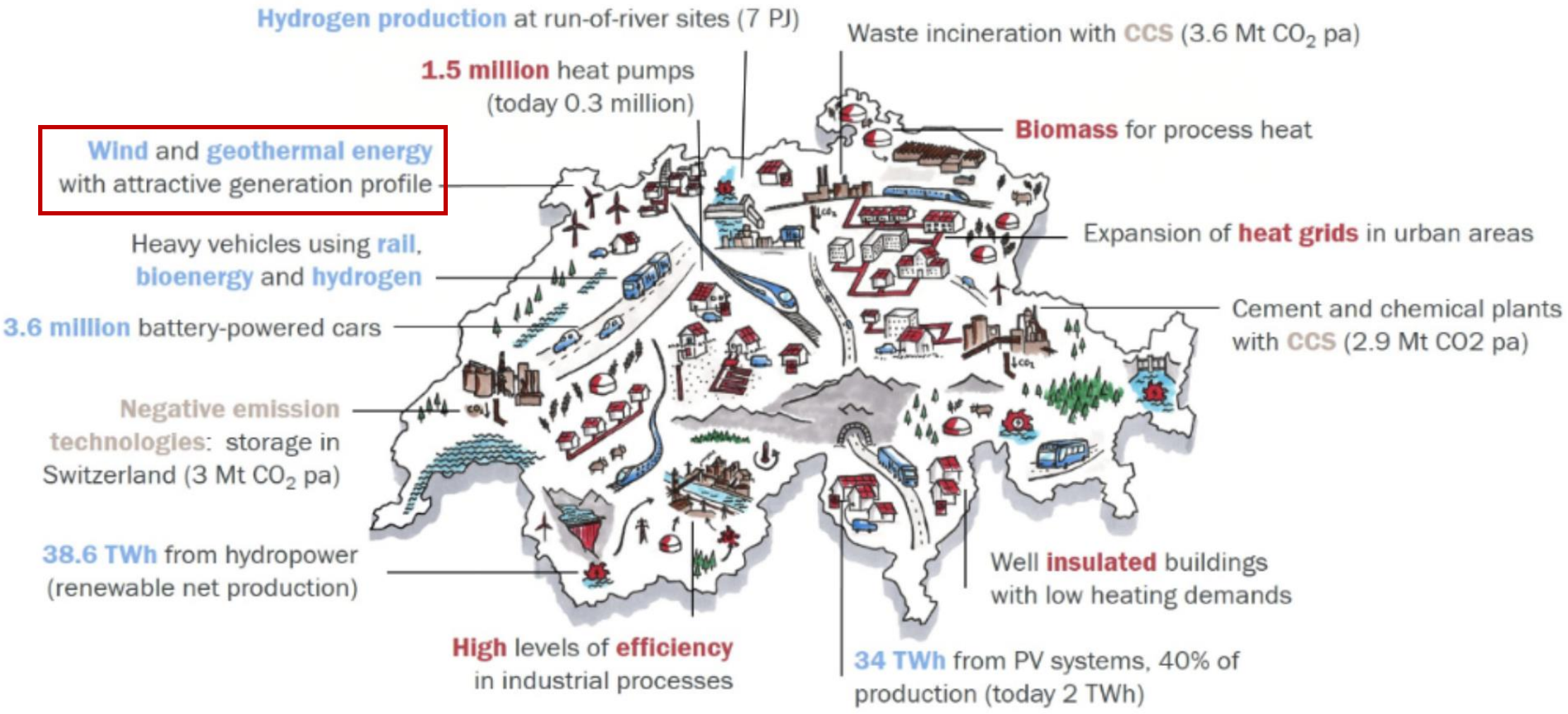
The BedrettoLab

Rebecca Hochreutener & Marian Hertrich

October 10th 2024

Swiss energy strategy 2050



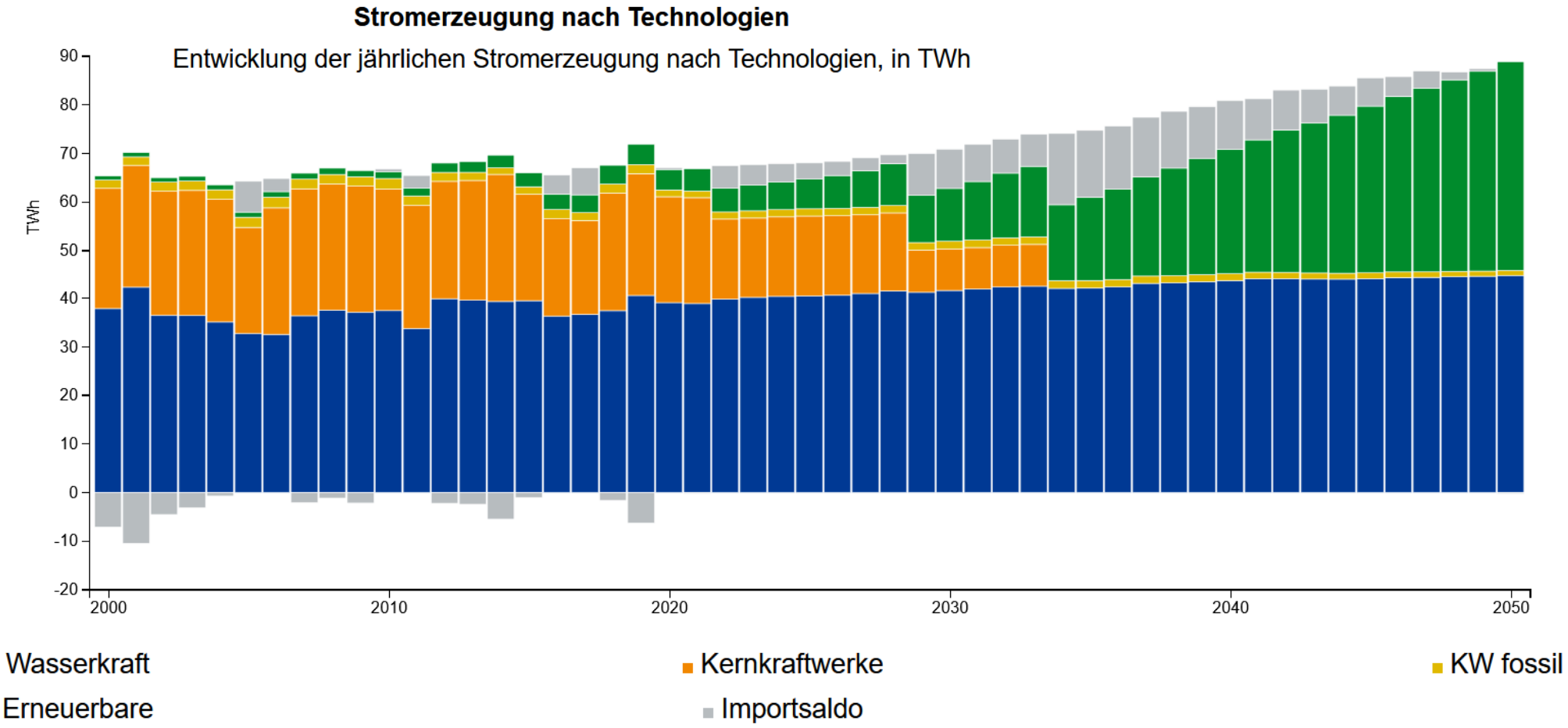
Graphics: Dina Tschumi; Prognos AG

Quelle Grafik links: https://www.bfe.admin.ch/bfe/de/home/politik/energieperspektiven-2050-plus.html

Swiss energy strategy 2050

Can we extract safely deep geothermal heat and produce at competitive costs 7% of the national baseload supply?

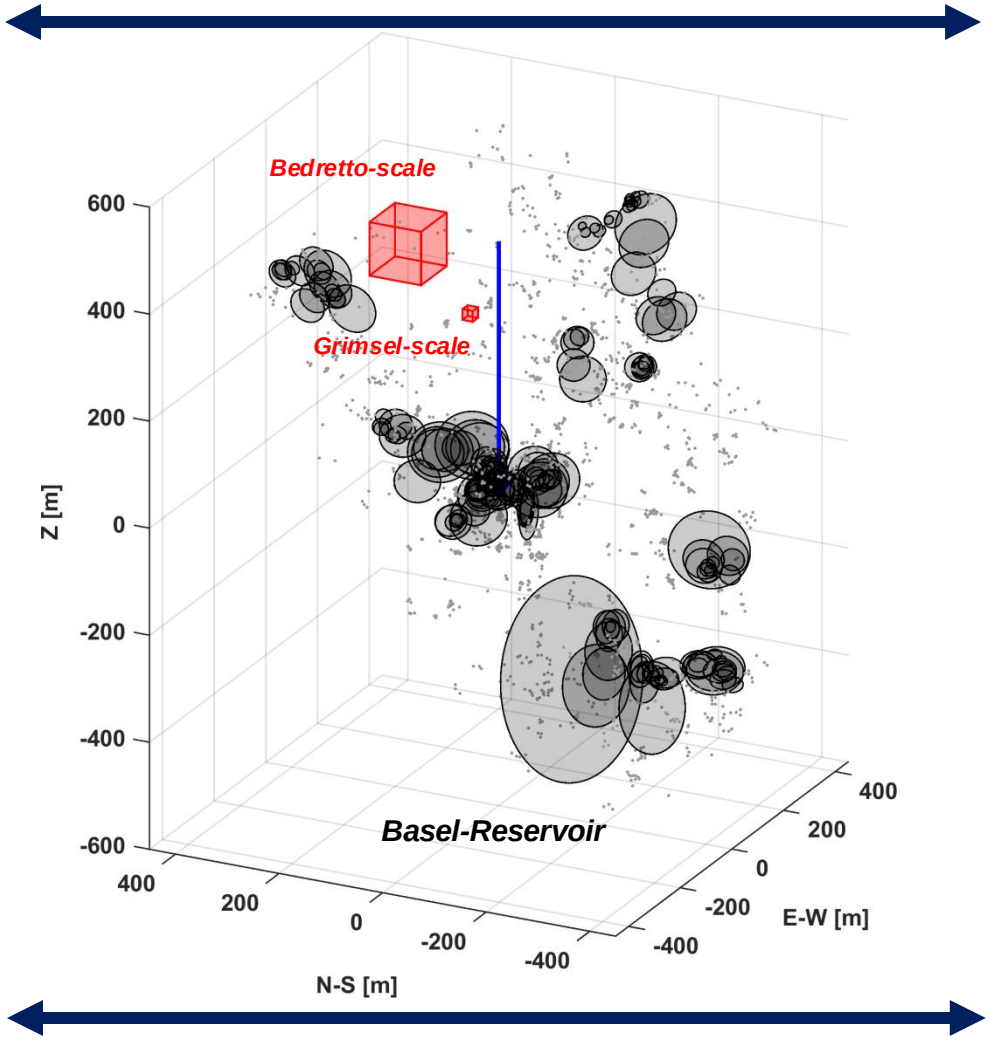
Can we use deep rock volumes as energy banks?

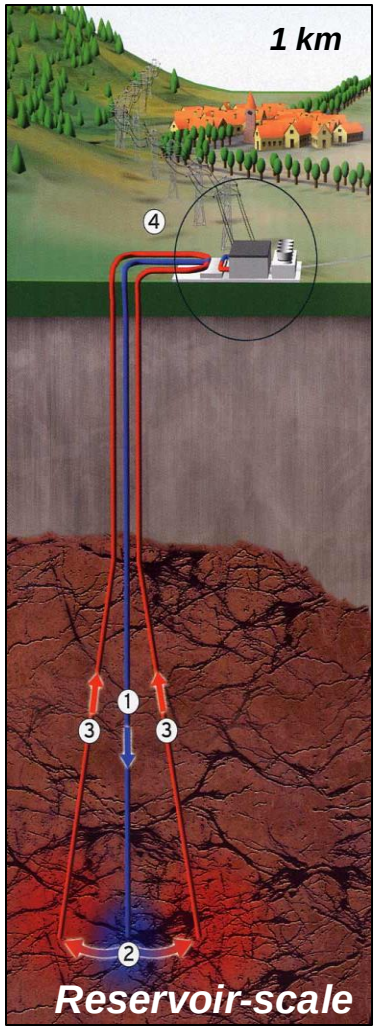


Source: https://www.uvek-gis.admin.ch/BFE/storymaps/AP_Energieperspektiven/index3.html?lang=de&selectedSzenario=ZB&selectedVariant=AJB&selectedNuclear=50

Deep Geothermal Energy (DGE)

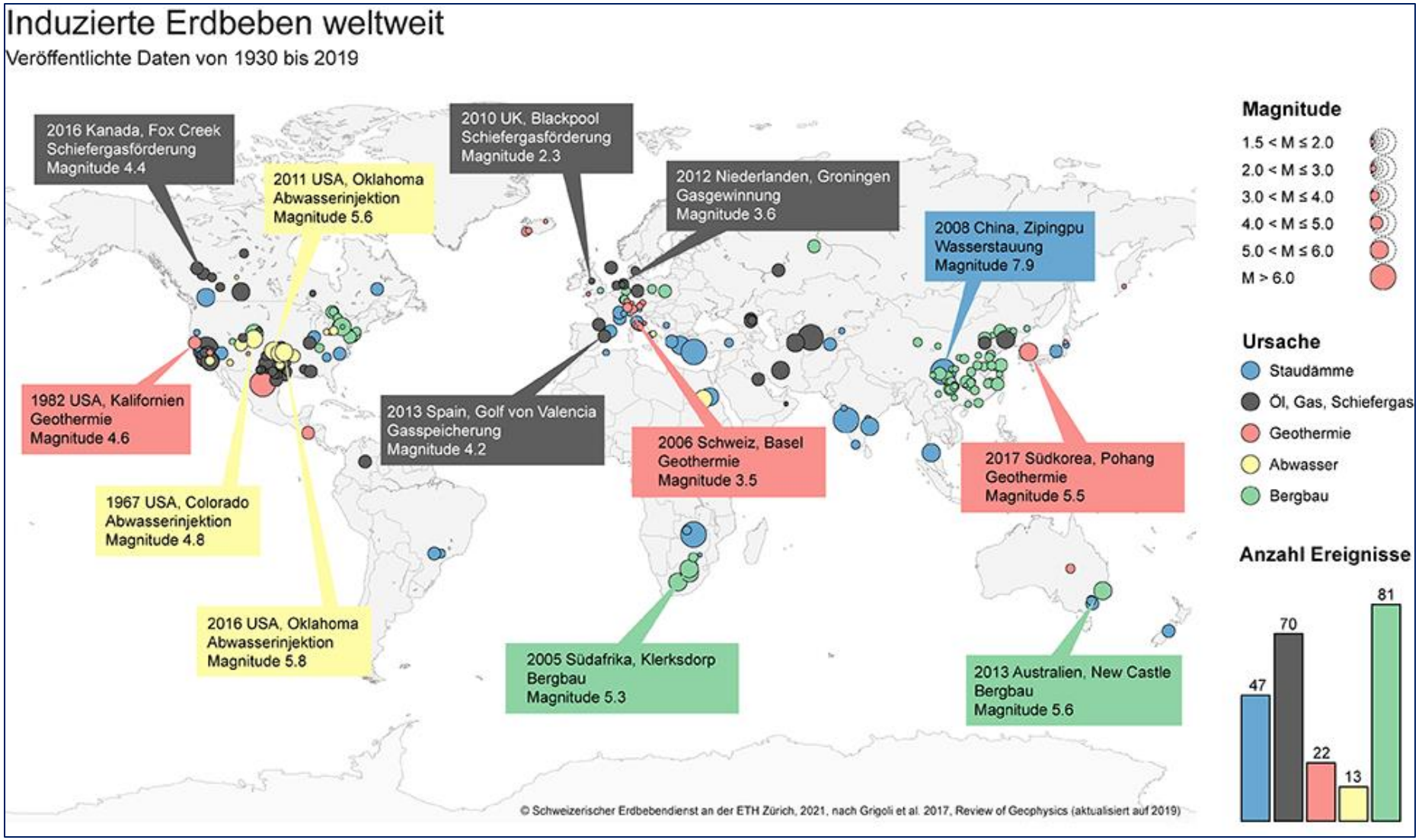
DGE is a possible source of up to 7% of future electricity supply in Switzerland → how can we establish a productive heat-exchanger at depth while controlling induced seismicity?





Induced seismicity worldwide

Induced seismicity is commonly observed in anthropogenic activities altering significantly the underground conditions of stress in the vicinity of seismogenic faults.

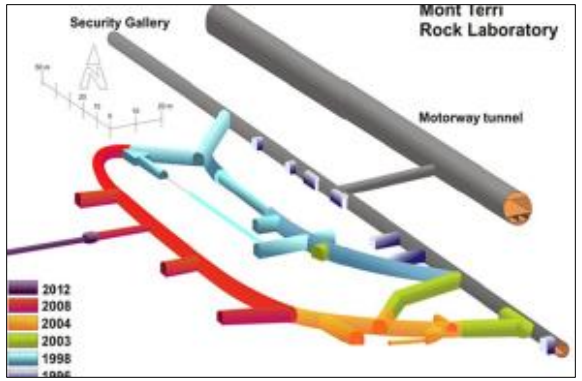


Underground laboratories in Switzerland

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

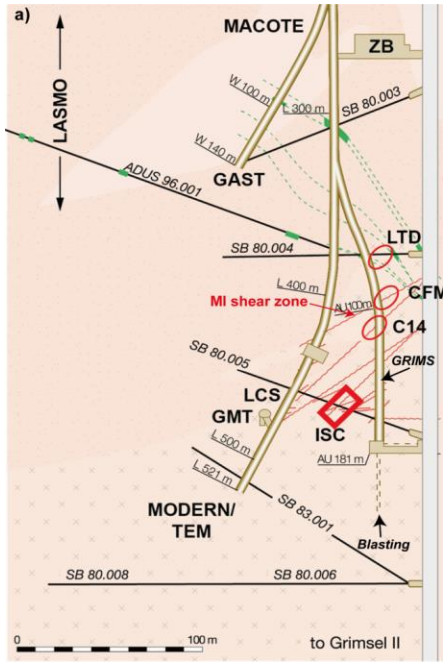
Federal Office of Topography swisstopo
www.swisstopo.ch

Mont Terri



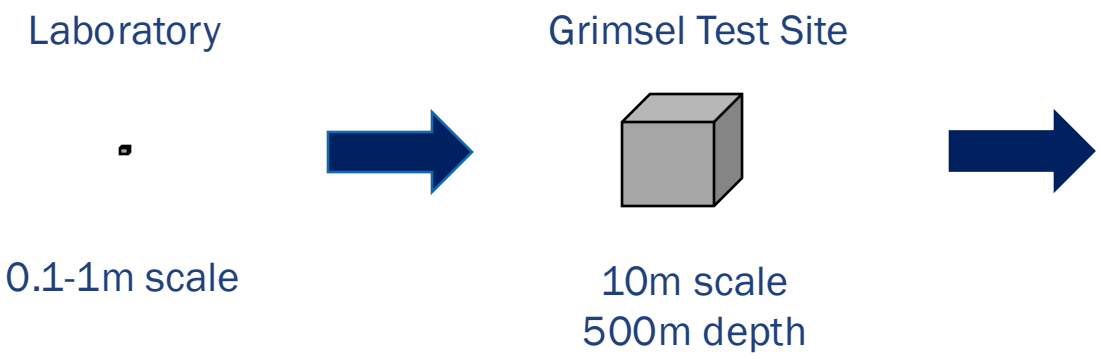
Grimsel

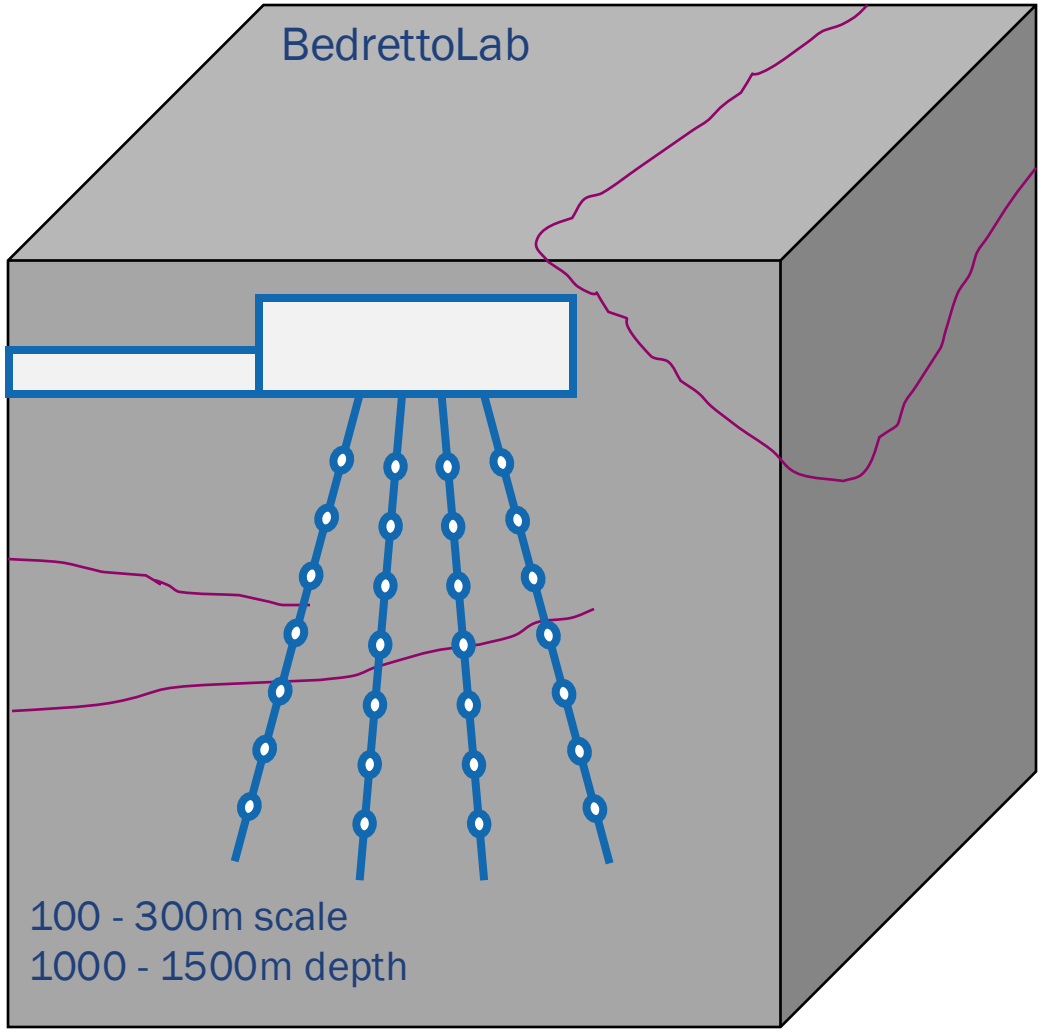
nagra.



