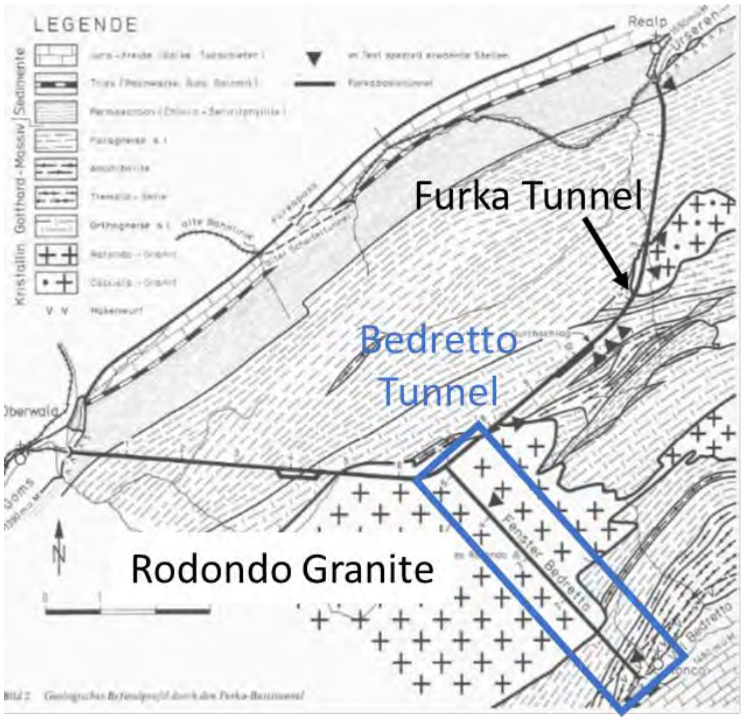
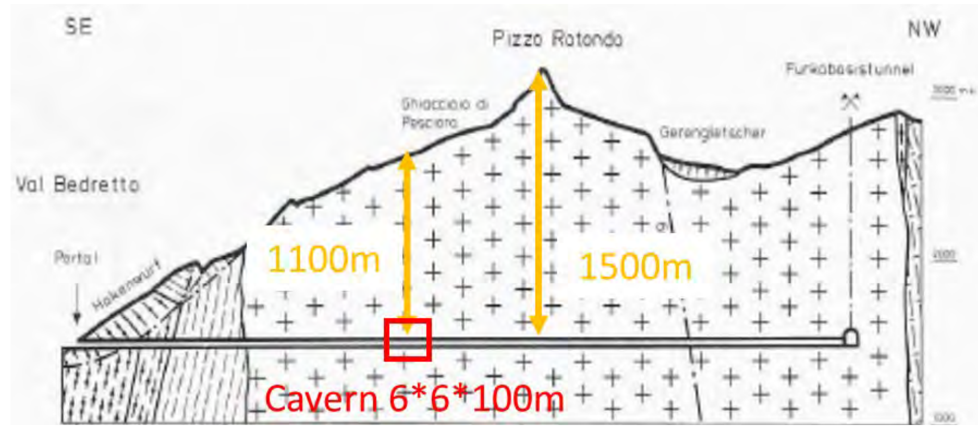
From rock-deformation laboratory to the deep underground laboratory of Bedretto: covering geothermal applications and earthquake physics at multiple scales

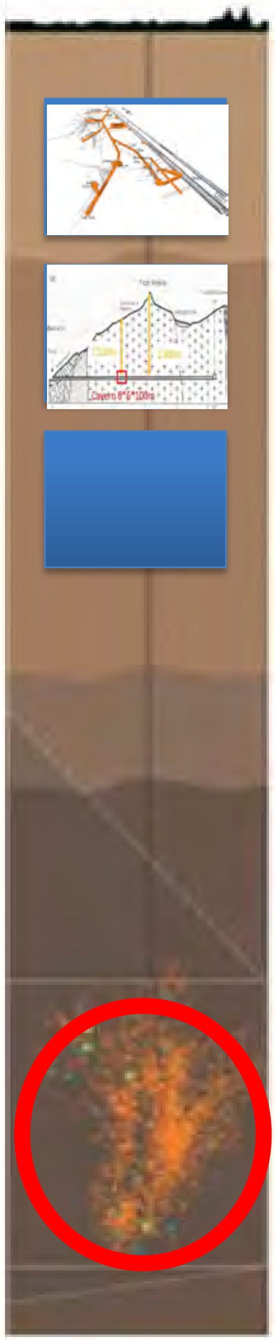
Domenico Giardini & the DUG-Lab team
ETH Zurich, SCCER-SoE

3nd Induced Seismicity Workshop, Schatzalp, 6.3.2019

Schatzalp 2017
Next Step: 100m-scale “Flagship” Experiment



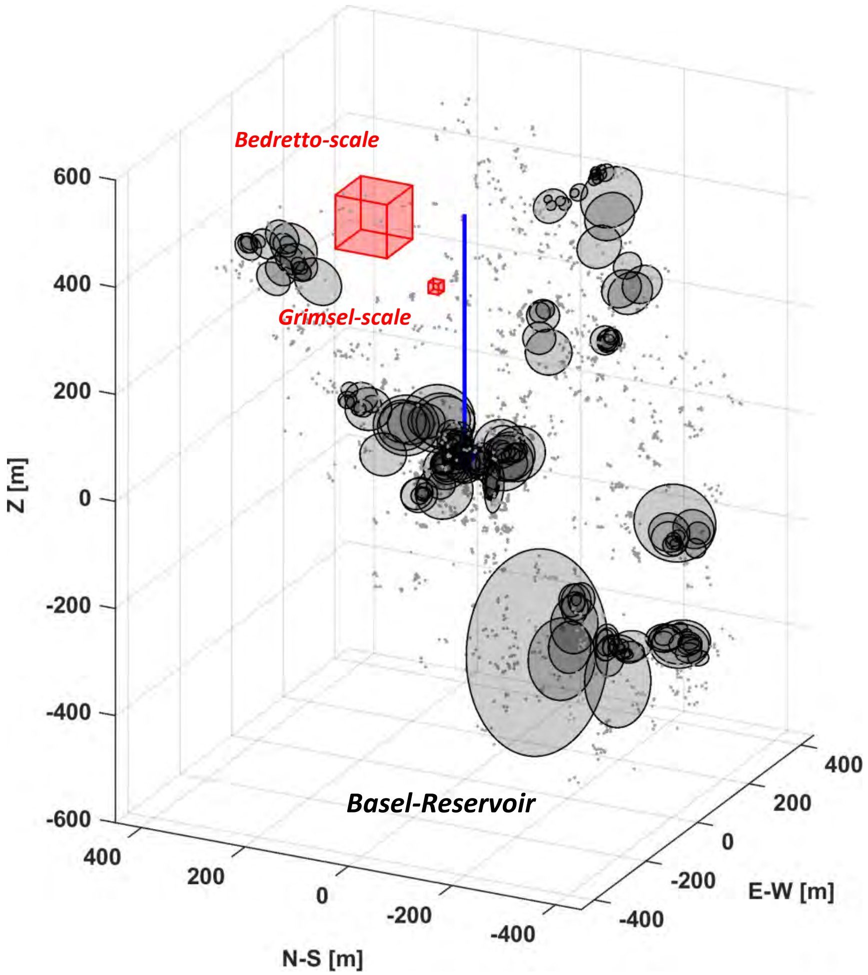


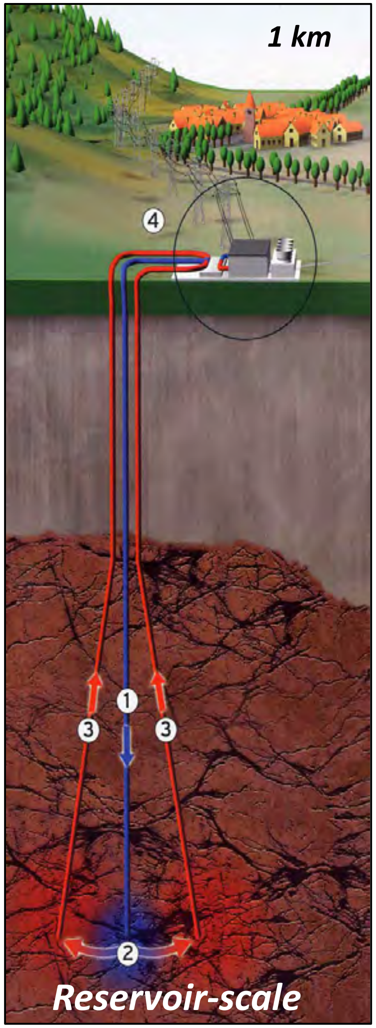


Why a deep underground laboratory ?

- ✓ To perform stimulation experiments under a fully controlled environment at increasing depths and realistic conditions
- ✓ To bridge between laboratory experiments (1-10 cm scale) and deep reservoir stimulation (1-5 km scale, 5 km distance, little/no local monitoring, scarse knowledge of local conditions)
- ✓ To validate protocols and safe procedures before deployment in deep EGS
- ✓ To provide a testing ground integrating experimental, modeling and monitoring technologies
- ✓ To develop and test innovative methodologies for reservoir engineering
- ✓ To increase public confidence in geo-energy technologies

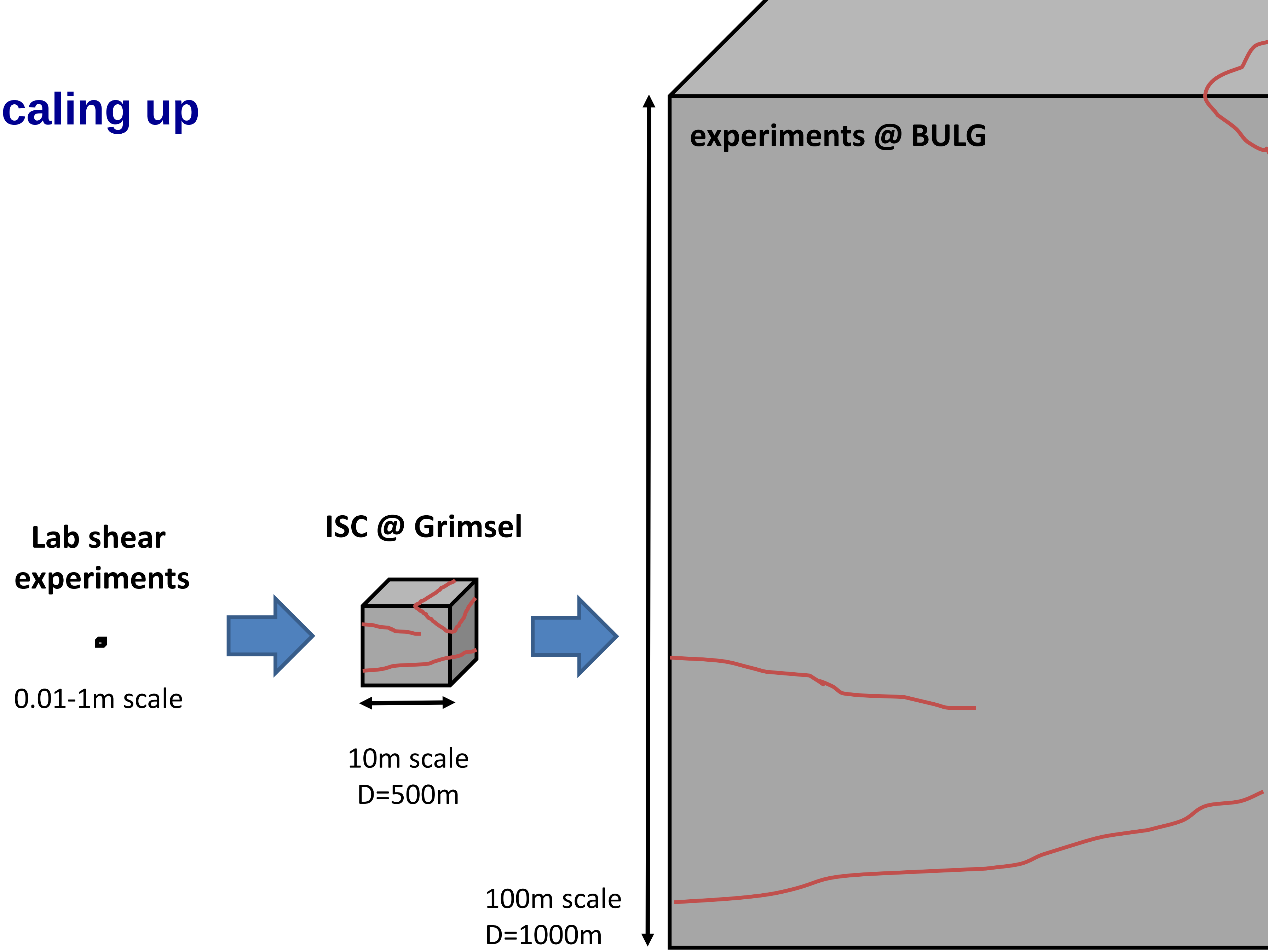
Why a deep underground laboratory ?





