CASTOR

CO_2, from Capture to Storage

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GEOGREEN

CSLF Technical Group Meeting
15-17 March 2010, Pau, France

CASTOR targets

- Develop and validate innovative technologies needed to capture 10% of CO_2 emitted in Europe (30% of CO_2 emitted by power and industrial plants)
  - Reduce the cost of CO_2 post-combustion capture,

    ⇒ *from 50-60 € to 20-30 € / ton of CO_2 avoided*
  - Contribute to the feasibility & acceptance of the geological storage concept

    ⇒ *study 4 new European storage sites*
  - Start the development of an integrated strategy connecting capture, transport and storage options for Europe

CASTOR Partnership

Funded by the European Commission under the 6th Framework Program

R&D	Oil & Gas	Power Companies	Manufacturers
IFP (FR)	STATOIL (NO)	VATTENFALL (SE)	ALSTOM POWER (FR)
TNO (NL)	GDF (FR)	DONG ENERGY (DK)	DOOSAN BABCOCK (UK)
SINTEF (NO)	REPSOL (SP)	RWE (DE)	SIEMENS (DE)
NTNU (NO)	ENI (IT)	PPC (GR)	BASF (DE)
BGS (UK)	ROHOEL (AT)	EON-UK (UK)	GVS (IT)
BGR (DE)		SUEZ-ELECTRABEL (BE)	
BRGM (FR)			
GEUS (DK)			
IMPERIAL (UK)			
OGS (IT)			
TWENTE U. (NL)			
STUTTGARTT U. (DE)			

Co-ordinator: IFP

Chair of the Executive Board: Statoil

31 partners from 12 European Countries

Duration: 4 years

Budget: 16 M€

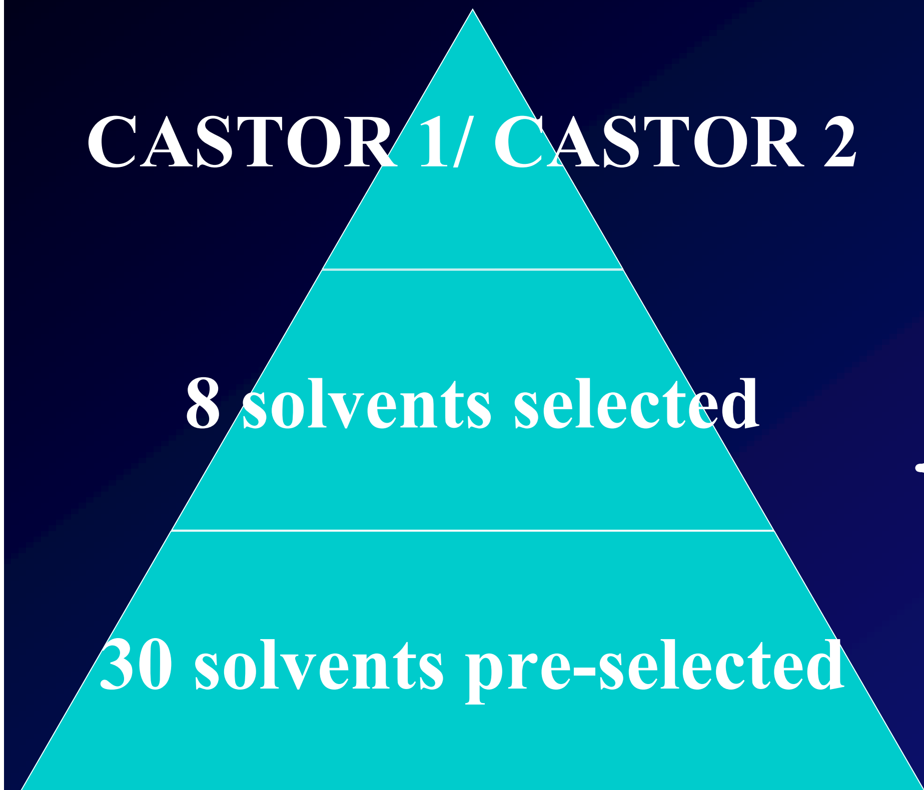
Post-combustion capture

- Objectives
  - Development of absorption liquids, with a thermal energy consumption of 2.0 GJ/tonne CO_2 at 90% recovery rates
  - Resulting costs per tonne CO_2 avoided not higher than 20 to 30 €/tonne CO_2, depending on the type of fuel (natural gas, coal, lignite)
  - Pilot plant tests showing the reliability and efficiency of the post-combustion capture process

Post-Combustion Capture
Fast track to market

- **Easy add-on to existing and new power/industrial plants (Retrofit)**
  - Solution needed for current installed base
  - New PCC ready plants is easy
- **Time to Market – large scale 2nd generation systems in 2015-2020**
  - Technically, all process steps are proven on reasonable scale
  - Further cost reduction and scale-up is the issue
- **Potential to reduce cost by 50% from 40 to 20 EUR/ton by 2020**
  - Learning by doing similar to introduction SO_2 capture
  - Learning by searching will lead to better solvents / processes
- **More flexibility in switching between capture – no capture**

Solvent development procedure



Pilot plant experiments

↑

Lab-pilot experiments

↑

Process design studies
Degradation studies
Corrosion studies
Solvent characterisation

↑

Solvent screening studies

⇒ Study and selection of 3 solvents for tests at pilot plant in Esbjerg: MEA, CASTOR-1 solvent, CASTOR-2 solvent

Corrosion test

Flat rectangular samples

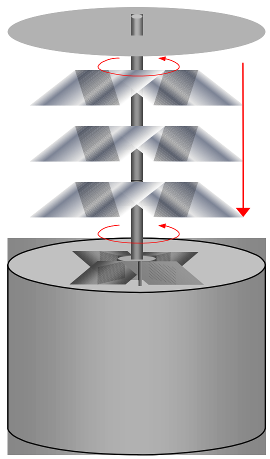
30mm x 30mm x 2mm

Polished to grade 600 SiC

Metal grades :

AISI 1028 (carbon steel)

AISI 304 / AISI 316 (SS)



Conditions:

- 120 °C
- 2 bar
- 1 – 3 months

Weight loss corrosion evaluation

$$\textbf{Corrosion rate } (\mu m/year) = \frac{\Delta g(g)}{area(cm^2) \times density(g/cm^3)} \times \frac{365 \times 10^4}{E.T.(days)}$$

Membranes contactors

- Three membrane types developed and tested:
  - Transversal flow module
  - Flat membrane module
  - Fibre module
- Practical data generated

