DHRTC Technology Conference 2021
Book of abstracts
Programme: Ekofisk and Tor Fm. Improved Recovery

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A modified strain rate dependent constitutive model for chalk and the effect of creep deformation on wellbore stability

*M.R.Hajiabadi, H.M. Nick*

This work illustrate a modified a 3D geomechanical constitutive model [1] that uses two independent yield surfaces composed of shear failure and a strain rate-dependent pore collapse.

This is used to evaluate the effect of viscous deformation on wellbore stability [2] in horizontal wells during the creep phase. A test called Single Lateral Hole test (SLH) was designed and undertaken to investigate the stability of horizontal open holes. With CT-Scan imaging at two stages of the SLH experiments, the breakout development caused by the creep phase are observed. A constitutive model describes the rate dependent behavior of chalk material with two yield surfaces, composed of shear and pore collapse yield surfaces for the numerical simulation.

References:


Application of DHRTC’s geomechanical model to DUC fields

Amour Frédéric, Hajiabadi M.R., Nick, H.M.

Despite the overall consistency of chalk in terms of reservoir properties across Danish North Sea fields, most of the constitutive models were successfully applied to one single hydrocarbon field. This study aims at building a comprehensive geomechanical model capable of predicting reservoir deformation under different geological settings and production strategies. This study consists of a series of 1-D simulations in two fields in the Danish North Sea (Dan and Halfdan field) using an in-house model calibrated against experimental data on Danian and Maastrichtian chalk. A strain rate dependent constitutive model simulates compaction along a vertical column including the reservoir and underburden. Two runs of simulation are carried out per study area by considering the initial and final yield stresses of chalk. Despite the underlying assumptions during 1-D simulation (e.g., stress path, overburden deformation), the geomechanical model provides a good fit with the observed seafloor subsidence data for most of the studied fields (Fig. 1). The proximity of major faults as in Model B located in the block B of the Dan fields (see Fig. 1) seems however to locally impact the stress path applied to the surrounding rock resulting in inaccuracy in the simulation output. In a next phase, the model will be implemented in 2/3-D to account for the interactions between overburden, sideburden, and reservoir during compaction and, thus, to improve the accuracy of compaction predictions.

Fig. 1. Comparisons between simulated and observed seafloor subsidence during years of hydrocarbon production for Model A (block A, Dan field), Model B (block B, Dan field) and Model C (Halfdan field) (after Amour et al., 2021, proceeding of the ARMA conference).
Sensitivity analysis of key input parameters on reservoir deformation
Amour Frédéric, Hajiabadi M.R., Nick, H.M.

Experimental studies have well-documented the elasto-plastic response of chalk under controlled laboratory conditions in terms of applied stress, water saturation ($S_w$), deformation rate, and temperature. The application of such knowledge to field case studies remains nevertheless challenging as the precise properties of the rock subject to in situ conditions are only partially constrained. Currently, geomechanical simulation studies do not consider these uncertainties associated with the input data. Such as for hydrocarbon reserves estimation at different confidence levels, acknowledging and quantifying the uncertainty in the simulation results is of primary importance to enhance the quality of predictive models.

In this context, this study consists of a series of 1-D compaction simulation tests, during which the values of the yield stress ($\sigma_y$) and $S_w$ of Danian and Maastrichtian chalk are modified. The model outcomes are then compared to assess the sensitivity of these two parameters on the total computed strain. The geomechanical modelling is applied to Danish fields and quality-checked by seafloor subsidence data. On the one hand, $\sigma_y$ values assigned to chalk vary between the initial $\sigma_y$ that corresponds to the stress at the onset of plastic deformation and the final $\sigma_y$ defining the onset of linear plastic deformation. The corresponding porosity-dependent functions for $\sigma_y$ are defined by Amour et al (2021) and Al Assaad et al. (subm.). On the other hand, for each case study, three simulations are run by considering i) fully oil-saturated chalk ($S_w=0\%$), ii) no change in initial water saturation ($S_{0w}$) during production, and iii) production-induced variation in $S_{0w}$ ($\Delta S_{pw}$) (Fig. 1).

