ETH zürich

Grimsel In-situ Stimulation and Circulation experiment: First results

SCCER Annual meeting 14 – 15.09.2017, Birmensdorf, Switzerland

J. Doetsch, F. Amann, V. Gischig, M. Jalali, H. Krietsch, B. Valley, C. Madonna, M. Nejati, M. Klepikova, K. Evans, A. Kittlilä, L. Villiger, B. Brixel, P. Giertzuch, N. Dutler, D. Giardini, HR. Maurer, M. Saar, S. Löw, S. Wiemer, T. Driesner

SCCER SoE

Grimsel ISC: field scale hydraulic stimulations

- How do we create an efficient heat exchanger while keeping induced seismicity at acceptable levels?
- To date, no densely-instrumented stimulation experiments in crystalline rock
- Detailed research questions (Amann et al., 2017, Solid Earth):
  - How does the transient pressure field propagate in the reservoir during stimulation?
  - How does the rock mass deform as a result of rock mass pressurization, fracture opening and/or slip?
  - How does stress transfer inhibit or promote permeability enhancement and seismicity along neighbouring fractures?
  - Can we quantify the transition between aseismic and seismic slip and the friction models (such as rate-and-state friction) describing slip evolution and induced seismicity?
  - Does hydraulic fracturing induce seismicity and increase permeability?
  - How do hydraulic fractures interact with pre-existing fractures and faults and how can the interaction be controlled?
  - How does seismicity evolve along faults and fractures of different orientation?
  - Can we quantify the link between spatial, temporal and magnitude distribution and HM coupled properties of fractures and faults?
  - …

Grimsel ISC: field scale hydraulic stimulations

- How do we create an efficient heat exchanger while keeping induced

Rolf Schmitz (presentation yesterday):

ENERGY RESEARCH MASTERPLAN 2017–2020 GEOTHERMAL ENERGY

Research topics (examples)

- **Properties of rock**: rock fluid interaction, cap rock integrity, creation of permeability
- Methods for increasing **rock permeability**: create optimal heat exchangers and geothermal reservoirs
- High-resolution **exploration methods** and associated fault architecture
- Integrated numerical **simulation methods** for dynamic flow processes in the subsurface
- Exploration and development methodologies for **reservoirs**: predictable, reliable, low-cost
- **Risk assessment**, monitoring, avoidance of induced seismicity, damaging earthquakes
- **Subsurface technologies**: processes and procedures in-situ, and installation of research infrastructure

► www.energieforschung.ch / www.energy-research.ch / www.recherché-energetique.ch

SCCER SOE ANNUAL CONFERENCE 2017 ▪ ROLF SCHMITZ 5

k

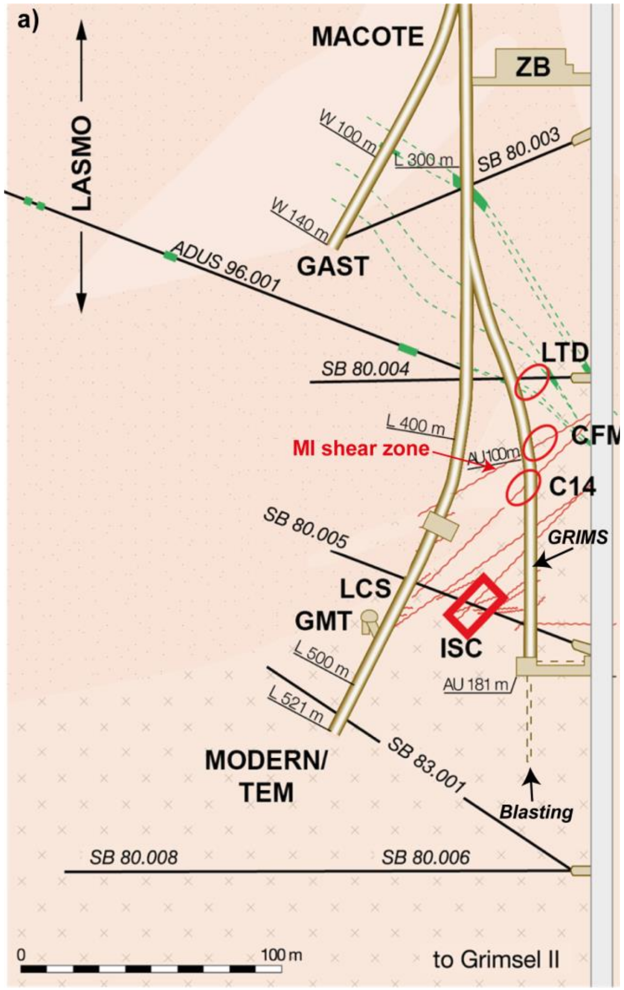
n?

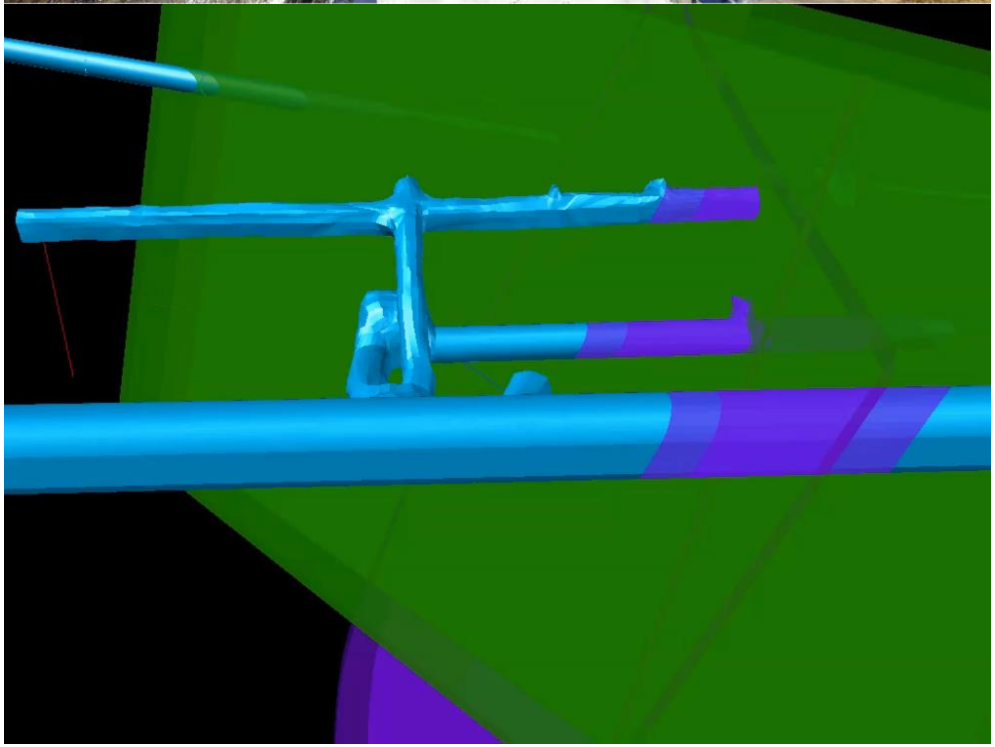
d

HM coupled properties of fractures and faults?

- …

ISC experiment at the Grimsel Test Site





ETH zürich

Last slide of last years presentation

Procedure and time-line

Aug. 2015 – Nov. 2016 → Dec. 2016 – May 2017 → Sept. 2017 – end 2017

Pre-Stimulationsphase

Seismic network
- regional scale
- tunnel scale

Stress measurements

Drilling

Characterization
- geophysical borehole logs
- hydraulic & thermal Tests
- geophysical charac. (GPR, active seismics)
- tracer Tests (dye tracer and nanotracer)

Monitoring boreholes
- strain and tilt
- pore pressure
- temperature
- micro-seismics

Stimulationsphase

Stimulation
- stimulation of existing shear zone
- hydraulic Fracturing in massive rock
- shut-in phases

Monitoring
- pressure und flow rates in active borehole
- pressure in passive borehole
- micro-seismicity in tunnels and boreholes
- pressure and temperature in boreholes
- tilt at the tunnel surface

Post-Stimulationsphase

Characterization
- geophysical boreholes log (OPTV, electrical resistivity, spectral gamma etc.)
- hydraulic test in boreholes and between boreholes (storativity and transmissivity changes)
- tracer Tests (dye tracer und nanotracer)
- active seismic tests and GPR between boreholes and tunnels

Preparation of circulation phase
- boreholes
- completion of boreholes with temperature sensors
- Installation multi-packer system