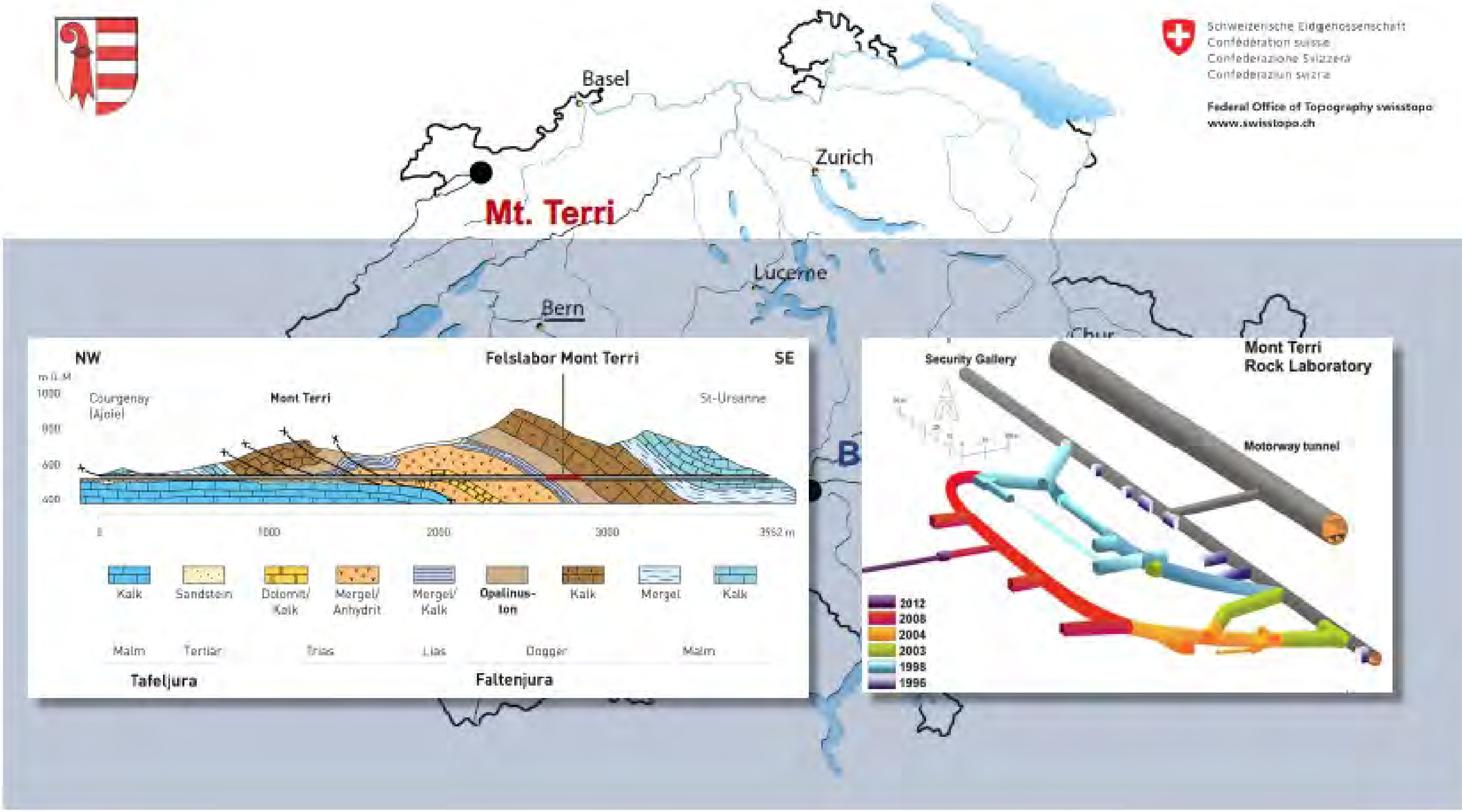
Questionable scaling, local control and monitoring difficult

Scaling up

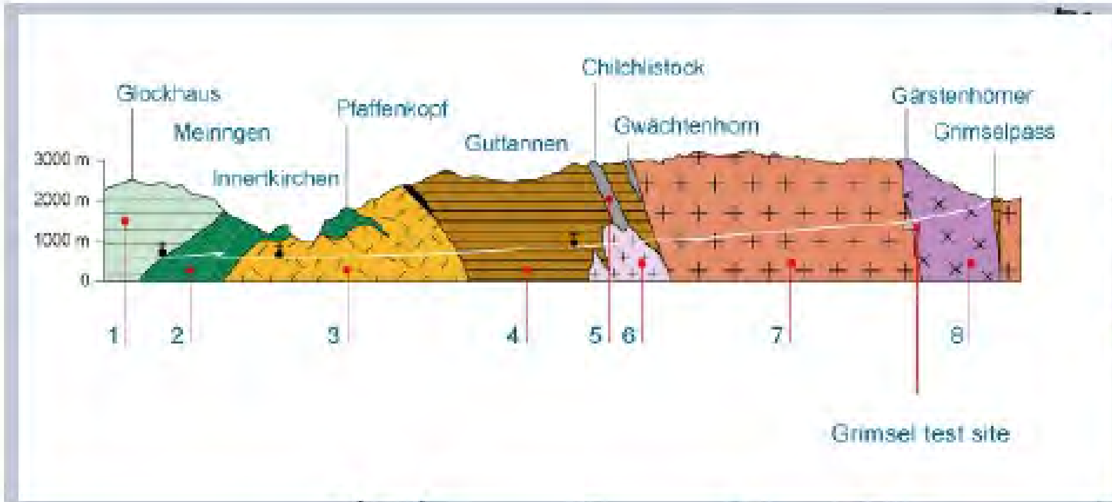

Lab shear experiments
0.01-1m scale
ISC @ Grimsel
10m scale
D=500m
experiments @ BULG
100m scale
D=1000m

