CO_2 Long-term Periodic Injection Experiment (CO_2LPIE)

Status and future works

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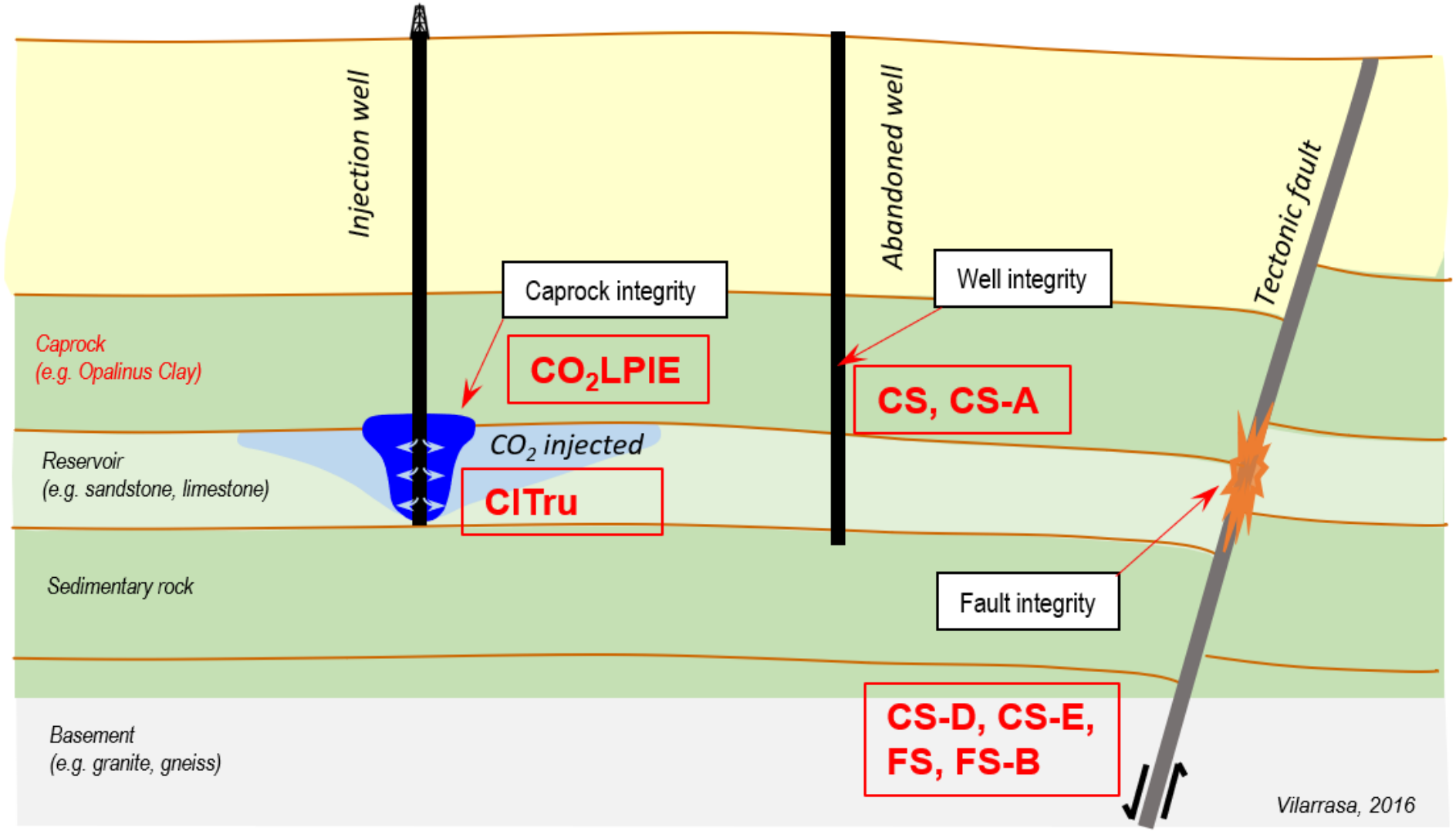
cem suisse

VBSA workshop, St-Ursanne

CO_2-experiments at the rock laboratory scale since 2011

Mont Terri Project



CO_2LPIE (CO_2 long-term periodic injection experiment)

Experiment on long-term caprock integrity

Aim

- The sealing efficiency of the clay shale matrix is key for long-term safety of the caprock (several ka)
- Assessment of influence of CO_2-saturated fluids on the integrity of geological barriers under realistic in-situ conditions
- Robust characterization of the test volume and high temporal and spatial resolution monitoring with novel systems

Concept

- Periodic CO_2-injection over a longer term (4+ years)
- Combined investigations on different scales (in-situ and lab analysis), combined with numerical modeling
- Development of Modular Multisensor Monitoring System (MMMS)
- High resolution temporal and spatial monitoring of CO_2-migration

CO_2LPIE – project organization

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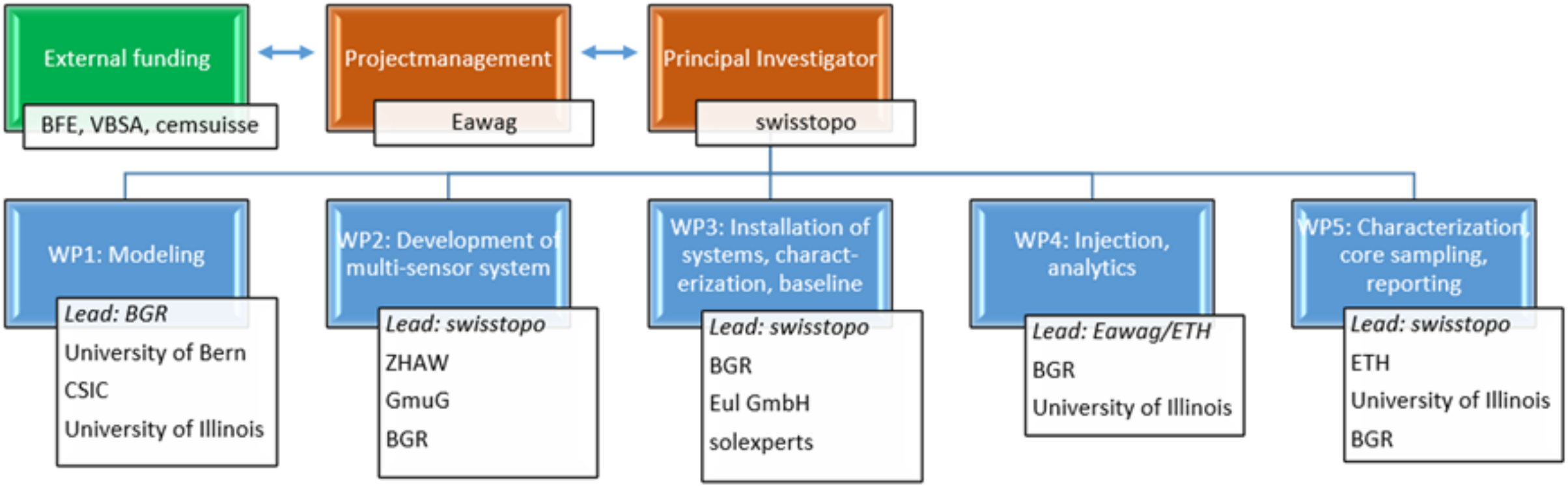

Overview of experiment boreholes (planned)

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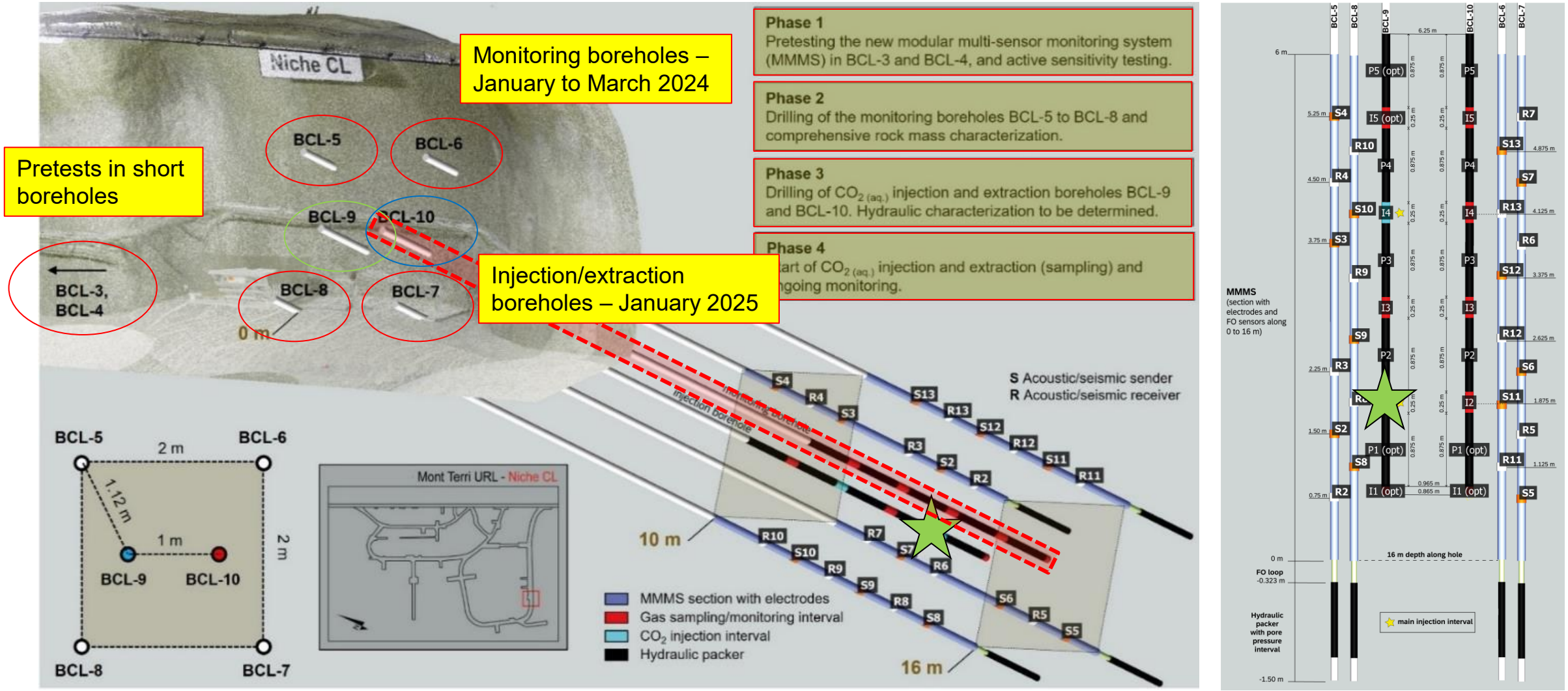