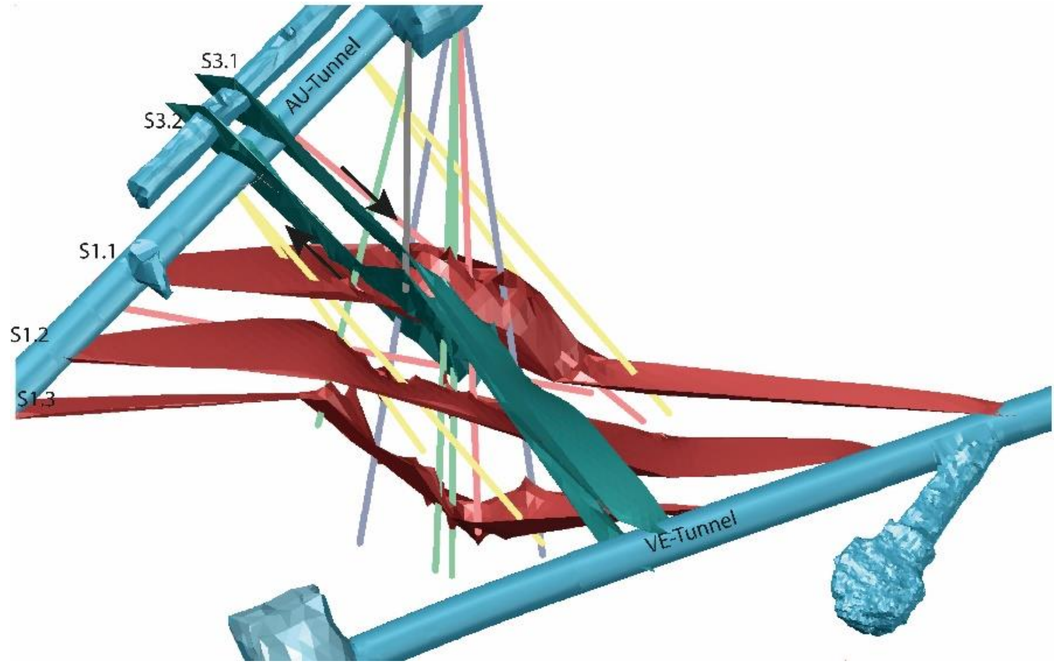
Circulationsphase

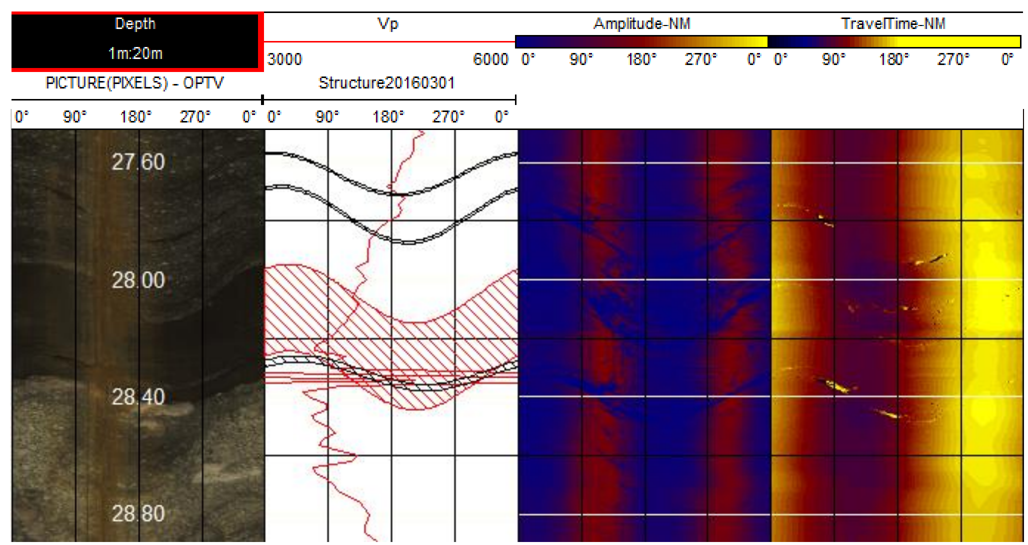
Circulation
- cold water injections
- warm water injections

Monitoring
- induced micro-seismicity
- thermal break-trough
- thermo-elastic strains and tilt
- pore pressure changes
- temperature in reservoir

Characterization

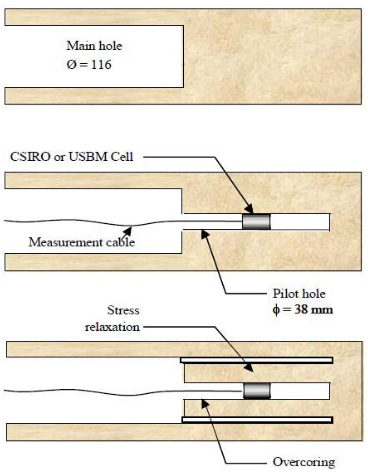
- Geological model based on
  - Tunnel mapping
  - Cores
  - Televiewers in boreholes
  - Geophysical borehole logging
  - GPR imaging
  - seismic tomography
- Hydraulic characterization (e.g., DNA, heat and salt tracers)

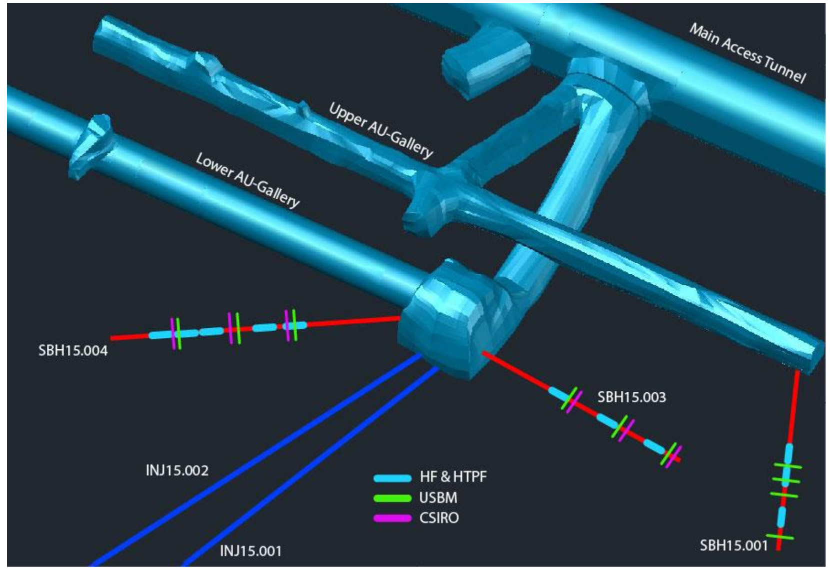




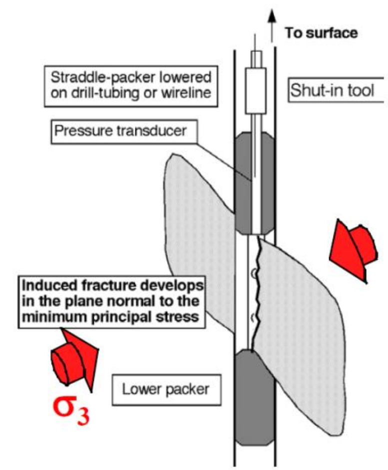
Stress measurements

Overcoring

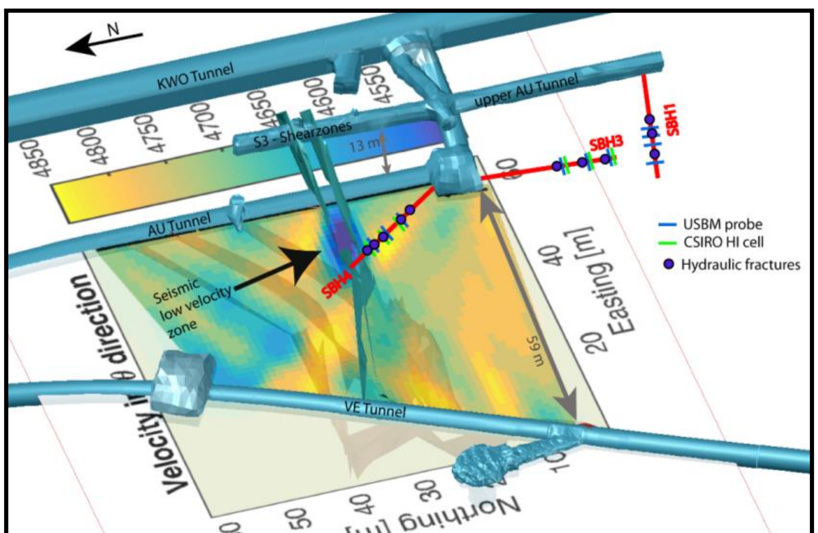


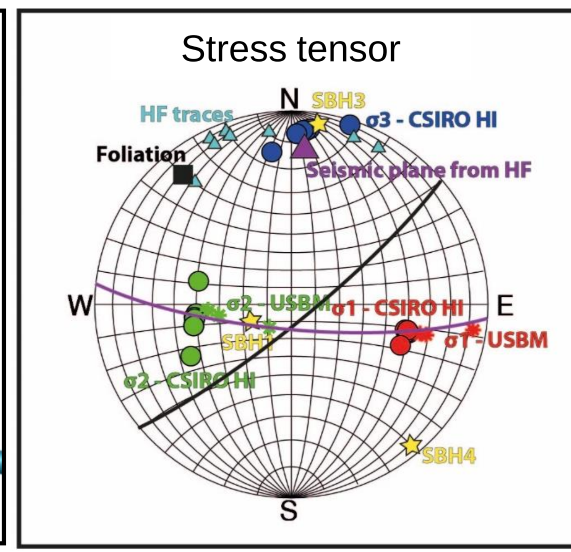


Hydraulic fracturing (HF)



- Important to combine overcoring and HF
- Anisotropy needs to be considered
- Decrease of stress approaching fracture zone

