ETH zürich

Grimsel In-situ Stimulation Project: What we can learn from scaled experiments

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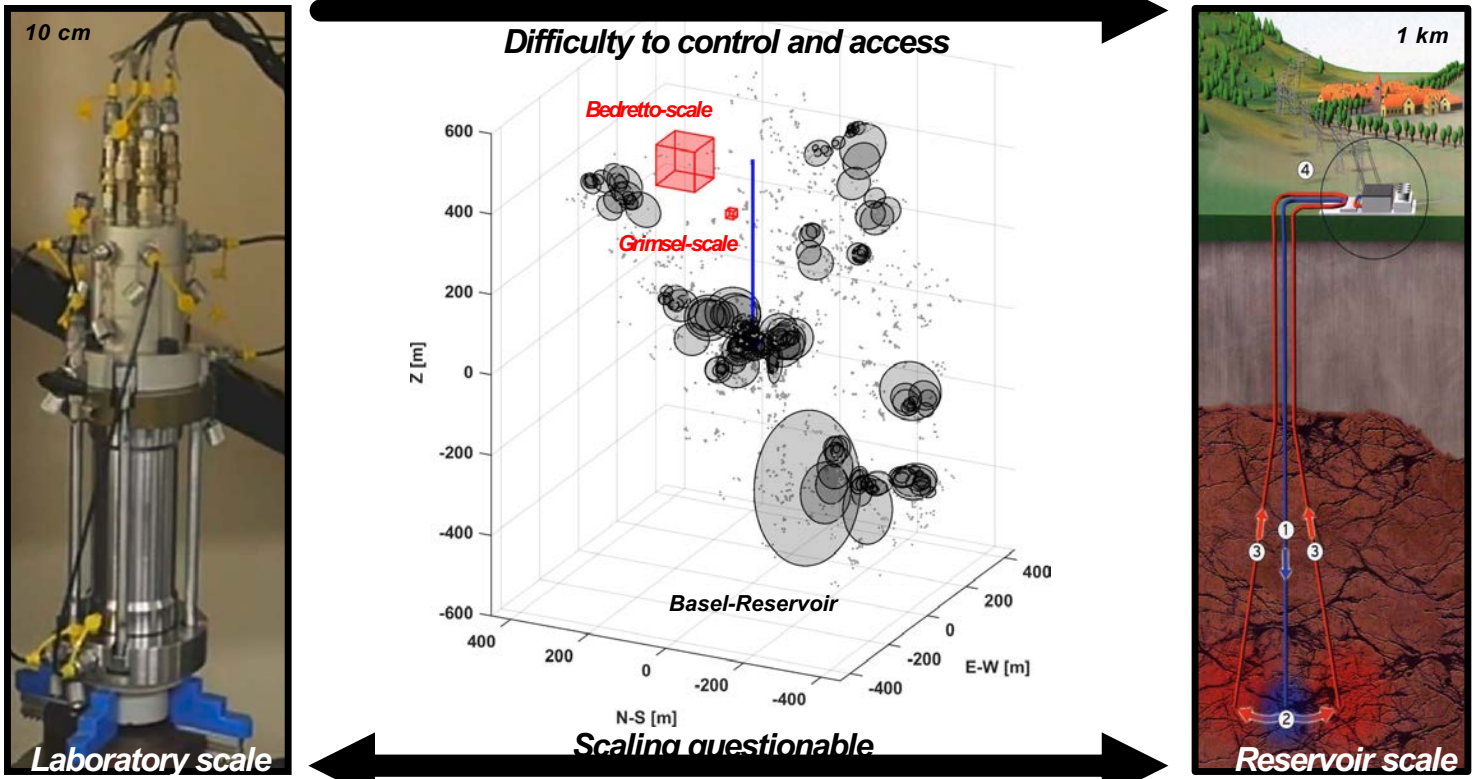
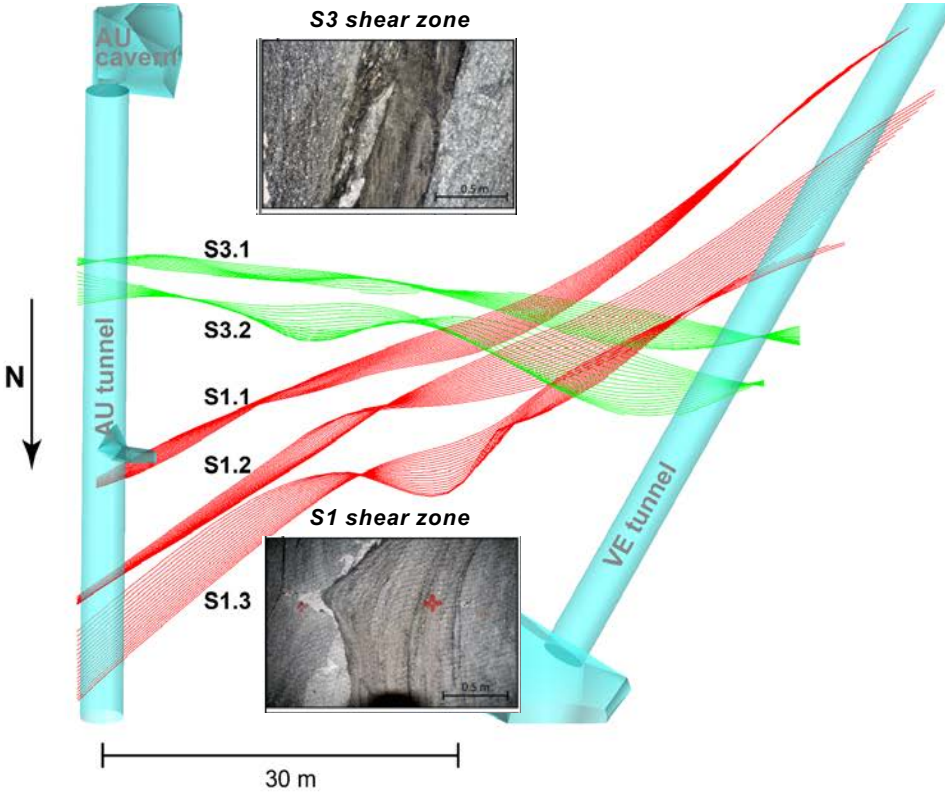
SCCER SoE

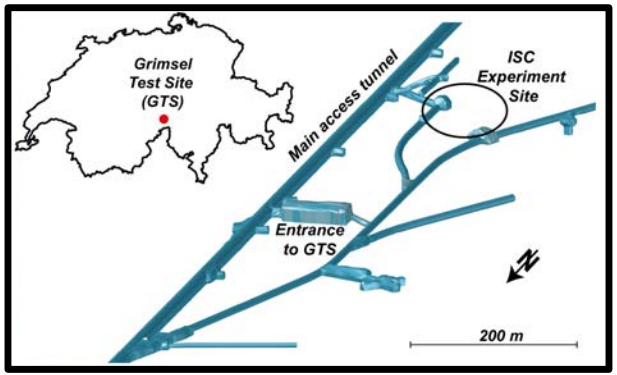
Why do we need in-situ experiments?