The experimental approach

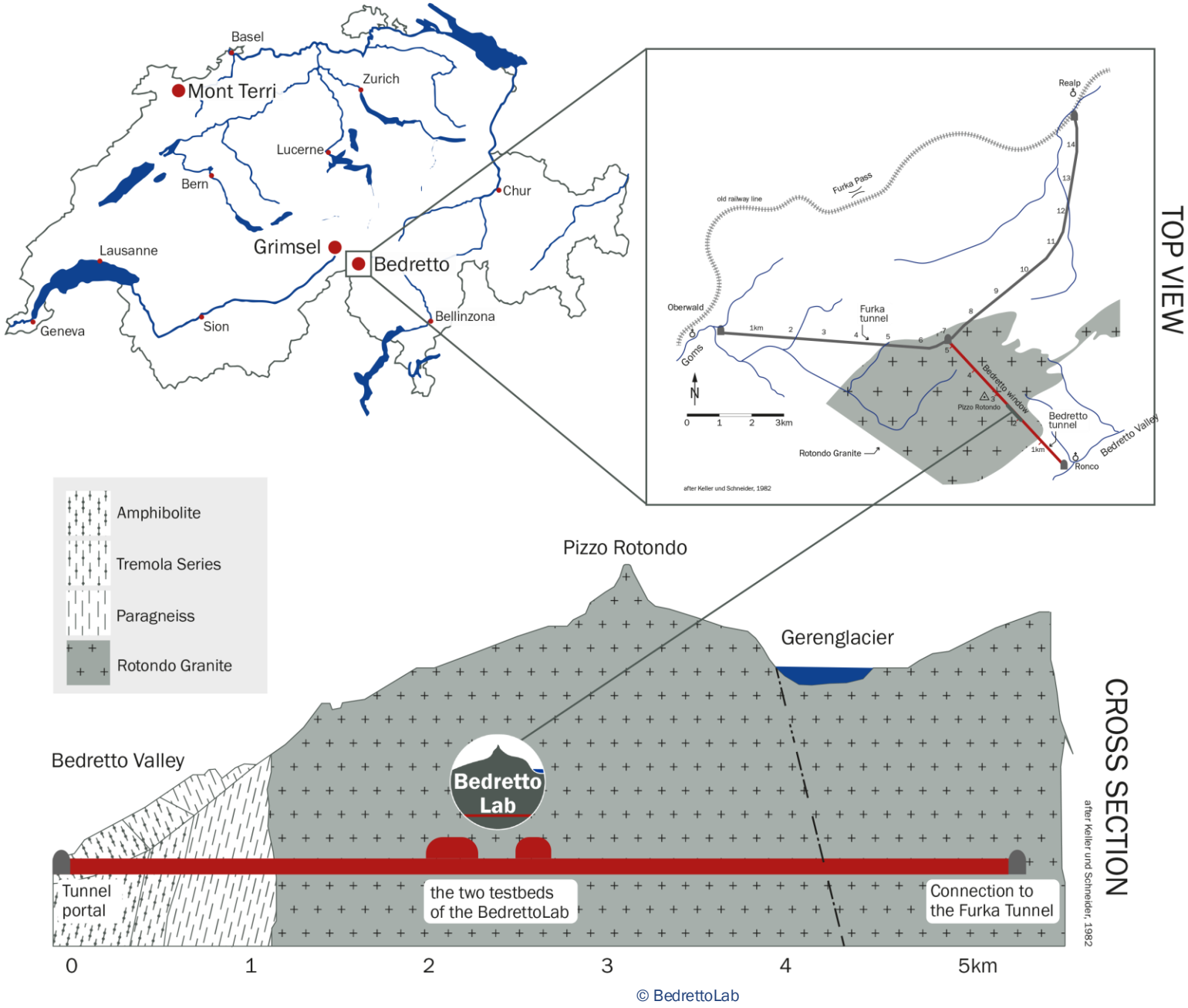
- Reach relevant depths, rock types and rock volumes
- Build an in-situ lab in these conditions
- Build experimental testbeds designed for specific scientific targets (geothermal energy, earthquake physics), cementing hundreds of sensors in deep boreholes to measure all physical and chemical parameters, and transforming the target rock volume in a large sensing environment





The BedrettoLab

- 5.2km long, connecting the Furka train tunnel to the Bedretto valley
- 1’000-1’500m overburden
- 3 large caverns, 6m wide and 50-100m long, ideal to host laboratories
- Remote area but excellent accessibility
- Two tunnel exits → safety!
- Longest tunnel of the Alps without wall overage, with complete access to bare rock face and faults
- Excellent cooperation by the owner MGB



History of the BedrettoLab

1973: built as a side-tunnel of the Furka base tunnel, as a possible train connection between Tessin and Valais

1983: abandoned after completion of the Furka railroad, partly blocked by rockfall

2000: first mapping and research

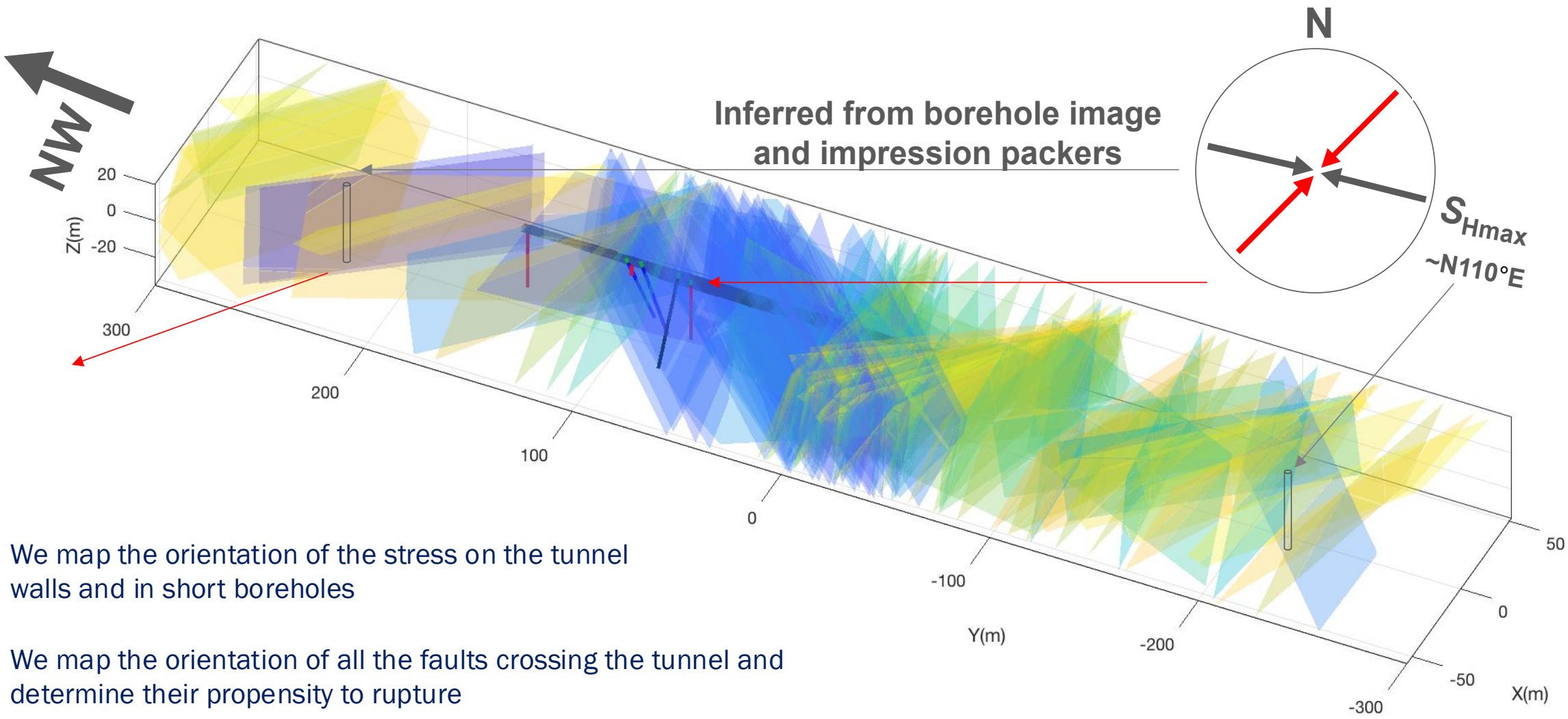
2012: partial reconditioning for Furka ventilation, enabling access to the full tunnel

2018: the tunnel is selected by ETH to host the BedrettoLab, after a discussion in the Consiglio Cantonale Ticino

May 2019: inauguration of the BedrettoLab

Two phases of construction

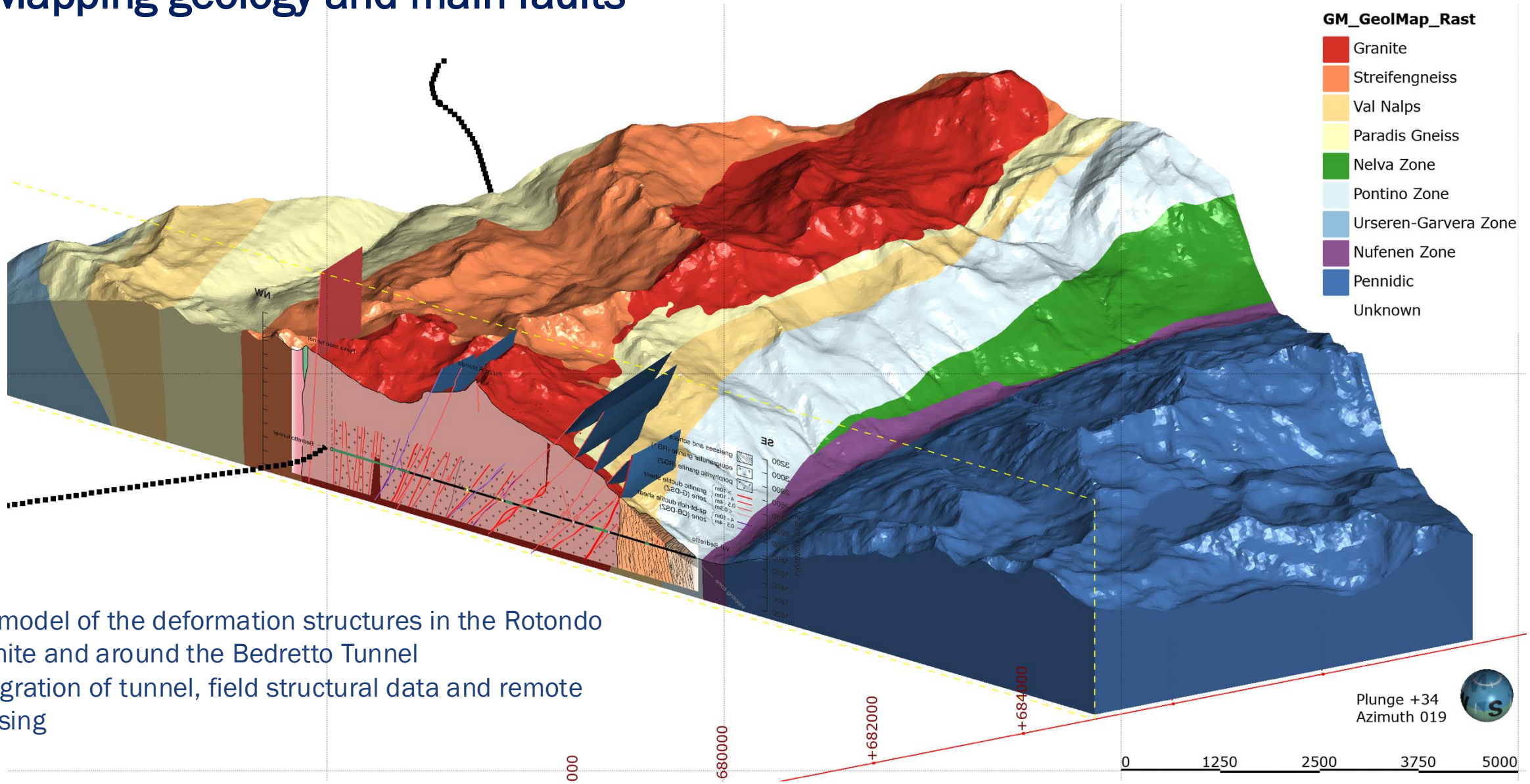
Mapping faults and stress orientation



We map the orientation of the stress on the tunnel walls and in short boreholes

We map the orientation of all the faults crossing the tunnel and determine their propensity to rupture

Mapping geology and main faults



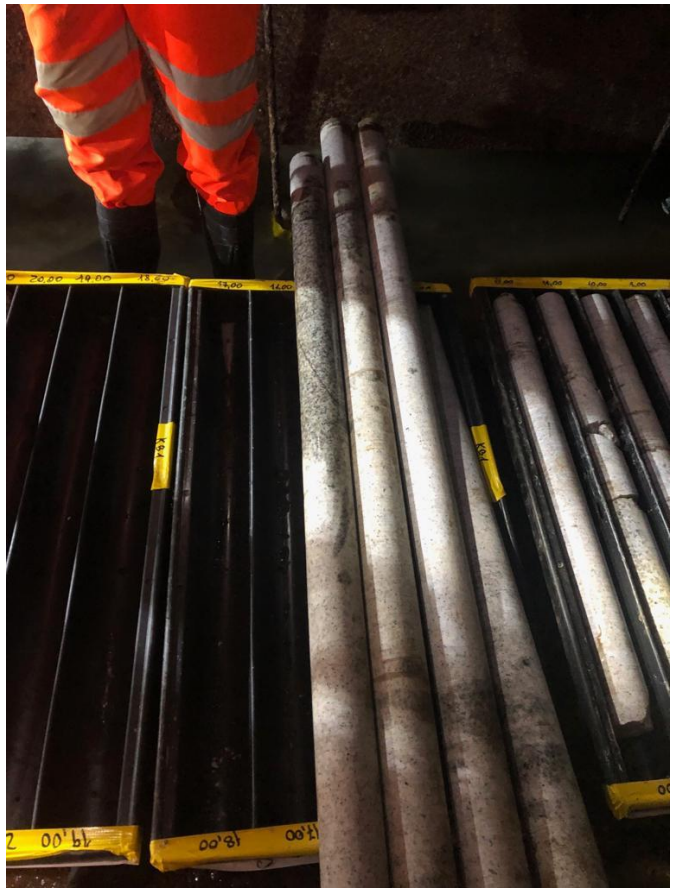
3D model of the deformation structures in the Rotondo granite and around the Bedretto Tunnel
Integration of tunnel, field structural data and remote sensing

(Ceccato, in preparation)

Kilometers of cores

A new storage facility built in Forch/Zääjuten, in a former military bunker near Zurich

All cores are scanned and fully characterized for the identification of faults



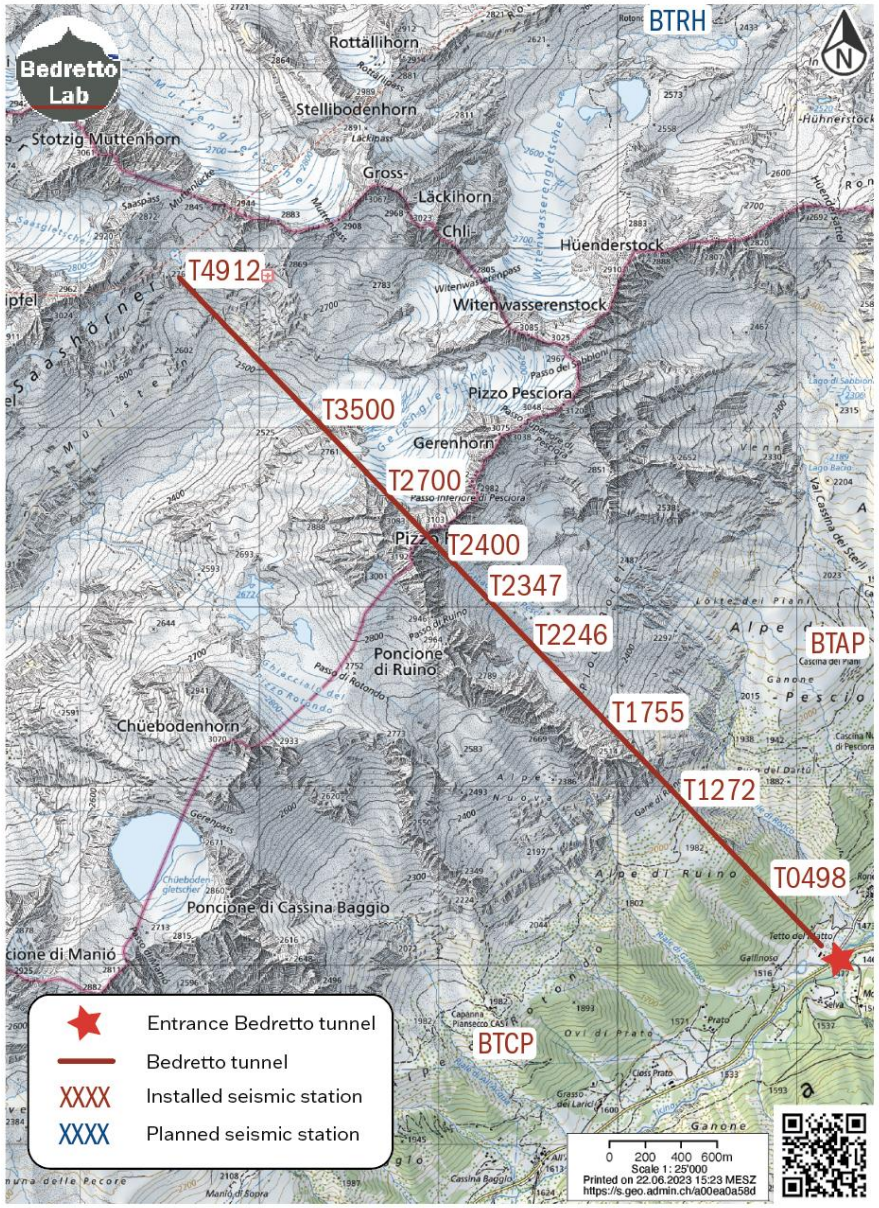
Seismic background monitoring

A dense, real-time, multi-sensor seismic array installed in the tunnel and on the surface… which sometimes also need protection !

BTAP seismic station

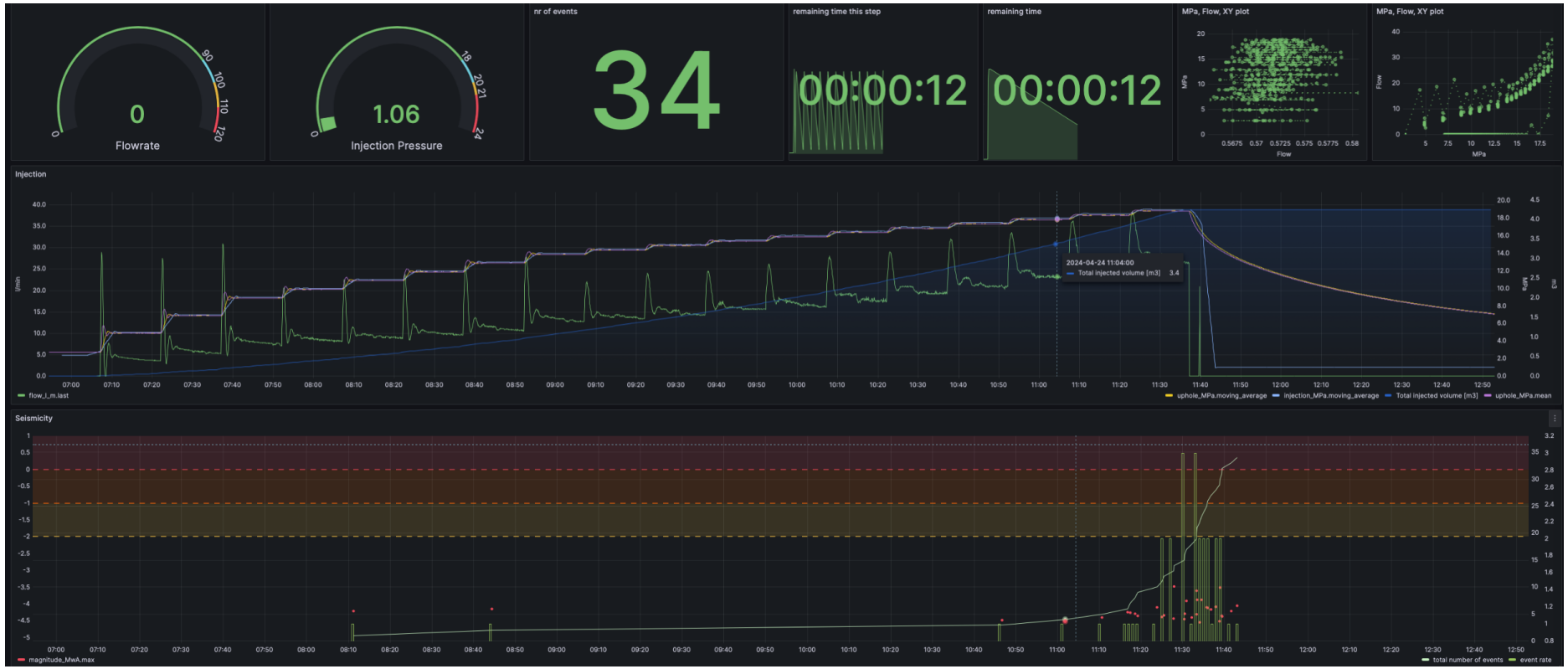
	Green (less than)		Yellow (greater equal)		Orange (greater equal)		Red (greater equal)	
	Mw	Ml	Mw	Ml	Mw	Ml	Mw	Ml
>50 m	-1	-2.75	-1	-2.75	0	-1.25	1	0.25
>100 m	-0.5	-2	-0.5	-2	0.5	-0.5	1.5	1
>150 m	-0.15	-1.5	-0.15	-1.5	0.85	0	2	1.75

Strict traffic light protocols. And yes, magnitudes can be negative !



Experiment Automatization - Remote Control

All experiment operations and data are visible directly through the Grafana Dashboard



a unique underground laboratory for Switzerland

Fundamental Research

Earthquake Physics: How do earthquakes start and stop? How do faults interact with the rock volume during an earthquake?

Hydromechanics: How does injected water changes rock conditions and brings it to failure? How is energy distributed in a fractured medium?

Geobiology: Life forms that exist and can develop in extreme environments; primordial life forms

Areas of societal relevance

Geoenergy: Safe and sustainable use of deep geothermal energy; heat storage in deep crystalline rock reservoirs

Earthquake risk: Possible identification of earthquake precursors and faults prone to fail

