The National IOR Centre of Norway

4D seismic and tracer data for coupled geomechanical/reservoir flow models

Project 2.7.7

Project manager: Lars Sønneland (2014-2015), Jarle Haukås (2015-2021)
Key personnel: Wiebke Athmer, Jan Bakke, Quinten Boersma, Aicha Bounaim, Marie Etchebes, Bjørn Harald Fotland, Martin Haege, Michael Nickel, Michael Niebling
Project duration: 2014-2021

The National IOR Centre of Norway

Final Project Report

4D seismic and tracer data for coupled geomechanical/reservoir flow models

Project number and location (UiS, NORCE, IFE):
Project duration: 2014-2021
Project manager: Lars Sønneland (2014-2015), Jarle Haukås (2015-2021)
PhD students and postdocs:
Other key personnel: Wiebke Athmer, Jan Bakke, Quinten Boersma, Aicha Bounaim, Marie Etchebes, Bjørn Harald Fotland, Martin Haege, Michael Nickel, Michael Niebling

Executive summary

This report summarizes Schlumberger's in-kind research contribution to the National IOR Centre of Norway. The main focus has been on improving the use of seismic data in parametrizing, evaluating and updating subsurface models; both conventional reservoir flow models and coupled models (which also consider the geomechanical impact of injection and production). In addition, Schlumberger has been involved in the development of IORSim, which allows water chemistry alteration to be included as tracer-like data in the flow model. Towards the end of the project, considerable efforts has been put into making the technology developed in the project available as composable workflow elements in Schlumberger's cloud platform DELFI.

During the lifetime of the Centre, Schlumberger has improved the technology used to detect, characterize and extract faults and fractures (fracture corridors) from seismic data. Through this technology, zones and regions which could have significantly different permeability or transmissibility from the surroundings are identified. Schlumberger has also further developed technology for detecting, characterizing and extracting zones and regions with significant and interpretable 4D seismic changes. The quest to better utilize this information resulted in the development of two main workflows, 1) automatically creating an ensemble of reservoir models honouring detected faults and fractures and exploring the impact of altering their permeability, and 2) evaluating an ensemble of subsurface models against 4D seismic data to identify opportunities to improve the models.

As part of the IOR Centre collaboration, the technology has been tested on data from the Ekofisk field, in collaboration with ConocoPhillips. However, the main focus has been on tools and methodology relevant for the entire Norwegian Continental Shelf and beyond. Over the last few years, the project team has therefore shifted the attention towards development of composable workflow elements, data liberation, automation and cloud deployment. The fact that most of the workflows developed in the project are now available as prototype solutions in Schlumberger's cloud platform DELFI, connected to cloud liberated data through APIs, is an important achievement. The patterns established with respect to cloud data access and workflow development will hopefully help bring research prototypes faster to the market in the future, as discussed in the workshop Schlumberger organized with the IOR Centre September 2021.

Schlumberger is pleased to have been part of the National IOR Centre of Norway for 8 years. This final report gives a high-level overview of activities and project results, with links to relevant papers and presentations. For more information, please contact Jarle Haukås, jhaukaas@slb.com

Introduction and background

The project was initiated by the late Lars Sønneland (died March 8th, 2019), with the objective to support task 5 (tracer technology), task 6 (reservoir simulation tools) and task 7 (field scale evaluation and history matching). In addition, competence on reservoir simulators was requested by task 4 (upscaling), which led to Schlumberger's contribution to the IORSim development project.

During the lifetime of the IOR Centre, Schlumberger has collaborated with several researchers within the Centre (Aksel Hiorth, Jan Sagen, Terje Sira, Jan Nossen, Jan-Ludvig Vinningland, Oddbjørn Nødland, Tuhin Bhakta, Geir Nævdal) and with ConocoPhillips (Robert Moe, Evgeny Tolstukhin, Carlos Pacheco and Per Gunnar Folstad) while testing new technology on Ekofisk data.

In addition, as a result of Schlumberger's external collaboration with TU Delft, PhD student Quinten Boersma worked with Schlumberger Stavanger Research in several periods during 2017-2020, and made significant contributions to the project.

Results

The first result obtained by the project was the implementation of a geomechanical simulation approach where rock displacements at the interface between the reservoir and the overburden as extracted from seismic data are used to simulate propagation of stress and strain changes into the overburden. From the simulation results, synthetic time shifts are estimated and compared with observed time shifts from 4D seismic data. The results are summarized in Bakke et al. (2014) (see Figure 1) and were later explored further in Niebling et al. (2017).

