Geological CO_2 storage works with appropriate site characterization and monitoring

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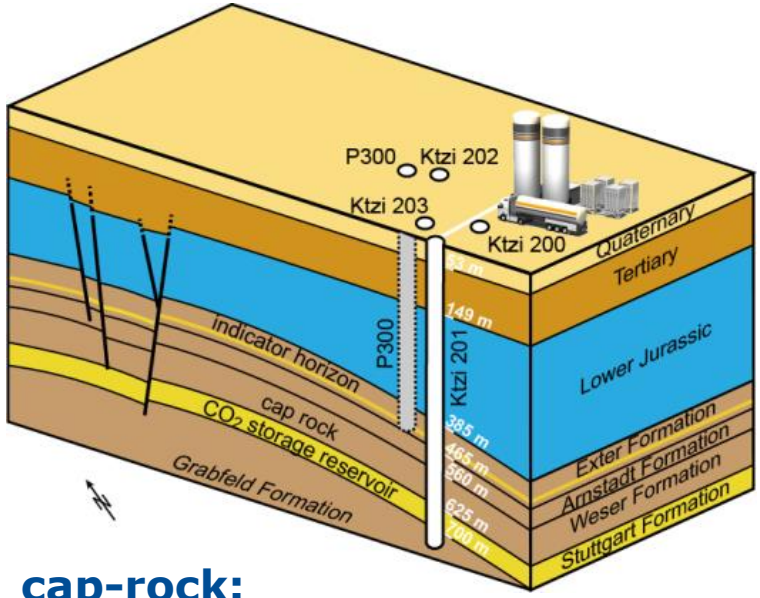
Monitoring objectives

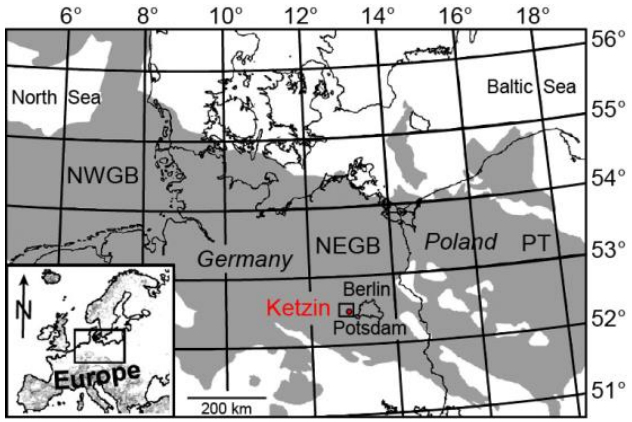
- **Regulation and operational performance**:
  - Health, safety and environment: no significant irregularities
  - Proof that CO_2 is within the reservoir/storage complex: no leakage
  - Mass balance verification: controlled storage into target formations for emission trading (ETS requirements)
  - Proven understanding of future behaviour and longterm stability of CO_2 plume (transfer of responsibility/liability)
  - Smooth injection operation – real time data
  - Risk assessment
  - Effectiveness of corrective measures

- **Research and engineering**:
  - Testing monitoring techniques and methodologies
  - Specific R&D questions require specific monitoring strategies

- **Public engagement**:
  - Making storage more understandable for the public

CO_2 on-shore storage in a saline aquifer at the Ketzin pilot site





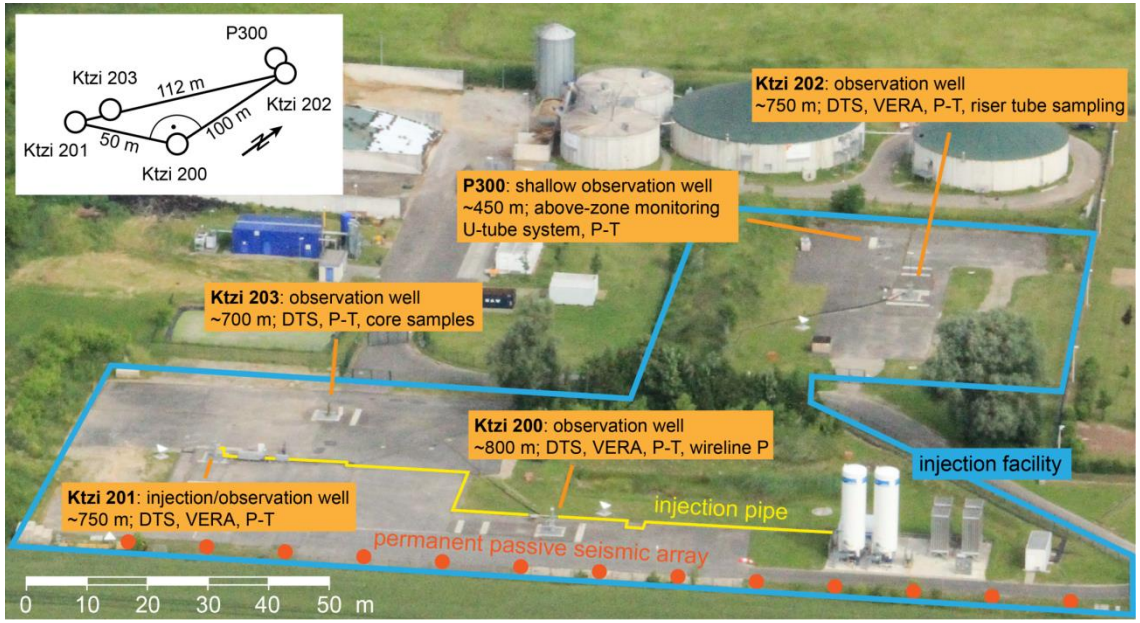
- located in the North East German Basin
- Ketzin-Roskow double anticline above salt pillow

cap-rock:

- Upper Triassic shales, >165 m

reservoir:

- sandstones of Upper Triassic Stuttgart Formation
- fluvial system, ~630 m depth
- lateral and vertical heterogeneous
- P/T_{ini} ~ 62 bar/33 °C



Fully equipped research infrastructure

The Ketzin pilot site – key data

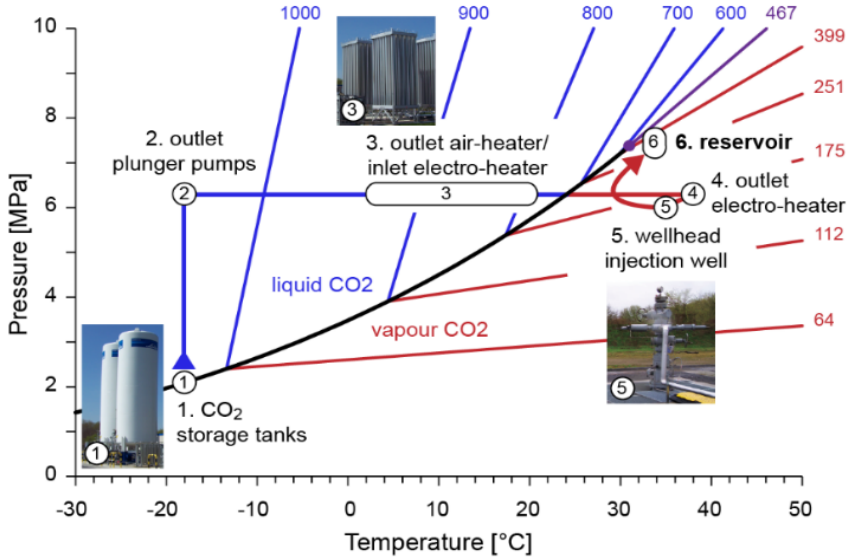
Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Assessment	Characterisation	Development	Operation	Post-Closure/ Pre-Transfer	Post Transfer

April 2004	July 2007	June 2008	August 2013	December 2017
Start project	Operation permit	Start injection	End injection	Transfer liability

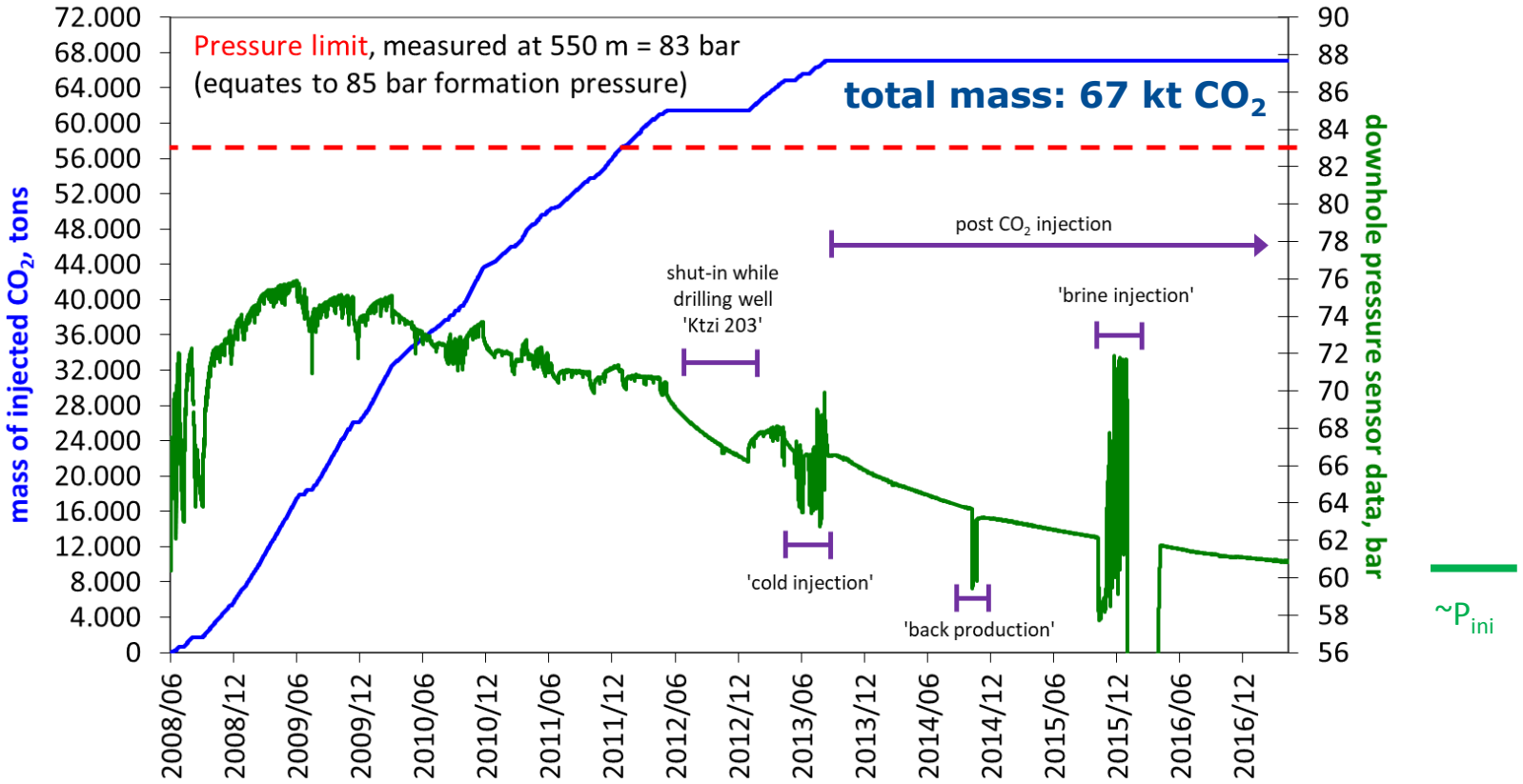
CO_2 sources and quality:

- food-grade CO_2 (Linde), > 99.9%
- 2011: 1,515 t CO_2 from Schwarze Pumpe oxyfuel pilot plant, > 99.7%
- 2013: 650 t CO_2-N_2 (95/5) co-injection

Total mass injected: 67 kt CO_2

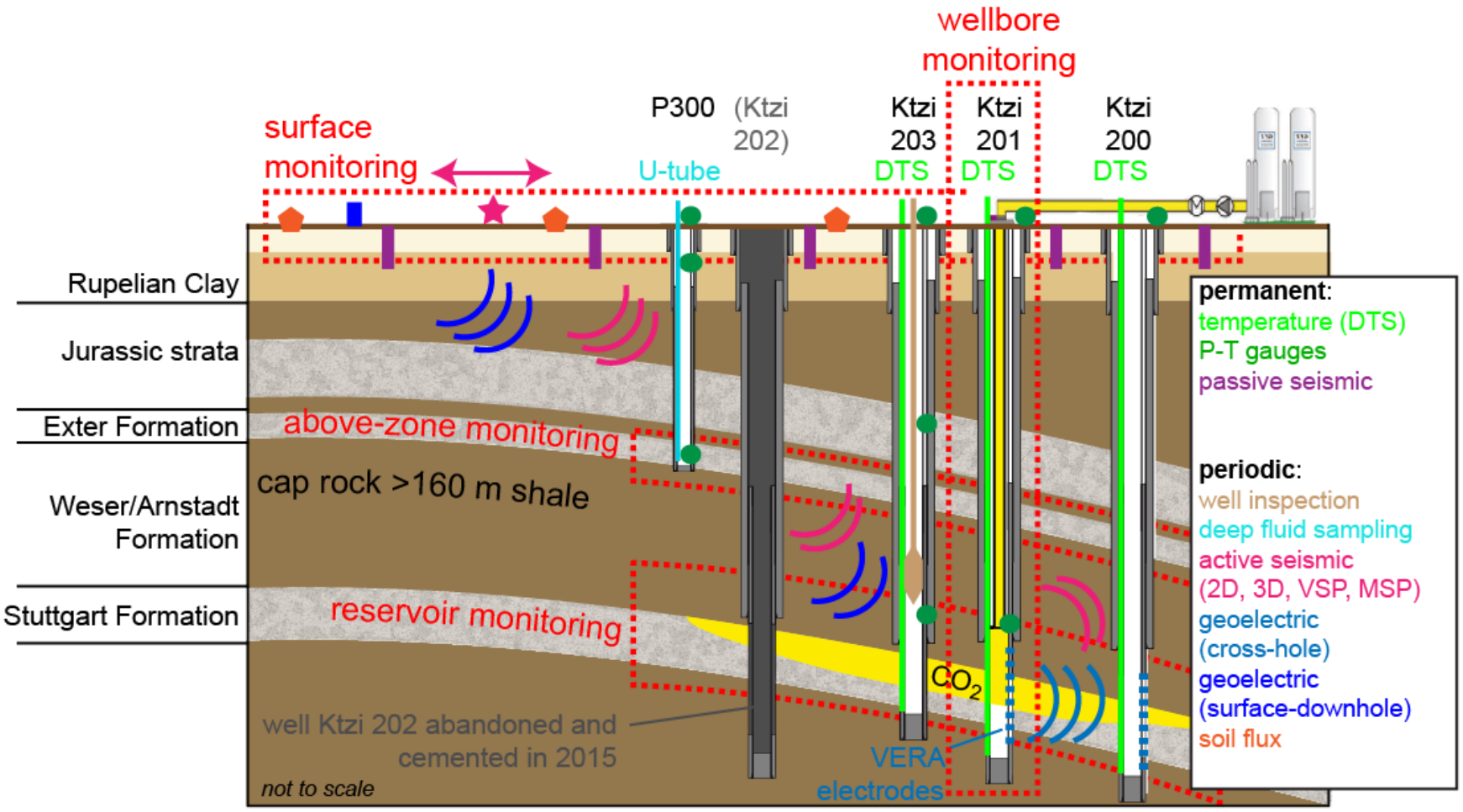


The Ketzin pilot site – key data



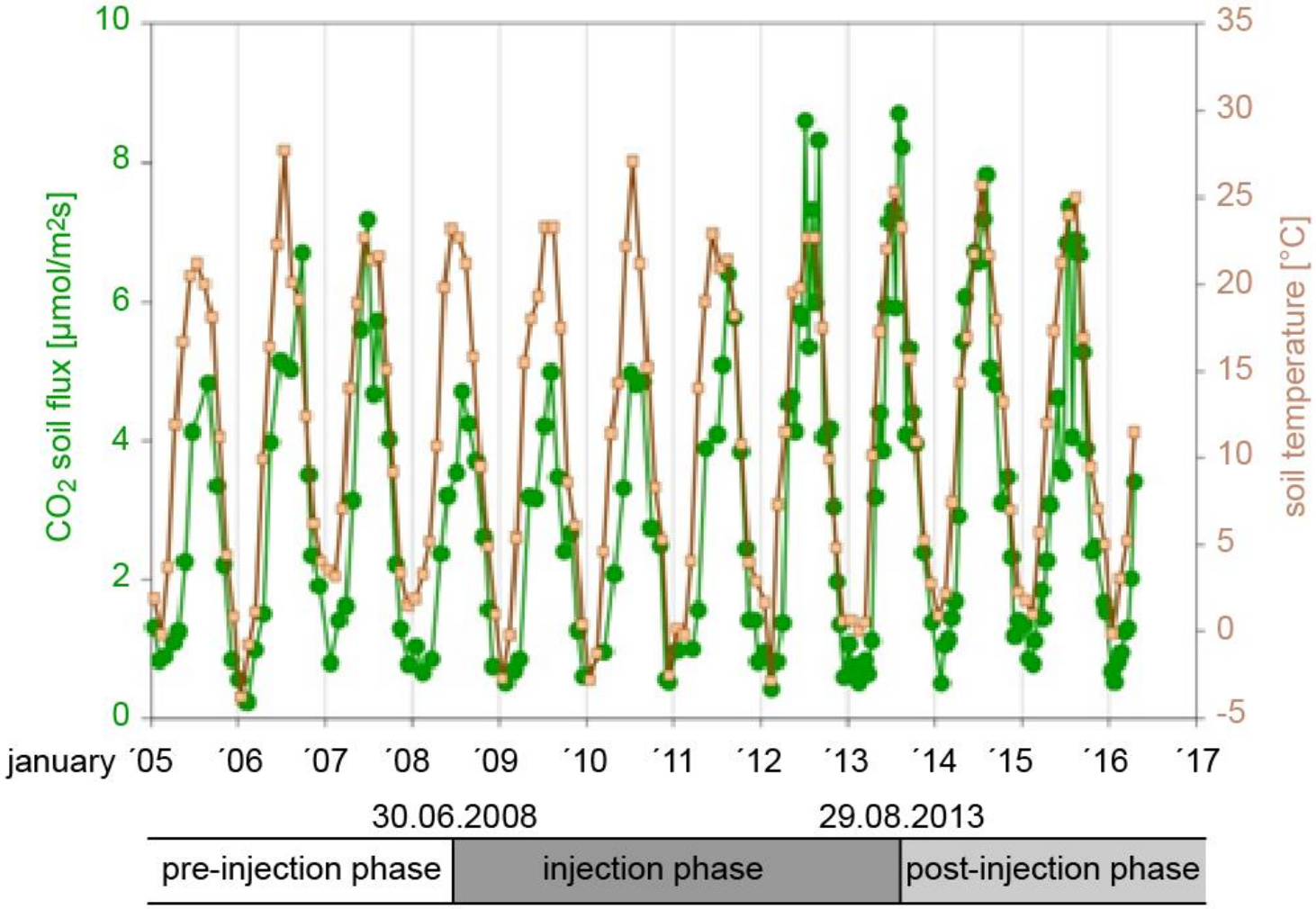
- smooth injection process, maximum P-increase ~16 bar
- no safety issues, P « pressure limit
- P-decline after stop of injection (= towards long-term stability)

Life-cycle monitoring concept at Ketzin



- combination of different geophysical and geochemical tools
- different monitoring targets

