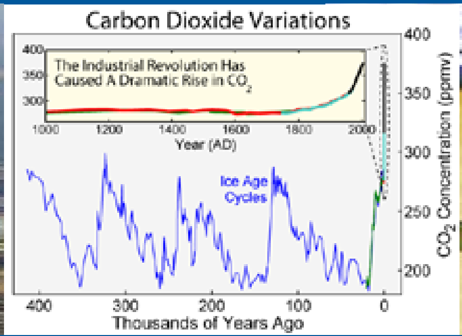
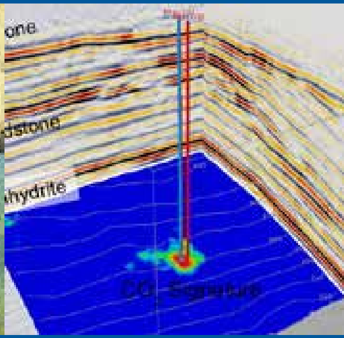
Geological CO_2 storage – concepts and state of knowledge

Axel Liebscher, Stefan Lüth

Helmholtz-Zentrum Potsdam
Deutsches GeoForschungsZentrum GFZ



DPG Annual Meeting, AKE 10, Münster, 28 March 2017

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Topics

Climate change mitigation and CCS

CO_2 storage

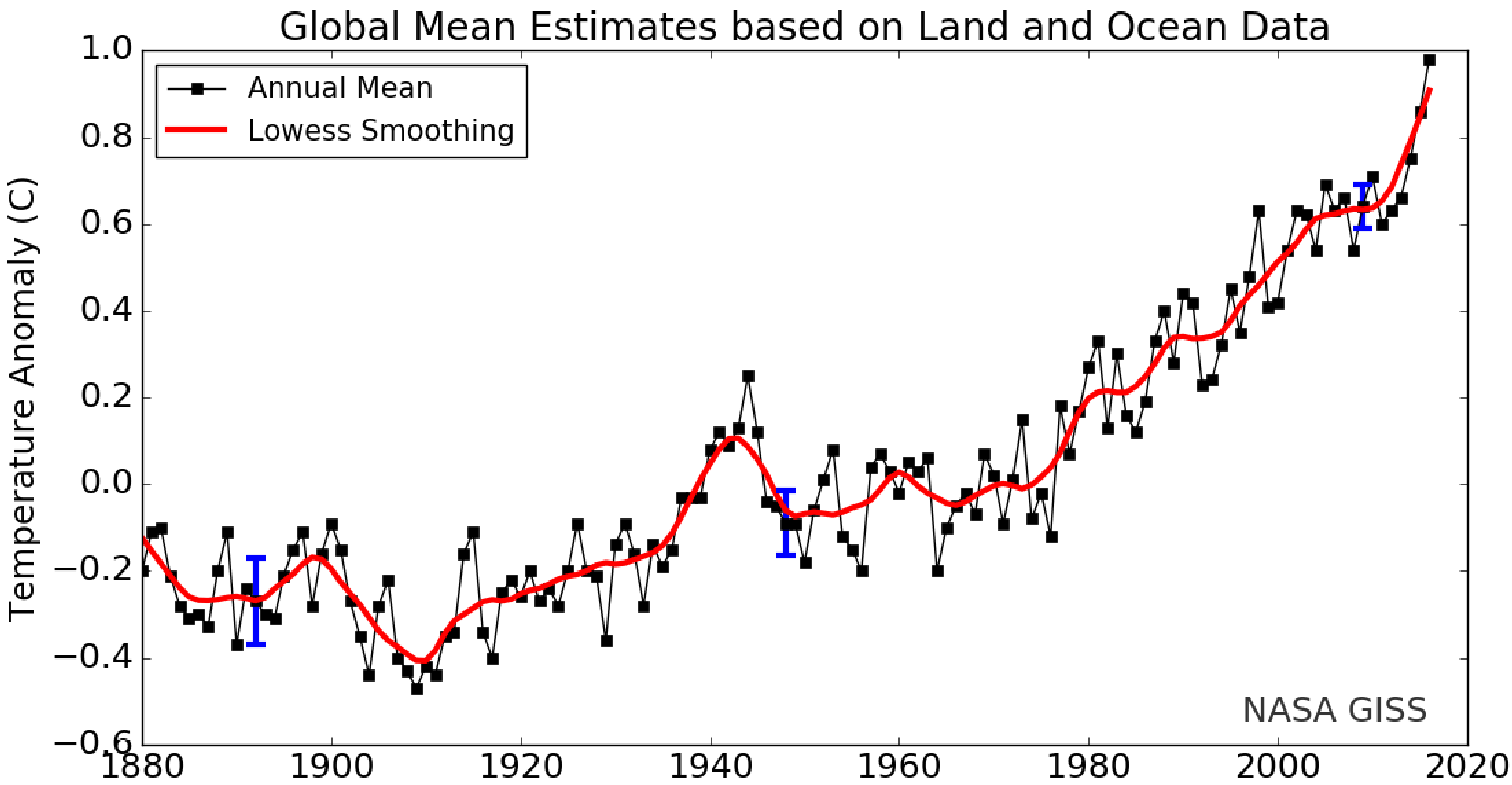
Field example 1: Sleipner

Field example 2: Ketzin

Long-term behaviour and conformity

Summary and conclusions

Climate change – global mean temperature rising



- Global trend of temperature increase since onset of systematic observations.
- Temperature increase faster than previous variations in Earth history.

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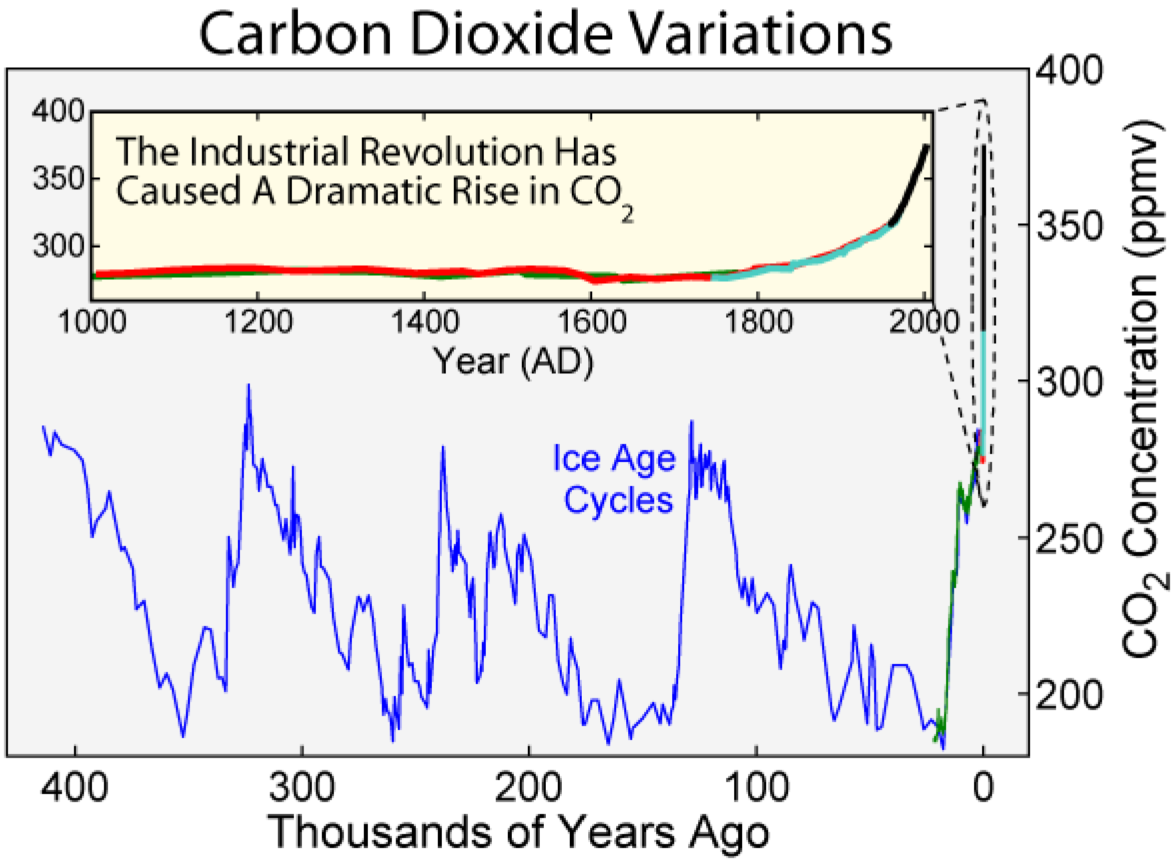
Carbon dioxide reached long-time maximum



Rohde, 2009
Data from ice core analyses and Mauna Loa Observatory.

- Increasing concentration of greenhouse gases commonly regarded as main cause for global warming.

Consensus about reduction of GHG emissions

Paris climate conference:

- Limit of global warming until 2100: 2 °C, aiming to stay significantly below that.