The second result obtained in the project was the implementation of a workflow for detecting and mapping seismic discontinuity volumes into grid properties used as inputs to reservoir simulators. A permeability model mimicking complex fault and fracture patterns in naturally fractured rock was used in Hiorth et al. (2017) to explore sodium-chloride water diversion with IORSim (Figure 2).

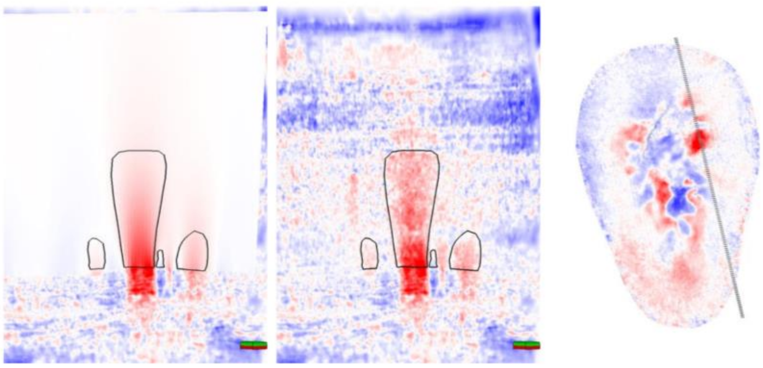

Figure 1: Comparison between simulated and observed overburden time shifts presented in Bakke et al. (2014)

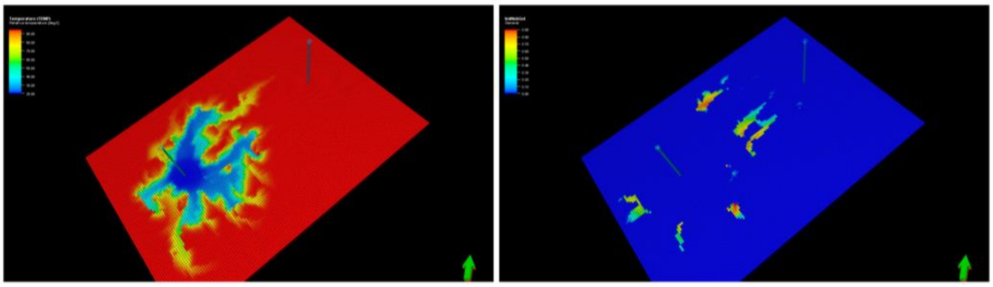

Figure 2: Simulation results using complex fault and fracture permeability model, presented in Hiorth et al. (2017)