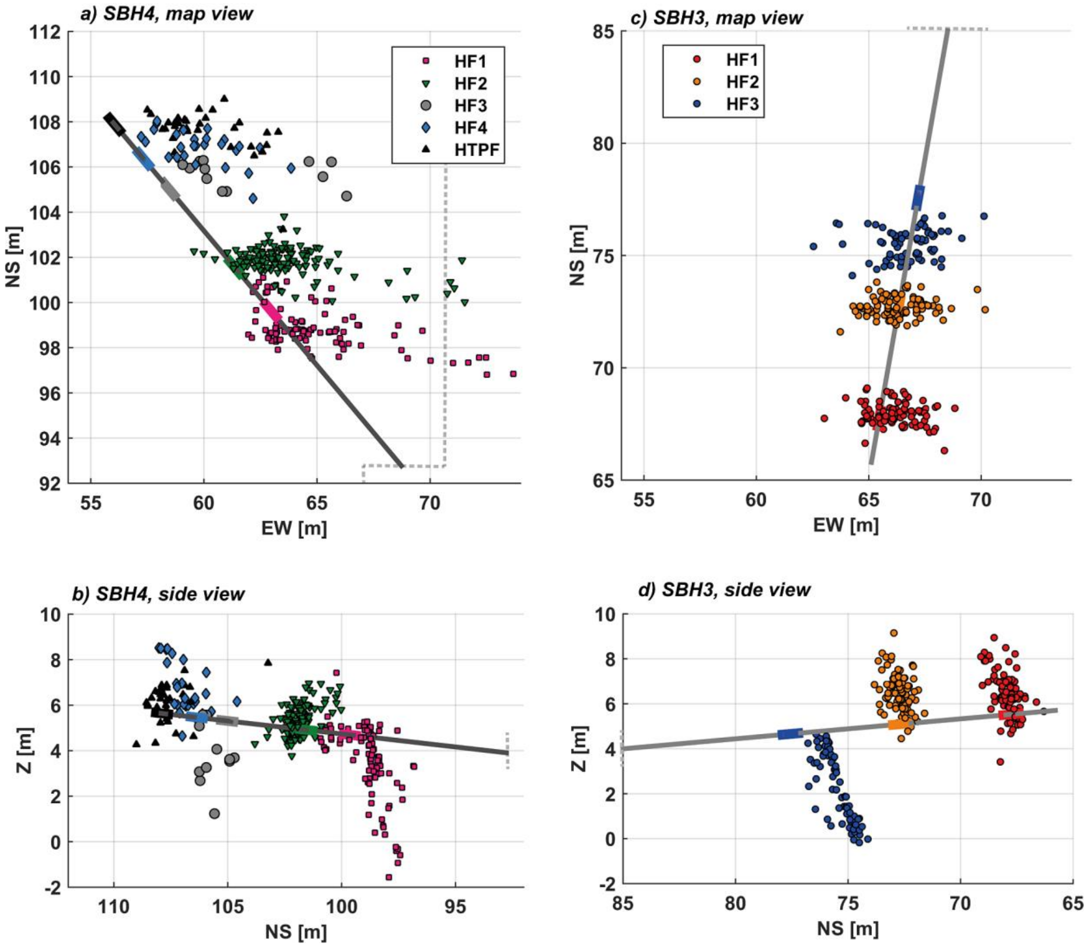




Krietsch et al., 2017

ETH zürich

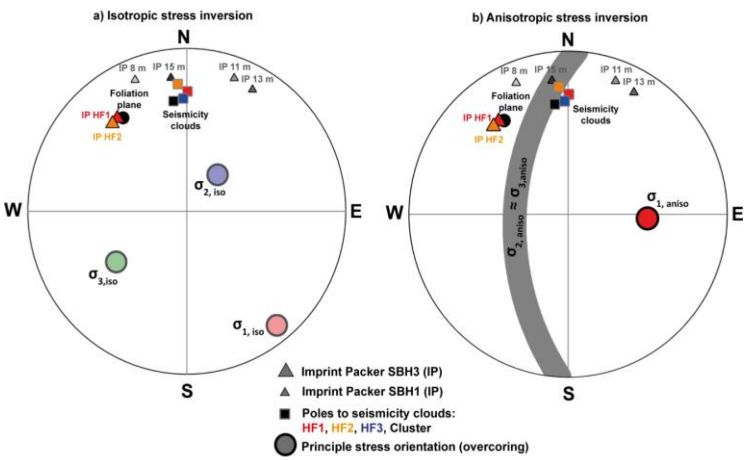
Micro-seismicity during hydraulic fracturing



Analyzed using

- joint locating
- station corrections
- anisotropic velocity model
- relative locations

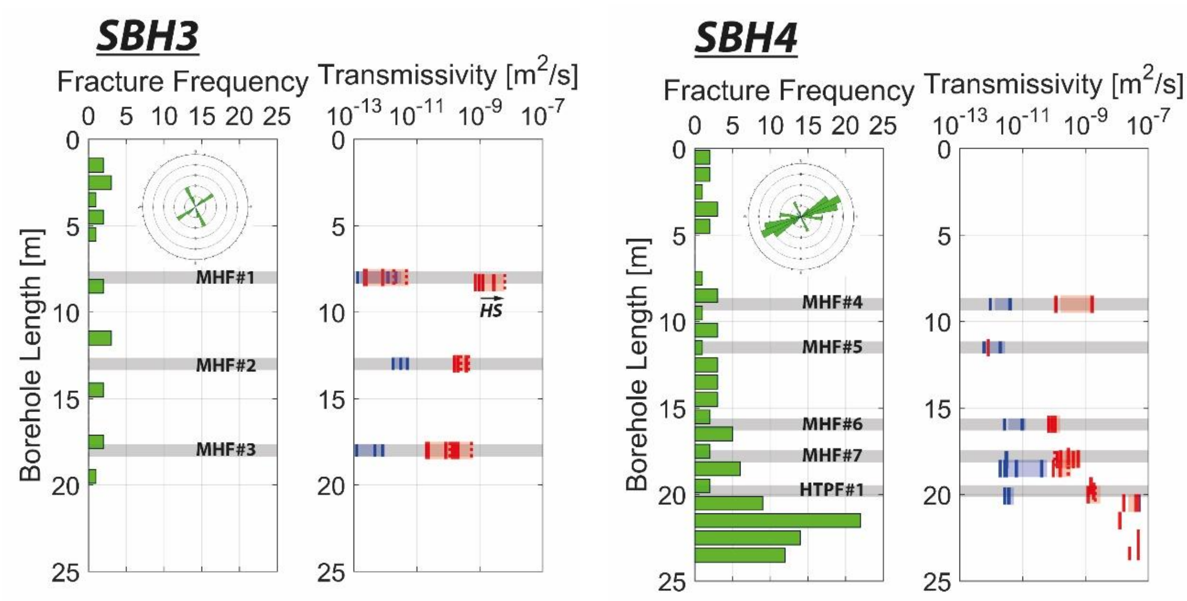
Important to validate and constrain overcoring results

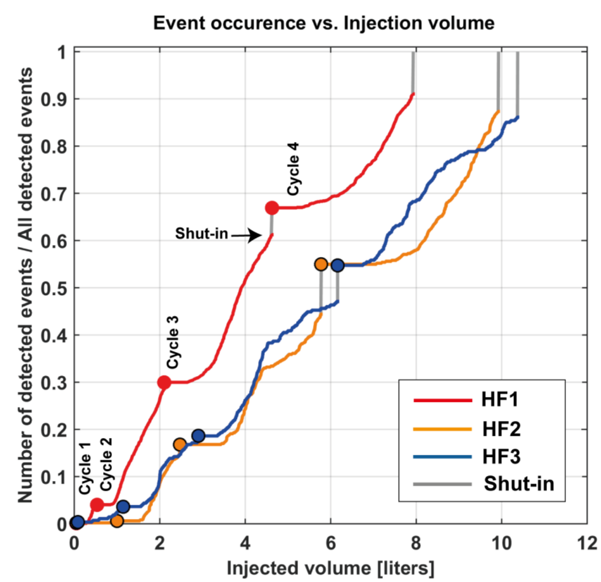


Gischig et al., 2017

Permeability change due to hydraulic fracturing

- Pure HF not expected to change permeability or induce seismicity
- HF tests show 100-1000 times increase in injectivity and significant seismicity





Jalali et al., 2017

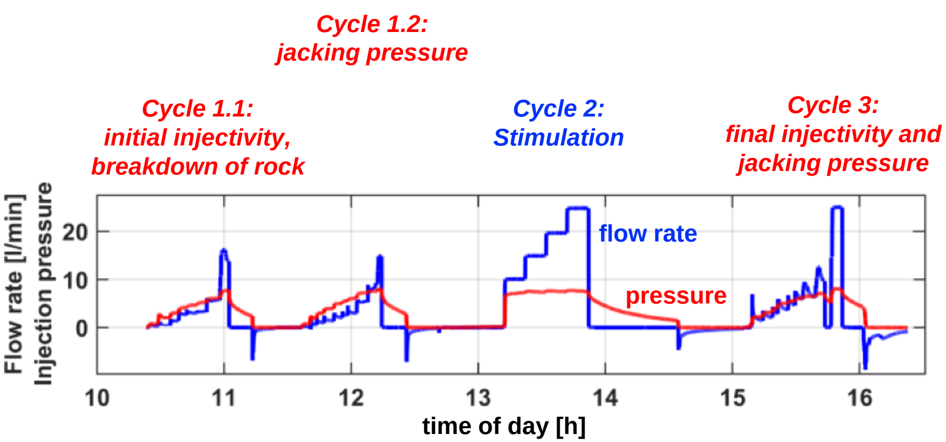
Hydraulic stimulations

Hydo-shearing (Feb 2017)

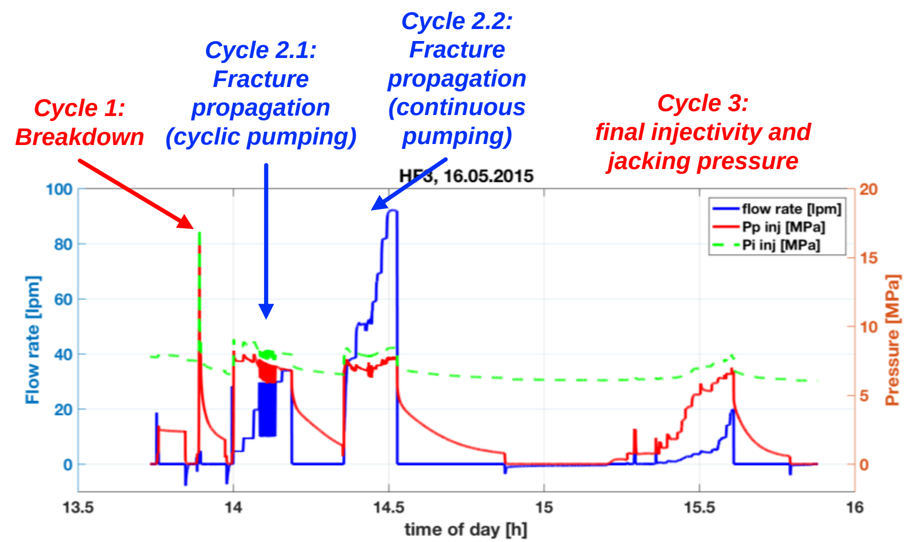
- Injection into existing structures
- Induce slip by utilizing shear stress

