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Danish Offshore Technology Centre
Technology Conference 2022

Chalk Deep Dive

Agenda – Chalk Deep Dive

Hosts: Frederic Amour, Hans Horikx, Birgitte Larsen & Ulla Hoffmann, Danish Offshore Technology Center

10:00 **Welcome / setting the scene**

10:10 **Geomechanics**

Presenter: Frederic Amour, (DTU Offshore)

Panel: Frederik Ditlevsen (GEO); Ida Fabricius (DTU Sustain); Finn Engstrøm (TotalEnergies)

10:45 **Recovery**

Presenter: Hans Horikx, (DTU Offshore)

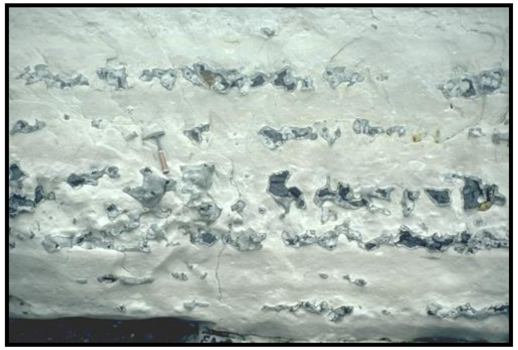
Panel: Vibeke Levi Nilsson (Noreco Oil Denmark A/S); Hamid Nick (DTU Offshore); Ken Wesnæs (Noreco Oil Denmark A/S)

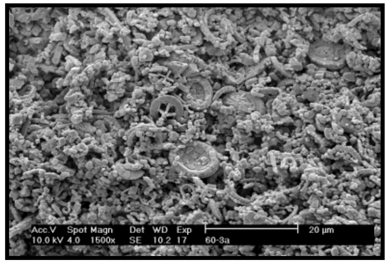
11:20 **Geology**

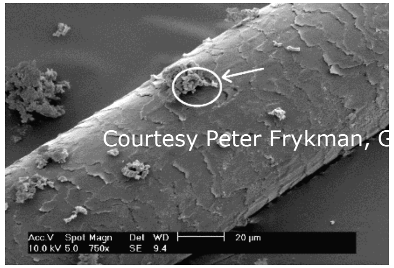
Presenter: Florian Smit (GEUS)

Panel: David Quirk (DTU Offshore); Ingelise Schmidt (TotalEnergies); David Pickering (Pickering Geoscience); Jan Kresten Nielsen (Noreco Oil Denmark A/S)

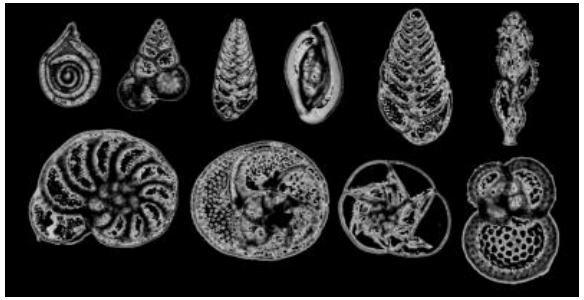
The beauty of Chalk







Courtesy Peter Frykman, G



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Chalk Deep Dive session

Geomechanics

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- Ida L. Fabricius, *DTU Sustain*
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Technology Conference 29-30/11/2022

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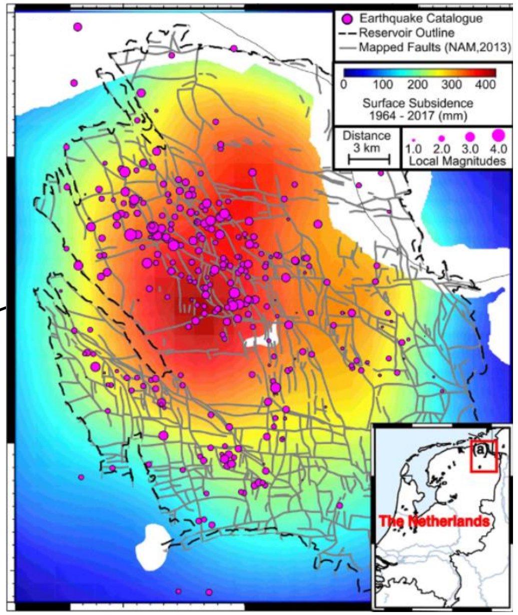
Rock mechanics in the energy industry and for carbon storage

Seafloor subsidence deformation

From www.energyfacts.eu

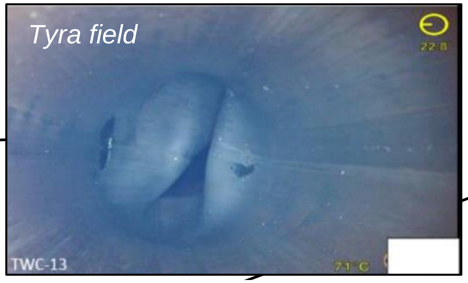
From www.conocophillips.com

Reservoir subsidence and seismicity



Smith et al., 2022

Overburden deformation



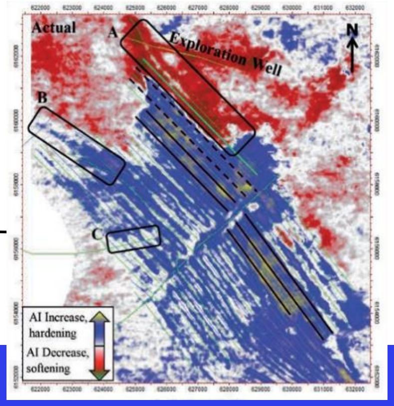
Schutjens et al., 2018

Two reservoir units

Upper Cretaceous-Danian chalk

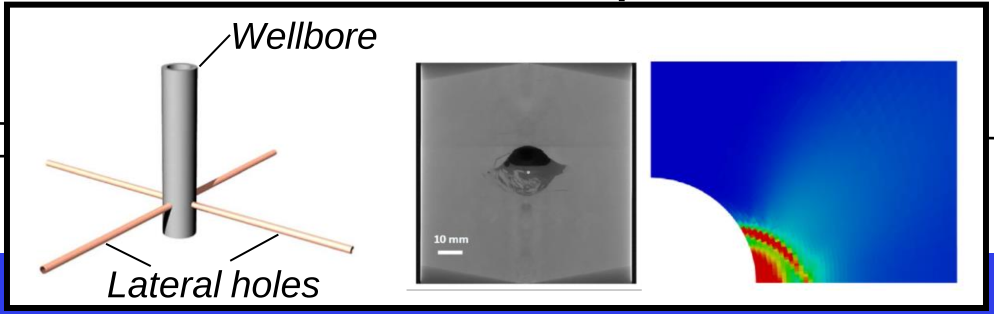
Lower Cretaceous chalk

4D seismic

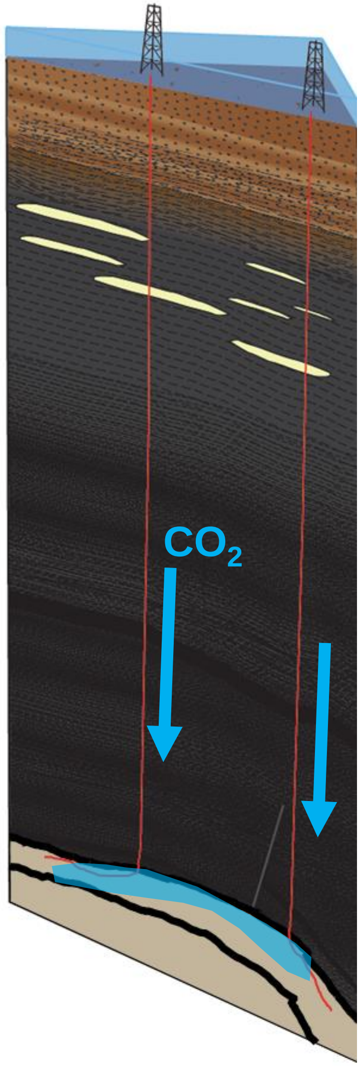


Calvert et al., 2014

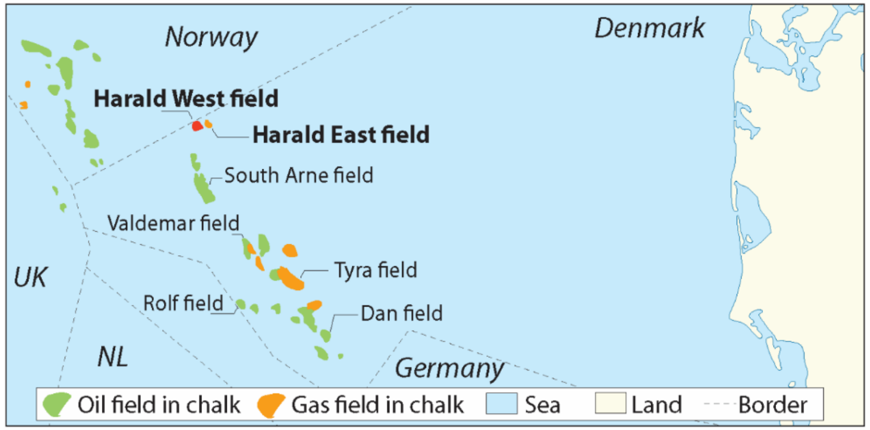
Wellbore collapse



Rock mechanics in the energy industry and for carbon storage



- Denmark aims at:
  - Reducing by **70%** greenhouse gas emission compared to 1990 by **2030**
  - Becoming **carbon-neutral** by **2050**
- **Feasibility study** of storing CO_2 in depleted gas reservoirs from the Danish North Sea:



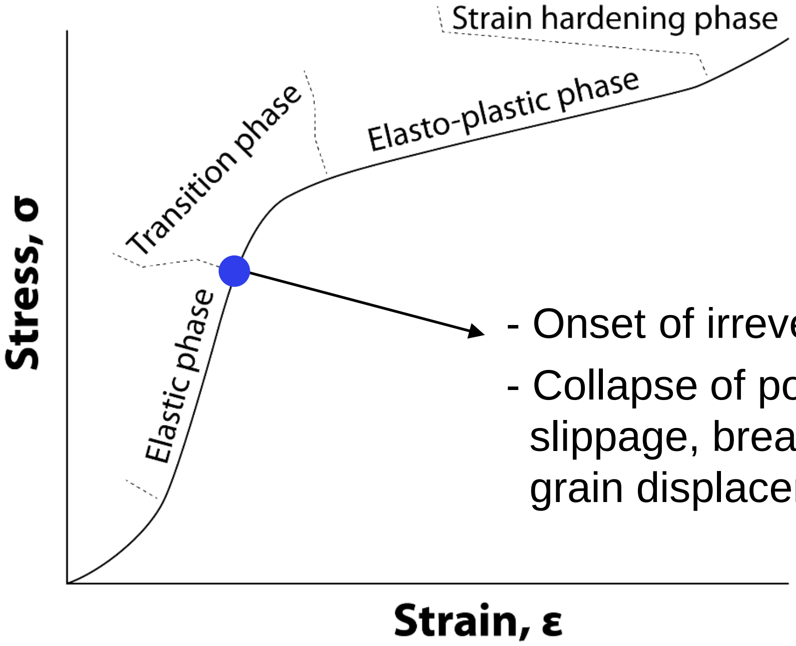
Modified after Abramovitz, 2008 and DEA, 2013

Outline

1. **Water weakening effect**
2. **Temperature effect**
3. **Transfer of laboratory data to field scale**
4. **Carbon storage in chalk**

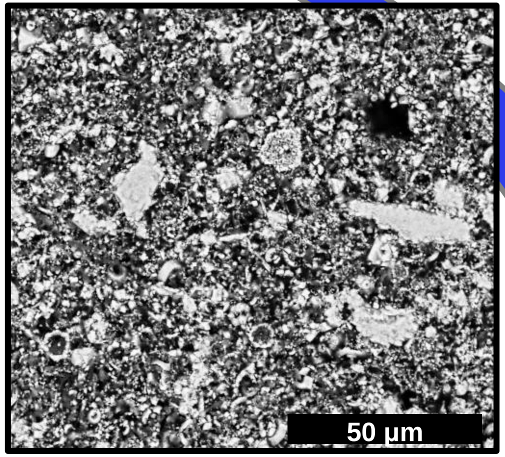
How does compaction propagate throughout the rock matrix ?