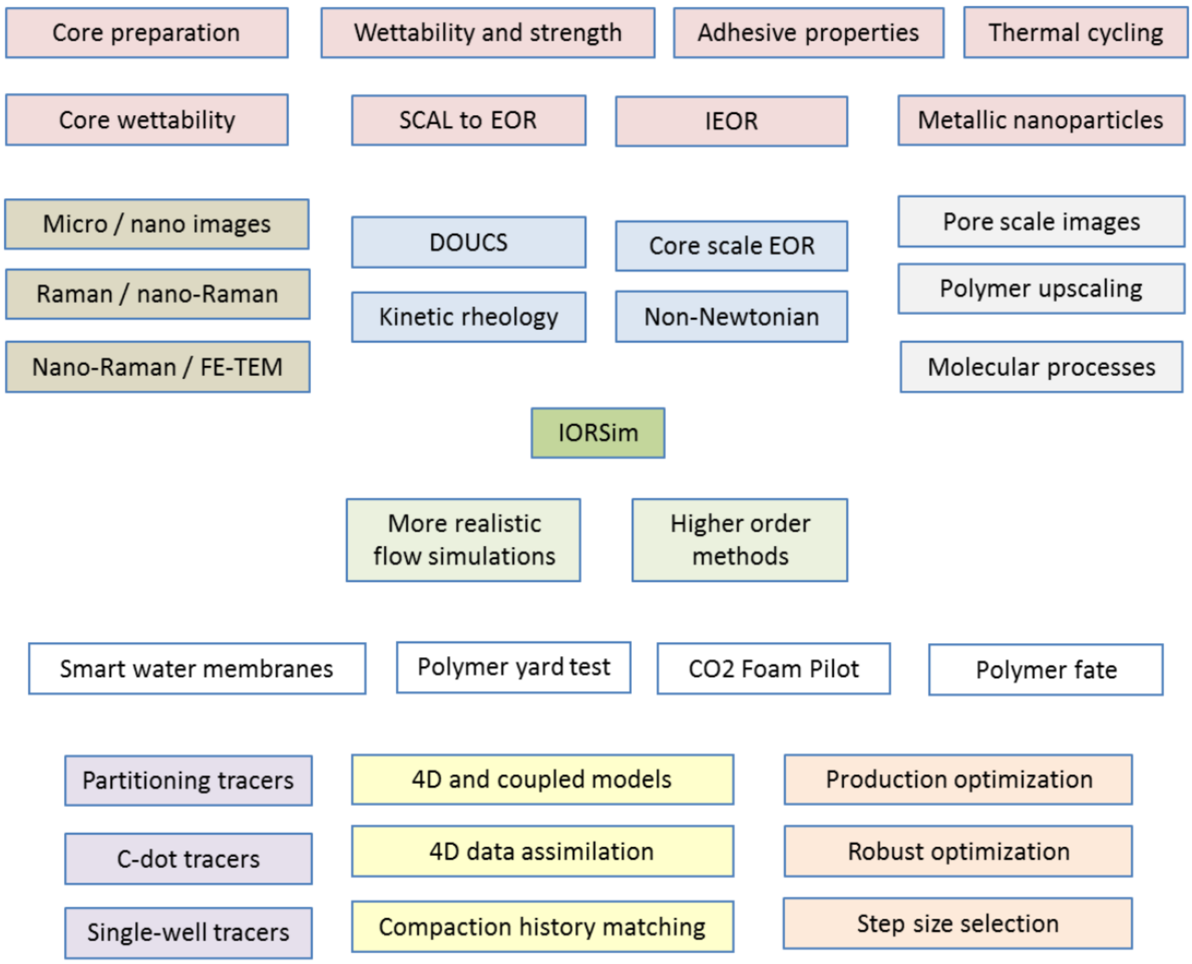

Figure 3: The full project portfolio of the National IOR Centre of Norway, as described in Haukås et al. (2017)

The third major achievement of the project was the integration work that came as a natural consequence of the fact that the project was spanning multiple tasks of the IOR Centre. During 2017, Schlumberger led the work to describe the integration of all work across the Centre, summarized in Haukås et al. (2017). Figure 3 shows one of the illustrations in the paper.

In 2018, the project team started exploring the combination of automated seismic interpretation and ensemble-based history matching. Using an advanced seismic data conditioning workflow, a detailed description of seismic discontinuities was obtained. To be able to incorporate this information in reservoir fluid flow modelling, a refinement of the full-field model was implemented, accompanied by an automated mapping procedure from seismic to simulation grids. This resulted in a new model parametrization approach, combining matrix rock permeability (background property), faulted rock permeability (grid blocks intersected by faults, with possibility to parametrize based on fault dip / azimuth) and fractured rock permeability (grid blocks populated according to modelled fracture density). The open-source ensemble based reservoir tool (ERT) was used to automate the creation of an initial ensemble, exploring a range of permeability scenarios. An important piece of work was the modification of ERT to handle INTERSECT simulation cases, with customized, python-based automation of the model parametrization. The project team also explored automating the rock physics modelling and generation of synthetic 4D seismic data for each of the realizations.

In summary, the work presented in Haukås et al. (2018) covers a broad range of results: 1) automated detection of seismic discontinuities, 2) refinement of simulation grid to capture the detailed seismic discontinuity description, 3) forward modelling of fractures to account for sub-seismic features, 4) automated parametrization of the permeability field by combining matrix, faulted and fractured rock parameters, 5) automated orchestration of ensemble based modelling using a modification of ERT able to handle INTERSECT simulation cases, 6) automated rock physics modelling to produce synthetic time-lapse seismic data, and 7) comparison of observed time-lapse seismic effects and simulated time-lapse seismic.

With reference to Haukås et al. (2018), Figure 4 shows an overview of the workflow elements and Figure 5 illustrates the workflow orchestration, i.e. combining ERT with customized Petrel plug-ins and python scripts to incorporate seismic data and INTERSECT simulations.