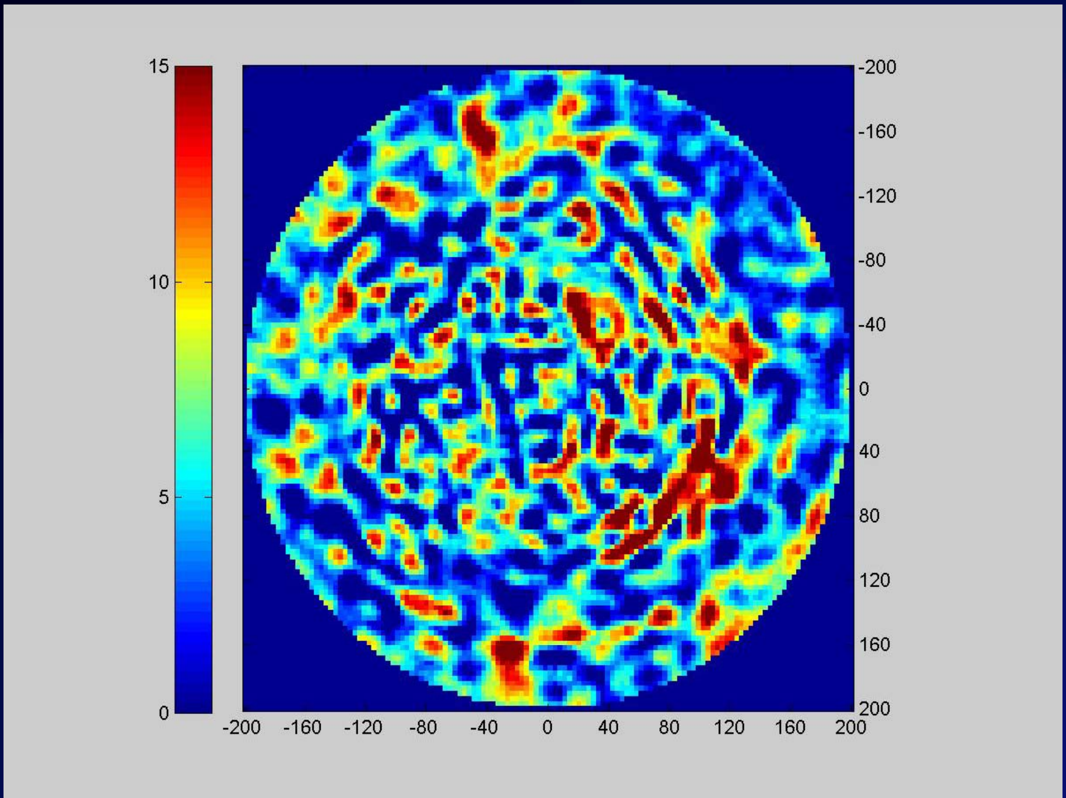
Advanced processes

- Process optimization of the absorption / desorption loop
- Packing material characterization
  - Two packings fully characterized (IMTP50 & ME252Y)
  - Hydrodynamic test on pilot plant (Esbjerg) equipped with IMTP50.

Random Packing
IMTP50
Koch Glitsch

Structured Packing
MellapakPlus 252.Y
Sulzer Chemtech

Advanced processes



Modeling on liquid distribution
For IMPT50 internals

Q_L = 35 $m^3/m^2/h$

CASTOR pilot plant

Absorber

Desorber

Capacity: 1 t CO2/h

5000 Nm3/h flue gas (coal combustion)

In operation since early 2006

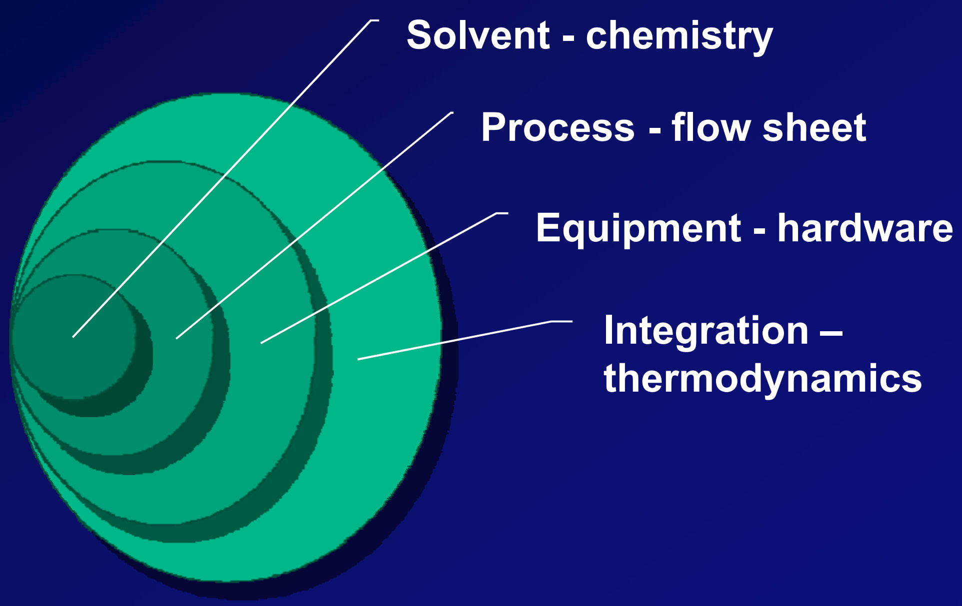
January - March 2006: MEA-testing for 1000 hrs
September - November 2006: 2nd MEA-testing for 1000 hrs
March - June 2007: CASTOR1-testing
September - December 2007: CASTOR2-testing

Base Case overview with and without capture (MEA)

Item	Bituminous coal		GTCC		Lignite DE	
	without Capture	Capture Integrated	without capture	Capture Integrated	without capture	Capture Integrated
Gross Capacity (MW, LHV)	600	600	393	393	1000	1000
Net power output (MW)	575	442	385	325	920	646
Thermal efficiency, % (LHV)	**45**	**34.0**	**56.5**	**47.6**	**49.2**	**34.5**
CO_2 emission (kg/MWh)	772	103	366	42	812	116

Major technical results / deliverables

- New solvents resulting in less heat for regeneration
- Advanced processes resulting in lower power output losses
- Advanced equipment (membrane contactors) resulting in lower investment costs
- Pilot plant operating with real flue gas allowing hands-on-experience with absorption technology
- Methods for integration and optimisation resulting in lower power output losses



Conclusions on capture (1)

1. Development of absorption liquids, with a thermal energy consumption of 2 GJ/tonne CO_2 at 90% recovery rates
   - Reference process: ~4GJ/tonne CO_2
   - With CASTOR2 solvent: down to 3.5GJ/tonne CO_2 (12%)
   - With integration: down to 3.2 GJ/tonne CO_2 (20%)

2. Resulting costs per tonne CO_2 avoided not higher than 20 to 30 €/tonne CO_2, depending on the type of fuel
   - Reference process: 40-50 €/tonne CO_2
   - With MEA process optimization: 35-37 €/tonne CO_2 (2005 ref)

$\Rightarrow$ First steps to the ambitious goals are made

Conclusions on capture (2)

3. European pilot plant tests showing the reliability and efficiency of the post-combustion capture process
   - Operational pilot plant
   - Validation procedures
   - Validation experience
   - Validation results
   - Environmental awareness
   - Queue of requests from industry

⇒ CASTOR made validation basis for Post-Combustion-Capture development

CO_2 Geological Storage

No capture without storage!

General objectives

- Develop and apply a methodology for the selection and the secure management of storage sites by improving assessment methods, defining acceptance criteria, and developing a strategy for safety-focussed, cost-effective site monitoring
- Improve the "Best Practice Manual", started with the SACS/Sleipner project, by adding 4 more real-site cases

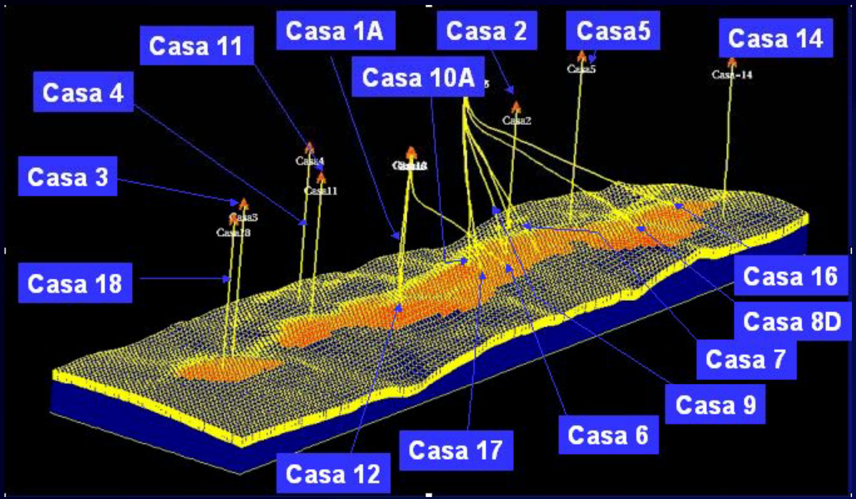
CO_2 Geological Storage

- Four field cases to cover some geological variability:
  - clastics (sandstones) vs. carbonates
  - onshore vs. offshore (consequences for monitoring)
  - storage site types: depleted oil field, depleted gas field, enhanced gas recovery, aquifer
  - some cases with good sample access, others with chance for monitoring
    (→ covers many methods, focus different from field to field)
  - cases in different countries to give many countries their “own case” (good for public acceptance)
- Two cross-disciplinary activities
  - Preventive and corrective actions
  - Criteria for site selection & site mgmt

