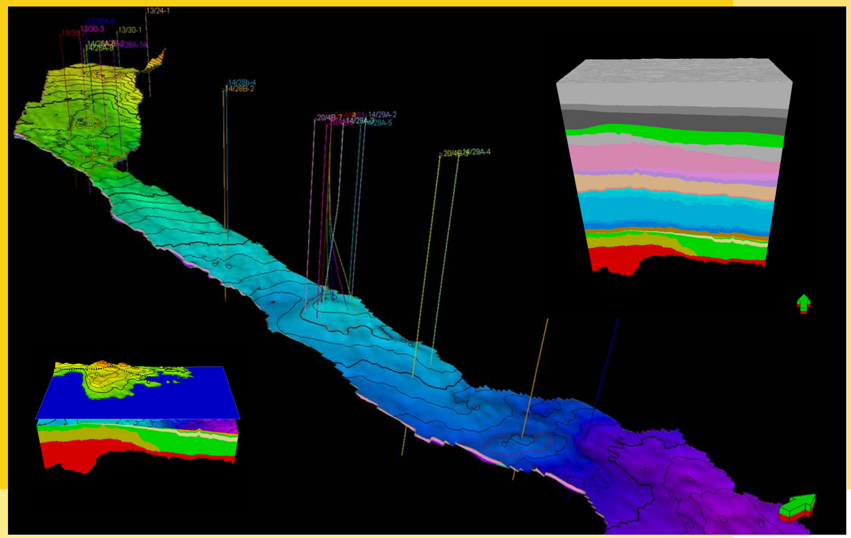
Geomechanical aspects of injecting CO_2 in an underground depleted gas reservoir

9th Euroconference on Rock Physics and Geomechanics
17-21 October 2011
Trondheim, Norway



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Acknowledgement: Rick Wentinck, Peter Schutjens

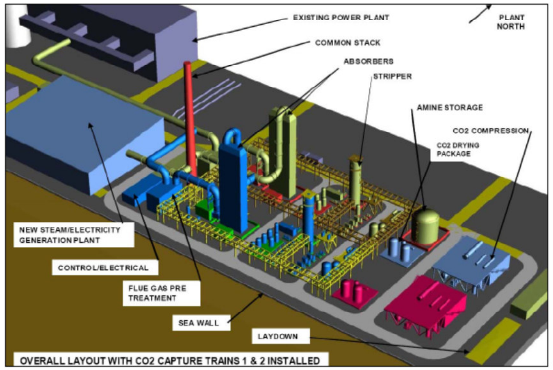
Outline

- Introduction to Goldeneye Project
- CCS project workflows and geomechanics
- How the geomechanical model of Goldeneye was build
- Results from geomechanical modeling of Goldeneye
  - Subsidence, tensile and shear failure, fault slip, thermal fracturing
  - Technology gaps
- Concluding remarks

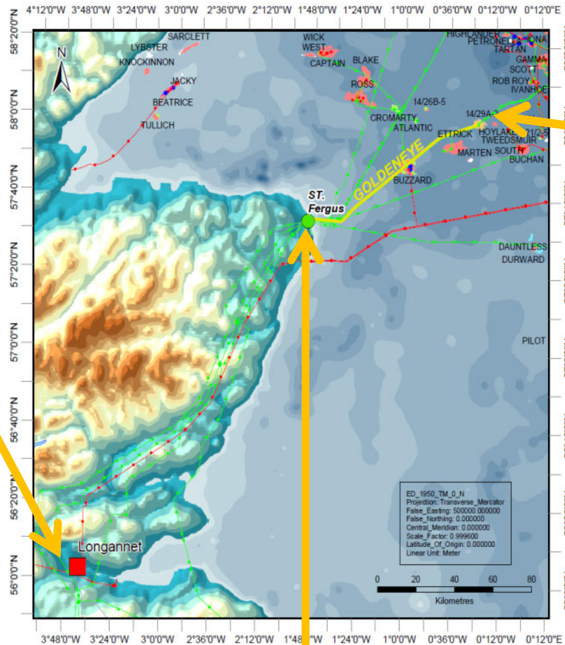
The Longannet to Goldeneye Project is a complete end-to-end solution

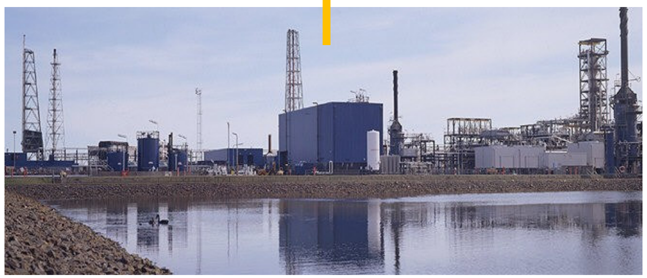
CO_2 extracted from flue gas at Scottish Power's 2.4 GW coal-fired Longannet Power Station

Carbon capture technology provided by Aker Clean Carbon, already tested on site with mobile pilot plant



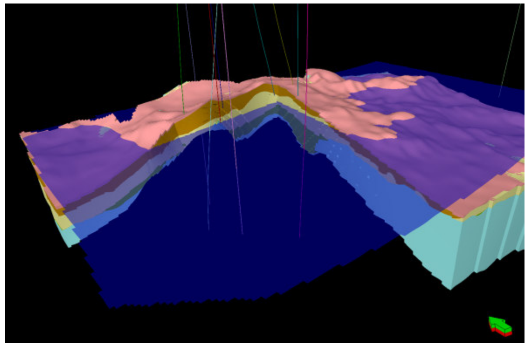
CO_2 piped to St Fergus Gas Terminal using existing National Grid gas pipeline



