Soft stimulation and induced seismicity

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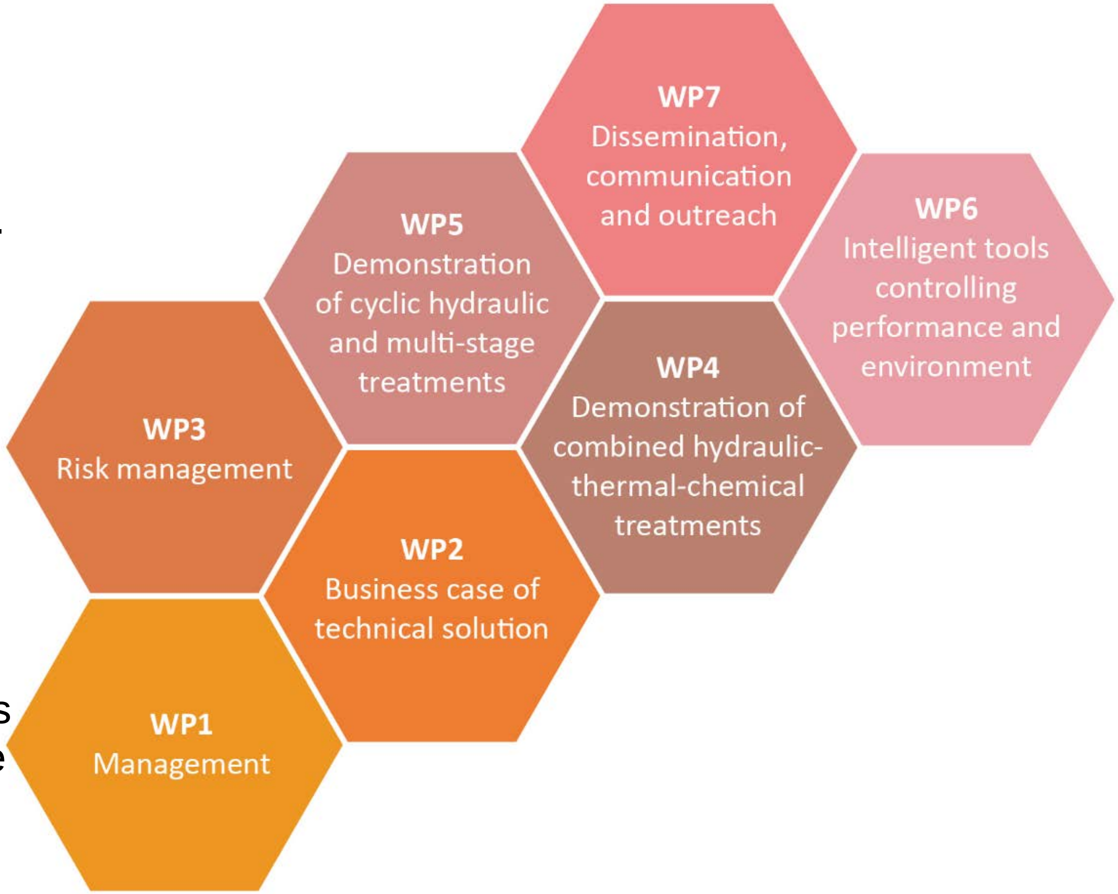
How Do We Define Soft Stimulation?

Soft stimulation is a collective term for geothermal reservoir stimulation techniques. It aims to achieve enhanced reservoir performance while minimizing environmental impacts including induced seismicity. Soft stimulation includes techniques such as cyclic / fatigue, multi-stage, chemical and thermal stimulation.

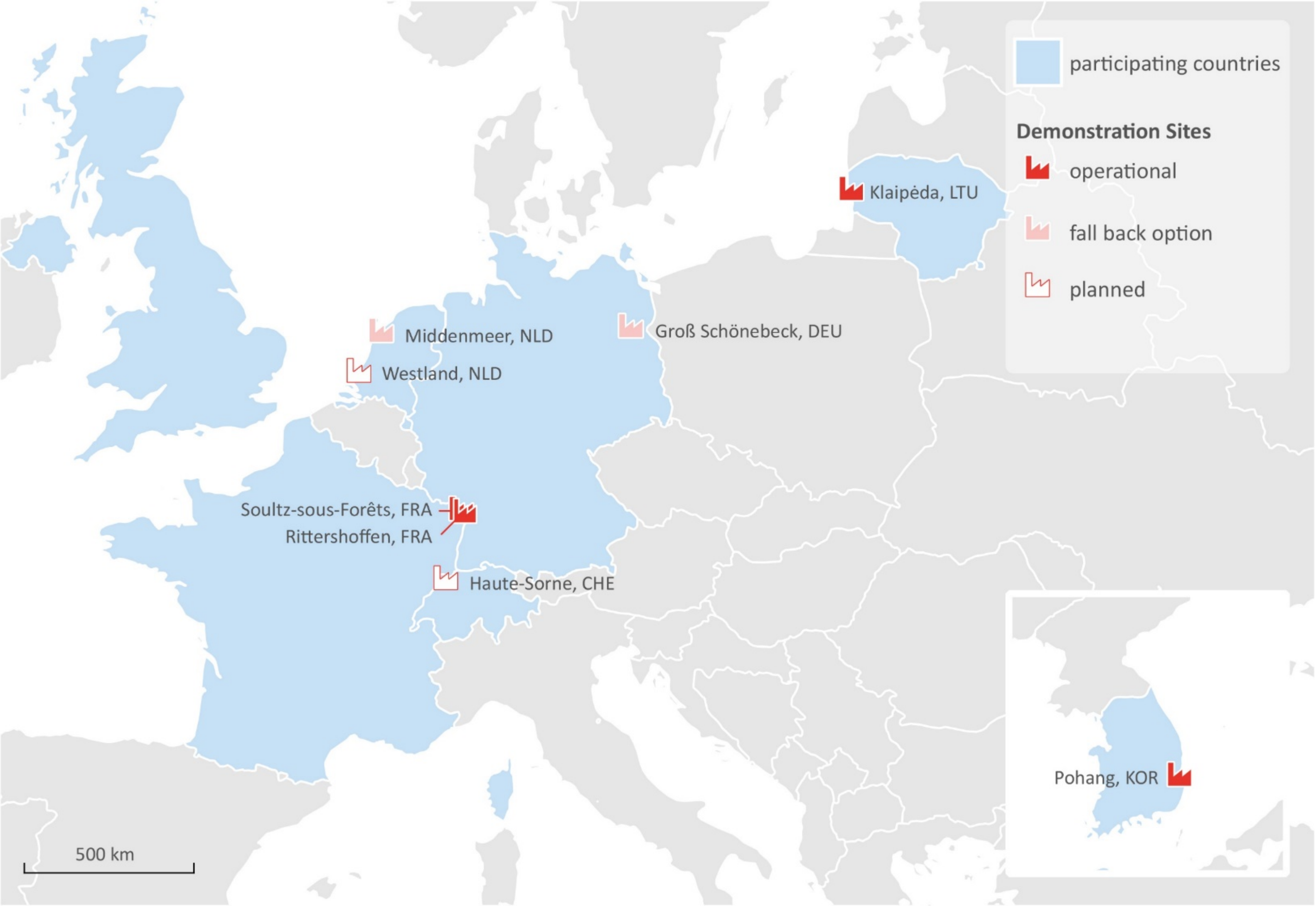
DESTRESS demonstrates methods of enhanced geothermal systems (EGS). The aim is to expand knowledge and to provide solutions for a more economical, sustainable and environmentally responsible exploitation of underground heat.