The results indicate that the choice of $\sigma_y$ has a significant impact on the total deformation simulated. For instance, the total vertical displacement of the reservoir top can vary by a factor of 30% to 40% in the Dan and Halfdan fields when changing the $\sigma_y$ value in the constitutive equations (Fig. 1). Besides, the simulation outcomes suggest that the softening of chalk strength caused by the presence of water in pore space is mainly caused by the amount of $S_w$ initially present in chalk prior to production. The water weakening caused by $\Delta S_{pw}$ accounts for a negligible amount of the total reservoir deformation (Fig. 1). This study represents the first step towards quantifying the uncertainties associated with compaction simulation.

![Fig. 1: Displacement of the reservoir top in the Dan (left) and Halfdan field (right) during production according to the different scenarios of change in $S_w$ and considering the initial (green) and final (red) yield stress values in the constitutive model.](image-url)

Fig. 1: Displacement of the reservoir top in the Dan (left) and Halfdan field (right) during production according to the different scenarios of change in $S_w$ and considering the initial (green) and final (red) yield stress values in the constitutive model.
Inverse problem for compaction analysis: Estimating mechanical properties from sparse measured data

M.R.Hajiabadi, F.Amour, H.M. Nick

The present study aims to construct a workflow for estimating elasto-visco-plastic material properties in chalk reservoir from subsidence data collected at the seafloor. The geo-mechanical model takes into account the rate-dependency and water weakening effect. The methodology is to predict the elasto-visco-plastic material properties by means of a genetic algorithm that optimizes the history matching between the vertical displacement of the sea-floor simulated by the constitutive model and observed by GPS monitoring surveys of the sea-floor. The suggested procedure is applied to the Dan field.
Recovery of carboxylic acid tracers in two phase flow experiments in chalk

Khoa Huynh, Rasoul Mokhtari, Simon Ivar Andersen, Karen Louise Feilberg

Distribution of oxygenated compounds, such as carboxylic acids, in different phases could significantly impact the wettability of the chalk surface and subsequently the oil recovery. Those active polar compounds could act as “anchors” binding crude oil on the chalk surface, which could also be removed with suitable flooding fluids. In order to reveal the oil recovery enhancement mechanism using smart waters, it is critical to understand the distribution of those “sticky molecules” in different phases. This study attempts to examine the distribution of different carboxylic acid molecules in two phase flow experiment using Danish reservoir chalk. The approach is to spike those tracers into crude oil and monitoring their recovery during the core flooding experiment by oil phase LLE and Q-Exactive orbitrap mass spectrometry analysis. The partitioning of those acids on chalk and aqueous phases was also examined in phase distribution experiments. We observed that poly-carboxylic acid are strongly adsorbed by the chalk reservoir and aqueous phase. The aromatic mono-carboxylic acids are moderately portioned into chalk material and aqueous phase depending on aromatic structure. Interestingly, aromatic mono-carboxylic acids retained strongly in the core flooding system, which were later eluted after a certain pore volume flooding with different brines, while the aromatic tri-carboxylic acids were eluted easily into aqueous phase. Understanding the adsorption of those tracers on different phases could help to interpret the wetting state of Danish reservoir chalk and to correlate the oil recovery with different flooding conditions, especially brine compositions.
Investigation of chemical effects of long-term water flooding on reservoir rocks

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In tight chalk reservoirs, the rock surface is of particular importance. The polar compounds contained in oil are capable of adhering to the surface of the reservoir rock in competition with water molecules. Depending on the composition of the oil and reservoir conditions, the resulting surface has different properties, denoted in petroleum engineering as oil- or water-wet. The polar molecules form strong bonds with the surface of calcite crystal, leaving their hydrocarbon tail facing outwards, where they can interact with other compounds in oil through hydrogen bonding or van der Waals forces, forming a thick immobile layer of crude oil on the rock surface. The effective application of water-injection methods requires considering the interplay of brine, oil and surface in order to optimize solutions for a particular reservoir. Due to the complex nature of the phenomena, accurate simulations are computationally challenging, but the composition of the crude oil has a pivotal impact.