Hydraulic fracturing (May 2017)

- Injection into intact rock
- Creation new fractures



Experiment 2,
HS4 9 Feb 2017



Stimulation overview

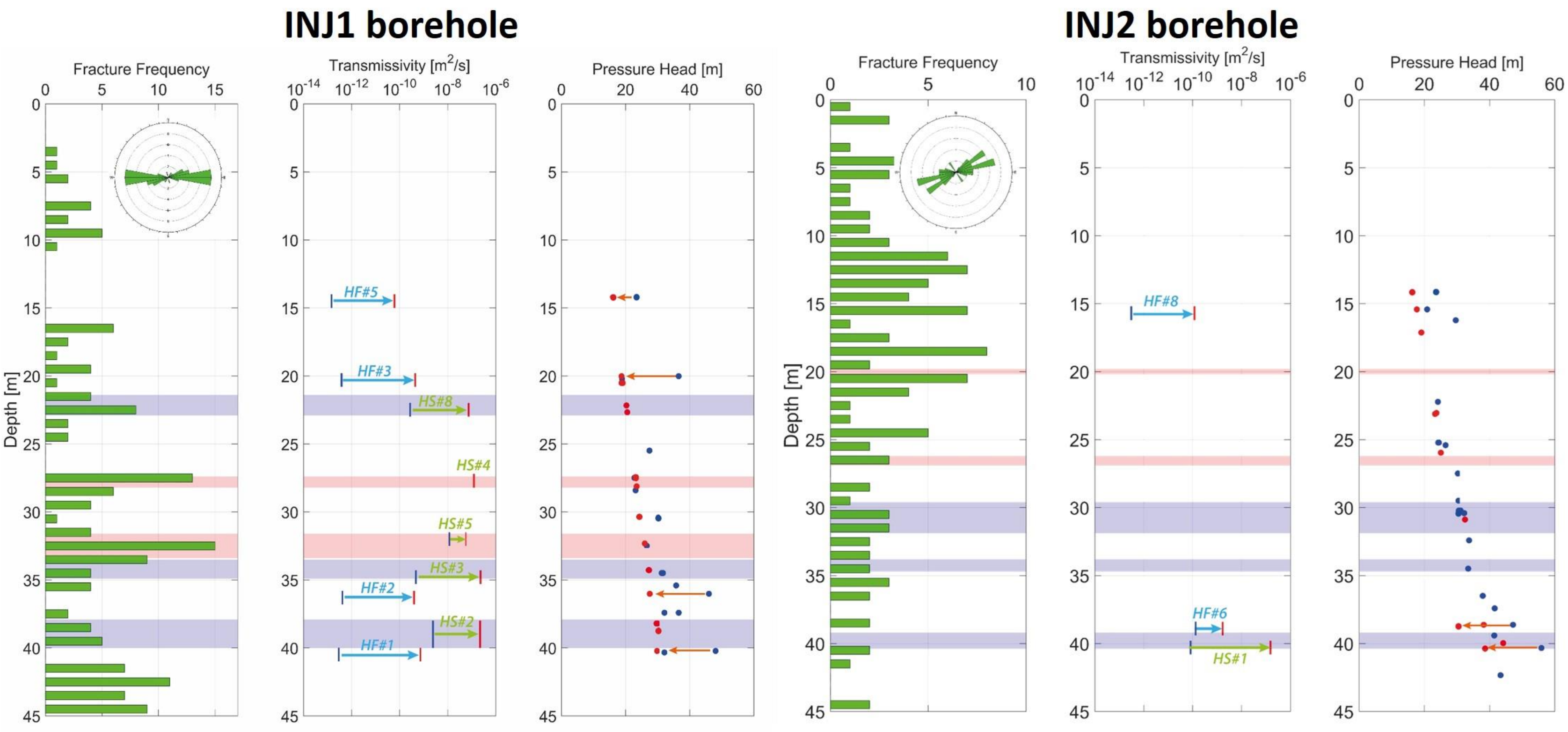
Borehole	Test	Structure	Injected Volume [lit]	Initial Trans. [m²/s]	Final Trans. [m²/s]	Change in Trans.	Detected Events
SBH3	MHF#1	---	7.9	3.8E-13	1.5E-10	380	1161
	MHF#2	---	10	3.2E-12	2.1E-10	70	482
	MHF#3	---	10.4	2.2E-12	5.0E-12	2	274
SBH4	MHF#4	---	10.9	1.9E-12	1.1E-10	60	2258
	MHF#5	---	9.7	5.9E-13	8.7E-13	2	1692
	MHF#6	---	9.1	2.2E-12	7.0E-11	30	772
	MHF#7	---	11.5	3.1E-12	2.2E-10	70	406
	HTPF#1	S3.1	28.8	3.8E-12	9.1E-10	240	253
INJ1	HS#2	S1.3	797	2.5E-09	2.2E-07	90	1203
	HS#3	S1.2	831	4.8E-10	2.3E-07	490	314
	HS#4	S3.1	1253	1.2E-07	1.2E-07	1	5606
	HS#5	S3.2	1211	1.2E-08	5.5E-08	5	2452
	HS#8	S1.1	1258	2.8E-10	7.5E-08	270	3703
	HF#1	---	971	2.9E-13	7.5E-10	2550	N/A
	HF#2	---	816	4.2E-13	4.0E-10	950	N/A
	HF#3	---	893	3.8E-13	4.5E-10	1190	N/A
	HF#5	---	1235	1.5E-13	6.1E-11	420	N/A
INJ2	HS#1	S1.3	982	8.3E-11	1.5E-07	1850	560
	HF#6	S1.3	943	4.0E-10	1.7E-09	4	104
	HF#8	---	1501	3.1E-13	1.2E-10	165	362