DESTRESS will improve the understanding of technological, business and societal opportunities and risks related to geothermal energy. Existing and new project sites have been chosen to demonstrate the DESTRESS concept.

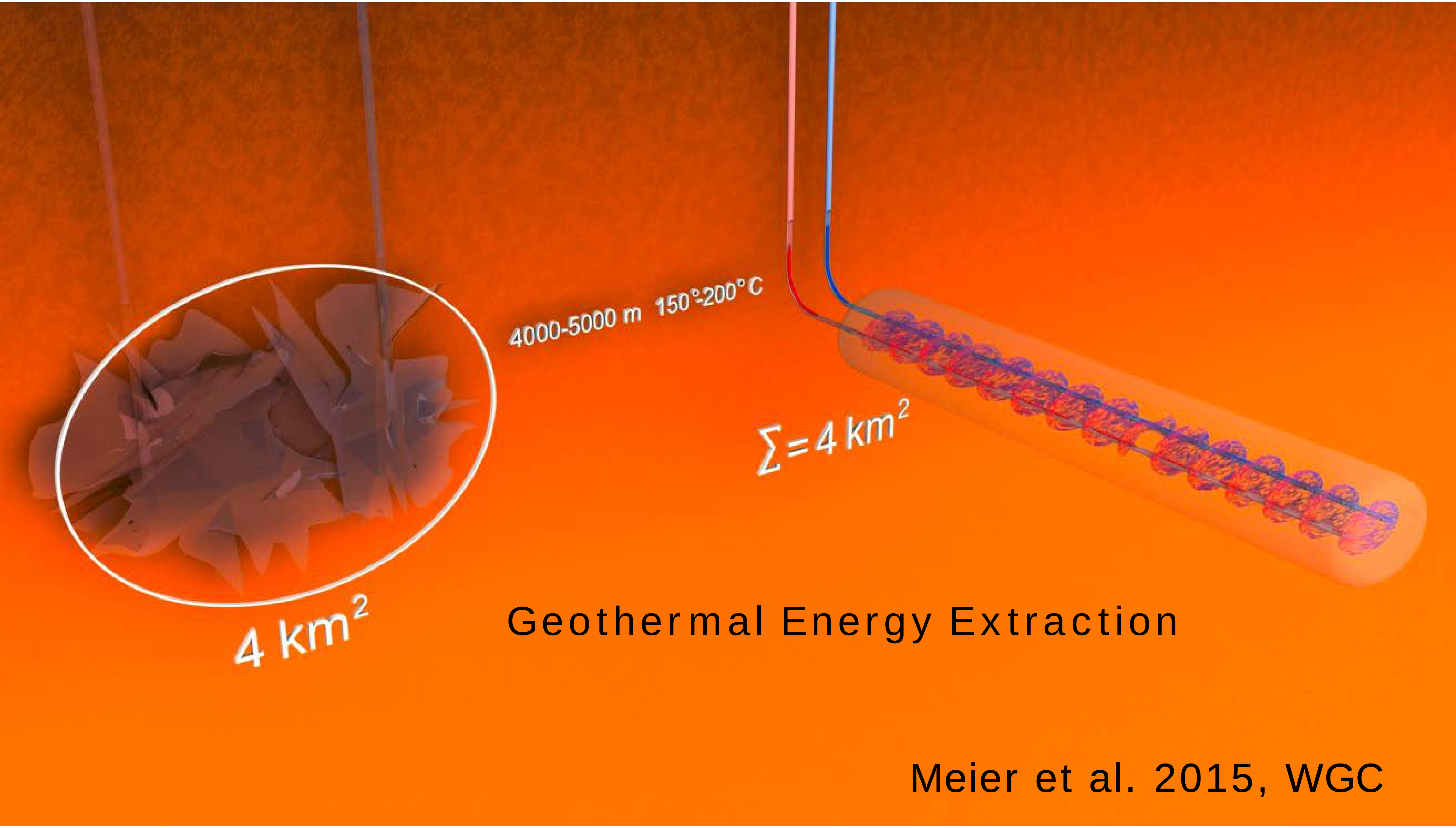
The demonstration sites are using **soft stimulation** treatments to minimise environmental hazards.



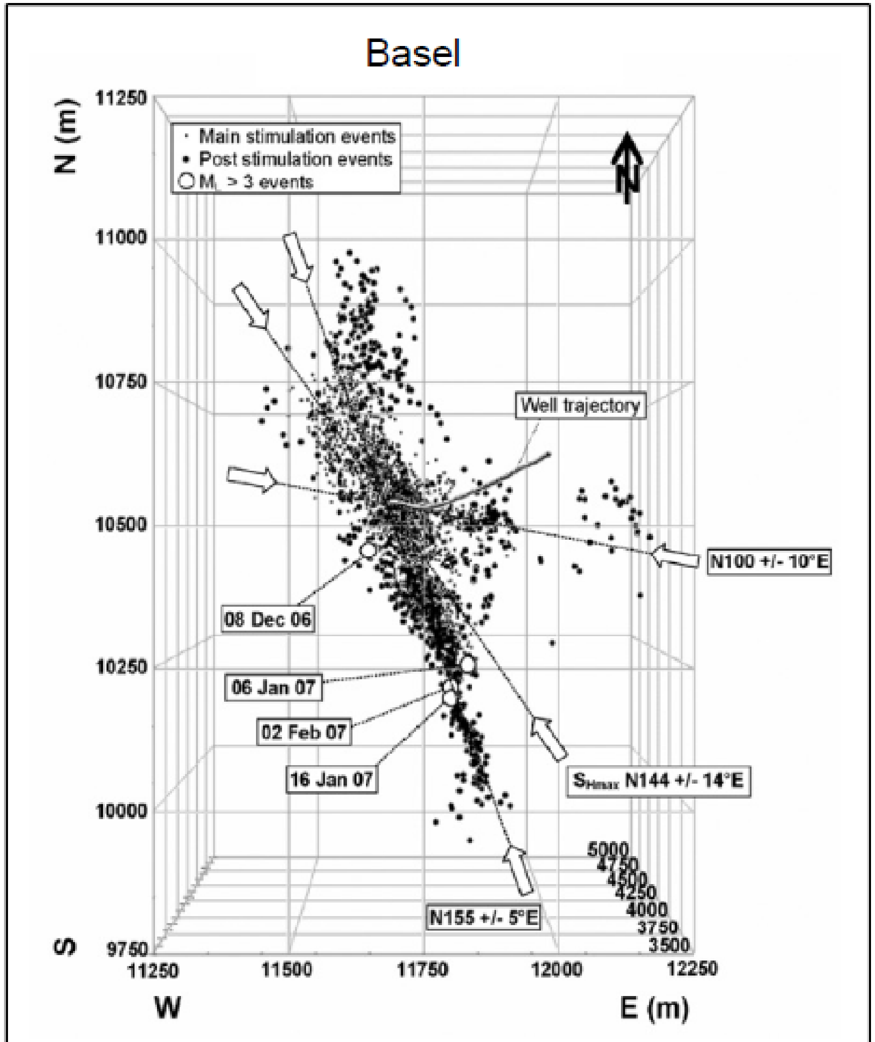
Participating Countries and Demonstration Sites



