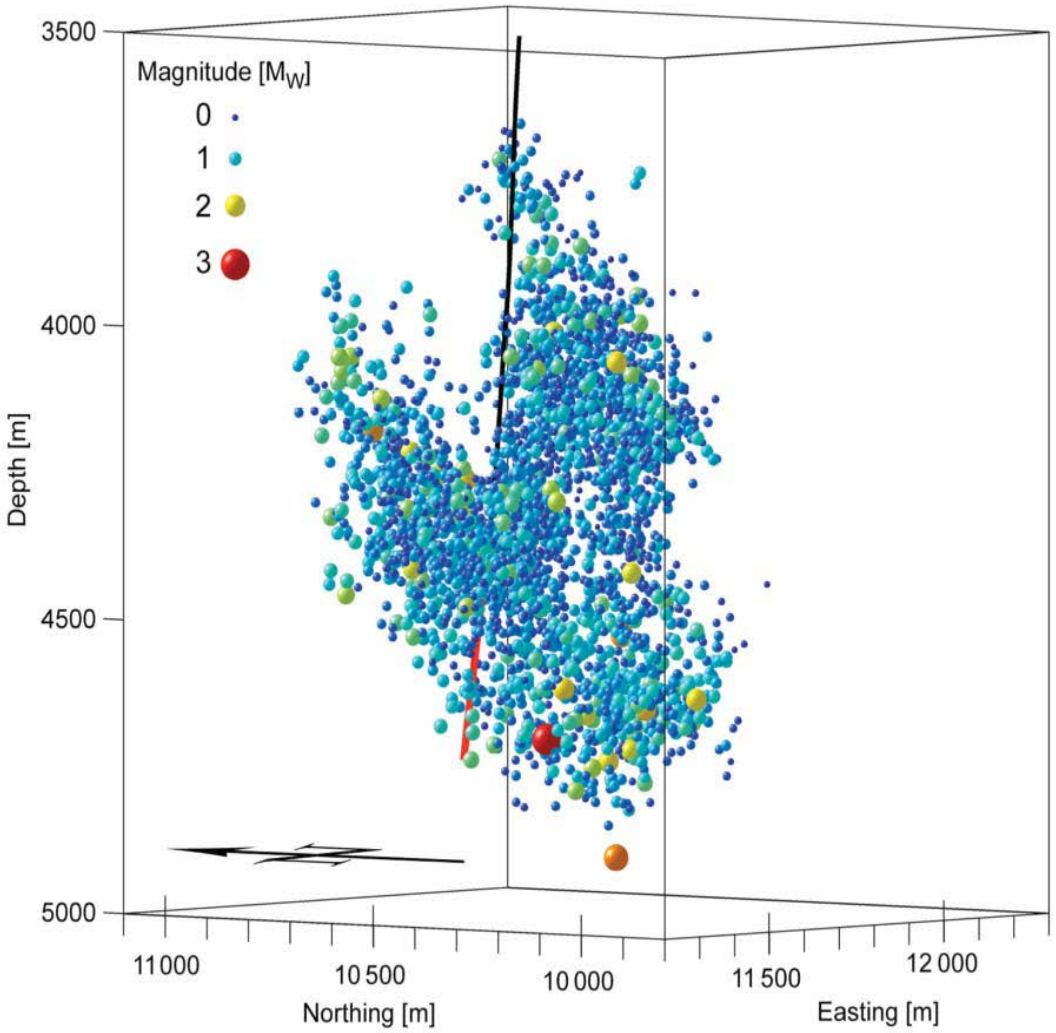
Basel deep heat mining



Location of the Basel EGS project

Goal: Geothermal heat and power

Seismicity cloud

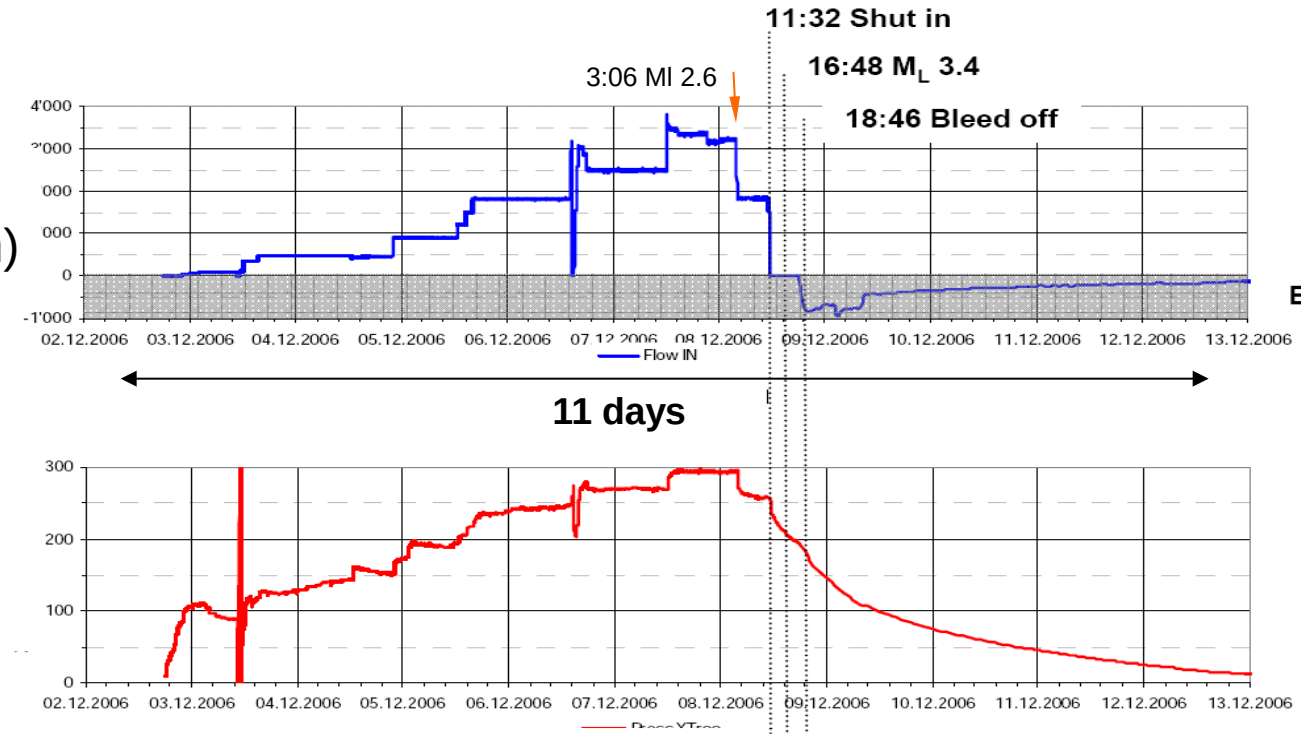


- Over 11‘000 events recorded at six borehole stations