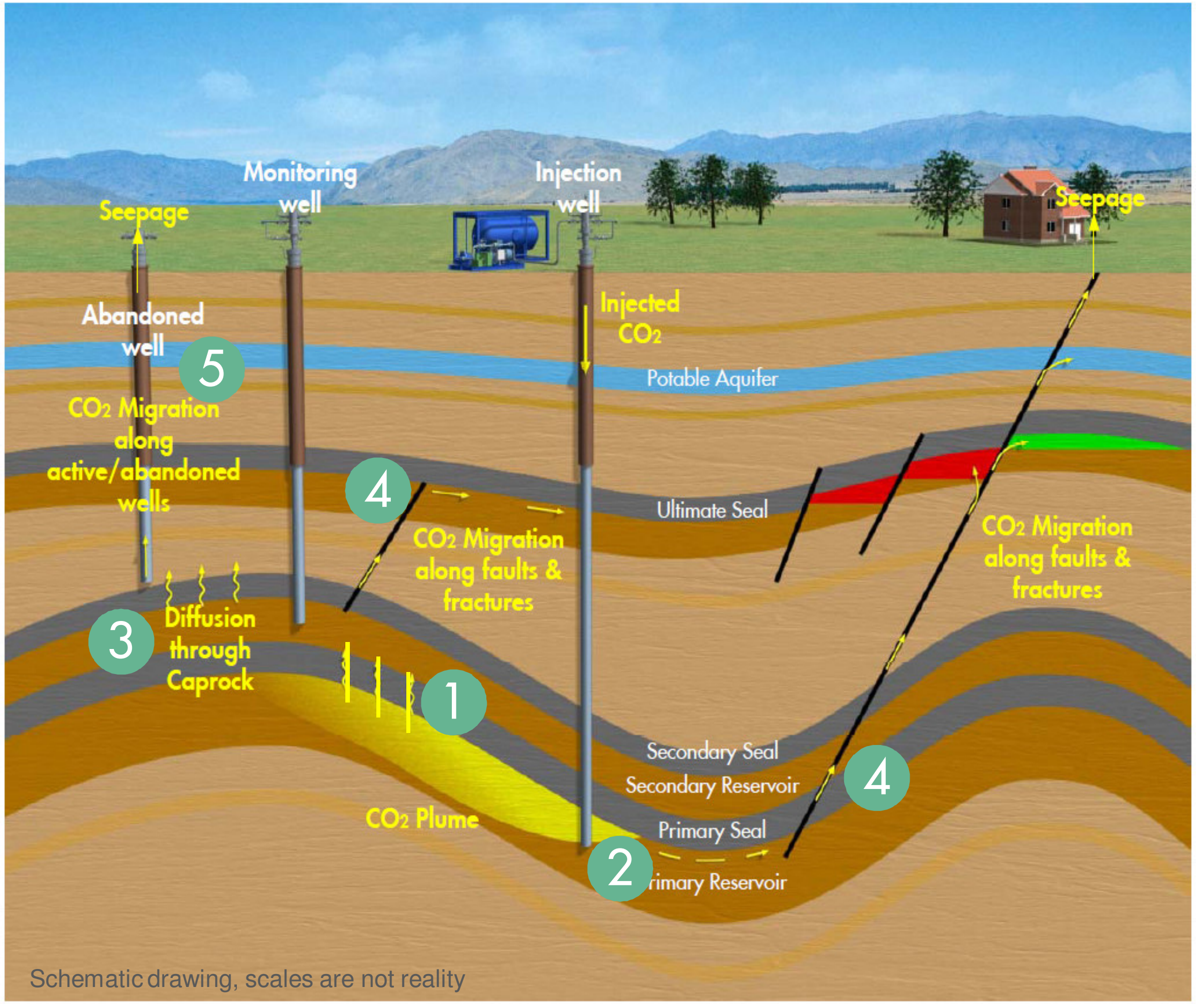


CO_2 transported to Goldeneye field using existing101 km offshore pipeline

CO_2 stored in the depleted gas reservoir, injecting via existing platform wells, 20Mt in 10 years