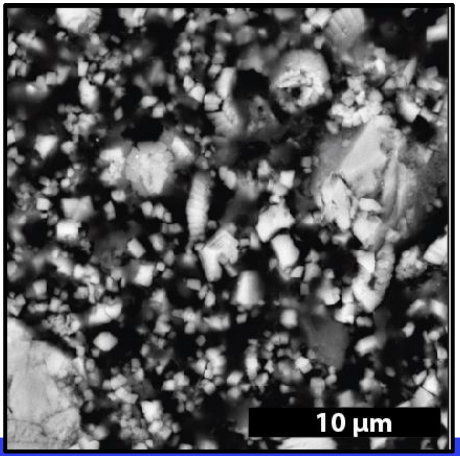
Typical strain-stress curve during chalk compaction



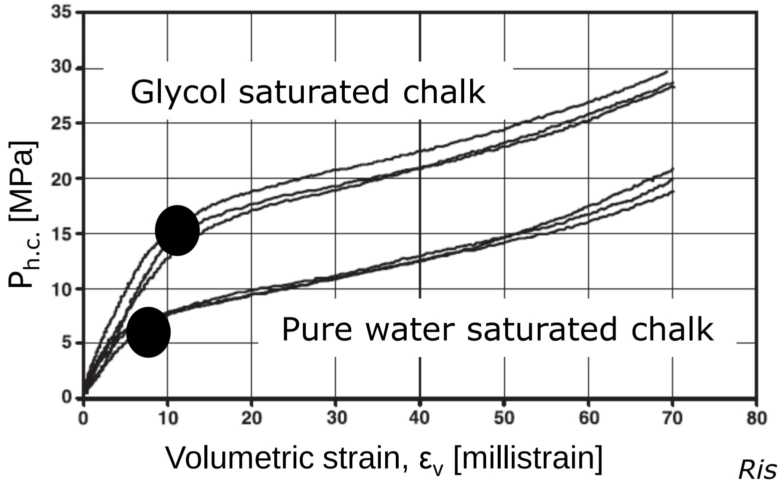
- Onset of irreversible deformation
- Collapse of pores, grain-to-grain slippage, breaking of contact cement, grain displacement, stress redistribution

3.6% Qz, 2.3% clay
Ø: 41.2%; K: 1.92mD



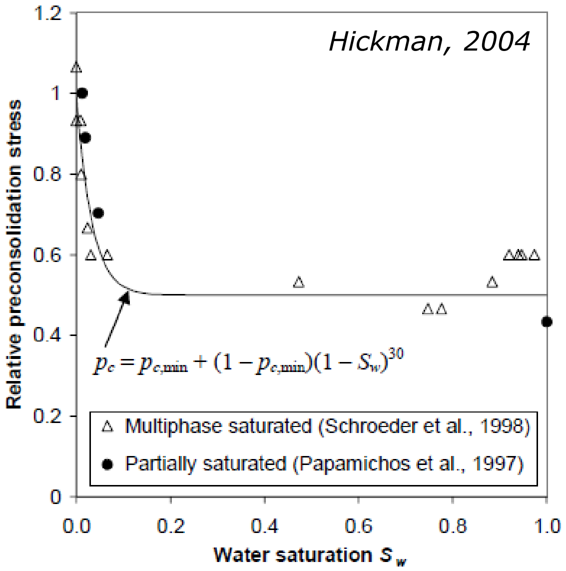


The water weakening effect



Risnes et al., 2005

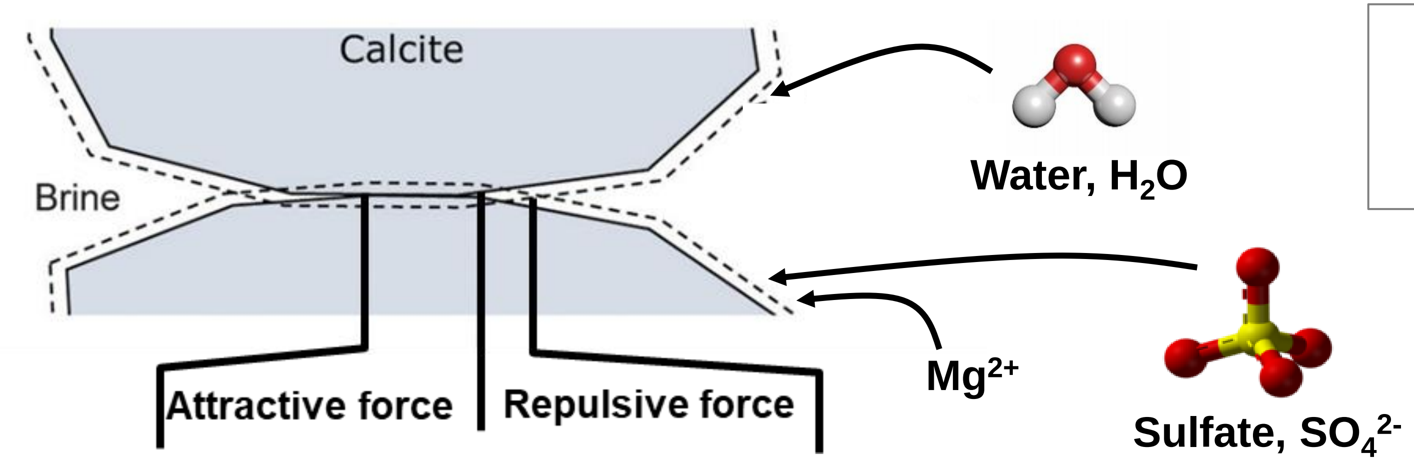
The pore collapse strength of chalk decreases by a **factor of up to 2** when water replaces oil in pore space



Hickman, 2004

What is the S_w range at which the water weakening effect takes place?

Two mechanisms proposed in the literature



After Nermoen et al., 2018

Røyne et al., 2015

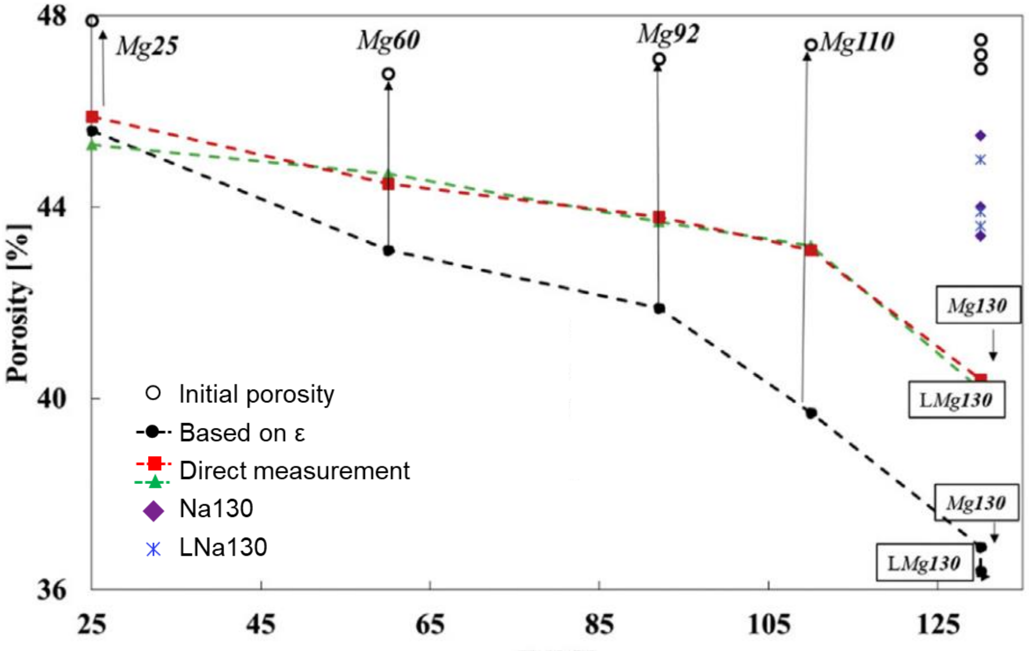
Repulsive hydration force due to water adsorption

Megawati et al., 2013

Electrostatic repulsive force caused by ions (SO_4^{2-}, Mg^{2+}) adsorption

Temperature effect

Long-term (2-4 months) flow-through experiments on outcrop chalk samples at 25˚C, 60˚C, 92˚C, 110˚C, and 130˚C using $MgCl_2$ and NaCl with identical ion strength



Minde et al., 2018

Two main mechanisms controlling porosity change during compaction at high temperature

