Sedimentation on the Adda Shelf – a condensed end-member of the Tuxen Formation facies spectrum

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Research Programme:
Lower Cretaceous

Abstract:
Cores in the Deep Adda-1 well represent a key end-member of Tuxen Formation facies variability, reflecting condensed carbonate sedimentation on a Hauterivian–Barremian structural high close to the margin of the Central Graben. They record the interplay between pelagic and benthic carbonate production, hemipelagic clay input and gravity-flow processes, and the subsequent biogenic reworking and early diagenesis that resulted in nodular and firm-/hardground fabrics. Studies of the macrofauna, nannoflora and ichnofauna are integrated with sedimentology and inorganic geochemistry to investigate the relative importance of these processes in this marginal, condensed setting and the implications for understanding the regional deposition of Lower Cretaceous reservoir chalks.

Irregular hardground surface capping the lower Tuxen Formation chalks, overlain by a lag of ?bored concretionary pebbles and inoceramid shell fragments at the base of a c. 2 cm graded marlstone and typical pinstripe laminated dark marlstones of the Munk Marl Bed (scale in cm).
Lower Cretaceous clay mineral distribution and microscopic characteristics in the Danish North Sea

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Abstract:
The Lower Cretaceous has been of great interest ever since the first recovery of hydrocarbons in the North Sea graben in 1977. However, the exact composition of the Lower Cretaceous, remains for the greater part unknown. Clay quantity and identification are of special interest since reservoir properties strongly rely on these parameters. A detailed clay mineral analyses in combination with a better understanding of the sedimentology and stratigraphy of the Lower Cretaceous might improve reservoir models. This could lead to an increase in hydrocarbon recovery and improve drilling and operations.
**Geochemical mapping of the Lower Cretaceous Chalk**

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**Research Programme:**
Lower Cretaceous

**Abstract:**
180 drill core samples were analysed at GEUS using ICP-MS. The samples represent the different stratigraphic levels present in core from N. Jens-1 (69 samples), Bo-2X (27 samples), Adda-3 (38 samples) and S.E. Adda-1 (46 samples).

The geochemistry can be used to fingerprint the source and character of the clay minerals in the chalk. An example showing variation with time is the distinctly lower K/Al ratio in Upper Sola as compared to the other units suggesting lower content of illite versus kaolinite here.

Many Lower Tuxen samples have high Nb/Al ratios. In one sample in particular both Nb and Zr is very high. This is characteristic for alkaline volcanics, and this sample may represent chalk with influx of volcanic ash from an alkaline volcano tied to the opening of the Atlantic Ocean.

U/Th ration is a function of the availability of oxygen in the sediment during sedimentation. The Ce/(La+Nd) reflect the availability of oxygen as well and by combining these ratios we can get a proxy for the environment at the seafloor during deposition of the chalk. The Munk Marl show signs of reducing environment whereas these ratios suggests that most Lower Tuxen samples as well as Upper Sola should have more oxygen compared to e.g. Lower Sola and Middle and Upper Tuxen and Lower Sola.

The content of Mn is high in Lower Sola – up to several % locally combined with high Fe content. Sr is an element that is mainly located in the carbonate and Upper Tuxen 1 samples from N. Jens 1 have distinctly higher Sr compared to Upper Tuxen 1 from Adda 3 and S.E. Adda 1 suggesting that there are lateral differences in the carbonate compositions.

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*Figure 1*

**ppm K versus ppm Al in Lower Tuxen chalk.**

*There is a lateral variation in the K/Al ratio between e.g. SE Adda-1 and N Jens-1. This variation is probably caused by differences in illite and kaolinite content reflecting different sources of clay.*
Modeling and Simulation of Oil Production from the Lower Cretaceous Tight Formation
Including Capillary Pressure Effects on Phase Behaviour

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Abstract:
The influence of porous media on phase behaviour is a topic of interest driven by the shale gas boom because many field observations suggest the saturation pressure in tight shale formation may change dramatically. There has actually been such a concern for other low permeable tight formation, such as the Lower Cretaceous (LCr) formation in the Danish North Sea, for decades. However, there is no consensus on the extent of the influence and also little analysis of the issue in the open literature. We modified a fully implicit compositional simulator by including the capillary pressure in the phase equilibrium calculation. The simulator was used to investigate natural depletion of a tight LCr reservoir in the Danish North Sea using different capillary pressure models. Differences in the production profiles were observed. In particular, changes in the producing gas-oil ratio due to compositional changes are not negligible.

Figure 1: Saturation profile after 8 years of depletion
Gas injection in Lower Cretaceous reservoirs

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Research Programme:
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Abstract:
The Danish Lower Cretaceous reservoirs are characterised as low permeability and not highly fractured. From the Valdemar field oil is produced through natural depletion. There is limited scope for improved oil recovery through water injection due to the low injectivity of water in these tight formations. Gas injection is a possible alternative.