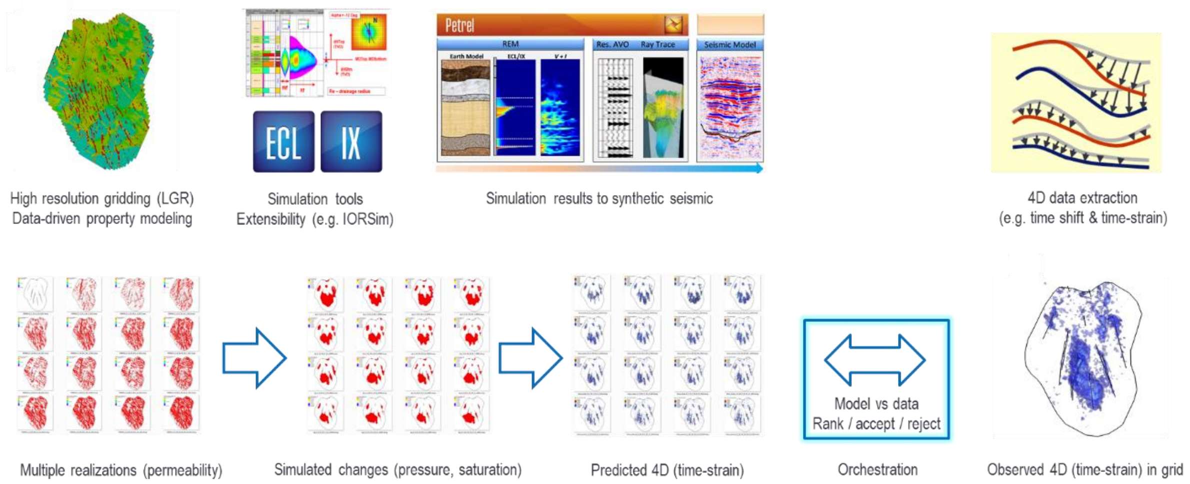

Figure 4: Overview of the elements of the workflow presented in Haukås et al. (2018)

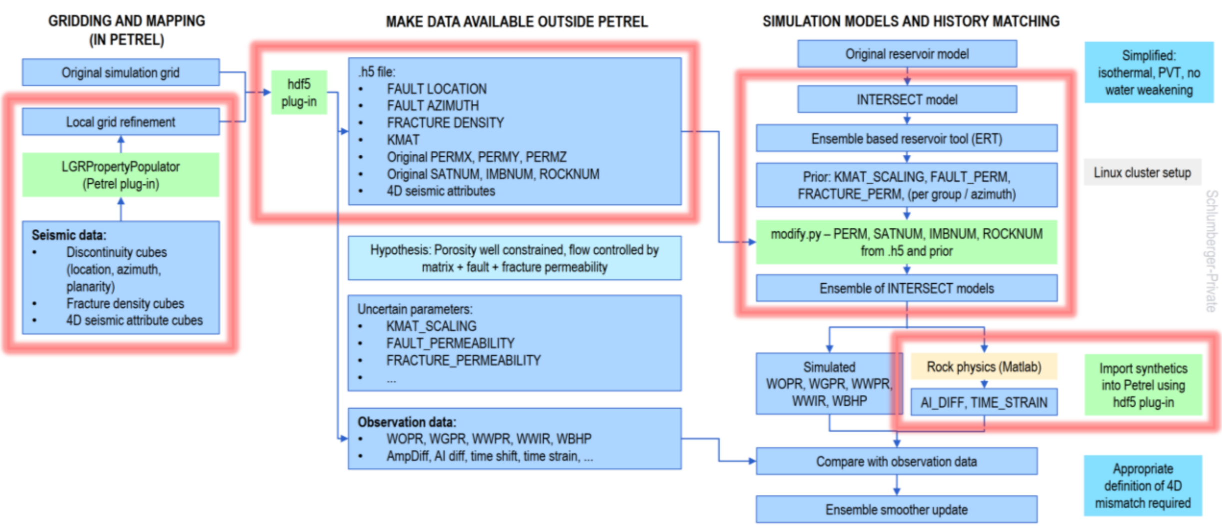

Figure 5: Workflow orchestration implemented to use seismic data and INTERSECT models with the ensemble based reservoir tool (ERT), as presented in Haukås et al. (2018)