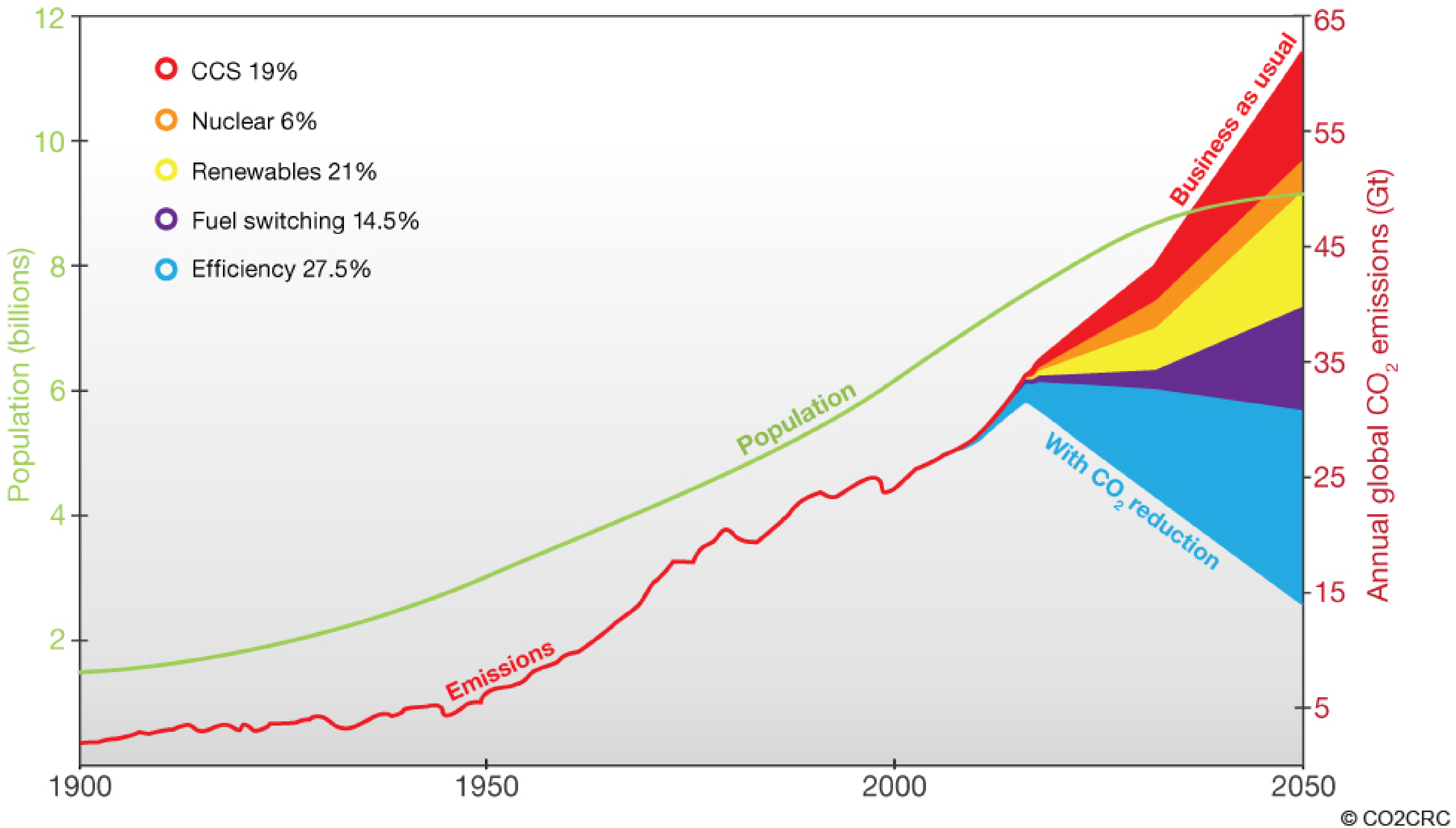
But: fossile energy sources (coal, gas) available and in use for decades – and strong process emissions from industry (e.g. steel and cement production).

CCS can contribute to reduction of GHG emissions.

On international level, new pilot and demo projects underway.

COP21 (2015)

CCS – part of the portfolio of GHG reduction



(CO2CRC with data from IEA)

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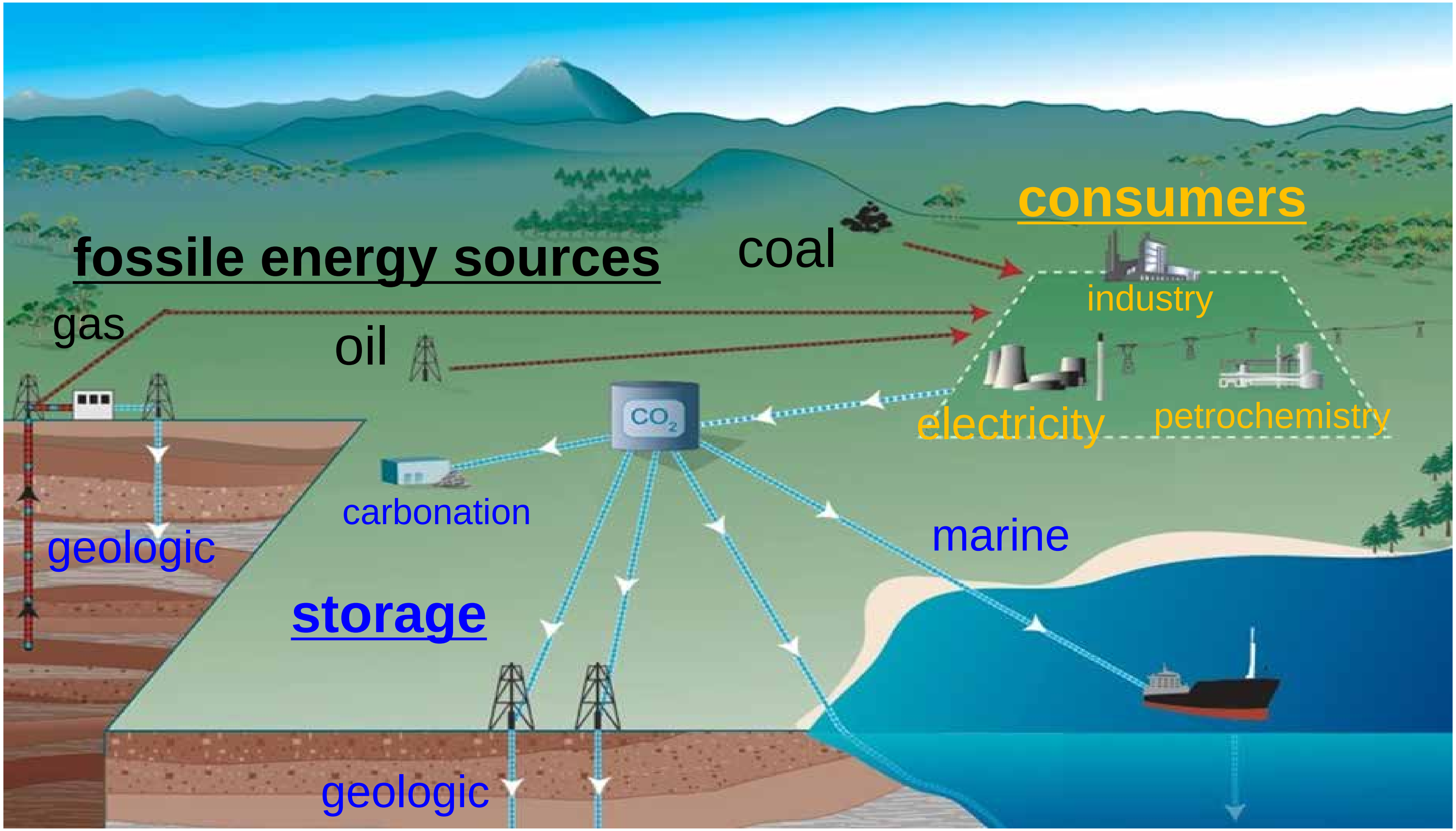
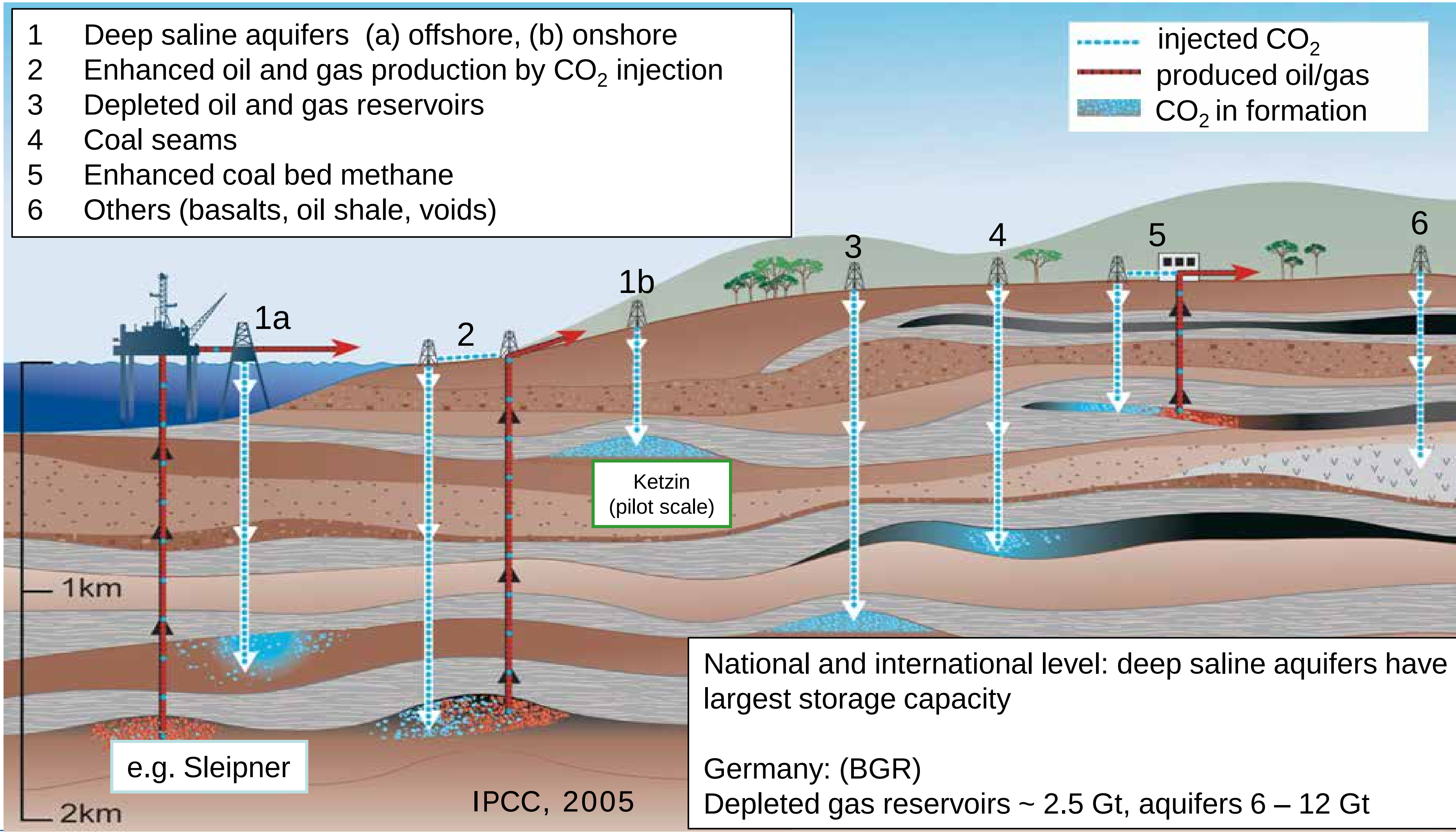
The CCS chain
capture – transport - storage