In this work we investigate the impact on recovery of injecting a number of different possible injection gases. With non-miscible gas injection enhanced recovery is achieved through simple displacement with the injected gas providing pressure to drive additional oil out. Miscible gas injection is achieved using a richer injection gas (e.g. CO₂) or a mixture of hydrocarbons. This enhances recovery through dissolving into the oil, causing swelling; stripping oil components into the gas which is then recovered; increasing reservoir pressure; and by becoming miscible with the oil achieving up to 100% recovery at the pore scale.

![Figure 1: Oil production enhancement through gas injection](image-url)
Nannofossil biostratigraphy and palaeoecology of the Tuxen and Sola Formations in the North Jens-1 well: a stratigraphic template for the LOCRETA project

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Lower Cretaceous

Abstract:
A high-resolution nannofossil dataset of the Tuxen and Sola Formations in North-Jens-1, compiled from GEUS analyses since 1997, provides a robust stratigraphic template that is now under extrapolation in the LOCRETA project to include key wells in the Bo, Boje and Adda structures. In addition to contributing to the palaeoceanographic understanding of the Early Cretaceous chalk system, this dataset provides the requisite framework to constrain seismic, petrophysical, sedimentological and geochemical correlations both within the Valdemar Field and semi-regionally in the Danish Central Graben.
Quality controlled PVT data from Lower Cretaceous chalk fields

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Abstract:
PVT data are essential for proper field development plan, accurate reserve estimation, reservoir simulation, material balance calculation, and optimum oil recovery plans. High quality and accurate PVT data can therefore reduce uncertainty in fluid modelling, fluid properties measurement, and construction of thermodynamic model for representative reservoir fluid.

In this work, we study the quality control of PVT measurements on collected samples from Lower Cretaceous chalk fields to select the representative reservoir fluid. An overview of different methods i.e. mass balance, cross plots and the K-values method, for verifying the consistency of PVT data is presented. Some of the reservoir fluid properties such as formation volume factor and density are modelled using an equation of state (EOS) and compared with experimental measurements from the sampling reports.
Stratigraphic modelling of the Tuxen and Sola Formations in the Danish Central Graben

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Research Programme:
Lower Cretaceous

Abstract:
The Lower Cretaceous Tuxen and Sola Formations in the Danish and southern Norwegian central graben consist of a heterogeneous succession of chalk, marl, and shale in which the clay content exerts a major control on reservoir properties, as known from the Valdemar and Adda fields.

In this study, we employ deterministic 4D multi-lithology forward stratigraphic modelling (DionisosFlow™) in order to evaluate the available sequence stratigraphic framework and assess the effect of various parameters on the clay distribution at the basin and field scales. The advantage of this method is that it provides an experimental approach that could be constrained by the available data while accounting for geological processes.

Here we present results of preliminary simulations on hypothetical basinal geometries illustrating the sensitivity of clay distribution to sea level variation in different realms of the basin (Fig. 1).

Fig.1. (a) 3D stratigraphic model of a hypothetical case with shallow water, deep basin, and basinal high realms with two clay sources (arrows) and carbonate produced in the water column. (Dashed line marks the cross section in (b)). (b) Extracted cross section across the realms of the model showing different evolution of facies in different realms. e.g. increased carbonate content upwards in the shallow water realm while the opposite is observed on the basinal high. (c) Chronostratigraphic diagram of the above cross section showing the facies development with eustatic sea level variation indicating different reaction to sea level fluctuation on the basinal high compared to deep basin and shallow water. (Red dashed lines mark maximum flooding surfaces, and blue dashed lines mark sequence boundaries).
Gas Injection in Valdemar Field

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Abstract:

The Valdemar Field is found in the Danish Central Graben, and the main production occurs in the Lower Cretaceous reservoirs. Due to the high level of clay, low permeability and extreme heterogeneity, the hydrocarbon production is challenging, and a large variation in productivity is observed in different parts of the reservoir. Gas injection was selected as one of the possible methods to rebuild the reservoir pressure, and consequently increase the oil recovery. A series of flooding experiments will be conducted on core scale to investigate the oil recovery potential of different gases, including methane and nitrogen, using reservoir material and representative life fluids. The pressure and temperature will simulate the real field conditions. The results of initial floods conducted on Stevns Klint outcrop cores are presented in this poster. The tests were conducted at 50 and 160 bar and 25°C, in order to get familiar with the setup, and identify the main challenges of this type experiments.
Experimental determination of phase behaviour in tight Lower Cretaceous formation

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Abstract:
The Lower Cretaceous rock has an extremely low permeability, this degree of confinement affects the thermodynamic behavior of fluids, which show properties different from the bulk fluids. Capillarity and surface adsorption phenomena are significant in this type of reservoirs due to the high surface-fluid interaction in the meso and micropores.

