DESTRESS

Demonstration of soft stimulation treatments of geothermal reservoirs

Deliverable D5.4: Report on ways and methods to lower the technical, geological and financial risks currently associated to EGS

WP 5: Demonstration of cyclic hydraulic and multi stage treatments in granites and tight sandstones

Lead Beneficiary	GES
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Liability claim

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Abstract

The present report presents the preliminary results of a test reservoir stimulation carried out in the Bedretto Lab between January 15th and February 5th 2020. This work is done in the framework of DESTRESS, a European Union Horizon 2020 research and innovation project that aims to demonstrate soft stimulation treatments for geothermal reservoirs.

The Bedretto lab is an underground facility developed and managed by ETH Zurich to "study techniques and procedures for a safe, efficient and sustainable use of geothermal heat".

Results from the test stimulation will serve as a basis for the conception of the multi-stage stimulation programmed for Q3 2020 (Task 5.3). The completion of a test before the multi-stage stimulation allows us to answer a series of technical questions that will considerably reduce the associated risks and increase the probability of success of the main stimulation phase. The mentioned questions concern the model behind the shear stimulation of granitic reservoirs, the control of the induced seismicity and the borehole design.

The test stimulation consists of a series of injections into different intervals isolated from the rest of the well by a dual-packer system. All injections are run individually (no multi-packer system) so the results are free of any interference effect. All injections are carried out in the same well (CB1) in the last 50m MD (250-300m MD). Seismic monitoring devices were installed in two adjacent wells (CB2 and CB3) as well as in CB1 at a shallower depth with respect to the stimulation intervals.

Preliminary analyses of the results show that the test stimulation achieved the desired results. Transmissibility around the CB1 well was increased considerably (x7-x60). This interpretation seems to be supported by hydraulic data as well as borehole ground penetrating radar, image logs and the detection of microsesimicity. This increase in transmissibility was achieved while keeping the seismicity levels to a minimum.

Preliminary results also show the significance of adapting the stimulation protocol to the specific characteristics of different intervals. In this case, intervals with predominant tight structures could be stimulated only after applying controlled mini-frac tests. This controlled mini-fracs nucleated newly formed axial fractures along the borehole wall that facilitated the subsequent stimulation of the natural fracture network. This contrasted with the behaviour of intervals containing naturally open structures where stimulation was more readily achieved.

Context and Objectives

The main objective of DESTRESS is to test and demonstrate reservoir stimulation methods that create enough permeability to efficiently extract underground heat while limiting the induced seismicity often associated to stimulation operations.

Work package 5 includes a series of tasks that aim to test the concepts of cyclic and multi-stage stimulations in different lithologies (granites, tight sandstones and basalts). The site of Haute-Sorne (Canton of Jura, Switzerland) was originally proposed to demonstrate the feasibility of segmenting the stimulated section and selectively inject in different intervals. The difficulties to develop Haute-Sorne in the time framework of DESTRESS triggered the need to find an alternative site. In this context, the recently furbished Bedretto underground lab presented ideal characteristics and was chosen as a fall-back option.

The present report describes the preliminary results of a test stimulation carried out in the Bedretto lab. This stimulation test was carried out previous to the main stimulation phase that will take place in during Q3 2020. This deliverable has been prepared in the framework of Task 5.4 ("Ways and methods to lower the technical, geological and financial risks currently associated to EGS"). In this context, the test stimulation carried out in Bedretto will contribute considerably in the design, planning and implementation of the multi-stage stimulation with the ultimate goal of reducing the environmental and financial risks associated to EGS projects.

Preliminary conclusions and Perspectives

Preliminary analyses seem to indicate an increase of transmissibility values around the stimulated borehole. This increase in transmissibility was achieved while keeping induced seismicity to a minimum in terms of number of events and magnitudes.

Further analyses are planned on this dataset in order to consolidate the observations, draw definitive conclusions and formulate the lessons learned to be applied to the planning and execution of multi-stage stimulation.

DESTRESS

Demonstration of soft stimulation treatments of geothermal reservoirs

Reservoir stimulation tests in the Bedretto Lab (January 15th - February 5th 2020)

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With contributions from X. Ma, H. Krietsch, A. Shakas and M. Hertrich (ETH, SCCER-SoE)

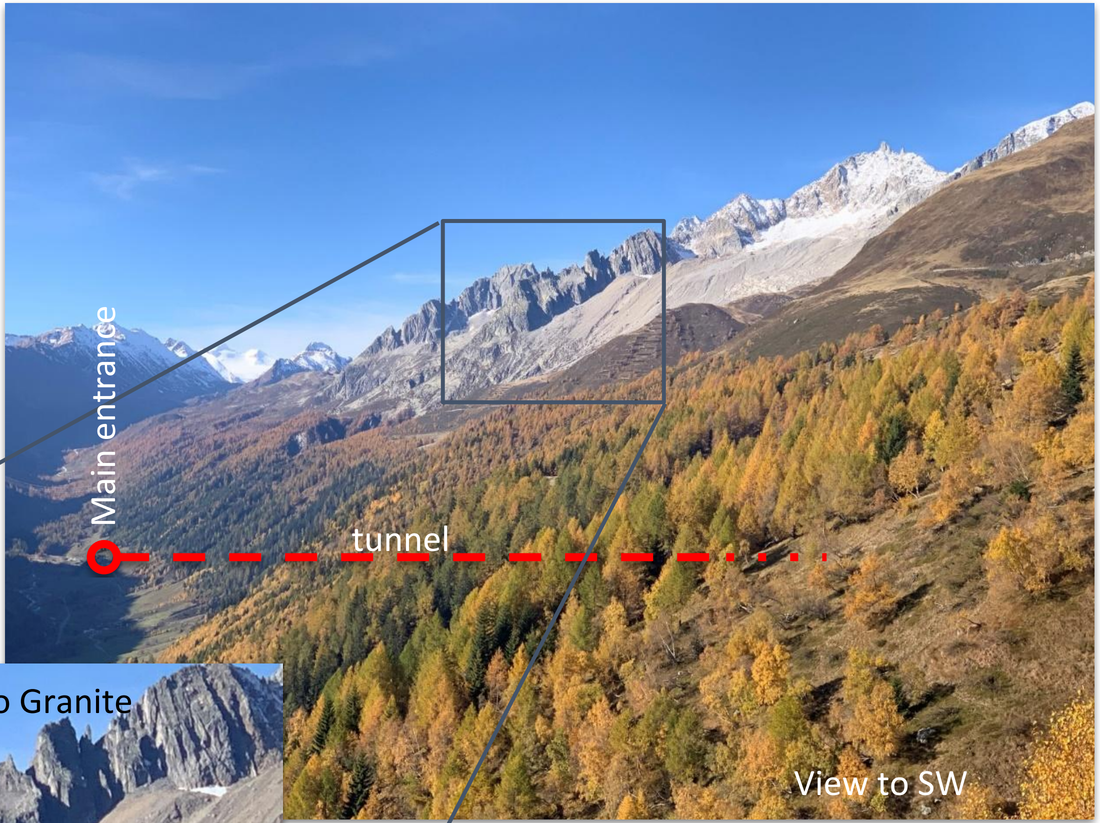
Pizzo Rotondo (https://commons.wikimedia.org/wiki/File:Pizzo_Rotondo_(Canton_Ticino).jpg)

Overview Bedretto Lab

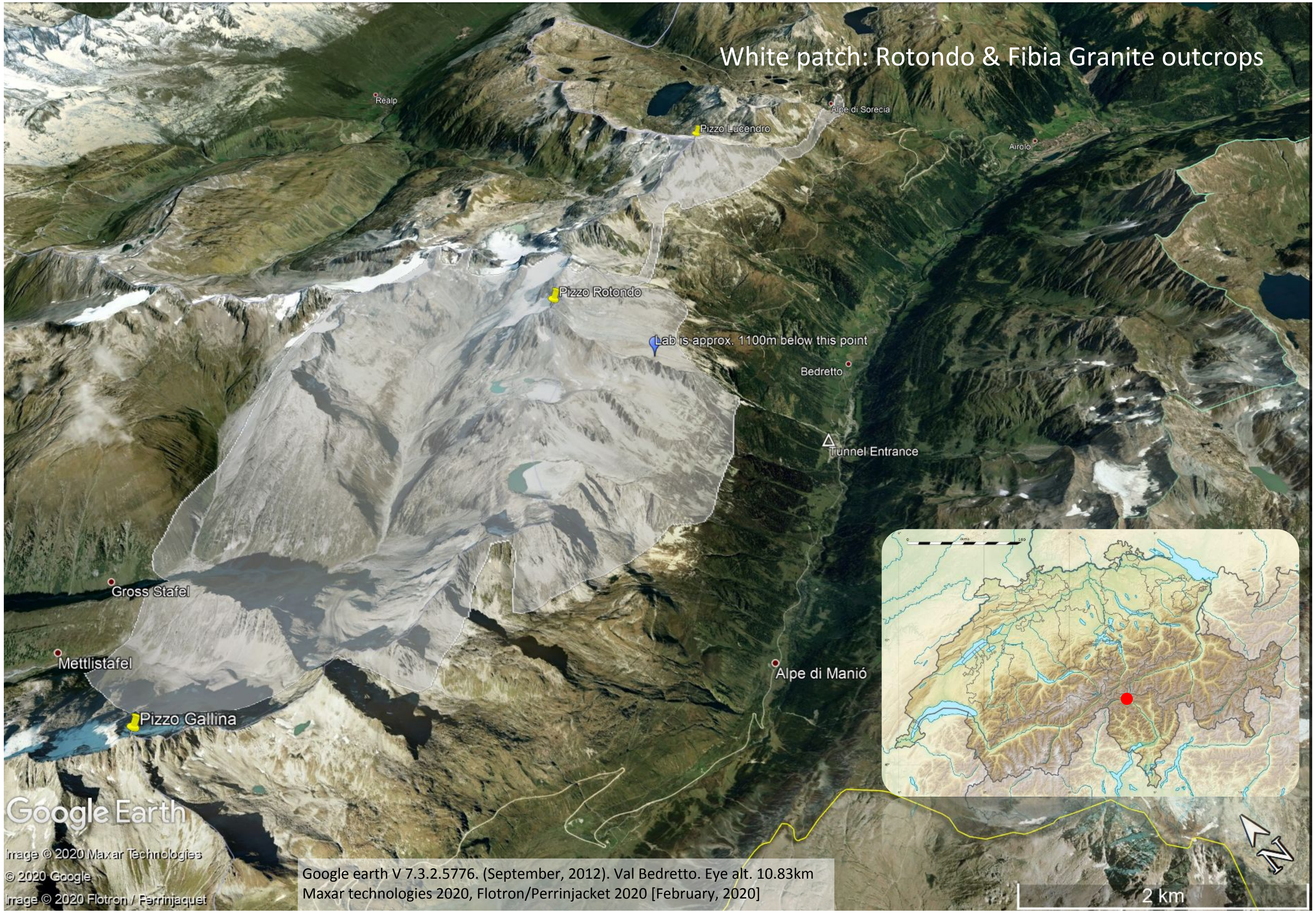
The Bedretto Underground Lab (I/III)

- ETH (Swiss Federal Institute of Technology) operates the Bedretto underground laboratory. GES is an industry partner.
- 1100 m depth below the surface.
- Hosted in granite (Rotondo Granite)

http://www.bedrettolab.ethz.ch/home/

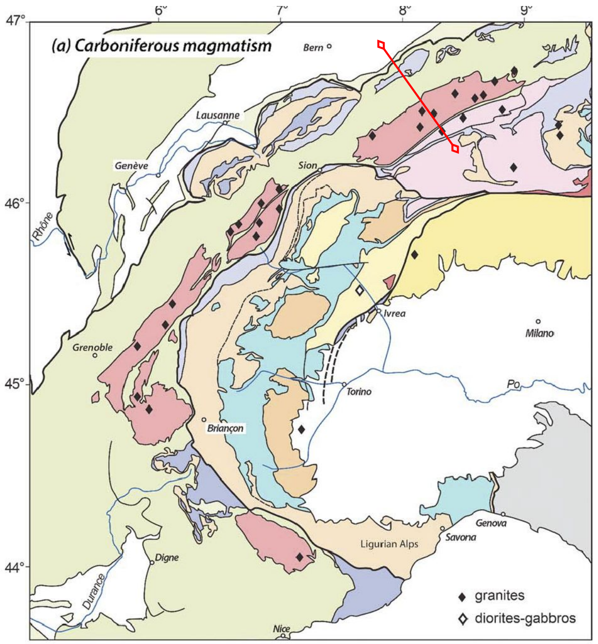


The Bedretto Underground Lab (II/III)



- The southern entrance of the Bedretto lab is located in the Val Bedretto (Canton of Ticino, Switzerland) at approx. 10km from the town of Airolo.
- The Lab (*sensu stricto*) is located in a 100m long, enlarged section of the tunnel at 2 km from the southern entrance.
- The overburden at the lab emplacement is approx. 1100m