Main research question: How can we **create an efficient heat exchanger** while keeping the risk of **induced earthquakes at acceptable levels**?

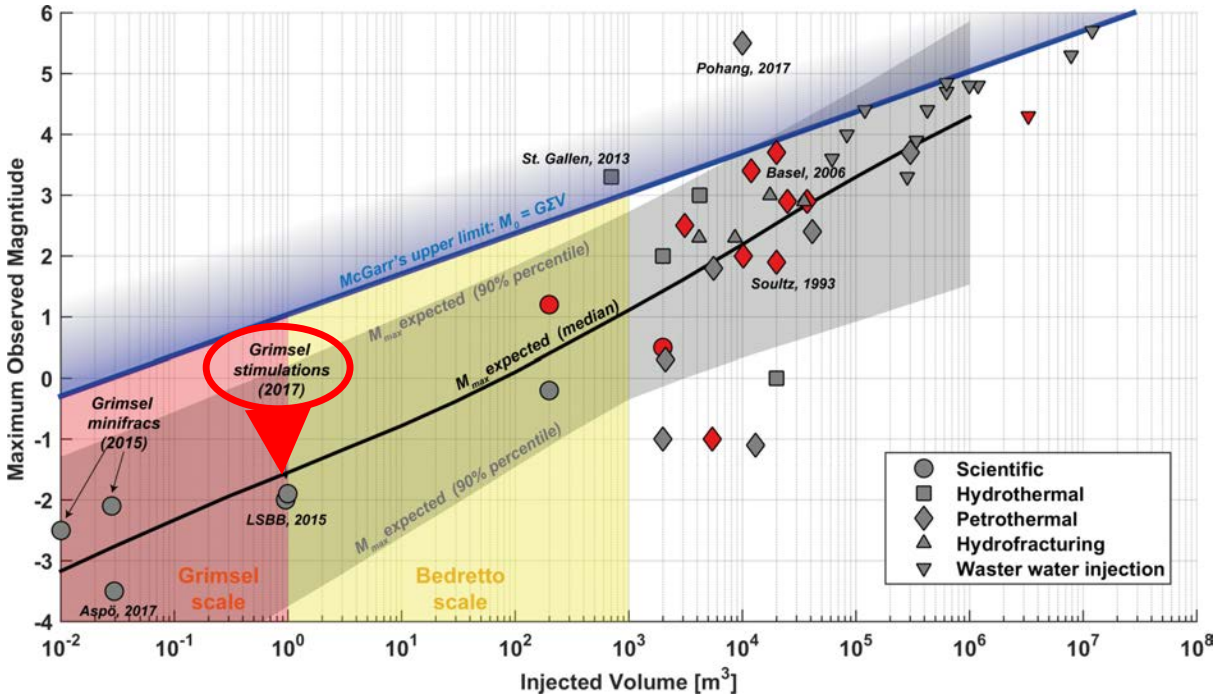


Grimsel Test Site and the In-situ Stimulation Experiment



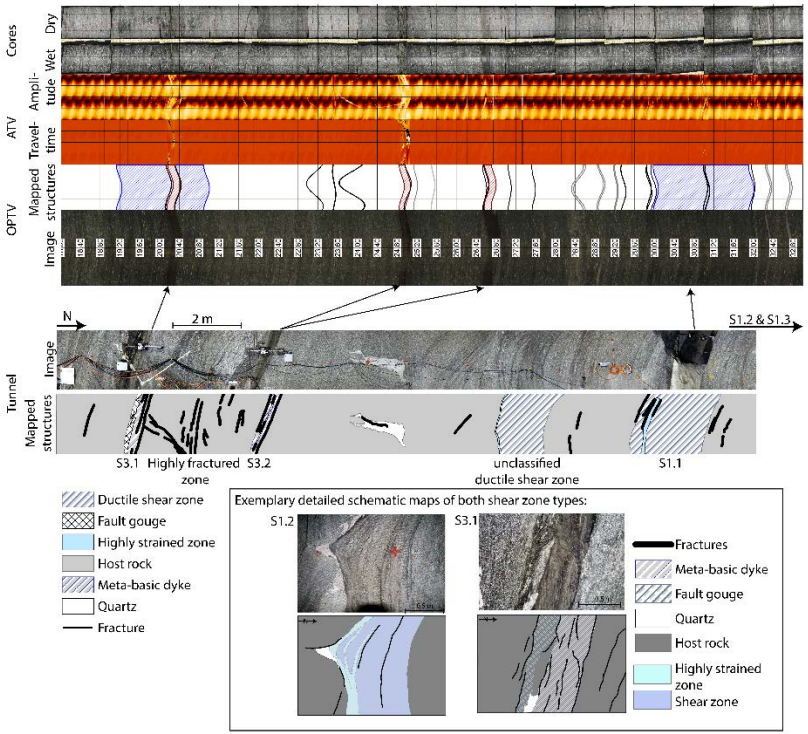


Preparation: Assessment of seismic hazard

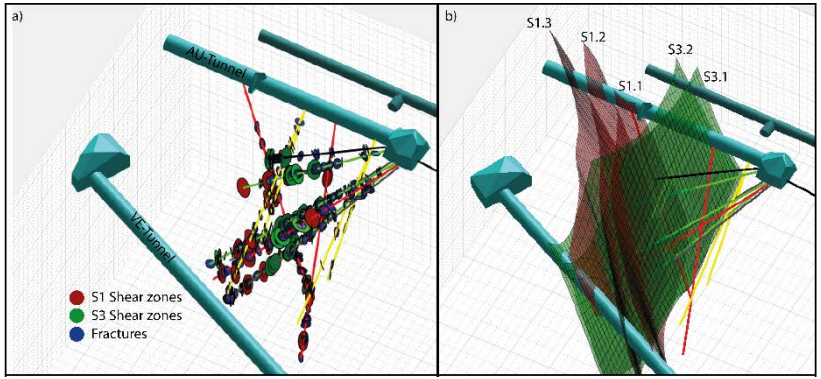


- Maximum expected magnitude ≈ maximum observed magnitude
- ➢ Hazard analysis useful
- ➢ New data in scale with few previous experiments