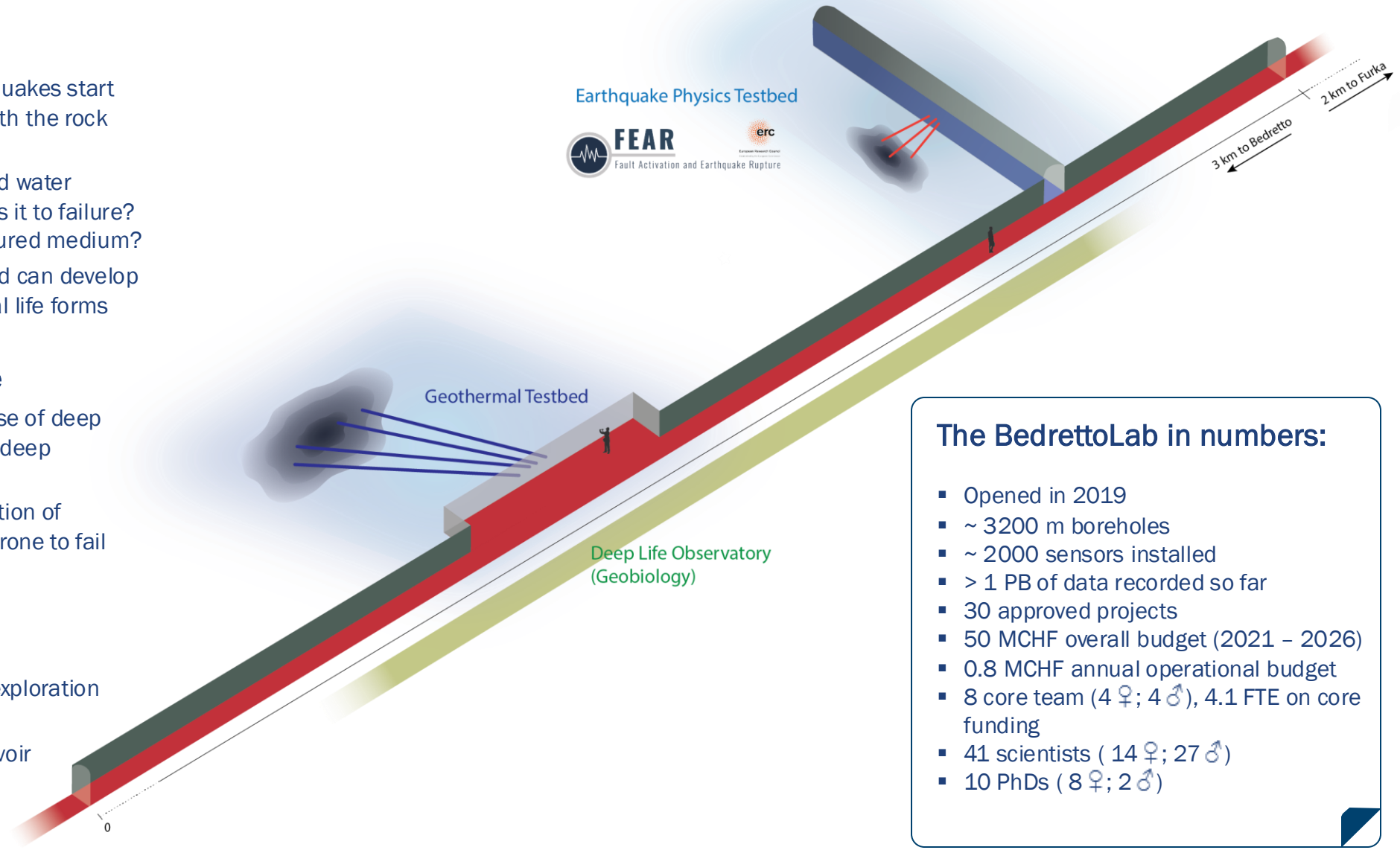
Origin and prevalence of life

Technology development

New instruments for underground exploration and monitoring

300-m scale fully engineered reservoir

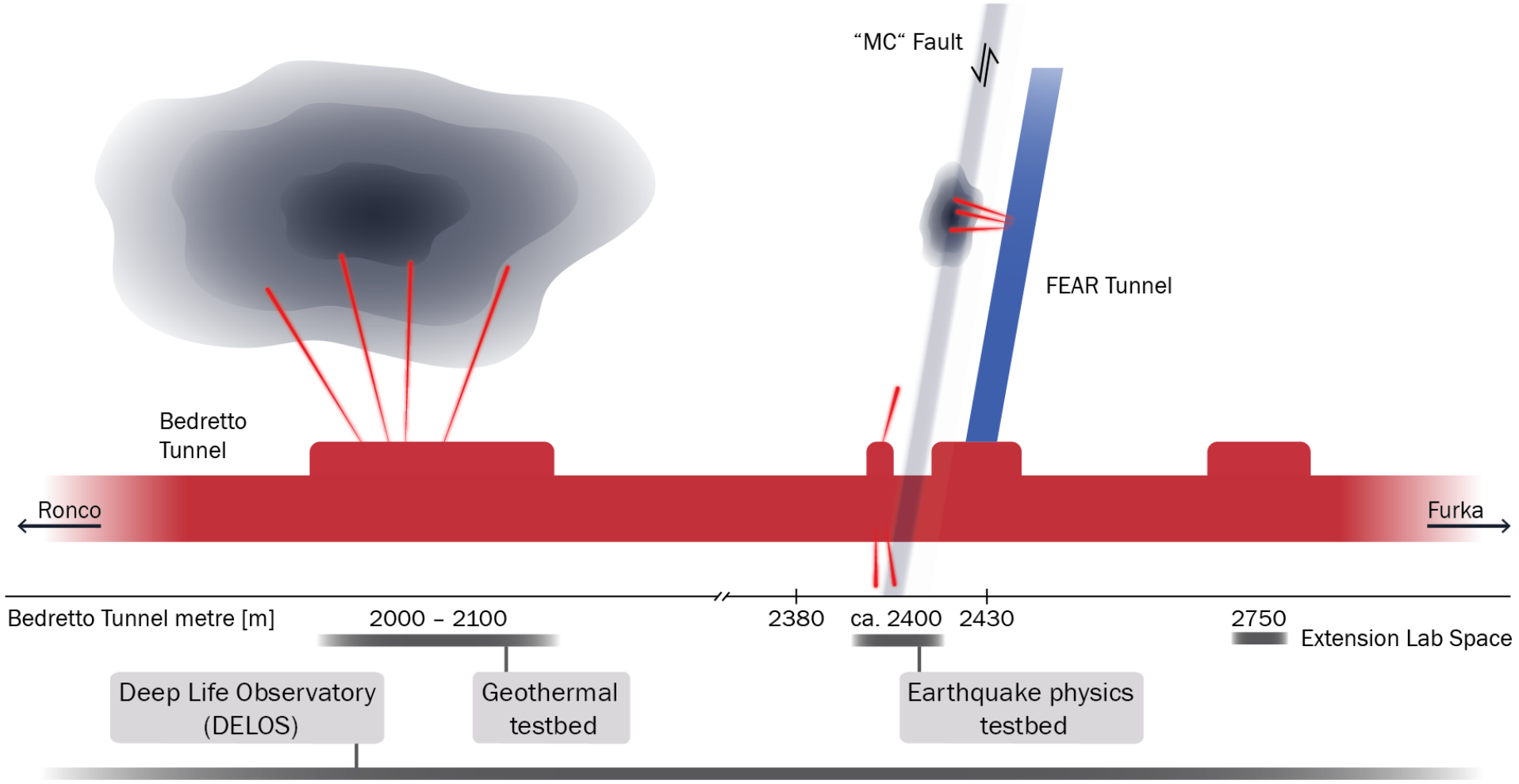
First-ever on-fault observatory



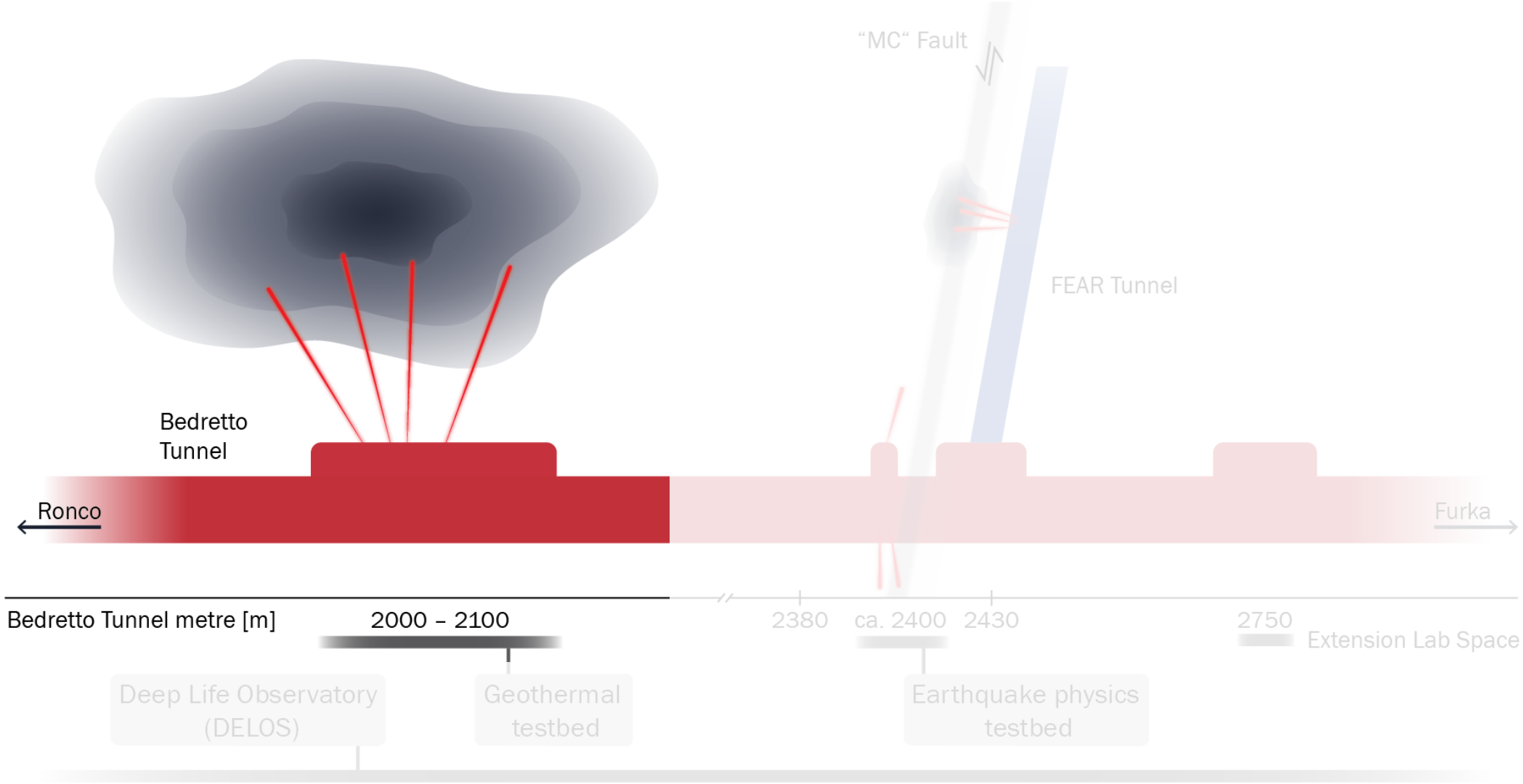
The BedrettoLab in numbers:

- Opened in 2019
- ~ 3200 m boreholes
- ~ 2000 sensors installed
- > 1 PB of data recorded so far
- 30 approved projects
- 50 MCHF overall budget (2021 – 2026)
- 0.8 MCHF annual operational budget
- 8 core team (4 ♀; 4 ♂), 4.1 FTE on core funding
- 41 scientists (14 ♀; 27 ♂)
- 10 PhDs (8 ♀; 2 ♂)

Three primary testbeds



Geothermal testbed



How it all began

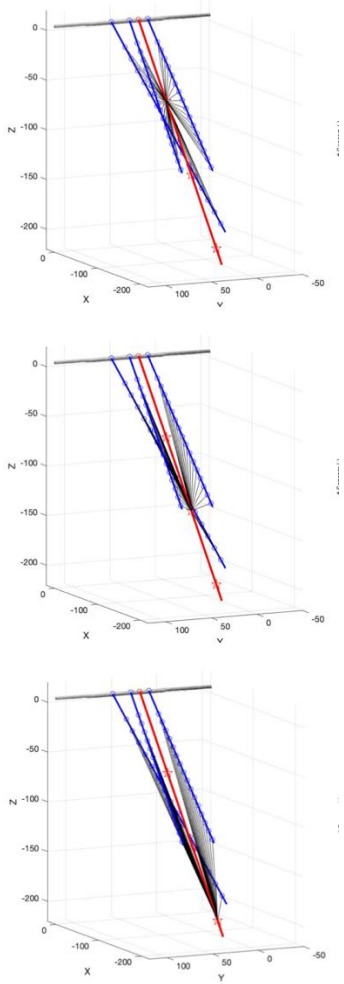
SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

3rd Schatzalp Workshop on Induced Seismicity 2019

ETH zürich

Design of the seismic monitoring network for the stimulation experiments in the Bedretto Deep Underground Rock Laboratory

Marian Hertrich, Linus Villiger, Joseph Doetsch, Anne Obermann, Xiaodong Ma, Nima Gholizadeh
ETH Zurich, SCCER-SoE, Switzerland, marian.hertrich@sccer-soe.ethz.ch



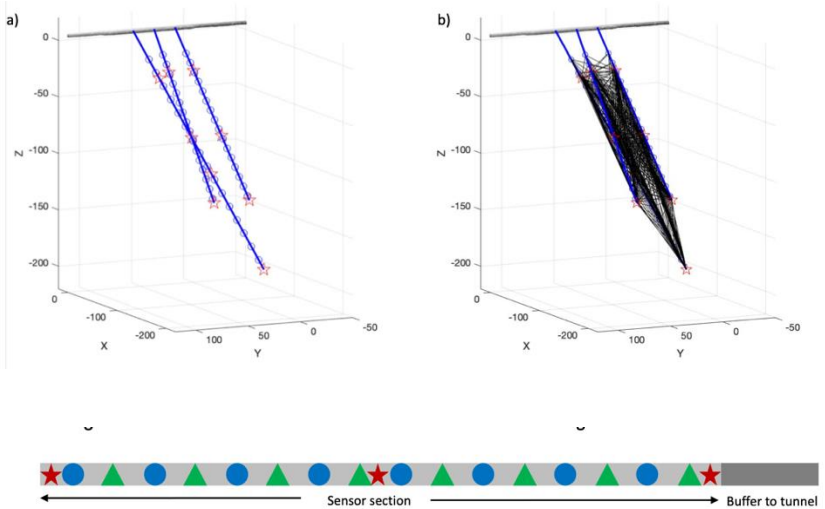


Figure 3: Conceptional instrumentation of a seismic monitoring borehole:
- 8 x high-sensitive acoustic emission sensors
- 8 x 3-component, calibrated accelerometers
- 3 x downhole sources per borehole for active tomography (piezo)

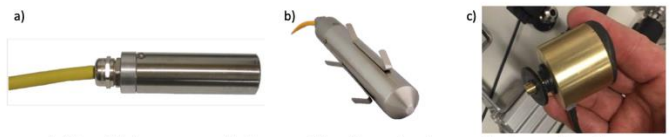
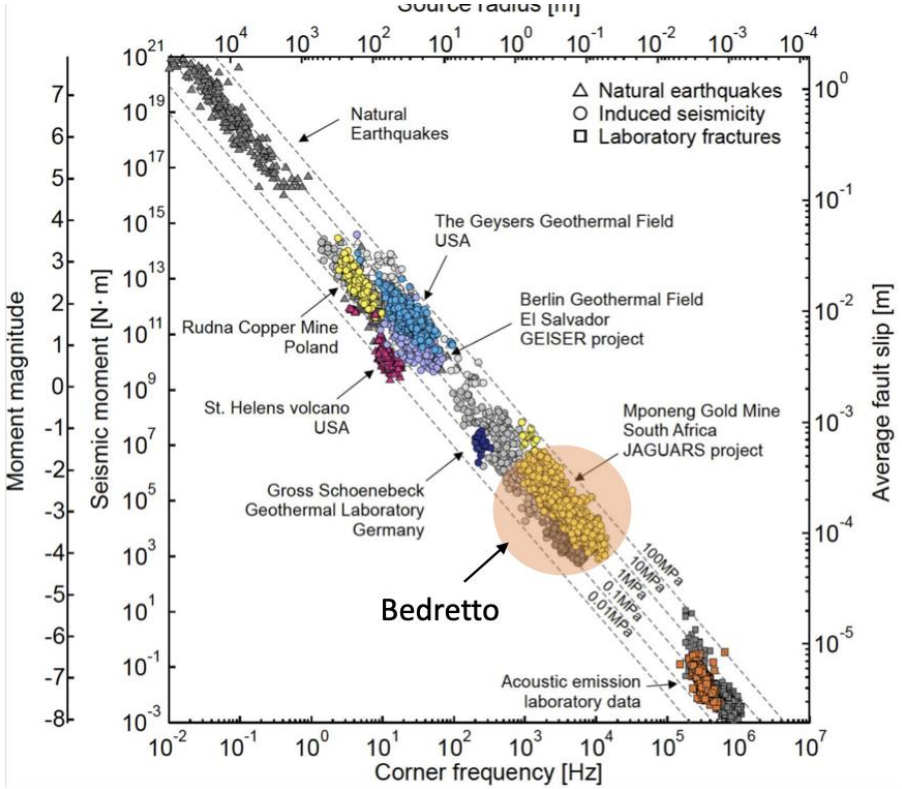


Figure 4: Candidate sensors to be used for the seismic monitoring network:
a) IMS 25 kHz accelerometer, frequency range: 2Hz – 25kHz, sensitivity: 0.1V/g
b) IMS 14Hz geophone, natural frequency: 14Hz, sensitivity: 56.1V/m/s
c) GMuG piezo acoustic emission sensor, frequency range: 50Hz – 35kHz



VALTER

DESTRESS

ZoDrEx

SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

ETH Zürich

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

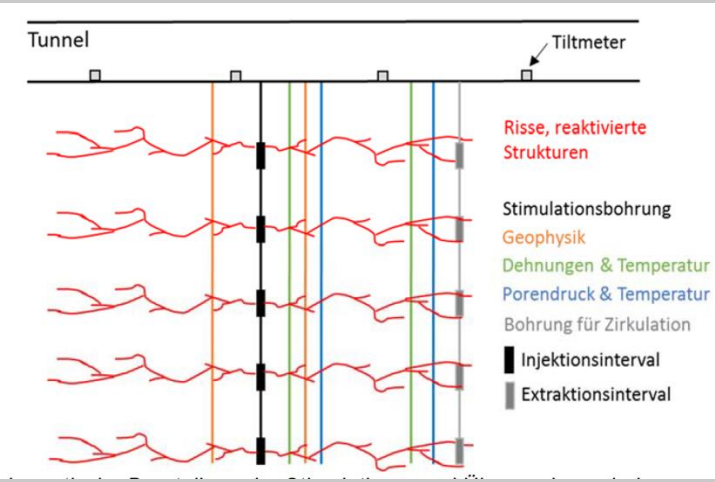
Bundesamt für Energie BFE
Swiss Federal Office of Energy SFOE

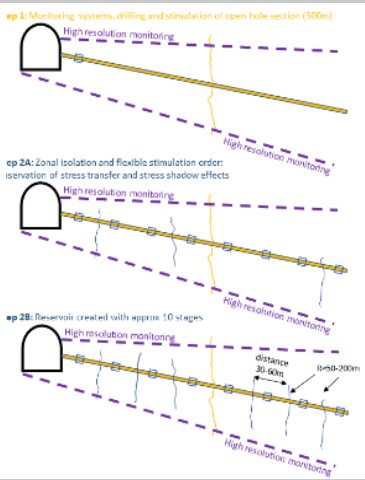
European Commission | Horizon 2020
European Union funding
for Research & Innovation

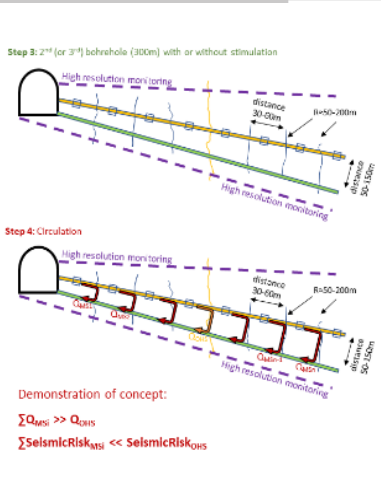
GEOTHERMICA

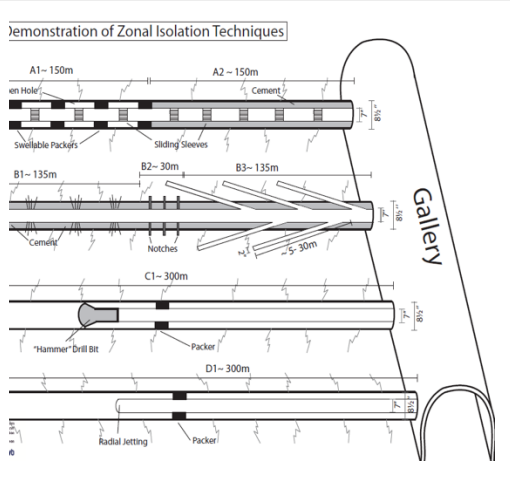
GEO ENERGIE SUISSE

GEO ENERGIE SUISSE









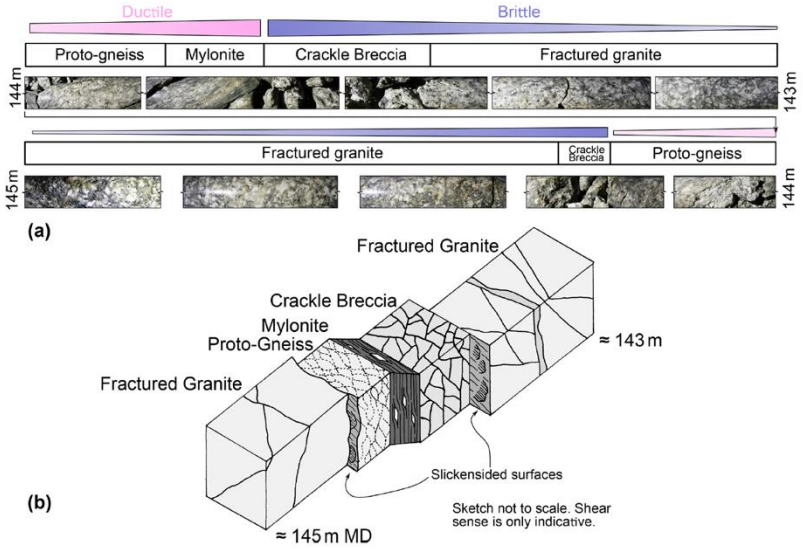
After three boreholes drilled

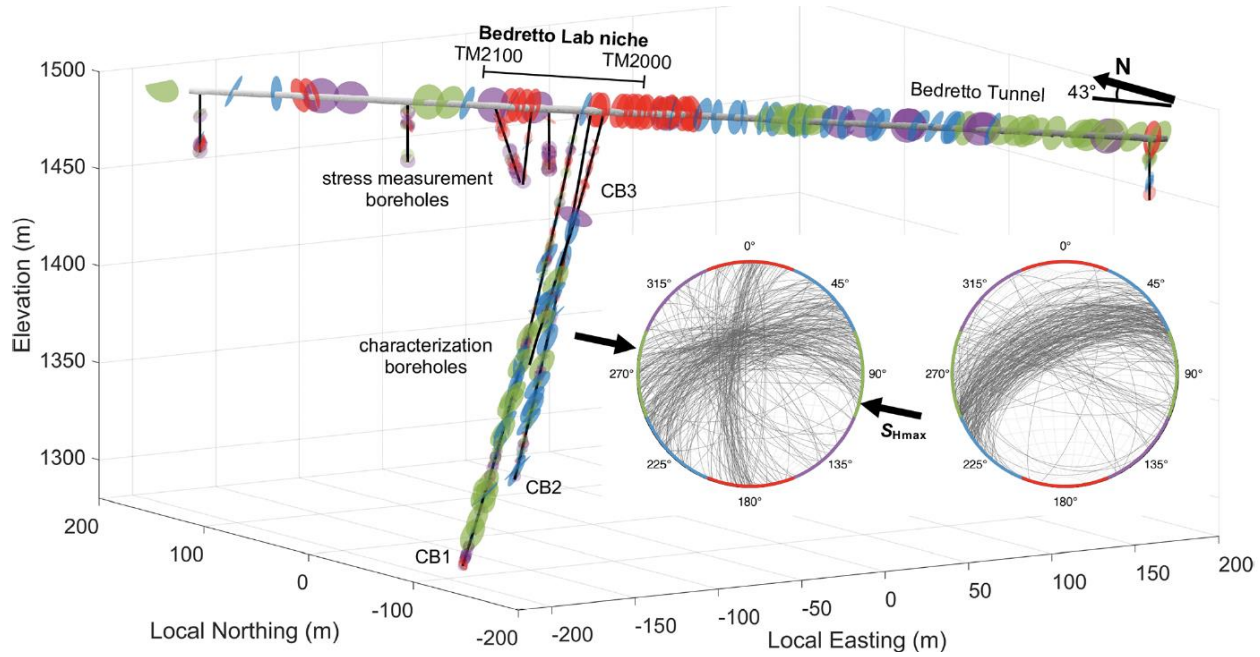
Solid Earth, 13, 301–322, 2022
https://doi.org/10.5194/se-13-301-2022

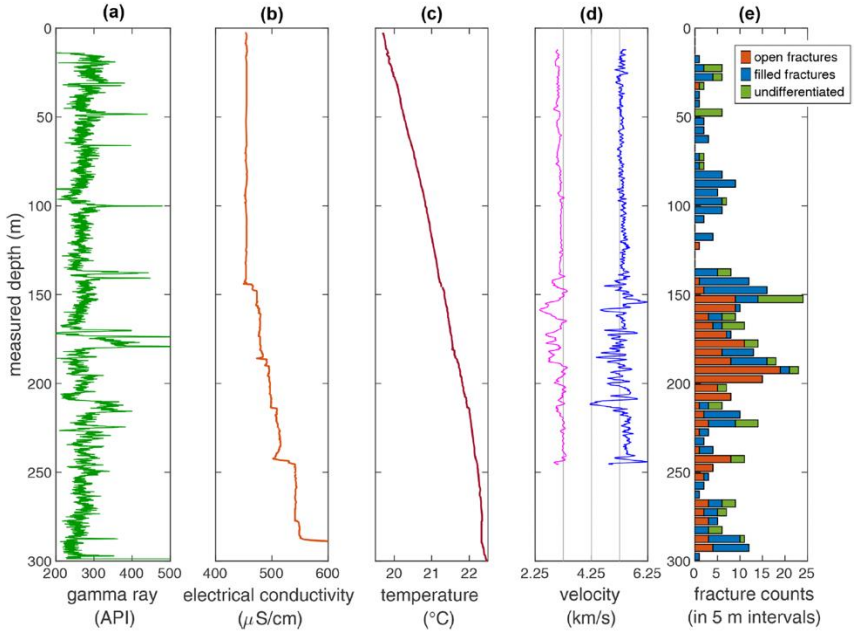
Solid Earth Open Access EGU

Multi-disciplinary characterizations of the BedrettoLab – a new underground geoscience research facility

Xiaodong Ma[1], Marian Hertrich[1], Florian Amann[2], Kai Bröker[1], Nima Gholizadeh Doonechaly[1], Valentin Gischig[3], Rebecca Hochreutener[1], Philipp Kästli[1], Hannes Krietsch[2], Michèle Marti[1], Barbara Nägeli[1], Morteza Nejati[1], Anne Obermann[1], Katrin Plenkers[1], Antonio P. Rinaldi[1], Alexis Shakas[1], Linus Villiger[1], Quinn Wenning[1], Alba Zappone[1], Falko Bethmann[4], Raymi Castilla[4], Francisco Seberto[4], Peter Meier[4], Thomas Driesner[1], Simon Loew[1], Hansruedi Maurer[1], Martin O. Saar[1], Stefan Wiemer[1], and Domenico Giardini[1]







Characterization by GPR

Geophysical Research Letters

RESEARCH LETTER
10.1029/2020GL088783

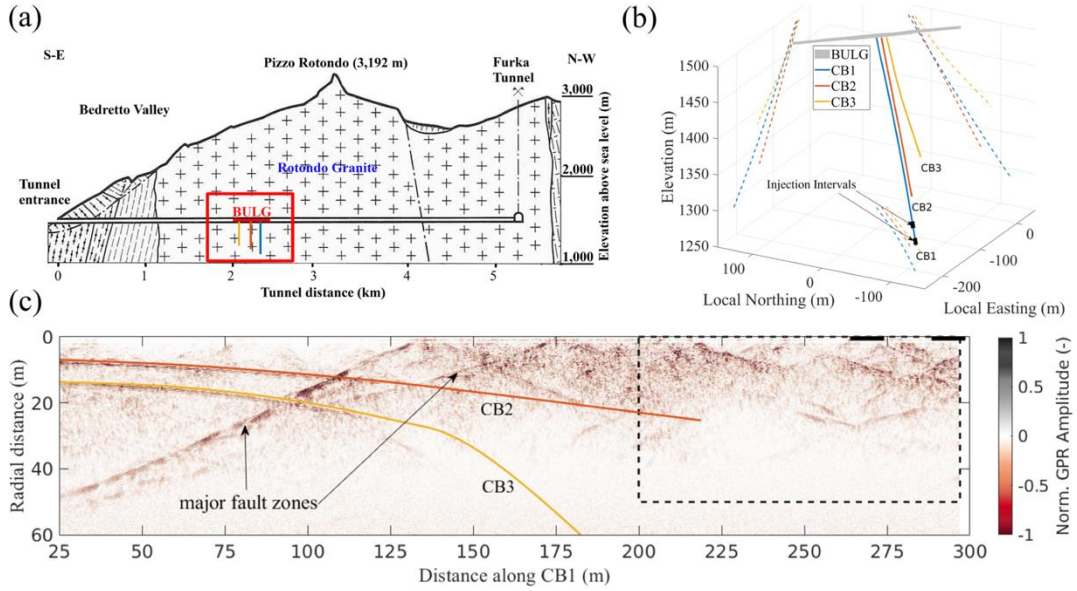
Permeability Enhancement From a Hydraulic Stimulation Imaged With Ground Penetrating Radar