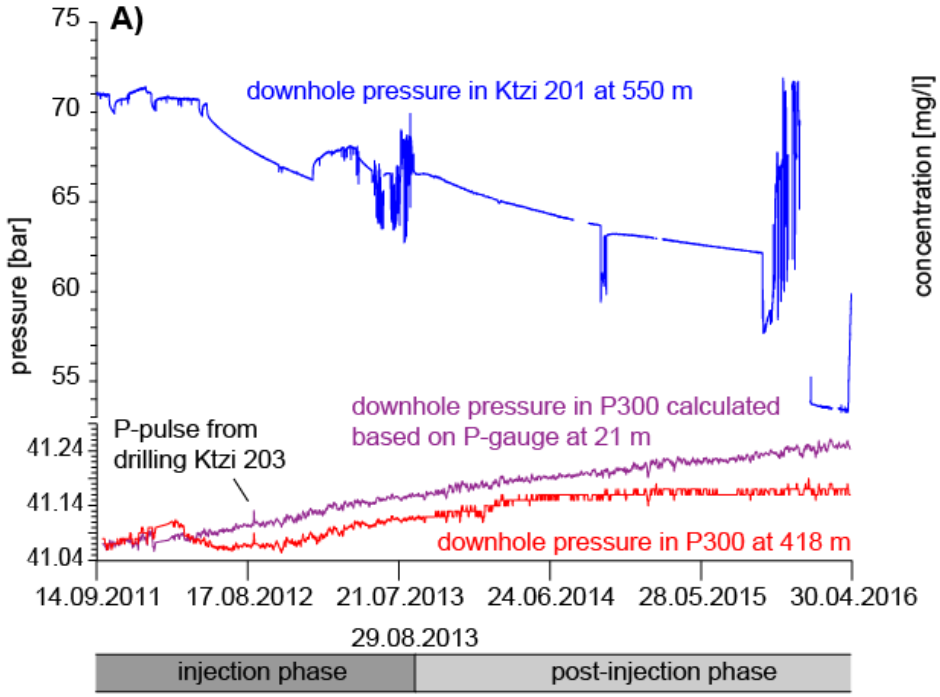
Surface monitoring at Ketzin

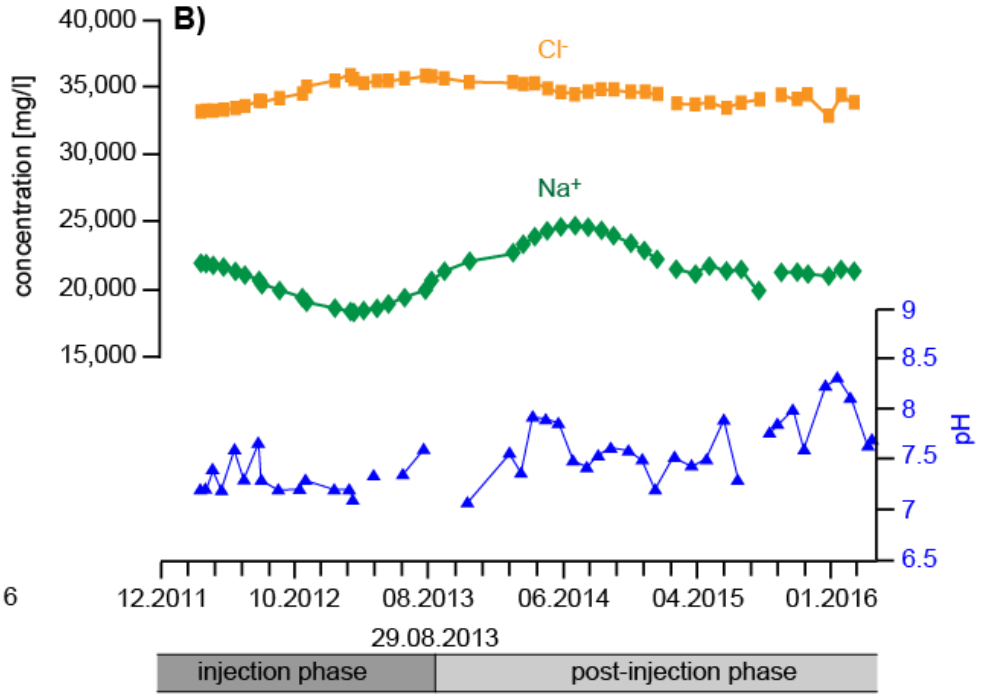


- no changes in soil flux detected so far
- low wintertime fluxes „preclude" leakage

Above-zone monitoring at Ketzin

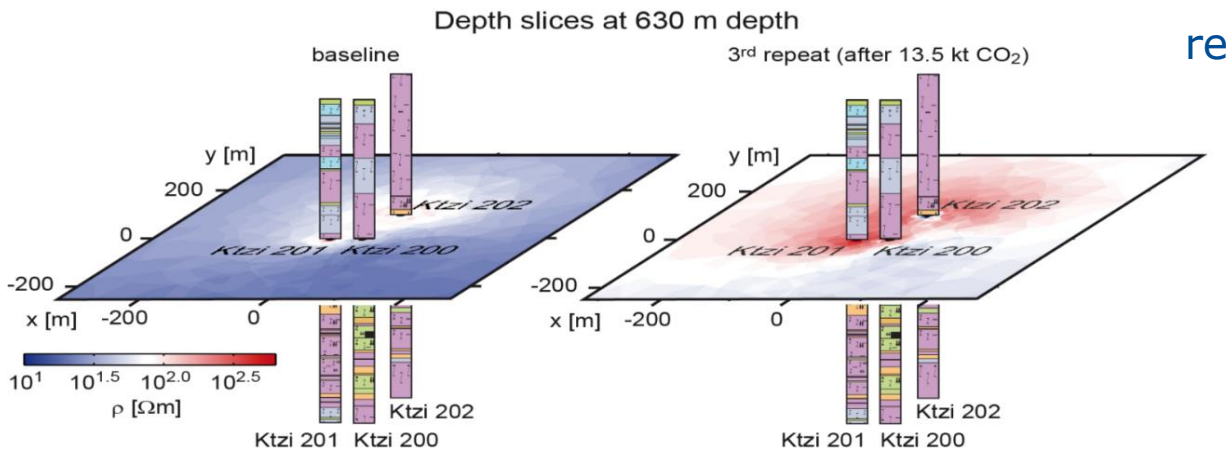