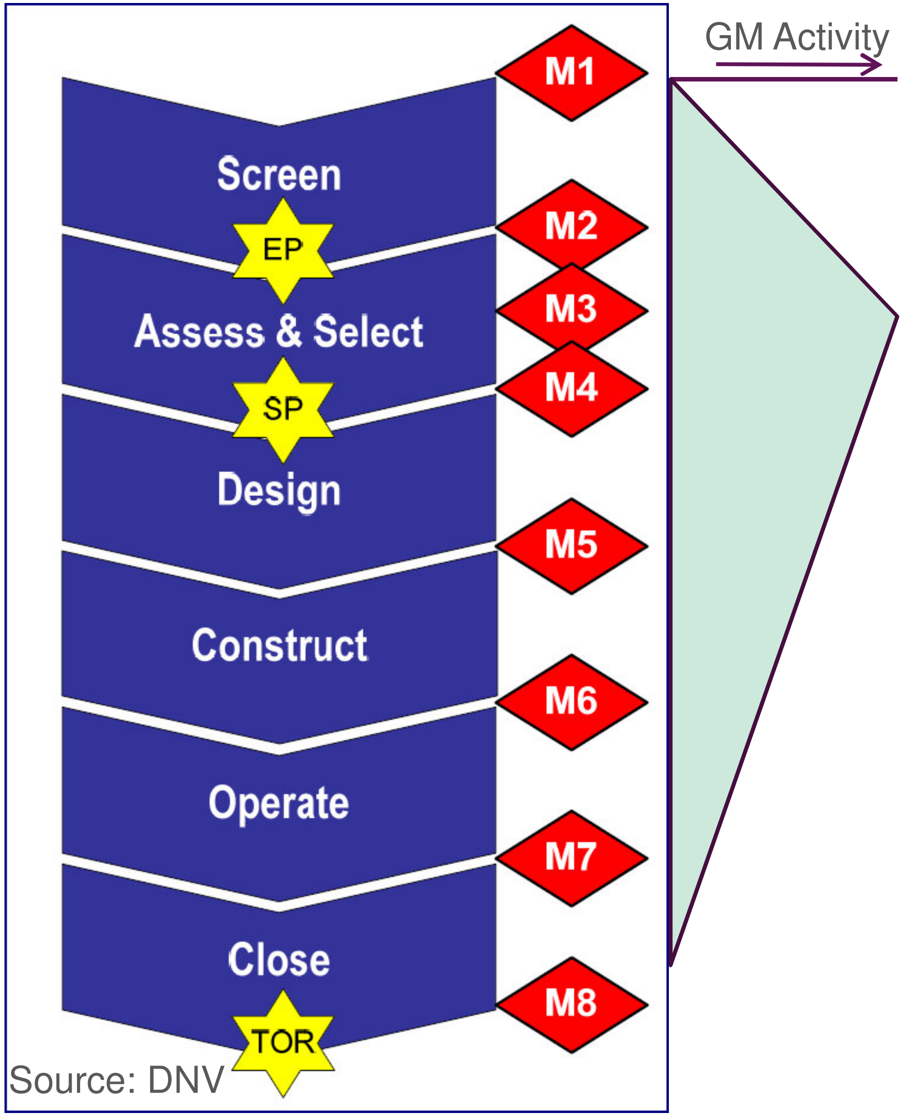
Potential routes for loss of containment



1. Fracturing Caprock / Seals *
2. Spill-point
3. Diffusion through seal
4. Migration along faults/fractures*
5. Migration along wells (*)

* Where Geomechanics has a critical Impact

CCS Workflow and Geomechanics



- What can Geomechanics do for CCS projects?
  - Assessment of containment
    - Caprock / seals and their integrity
    - Potential for injection-induced fault reactivation and seismic events
  - Reservoir response to CO2 (deformation)
    - Reservoir deformation and surface movement
    - Design of monitoring program
    - Risk of reservoir compartmentalisation
  - Operational guidance
    - Predicted maximum injection pressure
    - Predict hydraulic fracture propagation pressure and risk of breakthrough
  - Wells
    - Location and design of wells
    - Sand control and completion strategy
    - Life-cycle well integrity

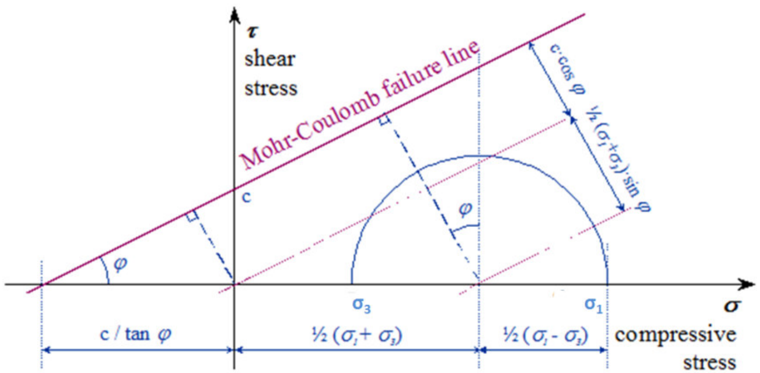
What to model and how

- We would like to quantify the risk on tensile or stress failure of the reservoir and caprock due to the injection of CO_2
- Compaction and subsidence
- Fault slip
- Effects of low temperatures close to the well

