Annual conference

September 13th , 2018

SCCER SoE

SWISS COMPETENCE CENTER for ENERGY RESEARCH

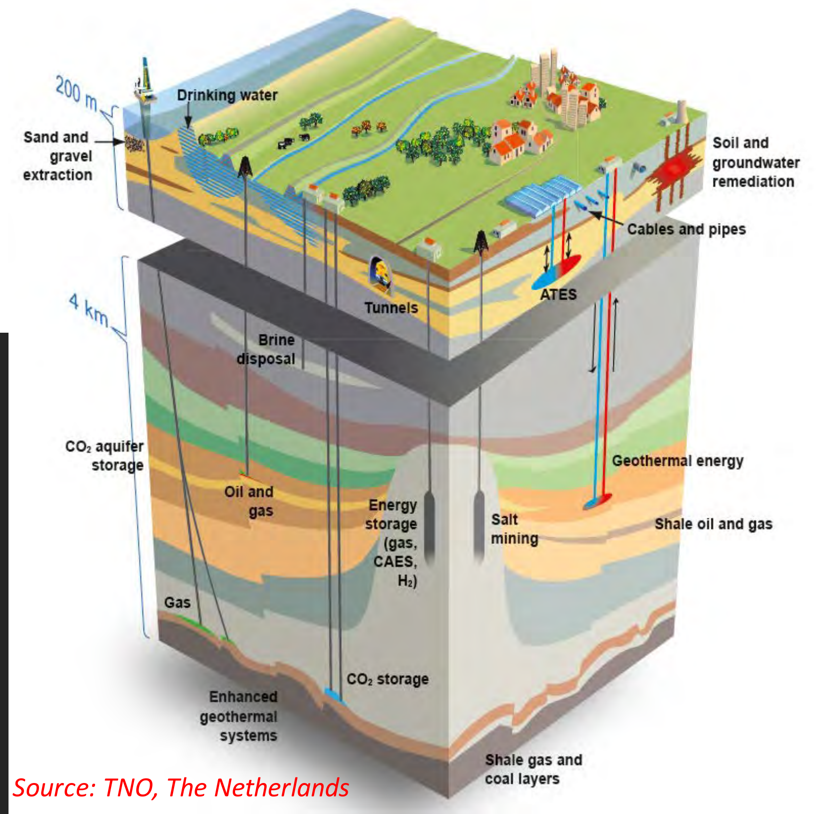
SUPPLY of ELECTRICITY

Highlights of the Geo-energies activites

Work Package 1

Lyesse Laloui

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE



Source: TNO, The Netherlands

Scope of the WP1: aims & challenges

Deep geothermal energy for power production

- How can we safely increase permeability at depth?
- Physics and modelling of hydraulic stimulation
- Grimsel in-situ experiment
- Technological aspects: drilling methodologies, well optimization

CO_2 sequestration to decarbonze fossil energy sources

- Main issues associated to injection and storage
- Identification of favourable geology
- Road to a pilot project?

Hydrothermal heat storage, exploitation, and production

- Exploration and implementation

WP1 organization

Task 1.1:
Resources exploration and characterization (Prof. L. Diamond)
UniBE, UniL, UniNE, ETHZ

Task 1.2:
Reservoir stimulation and engineering (Prof. T. Driesner)
ETHZ, UniNE, UniBE, EPFL

Task 1.3:
Hydrothermal heat exploitation and storage (Prof. A. Moscariello)
UniGE, UniNE, EPFL, UniBE

Task 1.4
Geo-data infrastructure and analysis (Mr. O. Lateltin)
Swisstopo, regional partners

WP1 General context

New leader for the WP1 since November 2017

- Attempt to be closer to industry needs and challanges
- Attempt to initiate more synergies inside the WP1

An event with industrial partners:

A workshop with the Swiss intrustrial companies supported by the SFOE:

- **To understand their expertise, needs and challenges**
- **To coordinate the research efforts with the real engineering aspects**

Organization facing delay!

Horw Sept 2018 → postponed

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Energie BFE
Swiss Federal Office of Energy SFOE

Workshop on Geo-energies

SCCER SoE

@ EPFL on June 5th

14 scientific talks

40 participants from SCCER-SoE partners

unine

Prof. Valley
- A. Dahrabou
- N. Dutler
- M. Kakurina

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Prof. Holliger
- N. Barbosa
- E. Caspari
- A. Greenwood

ETH zürich

Prof. Driesner
- J. Mindel
- J. Patterson

Prof. Wiemer
- L. Villiger

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Prof. Laloui
- B. Fryer
- A. Minardi

Prof. Lecampion
- T. Blum
- F. Ciardo
- H. Zia

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- stability of deep deviated wells
- in-situ stress determination
- hydraulic fracturing experiments

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- fracture characterization from borehole data

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- THM simulations and tool
- hydraulic shearing experiments

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- hydraulic stimulation: theoretical and experimental aspects
- CO_2 sequestration: caprock and seismicity

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Fracture characterization with borehole data

Grimsel Zone-Breccia fault

- **Hydrophone data**
  As alternative to geophone
- **Geophysical borehole data**
  Petrophysical properties
  Hydraulic characteristics
- **Full-waveform sonic (FWS) data**
  Fracture compliance

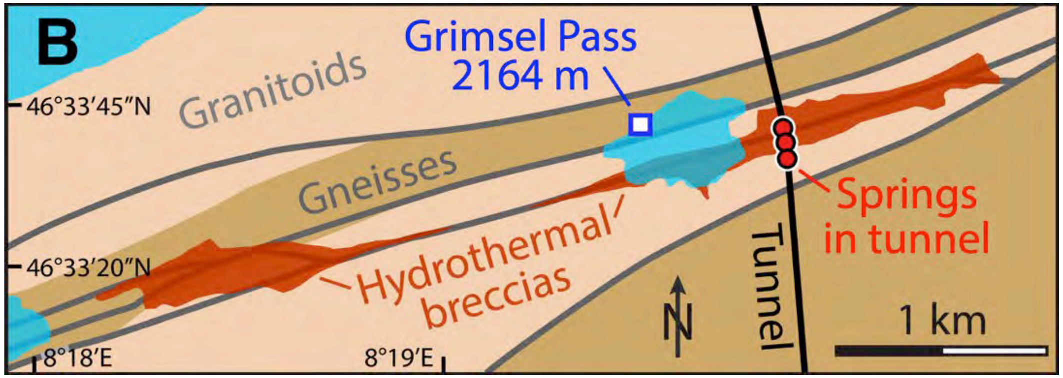
Grimsel Test Site (INJ2)

Objectives:

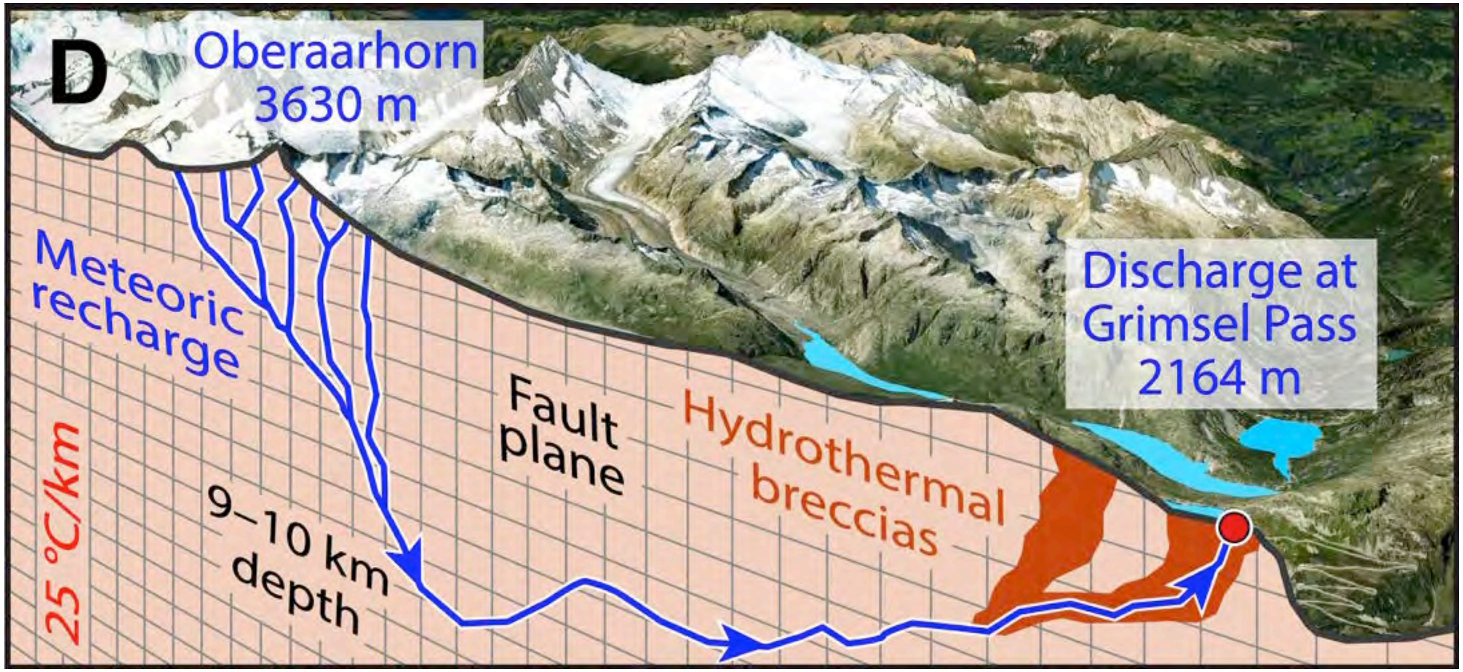
- Complementary to geophone data
- To analyze full-waveform sonic (FWS) log data from a borehole intersected by **single fractures** to infer the different contributions to the attenuation
- To assess the possibility of estimating **fracture compliances**

Characterization of fractured rocks based on seismic measurements and geophysical borehole logs – Klaus Holliger, UniL

Active, fault-hosted orogenic geothermal system at Grimsel Pass



Geochemical modelling of active springs show water is rising from 9-10 km depth where wall rocks are 230–250 °C



Posters: Diamond et al., Alt-Epping et al., Egli et al.

UNIVERSITÄT BERN

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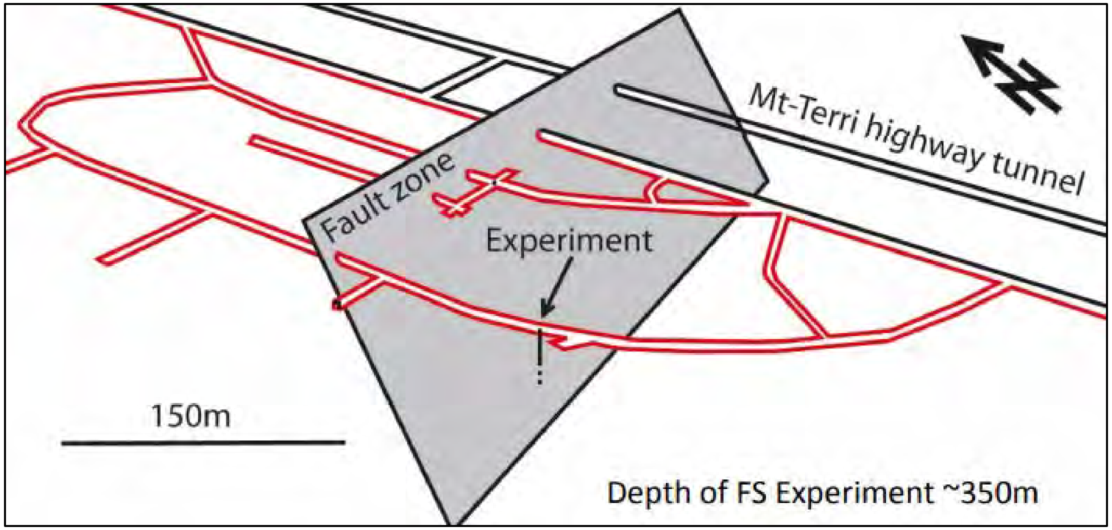
In-situ stress determination

