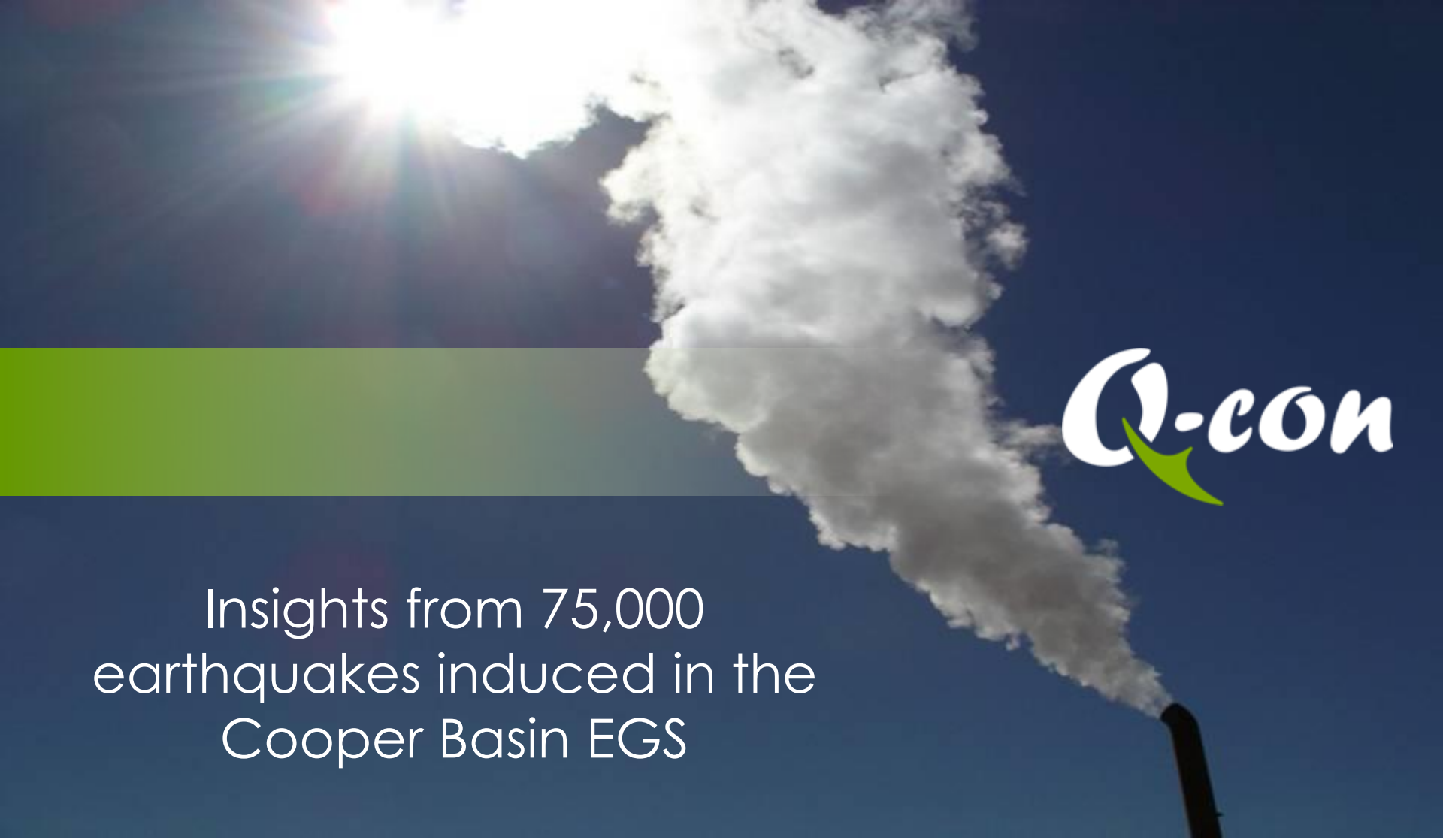


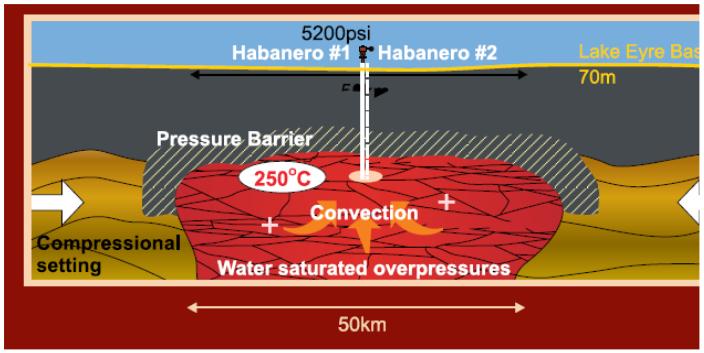
Insights from 75,000 earthquakes induced in the Cooper Basin EGS