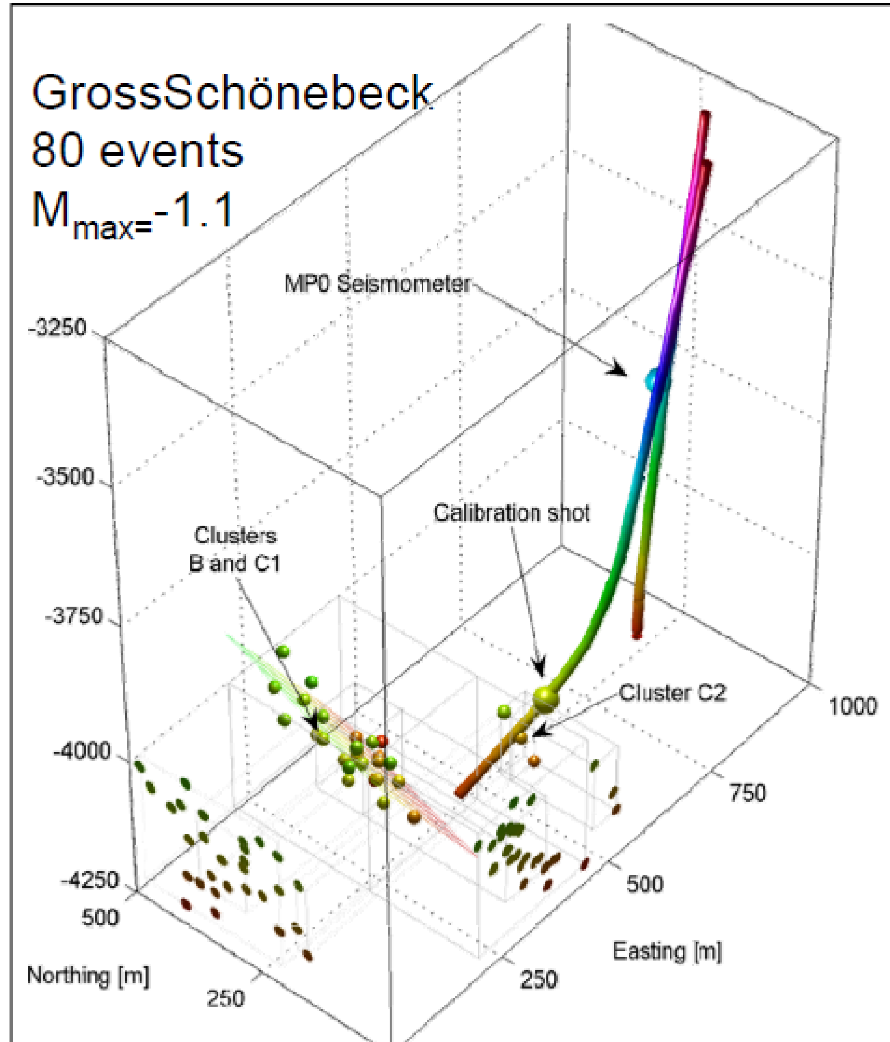
Motivation: Basel massive stimulation 2006 (left), and controlled, multi-stage fracturing (right)



Induced seismicity in Basel and Groß Schönebeck

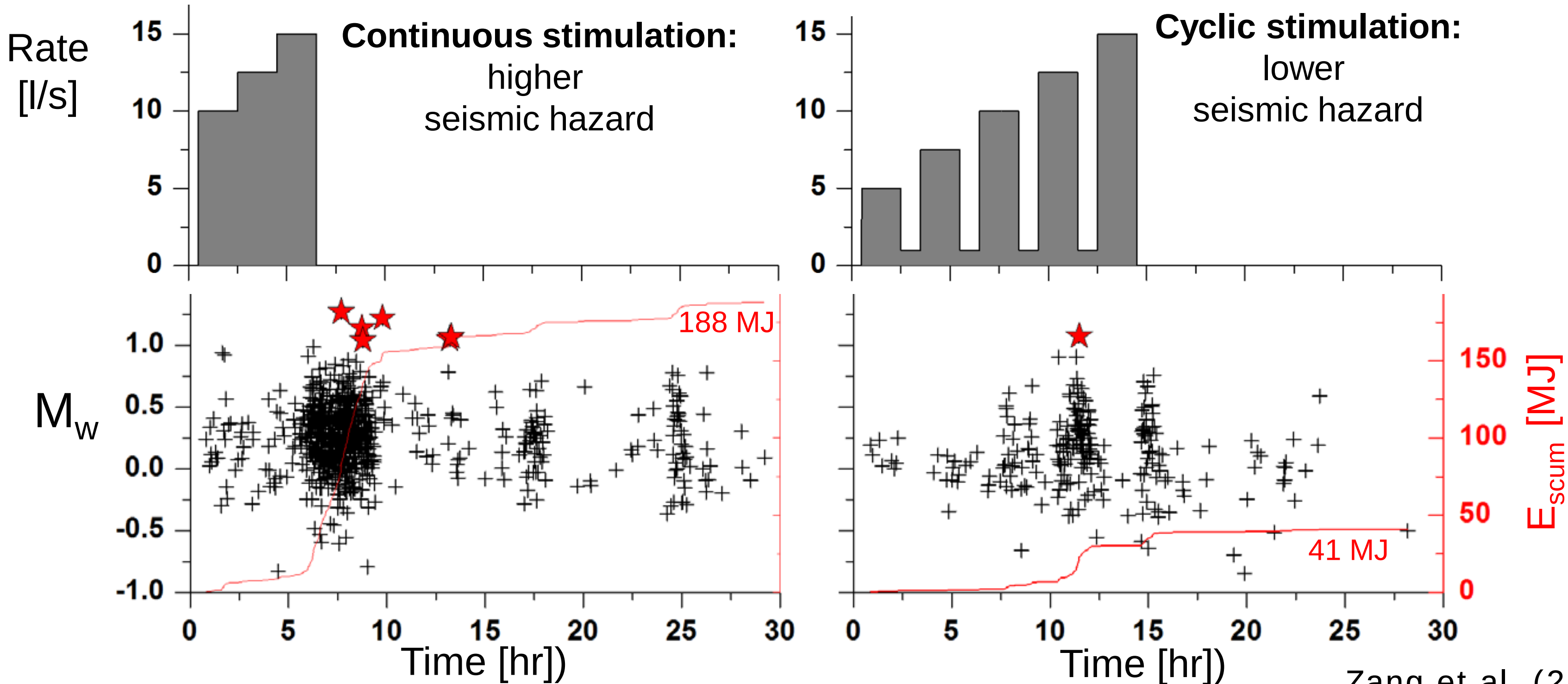


(Häring et al., 2008)



(Kwiatek et al., 2010)