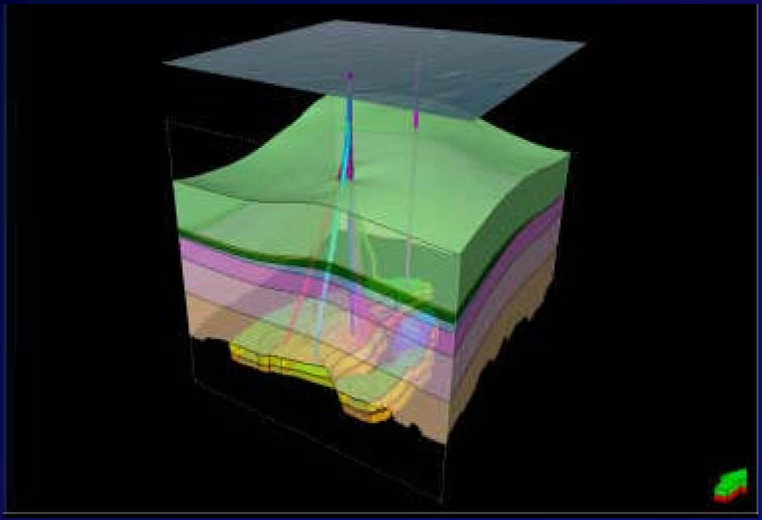
CASTOR CO_2 storage initiatives

- Spain: offshore oil reservoir (Casablanca, REPSOL)
- Norway: offshore aquifer (Snohvit)
- Austria: offshore gas field (Atzbach, Rohoel)
- The Netherlands: offshore gas field (K12b Gaz de France)

Ketzin (Germany) – CO2Sink EU project
In-Salah (Algeria)



Casablanca reservoir model



K12-B geological model

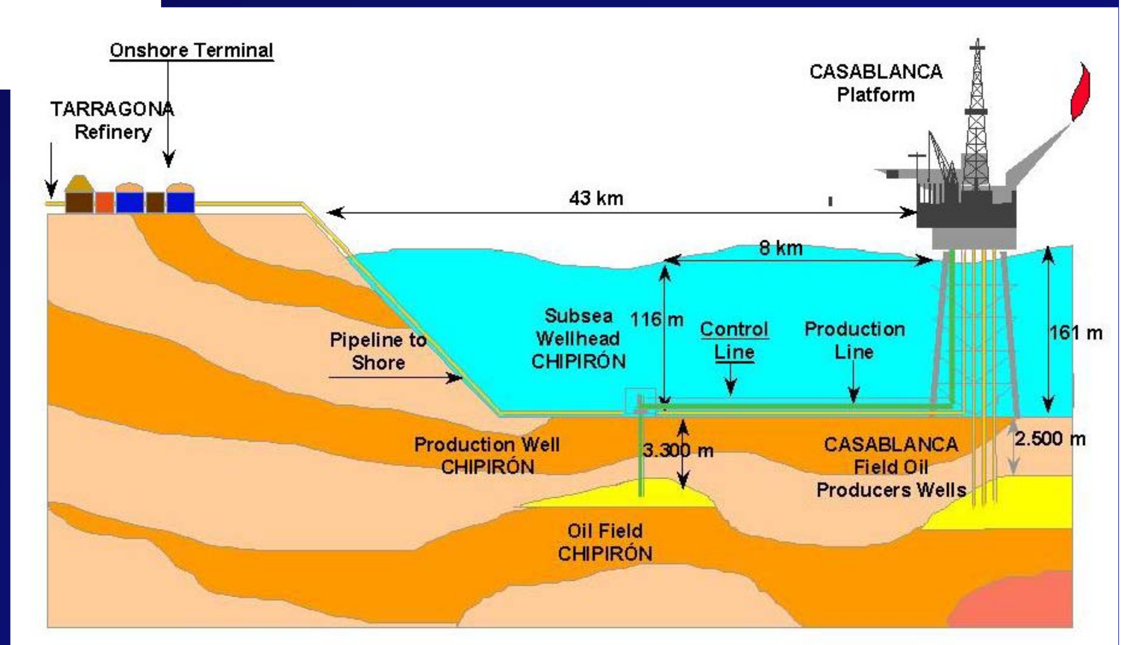
Rock samples from Atzbach

CASTOR Work Flow for Site studies

- Data gathering, geomodel building
- Analysis of fluid flow properties
- Reservoir simulation
- Geochemical, geomechanical experiments and simulations
- Well integrity analysis
- Long term modelling and simulation
- Monitoring of stored (and escaping!) CO_2
- Integrated risk assessment analysis

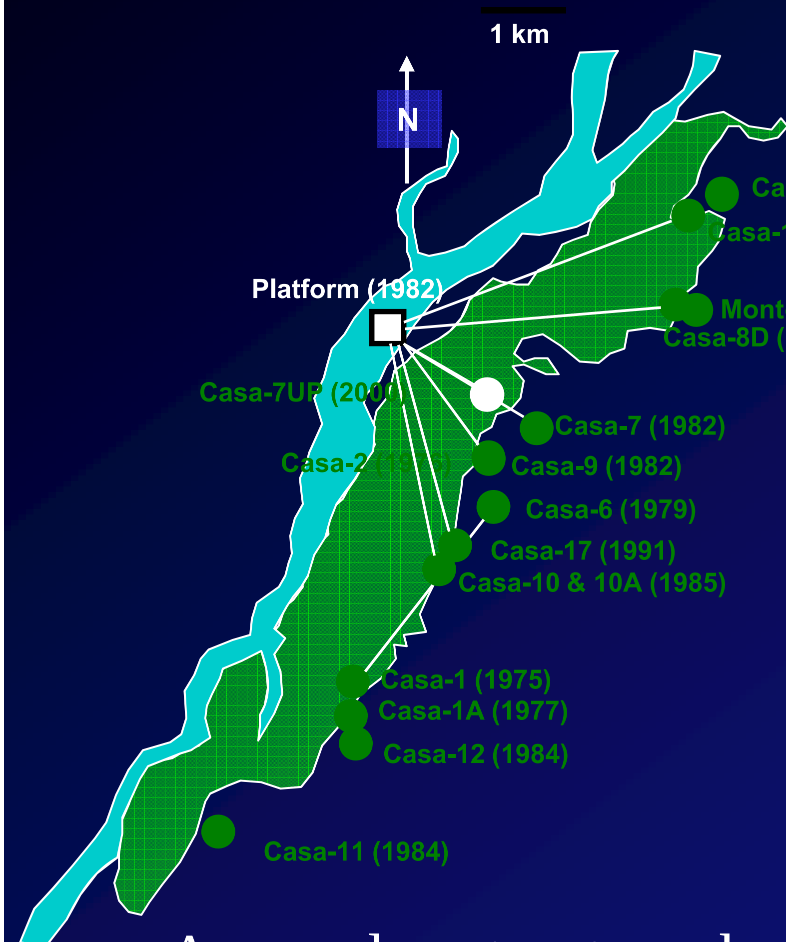
Casablanca oilfield (Repsol, Spain)