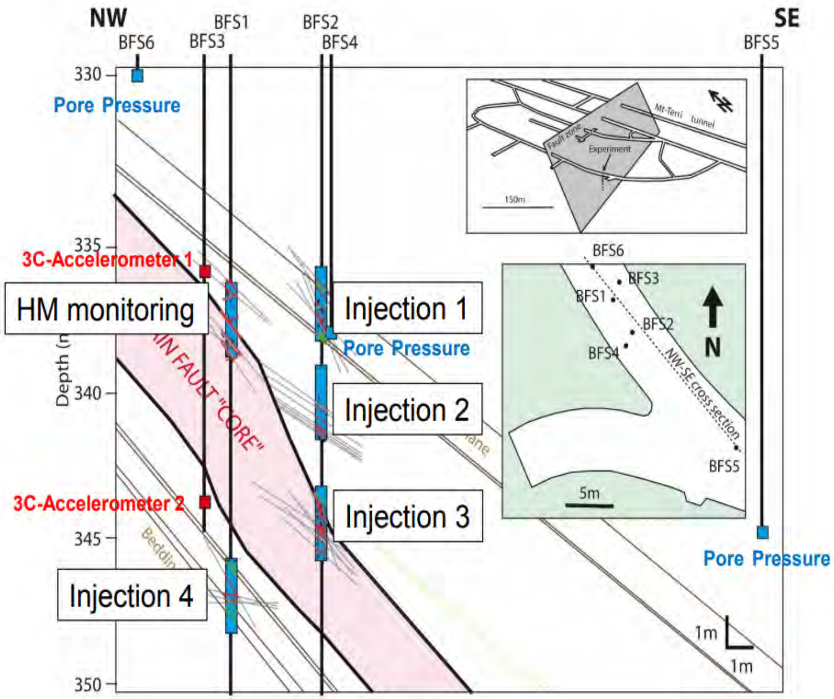
Development of a protocol to estimate the **in-situ stress using the 3D displacement data**

Fault Reactivation Experiment (Fault Slip)



- In-situ study of the aseismic-to-seismic activation of a fault zone in a clay/shale formation
- Implications of fault slip on fault permeability
- Monitoring Tool and Test Protocols Development

In-situ stress determination

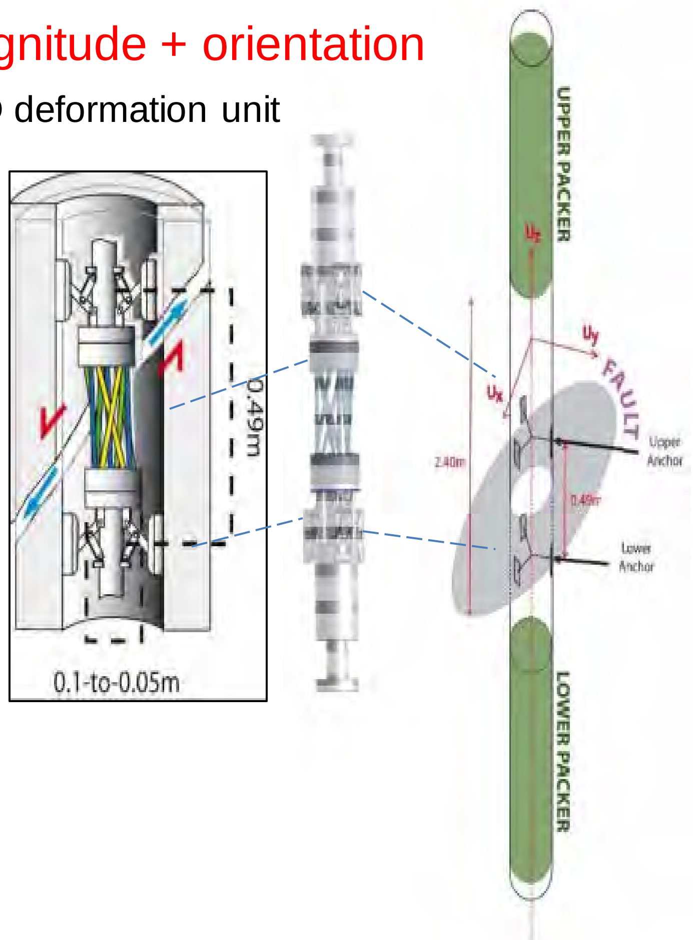


SIMFIP probe

Step-Rate Injection Method for Fracture In-Situ Properties

magnitude + orientation

3D deformation unit



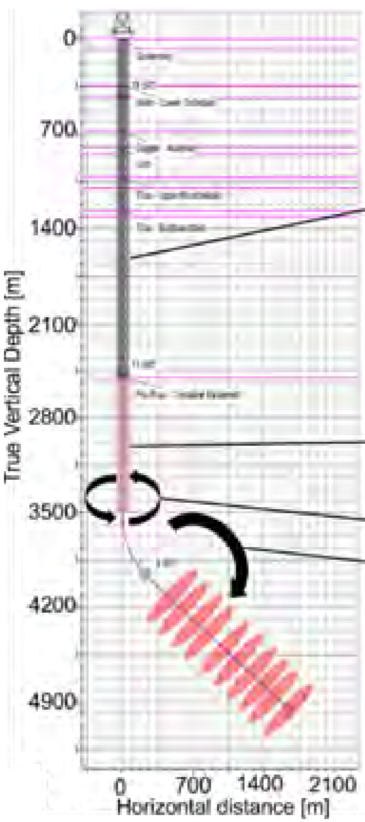
Below/above the Fault Opening Pressure (FOP) the 3D displacements align with minimum/intermediate principal stresses

How does 3D displacement data from fault reactivation experiment improve the estimation of the in-situ stress – Maria Kakurina, UniNE

Deep Geothermal Well Optimization

- ✓ Development of a **workflow** and a set of supporting **software tools** to define the optimal borehole direction for:

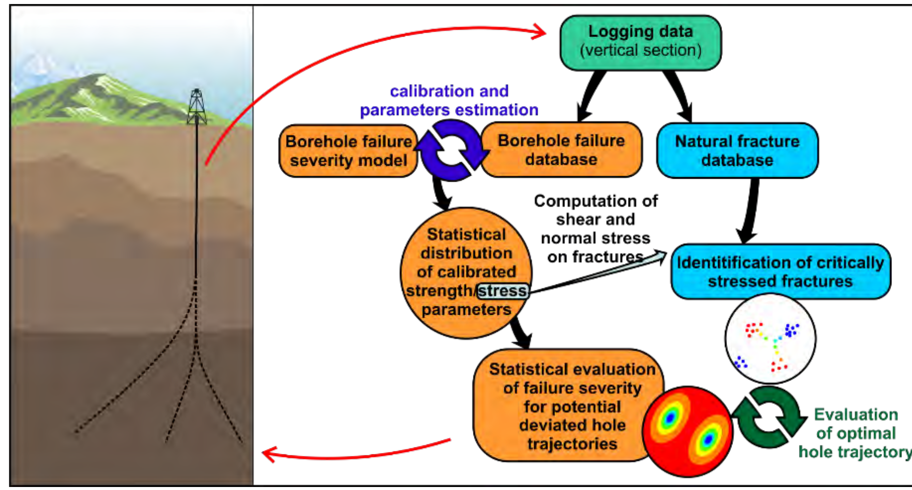
The technical solution developed has been implemented in a complete software solution that streamlines the execution of the workflow.



Cased hole in sedimentary cover

Open hole section within crystalline basement

Decision making workflow for predicting optimal well trajectory (prediction tool)



Observations to be used for models calibration and **parameter estimation**

Supported by **calibrated models** and **uncertainty analyses**

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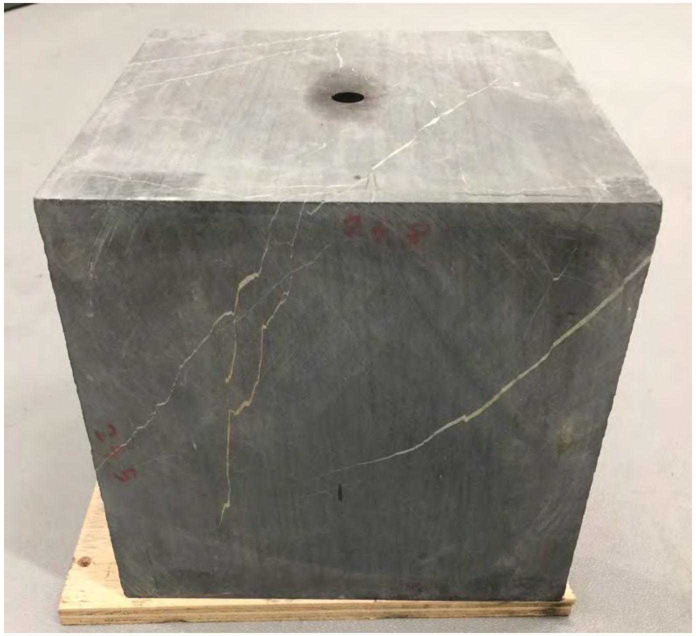
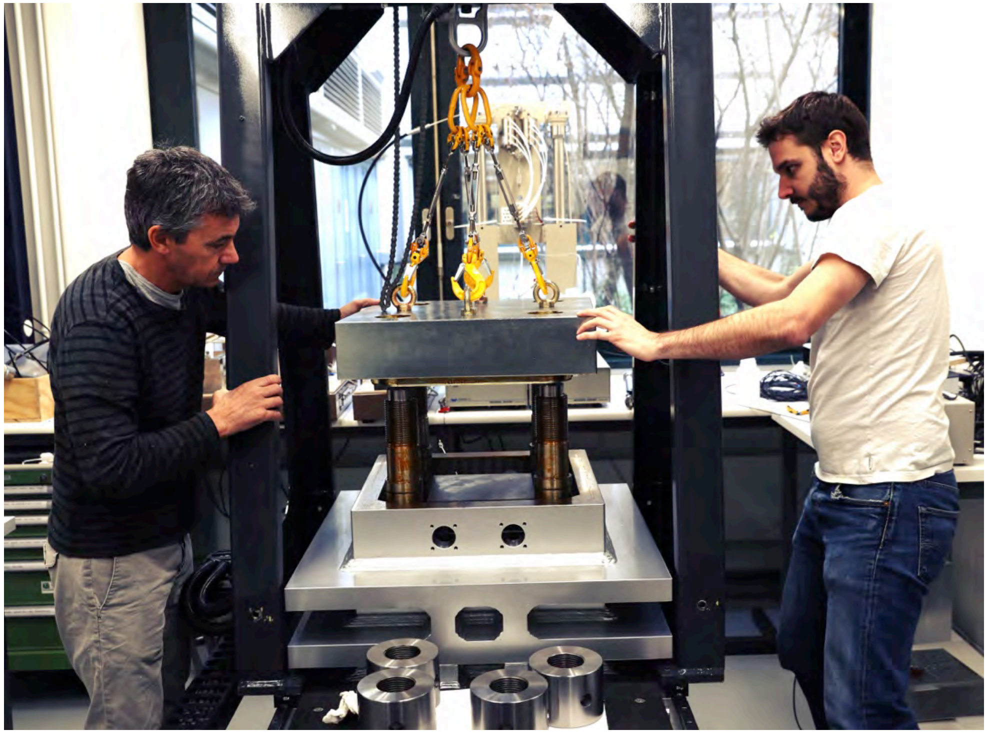
- hydraulic stimulation: theoretical and experimental aspects
- CO_2 sequestration: caprock and seismicity

Hydraulic stimulation: experimental activities

- True triaxial cell with independent confining stresses up to 25 MPa with flat-jacks
- Specimen size: 25 cm cube
- Scaled down fluid injections:
  50 MPa, flow from 0.001 up to 100 mL/min
- Injection durations on the order of tens of minutes

