De-risking geothermal plays in Zealand, Denmark with seismic AVO inversion

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Summary

A 2D seismic AVO inversion and well log analysis was performed to characterize a geothermal reservoir in the northern Zealand of Denmark in 2019. This case study shows how from the seismic inversion results it is possible to interpret different lithologies and estimate porosities through links established with well logs. The results revealed several layers of porous and clean sandstone as potential high-quality reservoirs for geothermal energy development within the Lower Jurassic unit and the Gassum formation. Even though the limited data available for the study caused some challenges, the obtained predictions seem generally reasonable when compared to existing regional well data, seismic interpretations and geological expectations. Ultimately, this study demonstrates the applicability of seismic AVO inversion for reservoir characterization as a tool for de-risking geothermal resources.

Introduction

Seismic AVO inversion has been a well-known and effective procedure for reservoir characterization in the oil and gas industry for multiple years (Buland et al., 2008). The use of seismic AVO inversion for the characterization of geothermal reservoirs seems valid as the aim is to identify different lithologies while estimating the porosity at the zone of interest. From seismic data, it is possible to invert for different elastic properties such as acoustic impedance (AI), P-wave and S-wave velocity ratio (Vp/Vs) and density. Typically for sedimentary rocks, AI is often correlated to the porosity while both Vp/Vs and AI can act as a good lithology discriminator.

This case study demonstrated how a 2D seismic AVO inversion can help de-risk a geothermal play by characterizing the reservoir in the northern Zealand of Denmark. Figure 1 shows the location map of the study area Hillerød, 5 2D seismic lines and the wells available for the study.

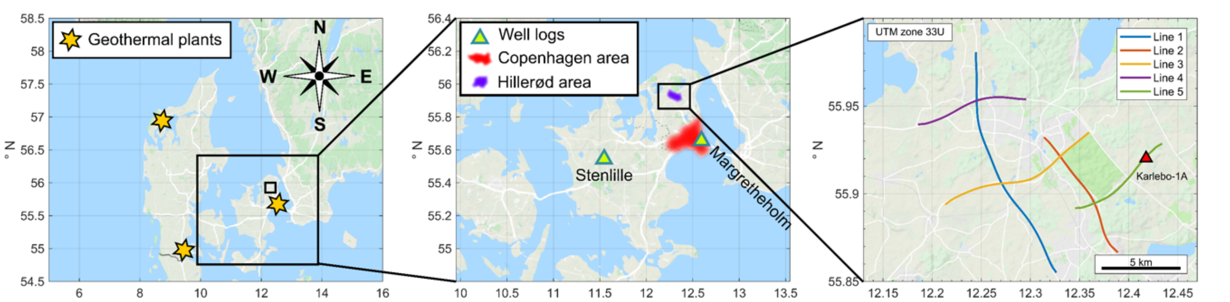

Figure 1. Location map of the study area in the Northeast of Zealand, Denmark highlighting well log and seismic data available for the study. Wells at Margretheholm and Stenlille are located approximately 30 and 60 km from the Hillerød prospect area respectively. Courtesy of Google Maps.

The target is located within the Lower Jurassic unit and the Gassum formation at an approximate depth of 2 km below the surface. Figure 2 shows the interpreted seismic section of Line number 5, highlighting the main geological formations with the Karlebo-1A well projected on top. The Gassum formation has proven very good reservoir quality at several locations and is also the geothermal reservoir for two other geothermal plants in Denmark. The temperature in the Gassum formation in this case is expected to reach levels around 50°C (Poulsen et al., 2016).

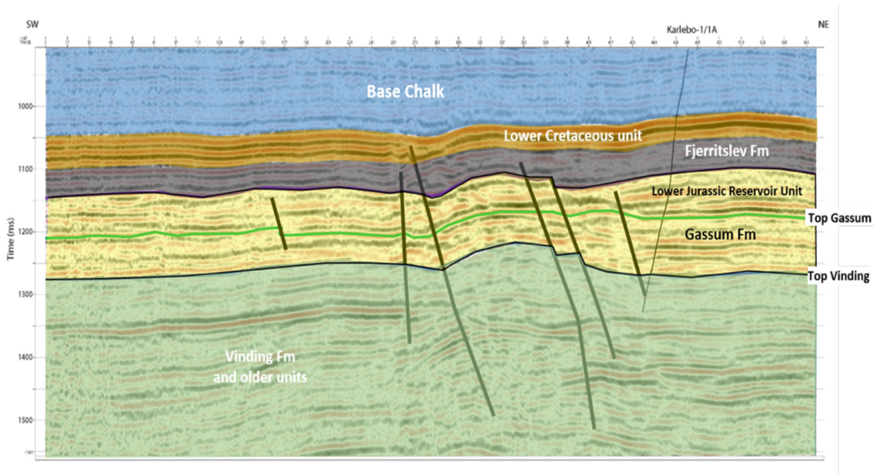

Figure 2. A geological interpretation of the main geological formations based on the seismic line number 5, about 7 km in length. The Karlebo-1A well path is projected on top.