Options for geological CO_2 storage

1 Deep saline aquifers (a) offshore, (b) onshore
2 Enhanced oil and gas production by CO_2 injection
3 Depleted oil and gas reservoirs
4 Coal seams
5 Enhanced coal bed methane
6 Others (basalts, oil shale, voids)



National and international level: deep saline aquifers have largest storage capacity

Germany: (BGR)
Depleted gas reservoirs ~ 2.5 Gt, aquifers 6 – 12 Gt

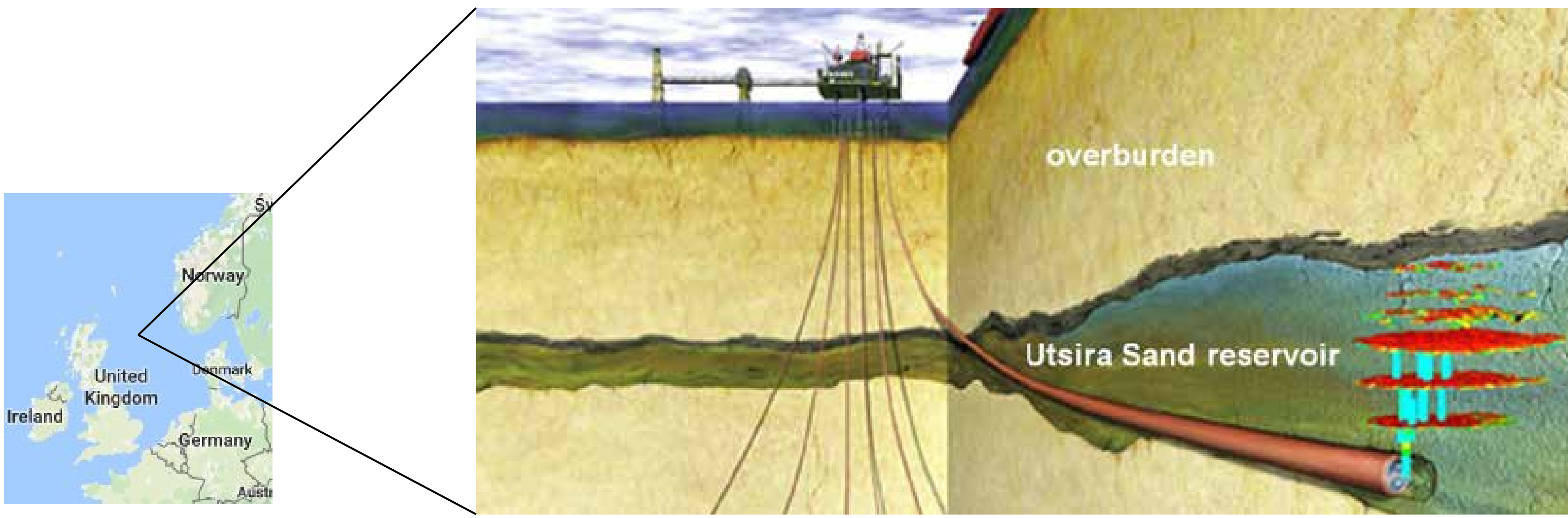
Global distribution of pilot to full scale projects

CO2CRC

Early pilots in USA (Frio) and Japan (Nagaoka), Sleipner oldest and largest storage project in Europe.

The Sleipner storage project

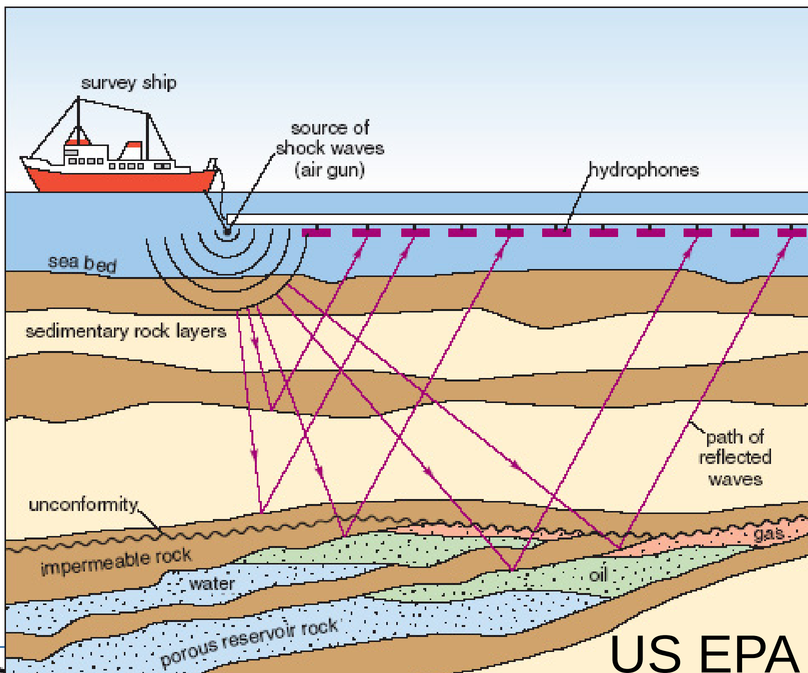
- Operator: Statoil, since Sep 1996.
- 850,000 tonnes CO_2 per year.
- Gas produced from Sleipner West field: 15 % CO_2. Instead of venting it into the atmosphere it is stored in a saline aquifer formation 1000 m below the seafloor thus avoiding Norwegian CO_2 tax.



Chadwick et al., 2014

Monitoring of the storage complex

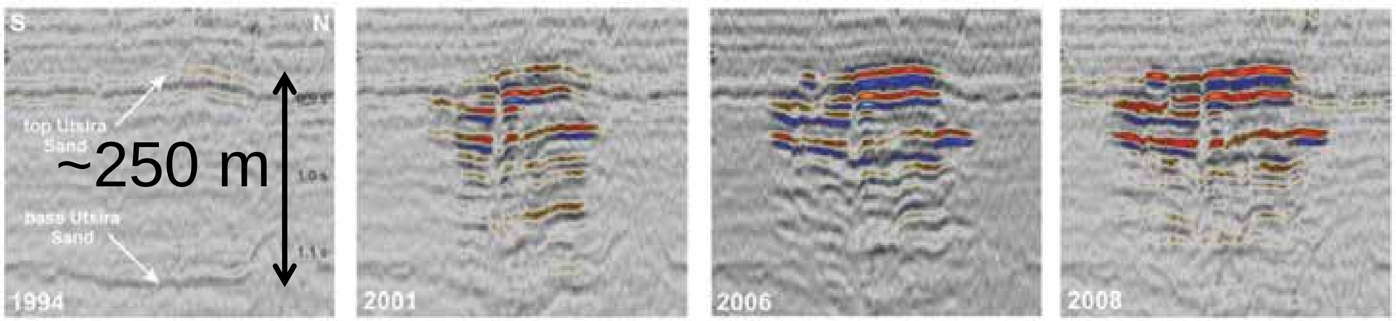
- Operator must assure that no leakage occurs and reservoir remains stable.
- Reservoir behaviour: pressure, temperature, CO_2 migration.
- CO_2 migration requires spatially distributed time-lapse observations – 4D seismic reflection surveys.