Over the lifespan of production processes in the reservoir, production conditions such as composition of the flooding fluid, the chemical composition of the contained crude oil and of the surface adsorbed material undergoes gradual change. These changes may result in significant alteration of the reservoir performance and require adapting production processes accordingly. The effect of the water flooding performed in the oil fields of the Danish North Sea has been investigated based on the composition of crude oil contained in drill cores. Samples were sourced from several geographical regions affected in varying degree by the water flooding.

Infrared (IR) spectroscopy has been used to perform chemical fingerprinting of the adsorbed oil to observe how properties of the surface may change in response to changing conditions. This information can then be used when designing injection strategies or to anticipate the reservoir response to production chemicals.
Adsorption & electrokinetic behavior at the calcite-brine-oil interfaces and their link to wettability

Bonto, M., Eftekhari, A.A, Nick, H.M.

In oil reservoirs, the preference of the mineral surface towards one of the phases, i.e., wettability, impacts the movement of oil and brine and eventually the final oil recovery. Wettability alteration is reported as the main reason behind the increased oil recovery during modified salinity waterflooding. For chalk reservoirs, the wetting conditions are eventually dictated by the interactions that take place between the calcite, ions in the brine, and crude oil components. To model the interactions in the overall system, we use two surface complexation models for the calcite-brine and brine-oil interfaces. We calibrate and then validate both models against a large database of zeta potential measurements at room temperature. To obtain the effect of temperature on the calcite surface reactions we used high-temperature zeta potential measurements, chromatographic wettability tests and microcalorimetry data. To model the relative change in the wettability state that may occur during the injection of a modified salinity brine, we hypothesize that the adsorption/desorption of crude oil on the rock surface is dictated not only by the zeta potential at the oil-brine and calcite-brine interfaces but also by the availability of sites at the rock surface that can bind basic and acidic groups present at the oil surface. Based on these assumptions, we define a wettability indicator “available adsorption sites” (AAS). Then, we showed its consistency with the remaining oil saturation from spontaneous imbibition tests on chalk. This parameter may help in screening brine recipes that could lead to additional oil recovery and be used to update the relative permeability and capillary pressure when modeling MSW in chalk.
Pore-scale insights into two-phase flow in chalk

Mohsen Farhadzadeh, Ali A. Eftekhari, Hamid Nick

Here, a solver has been implemented to simulate two-phase flow, ions transport, ions adsorption on the chalk surface and dynamic wettability. This provides a framework of pore-level modeling to study flow behavior during immiscible displacement influenced by brine chemistry.

We also investigate co-current and counter-current imbibition flows at the pore-scale using direct numerical simulations (DNS). The volume of fluid (VOF) method is used which represents the two-phase fluid system as a single mixture. In two-dimensional simulations, we explore the influence of pore-geometry, interfacial tension, viscosity ratio, and injection velocity on matrix-fracture interaction.
Modified salinity flooding in North Sea chalk: secondary and near-tertiary recovery

Rasoul Mokhtari, Karen Feilberg

Chalk reservoirs, due to their high storage capacity and very low permeability, is one of the most interesting cases for reservoir engineering research on carbonates. They show various fluid-rock interactions because of their active porous media as well as fluid-fluid interactions especially when they become exposed to low salinity water and a reactive crude oil. This research aims to investigate the effect of brine composition on oil recovery from reservoir chalk material by introducing a new tertiary injection scenario to mimic more accurately the reservoir condition. Then we would compare the results from this new proposed method with the ordinary core flooding method to evaluate the differences and address challenges.