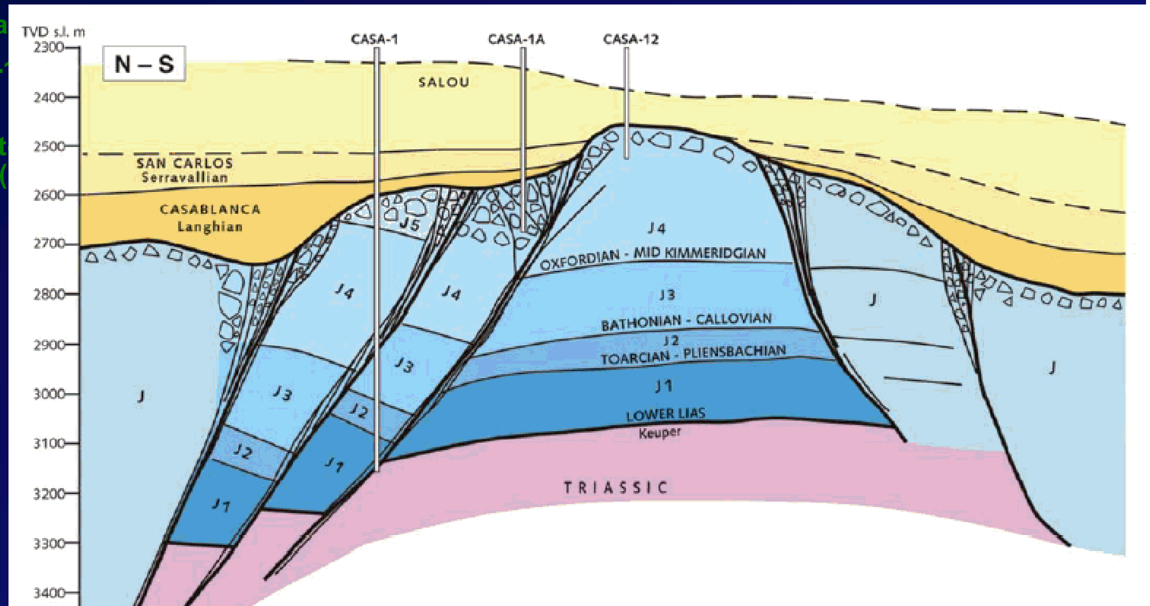
- Depleted oil-field in carbonates
- Depth: 2500 m
- Injection of 0,5 Mt CO_2 / year from the Tarragona Refinery



repsolypf.com

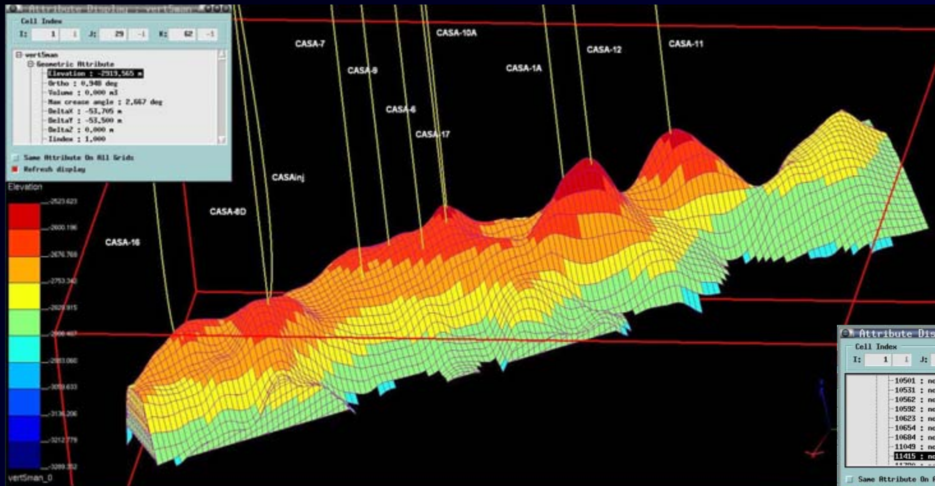
Casablanca oilfield (Repsol, Spain)

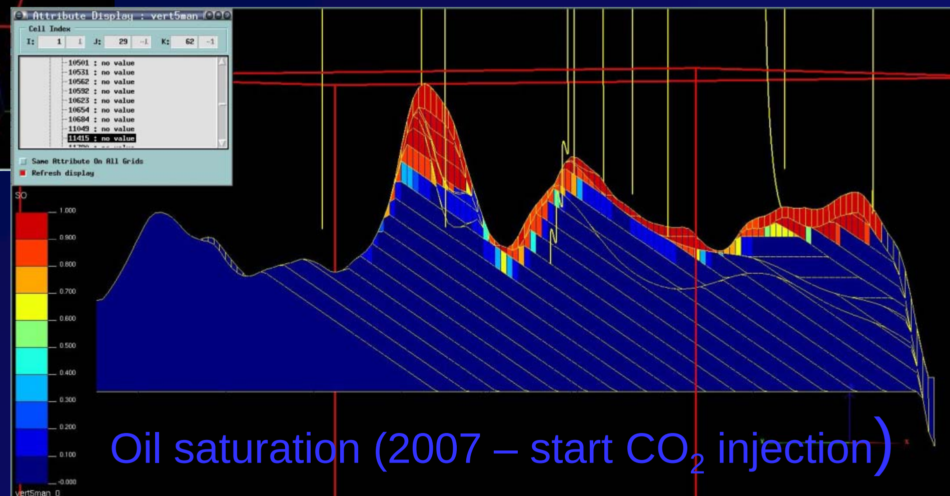




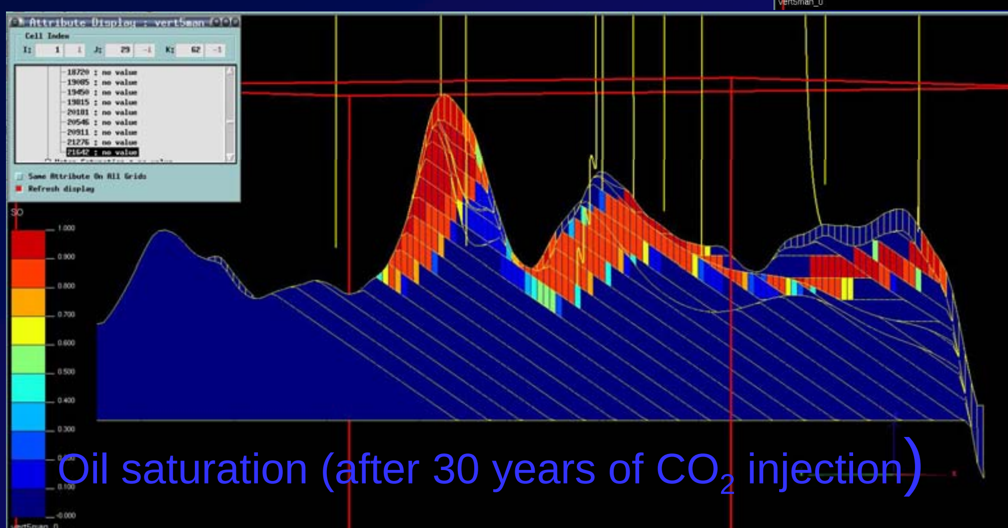
Cross section through Casa-1, Casa-1A and Casa-12