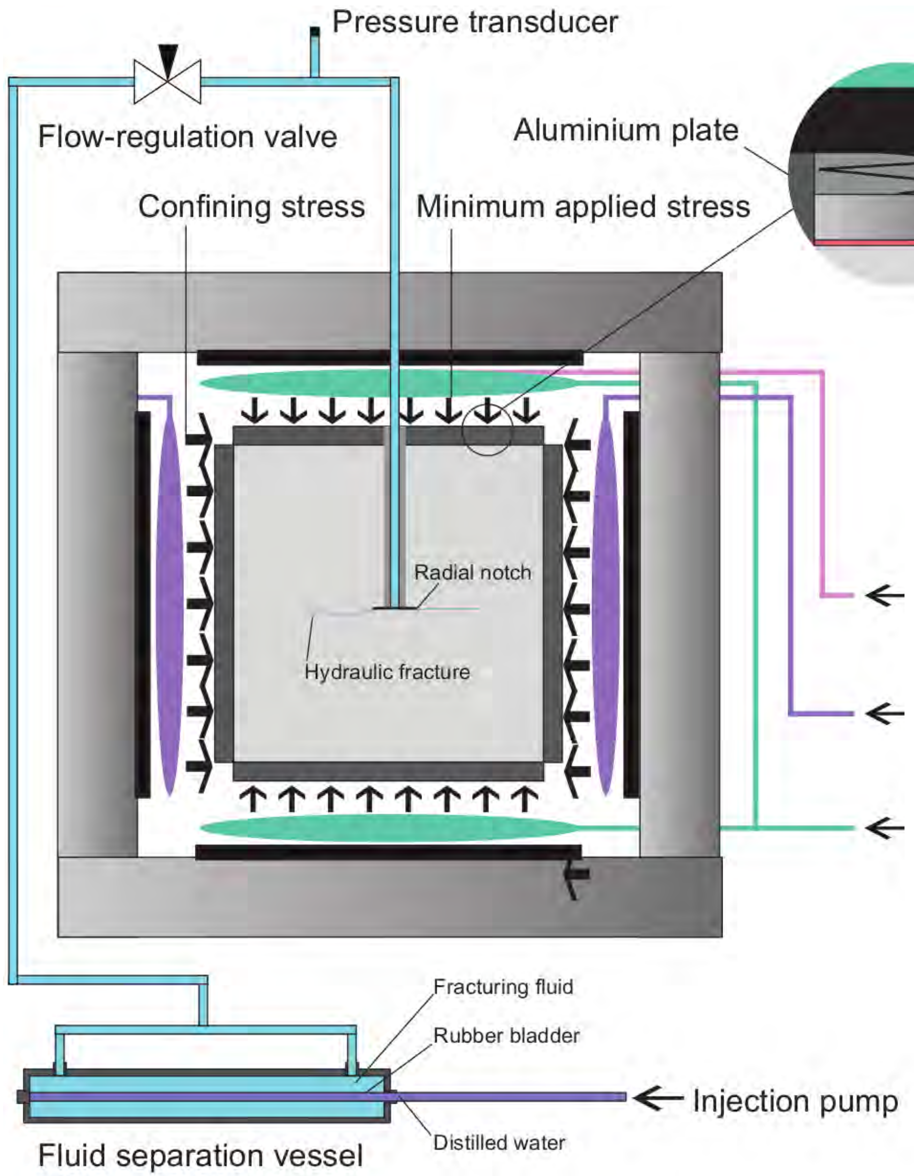
Slate with vertical beddings



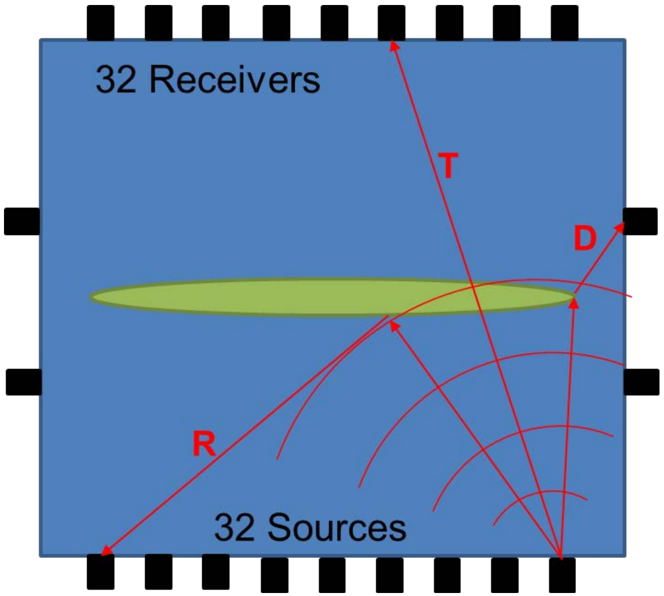


Hydraulic stimulation: experimental activities

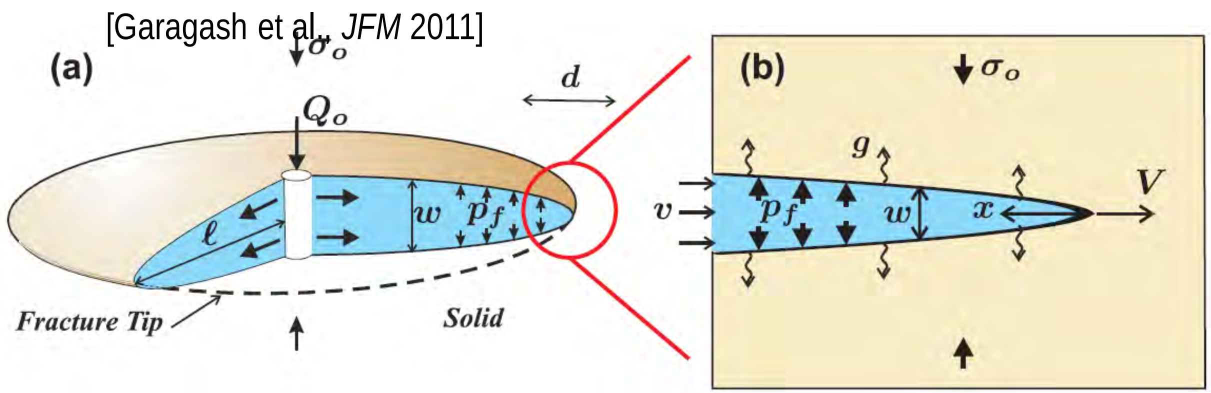
Experimental setup



Acoustic imaging of the fracture growth



Hydraulic stimulation: PyFrac simulator



PyFrac

fully coupled fluid flow/elasticity solver

based on the Implicit level set algorithm for planar 3D hydraulic fractures (Peirce & Detournay, 2008)

- PyFrac is a planar 3D hydraulic fracture simulator which is capable of taking into account
  - the injection and fluid properties such as the viscosity and density of the fluid, and the injection rate
  - the material properties such the fracture toughness, elasticity and the leak-off coefficient
  - the confining stress state

Version 1.0 of the code will be available online in the coming months.

Numerical models for the design of the hydraulic stimulation – Brice Lecampion, EPFL

GeoEnergyLab

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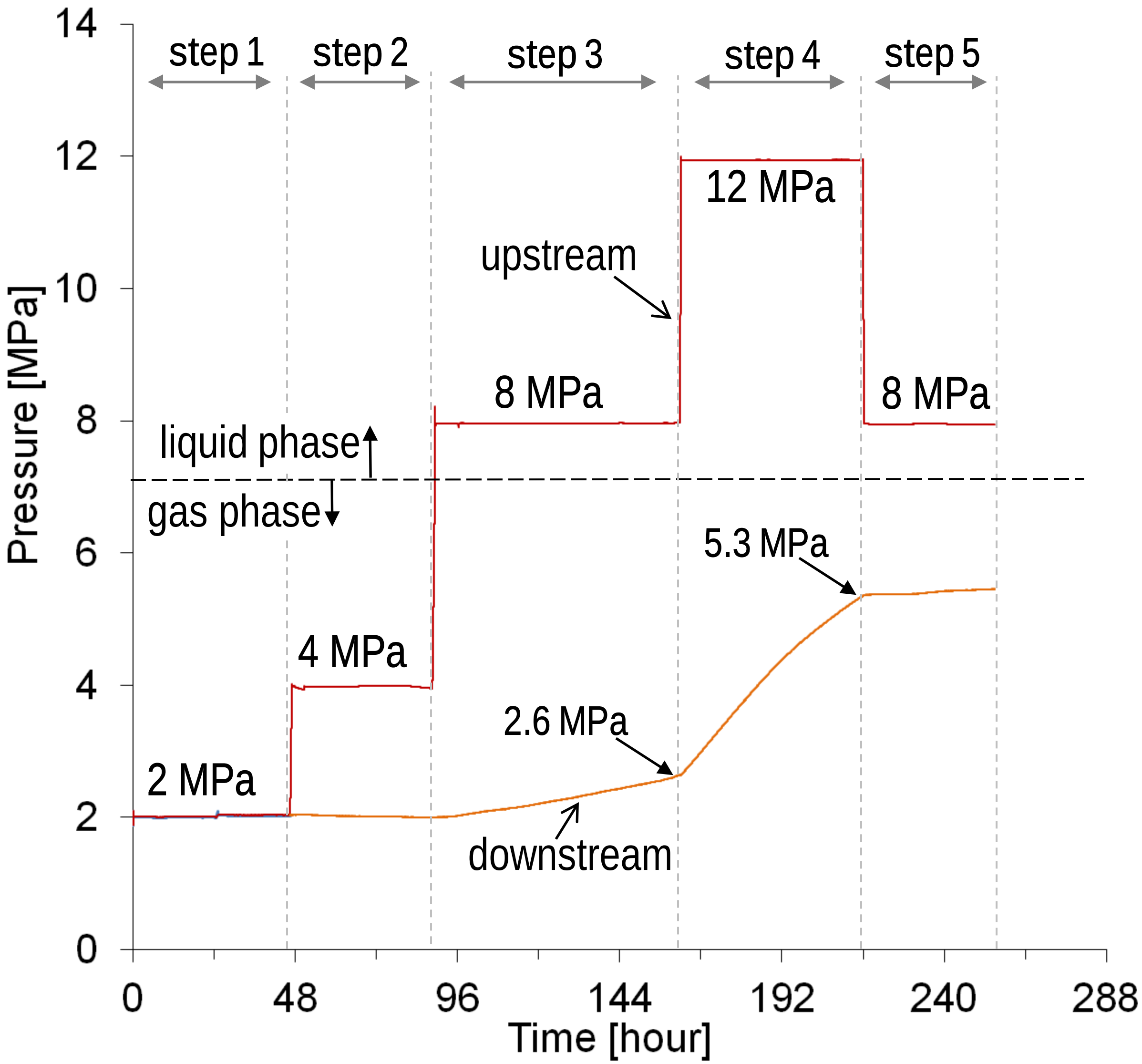
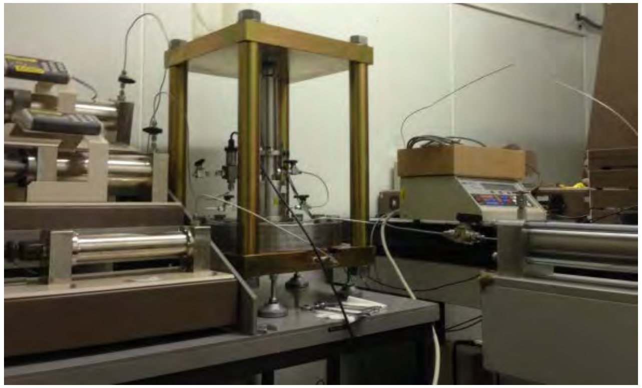
CO_2 sequestration: experimental activities



Experimental assessment of the **sealing capacity** of shaly caprock



CO_2 injection tests
testing protocol to evaluate the capillary entry-pressure from flow and deformation analysis