Mini-fracs

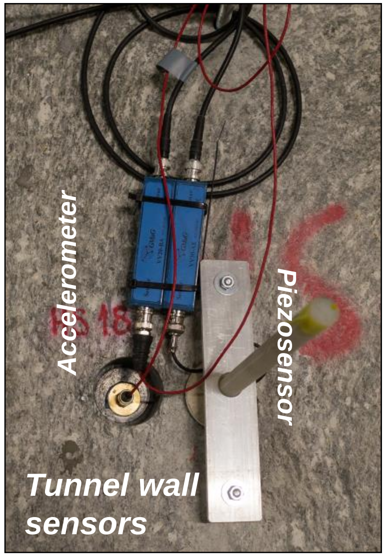
Hydro-shearing

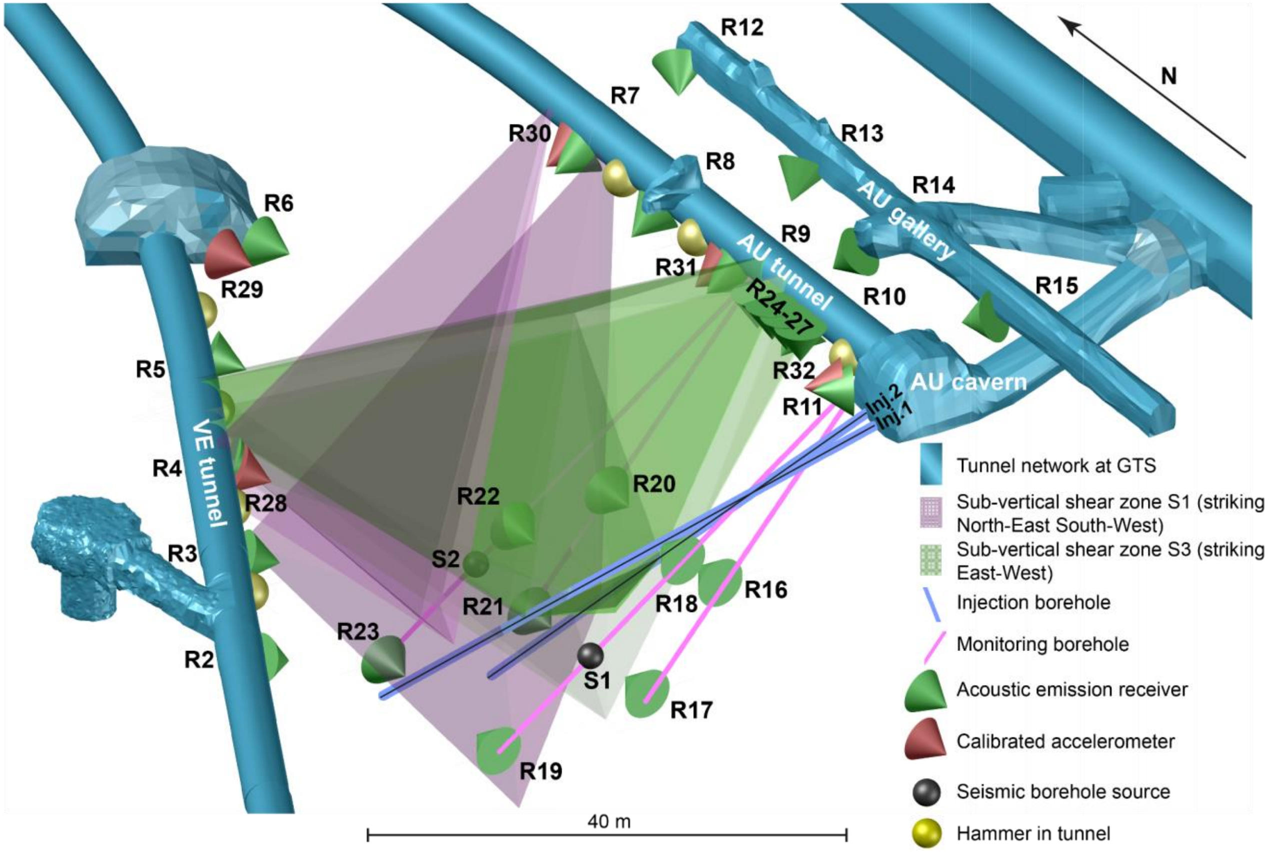
Hydro-fracturing

Stimulation overview



Seismic monitoring

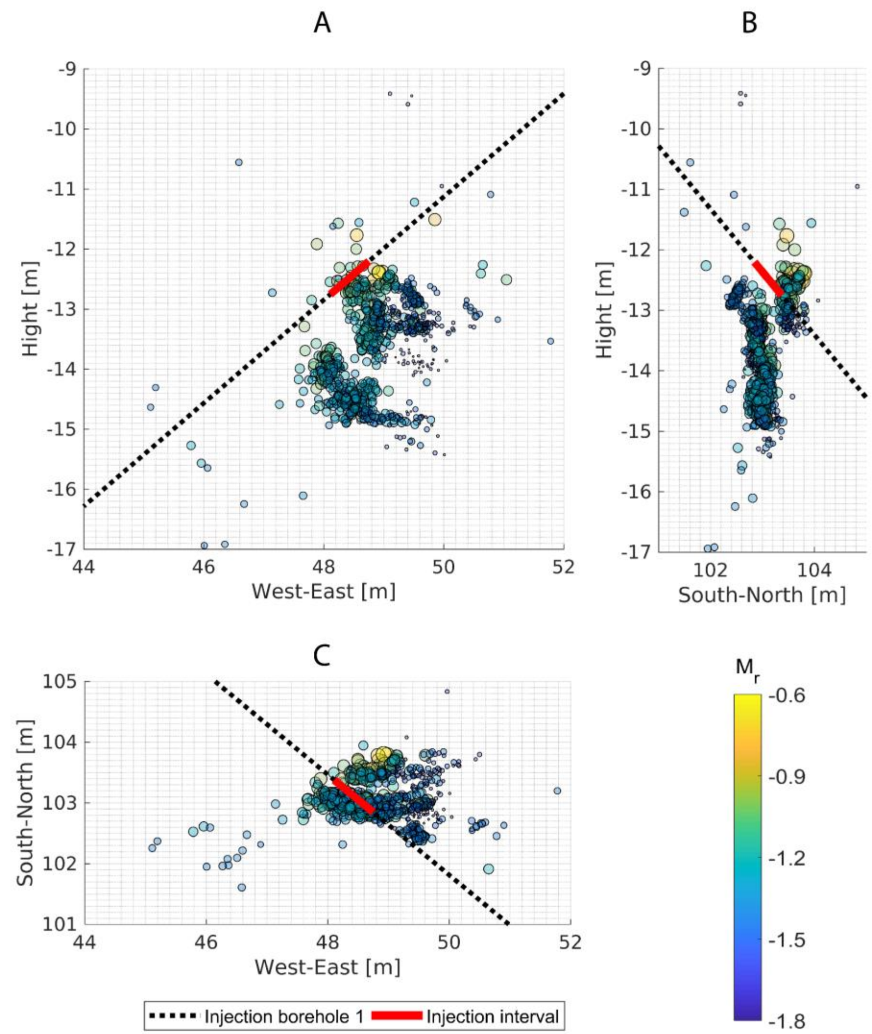


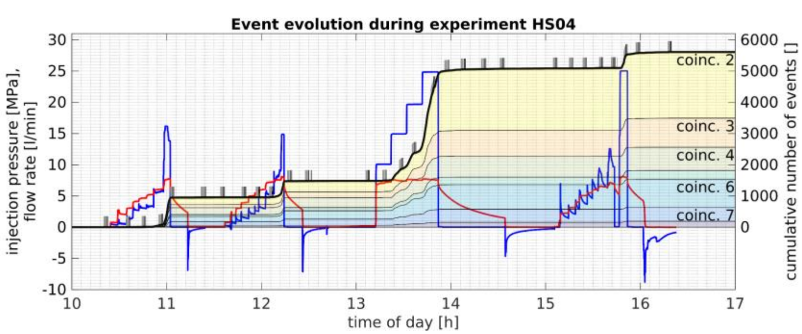


- ***32-channel triggered system***
- ***32-channel continuous recording system***
- ***200 kHz sampling rate***

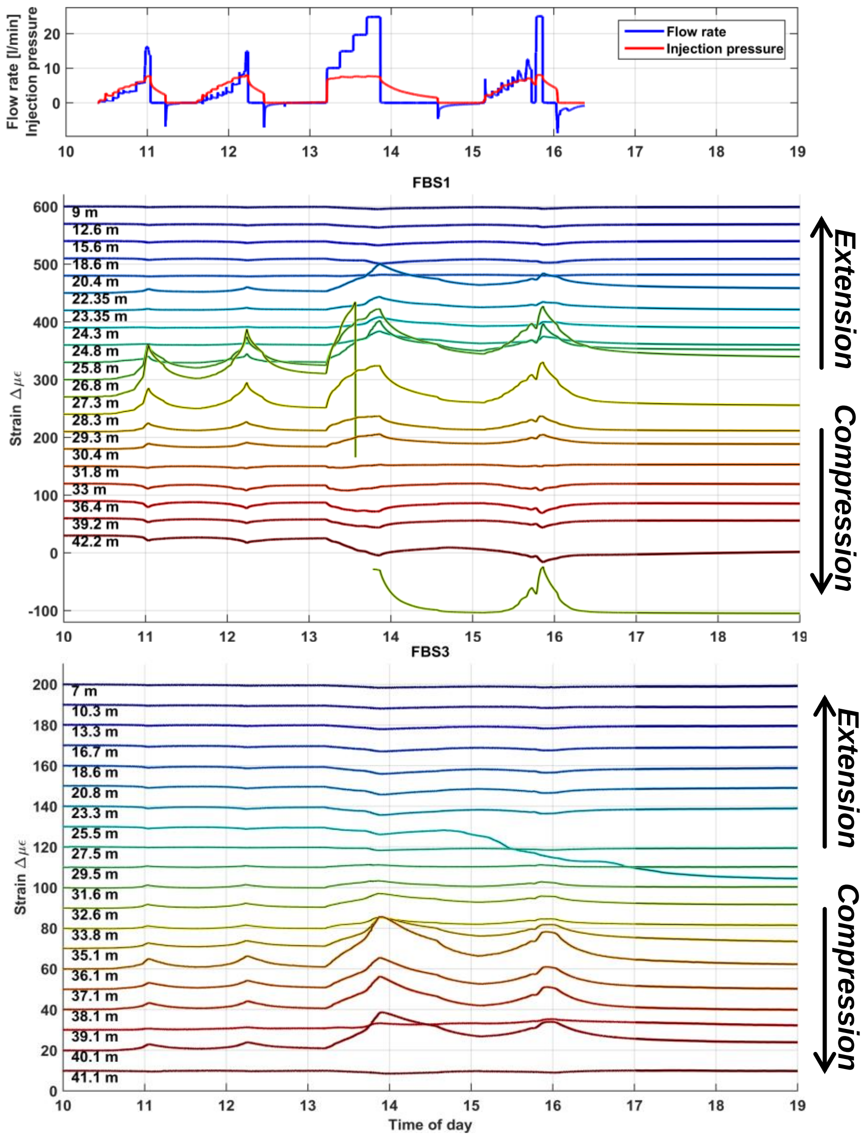
Seismic monitoring

- Traffic light system not triggered
- Live detection and visualization of seismicity
- >20.000 events detected
- Detailed location and magnitude analysis to follow

