Preparatory work for CO2 pilot injection into naturally fractured carbonate reservoir in the Czech Republic

Norway grants

CO_2 SPICER

Milan PAGAC (MND) pagac@mnd.cz

P. JIRMAN (CGS)
M. LIBCINSKA (VSB Ostrava)
R. BERENBLYUM, A. NERMOEN, E. FORD (NORCE)
& the CO2-SPICER project team

https://co2-spicer.geology.cz/en

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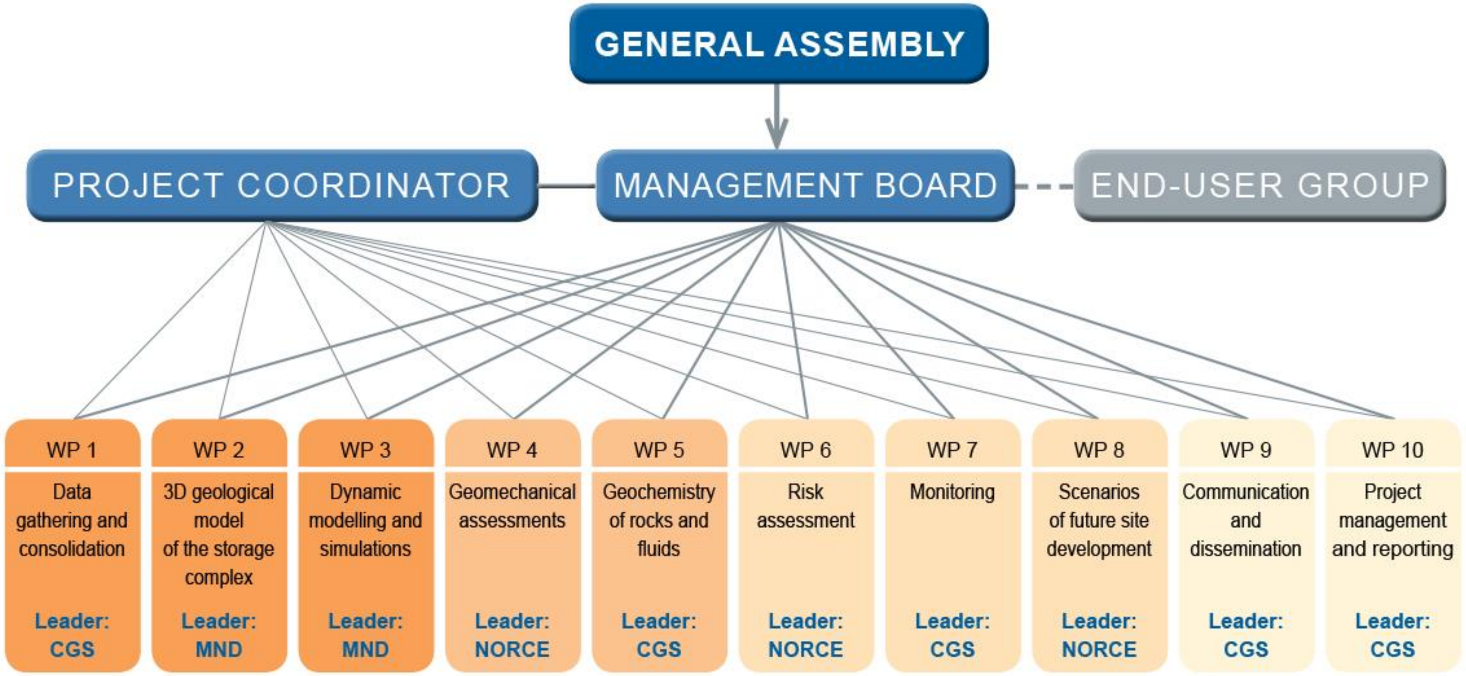
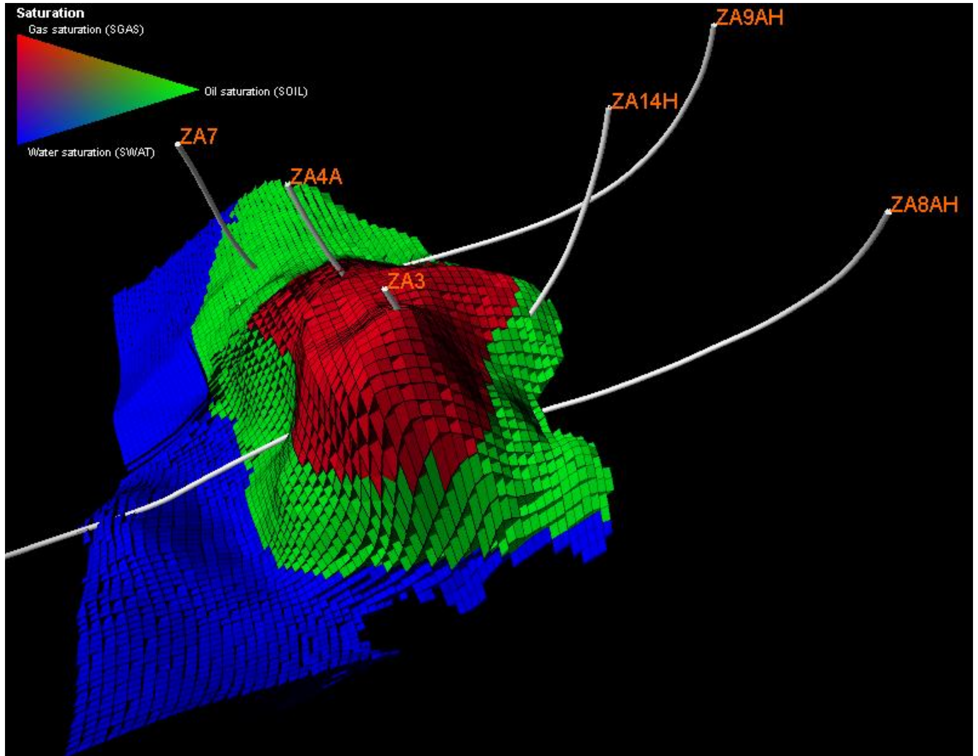
CO2-SPICER project

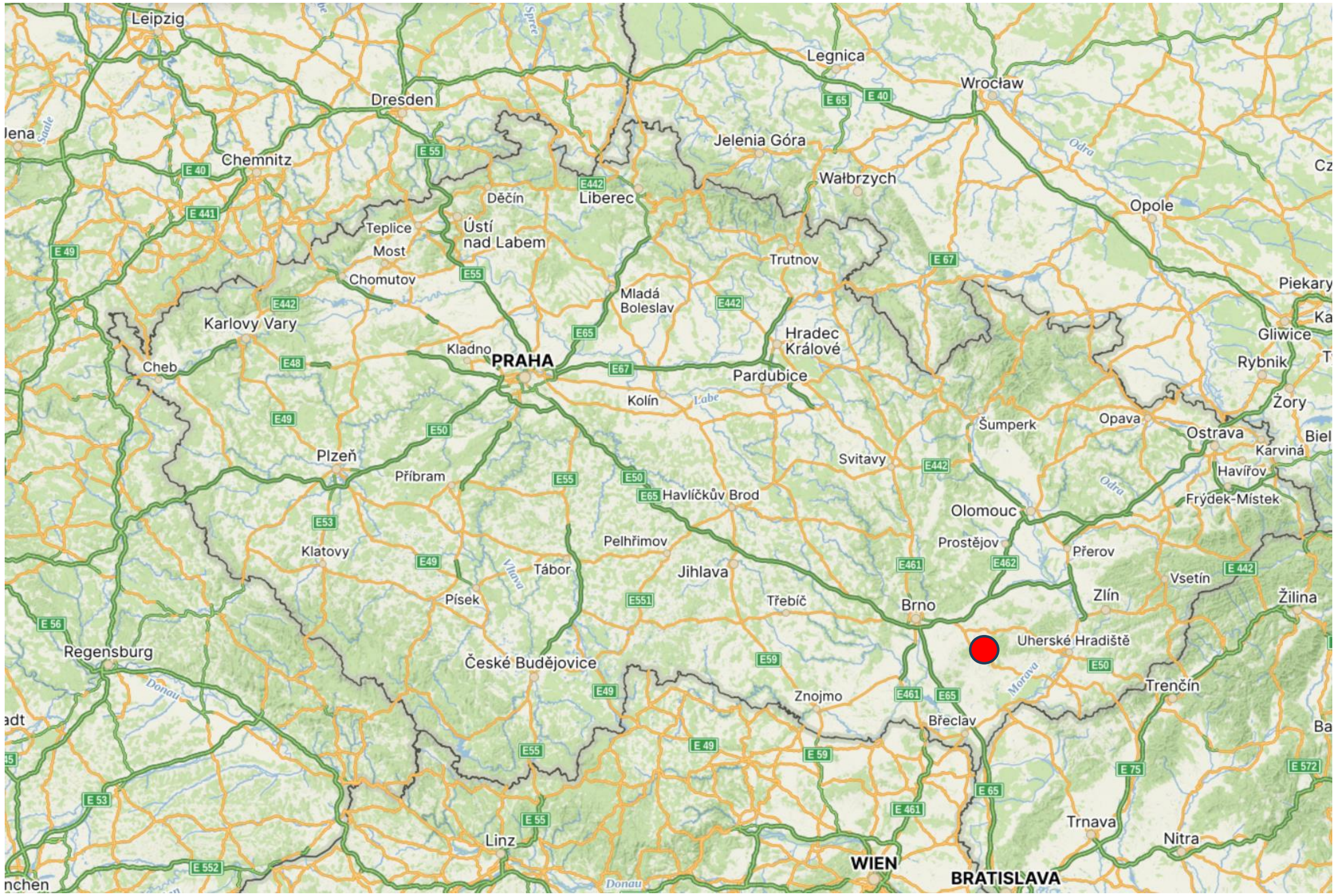
- Main project objective is to prepare implementation of a CO2 geological storage **pilot** project at the mature Zar-3 oil field (achieve implementation-ready stage, no real injection, not large-scale project)
- Czech-Norwegian cooperation within the project



Field’s introduction

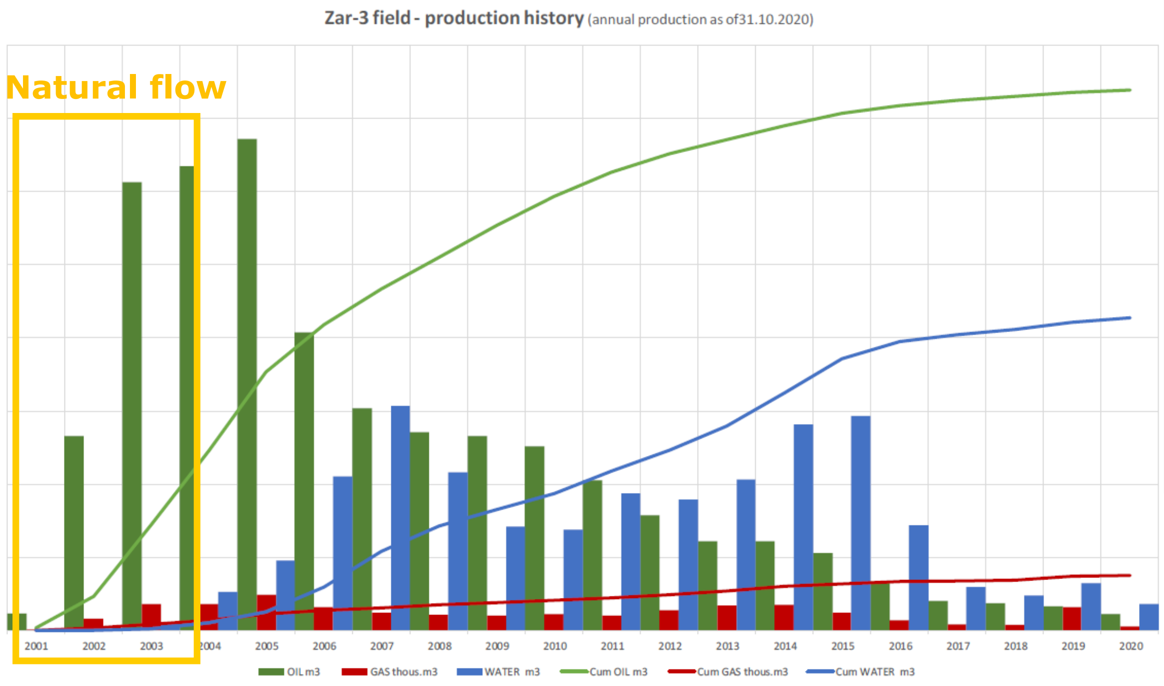
- Zar-3 field is located 30 km SE from Brno on the SE slopes of the Bohemian Massif
- Discovered in 2001 @ depth 1565 – 1872 m TVD
- Oil field with gas cap and aquifer
- Naturally fractured carbonates – Jurassic age