- ~3500 events located

Dyer et al. (2008)

Reservoir stimulation phase

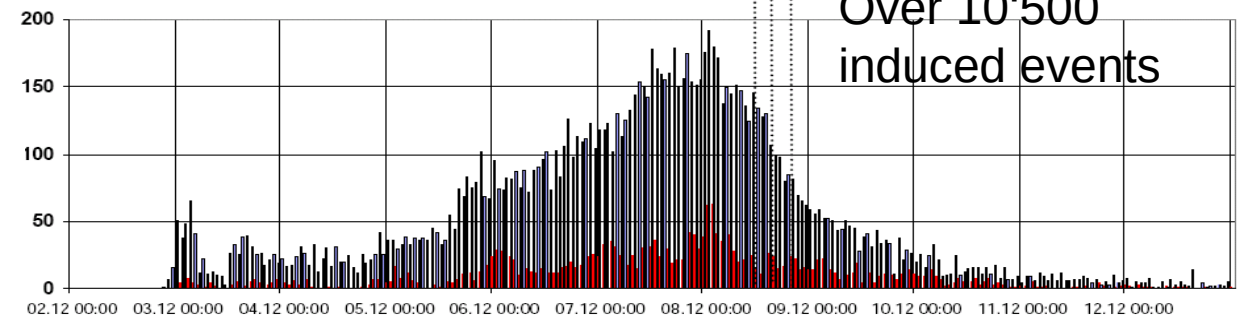
Injection Rate (l/min)



6 days of injection

Wellhead Pressure (bar)

Event Rate (h^{-1})

