Quantitative seismic interpretation of the Gassum Formation at the Stenlille aquifer gas storage

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Abstract

The Danish government aims at a 70% reduction in greenhouse gas emissions in Denmark by 2030, and net-zero emissions by 2050. Geological CO₂ storage will play a key factor to obtain these goals. Previous assessments have indicated that approximately 22,000 million tons of CO₂ could be stored in Danish saline aquifers. The most promising storage potential in Denmark is in high-porosity sandstone layers of Triassic-Jurassic age, widely distributed in the subsurface. Although several geological structures are identified as promising sites for geological CO₂ storage both onshore and offshore, none of them have been thoroughly de-risked.

The Stenlille aquifer natural gas storage facility, located approximately 60 km west of the Danish capital Copenhagen, receives increasing attention as a relevant reservoir analogue for nearby CO₂ storage prospects and as a potential demonstration site for onshore CO₂ storage. Natural gas has been injected and stored at Stenlille since the 1989, where the reservoir occurs within an anticline structure. The Gassum Formation forms the natural gas storage reservoir and consists of interbedded sandstones and shales. The natural gas is stored by displacing formation water. Overlying the Gassum Formation is the tight Fjerritslev Formation, which consists of marine mudstones and shales, and represents the regional caprock. The storage capacity of the Stenlille structure has been estimated to be three billion cubic meters, but due to reservoir heterogeneity, the gas is stored in several separate zones and compartments. The gas storage facility is covered by a 3D seismic survey from 1997 and well data from twenty injection, production and observation wells that have contributed to an improved understanding of the regional setting and petrophysical properties. Acquiring new and modern 3D seismic data and drilling exploration wells is a costly affair, and future CO₂ storage projects will probably need to limit costs through exploiting legacy surveys and repurposing existing wells. Hence, the Stenlille aquifer represents a good test site with geophysical data that may typically be available from natural gas storage aquifers.

As geoscientists working with maturing relevant CO₂ storage prospect and demonstration sites, performing some sort of reservoir characterization exercise is key. There exist a range of different workflows for this task depending on the availability of geophysical data and the site-specific geological properties. In our study, we have demonstrated some quantitative seismic interpretations based on the Stenlille dataset to investigate: (1) Is the seismic response of the natural gas stored in the Stenlille aquifer similar to a modelled CO₂ fluid at equivalent burial depths?; (2) Can we map the injected natural gas distributions stored within the various reservoir zones and compartments in the Stenlille aquifer?; and (3) Can we better resolve the spatial reservoir heterogeneities and zone boundaries in the Gassum Formation? Our approach involves employing a set of quantitative interpretation tools based on the available 3D seismic post-stack volume and well logs, including rock physics and pore-fluid substitution modeling, a relative seismic inversion (trace integration), and an absolute Bayesian seismic inversion for classifying various litho-facies with separable acoustic impedances in a probabilistic framework.

Our quantitative seismic interpretation study gave the following results. (1) The rock physics and pore-fluid substitution modelling of the in situ natural gas and a modelled CO₂ fluid exhibited similar seismic responses in the Gassum Formation. This indicates that the Stenlille natural gas storage is representative for predicting the seismic response of future CO₂ storage in geological settings similar to the Gassum Formation in the Stenlille aquifer. (2) The natural gas injected into the Gassum Formation yields a low acoustic impedance contrast that separates from the other facies, allowing us to seismically resolve and distinguish the gas using a Bayesian post-stack inversion. High-probability gas sandstone anomalies were predicted and outlined...
within the various reservoir zones utilized for gas storage. The outlined gas distributions were consistent with well log observations and conforms with the Stenlille anticline structure in a reasonable manner. (3) A relative trace integration volume was derived that improved the resolution of thin layers, making it easier to pick and delineate the reservoir zone boundaries. In total, the quantitative interpretation results provided additional reservoir insights useful for building a robust static model for subsequent CO2 storage de-risking, development, and management. However, the results have a significant uplift potential if modern high-quality seismic data in a pre-stack format would be available to constrain the non-uniqueness of the inverse problem and the associated uncertainties.

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