Stefan Baisch

Q-con

Geothermal reservoir engineering

The project



Enhanced Geothermal System

Cooper Basin

(objective >100 MW_{el})

- 6 deep wells in granite
- massive hydraulic stimulations

The project

Enhanced Geothermal System Cooper Basin

	cum# events
2003 H#1 stimulation	28,102
2005 H#2 stimulation, H#1 re-stimulation	45,525
2008 H#3 stimulation, H#1 - H#3 circulation	46,242
2010 Jol#1 stimulation	46,476
2012 H#4 stimulation	74,013
2015 project abandoned	76,343

The project

Q-con GmbH
Geothermal reservoir engineering

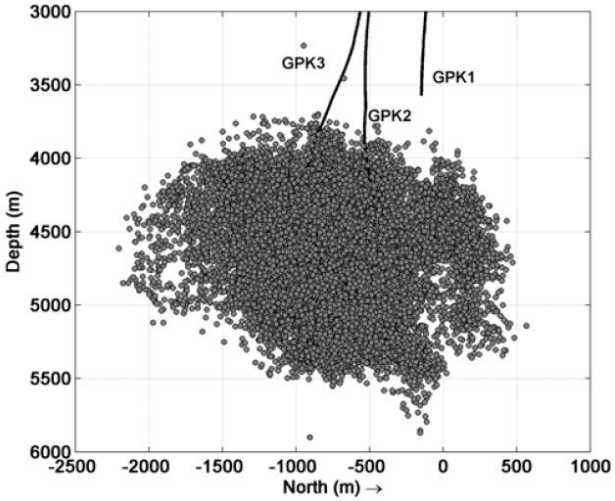
What remains?

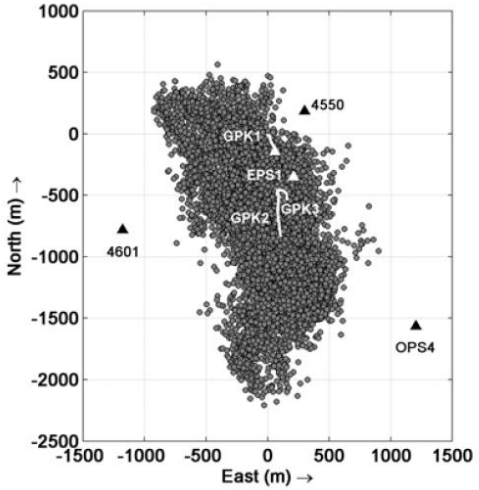
→ One of the largest and best controlled data sets of injection induced seismicity

- seismicity continuously monitored since 2005
- magnitude range M_L=-2 to M_L=3.7
- up to 24 local stations (surface seismometers, borehole geophones)
- complete record of hydraulic activities
- multi-well set up (cores, image logs, etc.) → 'ground truth'

The ‘geothermal perspective’ prior to the Cooper Basin project

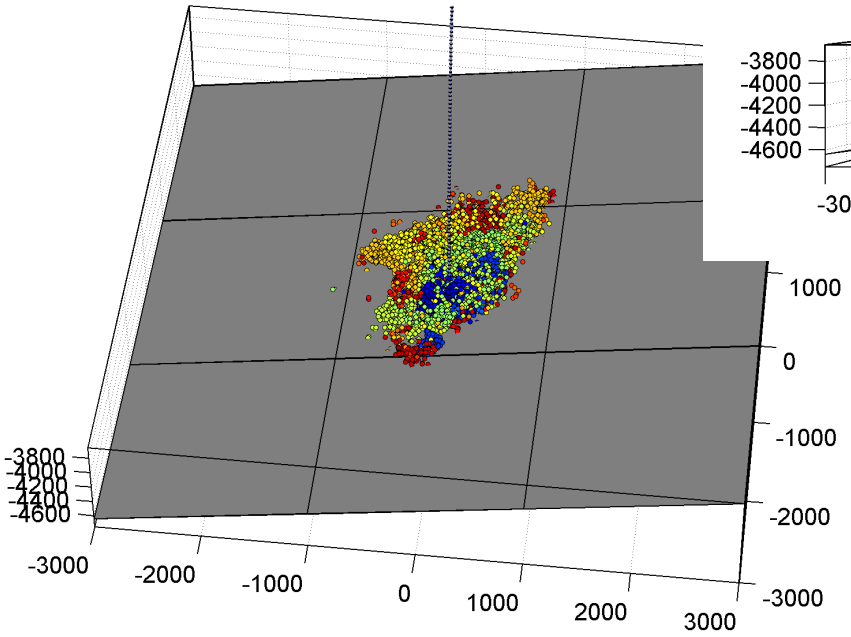
‚Hydraulic stimulations create complex, volumetric fracture networks as evidenced by spatial seismicity distibutions‘