Preparation: Geological Model

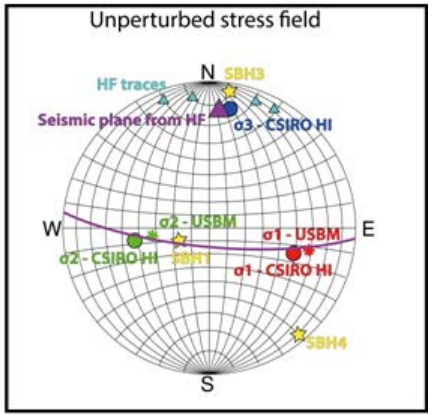


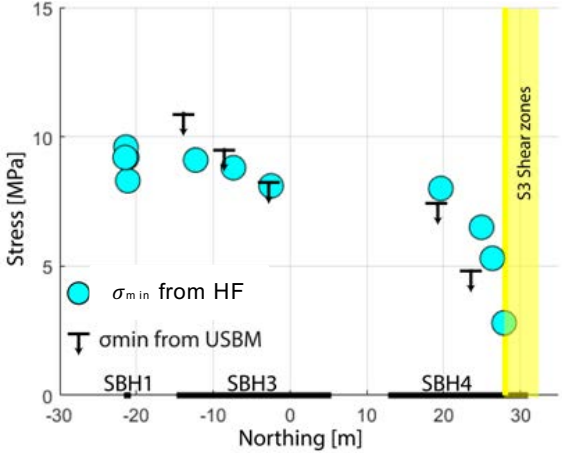
- Combination of Tunnel-mapping, core-logging, borehole-logging
- Large scale interpolations validated by: tunnel-tunnel seismic tomography and hydraulic cross-hole testing
- Basis for numerical modelling, discrete fracture network, ...

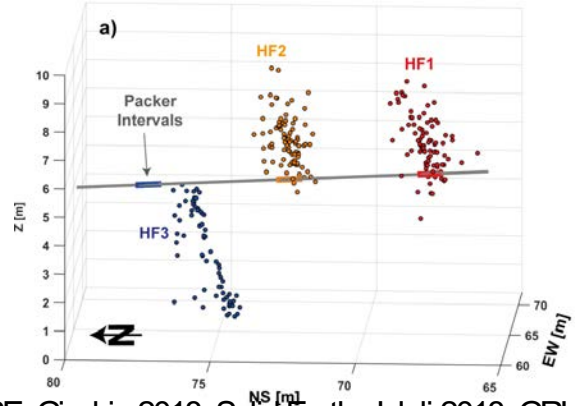


Krietsch et al., 2018, Nature Scientific Data

Preparation: stress measurements





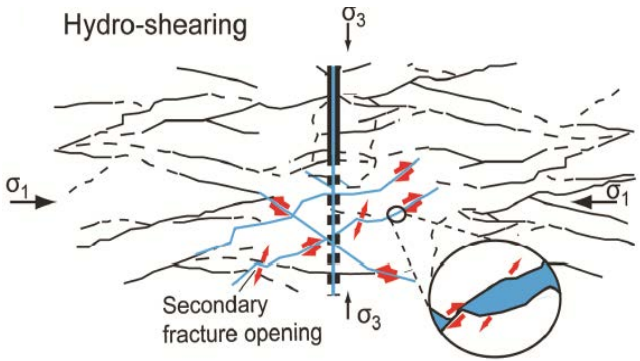


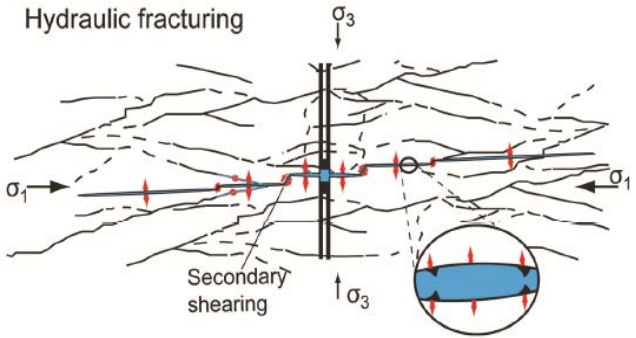
- Stress field influenced by topography
- Stress field is heterogeneous with σ_3 reducing towards shear zone
- Combination of methods important (overcoring, hydraulic fracturing with seismic monitoring)

Krietsch 2018, RMRE; Gischig 2018, Solid Earth; Jalali 2018, GRL

Stimulation concept

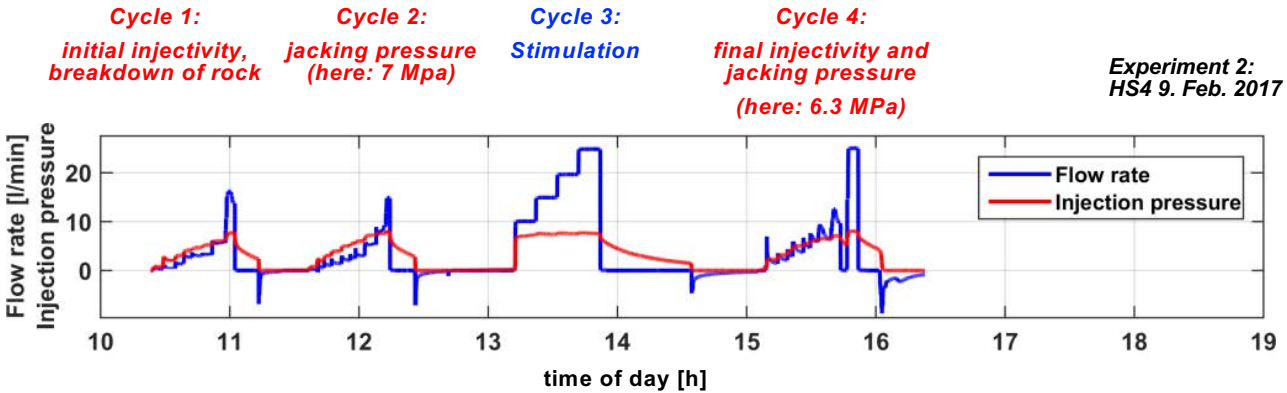
- 6 Hydroshearing (HS) experiments (Feb. 2017), 6 Hydrofracturing (HF) experiments (May 2017)