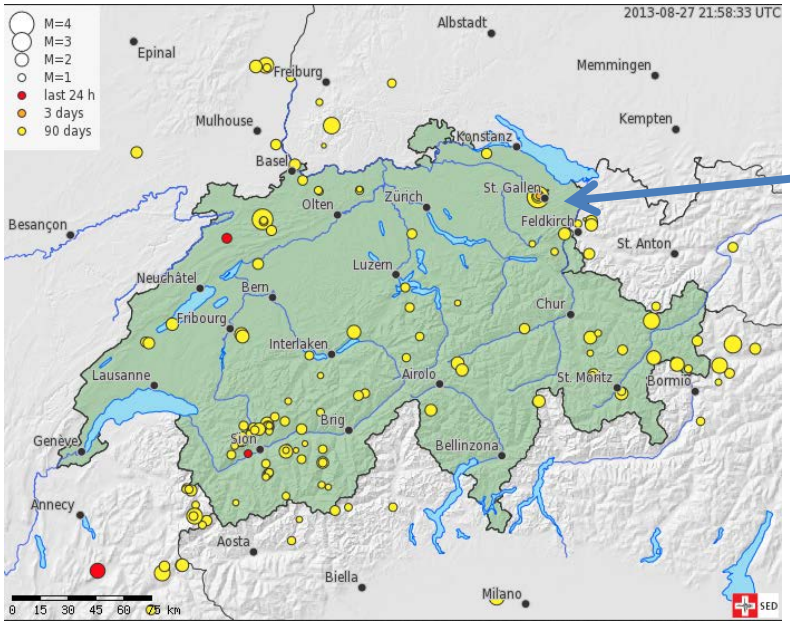


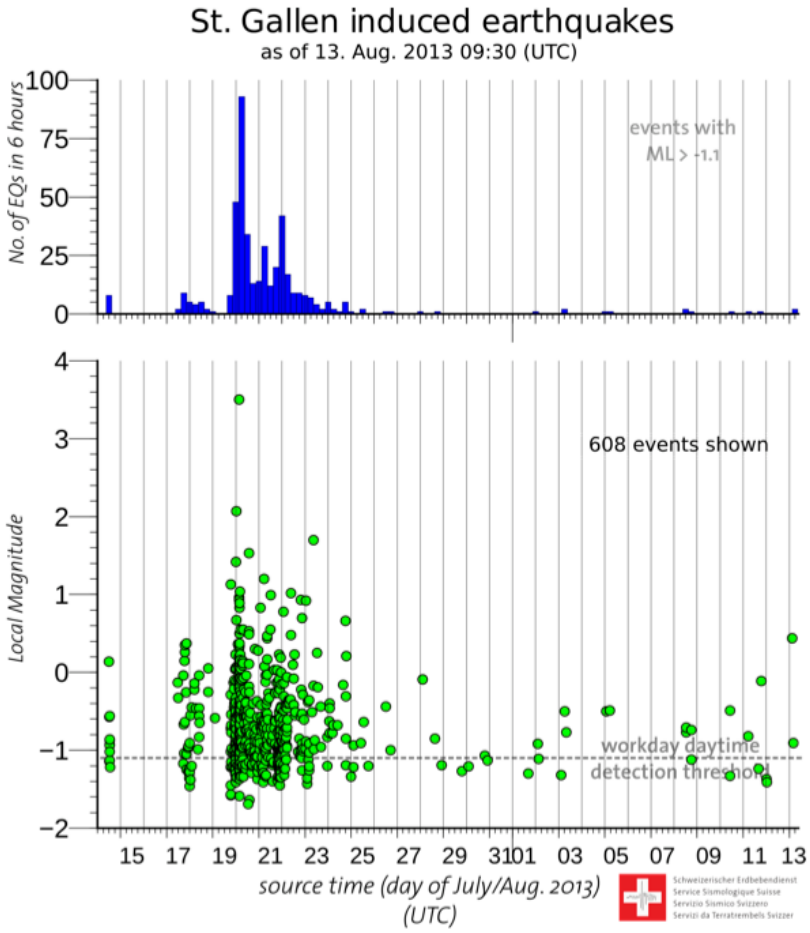
Over 10‘500 induced events

2006/12/08
03:06 ML 2.6
15:46 ML 2.7
16:48 ML 3.4
20:19 ML 2.5

Häring et al. (2008)