Deep underground laboratories in Switzerland

Mont Terri Project

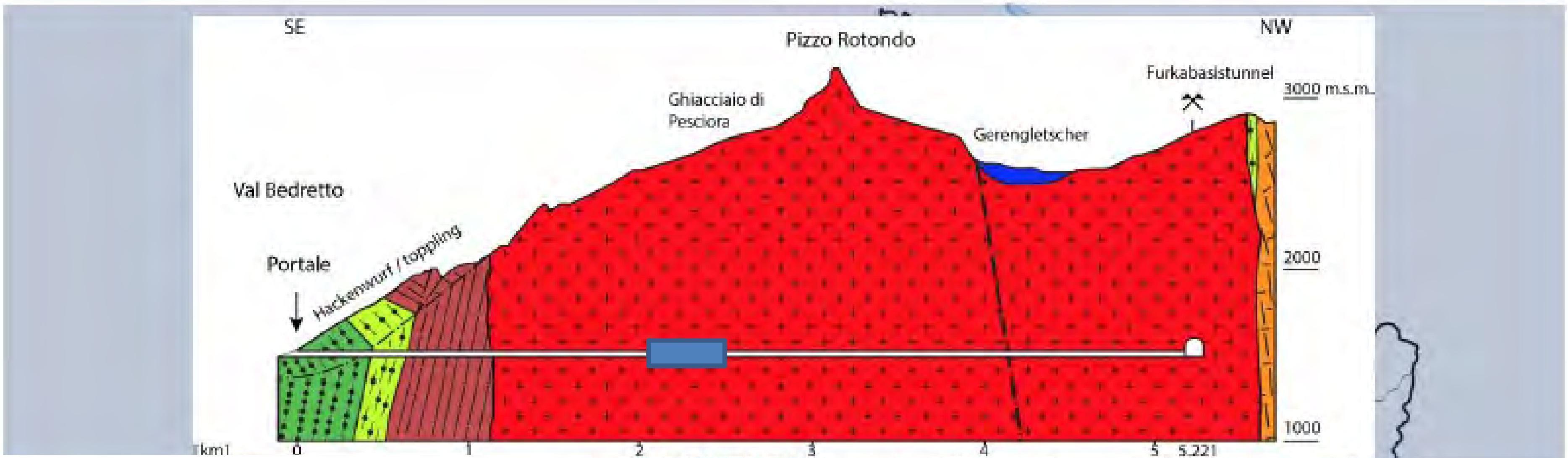


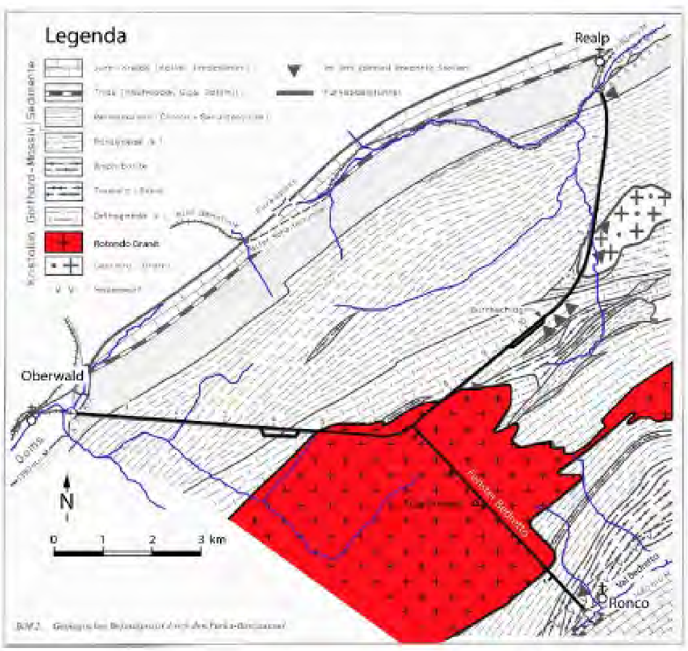
GTS: Grimsel Test Site



nagra

BULG: Bedretto Underground Laboratory for Geoenergies

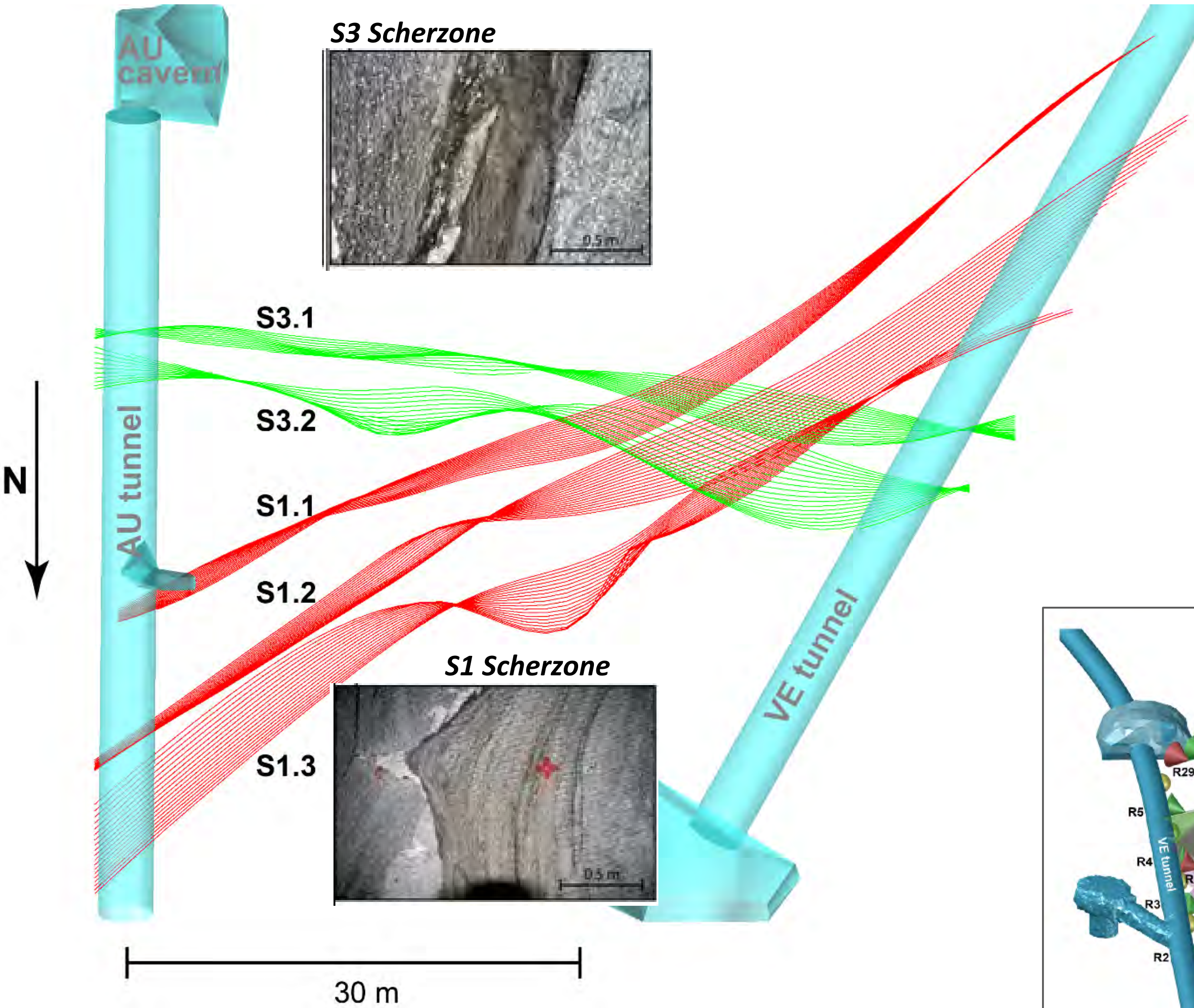


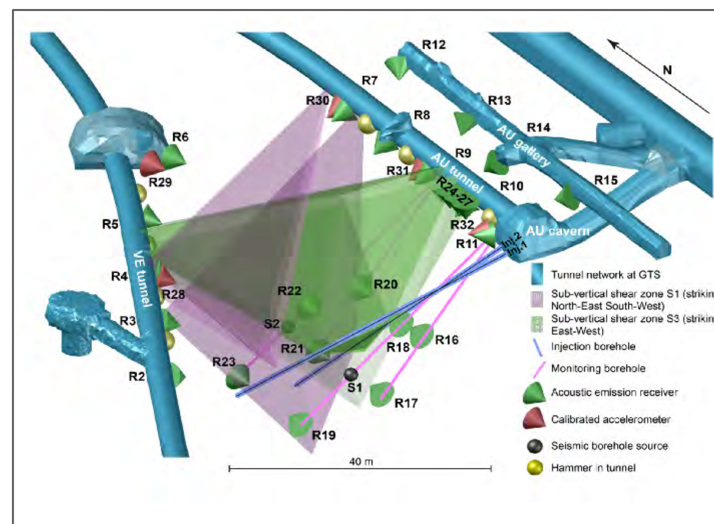


Keller & Schneider, 1982

ETH Zürich

In-situ stimulation project @ Grimsel (Doetsch, tomorrow 08:30)

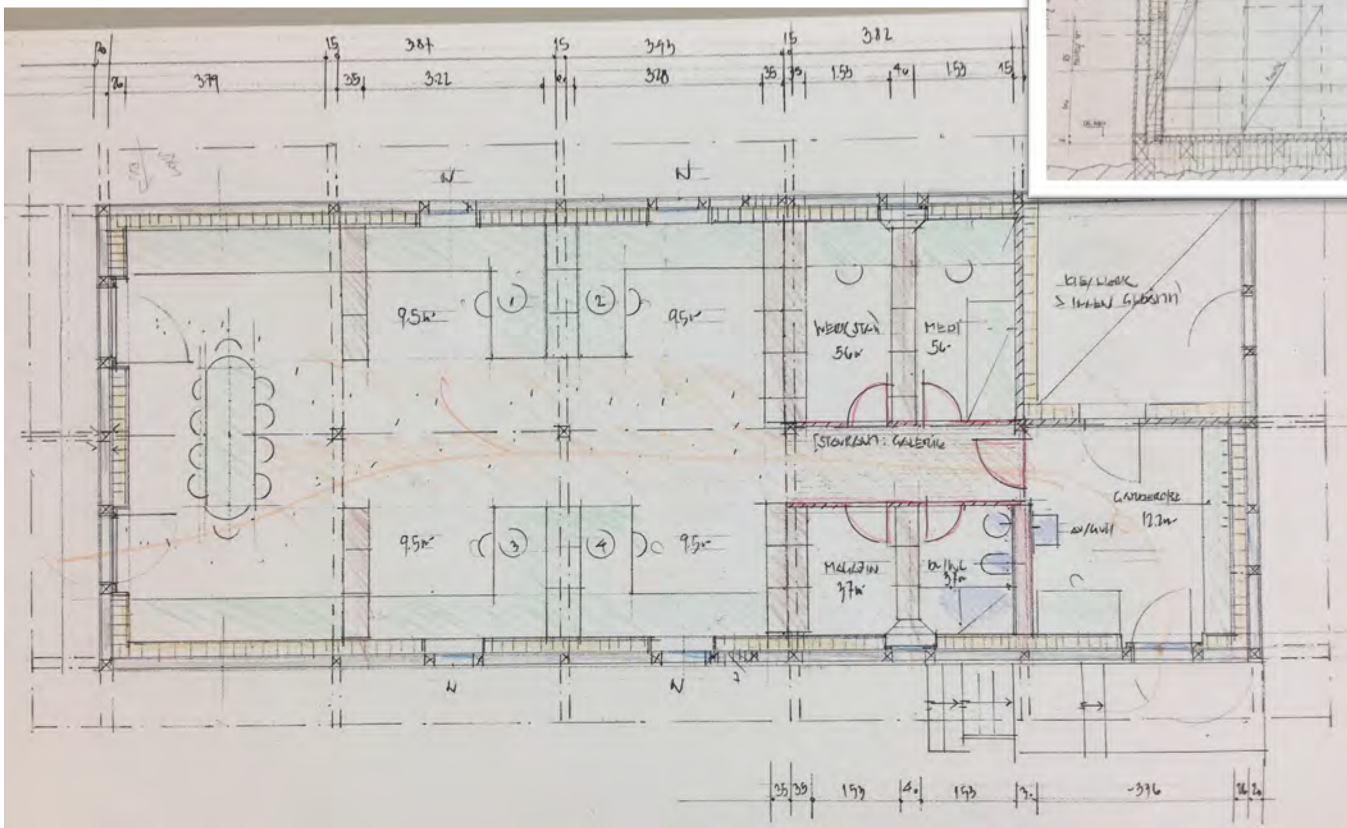


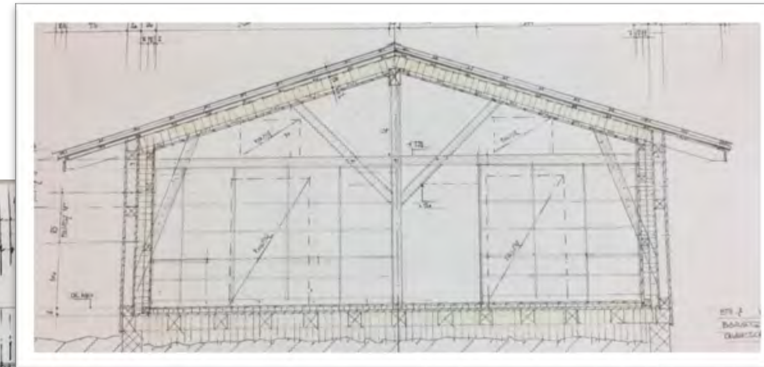


Bedretto before constructions

Bedretto under construction: inside the tunnel

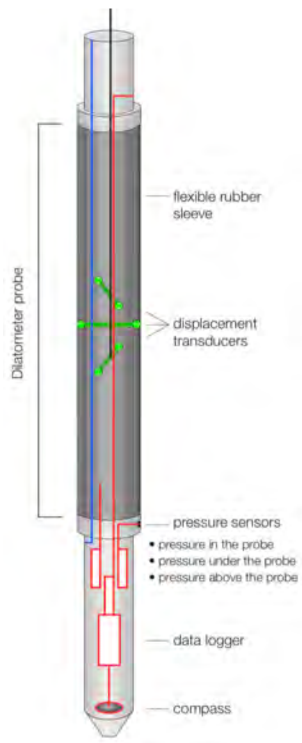
Bedretto under construction: outside the tunnel