Shallow well P300 with P-sensors @ 418 and 21 m and U-tube system for fluid sampling

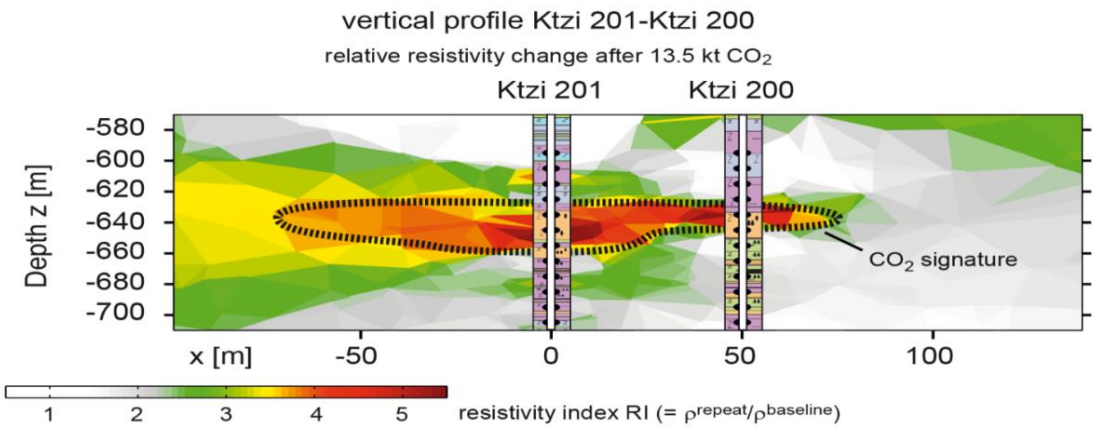




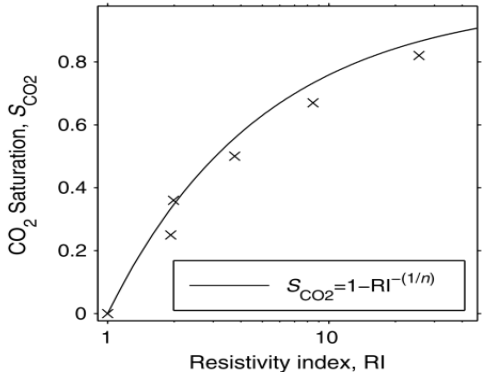
- no hints to any hydraulic coupling between reservoir and indicator horizon
- no chemical hints to either brine or CO_2 leakage