Chemical analysis of water samples by Uni Bern

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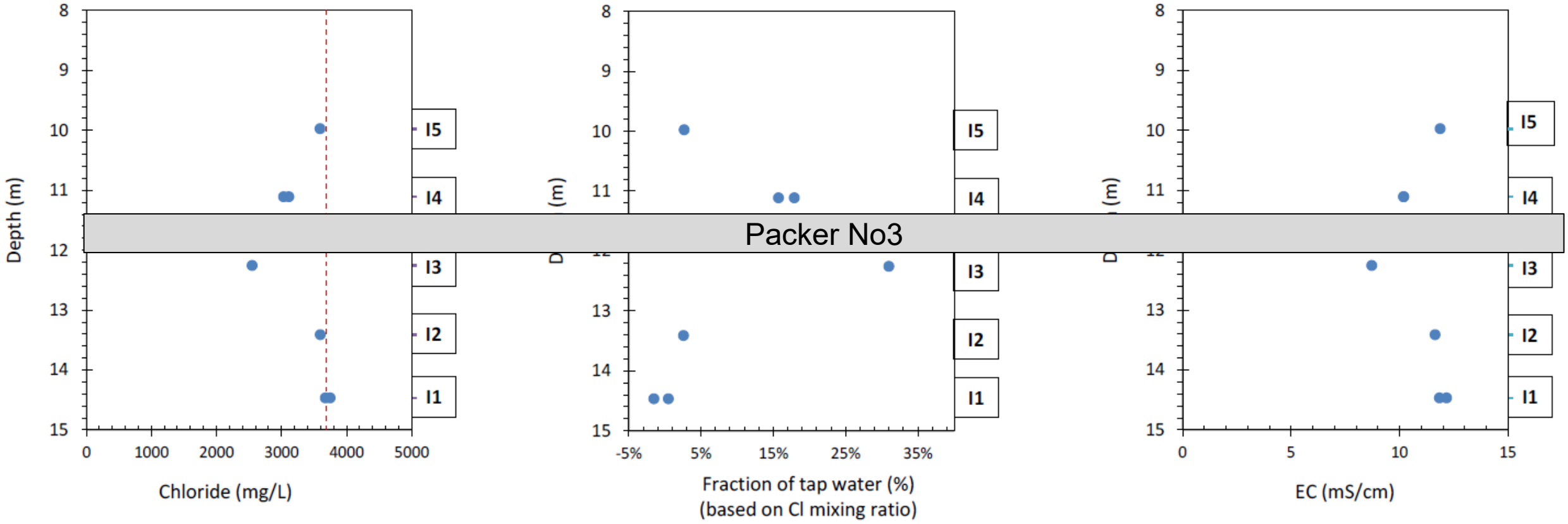

Overview of experiment boreholes (as is)

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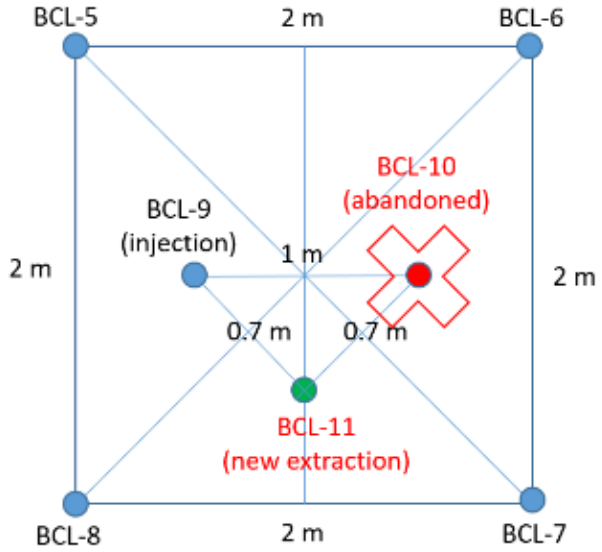
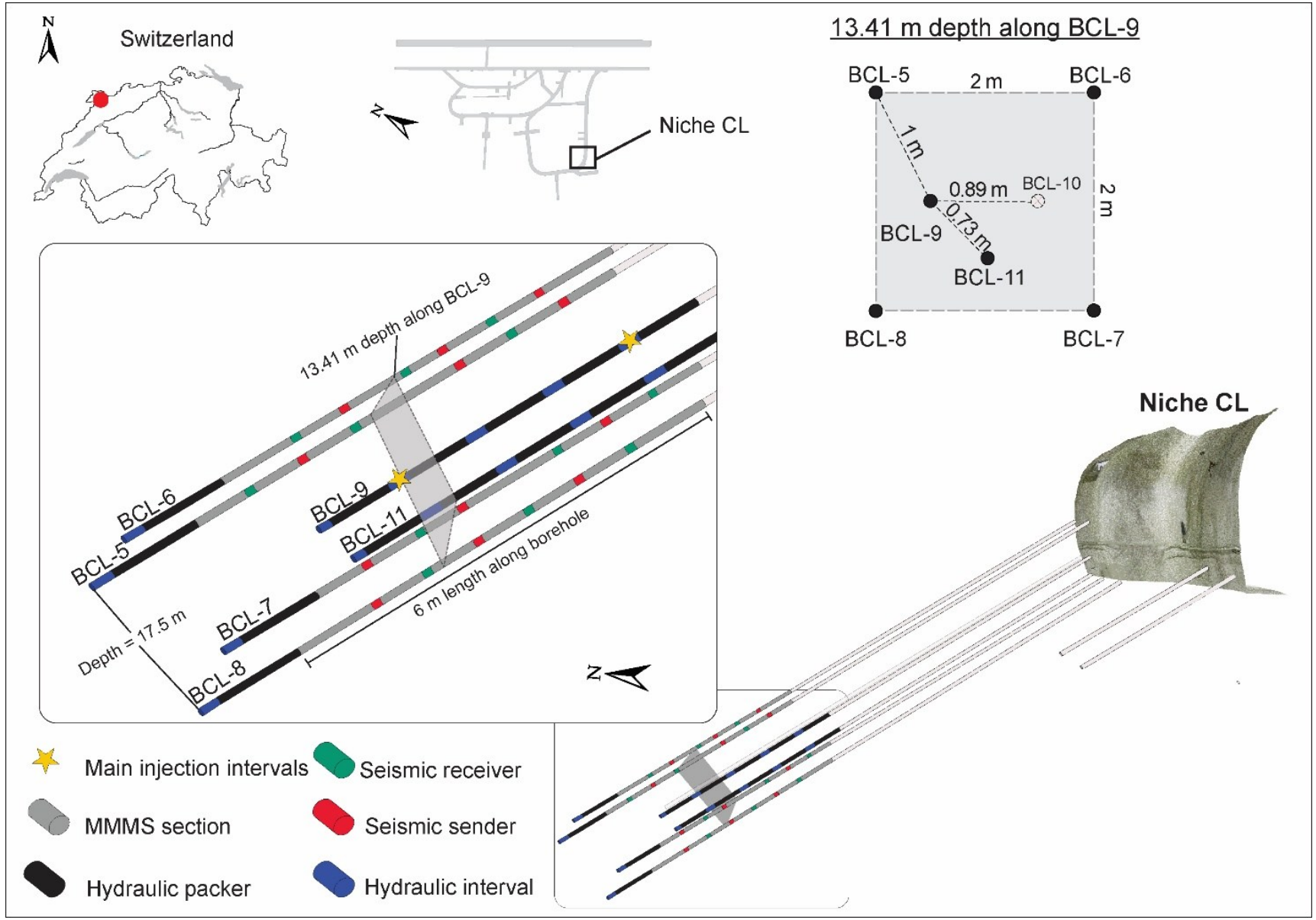


- Exchange of BCL-10 MPS (monitoring borehole) was necessary
- Identical system using new packer series was built and tested thoroughly on a longer term at realistic pressures
- In June 2025 the new system was installed