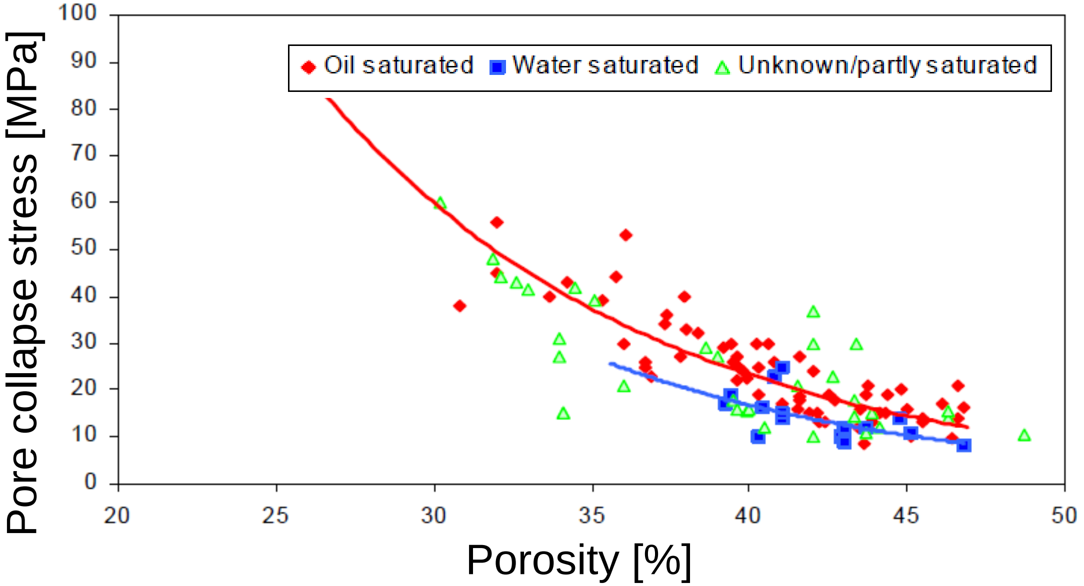
Mechanical compaction reducing porosity

Dissolution of opal CT and calcite enhancing porosity

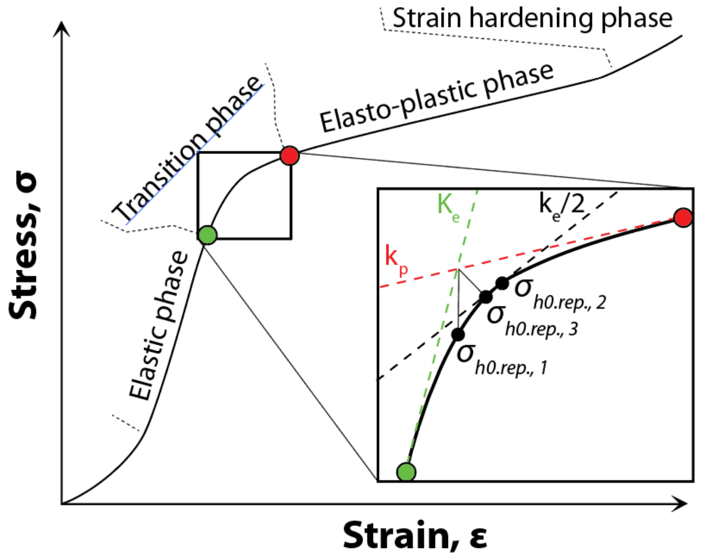
Do these findings relevant for reservoir chalk in which silica is present in the form of quartz ?

Transfer of laboratory data to field studies

Scattering of the data points



Different methodologies applied to estimate the pore collapse stress



$\sigma_{h0.rep}$ = Representative pore collapse stress

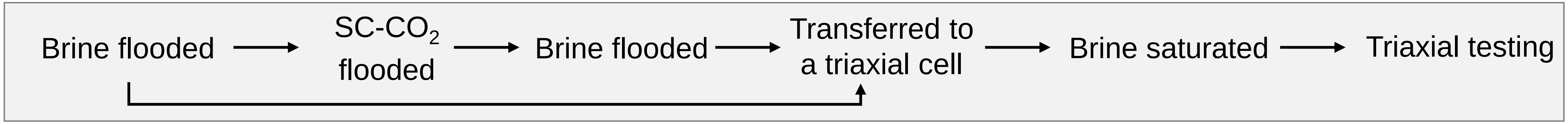
K_e = Elastic Modulus, K_p = Plastic modulus

→ **A non-negligible uncertainty is associated with the interpretations of the experimental data**

- Is there a need to quantify the **uncertainty** of the outcomes of geomechanical simulation and related to the experimental data?
- What are the possible **strategies** that can be implemented to do so?

Effect of supercritical CO_2

Flooding experiment **Geomechanical test**



Brine flooded → $SC\text{-}CO_2$ flooded → Brine flooded → Transferred to a triaxial cell → Brine saturated → Triaxial testing

No effect to a softening effect

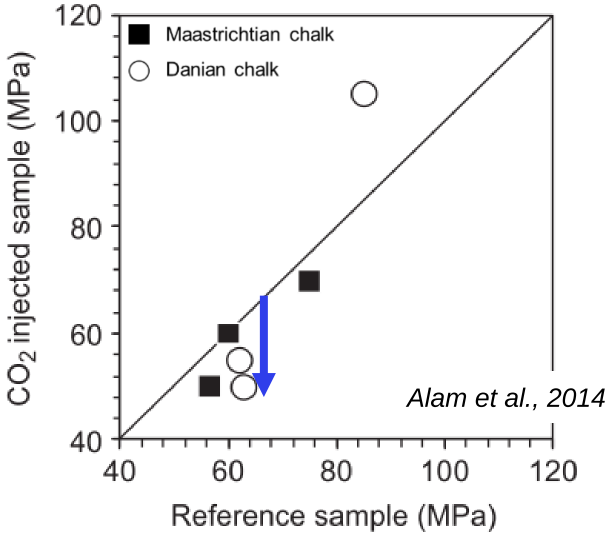
Injection phase:

- Hydrostatic conditions
- Temperature: 115˚C
- Pore pressure: 38 MPa

Mechanical test:

- Uniaxial conditions
- Artificial brine as saturated fluid

Pore collapse stress



Alam et al., 2014

No effect to a strengthening effect

	Yield stress value	
	oil*-/water-flooded	CO_2-flooded specimens
Schroeder et al., 2001 *80˚C; P_p = 9 MPa; hydrostatic conditions*	8-11 MPa	11-12.6 MPa
	18-22 MPa*	24-25 MPa
	18-22 MPa*	22.5 MPa

- **How to explain the different experimental results reported in the literature?**
- **Is it safe to use Danish chalk reservoir as carbon storage complex?**

Chalk Deep Dive session

Geomechanics

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- Frédéric Amour, *DTU Offshore*

Panelists:
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Danish Offshore Technology Centre
Technology Conference 2022

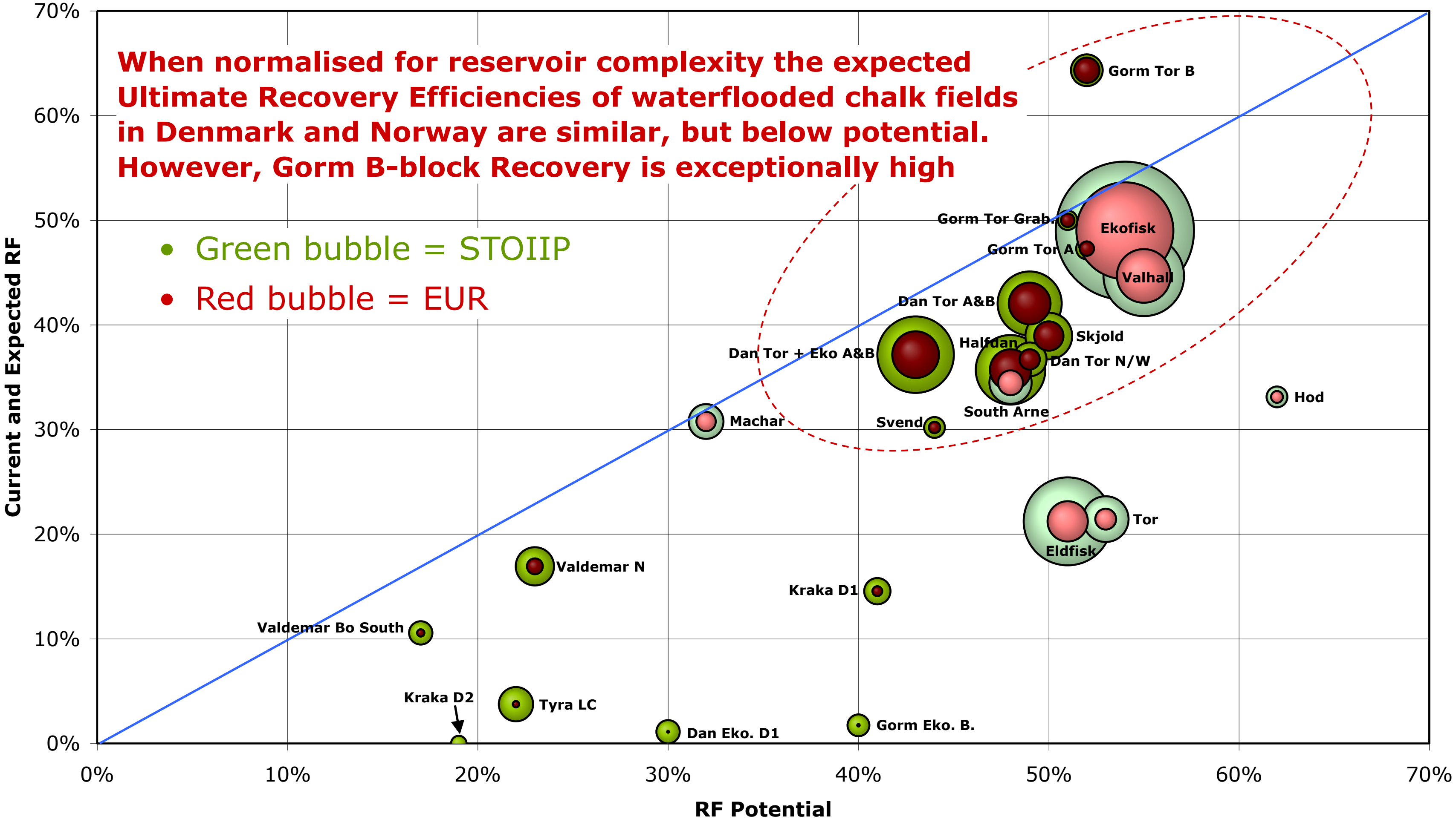
Chalk Deep Dive: Recovery

Chalk field Recovery Factor comparison

High complexity

Low complexity

Expected Ultimate Recovery vs RF Potential



When normalised for reservoir complexity the expected Ultimate Recovery Efficiencies of waterflooded chalk fields in Denmark and Norway are similar, but below potential. However, Gorm B-block Recovery is exceptionally high

High Permeability
Low oil viscosity
High Mobile Oil Fraction
(Soi – Sor)
High compaction
Low faulting & fracturing
High Net to Gross ratio
High vertical connectivity
No or small gascap
Thick oil column

Low Permeability
High oil viscosity
Low Mobile Oil Fraction
(Soi – Sor)
Low compaction
High faulting & fracturing
Low Net to Gross ratio
Low vertical connectivity
Large gascap
Thin oil column

SWIM = Smart Water Injection Method

LoSal™ =
Low Salinity waterflooding

SWIM =
Smart Water Injection Method

MSW =
Modified Seawater Injection

Possible roadmap for SWIM implementation

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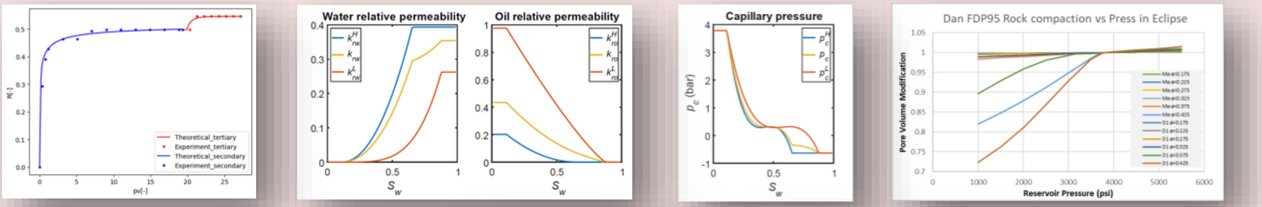
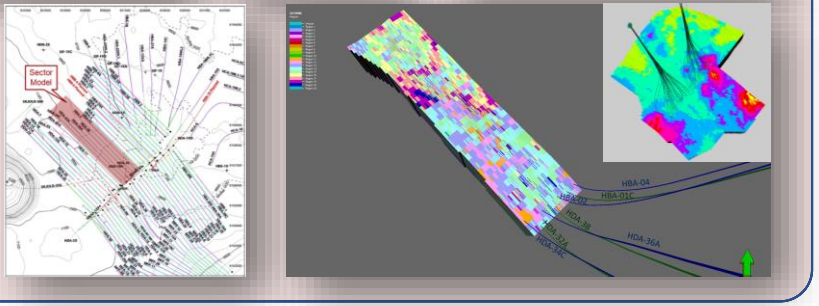
Coreflood results



