# Safe and successful $CO_2$ injection operation and post-injection monitoring – closing the life cycle of the Ketzin pilot site

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# The Ketzin pilot site

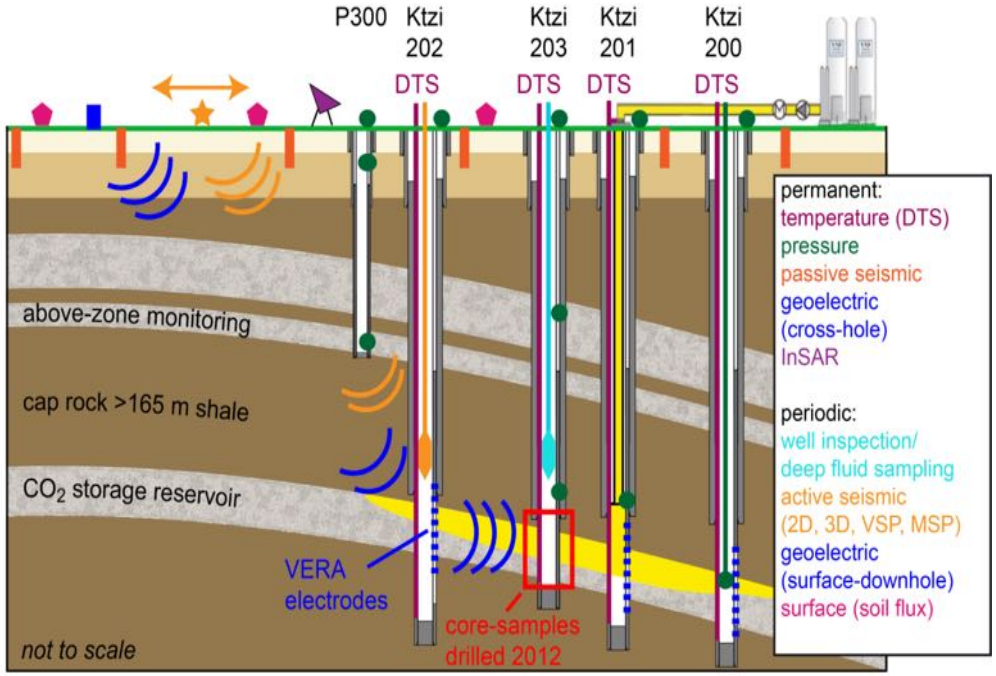
- only national on-shore $CO_2$ storage project
- as R&D site limited to maximum amount of 100 kt $CO_2$
- permitted under German Mining Law

Main objectives:

- Study complete life-cycle
- Show feasibility of on-shore $CO_2$ storage in saline aquifer
- Increase confidence in $CO_2$ storage

Main tasks:

- Successful site operation
- Monitoring & modelling
- Public outreach





**April 2004** Start project

**July 2007** Operation permit

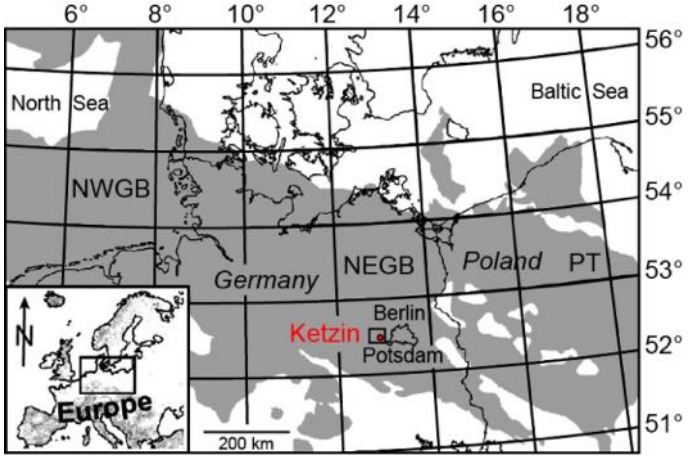
**June 2008** Start injection

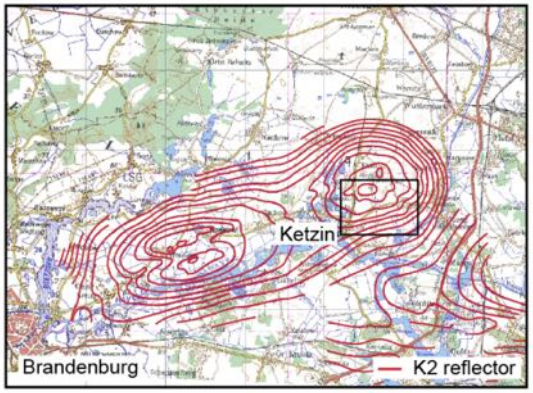
**August 2013** End injection

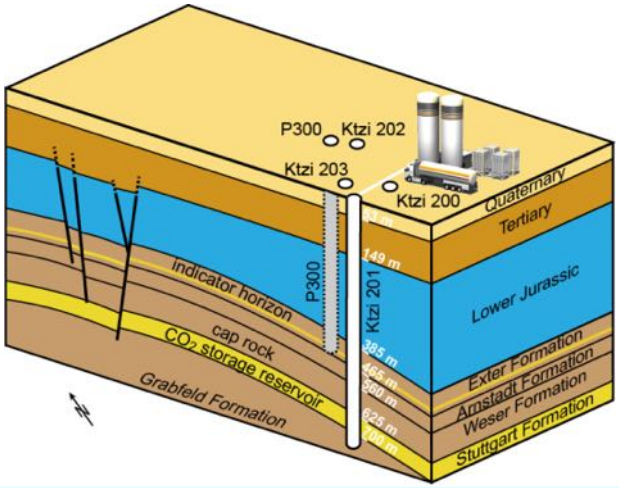
***December 2017*** *Transfer liability*

# Local geology of the Ketzin pilot site

- located in the North East German Basin - large Permo-Mesozoic sedimentary basin
- Ketzin-Roskow double anticline above salt pillow