Marine seismic surveys: Airgun source, hydrophone streamers

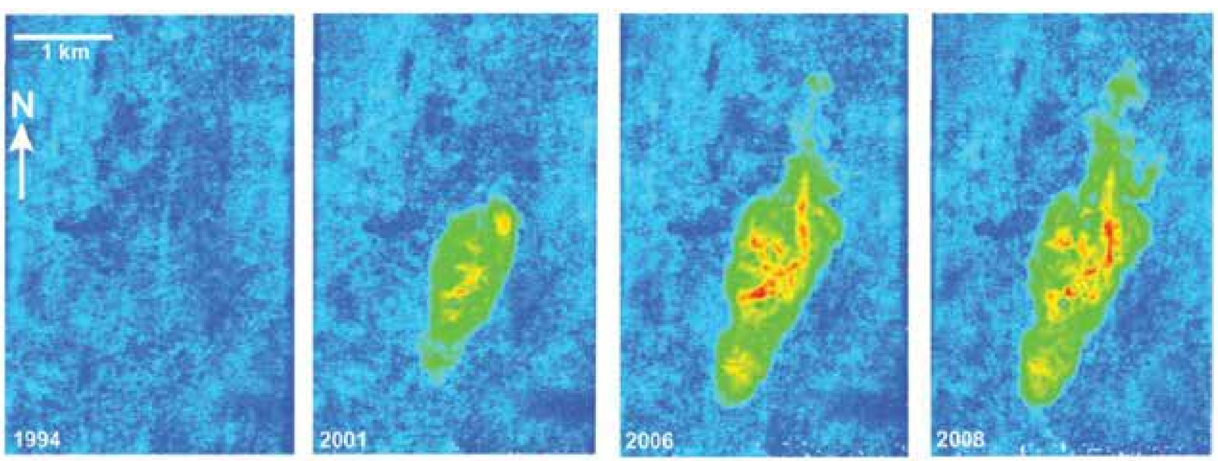
Monitoring of the storage complex

- 3D seismic surveys were acquired before CO_2 injection (baseline) and after start of injection.
- Injected CO_2 replaces initial pore fluids (brine) in reservoir formation.
- Fluid replacement results in changed reflectivity of reservoir.



Seismic monitoring

Cross-sections



Amplitude maps

Chadwick et al., 2015

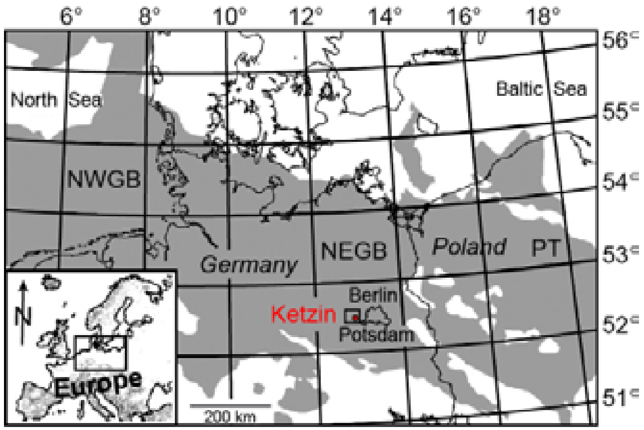
Ketzin pilot site

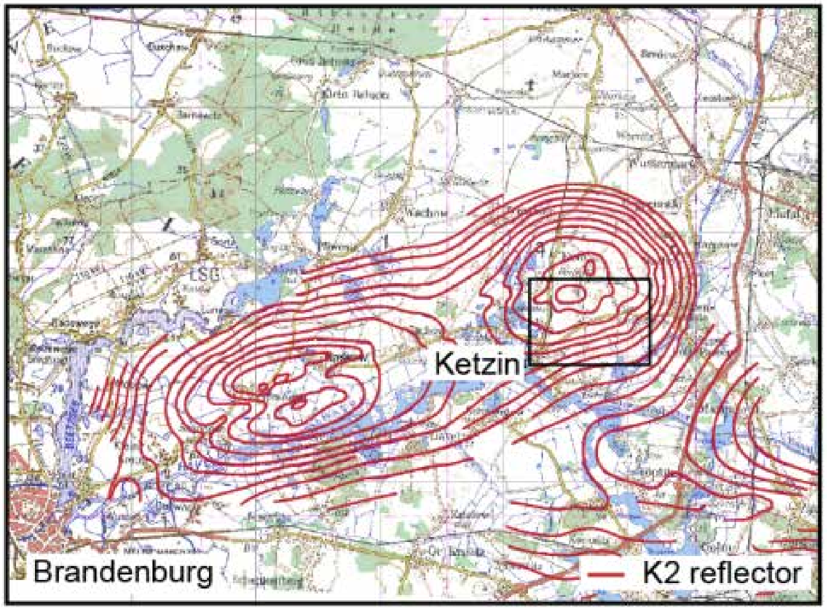
- Demonstration of full life cycle for storage site.
- Feasibility of onshore storage in saline aquifers.
- Assessment of established and innovative monitoring tools.

- First European storage site onshore.
- Research site – capacity restricted to 100,000 tonnes.
- Permit granted on the basis of German Mining Law.

Geographic and geologic framework

- North-East German Basin (NEGB).
- Double anticline formed by salt tectonic movements (structural trap).





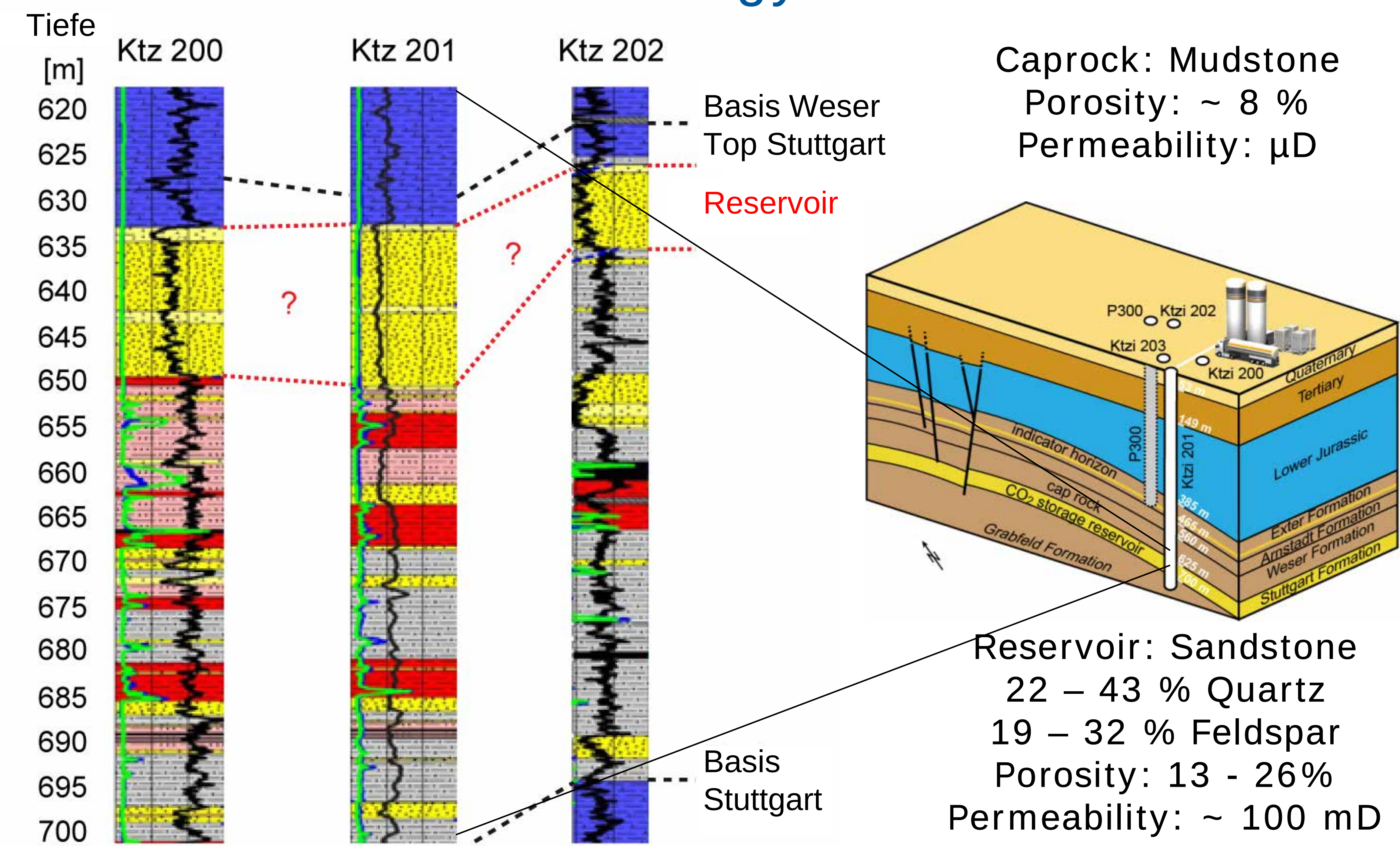
Caprock (seal):

- Mudstone, Upper Trias (~200 Ma), >165 m.

Reservoir

- Saline aquifer.
- Sandstone, Stuttgart-Formation, Upper Trias.
- Fluvial origin, heterogeneous.
- Depth: 630 – 650 m.