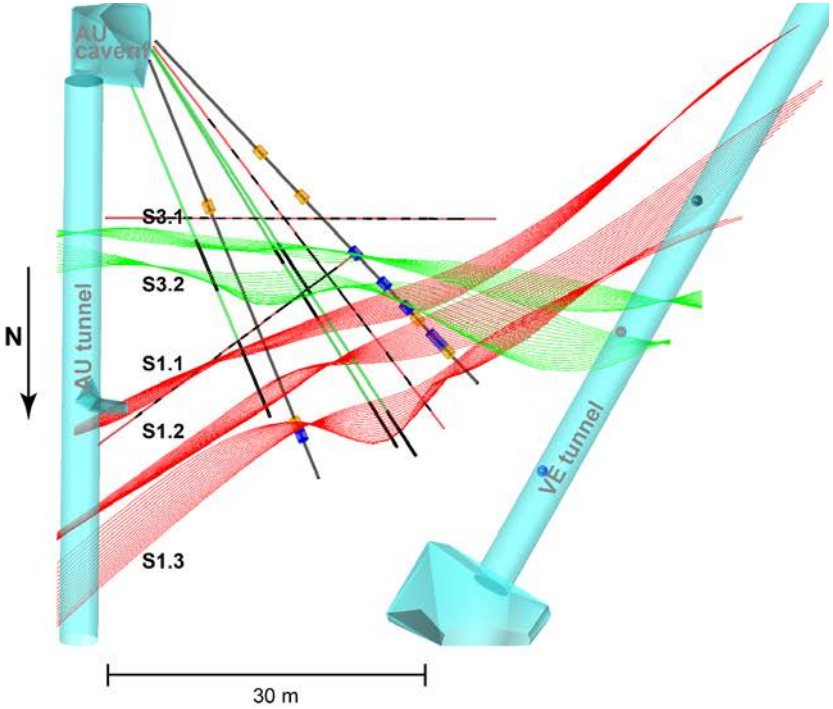


Stimulation concept

- 6 Hydroshearing (HS, Feb. 2017), 6 Hydrofracturing (HF) experiments (May 2017)
- Standardized injection protocol (one each for HS and HF)
- Injected volume ~ 1 m^3 in each experiment
- Variability in observations due to geology, not injection strategy



Stimulation experiments: Injection and observation setup



6 Hydroshearing intervals

6 Hydrofracturing intervals

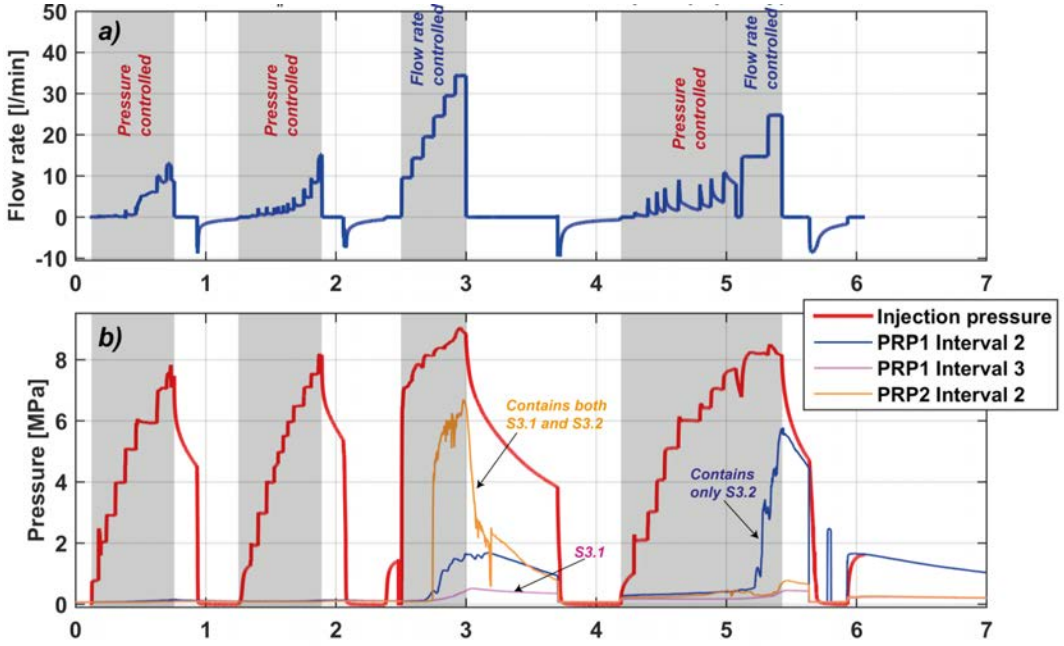
60 Strain sensors

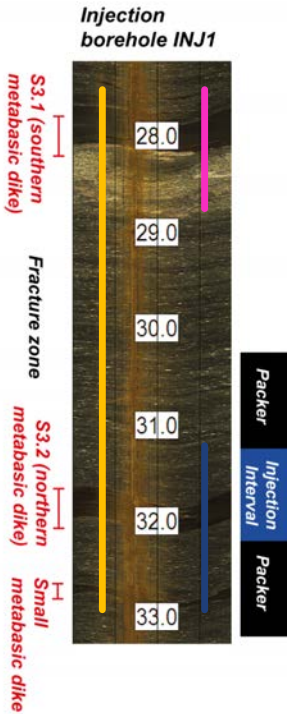
3 Tilt sensors

8 Pressure observation intervals

Seismic monitoring (active and passive)