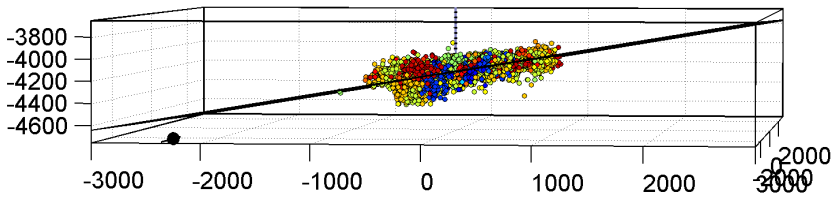




Soultz-sous-Forêts
(Figure from Michelet & Töksöz, 2007. JGR.)

Habanero: A planar reservoir

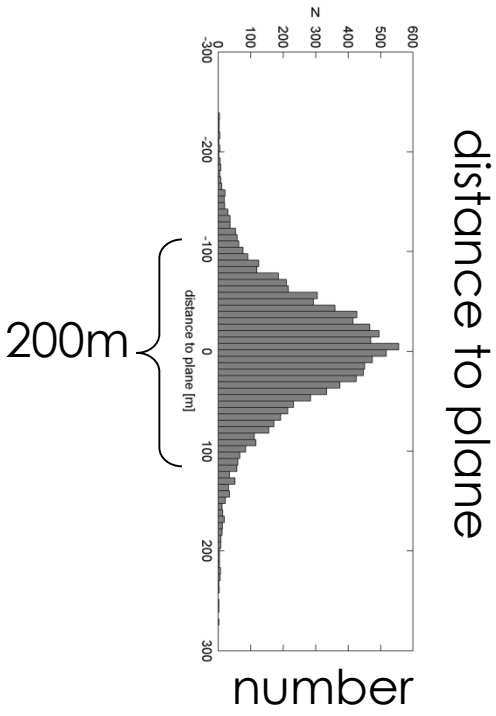




Baisch et al., 2006. BSSA

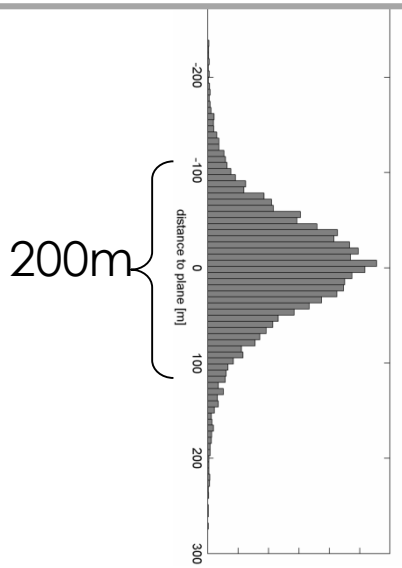
Habanero #1 stimulation

- > 28,000 induced events, M_L 3.7
- planar reservoir structure
- apparent thickness ~200 m
- vertical hypocenter location error (2σ): 118 m