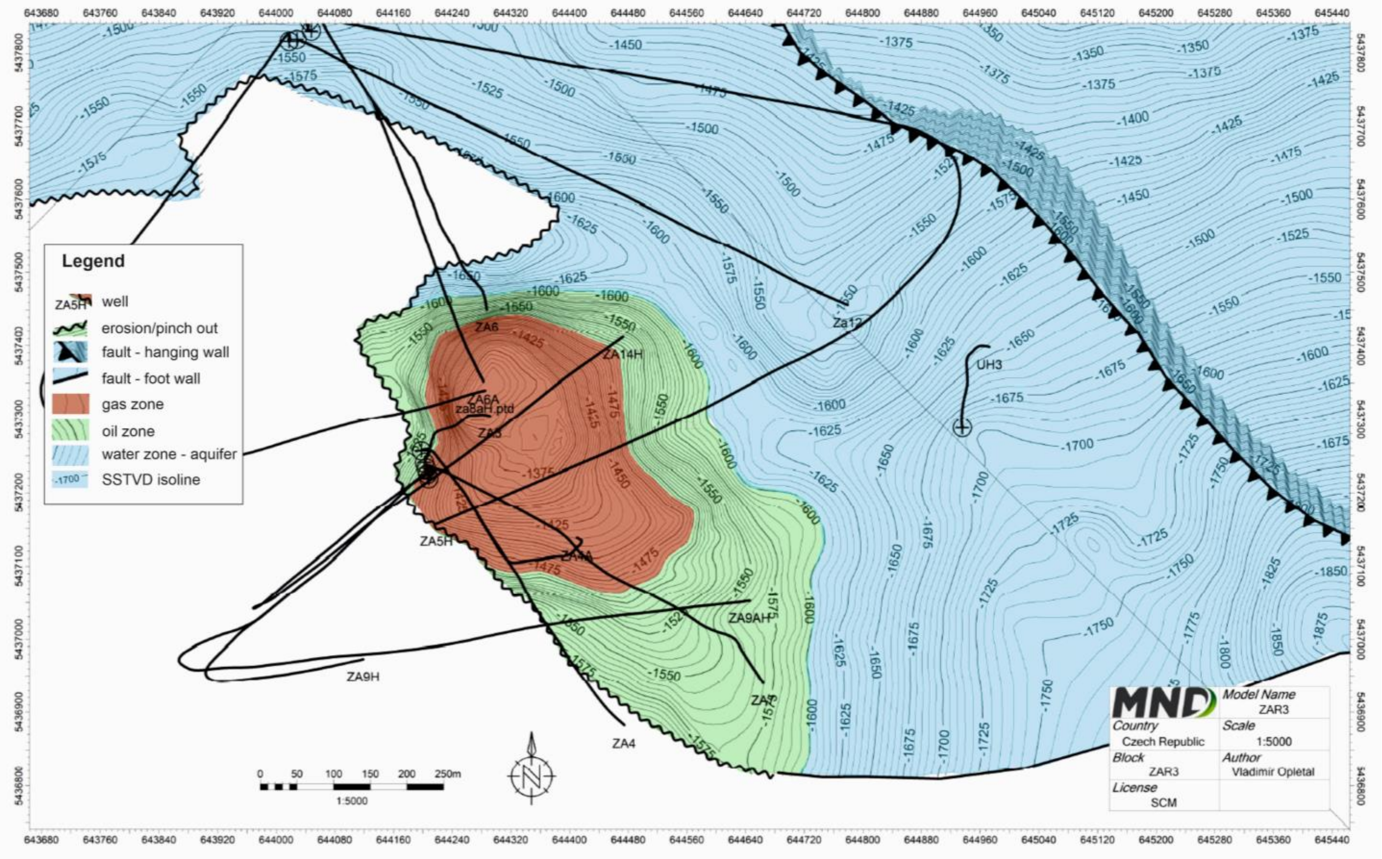




Field's introduction

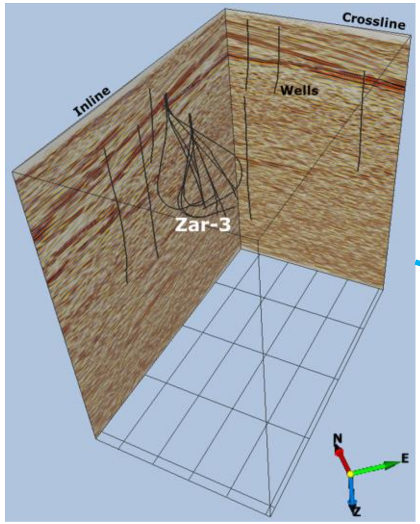
- 8 production wells were drilled, 4 of them horizontal
- Nearing the end of oil production