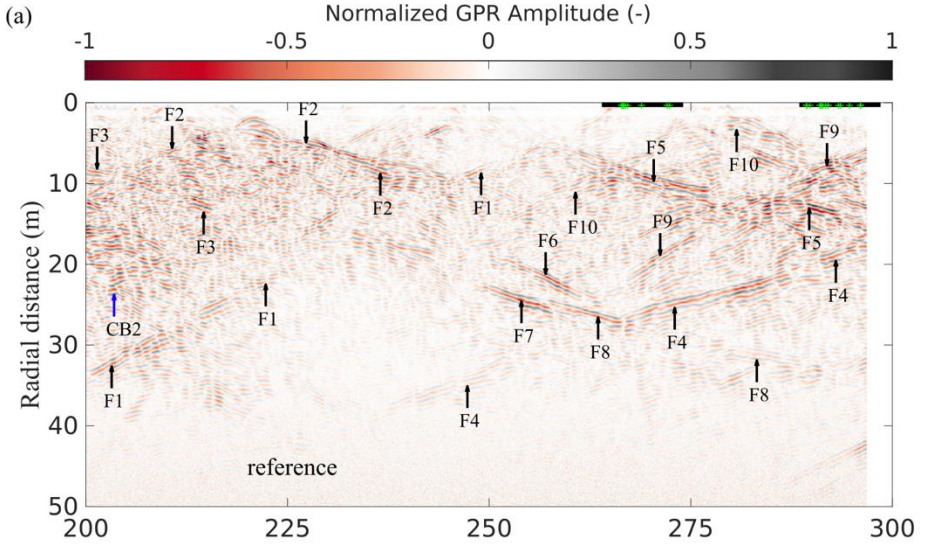
A. Shakas[1], H. Maurer[1], P.-L. Giertzuch[1], M. Hertrich[1], D. Giardini[1], F. Serbeto[2], and P. Meier[2]

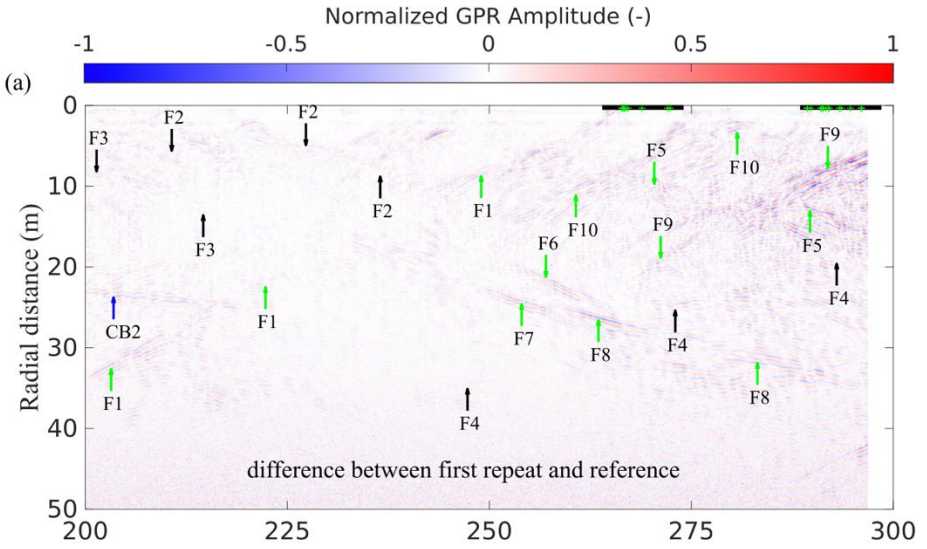
[1]Department of Earth Sciences, ETH Zurich, Zurich, Switzerland, [2]Geo-Energie Suisse AG, Zurich, Switzerland

Key Points:

- First-time direct imaging of stimulation-enhanced permeability in fractured rock
- GPR difference imaging reveals the DFN enhanced by the stimulation
- Information gained about the stimulation volume and radial







A first conceptual geological model

Conceptual Geological Model of the Bedretto Underground Laboratory for Geoenergies

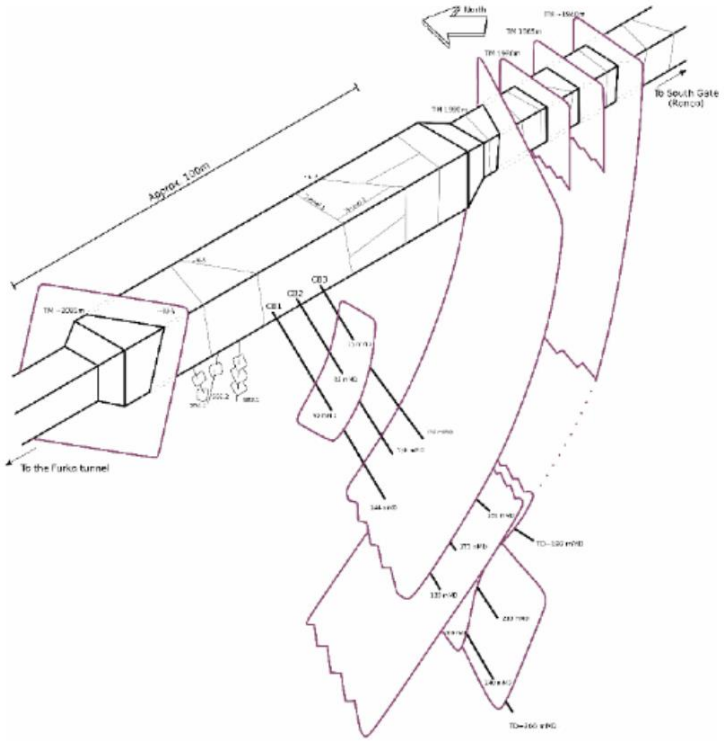
Authors R. Castilla[1], H. Krietsch[2], D. Jordan[2], X. Ma[2], F. Serbeto[1], A. Shakas[2], P. Guntli[3], K. Bröker[2], Meier[1]

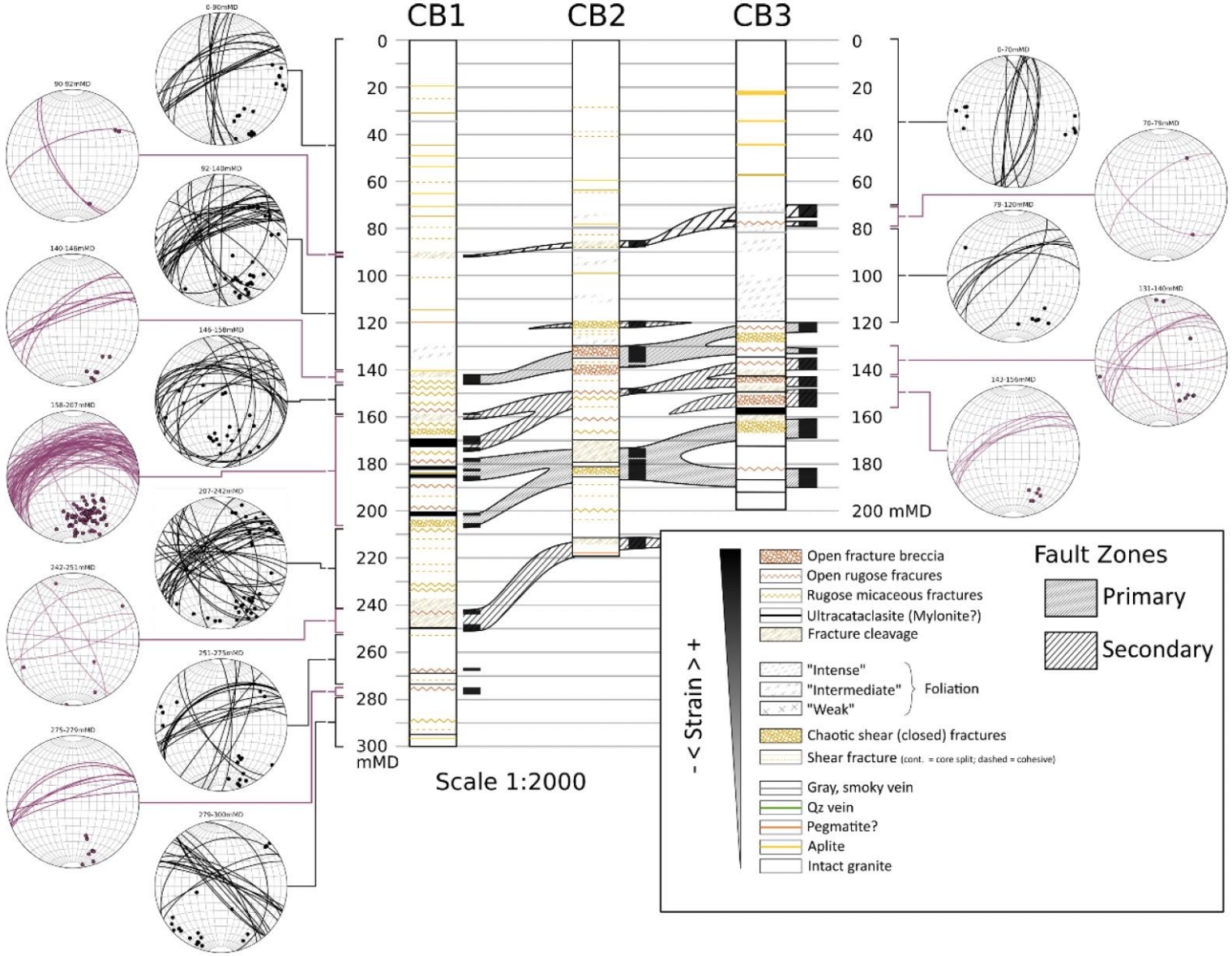
View Affiliations

Publisher: European Association of Geoscientists & Engineers

Source; 82nd EAGE Annual Conference & Exhibition, Oct 2021, Volume 2021, p.1 - 5

DOI: https://doi.org/10.3997/2214-4609.202011912





Stress State in the BedrettoLab

JGR Solid Earth

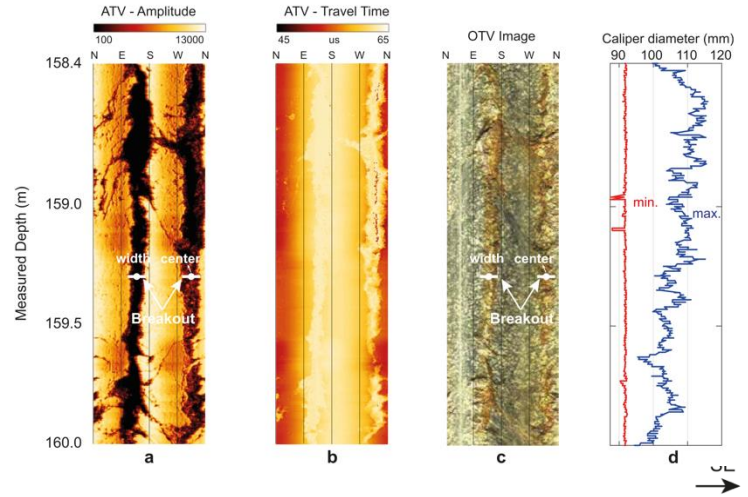
RESEARCH ARTICLE
10.1029/2023JB026477

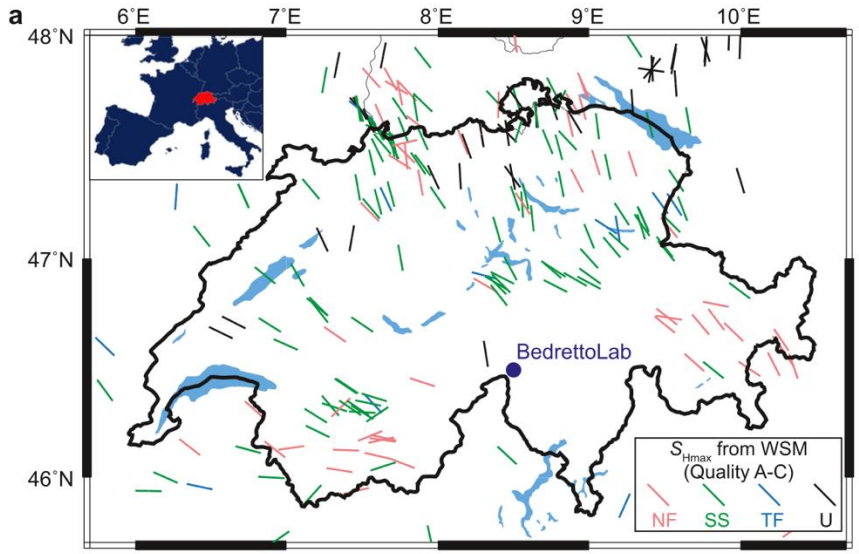
Special Section:
Heterogeneity, anisotropy and scale-dependency: Keys to understand Earth composition, structure and behavior

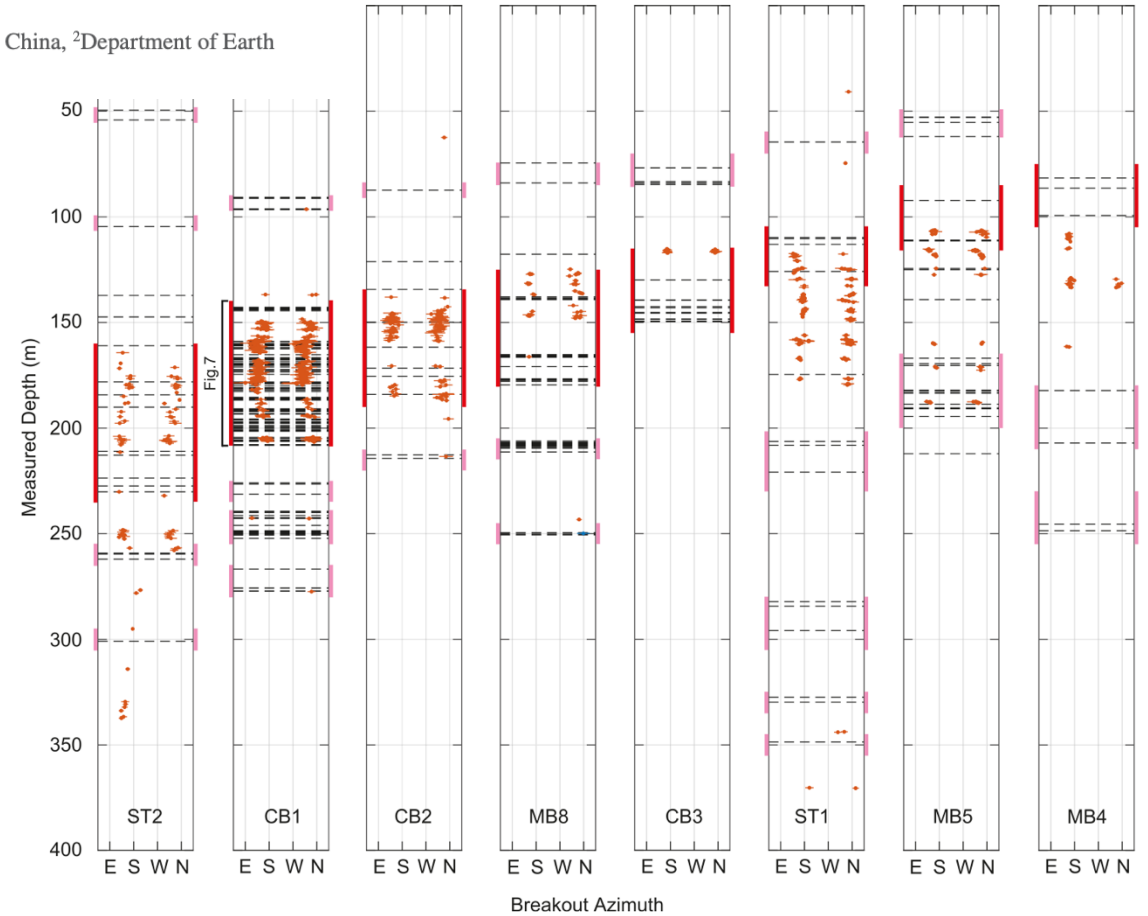
Fault Zone Spatial Stress Variations in a Granitic Rock Mass: Revealed by Breakouts Within an Array of Boreholes

Shihuai Zhang[1], Xiaodong Ma[1], Kai Bröker[2], Rutger van Limborgh[2], Quinn Wenning[2], Marian Hertrich[2], and Domenico Giardini[2]

[1]School of Earth and Space Sciences, University of Science and Technology of China, Hefei, China, [2]Department of Earth Sciences, ETH Zürich, Zürich, Switzerland







Valter Instrumentation

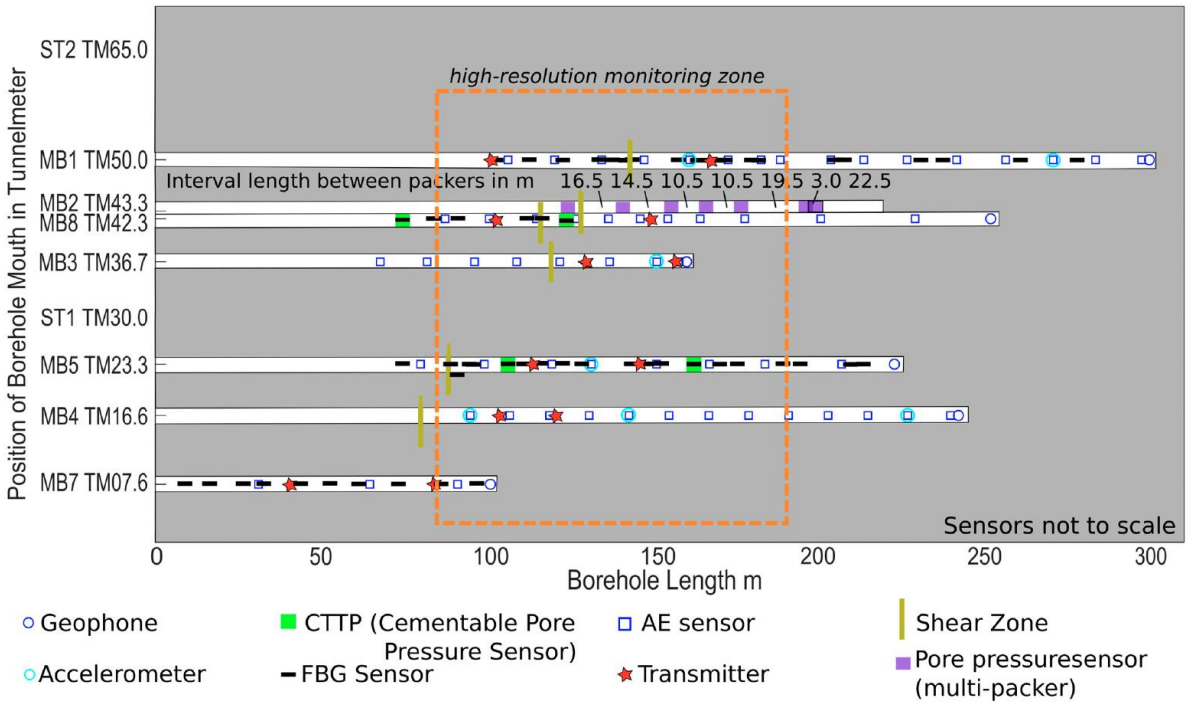
sensors

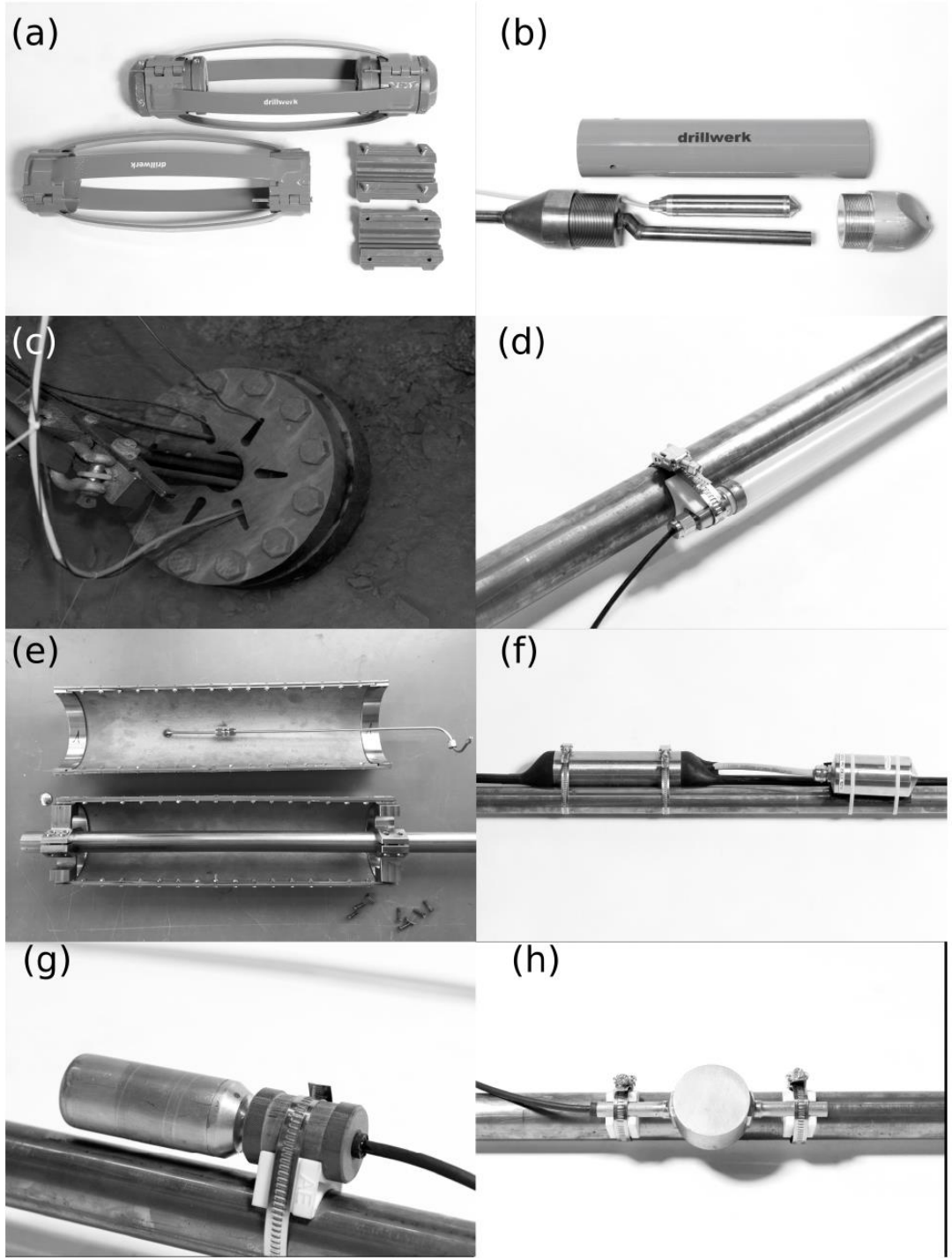
MDPI

Article

Multi-Disciplinary Monitoring Networks for Mesoscale Underground Experiments: Advances in the Bedretto Reservoir Project

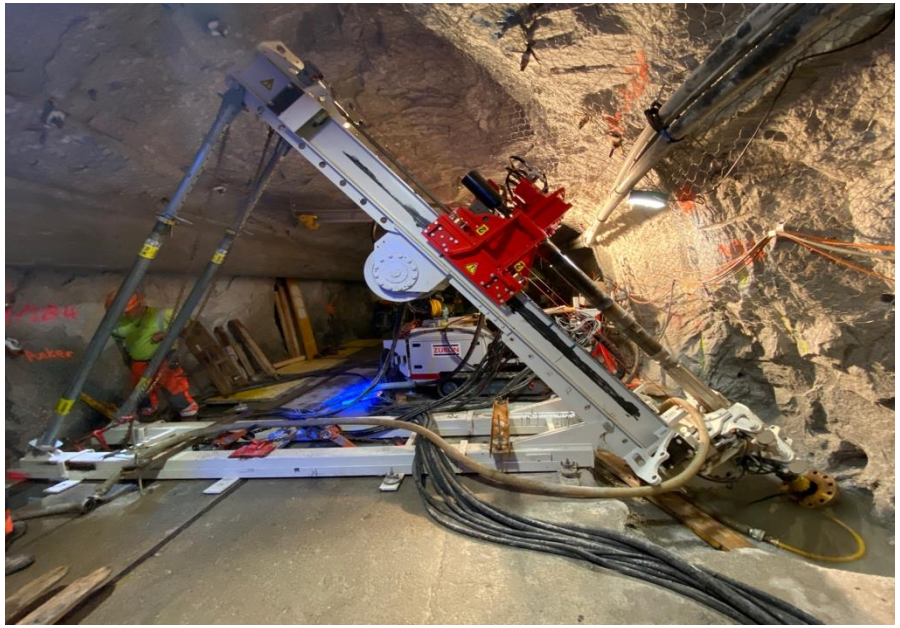
Katrin Plenkers [1,*,†], Andreas Reinicke [2,‡], Anne Obermann [3], Nima Gholizadeh Doonechaly [1], Hannes Krietsch [1,§], Thomas Fechner [4], Marian Hertrich [1], Karam Kontar [5], Hansruedi Maurer [1], Joachim Philipp [6], Beat Rinderknecht [7], Manuel Volksdorf [8], Domenico Giardini [1] and Stefan Wiemer [3]