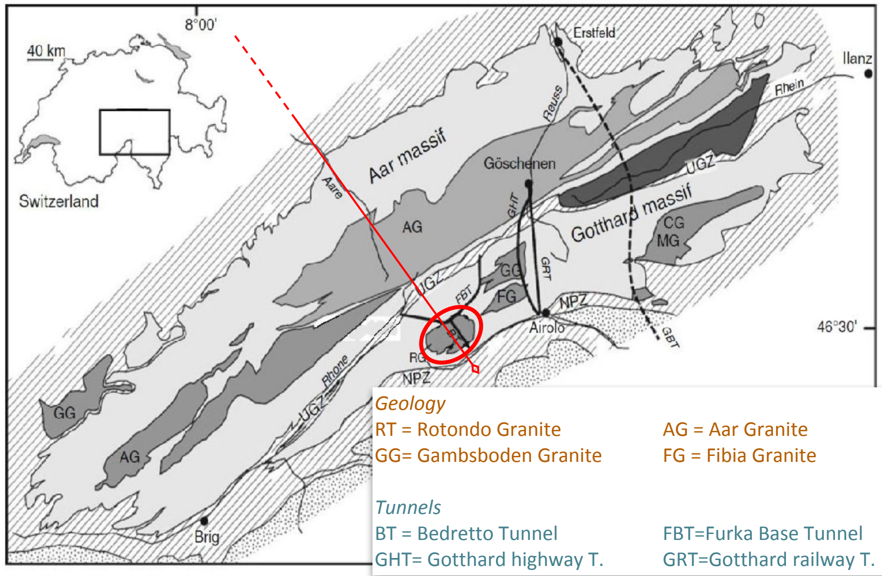
The Bedretto Lab - Regional Geological context



Ballevre et al. (2018)

External Massifs (dark pink) = remnants of old (pre-Alpine) rocks

Granitoids (black losanges) = Intrusive bodies emplaced at the end of the Variscan Orogeny (approx. 300 Ma ago)

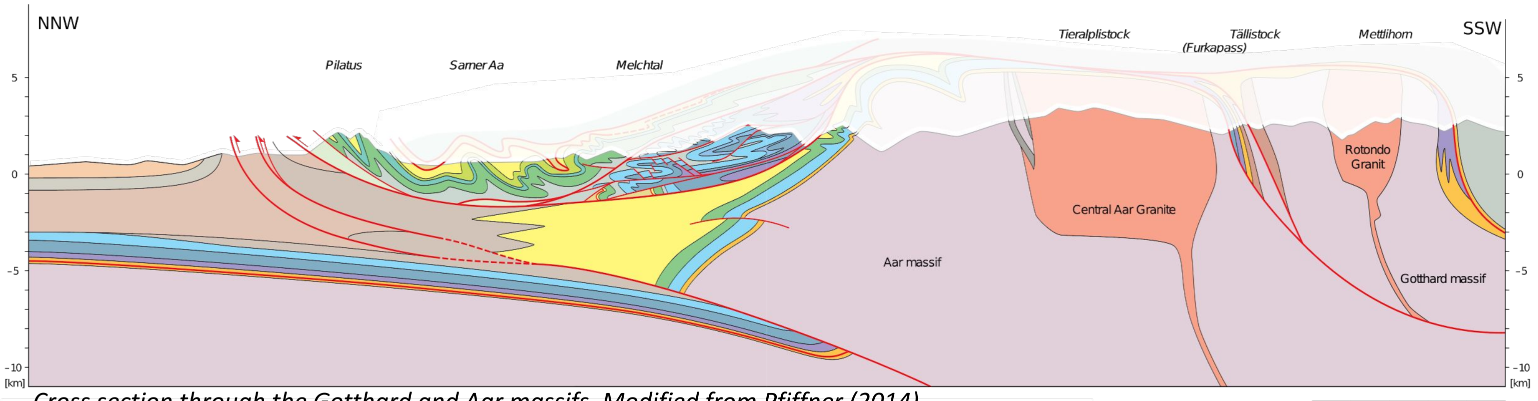


After Labhart et al. (1999

Geology
RT = Rotondo Granite
GG= Gambsboden Granite
AG = Aar Granite
FG = Fibia Granite

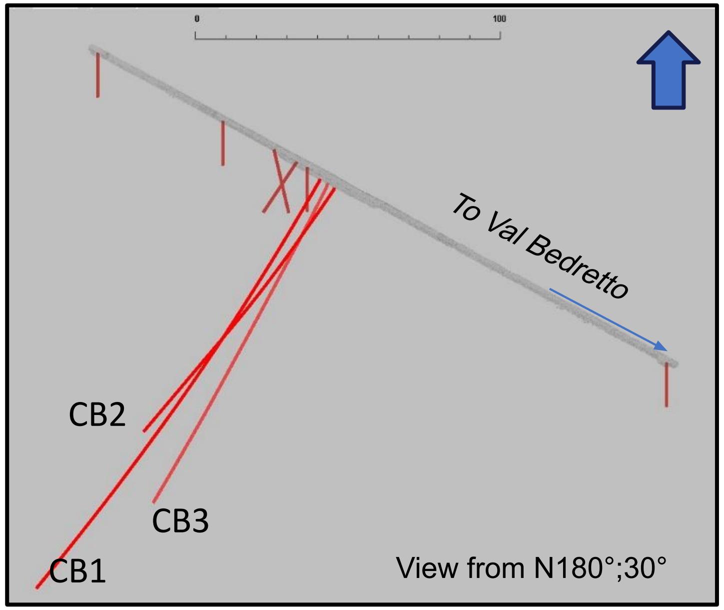
Tunnels
BT = Bedretto Tunnel
GHT= Gotthard highway T.
FBT=Furka Base Tunnel
GRT=Gotthard railway T.

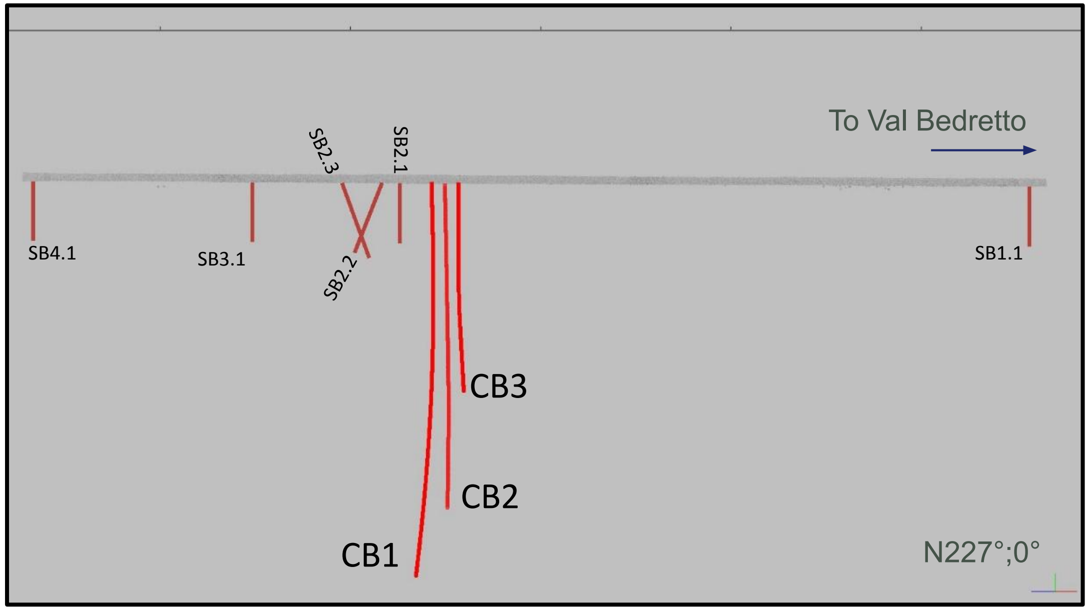
- Extensive magmatism with granite emplacement during Carboniferous and Permian.
- The Rotondo Granite is one of those magmatic bodies.
- The Rotondo Granite, as part of the Gotthard massif, suffered compression and uplift during the Alpine Orogeny.

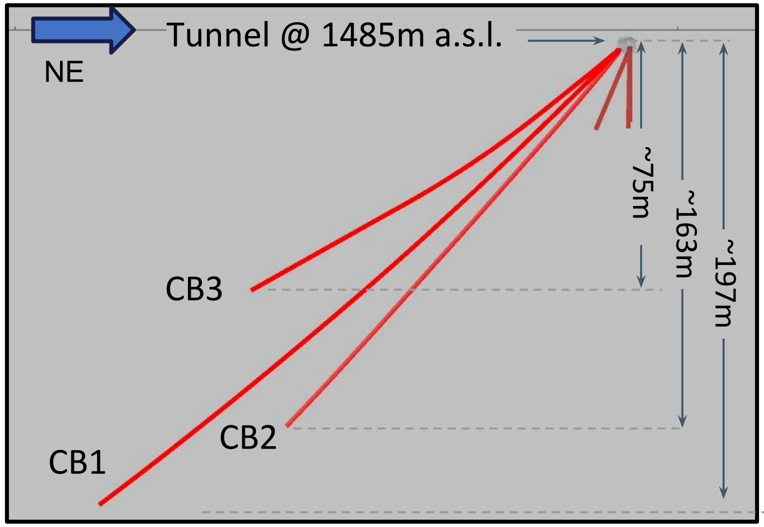


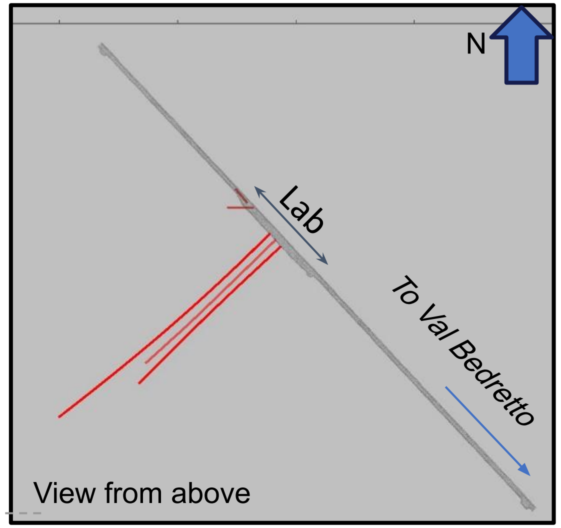
Cross section through the Gotthard and Aar massifs. Modified from Pfiffner (2014)

The Bedretto Underground Lab (III/III)







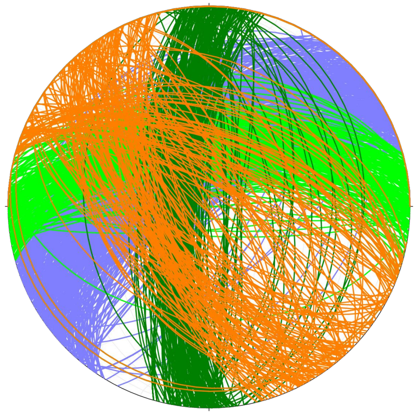


View from southern entrance (N137°;0°)