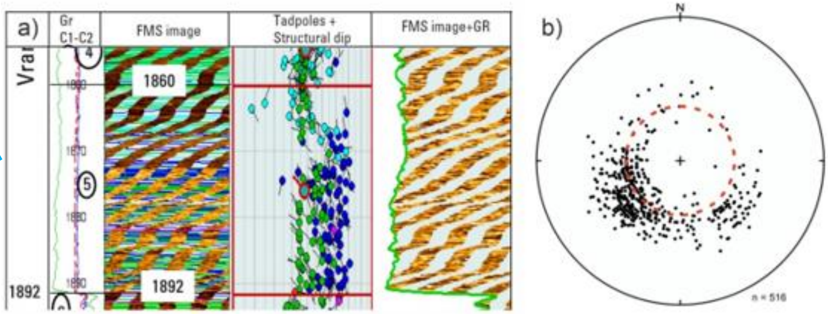


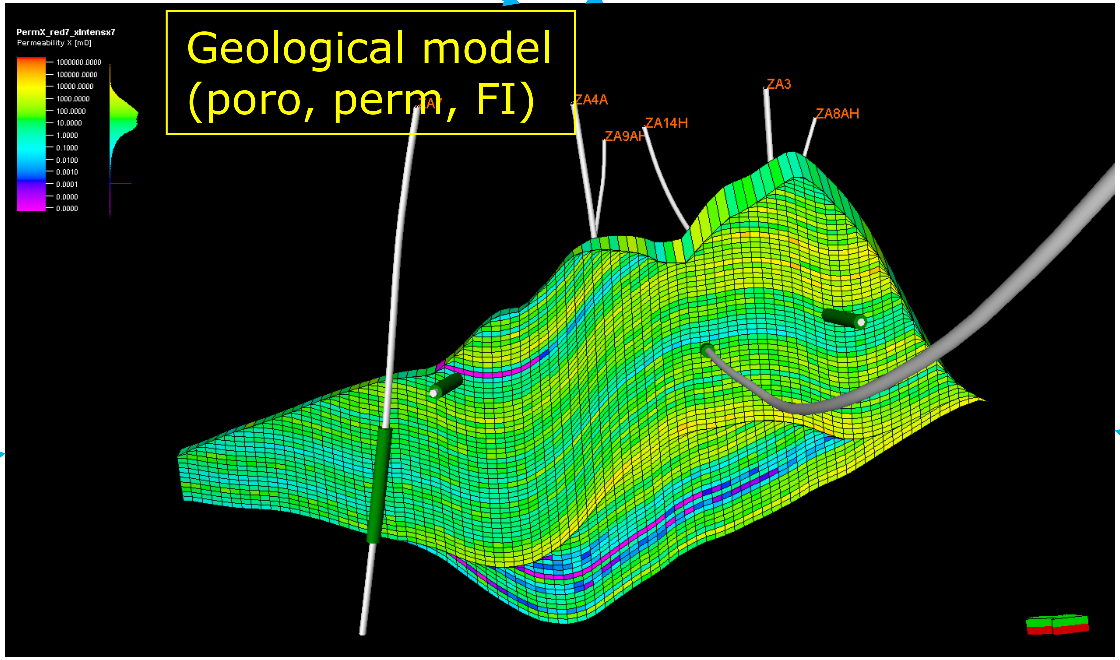
Inputs into geological model

3D seismic

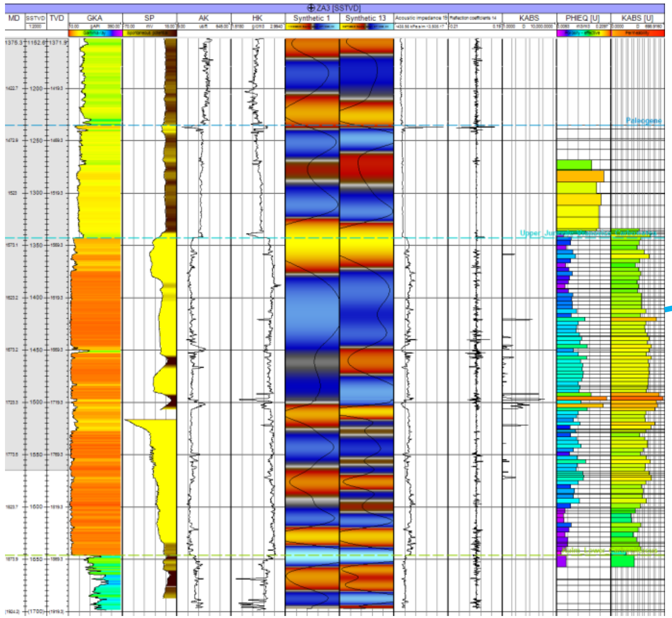


FMS/FMI - fractures





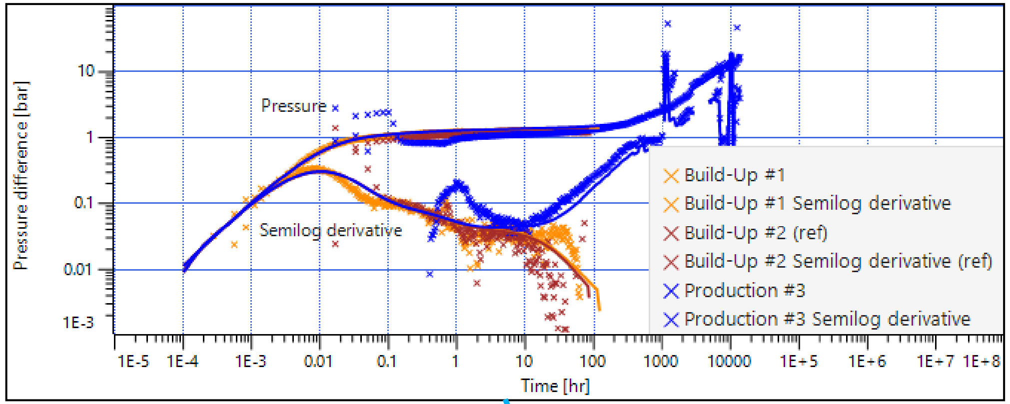
Open-hole logs

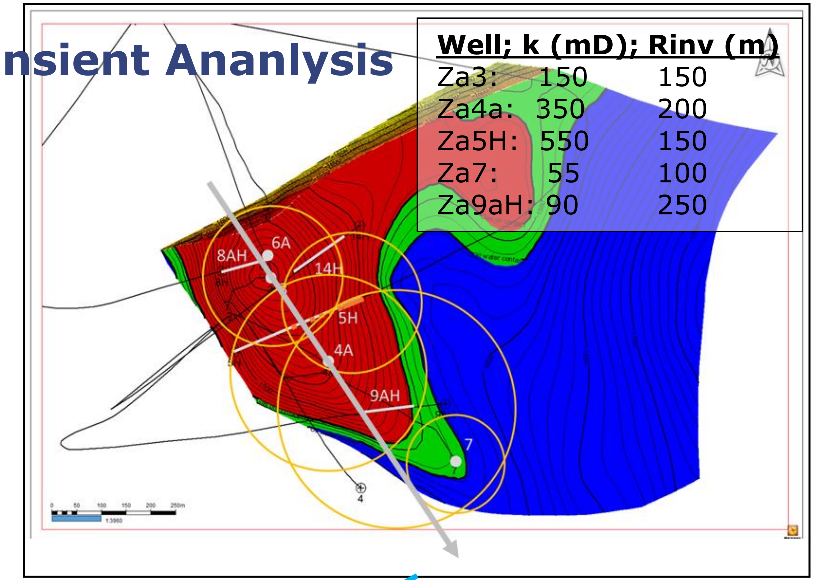


Whole core diameter analysis

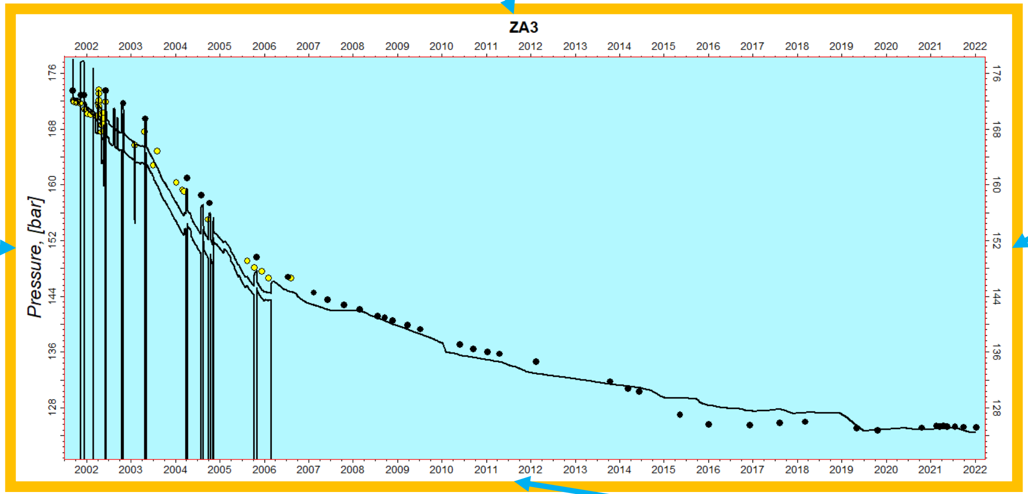
Inputs into simulation model

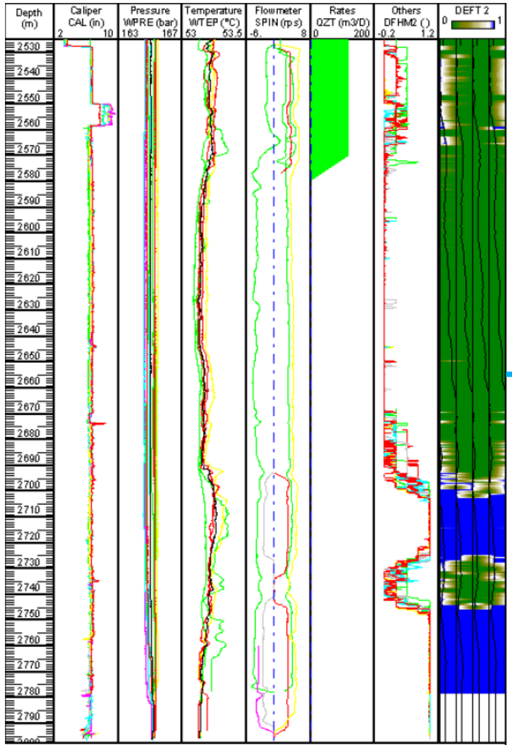
Pressure Transient Ananlysis





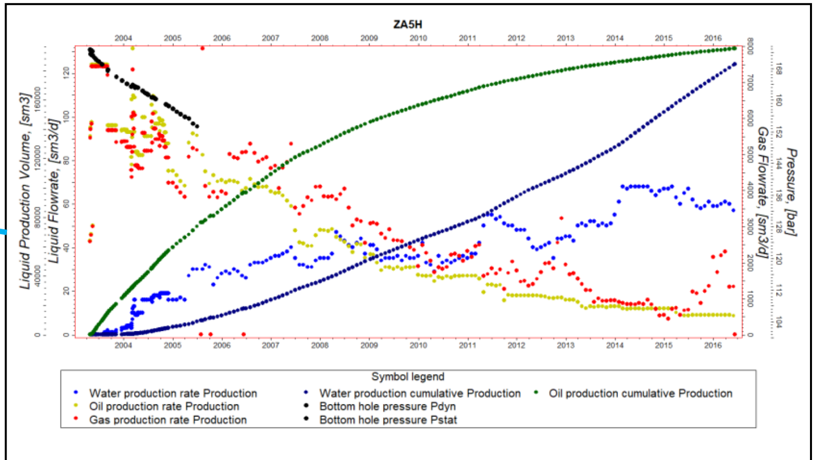
Well; k (mD); Rinv (m)		
Za3:	150	150
Za4a:	350	200
Za5H:	550	150
Za7:	55	100
Za9aH:	90	250





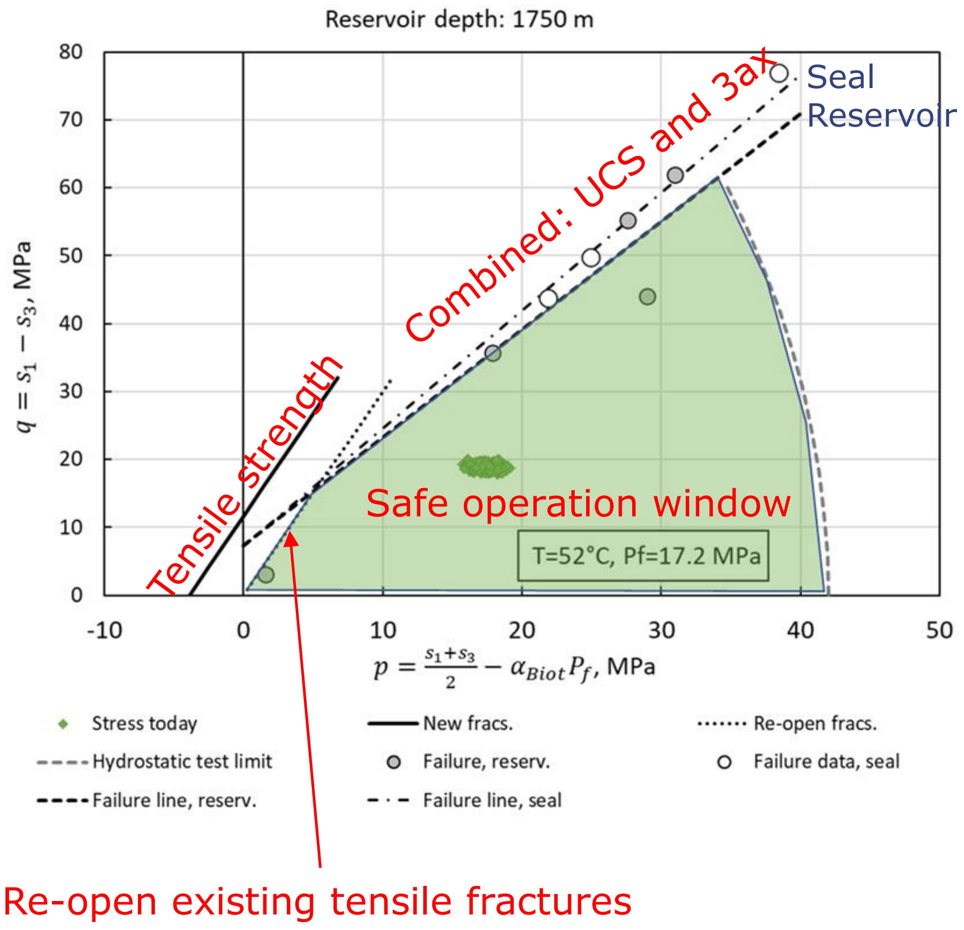
Production logging

Production history (20 years)



Geomechanics – determining the safe operation window during CO2 injection

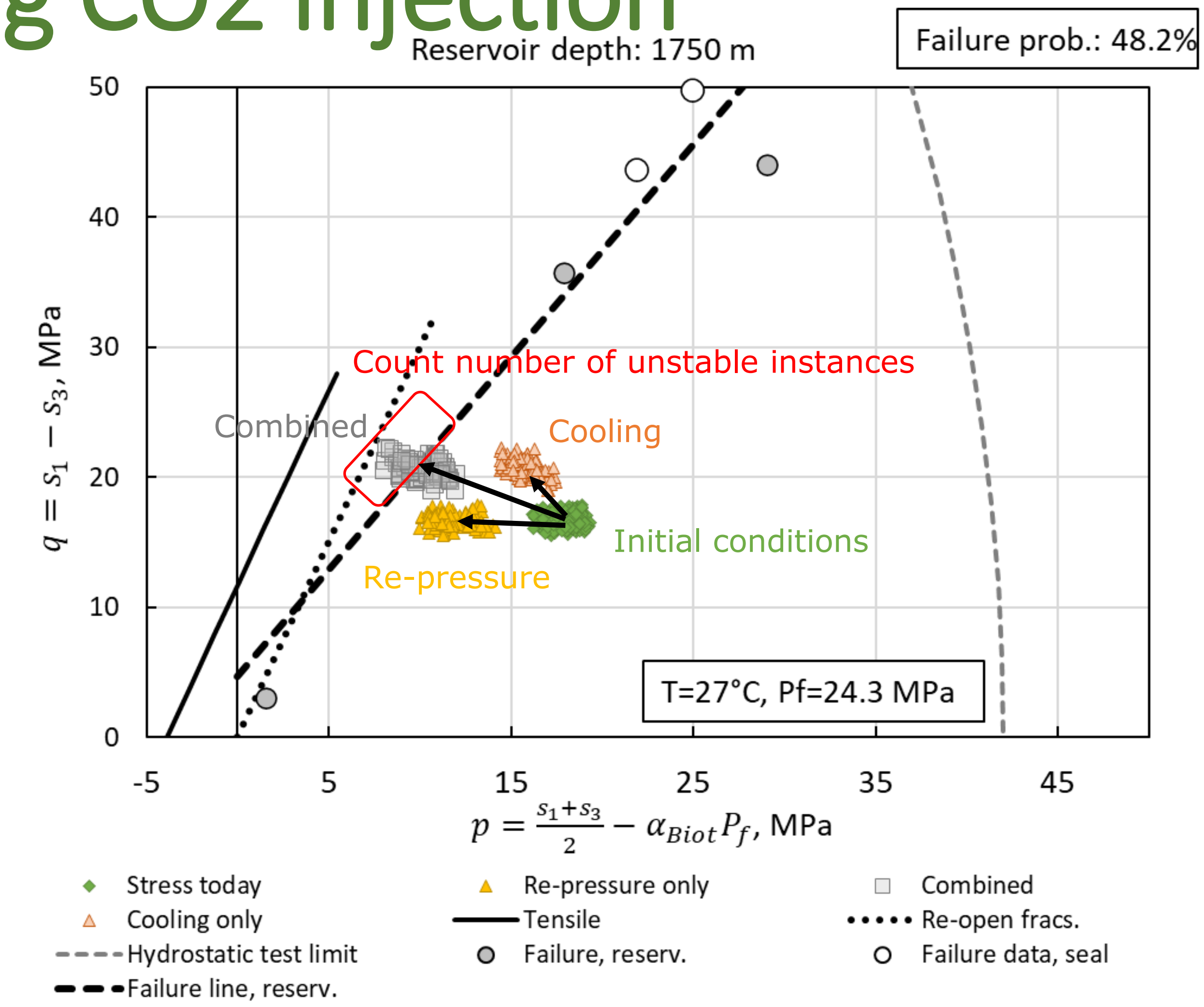
- Purpose: to identify the safe operation window to ensure mechanical stability (At what reservoir P and T will the reservoir or cap rock fail? At what probability?)
- Experimental program: is based on combined use of the strength failure envelope (from tensile, triaxial and unconfined compressive strength tests) and the estimated field stresses.
- Results: Sealing rocks stronger than reservoir rocks. If properly monitored, then rock failure can be predicted and actions can be taken to avoid propagation into overburden, stronger rocks.



Geomechanics – determining the safe operation window during CO2 injection

During CO2 injection the pore pressure and temperature are the only operationally controllable parameter. We use:

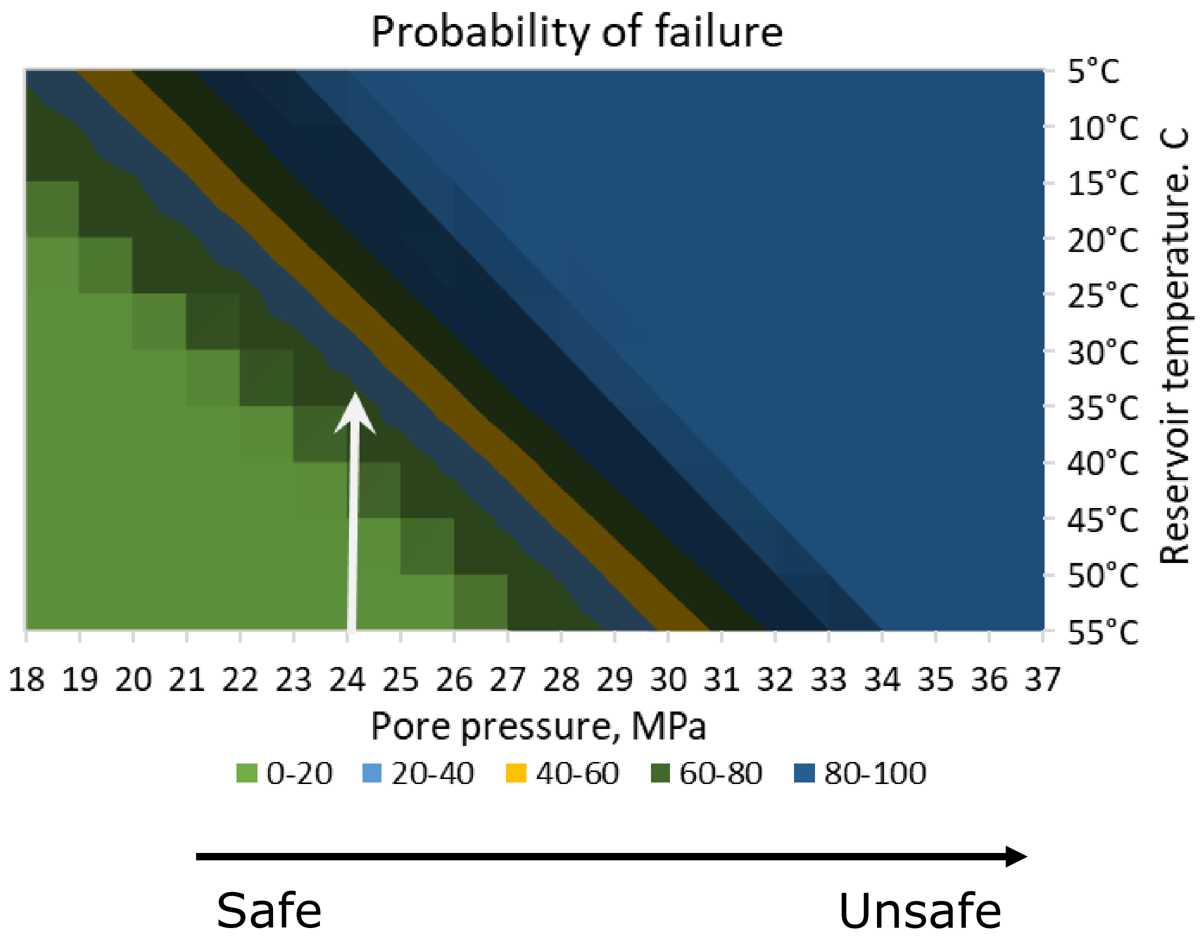
- Uncertain input parameters → Range of attainable stresses (i.e. a cloud of data)
- **Increased pressure** reduces the mean effective stress → shifts stress level to the left (yellow)
- **Cooling** by ΔT at constant overburden weight and uniaxial strain reduce s_3 → Shifts the stress level in NW direction (orange)
- **Cooling and re-pressurization combined** pushes cloud of stresses towards failure line (grey)
- Count the number of instances that exceed the experimentally determined failure line → probability of failure



