Using underground experiments to improve the understanding of induced seismicity

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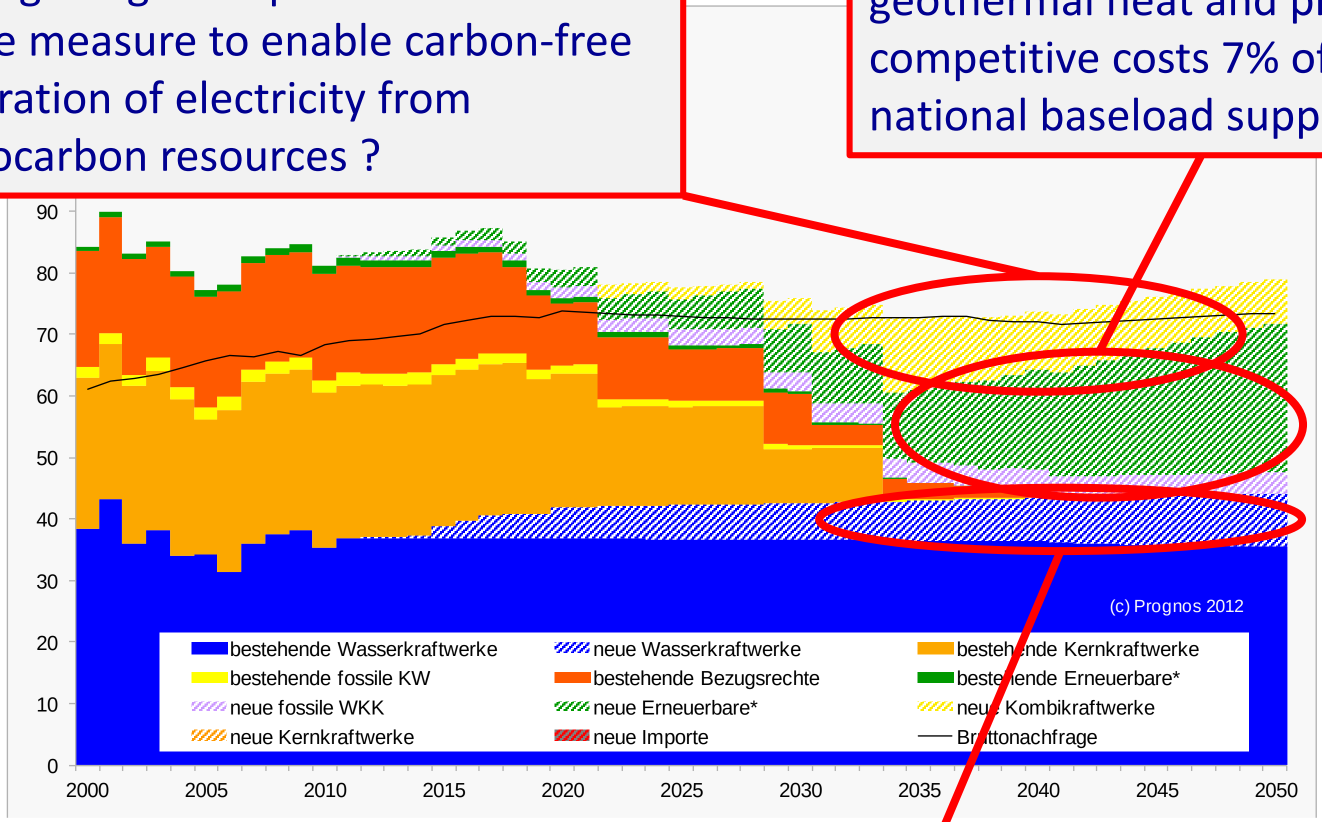
2nd Induced Seismicity Workshop, Schatzalp, 15.3.2017

Swiss Energy Strategy 2050: supply targets

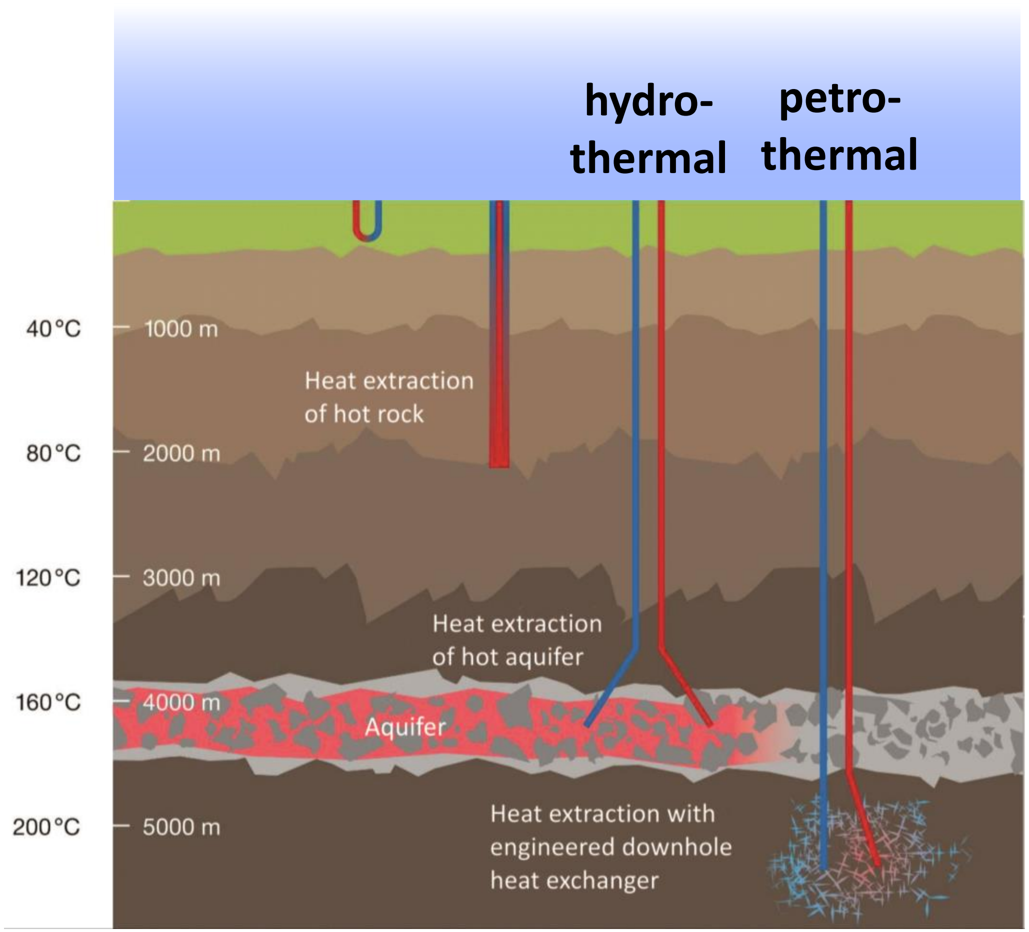
Is the geological capture of CO_2 a viable measure to enable carbon-free generation of electricity from hydrocarbon resources ?

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



Can we increase (i.e. by 10%) the present hydropower electricity production under changing demand, climate and operating conditions ?

DGE challenge #1: deep water resources



- High-enthalpy volcanic areas are few, limited and far between – Iceland, Italy – and cannot provide electricity to the whole Europe
- In many areas, hydrothermal DGE has great potential for heating, less so for electricity → water is scarse and not easily found
- We need to create deep reservoirs in hot rock (EGS) and circulate water from the surface

DGE challenge #2: efficiency, scaling up

Hot rock at depth is an unlimited resource, but ...

- ✓ The Carnot efficiency of the system is low compared to most other sources of electricity; the overall net efficiency of the conversion of heat to electricity in a DGE plant is expected to be (today) around 13-15%
- ✓ Under normal conditions, in Switzerland we find 170-190 C in crystalline basement rocks at 4-6 km depth
- ✓ A sustained water flow of 220 l/s at 180 C is required to generate 20 MWel
- ✓ The Swiss ES2050 target for DGE is 7% of Swiss electricity supply
  → 4.4 TWh/yr, >500 MWel installed
- ✓ The EU-28 area consumes 3'200 TWh of electricity per year; a 5% share of DGE would correspond to an installed capacity of the order of 20 GWel

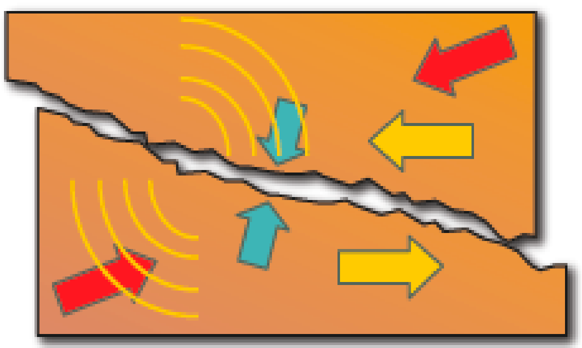
→ Europe will need 1’000 20MWel plants to meet the 5% quota

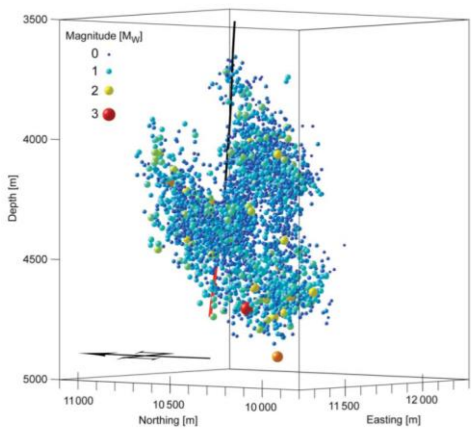
→ Switzerland will need 25 20MWel plants to meet the 7% quota

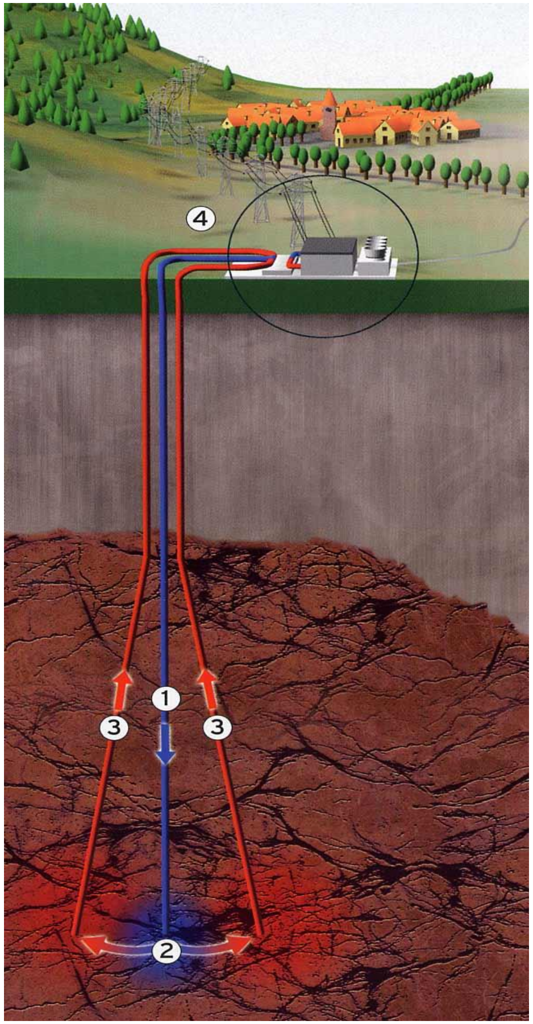
DGE challenge #3: engineering the reservoir

The main challenge is to create a sustainable heat exchanger at depth, a system that will operate for 20-40 years with no or minimal loss in flow, temperature and efficiency.