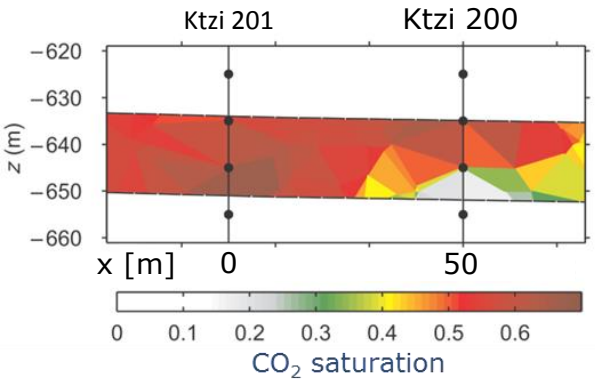
Geoelectric reservoir monitoring at Ketzin





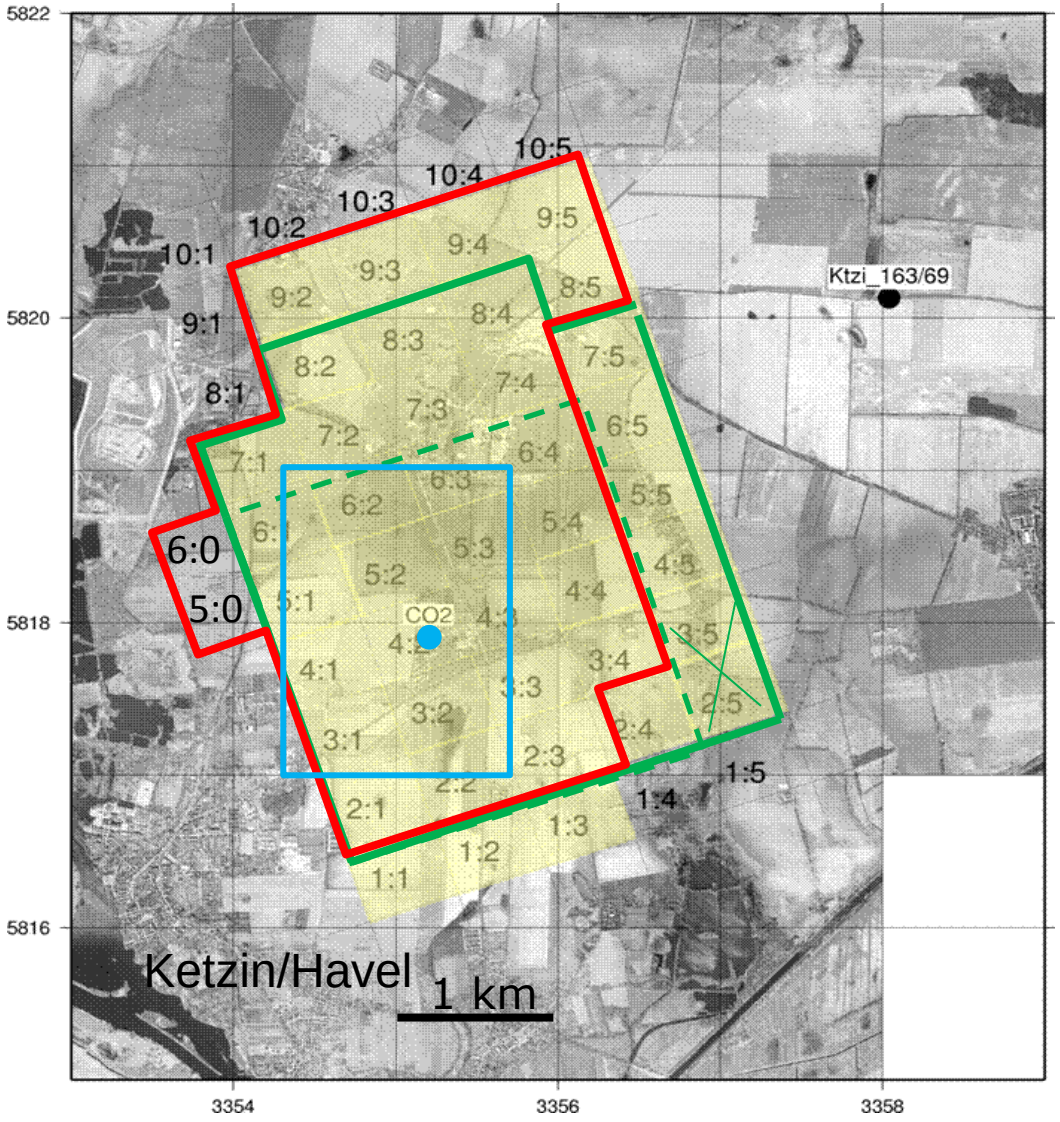
experimentally determined relation between resistivity index and CO_2 saturation