Geomechanics – Probability of failure as function of pore pressure and reservoir temperature – Monte Carlo simulation

2 000 realizations of possible field stresses, initial pore pressures, Biot coefficient, and thermo-elastic coupling coefficient for each pore pressure and temperature varied

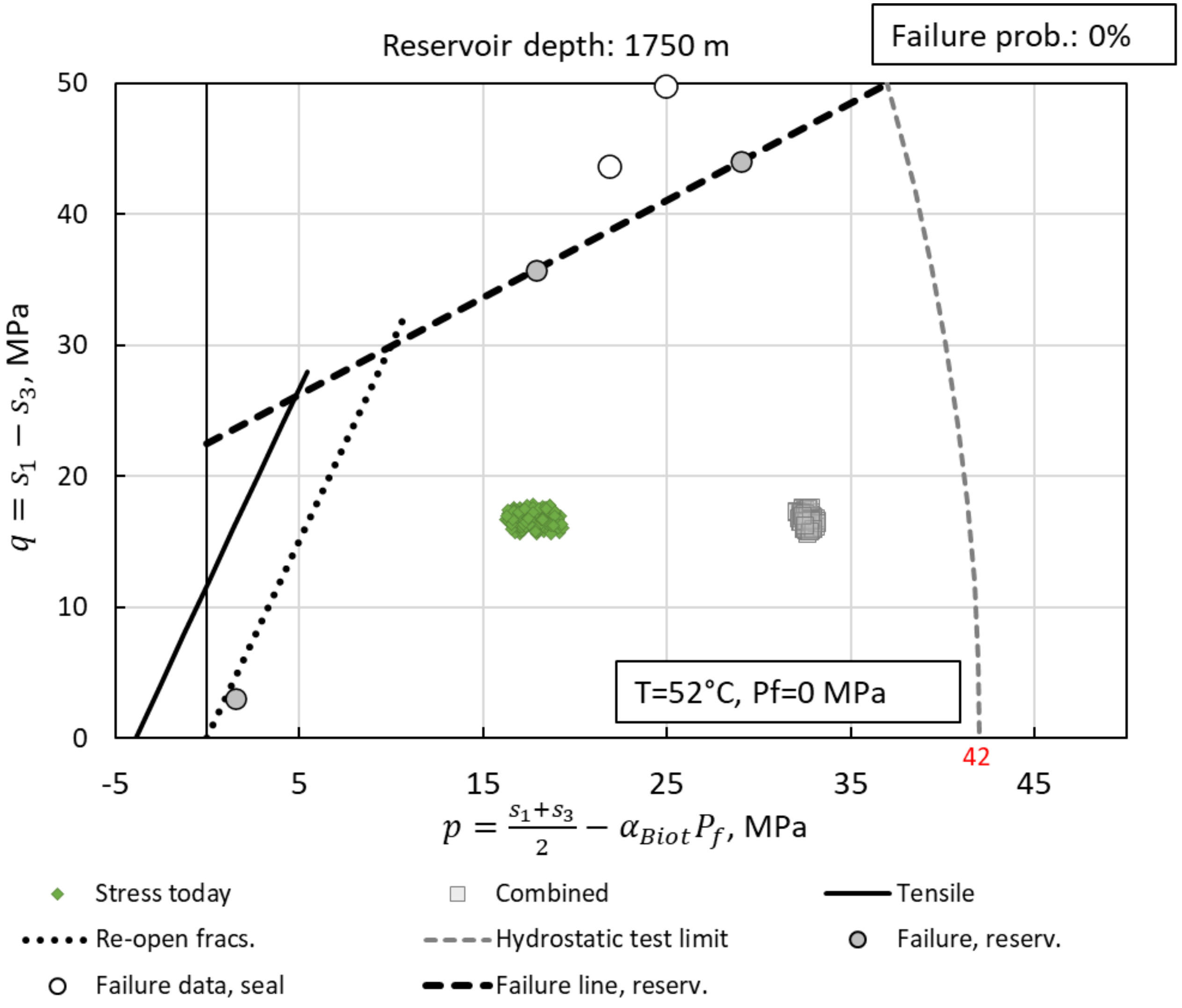
- Drawn from probability density functions measured in lab.
- Determine number of unstable instances for each pressure and temperature (between 17.2 and 36 MPa and 52 to 10°C)
- Safe injection envelope (green zone) can be identified



Geomechanics – Depletion limit

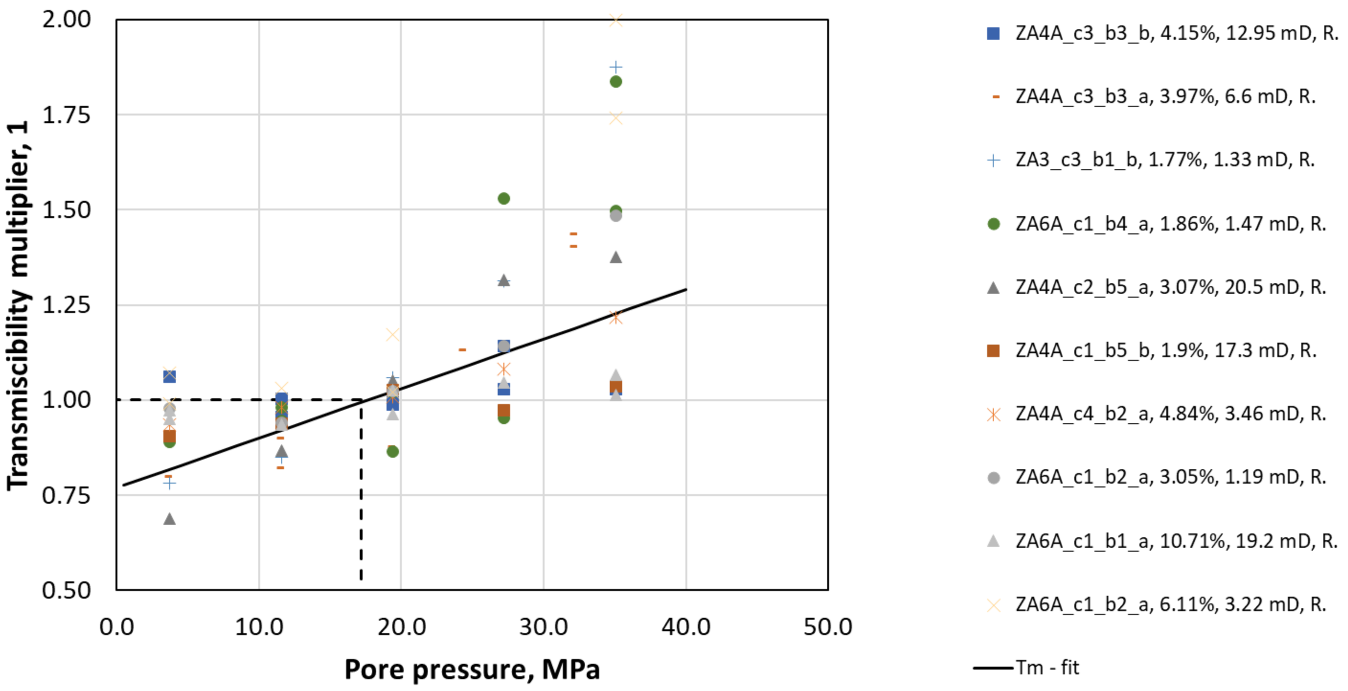
A plot of theoretical depletion down to 0 MPa shows that the cloud of data remains inside the compaction failure curve

The geomechanical compaction strength (grey dashed line to the right) of the cores tested seem to withstand the effective stress increase related to drawdown to 0 MPa as the cloud if data is well within the safe operation window.

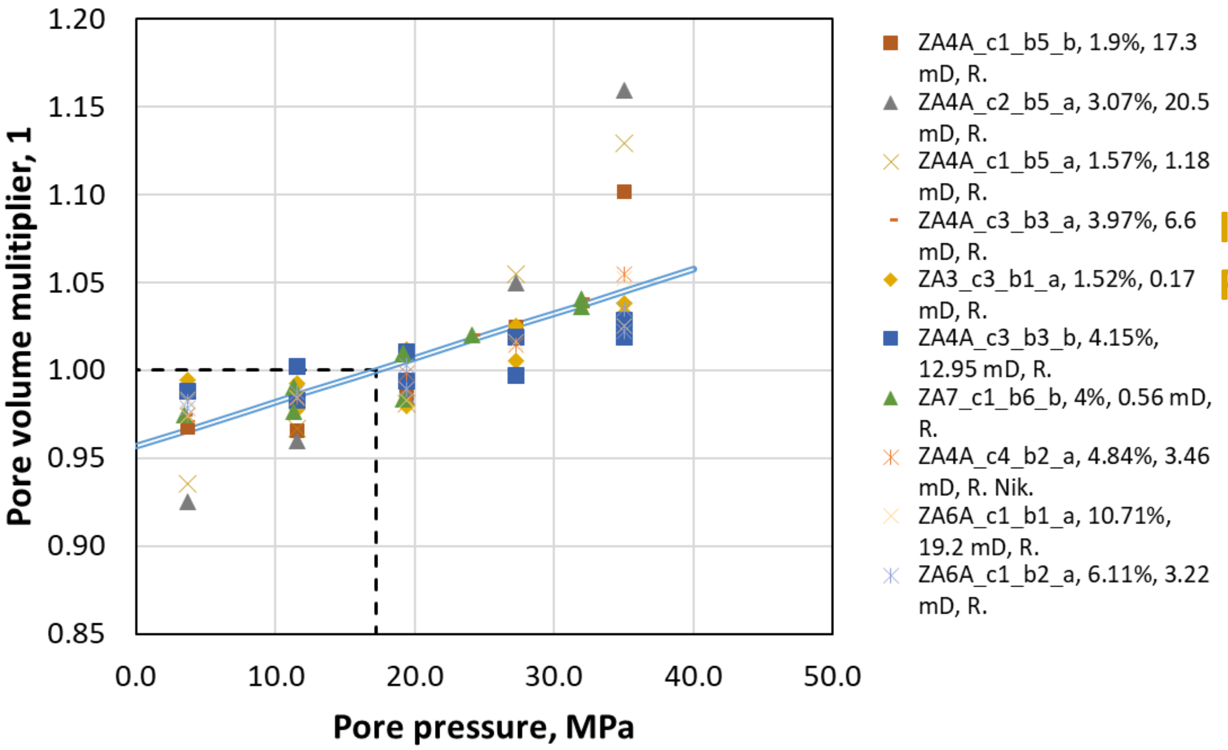


Geomechanics – Transmissibility multiplier

- Measure permeability and porosity during confining pressure cycle.
- Convert to pore pressure variation using the effective stress relation (x-axis)
- Re-scale by permeability at an equivalent pore pressure of 17.2 MPa
- Enables transmiscibility multiplier → relative changes in permeability as pore pressure is changed.
- Plot display spread in data for 10 reservoir cores.
- Next slide: Pore volume rescaled by the pore pressure at 17.2 MPa equivalent pore pressure → pore volume multiplier