Mechanical response of Opalinus Clay during CO2 injection
Alberto Minardi, EPFL

LABORATORY FOR SOIL MECHANICS | CHAIR GAZ NATUREL «PETROSVIBRI»
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

CO_2 sequestration: seismicity analysis

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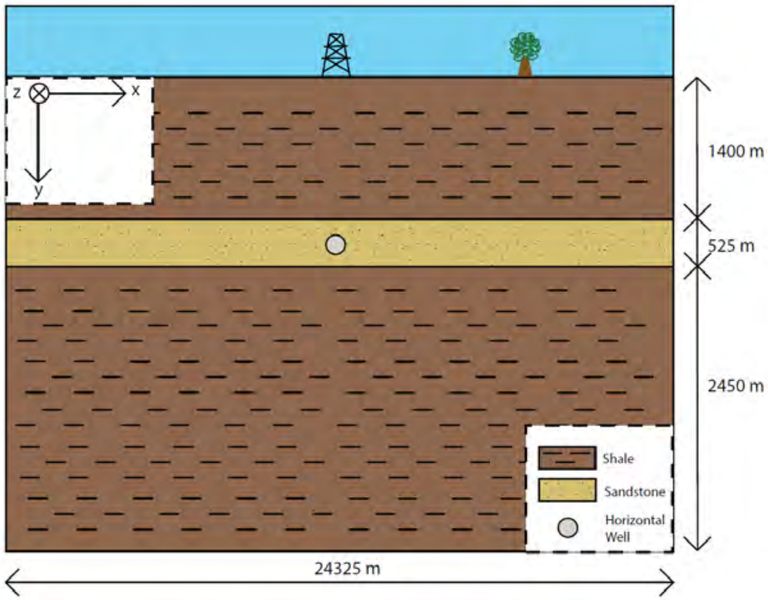
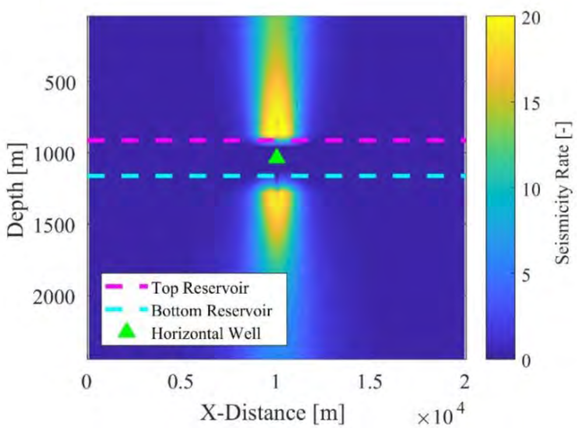


Evaluation of the impact of permeability loss due to compaction on **seismicity** with numerical experiment

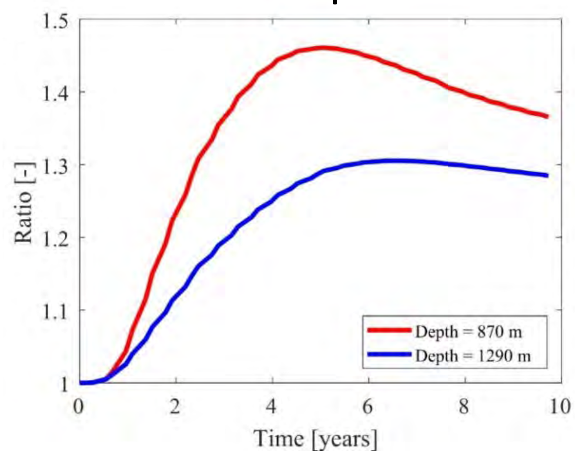
Seismicity model based on Coulomb stress

$$\tau = \tau_s - \mu_f \left(S_n - P \right)$$

Seismicity rate
no compaction



Seismicity rate
with compaction



Compaction

- Causes increased induced stresses
- Indirectly causing an increase in seismicity

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Reservoir stimulation's effect on depletion-induced seismicity
Barnaby Fryer, EPFL

@ EPFL on June 5th

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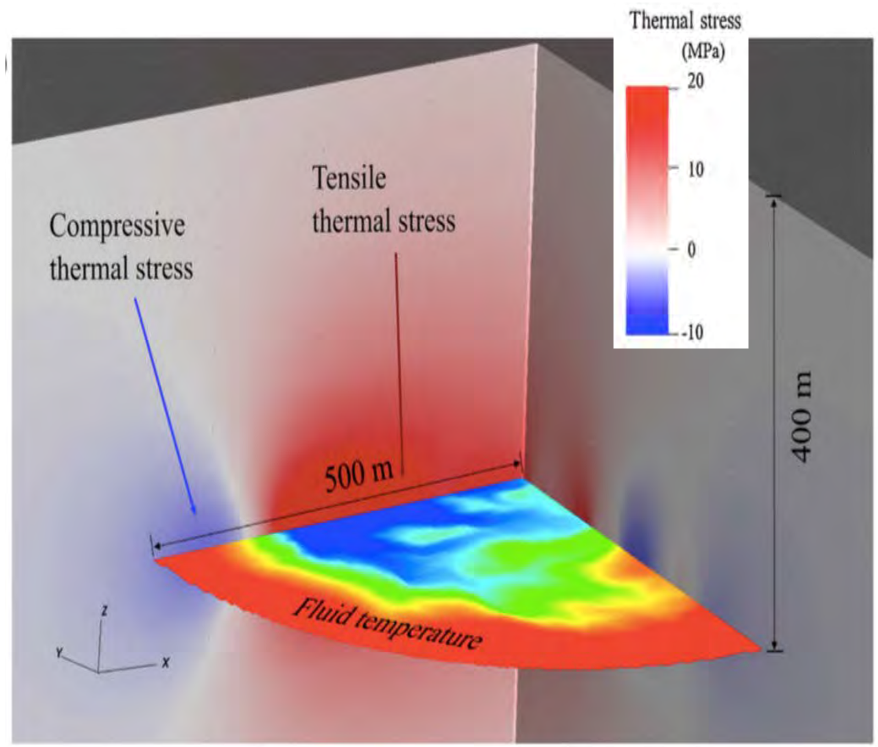
Flow modelling in fracture - THM

ETH zürich
Institute of Geochemistry and Petrology

- Including thermo-mechanics in EGS simulations…
  - reduces fracture normal stress
  - increases flow channeling
  - decreases production temperature

- Seldom mentioned:
  - increases normal stress in some places

- Questions:
  - what implications does it have?
  - how significant is it?

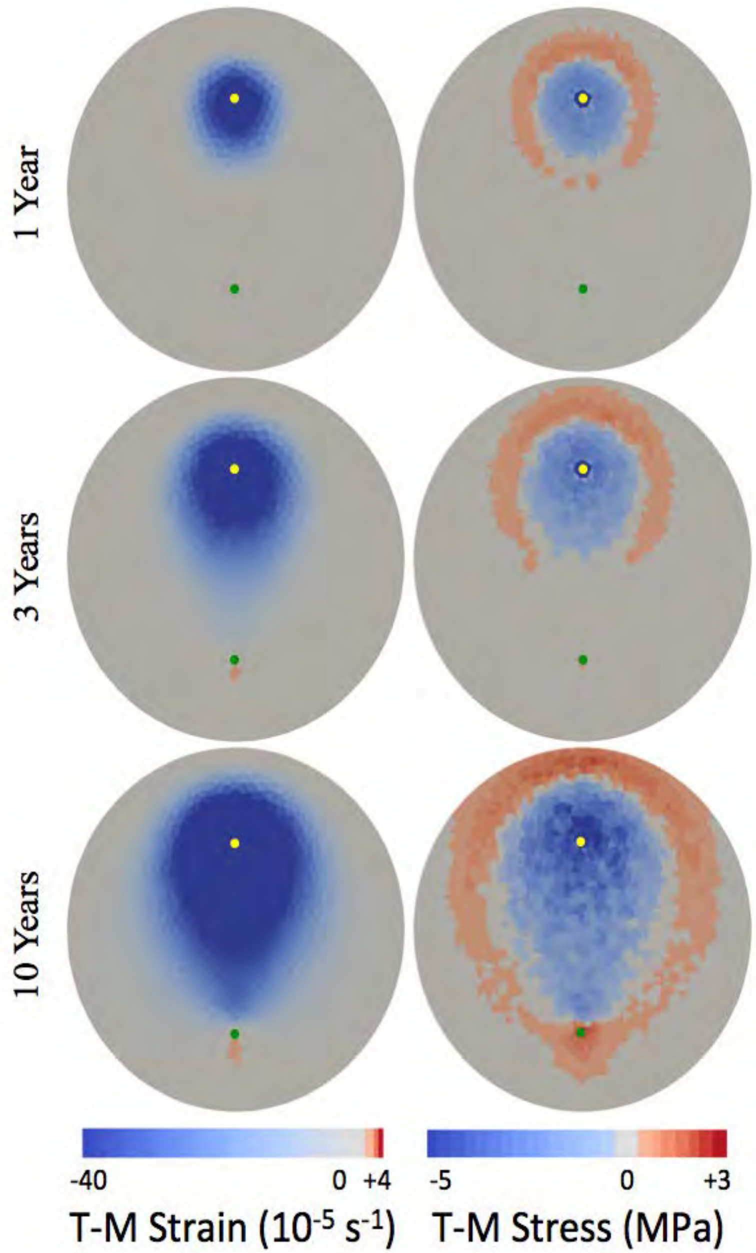


B. Guo, P. Fu, Y. Hao, C.A. Peters, C.R. Carrigan Thermal drawdown-induced flow channeling in a single fracture in EGS Geothermics, 61 (2016), pp. 46-62

Flow paths modelling in fractures – THM simulation

➢ Simulations support the presence of compression

- CSMP++ to model single fracture, 500 m radius, buried 3.5 km
  - Stress -> aperture (Barton-Bandis model)
  - Aperture -> permeability ("Cubic law")
- Forces must balance, is redistributed
  - Stress increases near large temperature gradients
- Strain is contractive, yet stress increases in some places
  - "stress-ring"



Flow paths modelling in fractures – THM simulation

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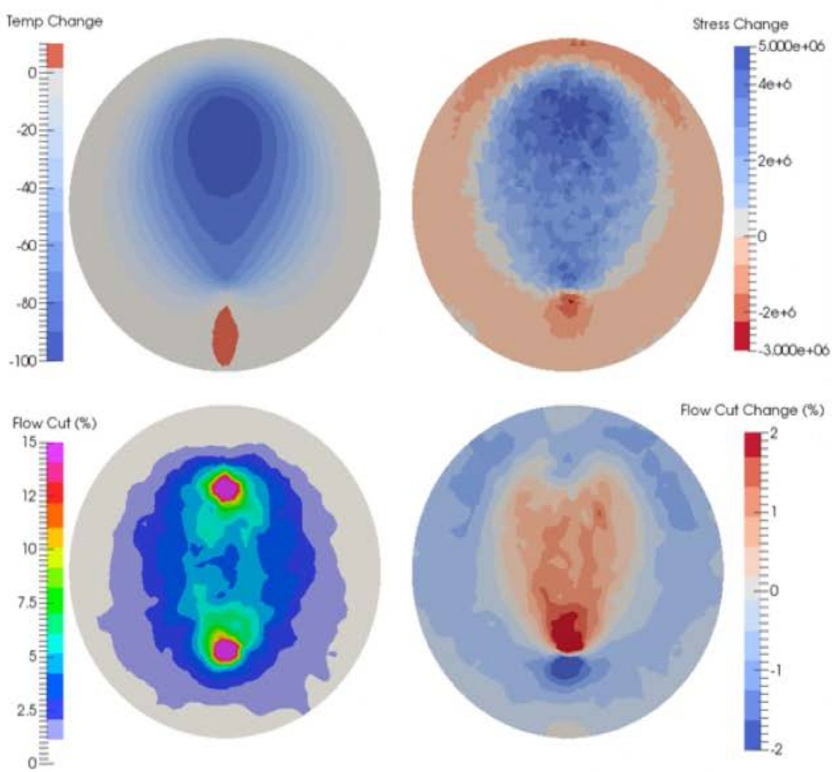
Institute of Geochemistry and Petrology