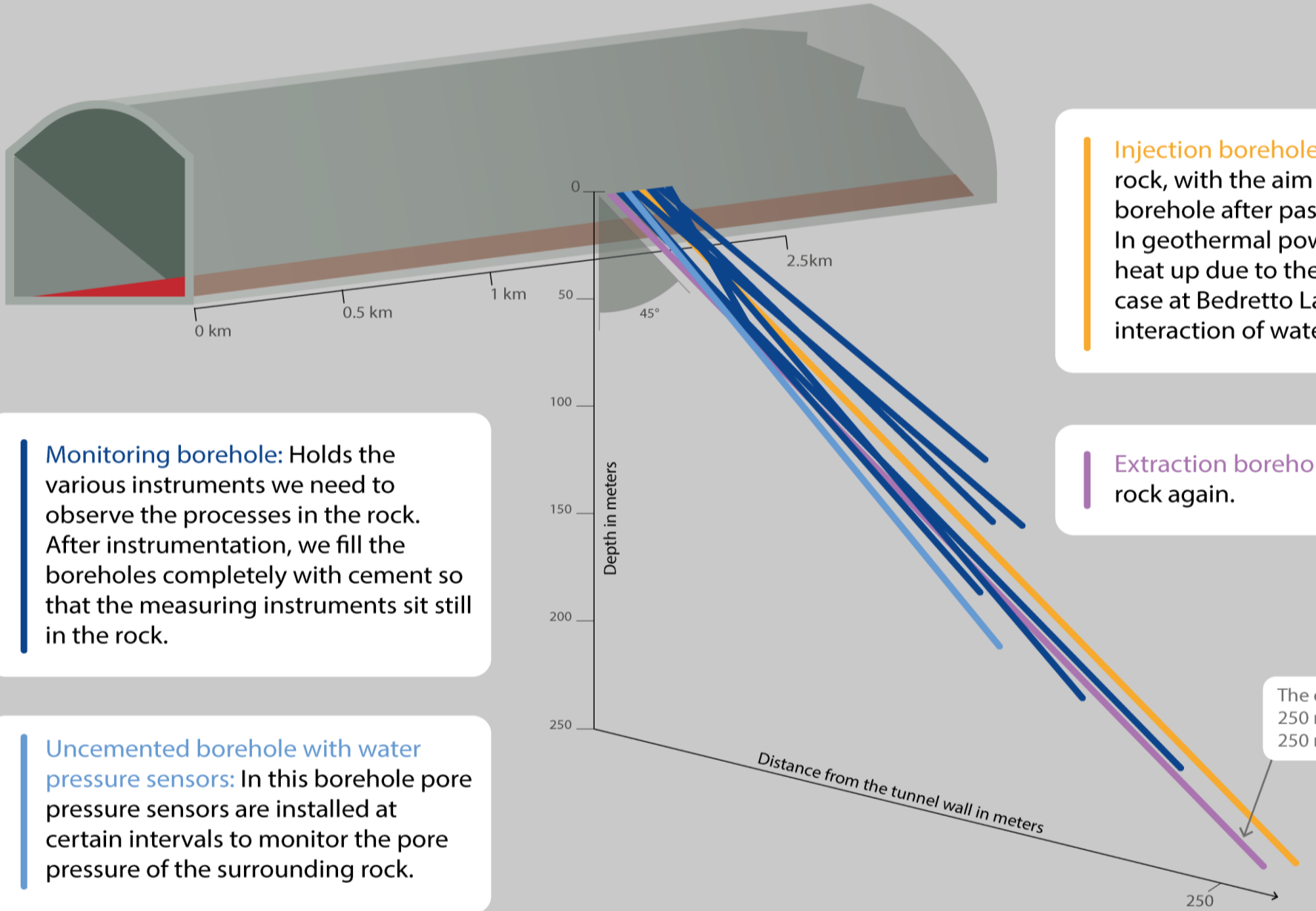


Geothermal testbed

We identified the target volume 100 – 400 m below the tunnel and drilled 8 monitoring boreholes and 2 injection boreholes, to install the full monitoring system and engineer the reservoir for injection experiments and long-term seasonal energy exchange and storage



Types of boreholes at the Bedretto Lab



Injection borehole: Here we press water into the rock, with the aim that it reaches the extraction borehole after passing through the rock volume. In geothermal power plants, the water would heat up due to the great depth. This is not the case at Bedretto Lab: here we research the interaction of water and rock.

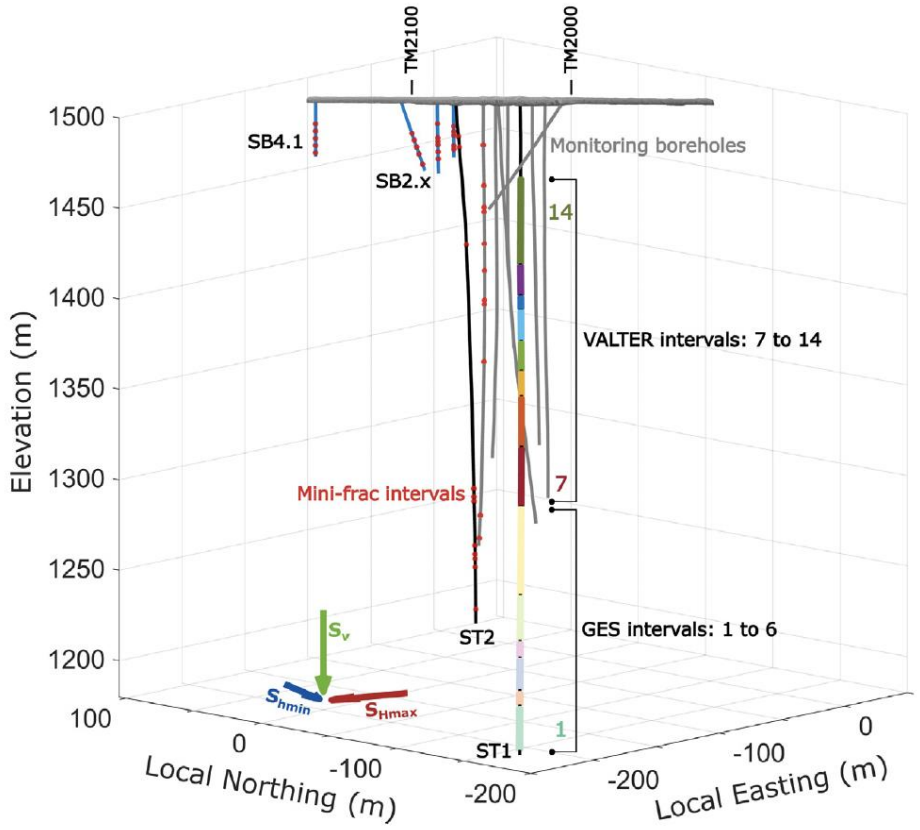
Extraction borehole: Here the water leaves the rock again.

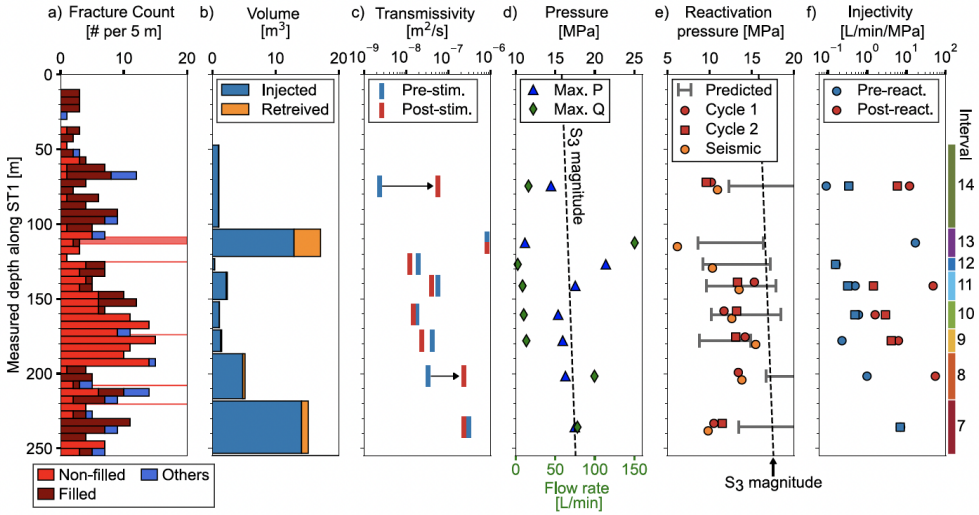
Monitoring borehole: Holds the various instruments we need to observe the processes in the rock. After instrumentation, we fill the boreholes completely with cement so that the measuring instruments sit still in the rock.

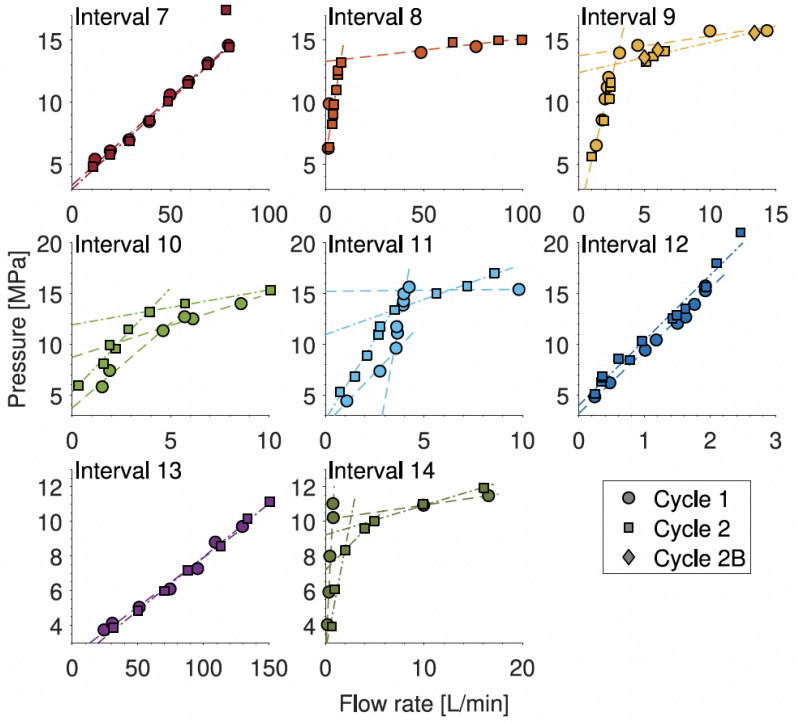
Uncemented borehole with water pressure sensors: In this borehole pore pressure sensors are installed at certain intervals to monitor the pore pressure of the surrounding rock.

The extraction well for example is about 250 meters deep and has a lateral offset of 250 meters from the tunnel wall.

Extended hydromechanical characterization







Contents lists available at ScienceDirect

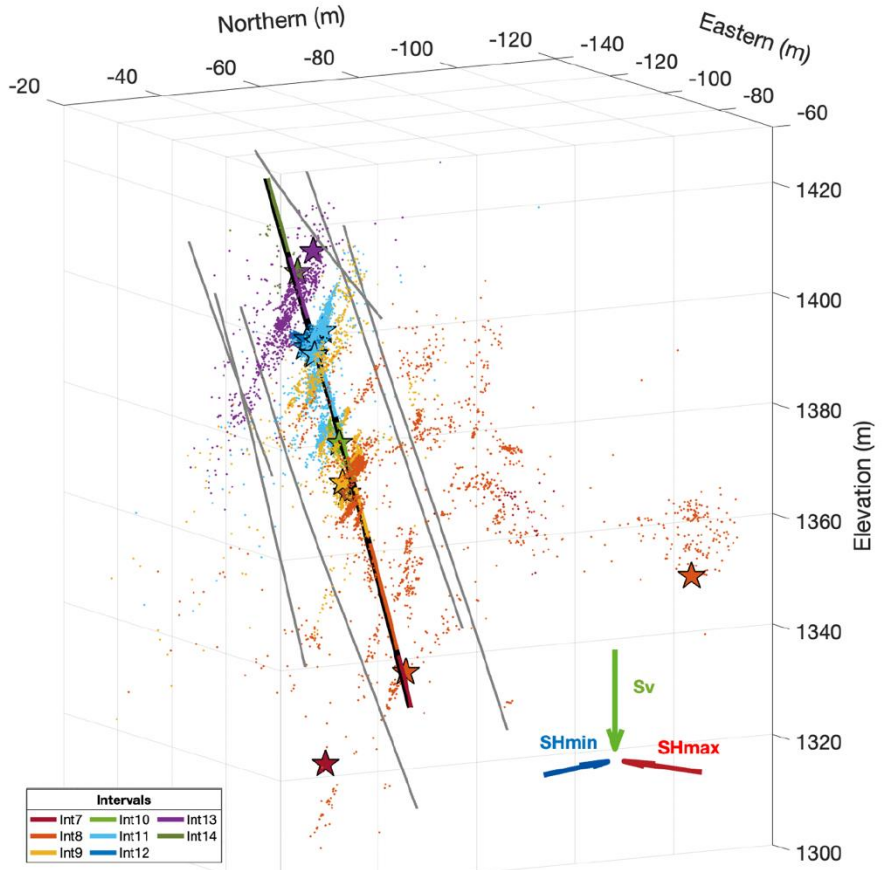
Geothermics

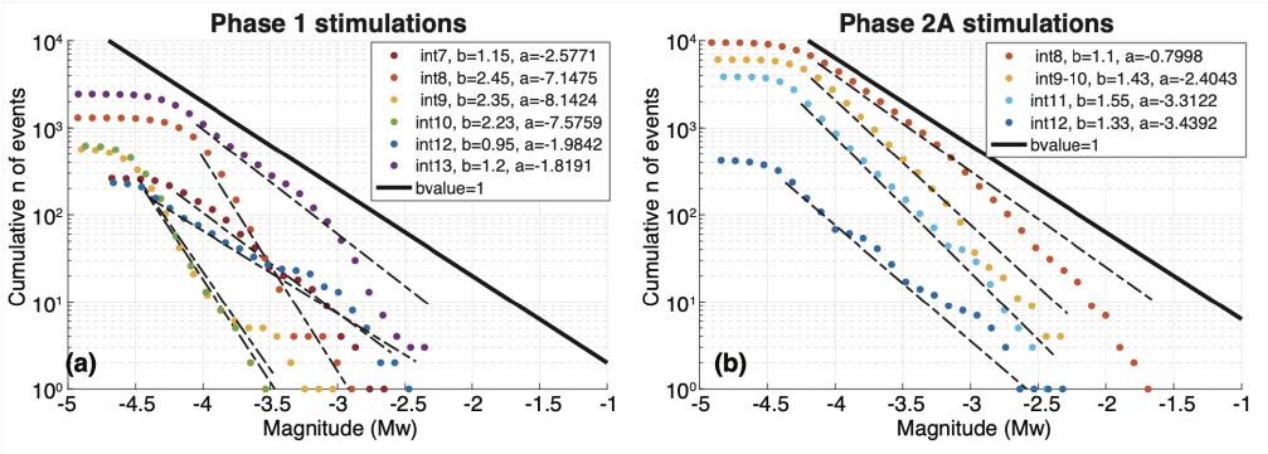
journal homepage: www.elsevier.com/locate/geothermics

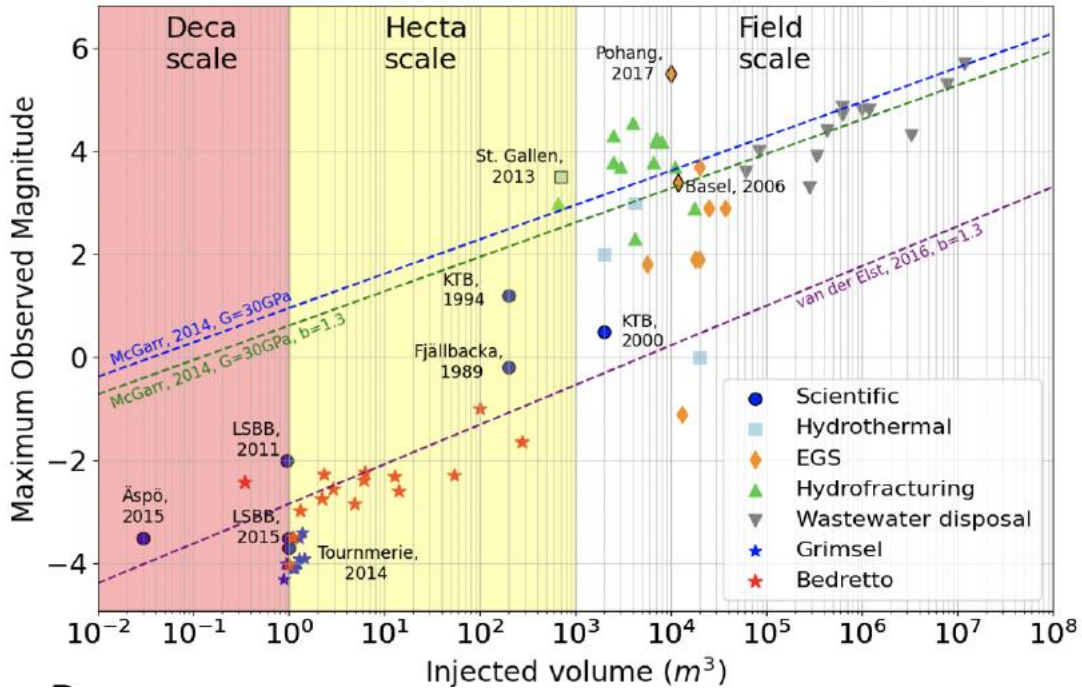
Hydromechanical characterization of a fractured crystalline rock volume during multi-stage hydraulic stimulations at the BedrettoLab

Kai Bröker[a,1], Xiaodong Ma[b,*], Nima Gholizadeh Doonechaly[a], Martina Rosskopf[a], Anne Obermann[c], Antonio Pio Rinaldi[c], Marian Hertrich[a], Francisco Serbeto[d], Hansruedi Maurer[a], Stefan Wiemer[c], Domenico Giardini[a], Bedretto Lab Team[a]

Analysis of seismicity during stimulation





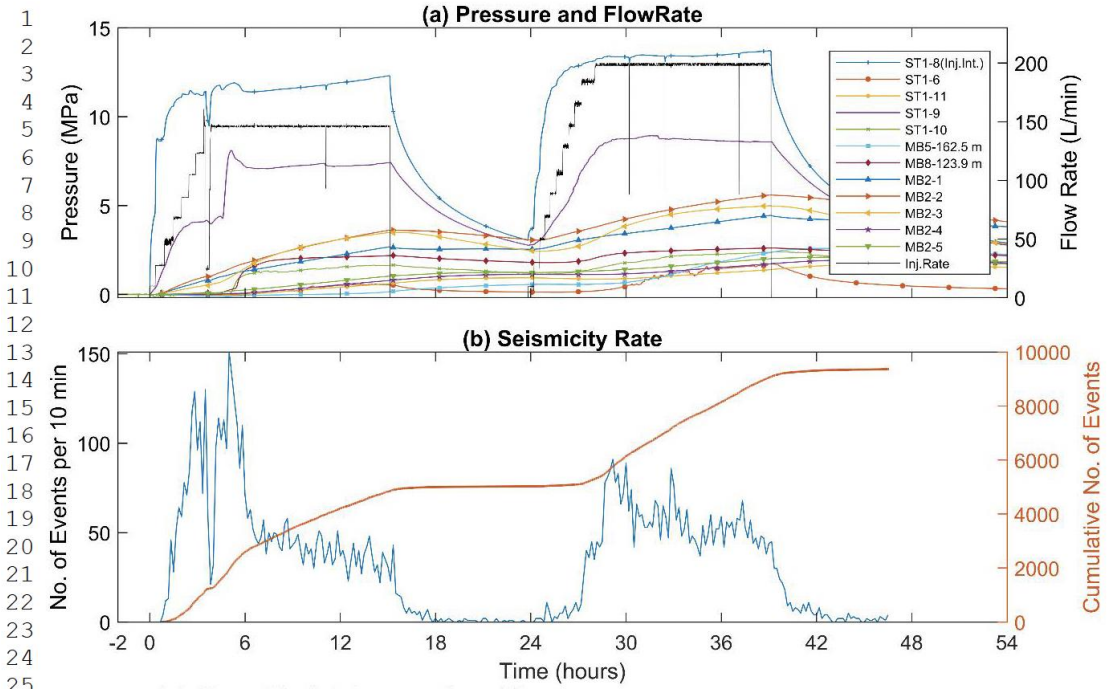


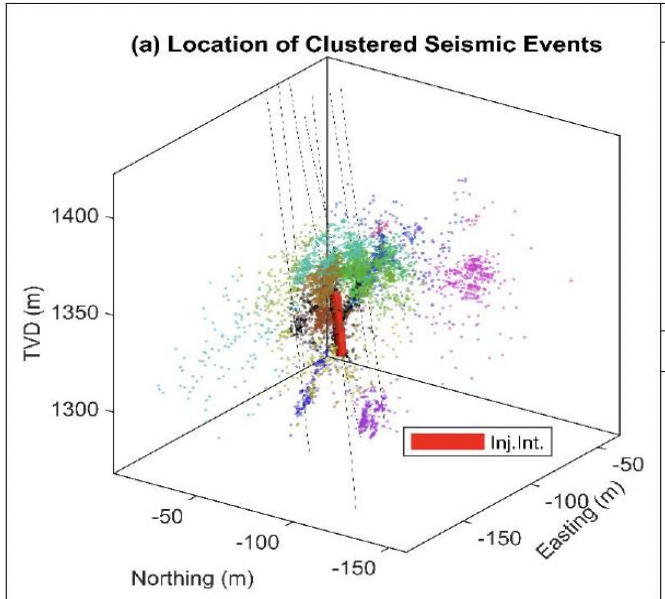
Seismic response of hectometer-scale fracture systems to hydraulic stimulation in the Bedretto Underground laboratory, Switzerland

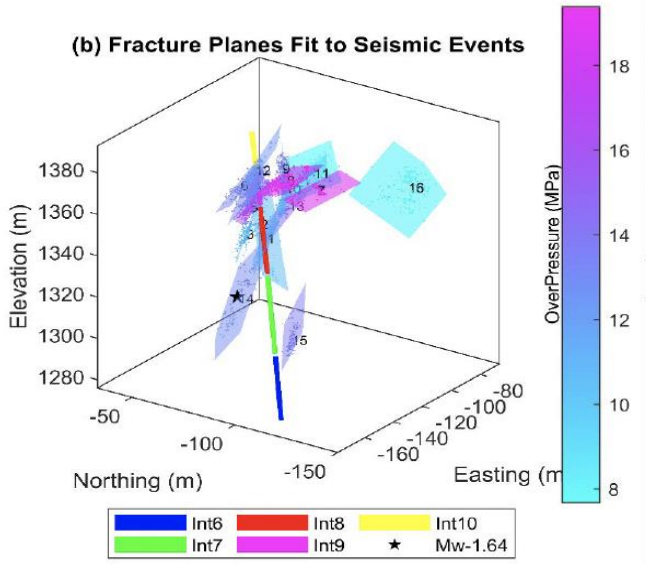
-under review-

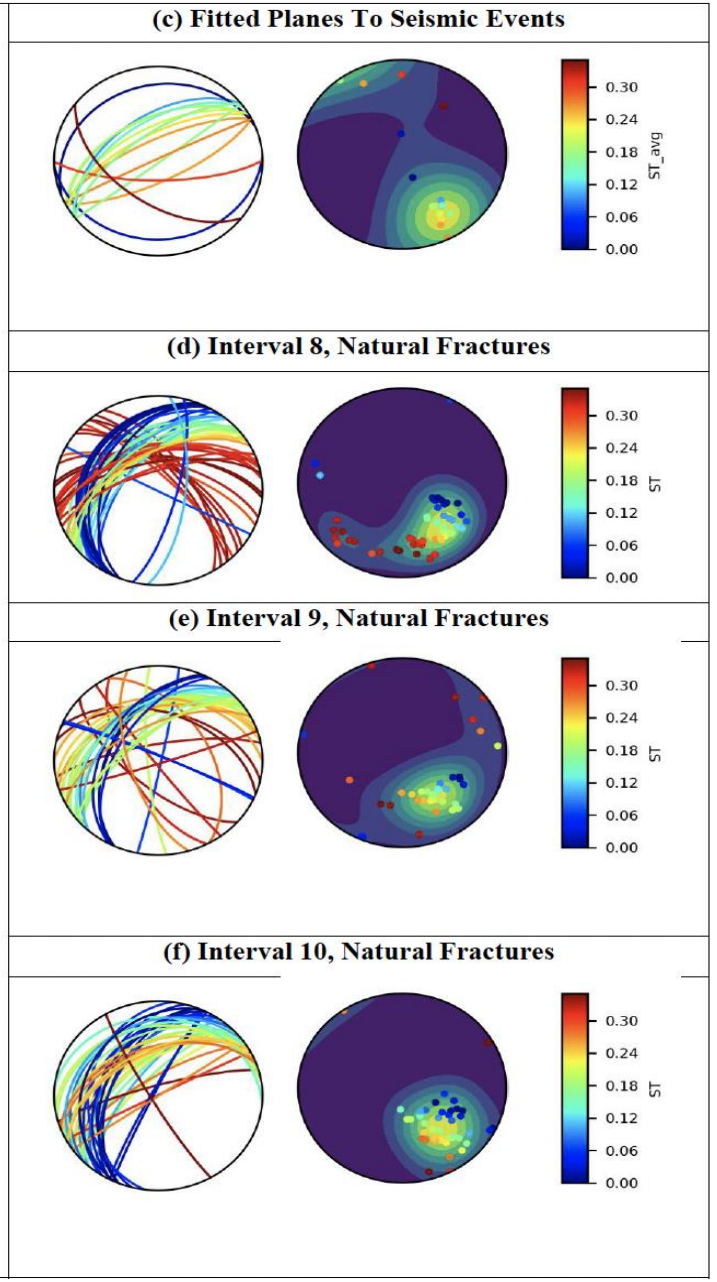
Anne Obermann[1,2], Martina Rosskopf[1,2], Virginie Durand[2], Katrin Plenkers[3], Kai Bröker[2], Nima Gholizadeh Doonechaly[2], Valentin Gischig[1,4], Marian Hertrich[2], Philipp Kästli[1], Xiaodong Ma[2], Hansruedi Maurer[2], Antonio Pio Rinaldi[1], Linus Villiger[1,2], Stefan Wiemer[1], Alba Zappone[1], Domenico Giardini[2]