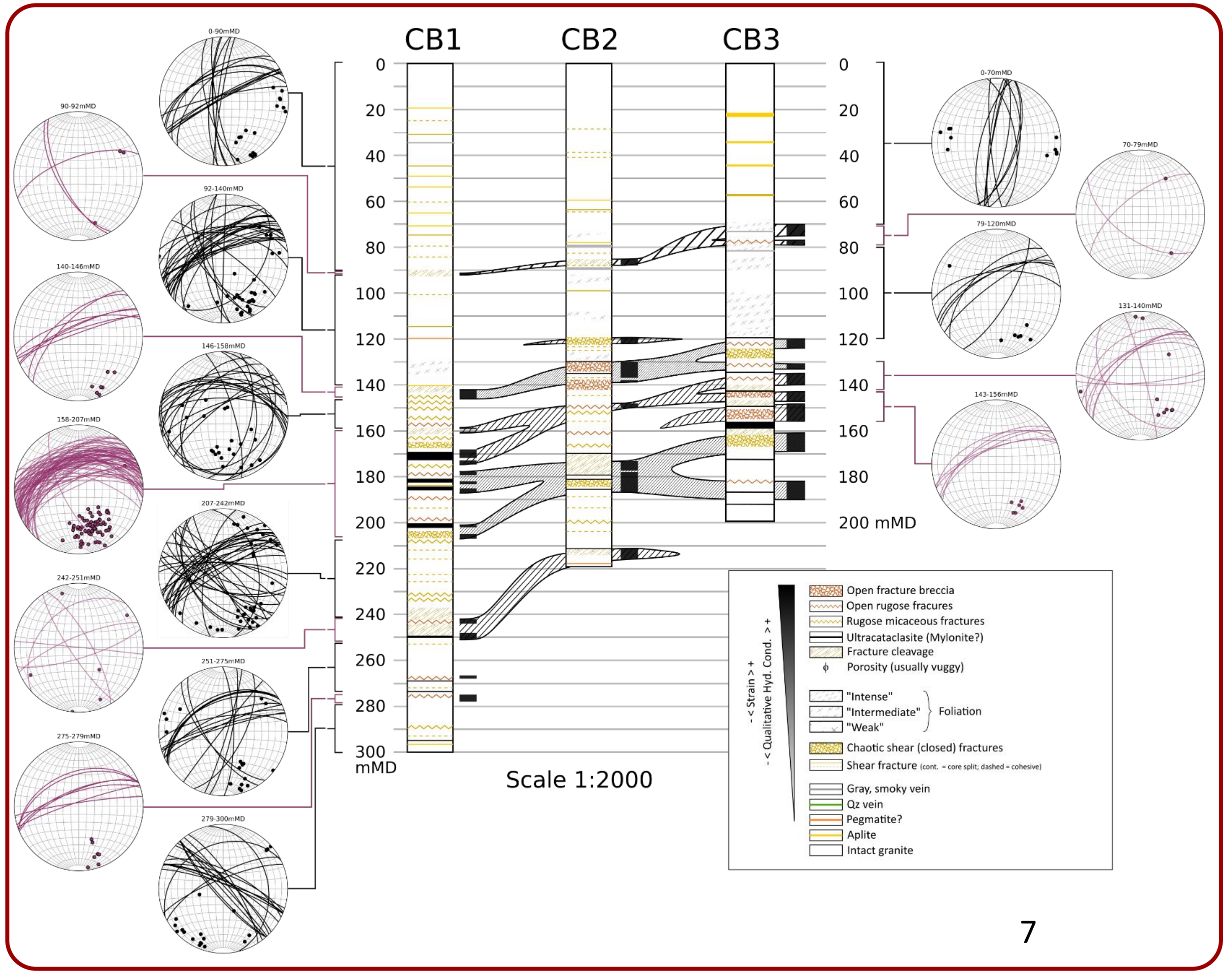
- Lab = 100 m long enlarged gallery in the tunnel.
- 6 short boreholes (30-40m):
  - SB1.1; SB2.1; SB2.2; SB2.3; SB3.1; SB4.1
- 3 long boreholes (190-300mMD):
  - CB1; CB2; CB3

Bedretto Lab - Structure

- Structural characterisation from core and image logging.
- Identification of intact/fractured rock and fault zones.

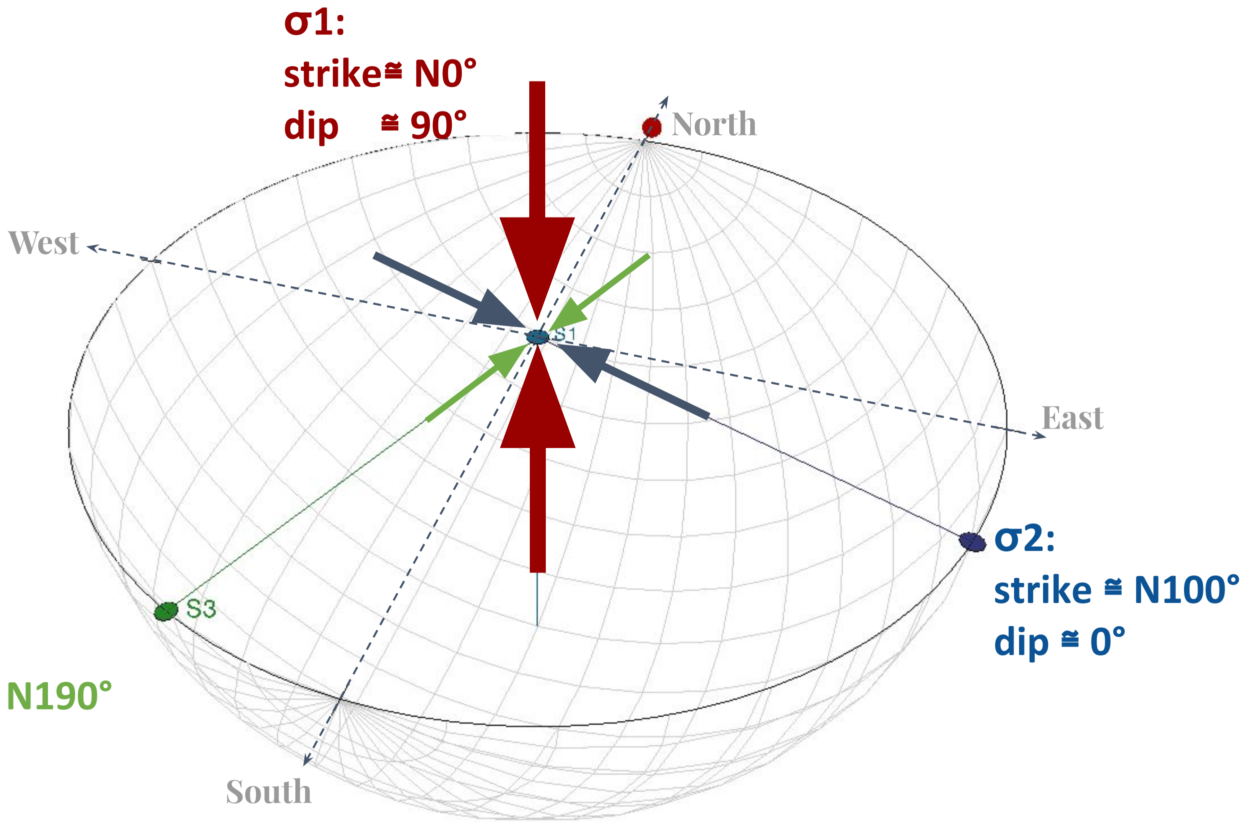


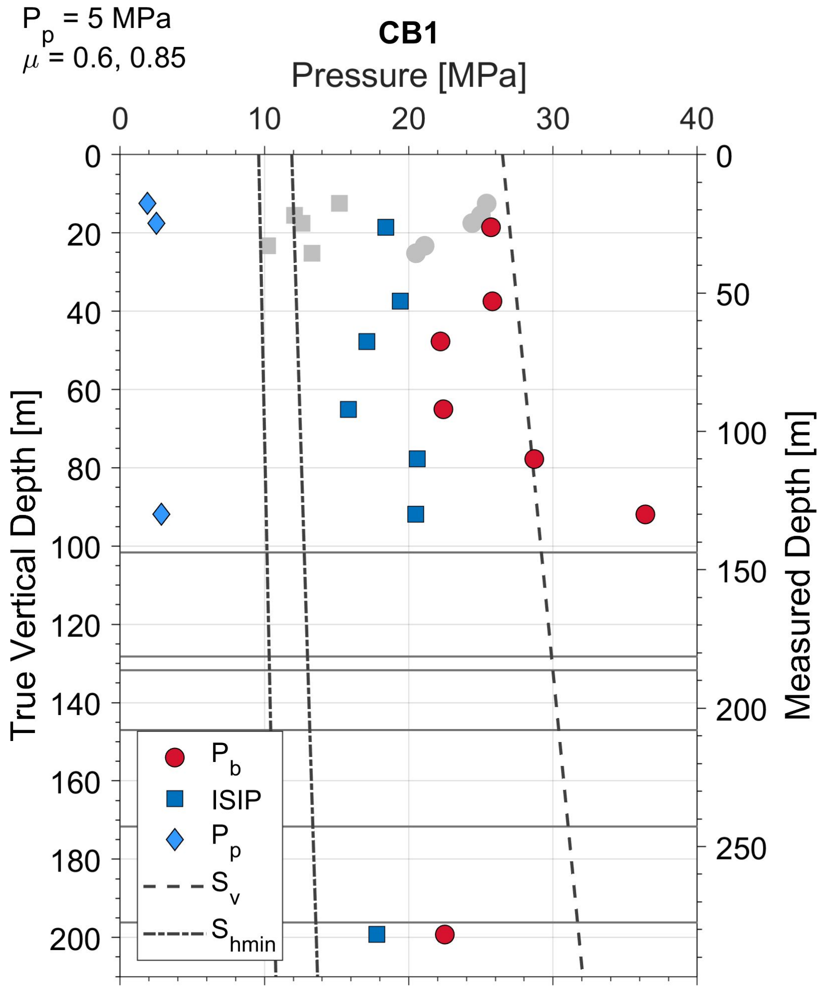
- NE-SW; dip north
- E-W; dip north
- N-S; dip west
- NW-SE



Stress

- Orientations and magnitudes from minifrac tests in short wells and CB1. (Ma et al. 2019 and ETH unpublished work)

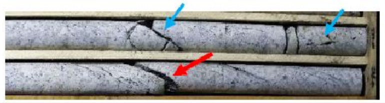




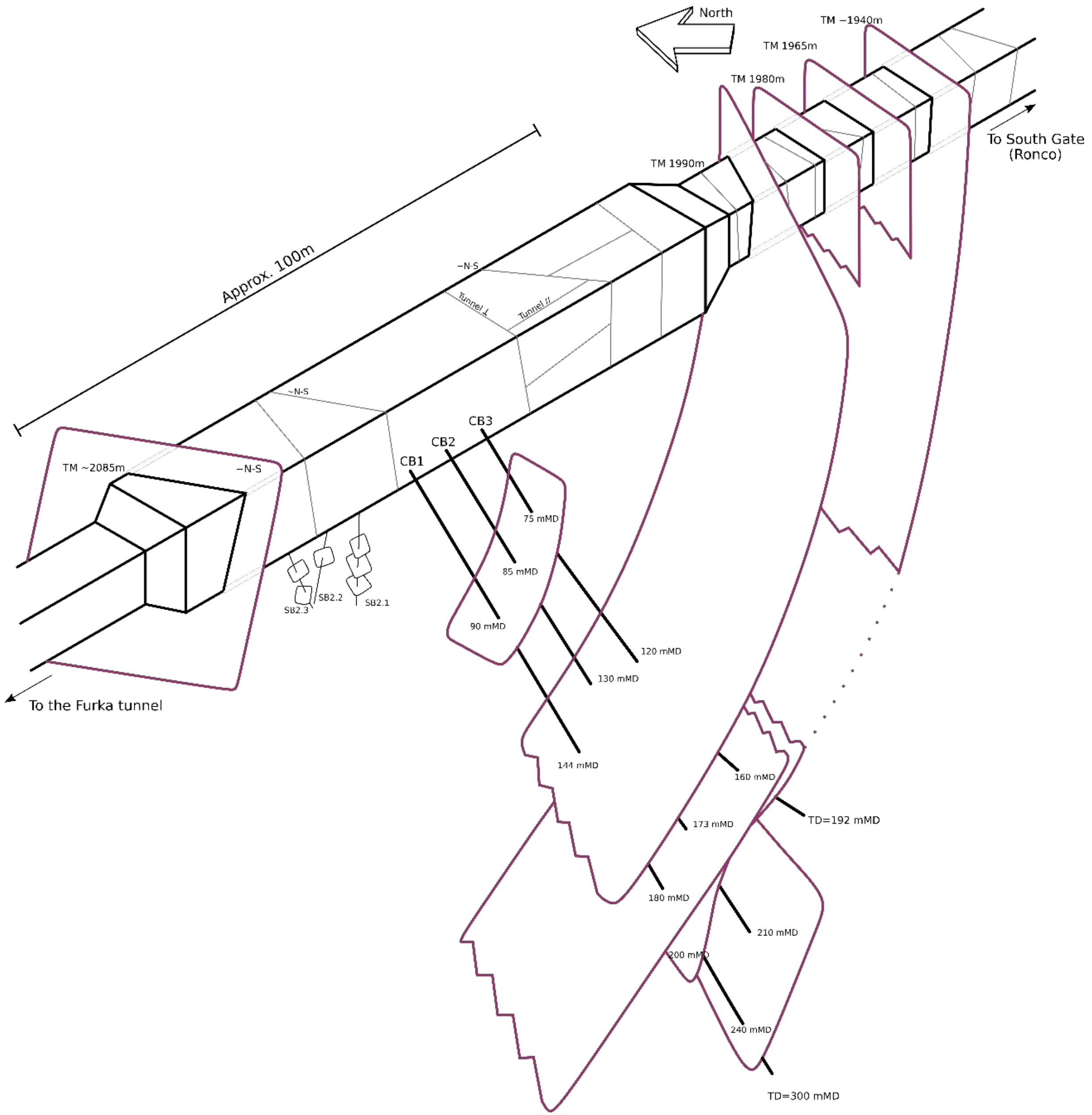
ETH, unpublished

Hydrotests previous to test stimulation

- Twelve intervals were tested to estimate hydraulic properties.
- Dual-packer tests. Inter-packer spacing of 8.7m.
- T of flowing fractures 1E-8 to 5E-7 m2/s comparable to Swiss crystalline basement values (Basel, Nagra boreholes)