Geomechanics – Pore Volume multiplier



Input into Eclipse ROCTAB keyword

```
ROCKTAB                                    -- Generated : Petrel
              10          0.9592          0.7831
              20          0.9617          0.7961
              30          0.9642          0.8091
              40          0.9667          0.8221
              50          0.9692          0.8351
              60          0.9717          0.8481
              70          0.9742          0.8611
              80          0.9767          0.8741
              90          0.9792          0.8871
             100          0.9817          0.9001
             110          0.9842          0.9131
             120          0.9867          0.9261
             130          0.9892          0.9391
             140          0.9917          0.9521
             150          0.9942          0.9651
             160          0.9967          0.9781
             170          0.9992          0.9911
             180          1.0017          1.0041
             190          1.0042          1.0171
             200          1.0067          1.0301
             210          1.0092          1.0431
             220          1.0117          1.0561
             230          1.0142          1.0691
             240          1.0167          1.0821
             250          1.0192          1.0951
             260          1.0217          1.1081
             270          1.0242          1.1211
             280          1.0267          1.1341
             290          1.0292          1.1471
             300          1.0317          1.1601
             310          1.0342          1.1731
             320          1.0367          1.1861
             330          1.0392          1.1991
 /
```

Geochemistry – Experiments in React chamber

RESULTS OF WATER SAMPLES

DEVELOPMENT OF THE COMPOSITION OF THE INPUT BRINE AFTER INTERACTION WITH THE ROCK AND CO_2 SATURATION

parameter	pH	ρ při 15 °C	vodivost	SO4-2	Cl-	HCO3-	NH4+	K	Mg	Na	Ca	Li	Sr	Mn	Fe
units	[-]	[g/cm3]	[mS/cm]	[mg/l]											
MND analysis	7.0715	1,017	36,5	535	12300	2580	32,6	252	107,0	8570	111	3,17	19,2	0,01	0,35
1st month analysis	6.716	1,016	36,9	640	13251	2702	9,1	257	99,6	4570	285	2,75	17	0,88	0,01
3rd months analysis	6.896	1,016	35,3	660	12728	3440	15,8	256	99,3	6260	315	2,88	13,6	1,08	95
4th months analysis	7.220	1,016	37,2	550	13047	3226	19,4	463	94,8	8750	348	2,78	16,3	0,731	18,9
6th months analysis	6.813	1,018	38,0	540	12444	3660	19,1	334	92,7	6770	702	2,72	13,4	0,421	60,8

legend:

decrease values

increase values

fluctuating values

X stagnant values

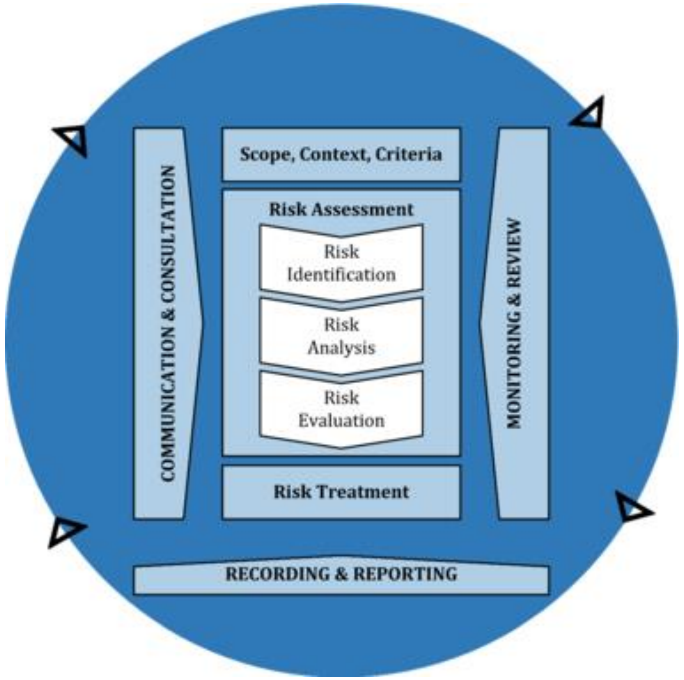
Gechemistry – Results from React chamber and modelling

- Dissolution of primary dolomite and precipitation of calcite during the first month of experiment (6 months experiment)

- Precipitation of secondary phases (kaolinite, muscovite, feldspar) reduces porosity and permeability depending on the distance from the injector, time, and dissolved CO2 concentration.

CO2-SPICER: Risk assessment process

- Risk assessment process is performed for the area of interest including the Zar-3 field in accordance with ISO31000:2018 and EU CCS Directive 2009/31/EC. Three main parts:
  - **Risk identification**
  - **Risk analysis**
  - **Risk evaluation**

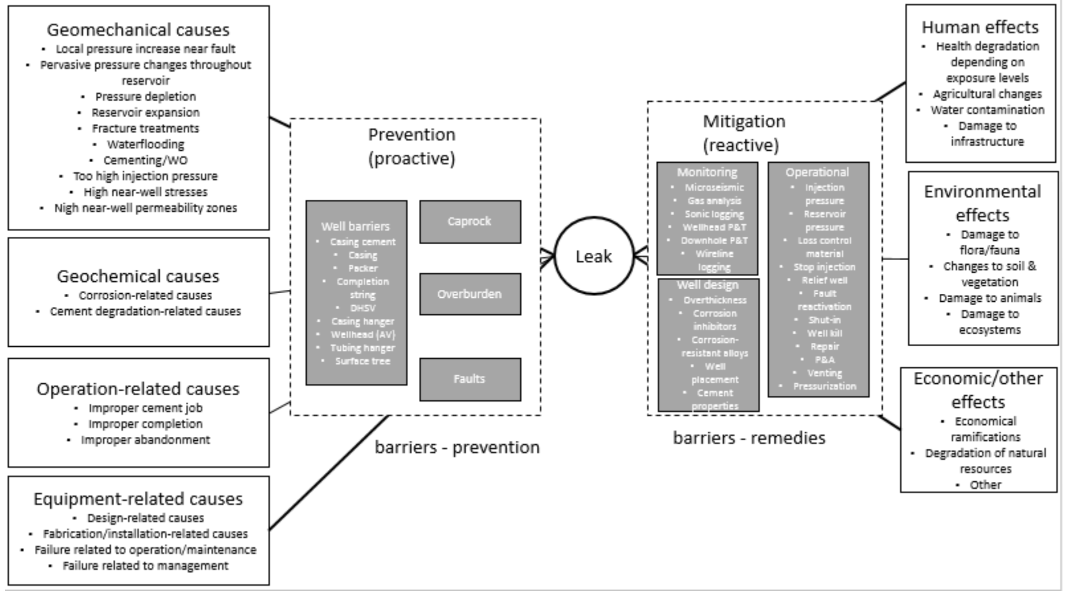


ISO31000:2018

Risk identification

Category	Considered items
Risk sources	Sabotage/intentional threats Injection pressure/temperature/volume CO2 impurities Wellbore design/barrier weaknesses Displaced hydrocarbons/metals/other Caprock weaknesses/limitations Faults/fractures (existing or induced)
Leakage causes	Well: Cement plug defects (cracks/microannuli) Well: Annular cement defects (cracks/microannuli) Caprock: Geomechanical degradation due to cooling/re-pressurization Caprock: Existing defects Fault/fracture: reactivation due to pressure Spill point: Exceeding storage capacity
Preventive barriers	Wellbore seals (plugs, annular cement, other) Casings Caprock/Overburden Sealing faults
Mitigating barriers (measures)	Seismic data monitoring Soil gas analysis Pressure/temperature adjustments Injection rate adjustments Relocation of injection wells Monitoring wells Re-abandonment
Consequences (possible targets at risk)	Humans in proximity Residential areas Industrial areas Infrastructure Soils/sediments Flora/fauna (plants, animals) Surface water Groundwater Atmosphere
Considerations/Concerns	Uncertainties Available information Timescale of leakage Stakeholders Regulations (current and future) Changes in land use Meteorology

Features/Events/Processes (FEP) analysis



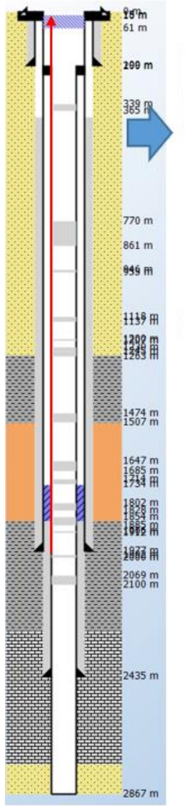
Bow-tie diagram

- **Leakage from abandoned wellbores**
- **Leakage through caprock**
- **Leakage through faults/fractures**
- **Leakage from spill point**

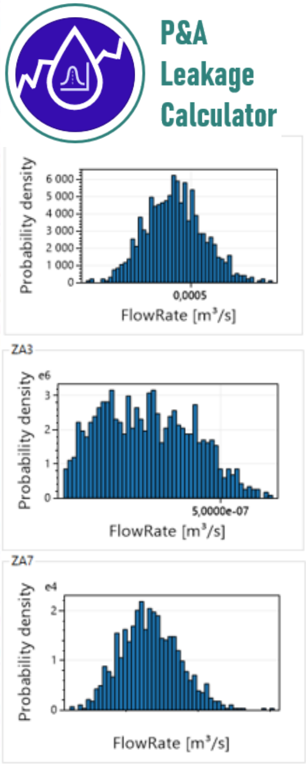
Main risks

Risk analysis

CO_2 leakage simulations from abandoned wellbores using a stochastic framework and well-specific data. Local metereological data used to simulate **CO_2 dispersion** from release points

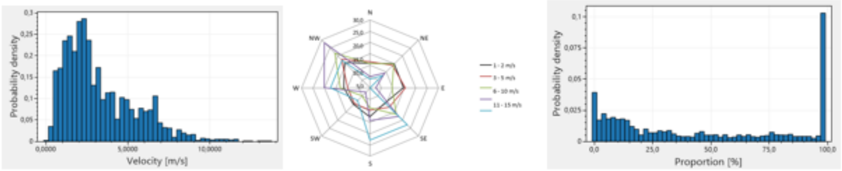

Likely leak path by breaching well barriers


Wellbore locations

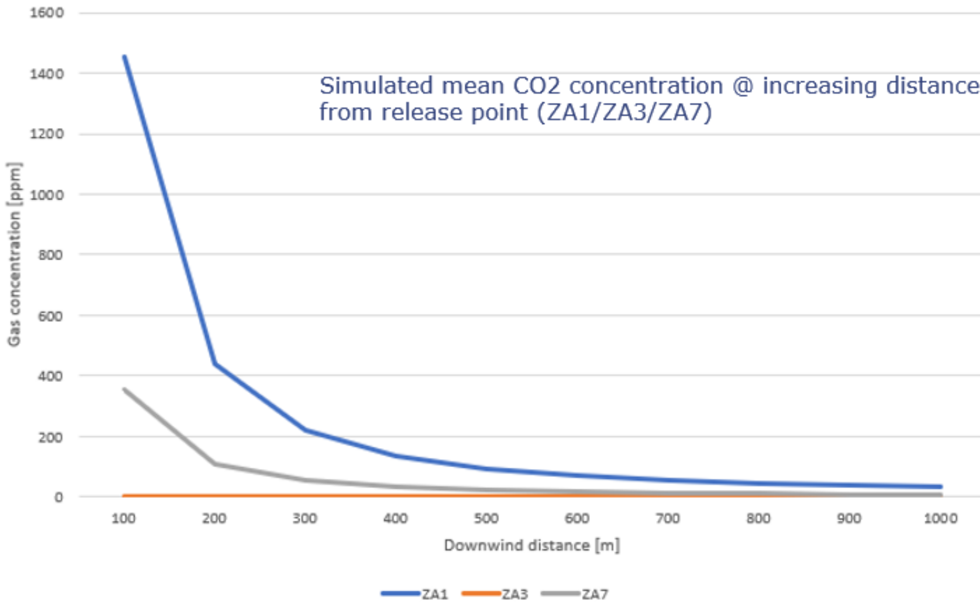


CO2 leakage rate simulations per well

Local metereological data



CO2 concentration vs downwind distance: ZA1 v ZA3 v ZA7

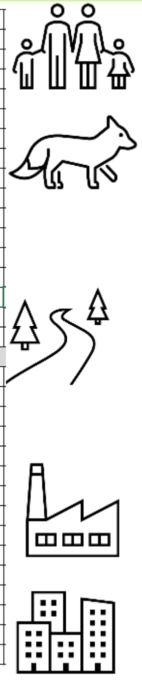


CO2-SPICER: Risk evaluation

- Ongoing: CO2 dispersion simulations will in turn be used as a basis for determining possible consequences for risk receptors, and as a basis for evaluating acceptable risk.

CO2 release scenarios: Examples only!

