Small-scale Reservoir Stimulation Experiments in the Deep Underground Laboratory at the Grimsel Test Site

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SUPPLY of ELECTRICITY

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Abstract

As a response to the Swiss government decision of fading out nuclear power by 2034, research and development in GeoEnergy has become a major topic in the Swiss energy research. As part of the work-package one of the newly-founded Swiss Competence Centre for Energy Research – Supply of Electricity (SCCER-SoE), we are currently planning a small-scale stimulation experiment in the Grimsel Test Site (GTS) – the rock laboratory dedicated to research on nuclear waste depositories and run by NAGRA. The granitic rock mass at the GTS has similar characteristics to those expected at potential enhanced geothermal system (EGS) sites in the deep underground (ca. 4-5 km) of the Swiss Plateau, and thus can act as a proxy for potential future EGS sites.

The objectives of the experiment are to explore
1) the interaction of hydro-fractures with the natural fracture system,
2) permeability and connectivity enhancement resulting from hydro-fracturing and hydro-shearing,
3) stress and pressure changes associated with stimulation and
4) induced seismicity characteristics during different stimulation procedures.

The GTS rock laboratory provides favourable conditions for such an experiment, because low fracture density and the wealth of information available from previous experiments allow construction of a near-deterministic rock mass model. Hence, the small scale and clear geological conditions provide us with maximum control on boundary conditions and evoked processes, the possibility to design an optimal monitoring system, and, at the same time, ensure that risk related to induced seismicity is low.

The experiment comprises a rock mass volume of a few tens of meters in diameter that includes both intact rock as well as rock that is dissected by pre-existing sub-vertical fault zones. In a sub-vertical injection borehole, stimulation is performed in short packed intervals that include either intact rock, where hydro-fractures are created, or natural faults along which hydro-shearing is induced. Due to the proximity of the intact rock portions to natural faults zones, interaction between hydro-fractures with the natural fractures is expected. Fans of both sub-vertical and sub-horizontal boreholes distributed around the experiment volume contain a comprehensive monitoring system that records hydraulic processes (e.g. transient pressure changes), mechanical processes (e.g. stress, deformation and fracture dislocation) as well as induced micro-seismic activity during and after stimulation.
The experiment is designed such that stimulation processes – like fracture propagation and interaction, seismic and aseismic slip front propagation, shear dilatancy, and the resulting enhancement of permeability and fracture connectivity – are recorded in a dataset that is unique in induced seismicity research and could not be obtained from stimulation experiments in inaccessible deep reservoirs typically targeted for EGS.

Research Goals

Obtain a detail understanding of processes associated with hydraulic stimulation of a natural fault

- Permeabilty and hydraulic connectivity before and after stimulation
- Changes of rock mass charateristics due to stimulation
- Stress field and stress changes around a stimulated fault
- Spatial and temporal evolution and scaling of induced seismicity
- Evolution of fault dislocation and pressure distribution during injection
- Heat exchanger propoerties before and after stimulation