Reservoir modelling

- Sector model
- Full Field Model

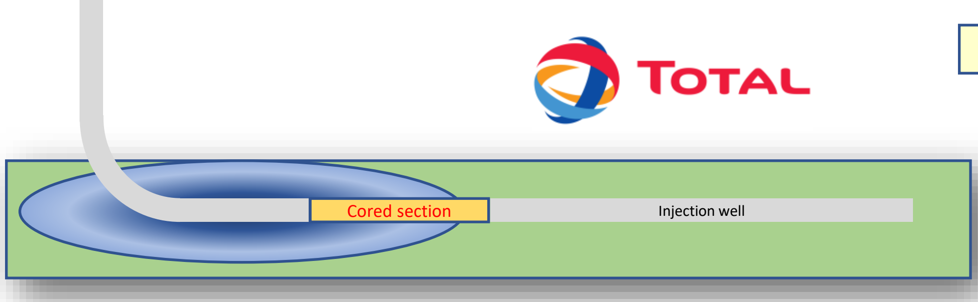
→ Business case



Field Trial

- Open-hole Injection pilot followed by coring of swept zone

TOTAL



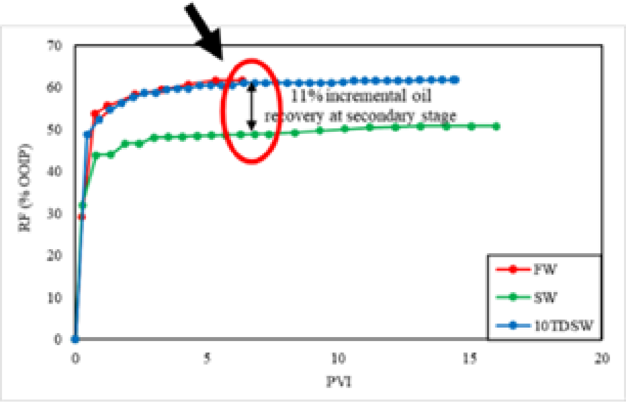
Field Implementation

- Circa 2700 tonnes of filtration units and chemicals packages

SWIM = Smart Water Injection Method

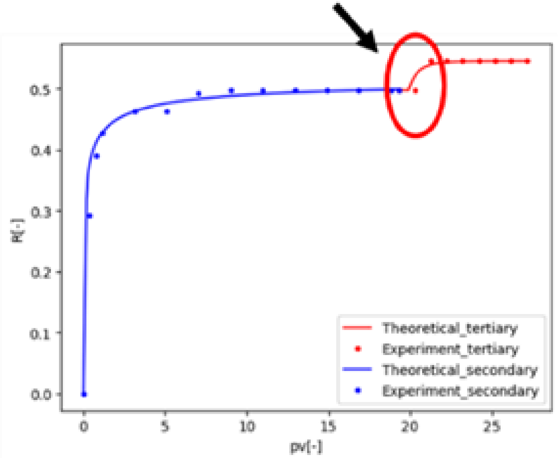
Step 1:
Demonstrate coreflood oil recovery can be enhanced by 10x dilution of injected seawater

Secondary recovery



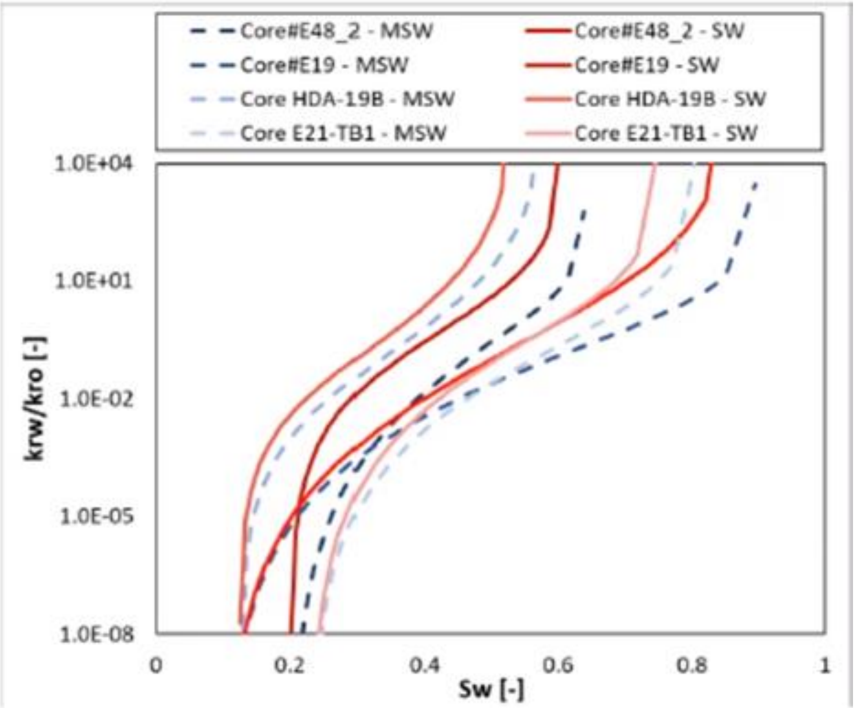
Secondary recovery is the comparison between RFs obtained by brine injection in **two different flooding experiments** on the same core plug. This is designed to mimic the effect of salinity modification in unflooded zones.

Tertiary recovery



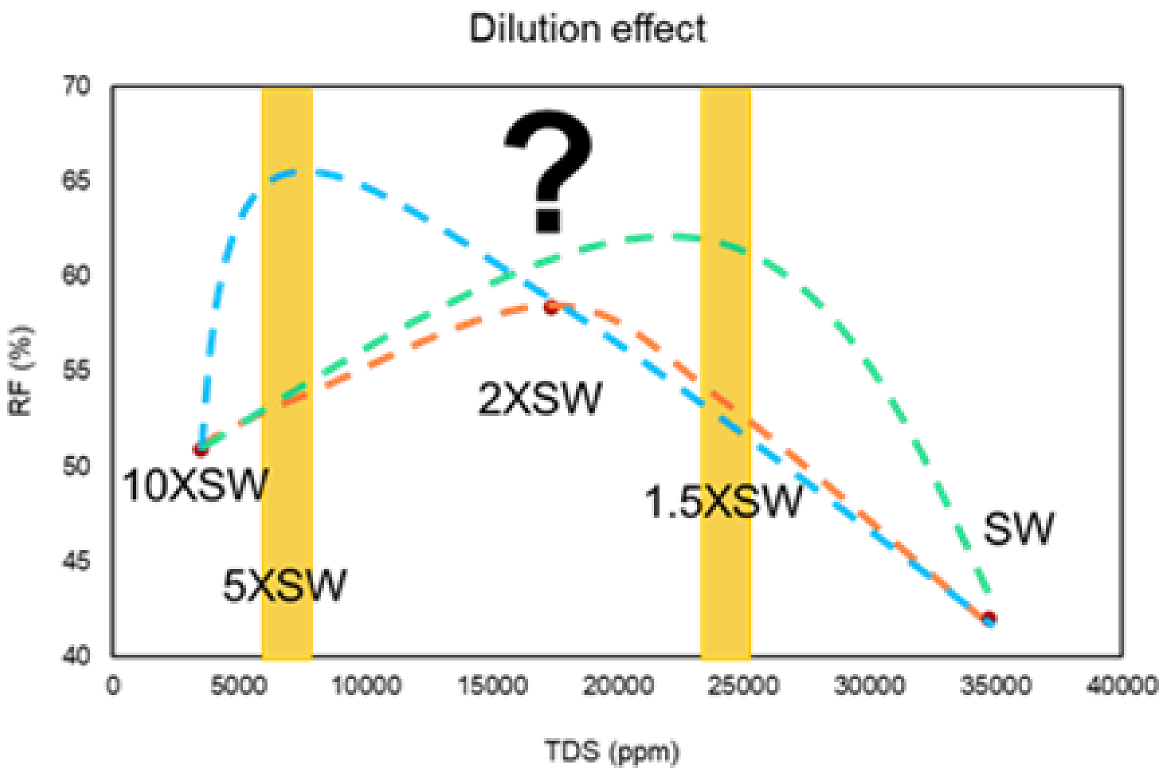
Tertiary recovery is the **additional** recovery obtained by injecting a modified brine **after** the first injection in the same experiment. This is designed to study the effect of changing injection brine in already flooded rock.

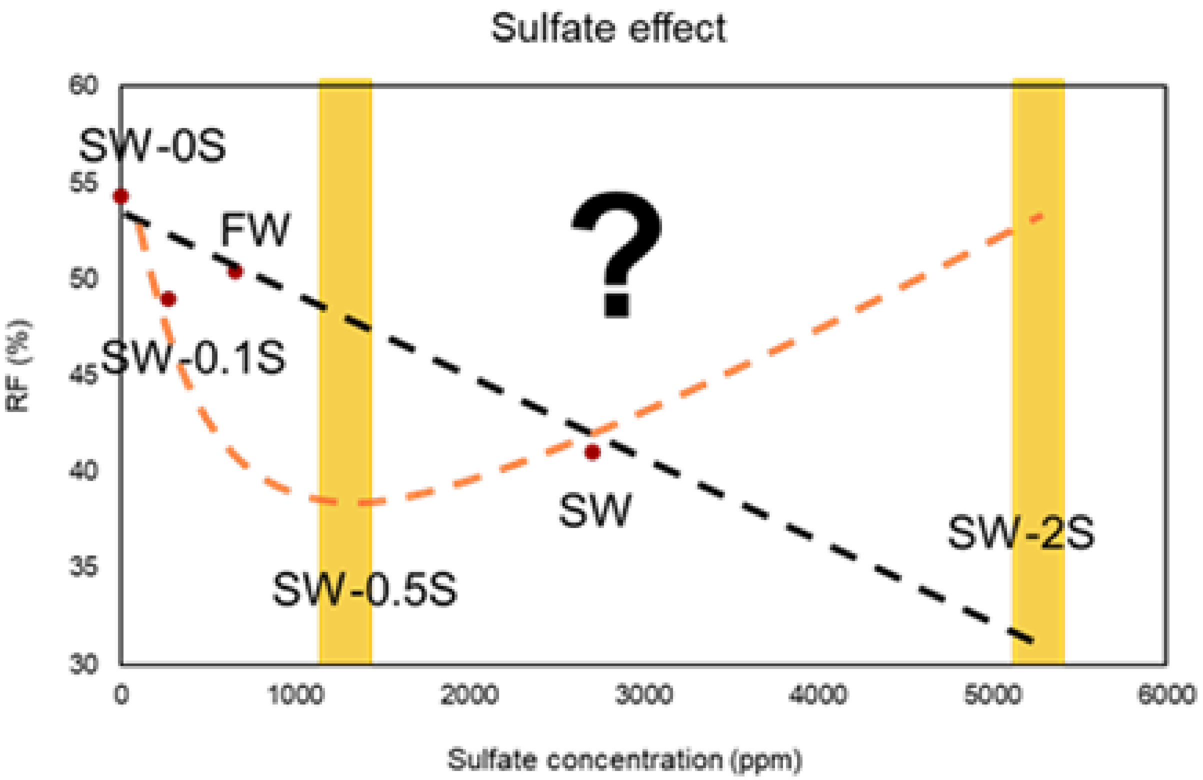
All relative permeability curves



SWIM = Smart Water Injection Method

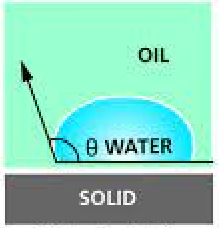
Step 2:
Determine optimum composition of injected seawater in corefloods