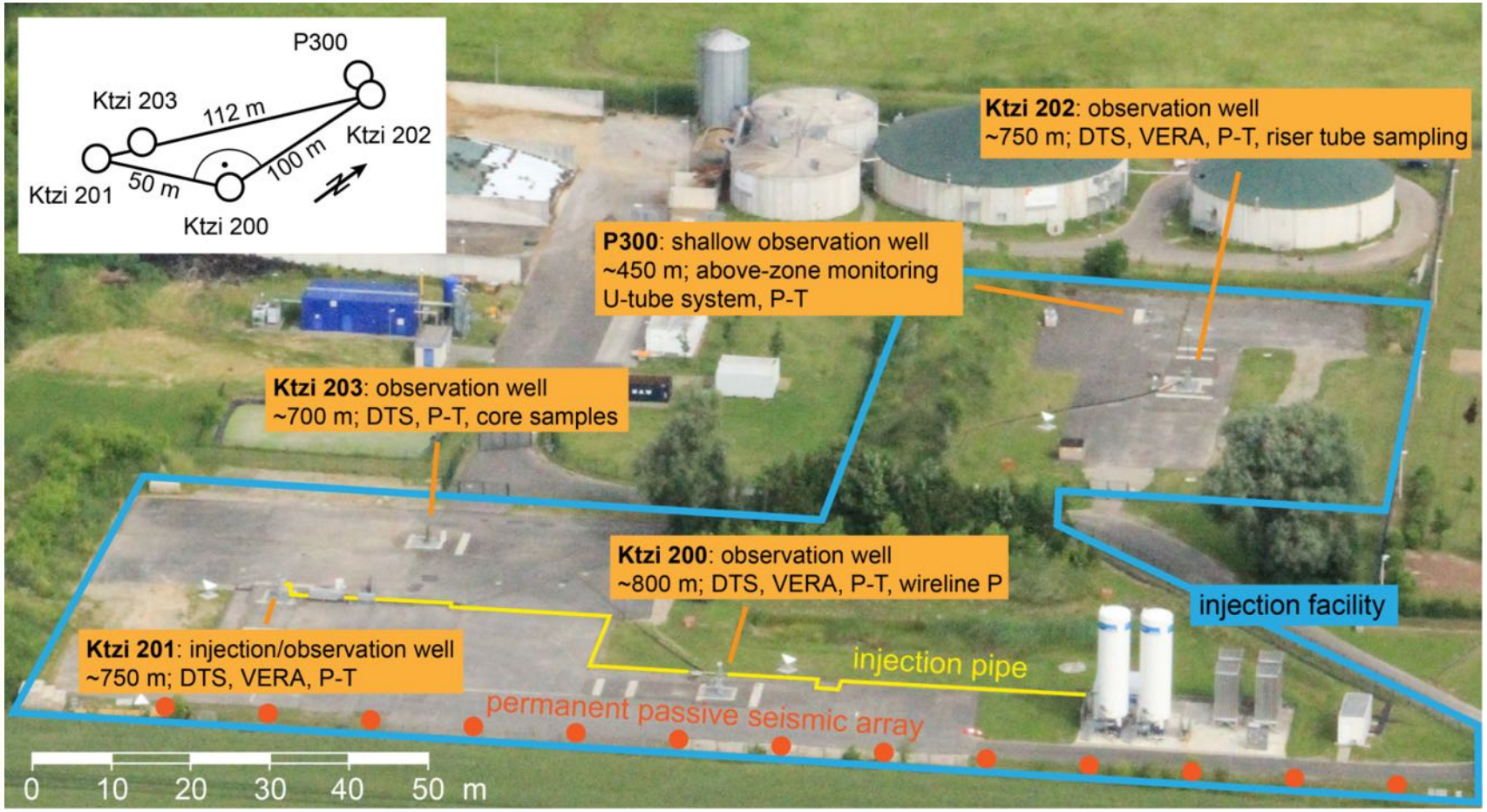

**cap-rock**:

- Upper Triassic shales, >165 m

**reservoir**:

- saline aquifer
- sandstones of Upper Triassic Stuttgart Formation
- fluvial system
- lateral and vertical heterogeneous
- 620 – 650 m depth