Lithology classification and porosity estimation

A classification of three facies: 1) clean sandstone, 2) shaly sandstone and 3) shale was performed based on non-Gaussian probability density functions (PDFs) estimated using a Gaussian kernel-density estimation. These PDFs are subject to interpretation and honor the known well log information from Karlebo-1A and Margretheholm-1A and the geological expectation of the area. The PDFs were applied to the inversion results. Figure 3 shows how the seismic lithology classification is matching the Karlebo-1A well, the shale package in the Fjerritslev formation is classified, and thin sand packages within the Jurassic formations are also observed. Given that the only logs available for Karlebo-1A well were porosity log, gamma-ray log, and sonic log. The porosity estimation was in this case the best way to evaluate the inversion results. Figure 3 also shows the seismic estimated porosity compared with the porosity from the Karlebo-1A well, a very good fit between the two is observed.

Conclusions

It was possible to predict lithologies and porosities at several 2D seismic lines by performing a seismic AVO inversion with well log analysis and supported by the geological understanding of the study area. This prediction can help characterize the reservoir in order to plan target zones for future geothermal energy plants in the area of Hillerød in Northern Zealand, Denmark.

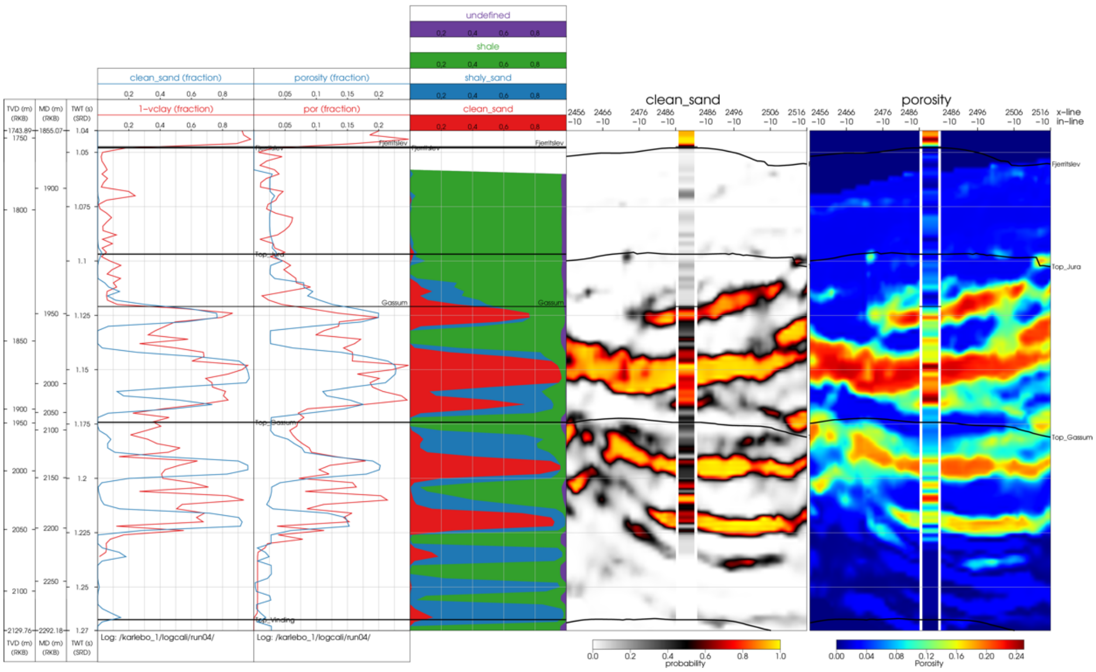

Figure 3. Lithology and porosity results predicted from the seismic inversion and projected on Karlebo-1A. First panel shows seismic predicted probability of a clean sand (blue curve) and volume of sand from well log (red curve). Second panel shows seismic predicted total porosity (blue curve) and porosity from the well log (red curve). Third panel is showing the probability of the different lithologies based on the seismic inversion. Fourth panel is showing seismic predicted clean sand at a mini-section crossing the well log. The Fifth panel shows the seismic predicted porosity at a mini-section crossing the well log.

The results yielded several porous and clean water-bearing sandstone layers as potential high-quality geothermal reservoirs within the Lower Jurassic unit and the Gassum formation. Although the data limitations encountered posed a significant challenge in our study, the predictions obtained seem fairly reasonable when compared with regional well data, seismic interpretations and geological expectations. Lastly, this case study demonstrates the potential of seismic characterization and AVO seismic inversion as tools for de-risking geothermal resources to increase hydrothermal production volumes.

Acknowledgements

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