New approaches are required to enhance rock permeability, with optimal distribution of micro-cracks and porosity to maximize heat exchange, swept area and water circulation.







DGE challenge #4: induced seismicity

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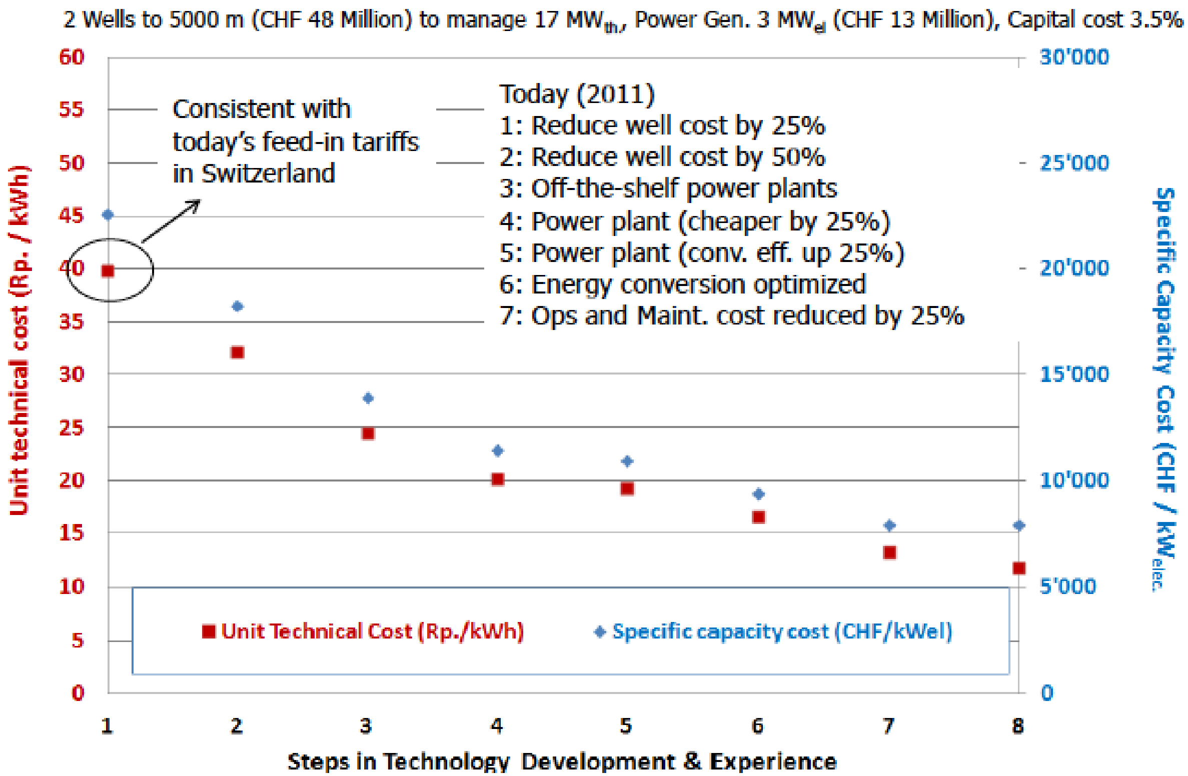
- ✓ Spain, 2011: the largest damaging quake in decades is associated with long-term ground-water extraction in Lorca
- ✓ Holland, 2012: Induced seismicity in Groningen, the largest on-shore gas field in Europe, is increasing and is forcing lower extraction rates, with significant impact on Dutch GDP and European supply
- ✓ Switzerland, 2006 and 2013: Induced seismicity released during a EGS stimulation (Basel) and hydrothermal injection (St.Gallen)
- ✓ UK, 2011: Felt seismicity stopped hydro-fracking in Blackpool
- ✓ Italy, 2012: 14 BE damage and 24 casualties from a sequence of M5-6 earthquakes, possibly associated to hydrocarbon extraction
- ✓ Spain, 2013: the EU-sponsored Castor offshore gas storage field near Valencia is halted after producing earthquakes during the first fill
- ✓ Italy, 2014: seismicity is induced by waste-water injection in Val d'Agri

DGE challenge #5: high cost

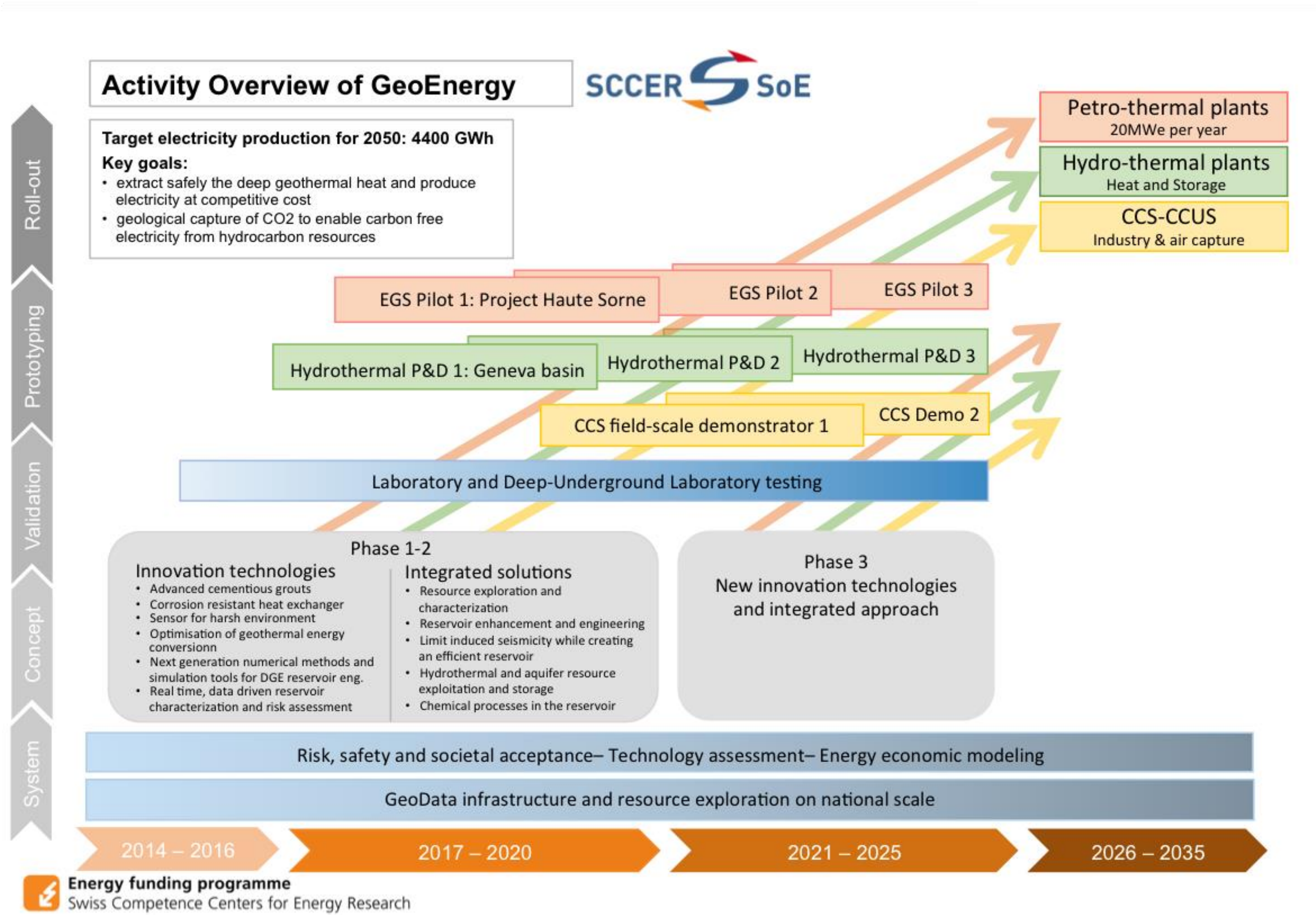
Today's costs are in the order of 40-50 cents/kWh (SFOE), we need to bring them down below 10 cents/kWh



R&D is needed to reduce costs for successful DGE exploitation: innovative drilling technologies, energy techniques, improved heat exchange and efficiency, corrosion, cooling, M&O, reservoir engineering, exploration and imaging, life-cycle sustainability, risk mitigation, monitoring and abatement of induced seismicity.