CB1 - 30.11.2019 Hydrotest Intervals	Conductive frak depth [m]	Packer Interval [m]	Q [L/min]
	143.8	137 145.7	0.8
 !!! Missing Core	181.7	180.6 189.3	1.7
	186.3	184 192.7	2.1
	198.3	192.3 201	0.7
	208.4	203 211.7	0.7
	213.8	211 219.7	0.9
	227.2	225.3 234	0.0
	236.3	229.6 238.3	0.005
	243.3	239.3 248	2.0
	250.5	249 257.7	0.008
	267.2	265.3 274	0.01
	277.6	275 283.7	9.0

3D conceptual model (preliminary)

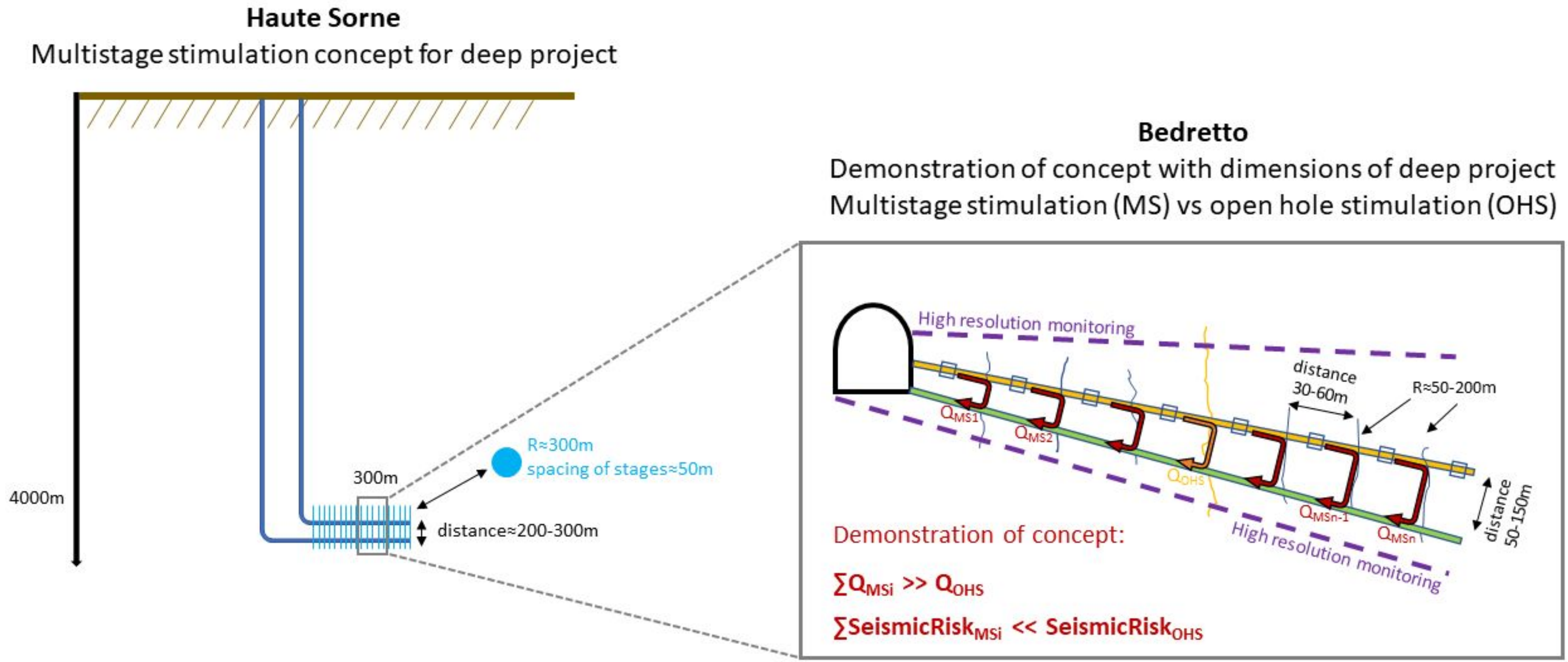


Bedretto & DESTRESS

Bedretto in DESTRESS

- Bedretto = Fall-back option that replaces Haute-Sorne.
- Reservoir creation experiment 2019/2020 led by GES at a smaller scale in Bedretto underground research lab
- Aims:
  - Demonstration of multi-stage stimulation concept to increase energy production and to minimize induced seismicity.
- Planning:
  - **January-February 2020:** Test stimulation
    - Injection in CB1 with dual packers and seismic monitoring from CB2 and CB3.
  - **Q2 2020:** Long borehole drilling.
  - **Q3 2020:** Multistage stimulation

Bedretto vs. Full scale deep EGS



Test Stimulation

Test Stimulation - General Concept

- General Concept:
    - To stimulate pre-existing structures in the CB1 borehole.
    - Individual intervals are isolated via a dual packer system.
    - Seismic monitoring from 2 adjacent boreholes (CB2 and CB3).

Test Stimulation - Motivation

- Motivation:
    - The test stimulation is needed as a basis for further planning.
    - The outcome delivers important data for the further planning and investments by answering the following questions
        - Is the model concept the right one?
            - How does the rock behave, do we shear or jack the formation ?
            - Are we able to (permanently) increase flow ?
        - Can we stimulate in a controlled manner?
            - Can we detect and locate induced earthquakes?
            - Can we calibrate our models to forecast seismicity?
        - Are the planned boreholes at the right spot?
            - Where does seismicity propagate to?

Test Stimulation - Implementation

- Previous Analyses:
  - Core & image logging.
  - Hydraulic tests on CB1.
- Choice of stimulation pressures:
  - Prognosis based on structural orientations and available stress scenario.
  - Induced seismicity hazard and seismic risk study by ETH (Gischig et al., 2019).
- Design of TSL and ATLS and associated reaction & communication plan.
  - Based on the Gischig et al. study mentioned above.
- Selection of intervals and packer spacing for stimulation on CB1.
- Choice of optimal depths for monitoring system in CB2 and CB3.

Selection of intervals

Stimulations candidates

- 6 parameters were used to choose the candidate structures for stimulation:
  1) How favourably oriented is the structure for shear reactivation?
  2) Is there any aperture associated to the structure (in core and ATV)?
  3) Is there any vuggy porosity in or around the structure?
  4) Does the structure seem to be isolated from others? (qualitative hypothesis)
  5) What was the flow in previous hydraulic tests?
  6) Are there good conditions for packers placement above and below?

Chosen intervals

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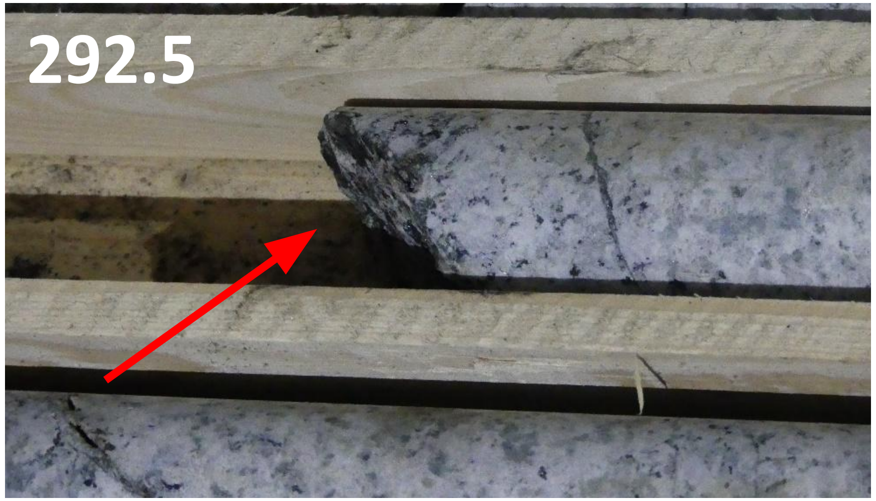
- Five intervals were isolated and stimulated
  - Two intervals 2.7m long
  - Three intervals 9.9m long

Interval designation *	Interval length (m)	Top	Bottom	Favourably oriented structure	"Open" structure	Vuggy Porosity	Isolated structure	Flow (l/min)	Packer seats on intact rock
STIM-250	2.7	249	251.7	✓	X	X	X	0.008	X
STIM-267	2.7	265.7	268.4	✓	✓	✓	X	0.01	✓
STIM-269	9.9	264.0	273.9	✓	✓	✓	X	0.01	X
STIM-292	2.7	290.7	293.4	✓	✓	X	✓	**	✓
STIM-295	9.9	288.5	298.4	✓	✓	X	✓	??	✓
HF-298	0.7	297.8	298.5						

* STIM = Main stimulation;
HF = Minifrac test carried out by ETH before DESTRESS stimulation (for stress determination)
** = Not possible to measure

Chosen intervals - Examples of targeted structures

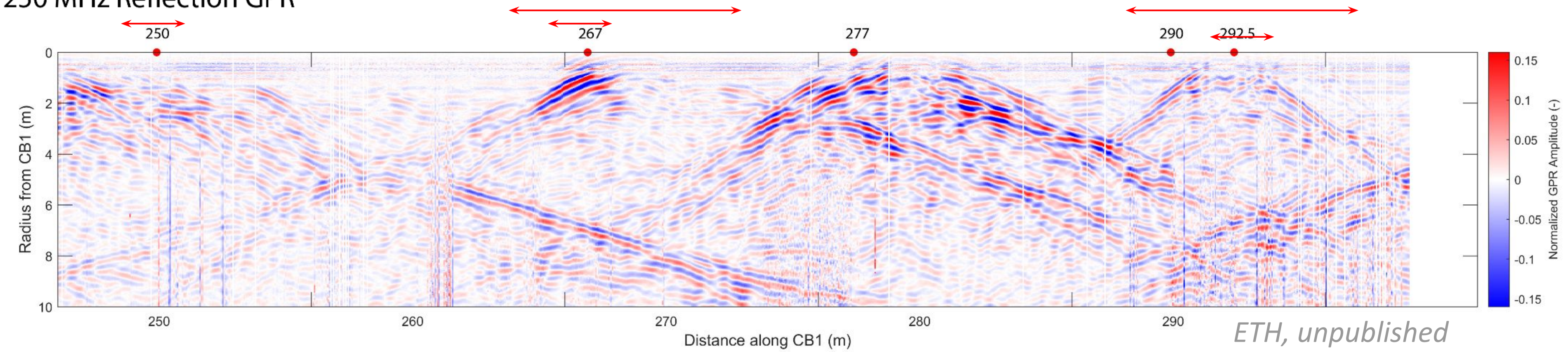
- A couple of rugose fractures very close to each other.
- They are part of a segment described in the core as a fault zone.
- Orientation is favourable for shear reactivation (strike=253°, dip=85°).
- Previous hydraulic tests yielded a flow rate of 0.01 l/sec.
- Vuggy porosity can be observed around these structures which might facilitate the injection.



- Closed rugose structure, well oriented for shear reactivation (strike=330°, dip=75°) but not too open.
- No previous hydraulic tests were run on this structure.
- Well imaged in radar data which means it has some water saturation.
- Given its characteristics, it might be challenging to inject fluid in it.