Valter III: Hydromechanics









Rock Mechanics and Rock Engineering

Insights from Subsurface Monitoring for Engineering of the Stimulation Pattern in Fractured Reservoirs

--Manuscript Draft--

-under review-

Nima Gholizadeh Doonechaly[1], Kai Bröker[2], Marian Hertrich[1], Martina Kirchkopf[1], Anne Obermann[1,3], Virginie Durand[4], Francisco Serbeto[5], Alexis Shakas[1], Xiaodong Ma[6], Antonio Pio Rinaldi[1,3], Victor Clasen Repollés[1], Linus Villiger[1], Men-Andrin Meier[1], Valentin Gischig[1], Katrin Plenkers[1,5], Hansruedi Maurer[1], Stefan Wiemer[3], and Domenico Giardini[1]

Mzero experiments

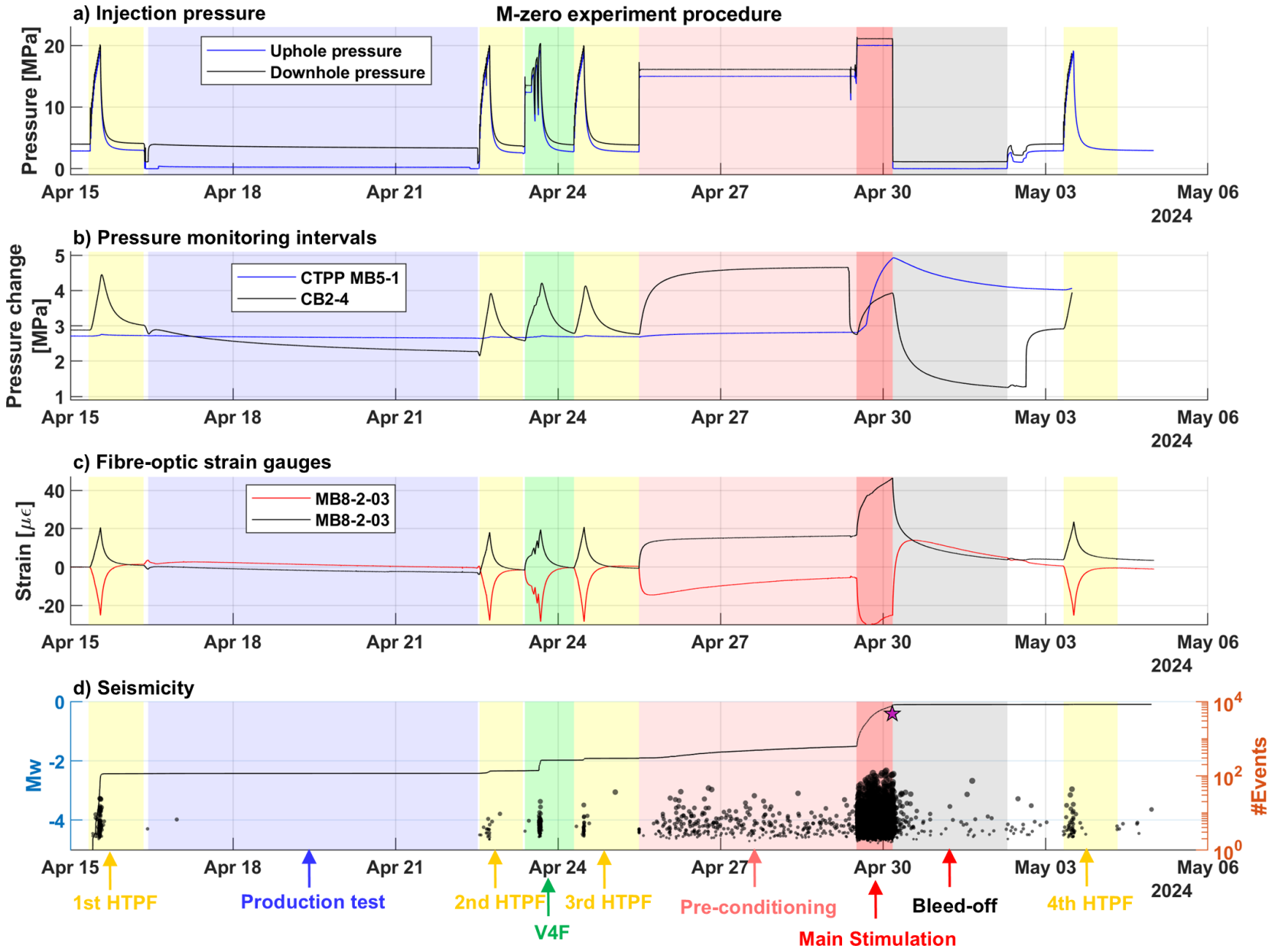
Two experiments:

MzeroA: with extended preconditioning, i.e. injection just below jacking pressure of 15 MPa followed by 20 MPa injection.

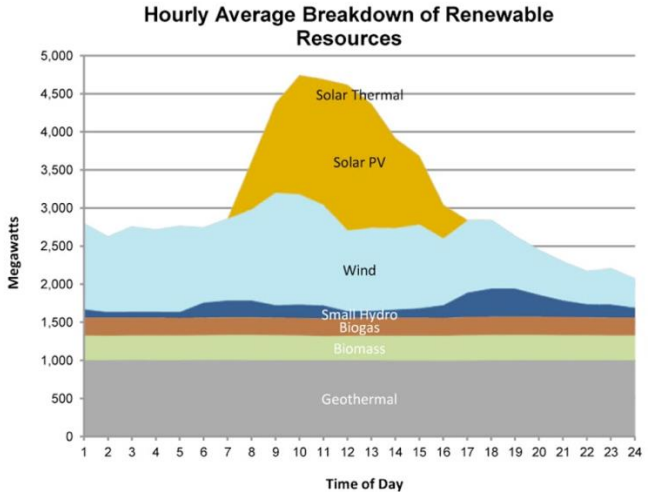
April/May 2024

MzeroB: without preconditioning, directly injecting at 20 MPa.

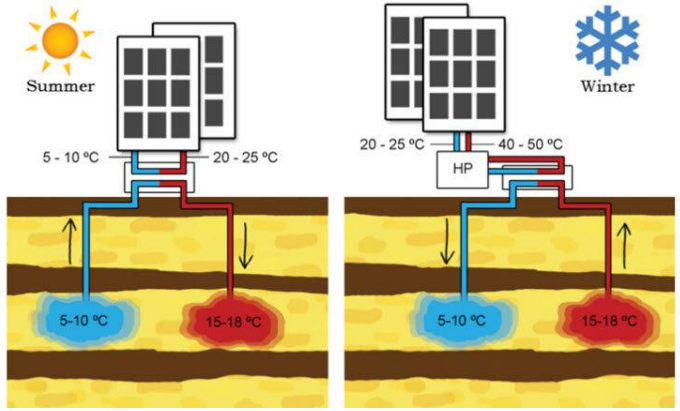
End of August 2024



BEACH (Bedretto Energy Storage and Circulation of Geothermal Energy)



Bundesverband Geothermie



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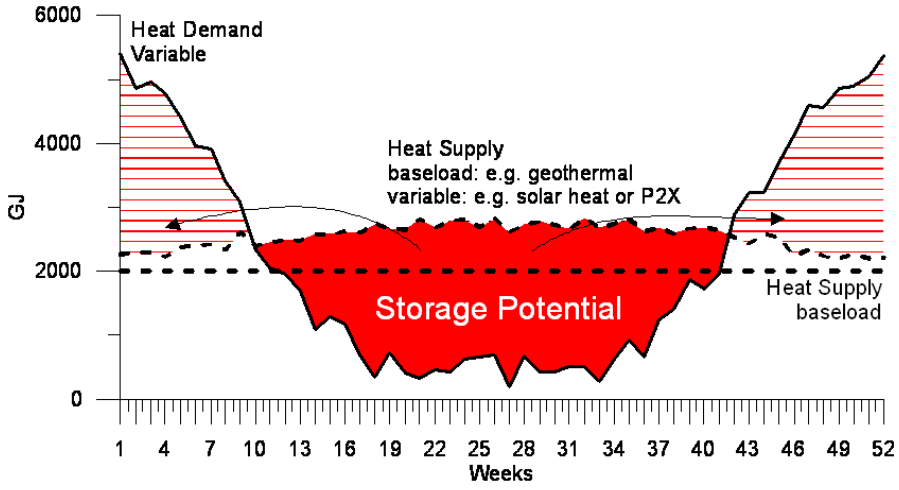
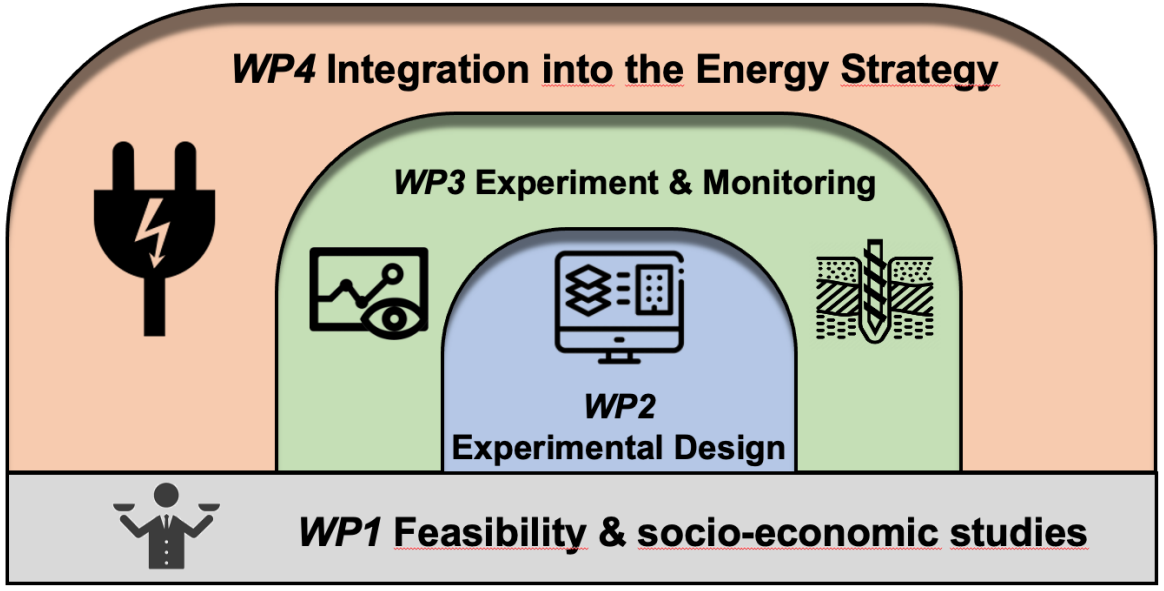
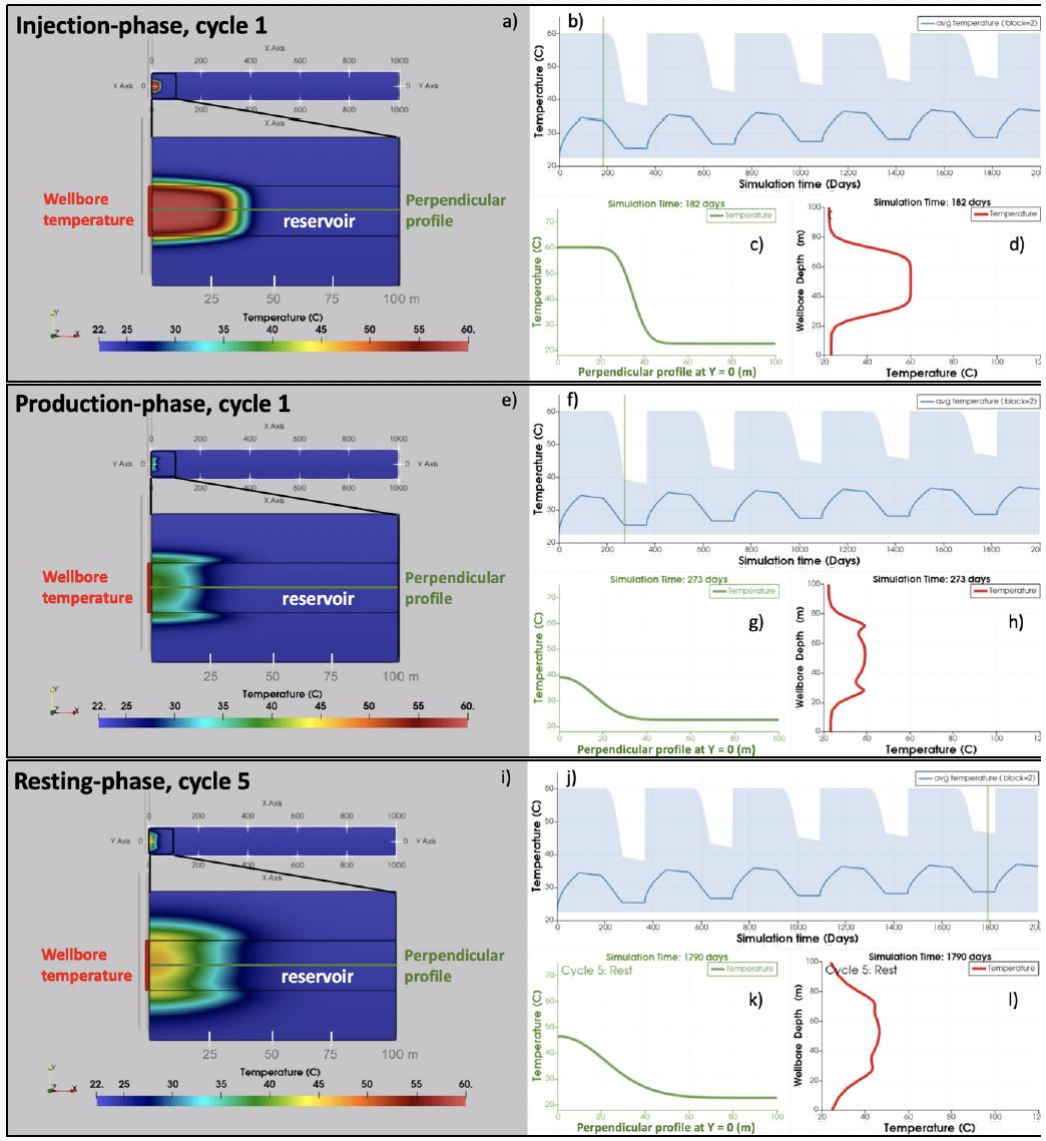
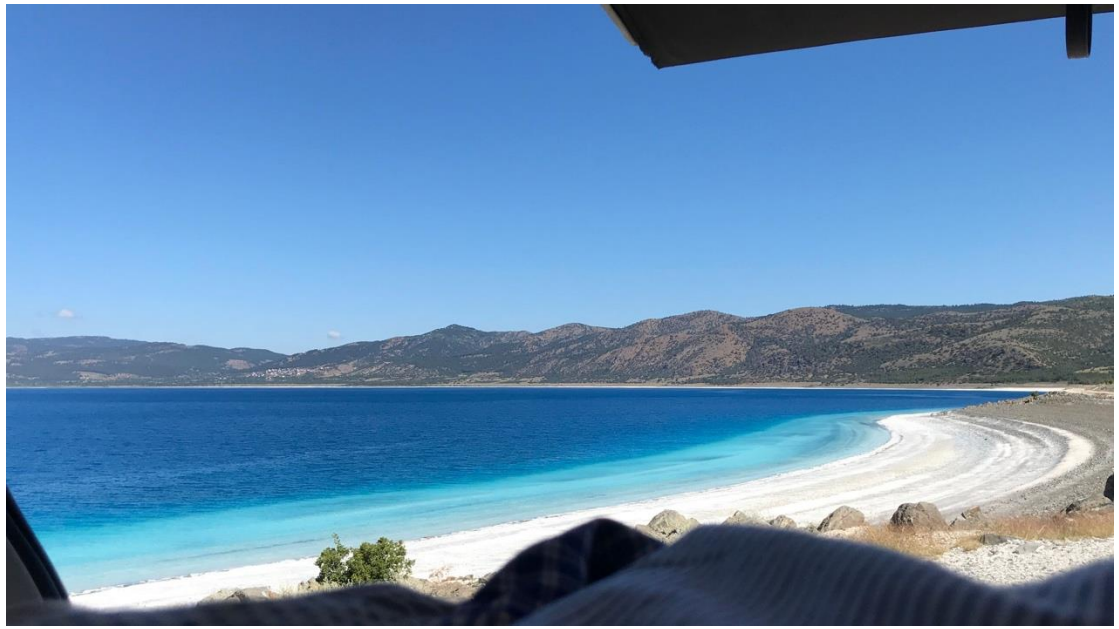
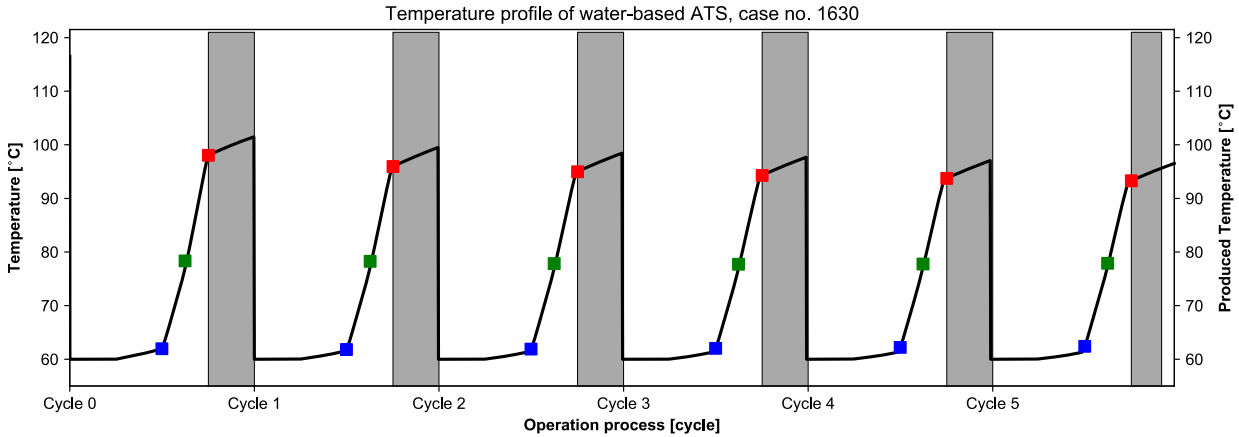




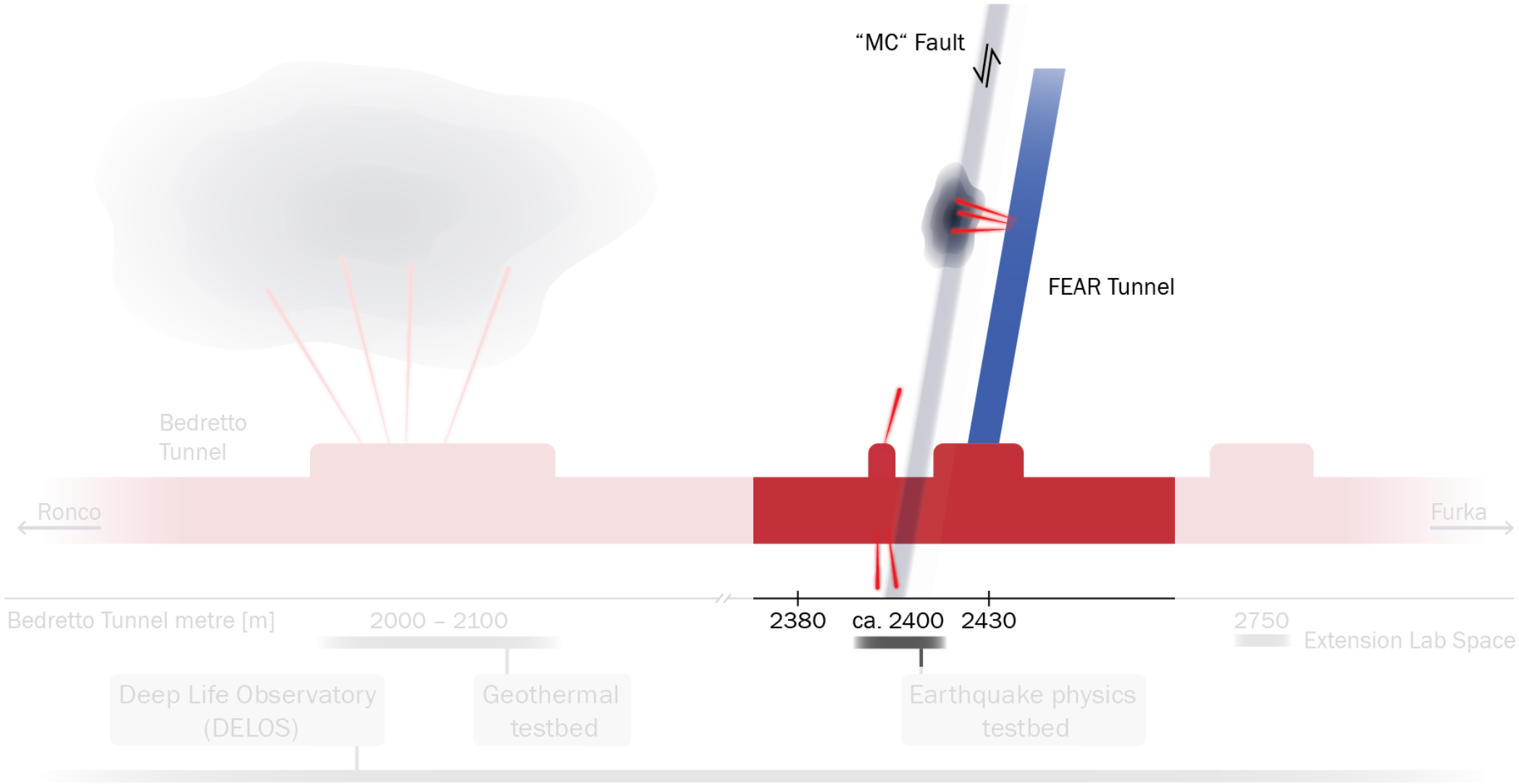
Bedretto Circulation and Heat Storage - BEACH