Geology

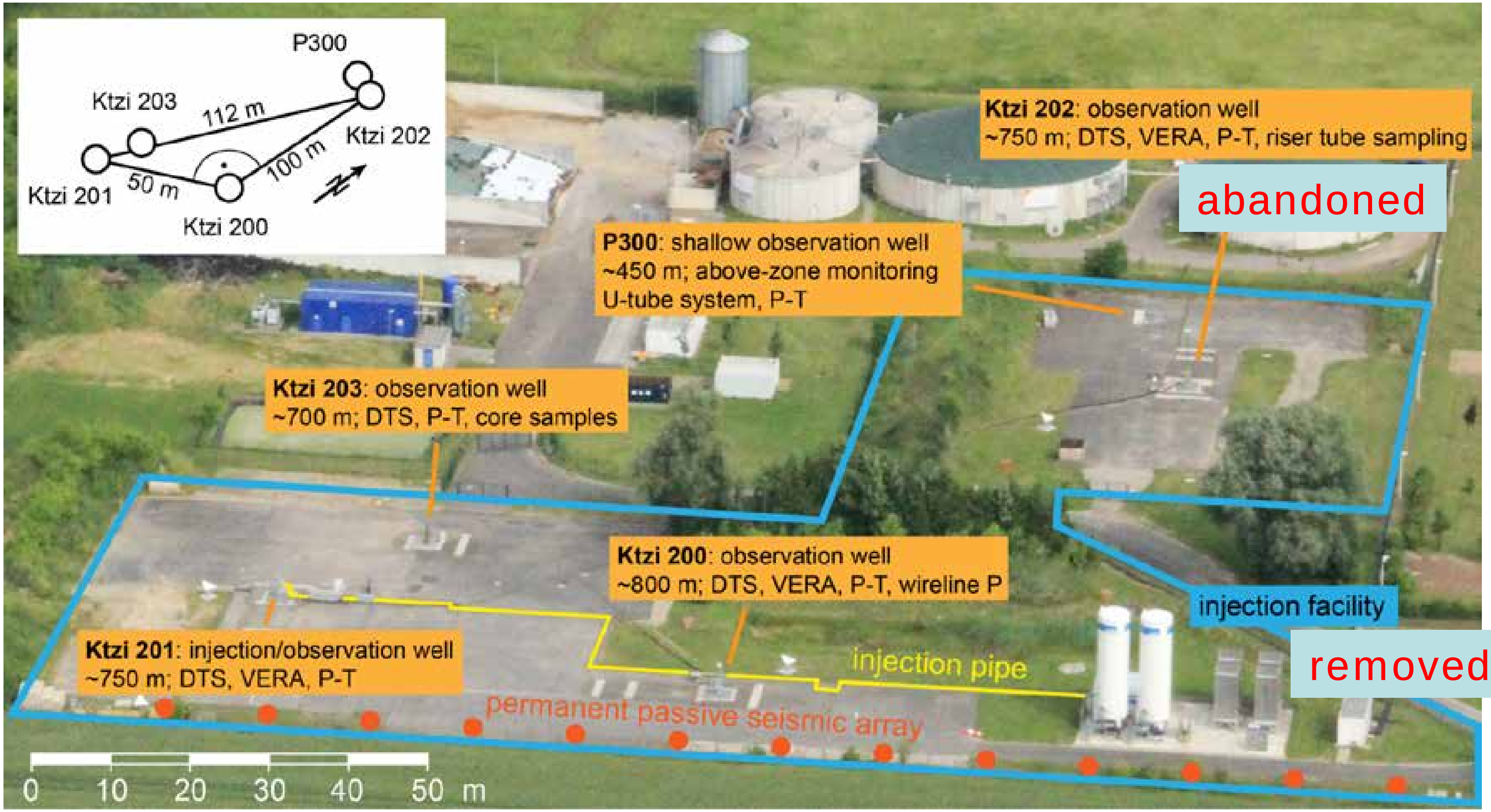


Caprock: Mudstone
Porosity: ~ 8 %
Permeability: µD

Reservoir: Sandstone
22 – 43 % Quartz
19 – 32 % Feldspar
Porosity: 13 - 26%
Permeability: ~ 100 mD

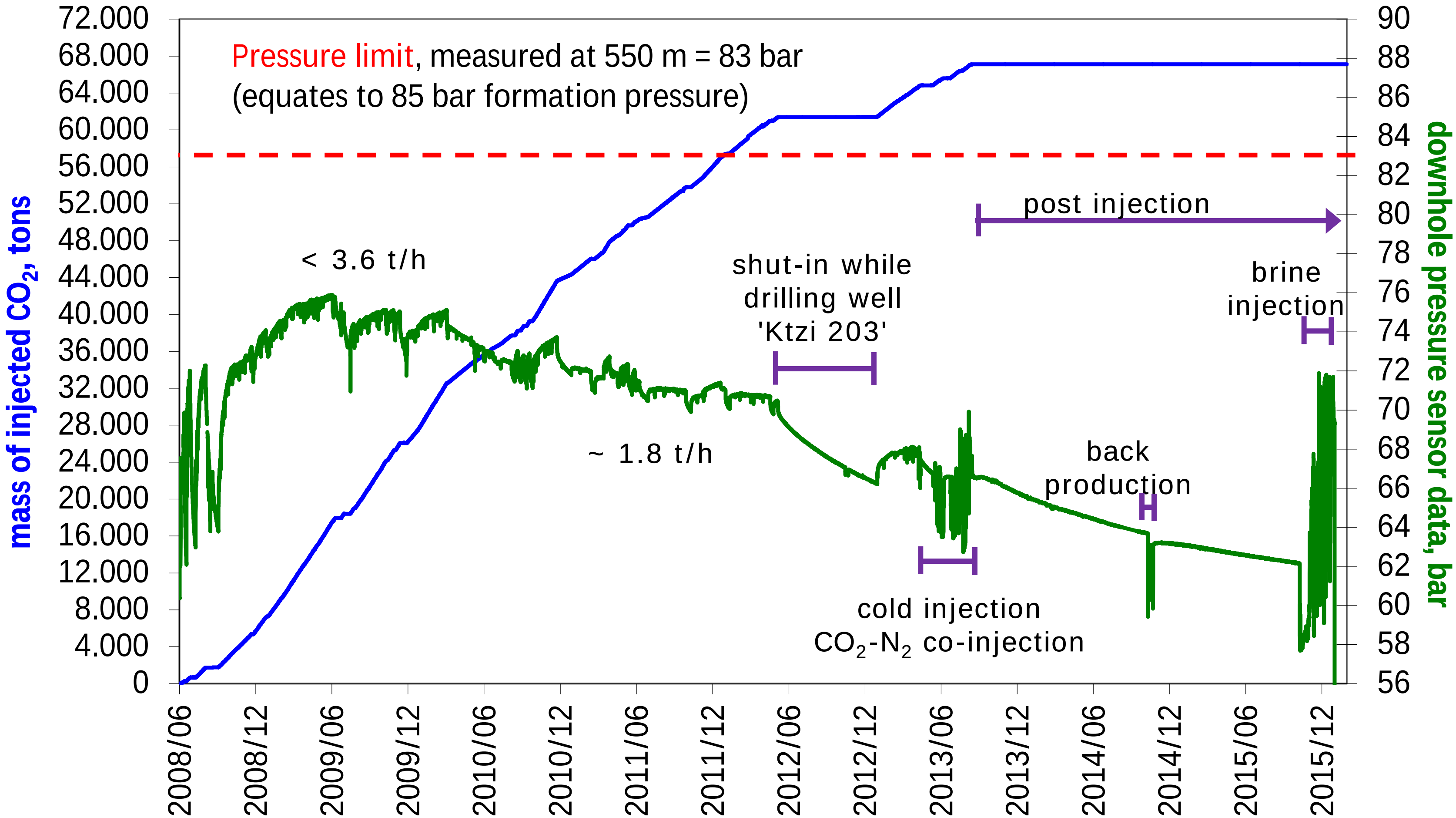
Petrology from Norden et al., 2007 / Förster et al., 2010

Facilities on the pilot site 2013



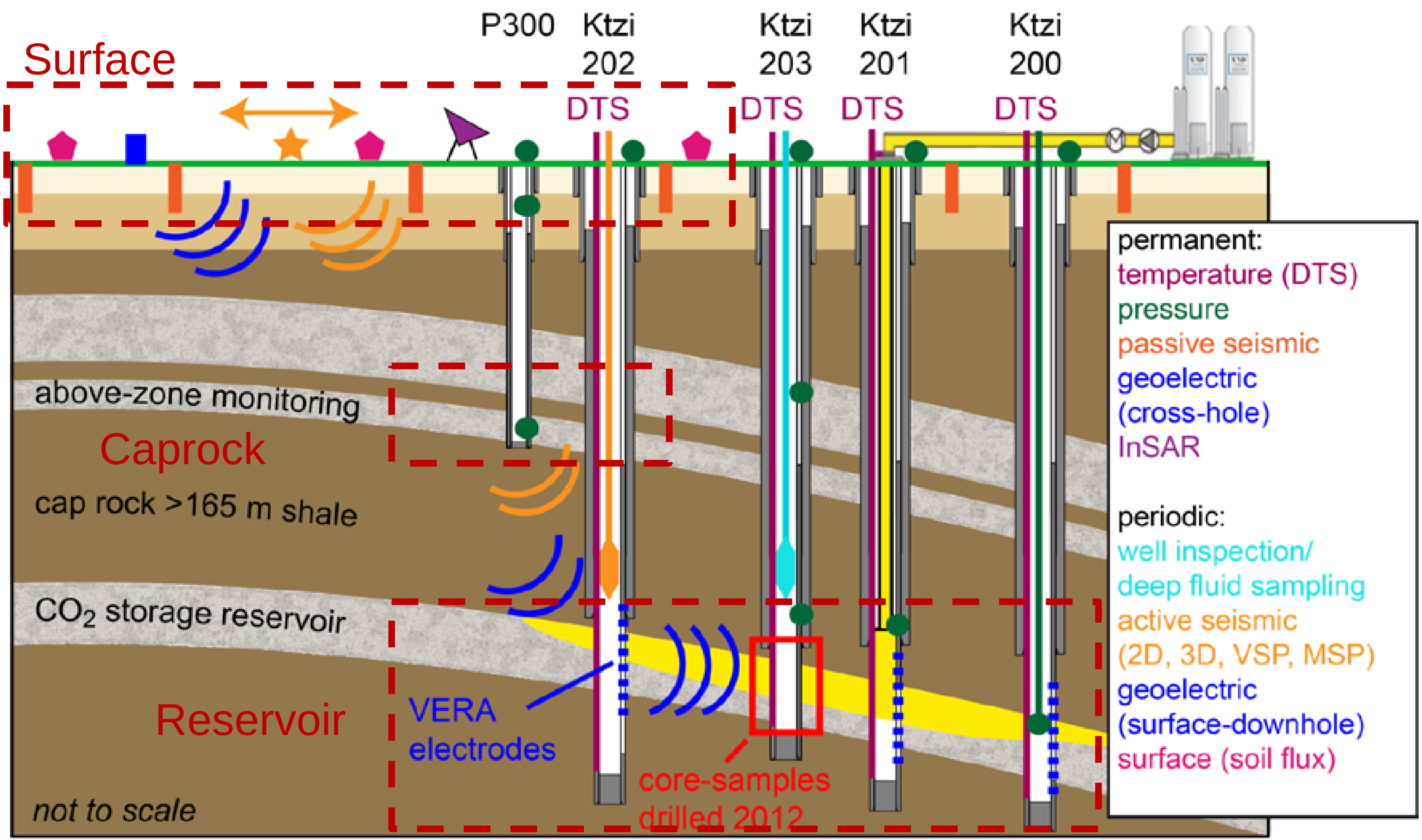
Site will be completely recultivated in 2017.