GPR of selected stimulation intervals

250 MHz Reflection GPR



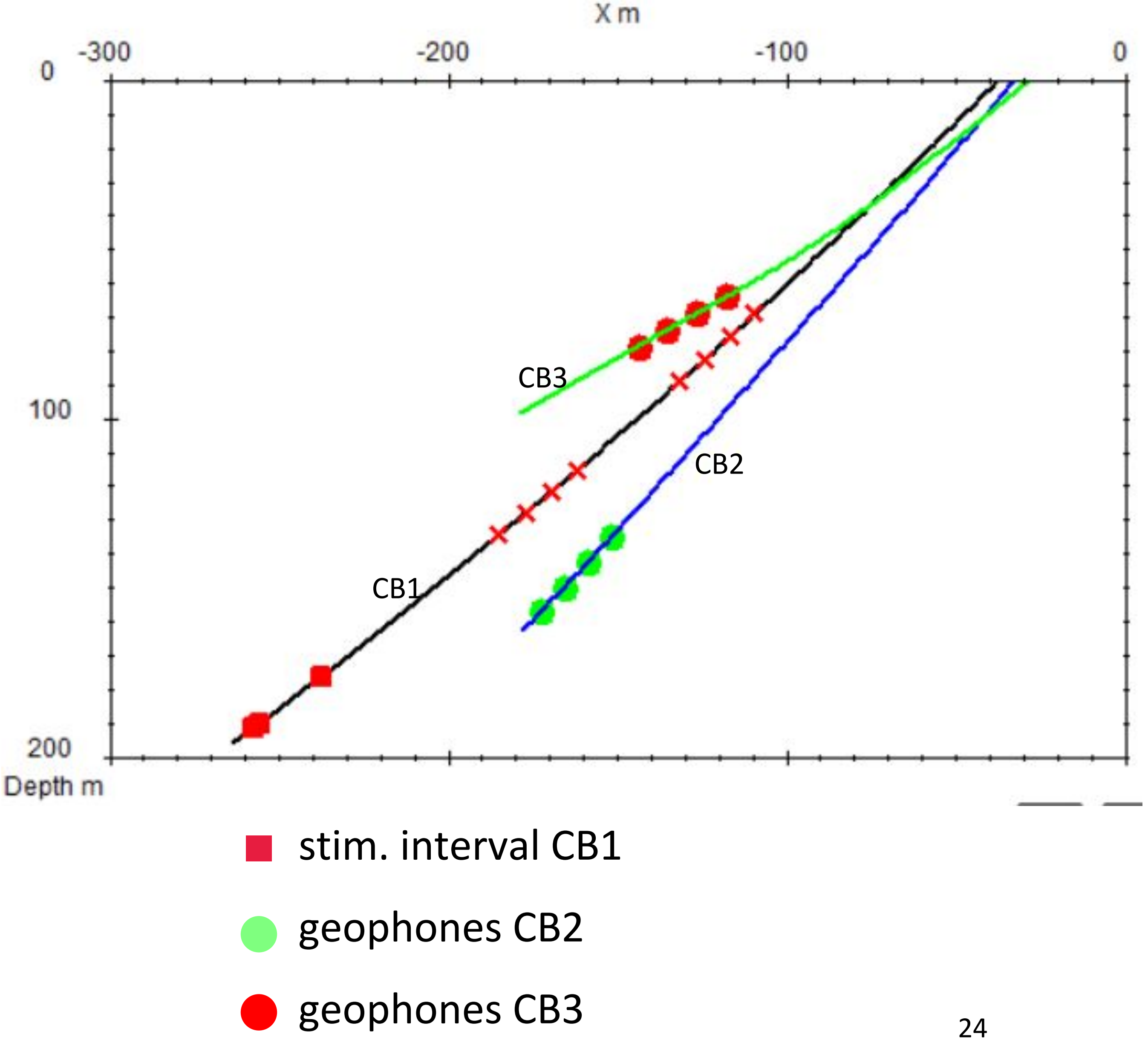
ETH, unpublished

- Intervals around 267 and 290m show structures intersecting the well.
- High amplitudes near the well at 250m indicate the presence of nearby structures.

Seismic monitoring

Seismic Network

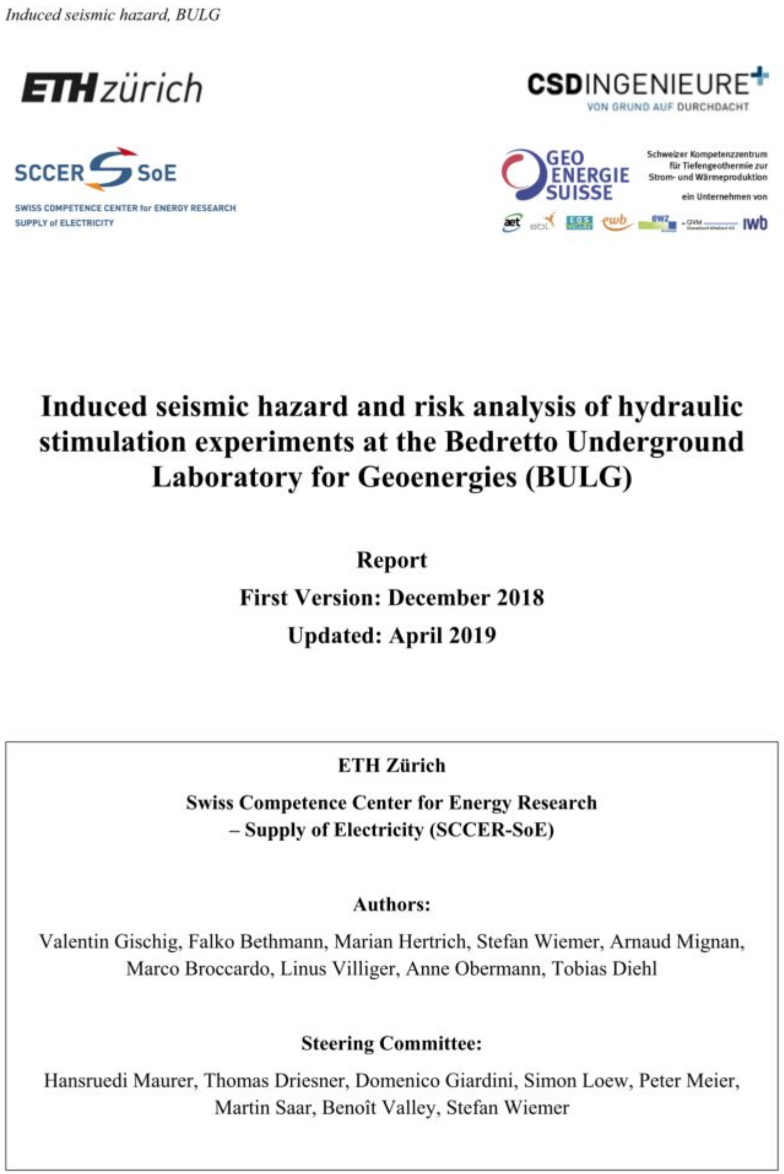
- Stimulation hole CB1 : two one-component sensors were placed on top of the upper packer
- Monitoring wells CB2 & 3: four 3-component geophones (4x 10m intervals) in places of low breakouts
- DAS in CB3 above last geophone to tunnel



Seismic Risk TLS & ATLS

Seismic risk

- A seismic risk study was conducted beforehand, with recommendations for injection volumes and traffic light thresholds.



Induced seismic hazard, BULG

ETH zürich

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Induced seismic hazard and risk analysis of hydraulic stimulation experiments at the Bedretto Underground Laboratory for Geoenergies (BULG)

Report

First Version: December 2018

Updated: April 2019

ETH Zürich

Swiss Competence Center for Energy Research – Supply of Electricity (SCCER-SoE)

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Seismic risk – traffic light

Derivation of proposed traffic light for stimulation test - with lower thresholds due to unknown rock parameters (high uncertainty in attenuation and magnitude)

- Taking proposed traffic light from risk study:

Green	Orange	Red
PPV < 5 mm/s Mw < 0.5 P(PPV>30 mm/s) < 0.01	PPV ≥ 5 mm/s Mw ≥ 0.5 P(PPV>30 mm/s) ≥ 0.01	PPV ≥ 30 mm/s Mw ≥ 1.2 P(PPV>30 mm/s) ≥ 0.1
No action	**Reanalysis of seismic hazard** If P(PPV>30 mm/s at 100 m) = a) < 0.01 proceed with caution at this interval b) 0.01- 0.1 abandon interval c) ≥0.1 turn to red	**Reanalysis of seismic hazard** Reconsider feasibility of experimental work at BULG

- Added extra safety factor ΔM~1.5 due to high uncertainties

- Proposed traffic light for stim test:

Green	Orange	Red
Mw<- 1 r_stim< 20m ppv<0.16mm/s	Mw>-1 r_stim >20m ppv>=0.16mm/s	Mw>0 r_stim >25m ppv>=1mm/s
No action	**proceed with caution** reduce injection rate 2 seismologists & 1 hydrologist at site consult ATLS prediction begin waiting period	**controlled bleed off (see bleed off concept)** convene a meeting

(Mw -1 ~ factor 100 below human perception @100m distance)

Reaction & communication plan

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- Red traffic light
  - Bleed off
  - Communicate and get advice from ETH expert team whenever a red event is detected.
  - Approval for continuation from ETH.

- Felt earthquake in tunnel
  - Bleed off
  - Assemble at lab entrance & leave tunnel
  - Inform Lab management team
  - Suspend operation
  - Watch SED tunnel seismometer data
  - Do not re-enter before O.K. of Lab management team

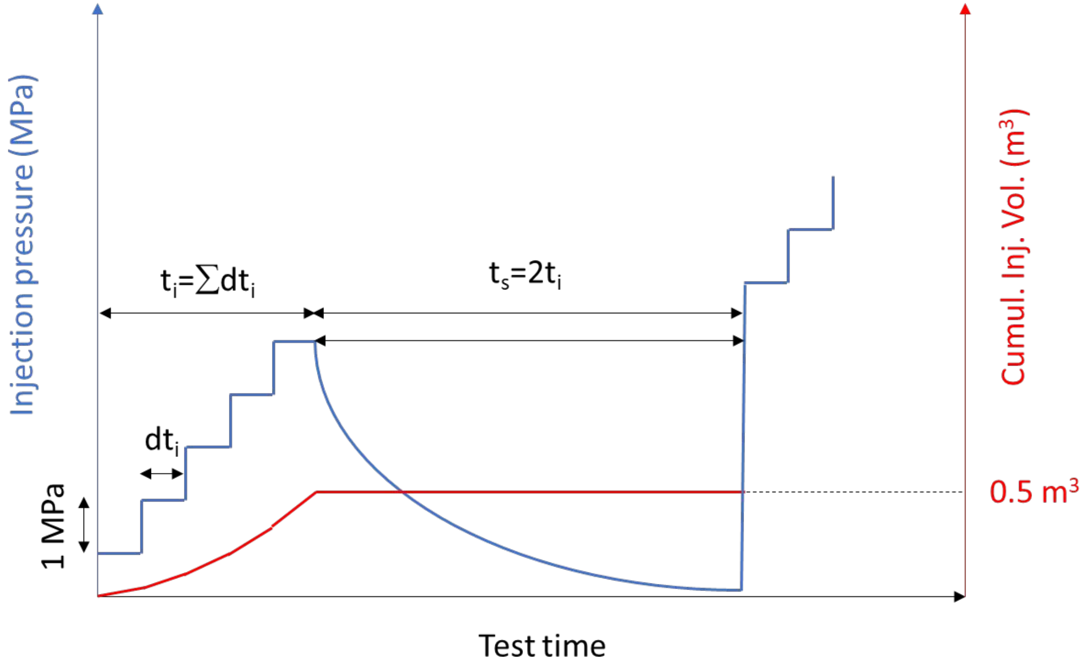
Seismic risk – Adaptive Traffic Light

- An ATLS prototype was run during the stimulation to be able to forecast seismicity in case of high seismicity rates and to test various forecasting algorithms
- The TLS was set up as a binding action scheme, the ATLS was planned for decision support
- In the end too few events were recorded to fully make use of the ATLS prediction capabilities

Stimulation scheme

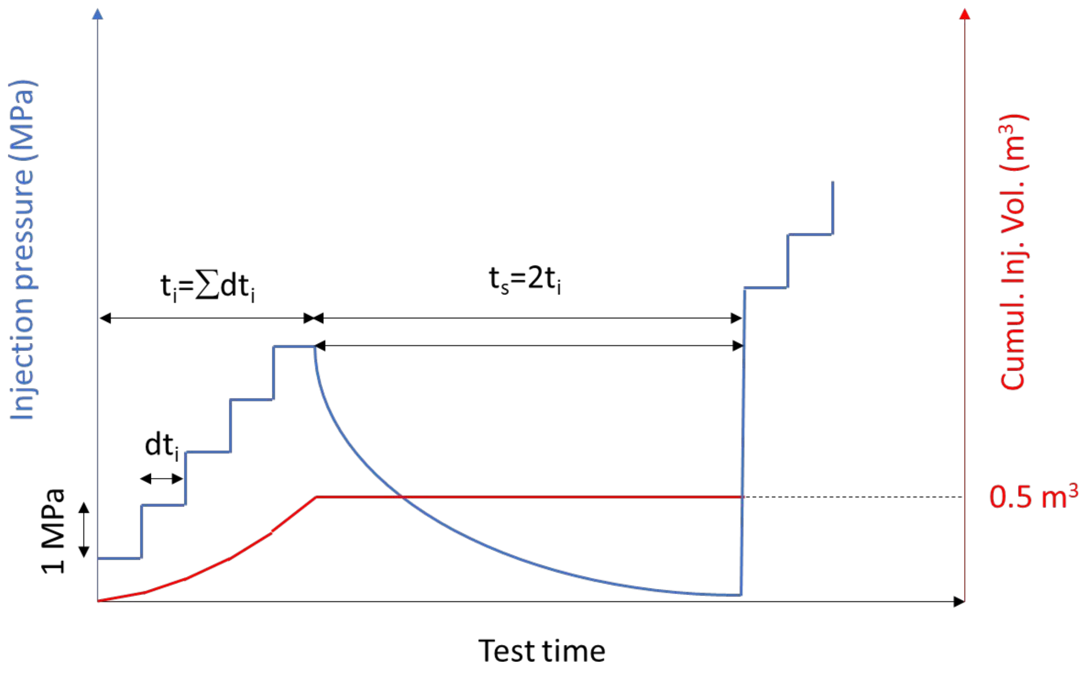
Stimulation scheme (I/III)