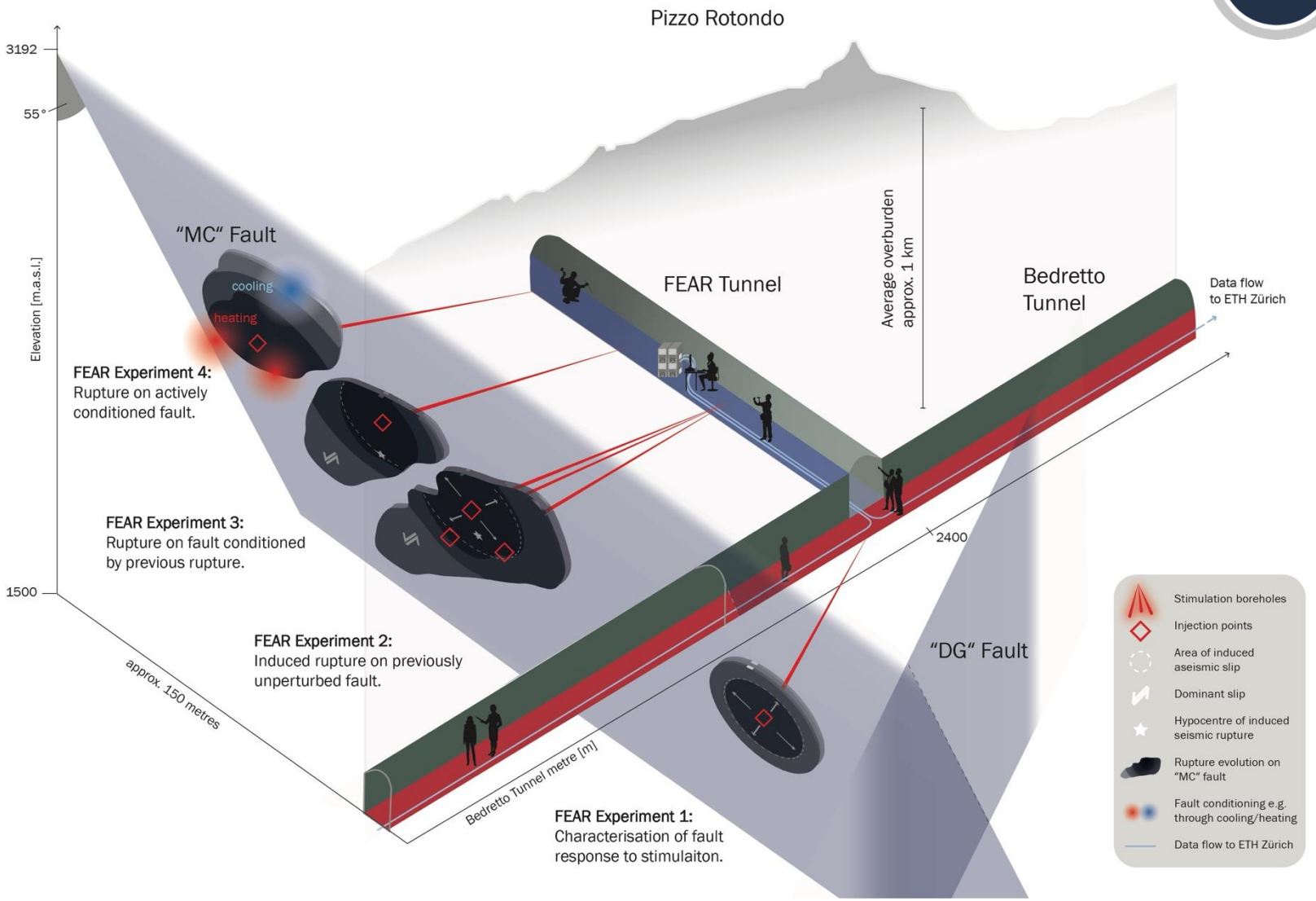


Earthquake Physics testbed



FEAR Project

FEAR
Fault Activation and Earthquake Rupture



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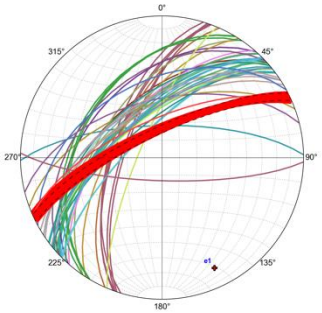
Swiss Seismological Service

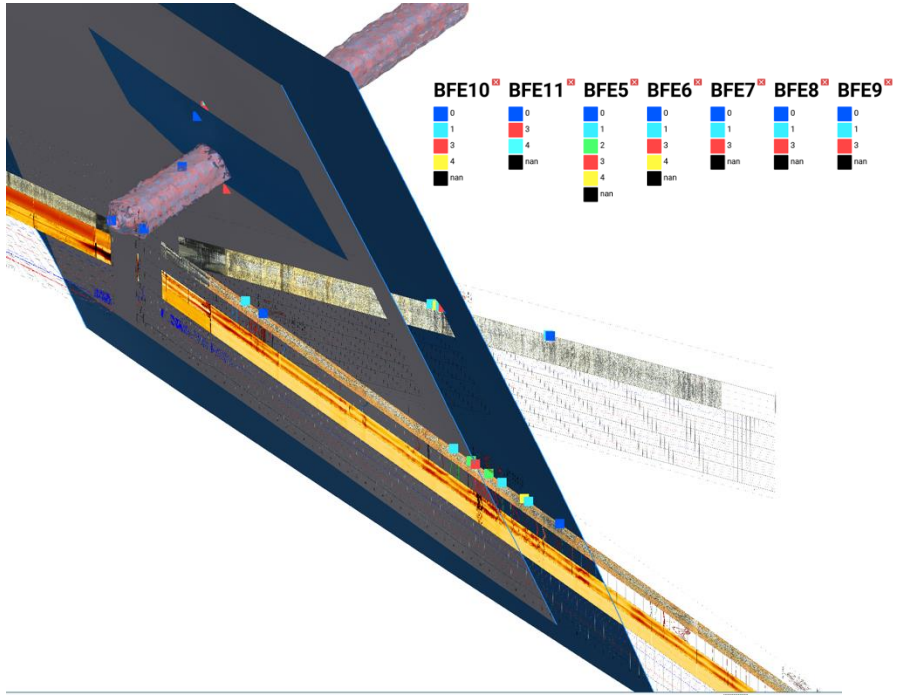
RWTH
RHEINISCH-WESTFÄLISCHE TECHNISCHE HOCHSCHULE AACHEN

INGV

Fault mapping

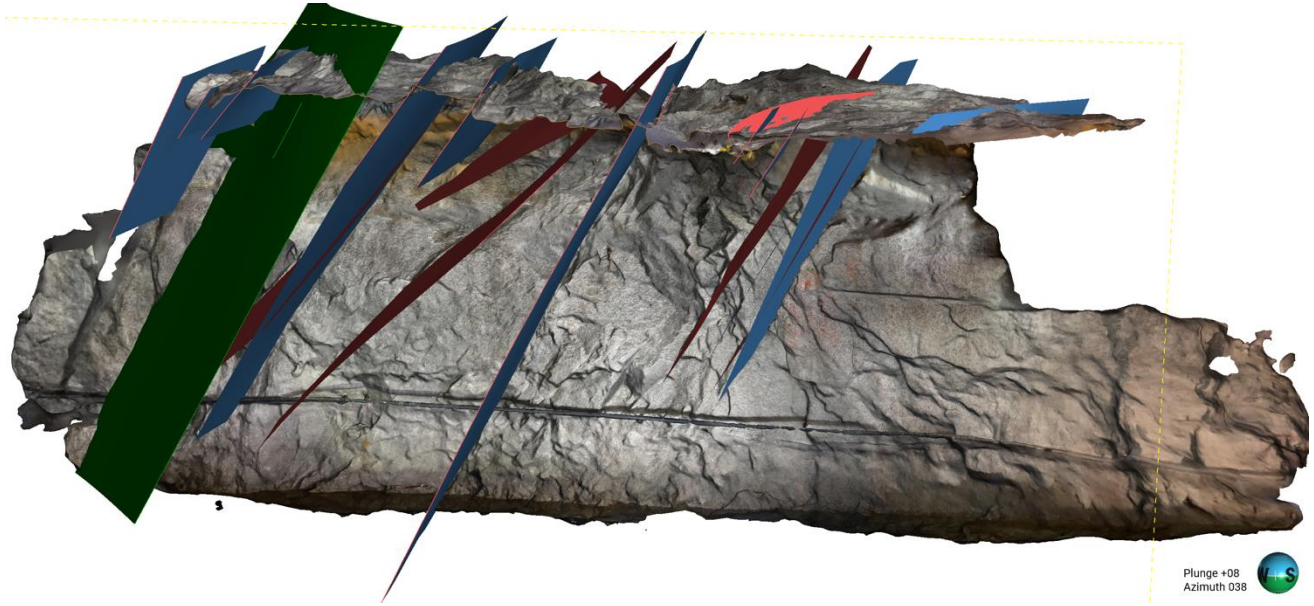


Red planes: surfaces from 3D geometry
Colored planes: fractures from tunnel wall mapping



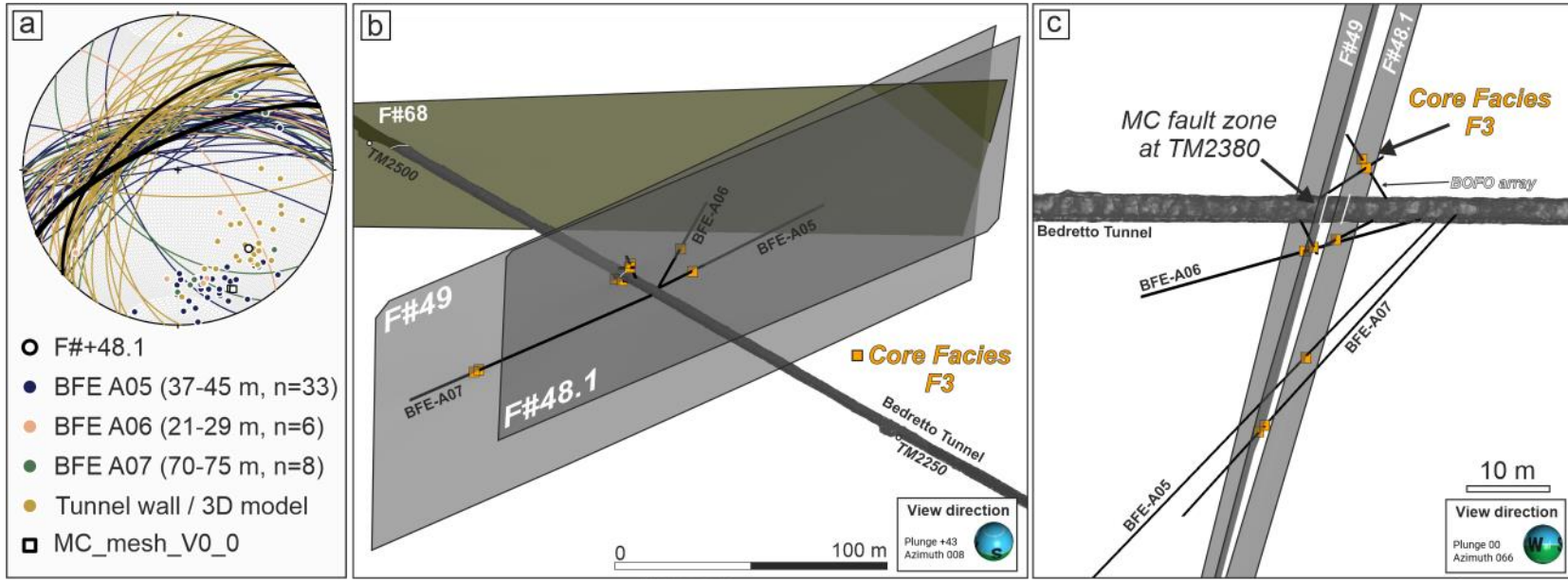
3D Fault zone geometry from tunnel mapping and borehole logs

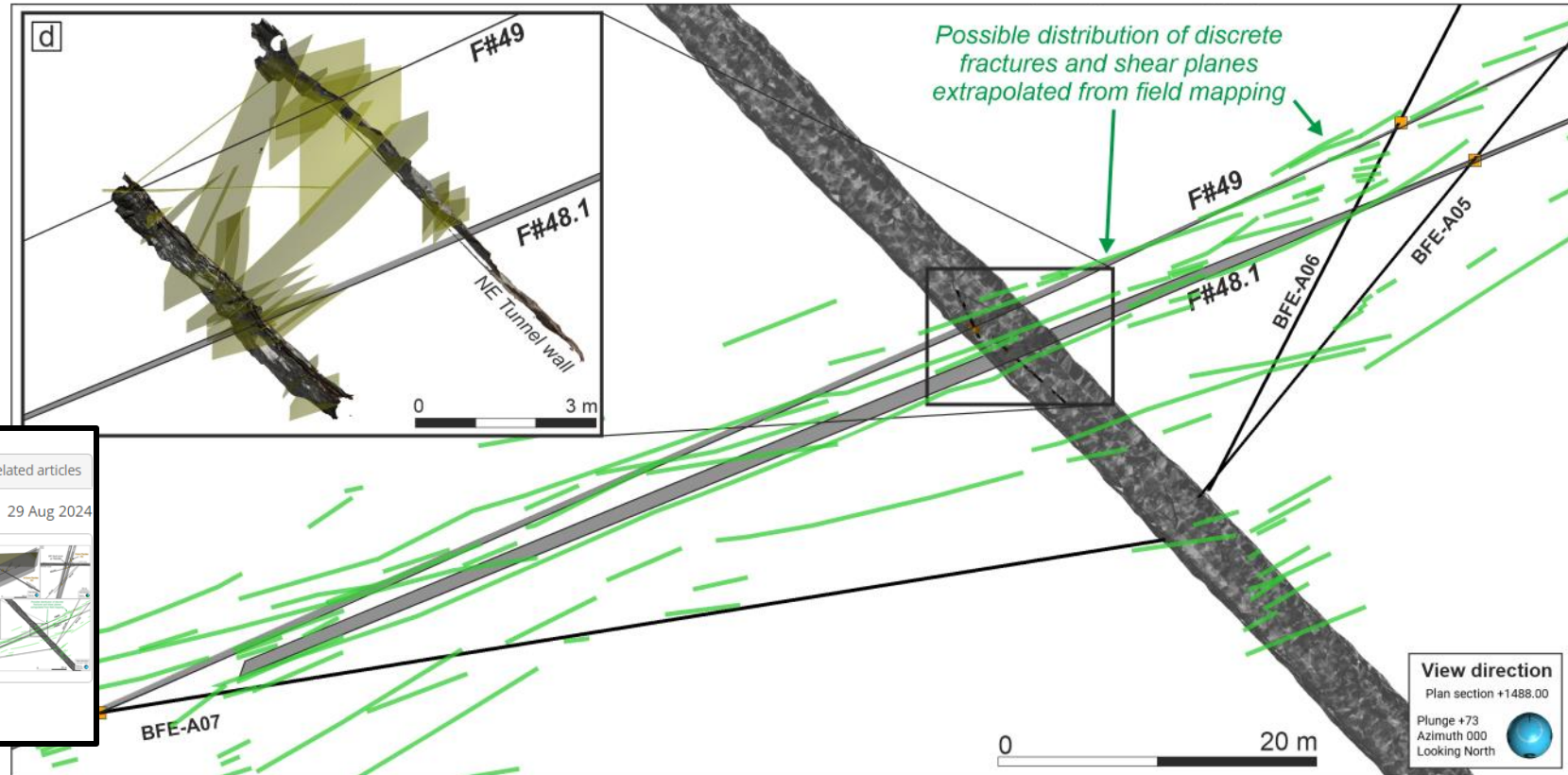
Tunnel wall fault mapping on virtual tunnel surfaces

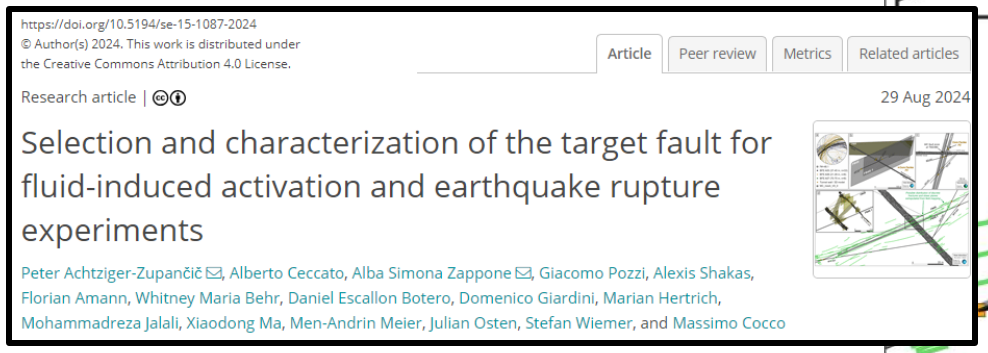


Fault zone model

Fault zone model integrating tunnel, borehole and field observations






https://doi.org/10.5194/se-15-1087-2024

Article | Peer review | Metrics | Related articles

Research article | 29 Aug 2024

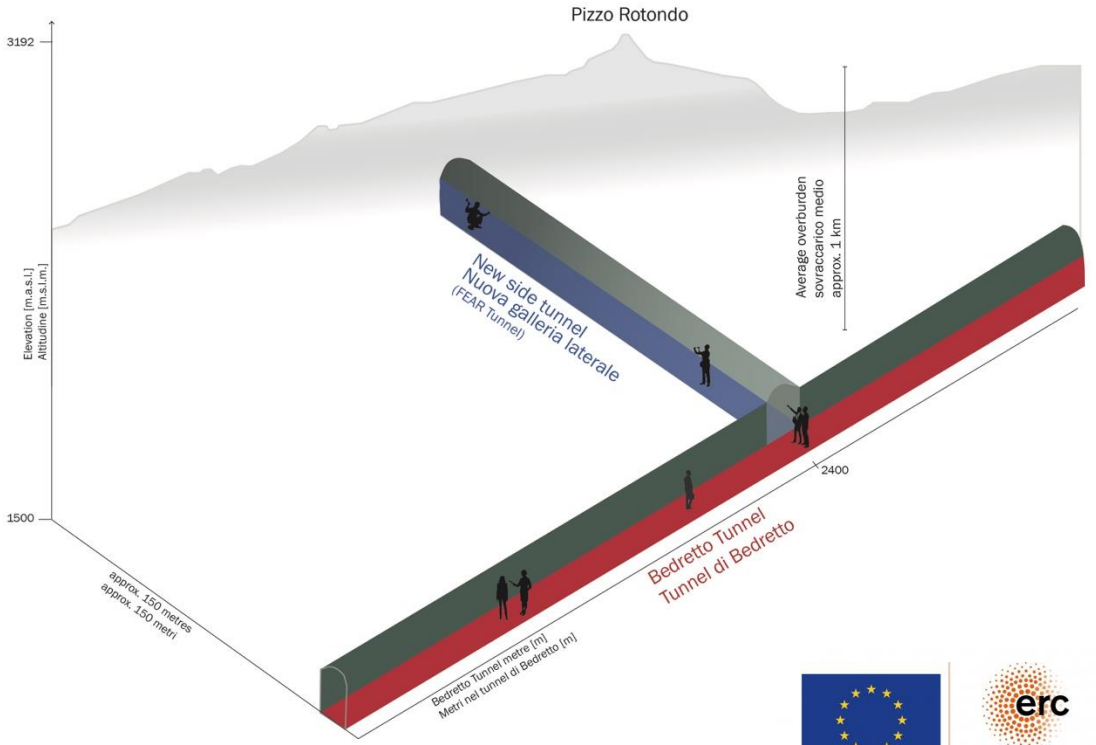
Selection and characterization of the target fault for fluid-induced activation and earthquake rupture experiments

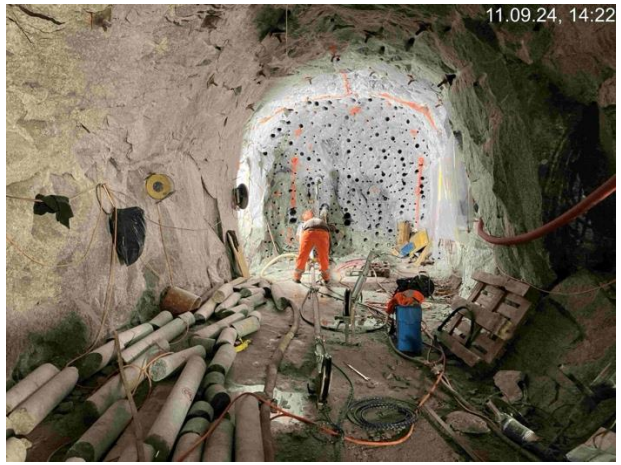
Peter Achtziger-Zupančič, Alberto Ceccato, Alba Simona Zappone, Giacomo Pozzi, Alexis Shakas, Florian Amann, Whitney Maria Behr, Daniel Escallon Botero, Domenico Giardini, Marian Hertrich, Mohammadreza Jalali, Xiaodong Ma, Men-Andrin Meier, Julian Osten, Stefan Wiemer, and Massimo Cocco

Tunneling activities

- Nisches and first 10m are done
- Continuation of Drill & Blast in January 2025
- To be finalized by Q3 2025

FEAR
Fault Activation and Earthquake Rupture





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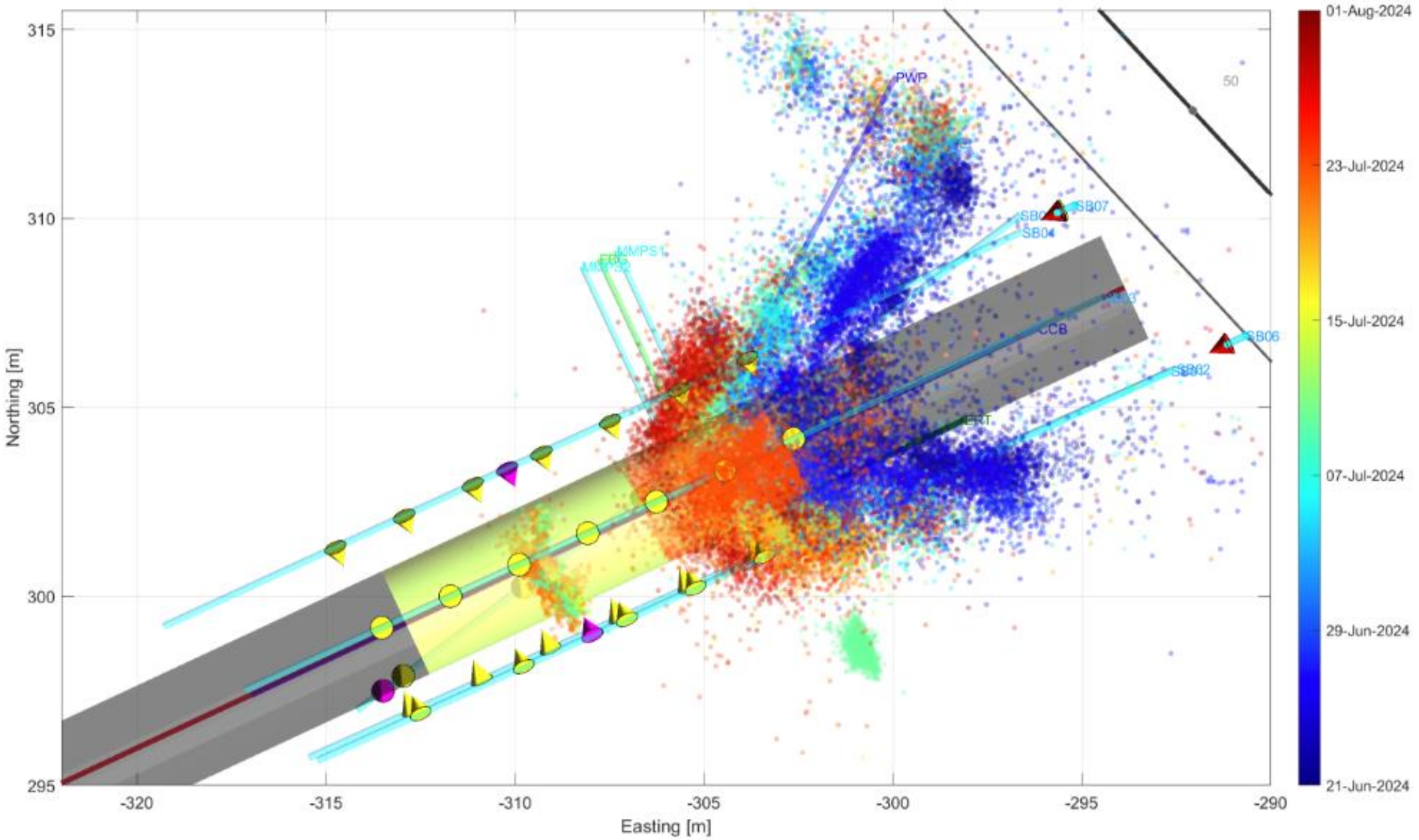
Swiss Seismological Service

PRECODE – Mine By



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FEAR Experiment 1

Understand how the MC fault zone (MCFZ) responds to injection into different fault zones segments and strands

- **Induce aseismic slip & small magnitude seismicity** (no dynamic 'main shock')
- **Hydraulics**: to what extent can we increase pressure across the entire MCFZ or on individual strands?
- **Microseismicity**: how easily is it the MCFZ seismically activated, and where in fault zone does seismicity predominantly occur?
- **Aseismic slip/deformation**: can we use strain observations to infer the aseismic slip distribution, beyond what can be measured at the injection point with a SIMFIP?