A complex structure: karstified limestones, but a good seal: marns and shales



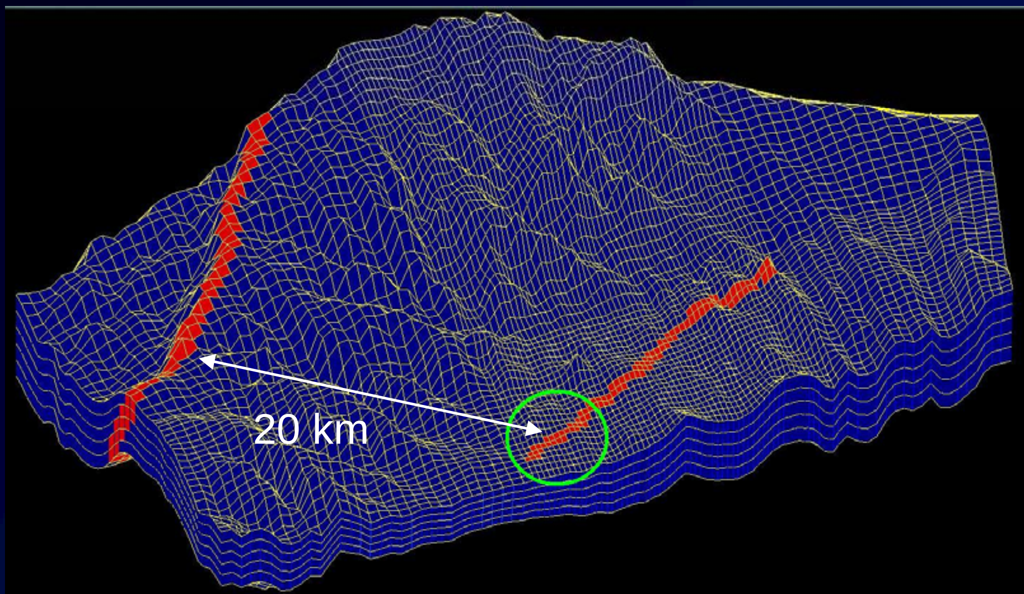


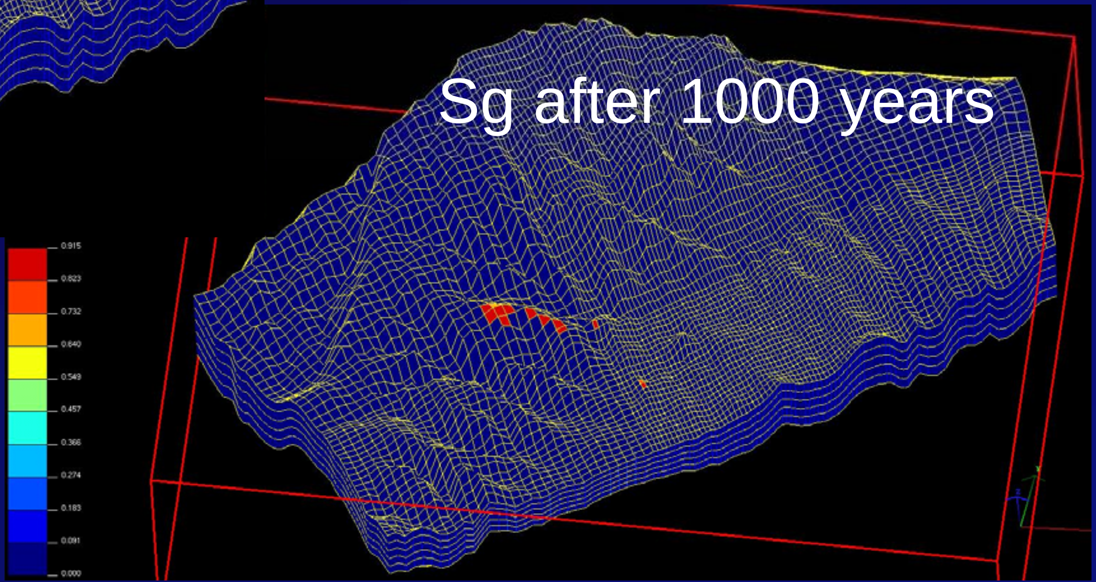
Oil saturation (2007 – start CO_2 injection)



Oil saturation (after 30 years of CO_2 injection)

Casablanca: Long term behaviour of the CO_2 and risk of leakage along faults

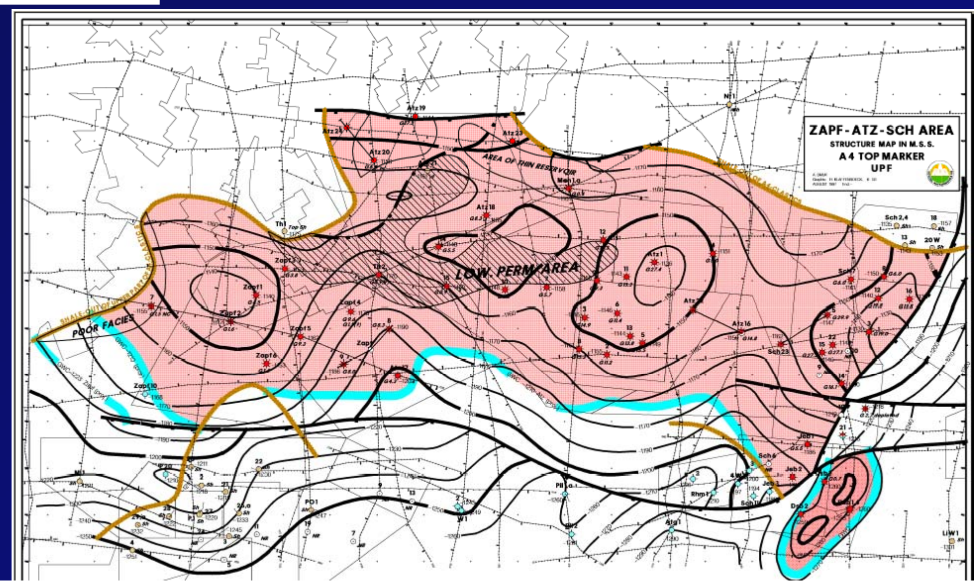




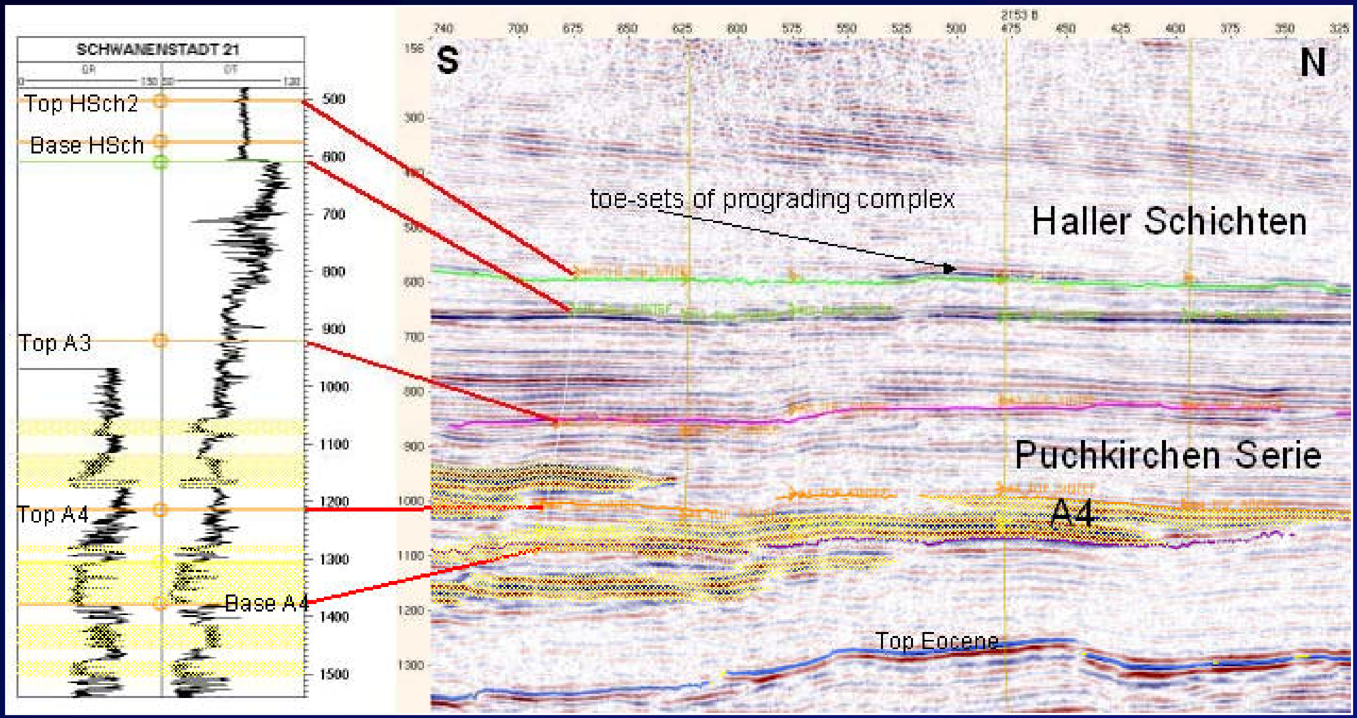
Result:
The CO_2 does not reach the major fault after 1000 years of leakage whatever the scenarios