Dilution effect

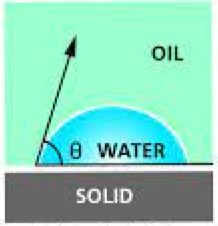

Sulfate effect

SWIM = Smart Water Injection Method

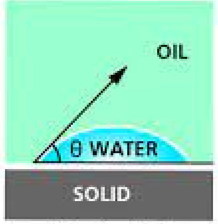
Step 2b:
Verify results with contact angle measurements



105 < θ < 180°
OIL-WET

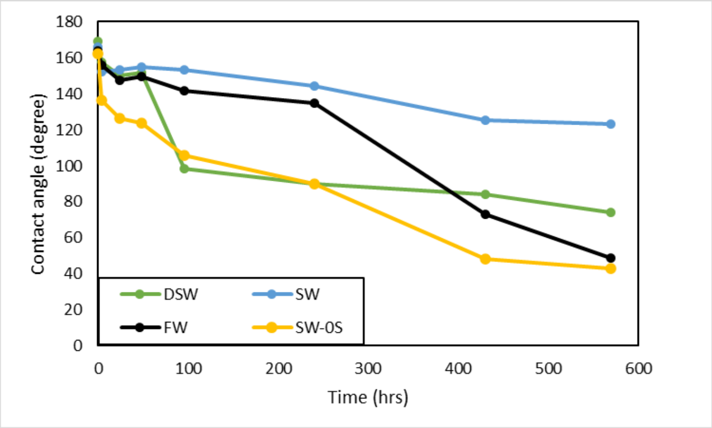


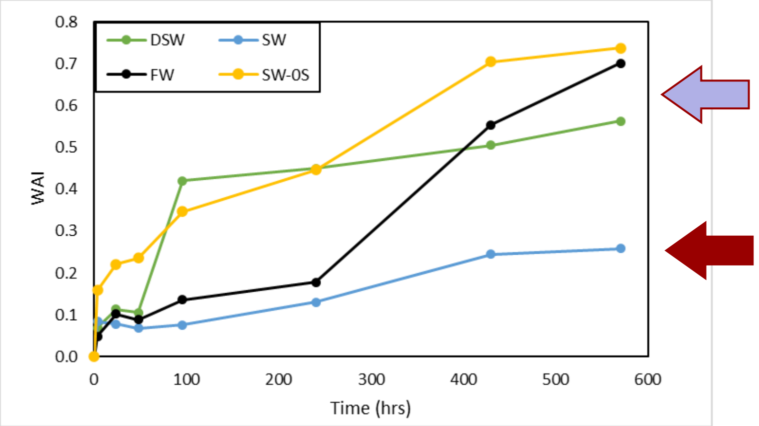
75 < θ < 105°
INTERMEDIATE-WET



0 < θ < 75°
WATER-WET

Reservoir sample





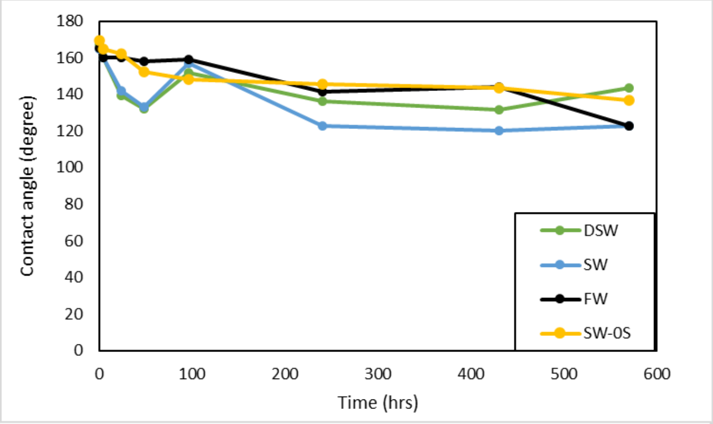
θ_f, final contact angle
θ_i, initial contact angle (before aging)
θ_0, original contact angle (after aging)

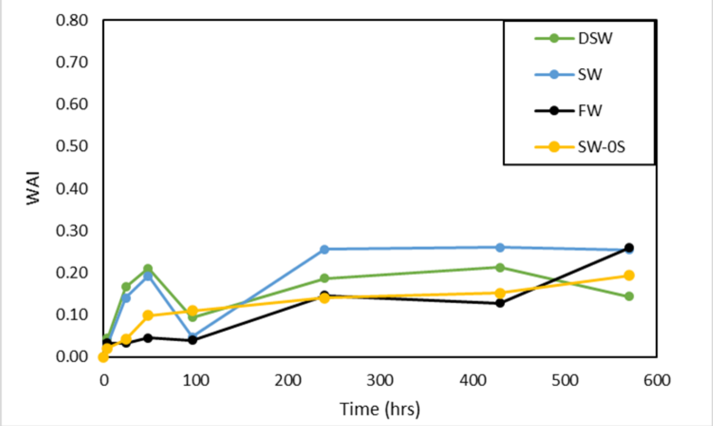
$$WAI = \frac{\theta_0 - \theta_f}{\theta_0 - \theta_i}$$

Changing to water-wet

Remaining oil-wet

Outcrop sample

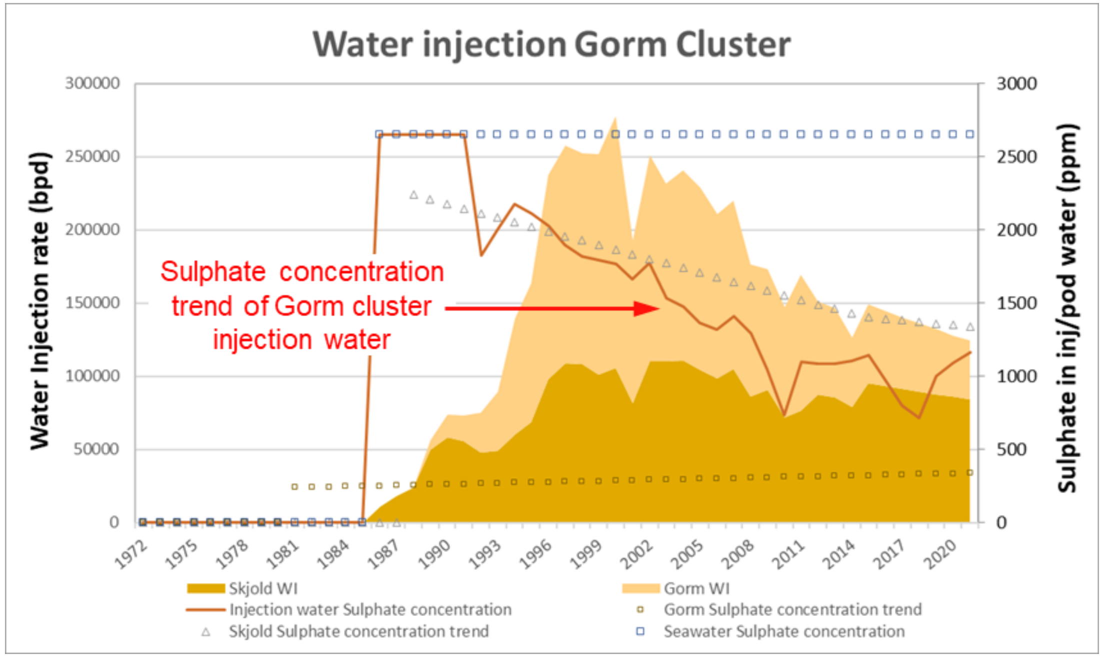


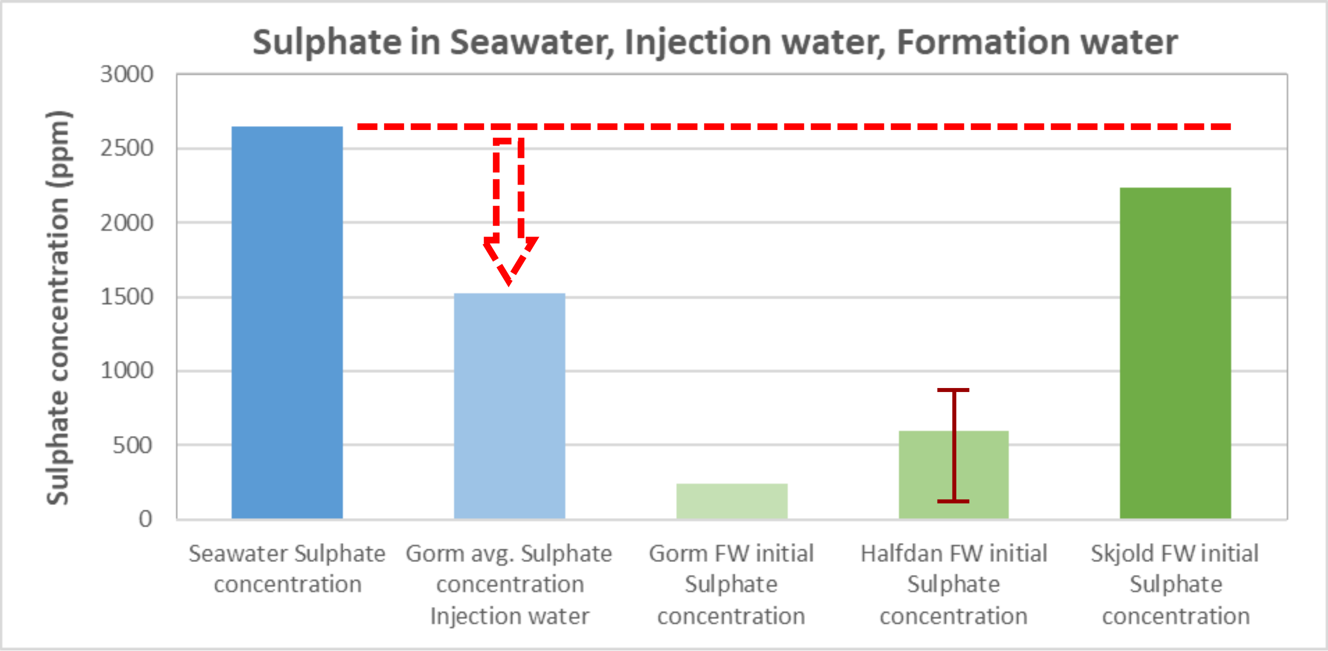


SWIM = Smart Water Injection Method

Step 3:

Investigate SWIM effect as possible explanation for Gorm RF anomaly





Skjold and Gorm have been waterflooded with a mix of seawater and produced water. Over time the injection water composition changed from high sulfate (2650 ppm, SW) to low sulfate (ca. 1000 ppm). This has benefitted the Gorm field more than the Skjold field, as water injection in Gorm started 4 years later than in Skjold.