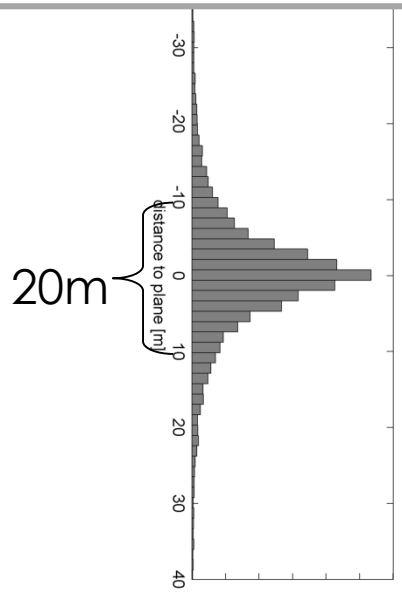


Habanero: A planar reservoir

absolute hypocenter locations



relative hypocenter locations



Baisch et al., 2006. BSSA

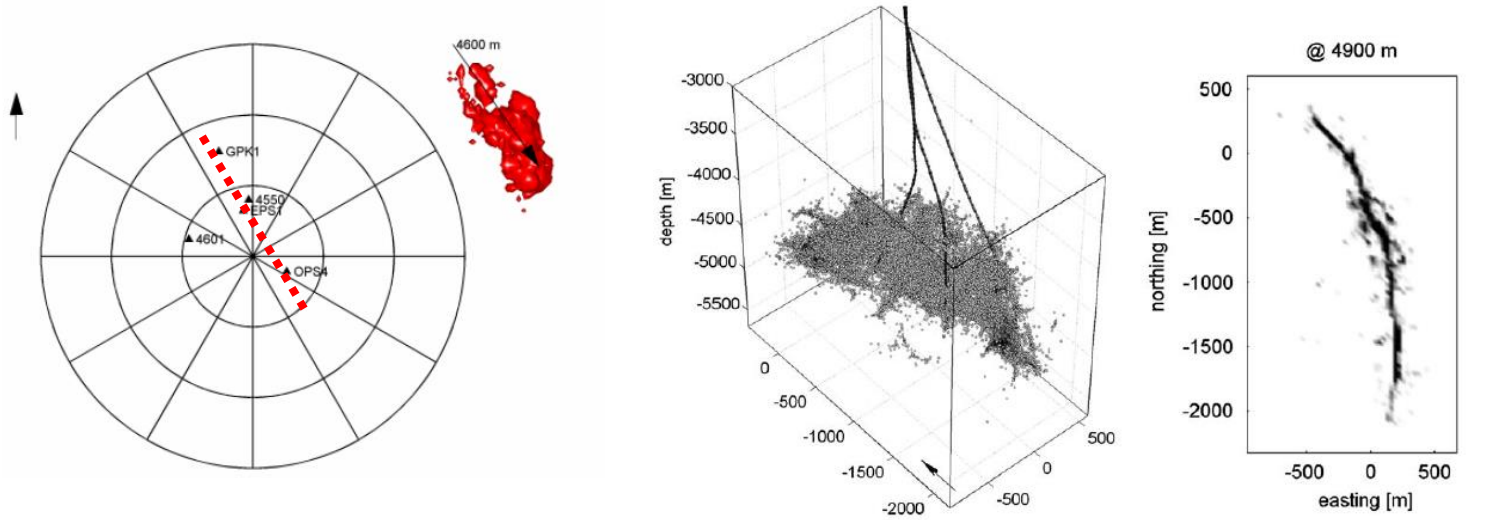
→ reservoir is dominated by a planar fault zone (thickness: meter scale or less)

→ confirmed by subsequent wells ('ground truth')

Are other geothermal reservoirs really volumetric?

Re-processing of Soultz-sous-Forêts data sets

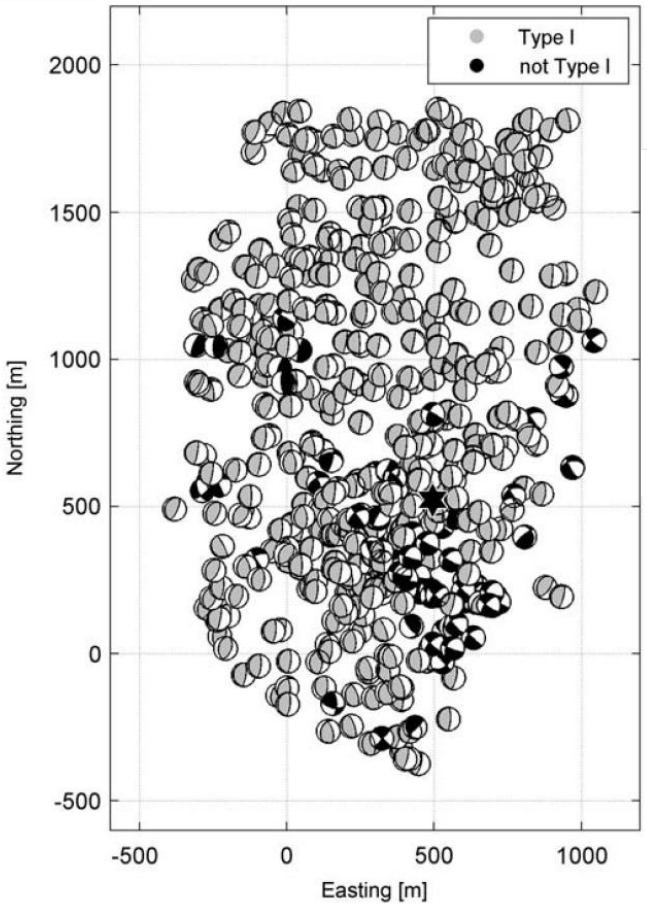
→ ill constrained data excluded
→ 'planar reservoir hypothesis' cannot be rejected