# Aerial view of Ketzin research infrastructure

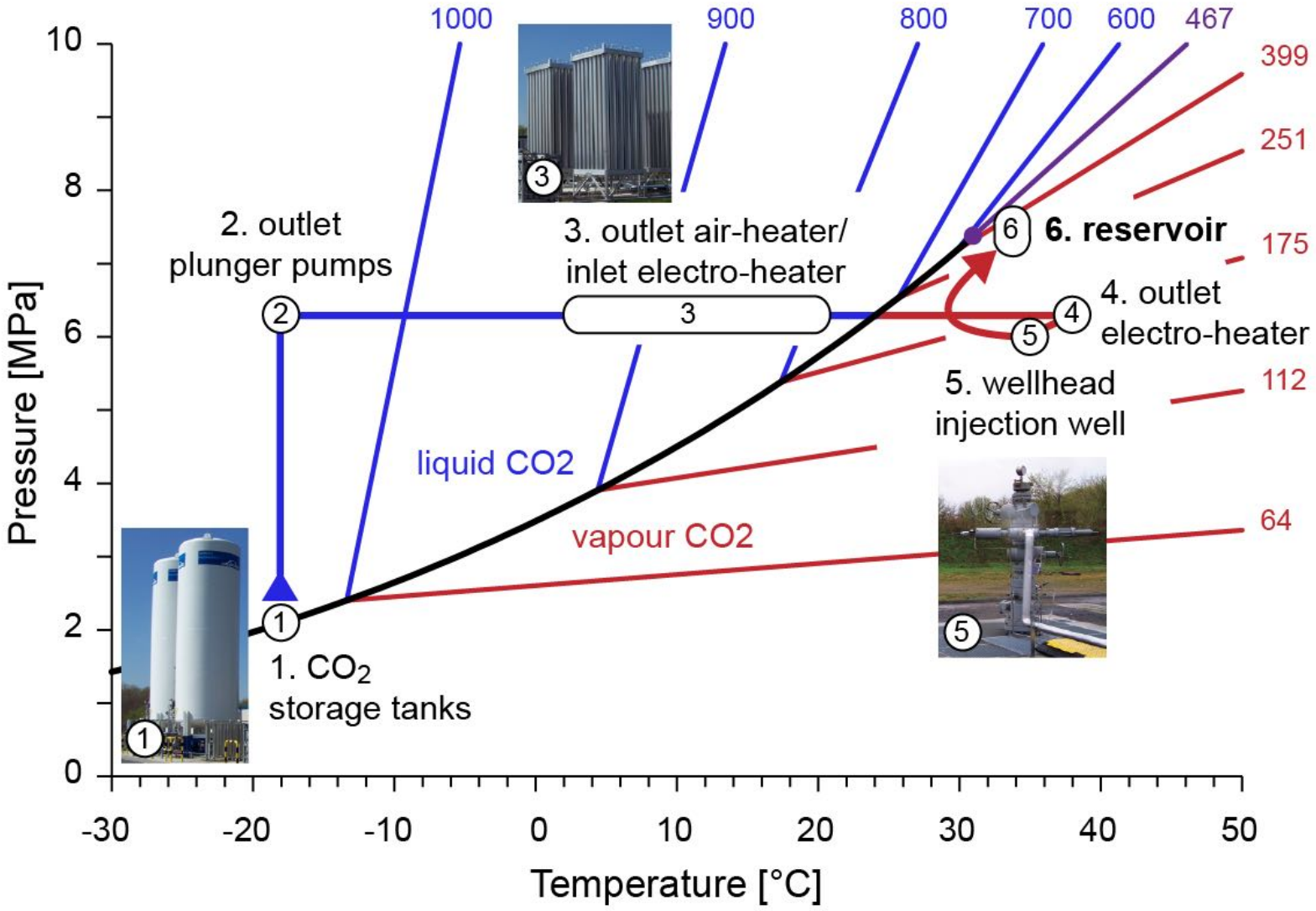



➔ unique, fully equipped research infrastructure for field experiments

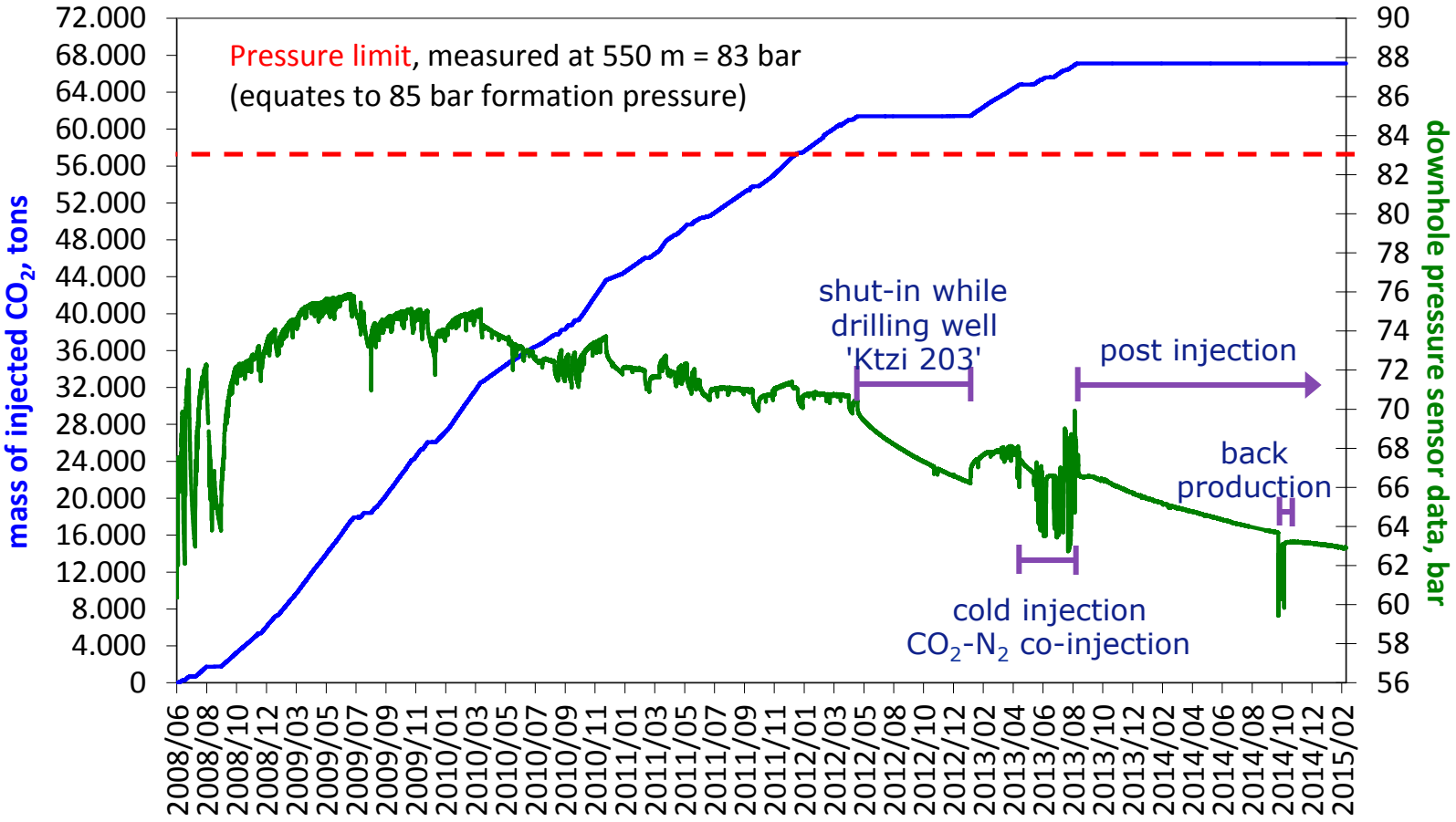
# The Ketzin storage site – Injection data

- Start of injection: June 30, 2008
- End of injection: August 29, 2013
  62 months of smooth, safe $CO_2$ injection
- **Total mass injected: 67 kt $CO_2$**
- ***$CO_2$ sources and quality***:
  - Food-grade $CO_2$ (Linde), > 99.9%
  - May to June, 2011: 1,515 t $CO_2$ from Schwarze Pumpe oxyfuel pilot plant (Vattenfall), > 99.7%
  - July to August, 2013: 645 t $CO_2$-$N_2$ (95/5) co-injection experiment
- ***Field experiments***:
  - March to June, 2013: "cold injection" experiment
  - October, 2014: "$CO_2$ back-production" in the frame of Carbon Capture Utilization and Storage