Humans	Site operators
	Humans in immediate surrounding area
Animals	Species in ONM
	Thermophilous insect species
	Grey Wolf
	Eurasian lynx
	Brown bear
	Elk
Vegetation	Bee orchid
	Military orchid
	White helleborine
	Fragrant orchid
	Star gentian
	Narrow-lipped helleborine
	Hairy flax
	Alcon blue
Protected nature/landscape	Ochozy Natural Monument (ONM)
Surface water	Nový pond
	Klášov Pond
	Panské Ponds
	Horní and Dolní Dražůvky ponds
	Balaton Pond
	Northern slopes of the Ždánický les Highland?
Infrastructure	Roads (I/54, II/431, II/419, II/381, class III/local roads)
	Main/local water supply
	Private water wells
	Wastewater treatment plant
	Klobouky-Loukov gasoline pipeline (300 m protection zone)
	V280 Sokolnice–Senica cross-border high voltage power line to Slovakia (220 kV)
	Domestic power line (110 kV) (both 15m protection zone)
Residential area	Zarosice (pop. 1100)
	Archlebov (~900)



Site-specific risk receptors

Input for evaluation

Impact →

Likelihood ↑	Negligible	Minor	Moderate	Significant	Severe
Very Likely	Low	Moderate	High	High	High
Likely	Low	Moderate	Moderate	High	High
Possible	Low	Low	Moderate	Moderate	High
Unlikely	Low	Low	Moderate	Moderate	Moderate
Very Unlikely	Low	Low	Low	Moderate	Moderate

Risk evaluation matrix

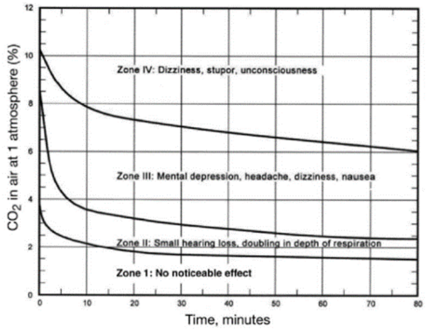


Fig. 7.1 Exposure of CO_2 concentrations to humans (Flemming et. al., 1997; IPCC 2005)

CO2 threshold levels

Monitoring

Base line – before CO2 injection

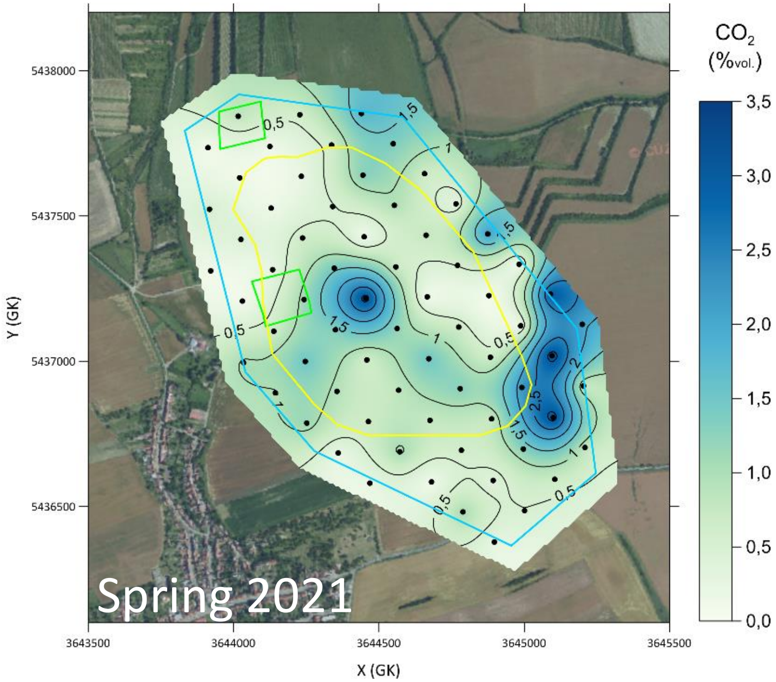
- Atmogeochemical monitoring
- Shallow groundwater monitoring
- Seismic monitoring

Feasibility study on applicability of seismic methods for CO_2 plume monitoring - ongoing

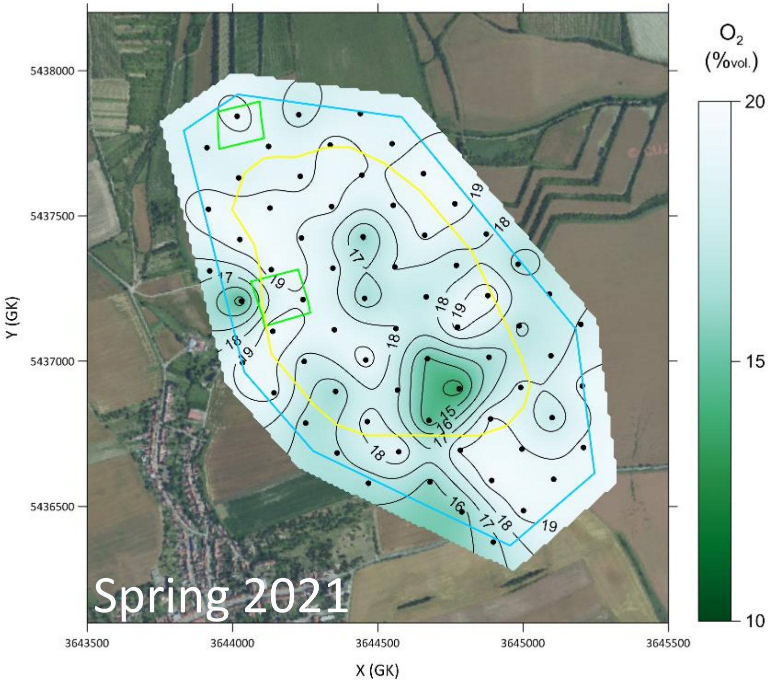
Baseline soil gas monitoring

- Main aim: to establish a soil gas baseline

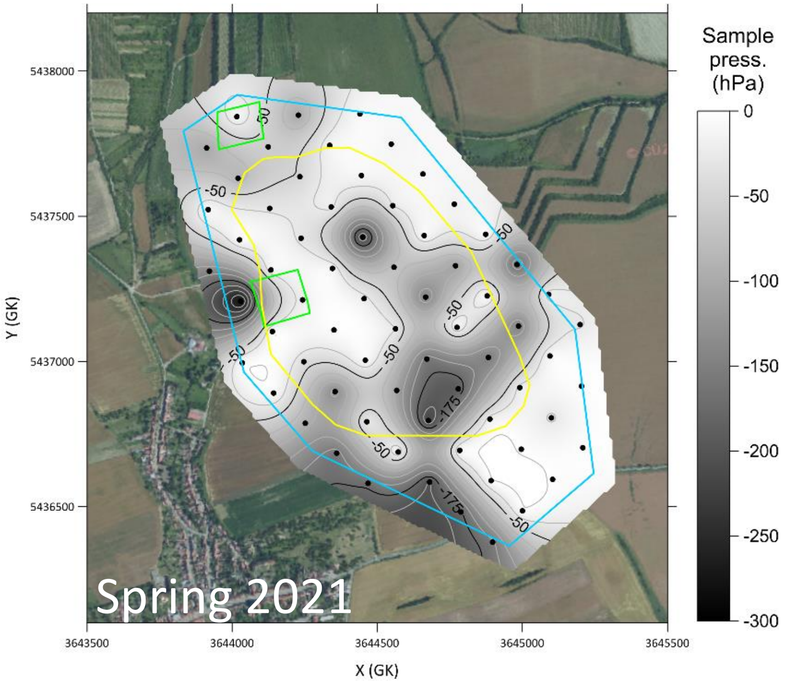
  to improve the storage site monitoring plan
- Periodical (3x/year) – CO_2, CH_4, TP, O_2 + permeability; Ecoprobe-5
- Continuous (every hour) – CO_2 using 5 permanent probes



Soil CO_2 ($\%_{vol.}$)



Soil O_2 ($\%_{vol.}$)

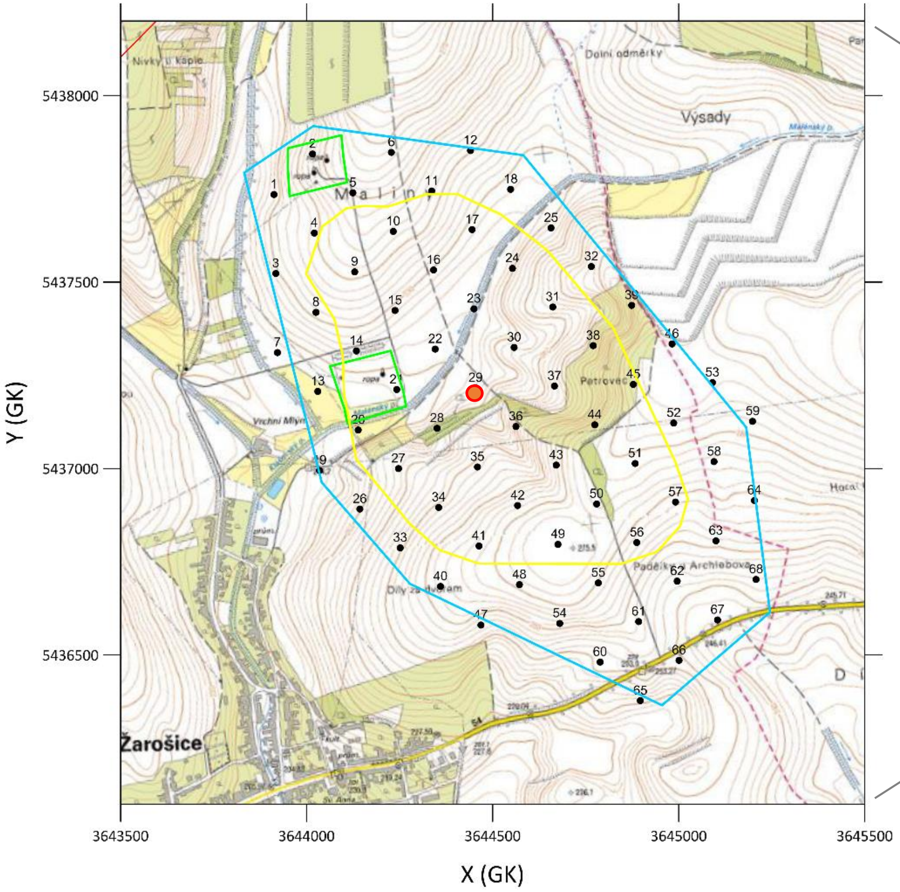


Sampling pressure (hPa)