Atzbach-Schwanenstadt Gas Field (Rohoel, Austria)

- Sandstone gasfield, onshore
- Depth: 1600 m
- Possible injection of 200,000 t CO_2/year
- Opportunity for EGR



Atzbach-Schwanenstadt Gas Field (Rohoel, Austria)



Focus: general storage site evaluation; seal properties (fluid flow, geochemistry, geomechanics); long-term safety / risk assessment; onshore monitoring methods; assessment of possibilities for enhanced gas recovery

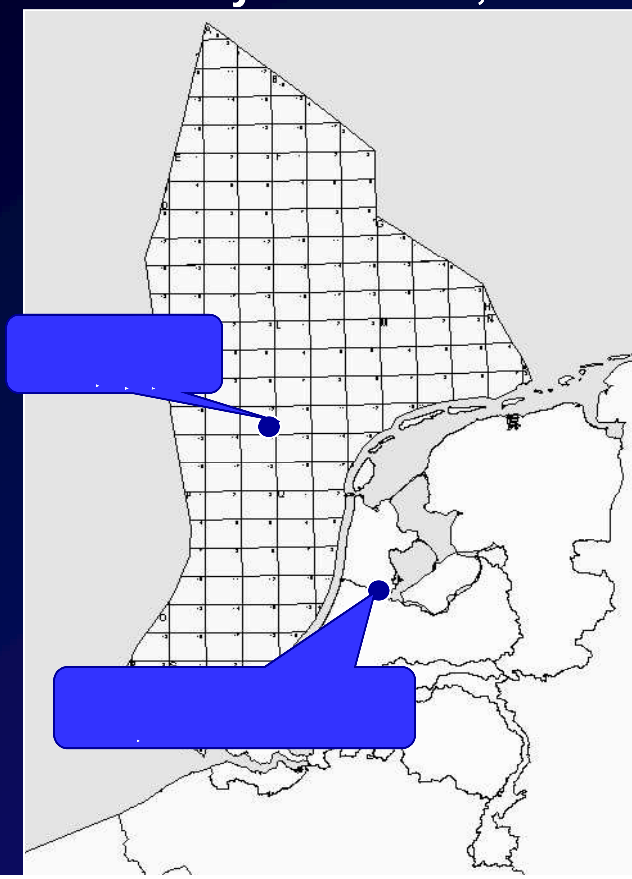
Atzbach-Schwanenstadt Gas Field: Soil gas monitoring

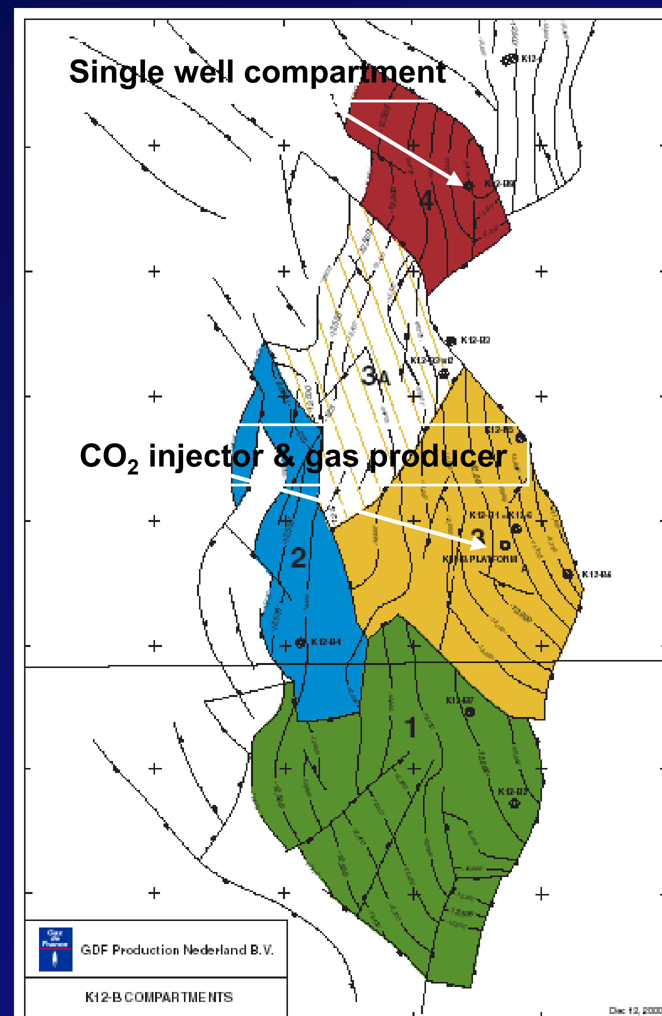
- Make recommendations for soil gas monitoring plan above potential CO2 storage site on land
- Soil gas composition (CH_4, CO_2, $\delta^{13}C$)
- Soil gas flux ($CH_4 + CO_2$, $g/m^2/day$)
- Results:
  - Soils are high CO_2 soils
  - CO_2 predominantly from oxidation of soil humic matter
  - CO_2 soil gas in the eastern sector partly from methane oxidation
  - CO_2 fluxes:
    - Highest during spring, very weak during winter season
    - Data from the summer season not satisfying up to now

- Additional monitoring station is planned (strong need for longer-term data sets at two different stations)
- CO2GeoNet likes to make this site an European test site

K12B Gas Field (Gaz de France, The Netherlands)

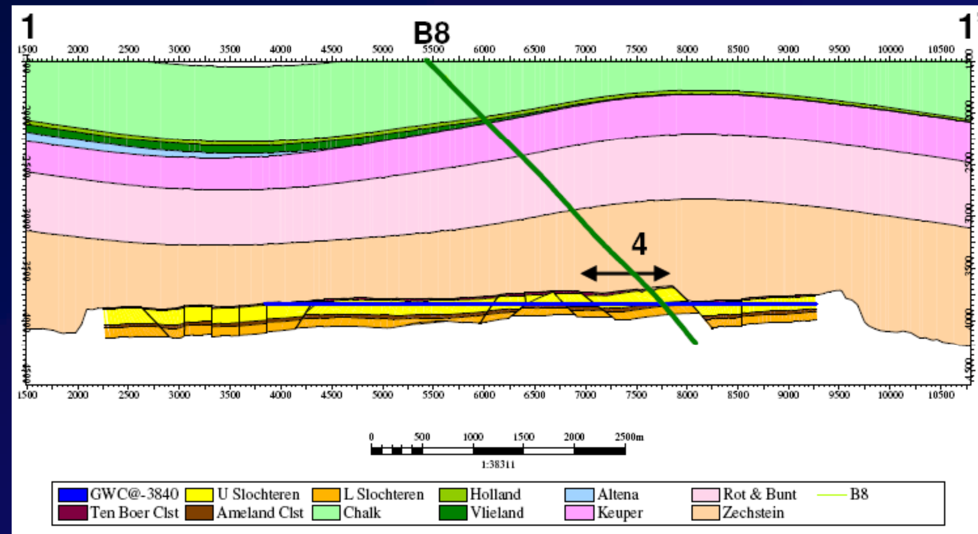
- Gasfield in Rotliengen clastics, offshore
- Depth: 3500-4000 m
- High temperature: 128 °C, low pressure: 40 bars
- Small-scale injection test: 20 000 t/year in mid-2004
- 480 000 t/year in 2008, 8 Mt total