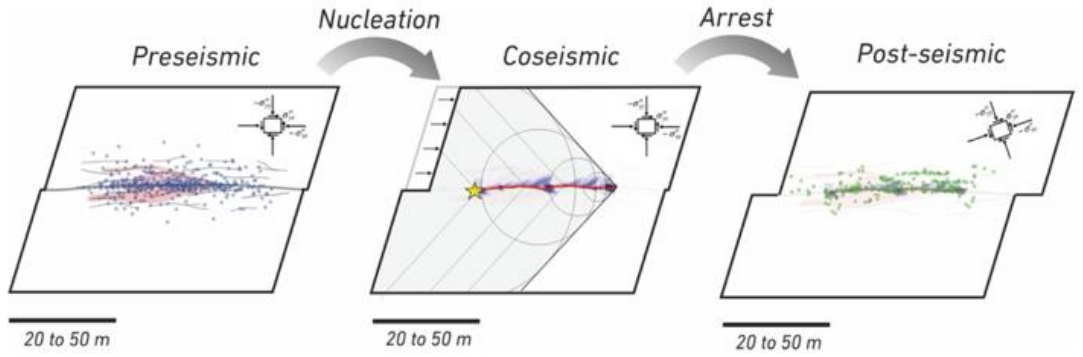
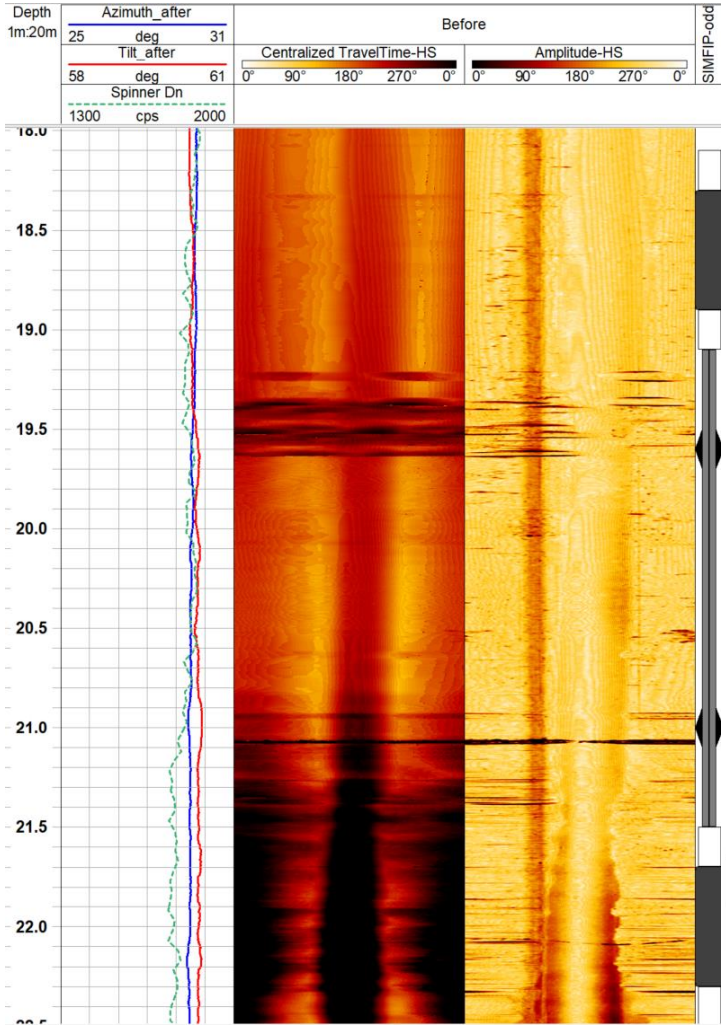


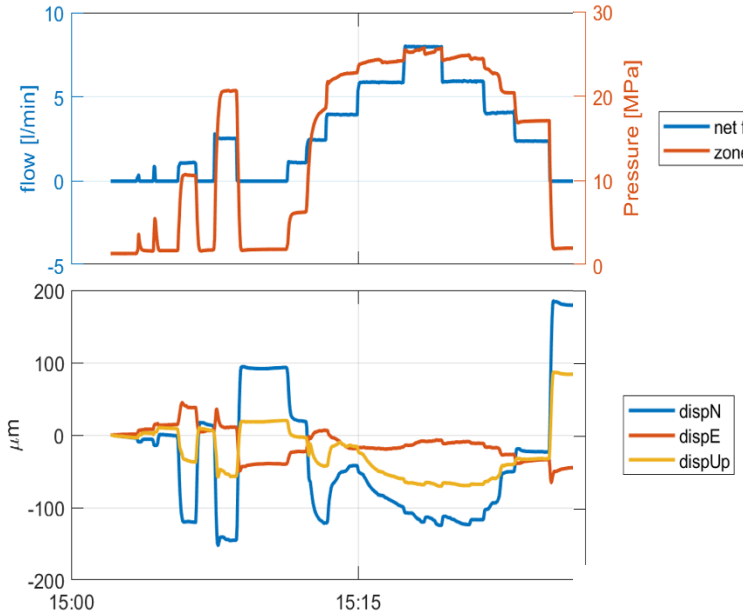
Figure from P. Seladurai

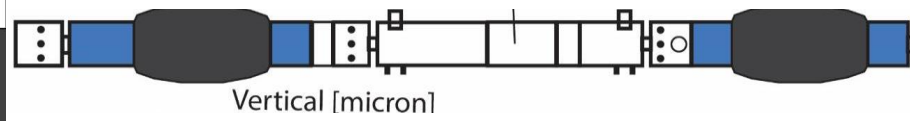
Geochemical analysis of water from the MC fault

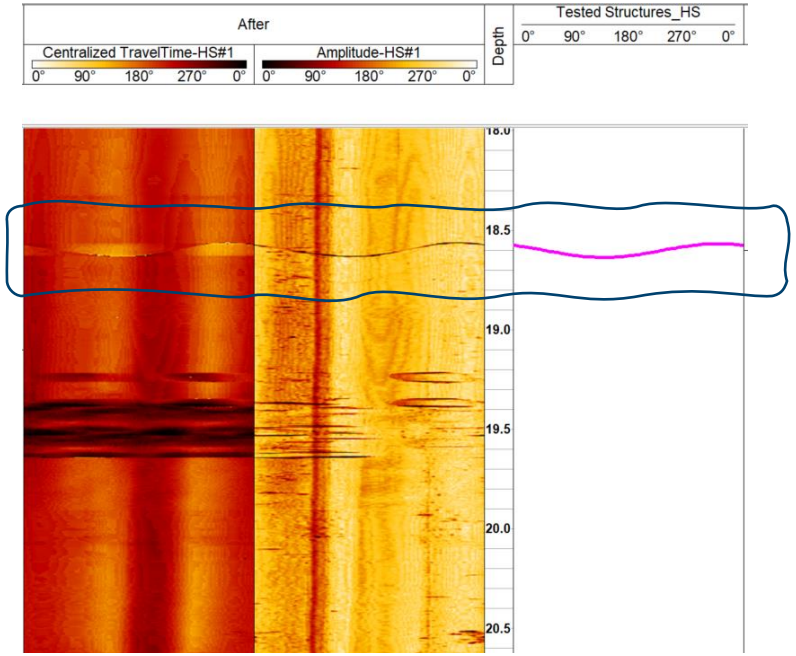
MiniRUEDI (mass spectrometer) measures gas concentrations in groundwater including: **He, Ar, Kr,** H_2, **CH_4,** CO_2, O_2, **N_2.**

Stress Profiling in Enhanced Geothermal Systems (SPINE)









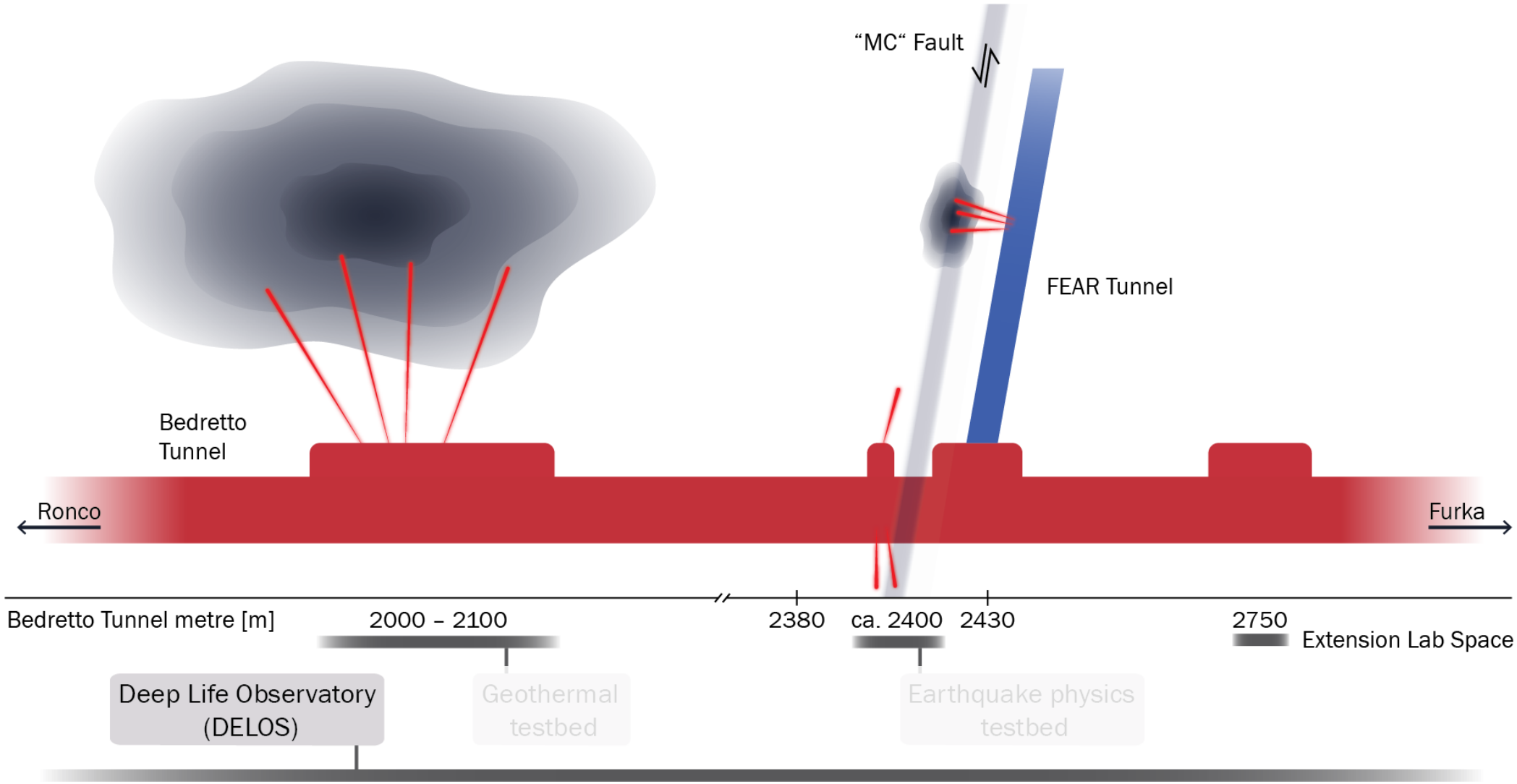
22nd Swiss Geoscience Meeting, Basel 2024

Stress profiling by inversion of fracture slip measurements at the BedrettoLab

Kai Bröker[1], Benoît Valley[1], Florian Soom[2], Paul Cook[2], Yves Guigliemi[2], Marian Hertrich[3]

[1] Center for Hydrogeology and Geothermics, University of Neuchâtel, Rue Emile-Argand 11, CH-2000 Neuchâtel (kai.broeker@unine.ch)
[2] Lawrence Berkeley National Laboratory, Energy Geoscience Division, Berkeley, CA 94720, USA
[3] Department of Earth Sciences, ETH Zürich, Sonneggstrasse 5, CH-8092 Zürich

Deep Life Observatory



Deep Life Observatory

Investigating the “Energy Limit” of Life

- **PHATES**: Microbial responses to rapid physical-chemical changes in the continental subsurface
- **C-FIX**: Carbon fixation in deep crystalline rock
- **ILLUME**: Investigations into the diversity of cell-cell associations and non-standard life using metagenomics and cryogenic electron microscopy

Swiss National Science Foundation

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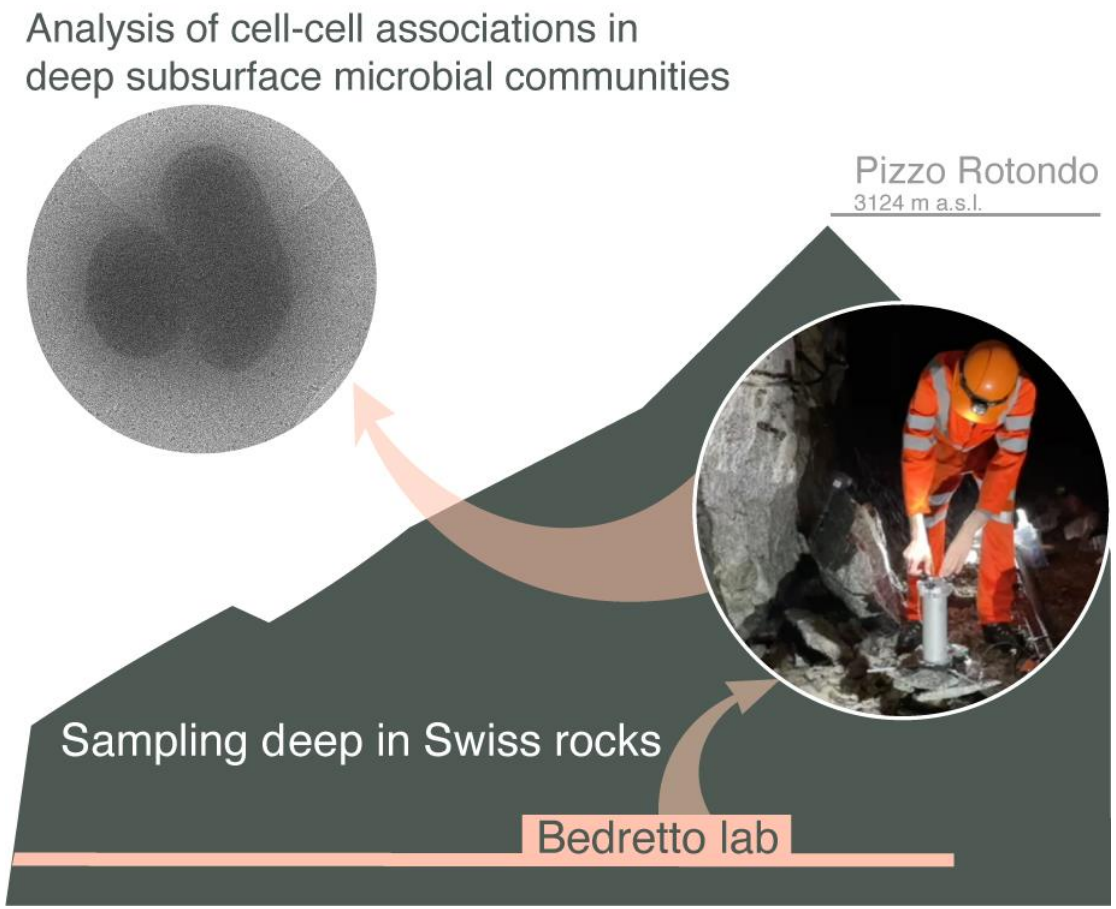
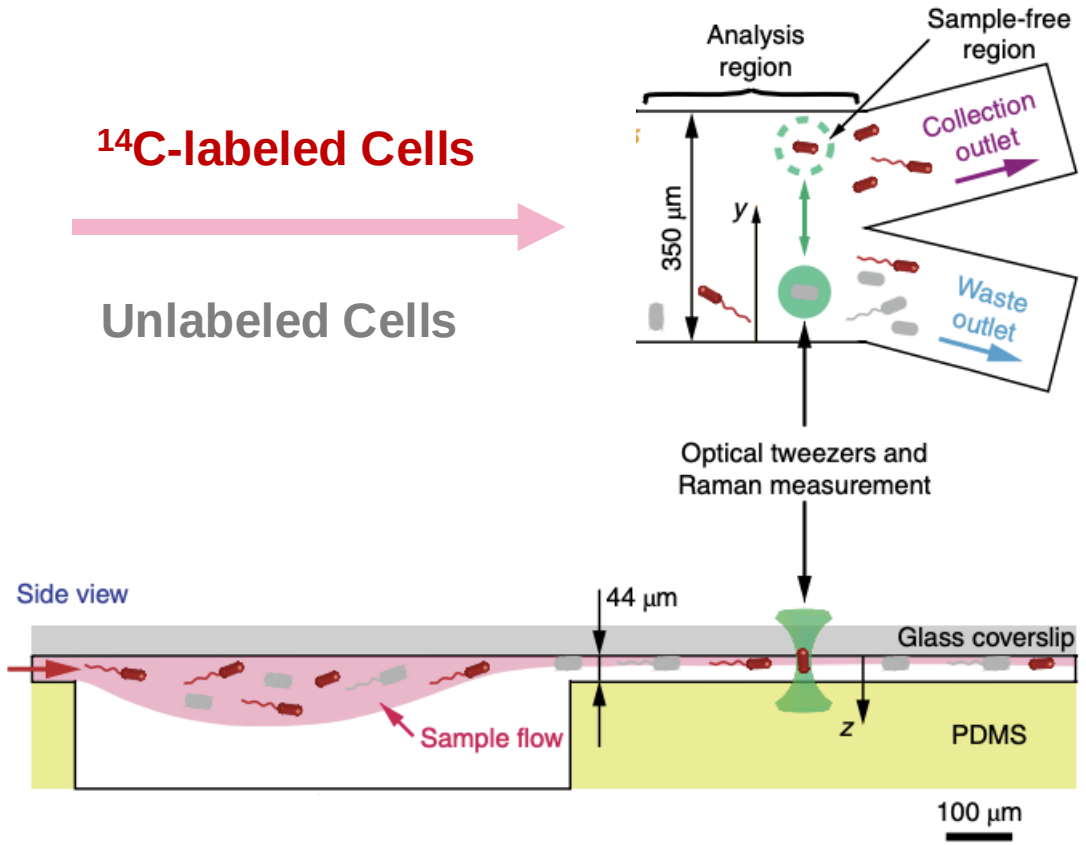
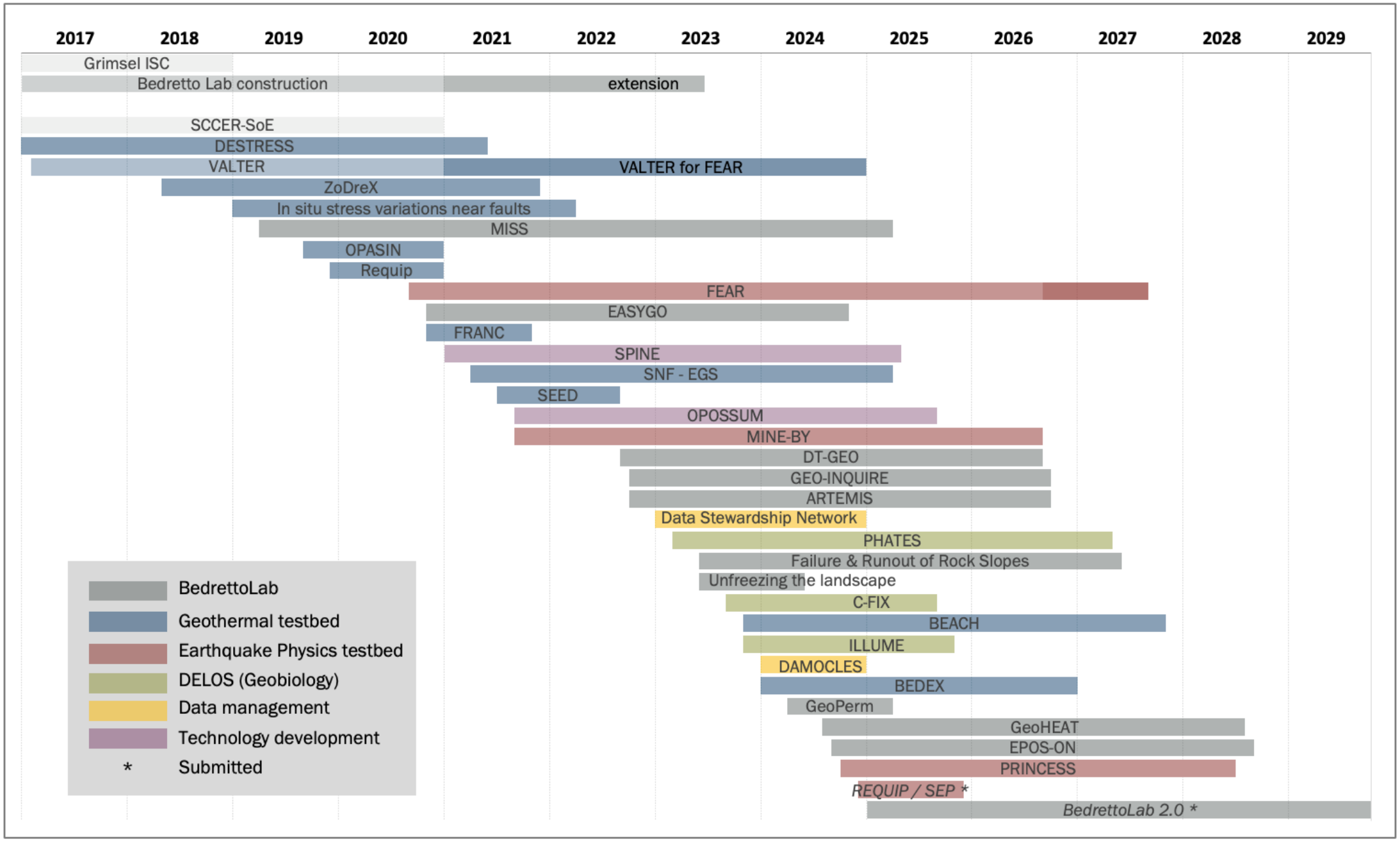
CENTRE FOR ORIGIN & PREVALENCE OF LIFE

Illuminating “microbial dark matter” and non-standard life





BedrettoLab Projects

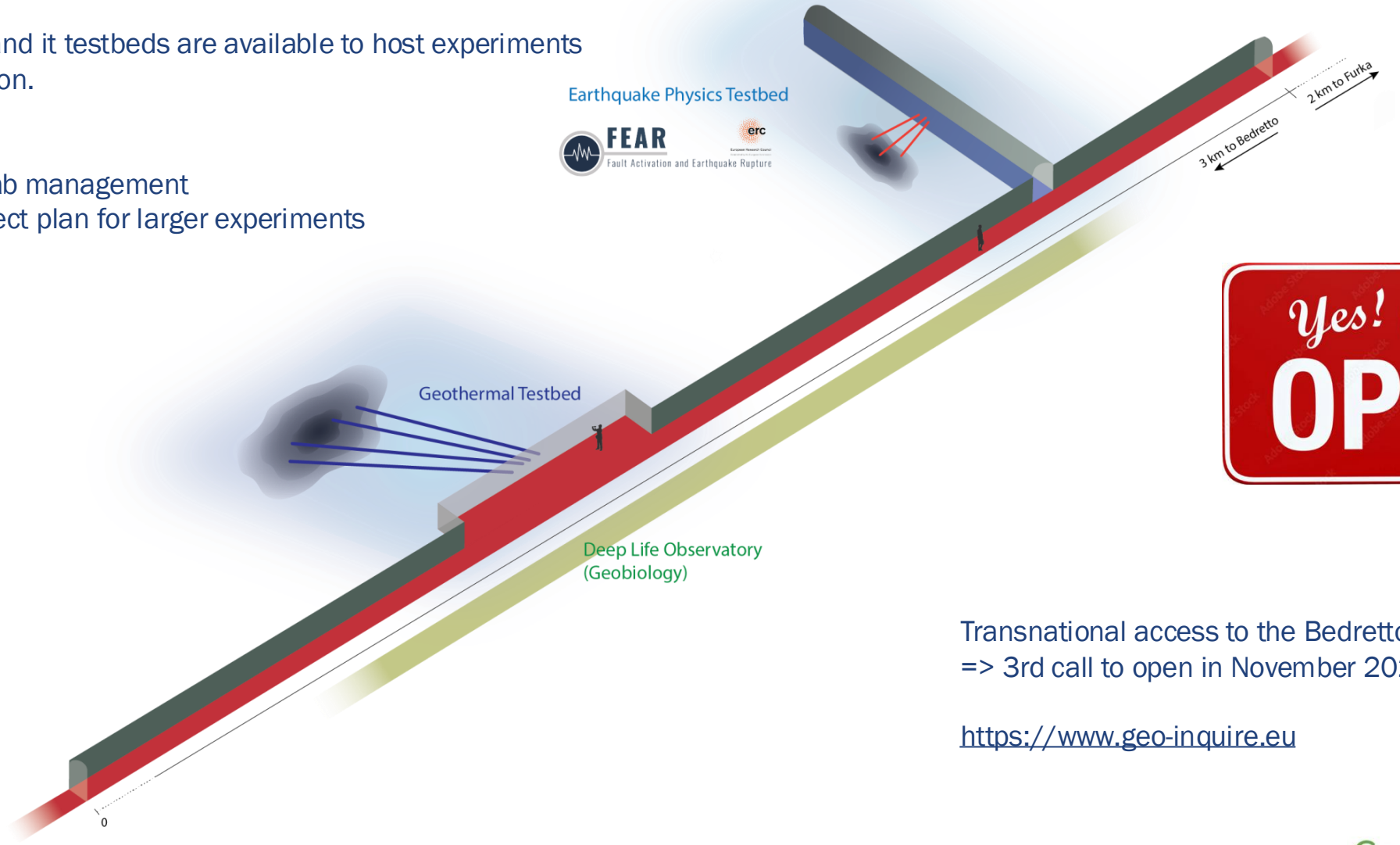


Access to the BedrettoLab

The BedrettoLab and it testbeds are available to host experiments and data acquisition.

How to's:

- Contact the Lab management
- Provide a project plan for larger experiments



Transnational access to the BedrettoLab
=> 3rd call to open in November 2024

https://www.geo-inquire.eu

Geo-iNQUIRE

Dr. Marian Hertrich
BedrettoLab Manager
marian.hertrich@eaps.ethz.ch

Rebecca Hochreutener
Programm Administrator
rebecca.hochreutener@eaps.ethz.ch

ETH Zürich
Bedretto Underground Laboratory for Geosciences and Geoenergies
Sonneggstrasse 5
8092 Zurich, Switzerland

www.bedrettolab.ethz.ch