# Regular injection process at Ketzin



# Injection history at Ketzin



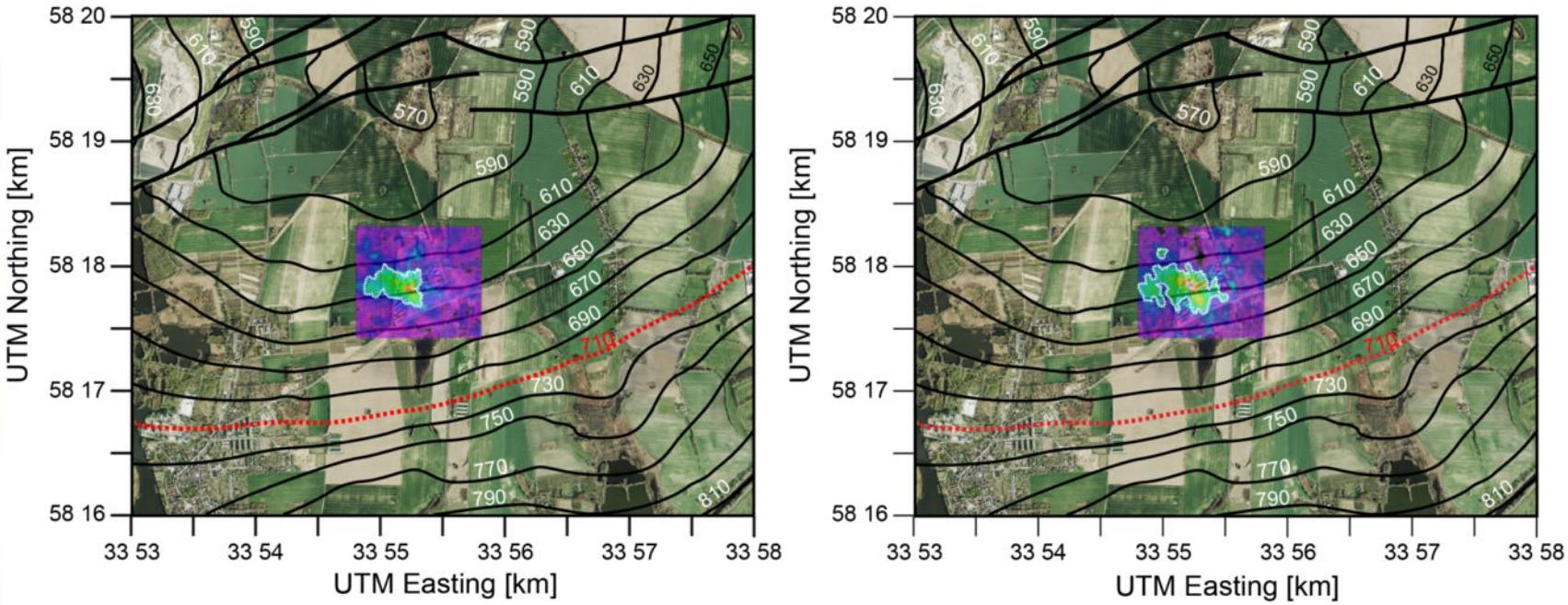

- smooth injection process, maximum P-increase ~16 bar
- no safety issues, P « pressure limit
- continuous P-decline after stop of injection

# Time-lapse amplitude changes image lateral extension of $CO_2$ plume

normalized time-lapse amplitude changes:

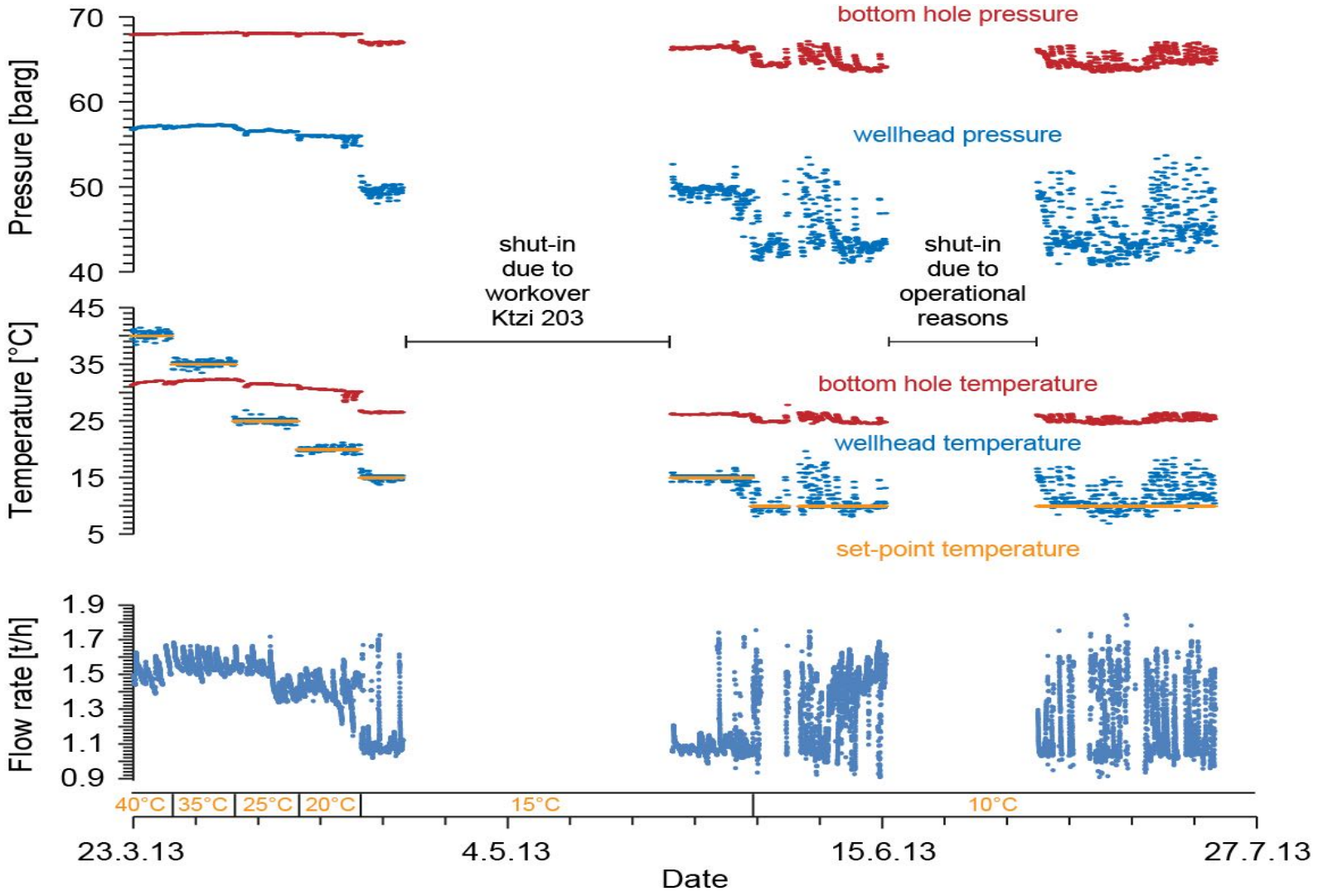
Baseline – 2009; 22 kt $CO_2$
**~ 0.08 km²**