Develop and test novel charaterization and monitoring methods

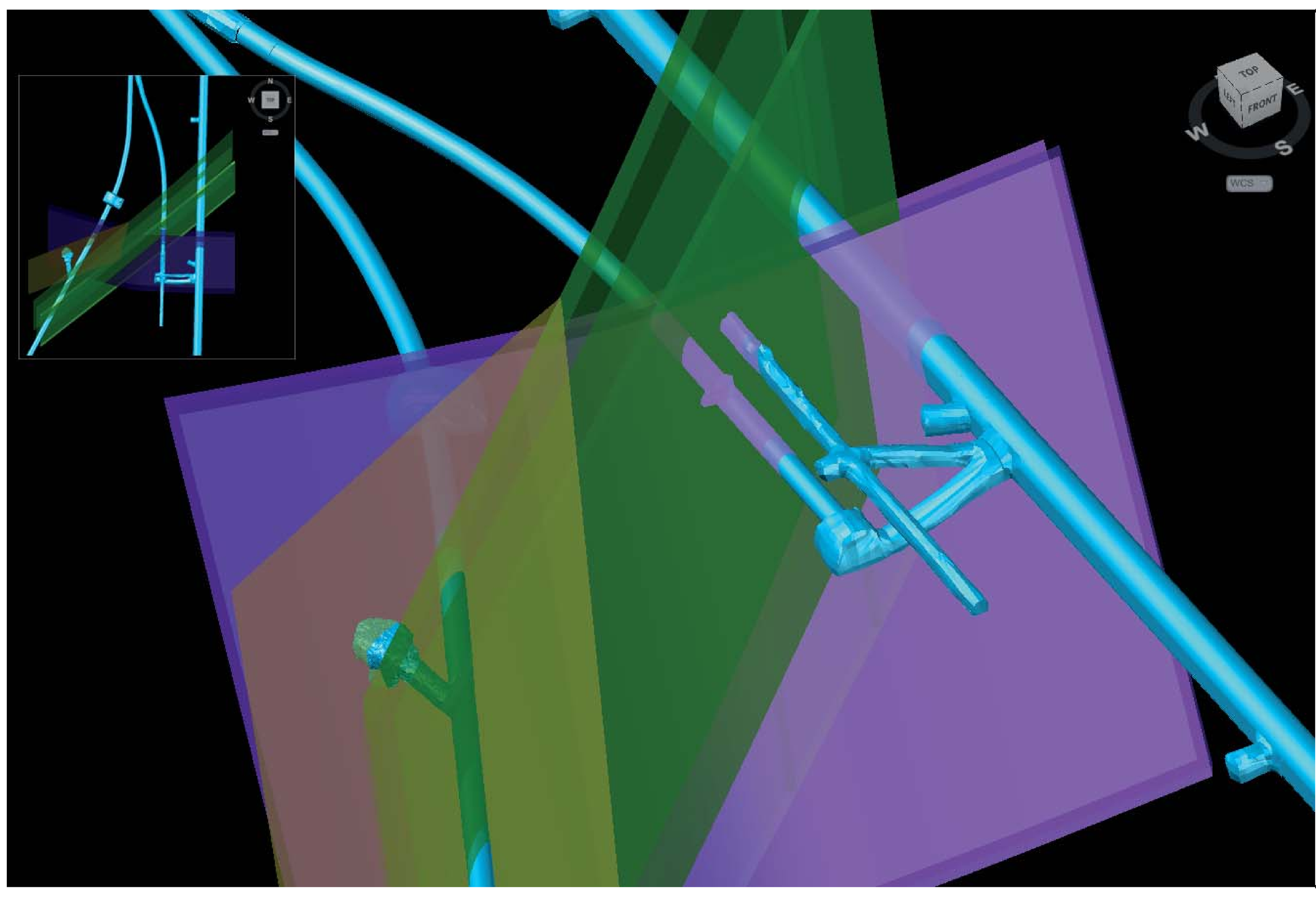
- Hydraulic characterization: hydraulic tomography based on heat tracer and solvent tracer tests
- 3D dislocation and pressure monitoring in the injection interval (SIM-FIP probe)
- High resolution strain and stress monitoring
- Multi-scale and multi-sensor-type seismic monitoring
- Geophysical imaging: new methods for 3D joint inversion and borehole reflection processing