Geological characterization – subfacies

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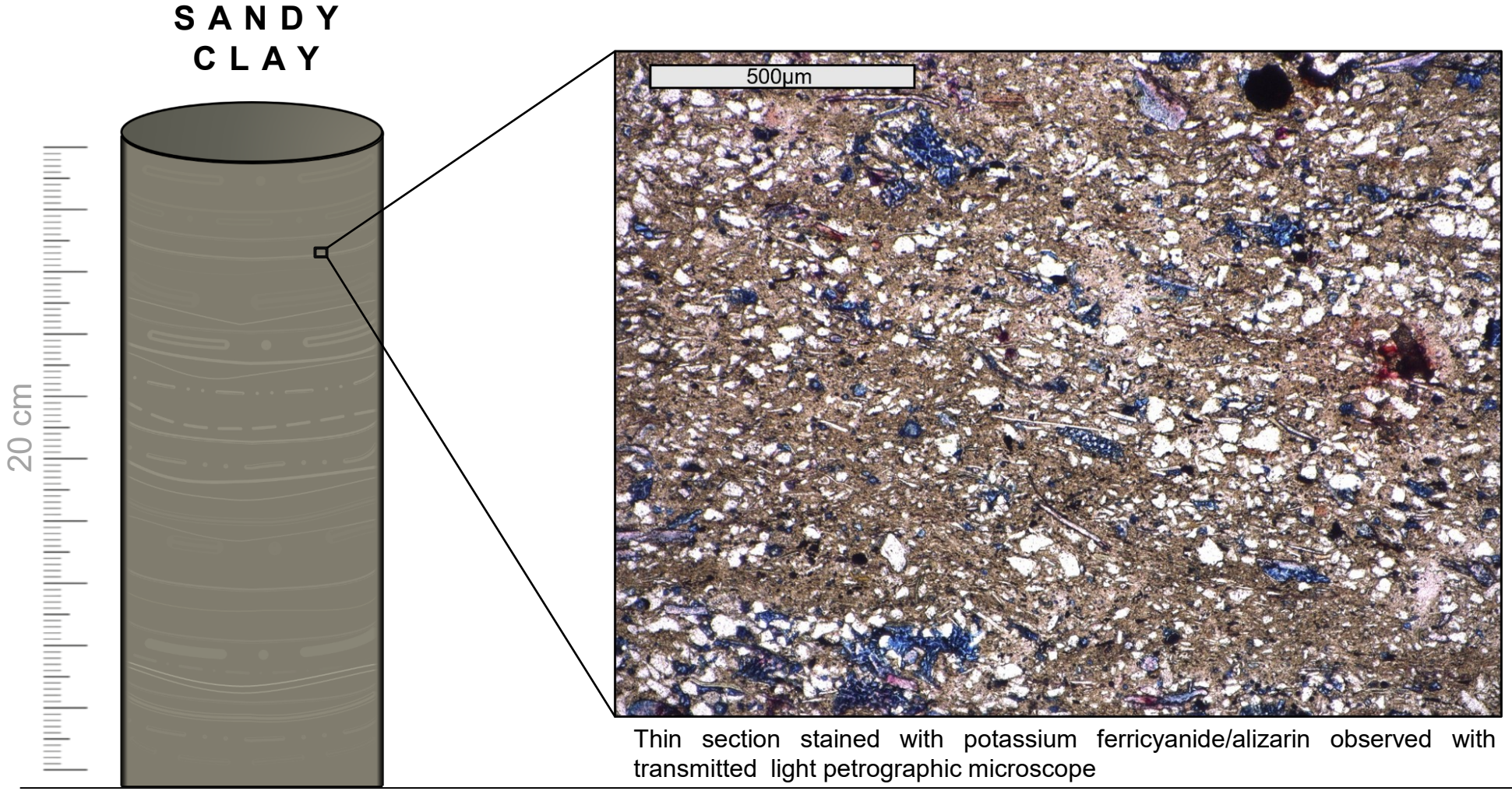
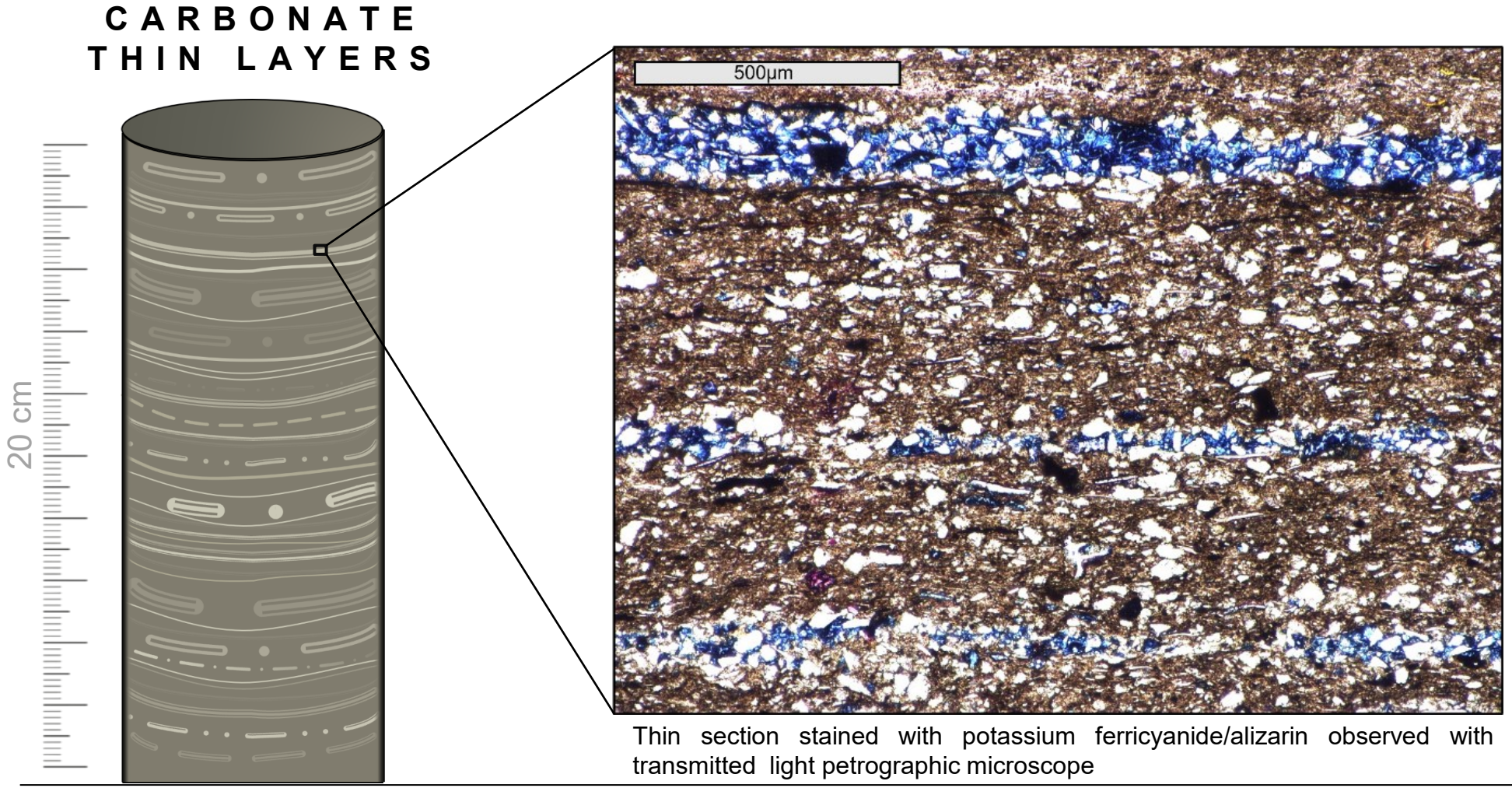


Thin section stained with potassium ferricyanide/alizarin observed with transmitted light petrographic microscope

Geological characterization – subfacies

Mont Terri Project



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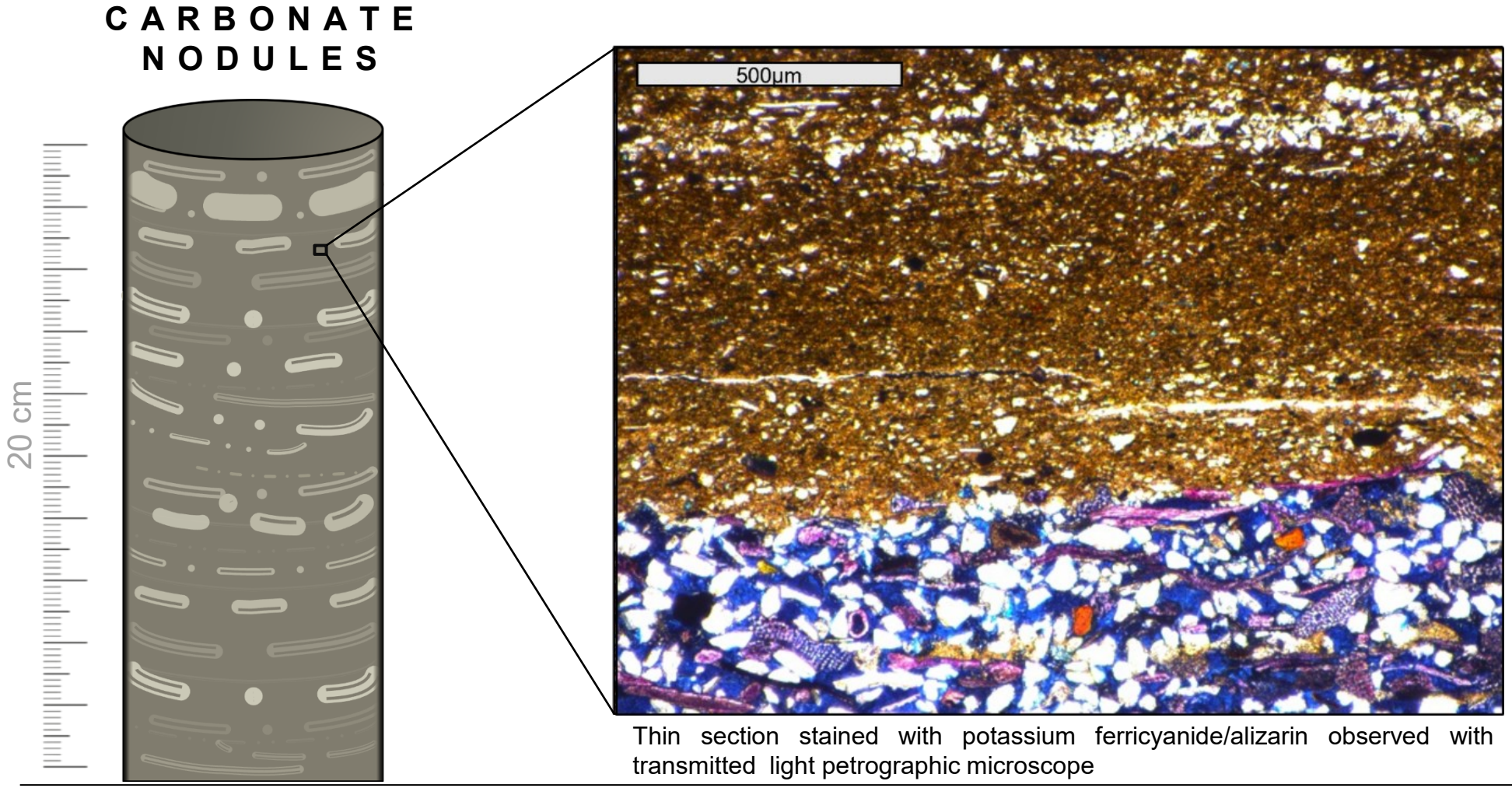
Geological characterization – subfacies