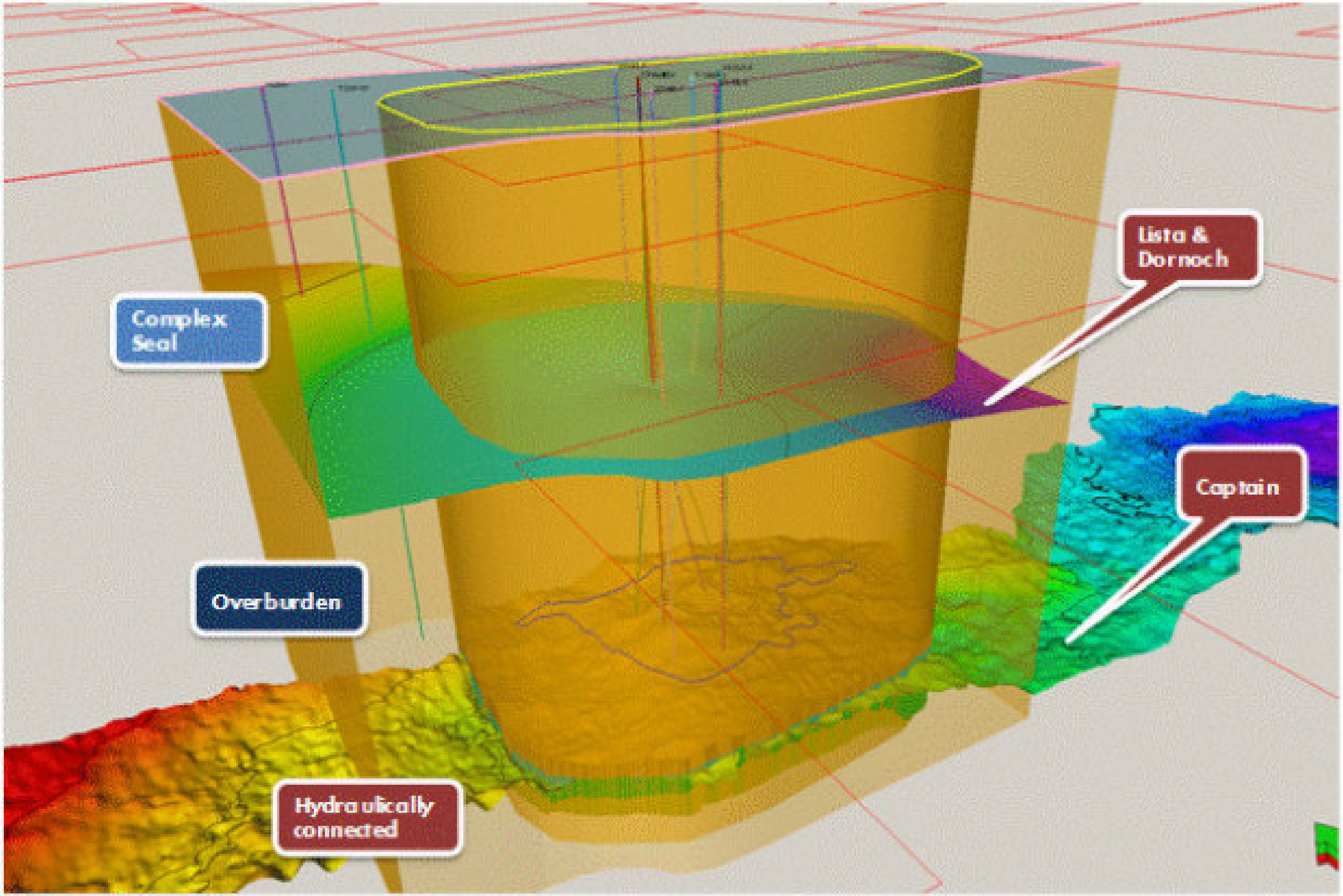
How is modeling done:

- 3D geomechanical model allows for a Finite Element Modeling that computes deformation and stress changes due to pressure changes in the reservoir
- Shear Capacity Utilisation (SCU)

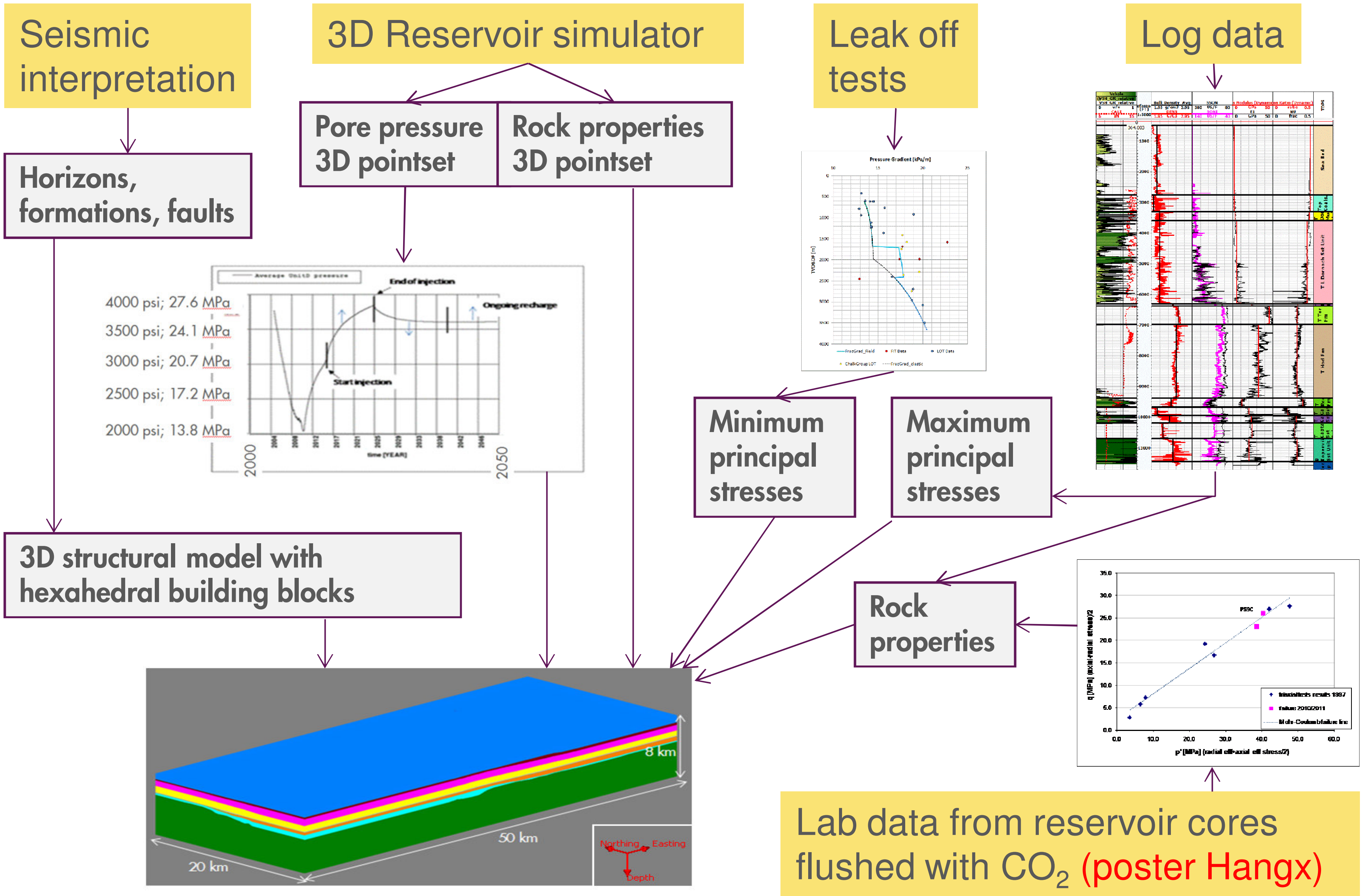
$$SCU = \frac{\frac{1}{2}(\sigma_1 - \sigma_3)}{C\cos\varphi + \frac{1}{2}(\sigma_1 + \sigma_3)\sin\varphi}$$