Example hydroshearing experiment: pressure propagation

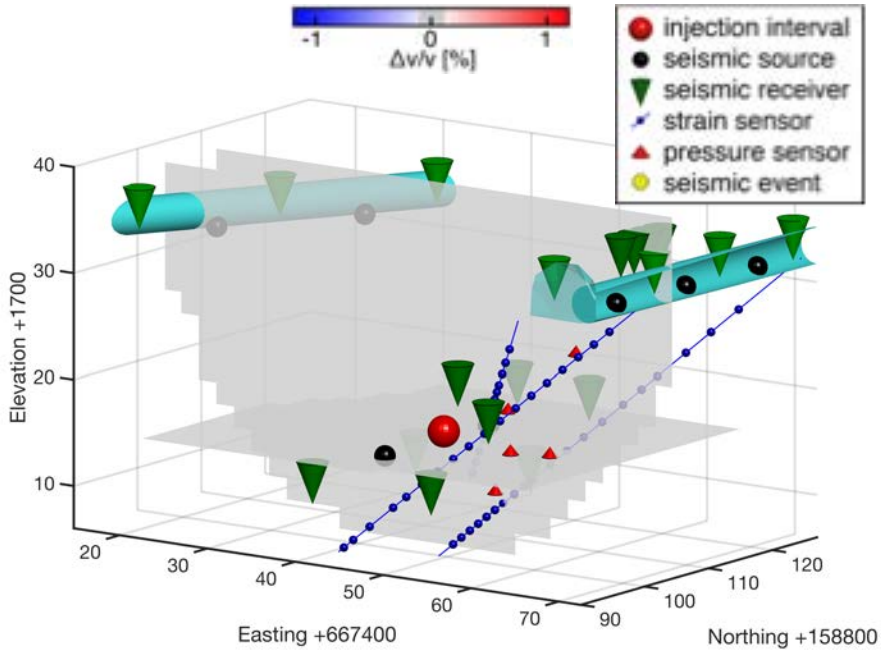




- Pressure pulses observed (only in this experiment)
- ➢ Strongly heterogeneous, channelized flow
- ➢ Flow paths changing during experiment

Pressure monitoring from seismic velocity observations

- Repeated seismic surveys during hydraulic stimulations show decrease of velocity
- Laboratory and field measurements show strong correlation between seismic velocity and pore pressure
- ➢ Active seismic monitoring as new technology for pressure monitoring



Doetsch et al., 2018, GRL

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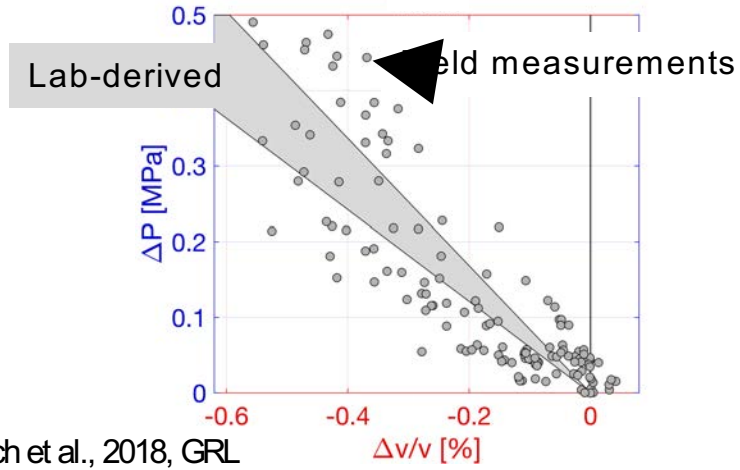

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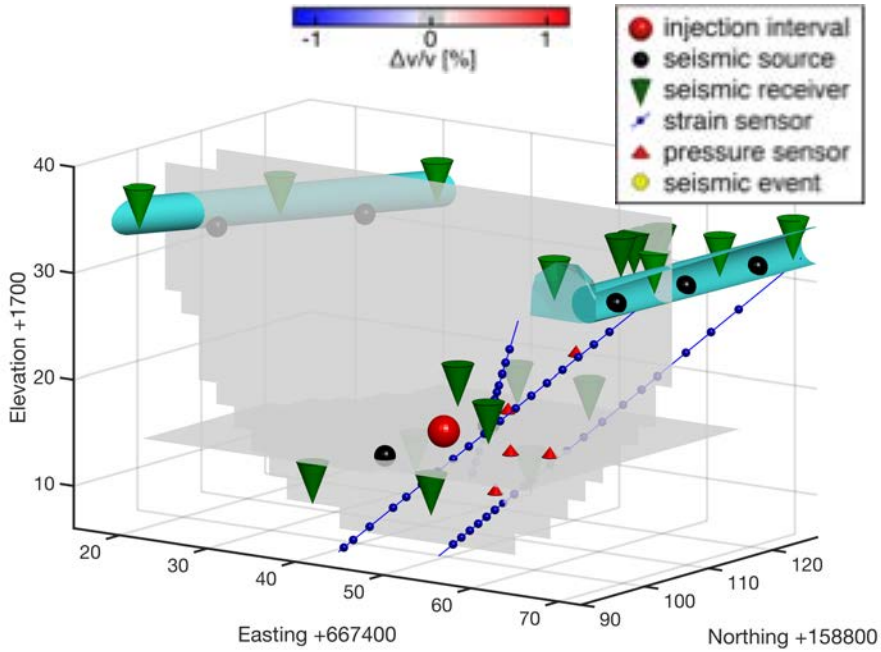
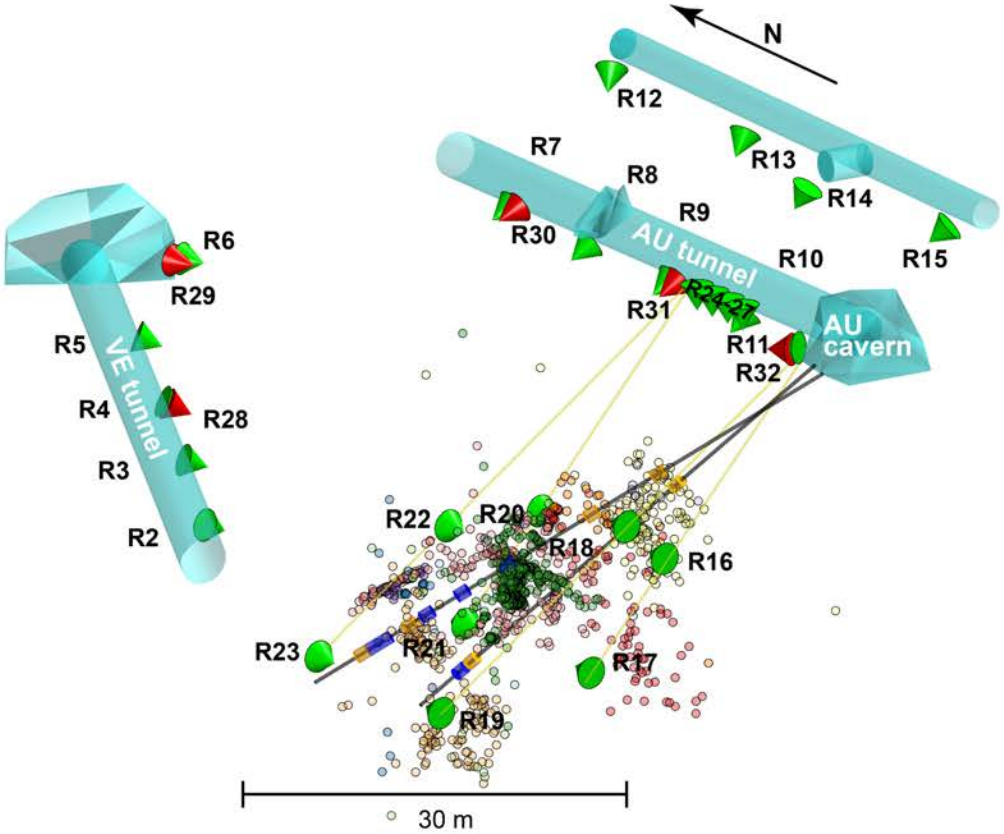