Mont Terri Project



Thin section stained with potassium ferricyanide/alizarin observed with transmitted light petrographic microscope

Geological characterization – faults

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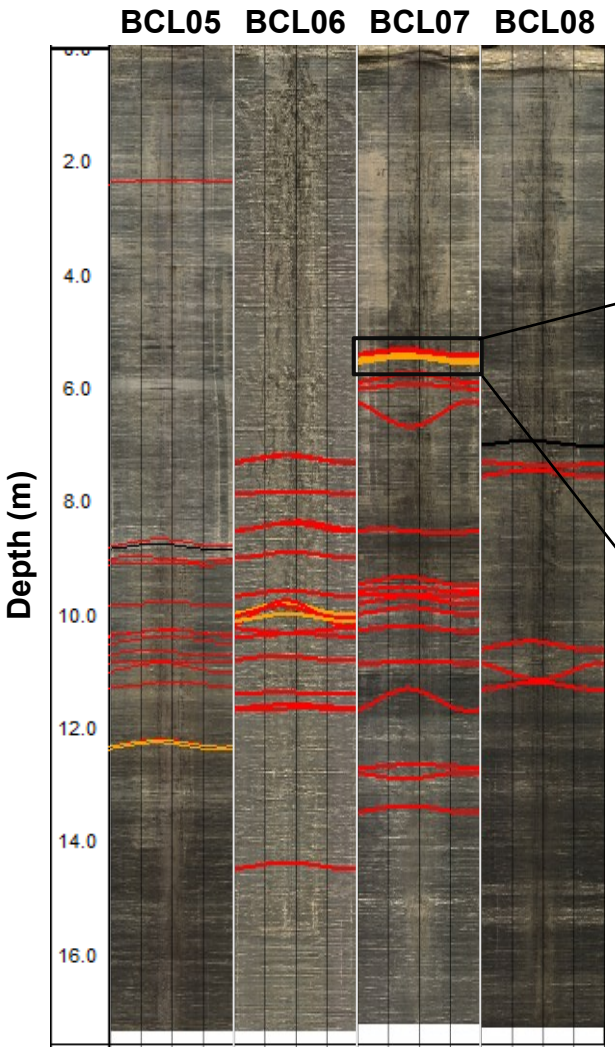
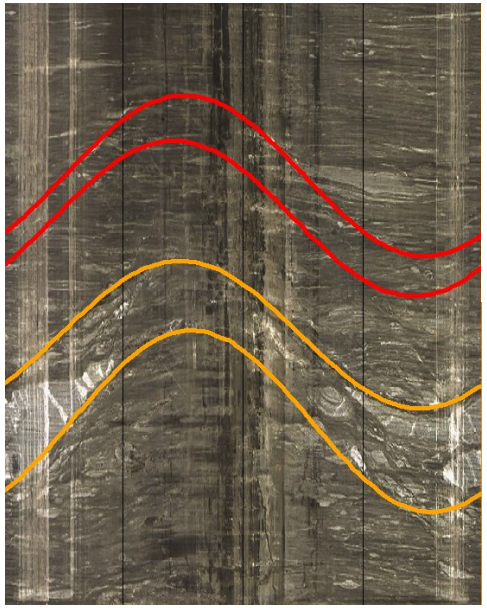


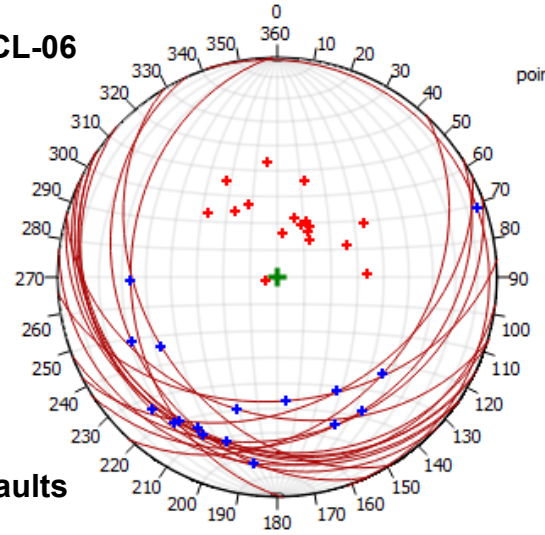
Borehole image

Borehole image + Mapped faults

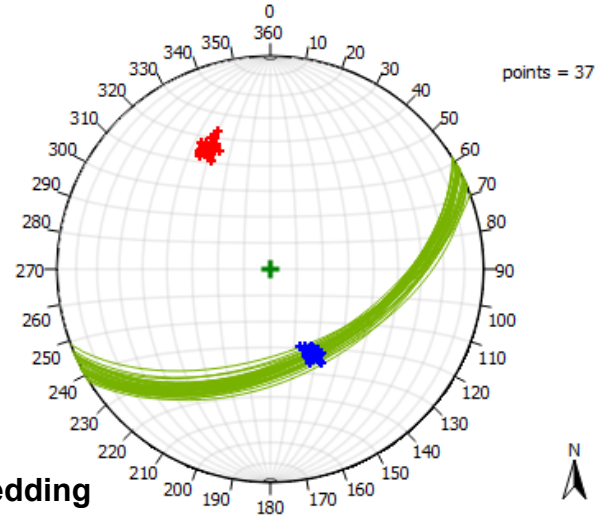


Fault plan
Fault zone
Fault gouge

BCL-06



Faults



Bedding

Results: Geological characterization

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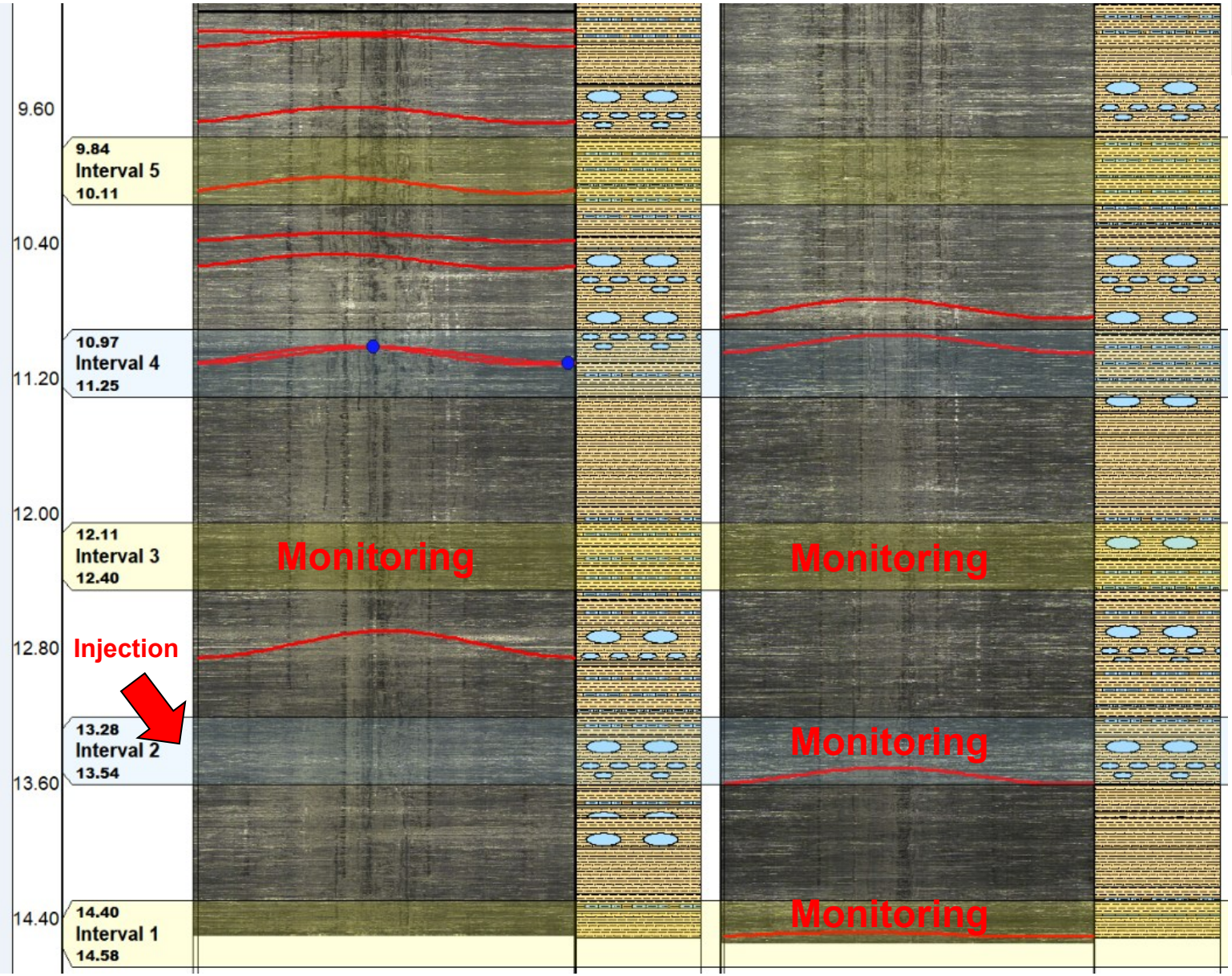
BCL-9