CO_2 injection and pressure history

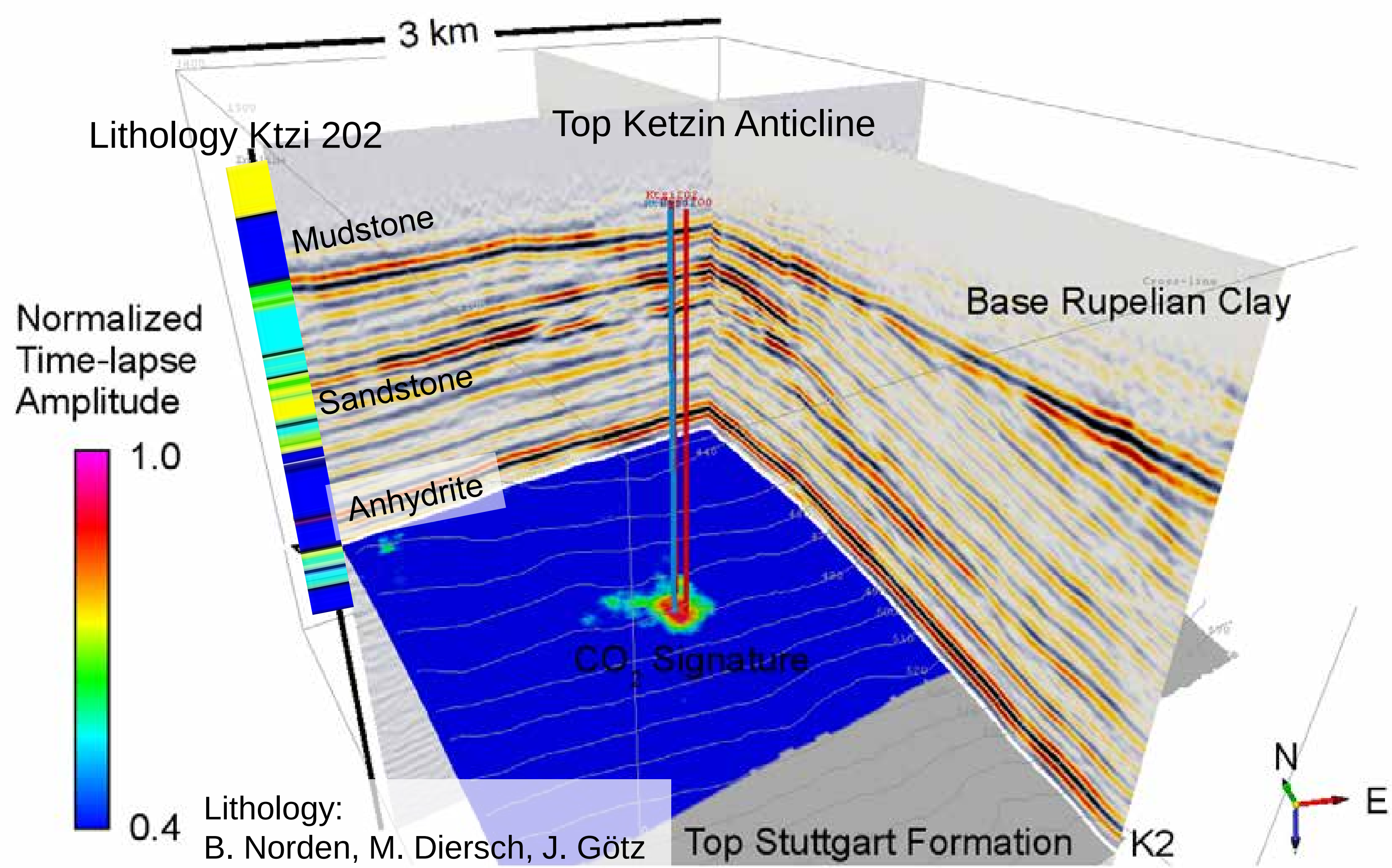


- Active injektion June 2008 – August 2013.
- 67.000 tonnes.
- Pressure response follows injection rate.

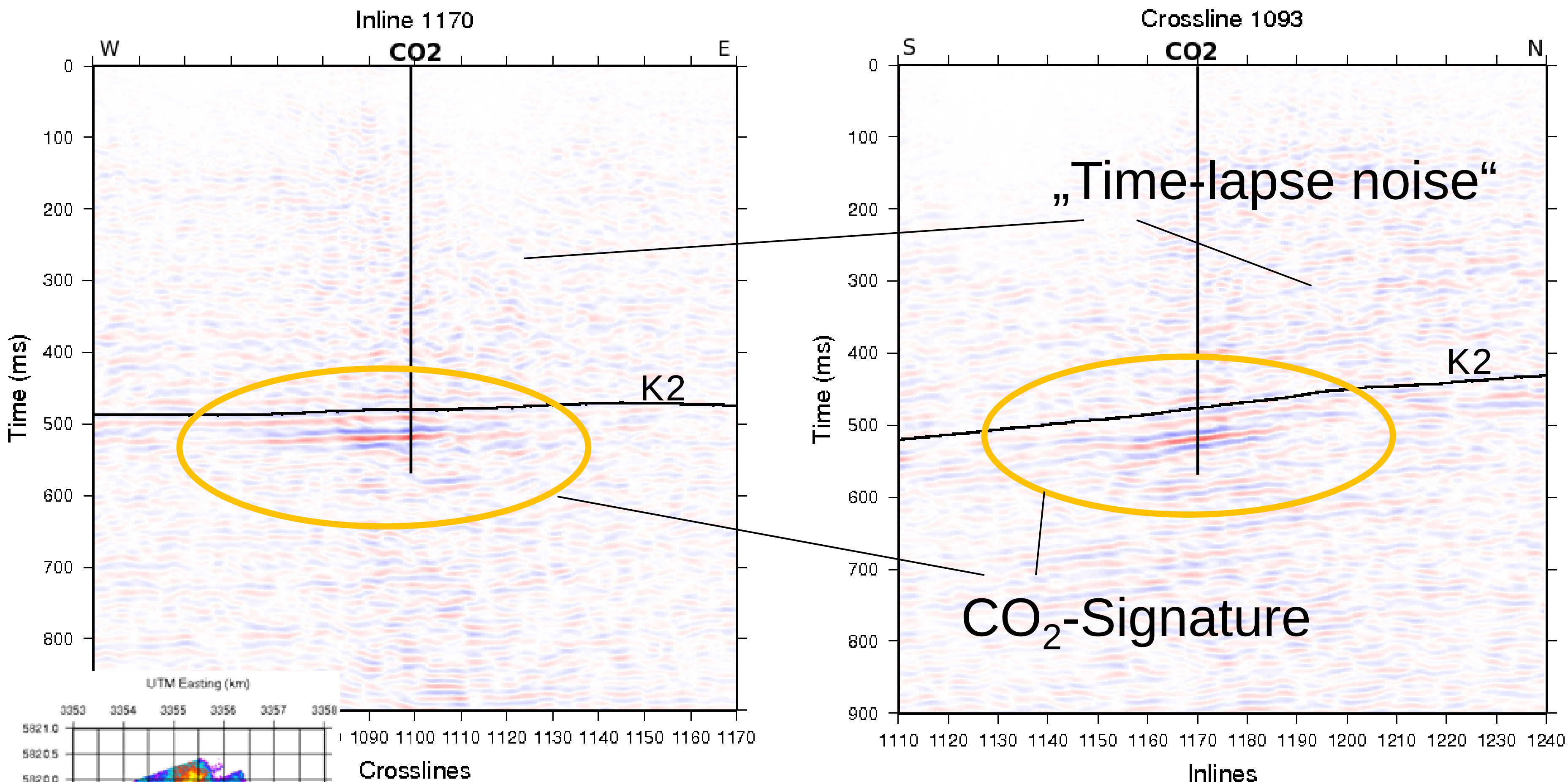
Integrated geophysical and geochemical monitoring

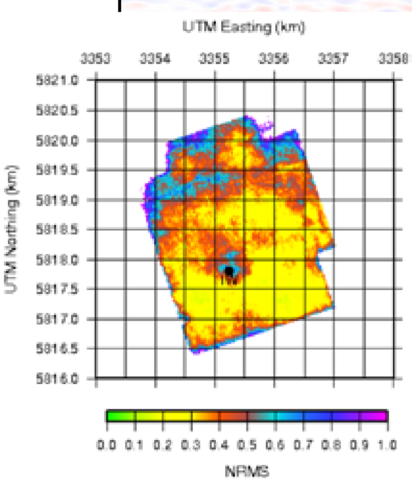


3D seismic monitoring – baseline data and time-lapse amplitude signature (2009)