DGE Roadmap

- ✓ A national Geodata Infrastructure, with 3D mapping to 5km depth
- ✓ 10-yr R&D agenda: resource and reservoir exploration, assessment and characterization; fractures and reservoir creation; reservoir modeling and validation; induced seismicity; monitoring; well completion; chemical interactions and transformations, innovative, high TRL-level technologies
- ✓ Two classes of experimental facilities:
    - i. National, distributed rock deformation laboratory to handle large samples at conditions found in 4-6 km depth
    - ii. National Deep UnderGround Laboratory infrastructure, to conduct 10-100m scale injection experiments at depth of 500-2‘000 m
- ✓ The installation of up to 3 deep EGS reservoirs over the next 10 yeras, conducted as P&D projects, with a target of 4-20 MWel installed capacity each



Activity Overview of GeoEnergy
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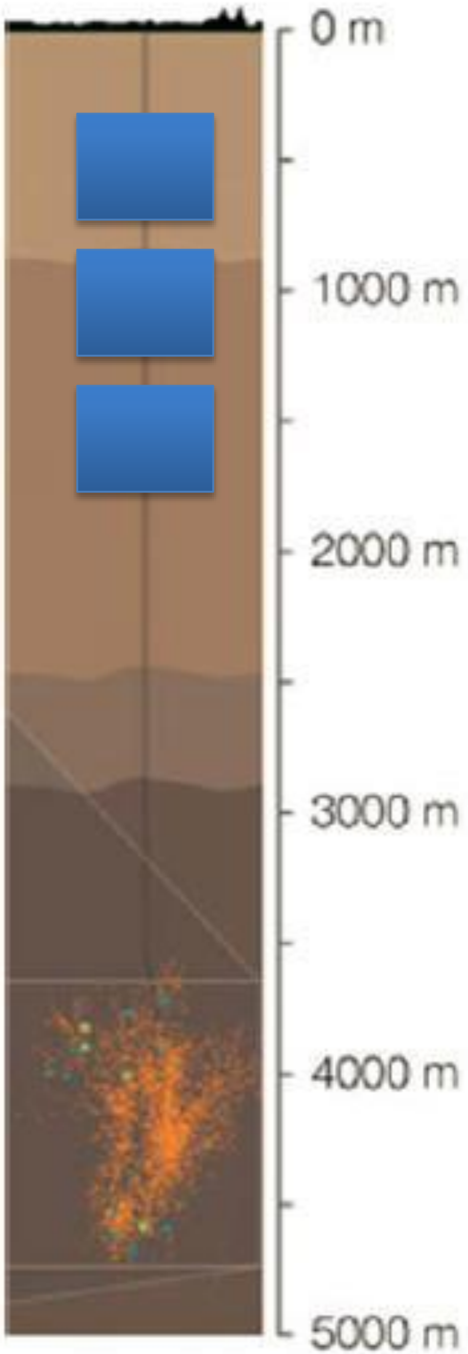
Target electricity production for 2050: 4400 GWh
Key goals:
• extract safely the deep geothermal heat and produce electricity at competitive cost
• geological capture of CO2 to enable carbon free electricity from hydrocarbon resources
Petro-thermal plants
20MWe per year
Hydro-thermal plants
Heat and 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
Roll-out
Prototyping
Validation
Concept
System
2014 – 2016
2017 – 2020
2021 – 2025
2026 – 2035
Energy funding programme
Swiss Competence Centers for Energy Research



Why a DUG-Lab ?

- ✓ 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

The ISC experiment in the NAGRA Grimsel laboratory

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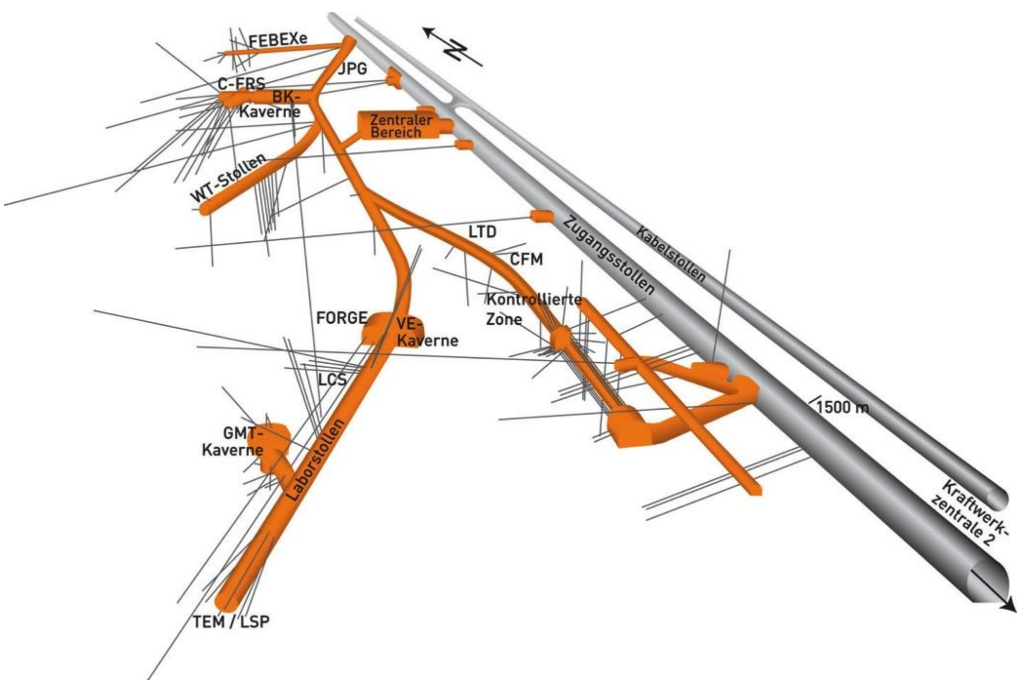
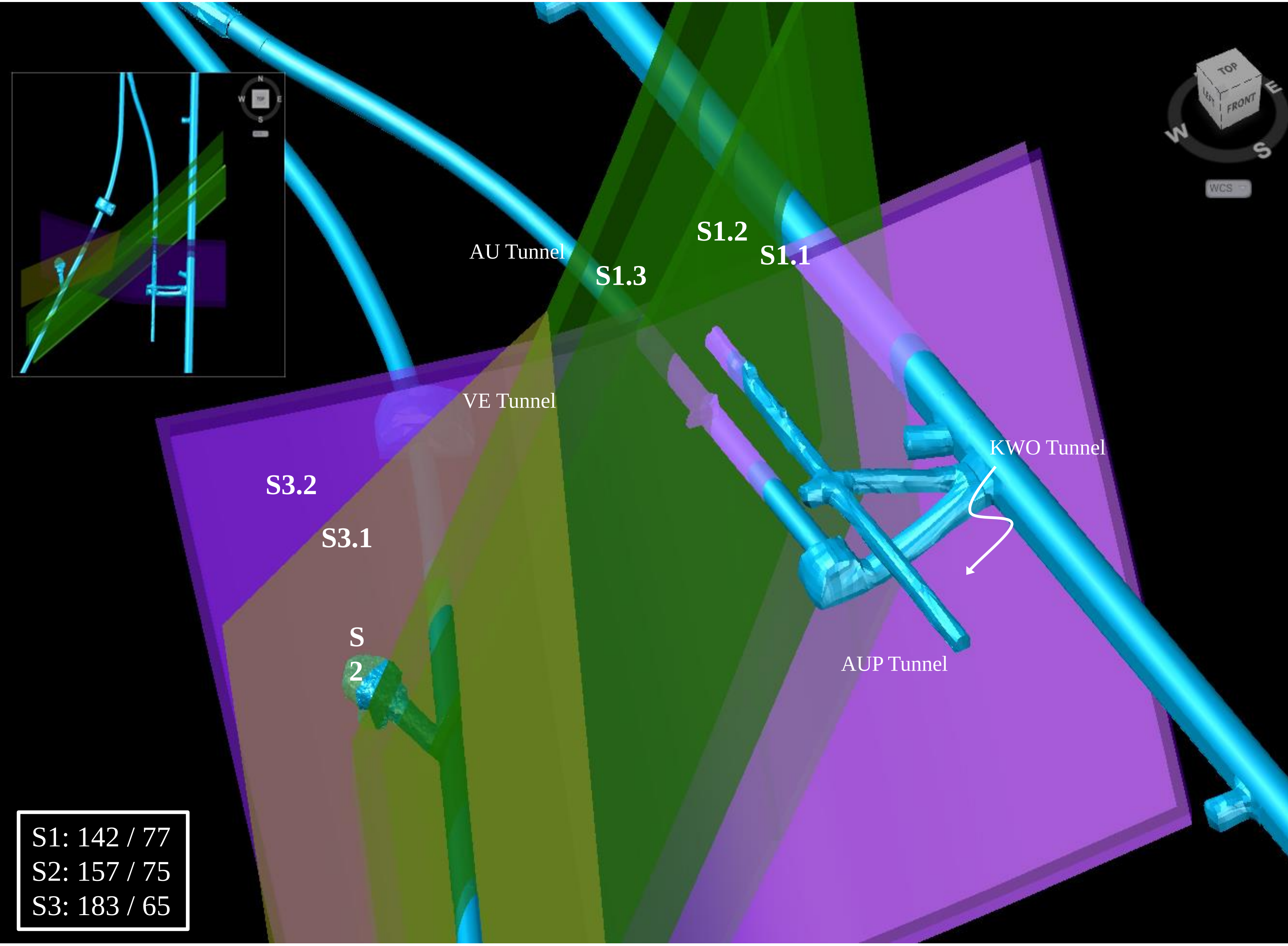
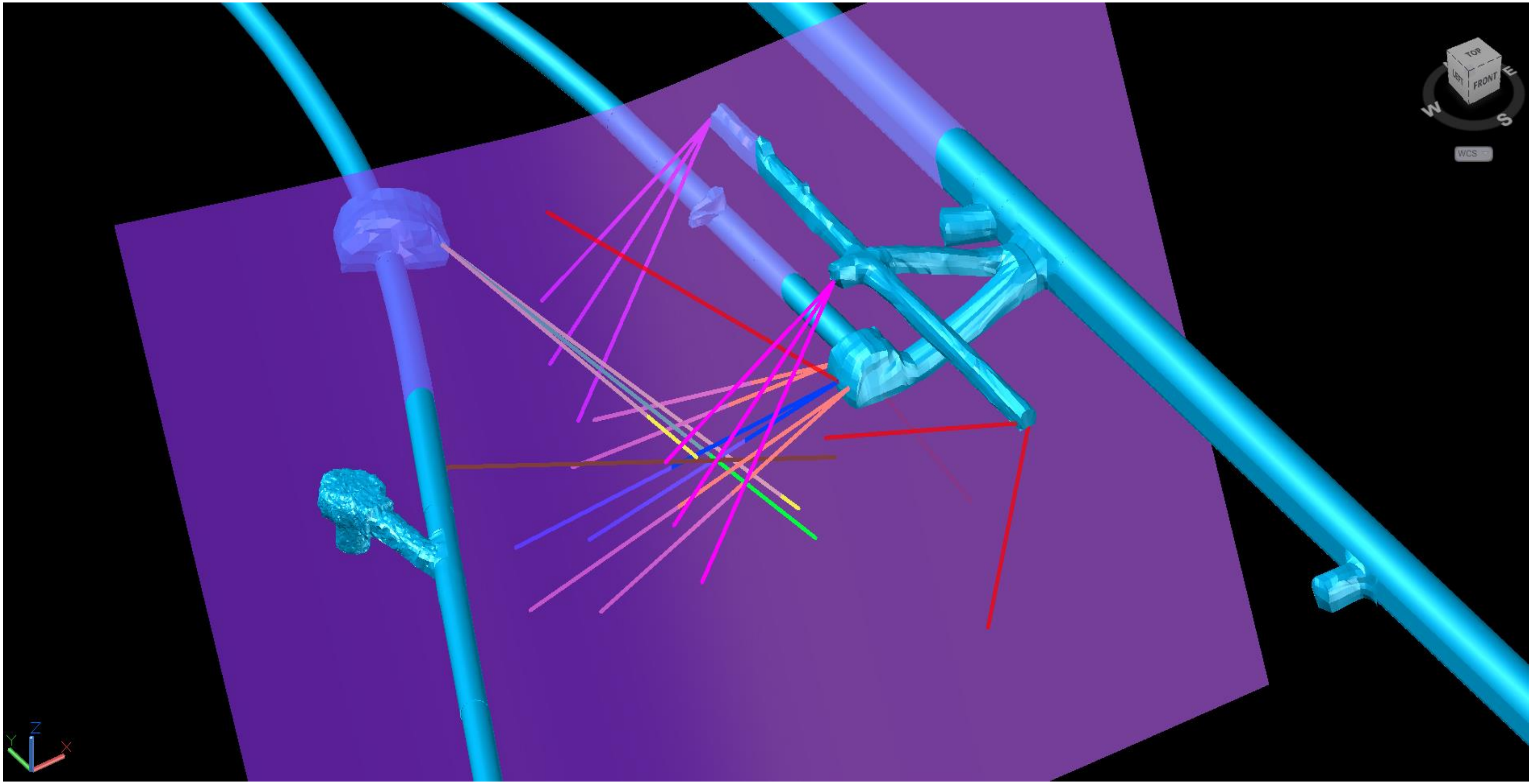