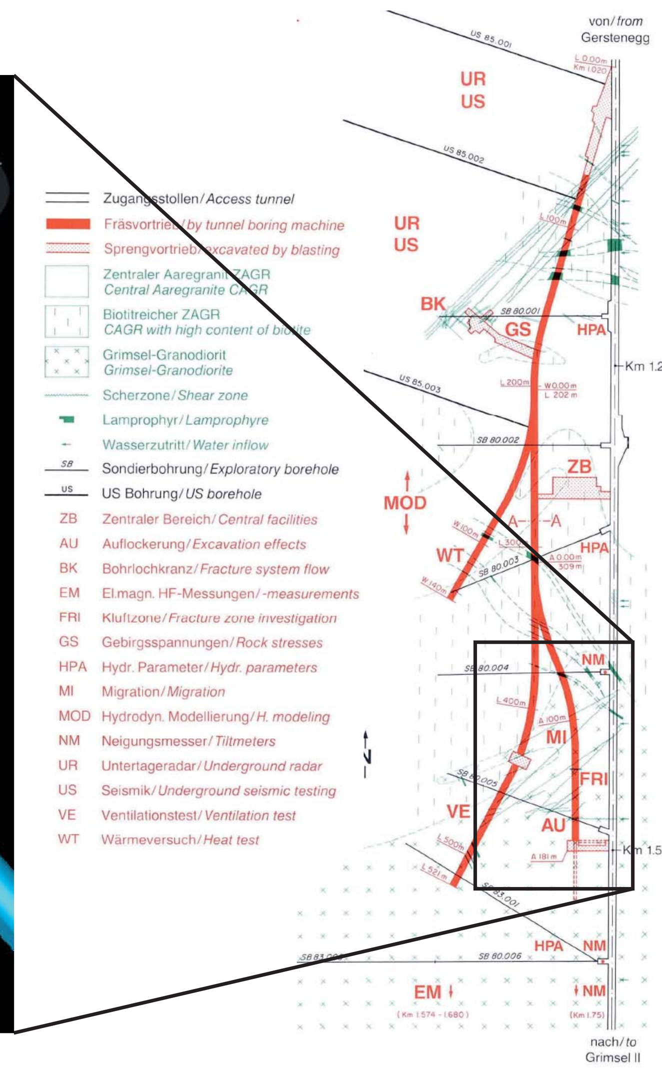
Create a test and benchmark data set for new numerical methods for reservoir simulation

- Constrain physical concepts for fast THM coupling
- Test bed for near real-time reservoir stimulators
- Test case for near real-time seismic hazard assessment tools (advanced/adaptive traffic light system)

Demonstration project for a fault stimulation at low seismic hazard

The Grimsel Test Site (GTS)

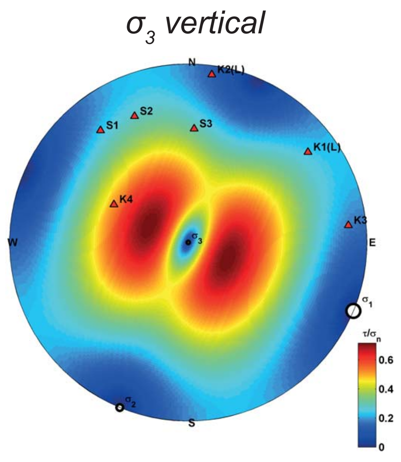




Pre-experiment investigations (Phase 1): Geological model, stress field characterization

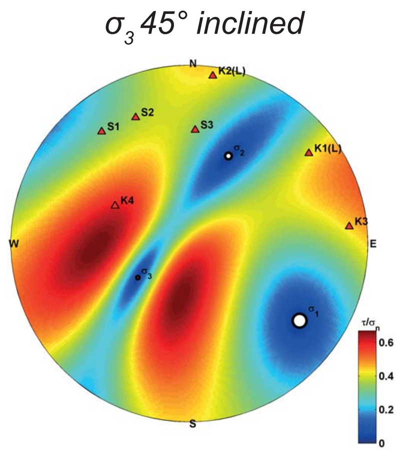
Currently available stress field estimates
Slip tendency analysis

σ_3 vertical



Pahl et al., (1989)