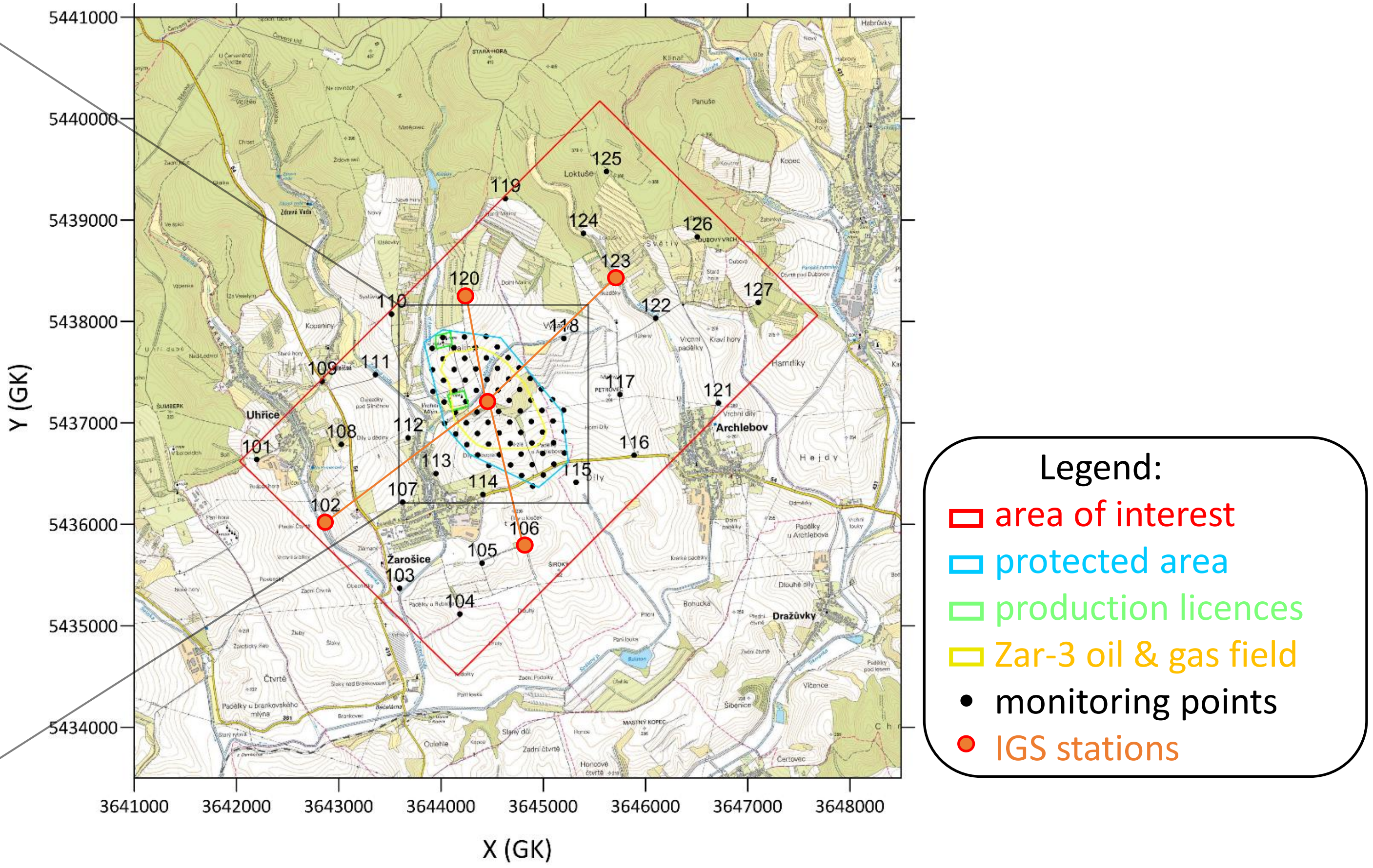
Baseline soil gas monitoring

- Grids: 68 + 27 points for periodical monitoring

  5 probes for continuous monitoring

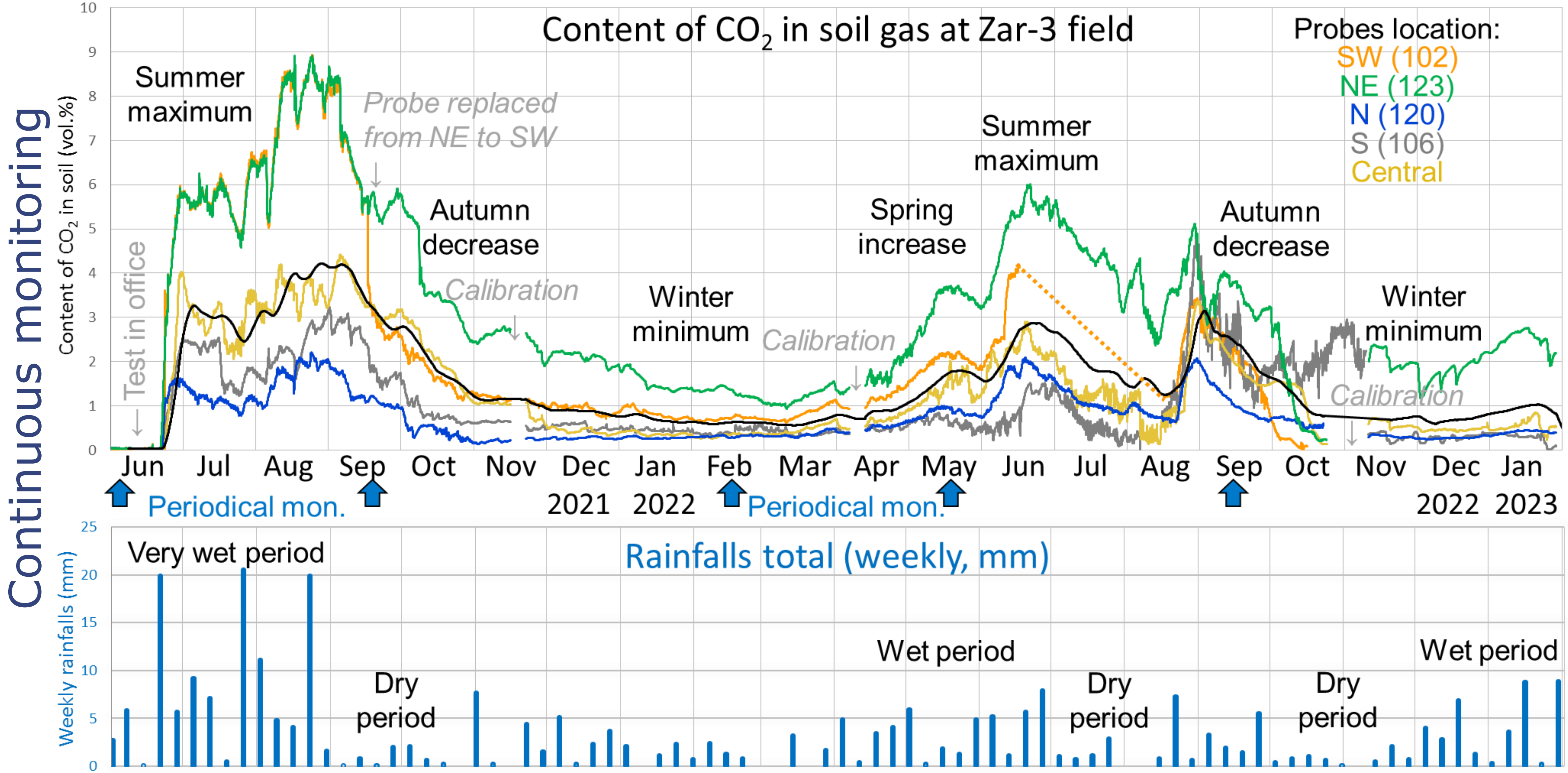


Smaller grid – 68 points above the field



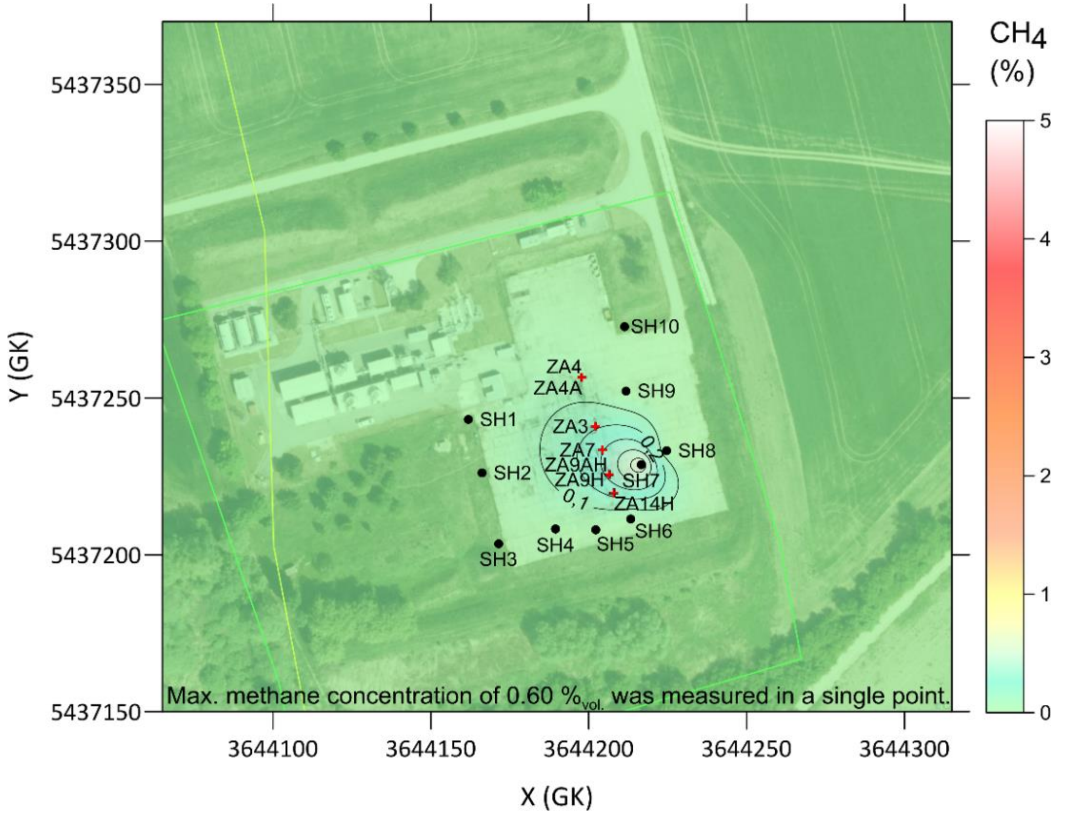
Larger grid – 27 points in wider area

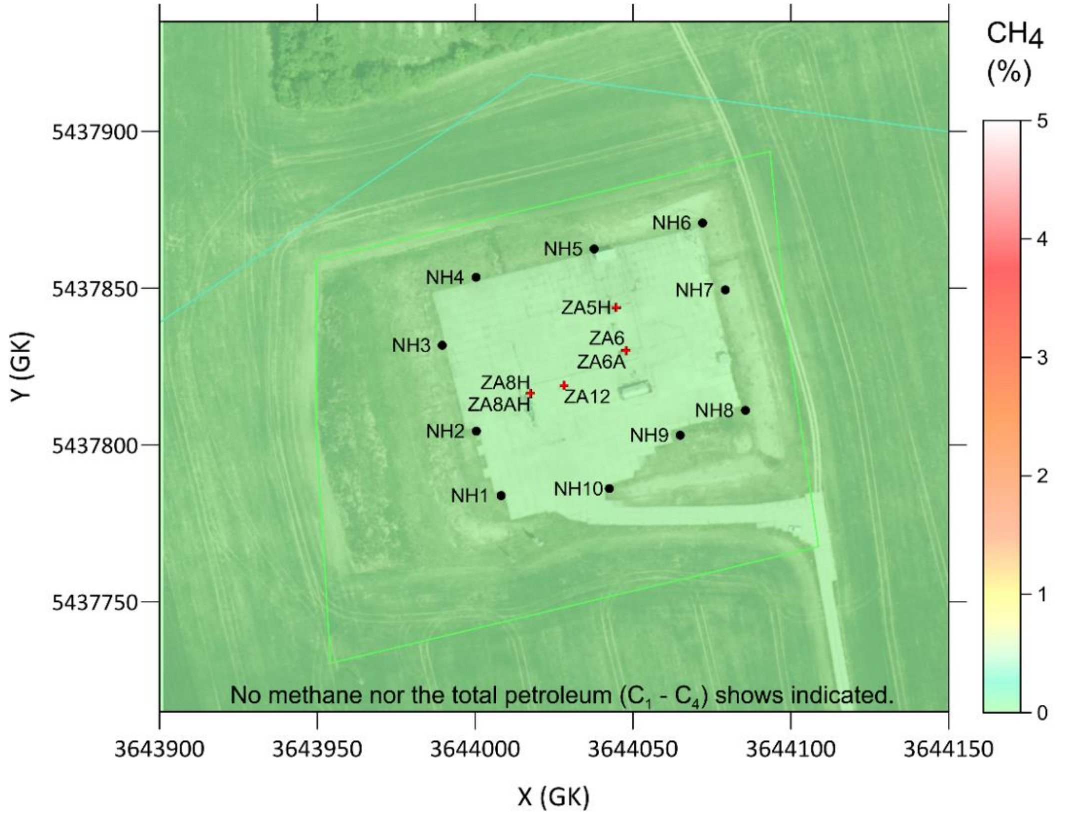
Baseline soil gas monitoring - results



Monitoring of existing boreholes

- To evaluate the potential leakage pathways via existing wells
- The boreholes in operation above the field are regarded as tight with no CH4 leakage indications based on the risk soil gas monitoring





Soil gas monitoring - Conclusions

Baseline soil gas monitoring

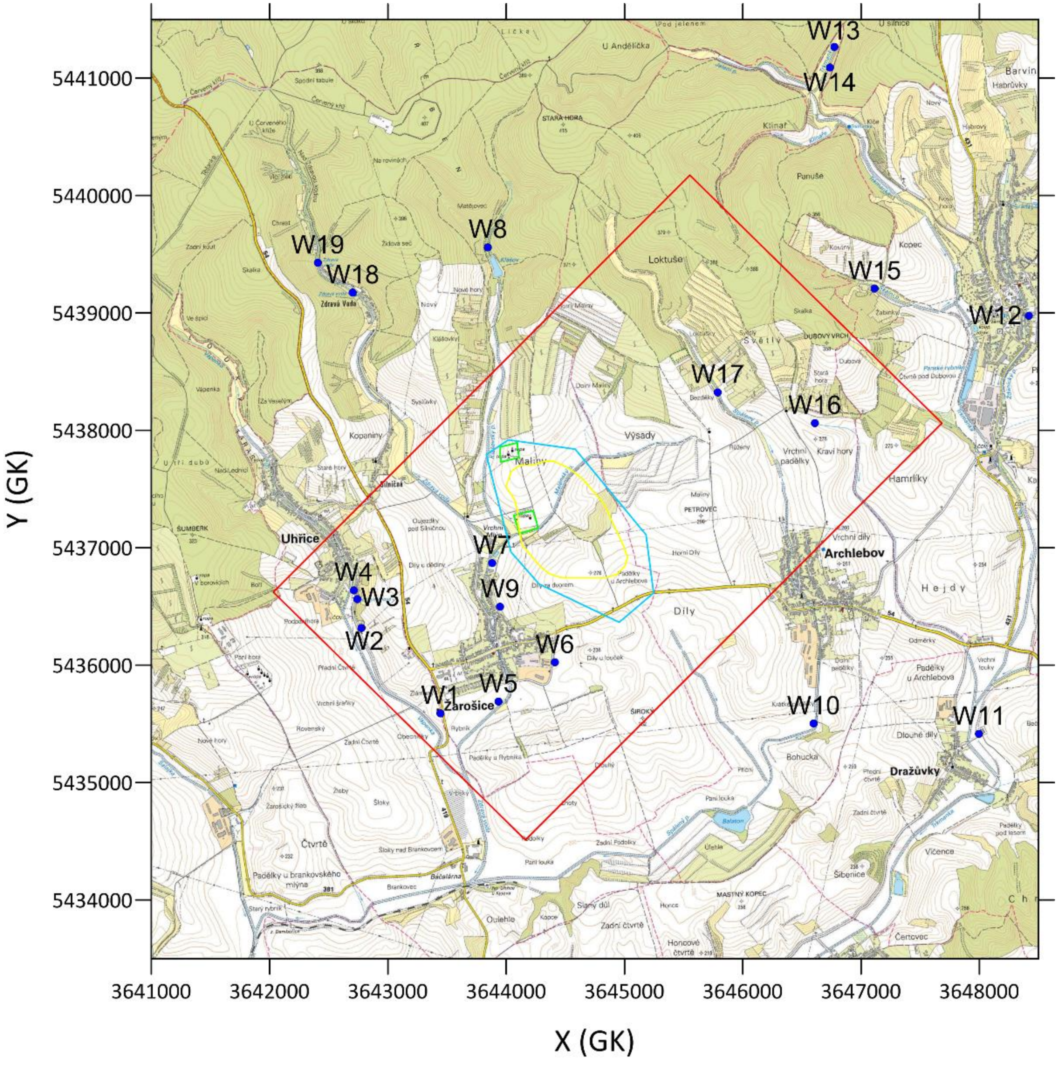
- Strong soil gas compositional **variability** provides evidence of influence by temperature (season of year), biological activity and soil wetness
- Land-use factors: the grasslands and forests show more stable soil gas composition when compared to cultivated fields.