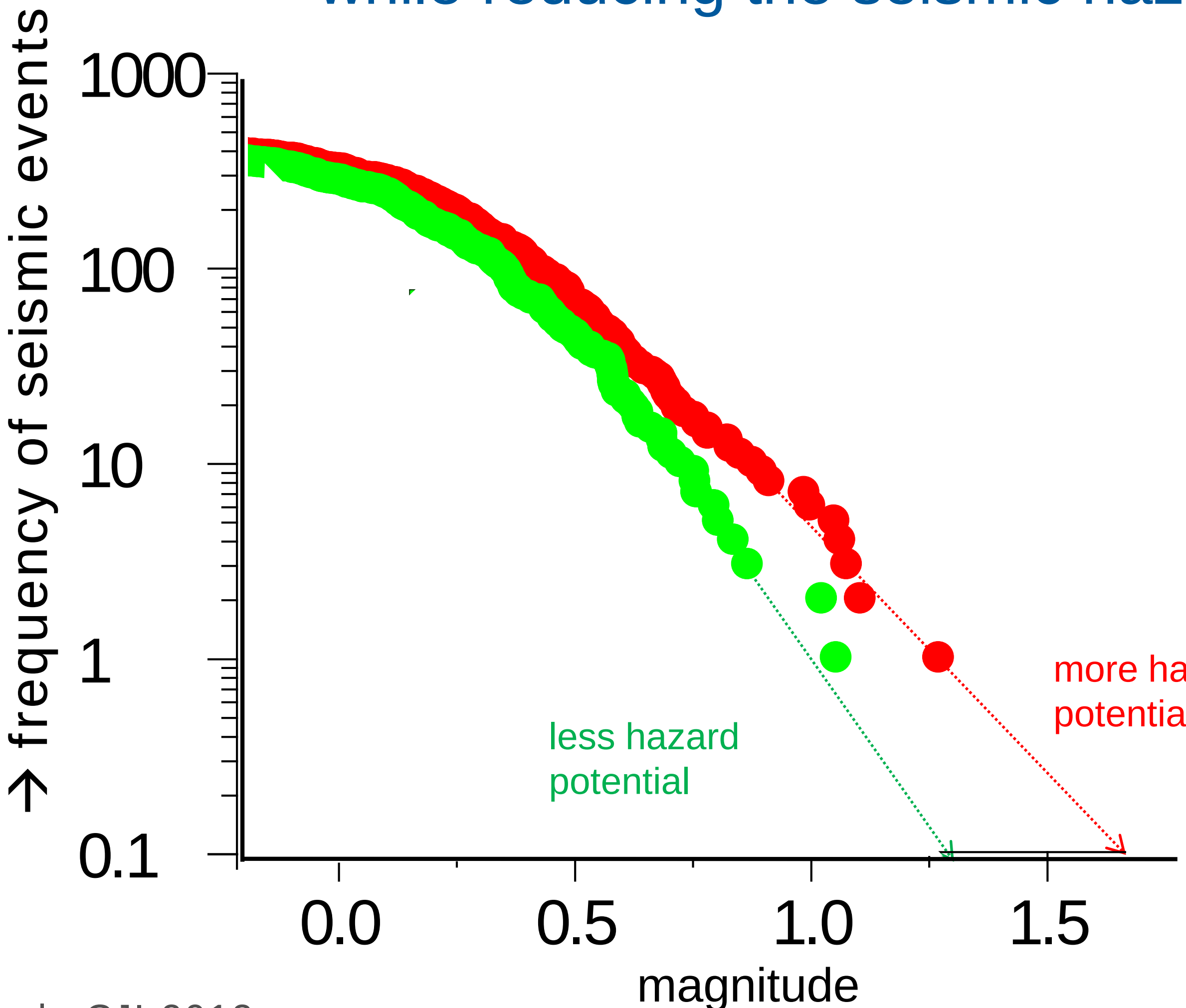
Induced Seismicity – Mitigation Strategy



Zang et al. (2013)
Yoon et al. (2014)

- Modelled stimulation scenarios to enhance hydraulic productivity while reducing number and magnitude of induced events

Refined stimulation treatments to enhance hydraulic productivity while reducing the seismic hazard



Zang et al., GJI 2013
Yoon et al., IJRMMS 2014

Seismic Activity Assessments based on Soultz-sous-Forêts data

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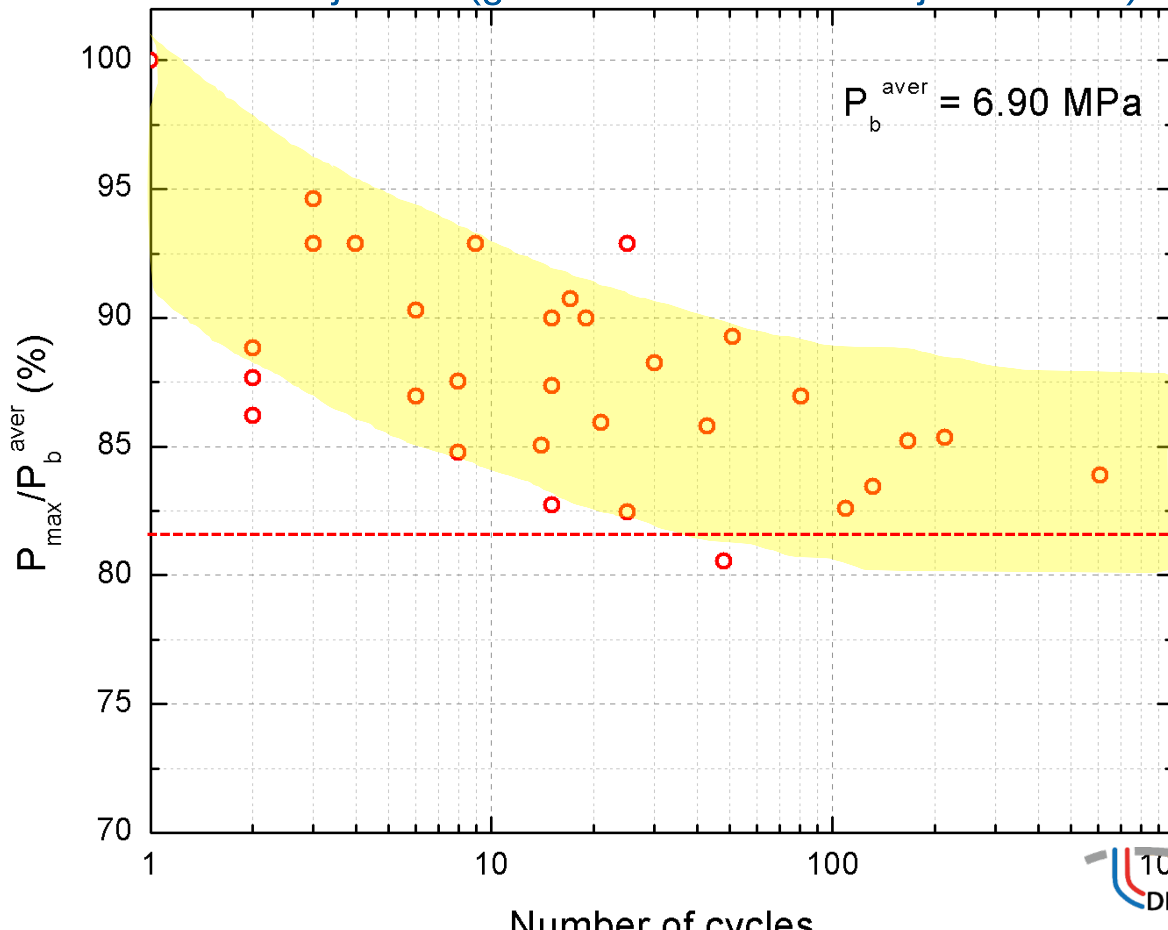
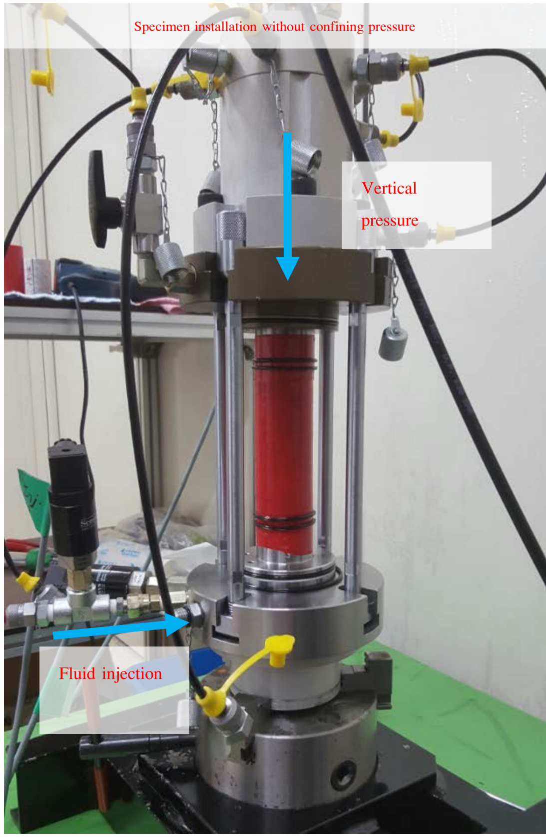
Preliminary Results from labscale HF test @ KICT