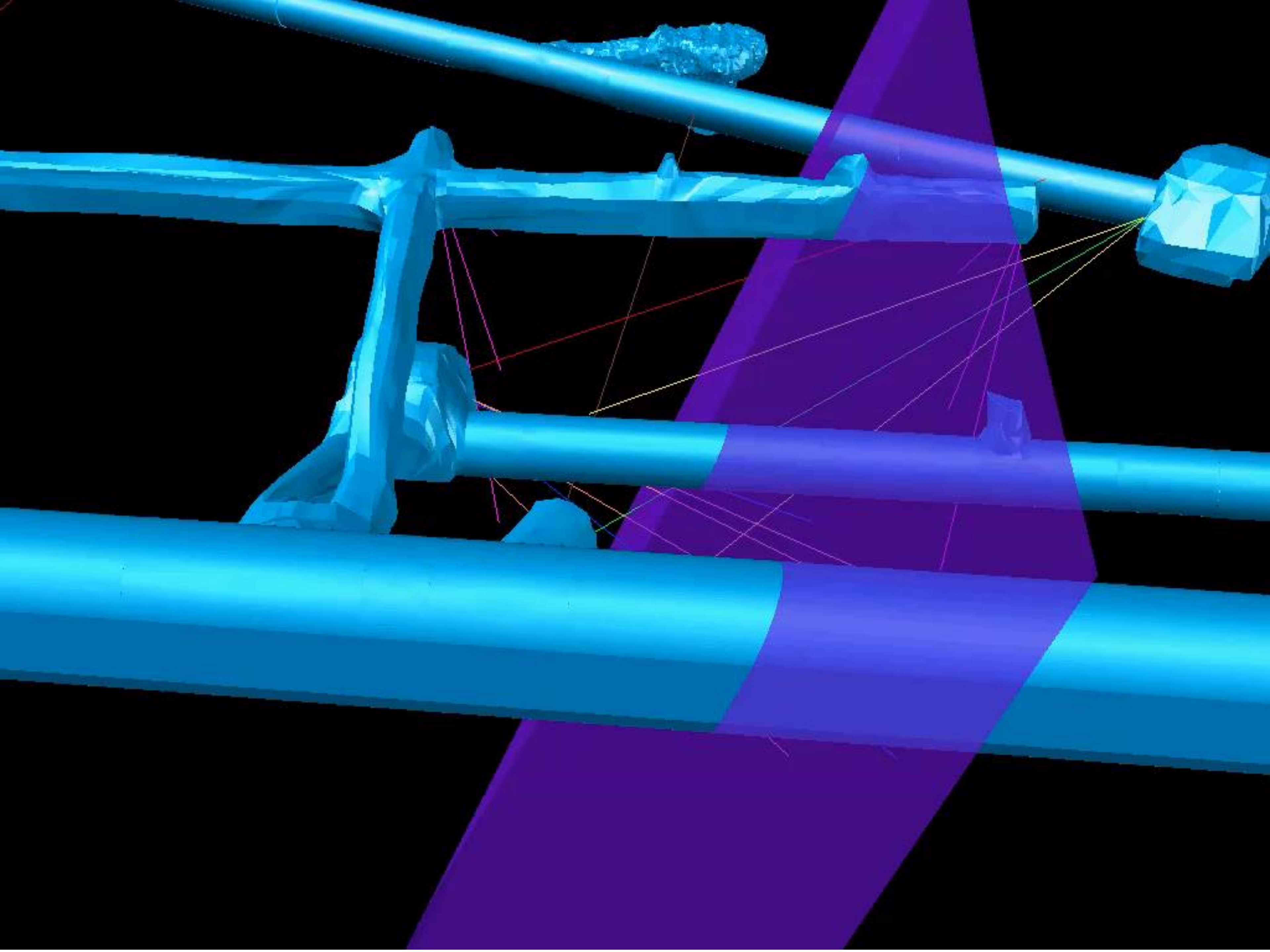


AU Tunnel
S1.2
S1.1
S1.3
VE Tunnel
KWO Tunnel
S3.2
S3.1
S
2
AUP Tunnel
S1: 142 / 77
S2: 157 / 75
S3: 183 / 65

Instrumenting the DUG-Lab



- Injection Borehole (BHINJ)
- Stress Measurement, Tilt-meter Borehole (SBH)
- GPR, Active Seismic Boreholes (BHAM)
- Passive Seismic Borehole (BHSM)
- Stress, Strain, Temperature (FBG) Borehole (BHST)
- Pressure, Temperature Borehole (BHPT)
- Strain, Temperature (DTS) Borehole (BHDS)



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Procedures and time-line

Aug. 2015 – Nov. 2016 → Dec. 2016 – Mar. 2017 → Apr. 2017 – end 2017

Pre-Stimulationsphase

Seismic network
- regional scale
- tunnel scale

Stress measurements

Drilling

Characterization
- geophysical borehole logs
- hydraulic & thermal Tests
- geophysical charac. (GPR, active seismics)
- tracer Tests (dye tracer and nanotracer)

Monitoring boreholes
- strain and tilt
- pore pressure
- temperature
- micro-seismics

Stimulationsphase

Stimulation
- stimulation of existing shear zone
- hydraulic Fracturing in massive rock
- shut-in phases

Monitoring
- pressure und flow rates in active borehole
- pressure in passive borehole
- micro-seismicity in tunnels and boreholes
- pressure and temperature in boreholes
- tilt at the tunnel surface

Post-Stimulationsphase

Characterization
- geophysical boreholes log (OPTV, electrical resistivity, spectral gamma etc.)
- hydraulic test in boreholes and between boreholes (storativity and transmissivity changes)
- tracer Tests (dye tracer und nanotracer)
- active seismic tests and GPR between boreholes and tunnels

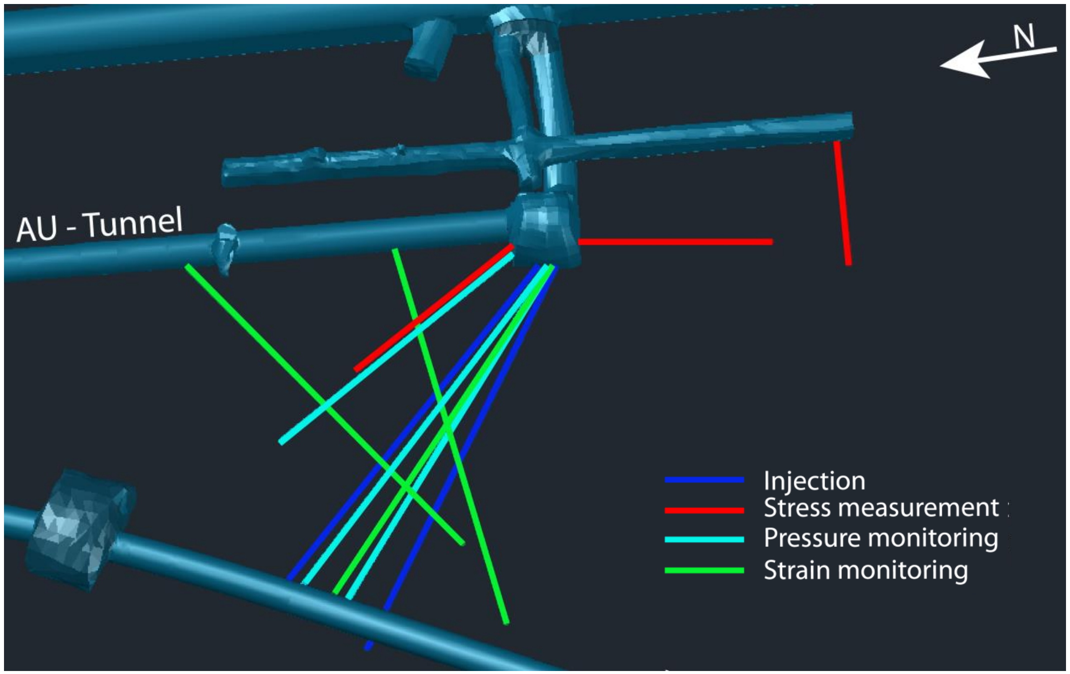
Preparation of circulation phase
- boreholes
- completion of boreholes with temperature sensors
- Installation multi-packer system

