Feasibility of quantitative seismic interpretation of the Lower Cretaceous unit in the Valdemar field

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Upper & Lower Cretaceous - Modelling natural fractures

Methods for quantitative seismic interpretation (QSI) aims at extracting information about reservoir quality based on seismic data, for example from amplitude vs. offset (AVO) and inversion analysis. Prior to QSI, it is important to perform a feasibility study to achieve some initial understanding of the basic relationships between reservoir properties, rock physics behavior and seismic observables based on well log data covering the geological interval of interest. The objective is to outline the potential and feasibility of various QSI techniques for a given geological target.

This study investigates the rock physics and seismic properties of a depth interval including the Tuxen reservoir in the BO-2X well located in the Valdemar field. The study is summarized by a three-step workflow:

1. Well log QC: Ensure that geologically and physically plausible log data are derived. We normally consider the compressional and shear sonic velocities, density, porosity, shale volume and water saturation logs to be of relevance.
2. Lithofacies discrimination: Identify key lithofacies within a depth interval by using a linear discriminant classifier based on porosity, shale volume and water saturation logs as input, and compare these results with a Bayesian lithofacies classification scheme based on sonic velocities and density logs as input.
3. Calibrate rock physics models: Select appropriate rock physics models for the reservoir target to link seismic properties (e.g. acoustic impedances and velocities) with reservoir properties (e.g. porosity, shale volume and water saturation).

This contribution is part of the LOCRETA (Consortium for Lower Cretaceous reservoir analysis) project funded by the Danish Hydrocarbon Research and Technology Centre (DHRTC).
The kinematics of Cretaceous-Paleogene basin inversion in the Danish Central Graben – New perspectives from 3D seismic data

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Tight Reservoir Development 1 – Lower

Complex basin-inversion structures host important hydrocarbon reservoirs in the Danish Central Graben. These elongated, anticlinal structures are bordered on one side by reverse faults, and formed during Cretaceous-Paleogene basin inversion following Late-Jurassic rifting. Although the timing of individual inversion phases have previously been constrained via seismic stratigraphy, the kinematics of these structures have yet to be fully explained.

We have interpreted a depth-converted 3D seismic data set covering part of the Danish Central Graben, in order to shed light on this matter and performed 2D structural restoration of sections in order to validate our model.

We find that a complex interaction between thinskinned-thickskinned extension/compression, controlled inversion in the studied area with Zechstein salt playing an important role. This is due to its ability to flow and act as a detachment layer for faults, i.e. decoupling deformation in the overlying basin (Mesozoic-Cenozoic) from the underlying “mechanical basement” during both extension and shortening. Furthermore, normal faults are abundant in the crests of the studied inversion structures, i.e. at reservoir levels. We find that these formed due to local crestal extension and -collapse during folding in an overall compressional regime.

A better understanding of the kinematics involved in the formation of basin-inversion structures, is important in order to predict zones of sub-seismic deformation that may affect reservoir quality.
Towards Improving Seismic Imaging of the Lower Cretaceous

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Upper & Lower Cretaceous - Modelling natural fractures

Seismic imaging of the Lower Cretaceous in the Danish sector of the North Sea is challenging presumably, in part because of the overlying, layered chalk package that generates interfering multiples and converted waves. Consequently, reservoir quality predictions from seismic data within the Lower Cretaceous are challenging and influenced by high uncertainty, which intricate near-field exploration and development. Therefore, this study aims at improving the seismic image and reduce the noise in the seismic data. By doing so, we aim at obtaining a clearer image of the target geology, as well as conditioning pre-stack seismic gathers to be more suitable for e.g. a subsequent pre-stack seismic inversion and amplitude vs. offset (AVO) analysis.

In this study, a composite test line of pre-stack depth-migrated (PSDM) data that intersects three key wells in the Valdemar field is investigated, focusing on the Lower Cretaceous unit. A processing-flow containing standard operations was used, including muting, spectral analysis and gain corrections, as well as gather conditioning such as residual moveout corrections. In addition, a pre-stack seismic inversion is targeted at estimating sections of the acoustic impedance and the P-to-S velocity ratio. The next step of our research will focus on using these seismic inversion results as input to quantitative seismic interpretations (QSI) of the Tuxen reservoir, where we aim at classifying various lithofacies and estimate the reservoir properties (e.g. porosity, shale volume and water saturation).

This contribution is part of the LOCRETA (Consortium for Lower Cretaceous reservoir analysis) project funded by the Danish Hydrocarbon Research and Technology Centre (DHRTC).
Enhanced visualization and extraction of fault-damage zones within the Lower Cretaceous Tuxen Formation on the Valdemar structure