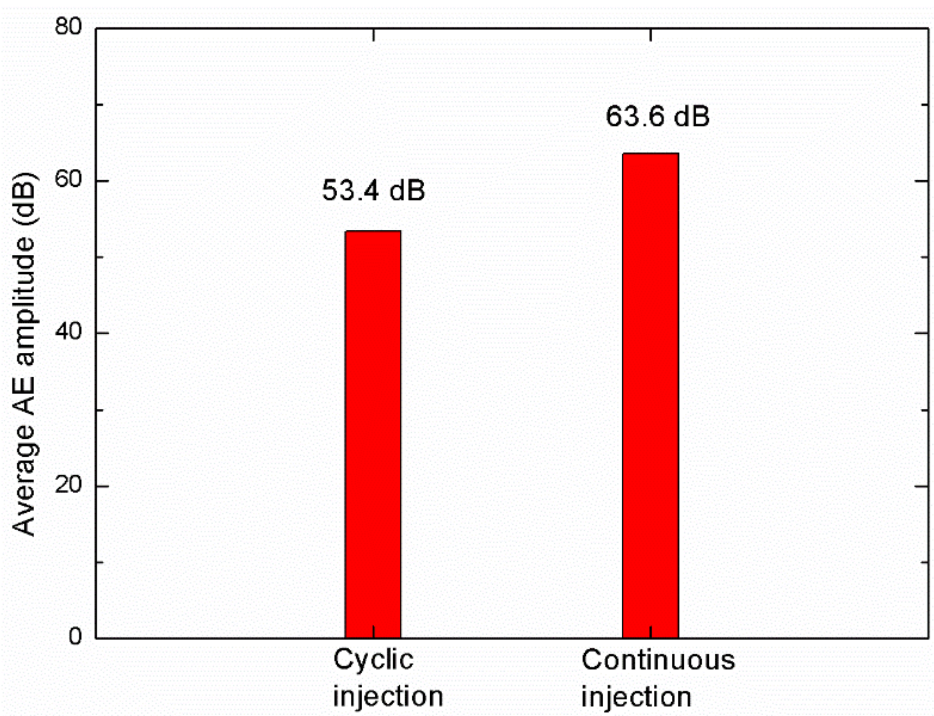
- Breakdown pressure lowering effect in cyclic injection
  - Only tensile fracturing, hydrostatic condition and intact rock material are considered in Lab. hydraulic fracturing tests.
  - Average breakdown pressure is measured by several continuous injection tests with cylindrical granite specimen.
  - For cyclic fracturing test, more cycles seem to lower down the breakdown pressure at 80% of continuous injection (given same constant injection rate)

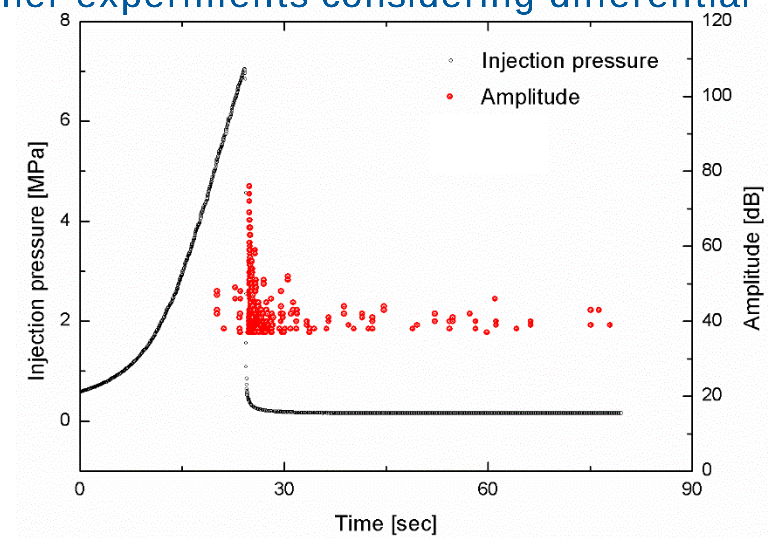


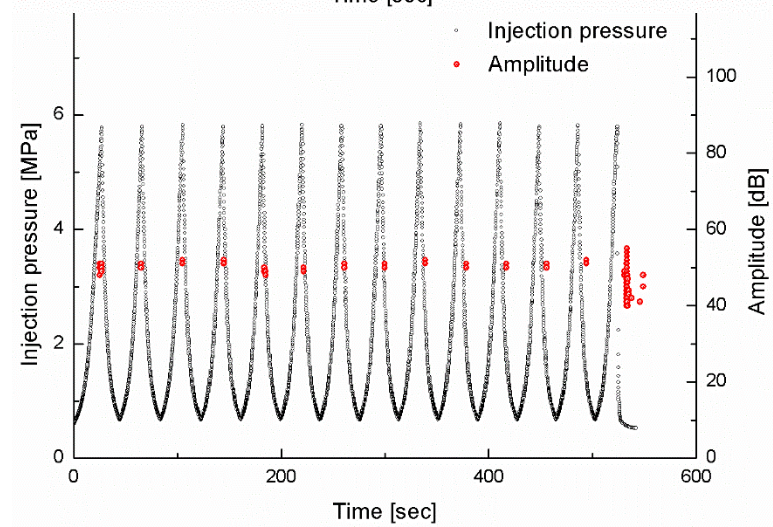


Preliminary Results from labscale HF test @ KICT

- Lower max. induced seismicity in cyclic injection
  - In spite of not sufficient number of cases, slight lowering of max. level of induced seismicity while fracturing can be observed in cyclic injection.
  - This effect needs to be confirmed through further experiments considering differential stress condition for field application.







The Geothermic Fatigue Hydraulic Fracturing Experiment at Äspö Hard Rock Laboratory

Concept in Zang et al. 2013, Experiment in June 2015 by GFZ and KIT

1. Hydraulic fracturing in 28 m long, horizontal borehole F1
2. Monitoring at 410 m depth: AE, seismic and electro-magnetic (KIT)
3. Validation of fracture path by modeling, and excavation