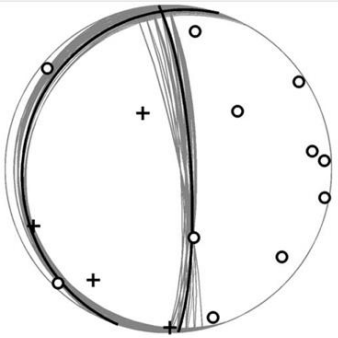


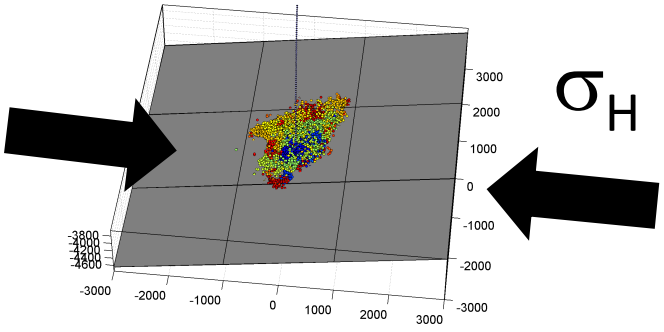
Baisch et al., 2010. IJRMMS

Baisch et al., 2015. BSSA

Fault mechanisms







→ most FPS are consistent with slip driven by the regional stress field and occurring on the planar structure as outlined by hypocenters

→ plane dips ~10° (optimum orientation ~30°)

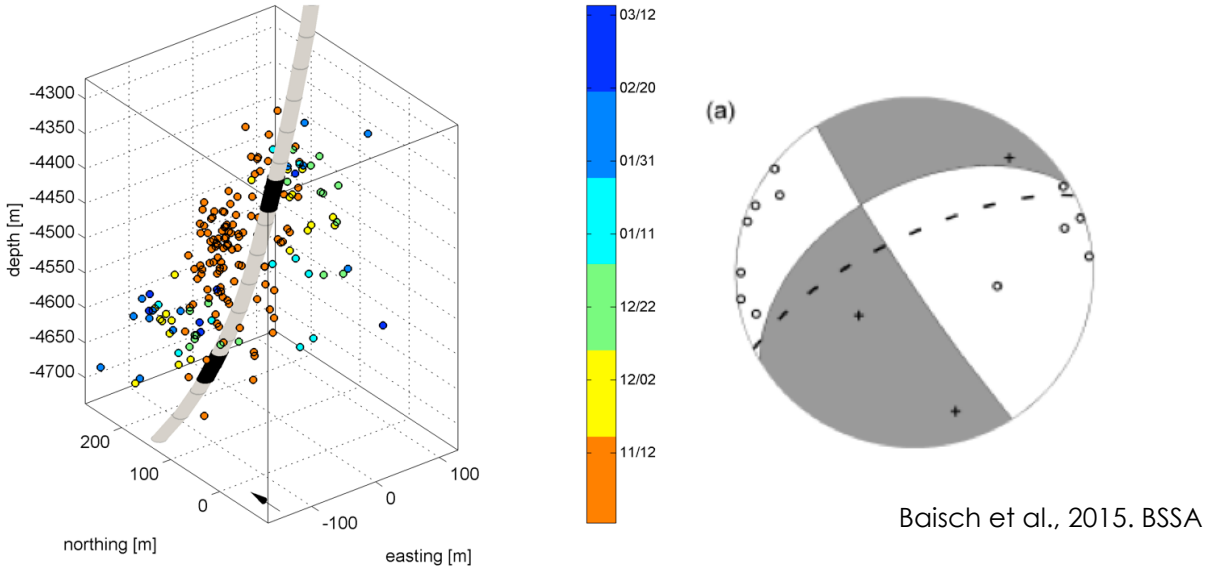
Why did this plane shear? Because no other orientations were available!

The role of natural fractures

- similar ‚experiment' conducted at Jolokia , 10 km away from Habanero
- no pre-existing flowing fractures at Jolokia
- stimulation failed (14 days, 700 bar → 1 l/s)