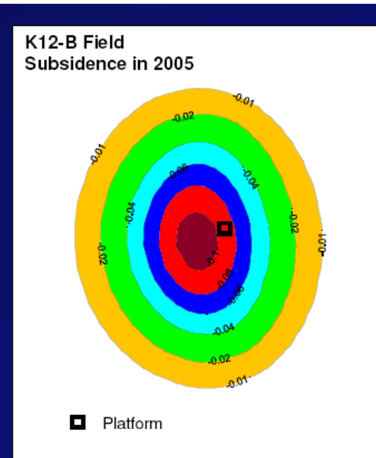


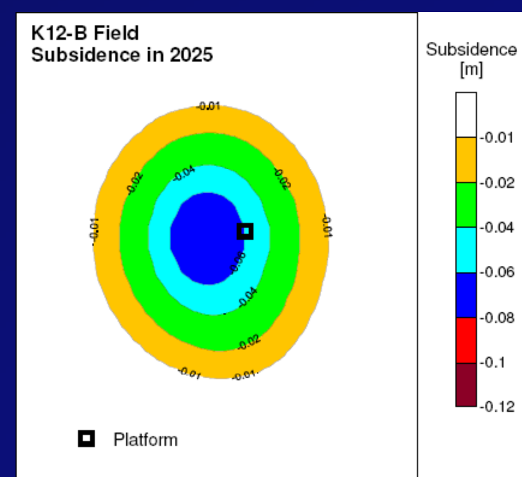


K12-B field case: Geomechanical impact

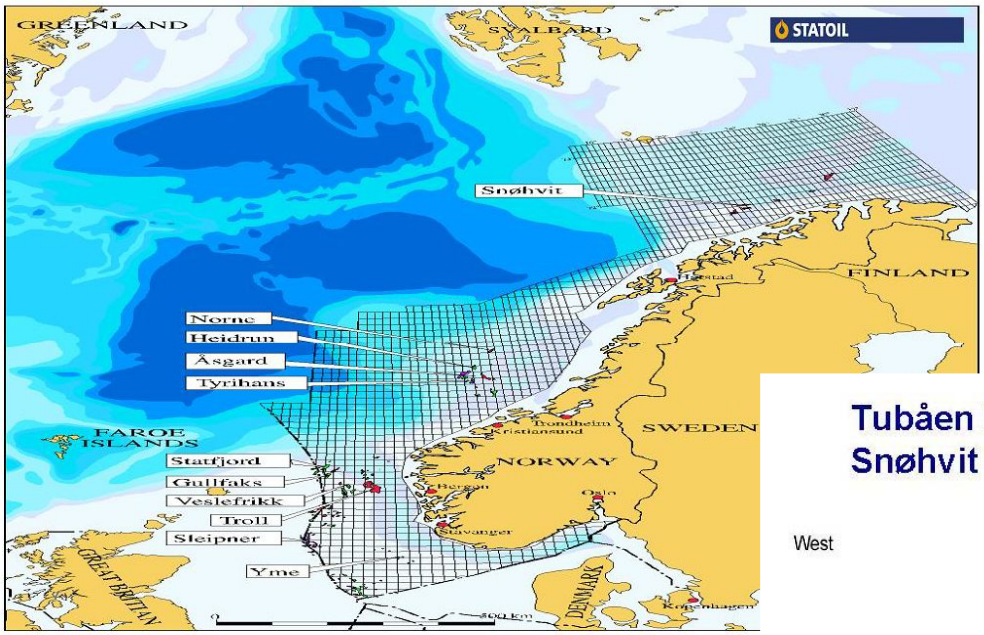
- Assess impact of reservoir depletion and subsequent CO_2 injection on mechanical stability and sealing capacity of bounding seals (caprock and faults)
- Based on improved geological and reservoir models developed in CASTOR
- Results
  - Impact very limited
  - Deterioration of mechanical properties of importance for sealing very unlikely
  - Reasons: Rock salt
  - Deformation of seabed of little importance



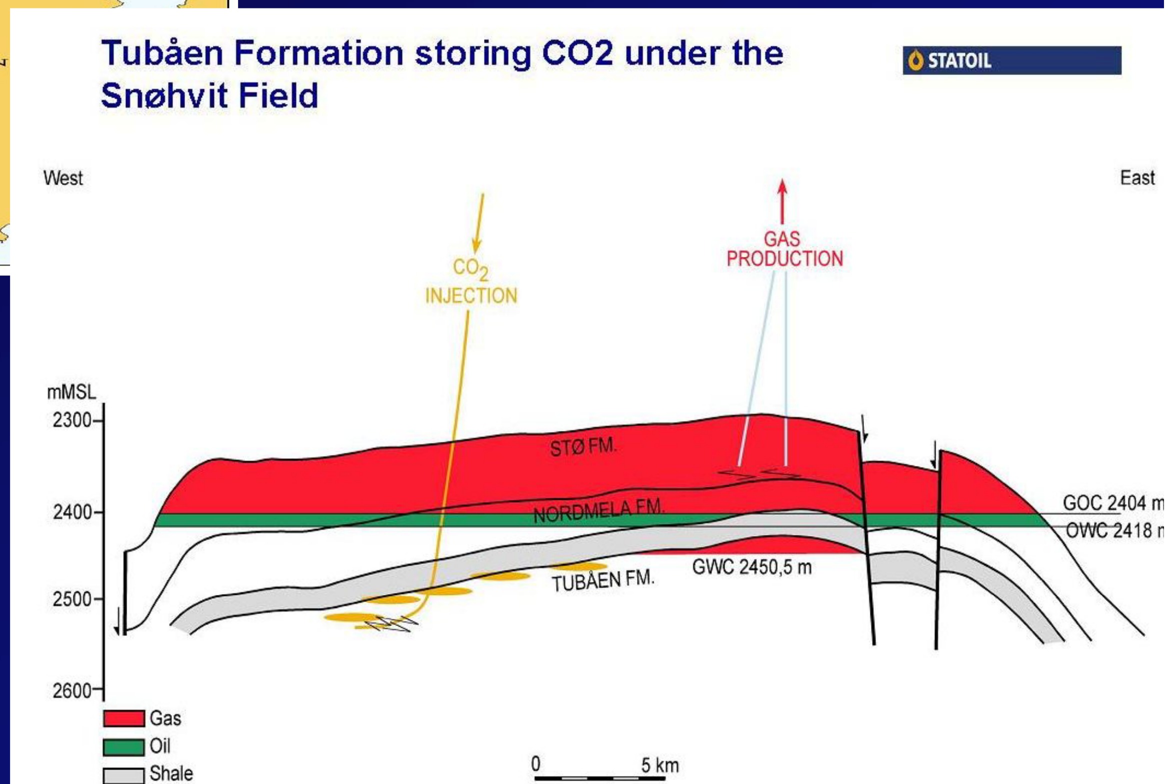




Snohvit Aquifer (Statoil, Norway)