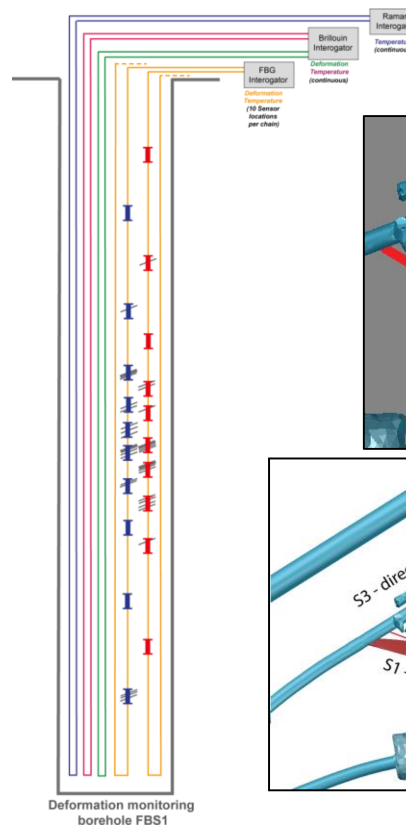


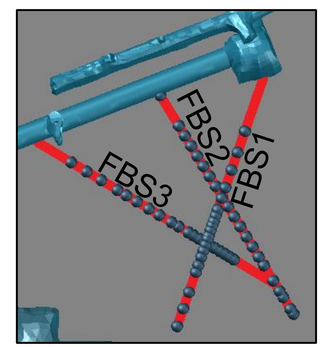


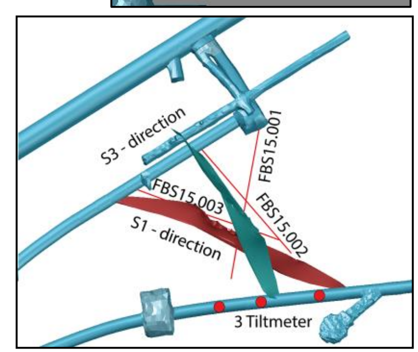
Deformation monitoring



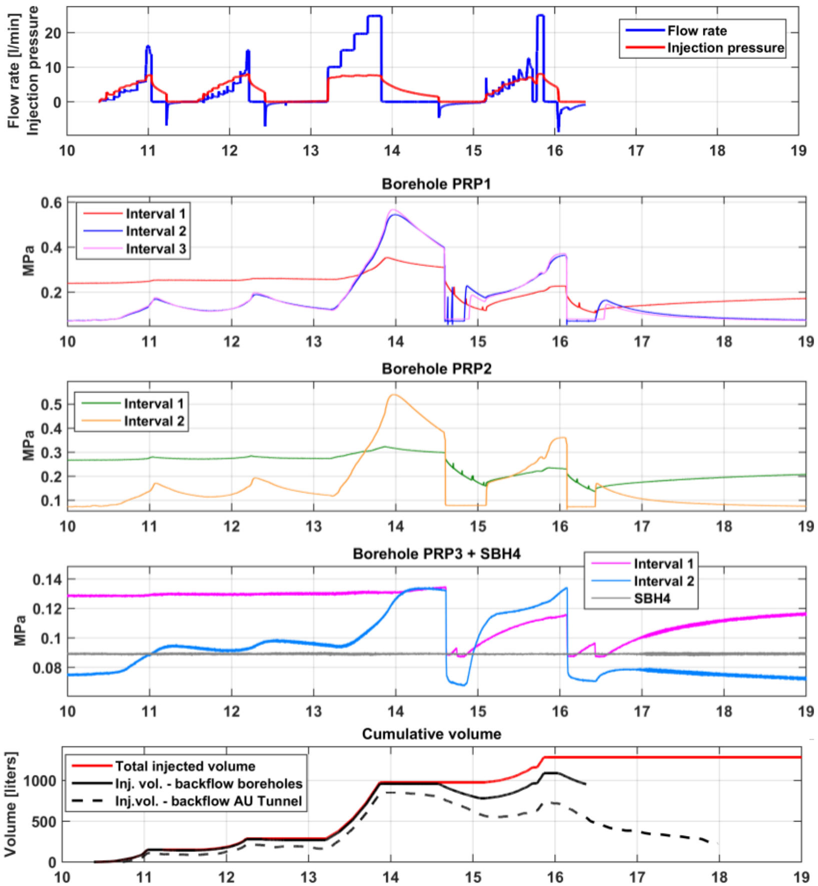
Longitudinal strain with fibre-optic sensors
60 FBG sensors and distributed strain sensing cable in 3 boreholes



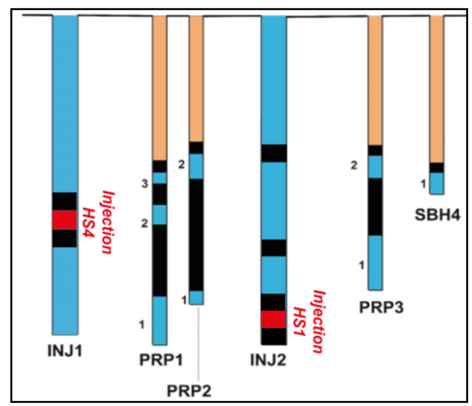


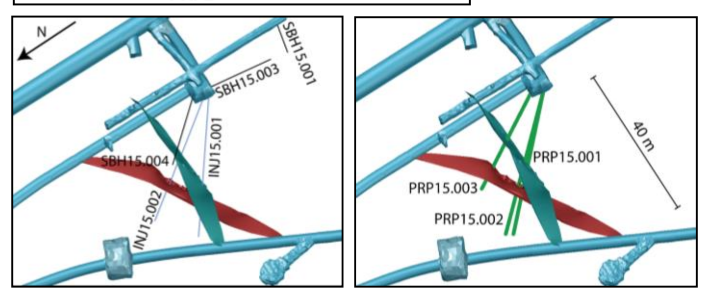


Pressure monitoring



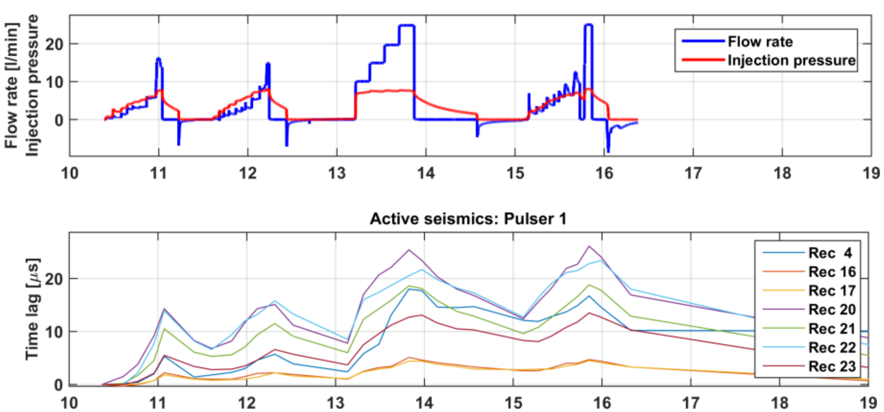
A total of 12 pressure observation intervals to record pressure evolution

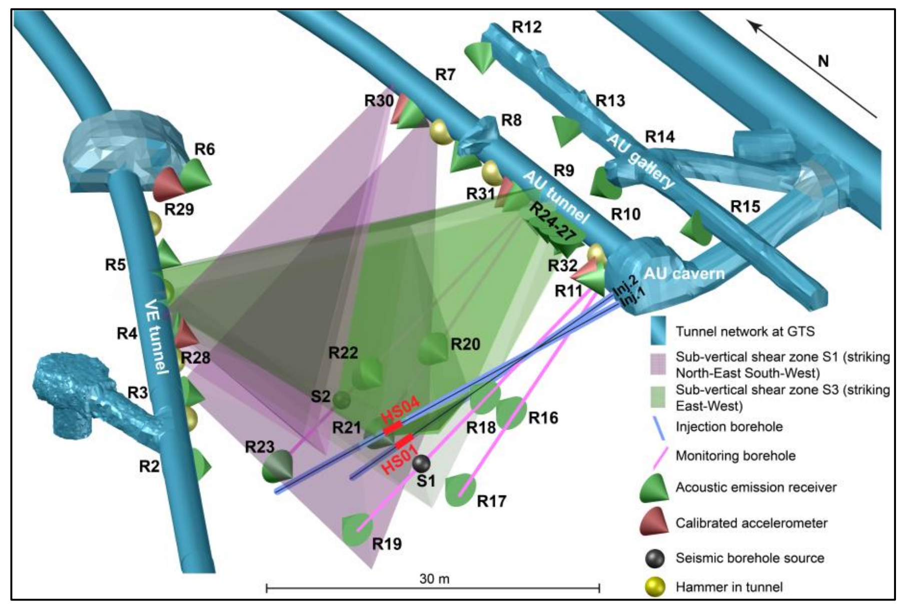




Active seismic monitoring

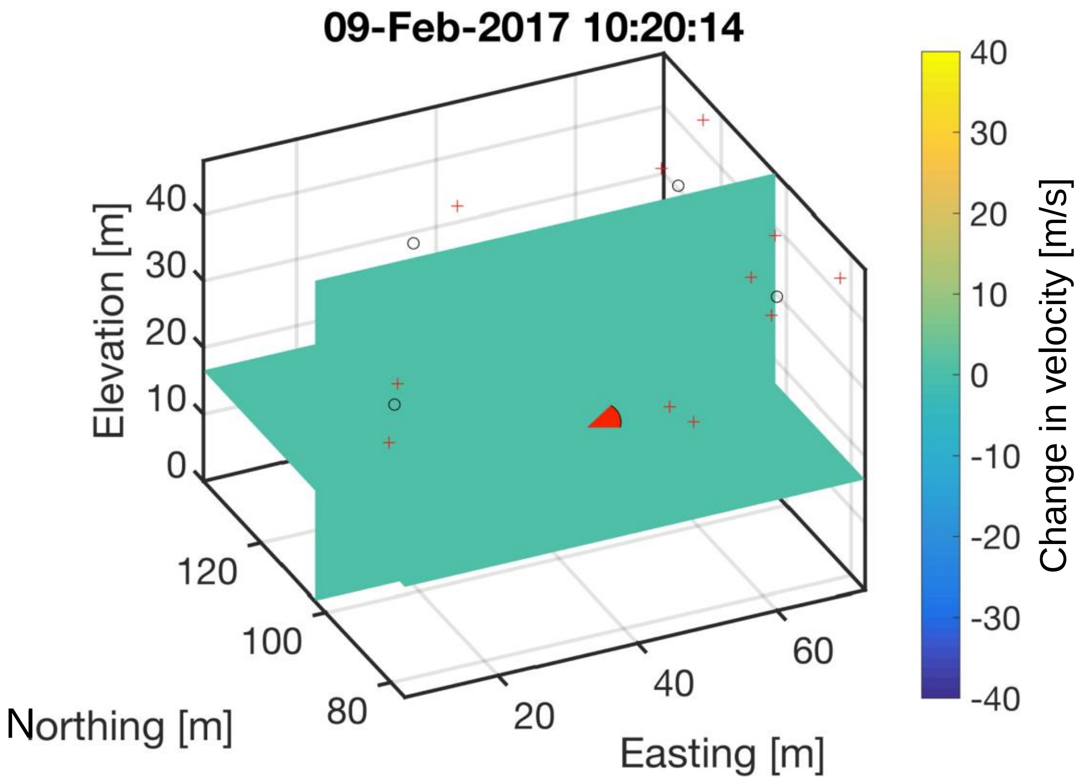
- Systematic p-wave travel time changes during stimulation
- Using travel time changes to invert for p-wave 3D velocity change