- Sequence of controlled injection pressure and shut-in steps, followed by a bleed-off.
- Injection steps:
  - Pressure increases gradually after constant injection intervals
  - Injection step ends if (1) TLS turns red, or (2) the pressure downhole exceeds 0.75*FBP (breakout pressure), or (3) the injected volume during current step is 0.5 m^3
- Intermediate shut-in steps to mitigate seismic risk
- A bleed-off is carried out if (1) the TLS turns red or, (2) the pressure downhole exceeds 0.75*FBP or (3) the total injected volume is 5 m^3 per interval.
- Design parameters:
  - Amount of pressure increase.
  - Duration of the injection intervals dt_i
  - Duration of the shut-in steps



Stimulation scheme (II/III)

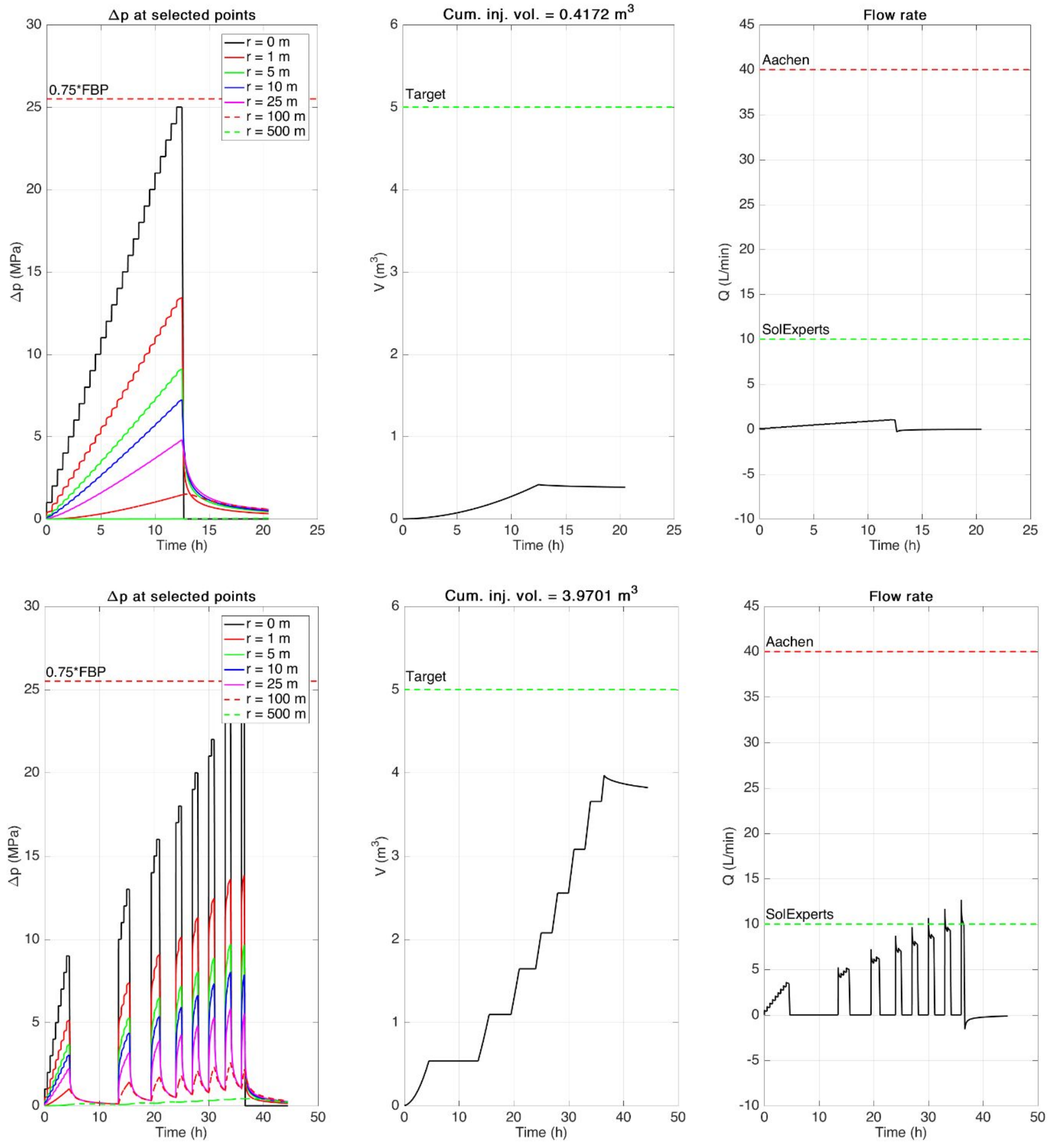
- Restrictions/targets:
  - A minimum overpressure of 5 Mpa at r=25m is required for 25% chances of shearing
  - The maximum flow rate (yield of the pump) is 40 L/min
- Methodology: 1D radial pressure model. T, S and r_{stim} do not vary with time
- Suggested design parameters:
  - Final design and test outputs largely depend on the initial transmissivity
  - Pressure increase=0.5-1 MPa (as in Grimsel).
  - Duration of the injection intervals dt_i=0.5-1h
  - Duration of the shut-in steps= twice the duration of the previous injection step.
  - Total expected duration= max. 24 hours.



Stimulation scheme (II/III)

Initial low T=1e-8 m^2/s

Initial high T=1e-7 m^2/s



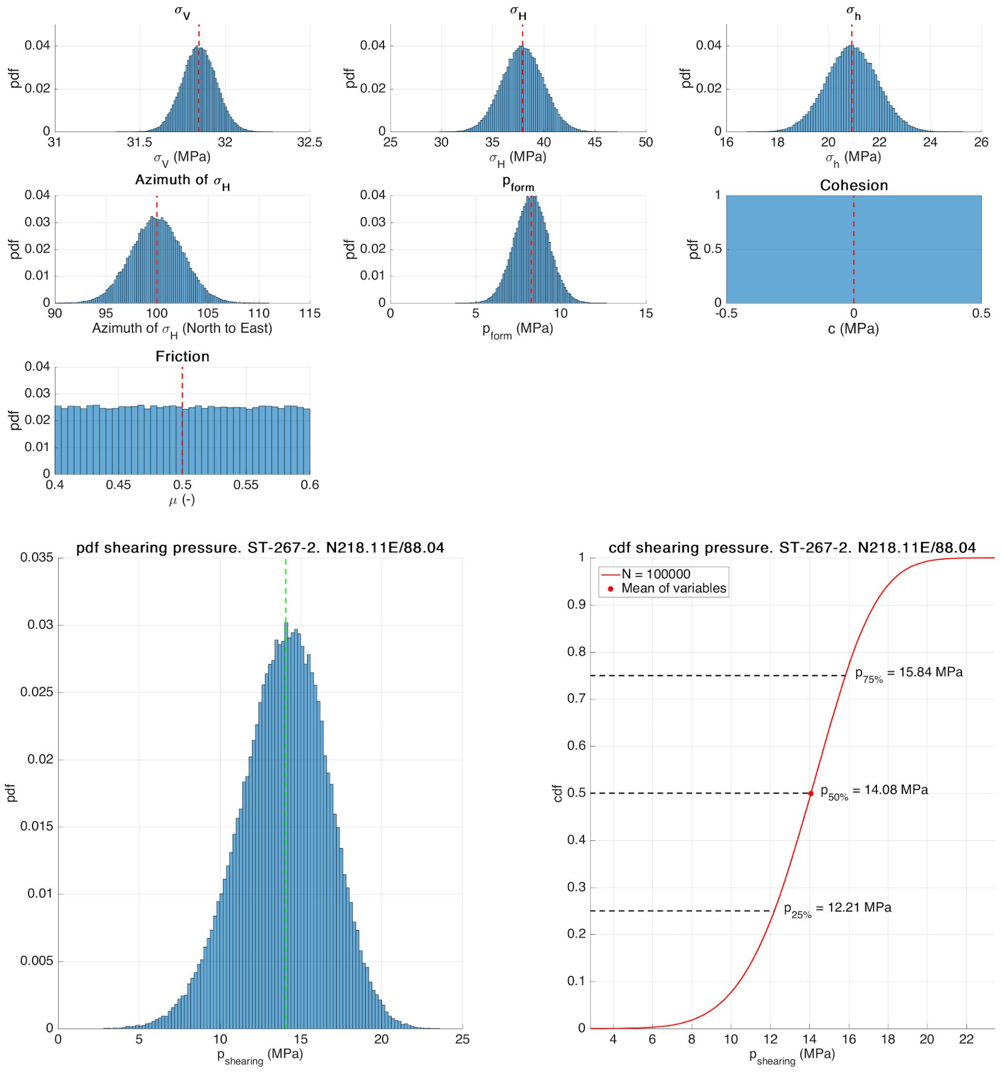
- Two extreme cases involving very low/high fracture transmissivity have been evaluated.
- Goals:
  - Evaluate if overpressure at r=25m (magenta lines in left panels) are enough to cause shearing
  - Evaluate if the available pump (Q=10 L/min) is capable of providing sufficient downhole pressure (right panels).
- As observed, the pressure at r=25m is ca. 5 MPa regardless of initial transmissivity. This low pressure is unlikely causing shearing at that distance (see slide xxx in this document).

Stimulation prognosis

Prognosis

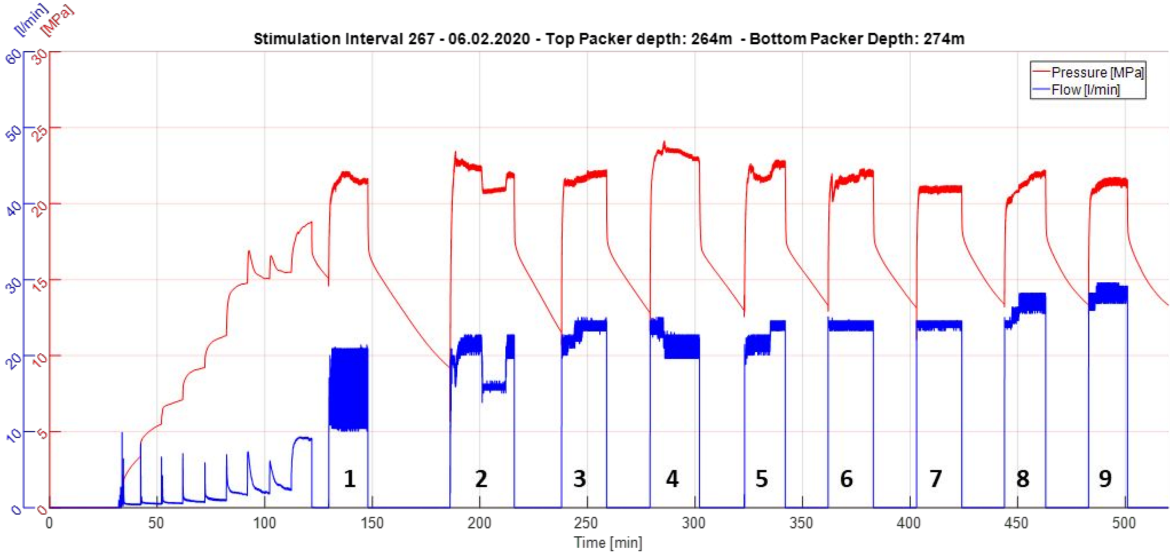
Prediction of injection pressures needed to shear the structures present in each interval.