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Seismic image processing (eXchroma plug-in for Petrel) applied to the Valdemar Field has helped to enhance the visualization of seismic-scale heterogeneities within the Tuxen Formation that possibly resemble structural features associated with faults. Compared to wavelet-based seismic attributes that utilize a relative long windows (5-10 vertical samples), the image processing technique has much better vertical resolution (1-3 samples). Comparison with these conventional attributes shows that not only more detail is acquired from seismic data, but also the spatial position (lateral and vertical) of heterogeneities is much improved, in particular features associated with fault damage zones (e.g. fracture swarms). Taking it one step further, recent software developments have made it possible to extract these structural data as discrete fault objects, creating a fault dataset with much larger detail than the manual-interpretation-derived counterparts. The possibility to filter these discrete objects by size and azimuth/dip allows the creation of several fault/fracture swarm sets, which can be compared to borehole-derived fracture picks. The next steps will be to investigate if these discrete objects influence production rates, and if so, whether or not orientation has an influence (e.g. open vs. closed structural lineaments). The improved visualization and extraction thus help us to better understand the lateral and vertical distribution of fault-associated damage zones, and its influence on production on the Valdemar structure.
Seismic geomorphology of the Lower Cretaceous strata

Florian W.H. Smit & Lars Stemmerik

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TRD WP-B

Seismic geomorphological analysis of the Lower Cretaceous Tuxen Formation reveals two newly identified types of features: 1) circular depressions, 100-500 m in diameters, 10-50 m deep; and 2) km-wide seismic hardening (high-amplitude reflector packages). Carbon isotope analysis of strata within the seismic hardening shows anomalously low δ¹³C values, indicative of methane-derived authigenic calcite. These features are underlain by normal faults that are well expressed at the Base Cretaceous Unconformity and seem to locally have offset Lower Cretaceous strata, indicating some continued tectonic activity in the post-rift phase. In addition, vertical amplitude dim zones, where seismic amplitude is lower and reflector continuity diminishes, can be identified underneath these sediments. Such zones are often interpreted as gas chimneys, where gas-bearing fluids have migrated vertically along permeable zones (such as fault damage zones and permeable beds), and influence velocity and density of the host rock. The circular depressions within carbonate rocks may have several origins, notably a hypogenic or epigenic karstification, or as a fluid expulsion crater (pockmark). The spatial overlap between MDAC/Gas chimneys and circular depressions suggest that a pockmark origin is most likely. Sources for pressurized (gas-bearing) fluids can be 1) compaction-driven pore-water escape; 2) de-hydration of clay minerals; 3) hydrocarbon-rich fluids from underlying organic-rich intervals (notably Bryne Formation). The results are important as they make us re-think the fluid migration history, its impact on reservoir quality (e.g. additional MDAC calcite within Tuxen Fm.), and possibly early charge and trap of Early Cretaceous strata.
Improved geomechanically-based fracture models

Michael Welch, Mikael Lüthje, Simon Oldfield DHRTC

Presenting author: Michael Welch

Programme your research belongs to: AWF1

At present fractured reservoirs are typically modelled either by modifying the bulk rock properties to take account of the fracture porosity and permeability, or using stochastically generated Discrete Fracture Network models (DFNs). Both methods tend to give a poor history match because the distribution, orientation, length and connectivity of fractures in the subsurface are not well constrained.

To solve this problem, we have developed a new method of characterising fractured reservoirs and building DFNs by simulating the process of fracture nucleation and propagation based on geomechanical principles. In this presentation, we will show how this model can replicate some of the complex fracture geometries observed in outcrops of chalk and other lithologies. In particular, we will examine the controls on the fracture length distribution, the fracture density and the fracture anisotropy. These are all factors that will influence the fracture permeability.

Finally, we will show how variations in the mechanical properties control the timing of fracture nucleation and the rate of fracture growth. We will show how this can be used to quickly generate multiple fracture models that capture the range of uncertainty in fracture patterns.
THM modelling of discrete fracture and matrix

_Luis Torres, Saeed Salimzadeh, Hamid Nick_

_Luis Torres_

_AWF.1_

We present a coupled thermo-hydro-mechanical model for discrete fracture model. This study illustrate the importance of coupled modelling in fractured reservoirs.
Discrete Fracture Flow and Matrix Modelling

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AWF1

We present applications of our developed discrete fracture-modelling platform. The mentioned applications including evaluating productivity index reduction as a result of solid-fluid interaction. Moreover, a surrogated model, which can be used to mimic the effect of solid-fluid interaction on fracture aperture alteration, is also presented. This model can reduce a computational cost while maintain an acceptable accuracy.
Two phase flow modelling on realistic discrete fracture models

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Is the presenting author a research assistant/MSc/PhD student/Postdoc? Yes

We analyze the waterflood performance using an outcrop-based model, representative of North Sea fractured chalk reservoirs. To this end, we consider published data on the fracture geometry of Lägerdorf quarry in northern Germany and create a two-dimensional Discrete Fracture-Matrix (DFM) outcrop-based model, populated with the rock and fluid properties, typical for North Sea oil reservoirs. We conduct several DFM simulations to study the dependency of oil recovery factor with respect to water injection rate under uncertainty in fracture apertures and orientations, using both sea and low salinity water as injection fluids. Based on simulation results, we show that if there is a noticeable impact of fractures on the flow, the slower injection rates lead to higher recovery in terms of water pore volumes injected. The main factor influencing the recovery efficiency is whether there is a direct communication between the inflow and outflow boundaries via highly conductive fractures. However, if the fractures’ apertures in the direct communication path are small enough, the capillary forces can counterbalance the viscous displacement in fractures thus leading to better recovery. We demonstrate that commonly used statistical measures of fractures orientation and connectivity cannot predict this type of behavior.