(a) Flushing borehole F1

(b) Roof installation of AE sensor

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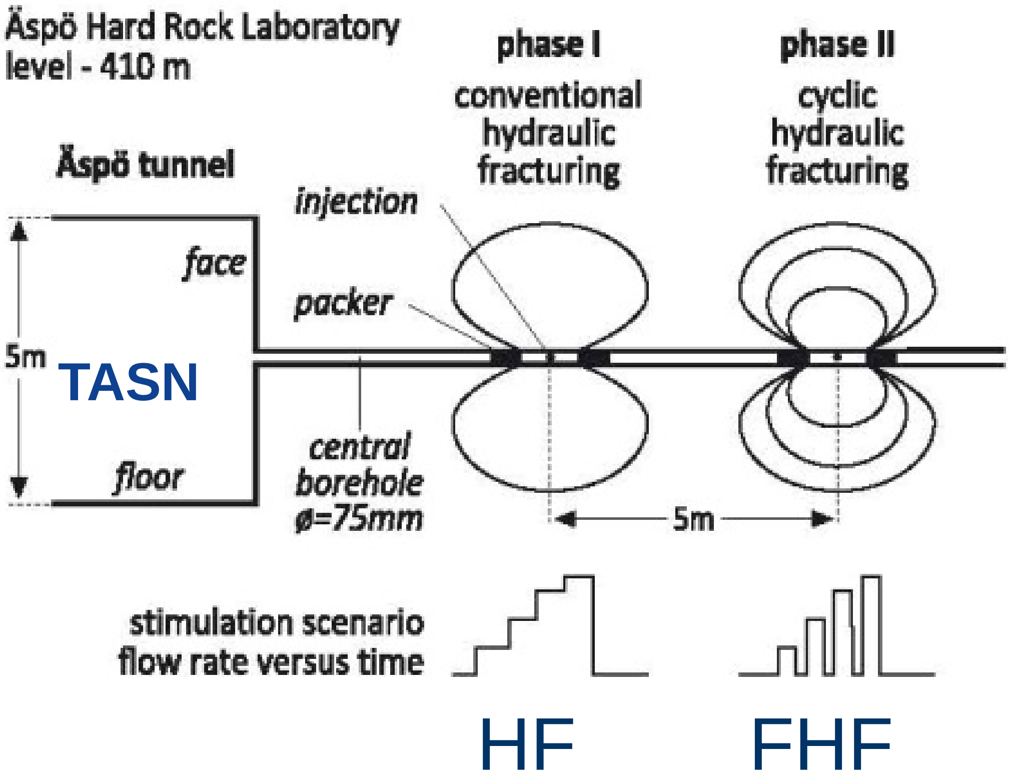
Äspö-Experiment, The concept



Conventional (HF) versus fatigue (FHF) hydraulic fracturing in situ test

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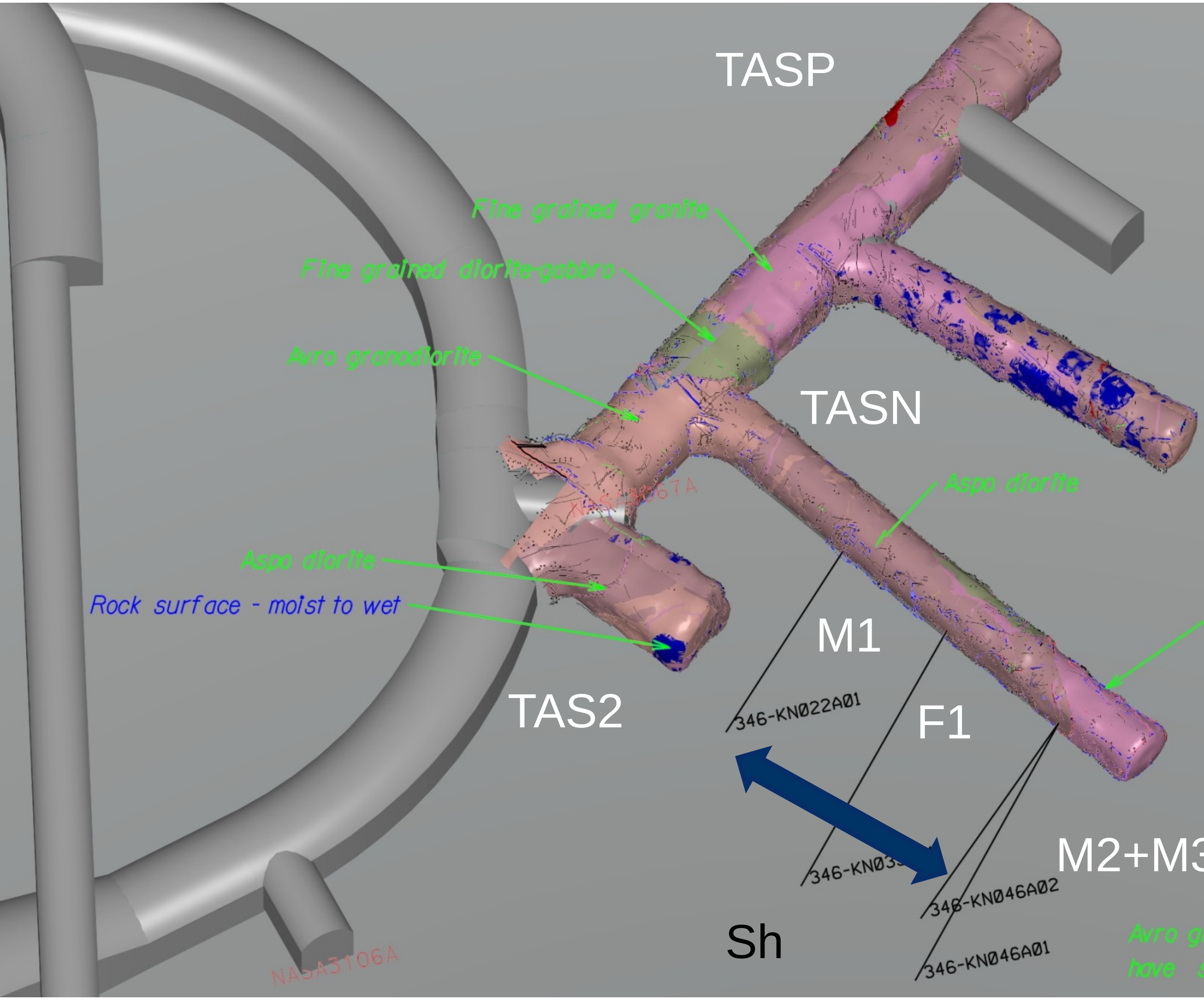
Hydraulic fracturing (F1) and monitoring boreholes (M1-M3) drilled from TASN



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Expected Fracture Extension

Hydraulic fracturing at Äspö HRL, June 2015

Hydraulic fracture monitoring in hard rock 795

Table 2. Overview about the six hydraulic fractures of the *in situ* experiments with start and stop times (in UTC), depth of testing interval, rock type, injection style, and company name performing the test. The fatigue concept is simulated in experiment HF3 (progressive injection) and in experiment HF5 (pulse injection). Hydraulic results include fracture breakdown pressure (P_c), reopening pressure (P_r) and horizontal minimum stress (S_h). S_h is determined from the instantaneous shut-in pressure (ISIP). P_r is measured at the first refrac (RF) of each treatment.

Experiment	Date	Start	Stop	Mid test interval [m]	Rock type	Injection style	P_c [MPa]	P_r [MPa]	S_h [MPa]	Company
HF1	June 3	9:40 13:44	10:17[a] 15:30[a]	25.0	AG	Continuous	13.1	8.9	8.3	MeSy
HF2	June 4	07:15	8:57	22.5	AG	Continuous	10.9	6.7	8.6	MeSy
HF3	June 4	12:07	13:13	19.0	AG	Progressive	9.2	8.8	9.2	MeSy
HF4	June 9	12:29	13:44	13.6	fgDG	Continuous	10.6	9.0	8.5	ISATech
HF5	June 10	12:49	14:02	11.3	fgDG	pulse	9.0[c]	8.6	7.5	ISATech
HF6	June 11 June 12	13:17 07:15	14:10[b] 8:38	4.8	fgG	Continuous	11.3	4.8	8.1	ISATech

[a]Interruption due to impression packer test.
[b]Underground time limit was exceeded, operation resumed next day.
[c]Determined during third cycle.