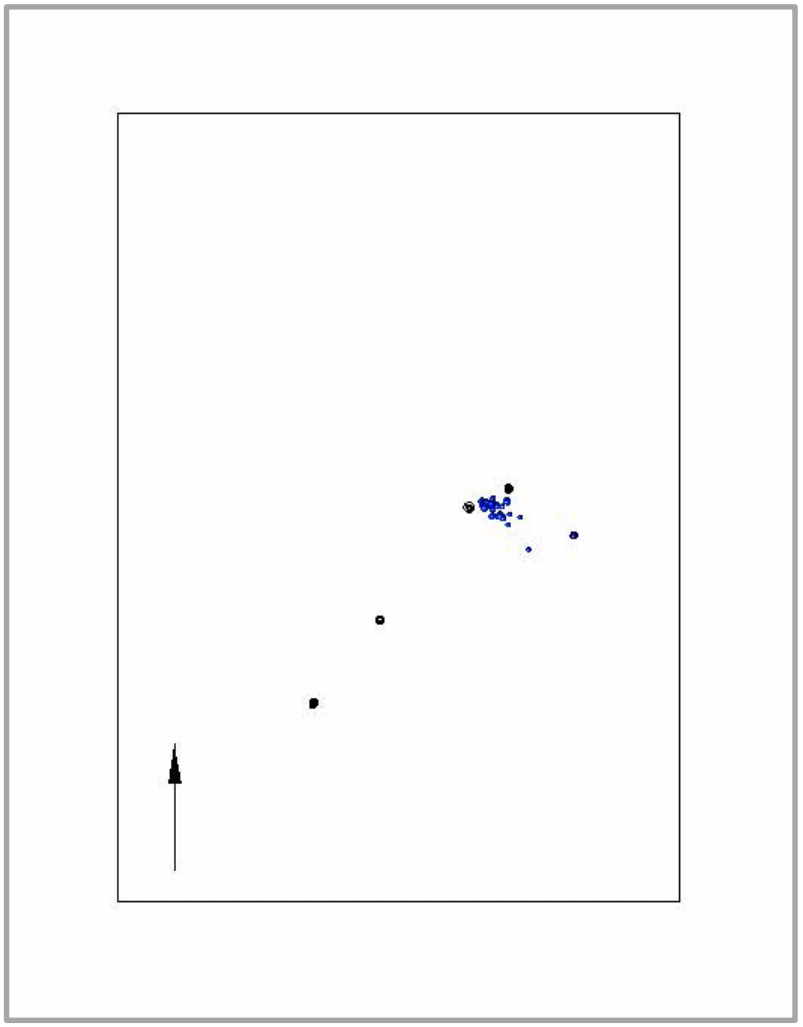
→ stimulation does not work everywhere!