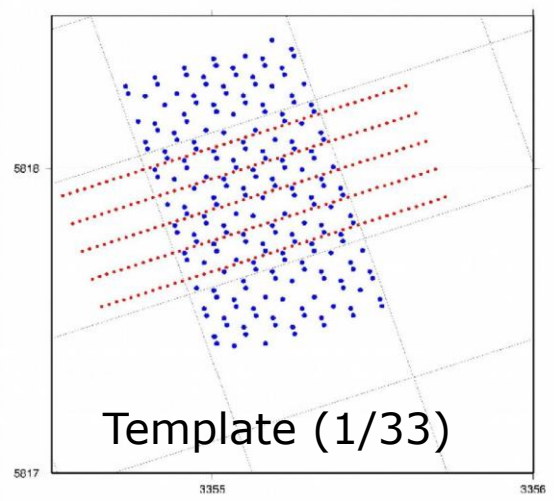
- clear geoelectrical signal already after 13.5 kt CO_2
- determination of CO_2 saturation based on inverted resistivity indizes

4D seismic reservoir monitoring at Ketzin



Baseline plus 3 repeats

Year	CO_2 (tonnes)	Symbol
2005	-	
2009	22.000	
2012	61.000	
2015	67.000	



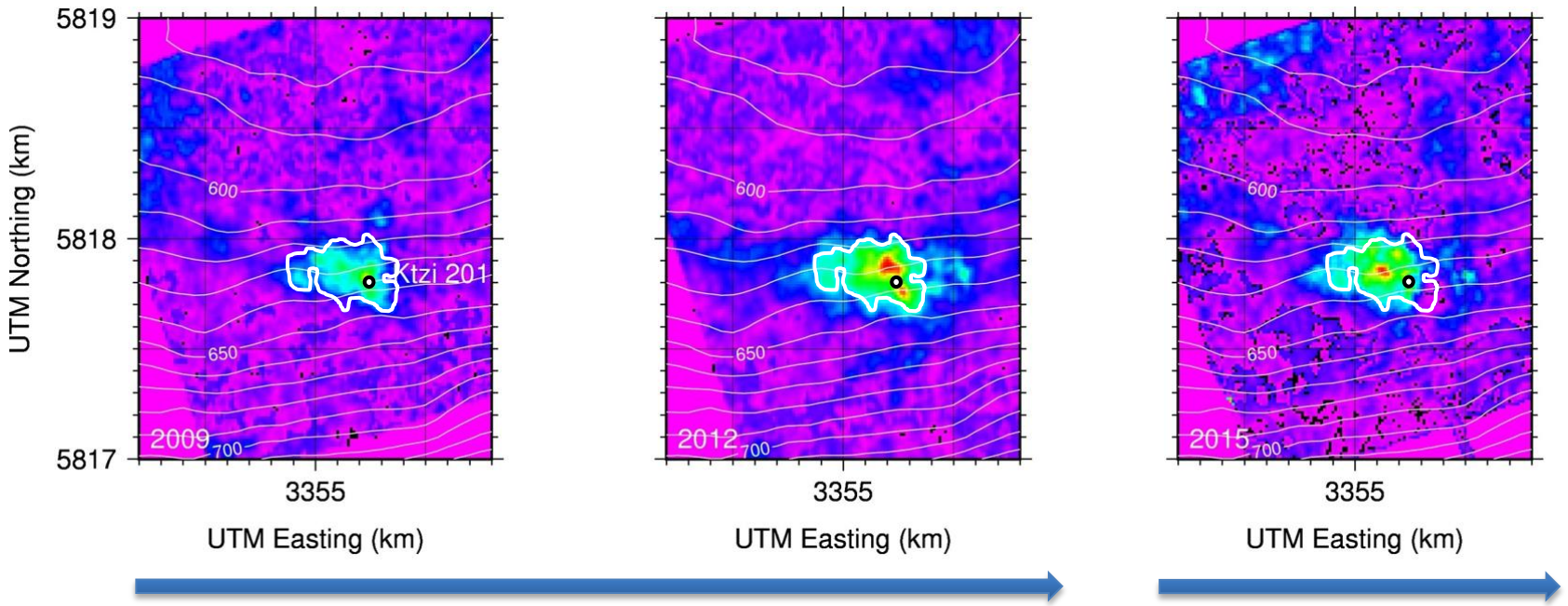
4D seismic reservoir monitoring at Ketzin

normalized time-lapse amplitude changes

Baseline – 2009
22 kt CO_2
~ 0.08 km²

Baseline – 2012
61 kt CO_2
~ 0.15 km²

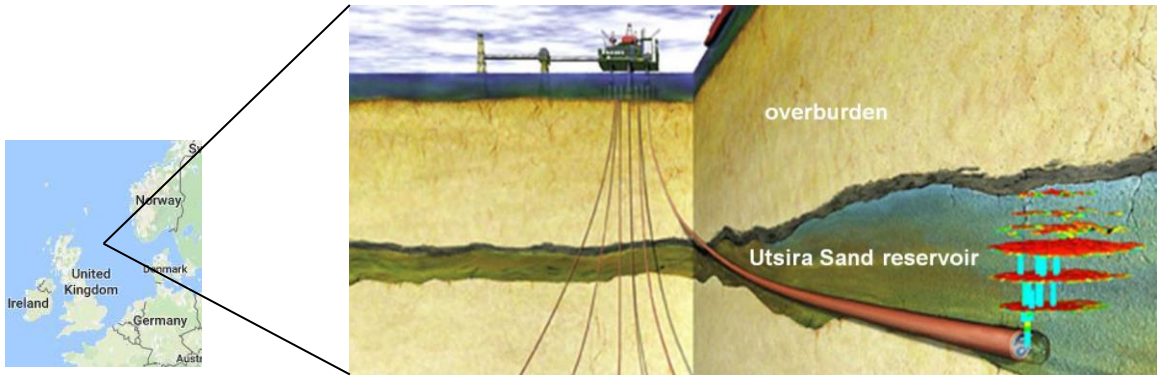
Baseline – 2015
67 kt CO_2
< 0.15 km²



active injection
- lateral and vertical plume growth
- greatest thickness at injection point
- no significant plume migration