Injection borehole

BCL-11

Monitoring borehole



Lithology

- Sandy clay
- Thin carbonatic layers
- Carbonatic nodules

Discontinuities

- Tectonic fault plane

Lab investigations on rock cores of CL

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Type	TS/petrophys	Diffusion	GAS	MA	SQS	orGeo	geochEx	Rock properties	Mechanical properties
Type	Thin section analysis/petrophysical parameters	Diffusion experiment	1. cores for autoclaves, and 2. cores weld in into gas bags	Mineralogical analyses	Squeezing samples	organic geochemistry	geochem experiments	THMC, fricitonal properties	stiffness, micromech. strength
Organizatio (responsibl		UniBE, P. Wersin	Eawag, C. Marion	swisstopo	UniBE, P. Wersin	BGR, C. Ostertag-Henning	BGR, C. Ostertag-Henning	ETHZ, A. Rinaldi	Uni Leoben, J. Bensing
Aims	mineralogy, density, wate content, porosity		gas tight packing to avoid degassing, isotopic	profile of mineralogical composition along borehole	characterise pore water geochemistry	characterization of organic matter in unit	investiagtion of extent of geochemical reactions	testing rock properties of clay exposed to CO2	testing rock stiffness anisotropy; testing micromechanical behaviour under the influence of CO2
Sample frequency	Every 2 m/every 1 m in target interval in two observation boreholes and BCL-9 and BCL-10	Two samples of interval, BC			6 samples	1/1m	1/1m	1/1m	
Sample length	5 cm	20 cm	10 cm	10		10 cm	10 cm	10 cm	30 cm
Core diameter	82 mm	82 mm	82 mm	82 mm	82 mm		82 mm	82 mm	subcoring of cylindrical samples of 30x60-75mm mm
Analysis on-site	Volume/weight/water loss at 105°C	Volume/weight/water loss at 105°C	no	no		no			no
Conditioning	TS: wrap in celophan foil, petrophys: put piece of 50 g into oven at 105°C	1x vacuum-sealed plastic bag + oxigen indicator + 1x vacuum-sealed aluminum bag	in autoclaves, gas tight aluminum bag, vacumize	wrap twice into aluminum foil and vacumize	1x vacuum-sealed plastic bag + oxigen indicator + 1x vacuum-sealed aluminum bag	1x vacuum-sealed plas + oxigen indicator vacuum-sealed aluminu			wrap into aluminum foil and
Analysis off-site	thin section preparation, microscopic analysis and pycnometry by swisstopo	Diffusion experiments at PSI in spring 2025	gas composition, pCO2, noble gas isotopes, $^{12}C/^{13}C$-ratio	XRF with MSCL, EDX at UniBE for bulk mineralogy	pore water samples	bulk and molecular organic geochemcial analyses	experiments with ana fluids/gases after/ experiment		

Microfacies, petrophysical parameters

Diffusion properties

Gas composition, noble gas isotopes

Mineralogical analysis

Pore water geochemistry

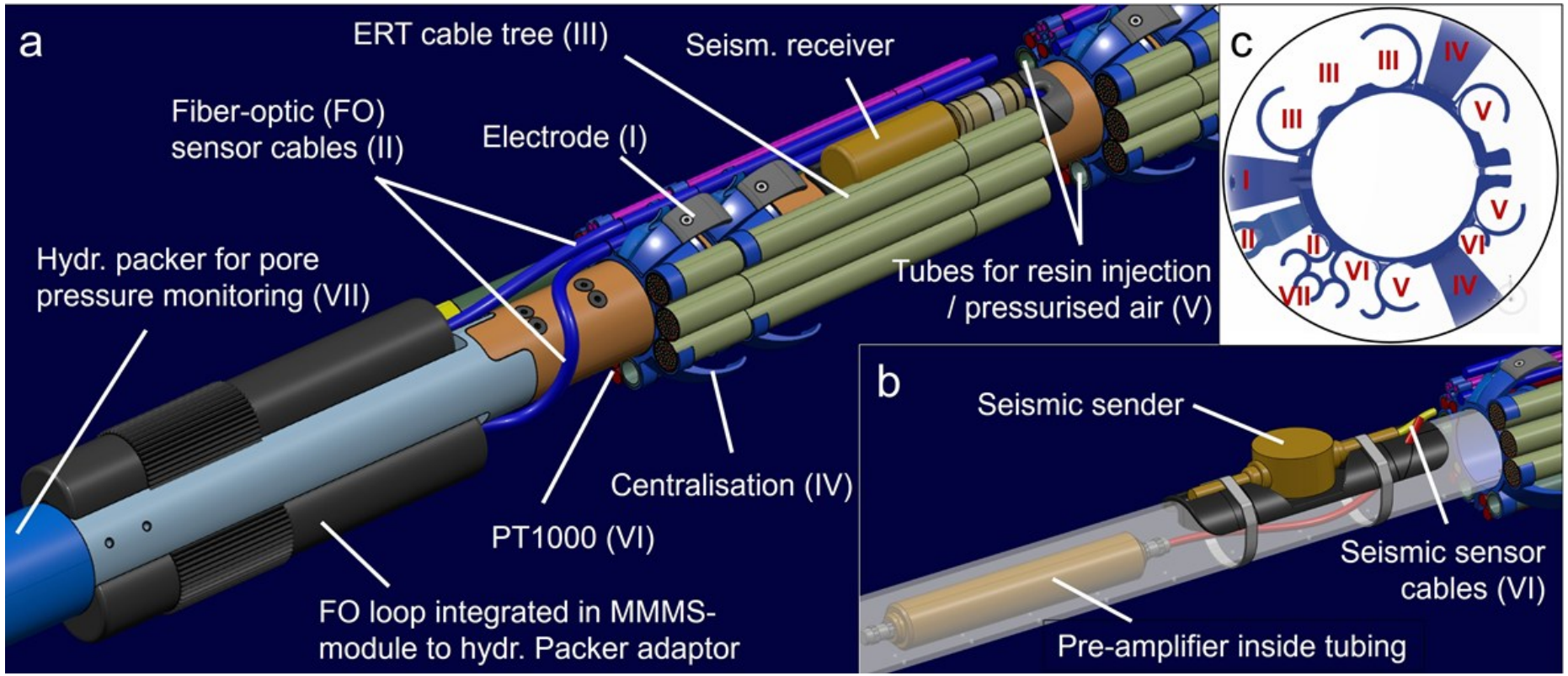
Organic geochemistry

Experiments on rock-water-gas interaction

CO_2-exposed THMC frictional properties

Rock mechanical properties

Development of MMMS with



- Sensors: electrodes for ERT, acoustic transmitters and receivers for active and passive recordings, fibre-optical strain/T, point T, pore pressure, orientation (used during installation)
- Annular gap filled with resin with low viscosity, long polymerization and low T, const. volume, elastic properties close to OPA
- Other topics: system stiffness, tightness, redundance, long-term chemical stability, coupling to rock, flexibility with modules, installation with drill rig → many pretests were carried out!

Installation of MMMS in BCL-5

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Preliminary results: Seismic monitoring @ CL

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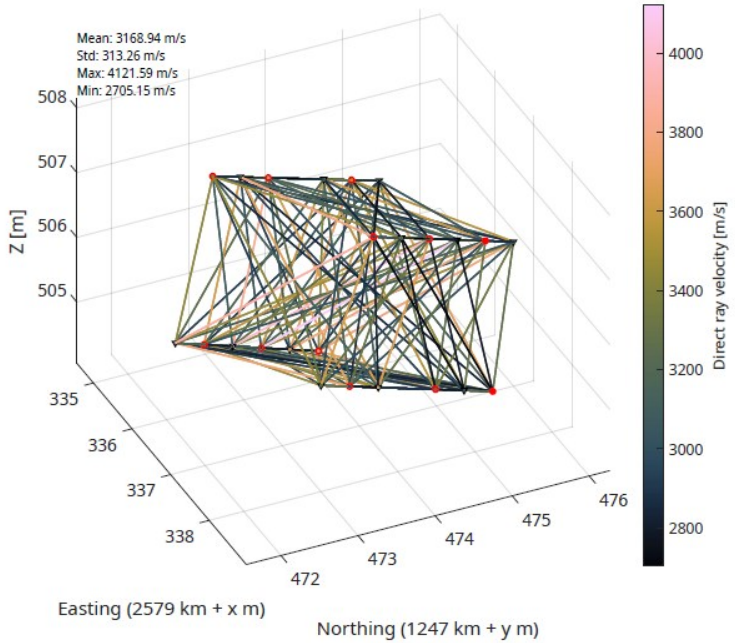