Jolokia stimulation

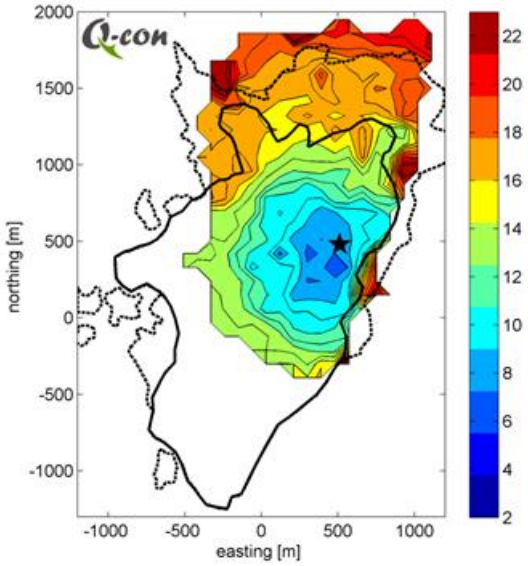


Baisch et al., 2015. BSSA

Spatio-temporal seismicity evolution: Constrains triggering mechanisms



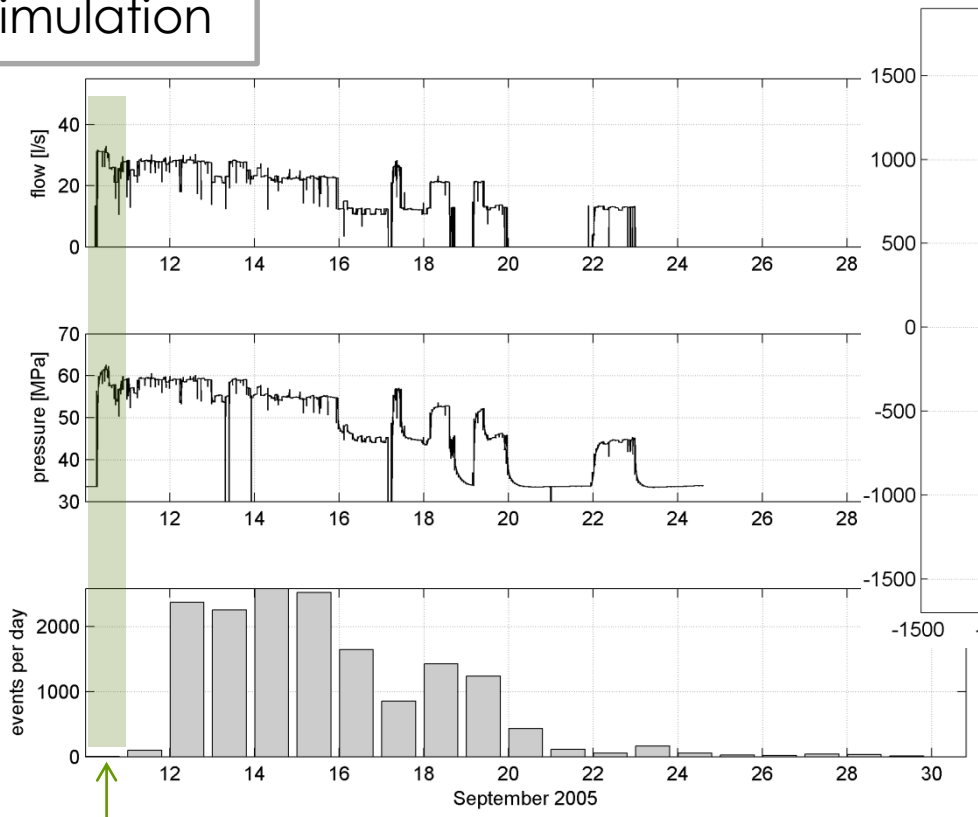
Baisch et al., 2015. BSSA

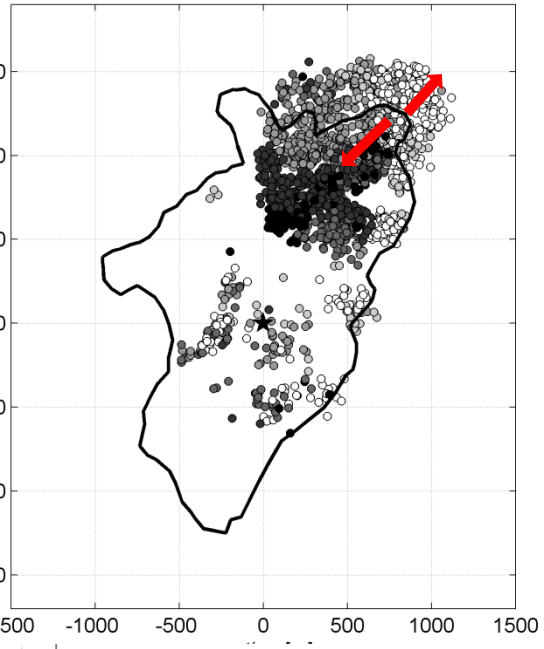


H#4 stimulation, map view
→ systematic in space/time

Kaiser Effect: Constrains triggering mechanisms

H#1 re-stimulation



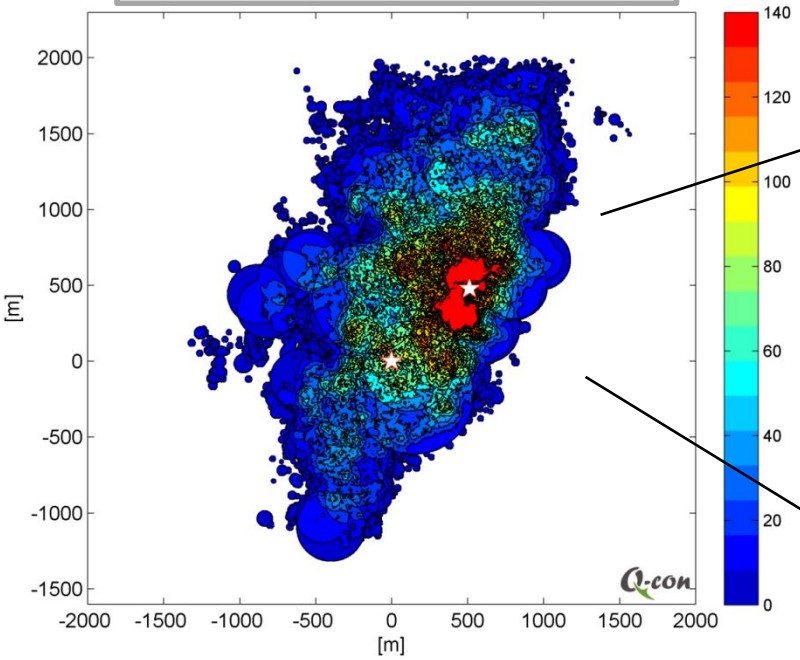


Baisch et al., 2009. BSSA

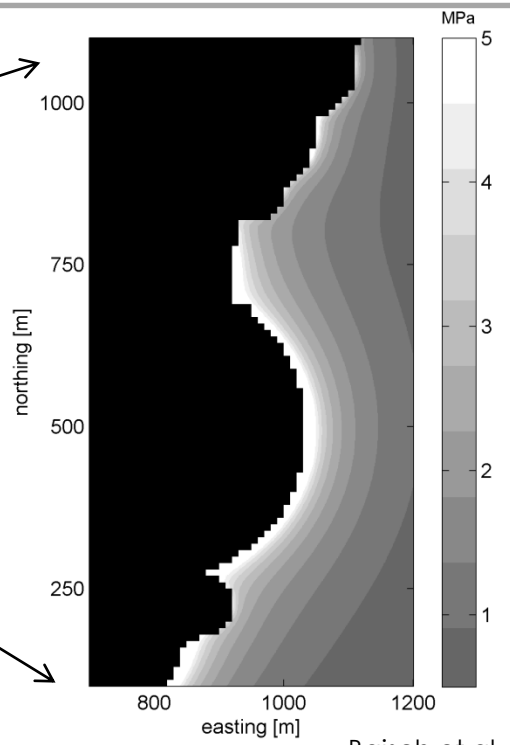
Kaiser effect (stress memory): seismicity occurs at those locations, where previous stress criticality is exceeded

How stimulations change subsurface stresses

cumulative slip [mm]



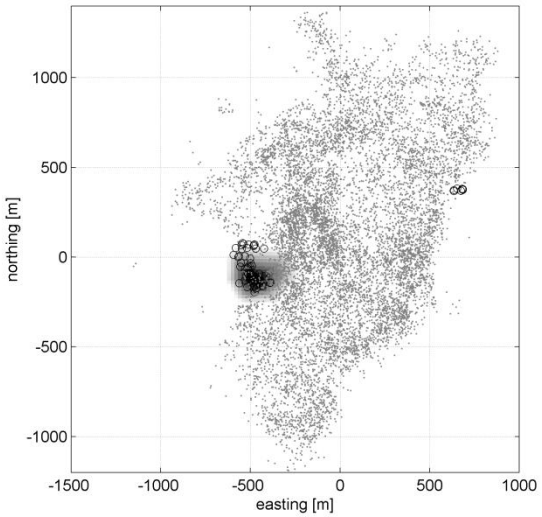
modelled shear stresses