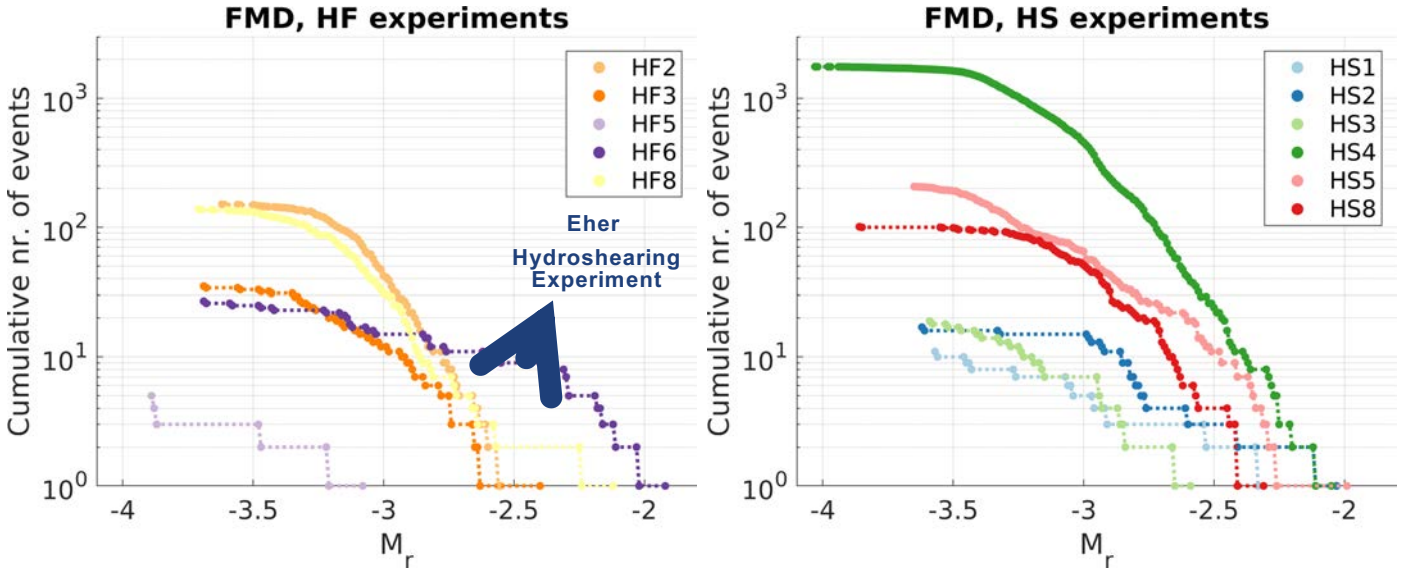
Seismic monitoring

- 26 AE sensoren (8 in boreholes)
- 5 accelerometers

- 20’824 detected microseismic events
- 2’605 manually picked and located events
- Location accuracy: 0.5 m
- Magnitude range Mr –4.0 to –2.0

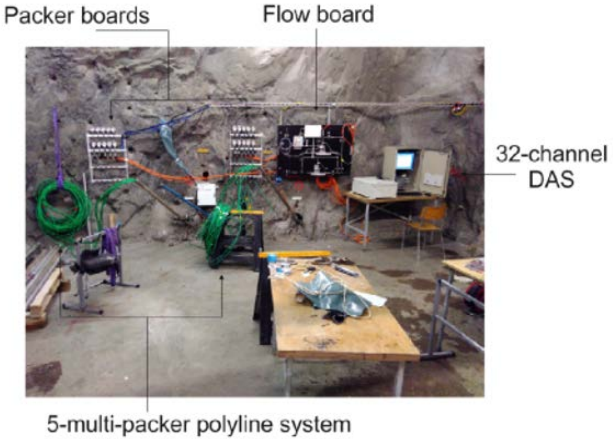


Seismicity of all experiments

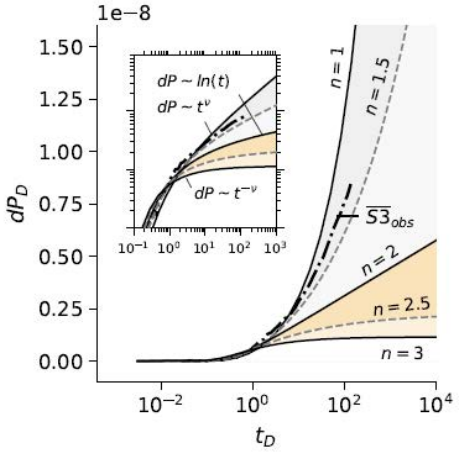


- Large variability within small rock volume
- Local (geological) conditions more important than injection protocol?