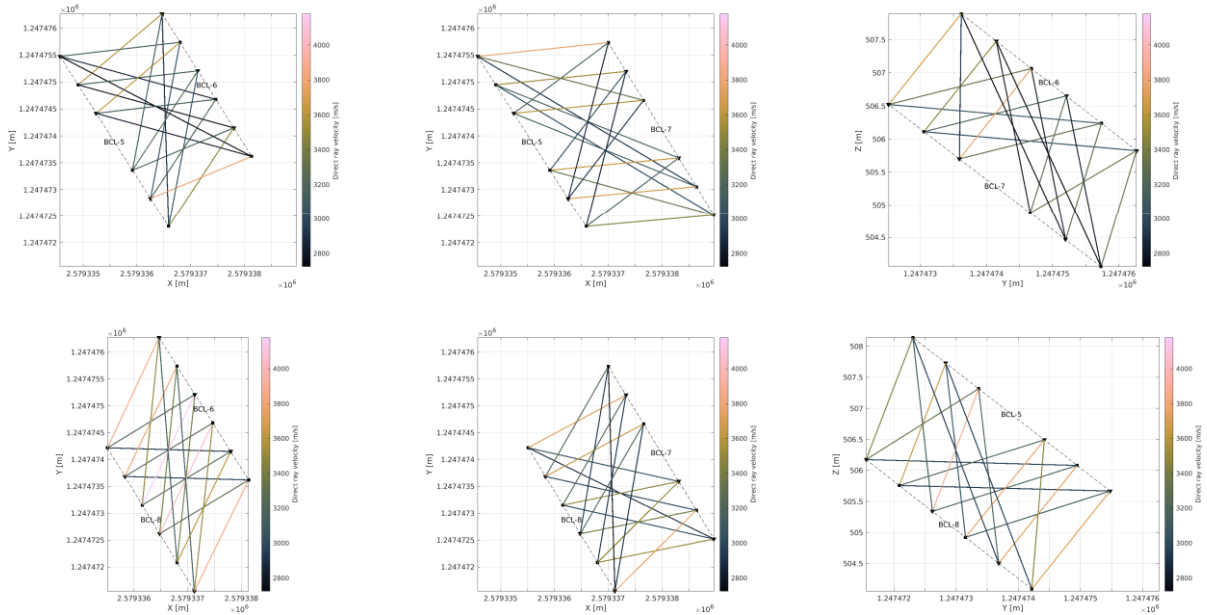

- Array of 12 pairs of seismic transmitter and seismic receivers with preamplifiers is available with high overlap in injection areas
- **High signal to noise ratios → good coupling!**
- **Direct ray velocities orthogonal to boreholes are faster than more parallel to boreholes → anisotropy!**
- Time series during baseline show increasing velocities with time and decreasing amplitudes
- Velocity variation and waveform coherence point to temporal variations

Preliminary results: Fiber optic sensing @ CL

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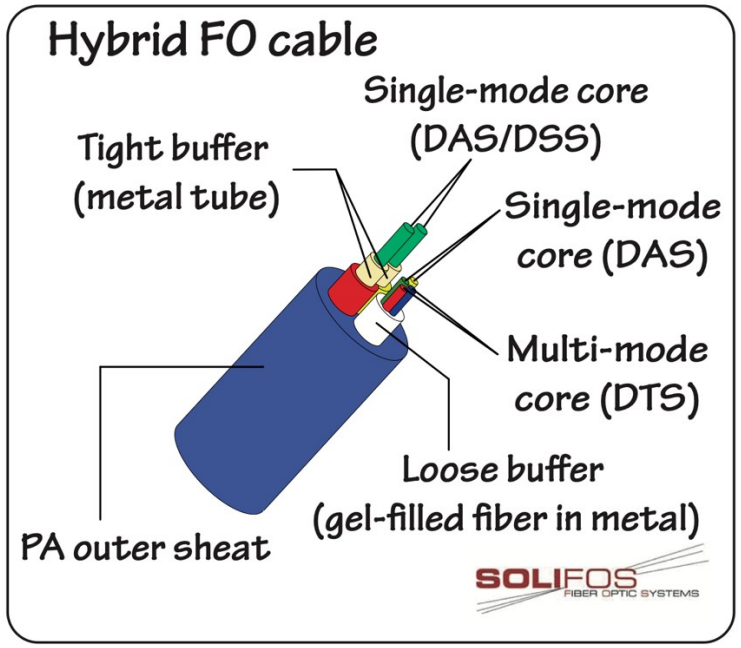
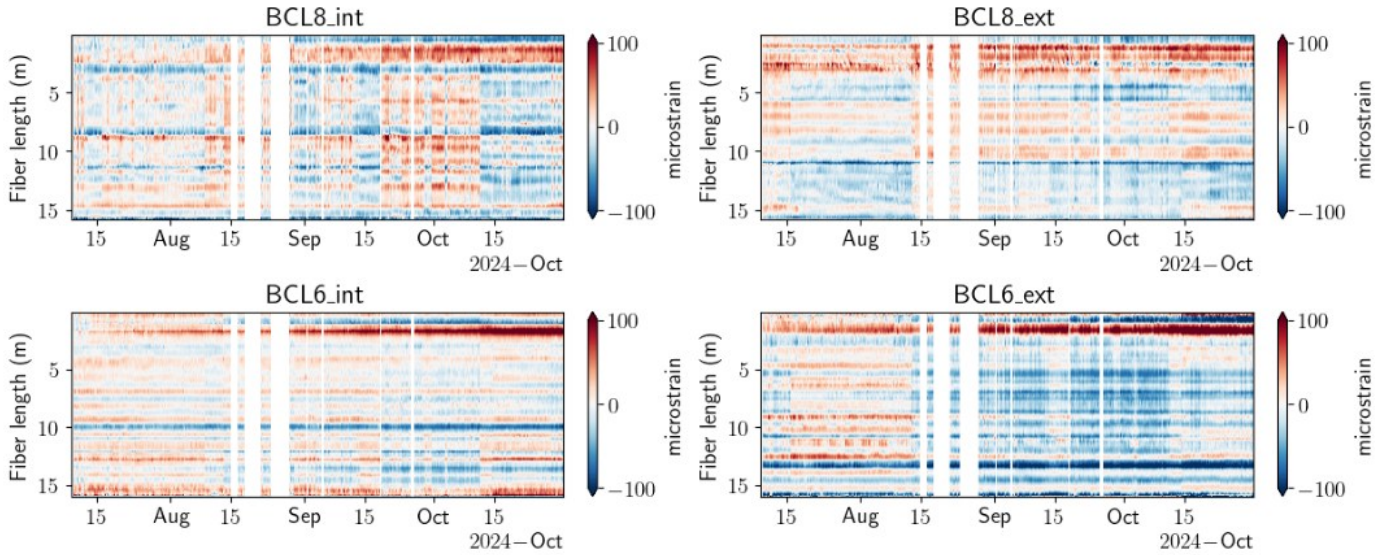


Monitoring of background (baseline)



- Hybrid cable installed in all boreholes
- Simultaneous monitoring of DTS, DSS, DAS
- Three tubes (two tight buffer, one loose)
- Strategy for CO_2LPIE: use loose tube for temperature correction of strain recorded on tight tube

- **Some long-term signal clearly visible** (e.g. at top of BCL-6)
- Further down sampling can also reduce noise level (here 180 minutes), spatial resolution at 0.5 m

Preliminary results: 3-D ERT @ CL

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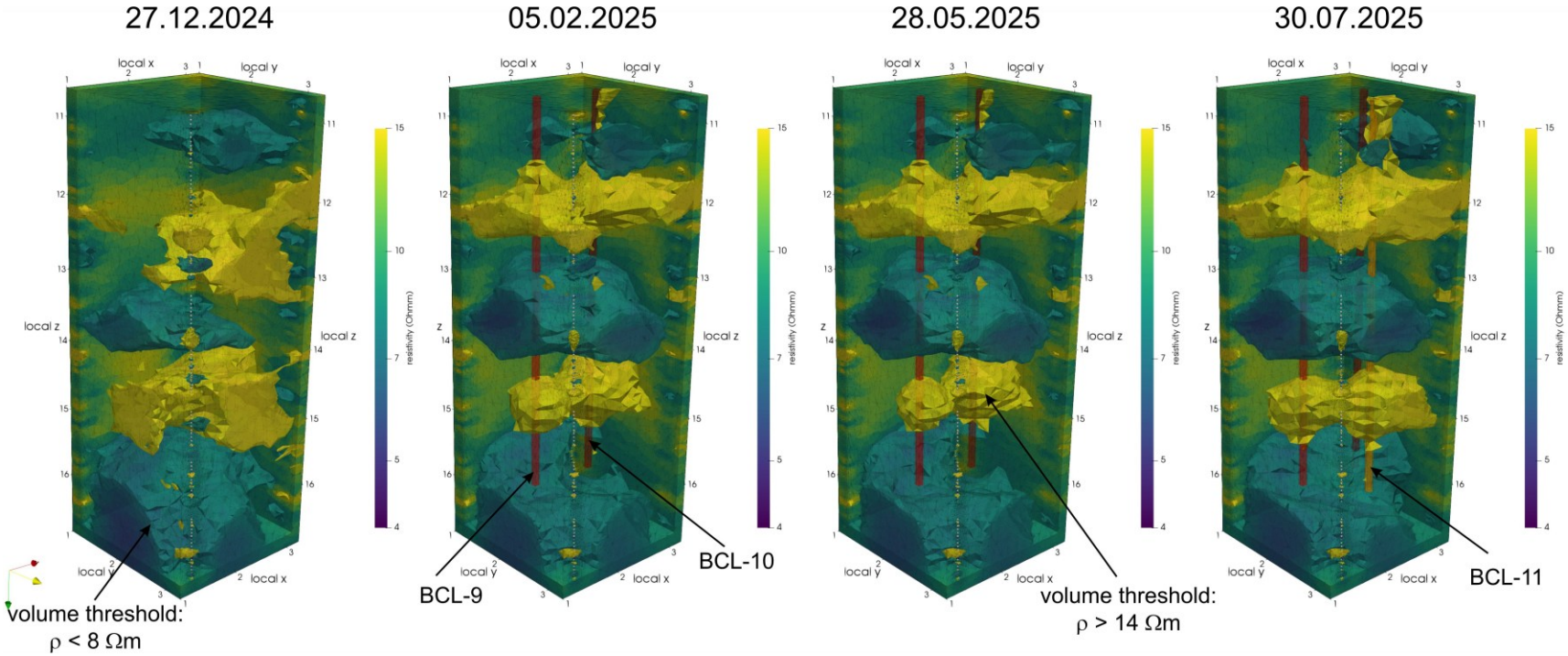