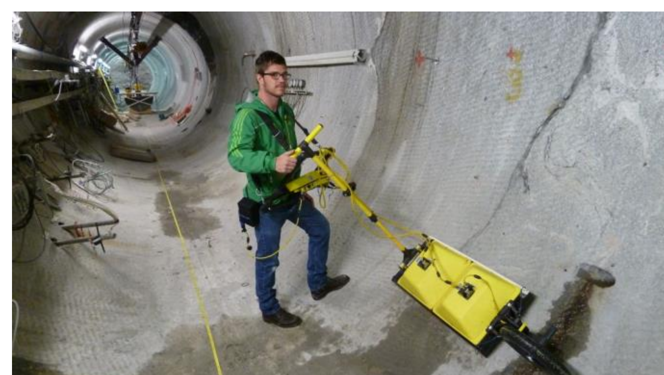
Circulationsphase

Circulation
- cold water injections
- warm water injections

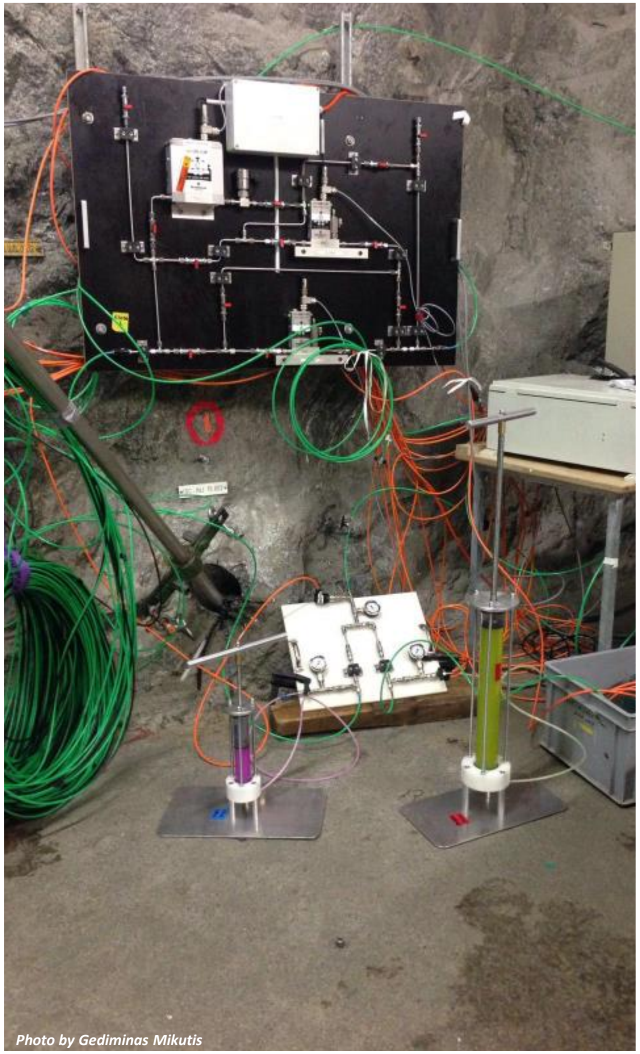
Monitoring
- induced micro-seismicity
- thermal break-trough
- thermo-elastic strains and tilt
- pore pressure changes
- temperature in reservoir

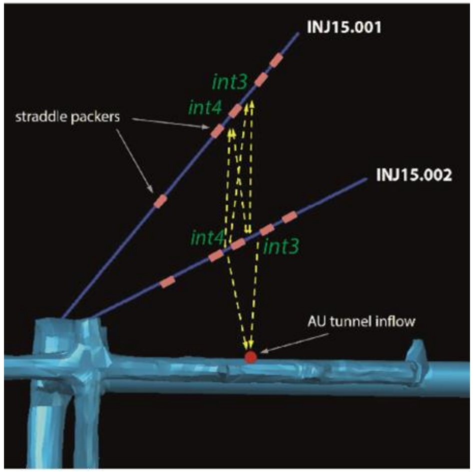
Boreholes and Characterization



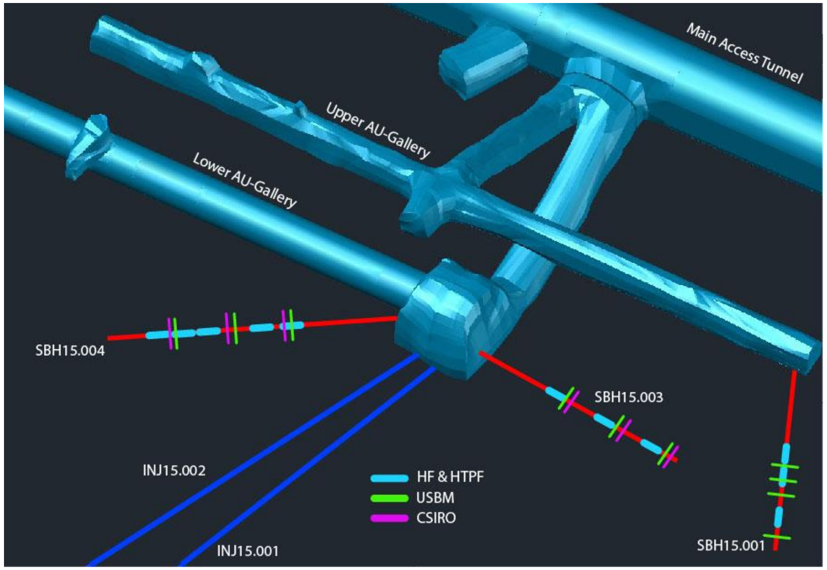


Characterization



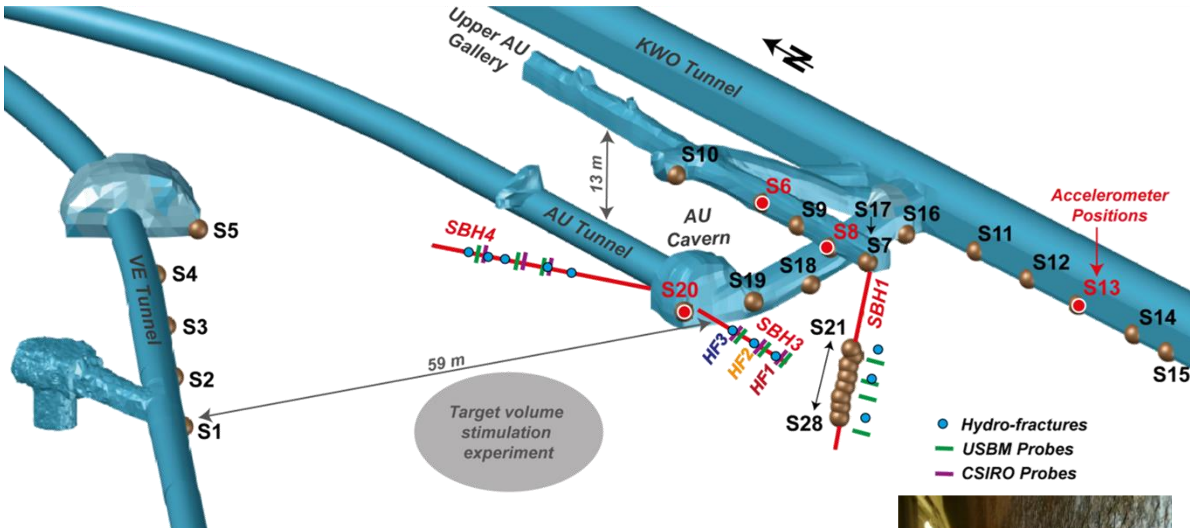


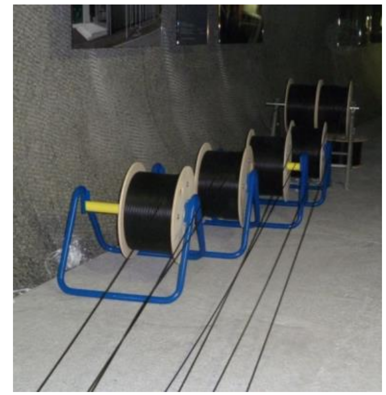
Stress measurements

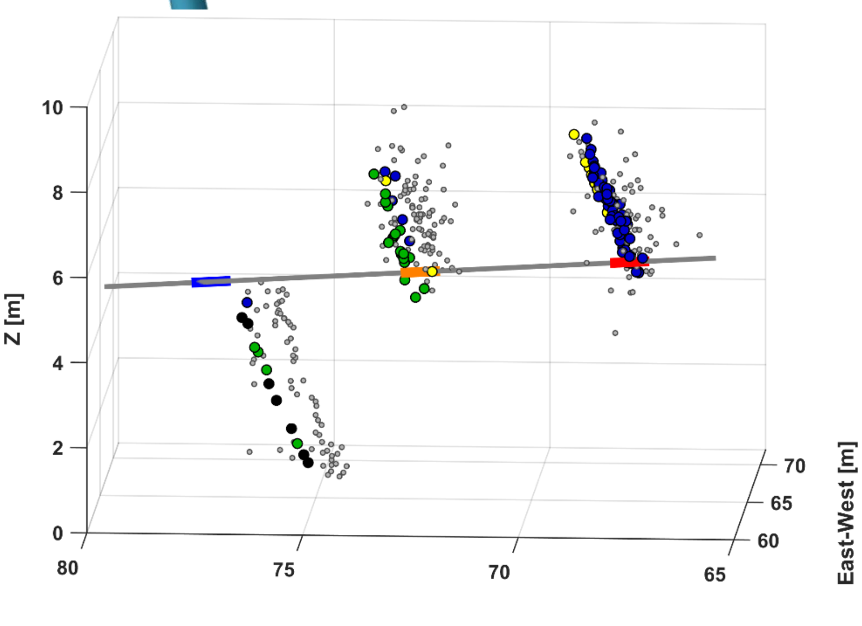


Acoustic Emissions during hydraulic fracturing

Gischig et al. (in prep.)