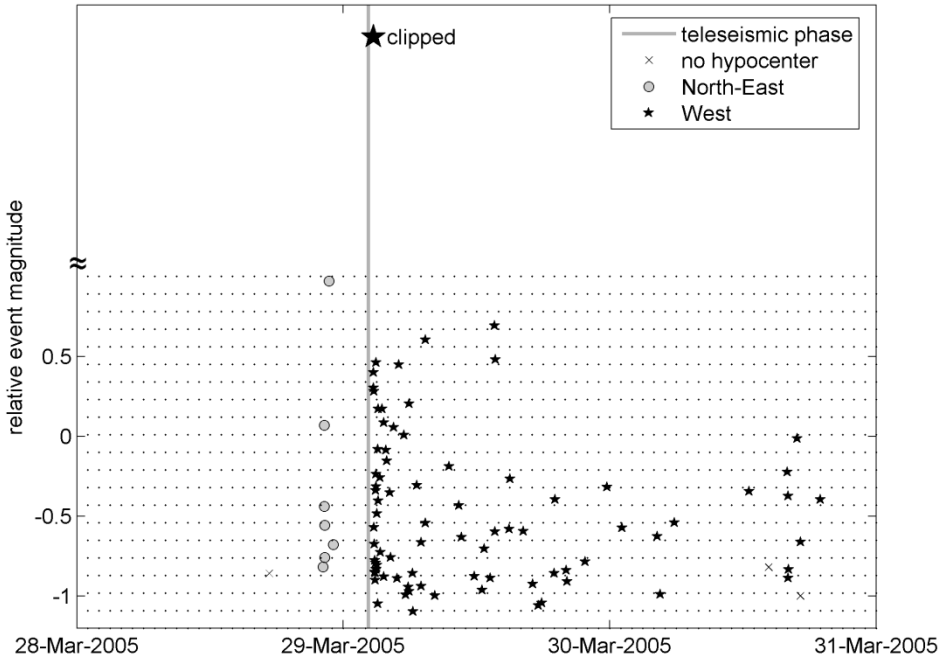
Baisch et al., 2015. BSSA

→ large shear stress concentration at outer rim

How stimulations change subsurface stresses



Baisch et al., 2006. BSSA



- Teleseismic earthquake triggered M_L=3.x earthquake at the outer rim of previously stimulated reservoir (no hydraulic activities within 12 months)
- a sequence of 84 aftershocks followed

→ after-deformation is likely to also play a role during stimulation

Conclusions

- Cooper Basin experiments provide one of the largest and best controlled data sets of injection induced seismicity.
- Insights from these experiments improved our conceptual understanding of geothermal reservoirs and our understanding of the physical processes associated with induced seismicity.


Thank you!