Goldeneye CO_2 storage container and seals

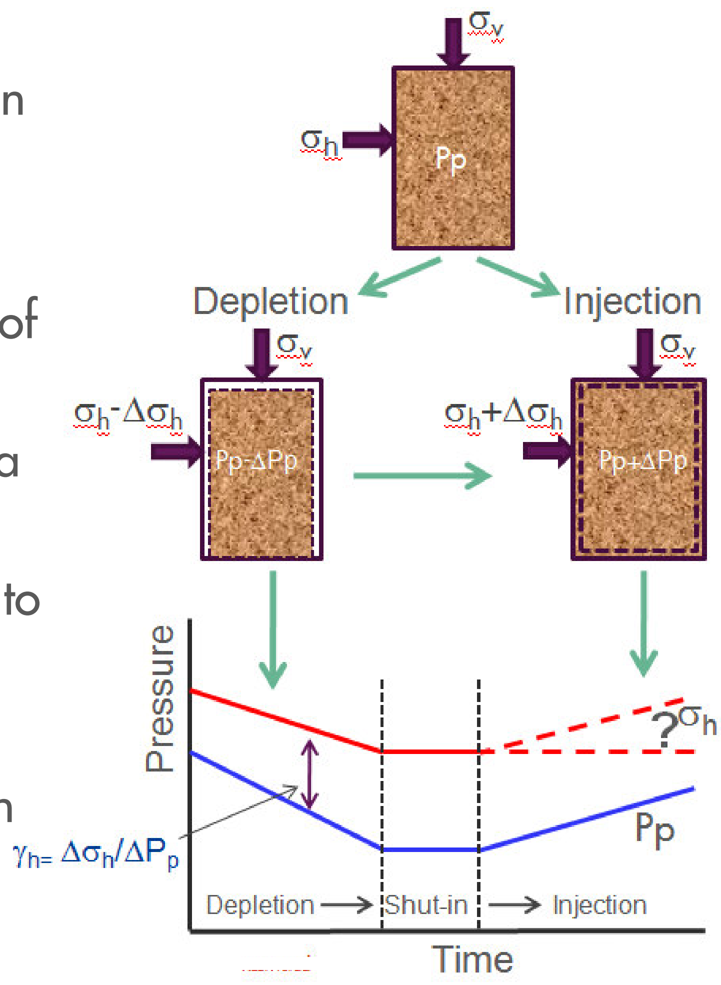


Goldeneye geomechanical model build



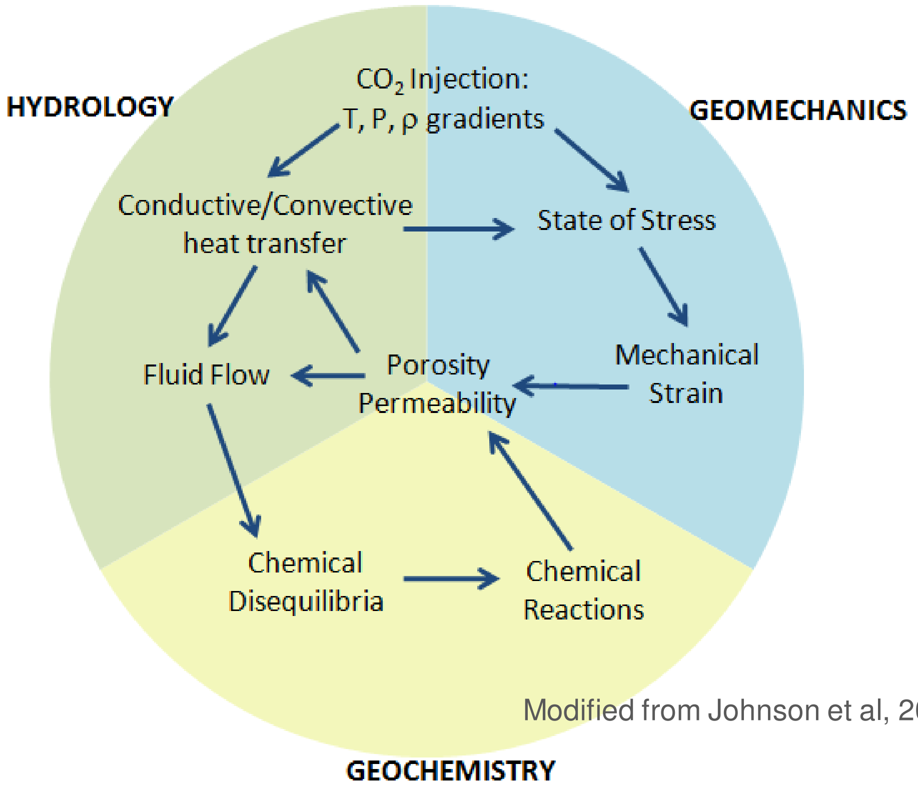
Reservoir Stress Path

- Injection of CO_2 into a previously depleted reservoir
- Issue – The effective in-situ stresses are directly impacted by the reduction and then the inflation in reservoir pressure
- Detail - We (industry) have a reasonable understanding of the ***depletion*** scenario in terms of the coupling between the in-situ stress and pore pressure, however, there is distinct paucity of data showing what happens with reservoir pressure ***inflation***. This is of major importance if we want to understand whether we are injecting CO_2 under matrix or fracturing conditions, as well as issues such as fault reactivation and surface deformation
- Risk mitigation: XLOT



Alteration of rock mechanical properties with time

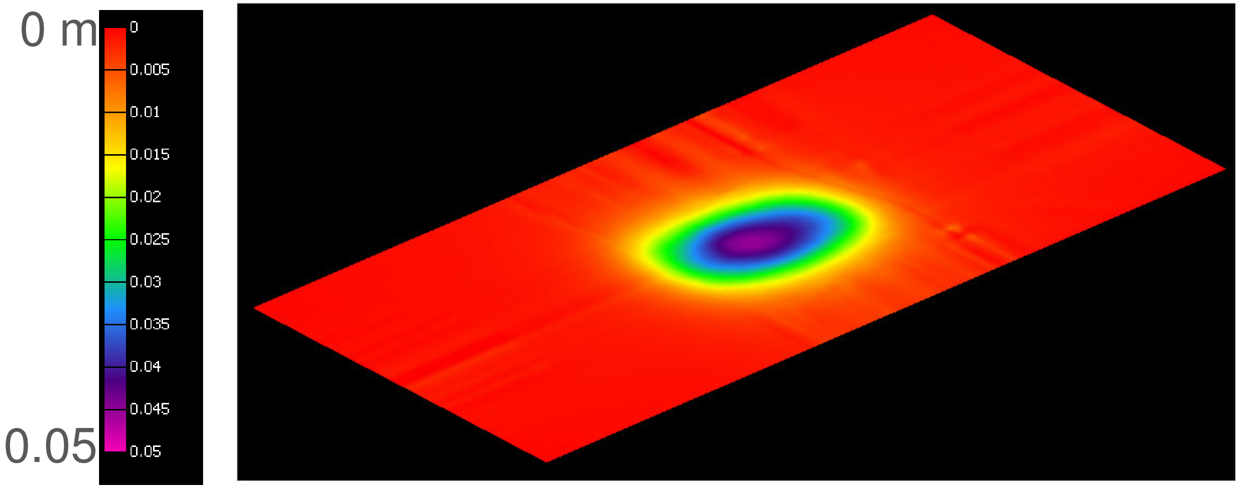