σ_3 45° inclined

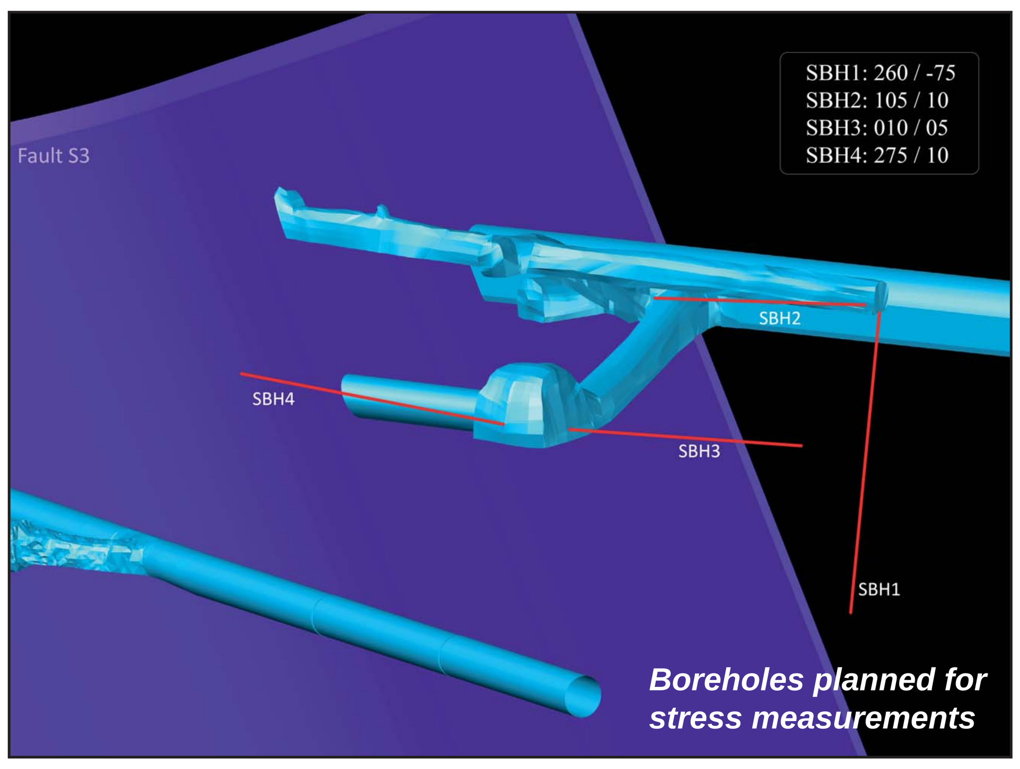


Konietzky & Marschall, (1997)

Failure pressure assuming friction coefficients 0.6 - 0.85, no cohesion:

S1: 19 - 23 MPa	S1: 10 - 14 MPa
S2: 15 - 19 MPa	S2: 7 - 11 MPa
S3: 11 - 15 MPa	S3: 6 - 9 MPa

Fault reactivation pressure is lower if σ_3 inclinde towards SW.
Detailed stress characterization before main experiment is essential



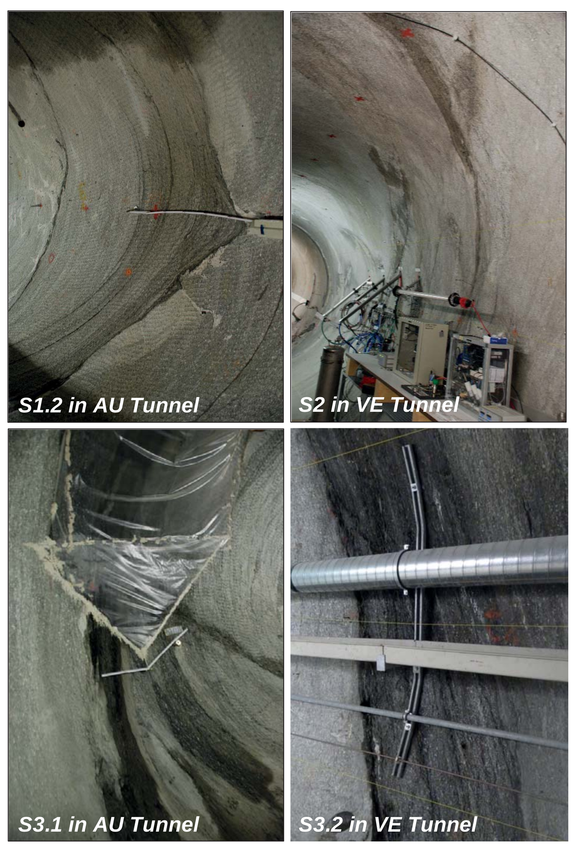
Goal:
- Measure ´far-field´ stress (20 - 30 m away from faults)
- Systematic stress changes associated with faults
- Estimating shear stress along target faults.