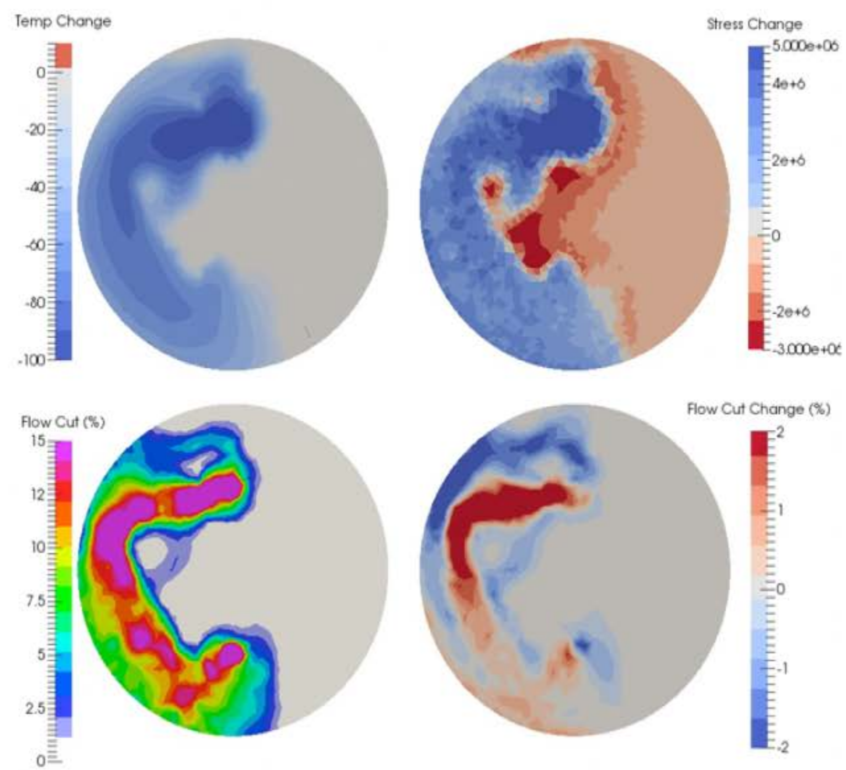
Fracture permeability heterogeneity

- ➢ impact on temperature, stress, and flow evolution

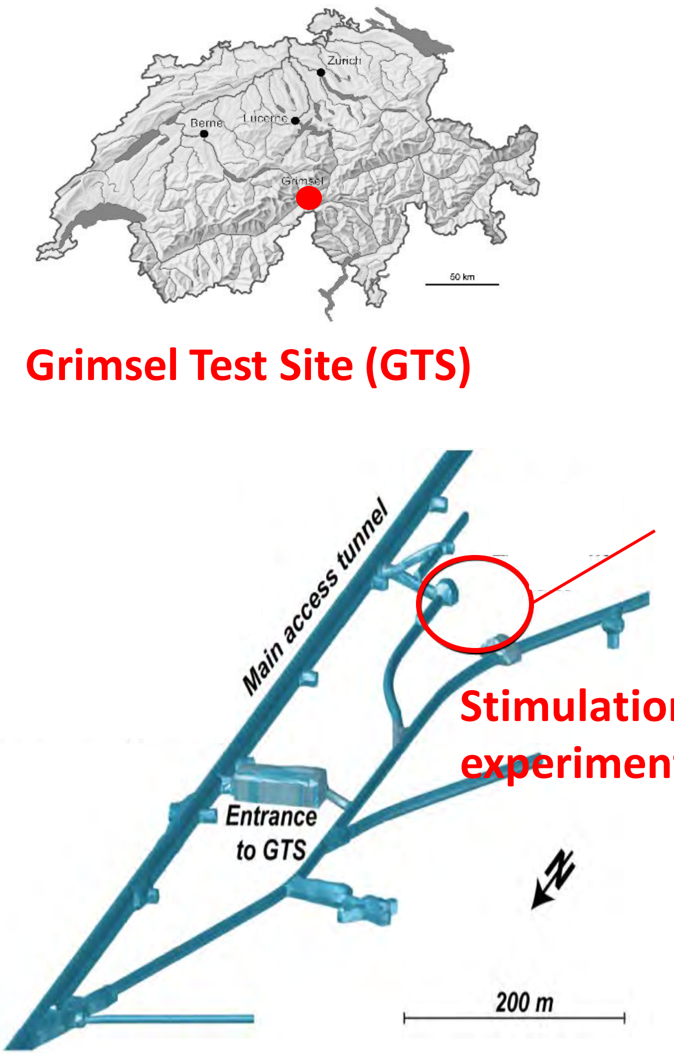
Homogeneous



Heterogeneous

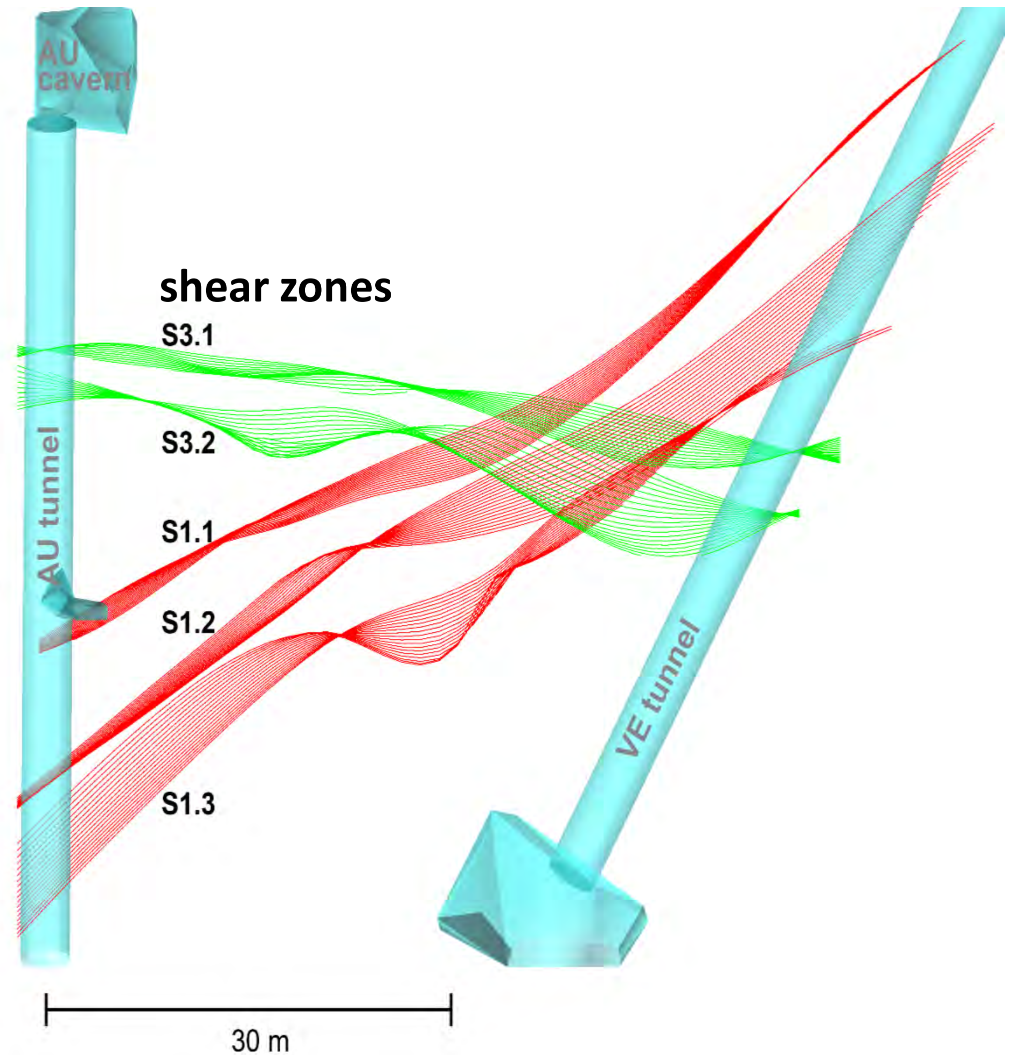


ISC Grimsel test – Experimental site



Grimsel Test Site (GTS)

Stimulation experiments



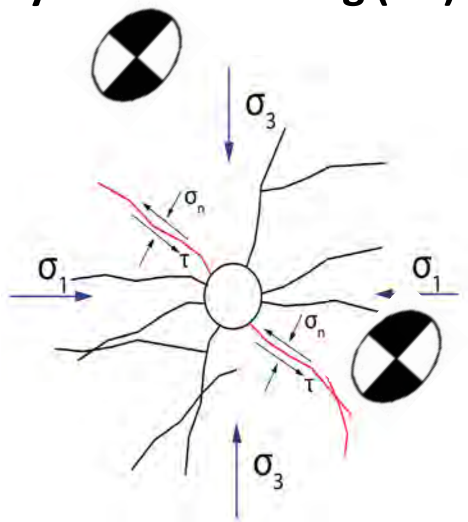
Grimsel In-situ stimulation project: what can we learn from scaled experiments – Joseph Doetsch, ETHZ

ISC Grimsel test – Experimental site

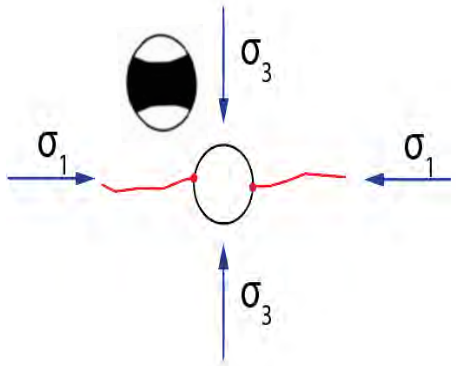
- In preparation for Enhanced Geothermal Systems (EGS)
  - **Hydraulic stimulation in intact, and fractured crystalline rock**

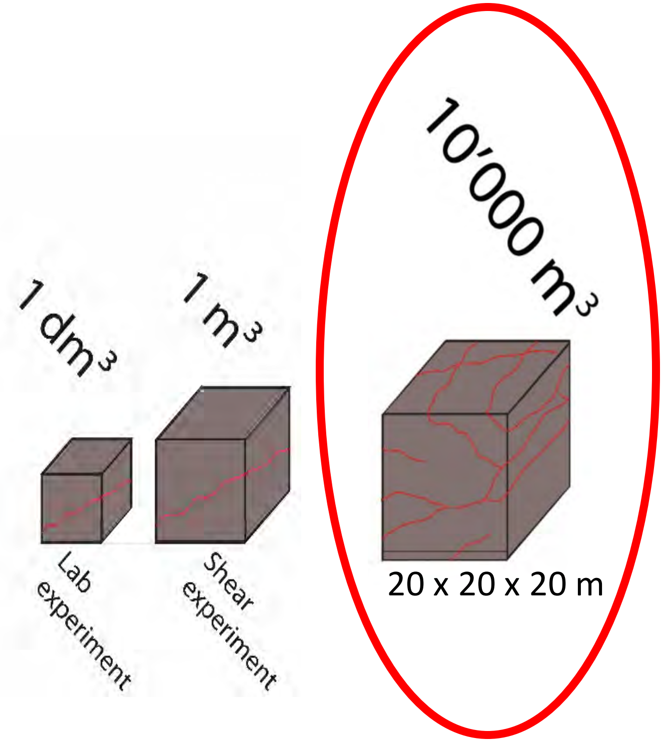
In-Situ Stimulation and Circulation (ISC) experiment

Hydraulic shearing (HS)



Hydraulic fracturing (HF)





- Goal: Understanding the seismo-hydro-mechanical response during hydraulic stimulations

- 6 **HS experiments** targeting natural geological discontinuities
- 6 **HF experiments** performed in intact rock

Complex interplay between hydraulic shearing and hydraulic fracturing observed during in-situ stimulations – Hannes Krietsch, ETHZ