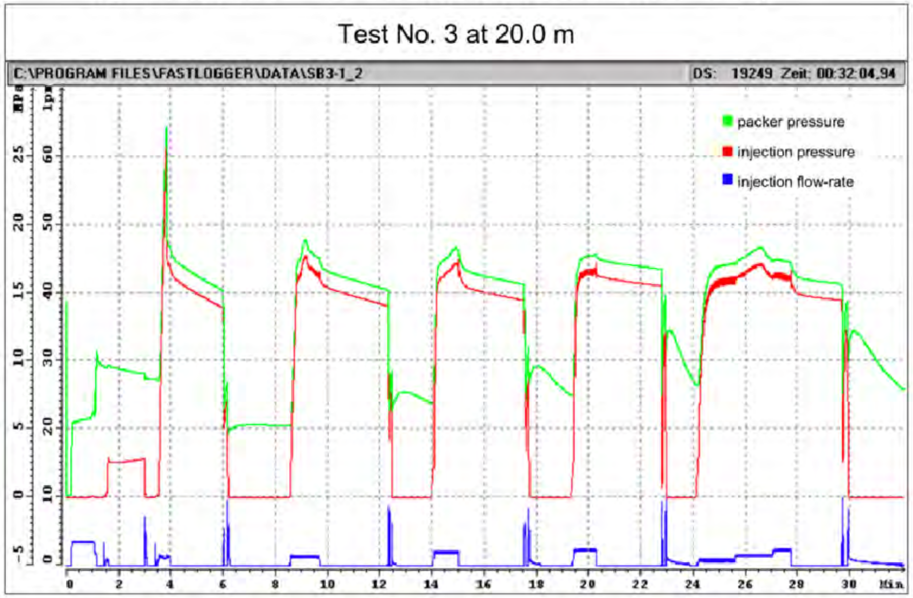


Preliminary investigations in the Bedretto tunnel: faults and stress orientation

- Micro Hydraulic Fracturing (MHF) was performed on three vertical boreholes
- Stress estimates indicate a maximum horizontal stress direction around 110°



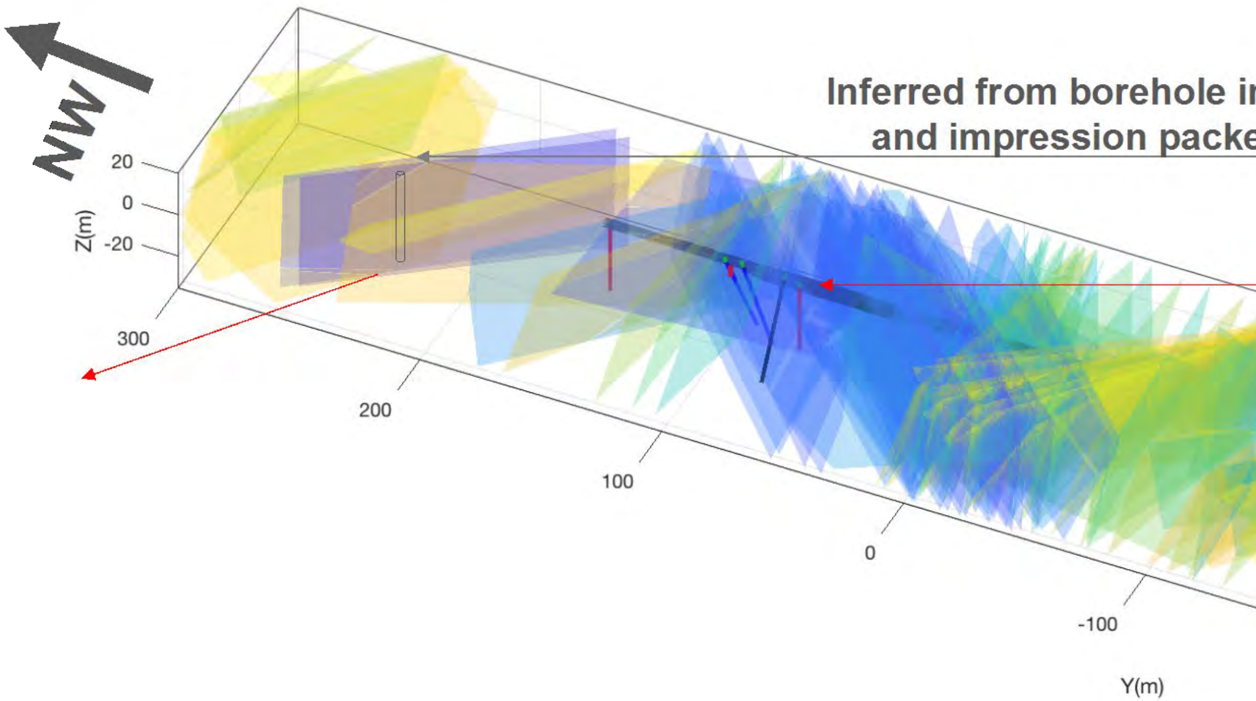
Injection volume: ~ 10 Liter in total
Injection rate: ~ 0.5 Liter/min for initial mini-frac ↓

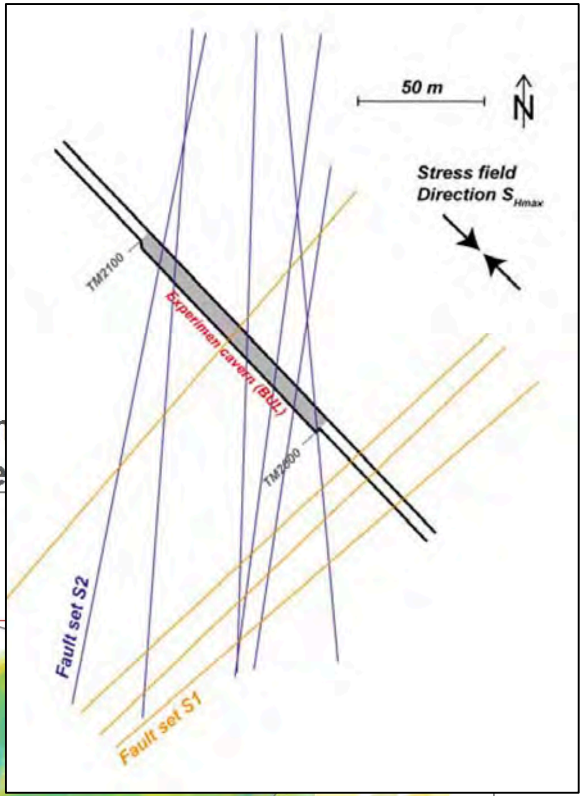


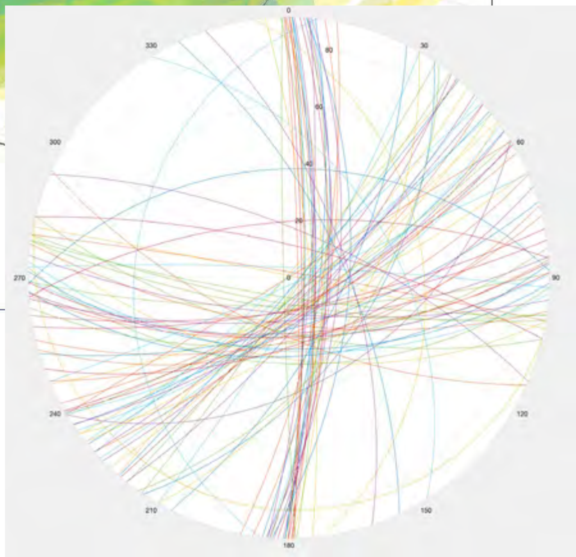
↑ mini-frac
pressure-time records

Poster Ma

Preliminary investigations: faults and stress orientation







- Derived slip tendency (colored planes) agree with local observation of fracture properties

Poster Ma

Experiments lined up for the first phase of BULG

- SFOE Pilot & Demonstration project *Validation of Technologies for Reservoir Engineering* (VTRE), for 100m scale reservoir stimulation
- ERANET-GEOTHERMICA project *Zonal Isolation, Drilling and Exploitation of EGS projects* (ZoDrEx)
- EU H2020 project DESTRESS: *Demonstration of Soft Stimulation Treatments of Geothermal Reservoirs*
- Flagship experiment *Mitigating induced seismicity for successful geo-resources applications (*Werner-Siemens Stiftung; ERC Synergy application, pending)

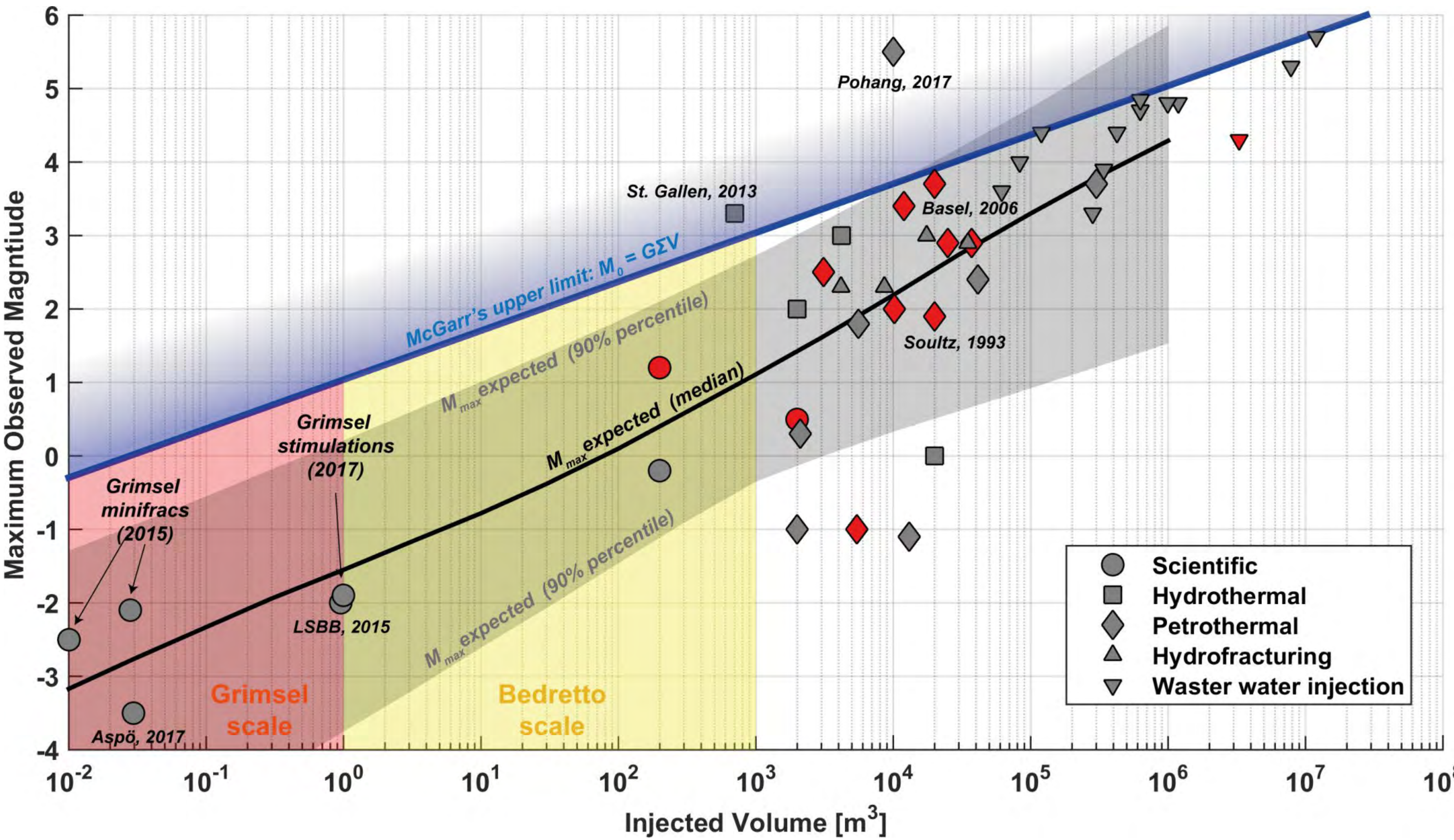
Partners include leading universities and research centers in Europe and worldwide:

- ETH Zurich, EPFL, University of Fribourg, RWTH Aachen University, Deutsches GeoForschungsZentrum Potsdam, Institut de Physique du Globe de Paris, Istituto Nazionale di Geofisica e Vulcanologia, Roma, University of Grenoble, University of Stanford, the KAUST University of Saudi Arabia, the GeothermieZentrum of Bochum University, US Geological Survey.

and leading industry partners in geothermal technologies:

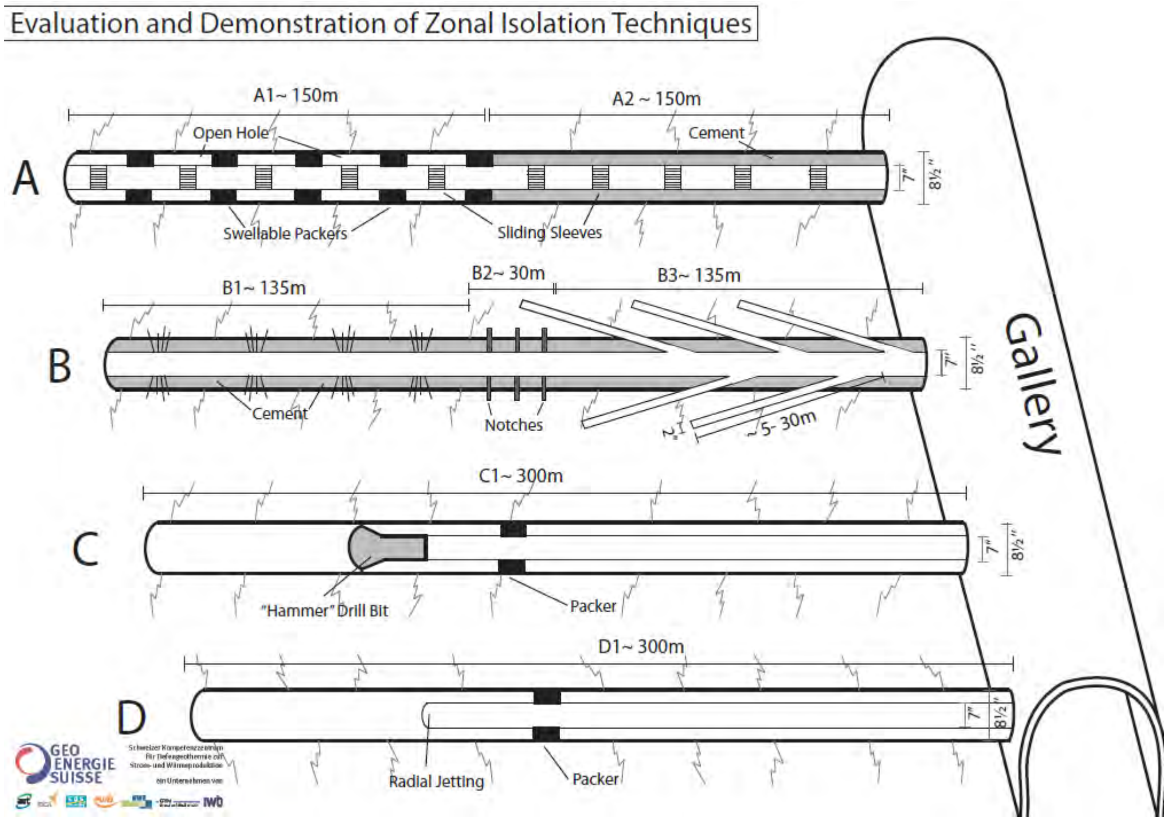
- Geo-Energie Suisse, ANGER’s SÖHNE (D), SIRIUS-ES (D), Welltec (DK), ES-Géothermie (F).

Scaling of deep underground experiments: Grimsel and Bedretto



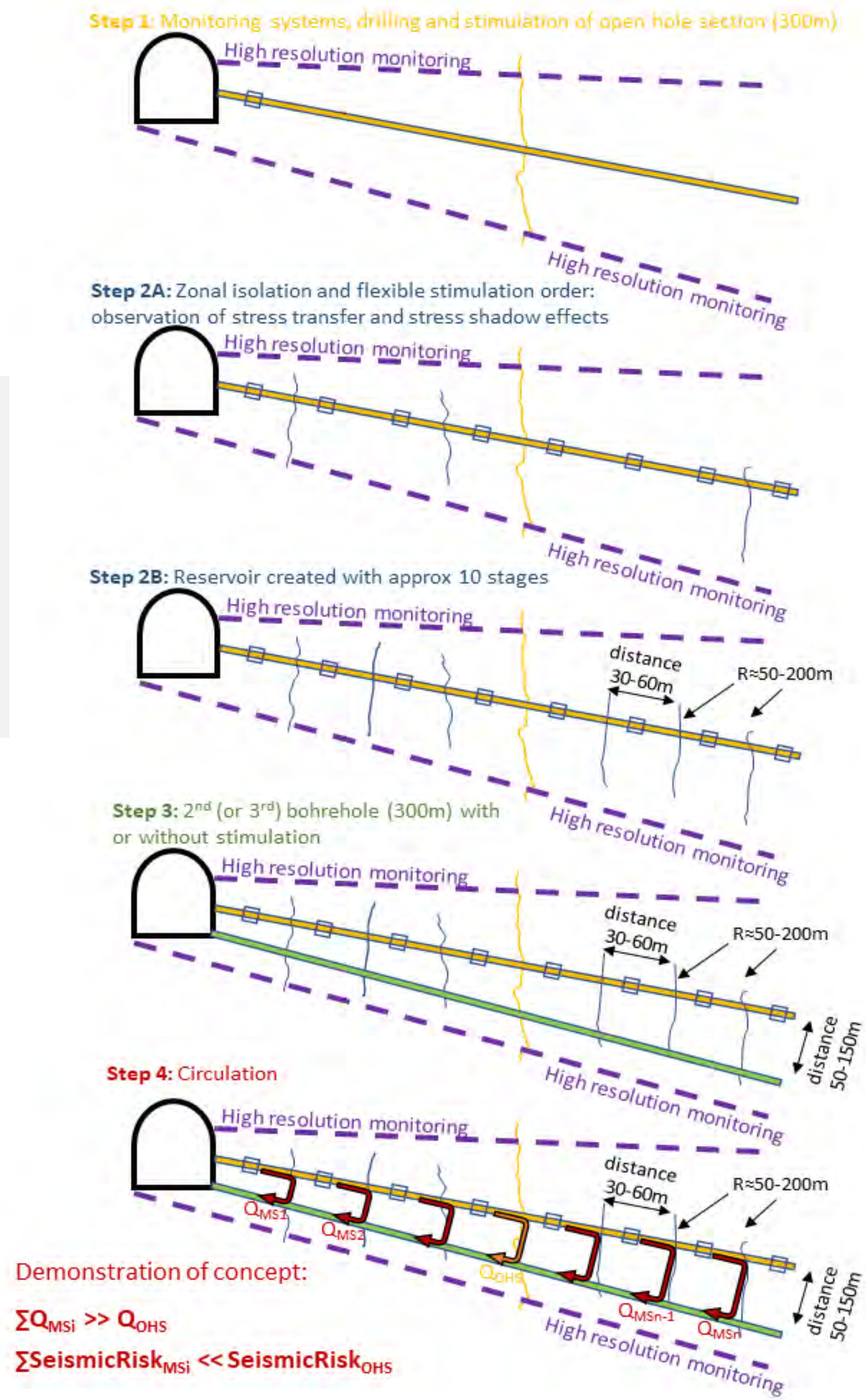
ERANET-GEOTHERMICA ZoDrEx:
Zonal Isolation, Drilling and Exploitation of EGS projects

- ✓ Focus on borehole completion, injection optimization, zonal isolation techniques, borehole-rock connection
- ✓ Strong industry participation and leadership (GES)

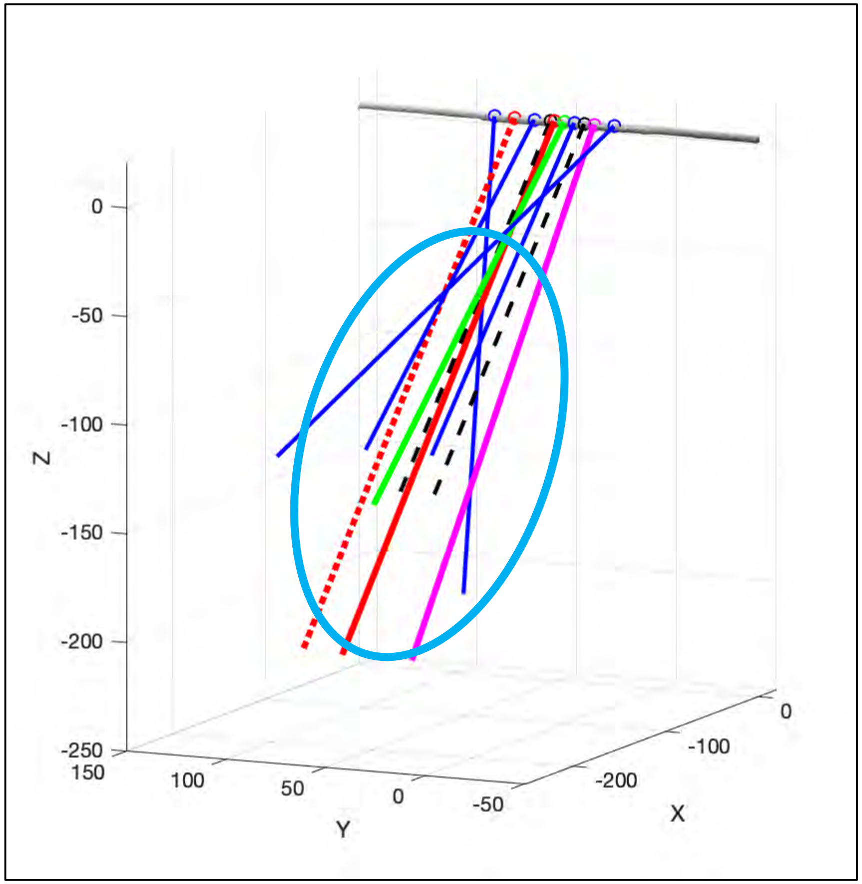


EU DESTRESS: Demonstration of Soft Stimulation Treatments of Geothermal Reservoirs

- ✓ Focus on soft-stimulation, reservoir engineering, demonstration of high-TRL technologies for industrial applications
- ✓ Strong industry participation and leadership (GES)