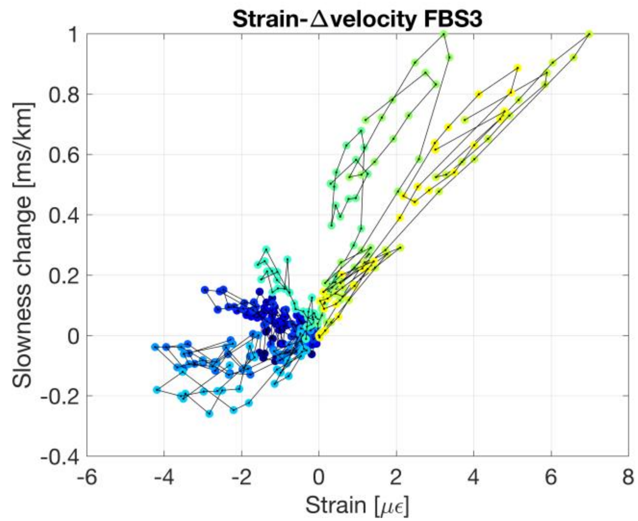
Active seismic monitoring

- Systematic p-wave travel time changes during stimulation
- Using travel time changes to invert for p-wave 3D velocity change

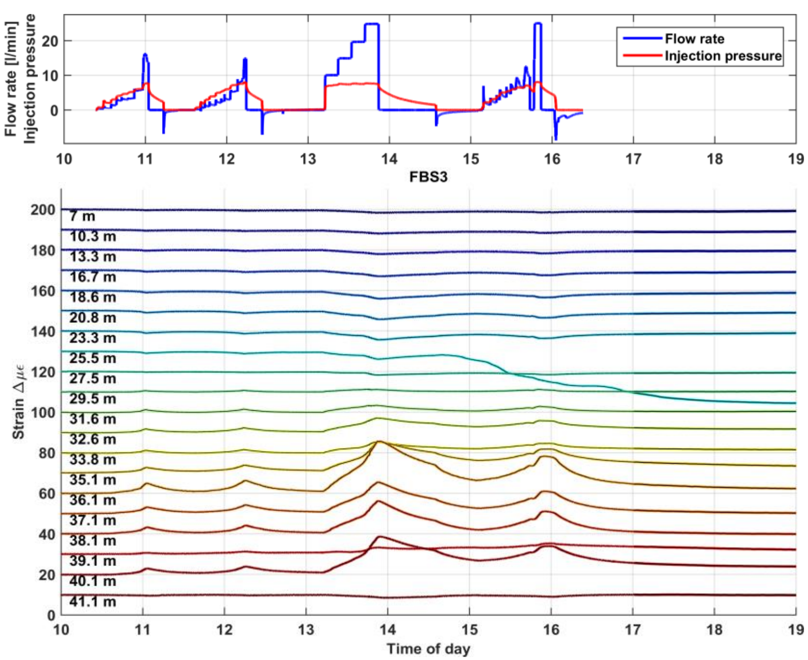


Active seismic monitoring

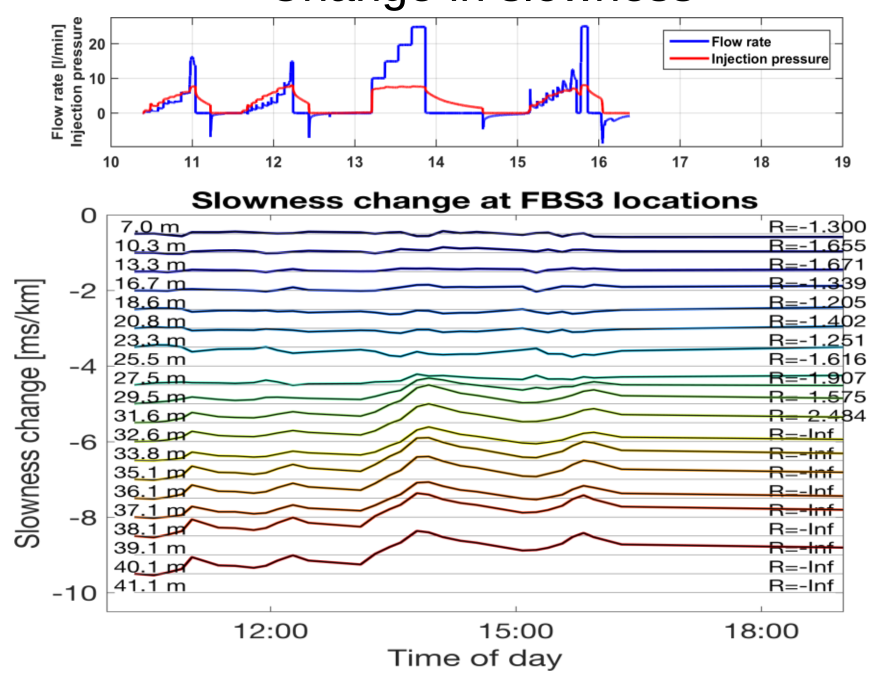
- Strong correlation between strain measurements and inverted change in seismic velocity (slowness)