- Injected CO_2 can react with mineral phases present in reservoir and caprock
- Issue – Rock mechanical material properties affected by interaction with CO_2 over time
- Detail – Chemical disequilibria imposed by introduction of CO_2 into reservoir both dissolves and/or precipitates mineral phases. Geomechanical modelling is required to account for the changes in rock properties with time to gauge the impact these processes have on containment
- Risk Mitigation:
  - Core tests (poster Hangx)



Modified from Johnson et al, 2004

Subsidence and compaction modeling results

- GeoMec model: 360.000 elements, FEM takes 6 hours for 2 depletion stages (after gas has been depleted, and after CO_2 has been injected)
- Bird's eye view of the sea-floor with subsidence:

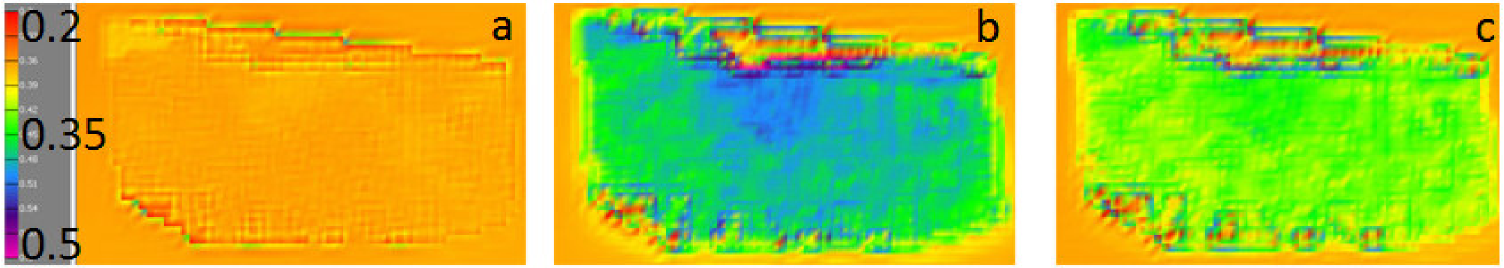


Subsidence	Seafloor	Top reservoir
After gas depletion	4.6 cm	8.9 cm
After CO_2 injection	3.6 cm	5.6 cm