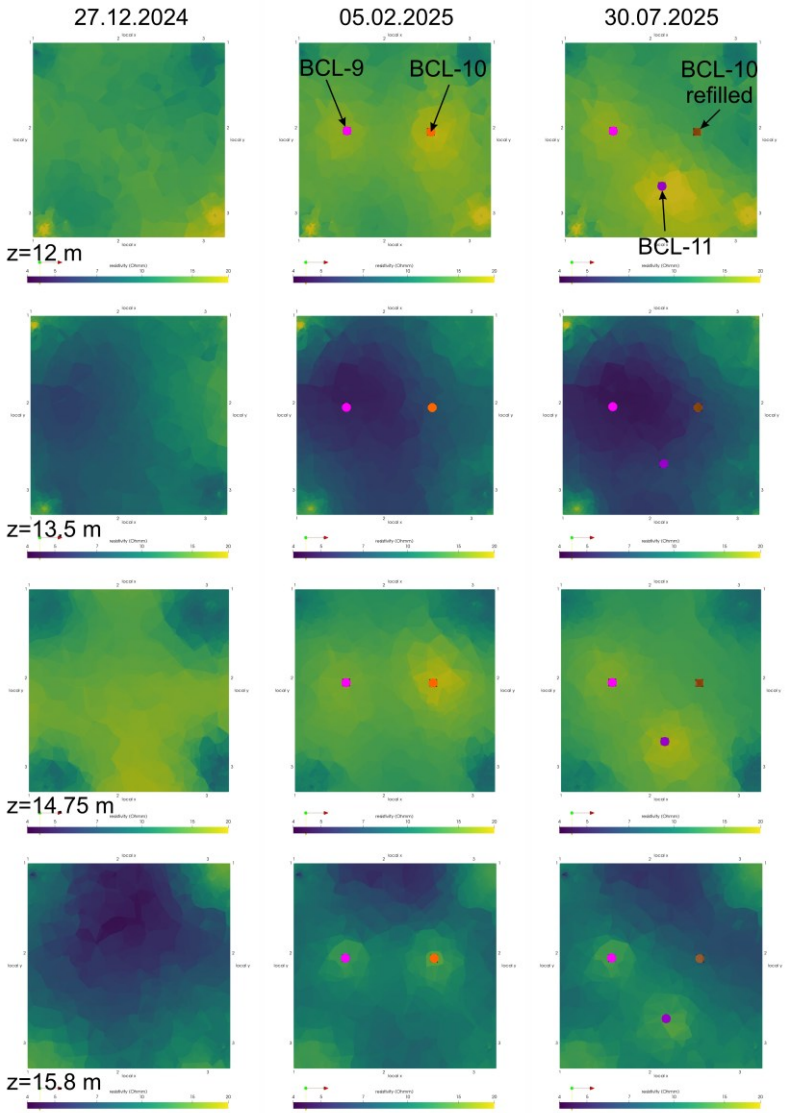

- Measurements: 4 single hole, 6 cross hole, 393 electrodes, 18’800 meas.
- **Excellent data quality**, isobodies with low specific resistance (< 9 Ωm) can be identified, showing **meter-scale heterogeneity** in the experimental volume
- **Influence of boreholes** on the experimental volume is clearly visible

BGR

(by M. Furche)

CO_2LPIE – on-site activities

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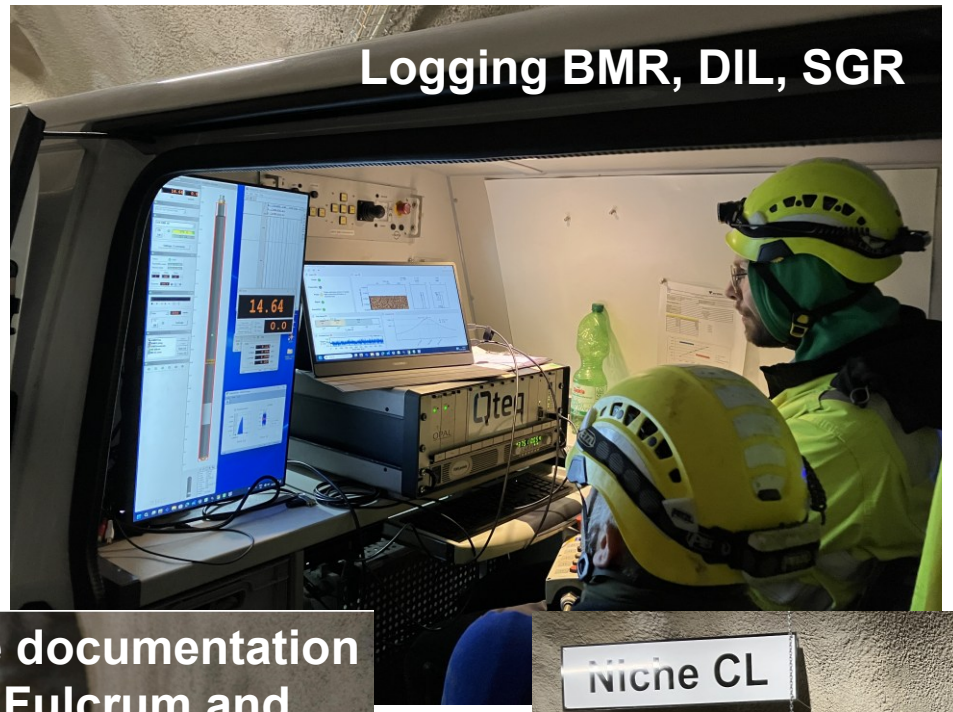

Overview of surface equipment

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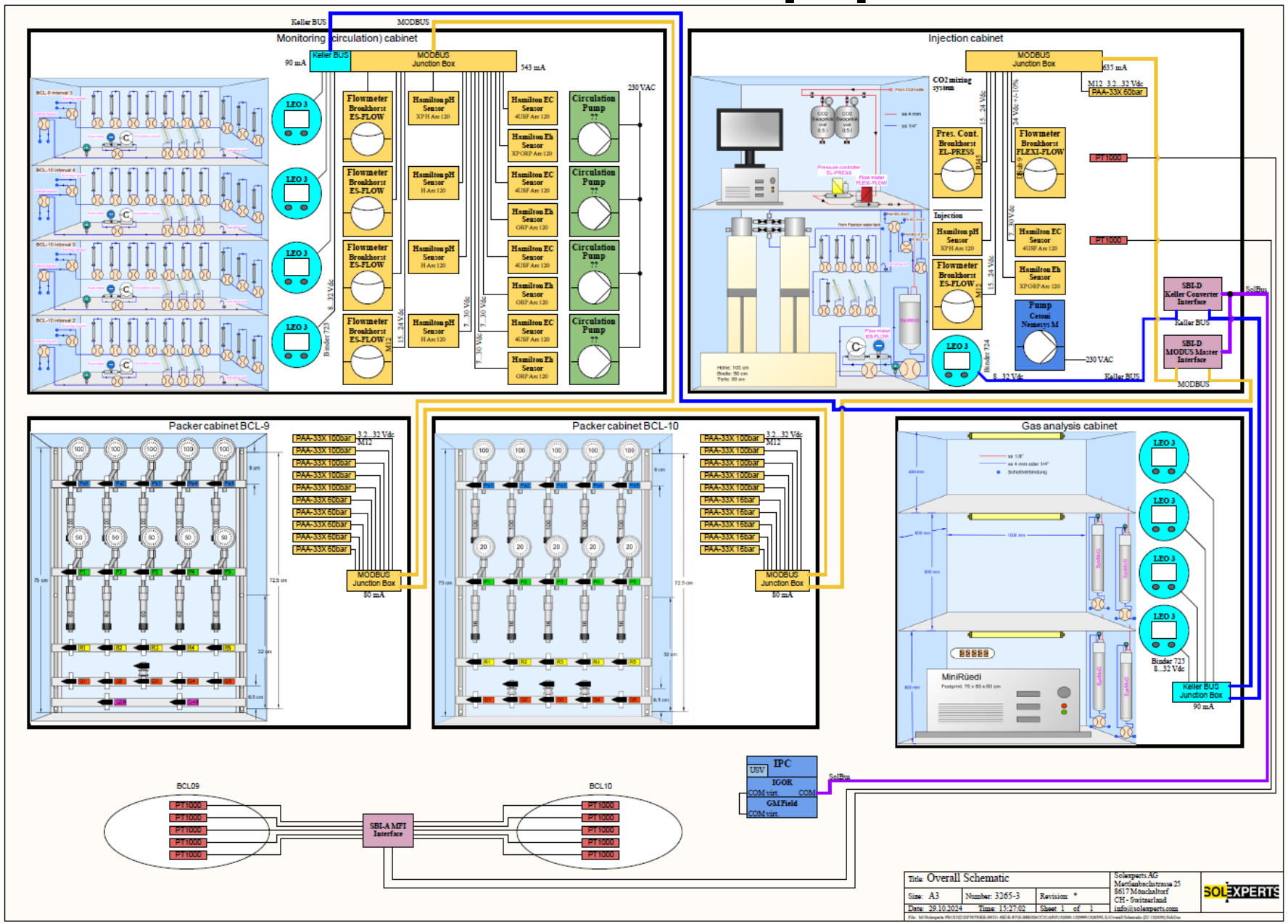

Status of installations

- MPS of BCL-9 and BCL-11 have been installed
- All cabinets have been installed and tested
- Circulation in injection circuit was started Thursday 16 October, interval circuit was connected on 20 October (hydrostatic, no CO_2 yet!)