Integrated VTRE-DESTRESS-ZoDrEx projects



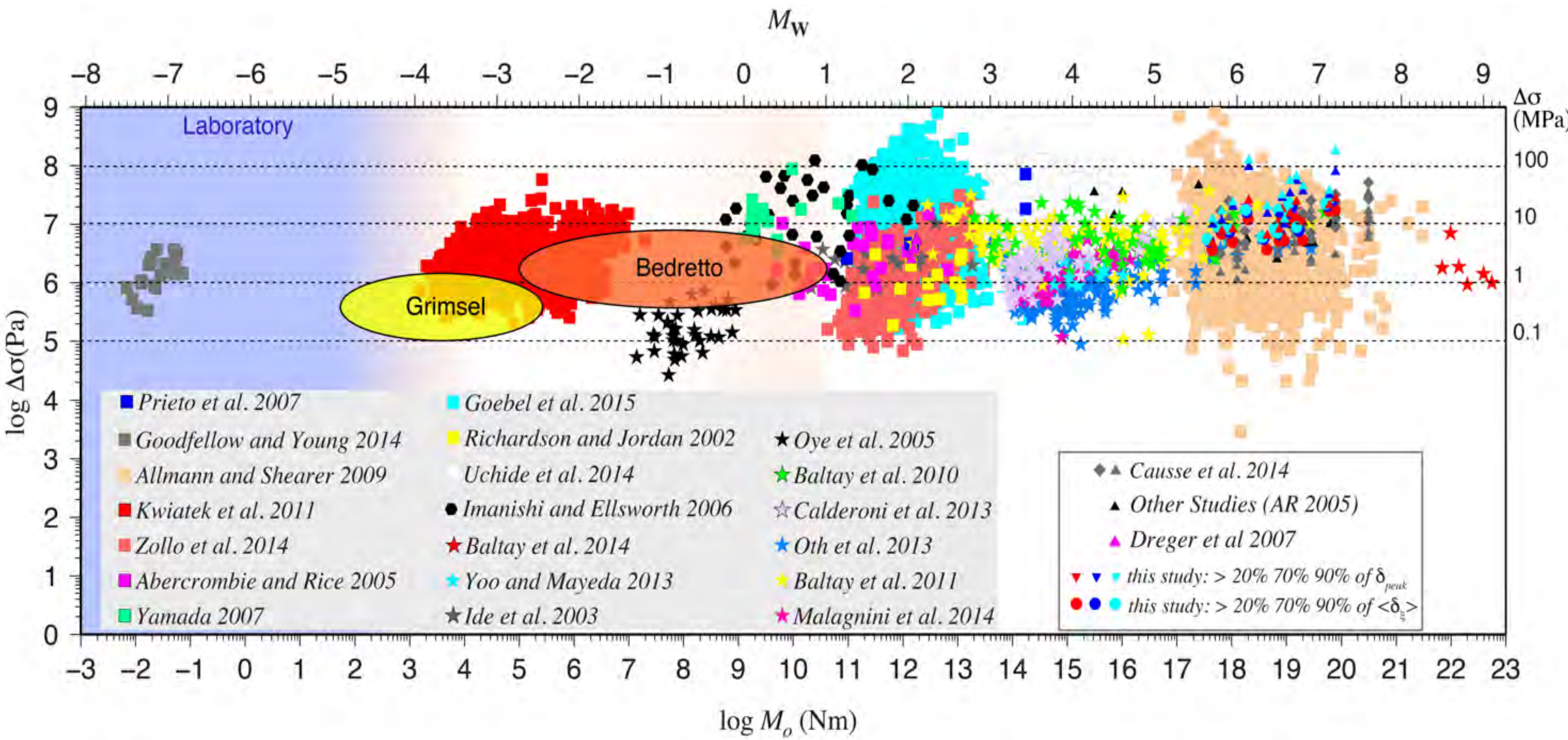
- ✓ The three projects join plans to optimize resources, schedule, monitoring strategies, equipment
- ✓ Present plan: 3 300m long injection holes, 6 250m long monitoring holes (strain, seismic, Vp-Vs, P, T, …)
- ✓ Duration: June 2019-2022
- ✓ Long-term experimental operation of reservoir for energy storage and extraction on a weekly, monthly and yearly timescale

MISS

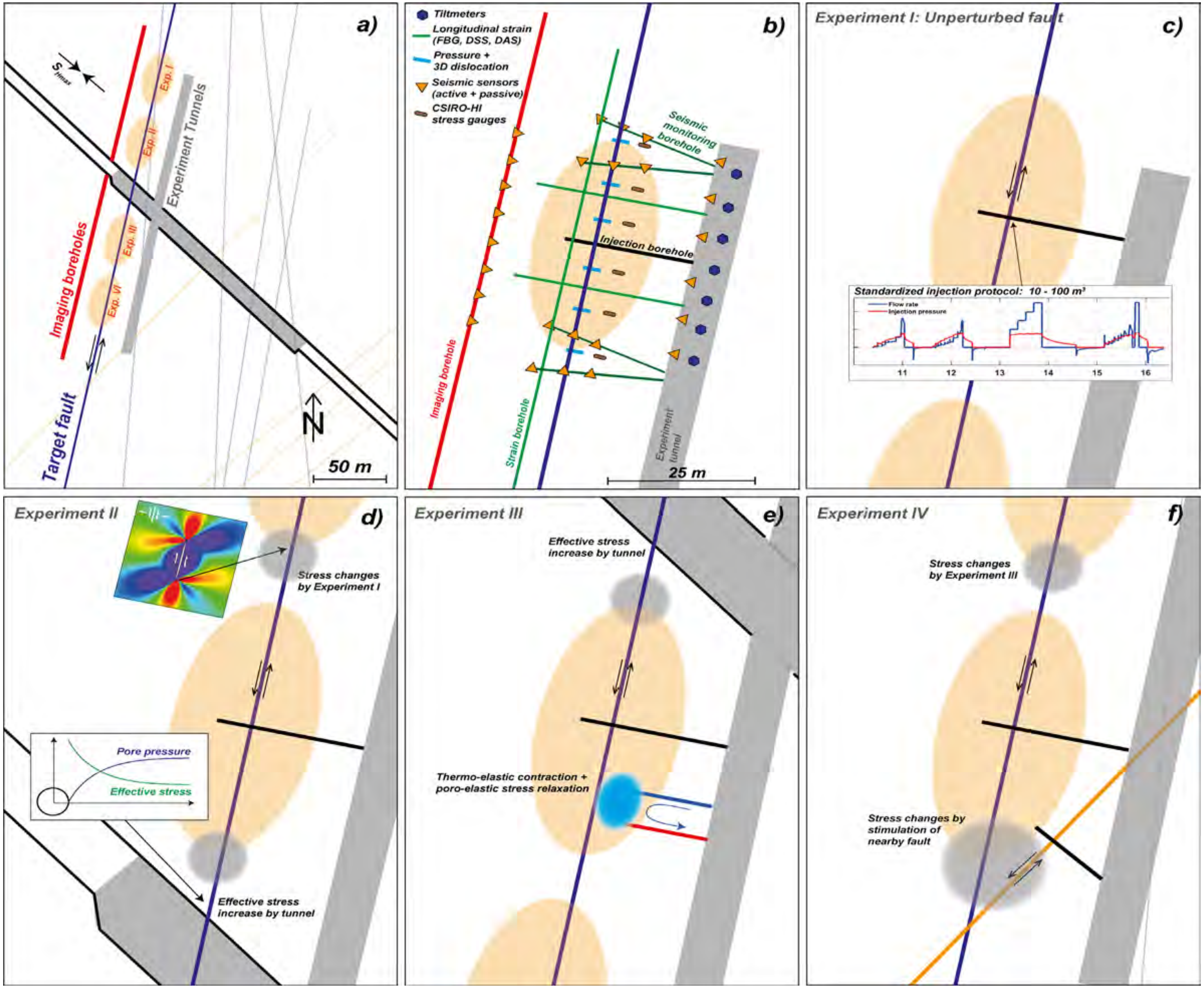
Mitigating induced seismicity for successful geo-resources applications

- ✓ The first-ever experiment to perform 50-100m scale fluid injection and fault stimulation experiments, at over 1'000m depth, conditioning the stress distribution on the fault and validating the results of deep experiments with tests in rock-deformation laboratories, numerical modeling and observations from natural earthquakes.
- ✓ Integrating fault mechanics, seismology and numerical modeling across scales: from laboratory to deep underground experiments to natural earthquakes
- ✓ Focus on accurate fault monitoring and characterization, multi-parameter analysis, fluid-rock interaction, earthquake initiation and stopping, physical understanding across scales

Scaling of deep underground experiments: Grimsel and Bedretto



Adapted from Cocco et al., 2016



a)
S_{Hmax}
Exp. I
Exp. II
Exp. III
Exp. VI
Experiment Tunnels
Imaging boreholes
Target fault
N
50 m
b)
Tiltmeters
Longitudinal strain (FBG, DSS, DAS)
Pressure + 3D dislocation
Seismic sensors (active + passive)
CSIRO-HI stress gauges
Seismic monitoring borehole
Injection borehole
Imaging borehole
Strain borehole
Experiment tunnel
25 m
Experiment I: Unperturbed fault
c)
Standardized injection protocol: 10 - 100 m³
Flow rate
Injection pressure
11
12
13
14
15
16
Experiment II
d)
Stress changes by Experiment I
Pore pressure
Effective stress
Effective stress increase by tunnel
Experiment III
e)
Effective stress increase by tunnel
Thermo-elastic contraction + poro-elastic stress relaxation
Experiment IV
f)
Stress changes by Experiment III
Stress changes by stimulation of nearby fault

MISS: key questions

Earthquake physics: How do earthquakes nucleate, propagate and arrest? What is the role of pre-stress conditions and geometrical/rheological complexities (i.e., barriers) on earthquake nucleation, propagation and arrest? What is the role of fluids and pore-pressure changes, heterogeneity of frictional properties and dynamic parameters?

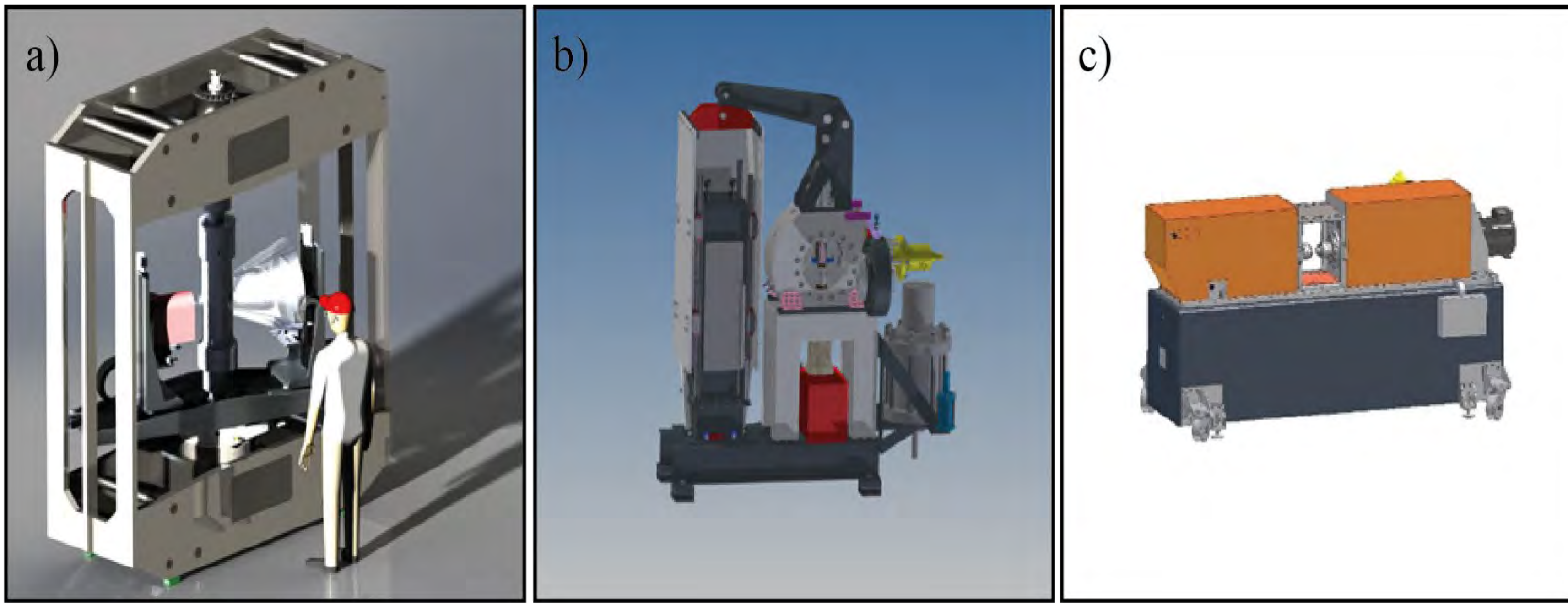
Earthquake precursors: Can we observe earthquake precursors? Are there transient process diagnostics of an impending rupture, or is the latter an unpredictable consequence of cascading interactions of slow and fast transients?