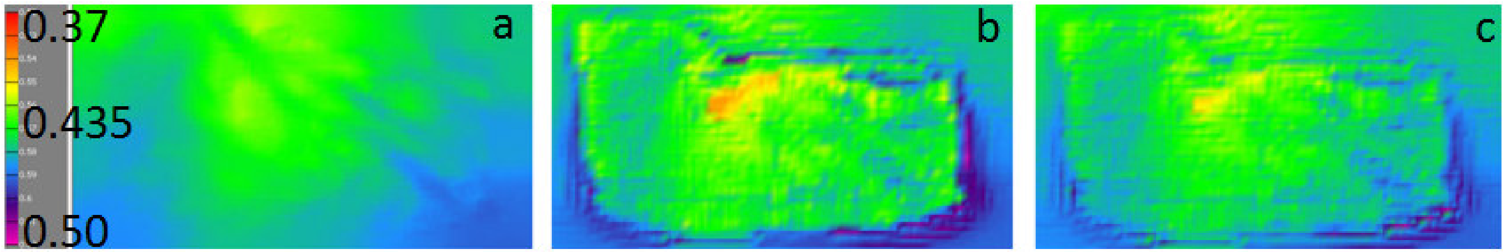
- So, injection of the CO_2 leads to a heave of the seafloor of about 1 cm (P50 case).

Tensile and shear failure modeling results

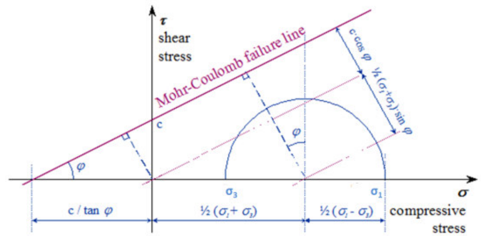
- As stresses are positive (compressive) everywhere, it can be concluded there is no tensile failure after the gas has been depleted and after the CO_2 is injected.
- Top view of the reservoir (Captain D&E) at initial (a), after gas has been depleted (b), and after CO_2 has been injected (c). Colours indicate the SCU.



- Top view of the caprock (Rødby) at initial (a), after gas has been depleted (b), and after CO_2 has been injected (c). Colours indicate the SCU.



- It can be concluded that shear failure is never predicted (SCU<1) for reservoir and caprock. This conclusion also holds for P10-P90 cases

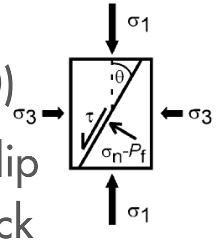


Fault slip

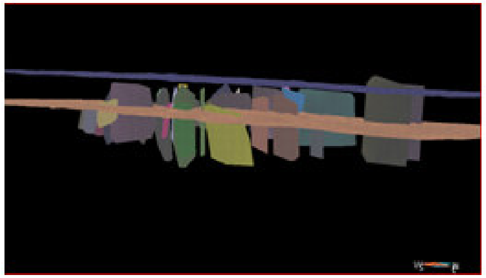
- Pressures that change in the reservoir due to gas depletion or CO_2 injection can potentially open fractures and cause slip on faults that exist in the reservoir, caprock, and overburden formations
- Issue – Some risk analysis of fault reactivation can be carried out using geomechanical tools, however, there is a distinct lack of data (in industry) available to show the impact of this
- Detail – We need to be able to predict the risk of leakage associated with fault reactivation predictions, using geomechanical tools and techniques. The impact of CO_2 and fault zone interaction is potentially significant and will change with time

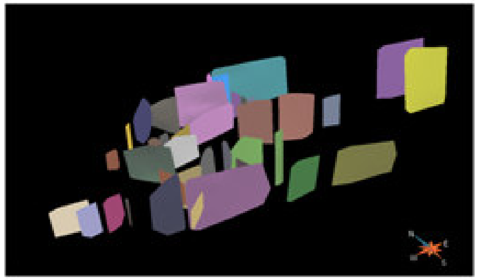
Fault slip modeling results

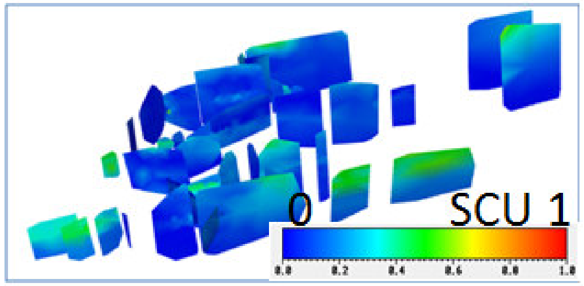
- Methodology:
  - Stresses from the 3D simulator are mapped on 40 interpreted faults (< P50)
  - Calculate the Shear Capacity Utilisation for the two cases where the fault slip properties are equal to the failure parameters of the reservoir or the caprock



- Assumptions:
  - Initial stress state of the faults, before depletion or injection, is the same as the initial stress sate of the surrounding rock
  - The faults are not critically stressed