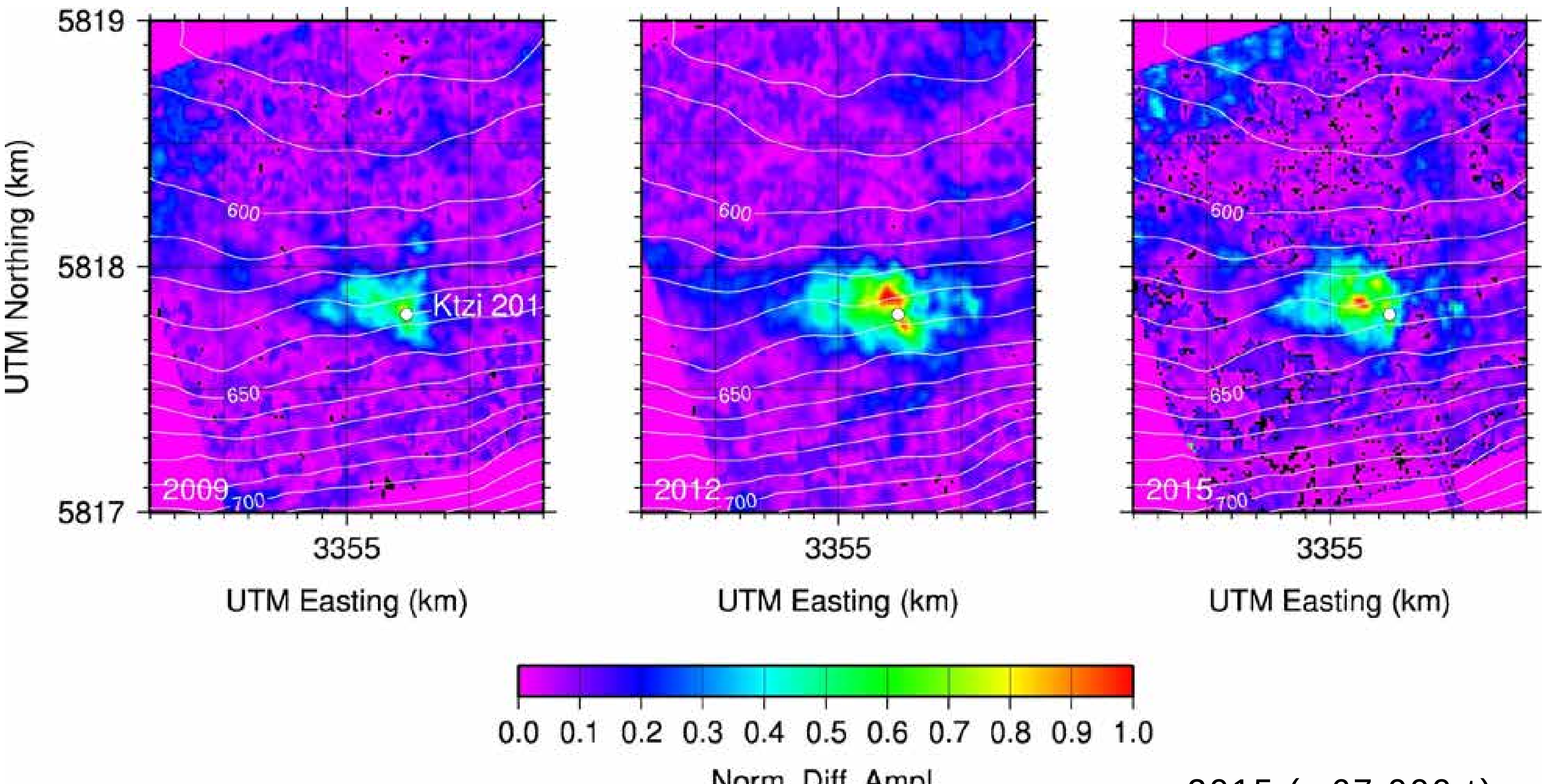
Sections of time-lapse amplitudes (2012-2005)





- Clear amplitude signature of the injected CO_2.
- Small NRMS (good repeatability).
- No indications of migration (leakage) to shallow layers.

Maps of time-lapse amplitudes in the storage layer showing stabilization of CO_2 plume



2009 (~23.000 t)

2012 (~61.000 t)

2015 (~67.000 t)
~ 2 years post-inj.

(Ivanova et al., 2012, Ivandic et al., 2015, Huang et al., 2016)

Long-term reservoir behaviour

April 2004
Start project

July 2007
Operation permit

June 2008
Start injection

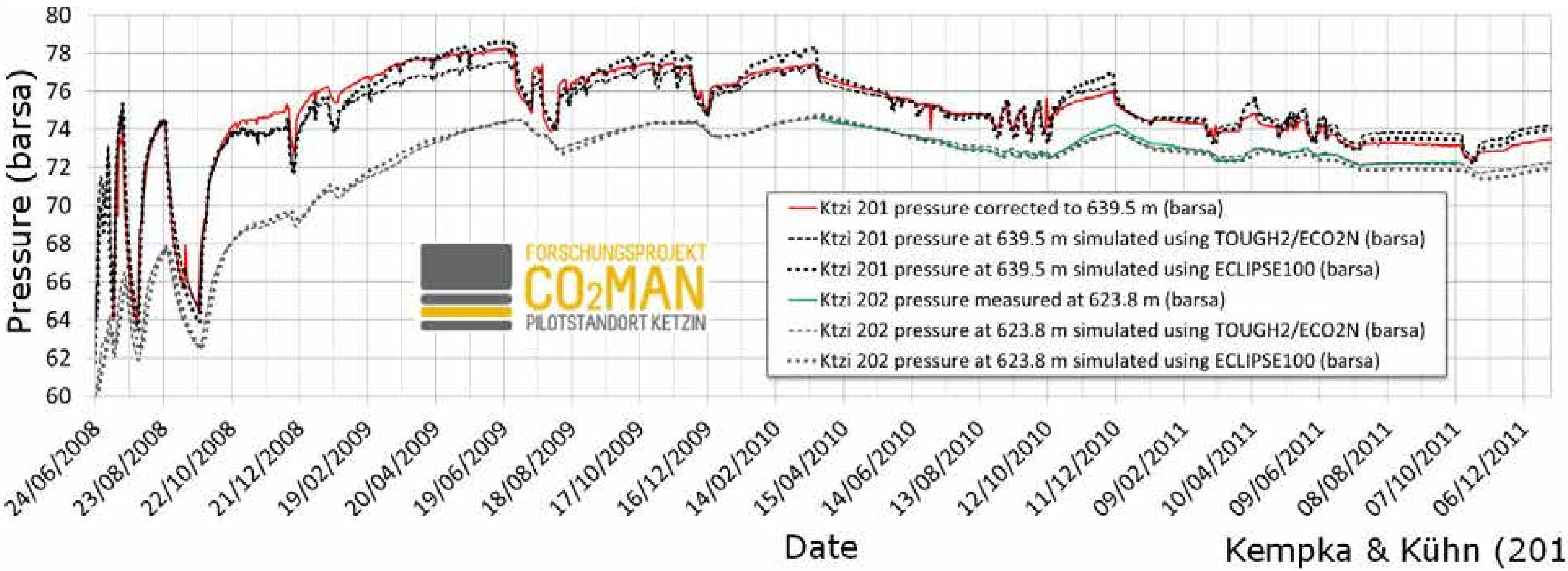
August 2013
End injection

December 2017
Transfer liability

- End of post-injection phase: Transfer of liability from operator to public.
- EU CCS Direktive defines high-level criteria for transfer:
  - **Conformity between observed and simulated reservoir behaviour.**
  - **No leakage is detected.**
  - **CO_2 plume is stable or developing towards a state of long-term stability.**
- Monitoring and numerical process simulations needed for demonstration that criteria are fulfilled.

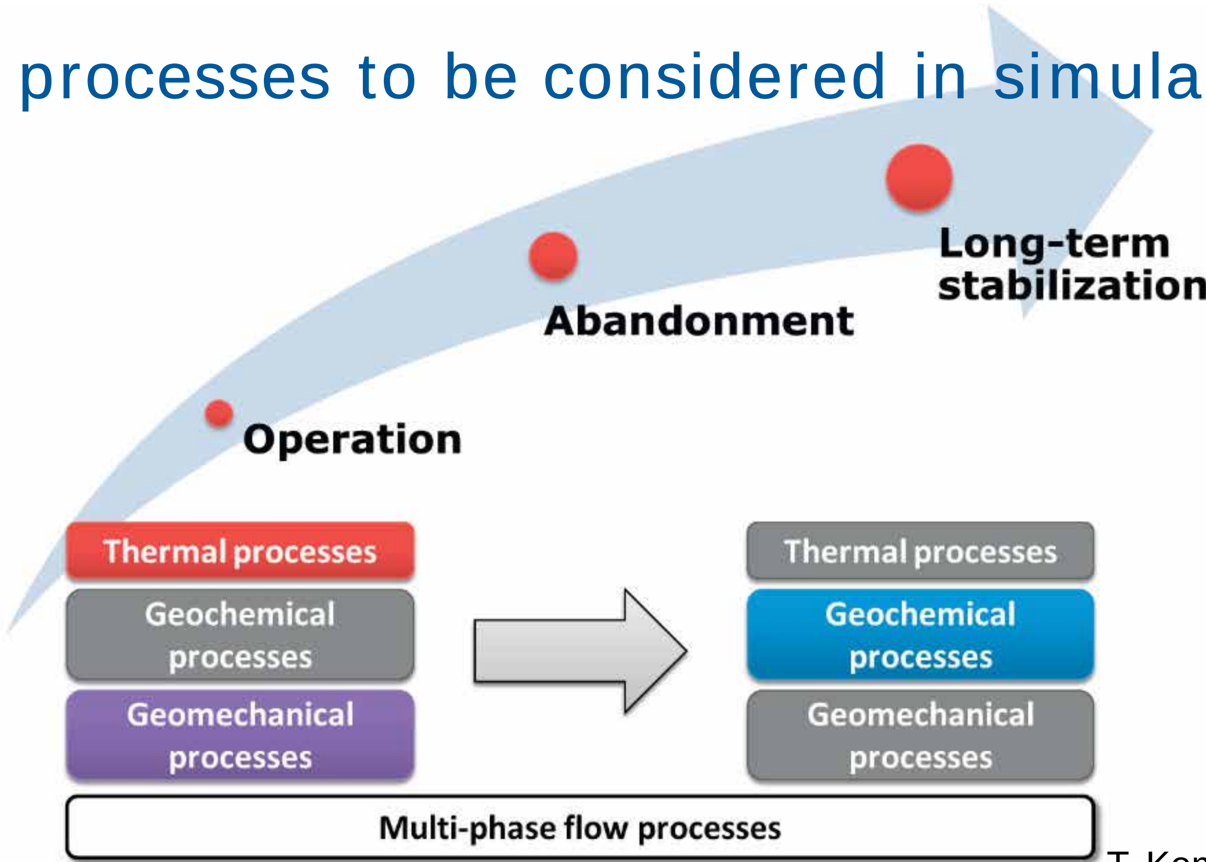
Conformity assessment and long-term stability