What happens on and around the fault zone? What is the inter-relation between seismic and aseismic deformation within the fault-zone and in the surrounding volume? What and how are the fault zone parameters controlling the degree of cross coupling between micro-seismic swarms, transient creep, and pore pressure transients?

Implications for induced seismicity in geo-energy applications: What stress conditions produce larger magnitude events? How can induced earthquakes, seismic and aseismic slip be controlled?

MISS: integration across scales

Validate the results of deep experiments with accurate fault monitoring and characterization, coring and tests in rock-deformation laboratories, numerical modeling and observations from natural earthquakes, integrating fault mechanics, seismology and physical understanding across scales: from laboratory to deep underground experiments to natural earthquakes



a) LabQuake(X) @ ETHZ, b) HighSteps @ EPFL, c) SHIVA @ INGV

BULG: Bedretto Underground Laboratory for Geoenergies

Propietario

matterhorn gotthard bahn

Committente della costruzione

ETH Zürich

swisscom

Operatore

ETH Zürich

DERDW EARTH SCIENCES

BULG Sponsors

ETH Zürich

WSS WERNER SIEMENS-STIFTUNG

Partner di ricerca

ZoDrEx

DESTRESS

SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH SUPPLY of ELECTRICITY

VTRE
Validation of Technologies for Reservoir Engineering

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

ETH Zürich

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Université de Neuchâtel unine

ANGER

cetim Grand Est

CSIC idæa

és géothermie

GEO ENERGIE SUISSE

GZB

LIH RWTH AACHEN UNIVERSITY

sirius e.s. drilling fluids

Welltec

Sicurezza

suva

SiBau

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

Costruzione

BAUMELER Leitungsbau

fretus

AECB Azienda elettrica comunale Bedretto

awa PlanBau GmbH Planung und Bauleitung

Cava di estrazione di ghiaia di Bedretto

Agenzie di finanziamento della ricerca

European Commission
Horizon 2020
European Union funding for Research & Innovation

GEOTHERMICA

ETH Zürich

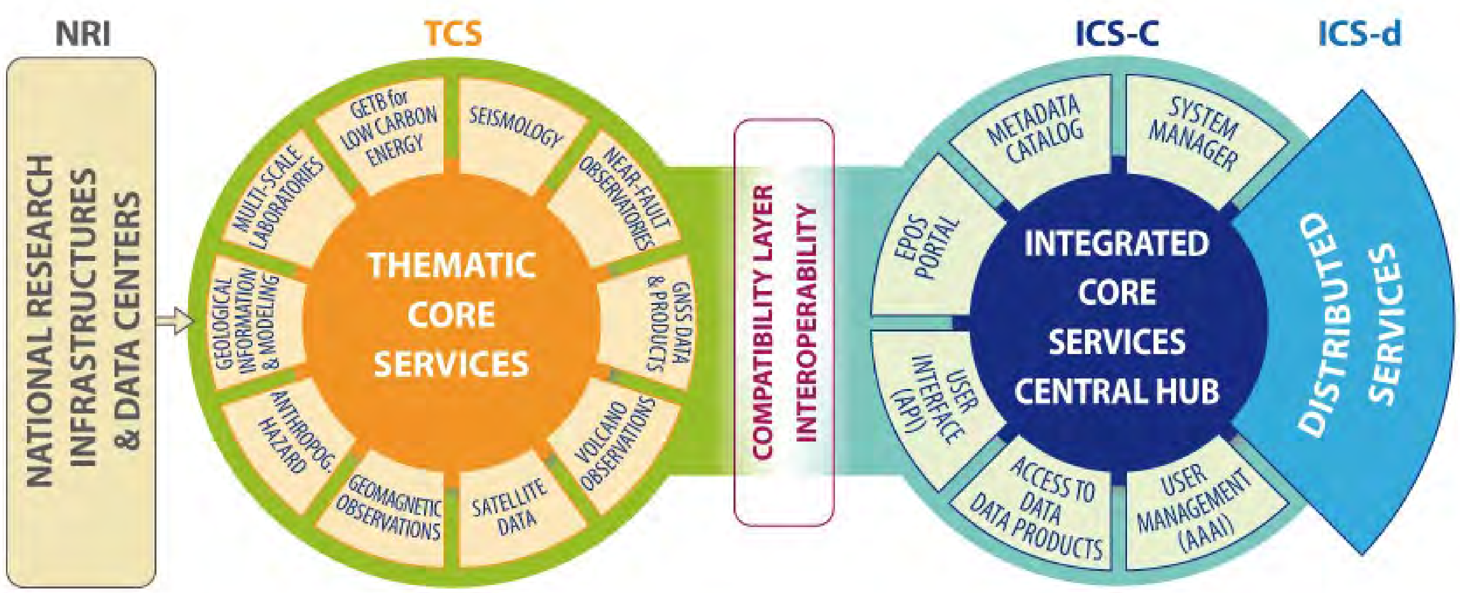
FNSNF ERA-NET
Fonds National Suisse
Schweizerischer Nationalfonds
Fondo Nazionale Svizzero
Swiss National Science Foundation

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Bundesamt für Energie BFE
Swiss Federal Office of Energy SFOE

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Innosuisse – Swiss Innovation Agency

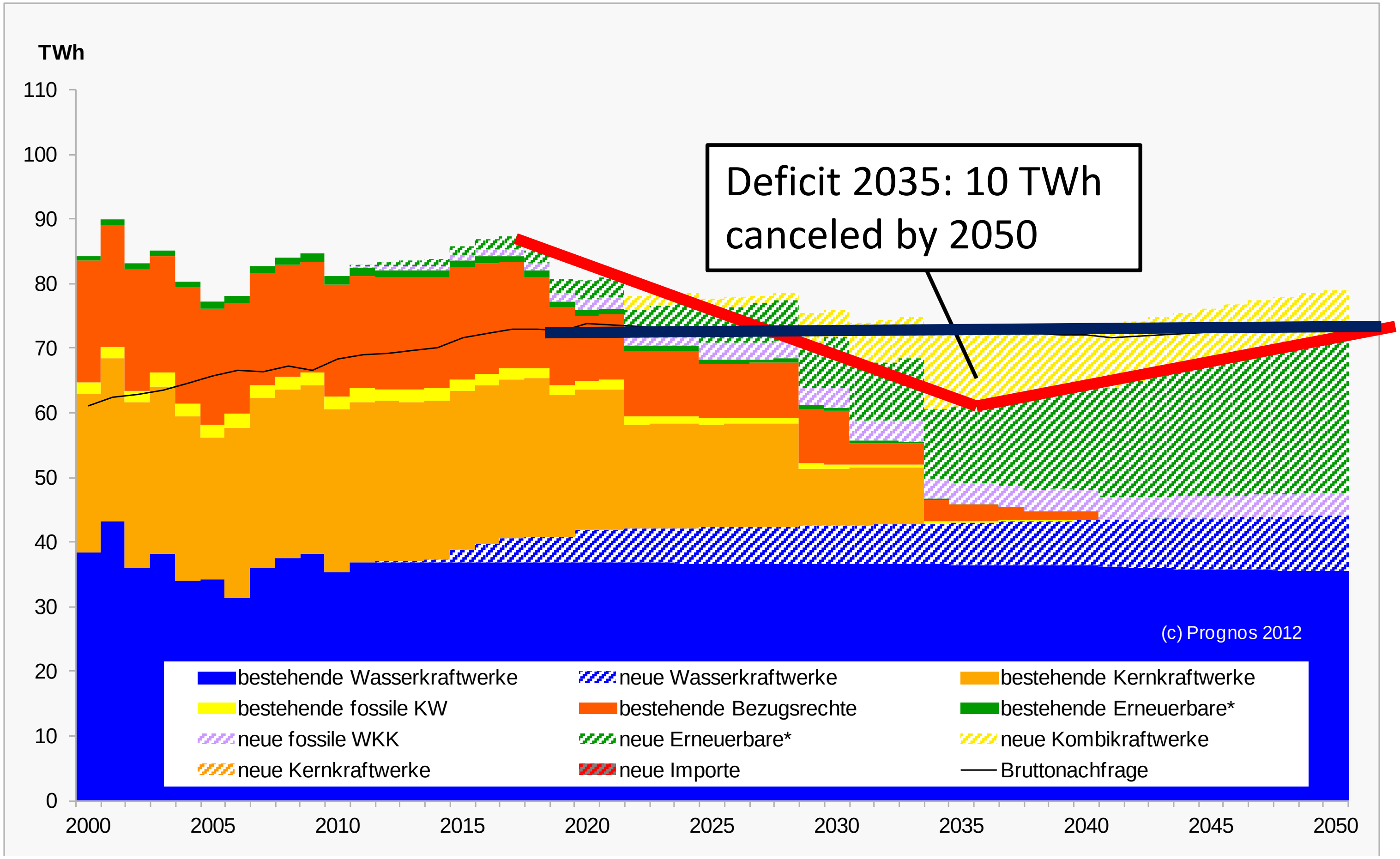
BULG: an international infrastructure

- Included in EPOS TCS GETB: Geo-Energy Test Beds for low carbon energy
- Included in SERA+ NA "Networking deep laboratories and geo-energy infrastructures" (H2020 proposal)
- Open for Trans-National Access in SERA+ (Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe) (H2020 proposal)