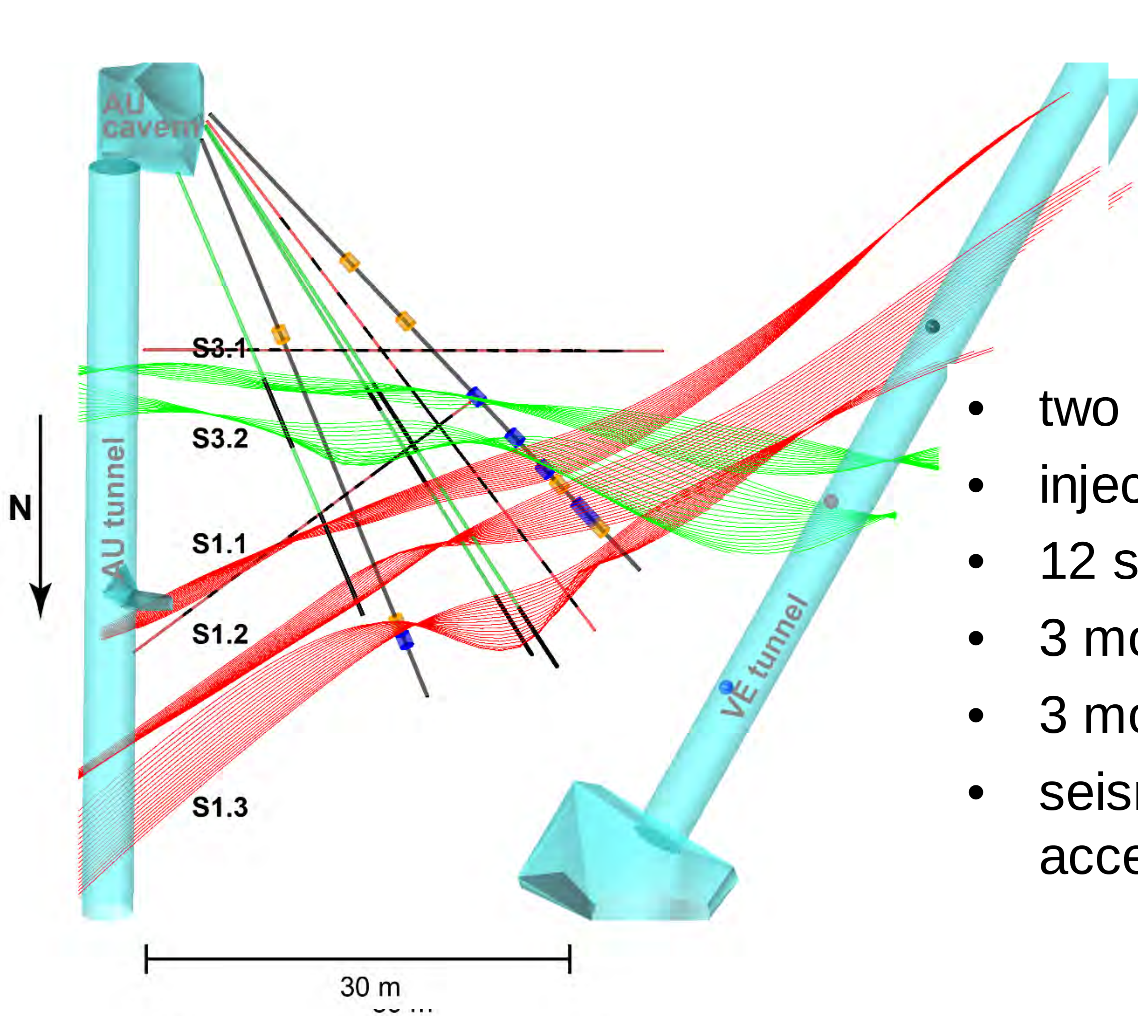
Hydraulic fracturing (HF) experiments

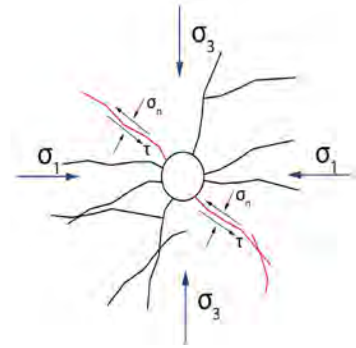
Experiment	Well	Depth [m]	Initial Transmissivity [m²/s]	Initial Injectivity [l/min/MPa]	Final Injectivity [l/min/MPa]	Total injected volume [l]	Recovery of injection interval [%]	Total number of seismic events	Located seismic events
HF1	INJ1	40.0-41.0	3.1E-13	**7.0E-6**	**1.22**	1565	24.8	N / A	N / A
HF2	INJ1	35.8-36.8	3.1E-13	**7.0E-6**	**3.69**	964	28.7	2204	154
HF6	INJ2	38.4-39.4	-	**-**	**2.77**	1222	58.4	94	27
HF3	INJ1	19.8-20.8	3.8E-13	**8.6E-6**	**0.88**	911	2.0	1997	35
HF5	INJ1	14.0-15.0	1.4E-13	**3.2E-6**	**0.16**	1553	0.3	1969	8
HF8	INJ2	15.2-16.2	3.1E-13	**7.0E-6**	**0.35**	1142	1.8	722	143

Increase of injectivity by six order of magnitude

Fracture growth and comparison to analytical solution for an in-situ hydraulic fracturing experiment– Nathan Dutler, UniNE

Hydraulic shearing (HS) experiments





- two injections boreholes
- injection intervals → blue cylinders
- 12 stimulation experiments
- 3 monitoring boreholes for strains
- 3 monitoring boreholes for pressure
- seismic monitoring (AE receivers + accelerometers)

Increase of **transmissivity** for experiments performed in the more ductile shear zone

Task 1.4: Geo-data infrastructure and analysis

SCCER SoE

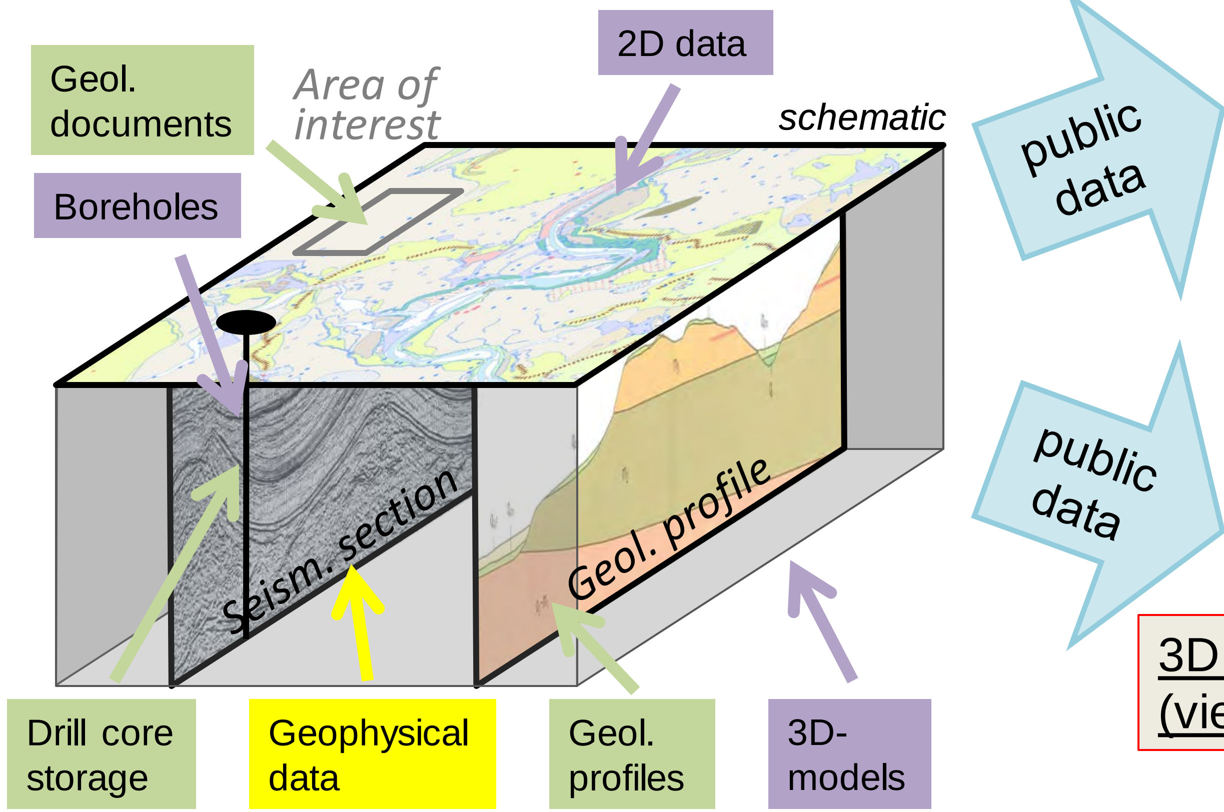
Program Workshop “Data Management in Science”, Bern, May 22nd

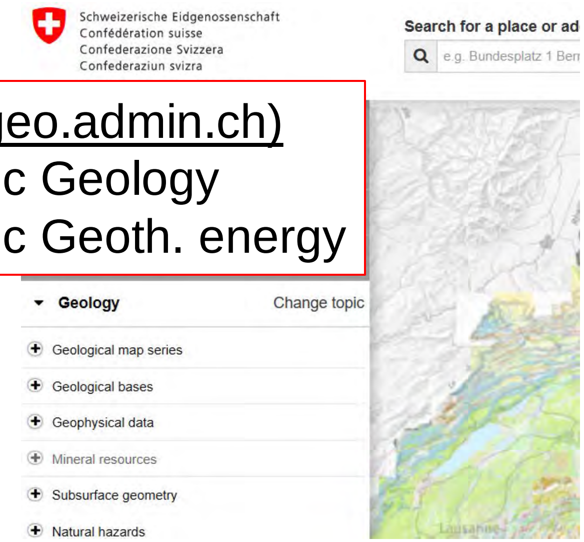
Morning session:

Time	Title of talk	Speaker
9:00	Registration	
9:30-9:40	Welcome	SCCER-SoE: G. Guidati
9:40-9:55	SNSF Open Research Data Policy	SNF: C. Sommer
9:55-10:05	No data – no clue	BFE: N. Lupi
10:05-10:30	The legal framework for managing geological data	kettiger.ch: D. Kettiger
10:30-10:40	Data Management Plan (DMP)	ETH Library: A. Sesartic
10:40-10:50	Active Research Data Management	ID Scientific IT Services (ETH): Henry Luetcke
Questions and coffee break (10:50-11:20)		
11:20-11:30	Research data file formats for long-term preservation	ETH Library: R. Suri
11:30-11:40	Long-term availability of geodata and archiving of geodata in the public administration	swisstopo: M. Schlatter
11:40-11:50	Publishing data in ETH Zurich’s Research Collection	ETH-Library: B. Hirschmann
11:50-12:00	Management of geological data at the Swiss Geological Survey – an example	swisstopo: N. Oesterling
12:00-12:10	Energy scenarios for CH 2050 – sharing and preserving knowledge	SCCER-SoE: G. Guidati

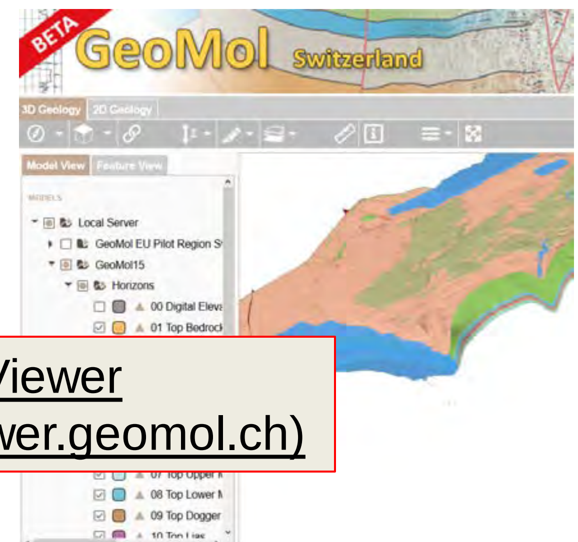
Development of new data management systems at swisstopo (programme GIPS):