A combination of:
- Overcoring with USBM probes
- Overcoring with CSIRO-HI probes
- Hydro-fracturing (HF)
- Hydraulic test of pre-existing fractures (HTPF, if possible)

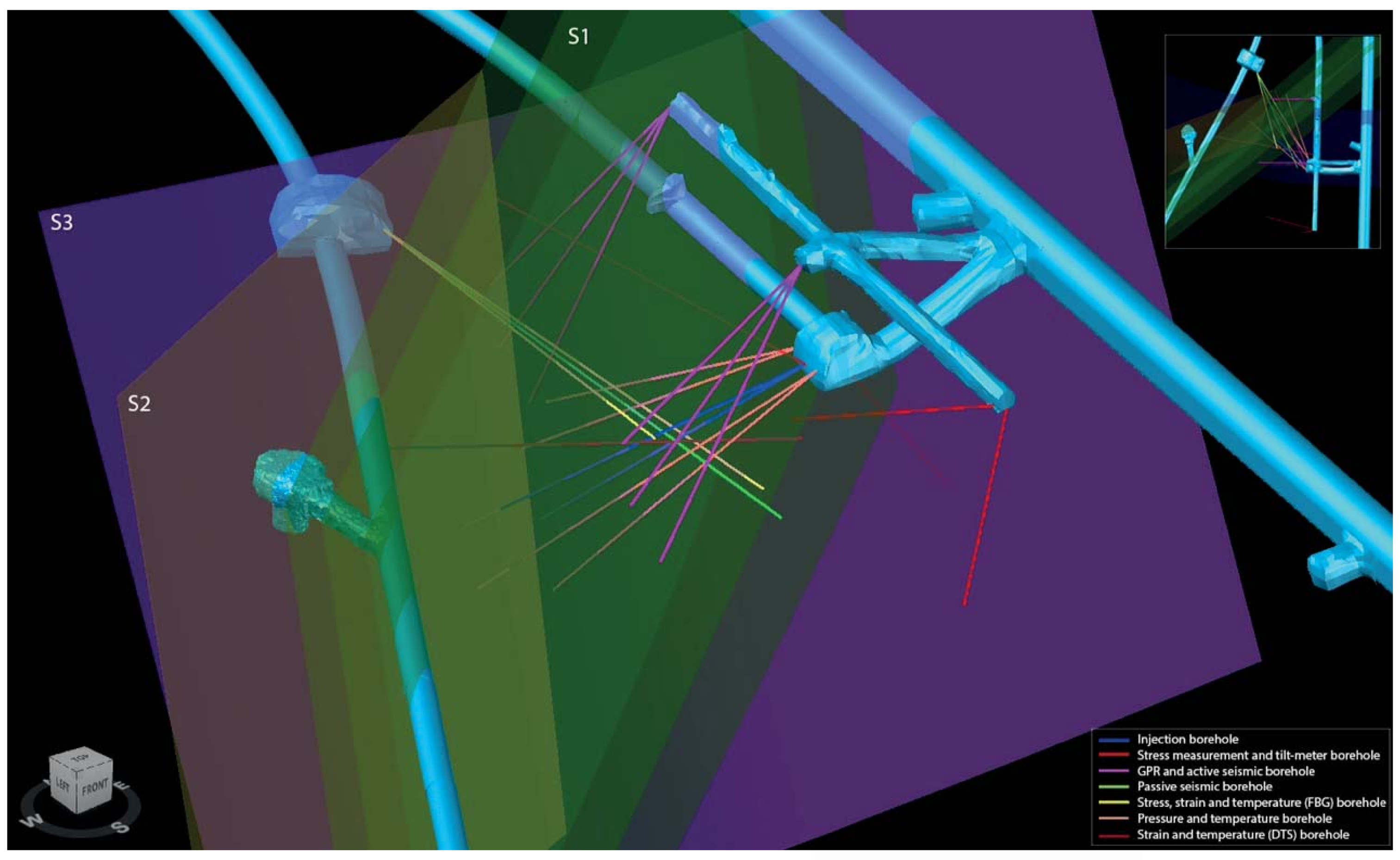
Seismic monitoring with tunnel-scale network:
- Test and optimize instruments and network geometry
- In-situ calibration of piezo-electric sensors
- Derive orientation of hydro-fractures for orientation of σ_1