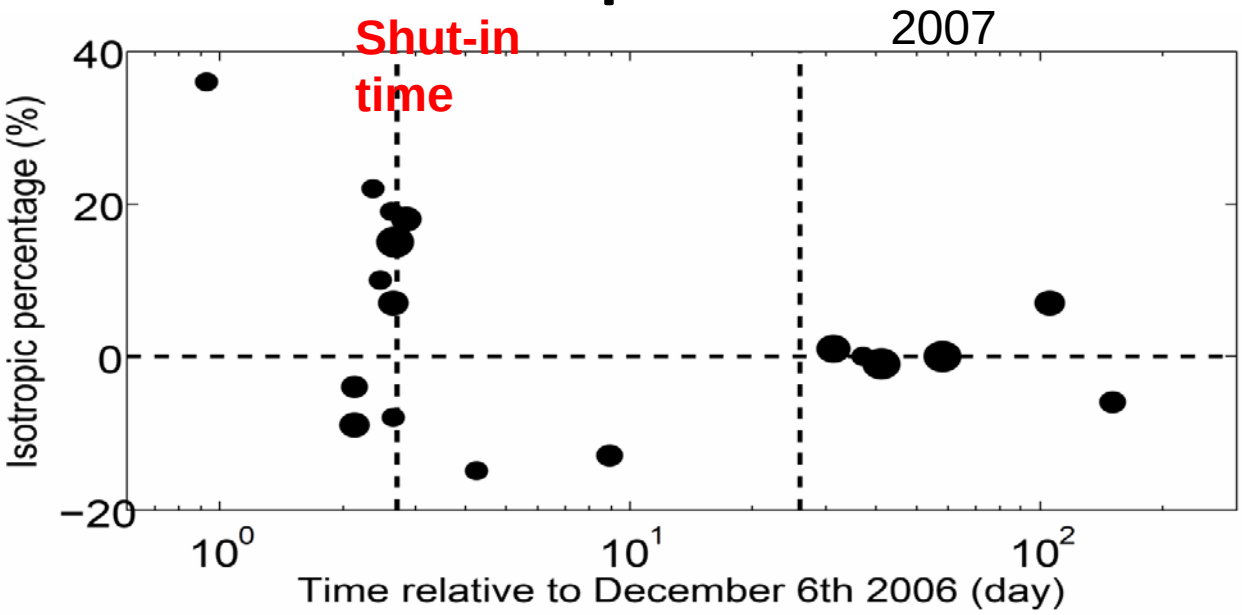
Geothermal projects in Switzerland, European champion in generating earthquakes



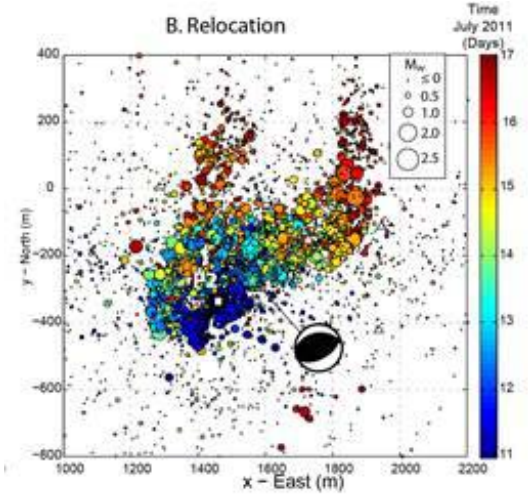


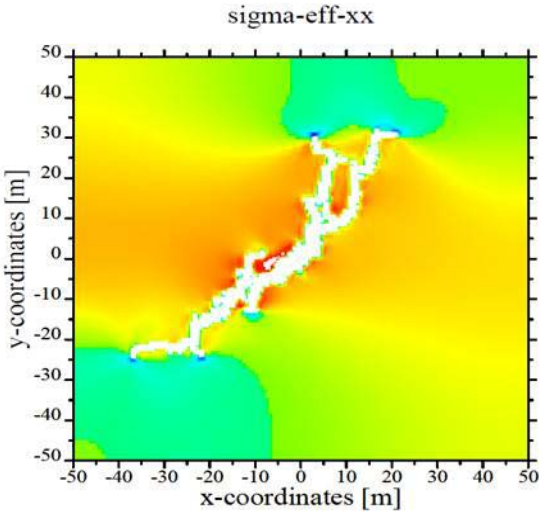
Next steps:

Moment tensor analysis at Basel: Temporal change of ISO component



integrate **fracture** modelling with occurrence of **microseismicity**





(IFE: Wangen, 2011, J. Petr. Sci. Eng.)

Acknowledgements

- EU FP7 project GEISER
- Geothermal Explorers Ltd, and ETH Zurich for providing data and for discussions with N. Deichmann