The average sulfate concentration of injection water used for waterflooding Gorm and Skjold is circa 1500 ppm, much lower than the 2650 ppm sulfate concentration of seawater

The SWIM effect may explain Gorm's high RF of 64% (12% higher than expected)

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10:45 – 11:20 **Recovery Panel discussion**

Panel:

- *Vibeke Levi Nilsson (Noreco Oil Denmark A/S);*
- *Hamid Nick (DTU Offshore);*
- *Ken Wesnæs (Noreco Oil Denmark A/S)*

How will the latest findings regarding injection water composition affect oil recovery in chalk fields?

- ***Possible applications in Denmark***
- ***Wider implications (scaling, corrosion & souring)***
- ***Environmental considerations***

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CHALK DEEP DIVE - GEOLOGY

Building geological models of the subsurface – approaches

30th of November 2022
DTU Offshore – Technology Conference

Florian W.H. Smit
Researcher
Department for GeoEnergy and Storage

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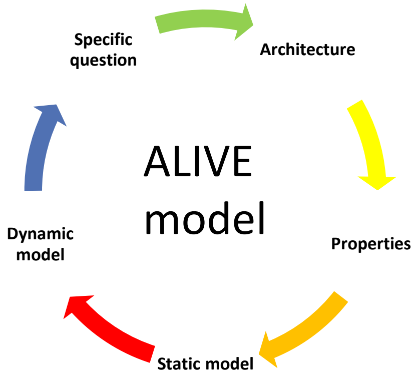
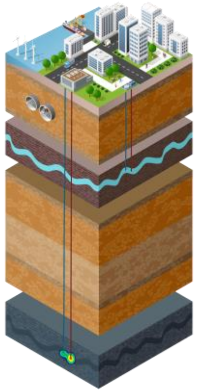
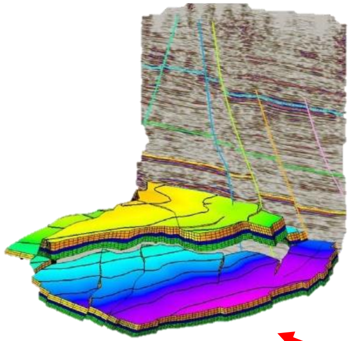
GEUS

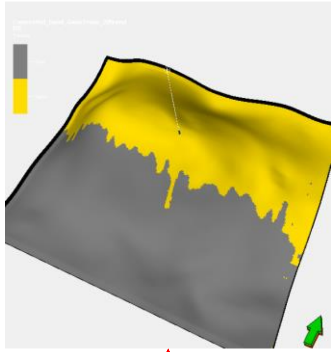
Why do we need geological models?

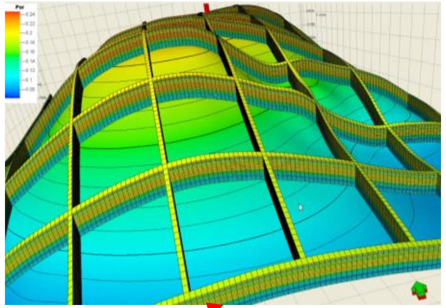


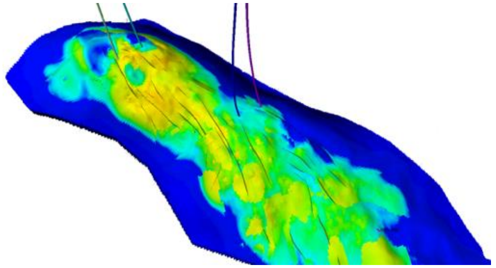
Interest/ Purpose → **Reservoir architecture** → **Reservoir properties** → **Static reservoir model** → **Dynamic flow model** → **Insights**

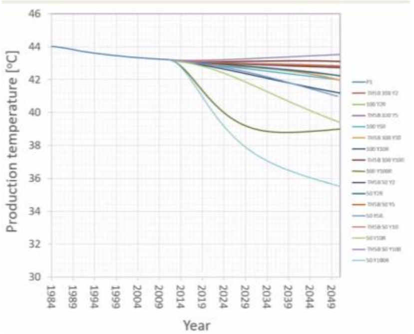












Choices

por, perm, NtG

Prediction reservoir architecture and properties

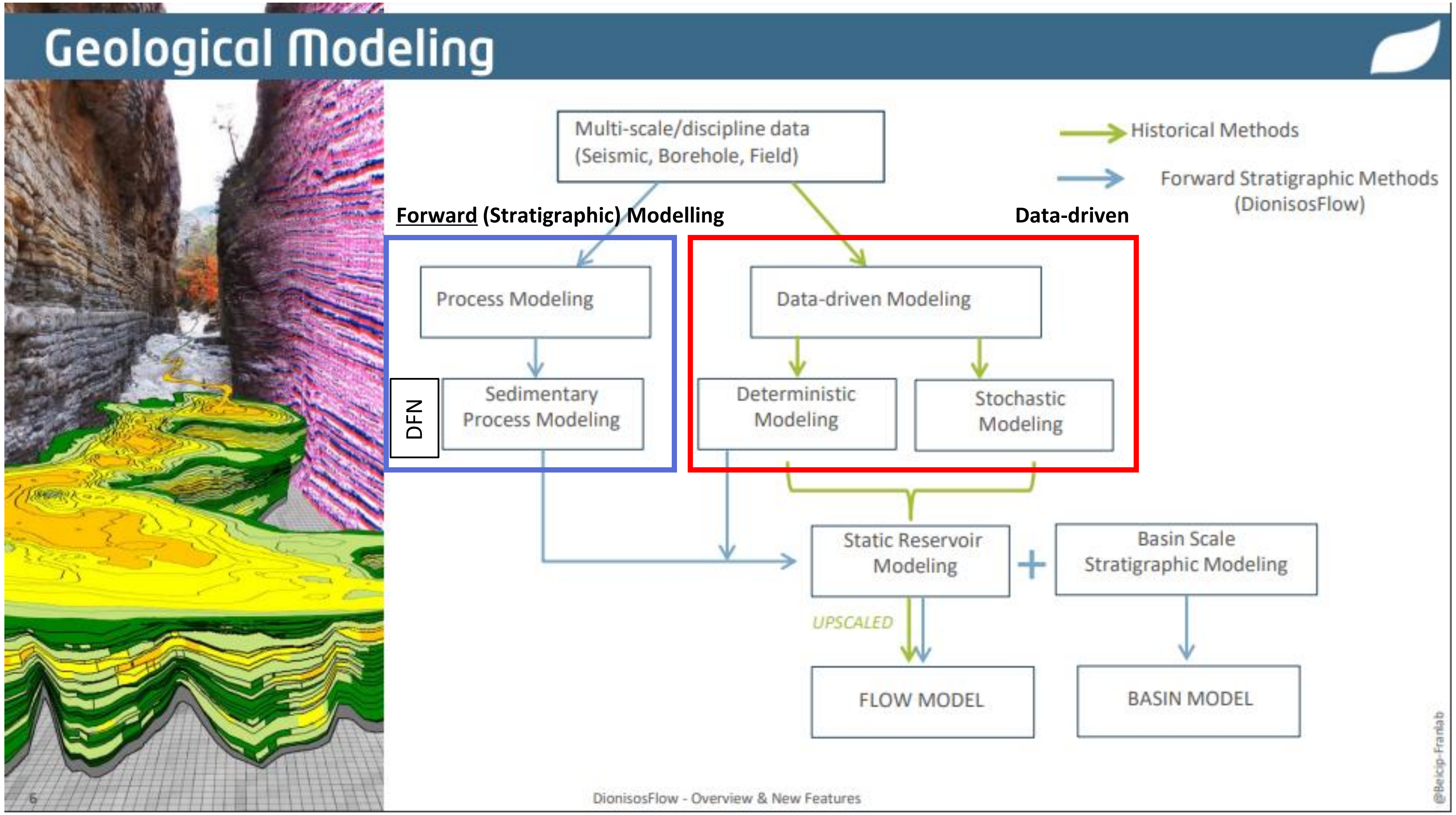
Implications for business case

Subsurface data integration

Aim: simulate

- **CO_2 storage**
- **Oil and gas extraction**
- **Geothermal energy extraction**
- **Groundwater**

Two main routes of modelling



Geological Modeling

Historical Methods

Forward Stratigraphic Methods (DionisosFlow)

Multi-scale/discipline data (Seismic, Borehole, Field)

Forward (Stratigraphic) Modelling

Data-driven

Process Modeling

DFN

Sedimentary Process Modeling

Data-driven Modeling

Deterministic Modeling

Stochastic Modeling

Static Reservoir Modeling + Basin Scale Stratigraphic Modeling

UPSCALED

FLOW MODEL

BASIN MODEL

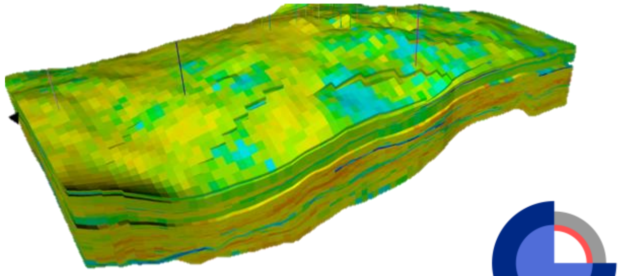
6

DionisosFlow - Overview & New Features

@Beicip-Franlab

Subsurface geological architecture:

1. **Data-driven approach**: mapping of the subsurface and extrapolation of that data
2. **Forward approach**: simulate the geological processes that led to the sedimentary successions

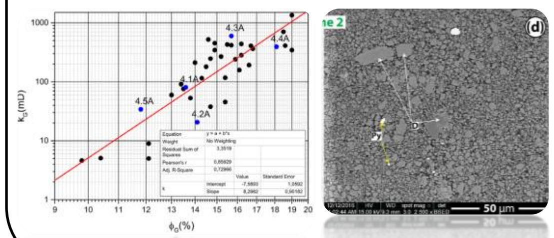


Static reservoir model:
- Layering
- Facies
- Physical properties

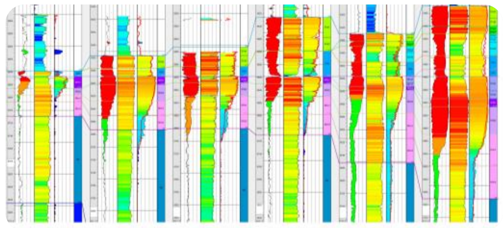
Constructing geological models of reservoirs/seals