Deformation

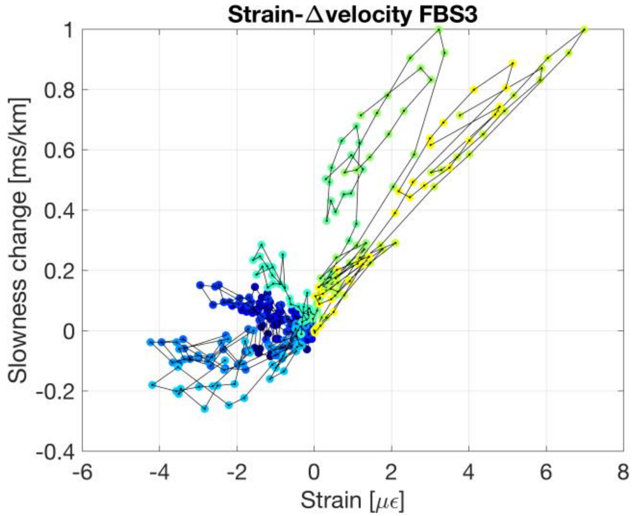


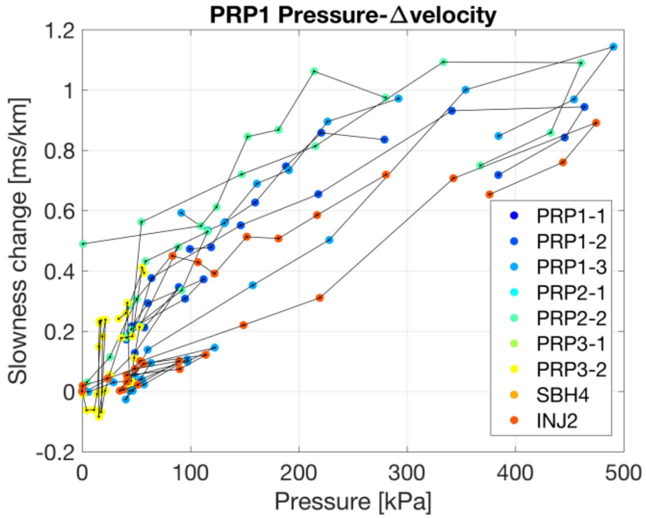
Change in slowness



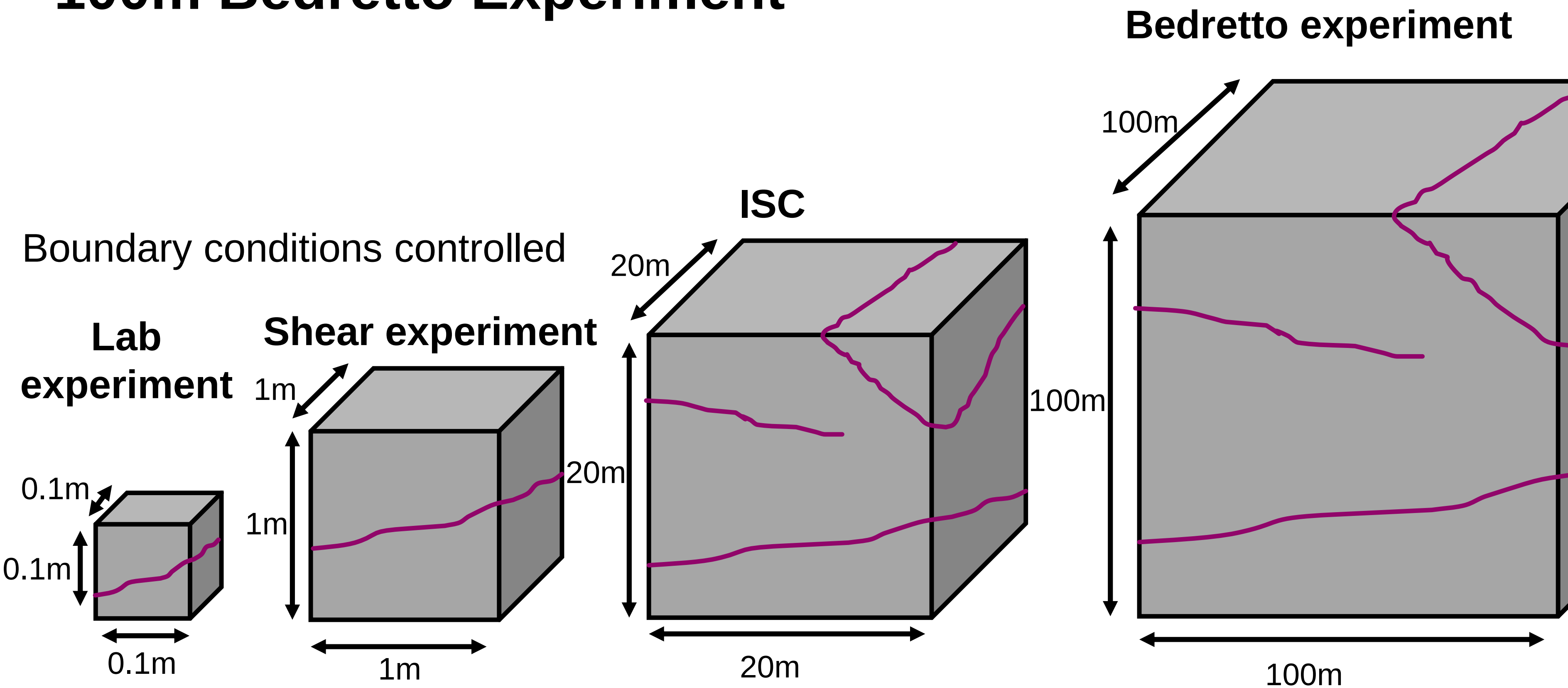
Active seismic monitoring

- Strong correlation between strain measurements and inverted change in seismic velocity (slowness)
- Even better correlation with pressure monitoring data
- This might open possibilities to non-intrusively measure pressure propagation and stress pertubations



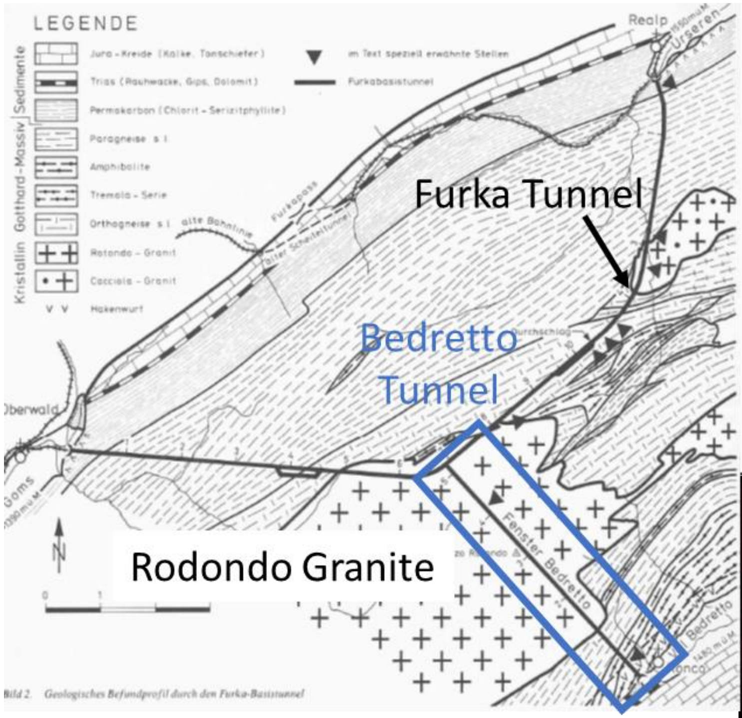


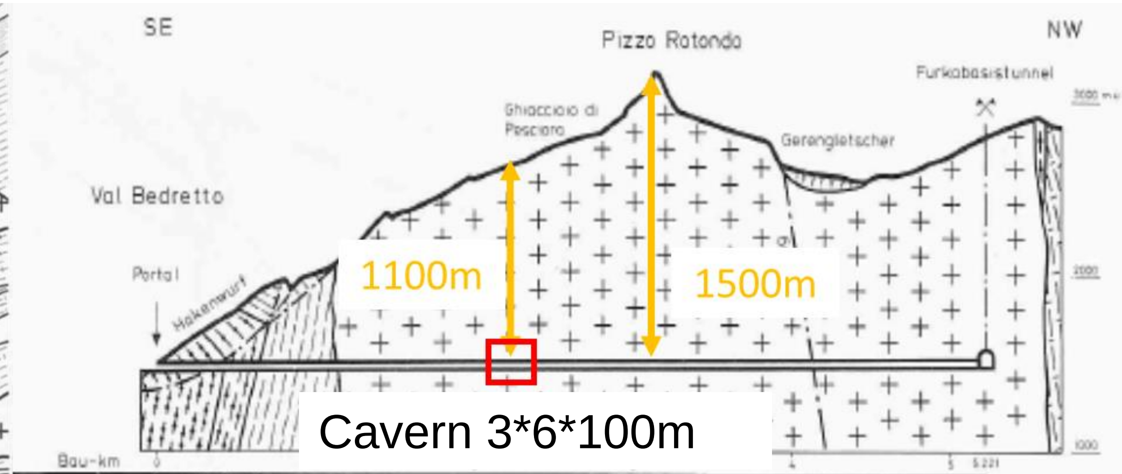
100m Bedretto Experiment



- → Testbed for stimulation techniques, heat storage, …
- → Open for project proposals from SCCER-SoE and external partners
- → …

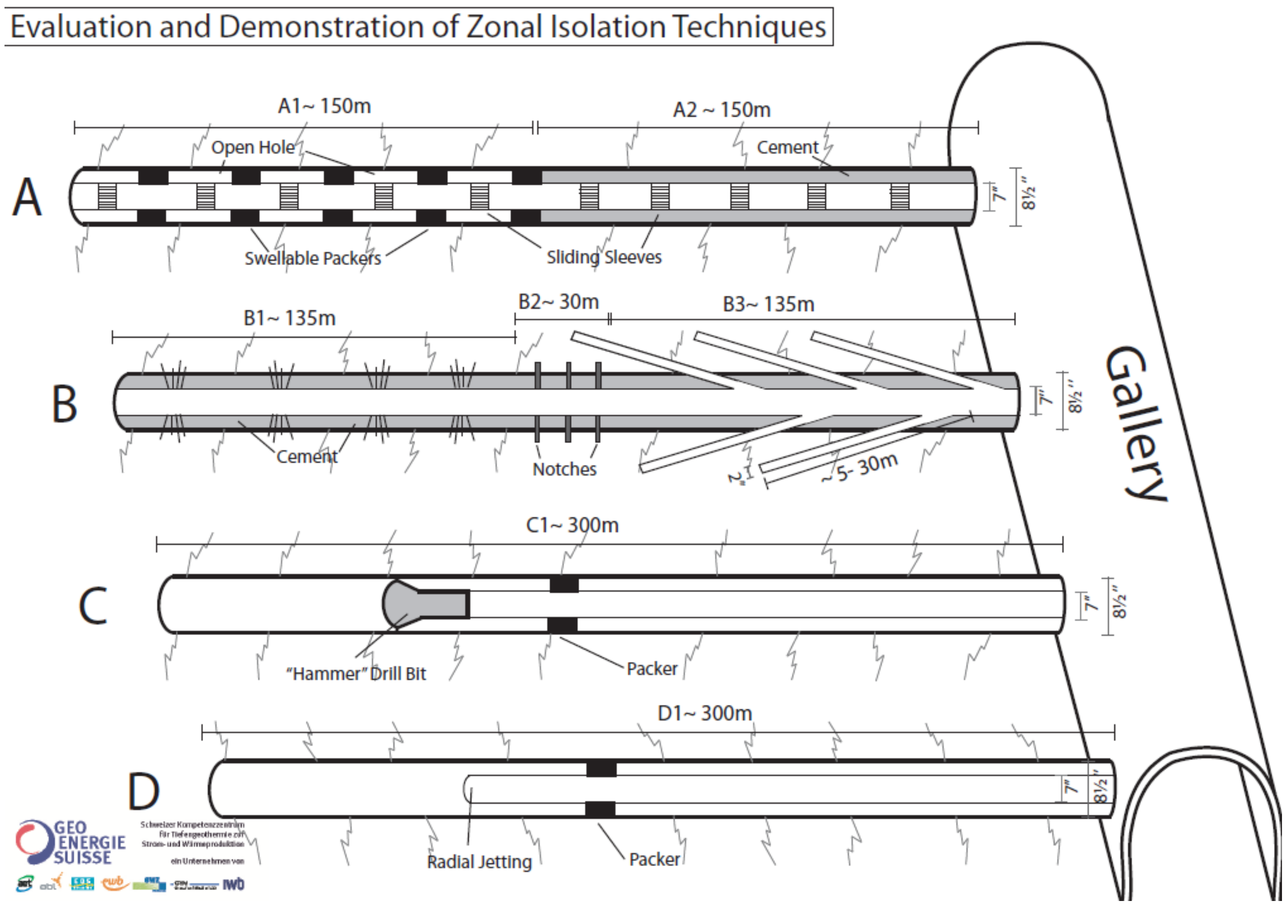
Bedretto project





- Construction to start soon
- First experiments next year

Test bed may provide great opportunities…



Collaborations and external partners welcome!

Conclusions & Outlook

- Grimsel ISC project
  - Experiments successfully completed
  - Variable stimulation response, with permeability increase between 1 and >1000
  - Initial processing shows high quality and versatility of data
  - Ideas and collaboration for data processing welcome!
- Bedretto laboratory
  - Infrastructure development within coming months
  - Ideas and proposals for experiments welcome!

Thank you for your attention