For this purpose, by means of computed tomography (CT) results, a homogenous short chalk core sample (1.5 cm in length), without any open fractures was selected. This core was saturated with reservoir fluids and aged at reservoir conditions using a dynamic aging method. Six different experiments (combination of injecting seawater, diluted seawater, and formation water at different secondary and tertiary order) were conducted at the same core. In the new tertiary method, we switched to the tertiary mode exactly at the time breakthrough happened. This allows us to switch to the tertiary mode while the oil saturation is far from its residual value. In addition to the oil recovery measurement, all the captured effluent brine samples were analyzed using ion chromatography method. This approach enables us to track the oil production and rock-brine interactions at the same time, which revealed great insights about the active mechanisms.
X-ray Computed Tomography (CT) methods can be used to study the internal structure of geomaterials non-destructively and with minor sample preparation. Previously, such methods have been utilized in the characterization of petroleum reservoirs, underground water resources, soil, ores, and carbon storage in aquifers. X-ray CT has the potential to characterize geomaterials at multiple length scales and as a function of time – in the dynamic imaging mode. Multiscale and dynamic imaging of geomaterials in X-ray CT scanners however require open hardware and software architectures that permit programming, scripting, and modifications. We describe the development of a flexible scripting system, FLEXT, to control the components of a non-commercial multiscale X-ray CT scanner for geological applications. The modified custom-built X-ray CT scanner is capable of imaging objects as large as 20 cm to smaller than 1 mm with three stages. Flow equipment that may be integrated in the software system permit realistic dynamic imaging experiments. Imaging of three rock samples at the 120-mm, 40-mm, and 2-mm length scales are presented as well as two dynamic evaporation experiments in a model glass-bead pack and a natural chalk core plug. The developed imaging system accelerates hardware and software modifications and permits new applications and discoveries in geosciences. The results of MRI of rocks to estimate saturation of core samples before and after modified salinity core flooding experiments will be discussed.

Deionized water evaporation in a glass-bead pack. Six segmented images demonstrate water (blue) evaporation from a glass-bead (gray) pack at different time steps. Watershed segmentation separated water, air, glass beads, and vial. The container and air are transparent. The deionized water evaporated and left pendular rings behind. It is possible to observe the movement of the geometry of the water phase and its reconfiguration at each time step.
SEM and AFM studies of surface wetting during aging of chalk in crude oil

Ming Li, Rasoul Mokhtari, Armin Afrough, René Wugt Larsen, Karen Louise Feilberg*

The degree and rate of oil displacement largely depends on interfacial properties of solid-oil-water systems, which are determined by physicochemical properties of oil, chemistry of water, and characteristics and wettability of the reservoir. Understanding the interfacial phenomena involved in petroleum production, such as oil recovery and oil-water emulsions, is critical for developing novel processes to improve oil production while reducing GHG emissions and other environmental impacts at a lower operating cost. Therefore chemical “surgery” was performed at the isolated interface between crude oil and chalk which governs the wetting properties. On the crude oil side, the ageing experiment was performed using pure CaCO₃ powder. The isolated layer is around 0.5 nm, which is calculated from AFM-IR data. These compounds were collected and analyzed by FTIR and XPS. The interface residues have more COOH and OH groups, and more N elements than the crude oils. The S element has also been found at interface, just at much lower concentrations. On the chalk reservoir side, cores from water flooding experiments were used in the measurement. The isolation at nm level is challenging, so the work was performed within a few microns depth via EDS analysis. The element Ca is relatively reduced after water flooding and other elements increase, including Si, Al, Mg, Sr, Ba and Na, some of these with correlation. The reasons for these increases are different for the individual elements but originate in the geochemical processes during water flooding.
From surface chemistry to multiphase flow in porous media: a DHRTC workflow

Ali A. Eftekhari, Maria Bonto, Behzad Hosseinzadeh, Helton Magno de Araujo Ciriac, Hamid M. Nick