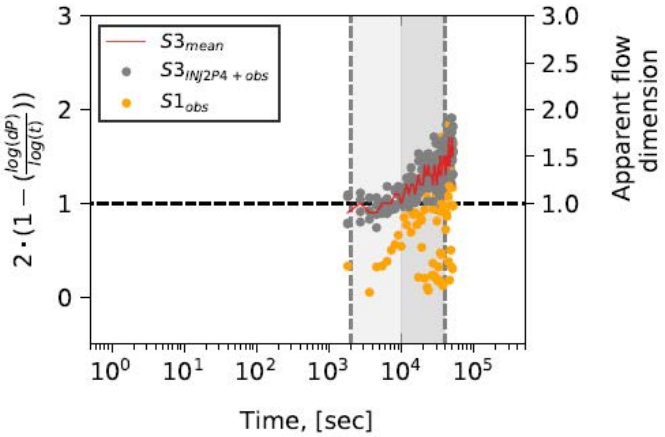
Hydraulic characterization



Fractal flow dimension



Time evolution



- Fractal flow dimension increases with time (volume)

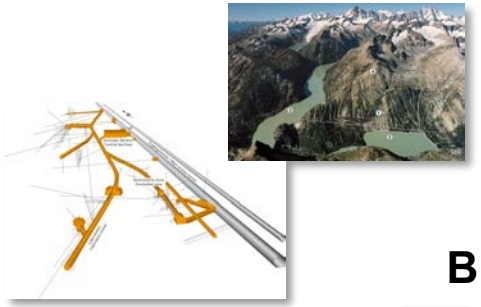
Summary Grimsel ISC

- Successful hydraulic stimulation
  - Final transmissivity similar for all HS experiments
  - Final transmissivity for HF smaller than for HS experiments
- Large variability in seismic response; difference between S1 and S3 injections
- Seismic hazard analysis correctly predicted maximum magnitude
- Pressure propagation: linear, non-linear and channelized flow observed during stimulations
- Interplay between hydraulic fracturing and hydraulic shearing observed
- New technologies successfully tested
  - Active seismic observations for pressure monitoring
  - DNA nano tracers, potential to record temperature along flow path
  - Fiber optic technology for temperature, strain and seismic signals
- Data publicly available for benchmarking numerical codes, testing new ideas, …

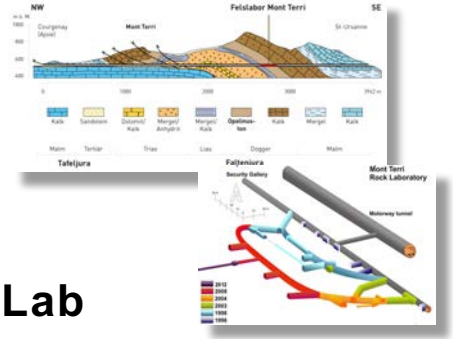
Thank you for your attention!

Bedretto – yet another rock lab?