IT-system **established** | IT-system **under construction** | IT-system **planned**





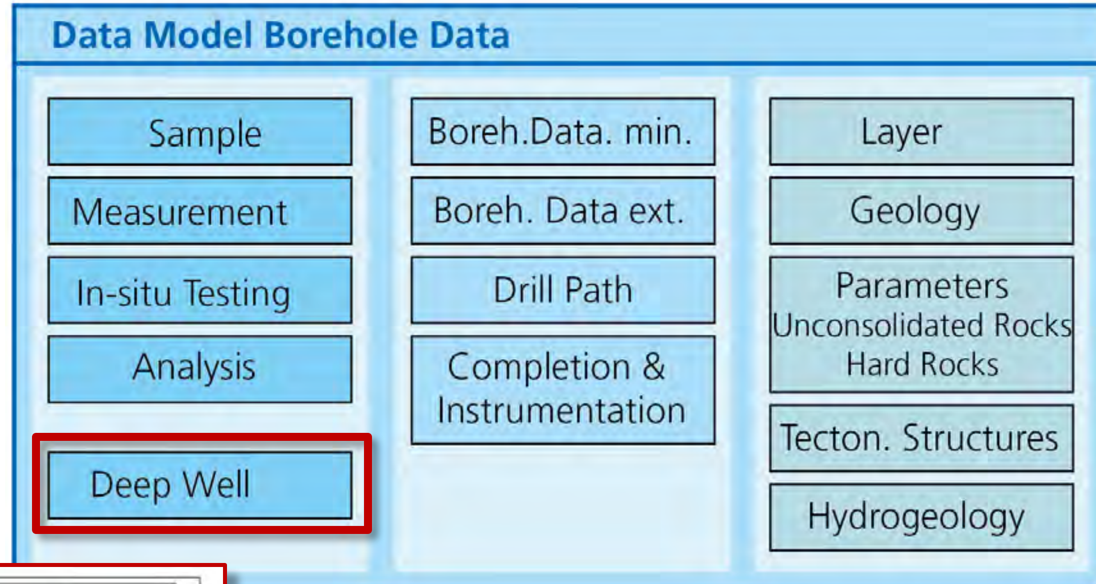
(map.geo.admin.ch)
- Topic Geology
- Topic Geoth. energy



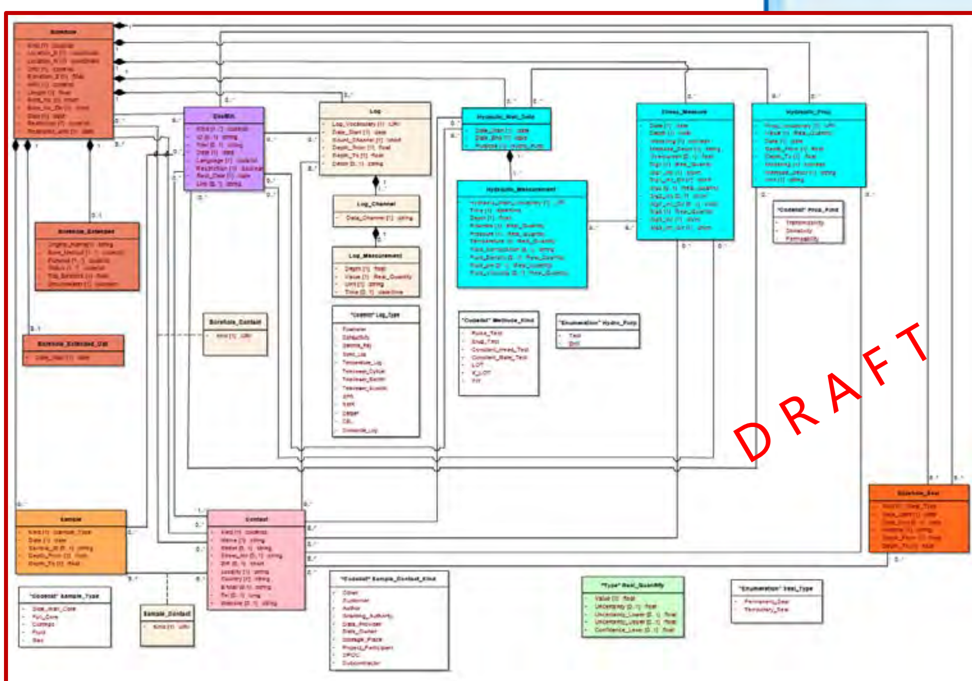
3D Viewer (viewer.geomol.ch)

Task 1.4: Model Borehole Data – Deep Well

Geothermal data is described in the module «Deep Well» of the «Data Model Borehole Data».



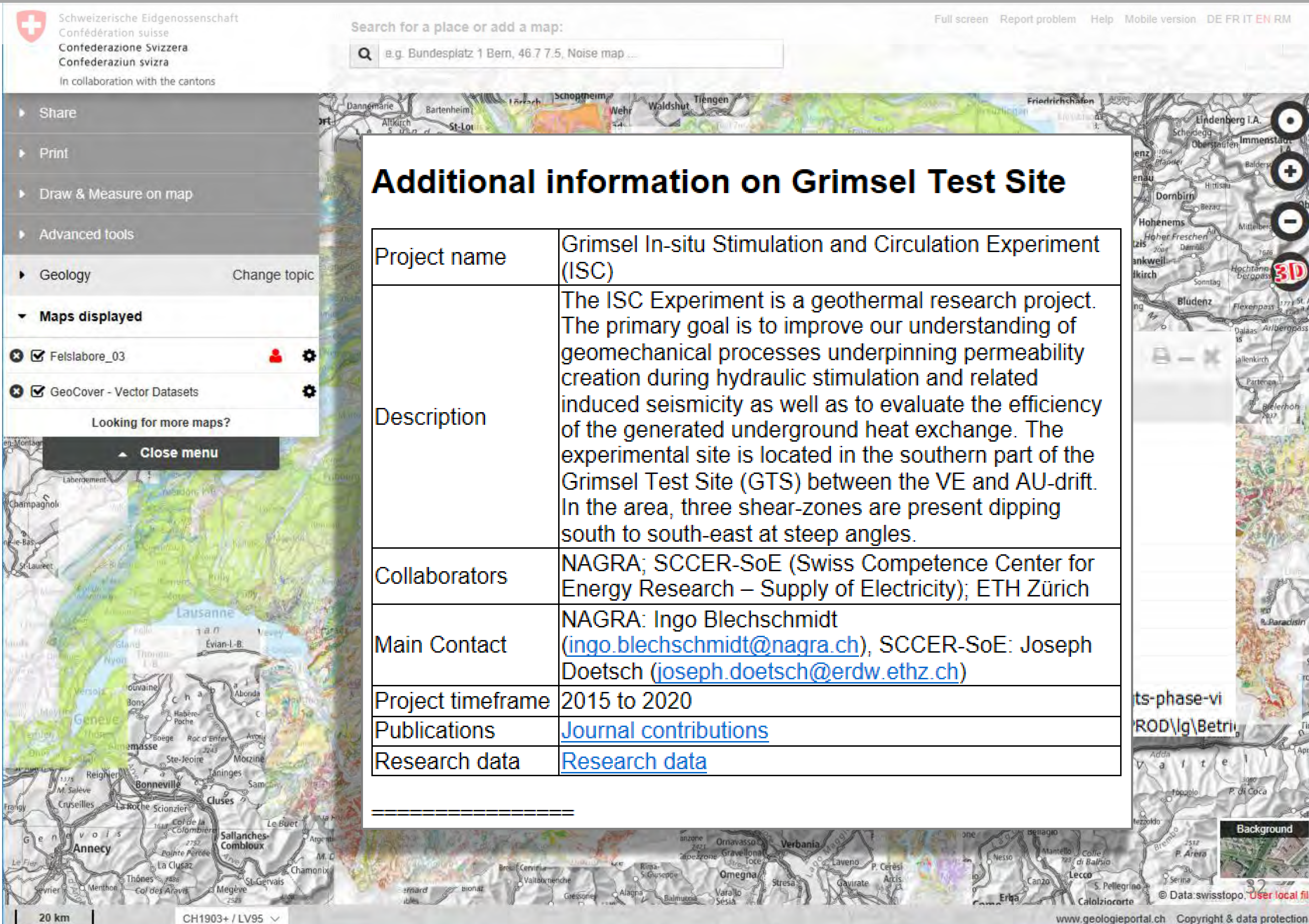
To be reviewed!



Themes:

- Processing of deep borehole (incl. class sampling)
- Logging (incl. class measurement)
- Injection and production
- Sealing of borehole

Task 1.4: SCCER-SoE Experiments @ Swiss Geoportal



Additional information on Grimsel Test Site

Project name	Grimsel In-situ Stimulation and Circulation Experiment (ISC)
Description	The ISC Experiment is a geothermal research project. The primary goal is to improve our understanding of geomechanical processes underpinning permeability creation during hydraulic stimulation and related induced seismicity as well as to evaluate the efficiency of the generated underground heat exchange. The experimental site is located in the southern part of the Grimsel Test Site (GTS) between the VE and AU-drift. In the area, three shear-zones are present dipping south to south-east at steep angles.
Collaborators	NAGRA; SCCER-SoE (Swiss Competence Center for Energy Research – Supply of Electricity); ETH Zürich
Main Contact	NAGRA: Ingo Blechschmidt (ingo.blechschmidt@nagra.ch), SCCER-SoE: Joseph Doetsch (joseph.doetsch@erdw.ethz.ch)
Project timeframe	2015 to 2020
Publications	Journal contributions
Research data	Research data

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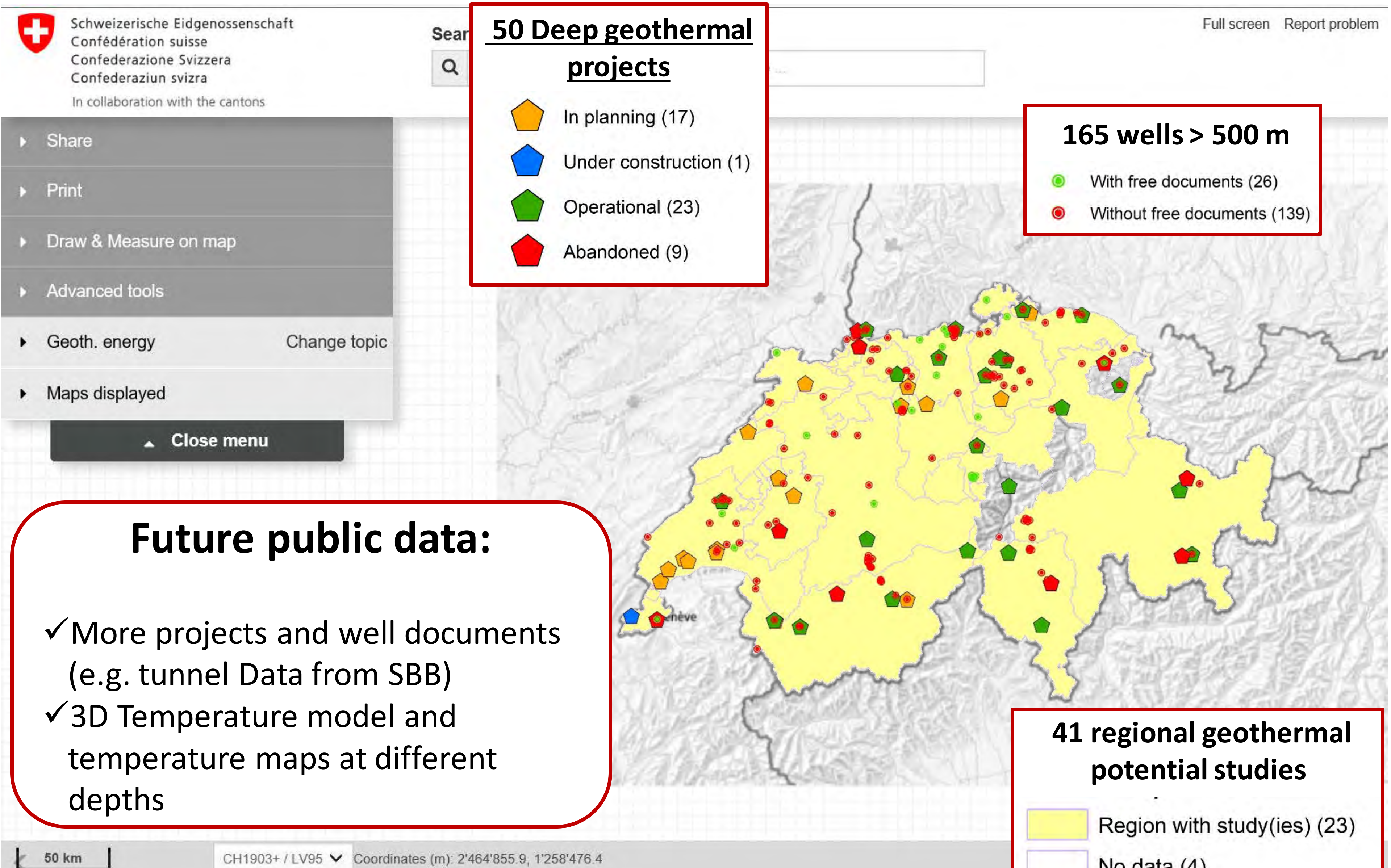
Task 1.4: GeoTherm Data @ Swiss Geoportal