Core flooding experiments that are traditionally conducted for the characterization of multiphase flow in carbonate reservoirs (e.g. North Sea chalk) are flawed in design and interpretation: two complex fluids, i.e. crude oil and brine, are injected into a rock with a complex surface (i.e. calcite and other minor constituents). The physicochemical interactions between the crude oil/brine/calcite that determines the mobility of oleic and aqueous phases are not explicitly included in the analysis of the core flooding data. At the DHRTC, we have developed a new workflow that addresses these shortcomings. First, we tune thermodynamically consistent surface complexation models to electrophoretic and chromatographic experiments conducted on chalk-brine and crude oil-brine systems. Then, we incorporate the thermodynamic models in a reactive transport formulation of the flow of oil and water. We then use the model to analyse the conventional core flooding experiments. Our lab provides complimentary effluent analysis that helps to further tune and/or validate the reactive transport model. We link the available sites for the adsorption of polar organic groups on the carbonate surface to the mobility of oil and water that are described by relative permeability correlations. The diffusion-controlled wettability alteration of the rock is also included in our models to avoid the misinterpretation of the observed oil- and water- breakthrough times. Finally, the complex and computationally expensive surface complexation models are reduced to Langmuir isotherms, which leads to a faster yet accurate model for conducting reservoir scale simulations and sensitivity analyses. The developed workflow and models are also suitable for environmental applications, e.g. produced water reinjection, predicting the flow of pollutants in aquifers and carbon capture and storage.
Fitting a reactive two-phase model to a combination of spontaneous and forced imbibition recovery data

Helton M de A. Ciriaco, Hamid Nick, Ali Akbar Eftekhar

Modified salinity water (MSW) flooding has been widely applied in chalk reservoirs to improve oil recovery. Many authors have suggested that wettability changes on the chalk mineralogy play a key role in helping to mobilize the oil. Due to the complexity of the underlying mechanisms of the modified salinity water flooding, mechanistic models are often utilized to better understand and predict its behavior in the field scale. The mechanistic models are a combination of several sub-models of different nature, each with several adjustable parameters. Adjusting these parameters by fitting the model to a limited number of recovery factors obtained from core flooding experiments is not a viable solution, often estimating highly uncertain values for the model parameters.

Previously, the chemical analyses of the effluent of the salinity water collected in single-phase core flooding were used as an indicator of wettability changes and for tuning thermodynamic models in chalk flooding. In a similar way, we attempt to fit a mechanistic two-phase reactive-transport model to a combination of conventional single- and two-phase flow experimental data. The effectiveness of modified-salinity water flooding is often tested in (qualitative) spontaneous and (quantitative) forced imbibition tests in the lab. While spontaneous imbibition experiments give us important insights on the capillary forces and wettability condition, forced imbibition experiments neglect these effects and can only be used to estimate relative permeability. Several mechanisms that are suggested for explaining the observed improved oil recovery cannot be distinguished in those traditional imbibition tests. Mechanistic models with adjustable physically-meaningful parameters exist for these mechanisms, e.g. carbonate dissolution, fines migration, water weakening, etc. However, obtaining these adjustable parameters by fitting “a mechanistic model that incorporates all these mechanisms” is not a good strategy.

Our mechanistic models are a combination of chemical equilibrium and kinetics models that describe the chemical reactions between the ionic species in the aqueous phase (electrolyte model with known parameters), chalk and oil surface complexation reactions, and an empirical parameter linking the surface reactions to the relative permeability and capillary pressure model parameters. When fitting the model to the core flooding data, the optimization algorithms are more sensitive to the relative permeability parameters. Moreover, the number of parameters are often too many and can result in a largely under-determined system of equations, for which the optimization algorithm is very sensitive to the initial estimates. In this work, we attempt to optimize the model parameters by simultaneously fitting the parameters to a set of core flooding, spontaneous imbibition, and single-phase chromatographic tests. We first obtain the initial estimates of the surface complexation model parameters by fitting the model to the zeta potential measurements performed on powdered carbonate suspensions. Then, we finally demonstrate the capabilities of our framework by optimizing model parameters for a set of in-house experiments performed on chalk cores from the North Sea reservoirs.
Reservoir simulations of modified salinity flooding in North Sea chalk

Behzad Hosseinzadeh, Frederic Amour, Mohammad Reza Hajiabadi, Ali Akbar Eftekhar, Hamid Nick