Results will guide final design of stimulation experiment
Input for pre-experimental seismic hazard and risk study

Faults



Stimulation experiment (Phase 2)



Workflow

Pre-stimulation phase

Installation multi-scale seismic network:
- Regional scale (Ground surface)
- Rocklab scale (Tunnels+existing boreholes)

Drilling of boreholes

First characterization phase
- Borehole logging, rock mass characterization
- Hydraulic tests
- Geophysical imaging (GPR, Active seismics)

Installation of permanent monitoring components (grouted components):
- Stress cells
- Fiber-optic systems
- Reservoir scale seismic network
- Permanent hydraulic packers

Stimulation phase

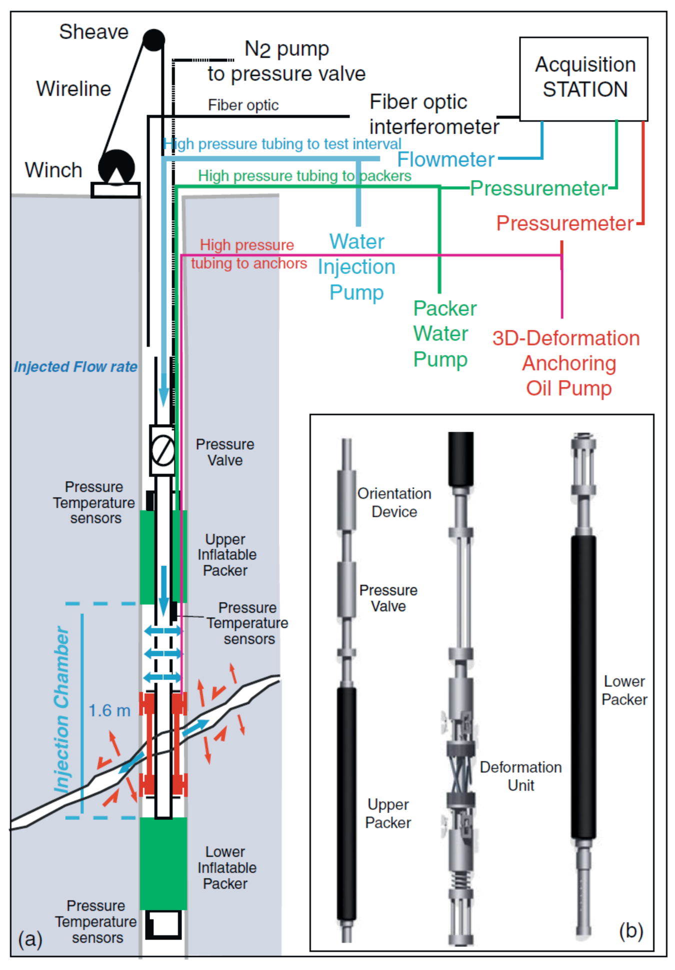
Stimulation with SIMFIP[1] probe

Circulation experiments:
(heat exchanger characteristics):
- Reseroir response to fluid temperature
- Heat tracer test
- Solvent tracer test