Baseline – 2012; 61 kt $CO_2$
**~ 0.15 km²**




- $CO_2$ plume indicate preferred WNW – ESE extension
- centered @ injection site, far from spill-point and central fault zone
- post-injection repeat scheduled for autumn 2015

# „cold"-injection experiment
# - from single-phase to two-phase flow -



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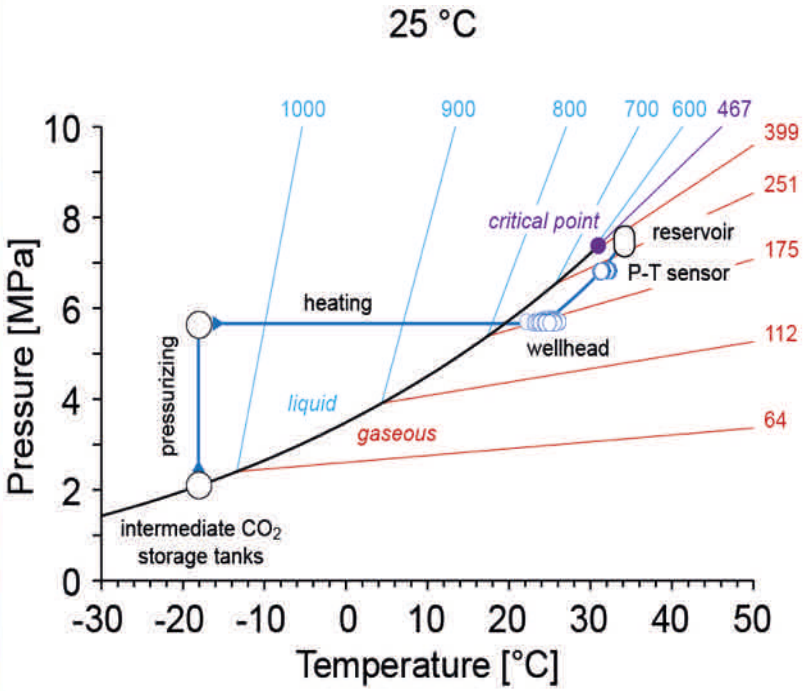
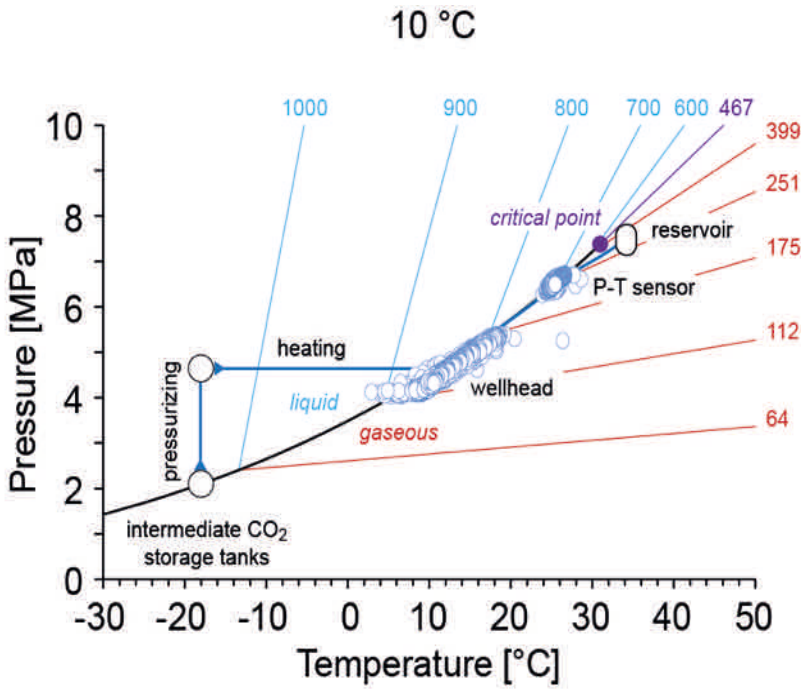