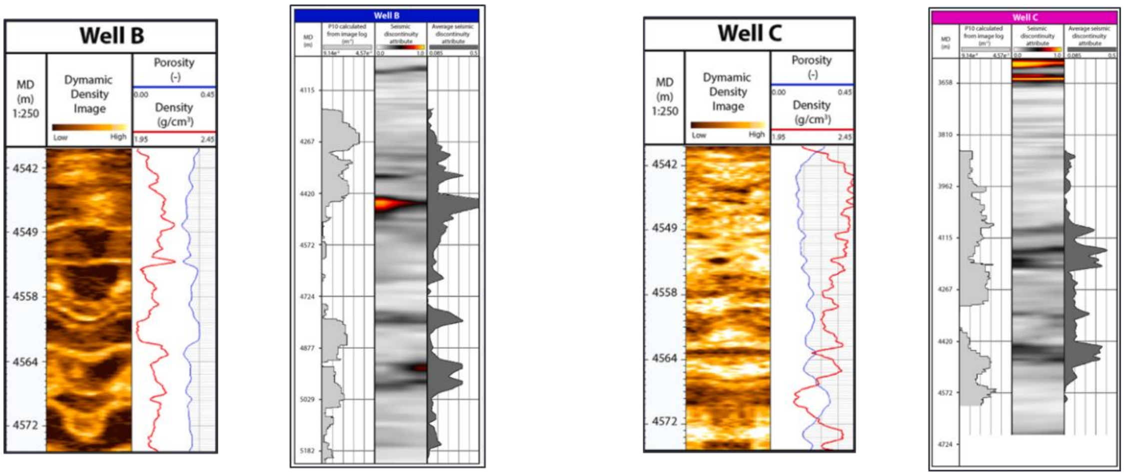

Figure 6: Image from Boersma et al. (2020) - validation of seismic fracture attribute using image log data

In 2019, the project team went deeper into the subject of model parametrization. Limitations of the fracture forward modelling approach were identified and addressed, resulting in a new and improved fracture prediction approach that incorporated well data validation and a seismic attribute as fracture indicator instead of the original forward modelling approach. The results were first presented in a conference paper, Boersma et al. (2019) and then more comprehensively in a journal paper, Boersma et al. (2020). The validation approach is illustrated in Figure 6 (illustration from paper).

In 2020, approaching the end of the lifetime of the Centre, focus was shifted towards making methodology and workflow elements available through Schlumberger software platforms. Aligned with the ongoing transition to cloud technologies through the introduction of the DELFI platform, workflow components were implemented as python modules, and connected to simulation models and seismic data stored in the cloud through APIs (Application Programming Interfaces), as outlined in Figure 7. This work has so far resulted in 1) a comprehensive tool set for analysing and updating reservoir models using seismic data, 2) automated workflows for generating data from simulation models to be compared with 3D and 4D seismic data (e.g. synthetic seismic attributes) and 3) ability to loop over multiple realizations in parallel, utilizing cloud computing scalability. The advantages of cloud liberated data and engines and bringing composable workflow elements to a broad range of users was discussed in the workshop organized by Schlumberger September 23, 2021.

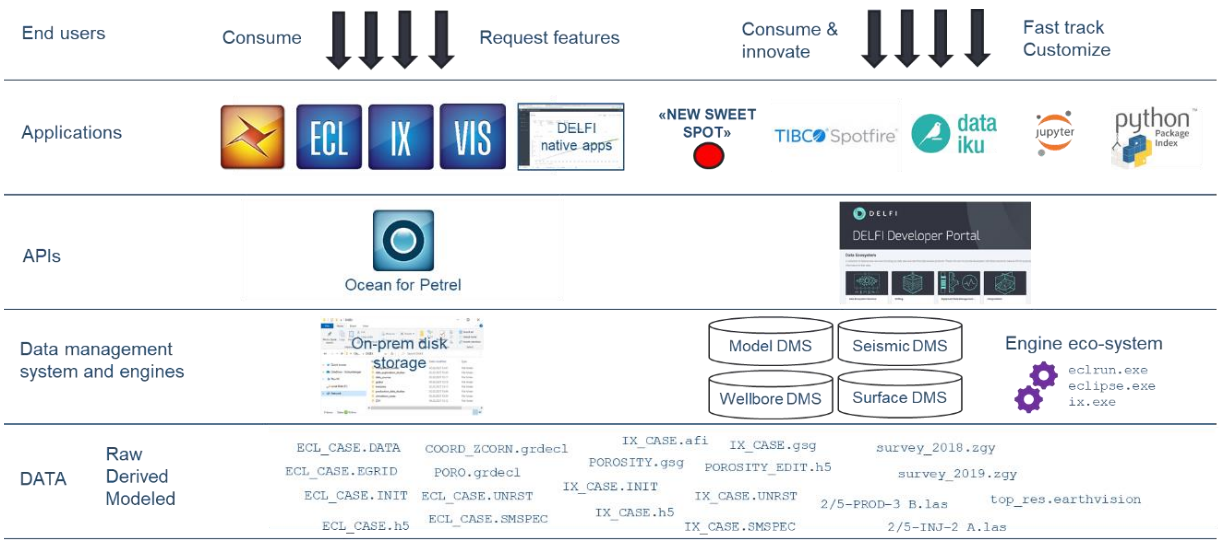

Figure 7: New access patterns and a new "sweet spot", enabled by liberated data and engines - illustration from presentation at IOR Centre workshop with Schlumberger September 2021.