Our work addresses various challenges of simulation of modified salinity waterflooding at the field scale for the North Sea reservoir chalk. First, we show the role of relative permeability hysteresis under the wettability alteration process. Then we discuss to what extent the instability of the modified salinity injection’s shock front can arise due to the impact of wettability alteration. Finally, we link the injection of modified salinity waterflooding with reservoir compaction and temperature to examine the impact of chalk compaction on ultimate oil recovery under such a process.
Dynamic X-ray 3D imaging of fluid flow in Stevns Klint chalk

Peter Winkel Rasmussen, Anders Bjorholm Dahl, Henning Osholm Sørensen, Anders Nymark Christensen

X-ray computed tomography (CT) is frequently used to provide detailed 3D images of rock microstructures. Imaging static samples have until recently been the only possibility in laboratory CT scanners, however, novel reconstruction methods lead to reduced scanning times and thereby enable dynamic measurements. Therefore, using these new techniques we have initiated a series of studies where we study the flow in side core plugs of chalk directly.

We have performed the first proof of concept experiment where a core plug was imaged dynamically in 3D during single phase flow.
Tri-axial flow cell for dynamic CT

Henning Osholm Sørensen, Peter Winkel Rasmussen, Anders Bjorholm Dahl, Anders Nymark Christensen

We present a tri-axial flow cell designing for performing in situ CT measurements. The cell is rated for 200 bar and can take a sample of 1 cm in diameter and 2 cm in length. The cell will enable studies of 1) fluid distributions during multiphase injection into chalk; 2) microstructural development during injection of reactive fluids and 3) follow the compaction of chalk from overburden pressure.

The first in situ CT measurements conducted using the new cell looks promising.
Discrete fracture and matrix (DFM) modeling of chalk
From CT-scans to numerical simulations of multiphase flow in chalk formations

Carlos A. S. Ferreira; Hamid M. Nick

The modelling of multiphase flow and geomechanics in fractured rocks due to oil and gas exploitation is of major importance in the understanding of the subsurface processes and the environmental impact of such activities. In addition, this knowledge is highly essential to predict unwanted effects from future carbon capture and storage (CCS) practices and geothermal applications. The mathematical description of the problem and its solution is challenging since the domain is generally anisotropic, heterogeneous, and has substantially discontinuous material properties that can span several magnitude orders. This work explores the mathematical modelling of fractured chalk samples imaged with CT-scanners by employing state-of-the-art skeletonization techniques and machine learning algorithms. The goal is to provide high-fidelity computational models from the CT-scans of fractured chalk samples for multiphase flow and geomechanics simulations, while balancing accuracy and computational cost.
UPSCALING OF REALISTIC DISCRETE FRACTURE SIMULATIONS USING MACHINE LEARNING
Nikolai Andrianov (GEUS)

Upscaling of discrete fracture networks to continuum models such as the dual porosity/dual permeability (DPDP) model is an industry-standard approach in modelling of fractured reservoirs. While flow-based upscaling provides more accurate results than analytical methods, the application of flow-based upscaling is limited due to its high computational cost.

In this work, we parametrize the fine-scale fracture geometries and assess the accuracy of several convolutional neural networks (CNNs) to learn the mapping between this parametrization and the DPDP model closures such as the upscaled fracture permeabilities and the matrix-fracture shape factors. We exploit certain similarities between this task and the problem of image classification and adopt several best practices from the state-of-the-art CNNs used for image classification. By running a sensitivity study, we identify several key features in the CNN structure which are crucial for achieving high accuracy of predictions for the DPDP model closures and put forward the corresponding CNN architectures.

Obtaining a suitable training dataset is challenging because i) it requires a dedicated effort to map the fracture geometries; ii) creating a conforming mesh for fine-scale simulations in presence of intersecting fractures typically leads to bad quality mesh elements; iii) fine-scale simulations are time-consuming. We alleviate some of these difficulties by pre-training a suitable CNN on a synthetic random linear fractures’ dataset and demonstrate that the upscaled parameters can be accurately predicted for a realistic fracture configuration from an outcrop data.