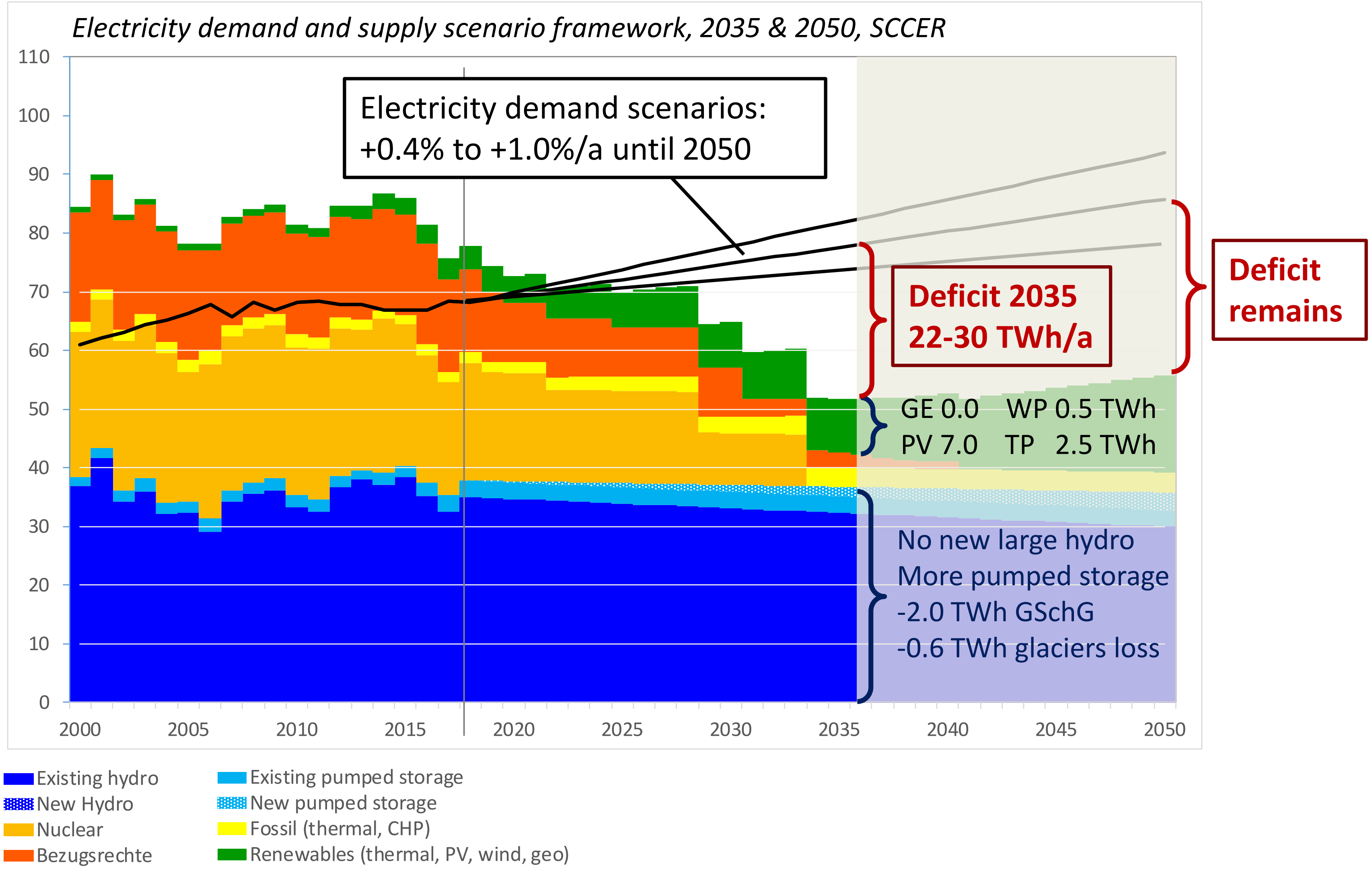


→ **BULG is open for collaborations and for new projects! Come with new ideas!**

Swiss Energy Strategy 2050: electricity supply

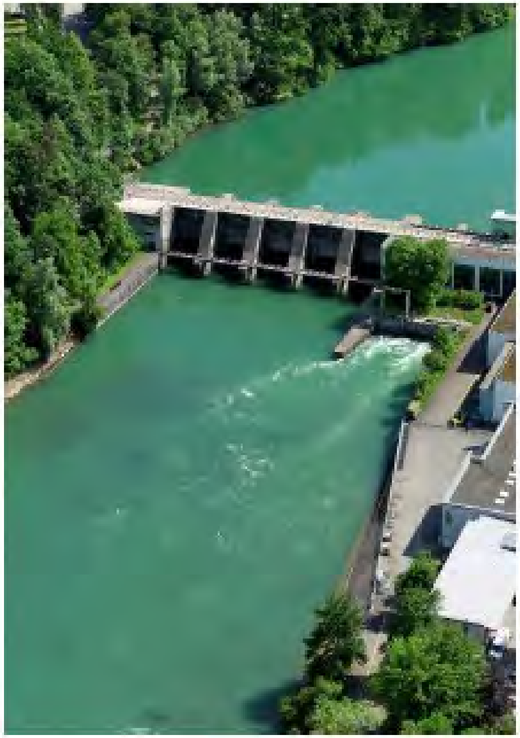


Swiss Energy Strategy 2050: electricity supply scenarios



How large is a 26 TWh/a deficit ?

260
medium-size
RoR dams

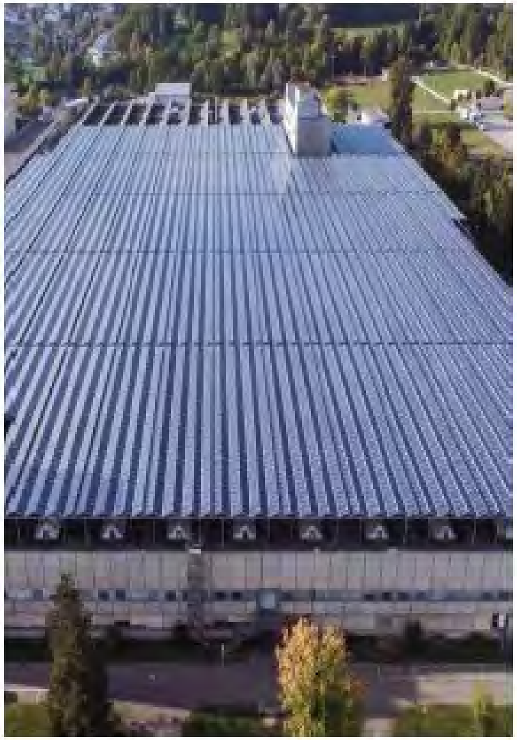


20 MW RoR, 100 GWh/a
KW Bremgarten-Zufikon, 1894

5’200
wind turbines

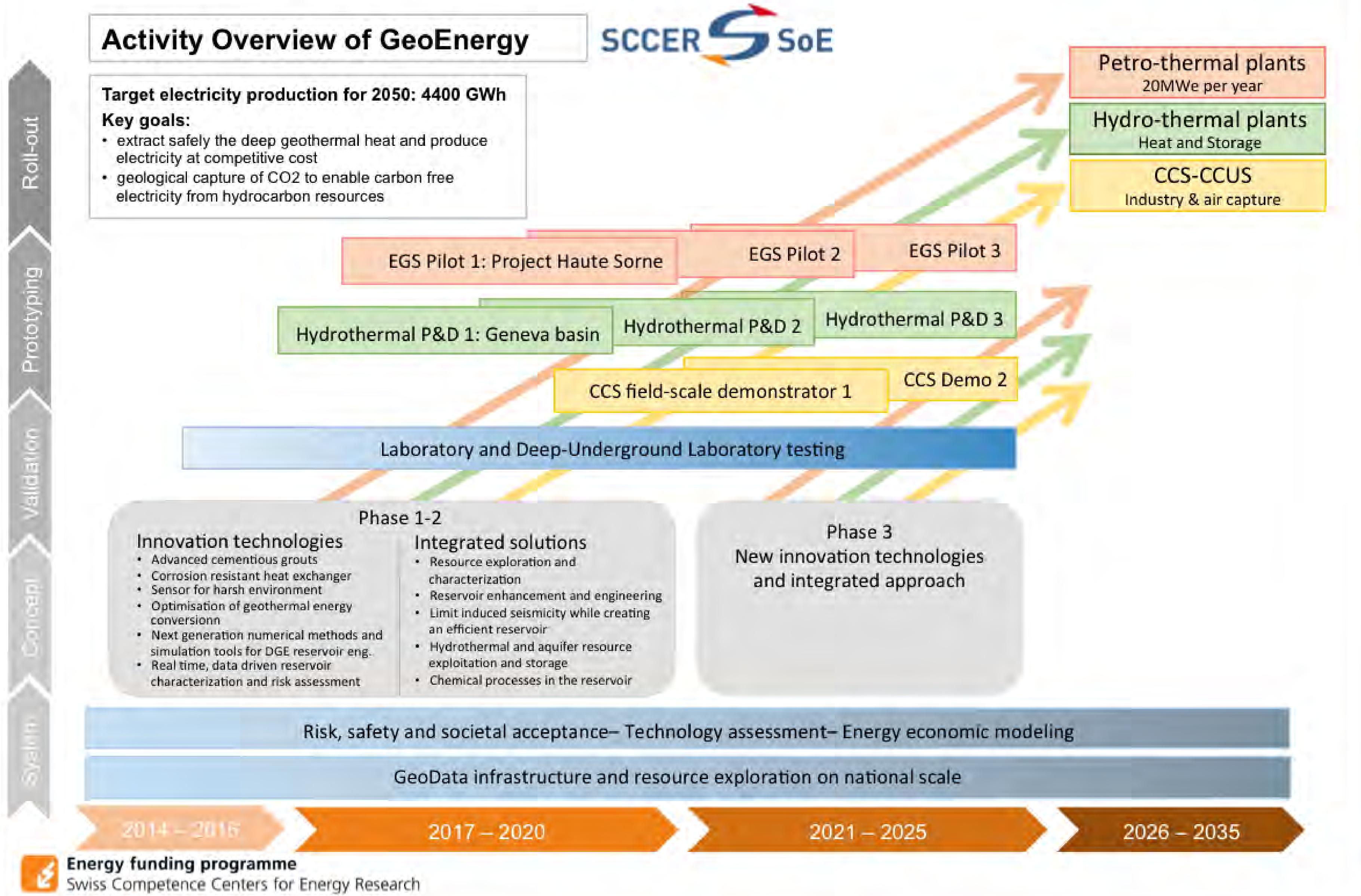
2 MW wind turbine, 5 GWh/a
RhoneEole Martigny, 2008

26’000
football field
PV plants



36’000 m2 (5 football fields), 5 GWh/a
Riverside in Zuchwil, 2015

modified from Schweizerischer Wasserwirtschaftsverband
Association suisse pour l’aménagement des eaux
Associazione svizzera di economia delle acque



Activity Overview of GeoEnergy
SCCER SoE
Target electricity production for 2050: 4400 GWh
Key goals:
• extract safely the deep geothermal heat and produce electricity at competitive cost
• geological capture of CO2 to enable carbon free electricity from hydrocarbon resources
Roll-out
Prototyping
Validation
Concept
System
Petro-thermal plants
20MWe per year
Hydro-thermal plants
Heat and Storage
CCS-CCUS
Industry & air capture
EGS Pilot 1: Project Haute Sorne
EGS Pilot 2
EGS Pilot 3
Hydrothermal P&D 1: Geneva basin
Hydrothermal P&D 2
Hydrothermal P&D 3
CCS field-scale demonstrator 1
CCS Demo 2
Laboratory and Deep-Underground Laboratory testing
Phase 1-2
Innovation technologies
• Advanced cementious grouts
• Corrosion resistant heat exchanger
• Sensor for harsh environment
• Optimisation of geothermal energy conversionn
• Next generation numerical methods and simulation tools for DGE reservoir eng.
• Real time, data driven reservoir characterization and risk assessment
Integrated solutions
• Resource exploration and characterization
• Reservoir enhancement and engineering
• Limit induced seismicity while creating an efficient reservoir
• Hydrothermal and aquifer resource exploitation and storage
• Chemical processes in the reservoir
Phase 3
New innovation technologies and integrated approach
Risk, safety and societal acceptance– Technology assessment– Energy economic modeling
GeoData infrastructure and resource exploration on national scale
2014 – 2016
2017 – 2020
2021 – 2025
2026 – 2035
Energy funding programme
Swiss Competence Centers for Energy Research