Knowledge of the phase behavior of the reservoir fluids under confinement is mainly theoretical, as conventional PVT are not able to study confined fluids. However, it is possible to determine boiling points under confinement through the analysis of the boiling endotherm, as previously reported by Luo et al.\textsuperscript{1} and Deo and coworkers\textsuperscript{2}. In this work we present experimental measurements of the boiling point of n-hexane and n-decane confined in silica nanopores (average diameter of 5 and 13 nm). A clear separation between the vaporization peaks of the bulk and confined fluid was observed.

Figure 1: DSC Thermograms of nanoconfined n-decane at 1 bar.

Sedimentology of Lower Cretaceous carbonates, Danish North Sea

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Lower Cretaceous

Abstract:
The Lower Cretaceous of the Danish North Sea has received significantly less scientific attention than other Mesozoic intervals and is consequently relatively poorly understood. The aim of this PhD project is to establish a depositional model and strengthen the understanding of the depositional processes and environments of the Lower Cretaceous pelagic/hemipelagic carbonates and marls in the Valdemar-Adda area. This poster summarises the preliminary results of detailed sedimentological logging of a core from the Boje structure. The core covers the interval spanning from the uppermost Valhall Formation to the lower Sola Formation, including the Tuxen Formation in its entirety with the exception of 13 ft. in the middle of the upper Tuxen. Lithologies in the cored section range from dark grey to black marls to off white to white chalk. The amount of clean chalk in the cored section is, however, very low with the bulk of the “chalky” sections being composed of slightly marly chalk. Five lithologies have been identified, mainly based on colour: marl, chalky marl, marly chalk, slightly marly chalk and chalk. The depositional facies are, with the exception of laminated marls, characterised by an extensively biomottled fabric. Facies showing evidence of shear deformation and potentially re-deposition also occur. Also present are abundant deformation bands, minor fractures and faults and intervals displaying a high degree of silicification. The vertical succession of facies is highly variable and the thickest slightly marly chalk units are approximately 6 ft. thick.
Abstract:

A basic hypothesis of the TRD1 work programme states that fractures (natural and induced) play an important role for the quality of the tight Lower Cretaceous reservoirs, since they increase permeability and porosity of the rock. These fractures are way below the resolution of any seismic data though.

From the interpretation of 3D seismic data, it is an aim of this PhD project to provide an improved structural model of the Valdemar Oil Field area in order to describe its deformational history and predict the occurrence of natural fracture zones. Integrated with well- and core data, this is expected to lead to a better understanding of the distribution of potential Lower Cretaceous pay zones.

This poster presents preliminary results from the project.
ROCK PHYSICAL MODEL FOR CHALK OF THE VALDEMAR FIELD

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Abstract:

The Valdemar field is a low relief marly chalk structure, sealed from the overlying Chalk by a calcareous shale. This study is based on core-calibrated well log data representing a range in clay content from pure chalk to pure shale over a depth interval of 200 m. The Iso-frame model was applied. It helps to explain the effect of clay on elasticity of carbonate sediments. The model quantifies on a scale from 0 to 1 to which extend the solids are part of the load-supporting frame of the sediment. Iso-frame modelling indicates that up to 40% clay softens the chalk, whereas higher clay contents stiffen the sediment.

![Graph showing Iso-frame model results]

Gas Liberation in Low Permeable Reservoirs

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Lower Cretaceous

Abstract:
The liberated free-gas phase, generated due to reservoir pressure decline, can either be a handicap or a benefit during oil production. The bad scenario is that disconnected immobile gas bubbles can block individual pore throats, lowering thus, the effective permeability of the reservoir. Unfavourable pore geometry along with capillary forces/wettability balance are the main contributors to that possibility. On the other hand, a favourable case is that the liberated gas bubbles coalesce easily forming a mobile gas phase, which can provide energy to the reservoir by a competent gas-oil gravity drainage mechanism. For such an effective upwards gas migration though, crucial parameters are permeability and dip of the reservoir, layering/stratigraphy, as well as the relative permeabilities of the fluid phases.

The experimental study of this work aims to determine the mobility of the formed gas bubbles and their effect on the effective permeability of the oil. The experiments involve gas liberation in a low permeability reservoir sample, induced by pressure decrease. The pressure will range from above to below the saturation pressure, while X-ray computer tomography will be applied to detect the in-situ gas liberation. Effective oil permeability versus pressure drop will be monitored. The onset of gas phase production, if occurred, will be monitored as well.

Along with the experimental work, the modelling part of the study will be developed. For calculating the amount of the produced gas, a previously developed thermodynamic model (DTU) will be adjusted and applied. The model involves oil and gas equilibrium under the action of capillary forces. If the released gas stays in the pores in the form of bubbles, a correlation between the amount of liberated gas and the reduction of oil permeability will be provided. In the case of gas phase production, a more advanced dynamic model has to be developed, for the determination of the gas-oil relative permeabilities.

The time being, the correlation between the amount of liberated gas and the reduction of oil permeability is modelled, using the method of the effective medium. The final experimental setup has been determined.