Risk monitoring

- The boreholes in operation above the field are regarded as tight with **no CH_4 leakage** indications

Shallow groundwater monitoring

- Essential for understanding the shallow GW regime and establishing a baseline
- 16 sites periodically monitored each season of the year
- Monitored parameters:
  water table level (m), temperature (°C), conductivity (µS/cm), pH (-)
  + spring yeld ($l*s^{-1}$)



Shallow groundwater monitoring objects

Shallow groundwater monitoring

Examples of monitoring objects

Spring

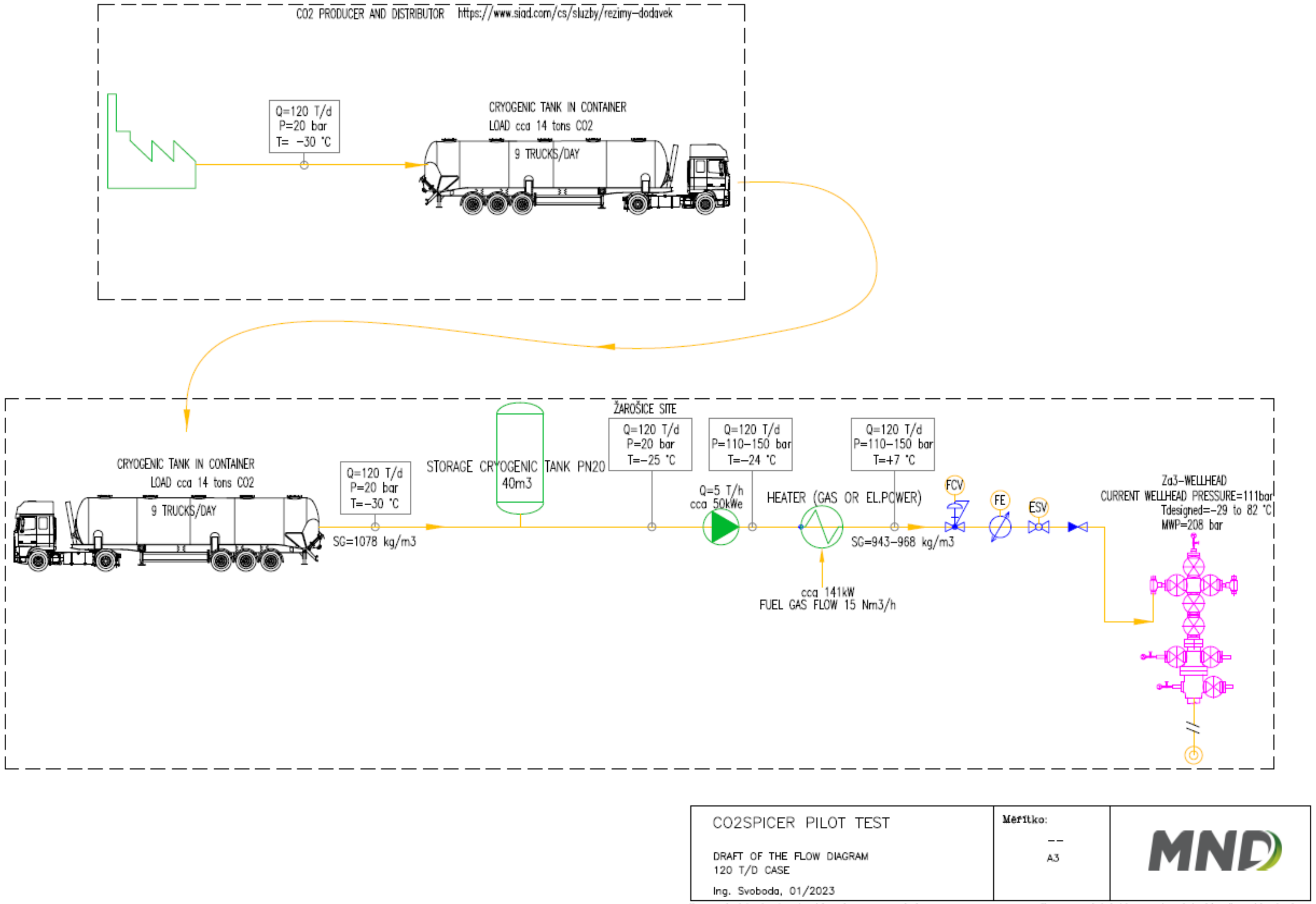
Shallow borehole

Water pump

Pilot CO2 injection

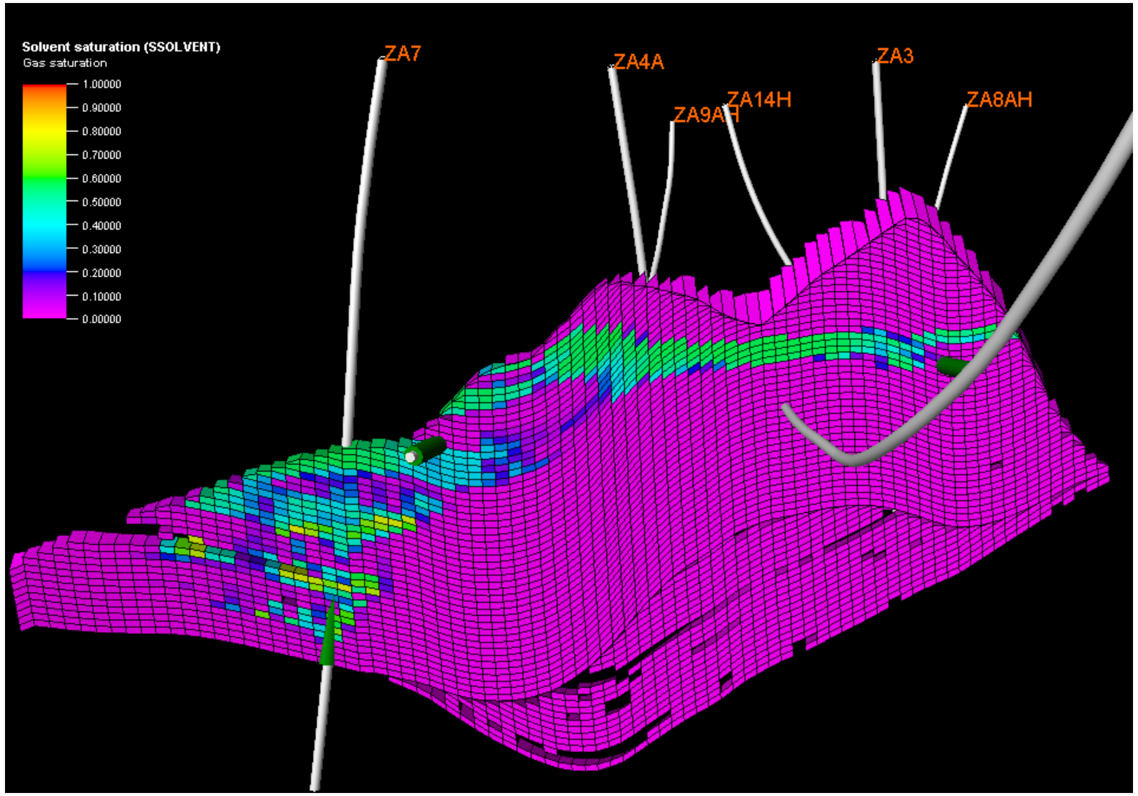
- Legislation allows maximum injection of 100,000 tons of CO2 **during pilot**.

- 2 main cases are being considered:
  1. Trucking liquified CO2
  2. Separating CO2 from the flue gas available directly at the Zar-3 gathering centre

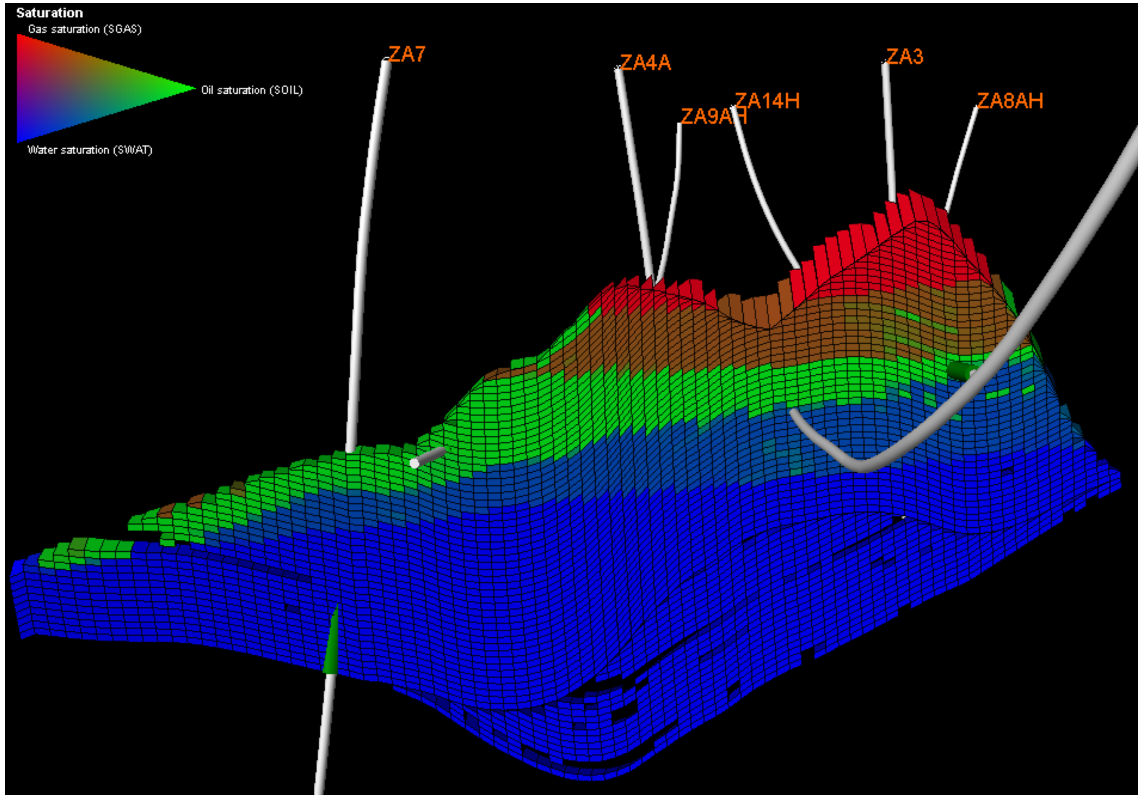


Pilot CO2 injection – Simulation results

CO2 saturation at the end of pilot



Reservoir fluids saturation at the beginning of pilot



Injection into water zone in Za7 well
120 t/d; 70,000 t cumulatively

Scenarios – Full-field Implementation

Several scenarios for full-field CO_2 storage (after the pilot) are under consideration:

- Basecase - storage after gas cap blowdown
- Alternative 1: Gas cap blowdown supported by CO_2 injection into water zone.
- Alternative 2: Blue hydrogen generation by burning gas from the gas cap and waste CO_2 injection into water zone
- Alternative 3: Classical EOR
- Alternative 4: Direct air capture

The CO2-SPICER project benefits from a € 2.32 mil. grant from Norway and Technology Agency of the Czech Republic.

PROJECT PARTNERS

CZECH GEOLOGICAL SURVEY

COORDINATOR

MND

VSB TECHNICAL UNIVERSITY OF OSTRAVA | FACULTY OF MINING AND GEOLOGY

INSTITUTE OF GEOPHYSICS OF THE CZECH ACADEMY OF SCIENCES

NORCE

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