50 Deep geothermal projects

- In planning (17)
- Under construction (1)
- Operational (23)
- Abandoned (9)

165 wells > 500 m

- With free documents (26)
- Without free documents (139)

41 regional geothermal potential studies

- Region with study(ies) (23)
- No data (4)

Future public data:

✓ More projects and well documents (e.g. tunnel Data from SBB)

✓ 3D Temperature model and temperature maps at different depths

Summary

- significant scientific and technological advances in the capability to model stimulation process and reservoir operations

- outcomes of the in-situ experiments (e.g. ISC) support the validity of the developed knowledge

- importance of the perfromed advances for the new in-situ projects (ELEGANCY, Bedretto)

- enabling the success of demonstration projects

Personal comments

In view of a significant contribution to the Swiss Energy Transition 2050, we need:

- **More Coordinated research activities**
- **Involvement of industry and interest in using the developed research results**
- **Specific goals on the technical maturation process. What types of tools and solutions will be developed in the course of the project?**
- **Clarification on how all fundamental research in the project could have a path to the application? How do we intend to increase the TRL for various topics? What would be the short and mid term benefit for the industry?**

SCCER SoE

SWISS COMPETENCE CENTER for ENERGY RESEARCH
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Geo-energies WP1
Poster Pitch Presentation

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ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Massachusetts Institute of Technology

Investigation on Hydraulic Fracturing of Granite

MASTER THESIS BY ARABELLE DE SAUSSURE

EPFL SUPERVISOR: PROF. L. LALOUI

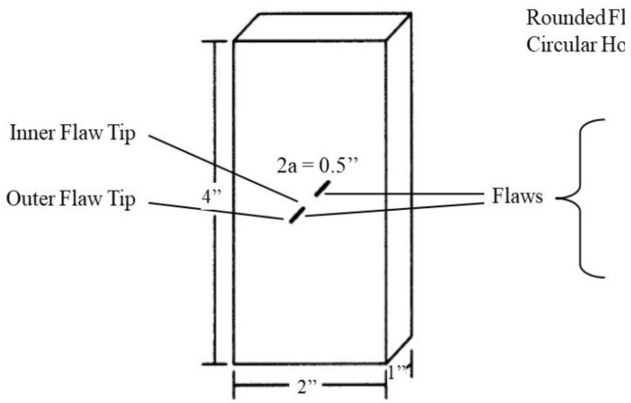
MIT SUPERVISOR: PROF. H. H. EINSTEIN

Motivation and Goals

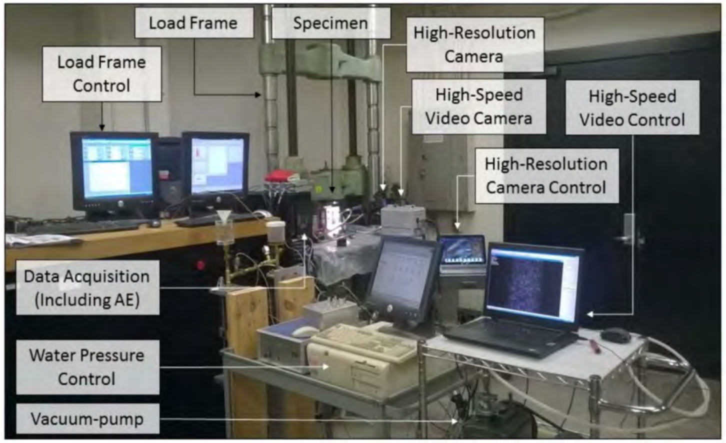
Hydraulic fracturing to increase rock permeability for Enhanced Geothermal Systems (EGS) in a naturally fractured environment

Objectives:

- Understand the interaction between hydraulic fractures and pre-existing non-pressurized fractures
- Observe the crack development with a high-speed camera
- Hydrofracturing and hydroshearing experiments
- Effect of geometries, pressurization devices and external loading conditions



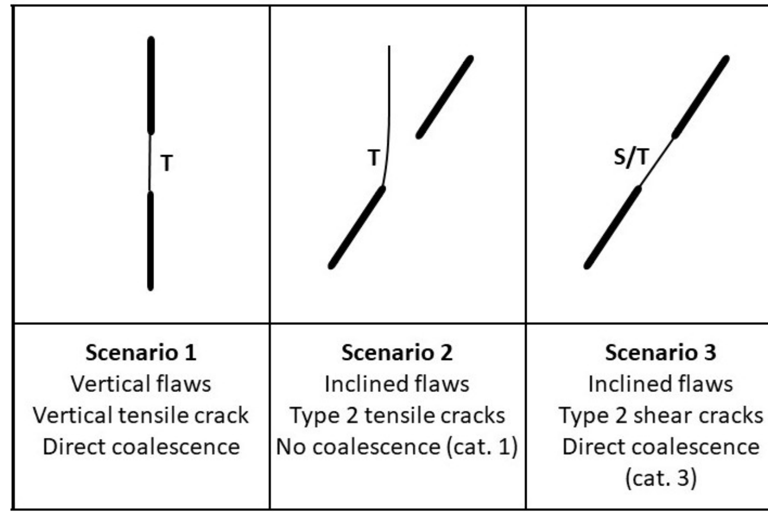
Pre-cut rock specimen



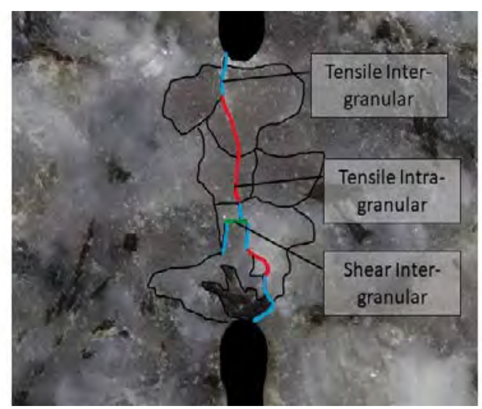
Experimental setup

Results and observations

- Different crack scenarios depending on the flaw pair geometry, the loading conditions and the hydraulic pressure
- Identification of a testing procedure leading to hydroshearing: en echelon crack patterns and dilatancy
- Observation of visible tensile and shear cracks, microcracks ("white patching") and interaction of the cracks with the grains structure in Barre Granite



Crack scenarios

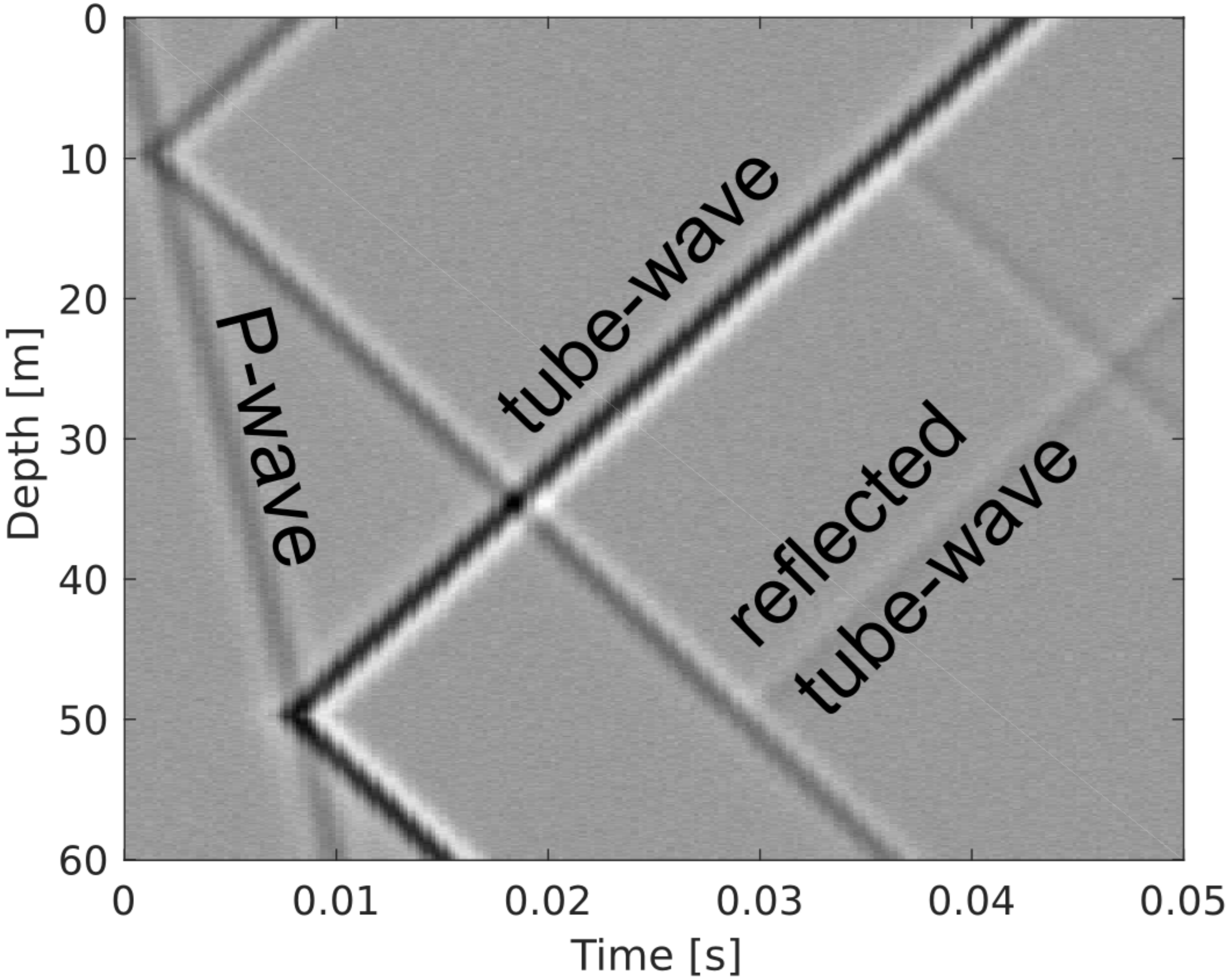


Crack types

Microcracks

Estimating fracture apertures and related parameters using tube-wave data

Jürg Hunziker, Andrew Greenwood, Shohei Minato, Eva Caspari and Klaus Holliger



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Bayesian inversion results