- Lab experiments and field trials describe relevant trapping processes over a limited spatial and temporal scale.
- Numerical simulations needed for long-term processes.
- Conformity between numerical simulations and monitoring results prerequisite for long-term predictions (e.g.: pressure evolution or CO_2 migration pattern).



Kempka & Kühn (2013)

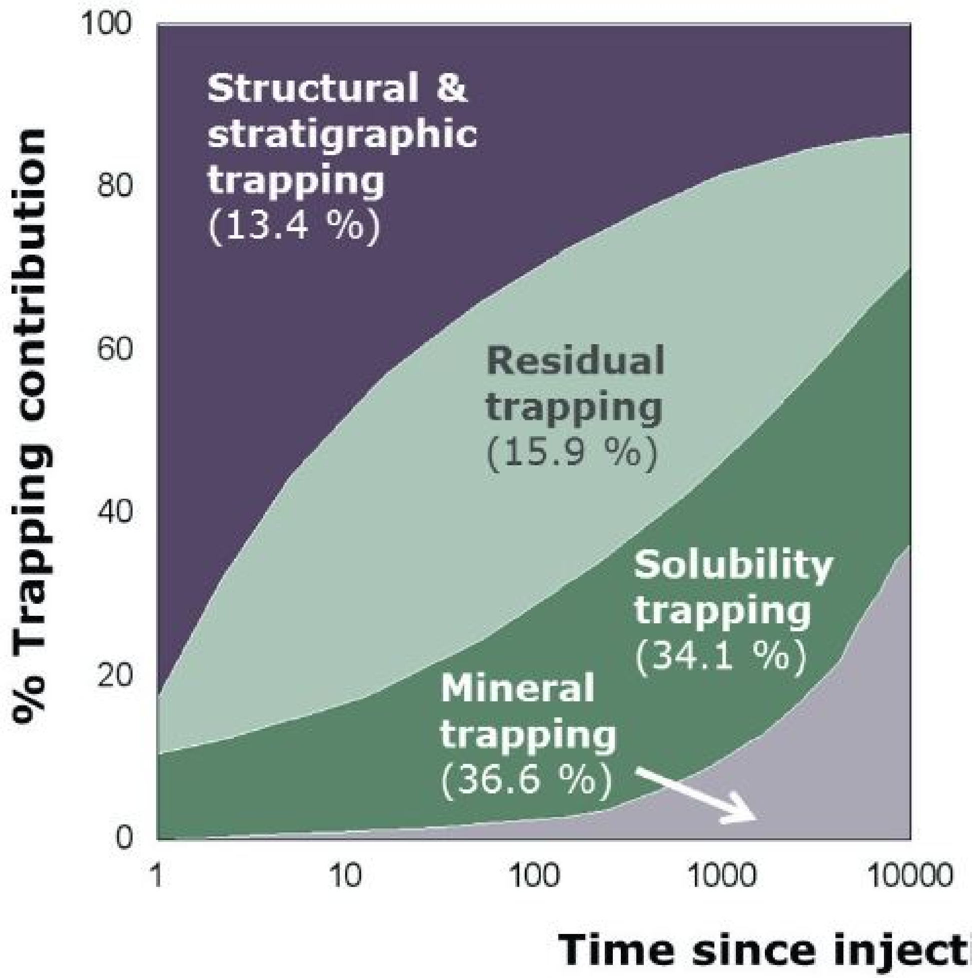
Various processes to be considered in simulation



T. Kempka (GFZ)

- Different processes dominate during operational, post-closure and long-term stabilization phases.
- Long-term predictions: simplified coupling of THM and C on coarse grid for reactive transport processes.

Quantification of trapping mechanisms

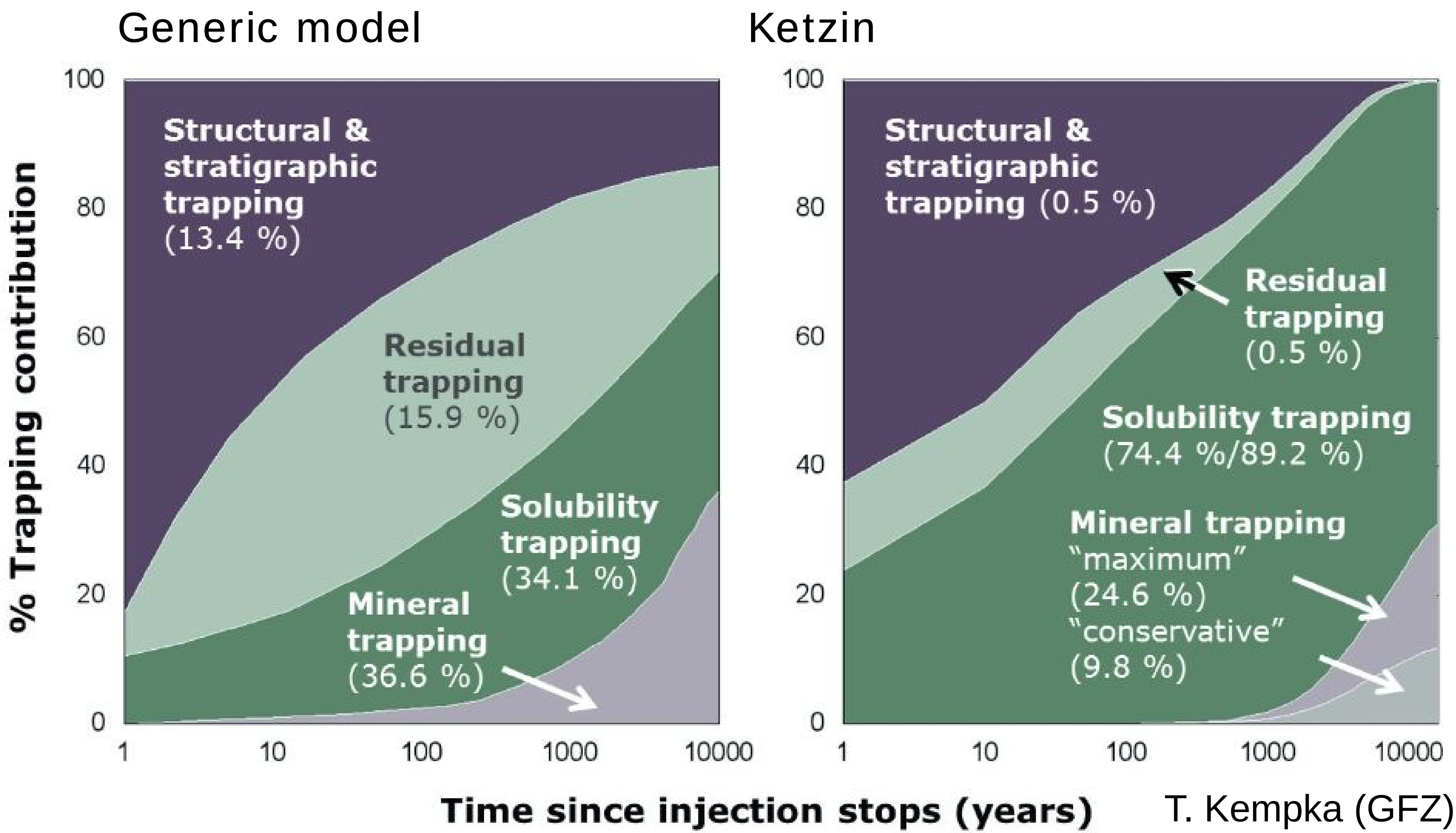


IPCC 2005:

Trapping mechanisms quantified for a generic model.

- Stratigraphy
- Residual trapping
- Dissolution
- Mineralization

Assessment for Ketzin shows site specific conditions



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Summary and conclusions

- Capture and storage of carbon dioxide (CCS) one of globally relevant options for reducing GHG emissions in transitional period of continuing usage of fossile energy sources.
- Several pilot and full scale storage projects have demonstrated feasibility of geological storage.
- Monitoring – modelling loop needs to be implemented for each storage site depending on site specific conditions.
- Long-term simulations suggest that dissolution and mineral trapping (carbonation) are most relevant (and safest) trapping mechanisms.
- Implementation of CCS needs open communication for gaining public acceptance.


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