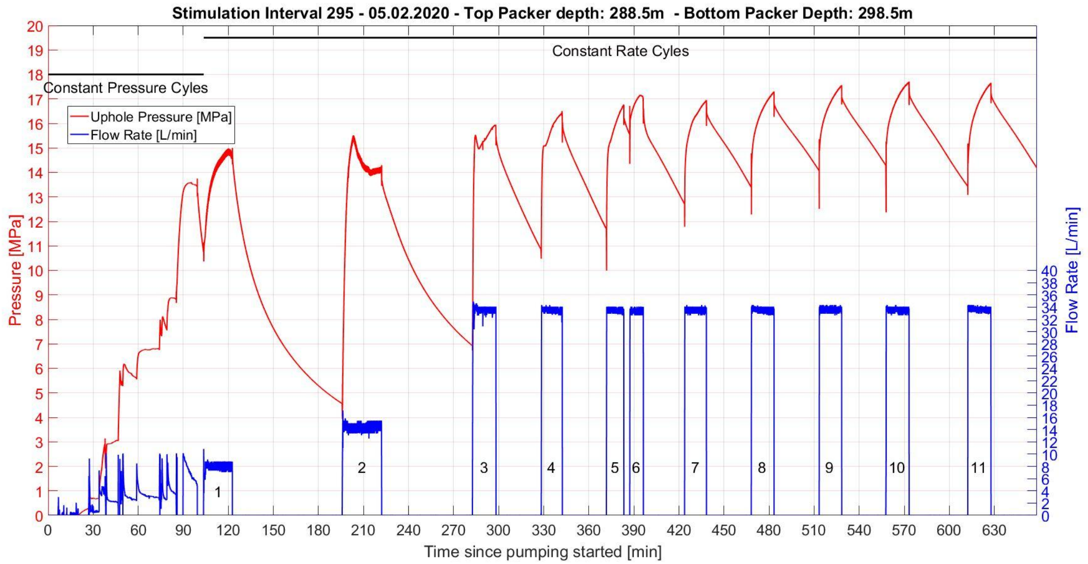
Interval designation	Interval length (m)	Top	Bottom	Orientation of dominant structure		Shearing pressure (MPa)		
				strike	dip	P25	P50	P75
STIM-250	2.7	249.0	251.7	227	38	12.7	14.2	15.6
STIM-267	2.7	265.7	268.4	218	88	10.2	12.1	13.8
STIM-269	9.9	264.0	273.9					
STIM-292	2.7	290.7	293.4	346	31	15.9	17.3	18.6
STIM-295	9.9	288.5	298.4					

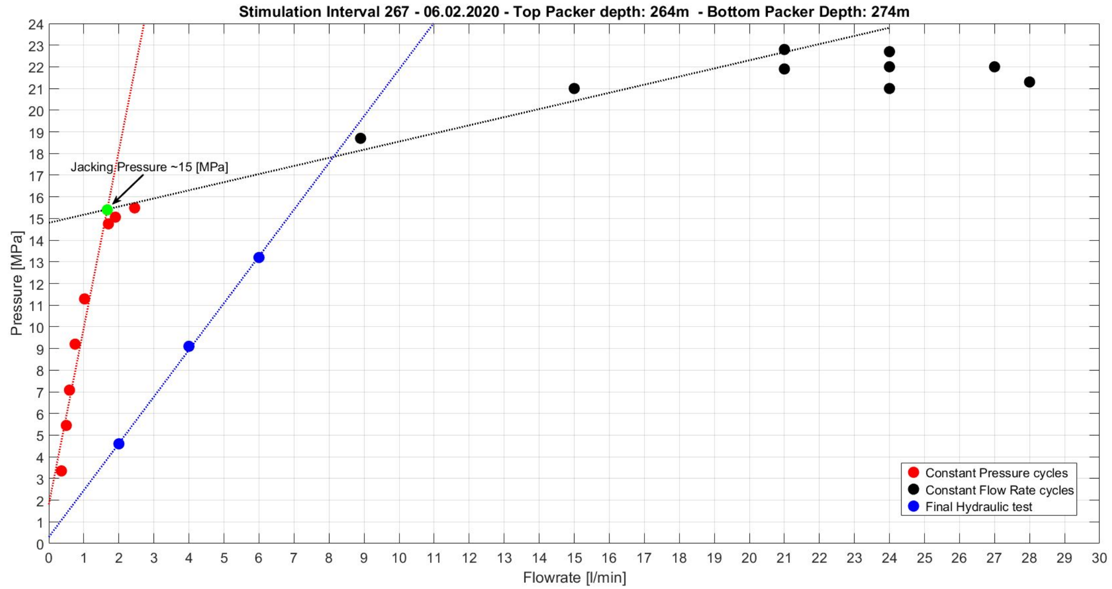


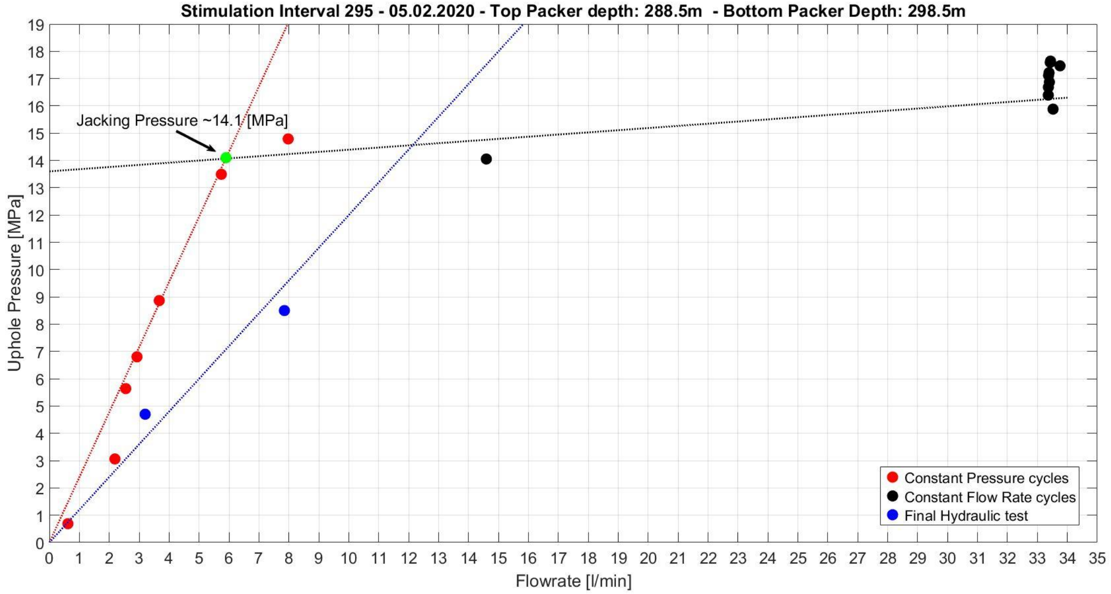
Results

Hydraulic data - Interpretation (I/II)









Hydraulic data - Interpretation (II/II)

Borehole	CB1	Interval Depth	264 m to 274 m
Test Interval	STIM-267	Target Fracture	267 m
Test Type	Double Packei	Testing Date	06.02.2020
Authors		Report Date	13.02.2020

Test Interval Specifications:

Interval Lengtł	10 [m]	Wellbore Radius	0.05 [m]
Jacking Pressure	15.41 [MPa]	Mean ISIP	17.55 [MPa]
Hydrostatic P	1.71 [Mpa]		

Test Description: A double-packer test system was installed at a depth of 264 m. A stimulation was conducted (see activity report). It was done in 4 sections: Constant Pressure (0 to 121m) , Constant Rate (121 to 536 min), Bleed-Off (536 to 1261 min) and Final Hydraulic Test (1261 to 1317 min).

Test Results:

Flow Model			Horner (1)	Nsights (2)	Cooper / Theiss (3)	Steady State (4)	Bisroy / C head (5)		ISIP	
Pulse test 29.10.2019		T			5.10E-10			[m2/s]		
Constant Pressure		T		8.30E-10				[m2/s]		
		S		4.30E-03				[-]		
Constant Rate	Cycle 1	T	2.40E-08					[m2/s]	16.93	[MPa]
	Cycle 2	T	3.78E-08					[m2/s]	17.35	[MPa]
	Cycle 3	T	4.71E-08					[m2/s]	1736	[MPa]
	Cycle 4	T	5.00E-08					[m2/s]	17.05	[MPa]
	Cycle 5	T	4.89E-08					[m2/s]	17.32	[MPa]
	Cycle 6	T	5.22E-08					[m2/s]	17.59	[MPa]
	Cycle 7	T	5.50E-08					[m2/s]	18.03	[MPa]
	Cycle 8	T	6.20E-08					[m2/s]	17.98	[MPa]
	Cycle 9	T	5.10E-08					[m2/s]	18.10	[MPa]
Bleed-Off		T				1.23E-08				
Hydraulic test	Step-Rate	T		3.56E-08	3.04E-08		2.93E-08	[m2/s]		
	Injection	S		7.26E-05	2.49E-04		2.40E-04	[-]		
	Shut-In	T	2.37E-08			1.04E-08		[m2/s]		
								[-]		
	Constant	T					7.80E-08	[m2/s]		
	Head	S					1.20E-05	[-]		

(1) Horner time T estimation using Theis recovery method
(2) Nsights simulator with n=2.
(3) Jacob-Cooper or Theiss solution
(4) Thiem Steady-State solution.
(5) Bisroy Deconvolution for Step-Rate or Jacob and Lohman solution for Constant Head

Borehole	CB1	Interval Depth	288.5 m to 298.5 m
Test Interval	STIM-295	Target Fracture	292 m
Test Type	Double Packer	Testing Date	05.02.2020
Authors		Report Date	13.02.2020

Test Interval Specifications:

Interval Length	10 [m]	Wellbore Radius	0.05 [m]
Jacking Pressure	14.09 [MPa]	Mean ISIP	16.08 [MPa]
Hydrostatic P	1.9 [Mpa]		

Test Description: A double-packer test system was installed at a depth of 288.5 m. A stimulation was conducted (see activity report). It was done in 4 sections: Constant Pressure (0 to 100m) , Constant Rate (100 to 650 min), Bleed-Off (650 to 1300 min) and Final Hydraulic Test (1300 to 1350 min).

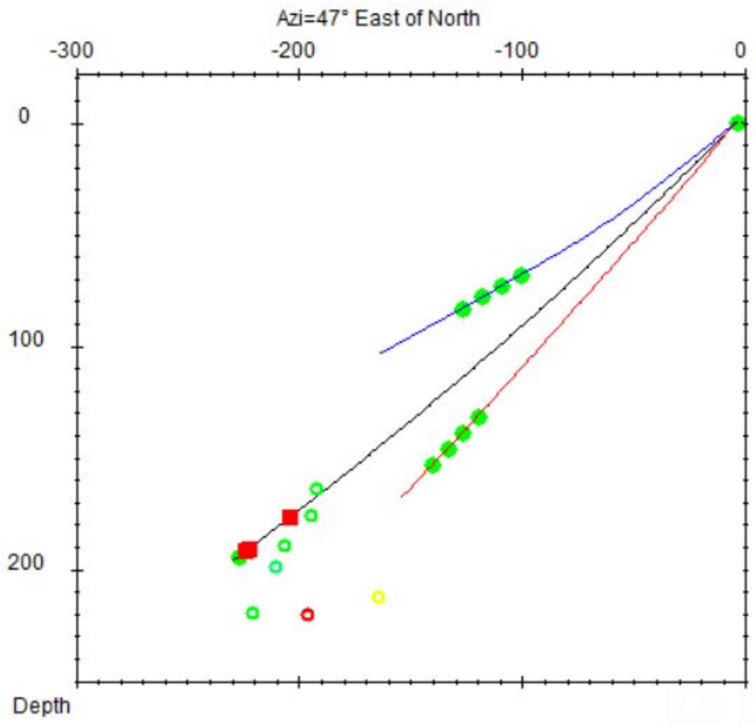
Test Results:

Flow Model			Horner (1)	Nsights (2)	J. Cooper (3)	Steady State (4)		ISIP
Constant Pressure		T		9.60E-09			[m2/s]	
		S		1.00E-02			[-]	
Constant Rate	Cycle 1	T	1.73E-08				[m2/s]	14.54 [MPa]
	Cycle 2	T	2.28E-08				[m2/s]	13.64 [MPa]
	Cycle 3	T	2.93E-08				[m2/s]	15.26 [MPa]
	Cycle 4	T	2.98E-08				[m2/s]	15.94 [MPa]
	Cycle 5	T	3.21E-07				[m2/s]	16.29 [MPa]
	Cycle 6	T	3.62E-08				[m2/s]	16.47 [MPa]
	Cycle 7	T	3.98E-08				[m2/s]	16.51 [MPa]
	Cycle 8	T	4.65E-08				[m2/s]	16.85 [MPa]
	Cycle 9	T	4.70E-08				[m2/s]	17.05 [MPa]
	Cycle 10	T	3.23E-08				[m2/s]	17.2 [MPa]
	Cycle 11	T	4.18E-08				[m2/s]	17.17 [MPa]
Bleed-Off		T				2.07E-08	[m2/s]	
Hydraulic test	Recovery	T	5.82E-08				[m2/s]	
	Injection	T			7.35E-08		[m2/s]	
		S			2.00E-04		[-]	

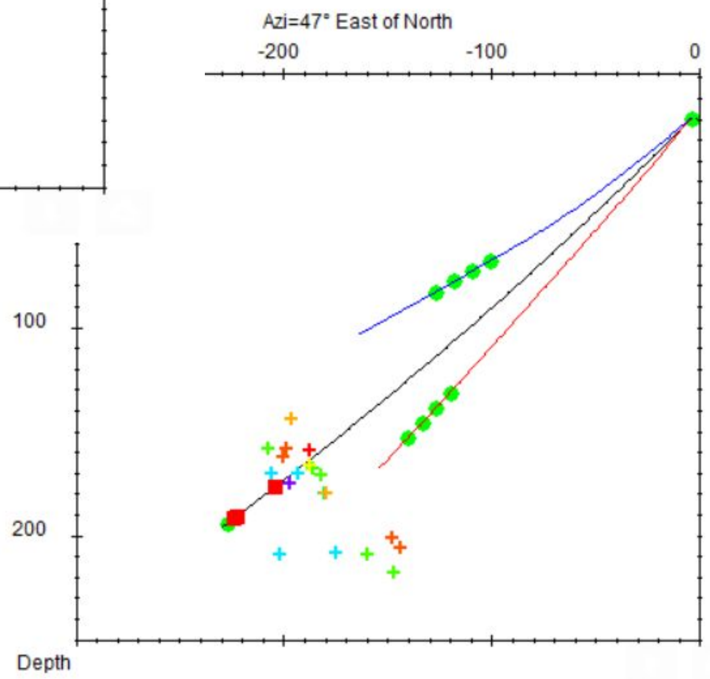
(1) Horner time assuming 4 days of continuous drawdown for BU-1. T estimation using Theis recovery method
(2) Nsights simulator with n=2.
(3) Jacob-Cooper solution
(4) Thiem Steady-State solution.