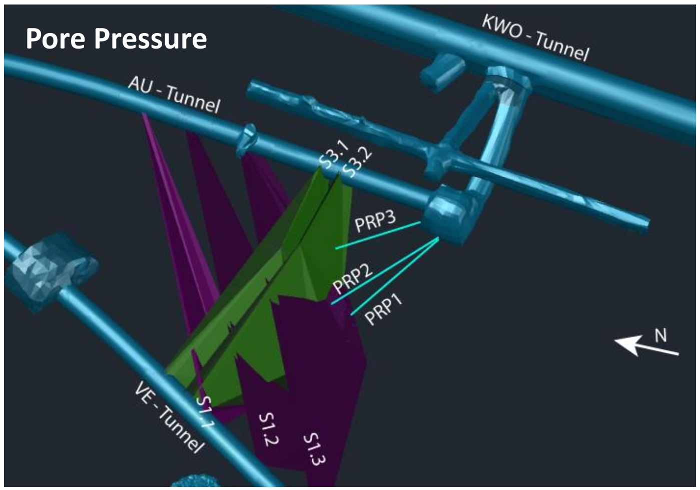


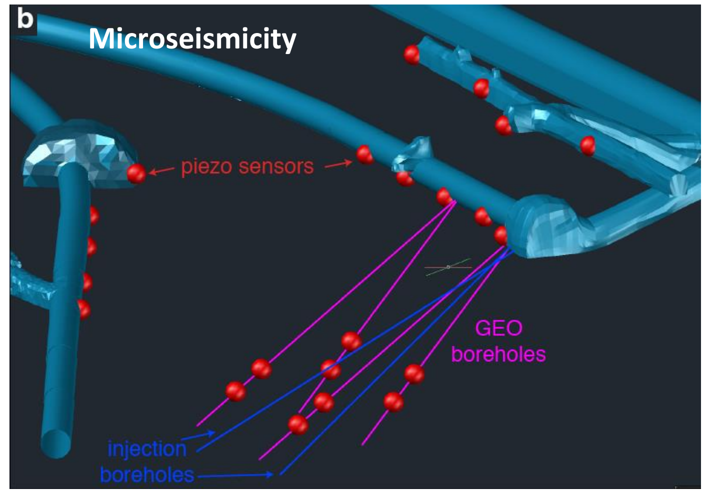


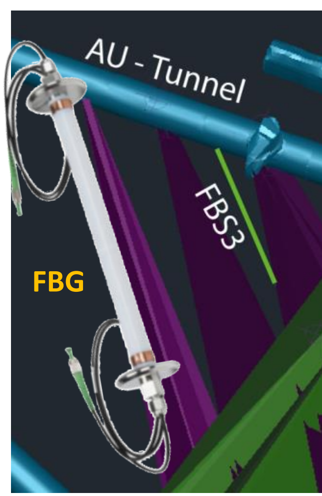
Talk: J. Doetsch et al.: Induced micro-seismicity observed during meter-scale hydraulic fracturing

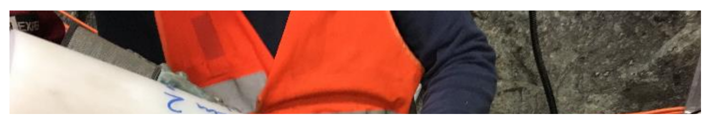
Poster: D. Vogler et al.: Numerical simulations of hydraulic fracturing during reservoir stimulation at the Grimsel Test Site, Switzerland

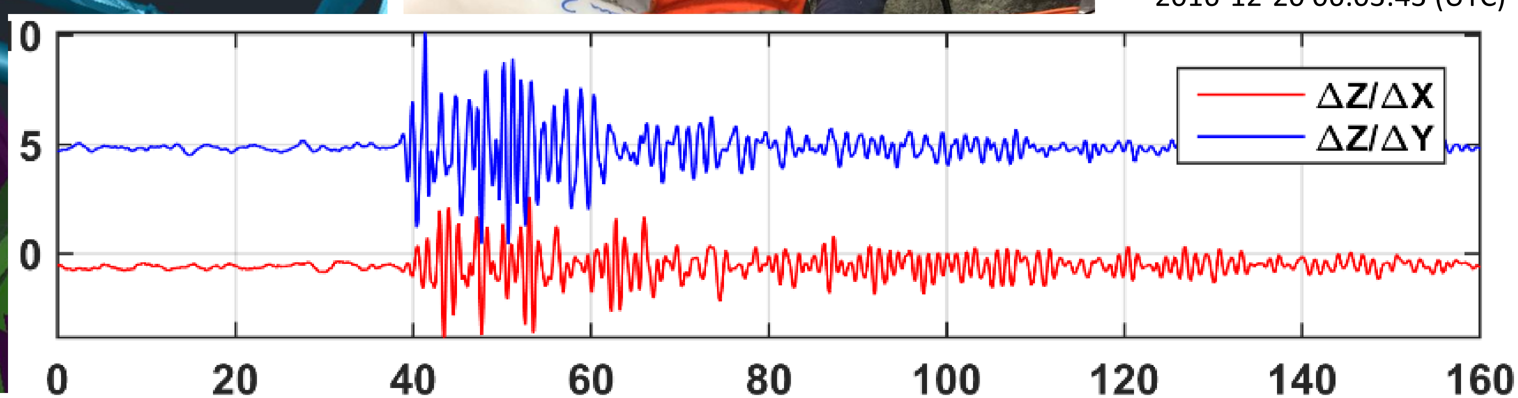
Monitoring during stimulation







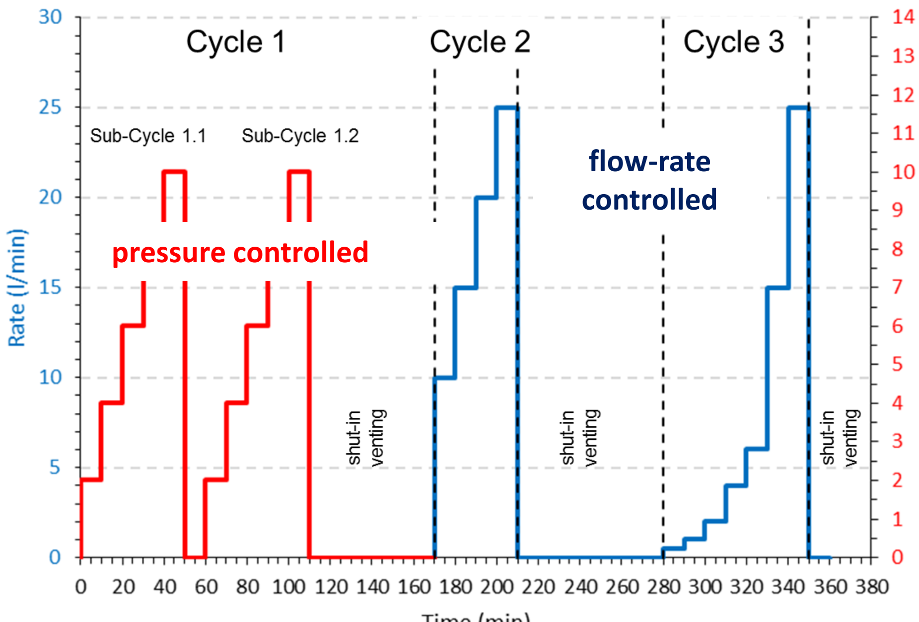


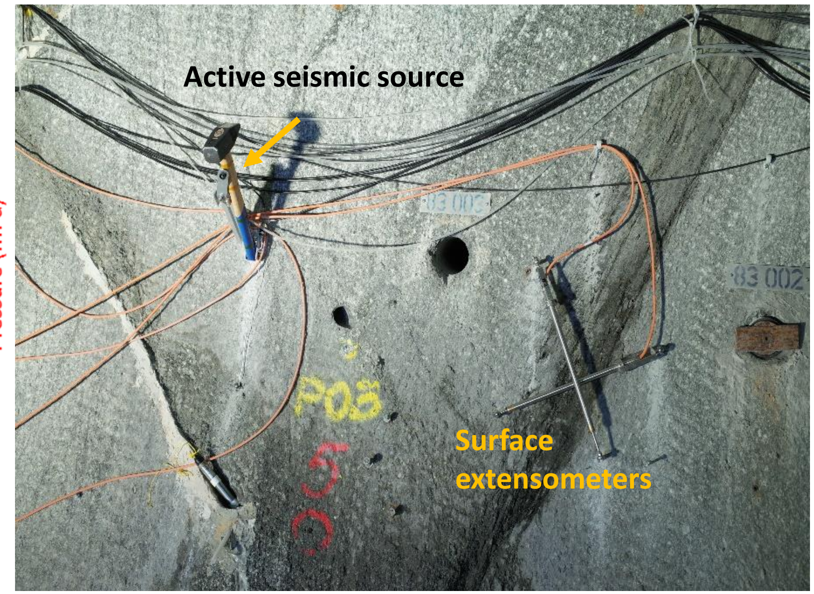


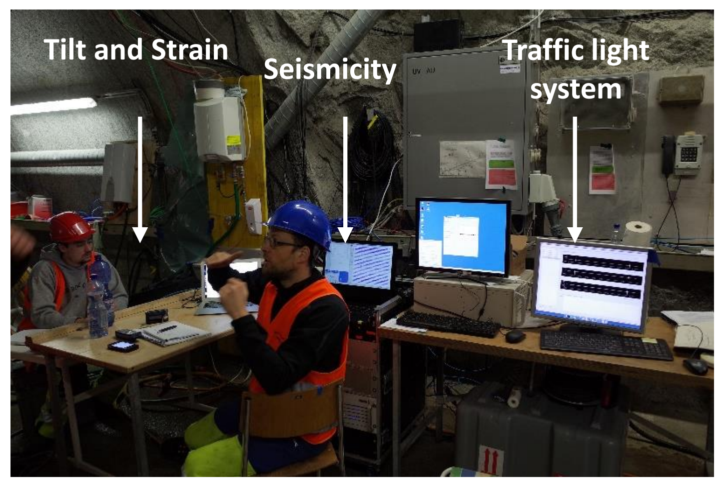
M5.5 earthquake at the Dodecanese Islands in Greece captured by the Tiltmeters
2016-12-20 06:03:43 (UTC)