Conclusion(s)

In summary, the project has produced a series of results, both in-depth and across domains and tasks. What started out as individual pieces of technology, somewhat complex to put together by combining various tools and technologies, including Petrel plug-ins, open-source ensemble based tools and simulator software, has through the adoption of new digital technologies resulted in a comprehensive library of solutions for cross-domain automation in the cloud.

Future work/plans

The final results of the project, related to exploring the advantages of liberated data and engines in the cloud, is summarized in a paper draft that is currently going through review internally (Schlumberger) and externally (ConocoPhillips and license partners) before submission.

The work on automating workflow elements and offering them as composable workflows in Schlumberger's cloud platform DELFI continues. Schlumberger offers testing, validation and further development of these workflows through so-called Innovation Factori projects, aimed at speeding up the digital transformation and adoption of new digital tools and technologies. For more information, contact Jarle Haukås, jhaukaas@slb.com

Dissemination of results

The project work has been presented publically at conferences and workshops (see References), and in private review meetings with ConocoPhillips.

References

J. Bakke, J. Haukås and L. Sønneland. Calibrating the overburden model with time-lapse data. Report to the National IOR Centre, August 2014. https://www.uis.no/sites/default/files/2021-10/2014_Calibrating%20the%20overburden%20model%20with%20time-lapse%20data.pdf

M. Niebling, J. Haukås, M. Nickel and J. Bakke. Detailed Modeling of Injection and Production Induced Rock Displacements. IOR 2017 - 19th European Symposium on Improved Oil Recovery. https://www.earthdoc.org/content/papers/10.3997/2214-4609.201700361

A. Hiorth, J. Sagen, A. Lohne, A. Omekeh, J. Nossen, J. Haukas and T. Sira. Simulation of Sodium Silicate Water Diversion Using IORSim. IOR 2017 - 19th European Symposium on Improved Oil Recovery. https://www.earthdoc.org/content/papers/10.3997/2214-4609.201700283

J. Haukås, M.V. Madland, K.M. Flornes, A. Hiorth, R. Valestrand, S.O. Viig, A. Stavland, U. Zimmermann, E. Jettestuen, A. Mebratu, T. Bjornstad, R. Klofkorn, S.M. Skjaeveland and G. Naevdal. Integration of IOR Research Projects through Generic Case Studies. IOR 2017 - 19th European Symposium on Improved Oil Recovery. https://www.earthdoc.org/content/papers/10.3997/2214-4609.201700260

J. Haukås, W. Athmer, J. O. H. Bakke, Q. D. Boersma, A. Bounaim, M. Etchebes, P. G. Folstad, B. H. Fotland, R. Moe, C. Pacheco and E. Tolstukhin. Analysis of enhanced permeability using 4D seismic data and locally refined simulation models. IOR Norway 2018, 23-25 April, 2018. https://www.uis.no/sites/default/files/2021-11/Analysis_of_enhanced_permeability_IOR_Norway_2018.pdf

Q. Boersma, W. Athmer, M. Etchebes, J. Haukås and G. Bertotti. Natural Fracture Prediction: A Multiscale Integration of Seismic Data, Image Logs and Numerical Forward Modelling. 81st EAGE

Conference and Exhibition 2019, London, June 3-5, 2019. https://www.earthdoc.org/content/papers/10.3997/2214-4609.201901301

Boersma, Q., Athmer, Haege, M., Etchebes, M, Haukås, J. & Bertotti, G. (2020): Natural fault and fracture network characterization for the southern Ekofisk field: A case study integrating seismic attribute analysis with image log interpretation. Journal of Structural Geology, Volume 141, December 2020, 104197. https://doi.org/10.1016/j.jsg.2020.104197

IOR Centre workshop with Schlumberger, September 23, 2021. https://www.uis.no/sites/default/files/2021-11/Workshop_with_SLB_23_Sept_2021.pdf