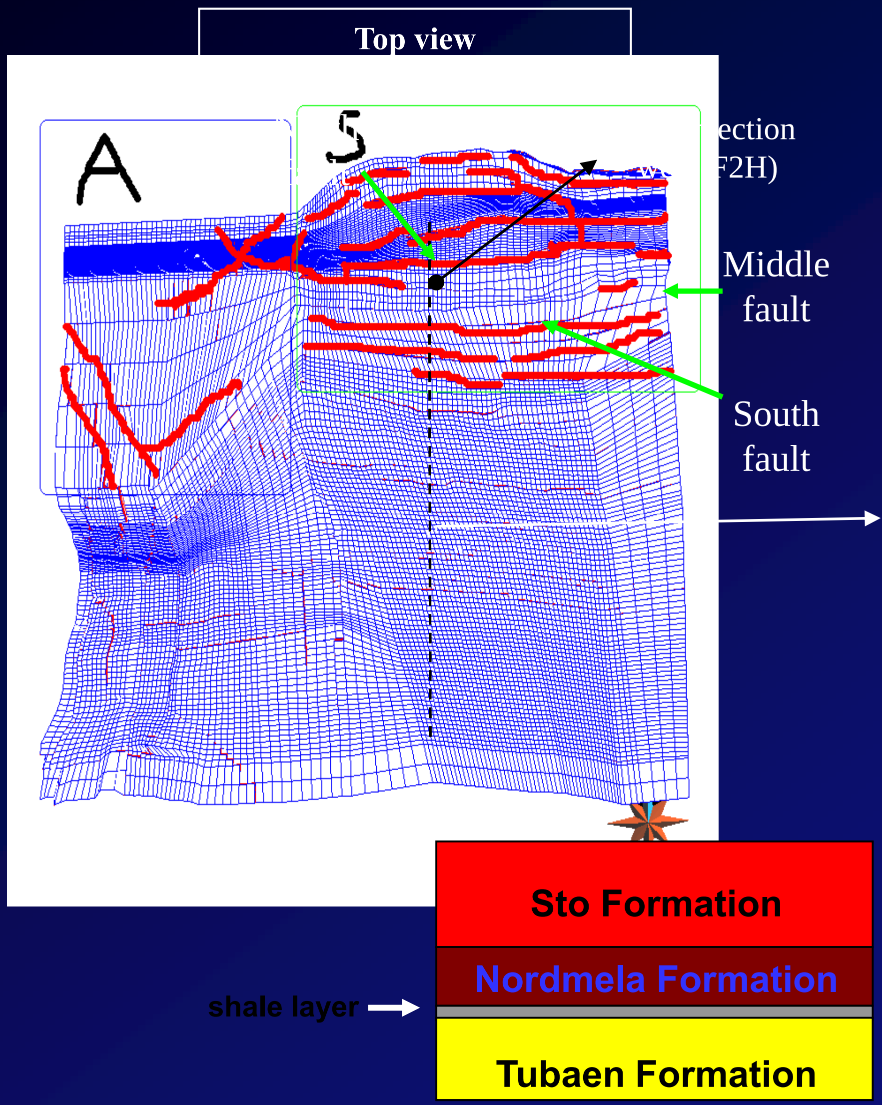


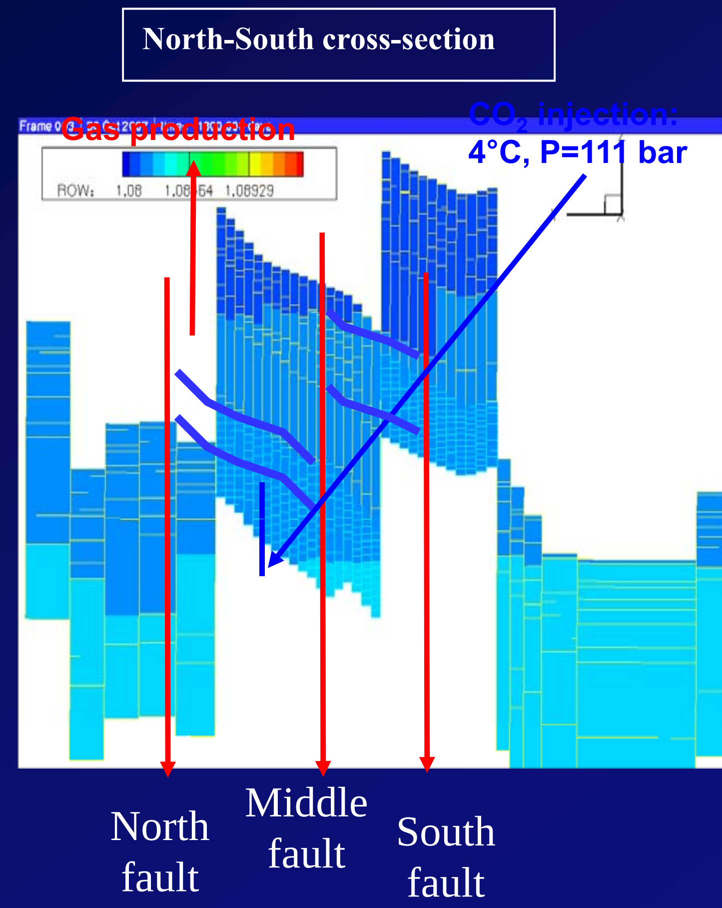
- Sandstone aquifer, offshore
- Depth: 2500 m
- 0.75 Mt CO_2 per year; Start in 2007 and last for 20 + years
- CO_2 source is removal from natural gas before cooling to LNG; limit 50 ppmvol.



Focus: Well integrity, Injectivity, Monitoring

Snohvit: Modelling of long term behaviour (1000 years)

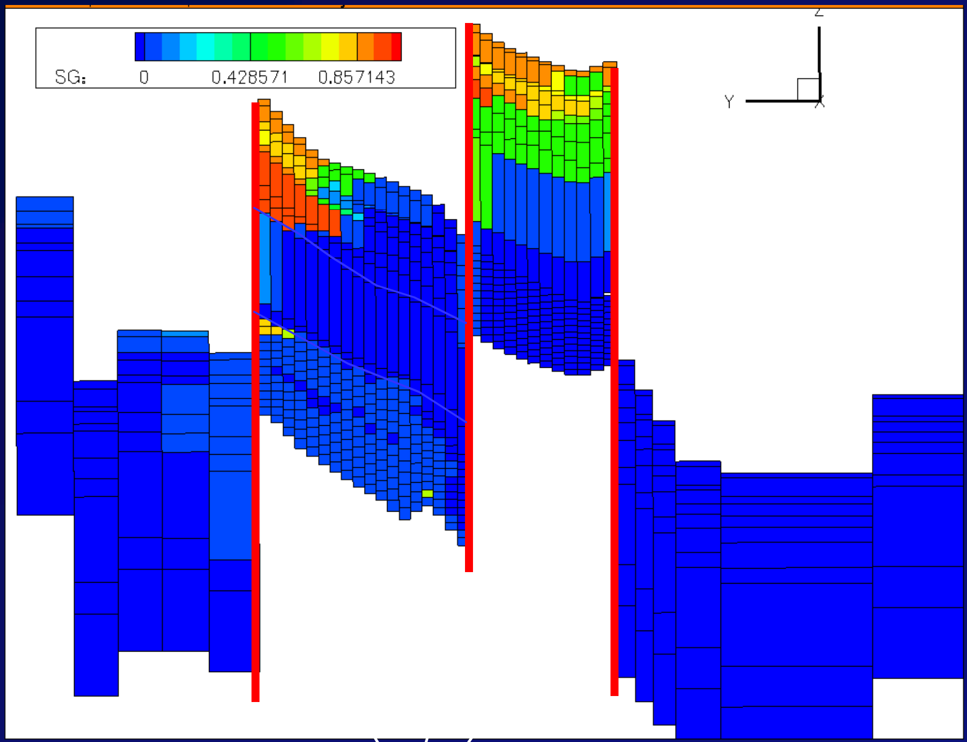




Snohvit: Main results of leakage along faults

- Sealing faults
  - No leak
  - Pressure increase in Tubaen
- Non sealing faults
  - Leak along the faults
  - Main migration of CO_2 to the Sto formation
  - So, CO_2 produced in F1H well
  - Some migration through the North boundary of the model

Time: 1030 years



Partially or fully opened faults

Conclusions – Storage

1. Complete assessments for 4 industrial scale storages sites
2. Completion of 2 transverse activities:
   - Development of preventive and corrective actions (wells, caprock)
   - Development of criteria for storage site selection and management (built on existing European Best Practice for Storage: SACS, SACS2 and CO2STORE EU projects).
3. Summary of advances in CASTOR
   - Geological characterisation with varied datasets
   - Consolidating geochemistry: Experiments and numerical modelling (inc. reaction-transport)
   - Fluid flow in caprocks: Long-term vs transient laboratory methods for gas permeability
   - Flow simulations: Exact history-matching, Far-field containment risks
   - Geomechanics: Integrated fluid flow and geomechanical simulators
   - Monitoring strategies: Tracers, Focussing on site-specific requirements
   - Well integrity / remediation
   - Risk analysis methodologies

Conclusions

- CASTOR is completed!
  - 110 technical reports
  - Over 150 publications (journals, proceedings …

CSLF Recognition Award, Cape Town, April 2008