The accuracy of the DPDP results with the predicted model closures is assessed by a comparison with the corresponding fine-scale discrete fracture-matrix (DFM) simulation of a two-phase flow in a realistic fracture geometry. The DPDP results match well the DFM reference solution, while being significantly faster than the latter.
Developing open-source photogrammetry hardware for digitising geological observations

Oldfield, S.J., Qian, J., Lüthje, M, & Welch, M.J.

Advances in computer vision and the availability of open-source hardware have allowed development of a low-cost open-source multi-camera rig with wide camera offset for geological applications.

In this poster we review the development of the handheld hardware and software components of the system and discuss the key advantages that it offers compared to both traditional and more recent drone-based data acquisition approaches.
This study focuses on a relatively narrow stratigraphic interval of the Danian Ekofisk Formation reservoir from well Sif-1X, from the Danish North Sea. The Ekofisk chalk in Sif-1X is characterized by two distinct fabrics distinguished principally by variations in calcite microcrystal texture, silica content, silicification types and clay content. The fabrics are interpreted to represent two different diagenetic pathways. Based on multi-scale data integration, we demonstrate that silica not only affects the chalk and other fine-grained carbonates through pervasive silicification but potentially also has a significant control on the carbonate system, leading to changes in the calcite microcrystal textures. This adds to the complexity of the porosity and permeability evolution in silica-rich chalk and other mixed silica-carbonate systems.
Core wettability is one the most important factors that dictate fluid flow in a porous media. When a core is retrieved from the field, several changes occur to the wettability of a plug due to the abrupt changes in pressure and temperature.

When the cores reach the lab, it is important to preserve and maintain the existing wettability the best way possible. For that reason, there are several core cleaning and restoration protocols used in the oil industry and academia that include the usage of different equipment, techniques, and materials. Strong solvents used in core cleaning can remove material that is part of the rock phase leading to more water–wet behavior. Large volumes of crude oil exposure in core restorations can result in high adsorption of polar organic components onto the mineral surfaces giving less water–wet behavior. Therefore, sufficient core cleaning should be targeted, involving no physical damage to the solid rock phase and effective crude oil exposure securing realistic water saturations, avoiding overexposure of crude oil.

The objective of this study was to establish an optimum core restoration process in terms of cleaning solvents and the amount of crude oil exposure, to re-establish the same core wettability from one core restoration to the next. Seven sandstone cores from a reservoir on the Norwegian Continental Shelf underwent a series of core restorations. Two different core cleaning procedures were used, in which mild (kerosene/heptane) and strong (toluene/methanol) solvents were involved, and furthermore, the cores were exposed to various volumes of crude oil.

After performing several spontaneous imbibition experiments, it was observed that mild core cleaning in combination with 5 pore volumes or more crude oil exposure resulted in a less water-wet state to the wettability of the cores. More aggressive cleaning using 5 pore volumes of crude oil exposure resulted in a more water-wet behavior in successive core restorations. The optimum core restoration procedure concluded by Spontaneous Imbibition experiments, was the mild cleaning scheme followed by 1 pore volume of crude oil exposure.
Application of geomechanically-based fracture models to a fractured chalk field, offshore Denmark

*Michael Welch, Mikael Lüthje & Simon Oldfield*

We have developed a method of created geomechanically-based Discrete Fracture Network models by simulating the nucleation and propagation of natural fractures over geological time, based on linear elastic fracture mechanics and subcritical fracture propagation theory. In this presentation we apply the method to the Kraka field offshore Denmark, which comprises a fractured chalk reservoir developed over a salt pillow. We calculate the magnitude and orientation of the horizontal strain experienced during development of the salt structure by backstripping, and use this as input to the fracture propagation model. We compare the results with fractures interpreted on borehole images from 5 horizontal wells, as well as lineations observed on ant-tracked seismic data, and find a good match in both orientation and fracture density.