Data-driven approach

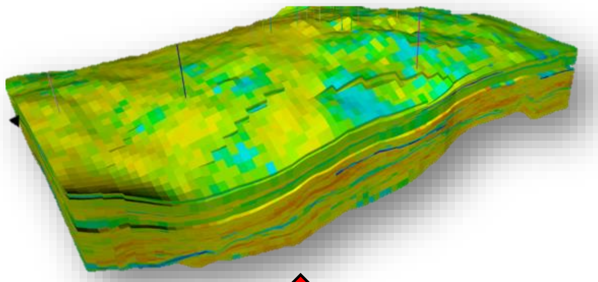
Core measurements



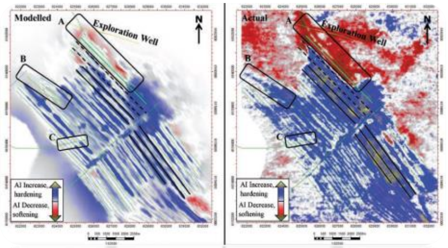
Well (log) data



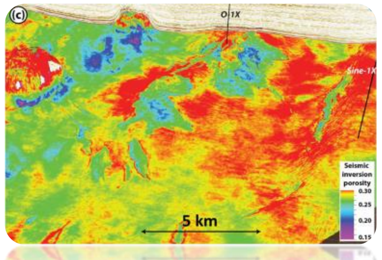
Biostratigraphy



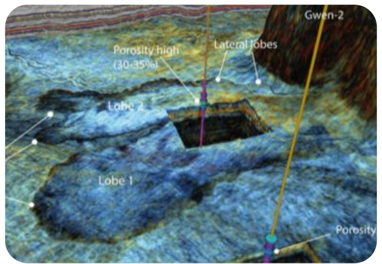
4D Seismic data



Seismic inversion



2D/3D seismic data



G E U S

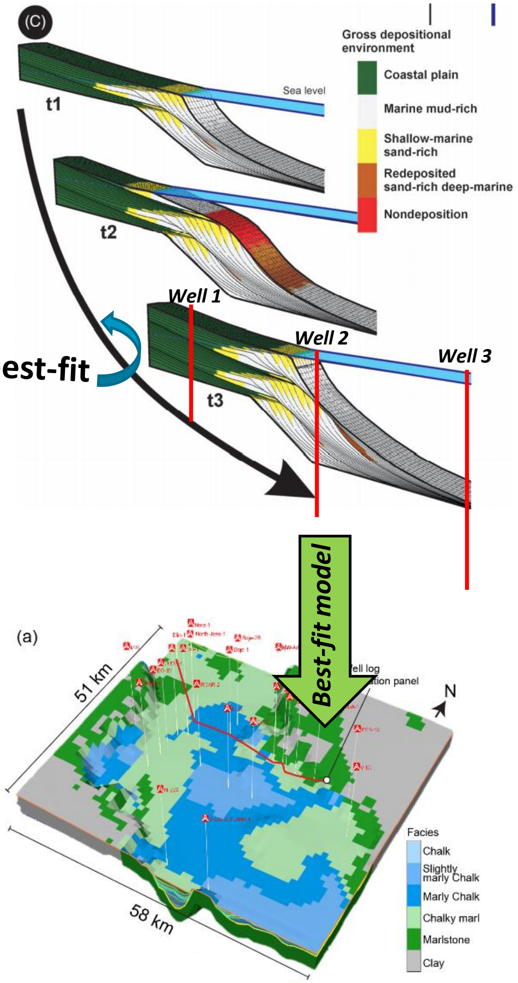
What if reservoir layering is below seismic resolution?

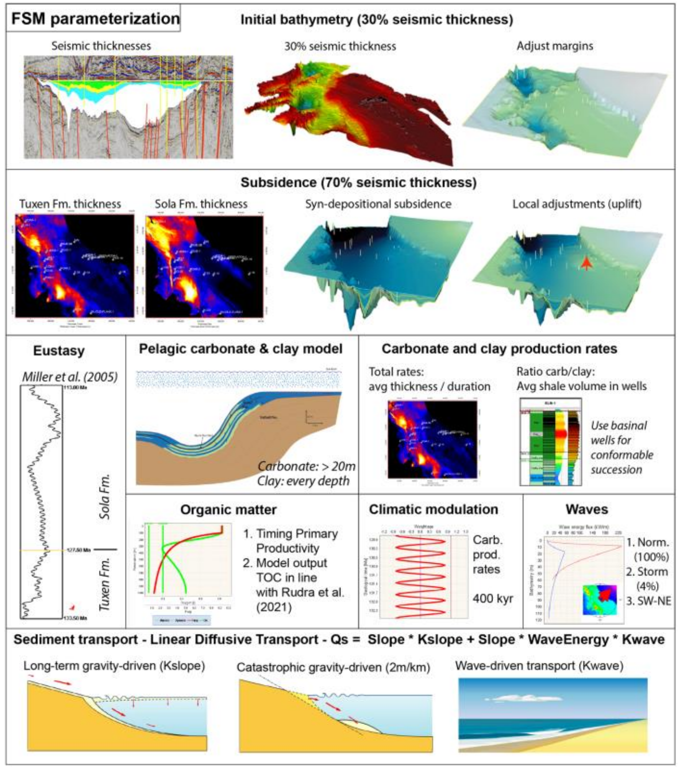
Process-based approach – forward stratigraphic modelling

- Simulating deposition of the sedimentary succession through geological time:
    - Accommodation space (subsidence + eustasy)
    - Clastic sediment influx
    - In-situ carbonate production
    - Sediment transport (diffusion)

Well/seismic calibration
Adjust parameters until best-fit

- Best-fit model: Calibrated 4D (3D space + geotime) rock properties grid based on geological principles rather than deterministic/statistical methods
    - Direct input to static reservoir model
- Run uncertainty and risk analysis to address non-uniqueness of best-fit model and quantify target variable uncertainty





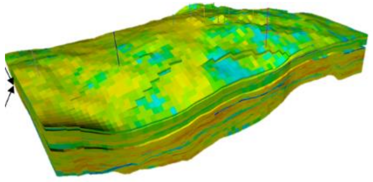
<u>Input from several TRD projects</u>

Structural evolution, seismic mapping, biostratigraphy, sedimentology, clay mineralogy, organic matter

G E U S

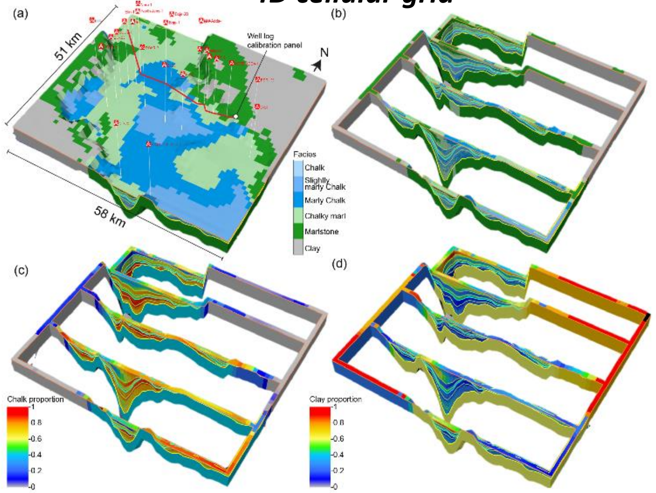
4D (3D + geotime) numerical property grid