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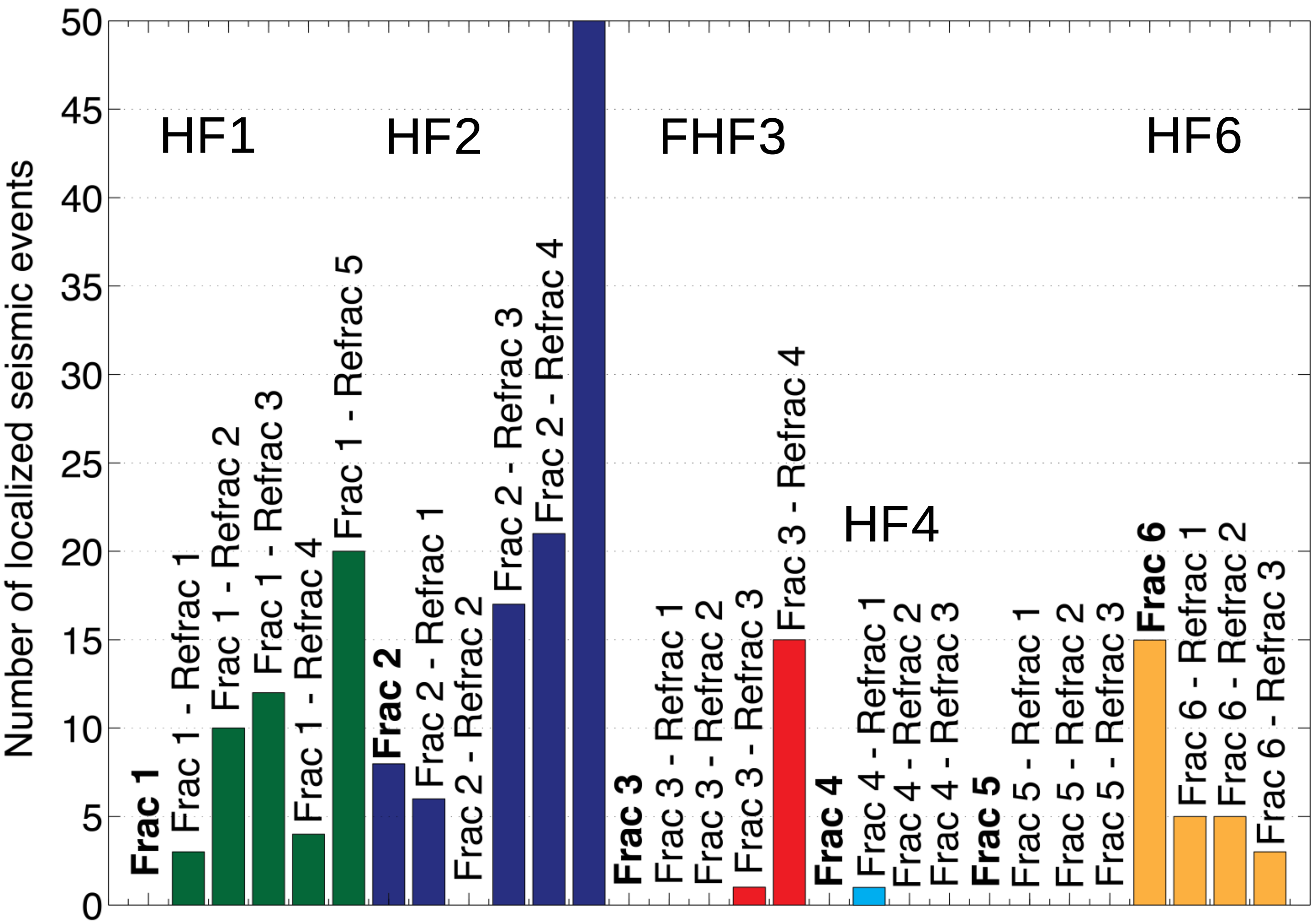
In-Situ Results AE-network



AE activity detected only during active fracturing.

In total 196 seismic events were confirmed so far.

Some fractures did not produce AE activity.

Number of events confirmed per fracture cycle. Conventional HF (green, blue and yellow) apparently produced significant more seismicity than others (FHF).

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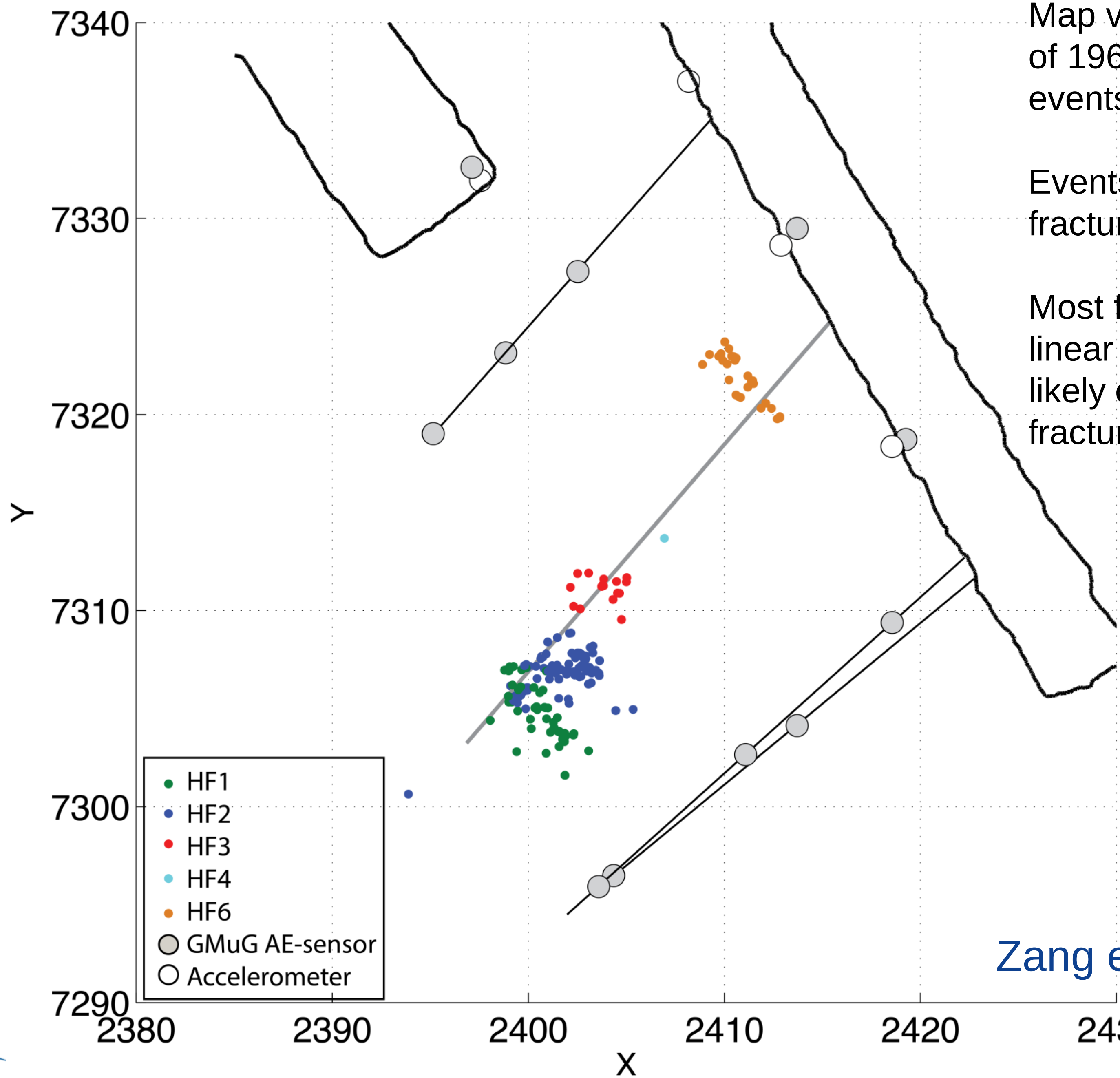
AE Results



Map view
of 196 localized
events.