Microseismicity

- 44 events were captured by automatic event detector
- 27 events could be auto-located
- Magnitude range from M=-3 to M=-2.6
- Post processing planned in the following week(s)



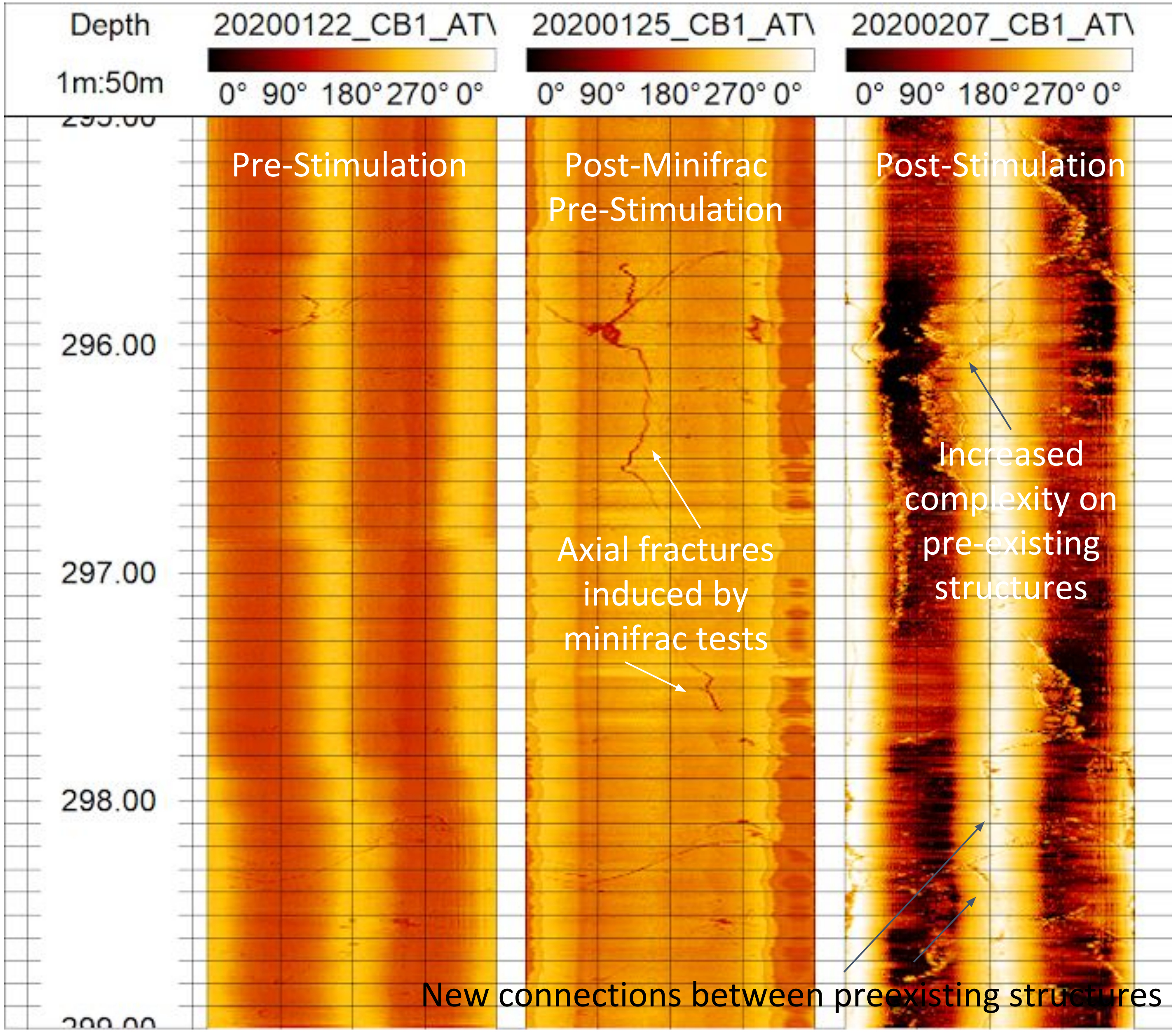
Seismicity during stimulation of bottom interval (STIM-295)



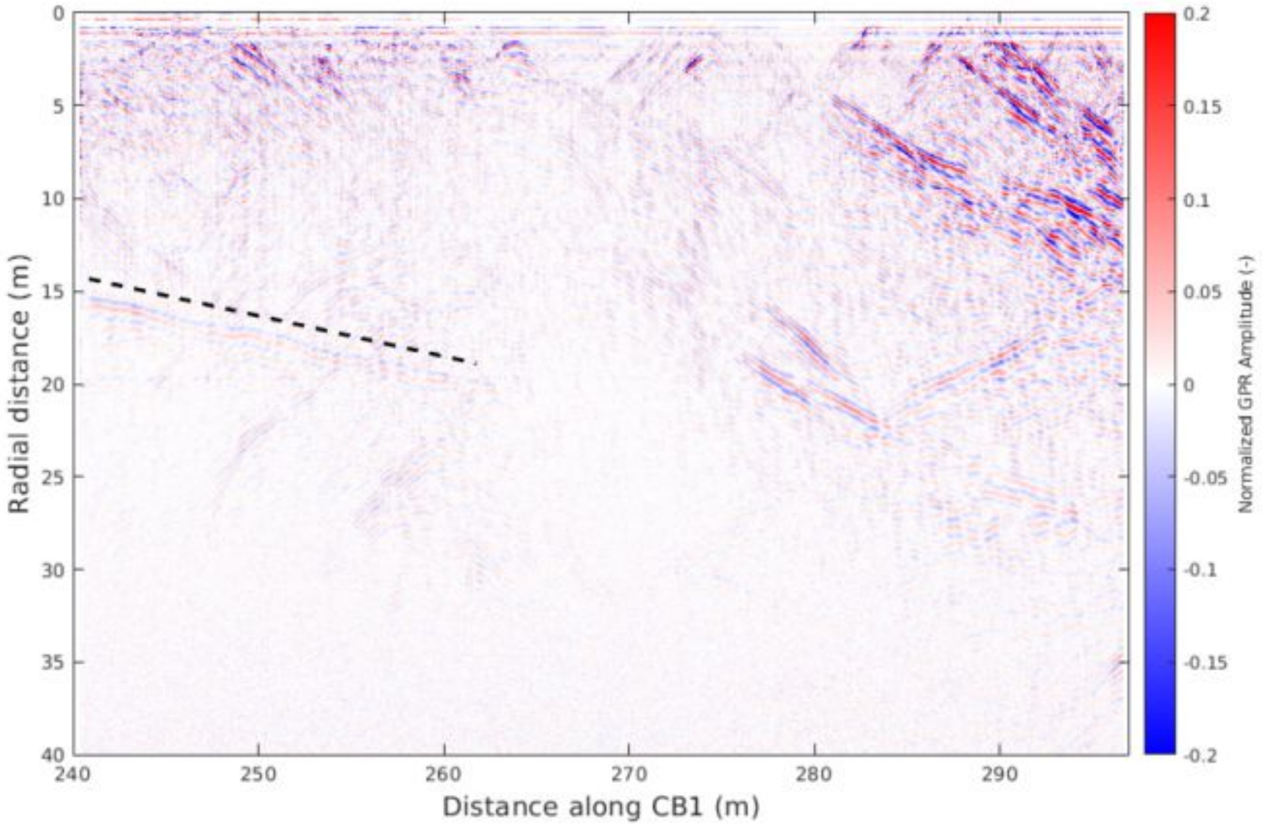
Seismicity during stimulation of top interval (STIM-269)

Image logs

- Most targeted intervals included exclusively natural fractures.
- Some intervals included axial fractures induced by minifracs tests (performed previous to the DESTRESS test).
- The presence of these axial fractures seems to have helped the stimulation of these otherwise tight intervals



Borehole Ground Penetrating Radar



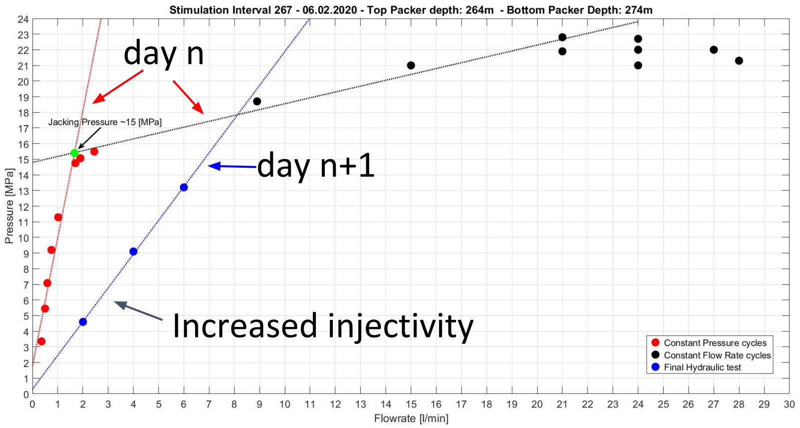
Difference for the 100 MHz GPR measurement induced by the stimulation experiments (ETH, unpublished).

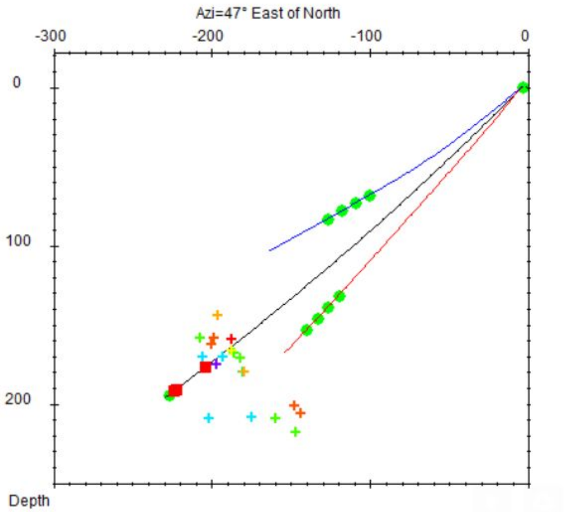
- Comparison of ground penetrating radar data before and after stimulation shows increased contrast in the lower (stimulated) part of well CB1.
- The main changes in reflectivity (hence aperture and water content of fractures) is seen in the lower interval of CB1, where GES successfully stimulated

DESTRESS

Achievements

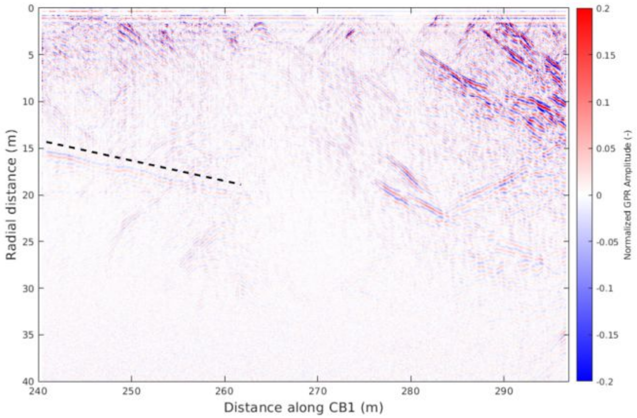
- The stimulation operations carried out in the Bedretto lab managed to successfully increase the transmissivity around the stimulated borehole by factors ranging from x7 to x60.
- Induced seismicity was detected. Magnitudes range between -3 and -2.6.
- Microseismicity was located around the well in the proximity of stimulated intervals





Seismicity during stimulation of interval STIM-269

BH GPR data shows increased amplitudes (increased aperture and water content) after the test stimulation



Lessons Learned

DESTRESS

- Stimulation of pre-existing structures in granitic rocks is possible with the consequent increase in transmissibility while keeping the induced seismicity to a minimum.
- Stimulation of tight structures (i.e. closed and healed fractures) proved to be very difficult.
- A previous step of controlled hydraulic fracturing might be necessary to run a successful shear stimulation afterwards in this kind of tight intervals (case of STIM-295).
- Previously open structures (STIM-267) can be successfully stimulated without previous hydraulic fracturing.

Preliminary conclusions and Perspectives

Preliminary analyses seem to indicate an increase of transmissibility values around the stimulated borehole. This increase in transmissibility was achieved while keeping induced seismicity to a minimum in terms of number of events and magnitudes.

Further analyses are planned on this dataset in order to consolidate the observations, draw definitive conclusions and formulate the lessons learned to be applied to the planning and execution of multi-stage stimulation.