Decreased wellhead temperature
near l/v equilibrium
but still single phase gas

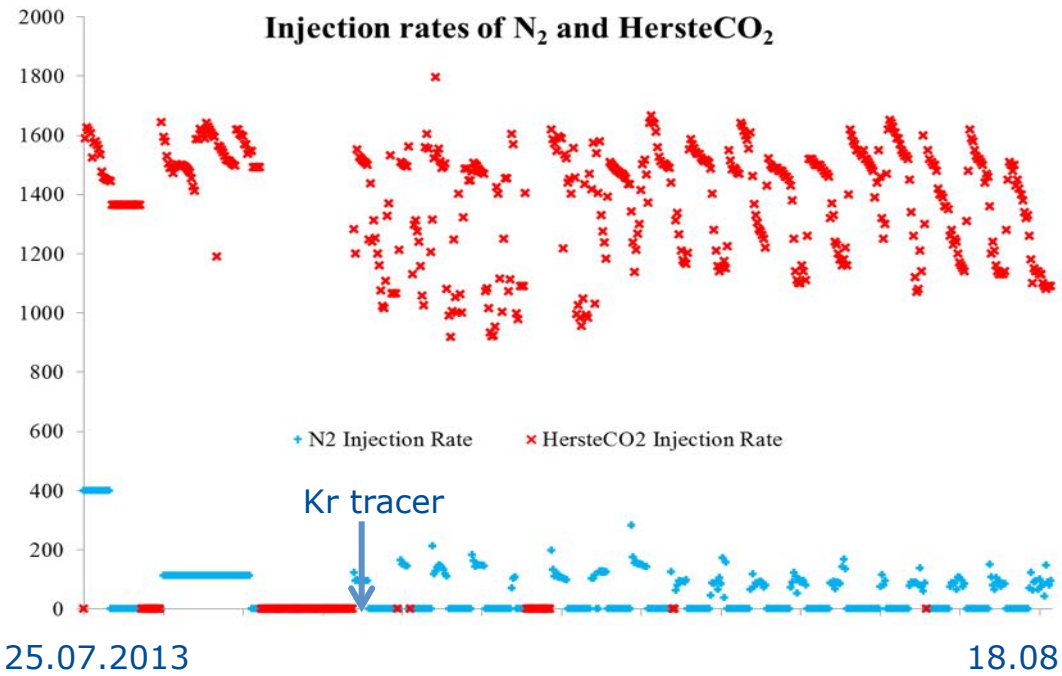
⇨

2 phase conditions at wellhead
and reservoir depth

➔ Despite larger variations in wellhead P-T and flow-rate, two-phase conditions did not pose any problems on injection process

# $CO_2/N_2$ co-injection experiment


- co-injection of 613 t $CO_2$ and 32 t $N_2$
- $CO_2$:$N_2$ ratio ~ 95:5
- $\delta^{13}C$=-3.4±0.2‰ vs. -30.6±0.4‰
- Kr tracer prior to regular experiment

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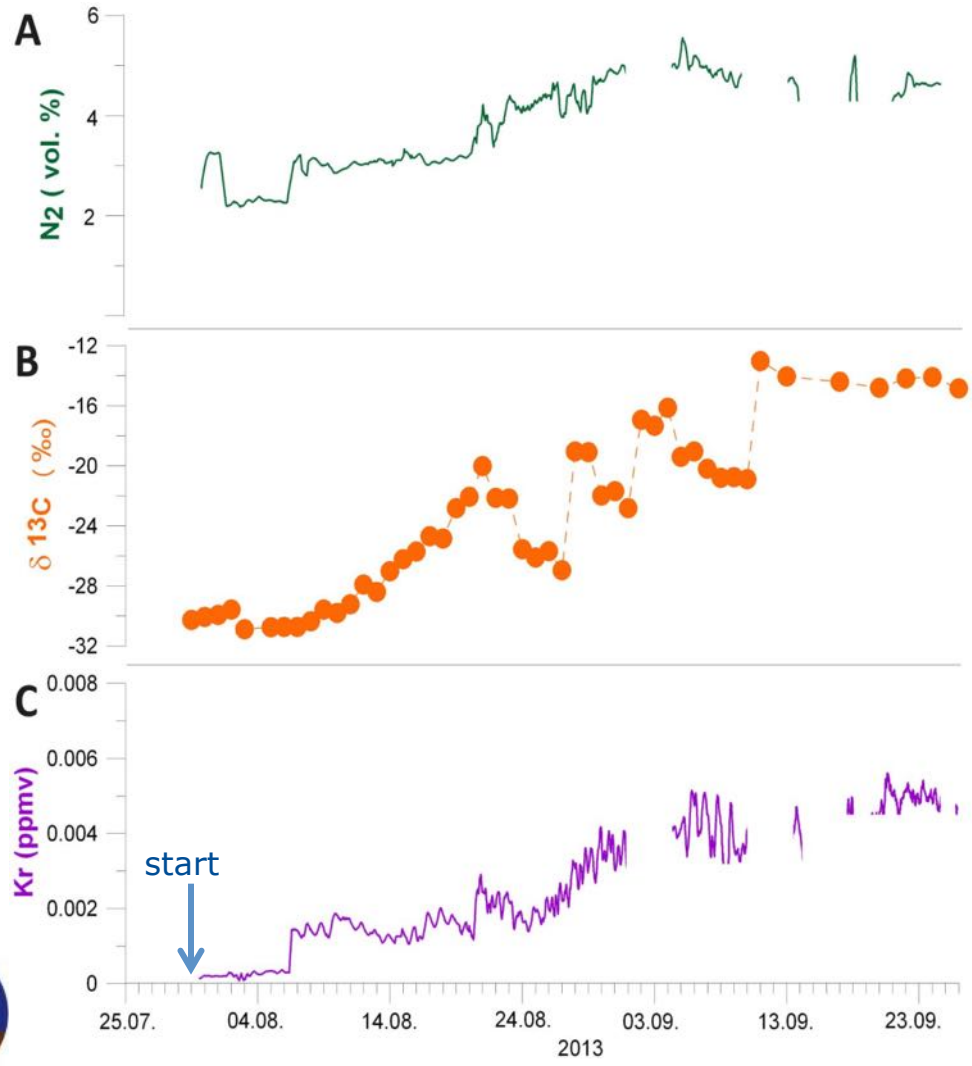
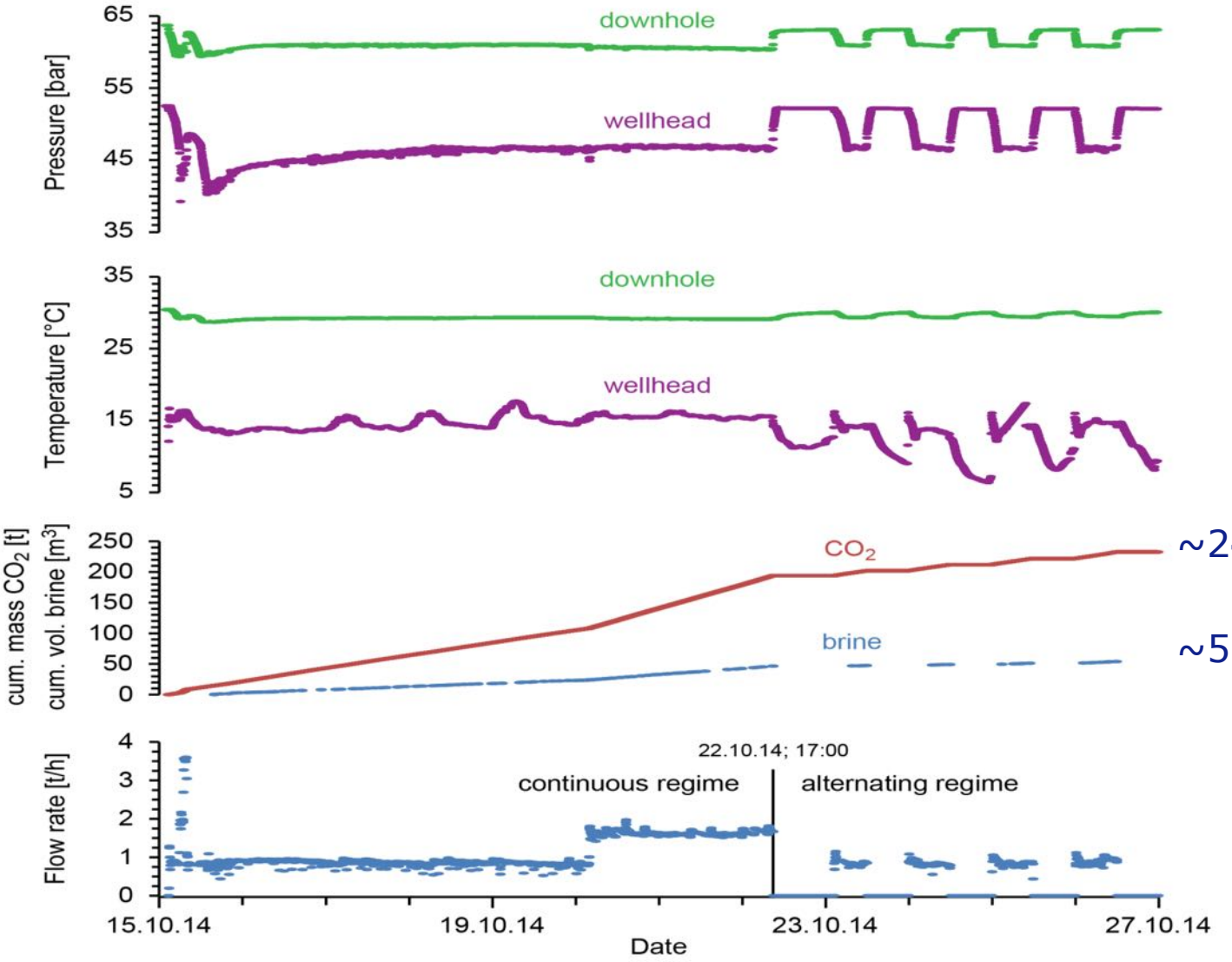