Events cluster close to
fracture borehole interval.

Most fractures show a
linear feature that
likely corresponds to the
fracture plane.

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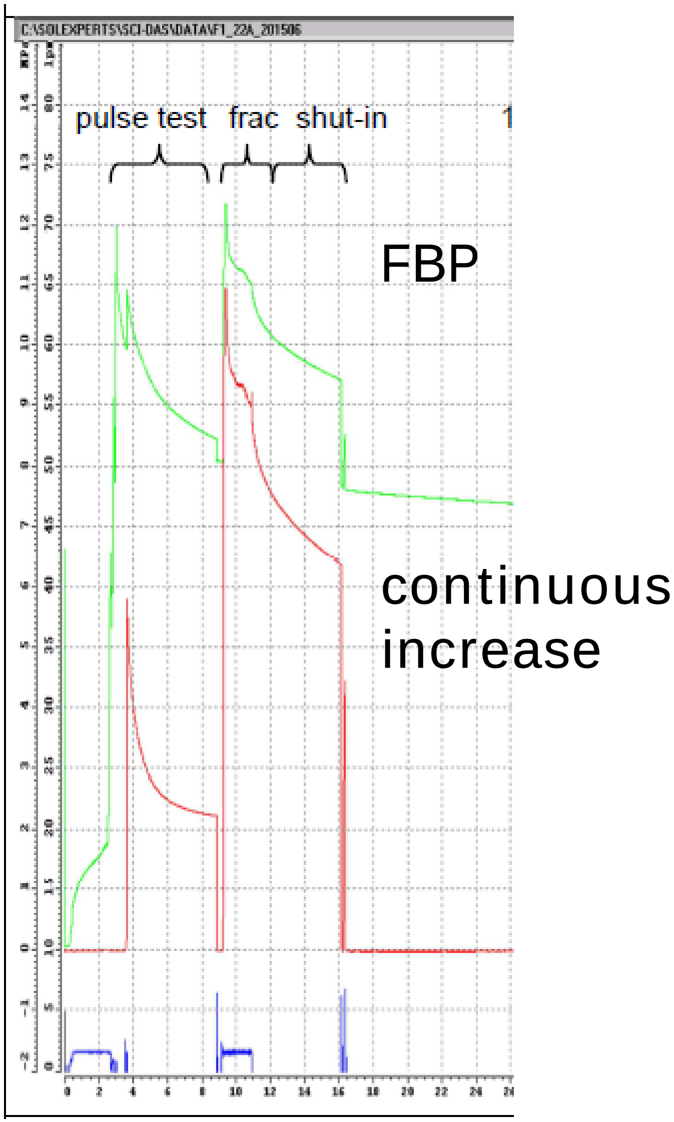
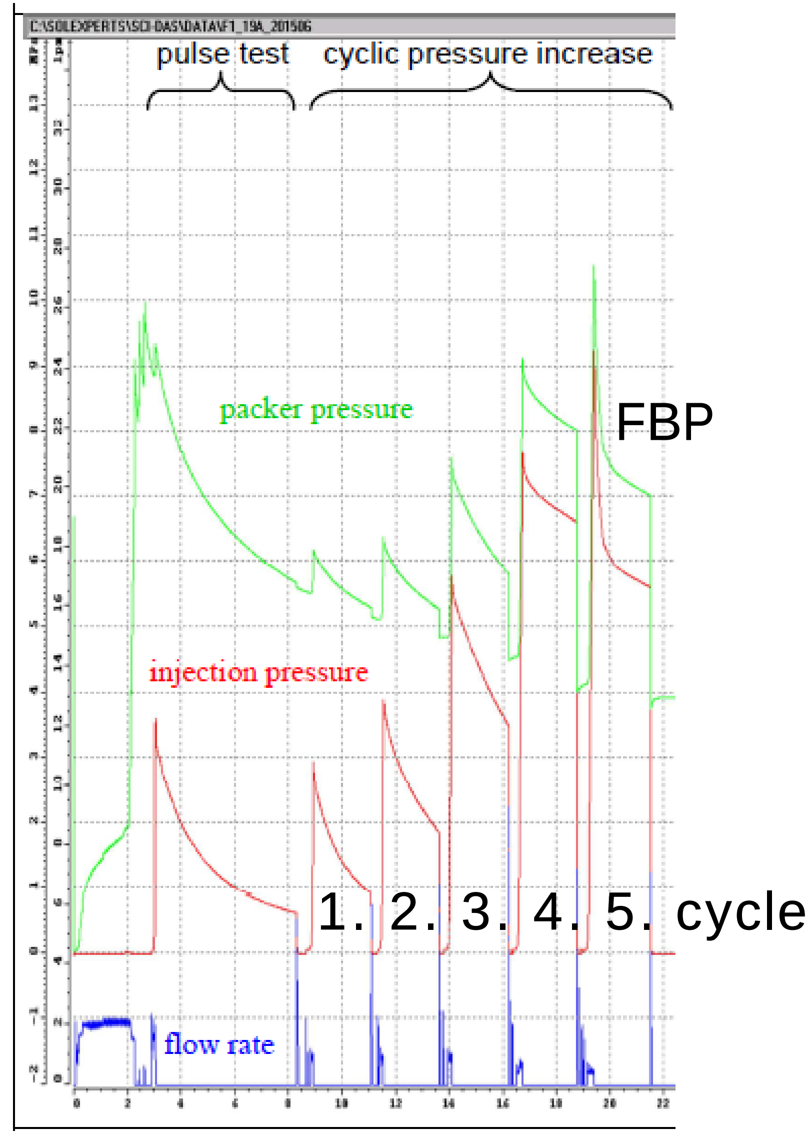
Conventional hydraulic fracturing test at 22,5 m



Cyclic (progressive with depressurization phases) hydraulic fracturing test at 19,0 m



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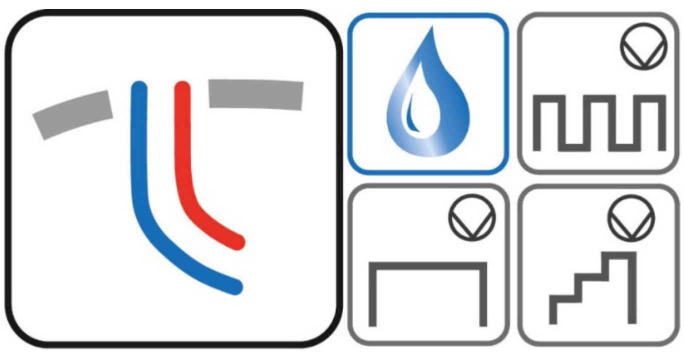
Outlook Pohang, South Korea 2017?

Operator: NexGeo
WP No: 5
Status: 2 wells in 2016



Foreseen Stimulation Techniques	Cyclic hydraulic stimulation (optional: multi-stage fracturing)
Type of Use	Provision of electricity
Soil Condition	Granodiorite formation
Production Horizon	Fractured granite/granodiorite
Upper Depth (m)	4248
Thickness (m)	>1000
T (C°)	140
Salinity (g/l)	<1

Conclusions

- Cyclic stimulation in Groß Schönebeck induced very low seismicity
- Modelling based on Soultz parameters including the achieved productivity shows significant reduced induced seismicity by cyclic stimulation compared to continous stimulation
- Laboratory measurements (in Korea) and hydraulic fracturing in a mine in Äspo (Sweden) indicates based on the number of limited tests reduced number of seismic events and lower break down pressure by cyclic (progressive) stimulation
- Forthcoming in situ experiments will test upscaling of these findings and the achieved productivity

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