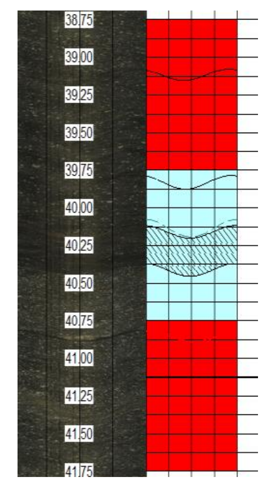
Six stimulations completed

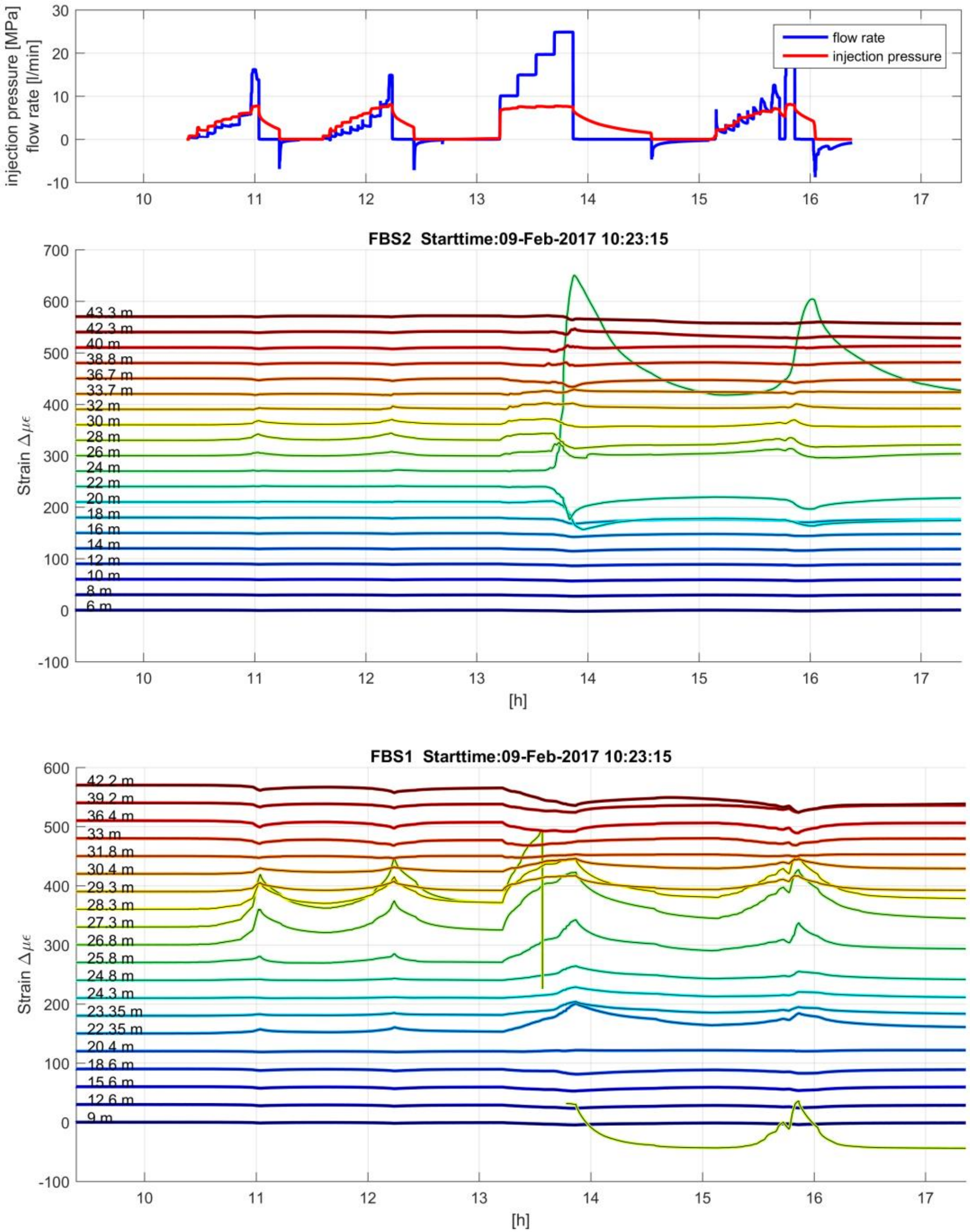
Poster: Linus Villiger et al.: Micro-seismic monitoring during hydraulic-shearing experiments at the Grimsel Test Site







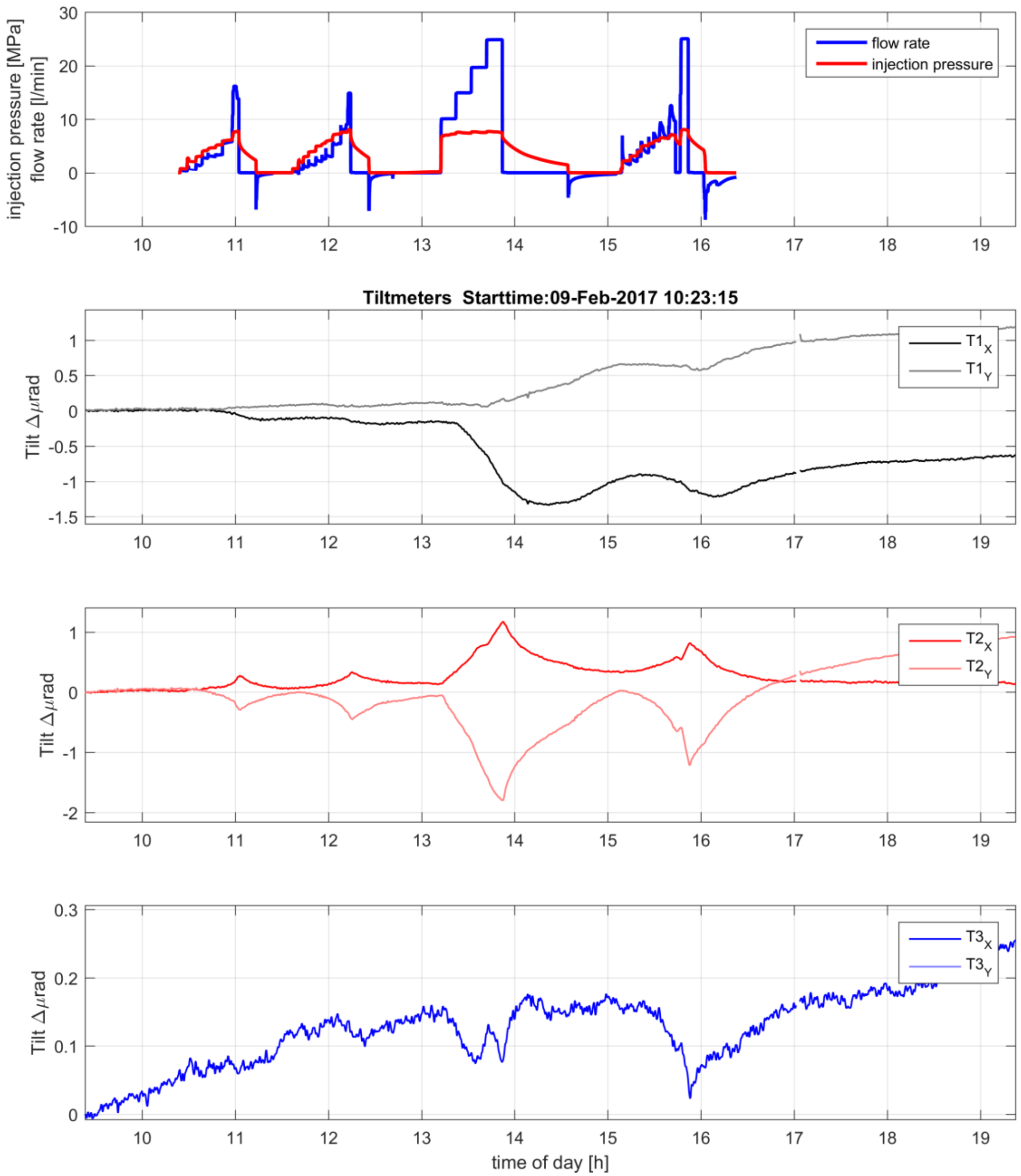




PRELIMINARY RESULTS

Stimulation effects measured by fiber-optic strain measurements (FBG) installed in boreholes.
In all the experiments we injected over four cycles.

In cycle 1, 2 we injected pressure controlled, cycle 3 is flow controlled and 4 is again a pressure controlled cycle. The negative flow in the figure represents back flow after venting of the stimulated sequence.