Overview of surface equipment

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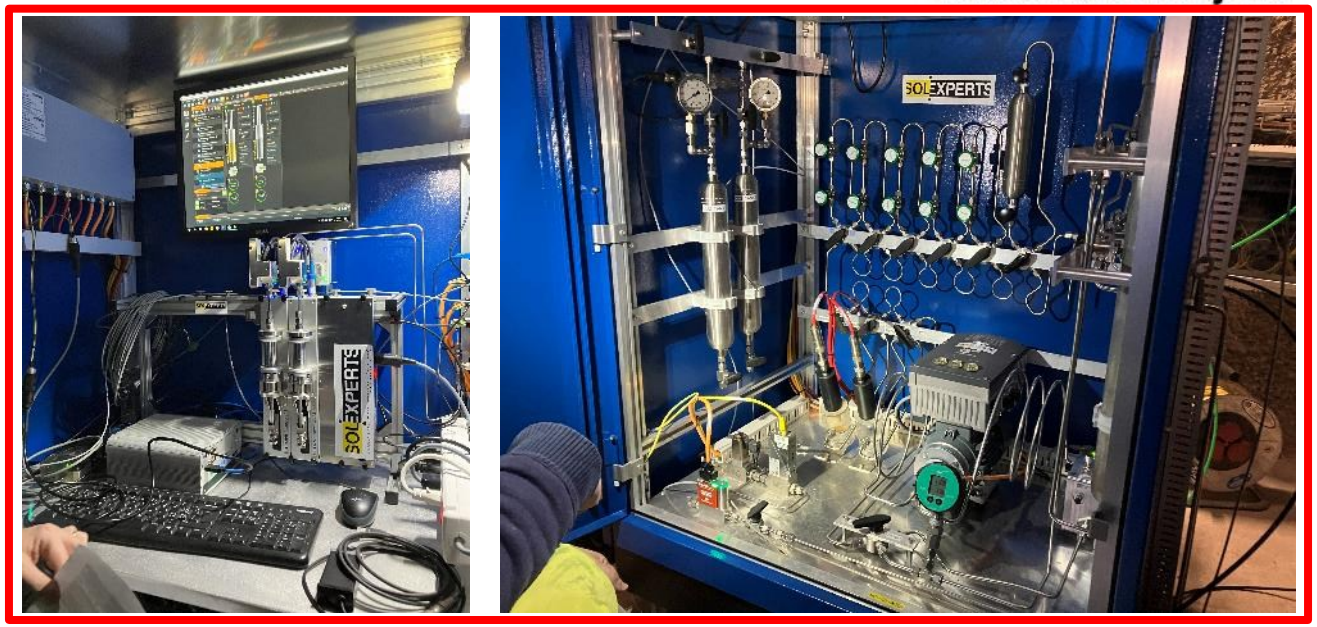
J. Gisiger observing the filling of the circulation units (S. Schefer, swisstopo).



- All cabinets for **injection** and **extraction** (water circulation and gas circulation) were installed by solexperts in July
- The circuits have been saturated and tested in August
- In September C. Marion (eawag) together with solexperts performed the gas tightness tests with N_2 and He

CO_2LPIE – test sequence, December 2025

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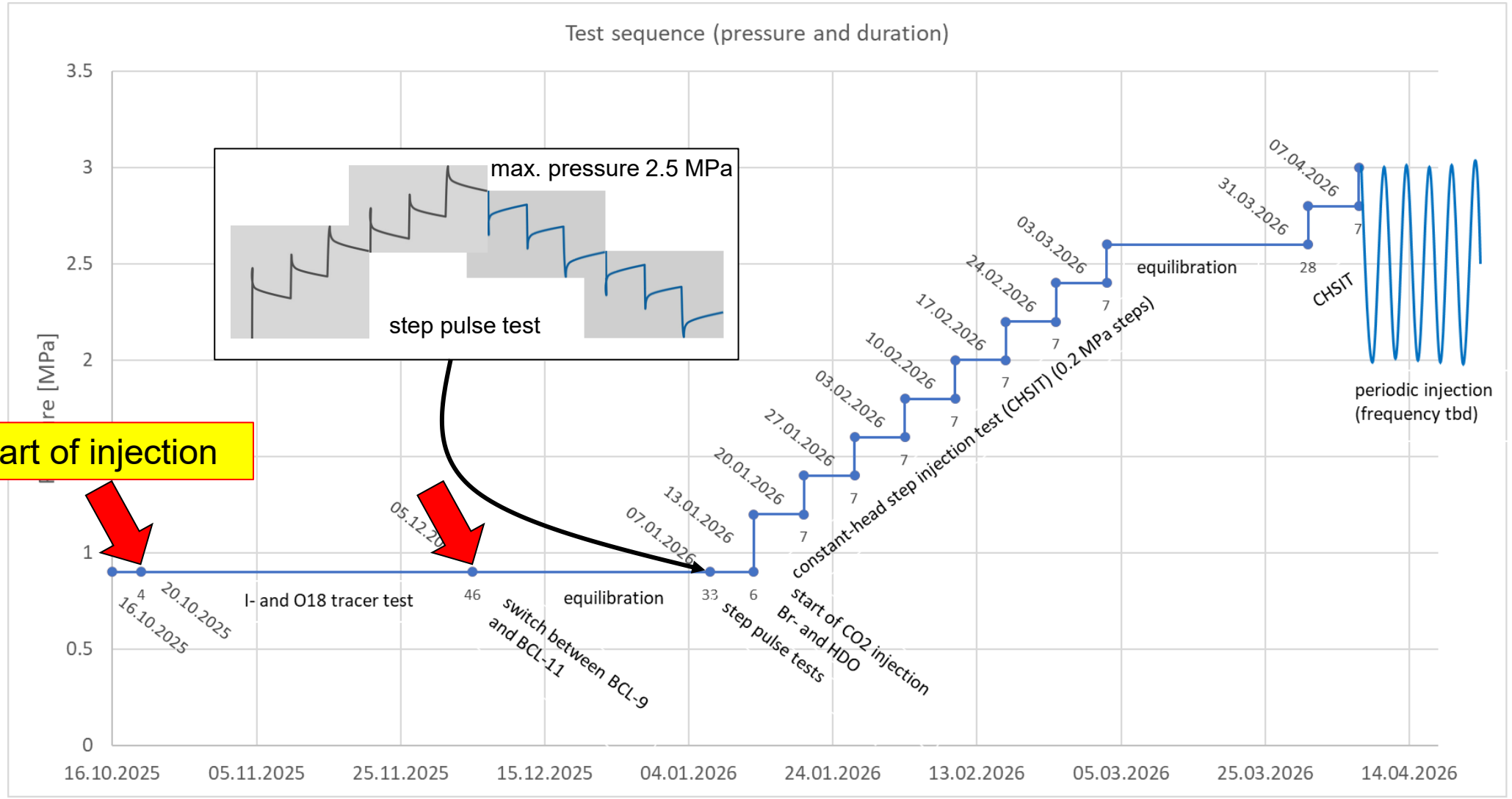


CO_2LPIE – modeling activities

Mont Terri Project

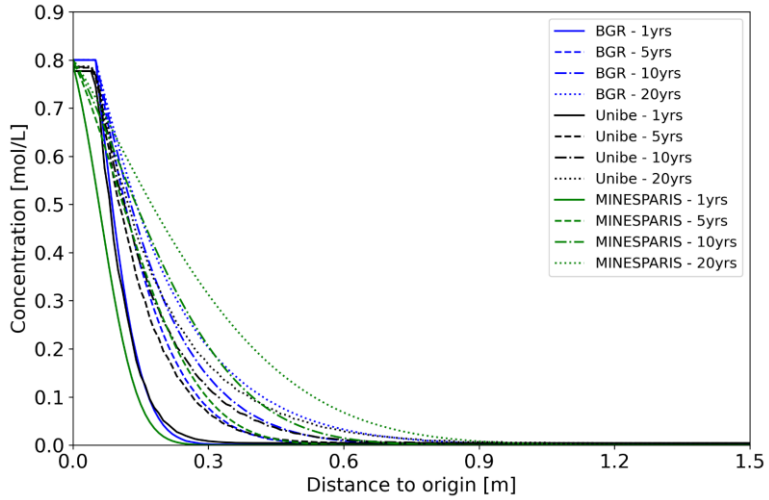
Lead: G. Ziefle (BGR)

Focus:

- Further **development and validation** of modeling approaches
- **Scoping calculations, sensitivity studies** and THM or THC **long-term calculations**
- **Effect of anisotropy and heterogeneity** for the CO_2LPIE experiment
- **Benchmarking** ongoing by BGR, UniBern, CSIC, MinesParis and NTNU

→ General understanding of the coupled effects

	BGR (OGS HC+ PhreeqC, OGS TH2M)	UniBern (PFLOTRAN)	CSIC (CodeBright)	Mines Paris (HYTEC: PhreeqC + CHESS)	NTNU (PFLOTRAN)
BM THC1/2	Rotational symm. (THC) 2D (TH2M)	Rotat. Symm	-	2D (thickness assumed)	
	Only H (Component transport: Water and CO2)	HC (Reactive Components: Porewater and CO2)		HC (Reactive Components: Porewater and CO2)	
BM THC3/4	With kinetics	With kinetics	-	No kinetics	
	Reactive components (Porewater, CO2, minerals)	Reactive components (Porewater, CO2, minerals)		Reactive components (Porewater, CO2, minerals)	
BM THM	2D, initial state with boreholes already excavated	-	2D		(+) 2D rotational, change from CodeBright to PFLOTRAN, 3D system without kinematics



Conclusions

Mont Terri Project

- **MMMS** was successfully developed and installed in all 4 monitoring boreholes
- **Sensor responses** are as expected, and the baseline monitoring data is of excellent quality
- **Injection over a diffusion system**, the system is ready, tested and installed – due to packer problems in BCL-10 the injection was postponed to October 2025 (conservative tracers) and January 2026 (CO_2)
- Rock mass **characterization** is completed, supportive **lab analysis** combined with **numerical modeling** is ongoing

We thank our external funding organizations to make this experiment happen!

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