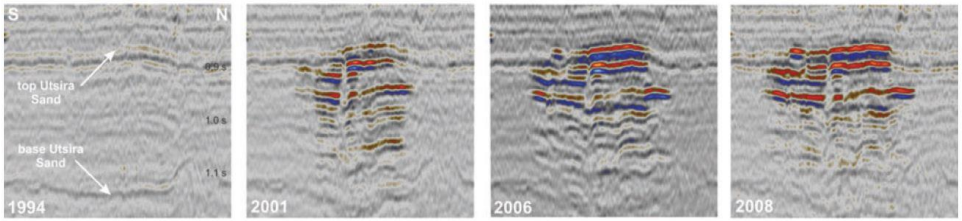
post injection
- shrinkage
- „stagnant" plume"

4D seismic reservoir monitoring at Sleipner

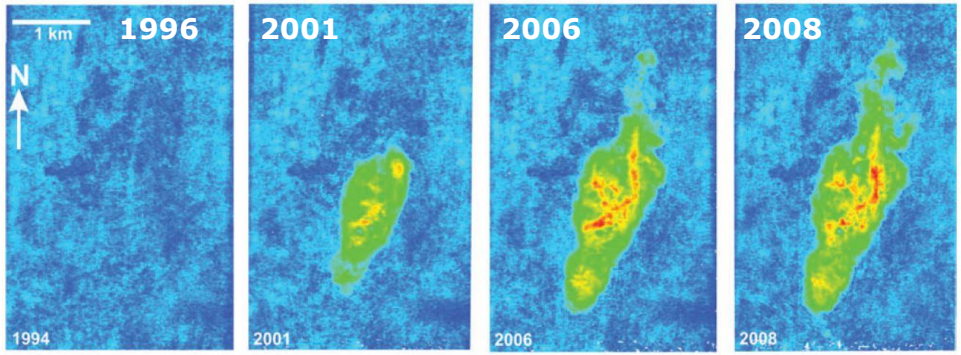


- injection into off-shore saline aquifer @ 800 to 1,100 m
- since 1996 > 17 Mt CO_2
- one injection well, no observation wells

cross-sections



amplitude maps



- relying on geophysical tools (**seismics**, gravimetry, electromagnetics)
- targeting on reservoir

(Chadwick et al., 2015)

Public acceptance via public outreach activities

- visitor centre
- >3000 visitors from all over the world
- annual open-house day

- school visits
- Long Night of Science
- - exhibition at local museum of Ketzin

- 7 documentary films on CCS technology/CO_2 storage
- virtual site tour with 7 short movies
- homepage CO_2Ketzin

CO_2 storage – status worldwide

Technical readiness level

Hontomin

~ 10 kt CO_2?

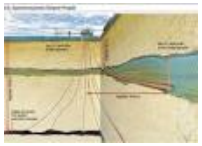
Ketzin

~ 67 kt CO_2
~ 0.01 Mt/a

Illinois Basin
Decatur Project

~ 1 Mt CO_2
~ 0.33 Mt/a

Sleipner



~ 16 Mt CO_2
~ 0.8 Mt/a

In Salah

~ 3.8 Mt CO_2
~ 0.5 Mt/a

Boundary
Dam

~ 1 Mt/a

Svelvik,
FRS

< 1 kt CO_2

Nagaoka

~ 10 kt CO_2
20~40 t/d

Otway Project

~ 65 kt CO_2
~ 0.04 Mt/a

field tests **0.01 Mt** pilot sites **0.1 Mt** demo projects **1 Mt** industrial sites

storage size

Proper site characterization together with adequate, site dependent monitoring concept enables safe and secure geological CO_2 storage

- geology is not the obstacle -

- general feasibility of CO_2 storage on-shore/off-shore proven
- site-adjusted geophysical monitoring capable of detecting even small amounts of CO_2:
  ~ 20 kt for seismics, ~ 13 kt for geoelectric methods

- for Germany, ~ 35 Mt CO_2/a of unavoidable, process related emissions predicted
- CCS currently only available technology to handle/reduce these emissions
- national storage capacity sufficient for several decades
- transport and storage infrastructures must/should be provided
- cluster solutions with cross-boundary transport of CO_2 are needed

ISO/DIN activities within CCS

- ISO/TC 265 Carbon dioxide capture, transportation, and geological storage
  - DIN NA 119-01-04 AA CO2-Abscheidung, -Transport und –Speicherung
- **Scope**: Standardization of design, construction, operation, environmental planning and management, risk management, quantification, monitoring and verification, and related activities in the field of carbon dioxide capture, transportation, and geological storage (CCS)

- WG 1: Capture
- WG 2: Transportation
- WG 3: Storage
- WG 4: Quantification and Verification
- WG 5: Cross Cutting Issues
- WG 6: EOR Issues

ISO/TC265 WG1 N0265

ISO

Preliminary NWIP for capture of CO2 from a CEMENT plant

Based on the discussion in 12th WG1 meeting (Paris, Sep.18-20, 2017), Norway prepared the document for the discussion on cement. Please find attached a preliminary NWIP proposed by Norway. The details are included in the Form 4 and annexes (A to D). Explanation of the documents is shown below.

For offering the earliest opportunity to review this proposal, the management team is circulating this Norway's proposal to all WG1 members. WG1 members are requested to have a chance to discuss with your experts of cement area in your mirror committee.

WG1 is going to discuss on this proposal in Sydney. This topic will be in the agenda of Sydney meeting.