- gas mixture arrived after about 4 days at Ktzi 203 ~20 m from injection well Ktzi 201
- increasing Kr concentrations correlate with increasing $N_2$ concentrations and $\delta^{13}C$ values
- $\delta^{13}C$ data indicate in-reservoir mixing between industrial $CO_2$ and Herste $CO_2$
- in-reservoir gas and C-isotope mixing are studied by post-injection back-production experiment

# Post-injection back-production experiment

- Eddy covariance
- Open-path FTIR

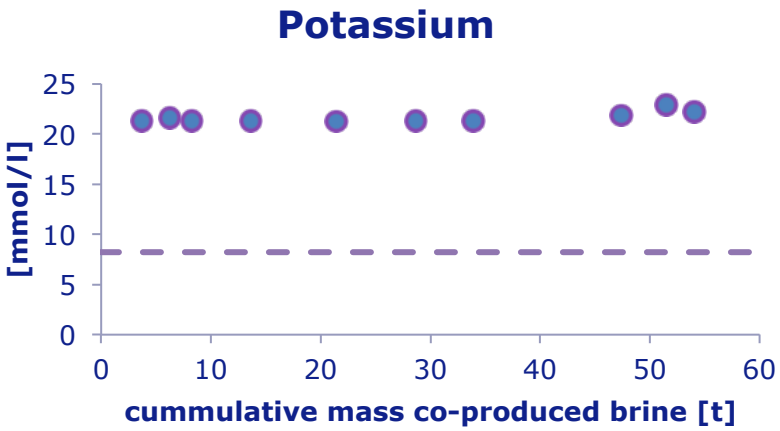
# Post-injection back-production experiment