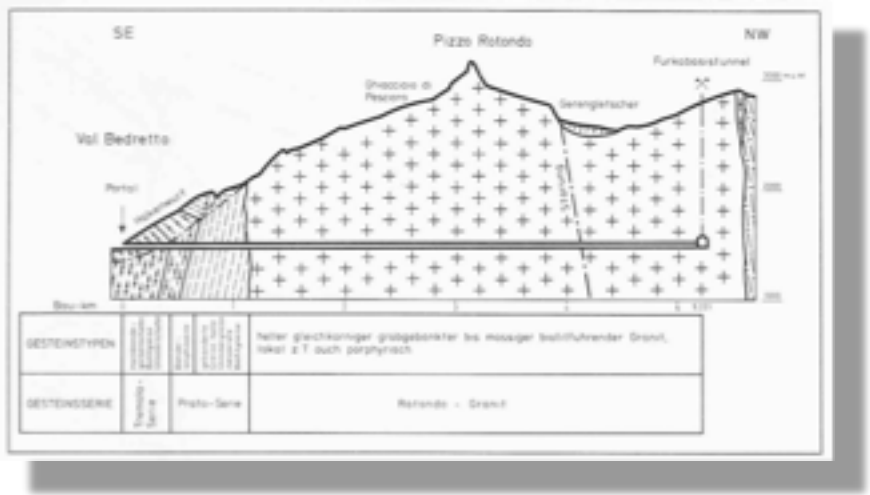
Felslabor Grimsel - FLG



Felslabor Mont Terri - FMT

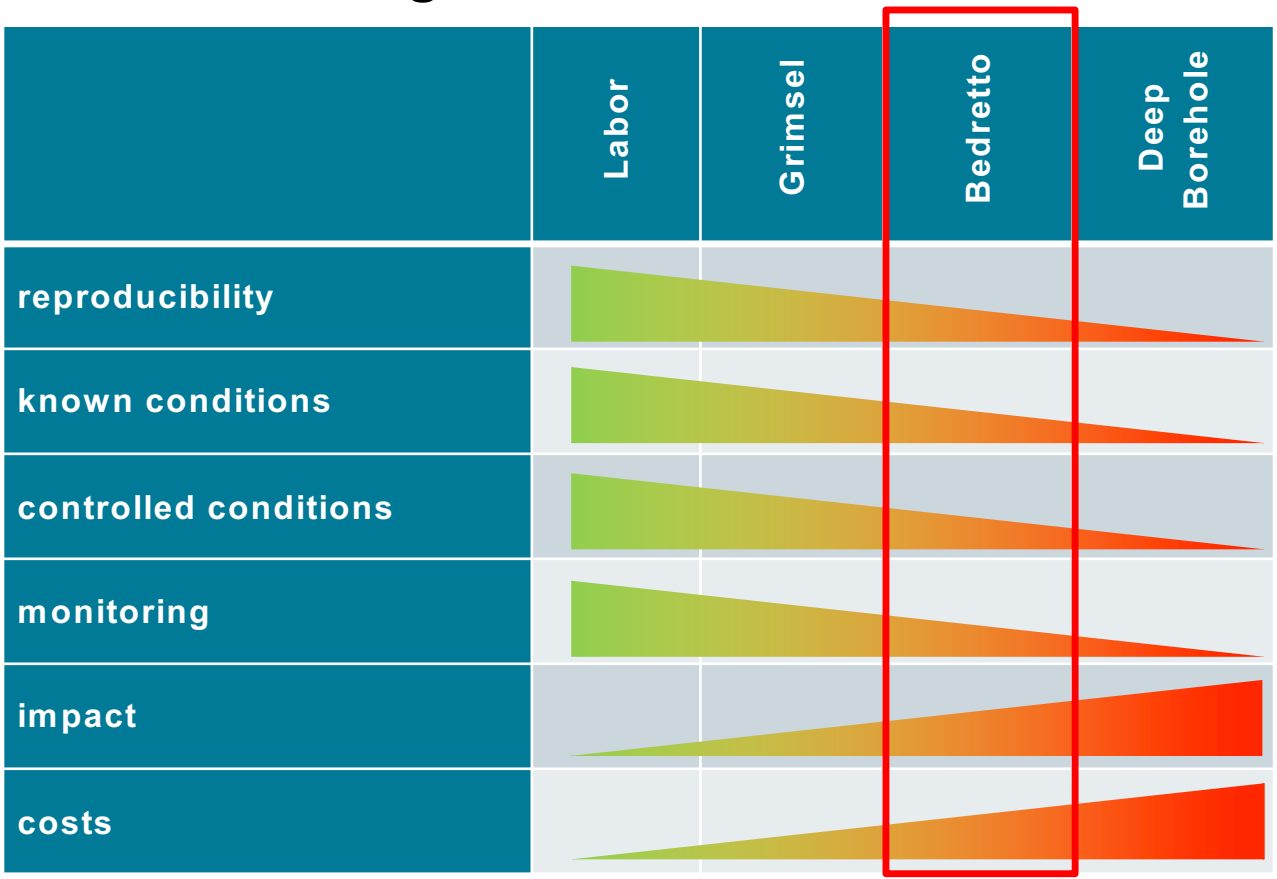


Bedretto Deep Underground Lab



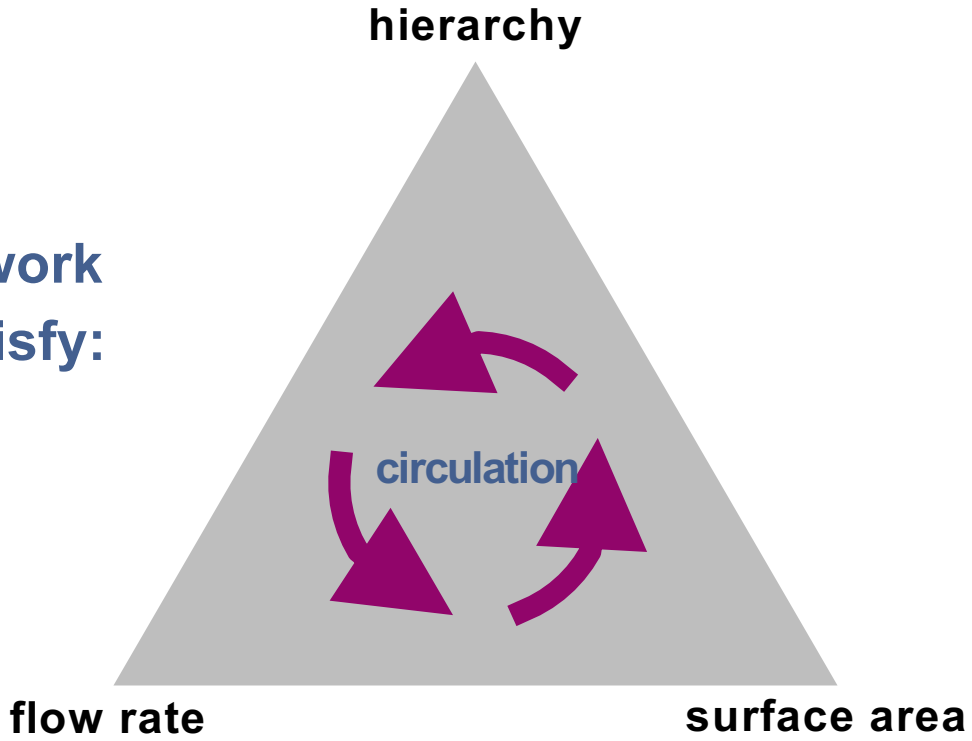
Situation Bedretto-Stollen

Scope of BedrettoUnderground Lab



Prerequisite for an effective, sustainable geothermal reservoir

fracture network needs to satisfy:



Increasing the complexity of network hierarchy

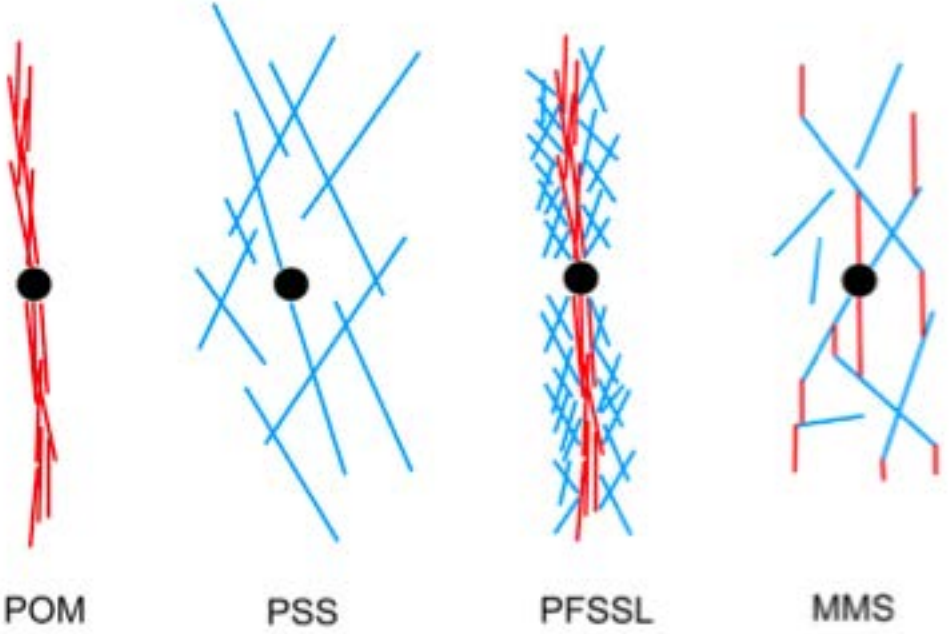
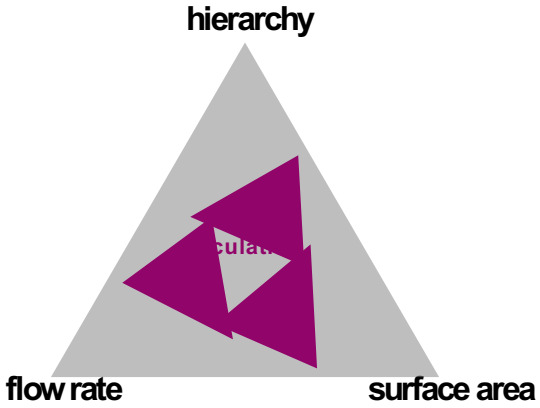


Fig. 1. Schematic of four conceptual models for the mechanism of stimulation in EGS. The black dot represents the wellbore. New fractures are represented with red lines, and preexisting fractures are represented with blue lines. The mechanisms are: pure opening mode (POM), pure shear stimulation (PSS), primary fracturing with shear stimulation leakoff (PFSSL), and mixed-mechanism stimulation (MMS).



McClure and Horne
(2014, IJRMMS)

Sneak Preview