Applications for geological model

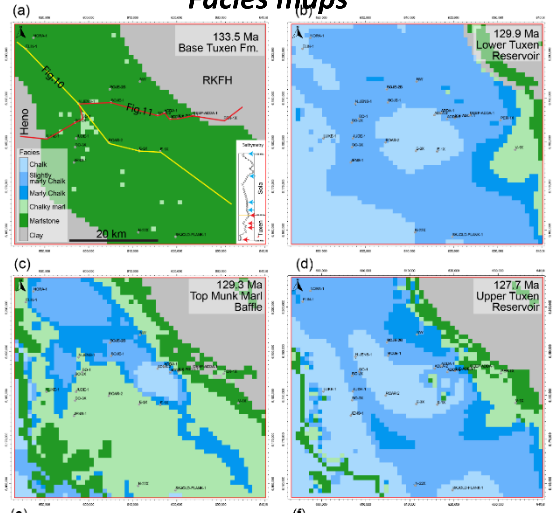


Architecture Facies models

4D cellular grid

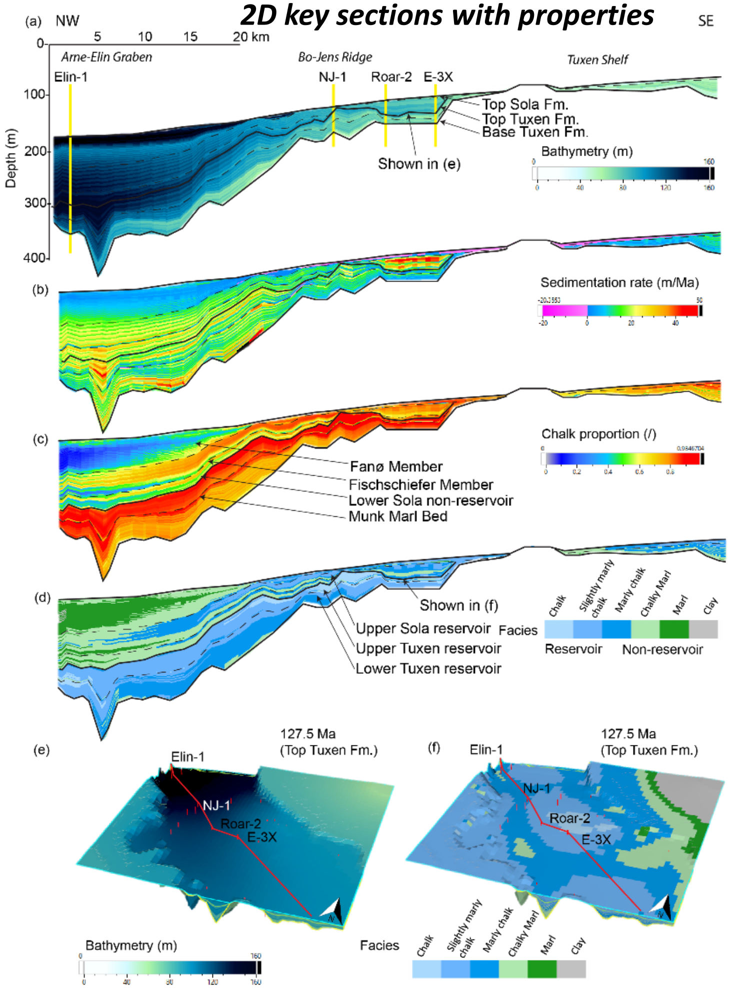


Facies maps

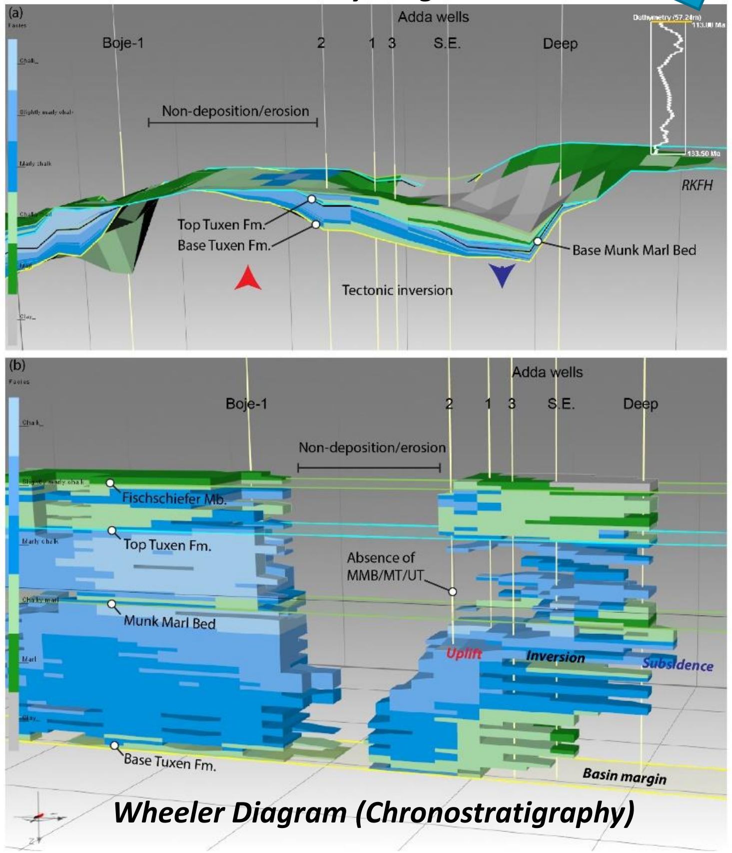


4D (3D + time) grid with layering and sediment proportions

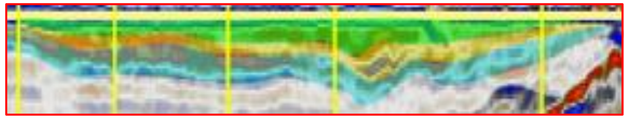
2D key sections with properties



Sub-seismic layering scheme



Wheeler Diagram (Chronostratigraphy)



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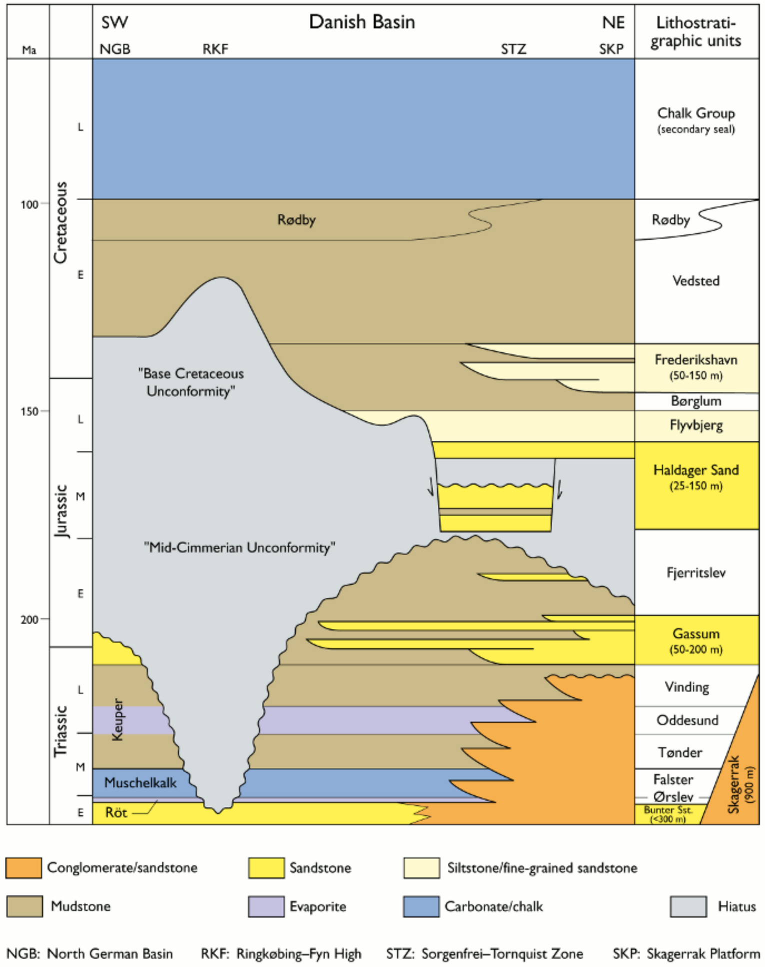
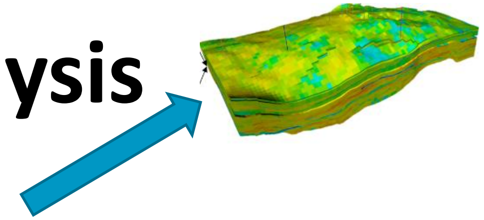
Application to CCS

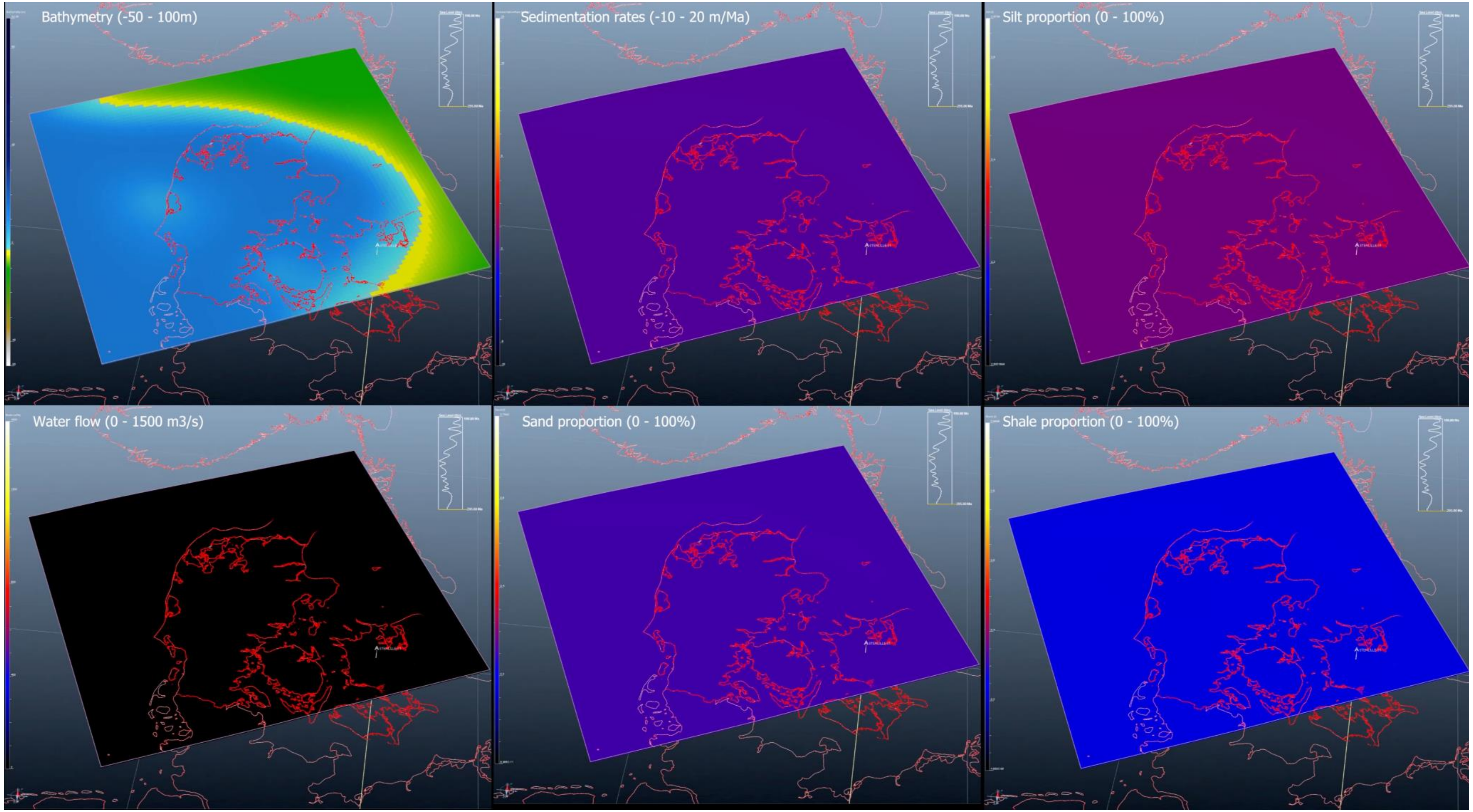
- Methodologies are universal and can be applied the promising reservoir/seal pairs for CCS
    - Cenozoic
        - Miocene sandstones
    - Cretaceous
        - Frederikshavn, Flybjerg, Haldager
    - Triassic/Jurassic
        - Gassum, Skaggerak, Bunter Sandstone
    - Permian
        - Auk Formation (Rotliegendes)
        - Volanics



Scaling up CCS in Denmark – input to play analysis

Regional models with limited data





Model properties

Dimensions
395 x 445 km
Cellsize 5 km

Incorporated parameters

- Initial bathymetry following North Sea profile
- Mapped structural elements
- Variable subsidence
- Eustatic sealevel curve (Haq 2018)
- Five fluvial sources feeding into basin (N-NE-E-SE-S)

Notes

1. Regional model acts as framework, higher resolution at regions/structures
2. **Not yet calibrated to wells or seismic thickness…**
3. Run sensitivity and risk analysis
4. Export to Petrel

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Agenda – Chalk Deep Dive

Hosts: Frederic Amour, Hans Horikx, Birgitte Larsen & Ulla Hoffmann, Danish Offshore Technology Center

11:20 – 12:00 Recovery Panel discussion

Panel:

- *David Quirk (DTU Offshore)*
- *Ingelise Schmidt (TotalEnergies)*
- *David Pickering (Pickering Geoscience)*
- *Jan Kresten Nielsen (Noreco Oil Denmark A/S)*

“***How do we build geological realistic reservoir models in the future, in relation to both oil and gas activities as well as CCS opportunities? Is the approach of simulating physical processes rather that the more traditionally data-driven approach a way for the future”?***

Thank you for joining this session

It is now time for lunch – it takes place in the restaurant from 12.00 to 12.45.

Meeting Place will be open from approximately 12.30 – it is the last chance to meet with the companies this year.

The next session will begin in Teatersalen (the main venue) from 13.00.
Please be there on time!