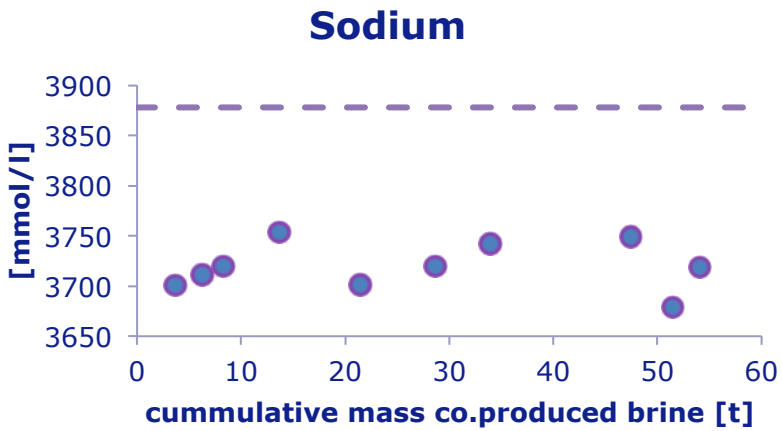


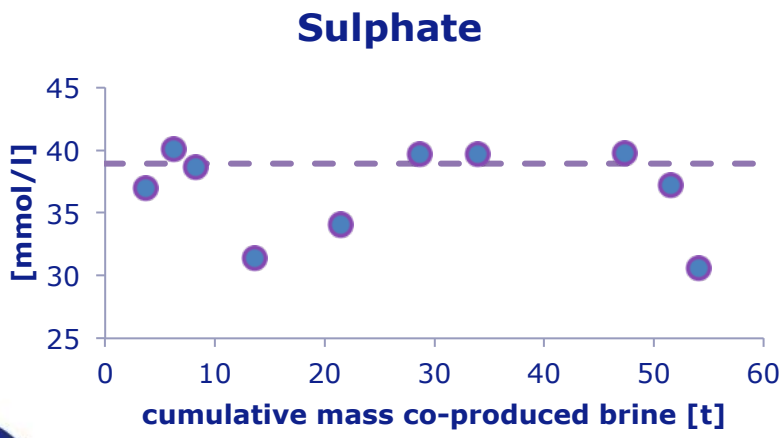

~240 t $CO_2$

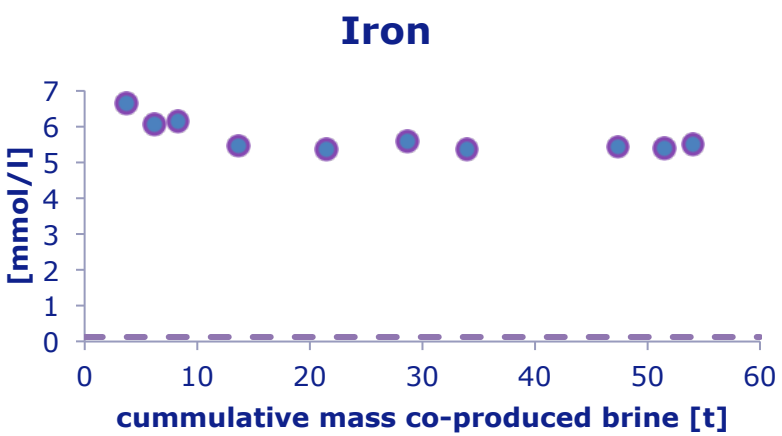
~55 $m^3$ $H_2O$

# Post-injection back-production experiment



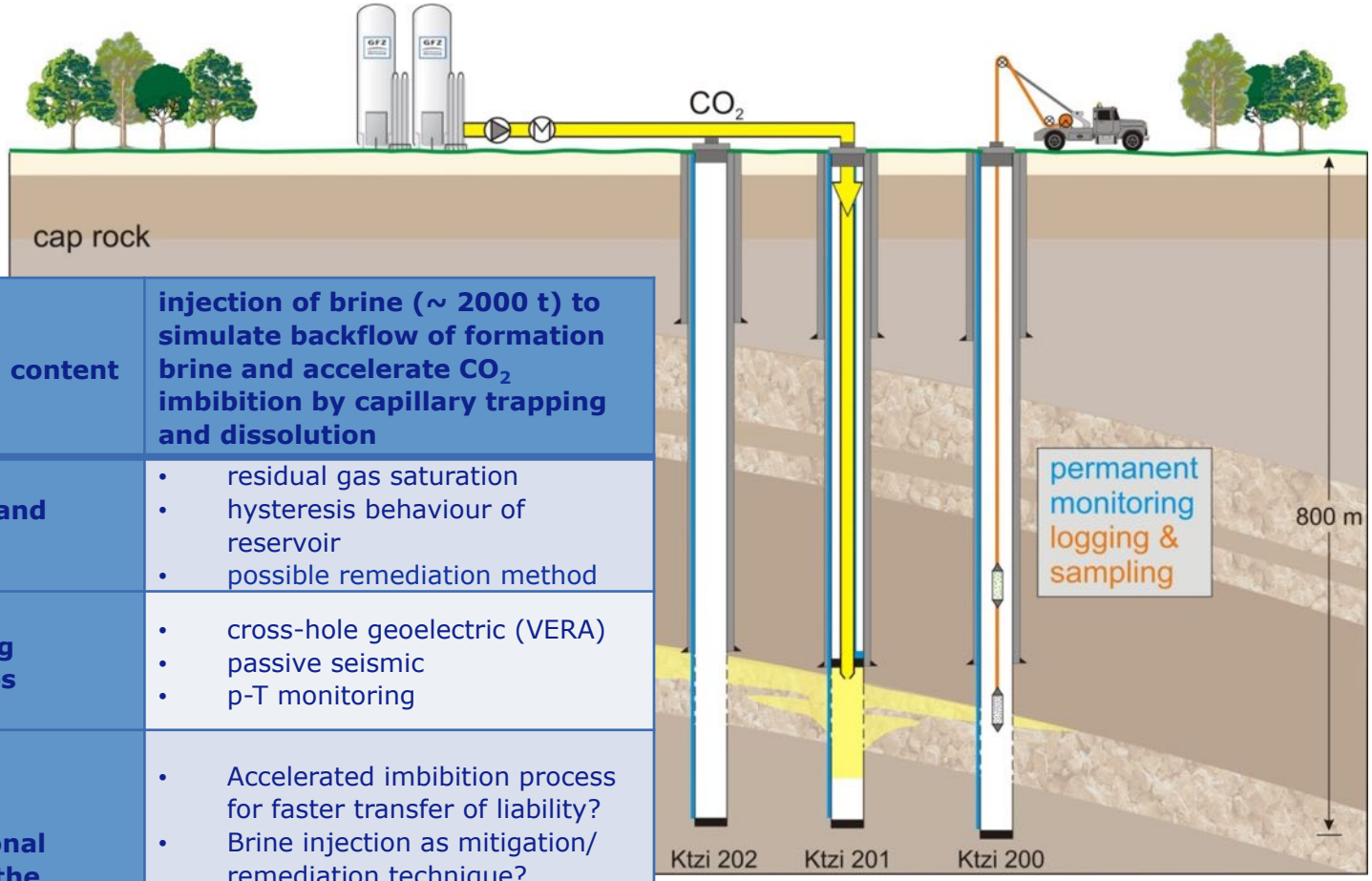




post-injection formation brine

pre-injection formation brine

# Brine-injection experiment

| | |
|---|---|
| **Campaign content** | **injection of brine (~ 2000 t) to simulate backflow of formation brine and accelerate $CO_2$ imbibition by capillary trapping and dissolution** |
| **Learning and outcome** | • residual gas saturation<br>• hysteresis behaviour of reservoir<br>• possible remediation method |
| **Monitoring techniques** | • cross-hole geoelectric (VERA)<br>• passive seismic<br>• p-T monitoring |
| **As additional benefits, the following topics will be addressed** | • Accelerated imbibition process for faster transfer of liability?<br>• Brine injection as mitigation/ remediation technique?<br>• assess improved injection strategies<br>• provide a benchmark for modelling tools |



# Performance of Ketzin Storage Pilot

- Prove safe and secure $CO_2$ storage operation in on-shore environments? — Yes 
- Build local confidence in/awareness of $CO_2$ storage? — Yes 
- Build national confidence in $CO_2$ storage? — No 
- Trigger national implementation of CCS on commercial scale? — No 

# Any need for pilot sites?

- General feasibility of $CO_2$ storage proven - urgent need for integrated demo projects
- Perform specific field tests - only possible at pilot sites
- Monitoring tool development - pilot sites not essential but an advantage
- Build confidence in $CO_2$ storage - pilot sites form a first, essential step

Successful pilot sites are essential to implementation of CCS

**but**

they do not guarantee implementation of CCS