Characterization of stimulated reservoir:
- Borehole logging
- Hydraulic tests
- Geophysical imaging

Repeated with different stimulation protocols

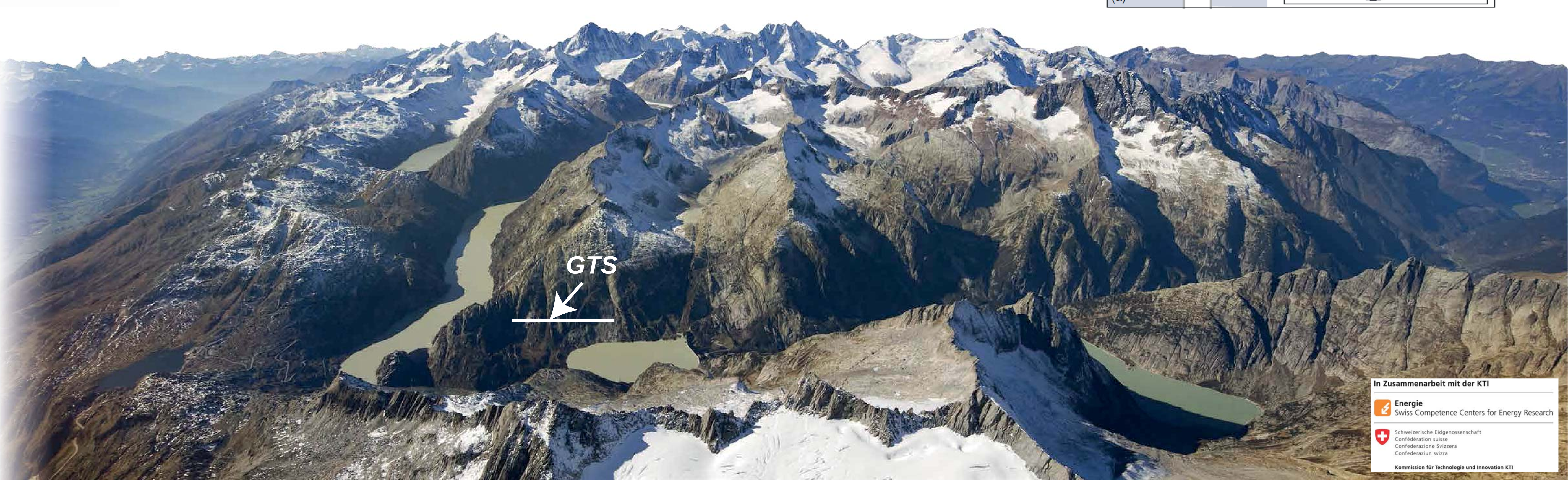
SIMFIP[1]



Instrumentation

- Two Injection boreholes (SIMFIP[1] probe)
- Tiltmeters
- Axial strain (Fibre-optic systems, FBG[2], DSS[3])
- Stress cells CSIRO-HI
- Geophysical imaging boreholes (GPR, actives seismics)
- Passive seismic sensors (piezo-sensors, accelerometers)
- Temperature sensors (Thermistors in packed intervals, DTS[3])
- Pressure sensors in permanent/removable hydraulic packer systems

[1] Step-Rate Injection Method for Fracture In-Situ Properties (SIMFIP), Guglielmi et al., (2014).
[2] Fibre Bragg Gratings: Fibre-optic strain monitoring, high accuracy and spatial resolution.
[3] Distributed Strain Sensing: Fibre-optic strain monitoring, high spatial coverage.
[4] Distributed Temperature Sensing: Fibre-optic temperature monitoring with high spatial coverage.



References

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