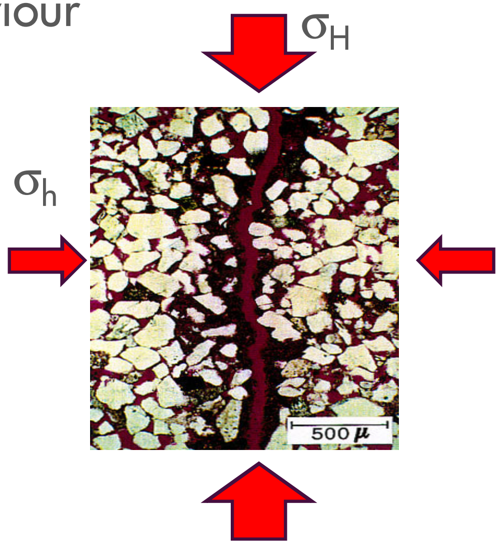


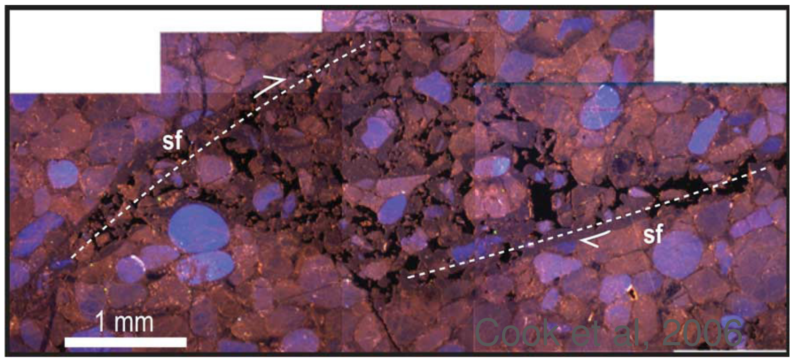


- No fault-slip is expected to occur. Even the worst case scenario (P90) was not significantly close to slip. This result implies that if faults are currently not leaking (which they are unlikely to be given that a gas field is present) then they are extremely unlikely to start leaking as a result of CO_2 injection.

Thermal response

- Significant cooling of the reservoir and (locally) the caprock occurs due to CO_2 injection and plume development
- Issue – Adjacent to injection wells, local cooling of the reservoir and caprock will enhance tensile and shear failure which could jeopardise containment
- Detail – Even though geomechanical modelling of the ‘scaled up’ reservoir shows minimal risk of loss of containment, there is very limited data and understanding of localised cooling induced shear failure of rocks, both in terms of the rock thermal response and the affect this has on the failure behaviour



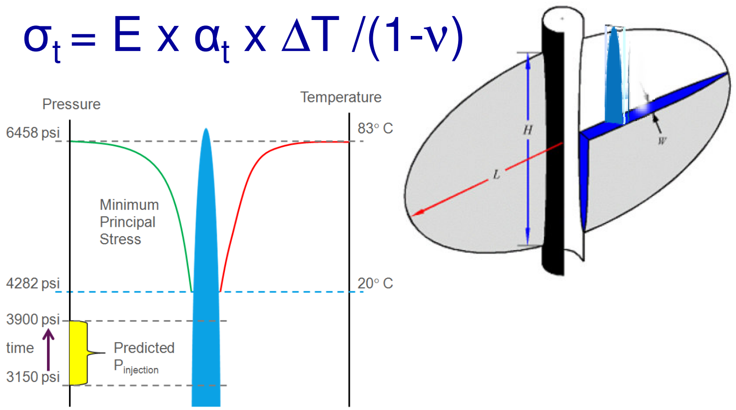


Thermal response modeling

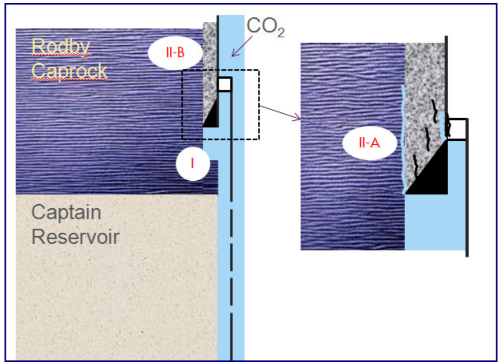
- Reservoir temperature is 83°C, CO_2 is 20°C. Two cases considered.
- Requires poroelastic-thermal coupled modeling
- Are suitable range of input parameters available?

- <u>Far away from the well</u>
- Typical water/fluid injection simulation for fracture modeling was carried out
- Thermal response only linked to where fluid leak-off occurs, i.e., the reservoir
- No account of thermal behaviour with caprock shale

$$\sigma_t = E \times \alpha_t \times \Delta T / (1-\nu)$$



- <u>Close to the well in the caprock</u>
- Very sensitive to thermal expansion coefficients of the brine and shale, and failure parameters of the shale
- 1D Analytical model was made with 3 different boundary conditions



- Recommendation: reduce uncertainty of input parameters

CCS and Geomechanics: Technical Gaps

- Fault Leakage Prediction
- Thermal Response (key technical challenge in the geomechanics modeling in the Goldeneye Project)
- Reservoir Stress Path
- Alteration of rock mechanical properties with time

- All gaps discussed at the IEAGHG Meeting in Perth AU, April 2011 "Modelling of CO2 Geological Storage and Wellbore Integrity" by Mark Davison, Shell

Concluding Remarks

- Geomechanics has a crucial role in trying to understand the containment of a storage complex
  - Also important for: understanding the surface/sub-surface deformation, providing input to operational guidelines, impacts on well integrity
- A developed workflow was applied to the Goldeneye project to identify threats and quantify risks before, during, and after injection of CO_2 to ensure containment
- From the 3D geomechanical modeling follows:
  - Seafloor subsidence: no risk
  - Tensile and shear failure in the reservoir and caprock: no risk
  - Fault slip: very unlikely
  - Thermal fracturing: ongoing study to reduce uncertainties

Acknowledgement

- UK Department of Energy and Climate Change (DECC) made a substantial financial contribution to do the studies on the Goldeneye project
  - All reports will be available soon via the internet
  - Longannet (coal plant) and/or Peterhead (gas plant)?