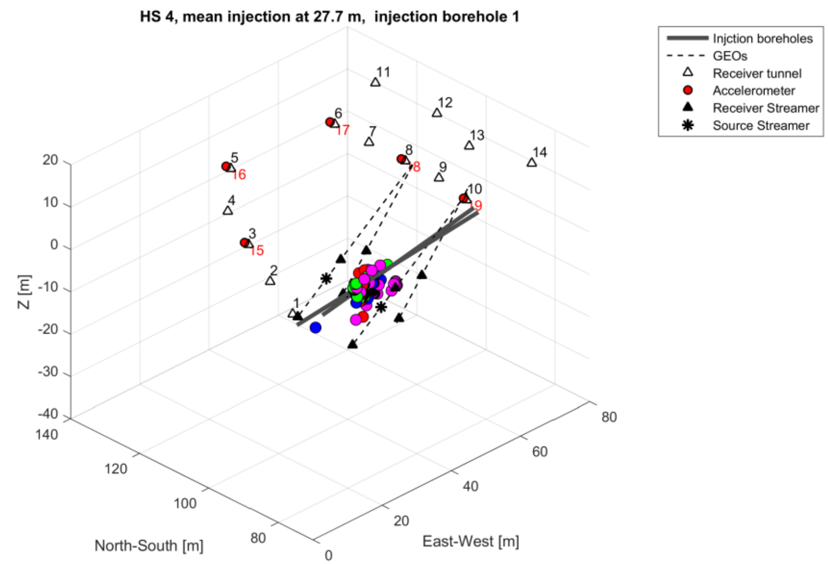


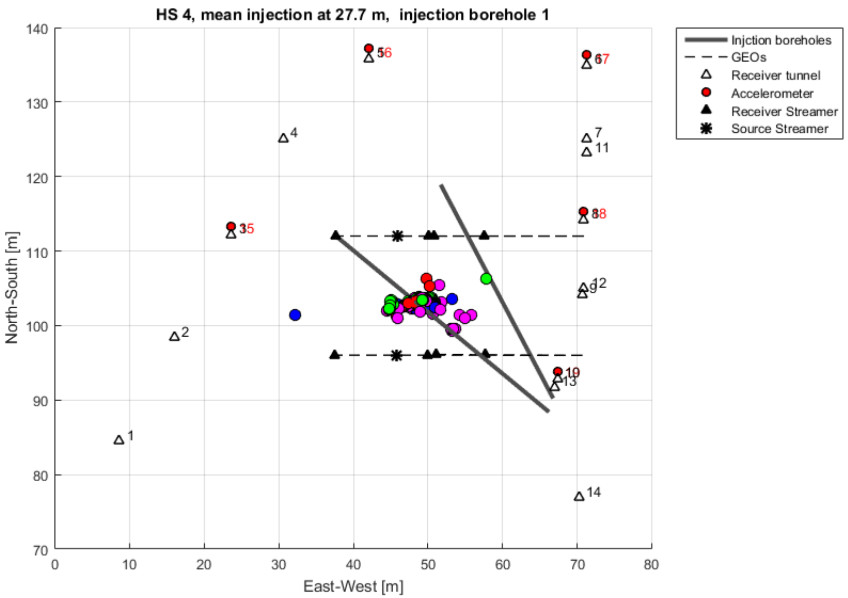
PRELIMINARY RESULTS

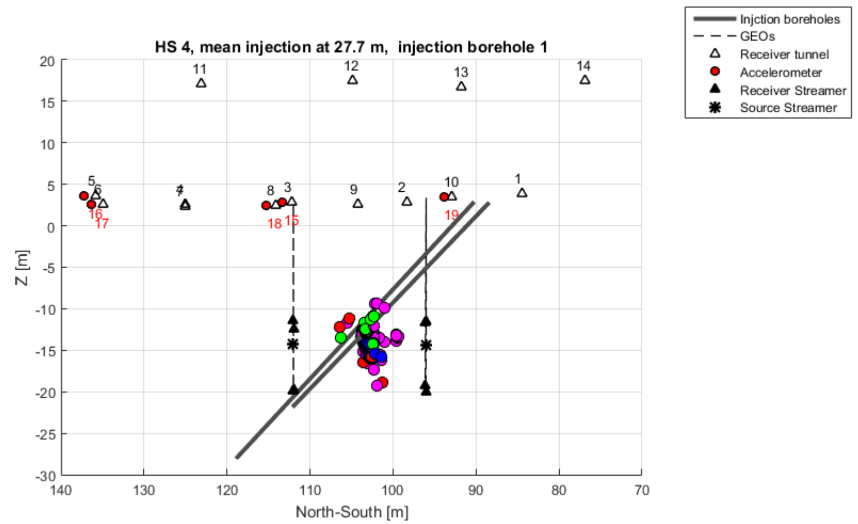
Stimulation effects measured by tiltmeters

PRELIMINARY RESULTS

Microseismicity induced during stimulation





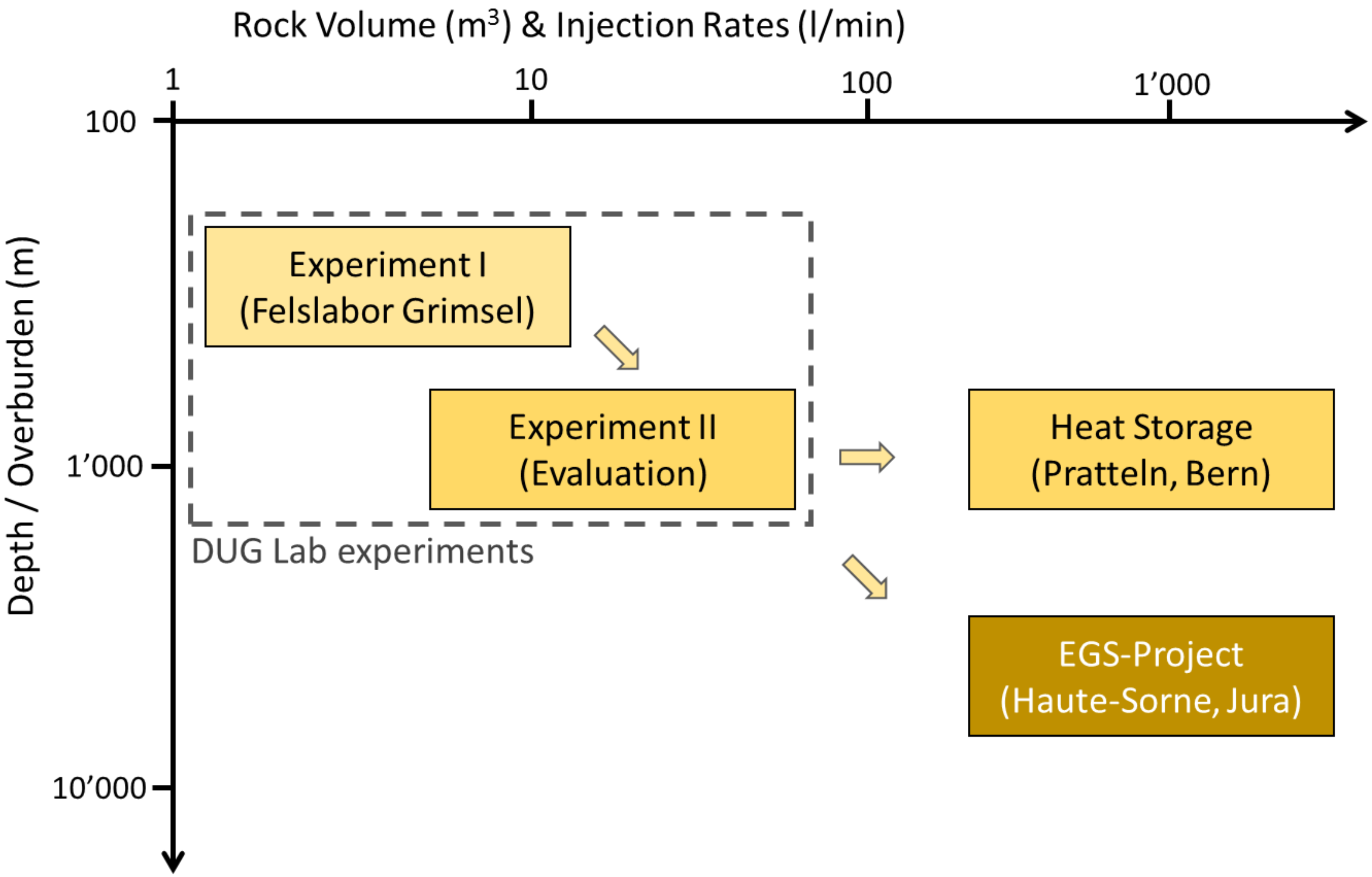


Six hydraulic shear stimulations completed
Six hydraulic fracking stimulations follow in May

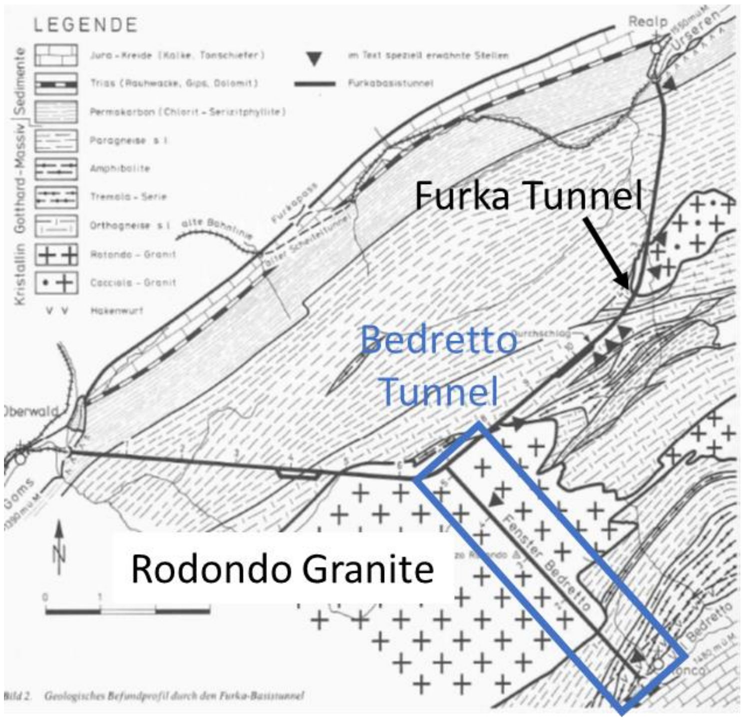
- Six stimulations successfully completed in February 2017 (injection rates up to 35 l/min; injected volumes of ~1m^3
- Initial injectivity between 0.0006 l/min/MPa and 0.95 l/min/MPa
- Injectivity after stimulation between 0.4 l/min/MPa and 1.6 l/min/MPa
- Some stimulations with > 700 micro-seismic events
- 6 hydraulic fracturing tests follow in May (after characterization)

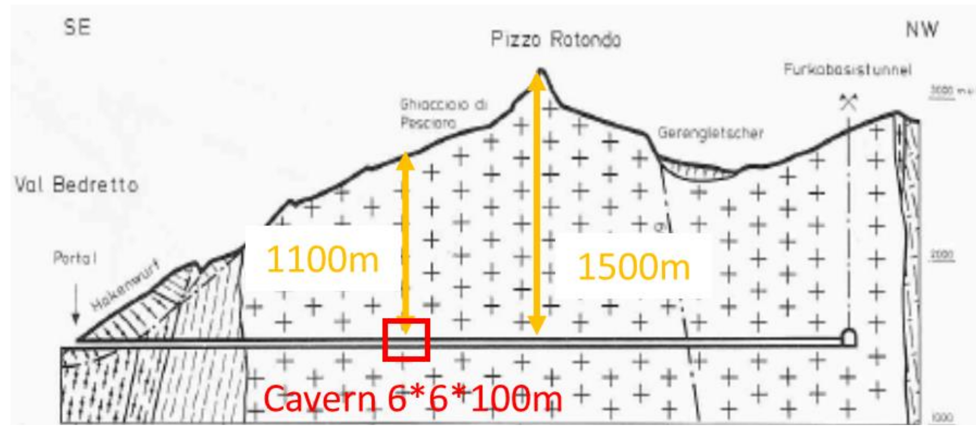
Stimulation	Initial (l/min/MPa)	Final (l/min/MPa)	Events
HS1	0.0006	1.1	few
HS3	0.0035	1.7	few
HS4	0.95	0.97	> 500
HS5	0.09	0.4	few
HS8	0.0019	0.5	>500
HS2	0.014	1.6	few

Next Step: 100m-scale "Flagship" Experiment



Next Step: 100m-scale "Flagship" Experiment





Conclusions

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- ✓ Induced earthquakes are a possible/probable consequence of the implementation of underground technologies and the extraction of deep geoenergy
- ✓ Deep underground stimulation experiments are a key tool to understand rock-fluid interaction and the origin of earthquakes, a precondition to understand and mitigate induced seismicity risk
- ✓ Large-scale, well controlled deep underground stimulation experiments require adequate resources and personnel → the DUGLab counts on 5 dedicated senior researchers, a host of professors and participating scientists, 5 PhD students, technical personnel, the support of NAGRA and of the Federal Office of Energy, and an overall budget of over 12 MCHF for 5 years
- ✓ We need a coordinated strategy and international cooperation to establish a network of world-class deep research infrastructures and geo-energy testbeds

Present and future challenges